First Expendable Bathythermograph Science Workshop

Workshop Report

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Australian Bureau of Meteorology Headquarters Building
700 Collins Street, Docklands
Room 3, 6th floor

Workshop hosted by Graeme Ball and Lisa Krummel at the Australian Bureau of Meteorology (ABOM)). It was moderated by Molly Baringer (AOML), Lisa Krummel (ABOM), Graeme Ball (ABOM) and Ann Thresher (CSIRO). Rapportuers summarizing individual sessions were Janet Sprintall, Rebecca Crowley, Pedro DiNezio and Tim Boyer (NOAA/NODC). The workshop was attended by scientists from Australia, South Africa, France, Numea, United Kingdom, United States, and Japan.

Introduction

The goal of the meeting was to bring together scientists to highlight the uses of XBT data. Topics included upper ocean heat budgets, transport, circulation, and variability of near surface temperature and salinity. The use of multiple data types was encouraged to contain novel inclusions of different instruments and was not strictly limited to XBT observations alone.

- Abstract submissions were encouraged for presentations on any topic and any region of the oceans provided that substantial use of XBT data was made. The goal of the meeting was to assess the general utility of the XBT data and its future direction;
- Heat budgets on global to regional scales;
- Seasonal to inter-annual variability of the upper ocean as observed by XBTs and other instruments;
- The role of XBTs and other upper ocean thermal measurements in constraining ocean data assimilation fields;
- Estimation of circulation fields on global to regional scales;
- Future of research and operations, and

- New technology, to include changes to the operation abilities of an XBT, and fall-rate estimation.

The meeting took place at the Australian Bureau of Meteorological Headquarters in Melbourne, Australia on 7-8 July, 2011. The workshop was divided in oral presentations and plenary discussions, held with the objective of exchanging ideas on how to proceed with the implementation, maintenance, and enhancement of the XBT Network.

The XBT Network

XBTs are valuable because they represent the largest fraction of the temperature profile observations since 1970s and until the fully implementation of Argo profiling floats in approximately 2005. In recent years, approximately 25,000 XBT are deployed each year, of which around 15,000 reach the GTS in real-time, representing close to 15% of the current total upper ocean thermal profile observations. Currently, studies performed using data from XBT observations are focused on, but not limited to: a) variability of surface, subsurface, currents and undercurrents, b) meridional heat transport, and c) thermal temporal variability along fixed transects. Most of the XBT transects are currently being used to study the variability of several surface, subsurface, boundary, and under currents, some of which have been monitored for more than 20 years.

There are 49 XBT transects recommended by the scientific community (Figure 1, Goni et al, OceanObs09, Ship Of Opportunity Program, 2011) in High Density (also referred as High Resolution) and Frequently Repeated modes. High Density transects are occupied at least 4 times per year XBT deployed at approximately 25 km intervals along the ship track. Frequently repeated tracks are occupied at around 18 times per year with XBT deployments at 100 km intervals. Low Density mode has been largely discontinued in favor of Argo profiling float deployments. The XBT network is very complex to maintain for which a strong collaboration between many organizations and countries are needed. The participants recognized that the logistics and problems linked to implementation of the XBT network are unique but with some common aspects with other observational platforms, discussed the distinctive contribution provided by XBTs that cannot be accomplished by any other network of observations, and highlighted the synergy that exists between XBT observations and observations from other platforms, such as altimetry, surface drifters, Argo, etc.

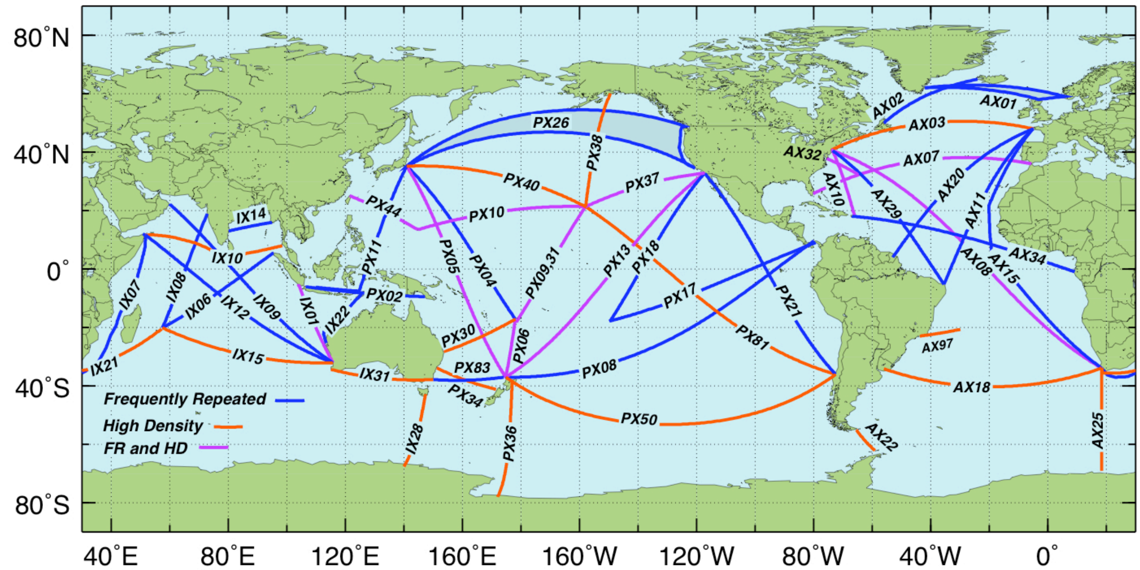

Figure 1. Recommended XBT transects.

Currently, the main focus of the XBT network is to maintain the High Density transects. The strength of the XBT data set currently lies on its length and on its ability to estimate transports across entire ocean sections and key choke-points, such as Drake Passage, Indonesian Throughflow, ACC south of Africa, etc. The scientific objectives of HD are summarized below:

- Measure the seasonal and interannual fluctuations in the transport of mass, heat, and freshwater across transects which define large enclosed ocean areas and investigate their links to climate indexes.
- Determine the long-term mean, annual cycle and interannual fluctuations of temperature, geostrophic velocity and large-scale ocean circulation in the top 800 m of the ocean. However, in some regions, XBTs reaching 800m cannot depict the complete vertical structures of fine but intense oceanic jets and a combined approach in terms of high density and deeper profiling float measurements is necessary.
- Obtain long time-series of temperature profiles at approximately repeated locations in order to unambiguously separate temporal from spatial variability.
- Determine the space-time statistics of variability of the temperature and geostrophic shear fields.
- Provide appropriate *in situ* data (together with Argo profiling floats, tropical moorings, air-sea flux measurements, sea level etc.) for testing ocean and ocean-atmosphere models.
- Determine the synergy between XBT transects, satellite altimetry, Argo, and models of the general circulation.

- Identify permanent boundary currents and fronts, describe their persistence and recurrence and their relation to large-scale transports.
- Estimate the significance of baroclinic eddy heat fluxes.

The main surface and subsurface current, undercurrent, and countercurrent systems currently being monitored and studied by XBT transects are (the year measurements began are in parenthesis).

- Upstream Kuroshio Current:
  - Upstream: PX44 (since 1991)
  - Downstream: PX05 (2009)
- Gulf Stream: AX10 (1997), AX32 (1981)
- Agulhas Current: IX21
- East Australian Current:
  - at 27°S: PX30 (1991)
  - at 33°S: PX34 (1991)
- East Auckland Current and Tasman outflow: PX06 (1986)
- California Current System:
  - Undercurrent: PX37 (1991)
  - California Current: PX37 (1991)
- Alaska Current: PX38 (1993)
- Leeuwin Current 32°S: IX15 (1987)
- Indonesian Throughflow: IX01 (1987)
- Solomon Sea current system: PX05 (2009)
- Antarctic Circumpolar Current
  - South of Tasmania: IX28 (1993)
  - Drake Passage: AX22 (1996)
  - South of South Africa: AX25 (2004)
- Brazil Current: AX97 (2004)
- Brazil/Malvinas Confluence: AX18 (2002)
- Agulhas Current at 28°S: IX21 (1994)
- Benguela Current and Agulhas Current Rings: AX18 (2002) and AX08 (2000)
- Atlantic Ocean Equatorial Current System: AX08 (2000), AX20 (2010)
- Florida Current: AX7 (1997)
- North Atlantic Drift Current: AX01 (1997)
- Labrador Current: AX02 (2010)

In addition, the use of XBT observations in High Density mode to monitor Meridional Heat Transport (MHT) in the Atlantic and Pacific basins were also highlighted:

- AX07: MHT in the North Atlantic Ocean;
- AX18: MHT in the South Atlantic Ocean; and
- PX37/40: MHT in the North Pacific Ocean

The implementation of the XBT transects and of data management requirements is done by the WMO-IOC Ship Of Opportunity Programme Implementation Panel (SOOPIP). Although the SOOPIP implements data management practices, they are usually not uniform as each Laboratory and country currently sets up procedures that are not standardized across the network.

Workshop format

This workshop was organized broadly into similar science topics such as the use of XBT observations to understand ocean circulation, boundary currents, heat transport and heat content changes. Interspersed in the science presentations were discussions. Below is a summary of the science presentations followed by a summary of all the discussions. Abstracts for the presentations are included in the workshop web page:

XBT Science presentations

Our knowledge in ocean circulation, heat content, and meridional heat transport has been impacted through the use of XBT observations, which is reflected by the large number of scientific publications and that were highlighted in several presentations made at the workshop.

The meeting was opened by Molly Baringer who provided an introduction to science results derived from XBTs. This introduction also emphasized that the meeting was patterned after the Argo science meetings and that it was a step towards building on the XBT operational base into a more science-oriented focus. A summary of scientific applications of the XBTs was presented, emphasizing on the High Density and Frequently Repeated transects, which are focused on the monitoring of mesoscale features, western boundary currents, meridional heat transport, and the synergy with other observing systems, such as Argo profiling floats.

A summary presentation on several ocean circulation studies and heat and mass transports was made by Dean Roemmich. It was recommended that XBTs be put forth as the existing boundary current monitoring system upon which other instrumentation such as gliders can build. Within this area of study it was indicated that the High Density XBT transects are underappreciated networks for sampling boundary currents. Argo data is complementary in that it can provide reference level velocities. However, XBTs are not limited to boundary currents, they also measure into the ocean interior. Time series of boundary current transport estimates using XBTs were presented, which included the East Auckland current where Argo data are too sparse to define the current, and the California Current system where the CalCOFI (California Cooperative Fisheries Investigations) program provides additional transport calculations, but not granular and offshore enough. A summary of estimates of heat and mass transport from XBT data was also presented. In general, altimetry satellite observations were identified as the best data set to complement XBT data when there is lack of temporal coverage.

Ocean Currents

A summary of the monitoring and analysis efforts of the northern limb of the subtropical gyre using HD XBT transects in the South Pacific Ocean was presented by Alex Ganachaud. Highly variable transport estimates (25-30 Sv) were determined from the biannual XBT transect (7 surveys since 2008) between New Caledonia – Vanuatu – Solomon Islands (roughly the southern portion of PX04/05) that crosses the northern limb of the South Pacific subtropical gyre. The North Vanuatu Jet was associated with various narrow westward streams impacted by topography and wind variability, while the eastward flowing South Equatorial Counter Current exhibited strong seasonality. The currents are characterized by strong deep shear to 1000 m, supporting the need for deployment of the deeper-reaching T-5 XBT probes to adequately resolve the geostrophic flow and transport at these depths. The continuance of French funding for this XBT transect is uncertain at present, yet it provides important information about the Coral Sea/Solomon Sea circulation system that are the focus of the CLIVAR-endorsed Southwest Pacific Ocean Circulation and Climate Experiment (SPICE).

A study of decadal Changes in the East Australian Current system and their relationship to changes in the South Pacific Gyre was presented by Katy Hill. Three long-running (20+ years), high-resolution, quarterly sampled XBT transects enclosing the Tasman Sea (PX09; PX31; PX34: the "Tasman Box") were supplemented by altimetry data and used to examine changes in the volume transport associated with the South Pacific boundary current system. On decadal time scales the eastward extension of the East Australian Current (EAC) – known as the Tasman Front – was found to be anti-correlated with the southward EAC extension, in response to basin wide changes in the wind stress curl. This appears to be associated with a strengthening/shift of the gyre rather than a change in the separation latitude of the EAC. Kathy Hill noted that there would be moored array deployed along PX31 off Brisbane in 2012 (PIs Ridgway and Sloyan, CSIRO) as part of a long-term monitoring effort of the EAC.

An overview of XBT observations from XBT transect AX22, which are used to investigate changes in the Antarctic Polar Front in the Drake Passage was presented by Janet Sprintall. Annually, between 6 and 8 realizations are carried out on the R/V L. M. Gould, 96 realizations since 1996. XBTs are dropped 6-12 km apart, XCTDs occasionally as well. Since ocean fronts coalesce in the Drake Passage, this is considered to be a good area to study frontal variability, in which small seasonal variability has been observed. When the seasonal cycle is removed, there remains a 50 km southward shift in the Polar Front. Observed changes in the location and depth of the mixed layer of the AASW were linked to SAM and La Nina indices.

Results obtained using observations from the XBT transect AX25 were presented by Isabelle Ansorge, which runs from South Africa to Antarctica. This transect has been occupied since 2004, with realizations carried out mainly during the summer months, 18 total to the date of the workshop. These XBT observations are used to help understand the flow between the Indian and Atlantic Ocean, monitor Agulhas Rings, and capture the variability of the various Antarctic Circumpolar Current fronts. This transect is linked to the French-Russian regional projects BONUS-GOODHOPE. Volume transports in the area are being estimated using a combination of XBT measurements and CTD observations. However, it was noted that more XBT and CTD measurements are necessary, particularly during the winter months, to improve these estimates. It was agreed on taking advantage of opportunities to carried them out. Besides the current XBT opportunities available during the December-February period, a new South African research ship may present a viable platform for additional transects and deployments.

A study on the Tropical Atlantic Variability during 1993-2010 using a combination of XBT and altimetry observations was presented by Marlos Goes. "Synthetic" temperature and salinity profiles were developed to link the dynamic height obtained from XBT observations with the altimetric sea surface height (SSH) and climatological reference levels, allowing estimation of the surface and subsurface currents since 1993. Good agreement is found for the synergistic transport estimates of the surface North Equatorial Counter Current (NECC), with weaker agreement found for the subsurface North Equatorial Under Current (NEUC) as the SSH signal is degraded. Results showed that the seasonality of the NECC is closely related to the meridional displacement of the ITCZ and strengthening of the North Brazil Current, while the NEUC exhibits both annual and semi-annual variability. In the South Equatorial Under Current, the XBT transport estimates show much higher variability compared to the transport estimates using the synthetic SSH profiles.

Results from the Indian Ocean HD transect IX01, which was implemented in 1980, presented by Steve Rintoul are needed to separate the numerous mechanisms driving low-frequency variability in the ocean. The transport estimates from IX01 indicate that the Indonesian Throughflow is driven both by the Indian Ocean Dipole (IOD) and ENSO via distinct physical mechanisms. As a result, some ENSO and IOD events interact constructively while others oppose. Results obtained using IX28 observations indicate that the polar fronts separate in filaments with very small spatial scales and with vertical structure can only be resolved with XBT observations collected along these fixed transects. Because these features are so small, other observing systems will be prone to aliasing.

Meridional Heat Transport

HD XBT transects have been key to obtain a multi-decadal record of meridional heat transport (MHT) at 26°N in the North Atlantic. Molly Baringer presented results from this transect, showing that the XBT-derived 15 year-long time series of MHT is inversely correlated with the AMO index, a key climatic index of the Atlantic basin. This relationship has been recently detected thanks to the length of the XBT record and will be used to validate numerical modeling results. The MHT is also being computed in the South Atlantic, and in combination with an altimetry based methodology. Preliminary results presented by Gustavo Goni show that between 20°S and 40°S altimetry together with hydrographic observations could be used as a proxy to estimate the variability of the MHT with latitude. In addition, satellite altimetry observations can be also used to extend back in time to 1993 the record of MHT.

Upper Ocean Heat Content

The recent GHRSST meeting as it relates to XBTs was reported by Helen Beggs. GHRSST is the global high-resolution sea surface temperature group. The main use that this group has for XBTs is as an independent validation of SST, although presently only the RSMAS component of GHRSST uses XBT data for validation. The main issue for GHRSST to use XBT data is the response time, as the first 3 meters of the XBT drop are usually not usable due to start-up transients and near-surface temperature spikes. However, it was reported that temperature values at deeper depths could still be used for validation. Requirements for XBTs for validation: 5 minutes time accuracy, 0.005 degrees accuracy in position, 0.01 meters resolution with 0.5 meters accuracy in depth, and 0.05 degree accuracy in temperature. In general, these values indicate that XBTs could be widely used for GHRSST validation purposes. [Please see Helens presentation to double check requirements.]

A novel methodology that uses EOFs to correct systematic errors in XBT profiles. was presented by Mathieu Hammond. This methodology is based on removing the decadal variations that captures the short term cooling produced by volcanic eruptions. The global trends obtained were consistent with WCRP CMIP3 trends. Results presented shows that XBTs may need a separate correction in the western Pacific, the area is where most of the XBTs are manufactured by TSK.

The key role being played by the XBT network in GODAE Ocean View, the new framework for ocean assimilation and forecasting originated after the completion of GODAE, was presented by Peter Oke. GODAE Ocean View aims to support the observational community with feedback on the impact of observations in forecast skill. Results from this project show that not assimilating in-situ observations can degrade seasonal predictions by 25%. While satellite altimetry has been identified as the most important component to adequately forecast the (short-range) evolution of mesoscale eddies, XBT observations still remain as one of the core dataset for short-range forecasting.

You-Soon Chang presented a study of OHC decadal changes and trends estimated with the GFDL ocean data assimilation (ODA) system, which assimilates historical XBT observations.

Various mechanisms that have been suggested to generate Pacific Decadal Variability (PDV), such as air-sea interaction in the North Pacific, tropical-extratropical teleconnections, internal tropical dynamics (e.g. ENSO), and rectification of ENSO. P. DiNezio examined various climate models and suggested that the PDV is associated with a weakly coupled mode that generates decadal ENSO-like SST variability via changes in the Walker Circulation that are amplified by ocean surface processes only, i.e. without participation by the equatorial thermocline. Pacific Ocean XBT and CTD data (1970-2010) were used to evaluate this theory. Thermocline development was identified where maximum dT/dz occurs in each profile and linked to wind and SST variability. The data supported the climate models and suggested that unlike during ENSO events, on PDV time scales warmer SST is associated with a shallower thermocline driven by weaker trade winds.

The U.S. Navy's Global Ocean Temperature and Salinity Climatology by Robert Helber. The US Navy develops a monthly, global ocean temperature and salinity climatology at 78 depth levels to 6600 m on a global 1/4 degree grid, using all available in situ profile data (e.g. Xbts, Argo, CTDs etc). After checking for outliers, 1.7 million XBTs are included in the final data set (up to July 2008). Improvements to the climatology focus on achieving accuracy in the vertical gradient of temperature, particularly near the coast or in regions of sloping bathymetry, as this quantity has important applications in Navy acoustics.

The effect of different XBT fall-rate corrections on ocean heat content calculations was presented by Tim Boyer. XBT data cover a large proportion of the ocean between 1967 and 2000's. In 2009, XBTs still represent a large fraction of the current profile data: 6% to 9% of the global database are XBTs and hence it is vital to correct XBT data as best as possible. Dr. Boyer showed the global heat content estimates using the currently available fall-rate XBT correction schemes. He applied XBT corrections to the same dataset WOD that included the Levitus correction (which contains no regard to XBT behaviour), Wijffels et al (2008; which is a pure depth correction) Ishii & Kimoto (2009), Gouretski & Reseghetti (2010; a depth, temperature and thermal bias correction), Good (2011: who generated a depth correction based on profiles that hit the seafloor), and DeNezio and Goni (2010; which used concurrent XBT and Argo data to estimate correction).

In general, there remains a large spread in heat content values using different corrections. However, all corrections remove the large heat content increase seen in the 1970-1980's. No corrections appear to work will in the northern Indian Ocean. Giese et al (2007) applied the W08 and Levitus correction in the SODA model and showed that the corrections improve model performance. Lyman et al (2010) performed a similar analysis and found similar comparisons.

A new approach to estimating XBT errors was presented by Rebecca Cowley. In this presentation a large database of XBTs and CTDs was used for analysis that resulted in 5000 CTD/XBT colocated pairs. The fine scale temperature structure in each profile is used to match each XBT to the collocated CTD at each depth by computing the maximum correlation at each depth, then fitting the depth "corrections" to a line (with slope and offset). What remains after this depth correction is termed the thermal bias. The analysis is done separately for each probe type and all data is initially corrected to the Hanawa fall-rate. In general, the study showed that the depth offset is constant over time and is around 1.2 m for depth error. The thermal bias varies over time and is larger before 1990, probably because of early analog systems and larger actual bias. High resolution, deep probes offset is about 0.4°C. The thermal bias is depth independent and largely responsible for the thermal hump in the 1970s. Removing that first leaves essentially no significant fall rate change over time (expect perhaps a small slowing of the fall rate with time since the mid-1990s). This study found no clear relationship between Temperature and fall rate (e.g. the rall rate does not seem to be different in colder verses warmer waters as some studies have suggested). The study recommends a minimum of 30 high resolution pairs and minimum of 50 low resolution pairs to get robust estimate.

Another new analysis on fall-rate coefficients was described by Lijing Cheng that uses a historical XBT data based of side-by-side profiles to estimate the depth with Depth = $at^2 + bt + c$, where a and b are the typical fall rate coefficients previously estimated and c is an "offset" term as described by Boyer and others. He showed that using an integrated method to calculate a, b and offset from that pairs database and using those estimates to correct the depth and thermal bias generally improve data.This study shows a clear relationship between latitude and the coefficient a and suggest that the 1970-1980 heat content "hump" could be caused by geographic aliasing of the data. Further this suggests that we could be overcorrecting the 1970-1980 warm period by using XBT buddies that have occurred largely in the tropical region. This analysis showed a pronounced shift in the fall-rate in 199, which is anecdotally linked to improved wire coating techniques applied by the manufacturer. It also showed a linearly correlated relationship between a and the offset.

In an effort to understand the possible physical mechanisms that could reasonably adjust the fall-arte of XBTs, Kimio Hanawa presented results where the weight of the XBT was systematically altered to check the fall-rate characteristics. In order to accomplish this experiment and assess the dependence of temperature, weight of probe and amount of wire, a numerical model of probe descent was developed and evaluated using several probe types (TSK and Sippican) compared to CTD profiles. Assuming a fall rate model like At^2+Bt, the A coefficient translates into something like initial speed as the probe hits the water and the B coefficient translates into reduction in mass with time as the wire spools off. This experiment showed that colder temperature probes fall faster than in warm water (similar to results of Kizu 2011). Heavy probes as expected fall faster than Lighter probes. TSK probes fall faster than Sippican probes (all other conditions remaining the same). The fall rate acceleration coefficient a increases by 0.06 for every 10g of weight increase. Interestingly, the observed fall rate changes do not match the numerical experiments, where weight was a secondary factor to probe shape. The overall recommendations are that probe shape and weight should be maintained as much as possible. These experiments are expected to be continued annual to evaluate the XBT probes through time and check the performance of the numerical model.

The experiment described above was possible through the careful procedures outlined by Shoichi Kizu. To reduce the weight of a probe, the inside of the nose cone is scraped out, eliminating 10 to 20 g in the cone. Sippican probes are lighter than TSK probes by about 12 g due almost entirely to the differences in the weight of the wires. The wire gauge is the same and the difference is the coating. The different structures and mass balance of the LMS and Sippican probes results in relatively similar fall rates. Largely due to the decreased weight of the Sippican probes, experiments demonstrate that the Sippican falls slower than the Hanawa 1995 fall rate by about 2% and the TSK probes fall about 2% faster than the Hananwa 1995 fall rate. Reducing the weight of the TSK probes so that they match the Sippican weights the Sippican still has a slower fall rate due to the structural differences. Even reducing the weight of the TSK by 20 g results in the Sippican probe still falling slower than the lighter TSK (-20g). The loss of wire does not slow the probes down proportionally. Drag of water probably affects the final fall rate, such as a reduction in the probe wobble with time could reduce the drag counteracting the impact of reduced weight. Sippican shows large temperature bias at depth in some probes with no characteristic changes in profile shape to indicate a problem. This is hypothesized to be an unspecified wire problem. In general weight tolerances of +/-1g (Sippican) and +/- 5g (TSK) is good enough to control fall rate to 1%. Discussions ensured about several changes to the XBT probe design that could possibly impact the fall rate. These include changes in the contact pin material, the contact gap size between nose and tail, the wire netting, the wire coating and also a change in the location of the manufacturing factory.

The historical XBT database comprises a large fraction of the time history of subsurface temperataures. A review of some of the issues associated generating with heat content time series estimates an the impact of the XBT fall rate issue was discussed by Catia Domingues. XBT data is clearly important to climate studies as 90% of the heat content is trapped in the ocean and thermal expansion contributes to sea level rise. In general, the XBT data was not designed for climate studies, but they are used in this way anyway. Quality control and rescue of metadata is important. A priority must be made of the rescue full resolution version data from the historical records. This presentation showed that mapping issues alone can change heat content even with different fall rate corrections applied to the historical data (i.e. mapping seems to make more of a difference than the actual fall-rate correction used). Using the ENACT data archive changed fairly dramatically the heat content variability between about 1998 to about 2002. In particular, the Lyman (REF) method tries to fill the gaps using satellite altimetry and Peter Glecker et al. (REF) use models to get a pooled noise to determine the signal (fingerprint), oth give substantially different results using the same underlying data. Ocean temperature anomalies can also partly be explained by the number of profiles available at any given time and location. Different XBT bias corrections give a similar result.

General Discussions

Funding and Research v. Operations

With the current emphasis of the XBT network in HD sampling, the transition of the XBT network from research to operational mode was discussed. In Australia, an operational network could probably secure funding. On the other hand, it was mentioned that transects funded by the US NSF respond to a scientific justification and not to monitoring efforts, therefore the need to remain them in research mode. Many of the global transects are still considered to operate in research mode, since their spatial and temporal sampling are still being assessed and all XBT data quality control is done at research facilities. It was argued that the scientific quality control that is applied to all XBT could also degrade if the maintenance of the network is converted into operational. It was agreed that perhaps it would be best to describe the operations of the XBT network as being in sustained mode.

It was suggested to obtain endorsement from an international agency, such as CLIVAR, to facilitate securing funding of the network. However, CLIVAR has not endorsed any other platform, such as Argo or surface drifters, but only scientific programs. It was agreed that funding would continue if the arguments to sustain the observations were compelling. However, different agencies are compelled by different arguments. For example, while the US NSF seeks new science, NOAA supports the ocean observing system for long term monitoring.

Lack of funding has already caused the termination of global frequently repeated transects. For example, in regions, such as the North Pacific HF transects were the only XBT repeated transects in place. In the Pacific Ocean, transects PX04/05 that are carried by IRD/Noumea are at risk of being discontinued. It was noted that given its importance, it might be possible for NOAA to help support this transect, provided that the data are made publicly available in near-real time. In the South Indian Ocean, HD transects may be also at risk of being discontinued due to lack of funding.

Logistics and implementation

The Ship of Opportunity (SOOP) Implementation Panel (SOOPIP) oversees several aspects of the logistics, implementation, and maintenance of the XBT network. A summary of SOOPIP activities and their link to the XBT network was given by Gustavo Goni. The SOOP is a component of the Global Ocean Observing System coordinated by JCOMM. Together with the Volunteer Observing Ships (VOS) meteorological observation network they form the Ship of Opportunity Team (SOT). SOOP activities include the recruitment of ships and riders, software development, collaboration to provide probes, real-time and delayed-mode data quality control, and data distribution. The maintenance of the XBT network and distribution of the data to researchers are also priorities of the SOOP. In addition to the XBT network there are smaller components of SOOP, such as thermosalinograph (TSG) observations.

The constant change of routes, partly because to adapt to world commercial trade, has always been an issue in the deployment of XBTs, surface drifters, and Argo profiling floats. However, the recruiting of ships that transect along fixed routes carried out at least 4 times per year constitutes an additional difficulty to the operations. In particular, these specific transects were discussed:

- It was noted that the transect PX50, which goes from New Zealand to Chile has essentially not commercial transit. A partial transect from Chile to Easter Island was proposed in order to at least monitor the eastern boundary current.
- HD XBT transect AX18, which goes from Cape Town to Buenos Aires/Montevideo, has been difficult to maintain because most ship routes currently go from Cape Town to Santos (Brazil) at 24°S and not to Buenos Aires at 34°S.
- Some logistical issues were closely related to funding issues. For example, transect PX04/05 needs a ship-rider and a continuous installation mostly on each realization with the vessel changes every few years necessitating the XBT system be reinstalled. At present, no data is entered in the GTS but are transmitted to Coriolis.

On climate quality XBT data

This presentation and the discussion that followed pointed to several recommendations:

1. Scientific community needs recommendations for XBT corrections.
2. Corrected data needs to be made available. Note that long term datasets must be clearly identified if corrections have been applied (e.g. WOD standard level data has XBT correction applies, but observed level data has no corrections).
3. There should be a web site with literature and fall-rate comparison data (NODC XBT bias page is a good start).
4. Implement yearly, global fall-rate comparisons tests (to augment Naval Postgraduate School annual testing since 1999).

5. Develop and document criteria for performance that can assessed annually.
6. Publish a summary white paper with recommendations for moving forward that also clearly describes each method so that users can easily chose the method most appropriate for them.

XBT Science Steering Team

One outcome of the workshop was the establishment of an XBT Science Steering Team (XBTSST). The focus of this Team should be to inform the oceanographic community on the benefits of XBT transect data for monitoring mass and heat transports in boundary currents, and studies of eddy and frontal variability, with the following goals:

1) Have a voice in the community to communicate scientific results. Much of this discussion was focused on developing a parallel model to that of the Argo community who have been effective in involving the broader oceanographic community in the utility of Argo data, and therefore more supportive of the continuance of the Argo program
2) Gather the XBT community to discuss scientific advances in the use of XBT observations;
3) Help to enhance international scientific collaboration;
4) Make recommendations and prioritize transects on the XBT network;
5) Make recommendations on data management;
6) Create links with other active/recognized scientific and operational panels; and
7) Must have some control over the activities carried out by the Ship Of Opportunity Programme Implementation Panel in order to be effective.

The terms of reference of the XBTSST were drafted and presented for review and comments:

1) The XBTSST will oversee the development of the global XBT network with the primary objective of obtaining profiles of temperature;
2) The XBTSST will define the scope of the XBT network with respect to the design and geographical extent of the network and the objectives of data management;
3) The XBTSST will provide advice on the contents, quality, and timeliness of the XBT data stream to ensure scientific and operational requirements are met;
4) The XBTSST will encourage observing system experiments and studies to guide the long-term development of the XBT sampling design and to complement the scientific justification of the transects already in place;
5) The XBTSST will provide advice and guidance relating to technical innovations relevant to the XBT operations and network;

6) The XBTSST will liaise with related global observing systems, including those concerned with satellite observations and with global scale ship-based hydrography, in particular GOOS and GCOS, through their oversight and coordination bodies, OOPC, GSSC, GCOS SC, JCOMM/OCG (including JCOMMOPS);
7) The XBTSST will provide scientific guidance to, and receive advice from, the relevant scientific panels (e.g. CLIVAR) and working groups;
8) The XBTSST will assist national and regional programs to help ensure sustained funding for the operation of the XBT network; and
9) The XBTSST will maintain fluid communications with and provide recommendations to JCOMM SOT and SOOPIP with reference to network implementation and data management.

The following accepted or were nominated (*) as potential members of the first XBTSST. The final membership of the first XBTSST will be made publicly available during 2012.

Janet Sprintall (UAA, SIO, co-chair for science)
Anne Thresher (Australia, CSIRO, co-chair for data management)
Gustavo Goni (USA, NOAA, co-chair for operations)
Dean Roemmich (USA, SIO)
Molly Baringer (USA, NOAA)
Gilles Reverdin (France, U. Paris)
Gopalakrishna Visa (India, NIO)
Mauricio Mata (Brazil, FURG)
Sebastiaan Swart (South Africa, UCT)
Rebecca Cowley (Australia, CSIRO)
Soichi Kizu (Japan)
Robert Helberg (USA, US Navy)
Alexander Ganachaud (Noumea, IRD)
Tim Boyer (USA, NOAA)
Charles Sun (USA, NOAA)
Loic Petit de la Villeon (France, IRD)
Birgit Klein (Germany, *)
Candyce Clark (ex-officio, USA, *)
Alberto Piola (Argentina, *)
Peter Oke (Australia, *)
Hellen Beggs (Australia, *)
* nominated, pending acceptance.

The future of XBT transects

Discussions were held in which the future direction of XBT observations were presented. The network has successfully transitioned into the High Density mode of sampling making available unique observations with emphasis in monitoring currents and meridional heat transport, which cannot be accomplished using data from other observational platform. XBT transects will keep providing unique and critical sampling of temperature sections along repeated transects, many of which have been carried out for longer than 15 years. The strength of the network also lies in that complementary observations can be obtained simultaneously during XBT deployments.

In addition, it was discussed how the observing system would look like in approximately 10 years under different scenarios, one with XBT data; where XBTs continue being the backbone of the boundary observing system; and another without XBT; where gliders took over observing the boundaries. It was agreed that this scenario may not occur soon because a) lack of investment in developing an appropriate platform, and b) gliders cannot yet *swim* against most oceans currents making, therefore, their use not appropriate to monitor strong boundary currents.

Technology development was also discussed, including improving auto launchers to the building of an XBT prototype with pressure switches and more accurate temperature sensors. Gustavo Goni noted that Sipppican volunteered to take the lead in the design of the prototype with AOML collaborating during the testing phase.

Action Items Summary

In summary, the group agreed:

1. To establish an XBT Science Team (XST) to make recommendations on the implementation, maintenance, and enhancement of the XBT network and data management practices, relying therefore on a single overseeing body to make recommendations and to set up priorities.
2. That the XST needs to be well coordinated with other operational groups such as OOPC, SOOPIP, etc.
3. Co-chairs were nominated (Janet Sprintal, Gustavo Goni and Ann Thresher) to the XST and numerous members suggested including Shoichi Kizu, Tim Boyer, Rebecca Cowley, Gopal, Robert Helber.
4. A draft terms of reference was approved for the XST and will be circulated to other interested parties.
5. There should be a Science Workshop or Science Team meeting hosted approximately every two years perhaps linked to SOOPIP or Argo science meetings. The format should consider XBT biases (1 day) and scientific advances (2 days).
6. A proposal to SCOR (IOC) should be pursued to constitute a science advisory panel to draft recommendations for the science community on fall rate corrections.
7. A plan for distributing corrected XBT data to the science and modeling community should be drafted.

8. A science paper on the unique utility of XBTs to capture boundary current transports and other major ocean currents should be completed.
9. Create and maintain a dedicated web page with information about the XBT Steering Team, and with products on ocean currents and meridional heat transport, distribution of quality control data (e.g. with links to data distribution centers). The web page should also clearly describe recommendations for XBT data corrections, meetings and links to various XBT sites.
10. The endorsement of CLIVAR should be sought.
11. A workshop summary should be submitted to EOS.
12. V.V. Gopalakrishna offered to host the next XBT science meeting in India.
13. Task the Science Team to assess the importance to carry out transects on marginal seas (Mediterranean, Gulf of Mexico) that could be critical because of lack of other type of sustained hydrographic observations.

Workshop Agenda

XBT Science Workshop Meeting Agenda 7 July - 8 July 2011
Day 1: Thursday 7 July 2011

Start	End	Time	Item	Speaker	Affiliation	Time Keeper	Rapporteur
9:00 AM	9:05 AM	0:05	Introductions	Molly Baringer	NOAA	Molly Baringer	Tim Boyer
9:05 AM	9:10 AM	0:05	Welcome/Logistics	Graeme Ball	ABOM		
9:10 AM	9:25 AM	0:15	The XBT Network Overview of Program Objectives	Gustavo Goni	NOAA		
9:25 AM	9:40 AM	0:15	Use and requirements for XBT surface temperature observations by the Group for High Resolution SST (GHRSST)	Helen Beggs	ABOM		
9:40 AM	10:40 AM	1:00	Ocean Circulation and the Mass, Heat, and Freshwater Budgets of Large Ocean Regions: The Synergies of High Resolution XBT Transects, Argo, and Satellite Altimetry	Dean Roemmich	Scripps		
10:40 AM	11:00 AM	0:20	BREAK				
11:00 AM	11:30 AM	0:30	Recent Science Highlights using Air-Sea Underway Observations in Drake Passage	Janet Sprintall	Scripps		
11:30 AM	12:00 PM	0:30	Understanding the ACC south of Africa	Isabelle Ansorge	UCT		
12:00 PM	1:00 PM	1:00	LUNCH				
1:00 PM	1:30 PM	0:30	On the High Density XBT lines	Steve Rintoul	CSIRO	Lisa Krummel	Pedro DiNezio

			in Australia		
1:30 PM	2:00 PM	0:30	Estimating the Meridional Heat Transport and Overturning Circulation from XBTs	Molly Baringer	NOAA
2:00 PM	2:30 PM	0:30	Variability of the Meridional Heat Transport and Overturning Circulation in the South Atlantic	Gustavo Goni	NOAA
2:30 PM	3:00 PM	0:30	Empirical correction of XBT data and global field reconstruction using EOFs	Mathieu Hamon	Ifremer
3:00 PM	3:20 PM	0:20	BREAK		
3:20 PM	4:20 PM	1:00	Observing System Evaluation activities under GODAE OceanView	Peter Oke	CSIRO
4:20 PM	4:50 PM	0:30	Basin patterns of the upper ocean warming for 1993-2008	You-Soon Chang	NOAA
4:50 PM	5:20 PM	0:30	Inter annual and intra seasonal variability of upper layer temperature fields in the south eastern Arabian Sea	Viss V. Gopalakrishna	NIO
5:20 PM	5:50 PM	0:30	DISCUSSION - Sustaining the Observing System	Alex Ganachaud	IRD
6:00 PM			RECEPTION - Summit Café (700 Collins Street)		

XBT Science Workshop Meeting Agenda 7 July - 8 July 2011

Day 2: Friday 8 July 2011

Start	End	Time	Item	Speaker	Affiliation	Time Keeper	Rapporteur
9:00 AM	9:30 AM	0:30	Observational Evidence for a Weakly Coupled Mode of Pacific Decadal Variability	Pedro DiNezio	NOAA CIMAS	Graeme Ball	Janet Sprintall
9:30 AM	10:00 AM	0:30	Monitoring the northern limb of the subtropical gyre with high-resolution XBT surveys in the South Pacific Ocean	Alex Ganachaud	IRD		
10:00 AM	10:30 AM	0:30	Decadal Changes in the East Australian Current system – the relationship to changes in the South Pacific Gyre	Katy Hill	IMOS		
10:30 AM	10:50 AM	0:20	BREAK				
10:50 AM	11:20 AM	0:30	The U.S. Navy's Global Ocean Temperature and Salinity Climatology	Robert Helber	NRLSSC		
11:20 AM	11:50 AM	0:30	Investigation of the Tropical Atlantic Variability during 1993-2010	Marlos Goes	NOAA CIMAS		
11:50 AM	12:20 PM	0:30	DISCUSSION - The way forward	Gustavo Goni	NOAA		
12:20 PM	1:20 PM	1:00	LUNCH			Ann Thresher	Rebecca Cowley
1:20 PM	1:50 PM	0:30	Effects of different XBT corrections on historic and recent ocean heat content calculations	Tim Boyer	NOAA		

1:50 PM	2:20 PM	0:30	A new analysis on fall-rate coefficients in historical XBT data based on side-by-side comparisons	Lijiong Cheng	IAP
2:20 PM	2:50 PM	0:30	A New View of XBT Biases	Rebecca Cowley	CSIRO
2:50 PM	3:10 PM	0:20	BREAK		
3:10 PM	3:40 PM	0:30	Trial to check XBT fall rate and to develop simple numerical model	Kimio Hanawa	TU
3:40 PM	4:10 PM	0:30	An assessment of the effect of variance in probe weight on the fall-rate of expendable bathythermograph and pure temperature bias	Shoichi Kizu	TU
4:10 PM	4:40 PM	0:30	Detection and Attribution of Upper Ocean Warming	Catia Domingues	ACE CRC
4:40 PM	5:10 PM	0:30	DISCUSSION - Wrap Up	Molly Baringer	NOAA

Abreviation	Institution
NOAA	National Oceanic and Atmospheric Administration
ABOM	Australian Bureau of Meteorology
Scripps	Scripps Institution of Oceanography, University of California San Diego
UCT	University of Cape Town, South Africa
CSIRO	Commonwealth Scientific and Industrial Research Organisation
NIO	National Institute of Oceanography, India
CIMAS	Cooperative Institute for Marine and Atmospheric Studies University of Miami, Miami, Fl
IRD	Institut de Recherche pour le Développement
IMOS	Integrated Marine Observing System, University of Tasmania
IAP/AC	Institute of Atmospheric Physics, Chinese Academy of

	Sciences
NRL	Naval Research Laboratory, Stennis Space Center
TU	Tohoku University

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Acronyms

ABOM	Australian Bureau of Meteorology
ADMT	Argo data management team
AST	Argo Steering Team
CalCOFI	California Cooperative Oceanic Fisheries Investigations
CLIVAR	CLIVAR is the World Climate Research Programme (WCRP) project that addresses Climate Variability and Predictability
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CTD	Conductivity, Temperature, and Depth
DBCP	Data Buoy Cooperation Panel
EAC	East Australian Current
ENACT	Tasmanian Database System
ENSO	El Niño/La Niña-Southern Oscillation
EOF	empirical orthogonal function
EOS	Eos, Transactions, American Geophysical Union
GCOS	Global Climate Observing System
GCOS SC	GCOS Steering Committee
GEM	Gravest Empirical Mode
GHRSST	Group for High Resolution Sea Surface Temperature
GODAE	Global Ocean Data Assimilation Experiment
GOOS	Global Ocean Observing System
GSSC	
GTS	Global Telecommunications System
IAP/AC	Institute of Atmospheric Physics, Chinese Academy of Sciences
IMOS	Integrated Marine Observing System, University of Tasmania
IOC	Intergovernmental Oceanographic Commission
IOD	Indian Ocean Dipole
IRD	Institut de Recherche pour le Développement
ITCZ	Intertropical Convergence Zone
ITF	Indonesian Throughflow
JCOMM	Joint Commission for Oceanography and Marine Meteorology
JCOMM SOT	JCOMM Ship Observations Team
JCOMM OCG	JCOMM Observations Coordination Group
JCOMMOPS	JCOMM Observing Platform Support Centre
MHT	Meridional Heat Transport

MLD	Mixed Layer Depth
NECC	North Equatorial Counter Current
NEUC	North Equatorial Under Current
NIO	National Institute of Oceanography, India
NOAA	National Oceanic and Atmospheric Administration
NODC	National Oceanographic Data Center
NSF	National Science Foundation
ODA	Ocean Data Assimilation
OHC	Ocean Heat Content
OOPC	Ocean Observations Panel for Climate
PDV	Pacific Decadal Variability
PI	Principal Investigator
SCOR	Scientific Committee on Oceanic Research
SIO	Scripps Institute of Oceanography
SOOPIP	Ship Of Opportunity Programme Implementation Panel
SSH	Sea Surface Height
SST	Sea Surface Temperature
TACE	Tropical Atlantic Climate Experiment
TSG	Thermosalinograph
UAA	
UCT	University of Cape Town
UK	United Kingdom
US	United States
WMO	World Meteorological Organization
WO8	World Ocean Database 2008
WOD	World Ocean Database
XBT	eXpendable Bathythermograph
XCTD	eXapendable CTD
XST	XBT Science Team