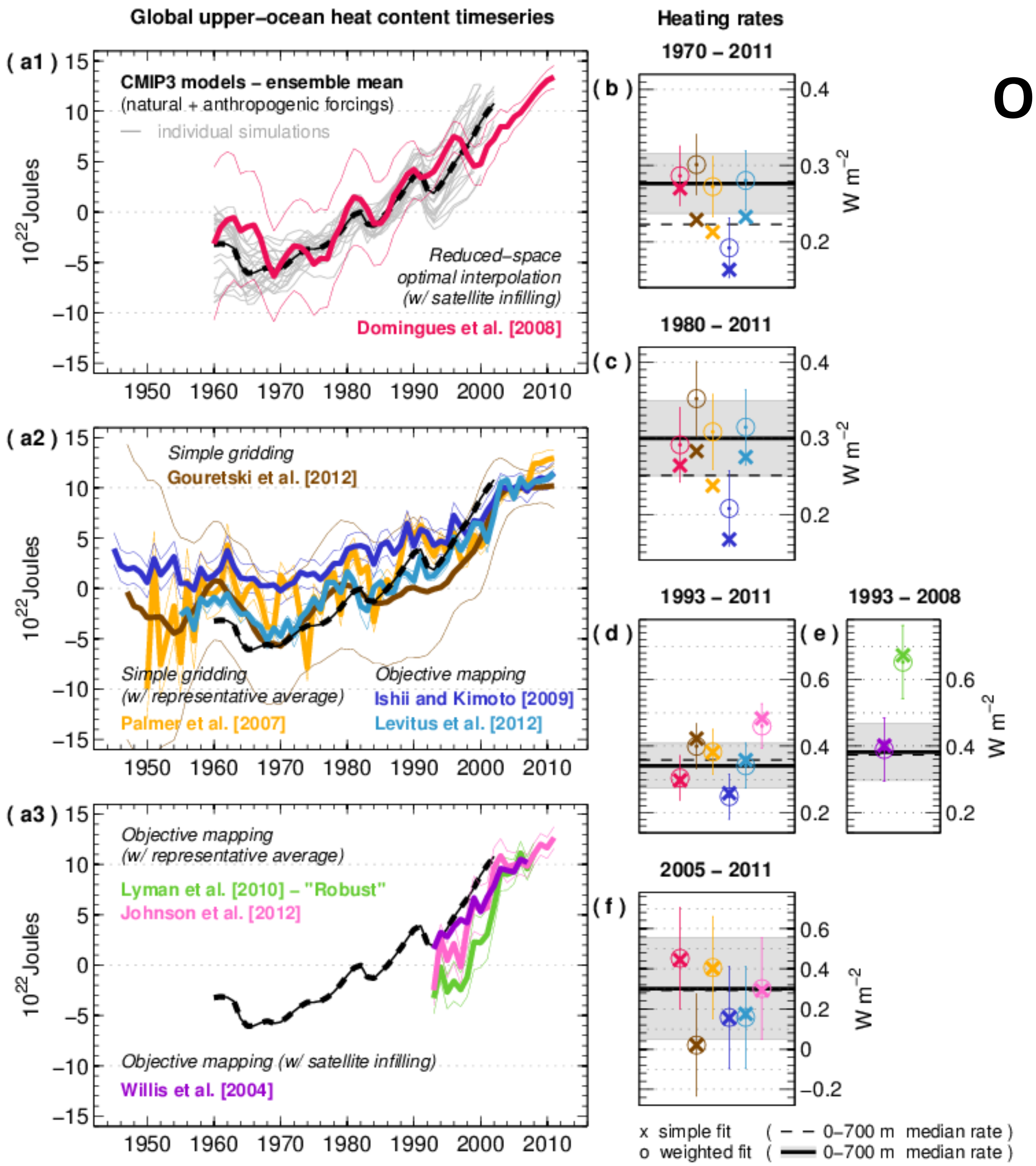
Upper-ocean heat content:

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.)

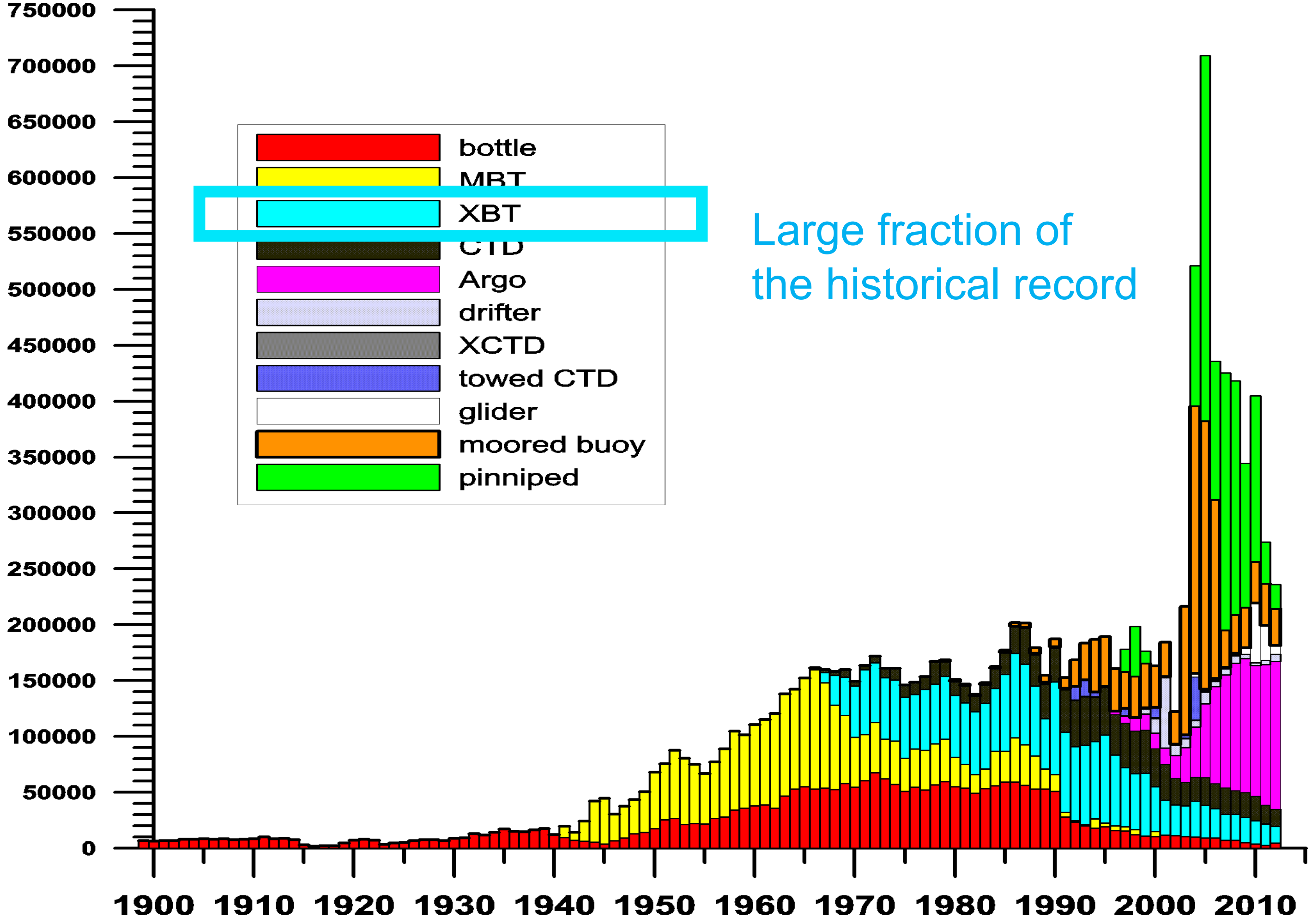
Spread in the OHC analyses mainly reflects the sensitivity of the calculations to different choices of:

- 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**



Source: Tim Boyer, NODC/NOAA

Numerous proposed XBT bias corrections

posterior to Gourestki and Koltermann (2007)

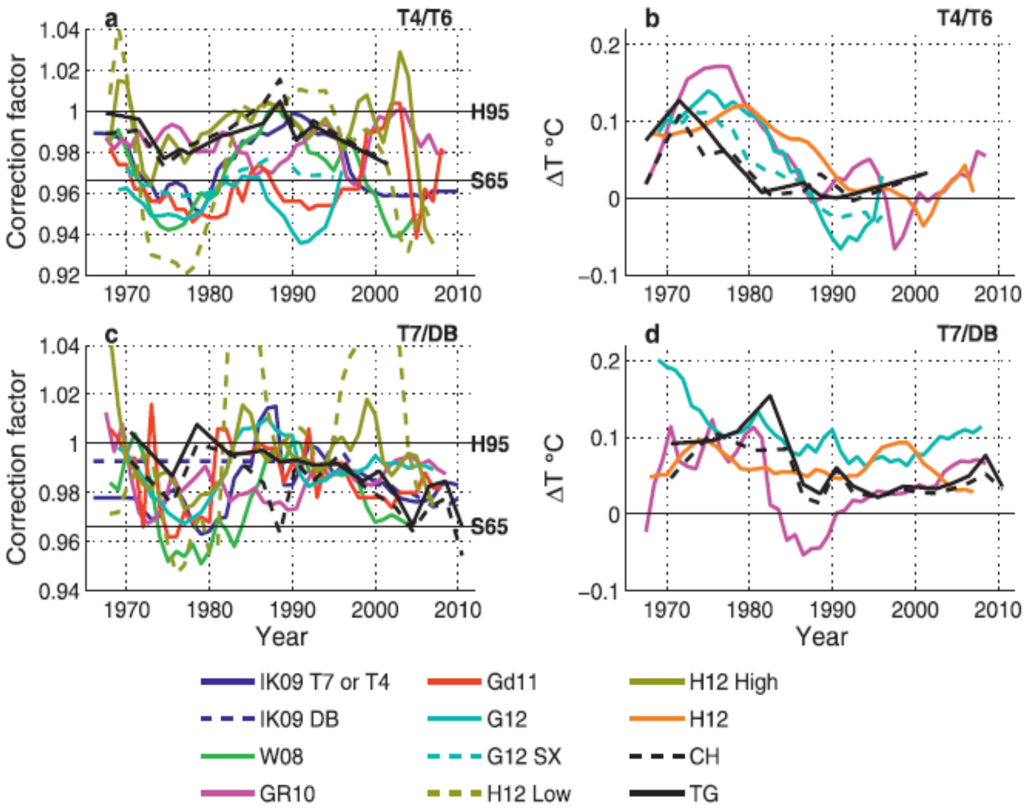


FIG. 16. Comparison of correction schemes for Sippican (top) T4/T6 and (bottom) T7/DB probe types for (a),(c) equivalent correction factors and (b),(d) diagnosed temperature bias over time. Correction schemes are from authors as listed in the text. Label G12 SX refers to the shallow XBT correction in G12. Labels H12 high and H12 low refer to the high and low temperature schemes in H12, respectively. Label H95 is the H95 equivalent fall rate, and S65 is the Sippican 1965 equivalent fall rate.

Cowley et al. (2013)

Distribution of XBT type/manufacturer per year in WOD09

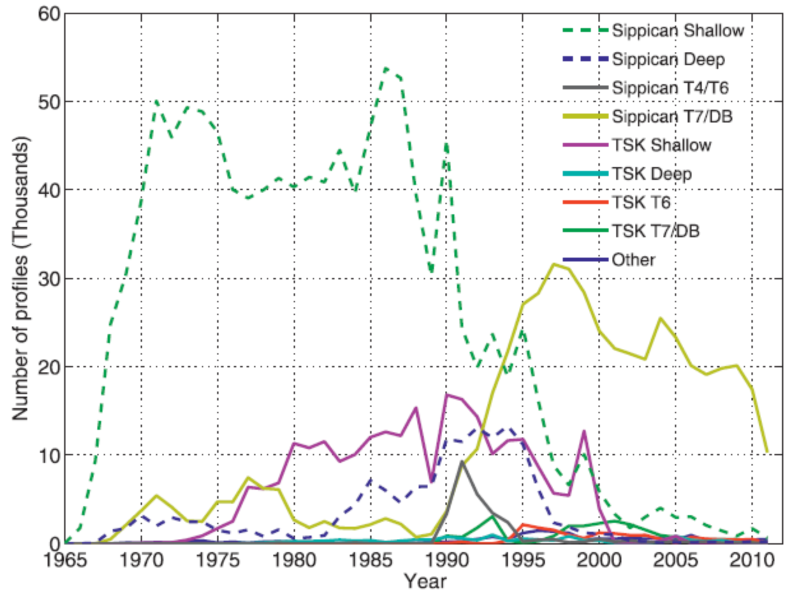
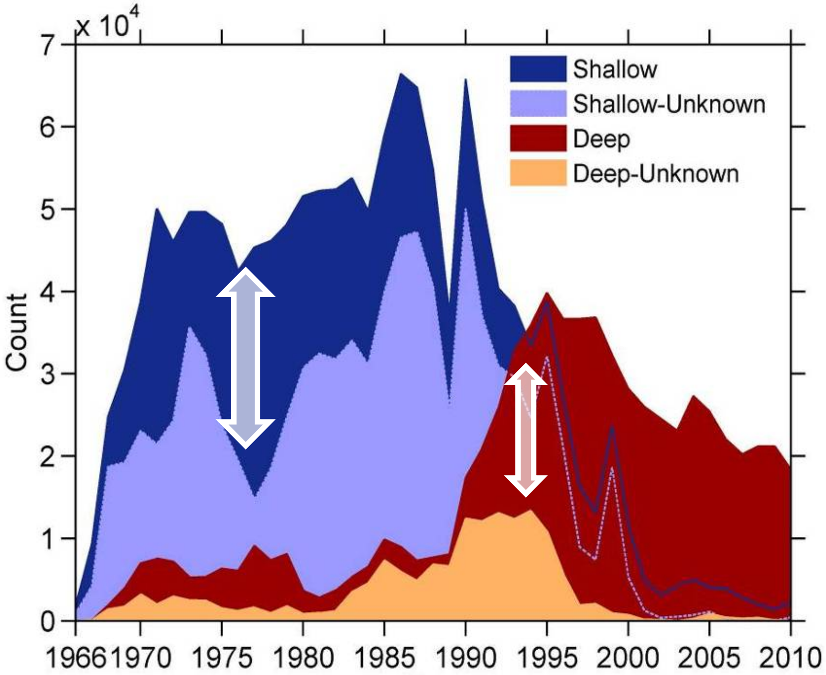


FIG. 1. The total number of XBT profiles by year, split by probe type and manufacturer, in the WOD09. Sippican T4/T6 includes casts marked as Sippican T4, Sippican T6, unknown T4 (non-Japanese), and unknown T6 (non-Japanese). Sippican T7/DB includes casts marked as Sippican T7, Sippican DB, unknown T7 (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 (non-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.

Difficulties in XBT corrections



include:

▪**limitations in the quality and quantity of** the observations and **metadata**

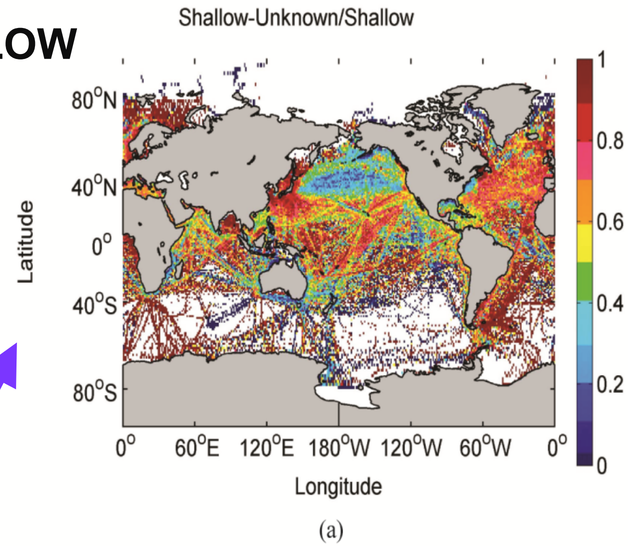
▪incomplete understanding of bias sources

▪unknown impacts of XBT manufacturing changes on measurements

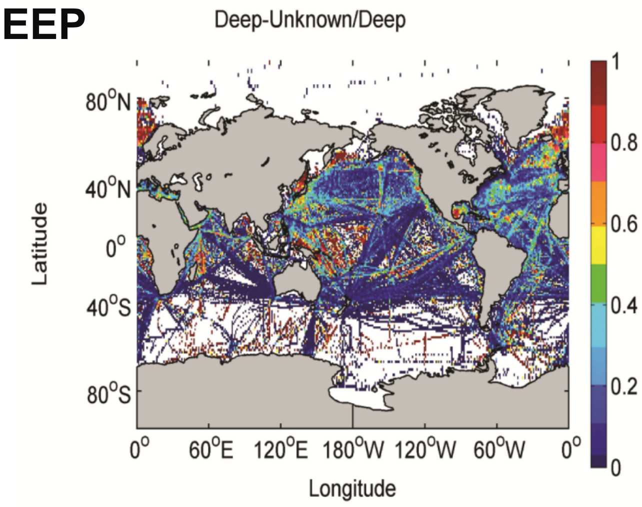
▪differences among bias correction models and parameter estimation methods.

Fraction unknown/known XBT types

SHALLOW



DEEP



Abraham et al. (2013)

Progress in XBT bias corrections

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).

Is there a broad agreement?

XBT biases:

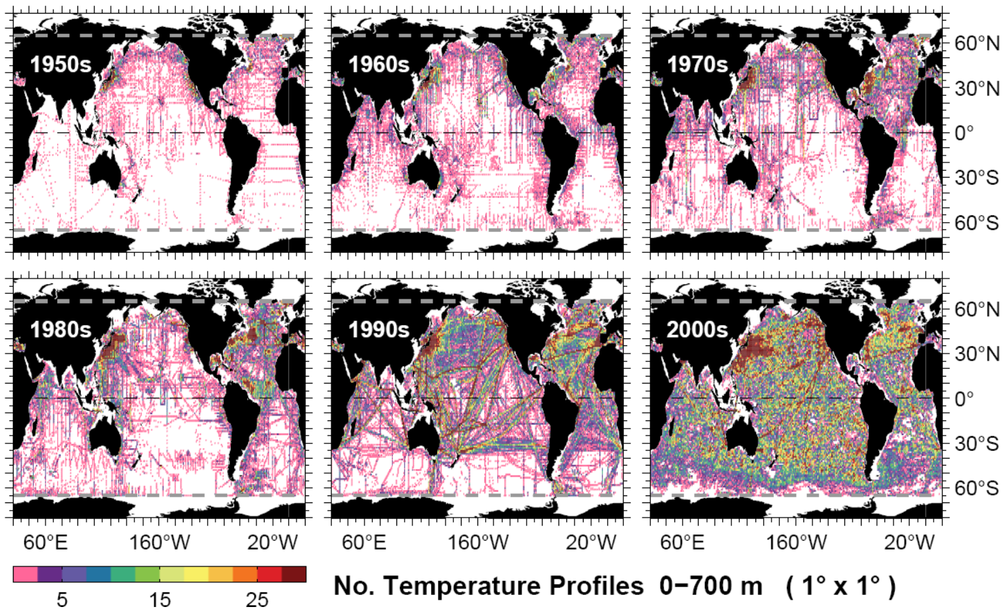
=> pure temperature error (independent of depth) + depth error (fall-rate issue)

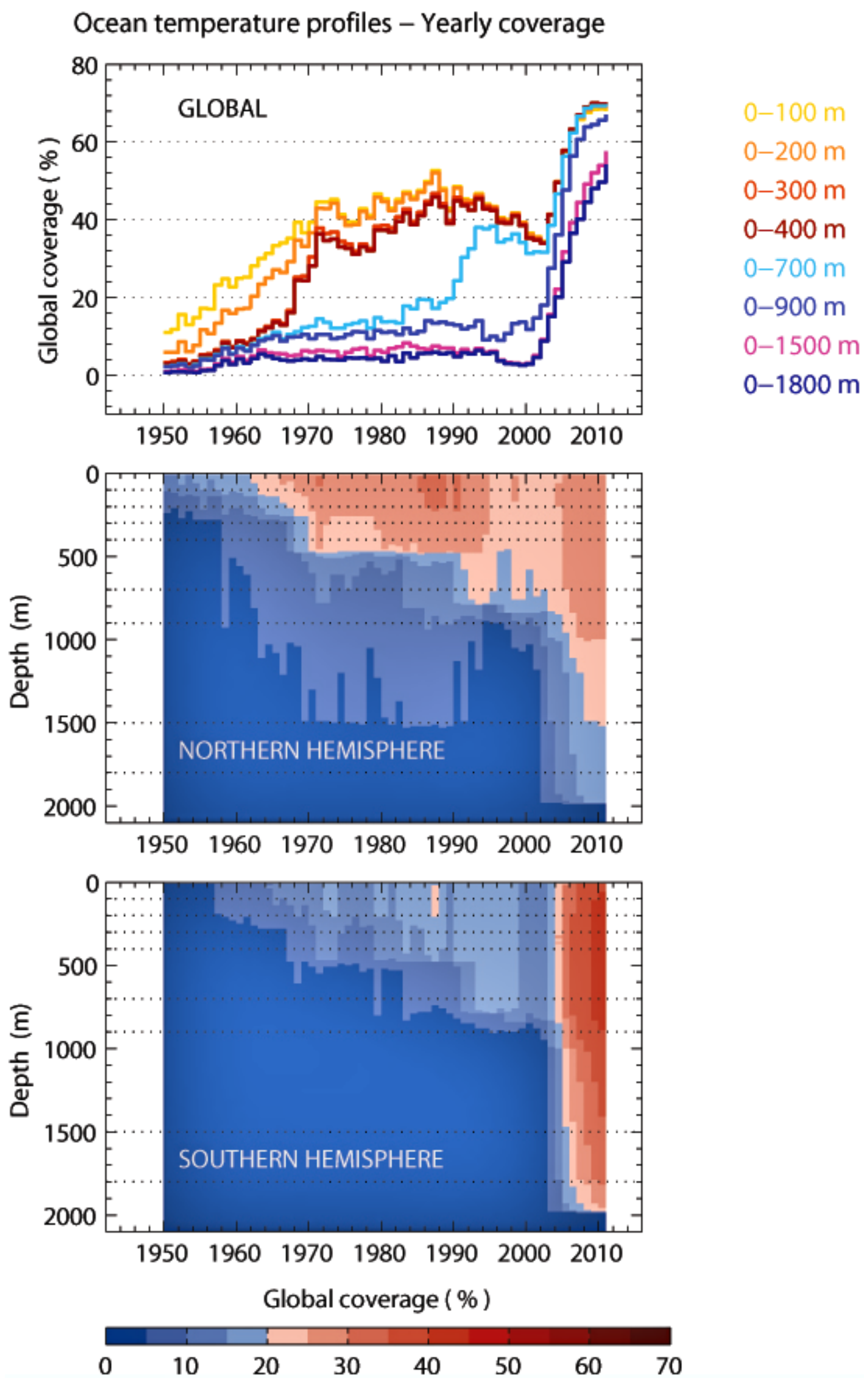
Most refined corrections currently available:

=> 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

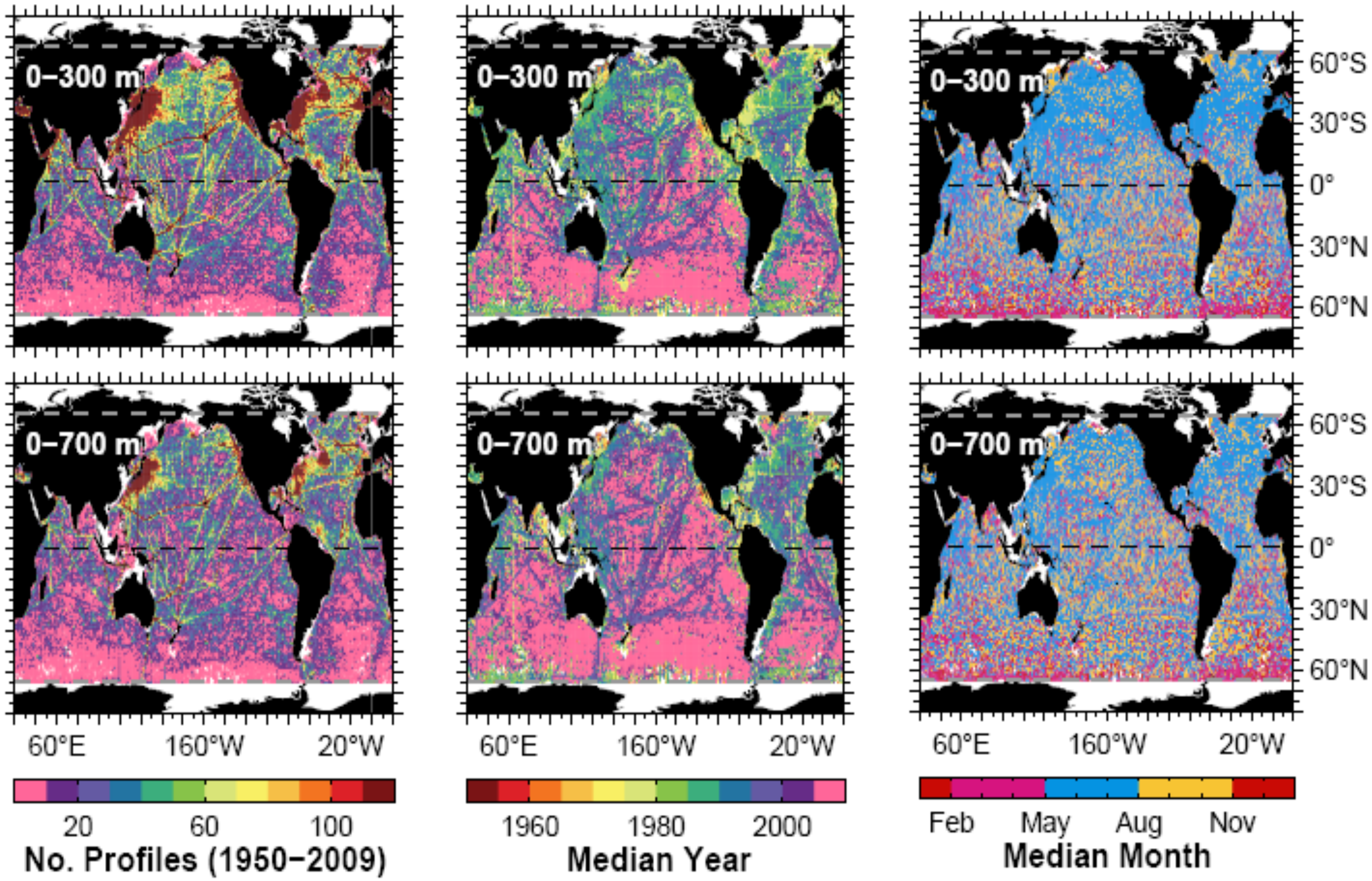
- standard (Ishii and Kimoto, 2009; Levitus et al., 2012)
- w/ representative average (Lyman et al., 2010)
- w/ satellite altimeter infilling (from 1993 onwards) (Willis et al., 2004)

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)

Mappping 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

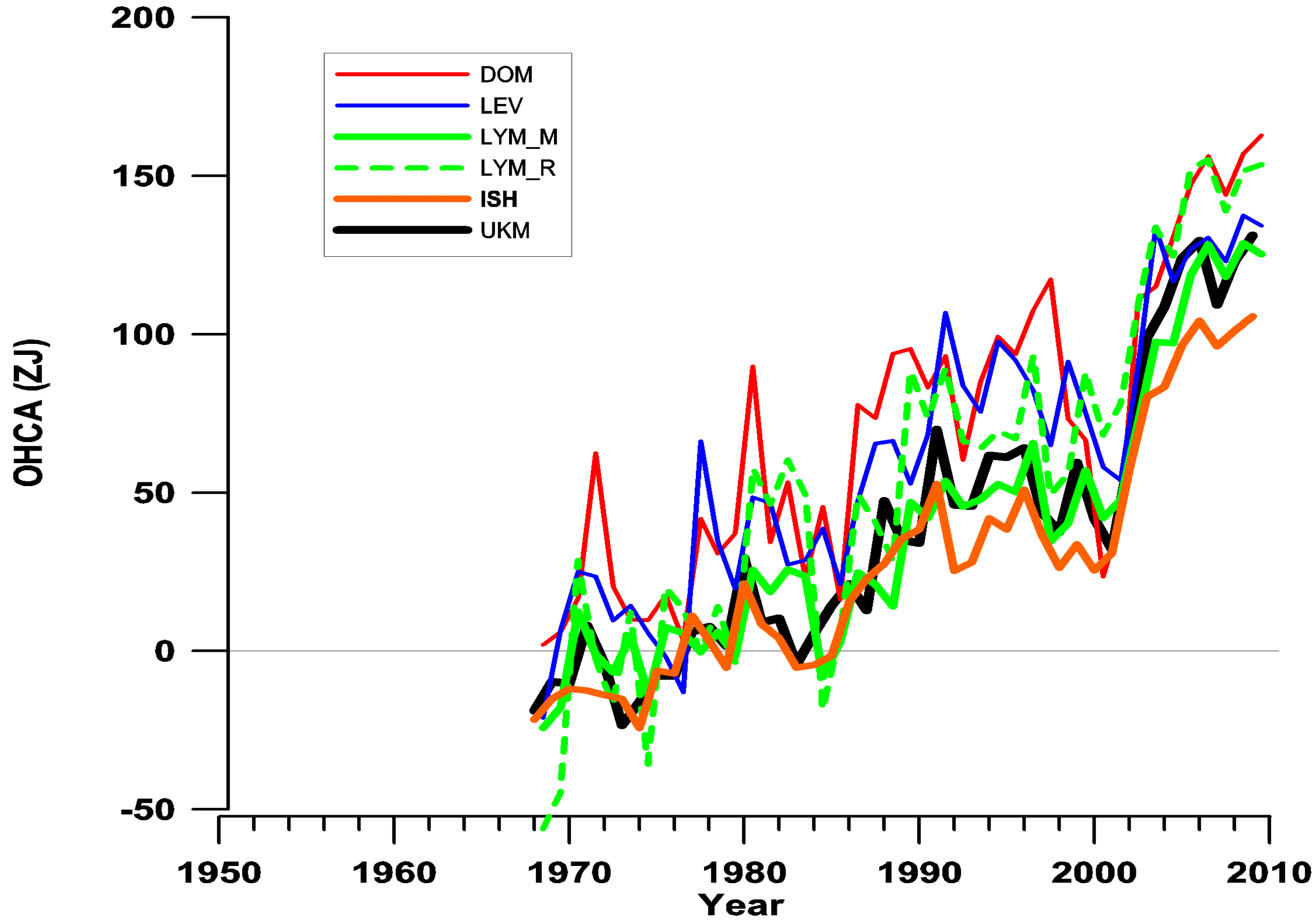
Mapping method = the set of procedures used to extrapolate/interpolate to ocean grids with no data and/or smoothing of gridded data.

Mapping Methods

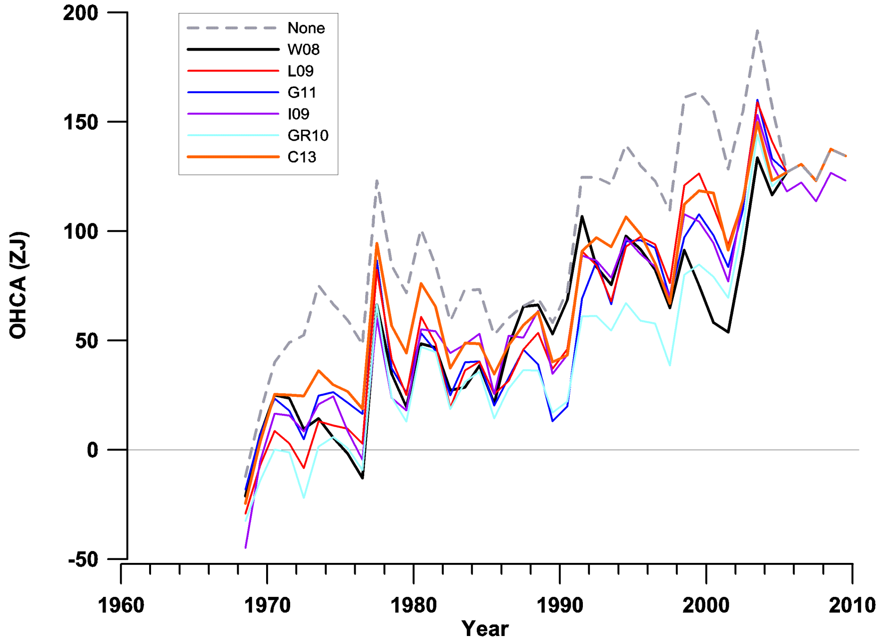
DOM – Domingues et al. 2008
LEV -- Levitus et al. 2009
ISH - Ishii and Kimoto 2009
LYM_M – Lyman & Johnson 2008 mean of the maps
LYM_R – Lyman & Johnson 2008 representative mean
UKM - Ingleby & Huddleston 2007

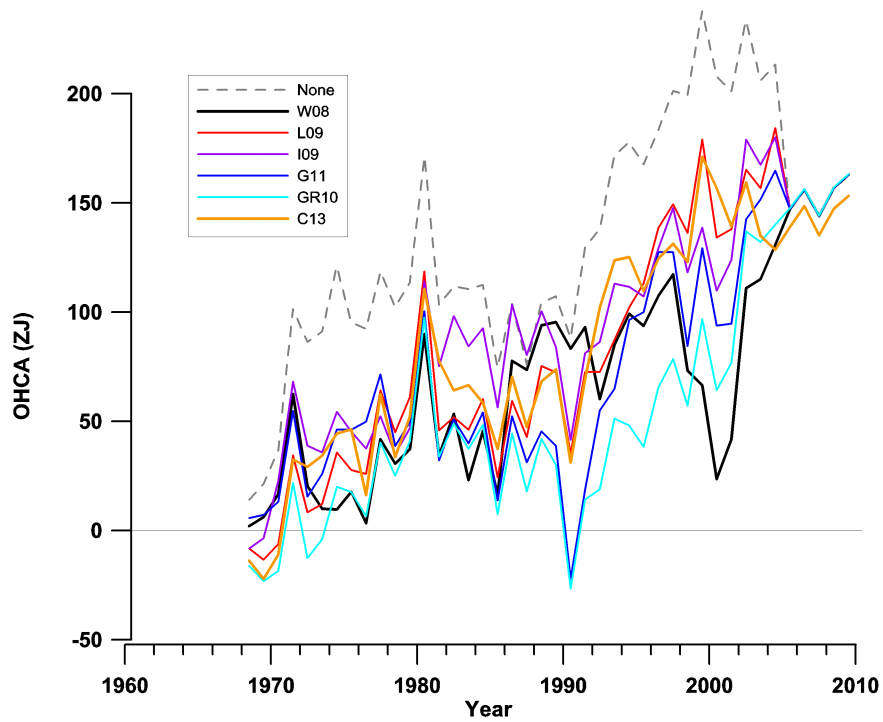
XBT Corrections

None – no correction
W08 – Wijffels et al. 2008 [Table 1]
L09 - Levitus et al. 2009
G11 - Good 2011
GR10 - Gouretski & Reseghetti 2010
I09 - Ishii & Kimoto 2009
C13 - Cowley et al. 2013



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.

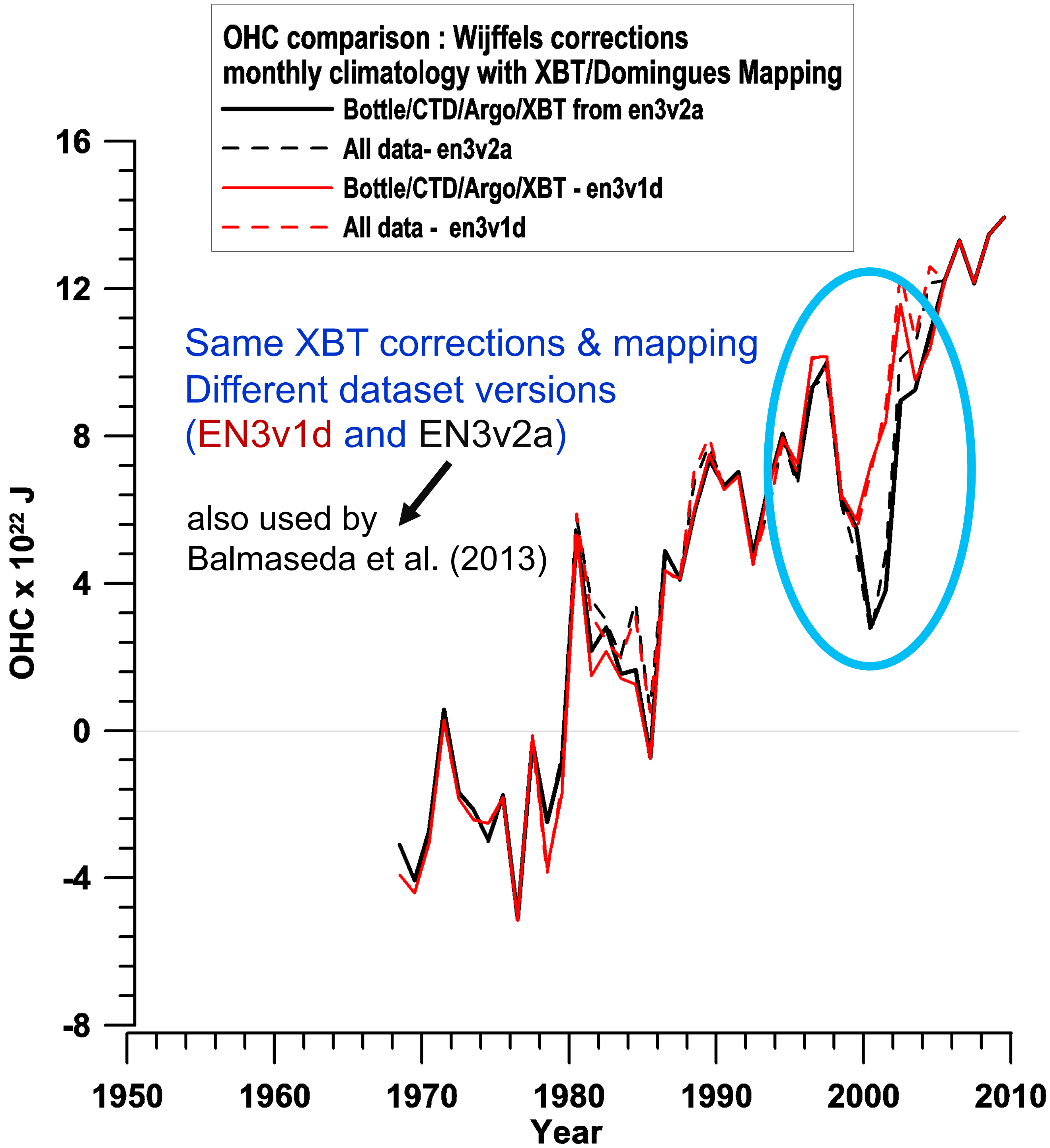




Levitus mapping method with different XBT corrections

Domingues mapping method with different XBT corrections

Different XBT corrections have a larger effect using the Domingues mapping than the Levitus mapping.


OHC comparison : Wijffels corrections
monthly climatology with XBT/Domingues Mapping
Bottle/CTD/Argo/XBT from en3v2a
All data- en3v2a
Bottle/CTD/Argo/XBT - en3v1d
All data - en3v1d
Same XBT corrections & mapping
Different dataset versions
(EN3v1d and EN3v2a)
also used by
Balmaseda et al. (2013)
OHC x 10²² J
16
12
8
4
0
-4
-8
1950
1960
1970
1980
1990
2000
2010
Year

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**.

CLIVAR-GSOP Coordinated Quality-Control of Global Subsurface Ocean Climate Observations

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.

June, 2013 – Hobart Australia

http://www.clivar.org/organization/gsop/activities/clivar-gsop-coordinated-quality-control-global-subsurface-ocean-climate

Workshop Summary

Internationaly 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.)

http://www.clivar.org/organization/gsop/activities/clivar-gsop-coordinated-quality-control-global-subsurface-ocean-climate