6th International XBT Science Workshop
Ostend, Belgium, 18–20 April 2018
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Workshop Participants

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1. INTRODUCTION

The 6th International XBT (Expendable bathythermograph) Science team workshop took place at the IODE Project Office of the Intergovernmental Oceanographic Commission (IOC) of UNESCO, in Ostend, Belgium from 18 to 20 April 2018 following on from the 5th IODE Steering Group for the International Quality Controlled Ocean Database (SG-IQuOD) meeting at the same venue. The workshop was divided into 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 19 scientists participated (4 remotely) from Australia, Brazil, China, France, Germany, India, Italy, Japan, South Africa, 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 global ocean heat content. One focus of the XBT Science team (along with IQuOD) is to improve and understand the accuracy of these historical data in order to assess the uncertainties in this climatically important time series.

The global XBT network is logistically complex and therefore requires strong collaboration between many institutions 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: (i) Monitor the variability of location and transport of key surface and subsurface ocean currents and boundary currents, (ii) Monitor the variability of the meridional heat transport and the Meridional Overturning Circulation and Meridional Ocean Heat Transport across ocean basins, (iii) 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 (iv) 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 of oceanic and climate phenomena.

The objectives of this XBT Science Meeting were:

- Present current results and discuss ongoing scientific 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.
- Discuss advancements to improve XBT data quality: Understanding XBT biases for climate research/operational challenges
- Assess synergies between XBT data and other in situ platforms and remotely sensed data
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 Section 2 followed by action items in Section 3.

The Workshop Agenda is in Annex I and a list of participants in Annex II.

![Figure 1. Global XBT transects that are presently occupied (green) or recommended or previously occupied (red).](image)

2. **XBT SCIENCE PRESENTATIONS**

2.1 **THEME: OCEAN HEAT CONTENT (CHAIR: MAURO CIRANO)**

Rachel Killick: Understanding the contribution of XBT bias correction to OHC uncertainty in the EN4 dataset

This work explored the Ocean Heat Content (OHC) calculated from the EN4 database and the uncertainties arising from XBT correction scheme, climatology choice and calculation methodology. It was found that the largest source of uncertainty arose from the calculation methodology and it was reiterated that the EN4 analyses should not be used for long term OHC trend analysis owing to their dependence on a background climatology. When comparing XBT correction schemes it was found that the Cheng et al., 2014 scheme and the Cowley et al., 2013 scheme were generally the most divergent. It was hypothesised that this could be due to certain XBTs not being corrected by the Cowley et al., 2013 scheme and could also be due to there being less up-to-date year dependent corrections for the Cowley et al., 2013 scheme. This work can be expanded in the future making use of synthetic profiles created at the UK Met Office and also making use of the intelligent metadata work of the IQuOD community.

Lijing Cheng: Examining the uncertainty in components of sea level budget: reduction of uncertainty related to XBT bias.

Global Mean Sea Level (GMSL) change is an integrated metric for climate change because it synthesizes both oceanic and cryosphere responses to anthropogenic global warming,
including ocean warming, ice sheets/glaciers melting and land-ocean water exchanges. Steric Sea Level (SSL), due to ocean warming and expansion, is the dominant component of the GMSL change. Here we quantify the uncertainty in SSL estimate induced by mapping method, XBT bias correction and choice of salinity field separately. We find that mapping method is the major source of error in SSL, which 2 standard error changing from 10-14 mm during 1940s to about 1 mm after 2005. Uncertainty due to XBT correction is comparable the uncertainty due to the choice of salinity field, which ranges from 0.5 to 2 mm after 1966. We further show that the three different source of uncertainty has distinctive spatial pattern: the mapping method induced larger uncertainty in Southern Hemisphere because of the sparseness of available observations. But the major impact of XBT bias correction is in subtropical oceans (10-30°S/N).

Timothy Boyer: The path of XBT data through the global oceanographic data system.

Adjusting XBT data for climate research has been a critical element of study observational oceanography for more than 10 years. One of the challenges in adjusting XBT data is gathering sufficient metadata to understand which adjustment to make and also understanding manufacture, collection techniques, and data recording and archiving processes. Outlining the history of XBT collection gives us some perspective on the limitations of data delivery and accuracy of early strip chart mechanisms, the switch to satellite and digital methods in the 1980s and the formalization of near-real time and delayed-mode data delivery with the advent of the Global Temperature and Salinity Profile Project (now Program; GTSPP) in 1990. Further the understanding of the different factors – drop rate, year of manufacture of probe, ship height, etc. has been slowly revealed over the years and not always sufficiently communicated to those delivering the data. This has left a metadata deficit which in many cases still needs to be addressed in historic data, and even in modern data going forward.

2.2 THEME: OCEAN TEMPERATURE AND HEAT TRANSPORT (CHAIR: GUSTAVO GONI):

Tata vs Udaya Bhaskar: Seasonal variability of temperature inversions in the Tropical Indian Ocean - A view from XBT and Argo.

The temperature inversions (TIs) in the Tropical Indian Ocean (TIO) was studied using all the profiles from XBT and Argo spanning the years 2001 - 2017. All the data were segregated into months irrespective of years and are gridded onto regular grid with a resolution of 1X1. The monthly climatology thus generated was used to study the seasonal variability of TIs in TIO. From the data it was observed that TIs formed near to Sumatra coast during April and then travelled along the coast of Bay of Bengal and reached the South Eastern Arabian Sea during February. The coastally trapped Kelvin waves along with the EICC are responsible for this mechanism.

Marlos Goes: TS relationship studies for XBT currents and meridional heat transport assessments.

Simultaneous temperature and salinity profile measurements are important for data assimilation and to determine water masses, currents, and stratification in the ocean. Here we introduce an updated method to estimate salinity from temperature profiles in the Atlantic (75S-60N) domain. We compare four different methodologies, two using local mean salinity and mean TS profiles, and two using regression techniques at each depth and horizontal location. The regression methods improve over the mean profiles techniques. Moreover, using seasonal harmonics instead of horizontal location as predictors in the regression methods, reduces the residual error in the top 150 m of the ocean. The sensitivity of the
meridional overturning and meridional heat transport calculations across 35S to the salinity estimated using these methods is performed.

Franco Reseghetti and L. Repetti: Trial of field intercomparison between strip chart and digital recording systems

In an early manual published in 1975, Sippican (now Lockheed Martin Sippican) described some characteristics of strip chart recording systems that are critical for a good acquisition (such as the speed of the chart driver and the duration of the acquisition mode). Later (IOC/INF.888 + ADD), Sippican stated that its digital recording systems correct the non-linear R to T equation in the computer while the chart recorders use a non-linear grid in order to apply such a correction. The driver speed and the duration of the acquisition has been measured for three different instruments still active on some unit of the Italian Navy. In March 2017, a short field comparison between XBT recorded by an analogic strip chart device and by a MK21 Ethernet was also done, even but for a total of 4 pairs contemporaneously deployed in a shallow area (110-120m depth). In addition, the launching platforms were at different height (H = 2.5m for the analogic recorder and H = 5m for the digital recorder) and XBT probes of different type were dropped (Sippican T4 for the analogic recorder and Sippican T10 for MK21 Ethernet). There is a rough agreement between the shape of the compared profiles, without evident systematic errors (only the last strip chart profile has an anomaly in the region close to the surface). Due to small sample it is impossible to apply any statistical analysis. It is planned to repeat the test with a larger sample of profiles and in a region with deeper bottom to evaluate the characteristics over a full profile. The precious help of Italian Navy and Italian Hydrographic Institute made possible this work.

G. Raiteri and F. Reseghetti: XBT vs. ARGO: reliability of XBT profiles from SOOP in the Mediterranean Sea (preliminary results)

The preliminary results of the comparison in the Mediterranean Sea between XBT profiles recorded during the SOOP activity with commercial ships (since Sept. 1999) and Argo profiles (since May 2004) are shown. The criteria for selecting the pairs of profiles are the following: |ΔLat| ≤ 0.1°, |ΔLong| ≤ 0.15°, |ΔTime| ≤ 7 days, |ΔDepth| ≤ 1m (the Rossby radius in that areas is close to 10 km while the cycle of Argo floats is 5 or 10 days). 115 pairs are obtained from 73 different XBT probes and 18 floats and the mean ΔT calculated over the whole water column is +0.14°C (but the median is +0.07°C) with St.Dev. = 0.53°C. If the region 0-100m (where thermocline is occurring) is excluded, ΔT = +0.06°C (the same value as for the median) with St.Dev. = 0.11°C. Therefore, XBT measurements below the near surface layer have ΔT = +0.06°C with 0.11°C as uncertainty on the value (slightly better than suggested by the manufacturer), independently on correction to the depth values. These values can be assumed as upper limit of the XBT capabilities in the measurement process in such an area. Further analyses are running. It should be highlighted that it is also necessary to consider uncertainties due to error measurements that all the equipment has. Also CTD and Argo showed a variability of behavior in operational situations that is probably greater than desired. Within the verification of these phenomena, it should also be noted, for example, the work undertaken by some Italian researchers concerning the uncertainties associated with T and S measurements in coastal areas.

2.3 THEME: IMPROVED XBT DATA: XBT BIASES

(CHAIR: MOLLY BARINGER)

Francis Bringas: XBT fall rate experiments for different probe weights, launch heights and ship speeds.

A series of experiments were conducted to study the impact of the deployment height, the ship speed and the probe weight variations on the XBT fall rate. The experiments included:
• Collect simultaneous XBT/CTD profiles, with XBTs deployed from different heights with the ship at rest.
• Collect XBT profiles with XBTs deployed from different heights with the ship moving.
• Determine the weight variations of the different components of XBT probes manufactured in different years.
• Verify and quantify the depth offset caused by the deployment height and estimate the depth bias in the profiles caused by the observed weight variations.

At sea experiments confirm previous result obtained in fresh water of a depth offset caused by the deployment height. This depth offset can be corrected by using a methodology proposed in BG15. The ship speed was not observed to be a factor in the depth offset for XBT profiles with different deployment heights. A maximum weight variability of ~ 15 g was observed for Deep Blue XBTs manufactured between 1996-2017. The wire was found to be responsible for ~ 80% of the total weight variability. This observed maximum variability represent a depth bias of 1.2% of the depth, more than half of the 2% depth uncertainty from the manufacturer.

Mauro Cirano: An assessment of the XBT Fall-Rate Equation in the Southern Ocean

In this study a set of 157 collocated XBT (DB/T7 type) and CTD stations distributed across three different regions of the Southern Ocean is explored using the manufacturers fall-rate equation (FRE), which is a classic correction method, and new correction methods to investigate how the regional environment characteristics may impact a probes descent and the corresponding depth estimates. Regional coefficients were estimated for all three basins and for the Southern Ocean as a whole. The manufacturers FRE proved to perform better in high latitudes than in the rest of the World Ocean, overestimating the true depth by only 2%. The overall depth bias was positive, further supporting the hypothesis of a regional dependence of the XBT fall rate on water temperature, which leads to a general overestimation of ocean heat content in the upper layer (~4.793109J or 10%). The pure thermal bias was found to be mostly negative, which is likely to be related to temperature errors. However, the Southern Ocean region is notoriously undersampled when compared to the rest of the World Ocean as well, as it is associated with strong spatial and temporal variability, thus raising the overall uncertainty on that estimate. Moreover, although the manufacturer has a satisfying performance in the Southern Ocean, the current community recommended correction method still leads to improved temperature values in those waters. Finally, more studies are needed in order to fully understand the XBT regional bias and its implications for climate studies in the region.

Charles Sun and Norman Hall: Logic of the Depth Correction Process for Archived XBT Data

1. Overview

In the mid-1990s it was found that some the fall rate (depth-time) equations provided by the manufacturers of expendable bathythermographs (XBTs) were not correct. Through work carried out by Hanawa, Paul, Bailey, Sy, and Szabados (Hanawa, K. et.al, 1995), it was found that Sippican and Tsurumi-Seike (TSK) T-7, T-6, and T-4 type XBTs fall faster than the rate given by the manufacturers’ depth-time equation. The computed depth errors are outside the manufactures' specifications. The International Oceanographic Commission publication entitled Calculation of new depth equations for expendable bathythermographs using a temperature-error-free method (application to Sippican/TSK T-7, T-6 and T-4 XBTs) (IOC Technical Series, 42, 1994) is the earliest reference to the problem and what can be done (UNESCO, 1994).
The NOAA National Centers for Environmental Information (NCEI) hosts the Long-term Archive Center (LAC) of the Global Temperature and Salinity Profile Programme (GTSPP), a joint World Meteorological Organization (WMO) and Intergovernmental Oceanographic Commission (IOC) programme designed to provide improved access to the highest resolution, highest quality data as quickly as possible. GTSPP LAC has preserved XBT data in the GTSPP Continuously Managed Database (CMD). It was suggested at one of the GTSPP data management meetings that LAC should work with its partners from Canada's Integrated Science Data Management (ISMD) and Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) to develop logic for the depth correction process.

The purpose of this write-up is to describe a logic of action to correct XBT depths for the fall rate problem.

2. Correction Strategy

The best strategy seems to divide the archives into two periods. The first period covers the time before the fall rate problem was known and the second after. The suggested division date is 1 January, 1995. Before 1995, XBTs would certainly have used the manufacturer's equations and therefore are guaranteed to have fault depths. It is then a question of identifying those profiles coming from XBTs and what probe type was used.

After this date, we have a mix of measurements with some having used the manufacturers fall rate and some using the new fall rate. So, during this period, we must not only identify XBTs and probe types but also determine what fall rate equation was used.

2.1. Identifying XBTs

Having partitioned archives by the date of collection, it is then necessary to determine which profiles are from XBTs and which are not. Once this is decided, information about the probe and fall rate can be exploited.

GTSPP LAC identifies XBT probes in the archives by querying data type, XBT probe type and fall rate equation stored in the database. The profiles of XBT probes are sorted into three categories: (1) Needs correction, (2) Doesn’t need correction, and (3) Undecided, because we do not have enough information for making depth correction decisions.

2.2. Making the fall rate correction

GTSPP LAC wrote depth correction programs for profiles having sufficient information about what probe type was used and the fall rate equation. Two algorithms for conversion from old to new depths will be used are: (1) the best linear approximation equation: \( Z_{\text{new}} = 1.0336 Z_{\text{old}} \) and (2) the new depth-time equation provided by the XBT manufacturers, \( Z_{\text{new}} = a m t + b m t^2 \), where \( Z_{\text{new}} \) is the corrected depth, \( am \) and \( bm \) are the new manufacturers fall rate coefficients, and \( t \) is the time of fall. The time, \( t \), can be obtained by solving the old depth-time equation. All conversion programs will be well documented and available to the users.

2.3. Preserving the changes in the archives

GTSPP LAC does not make depth corrections on the archived XBT data. However, if the DACs did make depth corrections, GTSPP LAC preserves the old depths by moving them to a different table, loads new corrected depths by the GTSP Data Assembly Centers (DACs) and use the existing database ID to link the new depths to old ones in the database. In addition, a new surface code, called “DPC$”, is created in the surface group table and attached to all profiles that are examined. It will have the following states:
01 = Known Probe Type, Needs Correction,
02 = Known Probe Type, No need to Correct
03 = Unknown Probe Type, Not enough information to know what to do, leave alone,
04 = Correction was done, and
05 = Unknown Probe Type, but a correction was done.

3. **World Ocean Circulation Experiment Upper Ocean Thermal DVD**

When GTSPP played a key role in the World Ocean Circulation Experiment (WOCE) and contributed to the final WOCE Data Resource DVD, the decision was made by the data product committee of WOCE that all XBT depths on the WOCE UOT (Upper Ocean Thermal) DVD shall have depths corrected.

Having determined which profiles are from XBTs by querying the data type, the XBT probe type and the fall rate equation stored in the XBT archives, GTSPP LAC used the “standard” depth correction equation agreed by the GTSPP team to simply multiply the existing depths by a factor of 1.0336. This was the technique employed with the multiplication factor stored in the file structure. The new surface code, “DPC$”, described in Section 2.3, was modified accordingly and ensured that all depth correction information described above are attached in the DVD.

4. **Coordinating the changes**

There will be need for some degree of coordination on the depth correction process in the future. GTSPP LAC continues coordinating within its partners to ensure identical implementations and recording of results.

**Lijing Cheng and Franco Reseghetti: Reliability of measurements with Sippican T5&T5/20 and preliminary results for Sippican T10 probes**

Despite the small number of probes compared to the total amount of XBT profiles, T5&T5-20 profiles represent a significant part of the measurements available at depths> 900 m, so an evaluation of their consistency is important. The data set used in this analysis consists of only two specifics field comparisons while the remaining profiles are extracted from the WOD or provided by colleagues. The selection criteria for the comparison are: |ΔLat| ≤ 0.05°, |ΔLong| ≤ 0.07°, |ΔTime| ≤ 2 h., with marginal differences depending on the area, for a total of 357 pairs (from 1990 to 2017), mainly in the North Atlantic. The fall rate coefficients were calculated through an improved version of Cheng et al. (2011), using a variable depth window (depending on depth), in order to better capture the thermal structures in the profile. The A and B values thus obtained are very close to those calculated in Boyd & Linzell (1993). The values for each subset do not show a great difference in the depth value when compared with the results obtained with the Sippican coefficients (difference in depth <2% almost everywhere). A dependence on water temperature has been identified (higher than for other XBT types) with increased speed in warmer waters, as well as on the weight of the probe and the diameter of the hole in the zinc nose. For both the cases there is a slightly decreasing falling speed as the values increase. The error on the temperature values after applying the new fall rate equation is dependent on water temperature and depth, even if this dependency seems to be fully attributable to the influence of water pressure on the thermistor, as suggested by Roemmich and Cornuelle (1987). Results from field tests and from the global scale analysis are not too close (discrepancy is increasing in recent years) while there is a significant and unexplained difference in the pure temperature error. Sippican
T10 is the XBT version that reaches the lowest depths. Linear density of the wire, nose diameter, diameter of the central hole of the zinc nose and weight in air for probes manufactured since 2011 are all within the range of values communicated by Sippican. Field tests vs. CTD have been conducted since 2011 in the Mediterranean for a total of 48 pairs of profiles. The shortness of T10 profiles makes a little harder the calculation of the fall rate coefficients, moreover the deceleration term has a negligible influence on the depth calculation. Preliminary A and B values are higher than those declared by Sippican, with a correlation between the water temperature and A. Pure temperature error seems to be almost constant after the application of new fall rate coefficients. Analyses on larger datasets are still running.

**Toru Suzuki and Team XBT - Japan: Digitization of XBT profiles**

We traced XBT profiles in 1980's by chart recorder in order to recover them as vertically high resolution profiles as same as recently data by digital converter. In this process we we recognized that temperature scale of strip chart is not linear and it is undocumented information, so that we also traced horizontal axis as the same manner as temperature profile and determined correction functions as traced temperature. Those traced and collected temperatures are correspondent with visual reading temperature which are stored in existing database. It is clear that we can replace visual reading temperature at standard depths with the recovered and vertically high resolution temperature profiles.

**Guilherme Castelao: Hands-on demonstration of an Expert QC system**

A new methodology to quality control (QC) profiles of temperature was presented. The novelty comes from the use of Machine Learning which approximates the speed of the automatic QC to the high-level manual classification from an expert. Such approach allows improving the quality of real time streamed data as well as re-assess large volumes of historical data. Finally, the web interface to train this classification system was demonstrated.

**Francis Bringas: Discussion Leader: Improvement of XBT Data Quality**

According to the manufacturer (Lockheed Martin Corporation) the accuracy of XBT probes is ± 0.1°C in temperature and ± 2% in depth. XBTs are widely used for applications including:

- Ocean current monitoring and variability,
- Trans basin Meridional Heat Transport,
- Front Identification,
- Eddies and ring characterization,

In addition, the data accuracy can be improved for applications such as Global ocean heat content estimates.

Different studies have been conducted in order to improve the data quality and accuracy. These studies include:

- Assessment of XBT biases from the co-located side-by-side inter-comparisons,
- Assessment of XBT biases from inter-comparison of binned reference and XBT data,
- Effects of different XBT correction schemes on ocean heat content calculations,
- Numerical studies of the XBT fall rate,
Managing the modern XBT data stream.

There is currently ongoing research in other areas such as:

- The influence of launch height and ship speed on the fall rate in the first few seconds.
- The impact of recorder system type on pure thermal bias.
- Laboratory testing of temperature bias dependence on water temperature.

A recommendation was made during the XBT Science Meeting to create a group within the XBT Science Team to assess the effectiveness of different correction methods and update the recommended correction scheme as needed.

2.4 THEME: BOUNDARY CURRENTS (CHAIR: RACHEL KILLICK)

Emma Heslop: Boundary Currents in the Mediterranean

A 6.5 year time series of quasi-continuous ocean glider endurance line observations are shown across the Ibiza Channel, a key ‘choke’ point in the Mediterranean basin-scale circulation. This ‘choke’ point governs the north/south exchange of different water masses, resulting in a multi-scale variability that affects shelf and open ocean ecosystems, including the spawning grounds of Atlantic Bluefin tuna. Through this long-term monitoring (SOCIB - Balearic Ocean Observing and Forecasting System) we have observed continuous high frequency (days-week) variability in the basin-scale circulation, significant interannual shifts in water mass and changes in heat exchange.

The presentation also discussed possible strategies for long-term monitoring of boundary currents. Where are the gaps and what is the main challenge to maintaining a boundary current array?

Molly Baringer: Gulf Stream studies

The Gulf Stream (GS) properties (position, transport, and speed) derived from satellite altimeter sea surface height (SSH) measurements are analyzed in the region from 80°W to 50°W. During the study period 1992-2017, the GS experiences a strong southward shift dominated by the region east of 65°W after the GS passes the New England Seamount. This southward shift is accompanied by a weakening of the GS, associated with the SSH increase to the north of the GS.

Marlos Goes: The Brazil Current

The seasonal and interannual variability of the Brazil Current (BC) across 22S is studied from a reconstruction using the AX97 XBT transect data and satellite altimetry since 1993. The seasonal cycle of the BC transport is improved from the original XBT only data estimates, which is aliased by the strong mesoscale activity in the region. The integrated wind stress curl across the basin (Sverdrup transport) is out-of-phase with the estimated BC transport, which is explained by the strong influence of the local winds on the BC. At interannual timescales, the BC is forced by both local winds and Sverdrup transport, the later with a lag of 19 months which agrees with propagating patterns of sea level across the basin. The BC transport is shown to be important for heat advection along the western boundary, potentially giving predictability for extreme summer precipitation events in South America.

Katherine Hutchinson: Variability of the oceans around South Africa, from seasonal to interannual and how it all started with XBTs
A comparison between direct and collocated XBT-CTD pairs in the Southern Ocean south of Africa (line AX25) revealed that XBT data possessed a positive net temperature bias. The total mean bias for all collocated pairs was found to be 0.101 ± 0.024 degC, and 0.130 ± 0.064 degC for the simultaneous subset. An investigation into the magnitude of the depth offset showed generally positive depth biases. This indicated an overestimation of depth by the fall rate equation, likely due to the slower fall rate than predicted in this high latitude area where the ocean is colder, and thus more viscous than the global average. A sizeable variation in bias between frontal zones was observed, along with an increase of net bias in regions of steeper temperature gradient (as expected). The significant variation in net bias between frontal zones exposes the need to address this problem in XBT profile correction schemes.

2.5 THEME: XBT GLOBAL NETWORK

Tom Rossby: Expanding and repurposing the use of expendable probes in the sustained ocean observation

Francis Bringas: The Ship Of Opportunity Program Implementation Panel (SOOPIP) Report

The Ship Of Opportunity Program (SOOP) is an international program mainly involved in the implementation, maintenance, enhancement, and data management of upper ocean measurements from Ships Of Opportunity (SOO), including:

- Expendable BathyThermographs (XBTs) but not limited to SOO,
- ThermoSalinoGraphs (TSGs),
- pCO$_2$ systems.

Additionally, SOOP supports other observational platforms, including the deployment of drifters and profiling floats.

The following is a summary of the current status and activities in the SOOP:

- Incorporation of CO$_2$ network into SOOP
- Reducing uncertainty in air-sea flux in CO$_2$ and quantification of temporal and spatial variability
- Review of metadata requirements for platforms and observations continues
- Submission of platform registration at JCOMMOPS
- Scientific research focus on boundary currents and trans-basin meridional heat transports
- Operational focus on validation of products obtained from numerical modelling and data assimilation
- Around 90 yearly scientific publications using XBT data
- There are ~70 active XBT ships
- There are ~ 50 automated underway CO2 systems
- The XBT Network is implemented with the participation of 12 institutions globally
- Data distribution in real time via GTS
- Supports VOS and GOSUD data acquisition, and Argo deployments
- 36 XBT lines: 32 active lines, 2 inactive lines (ship issues), 2 lines with limited data-sharing
• Approximately 15,000 XBTs are deployed per year on repeat transects and 2,000 elsewhere
• Several transects have provided repeat data for more than 20, 30 years.

Future plans and activities include:
• Improve submission rates of XBT metadata to JCOMMOPS
• Implement robust, sustained efforts to maintaining and tracking the network
• Maintain existing transects; recruit ships on inactive priority lines
• Harmonize with other panels in need of volunteer ships, and
• Migrate to unique ID scheme.

3. ACTION ITEMS

1. **Action** – provide inventory of NCEI XBT data that does not have metadata to AOML, SIO and CSIRO so that we can provide feedback to NCEI of possible missing information.
   
   **Who**: Tim Boyer and Charles Sun to provide information to Gustavo Goni, Janet Sprintall and Bec Cowley.
   
   **When**: September 2018.

2. **Action** – Form an XBT Data Quality Improvement Working Group that composes of XBT Science and IQuOD members to unify efforts leading to continuous improvement of the XBT profile data set.
   
   **Who**: Lijing Cheng (lead), Victor Gouretski, Shoichi Kizu, Franco Reseghetti, Francis Bringas, Gustavo Goni, John Abraham
   
   **When**: May 2018.

3. **Action** – Provide input to the OCG (Observation Coordination Group) in mid-May through the SOT chair (Darin). Provide him with a 1-page discussion on the outcomes of this meeting.
   
   **Who**: Gustavo Goni.
   
   **When**: May 2018.

4. **Action** – Request action to OCG (via Emma Heslop) that they initiate a connection of the XBT community with other observing system communities (e.g. gliders) to promote discussion on how to develop an integrated multi-platform observing system of boundary currents.
   
   
   **When**: May 2018.

5. **Action** – Contact BOON to directly initiate collaborative efforts to investigate BC monitoring strategies.
   
   **Who**: Gustavo Goni and Janet Sprintall.
   
   **When**: May 2018.

6. **Action** – EOS article summarizing the XBT Science meeting.
   
   **Who**: Janet Sprintall and Gustavo Goni.
When: May 2018.

7. **Action** – Develop a best practices manual for different components of XBT deployment, processing (e.g. like CSIRO cookbook etc.), fall rate correction (start with Cheng et al., 2014). Include applications for broader community. Frontiers Science have a (Best Practices) journal where this might be a good research topic.

**Who**: Janet, Charles, Uday, Justine, Franco, Francis, Bec, co-ordinate with Tim through auto-QC IQuOD.

**When**: September 2018.

8. **Action**: Update XBT membership to include all those interested in joining the XBT Science team. Membership is open to all. [http://www.aoml.noaa.gov/phod/goos/xbtscience/members.php](http://www.aoml.noaa.gov/phod/goos/xbtscience/members.php)

**Who**: All – let Gustavo know.

**When**: May 2018.

9. **Action**: Toru Suzuki to provide the digitized XBT data to Tim Boyer to be included in the NCEI.

**Who**: Toru Suzuki.

**When**: May 2018.

10. **Action**: Provide transect mode geostrophic velocity and temperature data for the high resolution/frequently repeated transects. This is useful for modelers for comparison purposes. Investigate who to host. Important to also provide NCEI with information on what casts are associated with what transect line so as they can serve the data to users so as to maintain the cohesive nature of the HR/FR-XBT data set.

**Who**: Catia (determine CSIRO host), Janet Sprintall, Gustavo Goni, Bec Cowley, Uday (and other PIs responsible for active HR/FR XBT transect networks). Tim Boyer to inform as to how best to provide information on casts associated with each transect on each transect line.

**When**: 2019.

11. **Action**: Decision whether to increase the frequency of Australian led PX11/IX22?

**Who**: SOOPIP decision (Bec Cowley).

**When**: 2019 SOOP meeting.

12. **Action**: Write a popular article for The Conversation about XBT science.

**Who**: Katherine Hutchinson.

**When**: September 2018.
# ANNEX I

## AGENDA OF THE MEETING

**Wednesday, 18 April 2018**

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
</tr>
</thead>
<tbody>
<tr>
<td>14:00 - 14:05</td>
<td>Welcome and Logistics (Pieter Pissierssens, Janet Sprintall, Gustavo Goni)</td>
</tr>
<tr>
<td>14:05 - 15:05</td>
<td>Ocean heat content session (Chair: Mauro Cirano):</td>
</tr>
<tr>
<td>14:05 - 14:25</td>
<td>Rachel Killick: Understanding the contribution of XBT bias correction to OHC uncertainty in the EN4 dataset</td>
</tr>
<tr>
<td>14:25 - 14:45</td>
<td>Lijing Cheng: Examining the uncertainty in components of sea level budget: reduction of uncertainty related to XBT bias.</td>
</tr>
<tr>
<td>14:45 - 15:05</td>
<td>Timothy Boyer: The path of XBT data through the global oceanographic data system.</td>
</tr>
</tbody>
</table>

**15:05 - 15:30**  Tea Break

**15:30 - 16:00**  Discussion (Chair: Catia Domingues): Understanding XBT biases for climate research

**16:00 - 17:00**  Ocean Temperature and Heat Transport (Chair: Gustavo Goni):
<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
</tr>
</thead>
<tbody>
<tr>
<td>16:00 - 16:20</td>
<td>Tata vs Udaya Bhaskar: Seasonal variability of temperature inversions in the Tropical Indian Ocean - A view from XBT and Argo</td>
</tr>
<tr>
<td>16:20 - 16:40</td>
<td>Marlos Goes: TS relationship studies for XBT currents and meridional heat transport assessments</td>
</tr>
<tr>
<td>16:40 - 17:00</td>
<td>Franco Reseghetti: Argo-XBT comparison in the Mediterranean and Strip chart vs Digital comparison of XBT profiles</td>
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</tbody>
</table>

**Thursday, 19 April 2018**

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
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</thead>
<tbody>
<tr>
<td>08:30 - 10:30</td>
<td>Improved XBT data: XBT errors and biases and processing (Chair: Molly Baringer)</td>
</tr>
<tr>
<td>08:30 - 08:50</td>
<td>Francis Bringas: XBT fall rate experiments for different probe weights, launch heights and ship speeds.</td>
</tr>
<tr>
<td>08:50 - 09:10</td>
<td>Mauro Cirano: An assessment of the XBT Fall-Rate Equation in the Southern Ocean</td>
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<tr>
<td>09:10 - 09:30</td>
<td>Charles Sun: Managing XBT data in the global temperature-salinity profile program (GTSSPP) database</td>
</tr>
<tr>
<td>09:30 - 09:50</td>
<td>Lijing Cheng and Franco Reseghetti: Update to T5 corrections and Examining T10 biases</td>
</tr>
<tr>
<td>09:50 - 10:10</td>
<td>Toru Suzuki Digitization of XBT profiles</td>
</tr>
<tr>
<td>10:10 - 10:30</td>
<td>Guilherme Castelao: Hands-on demonstration of an Expert QC system</td>
</tr>
<tr>
<td>Time</td>
<td>Session</td>
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<tr>
<td>10:30 - 11:00</td>
<td>Morning Tea</td>
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<tr>
<td>11:00 - 11:10</td>
<td>Discussion of improvement of XBT data quality (Chair: Francis Bringas)</td>
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<tr>
<td>11:10 - 12:30</td>
<td>Ocean Currents (Chair: Rachel Killick)</td>
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<tr>
<td>11:10 - 11:30</td>
<td>Emma Heslop Boundary Currents in the Mediterranean</td>
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<tr>
<td>11:30 - 11:50</td>
<td>Molly Baringer: Gulf Stream studies</td>
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<tr>
<td>11:50 - 12:10</td>
<td>Marlos Goes: The Brazil Current</td>
</tr>
<tr>
<td>12:10 - 12:30</td>
<td>Katherine Hutchinson: Variability of the oceans around South Africa, from seasonal to interannual and how it all started with XBTs</td>
</tr>
<tr>
<td>12:30 - 14:00</td>
<td>Lunch</td>
</tr>
<tr>
<td>14:00 - 14:30</td>
<td>Discussion (Chair: Molly Baringer). Developing sustained arrays in boundary currents from various platforms. How to integrate various observational platforms that monitor boundary, surface, and subsurface currents with different time and spatial resolution? How to entrain other ocean observing communities?</td>
</tr>
<tr>
<td>14:30 - 15:00</td>
<td>Discussion (Chairs: Gustavo Goni and Janet Sprintall). Outline of OceanObs 2019 Global XBT Network community white paper and writing assignments</td>
</tr>
<tr>
<td>15:00 - 15:20</td>
<td>Afternoon tea</td>
</tr>
<tr>
<td>15:20 - 15:30</td>
<td>Action items from 5th XBT Science Meeting (Chair: Janet Sprintall) Providing transect mode temperature and geostrophic velocity data - where to host?</td>
</tr>
<tr>
<td>15:30 - 16:00</td>
<td>SOOPIP: Status of XBT observations and line/transects, discussion of prioritization of lines, international membership of SOOPIP (Chair: Uday Bhaskar)</td>
</tr>
<tr>
<td>15:30 - 15:40</td>
<td>Tom Rossby: Expanding and repurposing the use of expendable probes in the sustained ocean observation</td>
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<tr>
<td>15:40 - 15:50</td>
<td>Francis Bringas: SOOPIP report</td>
</tr>
<tr>
<td>15:50 - 16:00</td>
<td>General Discussion</td>
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<tr>
<td>16:00 - 16:30</td>
<td>International participation and reports (Chair: Marlos Goes)</td>
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<tr>
<td>16:00 - 16:30</td>
<td>Janet Sprintall: XBT Science at SIO</td>
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<td></td>
<td>Gustavo Goni: XBT Science at AOML</td>
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<td></td>
<td>Other international reports and discussion</td>
</tr>
<tr>
<td>16:30 - 17:00</td>
<td>Meeting Wrap-up, Action Items (Chairs: Janet Sprintall and Gustavo Goni)</td>
</tr>
</tbody>
</table>

Friday, 20 April 2018

09:00 - 12:00 | XBT Action Item Discussions (Chairs: Janet Sprintall and Gustavo Goni) |
ANNEX II

LIST OF PARTICIPANTS

Tim BOYER
NOAA, National Oceanographic Data Centre, Silver Spring, United States of America

Molly BARINGER
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Tata VS UDAYA BHASKAR
Indian National Centre for Ocean Information Services, India
ANNEX III

LIST OF ACRONYMS

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
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<tbody>
<tr>
<td>BC</td>
<td>Brazil Current</td>
</tr>
<tr>
<td>CMD</td>
<td>Continuously Managed Database</td>
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<tr>
<td>CSIRO</td>
<td>Australia's Commonwealth Scientific and Industrial Research Organisation</td>
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<tr>
<td>DAC</td>
<td>Data Assembly Center</td>
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<tr>
<td>FRE</td>
<td>fall-rate equation</td>
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<tr>
<td>GMSL</td>
<td>Global Mean Sea Level</td>
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<tr>
<td>GS</td>
<td>Gulf Stream</td>
</tr>
<tr>
<td>GTSPP</td>
<td>Global Temperature and Salinity Profile Project</td>
</tr>
<tr>
<td>IOC</td>
<td>Intergovernmental Oceanographic Commission</td>
</tr>
<tr>
<td>IODE</td>
<td>International Oceanographic Data and Information Exchange</td>
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<tr>
<td>ISMD</td>
<td>Integrated Science Data Management</td>
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<tr>
<td>NCEI</td>
<td>NOAA National Centers for Environmental Information</td>
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<tr>
<td>OHC</td>
<td>Ocean Heat Content</td>
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<tr>
<td>QC</td>
<td>Quality Control</td>
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<tr>
<td>SG-IquOD</td>
<td>Steering Group for the International Quality Controlled Ocean Database</td>
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<tr>
<td>SOCIB</td>
<td>Balearic Ocean Observing and Forecasting System</td>
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<tr>
<td>SOO</td>
<td>Ships Of Opportunity</td>
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<tr>
<td>SOOP</td>
<td>Ship Of Opportunity Program</td>
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<tr>
<td>SOOPIP</td>
<td>Ship Of Opportunity Program Implementation Panel</td>
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<tr>
<td>SSH</td>
<td>sea surface height</td>
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<tr>
<td>SSL</td>
<td>Steric Sea Level</td>
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<tr>
<td>TI</td>
<td>Temperature Inversion</td>
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<tr>
<td>TIO</td>
<td>Tropical Indian Ocean</td>
</tr>
<tr>
<td>TSG</td>
<td>ThermoSalinoGraphs</td>
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<tr>
<td>UNESCO</td>
<td>United Nations Educational, Scientific and Cultural Organization</td>
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<tr>
<td>WMO</td>
<td>World Meteorological Organization</td>
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<tr>
<td>WOCE</td>
<td>World Ocean Circulation Experiment</td>
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<tr>
<td>XBT</td>
<td>Expendable bathythermograph</td>
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