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Systematic Errors in the Hydrographic Data and Their Effect on Global Heat Content Calculations

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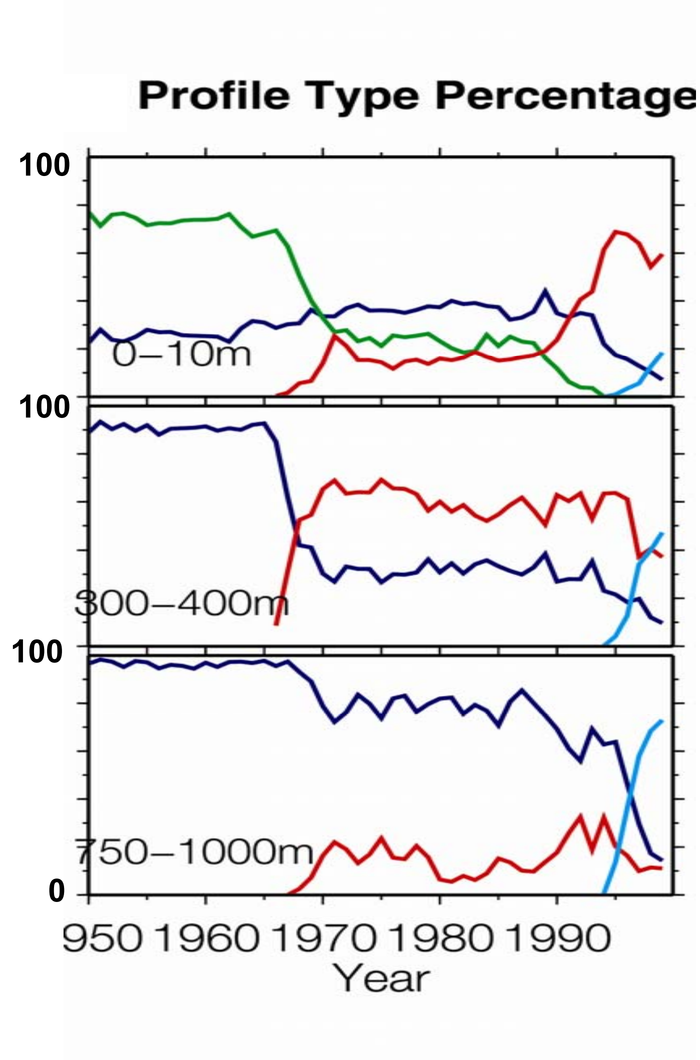
Overview

- Global hydrographic data set
- Biases in bathythermograph data
- Biases impact on Ocean Heat Content Anomaly time-series
- Surface versus subsurface temperature anomaly timeseries

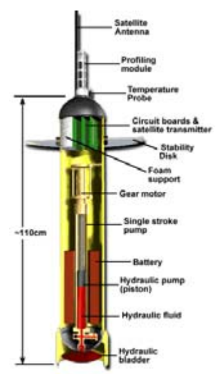
Global subsurface database is inhomogeneous → each data type has specific bias(es)



MBT

BOTTLE

XBT



PFL

CTD

XBT data

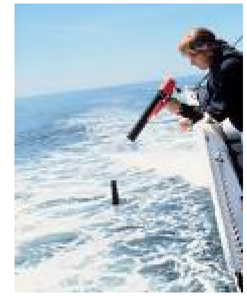
Are important for climate studies because:

- Represent by far the largest group among the subsurface data between 1968 and 1996
- Cover the upper 450-750 meters

Are problematic because:

- Were not initially designed for climate applications
- Consist of several probe types
- Are produced by two different manufacturers
- Are biased both in depth and temperature!

XBT Bias sources:



- Uncertainty in fall rate equation $Z_{xbt} = at - bt^2$

  (uncertainty in coefficients, overall validity questionable)

- Manufacturing instabilities of probe/wire characteristics
- Offsets due to different acqusition system (strip-chart/digital recorders,ETC,...)
- Very different launch conditions (height, air temperature, sea-ice, ship-wake ...)
- Different ambient conditions during the fall (water temperature affects viscosity)

- All this is known since 1970s and described in the literature (peer-reviewed papers + technical reports)

- Unfortunately numerous technical reports are unavailable

Heinmiller et al. 1983: One of the early papers on XBT biases (systematic T- and depth errors identified)

Depth bias

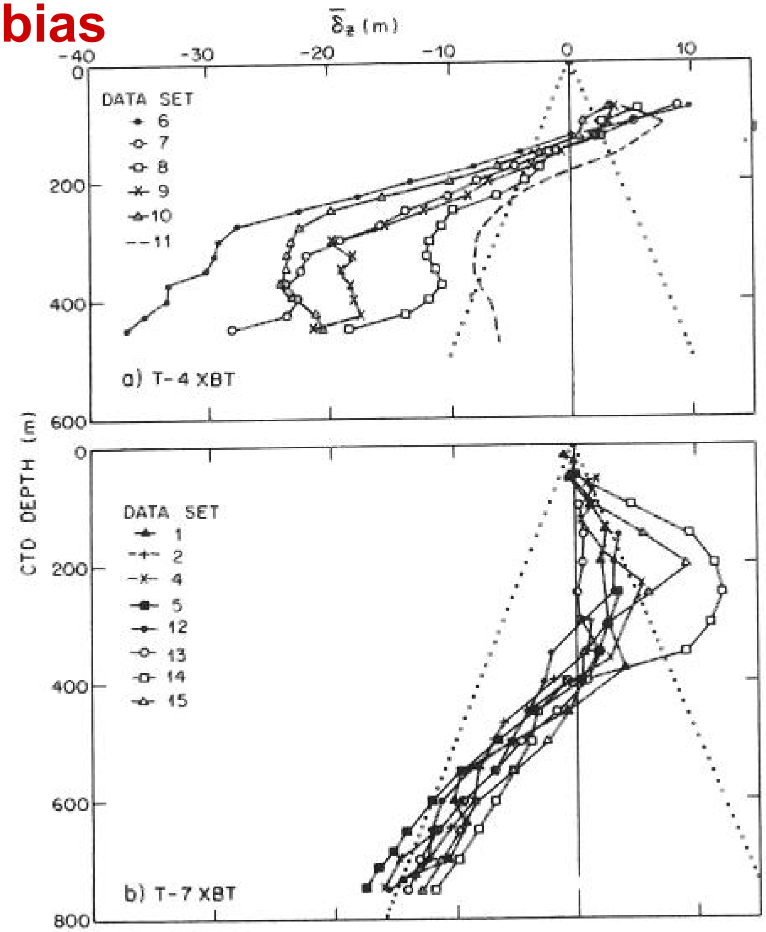


Fig. 2. Vertical profiles of mean XBT–CTD depth differences ($\bar{\delta}_z$) for T-4 (a) and T-7 (b) X
Dotted lines represent 0.02 times CTD depth. Numbers denote data sets (Tables 1 and 2).

Table 3. Mean and standard deviation of XBT–CTD temperature differences at selected depths for T-4 and T-7 XBT's

Data set No.	Depth (m)	XBT–CTD temperature differences Mean (°C)	s.d. (°C)
T-4 XBT			
6	25	0.28	0.32
7	25	0.31	0.25
8	25	0.23	0.22
9	25	0.16	0.19
10	25	0.12	0.19
11	25	0.05	0.18
Mean		0.19	0.23
T-7 XBT			
12	25–125	0.17	0.08
13	250–350	0.10	0.10
14	175–350	0.10	0.11
15	175–375	0.13	0.16
Mean		0.13	0.11

Thermal bias

Hallock and Teague, 1992: A new T-7 FRE presented

Example of the depth bias for the (deep) T-7 probe type

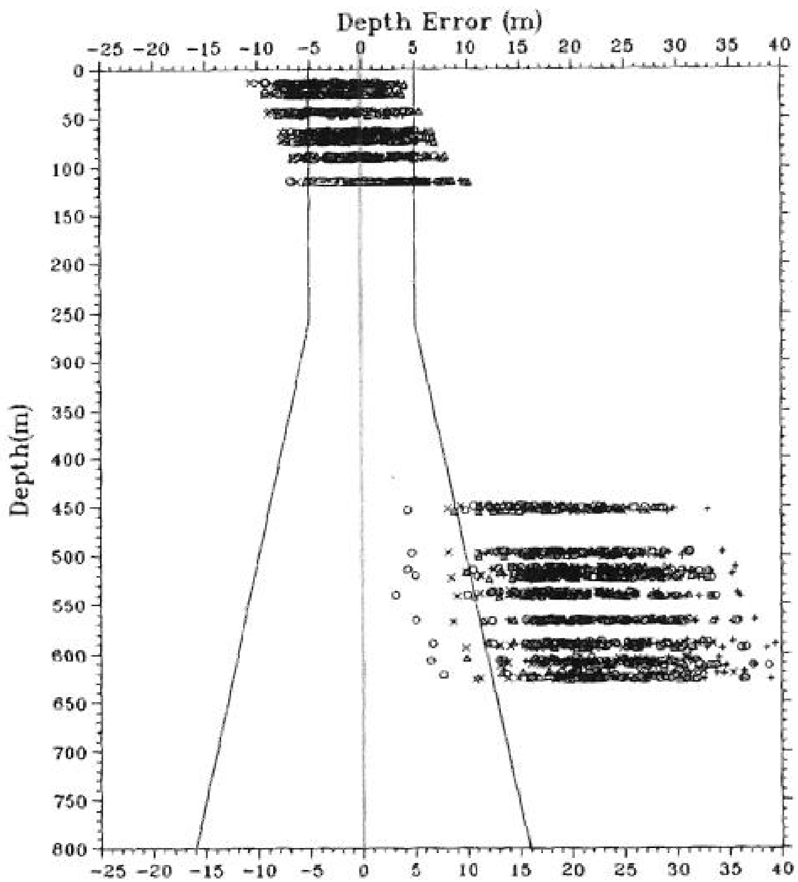


FIG. 4. Depth error ($Z_{CTD} - Z_{XBT}$) for selected features. XBT depths calculated with the Sippican FRE. Different symbols denote different LAS's.

Thadathil et al 2002: Fall-rate is different for cold and warm water regions

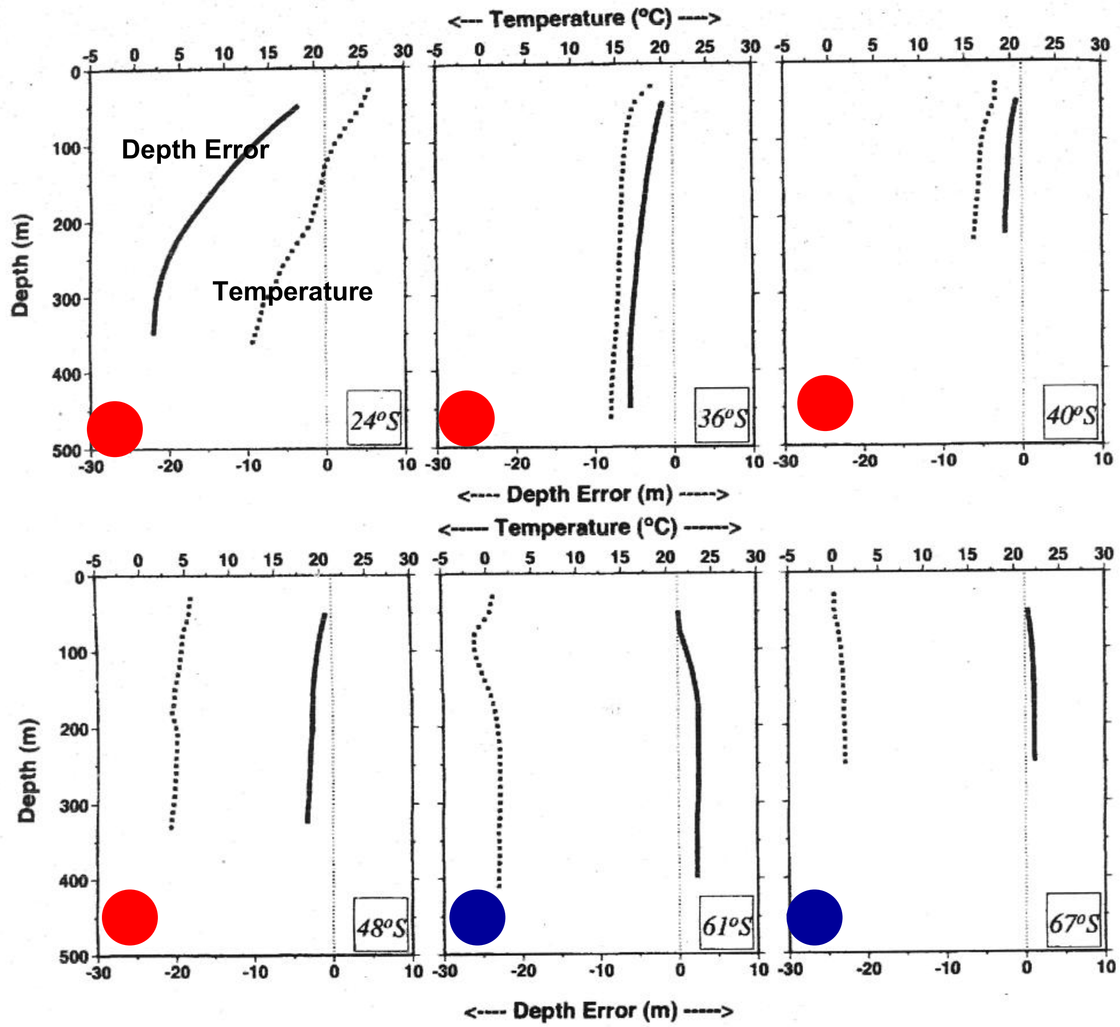


FIG. 9. Analytical depth errors for different latitudes from the tropical to polar regions along with the corresponding temperature profiles. Solid lines represent depth error and dashed lines represent temperature.

Hanawa, Rual, Bailey, Sy, Szabados (1994, 1995):
A comprehensive depth-error study. New fall-rate equation for T4,T6 and T7 probe types obtained. CTD vs XBT colocated analysis for nine geographical regions

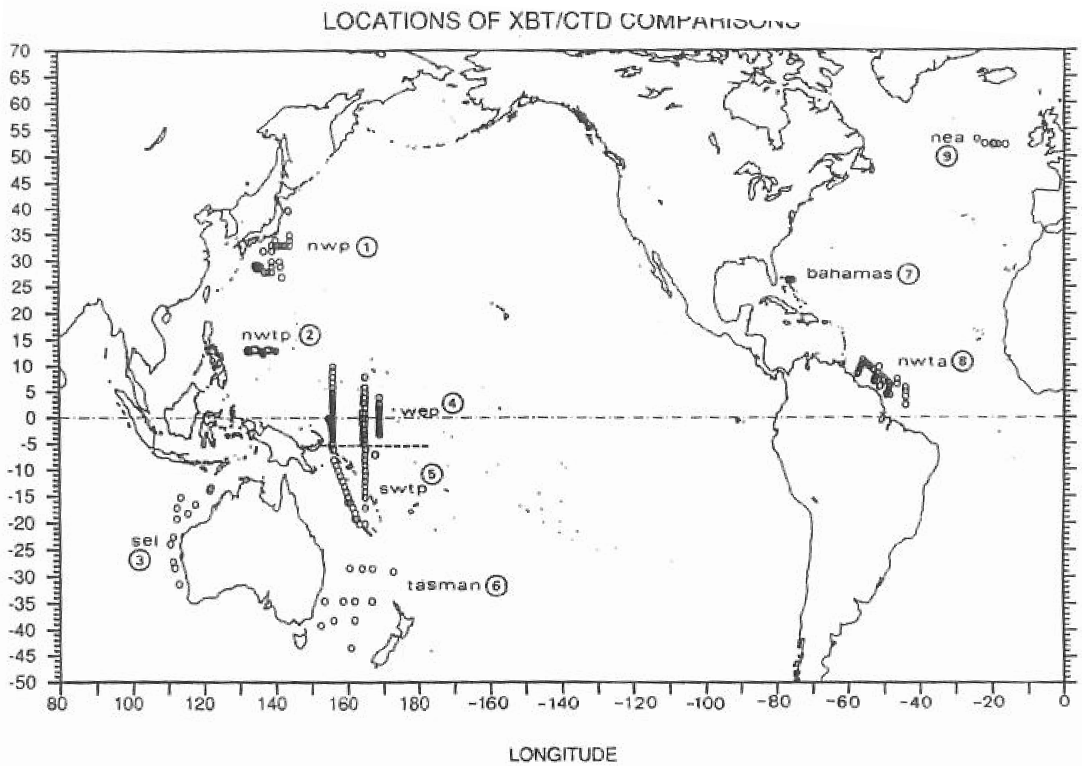


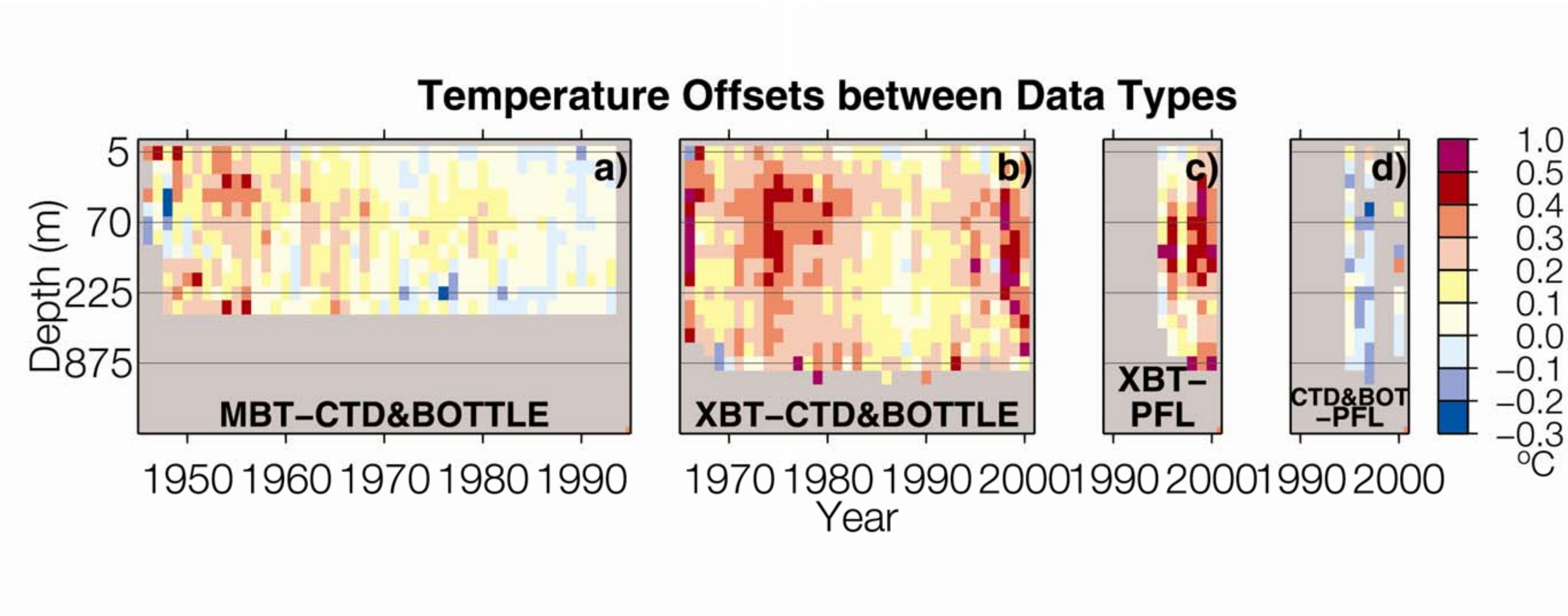
Fig. 1. Locations where the XBT/CTD comparison experiments were conducted (see also Table 1). The dashed line at 5°S in the western Pacific shows the limit between the wep and swtp data sets.

- **Only depth bias quantified!**

- **Fall-rate is faster than according to the fall-rate eq.**

- **Strong recommendation not to implement the new FRE in databases (recommendation often ignored)**

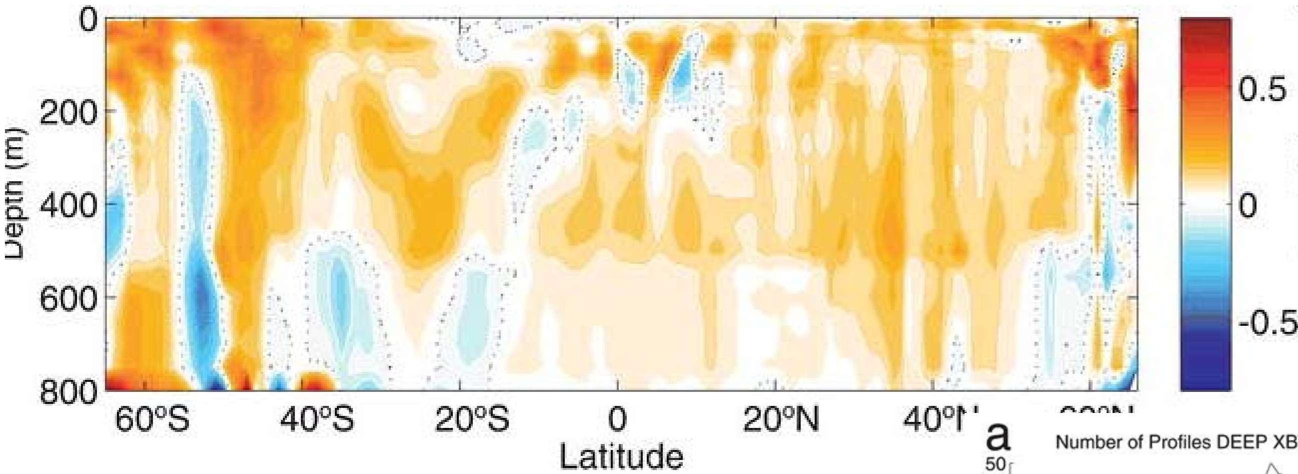
Gouretski and Koltermann, 2007. Global inter-comparison of colocated binned XBT and CTD/bottle temperatures. First evidence of the overall warm bias on the global scale (Hanawa et al. FRE assumed)



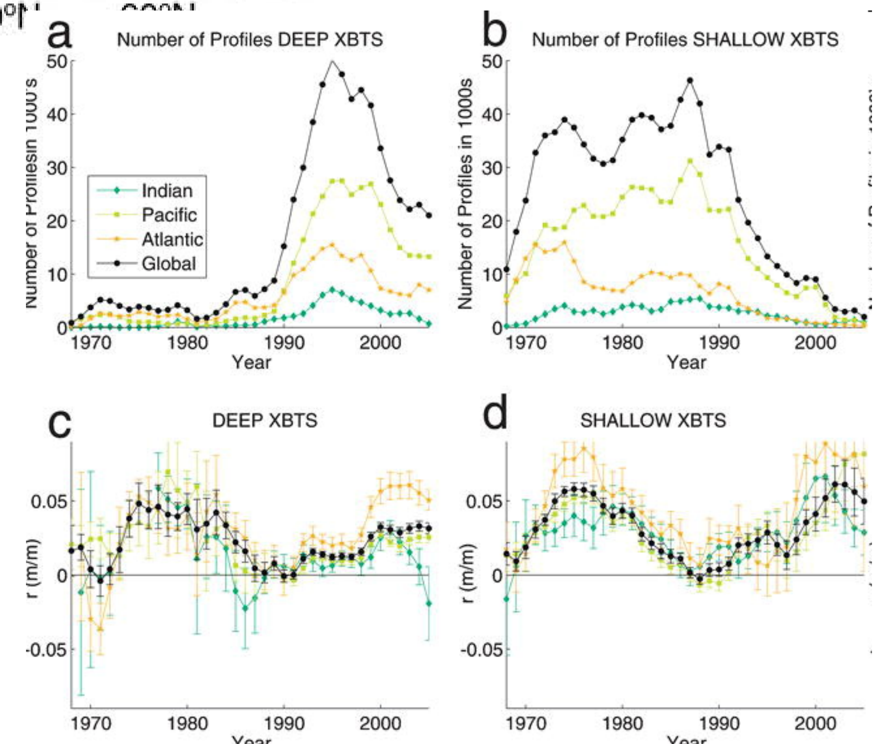
- **Globally averaged total T-bias varies in time and with depth**
- **Bias is positive**

Gouretski&Koltermann, 2007

Wijffels et al., 2008: confirmed G&K2007 results and suggested depth corrections.



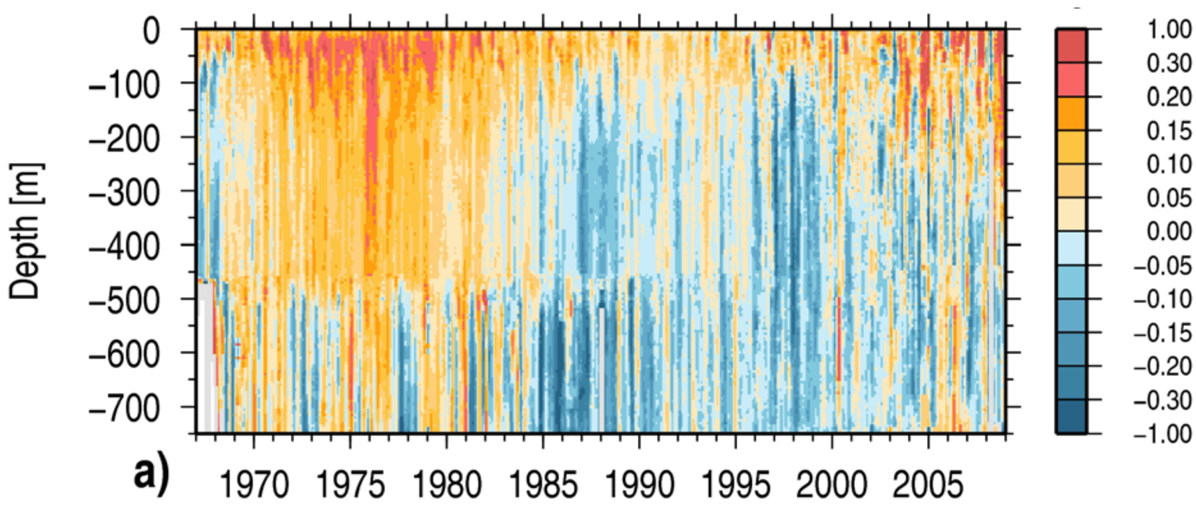
- **Bias is attributed solely to the time-variations in the fall rate**
- **Depth correction factor uniform over depth**
- **Thermal bias neglected**

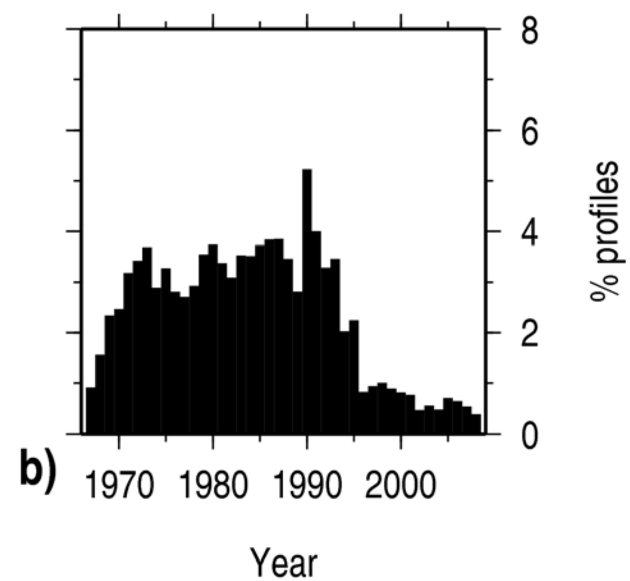


Wijffels et al. 2008

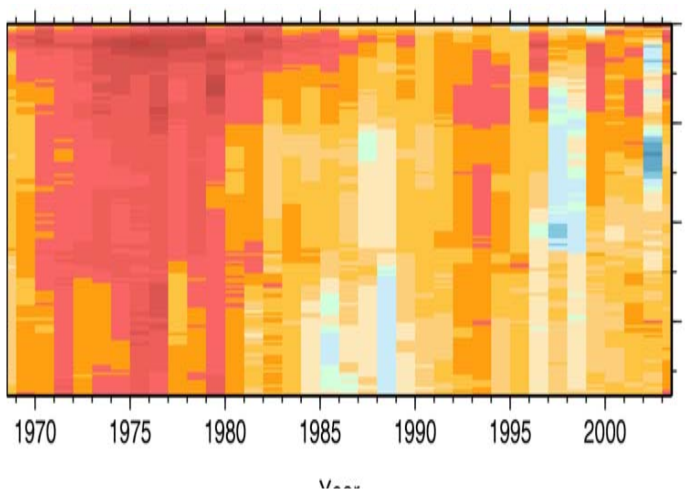
Globally-averaged T-blas plotted vs depth and time

- *Original Sippican FRE*





Hanawa et al. FRE



Application of Hanawa et al. 1995 corrections lead to the increase of the warm bias!

(Gouretski&Reseghetti, 2010)

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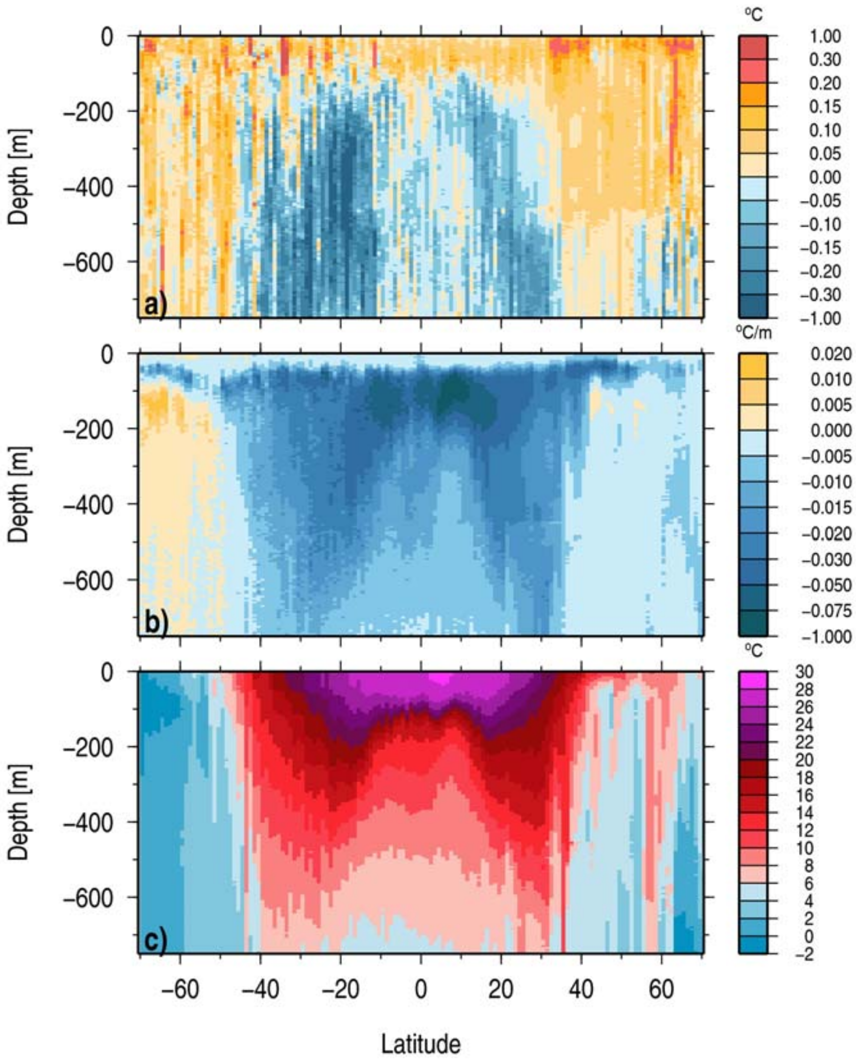
T-bias, dT/dz, and temperature plotted vs depth and latitude



- ***Common geographic pattern***
- ***Positive bias in low-gradient region implies the existence of a pure thermal bias***

(Gouretski&Reseghetti, 2010)

- **Globally-averaged bias is represented as a sum of a thermal bias and the bias due to the error in depth**

$$B(z,t) = B_T(t) + z_x(z,t) \cdot [1 - s(z,t)] \cdot G(z,t)$$

z – actual depth

t –time

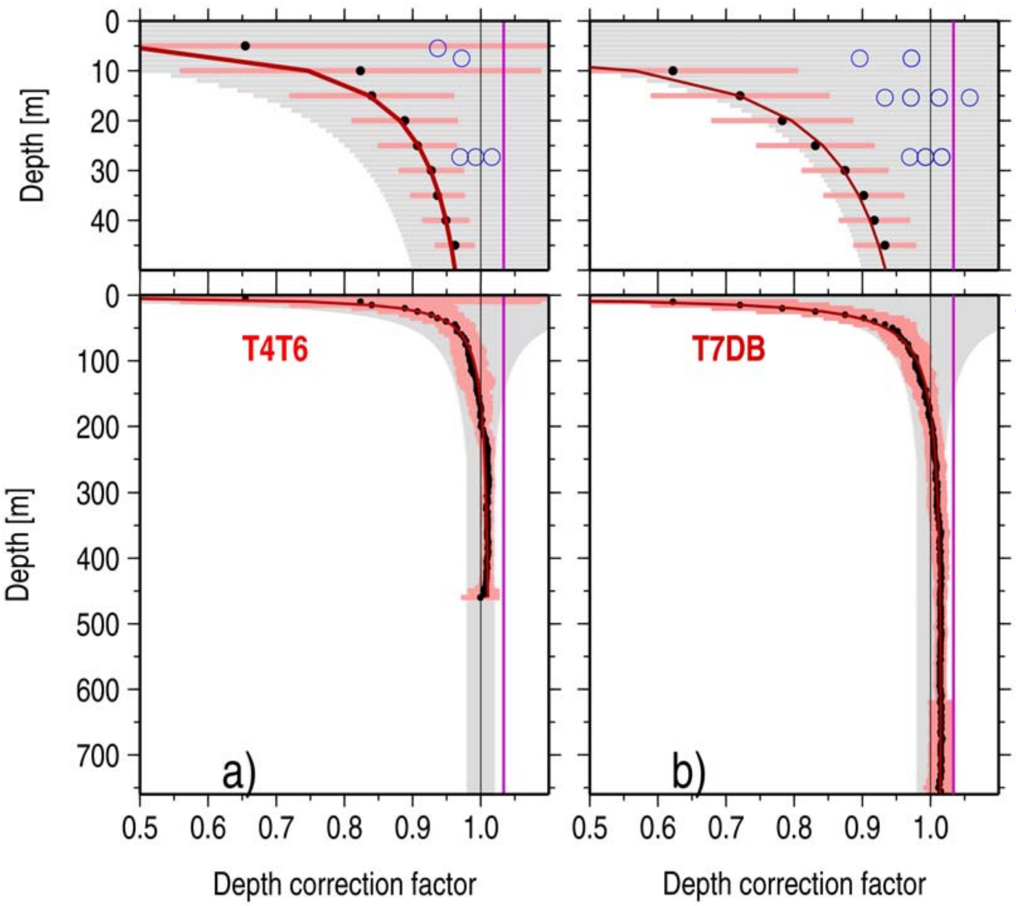
$B_T(t)$ – thermal bias

G– vertical T-gradient

$s(z,t) = z/z_x(z,t)$ depth correction factor:

Depth correction factor is caculated for each depth

Time-mean depth correction factor for T4/T6 and T7/DeepBlue models

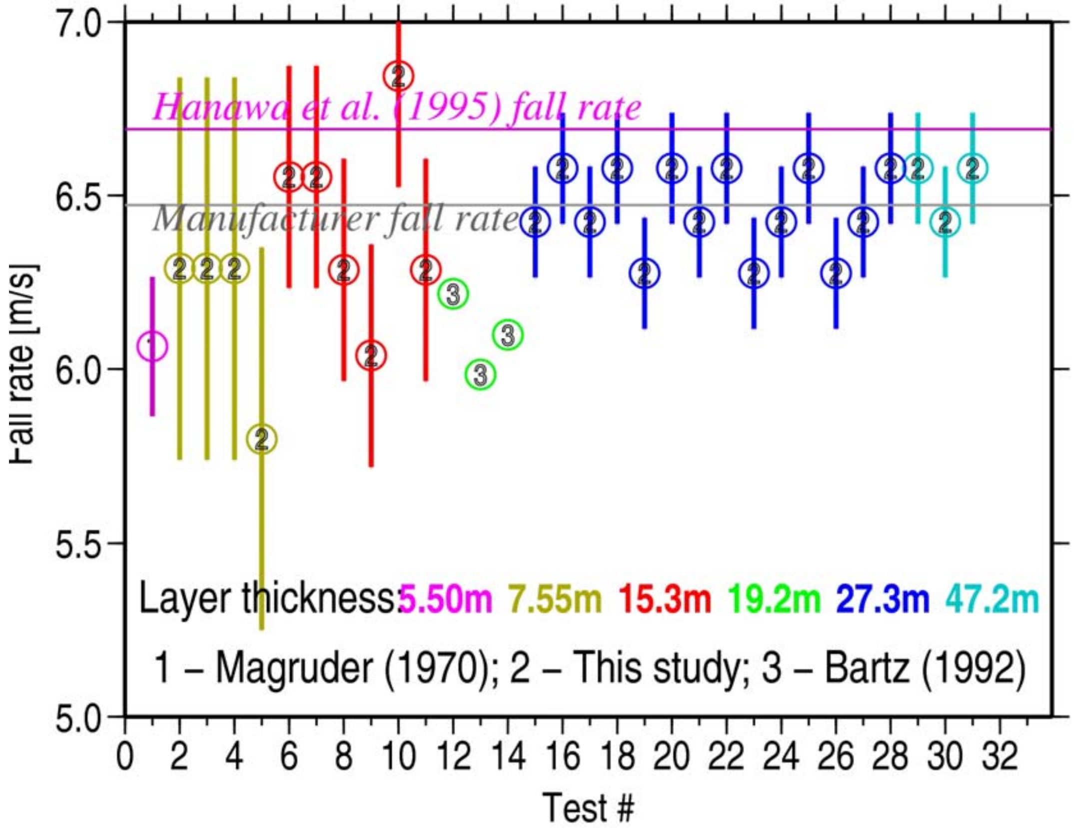


- Correction factor varies with depth!

- Depth is overestimated /underestimated in the upper / lower part of the profile

Gouretski&Reseghetti, 2010)

Direct measurements of the XBT fall velocity



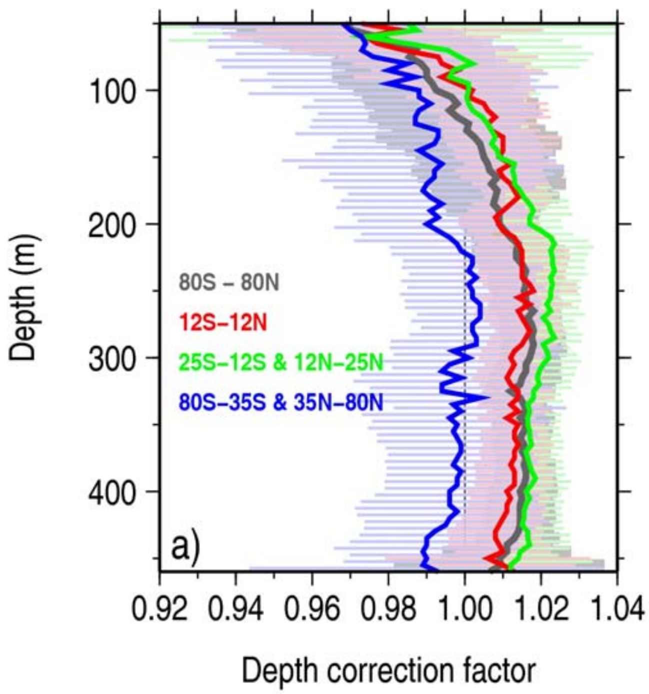
Slower fall rate in the upper layer confirmed but statistics are poor

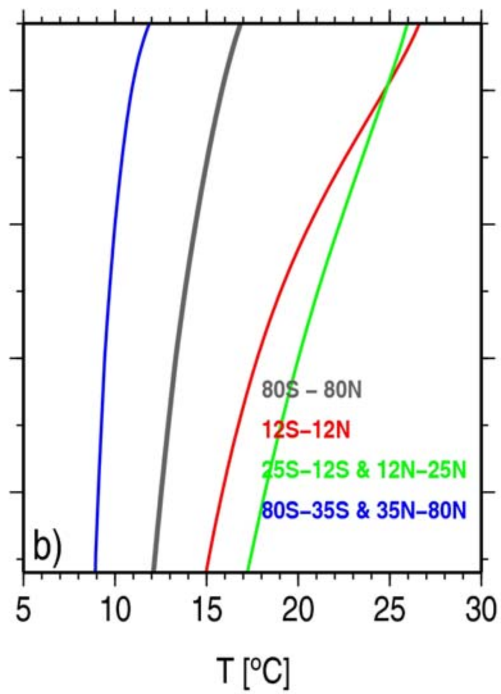
Gouretski&Reseghetti, 2010)

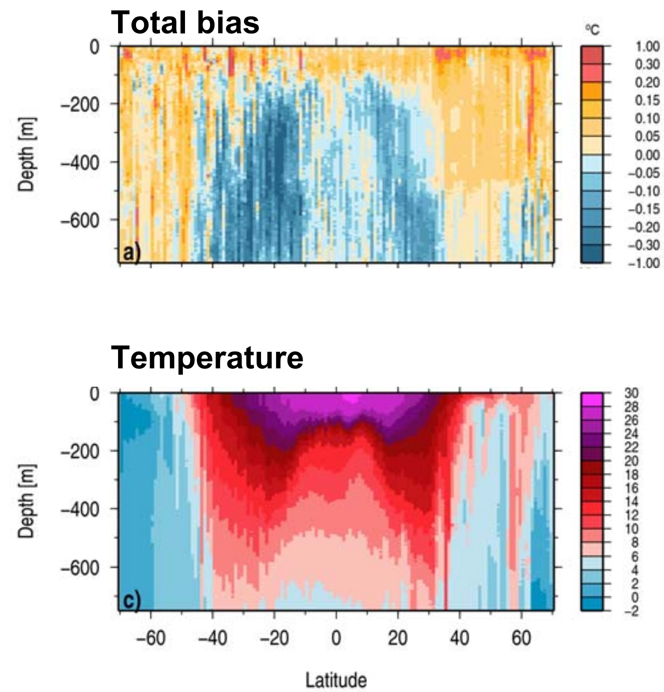
FALL RATE DEPENDENCE ON TEMPERATURE

Depth correction factor in selected latitude belts

T-Profiles averaged between 0 and Z meters







Depth correction factor

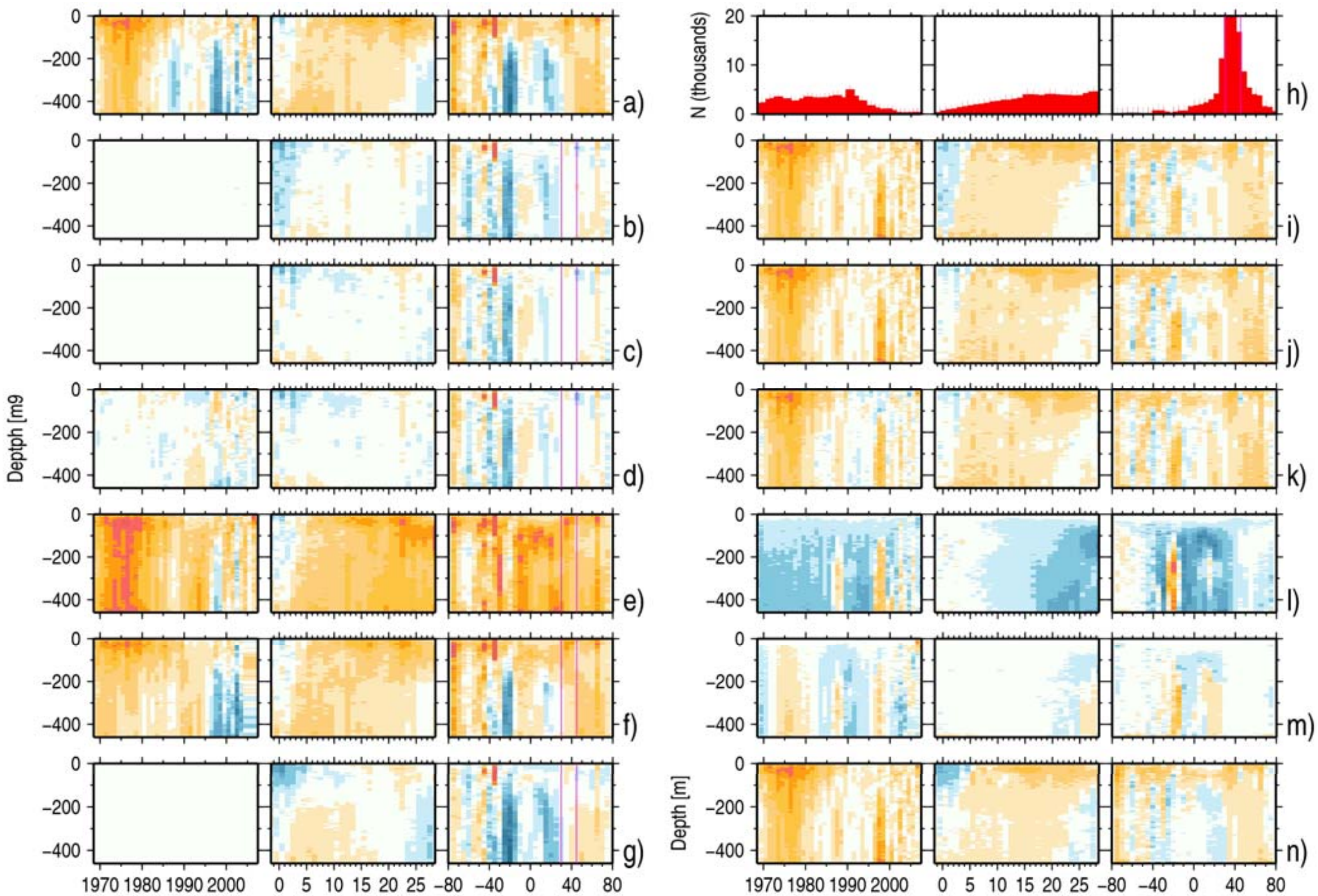
$$s = s_o + k\Delta\check{T},$$

$\Delta T = \check{T}_o - \check{T}$ and $\check{T}_o$ and $\check{T}$ are global mean and observed temperature averaged between the surface and level z

(from Gouretski&Reseghetti, 2010)

Original and residual bias for different bias models: T-4/T-6 probe types
Best results for models accounting for both thermal and depth bias

Total T-bias ***Absolute bias reduction***



Original

$S=s(z,t)$

$S=s(z,t,\Delta\check{T})$

$S=s_o(z, \Delta\check{T})$

S=1.0336

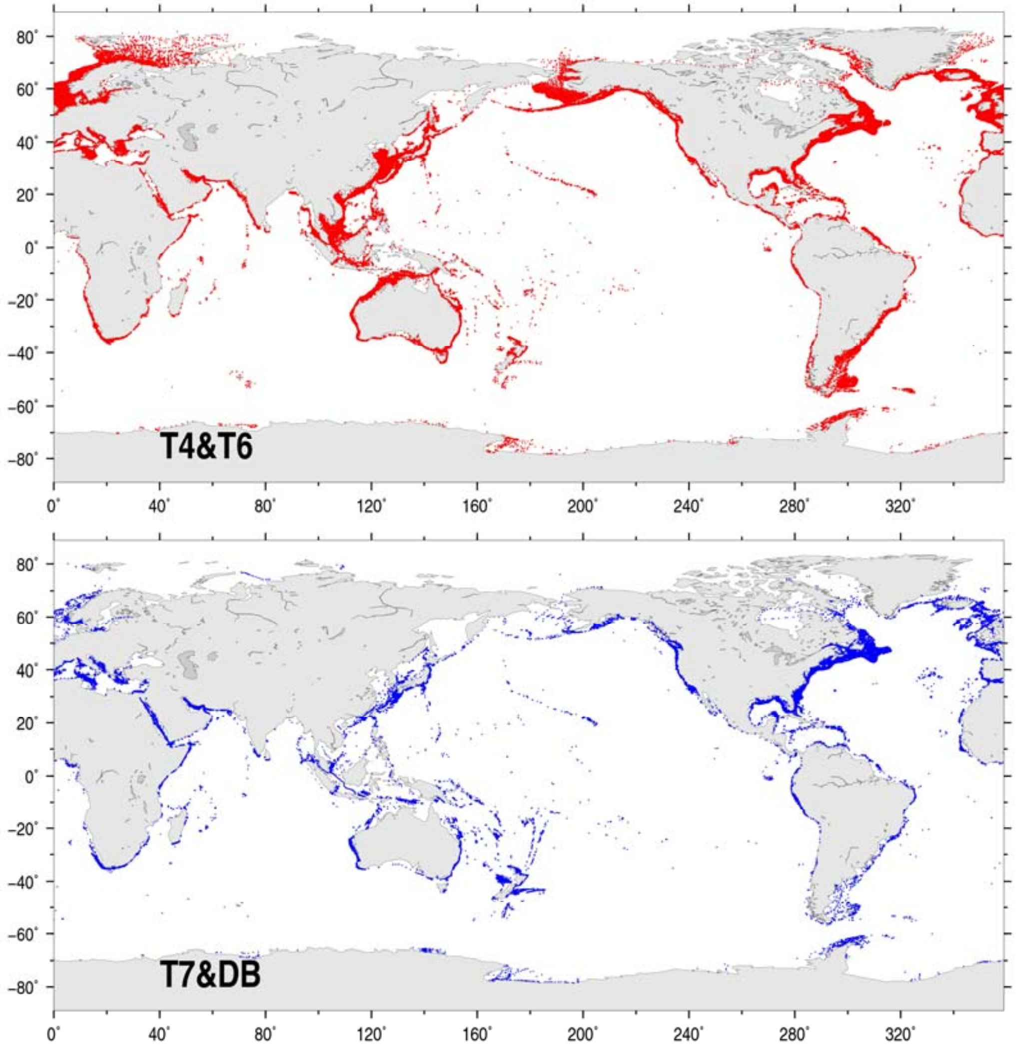
$S=s(t)$ **(Wijffels et al.2008)**

S=1.0

$C_T=C_T\ (z,t)$

(Gouretski&Reseghetti, 2010)

Inferring XBT depth bias through a comparison with GEBCO digital bathymetry: an alternative approach



Method first suggested and implemented by S. Goods (2011)

GEBCO 30 arc second resolution digital bathymetry is used as a reference

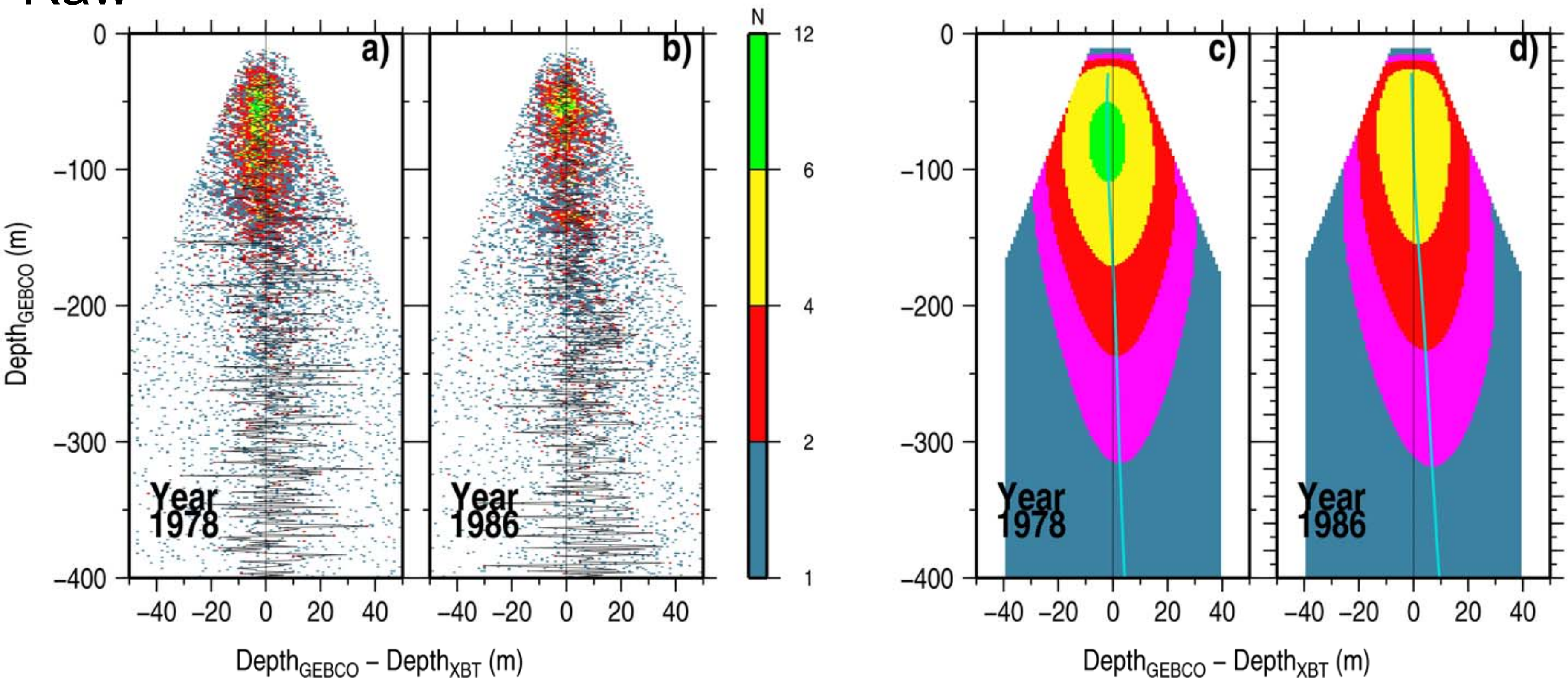
Analysis possible to the depths of ~450/750 metgers

submitted

XBT-Gebco depth-difference histograms

Raw

Smoothed

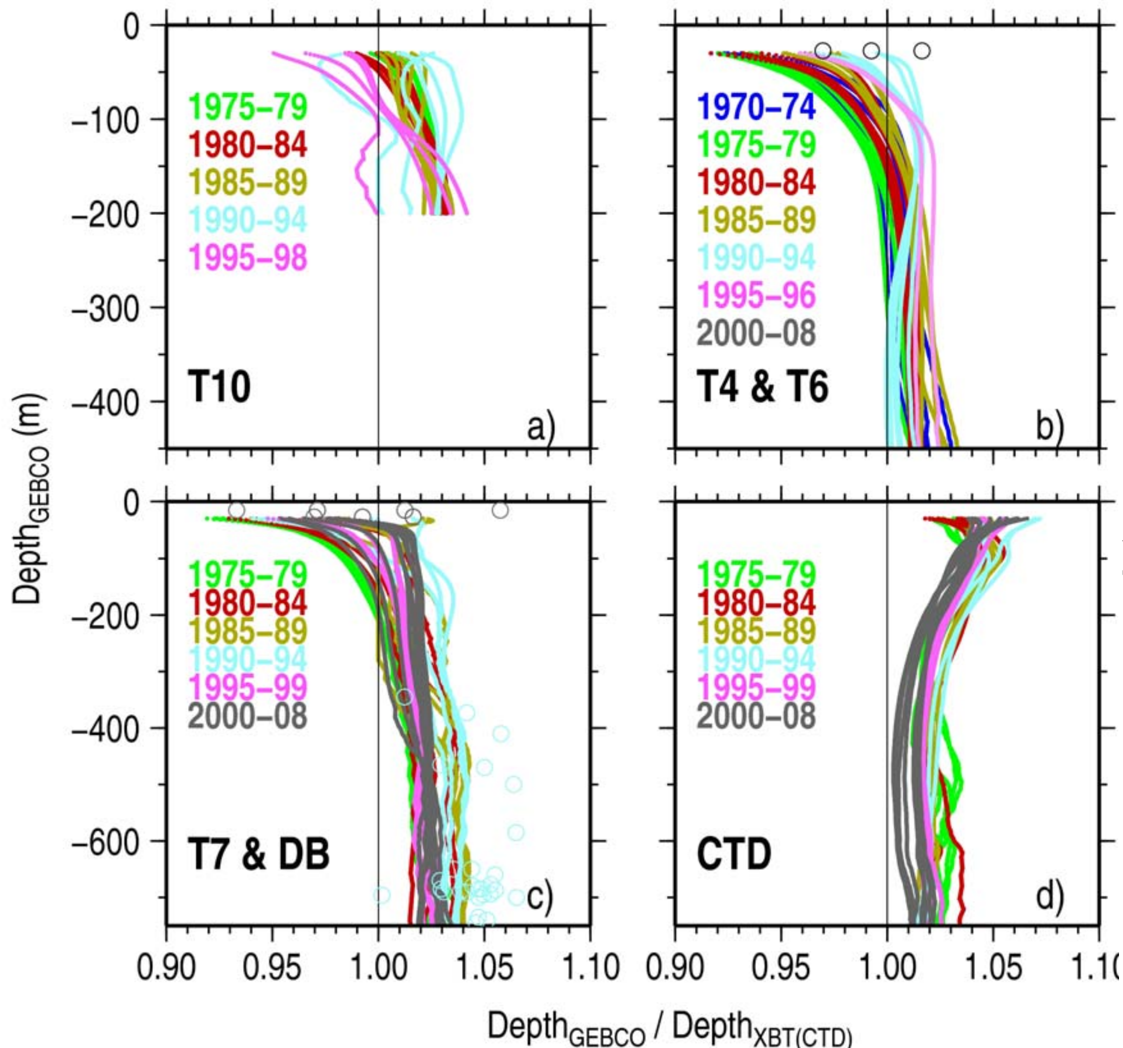


Distribution mode is linked to the depth bias in the XBT data

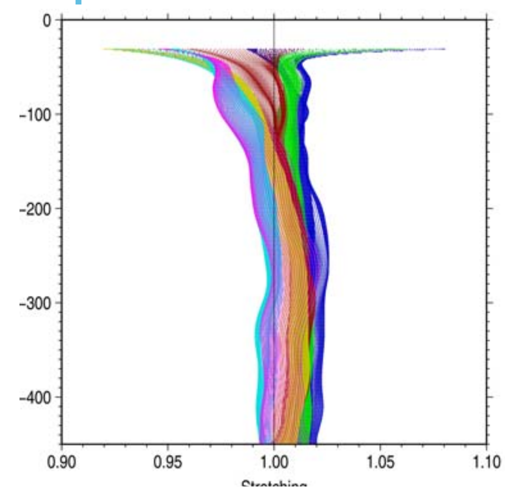
submitted

Estimates of depth correction factor

Comparison with GEBCO



Comparison with CTD/Bottle



XBT Depth correction multiplicative factor varies with depth

Method gives reasonable distance between the CTD rosette and the bottom

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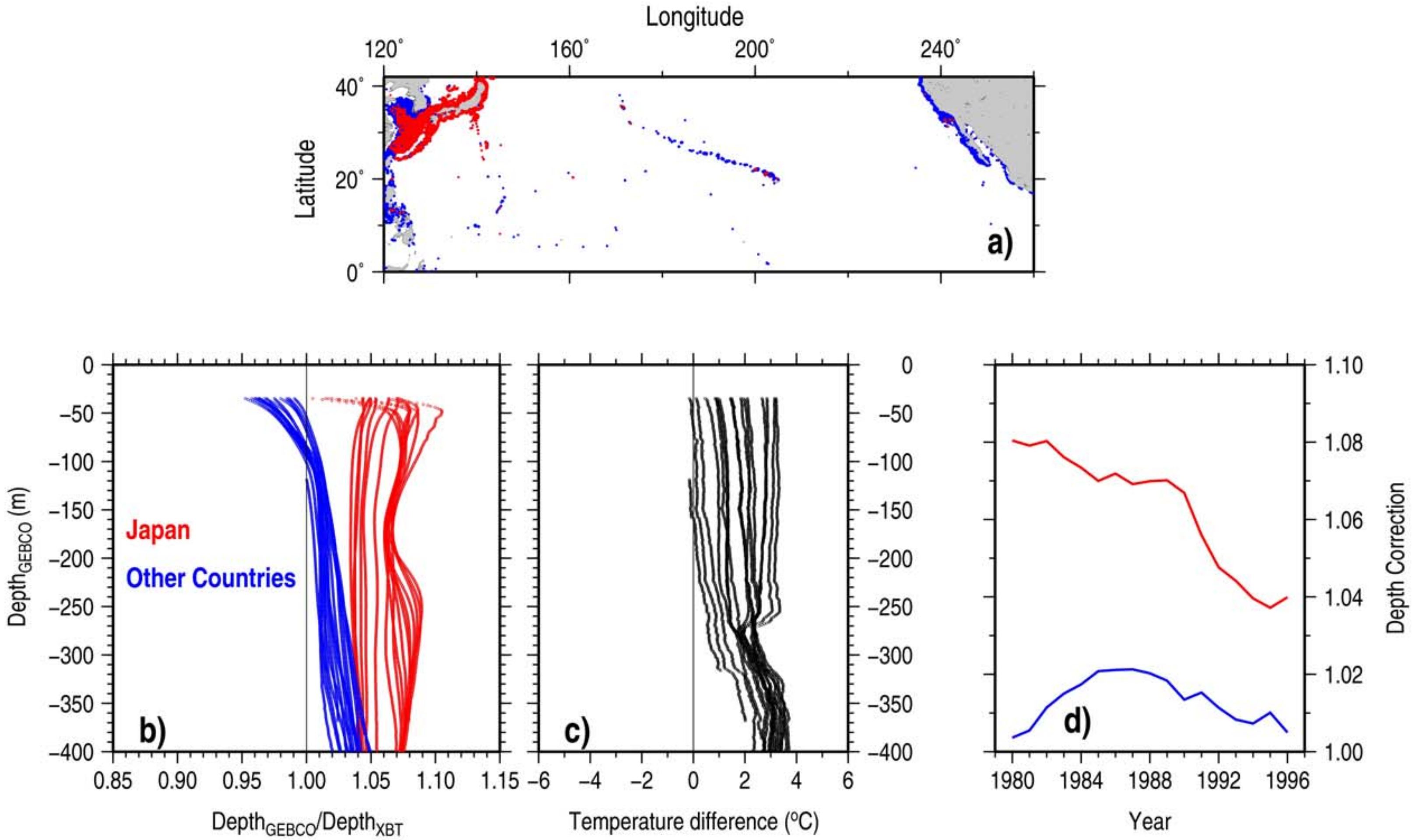
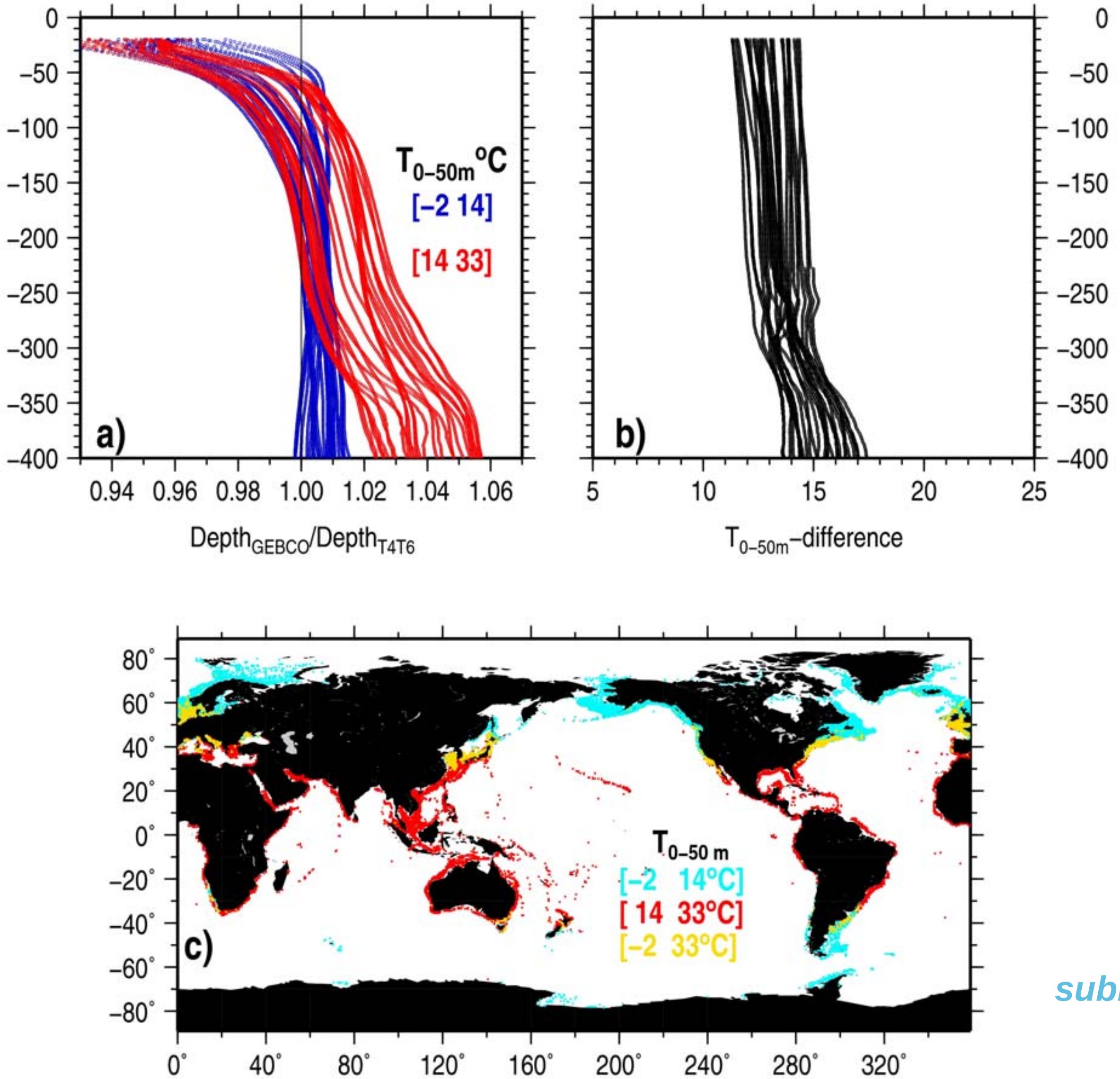
Different corrections for different manufacturers



submitted

Dependence of the depth correction on water temperature



submitted

XBT Bias Summary

- XBT biases are now well documented and relatively well understood
- Thermal bias not-negligible and explains part of time variations in the total T-bias
- Depth-varying depth-correction factor required
- Fall-rate depends on the ambient water temperature
- Different FREs needed for Sippican and TSK probes

(XBT fall-rate and bias workshop, August 2010, Hamburg, KlimaCampus)

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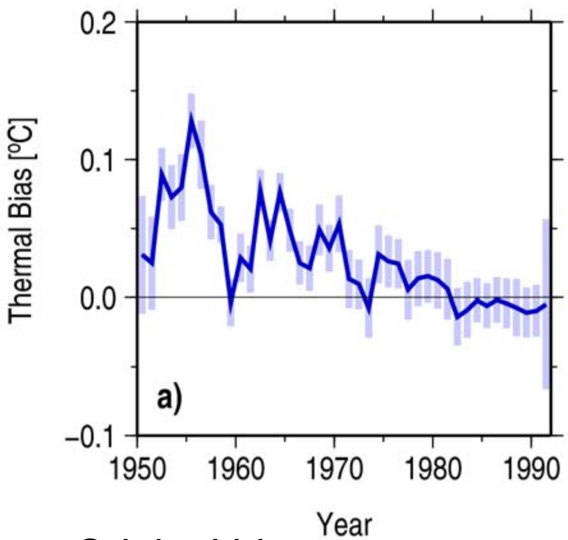
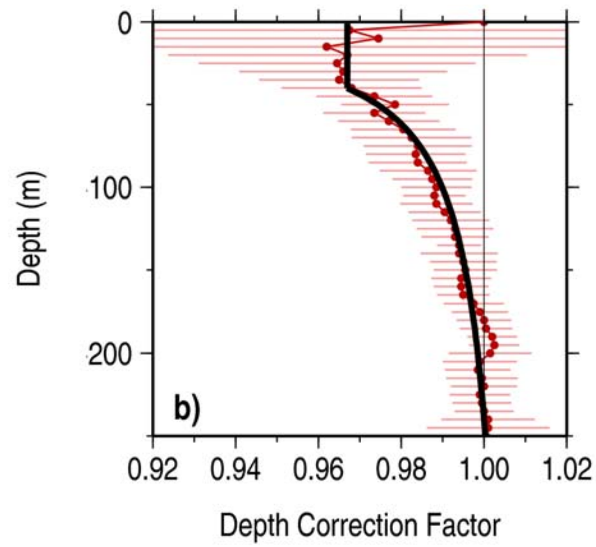
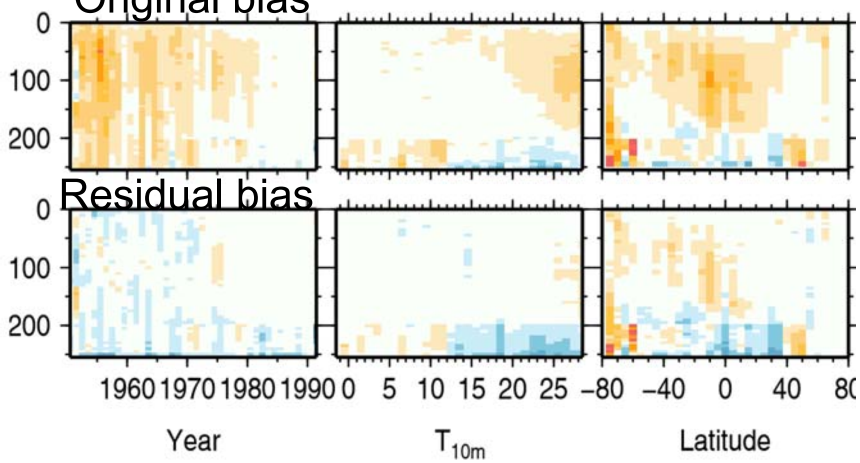
BIASES IN THE MBT DATA

Thermal bias



Depth correction factor





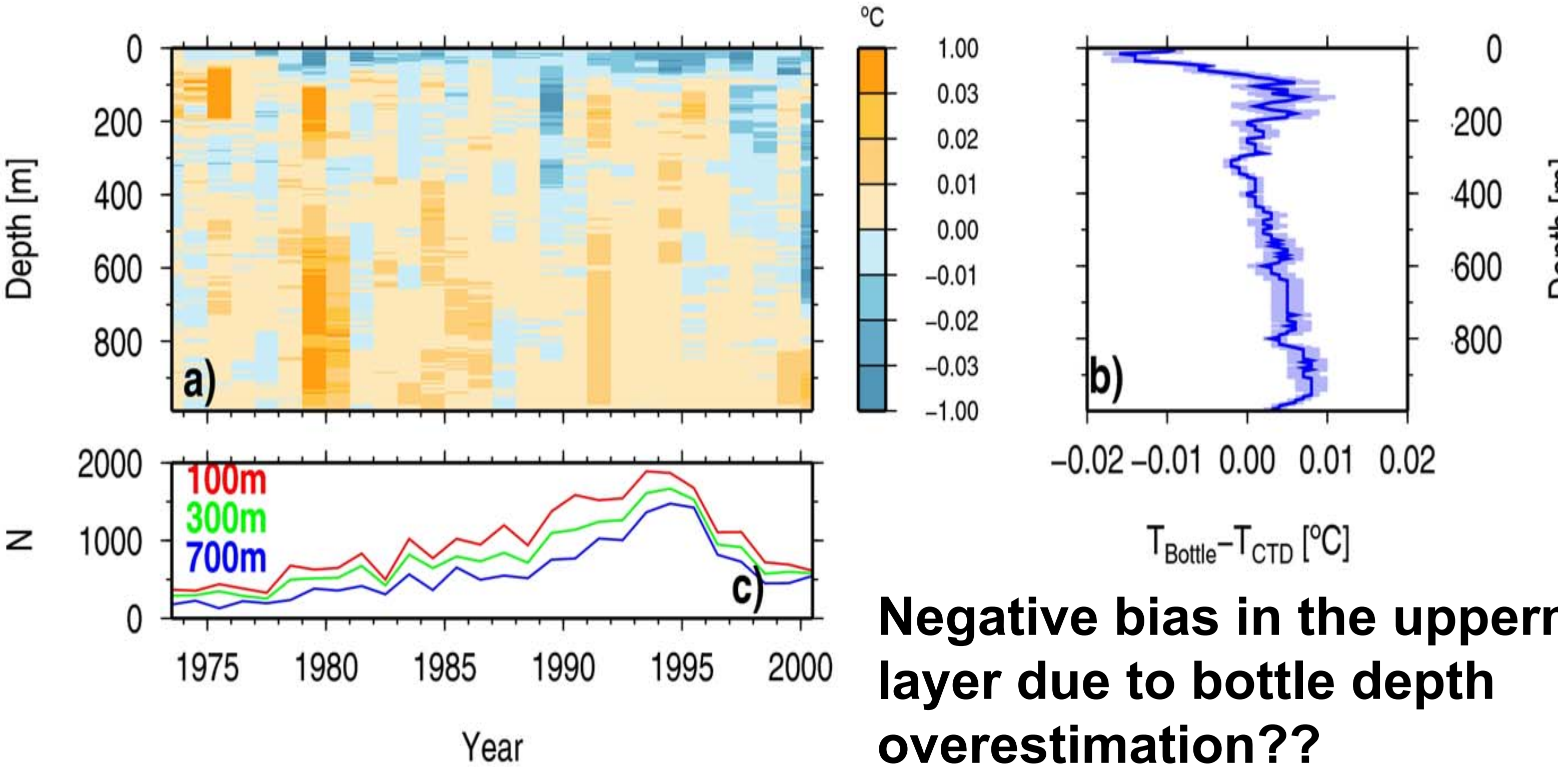
MBTs have two sensors ➔ respectively to biases possible

Same bias model effectively reduces total temperature bias

(from Gouretski&Reseghetti, submitted)

Consistency of the (reference) CTD&Botlle Dataset

Yearly T-difference (Bottle – CTD) as the median of all collocated bins



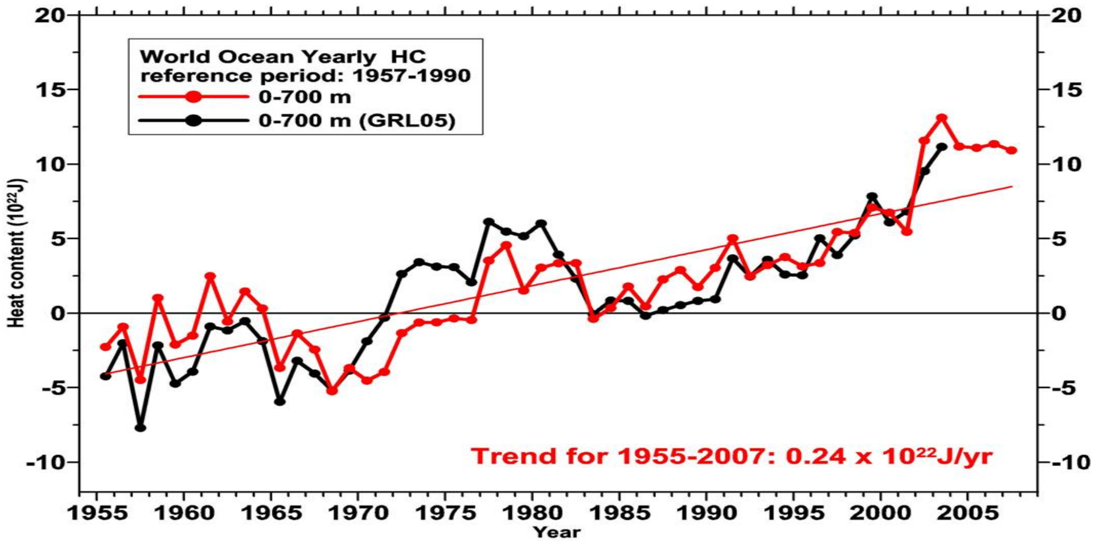
Negative bias in the uppermost layer due to bottle depth overestimation??

(Gouretski&Reseghetti, 2010)

Global Heat Content and Biases in the XBT Data

- **XBT temperature profiles are systematically warm biased (Gouretski and Koltermann, 2007)**

- **Biases must be assessed and excluded before using XBT data in climate studies.**



Levitus et al., 2009

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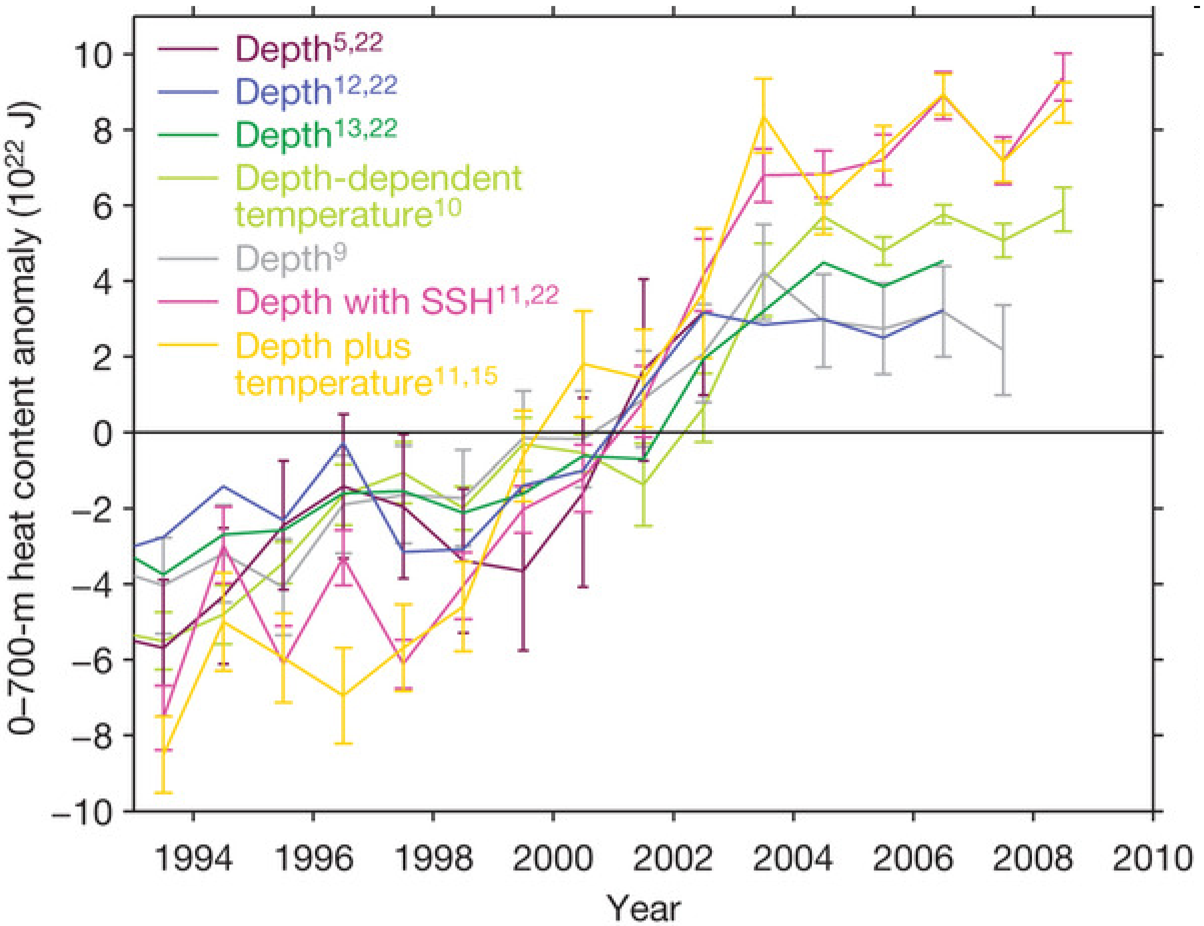
Robust warming of the global ocean since 1994: biases obviously smaller than the warming signalduring this time period



Lyman et al. 2010

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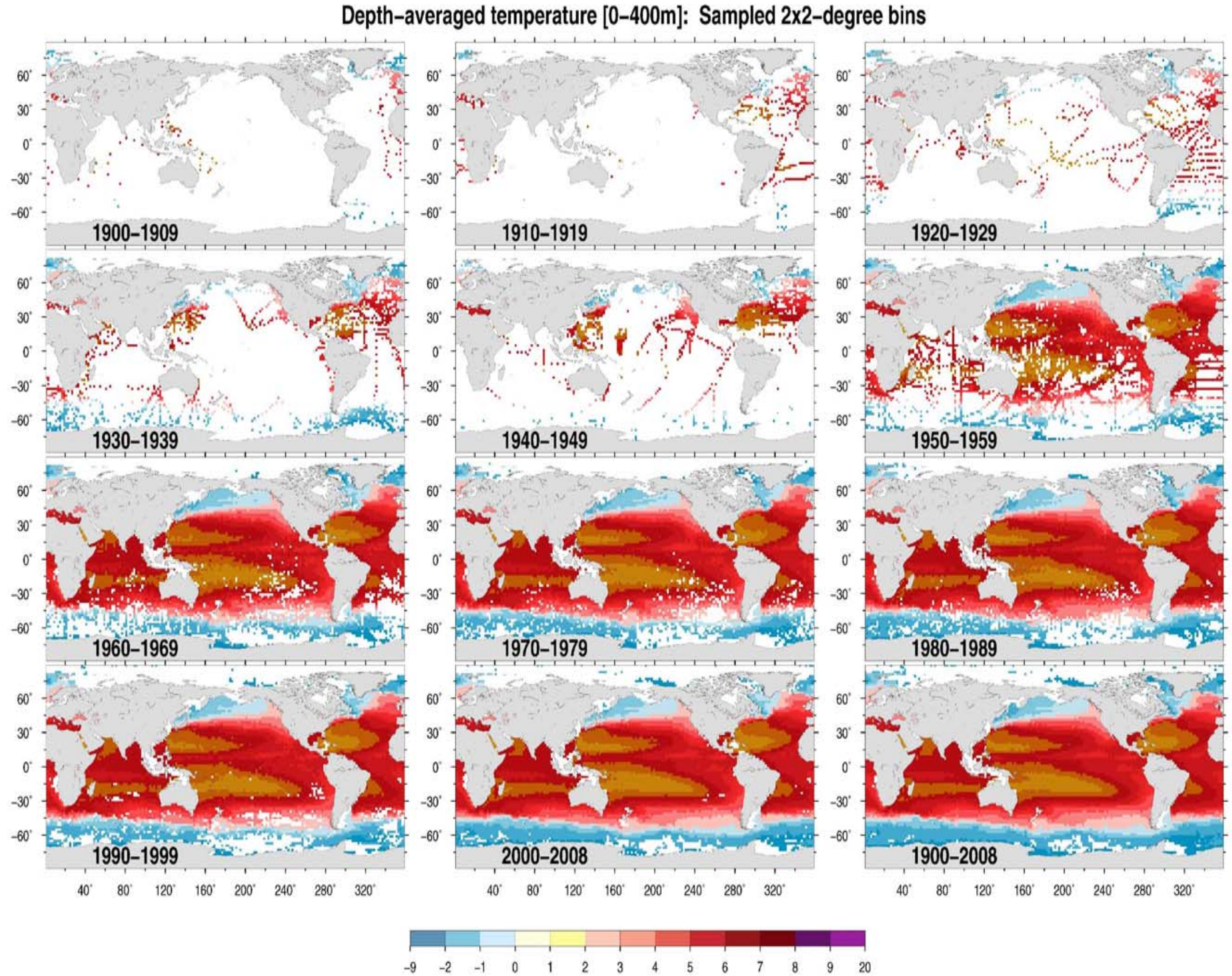
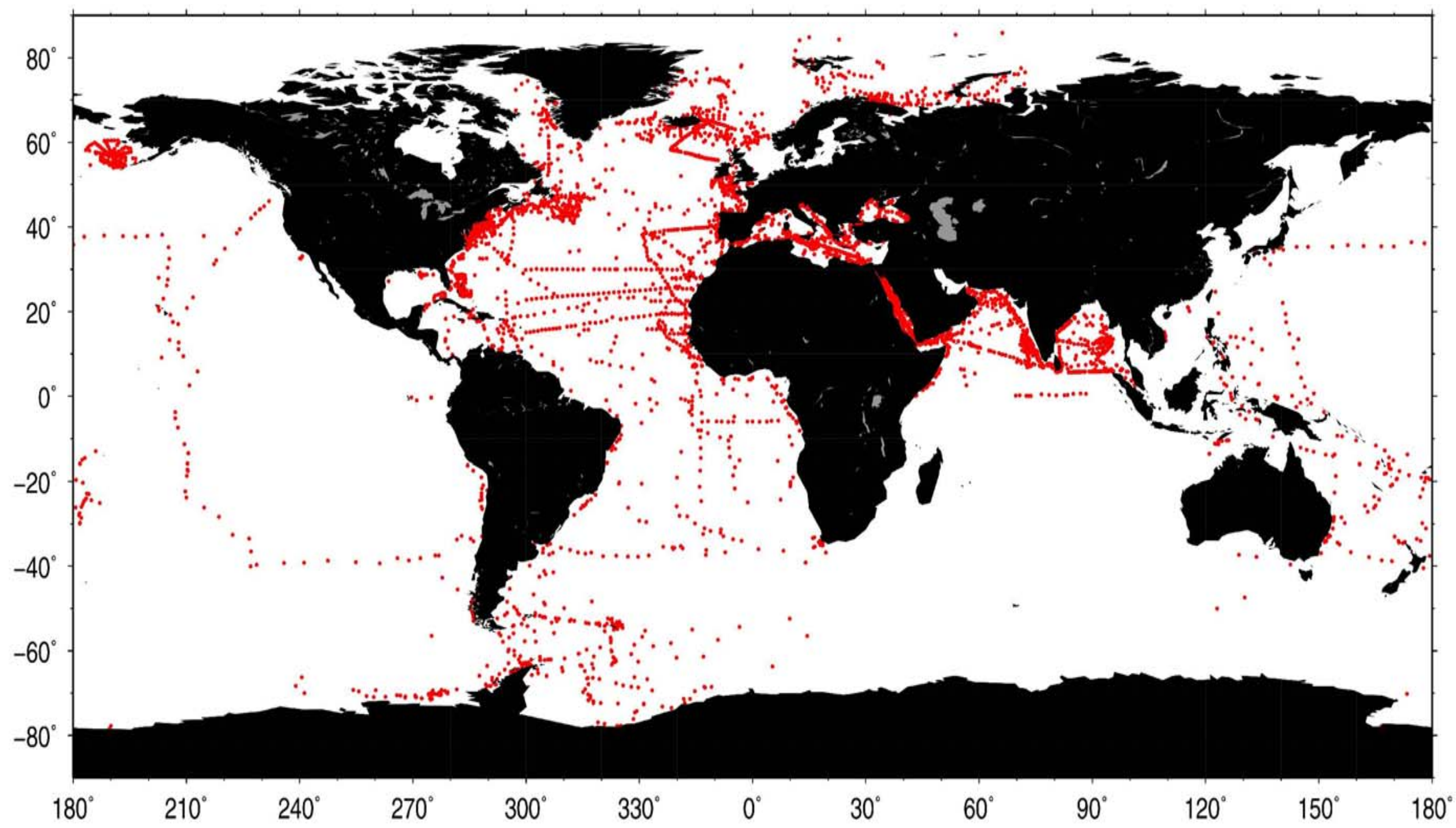
Time series of depth-averaged temperature: calculation details

- Reference period: 1999-2008
- Reference data types: Bottle+CTD+FLOATS
- Layer-averaged profiles
- Point anomalies referenced to monthly climatology
- Binning (222 km x 222 km x 1 month)
- Global averaging

Sampled 2x2-degree boxes: a very irregular coverage over time ➔ uncertainties in the heat content calculations are large before ~1950



Historical Hydrographic Profiles digitized in BSH (before 1940)
These were added to the WOD09 data



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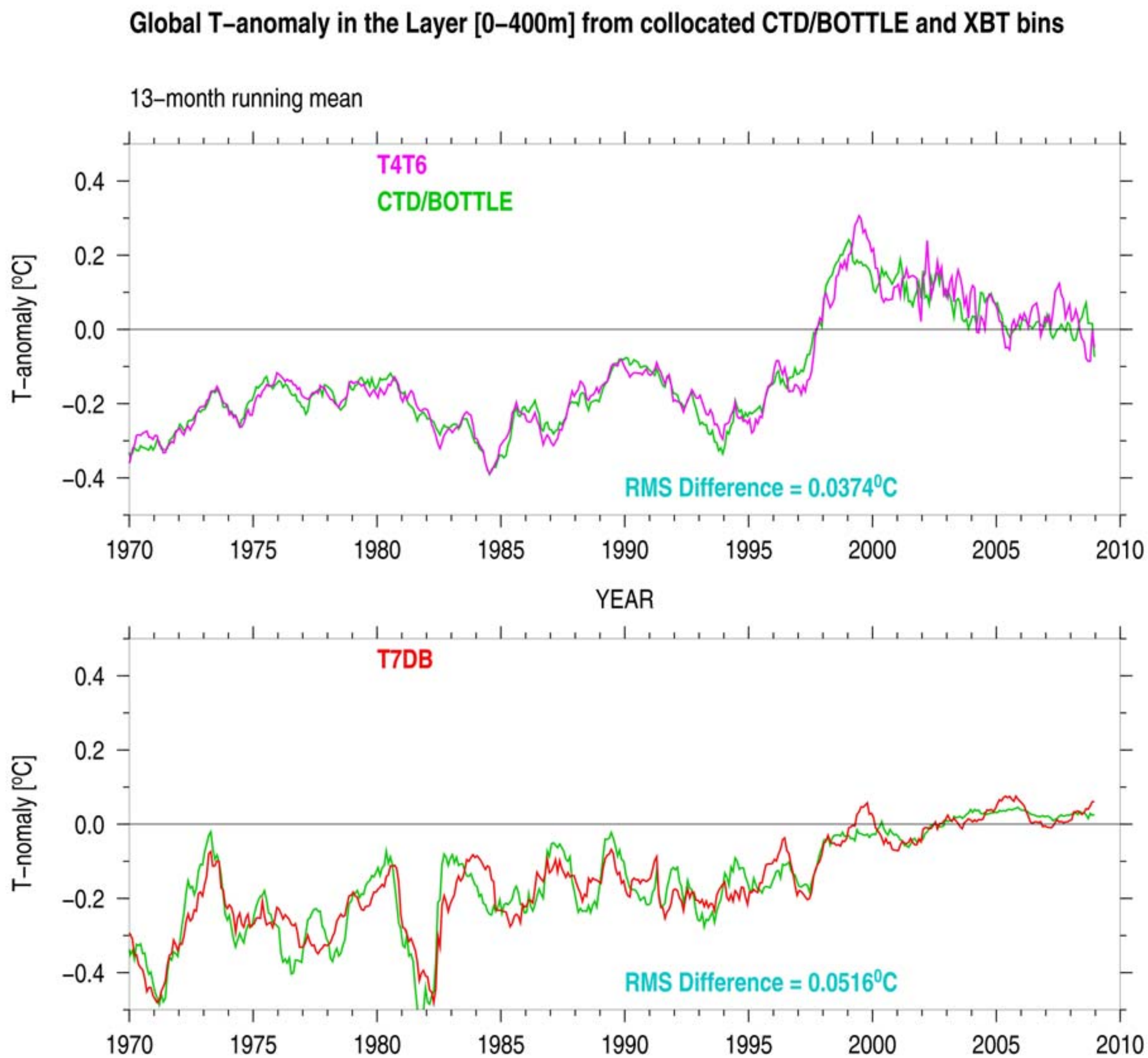
Estimates of the residual bias: XBT vs CTD/BOTTLE time series for colocated bins



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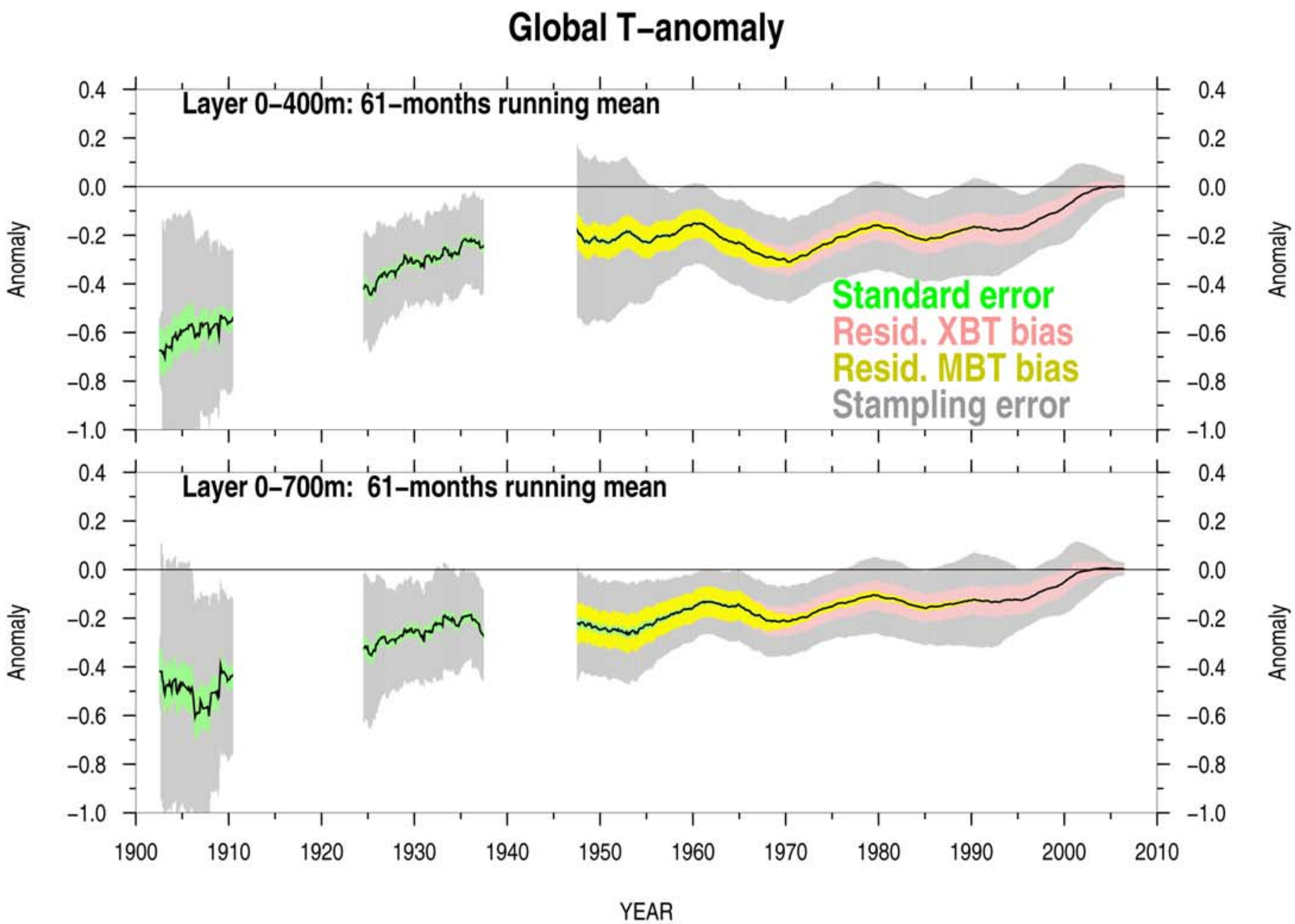
Layer mean global T-anomaly with uncertainties



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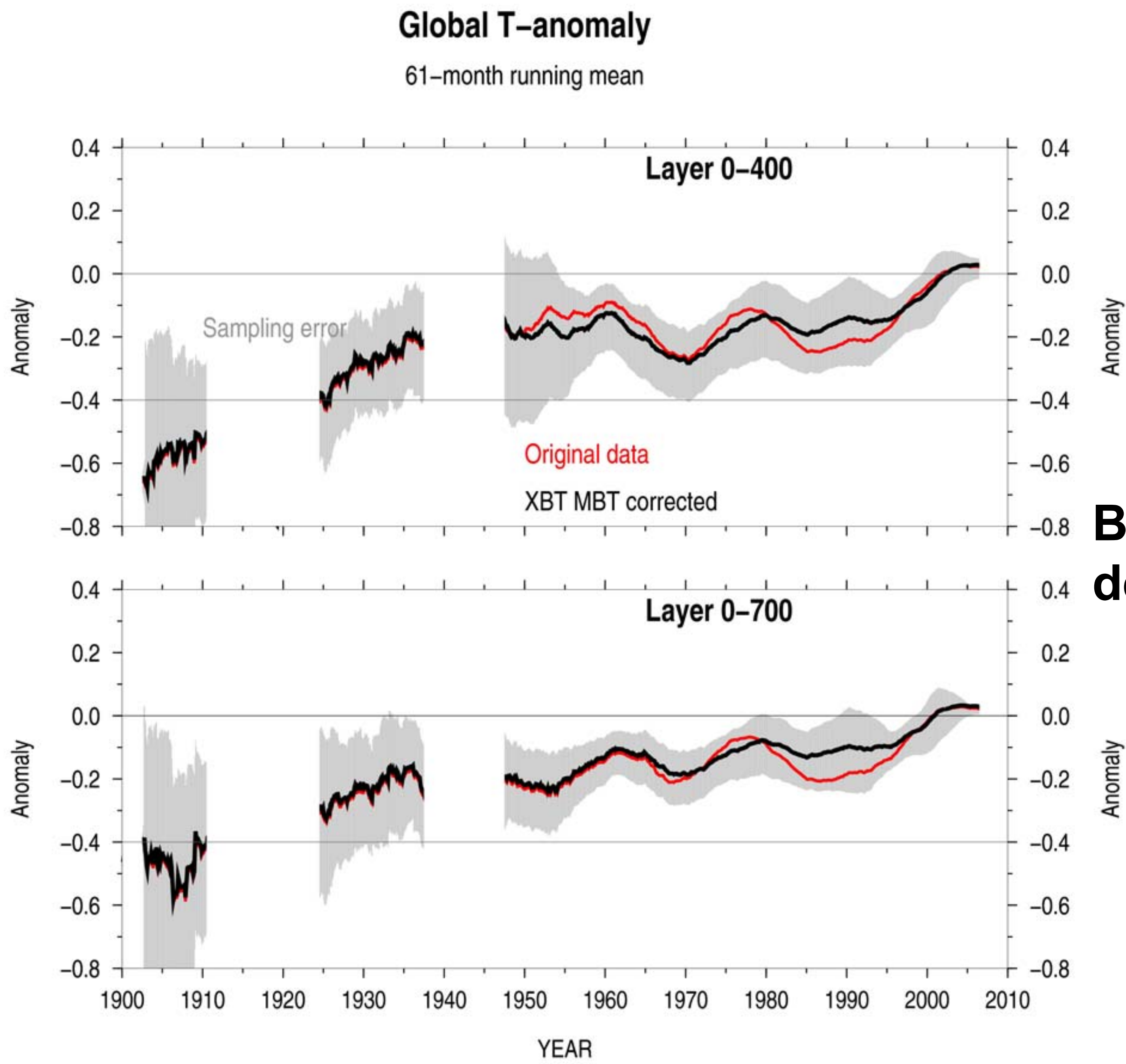
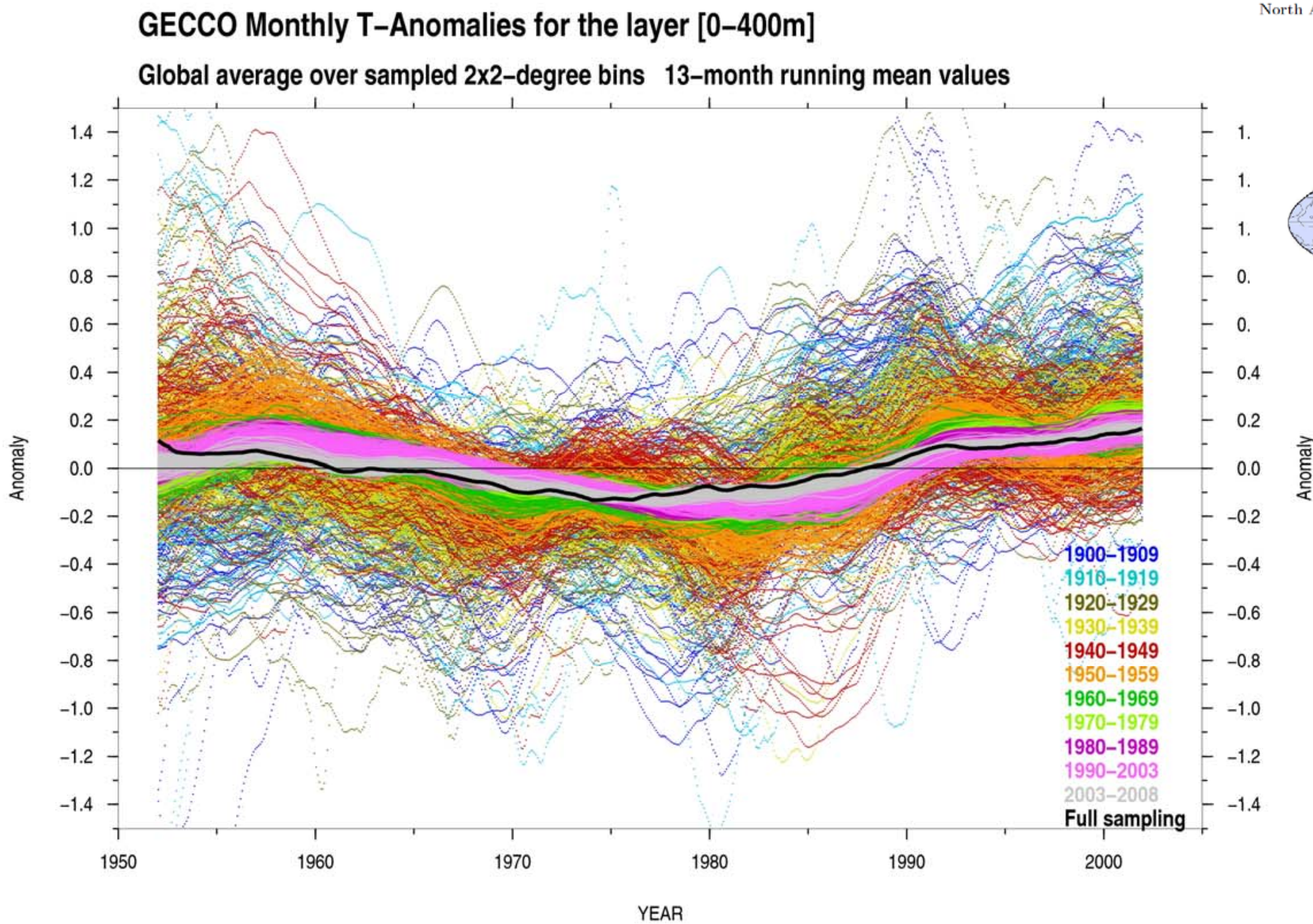
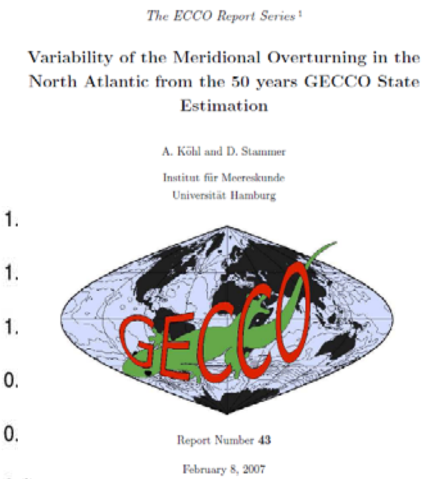
Global T-anomaly: Original vs corrected data (Sippican FRE)



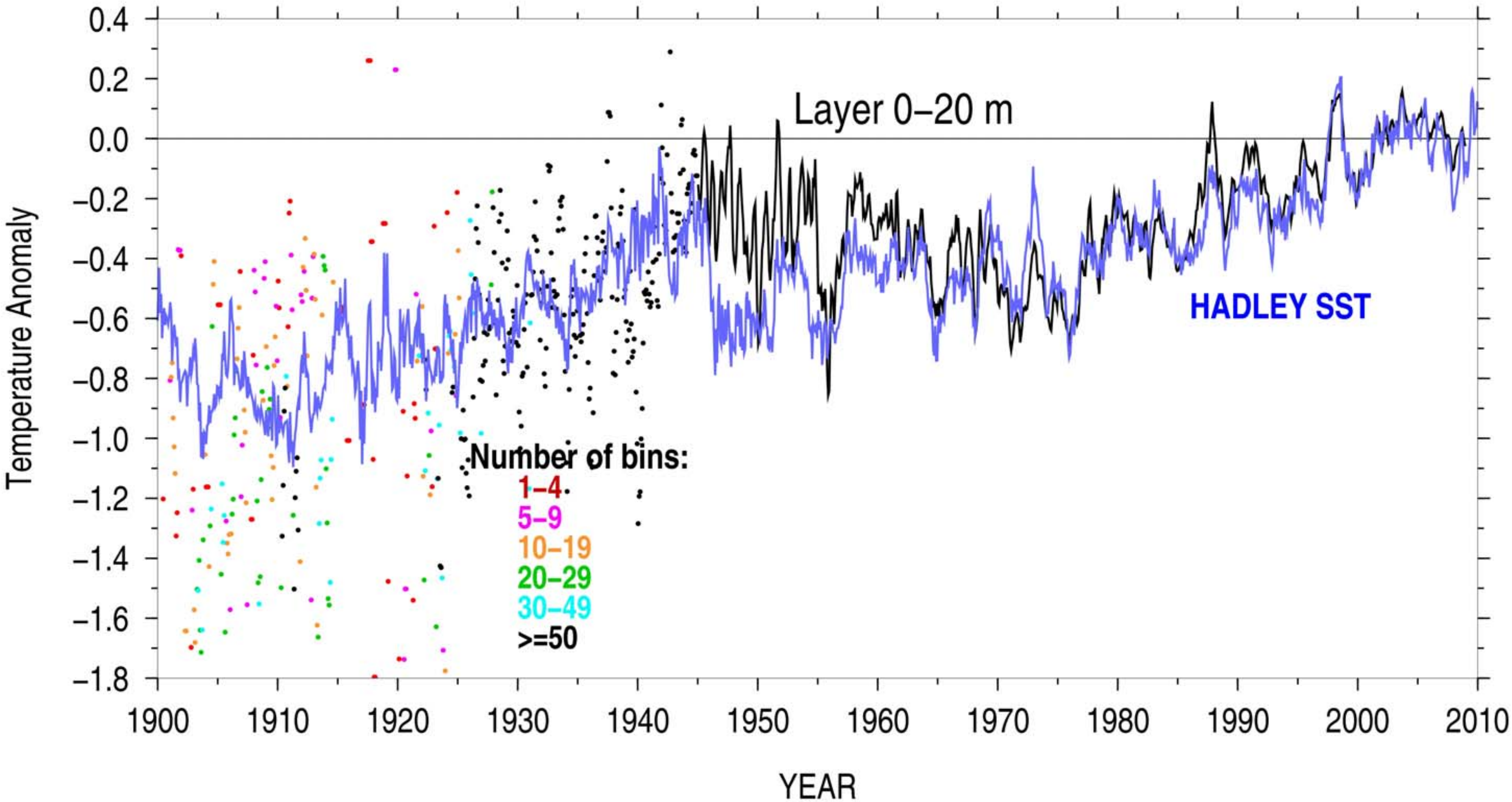
Bias elimination reduces decadal-scale variability

Estimating sampling error from GECCO reanalysis

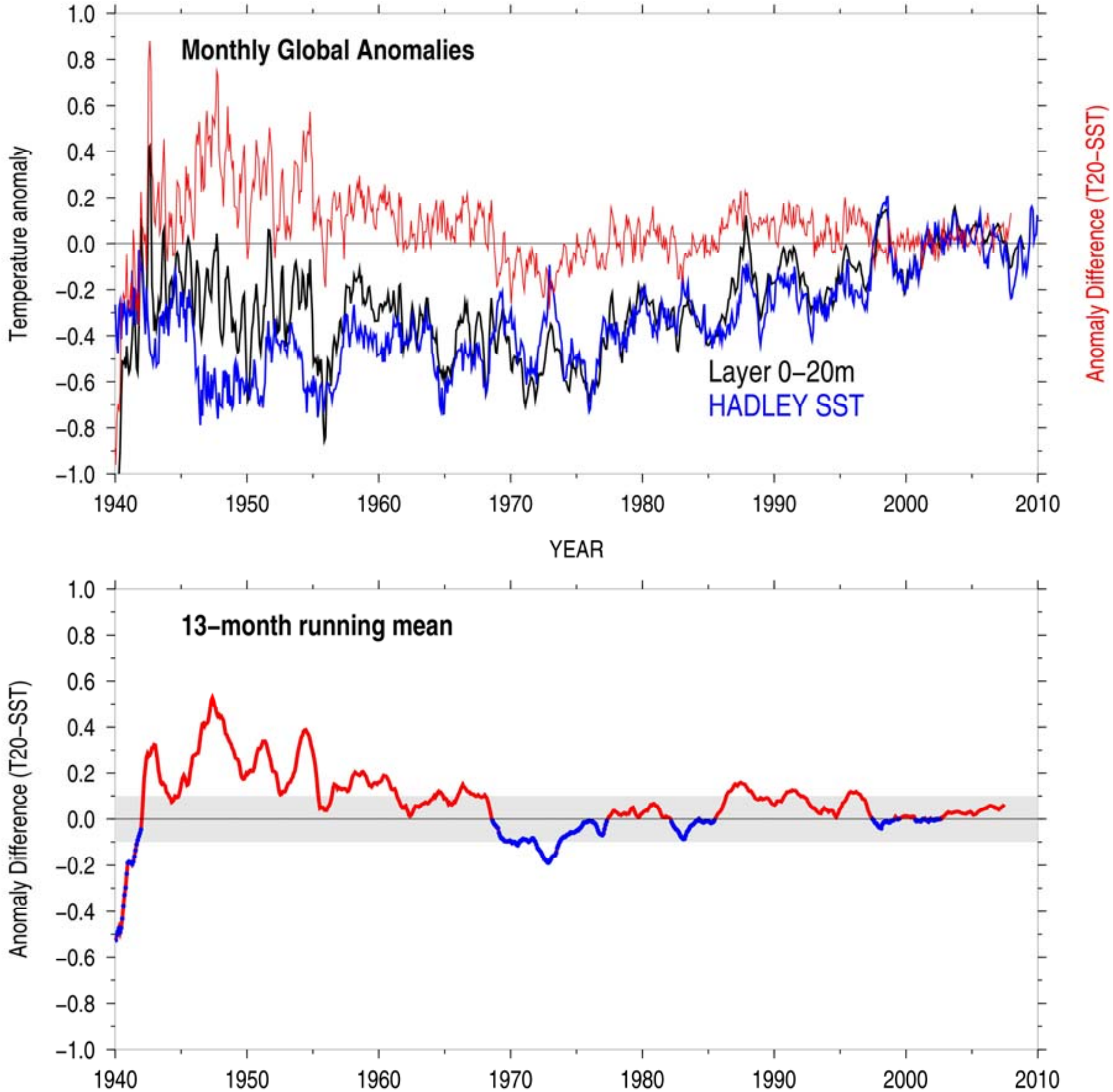




Comparison with Hadley SST time series (monthly T-anomalies)



Difference $\Delta T_{0\text{-}20m}$ - ΔSST_{HAD}



CONCLUSIONS

- Research quality profile data set is needed to reduce uncertainties in global heat content estimates
- Growing databases open a possibility for re-evaluation of the data quality and for the assessement of systematic errors
- Progress in understanding XBT biases achieved, but more metadata and dedicated in situ tests/inter-comparisons are still needed
- Good agreement between the independent SST- and mean subsurface temperature time series. Analysis of differences helps to identify biases

Thank you !