Upper-ocean heat content: observational analyses and uncertainties
OHC estimates

- Differences in upper-ocean heat storage between analyses/periods.

- Differences in "interannual to decadal variability" between analyses.

Abraham et al. (2013) (in review: Rev. Geophys.)
Spread in the OHC analyses mainly reflects the sensitivity of the calculations to different choices of:

- quality, types, and amount of data included
- correction for instrumental biases
- mapping approach
- climatological reference

Palmer et al. (2010); Lyman et al. (2010); Abraham et al. (2013)
World Ocean Database: contains a large and changing mix of instruments with various accuracies and biases

Large fraction of the historical record

Source: Tim Boyer, NODC/NOAA
Numerous proposed XBT bias corrections posterior to Gourestki and Koltermann (2007)

Fig. 1. The total number of XBT profiles by year, split by probe type and manufacturer, in the WOD09. Sippican T4/T6 includes casts marked as Sippican T4, Sippican T6, unknown T4 (non-Japanese), and unknown T6 (non-Japanese). Sippican T7/DB includes casts marked as Sippican T7, Sippican DB, unknown T7 (non-Japanese), and unknown DB (non-Japanese). TSK T6 includes casts marked as TSK T6 and unknown T6 (Japanese). TSK T7/DB includes casts marked as TSK T7, TSK DB, unknown T7 (Japanese), and unknown DB (Japanese). Sippican shallow includes casts marked T10, T11, Sparton XBT-1–Sparton XBT-4, Sparton XBT-6, Sparton XBT-10, and unknown XBT type with maximum depth ≤ 550 m (non-Japanese). Sippican deep includes casts marked Fast Deep, Sparton XBT-7, Sparton XBT-7DB, Sparton XBT-20, Sparton XBT-20DB, and unknown XBT type with maximum depth > 550 m (Japanese). TSK shallow is unknown XBT type with maximum depth ≤ 550 m (Japanese). TSK deep is unknown XBT type with maximum depth > 550 m (Japanese). Other includes T5s, air-drop XBTs, submarine launch XBTs, and National Academy of Sciences of Ukraine Marine Hydrophysical Institute XBTs.

Cowley et al. (2013)
include:
- limitations in the quality and quantity of the observations and metadata
- incomplete understanding of bias sources
- unknown impacts of XBT manufacturing changes on measurements
- differences among bias correction models and parameter estimation methods.

Abraham et al. (2013)
Overall, recently proposed XBT corrections have considerably reduced systematic errors in global/regional upper OHC analyses, however, the international community is still working towards a better understanding of these biases and the best possible way of correcting them (e.g., http://www.nodc.noaa.gov/OC5/XBT_BIAS/xbt_bias.html).

XBT biases:

=> pure temperature error (independent of depth) + depth error (fall-rate issue)

Most refined corrections currently available:

=> Cowley et al. (for a large fraction of XBTs but not all types)
Mapping approaches: how to deal with observational gaps

Observational coverage is historically sparse (particularly earlier in the record, south of 30°S and towards deeper levels) prior to the Argo era (from ~2005).

Abraham et al. (2013) (in review: Rev. Geophys.)
Mapping techniques

Simple gridding
- standard (Gouretski et al., 2012)
- w/ representative average (Palmer et al., 2007)

Objective mapping
- standard (Ishii and Kimoto, 2009; Levitus et al., 2012)
- w/ representative average (Lyman et al., 2010)
- w/ satellite altimeter infilling (from 1993 onwards) (Willis et al., 2004)

Reduced-space optimal interpolation
- w/ satellite altimeter EOF infilling (Domingues et al., 2008)

All of these techniques have their own advantages/limitations. Similar techniques might also differ in application details.
Observational coverage biases can impact climatological references and temperature changes.

- N. observations & age biases: N/S hemispheres; coastal/interior; shallow/deep
- “Hemispheric summer” bias towards higher latitudes

Source: C. Domingues, ACE CRC
To what extent can the observed current spread in estimates of global and regional ocean heat content (or thermal expansion) be reconciled?

Characterisation of “structural errors”, introduced by the mixture of current observational estimation approaches, is required to understand/reduce uncertainties in analyses of OHC (thermal expansion).

A common framework has been established to investigate the contribution of relevant estimation parameters to the “total structural uncertainty”.

Various groups have adhered to this common framework and are conducting a large ensemble of sensitivity tests (Boyer et al.). Some preliminary results are illustrated.
Common framework for systematic intercomparisons

Global datasets
• EN3v1d
• En3v2a

Instrument types
• Bottles, CTDs, XBTs, Argo
• Bottles, CTDs, XBTs, Argo, MBT
• All types

Climatological references
• Bottles, CTDs
• Bottles, CTDs, Argo
• Bottles, CTDs, Argo, XBTs
• Argo (only/period)
• Seasonal cycle (included/removed)
• Linear trend (removed)

XBT and MBT corrections
• Wijffels et al. (2008), Table 1 & 2
• Ishii and Kimoto (2009)***
• Levitus et al. (2009)***
• Gouretski and Reseghetti (2010)
• Good (2011)
• Hamon et al. (2011)
• Gouretski (2012)
• Cowley et al. (2013)

Mapping methods
• Domingues et al. (2008)
• Gouretski et al. (2012)
• Ishii and Kimoto (2009)
• Levitus et al. (2009)
• Lyman et al. (2010)
  mean and representative
• Palmer et al. (2007)
Key to Mapping Comparison Experiment Graphs

Mapping method = the set of procedures used to extrapolate/interpolate to ocean grids with no data and/or smoothing of gridded data.

<table>
<thead>
<tr>
<th>Mapping Methods</th>
<th>XBT Corrections</th>
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<tbody>
<tr>
<td>DOM – Domingues et al. 2008</td>
<td>None – no correction</td>
</tr>
<tr>
<td>LEV -- Levitus et al. 2009</td>
<td>W08 – Wijffels et al. 2008 [Table 1]</td>
</tr>
<tr>
<td>LYM_M – Lyman &amp; Johnson 2008</td>
<td>G11 - Good 2011</td>
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<td></td>
<td>mean of the maps</td>
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<tr>
<td>LYM_R – Lyman &amp; Johnson 2008</td>
<td>GR10 - Gouretski &amp; Reseghetti 2010</td>
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<td>representative mean</td>
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<td>UKM - Ingleby &amp; Huddleston 2007</td>
<td>I09 - Ishii &amp; Kimoto 2009</td>
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<td>C13 - Cowley et al. 2013</td>
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Mapping Method Experiment: Same XBT correction (Wijffels Table 1),
Same quality control, same input data, same baseline mean, different mapping method. Yearly standard deviation averages 20.9 ZJ, compared with Lyman et al. (2010) uncertainty from mapping method < 5 ZJ.
Different XBT corrections have a larger effect using the Domingues mapping than the Levitus mapping.
Same XBT corrections & mapping
Different dataset versions
(EN3v1d and EN3v2a)

also used by
Balmaseda et al. (2013)
Fact:
The historical archive of global ocean subsurface temperature contains a large proportion of poorly quality-controlled as well as biased data. As a result, efforts to analyze past ocean change and variability are confounded, as is the use of ocean data assimilation systems (e.g. Bluelink, SODA, ORAS4, etc).

Currently many data centers perform automated 'quick and dirty QC' – with large duplication of effort around the world. There have been no previous efforts to maximize the quality and consistency of the historical archive for climate research. No single group has the manpower and resources to do the job properly - thus international cooperation is needed.
The Need:

Climate change science: the ocean’s role in the planetary heat budget and in detection of climate change/attribution studies is becoming more important. Thus the details of how we got from 1900 to 2013 is becoming more important.

As for the atmosphere, more and more ocean science will be done using ‘reanalyses’ - underpinning data sets and their associated accuracy and consistency becomes more and more vital.

As models improve, so must the observations used to initialize, validate and challenge them.

We will learn lessons (again) to help us do better in the future - e.g. underscore the need to cross-check observing systems.
Project proposal: To deliver the highest quality possible historical subsurface ocean temperature (salinity) global dataset, along with the most complete metadata information, quality control flags, and uncertainty estimates for each measurement for climate research.
Workshop Summary

Internationally coordinated strategy:

**Step 1:** Compare current methods and agree on an optimal set of automated quality control procedures.

**Step 2:** Use the World Ocean Database as a starting point, assign quality flags to all measurements based on automatic quality control procedures.

**Step 3:** Manually examine all temperature profiles/measurements which fail automatic quality control to set final flags (different groups internationally).

**Step 4:** Estimate uncertainty for each observation and assign “intelligent metadata” where that information is missing.

**Step 5:** Assemble results and disseminate.

**Legacy:** Leave a system for groups to follow in order to add newly discovered historical data/recent data to this internationally coordinated quality control dataset. Template for future inclusion of extra parameters (e.g., salinity, oxygen, etc.)