Workshop Report
5th XBT Science Workshop
5-7 October 2016, Tokyo

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Venue:
JAMSTEC Tokyo Office
Fukoku Seimei Bldg. 25F,
2-2-2 Uchisaiwaicho, Chiyoda City, Tokyo
100-0011, Japan

Local hosts:
Shoichi Kizu (Tohoku University, Japan)
Masayoshi Ishii (MRI/JMA, Japan)
Toru Suzuki (MIRC, Japan)
Kanako Sato (JAMSTEC, Japan)

Meeting organizers:
Janet Sprintall (SIO, USA)
Gustavo Goni (AOML/NOAA, USA)
Shoichi Kizu (Tohoku University, Japan)

Session Chairs and Rapporteurs:
Molly Baringer (AOML); Tim Boyer (NCEI); Rebecca Cowley (CSIRO, Australia); Gustavo Goni (AOML); Shoichi Kizu (Tohoku University); Alison Macdonald (WHOI); Janet Sprintall (SIO); Ann Thresher (CSIRO Australia)

1. Introduction

The 5th International XBT Science meeting took place at JAMSTEC Headquarters in Tokyo, Japan on 5-7 October 2016, following on from the 4th IQuOD workshop at the same venue. 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. A total of 45 scientists participated (7 remotely) from Australia, Brazil, China, France, Germany, India, Italy, Japan, UK, and the USA.

XBTs represent the largest fraction of the temperature profile observations since 1970s until the full implementation of Argo profiling floats in approximately 2005. These historical XBT profiles comprise most of the temperature data base that is used to compute time series of ocean heat content. One focus of the XBT Science team (along with IQuOD) is to improve and understand the accuracy of these historical data so that we can understand the uncertainties in this climatically important time series.

The global XBT network is logistically complex and so requires strong collaboration between many organizations and countries (Figure 1). Many of these transects have now been in place for multiple-decades. Today XBT transects mainly operate 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. The repeat sampling nature of XBT transects along fixed transects makes the XBT profiles our best present observing system for the important boundary current systems (including the Antarctic Circumpolar Current) that convey heat, freshwater and nutrients around the global ocean.

XBT observations are currently used mainly to: 1) Monitor the variability of location and transport of key surface and subsurface ocean currents and boundary currents, 2) Monitor the variability of the meridional heat transport and the Meridional Overturning Circulation across ocean basins, 3) Provide a significant amount of upper ocean thermal observations, particularly in areas undersampled by other observational platforms, used for global ocean heat content estimates, and 4) Initialization and validation of numerical ocean forecast models. A strong synergy exists between XBT observations and observations from other platforms, such as altimetry, surface drifters, Argo, etc. the enables more robust scientific analysis. For more information on XBT Science, please visit http://www.aoml.noaa.gov/phod/goos/xbtscience/

The objectives of the meeting were:
● understanding and correcting XBT biases for climate research (e.g. ocean heat content) and physical oceanography studies.
● scientific and operational uses of XBT observations, to better understand critical

ocean phenomena, processes, such as Meridional Overturning Circulation, currents including Western Boundary Currents, and ocean heat budgets.
● exploring the synergy of XBT data with data from other observational platforms such as Argo floats, satellite altimetry, surface drifters, etc.

The meeting was broadly organized following these three objectives interspersed with discussion on the future of the XBT network. A brief discussion of the main science presentations is found in the Section 2 followed by meeting outcomes and action items in Section 3. The Workshop Agenda is in Appendix A, a list of participants in Appendix B, and acronyms in Appendix C.

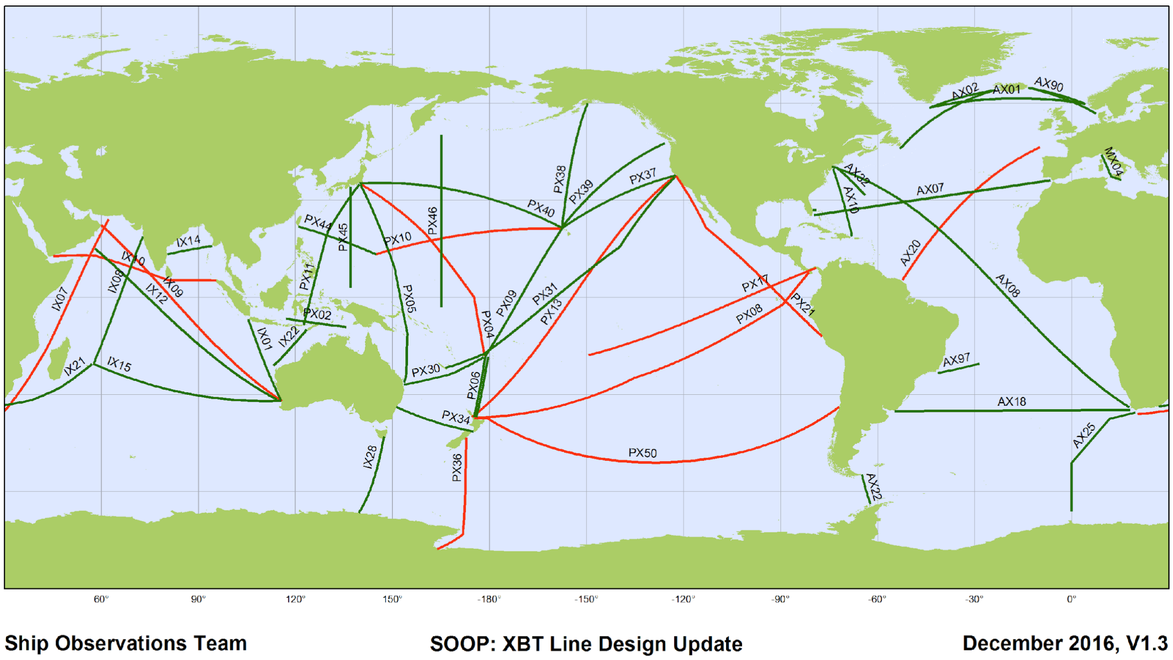

Figure 1. *Global XBT transects that are presently occupied (green) or recommended or previously occupied (red).*

2. XBT Science Presentations

Theme 1: Understanding and correcting XBT biases for climate research
Chair: Shoichi Kizu
Notetaker: Rebecca Cowley

John Abraham (Invited Speaker) discussed fall rate biases of XBTs. Abraham's fluid dynamics (FD) model uses a forward-stepping algorithm to calculate the fall rate. The study examined T5s initially, but did some analyses on the other types of XBTs too. Interest was focused on velocities around the probe, shear stresses and derived a drag coefficient. The advantage of the modeling approach is that parameter space can be explored - weight, launch heights, wire thicknesses etc and the fall rate can then be recalculated. The study used the XBT/CTD pair database to look at the FD model results and applied the full FD model to 269 pairs. Note that the pairs are not needed to make the corrections, just to do the analysis of the impact of the corrections. Also examined the effect of impact on the fall rate by looking at spheres and compared to published data: this was undertaken by dropping a sphere from controlled heights and took high-speed photos. Simulations under-predicted the depth compared to experimental data. Future work would extend this to XBT probe shapes. XBTs hit the water at different angles and more data is needed to compare these to simulations. Variables of importance to quantify include the launch height and the ship speed. The effect of viscosity might also quantified by including it in the fall rate equation that accounts for different temperatures. Other datasets are needed to confirm the results. Ongoing work is for OHC updates to CH14 etc. in the top 700m and in a multi-model results.

Lijing Cheng examined the impact of quality-control processes on XBT bias, specifically WOD vs EN4. Different numbers of XBT data are included in WOD vs EN4, with different QC processes and differences in vertical resolution. The analysis used the same XBTs found in each dataset, with the flags from each dataset applied. A warm tail was found in temperature in both datasets. Another study applied the WOD flags to EN4 dataset with the same pairs. The QC was found to have a big impact on the upper ocean difference between the datasets, but not in the lower ocean. This might be because of the removal of the upper 4m of the profile. The conclusion was that data processing has a big impact on the deeper ocean (QC flags).

Lijing Cheng also asked whether we can explain the difference in OHC when using different correction schemes? The evaluation of the 10 XBT schemes was undertaken and he found CH14, L09, GR10, G12 worked well for historical corrections. C13 was found to be good for future corrections. When the analysis was restricted to high quality pairs, the CH14, L09, GR10 methods produced comparable OHC estimates. A single mapping method was used with these three different correction schemes. Major differences occured in the sub-tropical regions (particularly the Pacific), with GR10 producing a lower OHC than the other L09 and CH14, CH14 is in the middle. Spatial differences of XBT bias needs to be kept in mind. The meeting thought that XBT and IQuOD should support each other with bias correction recommendations and the provision of XBT data with smallest biases and errors. Finally, Lijing discussed the recovery of Chinese observations of SST and down to 15m that are currently on paper. Lijing is getting these data digitized for OHC use, but they may still not be made available publicly. The meeting noted that the data needs to be public for the results to be defendable.

Viktor Gourestki provided an update for GR10 XBT bias correction scheme. The dataset was updated and completed the ICDC auto QC on the data before the corrections were derived. The bottom hit is mostly successfully picked up by the AutoQC. Collocation of data pairs used in the analysis was mostly within 2km, 1 day in the northern hemisphere, with nearly nothing in the Southern Hemisphere. Thermal bias is excluded first – so the corrections are calculated using the data from low gradient regions. The conclusion is that the thermal bias is affected by temperature. The study assumed that the thermistor temperature bias is non-probe type specific: wire length can make a difference, but the thermistor is the same in both T4/T6 and DB/T7 probe types. Two models were applied to account for temperature independent/ dependent thermal bias. Temperature dependent thermal bias correction makes a very small difference, so it is not worth including in a correction model. However while temperature dependency on the bias might not be important on the global mean, regional means might differ. Some data from colder water might be useful for this sort of study. Acquisition systems also have an effect.

Lijing Cheng examined T5 bias using both side-by-side data and global scale data. T5 measurements are important contributors to measurements in the deeper oceans in the late 1990s. More than 200 side-by-side T5 XBT data pairs were recovered. A 2.6m bias was found in MK21 and 1.4-1.6m in MK12 systems. Bath calibrations with T5s show variability with time, not with temperature. The Sippican T5 fall rate was recalculated to produce an offset value with launch height and Fallrate A coefficient with ocean temperature. In the Mediterranean Sea, the correction results in a higher time-bias offset than the uncorrected data. Temperature bias with temperature was also found to have a very strong impact.

Tim Boyer discussed the sensitivity of global upper-ocean heat content estimates to mapping methods, XBT bias corrections, and baseline climatologies. Sparse datasets make OHC estimates difficult and the mapping methods often differ from study to study. Eight (8) different mapping methods were compared. The modern climatologies were found to give a different OHC result when a zero-first guess field is used. In this case a longer-term climatology is needed. XBT bias correction uncertainty can be reduced by the XBT Science community through assessment and agreement.

Nicholas Pittman gave a remote presentation from Australia to discuss the upper-ocean thermosteric sea level (heat content). Specifically he explored the sensitivity of the CSIRO-ACE CRC IMAS estimates to 10 XBT bias corrections. The Domingues method was found to have a higher standard deviation in heat content than the other mapping methods. To determine why, both Domingues and CH14 were examined using the data from the Boyer et al. paper. Standard deviation was found to be highest in the 1997-2000, although there were large differences between each method. The meeting thought that an ensemble mean of XBT bias corrections might be a solution and worth examining.

Natalia Ribeiro Santos gave a remote from Brazil providing an assessment of the XBT fall-rate errors in the Southern Ocean (SO). The SO is warming faster than other regions and the FRE might not be correct in these cold regions and this bias might affect the OHC estimates. The study suggested that XBT profiles are overestimating the heat by 10% in the SO and that this needs correction. The study derived new regional equation for each SO choke point as well as overall for the SO using a CTD-XBT data base for drops south of the Polar Front. Crucially they found that 70% of XBTs were warmer than CTDs, with the rest colder. Found A coefficients lowest for Australian region but similar to Sippican fall rate coefficients. XBTs were warmer than CTD in Australian sector and South of Africa sector but colder in Drake Passage. Some seasonal variability complicated analysis in Drake Passage. Overall, CH14 provided the best fit except for Drake Passage at depths > 600m. The SO bias was different (larger) than general bias estimates perhaps because of fewer profiles. H95 was assessed as the worst fall rate in SO, CH14 worked best for Australia and Africa but Sippican works best for Drake Passage. Overall, Sippican works best for southern ocean. Natalias's talk generated much discussion. In a homogeneous water column such as in the SO, temperature bias could be more important than fall rate bias, but these biases were not calculated. Regional differences might be because of seasonal variation in Drake Passage affecting the pairs chosen, and XBT production batches could also be problem but metadata is limited. In addition, launch heights and acquisition system of much of the data were unknown. Australia volunteered to provide metadata and more pairs for study. Finally, the meeting recommended a more rigorous error analysis that might show the differences in FRE between each SO region might not be significant. Other studies have concluded that SO ocean heat content was underestimated (e.g., Gille) NOT overestimated so there is a need to compare Natalia's results to determine what the XBT contribution is to the heat content in the SO.

Francis Bringas discussed current experiments of XBT fall rate equation at NOAA/AOML. The XBT fall rate is a combination of coefficients, T bias and Depth bias. Video cameras were used to examine fall rate and effect of position when hit the water in various water tanks/pools. The study found depth offset depends on height of launch and this depth offset takes ~2 seconds to fully develop and then is constant. The videos suggest that the XBT never went straight down! This may well impact models and should be included but it's very difficult to model. Experiments were also undertaken at sea, at different launch heights and ship speeds and the recording systems. AOML are developing their own recorder and are also testing using CSIRO timing box. Current tests show high variability and confidence in these results are uncertain. Future plans are to deploy XBTs with underway CTDs as test pairs as well as further CTD cruises. The meeting discussed the general need for investigation into an array of different deployment heights to determine relationship to offset. This offset might also be time dependent and so depends on where you are in the profile, although eventually the XBT decelerates to terminal velocity. Comparisons of deployment when not from a moving platform might be different than those when ship underway.

Francis Bringas also discussed the impact of deployment height and ship velocity on XBT fall rate computations. Offsets are a result of recorder offset, position or attitude of probe and different deployment heights that result in different entry/initial velocities. These all translate into a depth error. This error can vary from -4 to +4m depending on launch height. An experiment compared launch heights of 2.5 and 8m at ship speed of ~9 kn. Corrections were based on FRE of H95, CH14 and HT92. Most of the effect occured in the first 20m. The 8m deployment height profiles should show shallow bias, and 2m XBTs should show deep bias. HT92 best modeled depth for both launch heights – the error is 0.05m compared to 1.6m from other methods. Screening found that 70% of 2m XBTs were greater than 8m XBTs. This agrees with expectations. Found difference of 1.6m depth offset, which is consistent with previous results. However CH14 applies a 4m offset which may be too large. HT92 seems to eliminate the depth offset effect when compared to H95 and CH14. Ship speed appeared to introduce no further effect. This implies that stationary comparisons are valid to apply to real deployments from a moving platform. This conclusion is important for historical profiles and contemporary profiles without metadata. Future deep tank testing might be possible at REMO/UFRJ Brazil and Brest France.

Rebecca Cowley discussed results from XBT deployment height experiments. Probes deployed from the Bridge hit bottom soonest i.e. fell faster compared to deck launch, although the result was not consistent from pair to pair. Regressions showed a ~1.6m difference while the bottom hit signal produced a much larger 4.2m offset. Drop tests at 2m and 8m height (AOML) and at 5m and 20m (CSIRO) and produced similar offsets of 1.6m. Swimming pool experiments (AOML) found similar offsets from 5m is ~1m and from 20 m is ~3m.

Thomas Rossby discussed a new prototype XBT deployment technology AXIS – a solar-powered autonomous expendable instrument system developed in collaboration with WHOI, a 12 XBT autolauncher that is controlled from the beach through iridium communcation. The system has been operating on R/V Oleander since 2011. The system is reloaded as required by ship-based personnel. It is based on the Sippican MK21 system and uses a carousel mechanism. Daisy chain carousels can be implemented as well with single operating system. Various parameters such as latitude, spacing both in time and lat/long can be programmed, but the mission can be changed via iridium, which is useful if inclement weather expected. Axis permits work independent of crew and observers - cost effective and very reliable and improves failure rate of probe deployment. It also allows repeatability of sections because the drops are automated. However, sometimes ship-riders ensure a successful XBT transect because having someone to troubleshoot when needed can be critical, even though likely more expensive than AXIS approach.

Marlos Goes gave an Invited Talk on the desire and value of an enhanced XBT probe. Development of new probes can improve the accuracy and reliability of XBTs. For example pressure switches can constrain the depth equation for each probe, but they are costly and demand isn't that high. There is a need to improve Temperature accuracy and secondary goal to improve depth estimates. Current estimates of T accuracy ~0.1 degC and Depth offset +/- 5m and linear depth bias ~2% of depth. The study compared 21 experimental and 21 normal XBTs to 4 CTDs. One experiment extended the types of XBTs tested to include those with tight weight tolerance. The enhanced XBT has weight control with smaller tolerance for weight variability.   Current weight variability reduced from ~+/-2.5g to 1.1g. If we reduce this variability this may affect the variability of the depth. It is important to know what fraction of the wire weight is copper and what fraction is the coating, which should be neutrally buoyant. Is the variance in weight because of wire length differences in combination with coating differences? It is though that weight is important, not length. These are important issues since XBT mass decrease is part of the FRE, but the linear density of wire can change throughout one probe so this affects the calculations. Manufacturer calibration of Temperature was also examined in Deep Blue probes. Screened thermistors must fall within 0.05 degC of bath Temperature. The gradient method was used to calculate depth offset, the depth was corrected and then T bias calculated. Standard probes have mean T0 of 0.08°C, whereas screened probes showed a 0.04°C offset. Second group with standard, experimental and tight weight probes: all T biases were positive with standard probes having the higher offset. Wire imbalance was found to have little effect on Temperature. Thermistor calibration shows strong improvement, especially for NON standard probes. Standard probes are overcorrected. Time Constant correction was found to have little impact. An interesting pattern in depth biases was found but not understood. Note that all Temperature s are within manufacturer specifications but new probes do better and reduce temperature bias. Depth offset is better with tight tolerance probes but the spread is larger. Experiments by Sippican showed tighter spread for enhanced probes when compared to standard probes. A final experiment tested screened/calibrated standard probes compared to standard probes. The calibration variability decreased significantly but FRE coefficients showed no significant difference between probes. Simply calibrating thermistor improves T offset as much as using an experimental XBT. If you combine these results, mean temperature bias goes almost to 0. In conclusion, thermister screening is most important factor in reducing T offset. Pressure switches may lead to improve depth accuracy but more sea trials are planned to improve statistics, and their expense is prohibitive. So to solve depth bias we need to continue development of current methods. Sippican expect to introduce tight weight tolerance and thermistor calibration/screening, and are ready to produce enhanced XBTs now but need feedback from the XBT community.

Shoichi Kizu discussed recent sea tests of XCTDs: how are they different from XBTs? XCTDs are more expensive that XBTs but provide salinity measurements, although there may be potential issues with the accuracy of the salinity. Various forms of FR equations are used for 4 different types of XCTDs on the market that vary in depth range and ship speed. External design varies between the 4 different XCTD types as well. The wire is fundamentally different between XBT and XCTDs. For XBT, wires are part of circuit and so length of circuit is very long. In XCTDs, the wires only provide data transmission - entire circuit for Temperature measurement is within the probe. This would make addition of a pressure sensor in the XCTD very simple and XCTD manufacturer TSK is developing a prototype. All thermistors are calibrated in the factory. The outer shape of the XCTD probe differs with a flat nose in XCTDs, which introduces turbulence. Some XCTDs also have a ‘ring hood’ at the tail that stabilizes the fall. Depth error for XCTDs is small and unbiased. XCTDs without ring hood (XCTD3) are less stable and falls very differently with larger depth error. XCTD3s fall faster in warmer water or this might be result of stratification. The XCTD ‘a’ coefficient effect of T is smaller than for XBTs. This implies flow is more turbulent for XCTDs so they are less sensitive to T changes. XCTDs require slower speed ships although the

XCTD-3 is designed to fall faster at higher ship speeds. XCTD4 has smaller ring and can be deployed at a LITTLE faster speed than others. XBTs fall faster and so can be used on faster ships.

Theme 2: Scientific and operational uses of XBT observations
Chair: Gustavo Goni
Notetaker: Molly Baringer

Rebecca Cowley an Invited Speaker discussed the Status of the XBT network from the viewpoint of SOOPIP – the Ship of Opportunity Implementation Panel, of which she is Chair. Nine countries - Argentina, Australia, Japan, France, Italy, USA, Brazil, S. Africa and India participate in SOOPIP. SOOP is part of the Ship Observation Team (SOT), together with the Voluntary Observing Ship (VOS), and ASAP. JCOMMOPs is conducting a review of XBT metadata requirements to assess network capacities, future implementation and the implementations of other networks. JCOMMOPS request that deployment opportunities/planning be submitted before the cruise. New metadata for XBTs include platform and cruise metadata, and delayed mode deployment information. There is a strong need to reassess the XBT network including scientific needs and ability to maintain the transects and the community was asked to upgrade the existing map of the network to better reflect the active/inactive and desired network. Most of the lines became inactive not due to a lack of scientific interest, but rather due to logistics: changes in ship tracks, institutions no longer supporting XBT lines, countries not sharing data, funding, etc. A new map with recommended XBT transects will be presented by the XBT Science Team.

Janet Sprintall discussed XBT science at SIO. The success of the SIO high-resolution XBT (HR-XBT) lines relies on many international partners. SIO has just celebrated 30 years since the introduction of the first High Resolution XBT transect. The main science objective of the HR-XBT network include annual cycle, interannual variability and long-term mean of T, Vg and transport. About 10 PhD theses based on the HR SIO XBT lines, and all data is available in transect form at http://www-hrx.ucsd.edu. Ongoing science efforts include the production of a climate index of boundary currents using HR-XBT, altimetry and Argo data. The HR-XBT line enables denser coverage as well as into the shallow areas not available via either ARGO or altimetry. The Drake Passage HR transect AX22: Punta Arenas to Antarctica measures multiple parameters from XCTDS, ADCP, underway pCO2 and met data. A recent analysis examined eddy variability and noted a strong asymmetry in eddy heat content from within the eddies. The HR-XBT data are all involved in Data Assimilation models of the Pacific. Major challenge to the HR-XBT network remains transient nature and routing changes of the commercial shipping industry.

Gopalakrishna Visa discussed low frequency variability of western boundary currents in the Bay of Bengal, as revealed by the 25-year long record of repeated XBT observations. Two transects collected XBTs (occasional xCTDs and water samples) approximately monthly since 1990. The Bay of Bengal is a semi-enclosed tropical basin with strong precipitation seasonally varying and the development of barrier layers. The EICC (East India Coastal Current) reverse direction twice a year in response to the monsoons, sending low salinity water out of Bay of Bengal during winter and high salinity water from the Arabian Sea in summer. Average northward flow of 5 Sv, while southward flow averages 3Sv with a very large variability. They compared transport time series with Dipole Mode Index (DMI) and found a positive correlation between DMI and the North/South flow.

Shoichi Kizu gave a review of Japanese transect PX-40: sampled over 16 years with T/V Miyagi Maru. The TOLEX line that crossed the Kuroshio was sampled every 2 months from Aug 1988 - Mar 2005 with XBTs and ADCPS (90 transects). The JAHMP transect - Japan to Hawaii – sampled 3/year from Oct 1998 to June 2014 became PX40 in 2002, and included an ADCP after 2003, but ended in June 2014 when costs became too high. In addition unstable tracks due to sea conditions, accidents, operational policy etc. and incomplete transects, and 3/yr was insufficient sampling in highly energetic KE region. The data have been successfully used in estimates of heat transports.

Mauro Cirano discussed the Brazil Current structure and variability: in particular to address the representativeness of the MOVAR-NOAA AX97 High-Density XBT transect. Starting in 2004, they took advantage of line to Trindade Island that the Navy services regularly. To date 90 sections are collected. The study considered how representative this section was for capturing the Brazil Current variability and relate that to the large scale weather, circulation and climate signals. Used a compiled T/S climatology to estimate salinity for the XBT section and a reference level at the 26.8 isopycnal that separates the surface waters with intermediate water masses. The study compared the XBT observations with three model analysis systems, GLORYS, HYCOM and FOAM. Compared the shear of the models to the data (so that the reference level issue is removed). All models overestimate the mean flow, but show reasonable spatial structure. Subsampled models at time of the cruises and confirmed that the models also had a reduced Brazil Current transport (like the observations). Confirmed that the BC sampling of the observations needed to include more near-shore stations to fully capture the Brazil Current. Can find up to 40% of the Brazil Current variability inshore of the XBT section. It is one of their priorities to put an ADCP on the ship, but the ships vary from cruise to cruise.

Marlos Goes discussed the structure and variability of the Brazil Current, the South Atlantic western boundary system that flows south and sheds a lot of eddies. Summer has stronger eddy variability than winter. AX17, AX18, AX97 - can be used together to look at meridional coherence. Improved estimates for the BC (up to 30% of transport on shelf) were achieved by using an updated Salinity lookup based on Argo; extrapolation to the shelf using altimetric SSH; and an SSH height correction. An EOF isolates the mean current and a representation of the eddy variability in modes 1 and 2 (which total 70% of variance). Strong SST anomalies occur in 2010, also with a strong precipitation event that may have been forced by the ocean. The strength of gyre was correlated with SST. High-resolution model results also suggest that precipitation in 2010 may be linked to ocean circulation.

Shenfu Dong presented Interannual variations of the Gulf Stream transport and location from 20 years of XBT measurements. The Gulf Stream transect AX10 NYC to Puerto Rio section has been taking measurements since 1996 (crosses at 72W), with 77 realizations. Gulf Stream may impact mid-latitude storm tracks and intensity. Comparing Sept 2000 to Aug 2005, stronger Gulf Stream temperature gradients are evident including variability in thermostad representing 18°C water and large meridional shift between these two realizations. Indeed, much of the temperature variability is due to these meridional shifts, so they are much less obvious in stream coordinates. It is therefore essential to look in stream coordinates as it tightens up the jet and increases mean and maximum velocity estimate. To compute Gulf Stream location used salinity from Argo monthly averages with an 800 m reference level. Uses maximum cross-stream velocity to specify the current core location and compared it to an altimetric derived cross-front height difference, used as proxy for transport. GS location and transports are negatively correlated (-0.52) but there are no trends in either. Lower transport tends to occur when GS is in a more southerly position and vice versa, but this is the opposite relationship between N/S shift vs mode water formation from Joyce or Molinari. Maximum GS surface velocity is most highly correlated with subsurface velocity (near 400m). Suggests GS strength is linked to mode water formation. Zonal averages of GS properties do show linear trend in time. GS position moving southward, GS speed decreasing. This is driven by variability to the east of 60W and hence AX10 line is not resolving these trends. Suggests that these large scale patterns are associated with large scale climate decadal variability like the NAO. Compared NAO lead/lag correlations of GS with the NAO. It would be useful to compare these results to that determined from Oleander data: Oleander ADCP can also provide the reference velocity at 800m.

Gustavo Goni gave a talk on The South Atlantic Meridional Overturning Circulation. To investigate latitudinal and temporal changes of the MOC & MHT with satellite and XBT observations represents an extension of the Dong et al 2015 paper using altimeter to compute MOC/MHT at several latitudes. This extends the observations of the AX18 section at 34.5S as "ground truth" to train the algorithm to estimate subsurface data from altimetry. Use historical T/S relations from the estimated subsurface T. Heat transport is computed across 35S, 30S, 25S and 20S. At 20S, MOC has a negative trend since 2007, and the MOC dominated by Ekman component from 1992 to 2011. After 2011 the geostrophic component dominates the MOC. At 30S, MOC also have a negative trend since 2007, etc. At 35S, the MOC trend is slightly positive. Also generally more dominated by geostrophic component at various times. Location of the Brazil Current separation has shifted southward over the last 20 years. The MOC is correlated 20-30S yes, but not with 35S.

Theme 3: Exploring the synergy of XBT data with other components of the observing system
Chair: Janet Sprintall

Notetaker: Rebecca Cowley

Thomas Rossby was an Invited Speaker and discussed direct measurements of poleward heat fluxes. Three ships are measuring transports using XBTs and ADCPs: Oleander across the GS, Nuka Arctica (Greenland to Denmark) and Norrona Ferry (Iceland-Faroes, Faroes-Scotland). The Iceland Basin shows significant changes in transport. HADCM3 coupled model outputs are larger than observed velocities. Norrona ferry data shows large variations in the transport, but no evident trend yet. Changes in salinity have also been detected. All data except Nucca Artica are online at URI's web sites:-
http://po.msrc.sunysb.edu/Oleander/
http://oleander.bios.edu/

Molly Baringer discussed North Atlantic Meridional Overturning Circulation (MOC) from XBT observations along AX07 and the RAPID/MOCHA/WBTS project. MOC/MHT changes impact Europe. Transport estimates use a T/S climatology for missing salinity data and data below XBT depths. Using the CTD hydrographic sections comes up with an error from XBTs that is low. Subsampled XBT data gives a good representation of the Florida Current. MHT and MOC are dominated by geostrophic flow, since the line falls in the doldrums. Insignificant seasonal variability is found in both MHT and MOC. When looking at density coordinates, the MOC is ~50% larger. Heat transport is ~0.86PW, MOC transport = 10.1 Sv. Presently examining where the difference between the estimates and the RAPID results comes from. There is little correlation with the South Atlantic XBT transport estimates (SAMOC).

Marlos Goes discussed the impact of measurements from XBTs and other observational platforms on AMOC computations using an OSSE system. How can we improve our observing system using models? XBT transects are useful for transport estimates but we need to fill salinity, temperature gaps using climatology, and there are spatial and temporal gaps. This study assessed the uncertainty of the observing systems by including or excluding features in the model. Is the quarterly sampling of AX18 able to capture seasonal variability? RMSE diagram shows reduction of error with more years of data and increased sampling frequency. Same results were determined for spatial sampling: to adequately resolve the western boundary current needs to reduce the spacing between probes to every 20km instead of 25km. Reference level for velocity is best at ~3.5km. XBT biases also affect AMOC and MHT estimates - manufacturer tolerances account for ~3% and 8% of the AMOC and MHT. The linear depth bias in XBTs gives the biggest affect on the calculations (compared to offset and temperature bias), but it is still relatively small. The study concludes that XBT biases should be corrected for the calculation of long-term trends. More transects would significantly reduce the uncertainty.

Akira Nagano discussed heat transport variation by the North Pacific subtropical gyre interior flow change during 1993-2012. The Kuroshio volume transports were calculated using PXO2 and PX40, PX37. The difference in Temperature between two different time periods is ~0.4°C - is this due to PDO or seasonality? Use an altimetric synthetic method with XBT for temperature and gridded Argo data for salinity. Uses AEGM fields to calculate geostrophic velocities and determined volume transport weighted temperature. The net heat transport compared to the North Pacific Index shows an inverse relationship with a lag of around 1 to 4 years that is thought to be wind-driven.

3. General Discussions

A review manuscript of XBT Science Contributions

Gustavo Goni discussed producing a science summary scientific review manuscript for possible submission to Annual Review of Geophysics. The manuscript would discuss uses and the unique attributes of the XBT program and highlight key scientific results. All were enthusiastic about this project and many contributions are expected to follow. A first draft was sent in September 2016 and expected submission for February 2017. See https://docs.google.com/document/d/1Gf6OTe9NuOf3kNXDQXFJ8xB0x1jlAxp3pYPn7Dl05FE/edit

The state of the most updated XBT FRE

XBT observations are critical to understanding the ocean. Some processes can only be achieved by using XBT transects such as boundary heat flux contributions as XBTs allow us to span basins that cannot be done with other instruments. However the XBT community also needs to work on correcting biases, to keep improving the data, and the community also needs to recognize that we are only achieving 50-60% of our goals and this is partially because we were ambitious. Our goals need to be constantly revisited based on our scientific needs. We need a unified front to further improve the data by deciding on the best current scheme to depth correct our data.

The XBT community recognizes that we need a new, consistent FRE but we are not quite agreed as yet. Still the community recognized that this should be applied as a CORRECTION, and not as a new equation applied going forward. There are also changes in the manufacturer processes over the years that warrant a time-dependent fall-rate correction. What if in 10 years the equation changes again? Do we keep moving the coefficients? Testing is always behind the current production. But the community agreed that all current data submissions should be consistent with the current agreed practice.

The XBT community recognized we need to propose/recommend the best correction currently so scientists can start applying it. CH14 provided various corrections for that recommendation. The XBT community should make a single recommendation for IQuOD for delayed mode data sets. The meeting had vigorous discussion about what correction might be applied universally to the data sets, as well as determine a central repository to provide the best dataset possible transect by transect. GTSPP was the repository for this sort of development, but GTSPP cannot serve data with different equations - this needs to be developed. It was proposed that IQuOD become the official delayed mode source for XBT data, and this can be sub-setted by transect etc depending on availability of metadata.

How can the XBT community enhance its interaction with other observational communities, and increase science and operational impact of its observations?

The XBT community needs a stronger presence in other observational communities. We discussed the importance of having a presence at other observational community meetings such as OceanSites, Argo, altimetry etc. to report on our status and enhance our general interactions with these communities.

4. Action Item Summary

Wrap-up and Conclusions
Chairs: Janet Sprintall and Bec Cowley

Action: Set up task teams from within the XBT Science team to work on producing an updated, improved and reduced error FRE. This effort should include:-

- collection of side-by-side pairs data and recommend future pairs collections, do the comparisons and work with international programs to perform the tests (Bec Cowley, Francis Bringas, John Abrahams, Marlos Goes, Franco Reseghetti, Mauro Cirano)
- Storage/curation and retrieval of side-by-side data (Bec Cowley/Tim Boyer/Thierry Carval/Viktor Gourestki/Franco Reseghetti to co-ordinate with all)
- co-ordinate assessment of pure temperature biases, pure depth biases and offsets (Viktor Gourestki, Franco Reseghetti, Lijing Cheng, Gustavo Goni, Francis Bringas, Catia Domingues, Ishii Masayoshi)

Action: Report to IQuOD Steering Committee that the XBT Science group recommends using CH14 in the “adjusted” fields of the IQuODv0.1 data set release

Action: Provide a global XBT transect ‘product’ for users. This would include assessing existing products and then extending the most useful format to all global transects. This could potentially be provided through WOD. Discuss application of CH14 correction. Bec Cowley/Janet Sprintall/Gustavo Goni

Action: The T5 data is not presently in the pairs database. Follow up on availability of T5 data from the geological surveys - Franco Reseghetti and Tim Boyer

Action: Production of new XBT transect map for SOOP, feedback to JCOMMOPS. Bec Cowley (with some more input from Janet Sprintall/Gustavo Goni, other SOOP operators)

Action: Provide input to Gustavo Goni for XBT Science Paper - all

Action: Next Ocean Science meeting propose a session dedicated to 50 years of XBT measurements - Janet Sprintall, Gustavo Goni.

Action: Indian XBT lines are being discontinued. XBT Science group to send a letter of support. Uday to provide contact information and some details about the problems to Bec Cowley (SOOPIP Chair), Janet Sprintall, Gustavo Goni, Ann Thresher.

Action: Meeting summary to EOS to highlight progress - Janet Sprintall, Gustavo Goni, Lijing Cheng

Action: Next XBT Science Meeting again be joint with IQuOD, given significant overlap of communities, perhaps at the IAPSO meeting to be held in Capetown, South Africa in September 2017. The XBT Science meeting might also be coordinated with the Argo Science meeting, or have a one-day session during the Argo Science meeting.

Appendix A

Meeting Agenda Plan (ver.3; 16 Sep 2016)

Wednesday 5 October 2016

14:00 – 14:10: Welcome, local logistics and Meeting Objectives: Shoichi Kizu and Janet Sprintall

Theme 1: Understanding and correcting XBT biases for climate research

Chair: Shoichi Kizu

Notetaker: Rebecca Cowley

14:10 – 15:10 John Abraham (Invited Speaker): Fall rate biases of XBT devices and new estimates of ocean heat content

15:10 – 15:30 Lijing Cheng: Examining the impact of quality-control processes on XBT bias

15:30 – 16:00 Coffee Break

16:00 – 16:20 Viktor Gourestki: Updating the XBT bias correction scheme

16:20 – 16:40 Lijing Cheng: T5 bias as investigated by both side-by-side data and global scale data

16:40 – 17:00 Tim Boyer: Sensitivity of global upper-ocean heat content estimates to mapping methods, XBT bias corrections, and baseline climatologies

17:00 – 17:20 Nicholas Pittman (in remote, from Australia) : Upper-ocean thermosteric sea level (heat content): Exploring the sensitivity of the CSIRO-ACE CRC IMAS estimates to 10 XBT bias corrections

Thursday 6 October 2016

Theme 1: Understanding and correcting XBT biases for climate research (cont'd)

Chair : Shoichi Kizu

Notetaker: Ann G. Thresher

08:40 – 09:00 Natalia Ribeiro Santos (in remote, from Brazil): An assessment of the XBT fall-rate errors in polar region: an application to the Southern Ocean

09:00 – 09:20 Francis Bringas: Current experiments of XBT fall rate equation at NOAA/AOML

09:20 – 09:40 Francis Bringas: The impact of deployment height and ship velocity on XBT fall rate computations

09:40 – 10:00 Rebecca Cowley: Results from XBT deployment height experiments

10:00 – 10:20 Thomas Rossby: A new XBT deployment technology

10:20 – 10:50 Coffee Break

10:50 – 11:50 Marlos Goes (Invited Speaker): The enhanced XBT probe

11:50 – 12:10 Shoichi Kizu: Sea tests of XCTDs: how are they different from XBTs?

12:10 – 12:50 Discussion: The state of the most updated XBT FRE (Gustavo Goni)

12:50 – 14:00 Lunch

Theme 2: Scientific and operational uses of XBT observations

Chair: Gustavo Goni

Notetaker: Molly Baringer

14:00 – 15:00 Rebecca Cowley (Invited Speaker): Ships of opportunity: Status of the XBT network

15:00 – 15:20 Janet Sprintall: XBT science at SIO

15:20 – 15:50 Coffee Break

15:50 – 16:10 Gopalakrishna Visa: Low frequency variability of western boundary current of the Bay of Bengal as revealed by the 25-year long record of repeated XBT observations

16:10 – 16:30 Shoichi Kizu: A review of Japanese PX-40: 16 years with T/V Miyagi Maru

16:30 – 16:50 Marlos Goes: The structure and variability of the Brazil Current

16:50 – 17:10 Mauro Cirano: Brazil Current structure and variability: the representativeness of the MOVAR-NOAA AX97 High-Density XBT transect

Friday 7 October 2016

Theme 2: Scientific and operational uses of XBT observations (cont'd)

Chair: Gustavo Goni

Notetaker: Molly Baringer

09:00 – 09:20 Shenfu Dong: Interannual variations of the Gulf Stream transport and location from 20 years of XBT measurements

09:20 – 09:40 Gustavo Goni: The South Atlantic Meridional Overturning Circulation

09:40 – 10:00 Discussion: A review manuscript of XBT observation contributions (Gustavo Goni)

10:00 – 10:30 Coffee Break

Theme 3: Exploring the synergy of XBT data with other components of the observing system

Chair: Janet Sprintall

Notetaker: Tim Boyer

10:30 – 11:20 Thomas Rossby (Invited Speaker): Measuring poleward heat fluxes directly

11:20 – 11:40 Molly Baringer: North Atlantic Meridional Overturning Circulation from XBT observations and the RAPID/MOCHA/WBTS project

11:40 – 12:00 Marlos Goes: The impact of measurements from XBTs and other observational platforms on AMOC computations using an OSSE system

12:00 – 12:20 Akira Nagano: Heat transport variation by the North Pacific subtropical gyre interior flow change during 1993-2012

12:20 – 12:50 Discussion: How can XBT community enhance its interaction with other observational communities, and increase science and operational impact of its observations? (Molly Baringer and Gustavo Goni)

12:50 – 13:10 Wrap up and conclusions of the meeting

Plan for the next meeting?

Appendix B: Participants

In alphabetical order, * means remote participation ** means reception only

John Abraham University of St Thomas, USA
Kenichi Amaike Tsurumi Seiki Co., Ltd., Japan
Hiroshi Bandow Assoc. of Int'l Research Initiatives for Environ. Studies, Japan
Molly Baringer NOAA/AOML, USA
Tim Boyer NOAA/NCEI, USA
Francis Bringas NOAA/AOML, USA
Thierry Carval IFREMER, France
Lijing Cheng IAP/CAS, China
Mauro Cirano REMO/UFRJ, Brazil
Christine Coatanoan IFREMER, France
Rebecca Cowley CSIRO, Australia
Steve Diggs Scripps Institution of Oceanography, USA
Catia M. Domingues IMAS - ACE CRC, University of Tasmania, Australia
Shenfu Dong NOAA/AOML, USA
Paul Durak* Lawrence Livermore National Laboratory, USA
Matteo Guideri* Italian Hydrographic Institute, Italian Navy, Italy
Marlos Goes University of Miami/CIMAS and NOAA/AOML USA
Gustavo Goni NOAA/AOML, USA
Visa Gopalakrishna National Institute of Oceanography, India
Viktor Gouretski University of Hamburg, Germany
Kimio Hanawa Tohoku University, Japan
Tetsuro Ino Tsurumi Seiki Co., Ltd., Japan
Masayoshi Ishii MRI/JMA, Japan
Rachel Killick Met Office, UK
Shoichi Kizu Tohoku University, Japan
Alison Macdonald WHOI, USA
Takeharu Miyake Japan Oceanographic Data Center, Japan
Kouji Muneda Japan Oceanographic Data Center, Japan
Akira Nagano JAMSTEC, Japan
Toshiya Nakano JMA, Japan
Matt Palmer* Met Office, UK
Nicholas Pittman* University of Tasmania, Australia
Luca Repetti* Italian Hydrographic Institute, Italian Navy, Italy
Franco Reseghetti* ENEA - Italian National Agency for New Tech., Italy
Natalia Ribeiro Santos* Federal University of Rio Grande - FURG, Brazil
Thomas Rossby University of Rhode Island, USA
Kanako Sato JAMSTEC, Japan
Janet Sprintall Scripps Institution of Oceanography, USA
Toshio Suga Tohoku University/JAMSTEC, Japan
Satoshi Suyama Tsurumi Seiki Co., Ltd., Japan

Toru Suzuki Marine Information Research Center, Japan
Michihiko Tachikawa** Tsurumi Seiki Co., Ltd., Japan
Ann G. Thresher CSIRO, Australia
Hiroyuki Tsuda Tsurumi Seiki Co., Ltd., Japan
TVS Udaya Bhaskar INCOIS, MoES, India

Appendix C: Acronyms

CTD - Conductivity, Temperature, Depth sensor
CH14 - Cheng, L., Zhu, J., Cowley, R., Boyer, T., and Wijffels, S. (2014) Time, Probe Type, and Temperature Variable Bias Corrections to Historical Expendable Bathythermograph Observations. Journal of Atmospheric and Oceanic Technology, 31, 1793-1825, doi: 10.1175/JTECH-D-13-00197.1.
EN4 - Good, S. A., M. J. Martin, and N. A. Rayner (2013), EN4: Quality controlled ocean temperature and salinity profiles and monthly objective analyses with uncertainty estimates, J. Geophys. Res. Oceans, 118, 6704–6716, doi:10.1002/2013JC009067.
OHC - ocean heat content
QC - quality control
SOOPIP – Ship of Opportunity Implementation Panel
WOD - world ocean database (NCEI)
XBT - expendable bathythermograph probe
XCTD - expendable Conductivity, Temperature, Depth probe