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Biases in the XBT data and their corrections: a review

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KlimaCampus, University of Hamburg

Hamburg, 25-27 August 2010

Zentrum für Marine und Atmosphärische Wissenschaften

Max-Planck-Institut für Meteorologie

GKSS Forschungszentrum Geesthacht

Deutsches Klimarechenzentrum

With my special thanks to Franco Reseghetti

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Global subsurface database is inhomogeneous

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XBT Bias sources

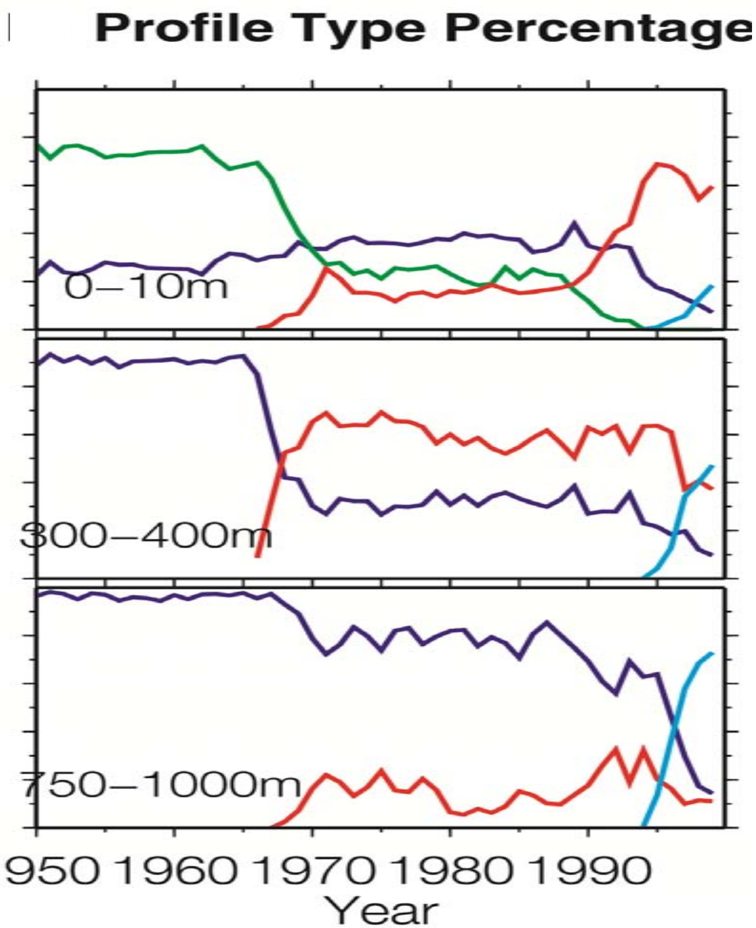
Global XBT/CTD inter-comparison

MBT biases

Reliability of reference data

Summary and plans for the future

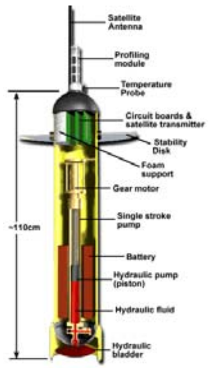
Biases and global heat content anomaly estimates



MBT

BOTTLE

XBT



PFL

CTD

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Arthur D. Little, Inc	1965	Experimental evaluation of XBTs.	
Magruder	1970	XBT accuracies	FR-velocity, chart recorder description
Flierl, Robinson	1977	XBT measurement during MODE	XBT depth underestimated
Mc Dowell	1977	On XBT accuracy	XBT depth underestimated
Anderson	1980	XBT accuracy studies	Error statistics, warm T-bias, Sippican comments presented
Seaver and Kuleshov	1982	Experimental and Analytical XBT error study	Depth error study
Heinmiller et al	1983	Systematic errors	Depth errors, thermal bias, new FRE
Green	1984	Bulk dynamics	Analytical depth-error study. Suggested that hydrodynamic drag varies linearly with depth
Hanawa, Yoritaka	1987	Detection of systematic errors	Depth and T-error description
Roemmich, Cornuelle	1987	Calibration of XBT probes	Laboratory T-error study
Wright, Szabados	1989	Evaluation of XBT systems	Depth- and T-error field study, different systems compared
Sy	1989	DB fall-rate errors	Fall-rate error estimates

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Singer	1990	XBT T7 errors	T7 depth-error study, new FRE
Watts, Mohammed, Fields	1990	XBT systematic depth error	T-7 systematic depth error
Baily	1990	The “Bowing” problem	Description of the bowing problem
Szabados	1991	Fall rate estimation	FRE evaluated, mixed-layer T-bias reported
Hanawa,Yoshikawa	1991	Re-examination of depth-error	A new FRE for T-6 and T-7
Wisotzki,Fahrbach	1991	“Polarstern” XBT data	Study of T-differences using Heinmiller et al corrections
Hallock, Teague	1992	XBT T7 fall rate study	A new T-7 FRE
Hanawa, Yasuda	1992	XBT T7 Depth-error	A new T-7 FRE
Bartz	1992	Development of an expendable sensor	Experimental results for the XBT fall rate
Budeus, Krause	1993	On cruise XBT calibration	On board XBT-calibration
Kezele, Friesen	1993	XBT Test data, analysis	All important error-related problems posed (FR, thermal bias, FR dependence on ambient T
Boyd, Linzell	1993	T5 T- and Depth-accuracy	A new T-5 FRE
Hanawa et al	1994	A new fall rate equation	A new T-4/6/7 FRE

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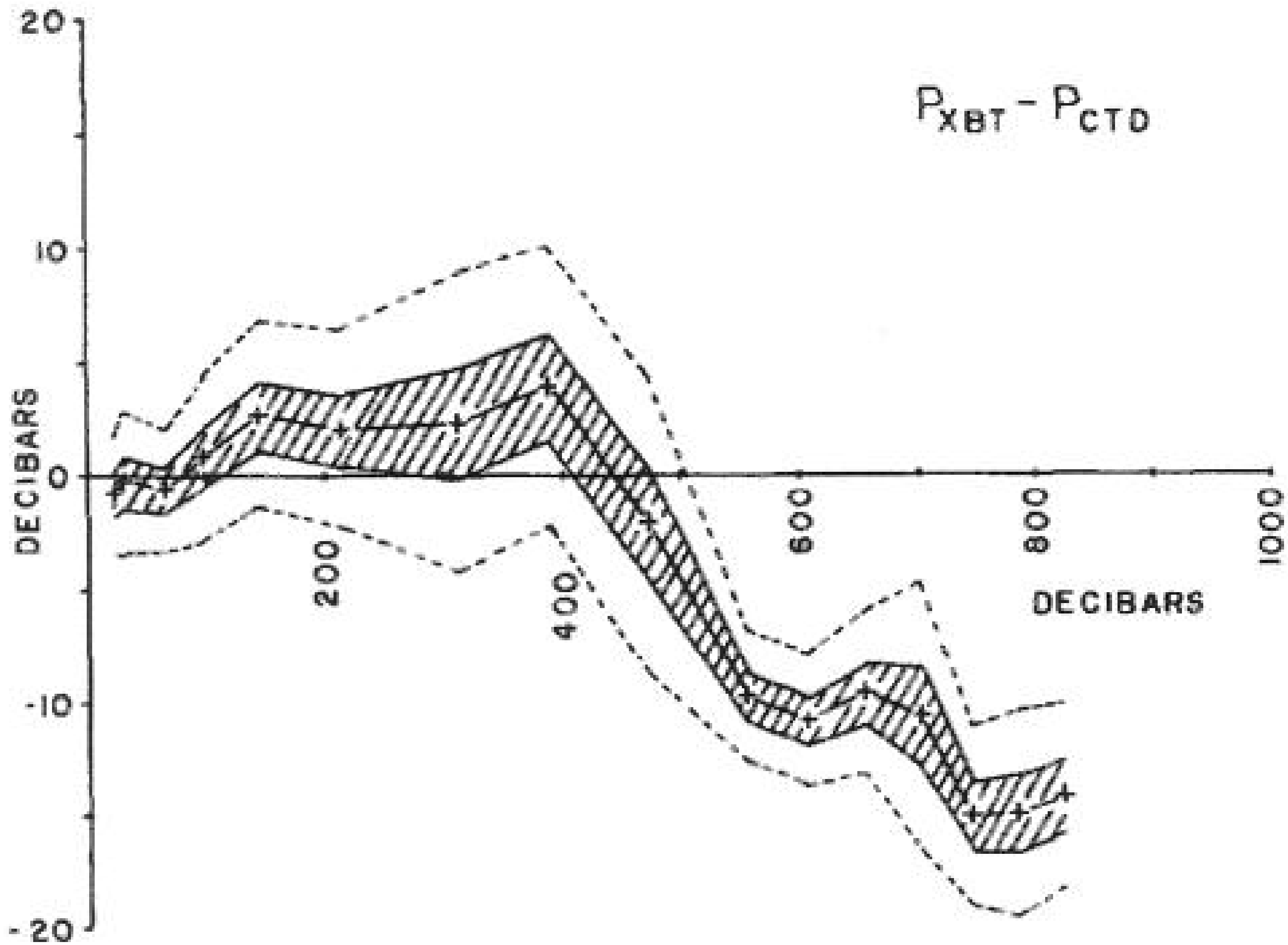
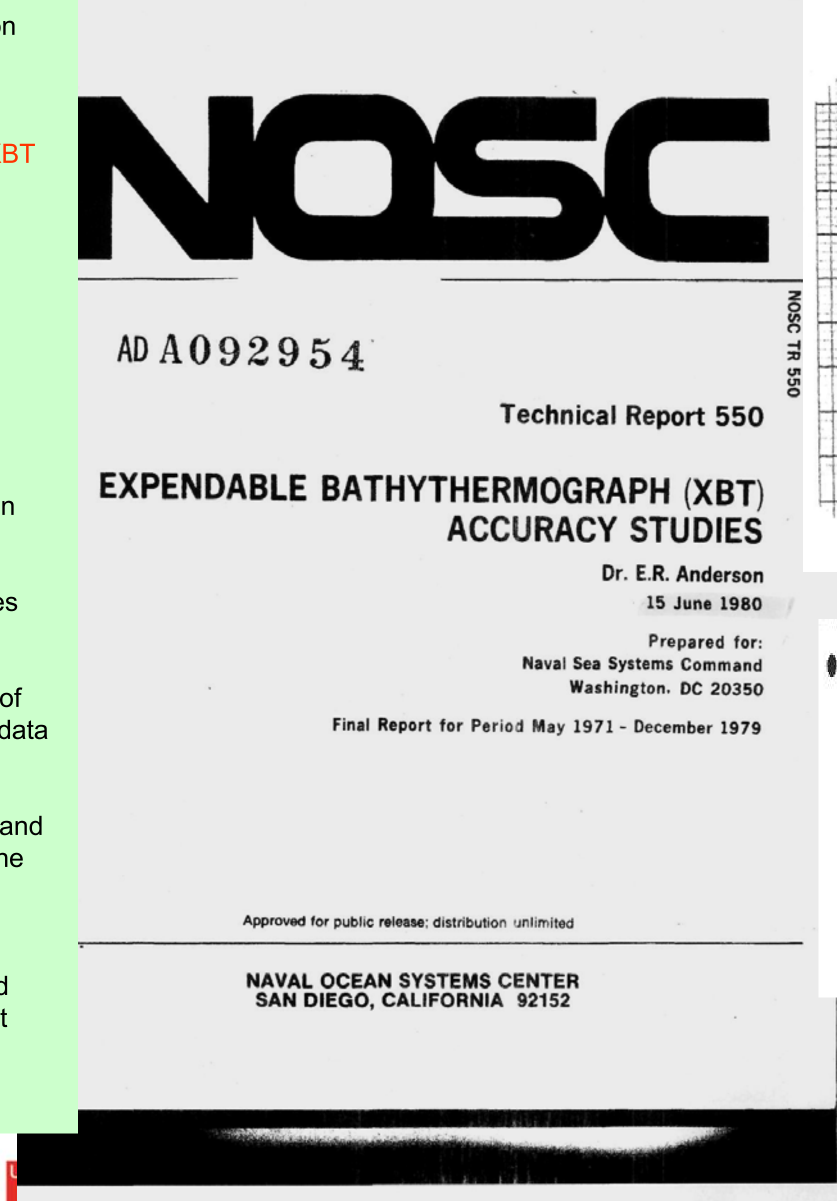
Thadathil et al.	2002	Fall rate at extreme temperature	Indication of a slower fall-rate in the Antarctica
Kizu, Hanawa	2002	Start –up transients	Start-up transient statistics
Kizu, Hanawa	2002	Recorder-dependent error	Bowing found for two recorders
Kizu, Yoritaka, Hanawa	2005	A new T5 FRE	A new T5 FRE
Kizu, Ito,Watanabe	2005	T5: Inter-manufacturer differences and Fall-rate temperature dependence	Sippican vs TSK T-5 Fall-rate study
Reseghetti, Borghini Manzella	2007	Factors affecting XBT quality	Causes for XBT bias, T-bias correction
Gouretski and Koltermann	2007	How much is the ocean warming	XBT T-bias identified on a global scale
Ishii, Kimoto	2008	Re-evaluation of OHC using XBT corrections	Depth corrected using a linear bias equation
Wijffels et al	2008	Changing XBT fall rates and their impact on estimates of Sea level rise	Overall T-bias is attributed to FR changes with time. New depth corrections
Reverdin et al	2009	XBT errors during French cruises	Thermal bias identified within the mixed layer
diNezio, Goni	2009	Biases between XBT & Argo	Changes in fall-rate with time identified
Levitus et al	2009	Global heat content anoamaly	Revisited in light of recent bias studies
Ishii and Kimoto	2009	Re-evaluation of OHC using XBT corrections	Bias is attributed to depth error
Gouretski, Reseghetti	2010	Depth and T- biases (global analysis)	Global assessment of both T- and depth-biases

Flierl and Robinson, 1976: XBTs have systematic errors of up to 15 dbar



E. Anderson (1980) One of the most detailed inter-comparison studies. XBT temperatures found to be warm-biased. Some error causes explained



NOSC

AD A092954

NOSC TR 550

Technical Report 550

EXPENDABLE BATHYTHERMOGRAPH (XBT) ACCURACY STUDIES

Dr. E.R. Anderson

15 June 1980

Prepared for:
Naval Sea Systems Command
Washington, DC 20350

Final Report for Period May 1971 - December 1979

Approved for public release; distribution unlimited

NAVAL OCEAN SYSTEMS CENTER
SAN DIEGO, CALIFORNIA 92152

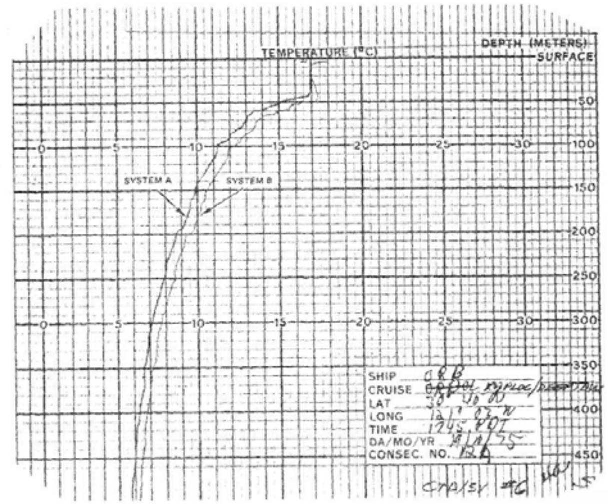


Figure 46a. Temperature profiles for RAPLOC/DEEPTOW XBT pair 4.

- Of a total of 1961 attempted 460-m profiles, the following percentages apply:

  Visually acceptable to the maximum depth.........80.1%

  Partially successful..........................10.8%

  Catastrophic failures..........................6.4%

  Miscellaneous failures.........................2.7%.

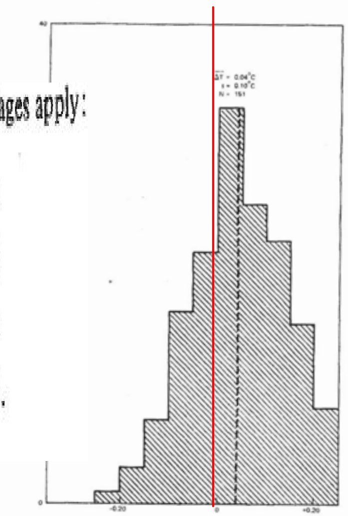


Figure 11. Comparison of CAPER's DE STEIGUER mercury-in-glass thermometer surface temperatures with XBT surface temperatures.

Txbt - Tref

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Siever and Kuleshov, 1982. Analytical and field study of systematic fall-rate errors. XBT accuracy analysis.

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- **Review of selected XBT studies**
- XBT Bias sources
- Global XBT/CTD inter-comparison
- MBT biases
- Reliability of reference data
- Summary and plans for the future
- Biases and global heat content anomaly estimates

NOTES AND CORRESPONDENCE

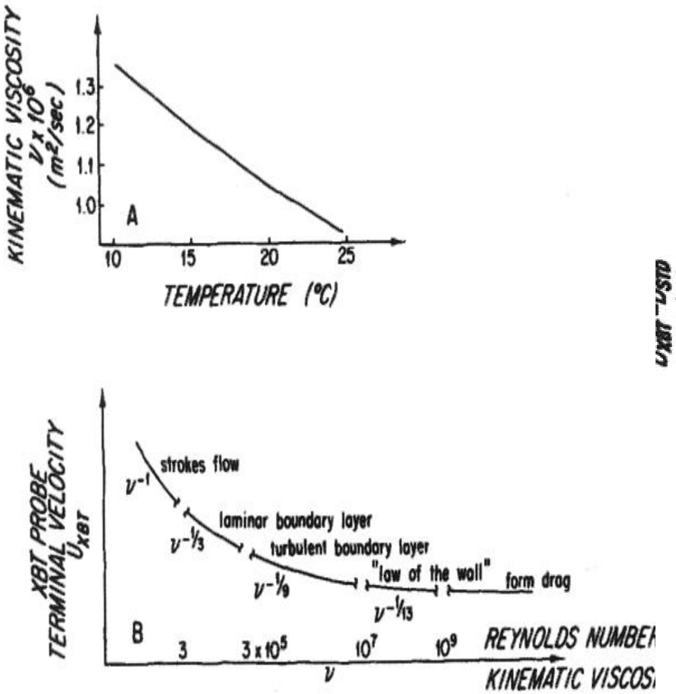

FIG. 3. Temperature, viscosity and terminal velocity for streamlined bodies: kinematic viscosity vs temperature (after Horn, 1969), (b) terminal velocity viscosity (after Schlichting, 1955).

NOTES AND CORRESPONDENCE

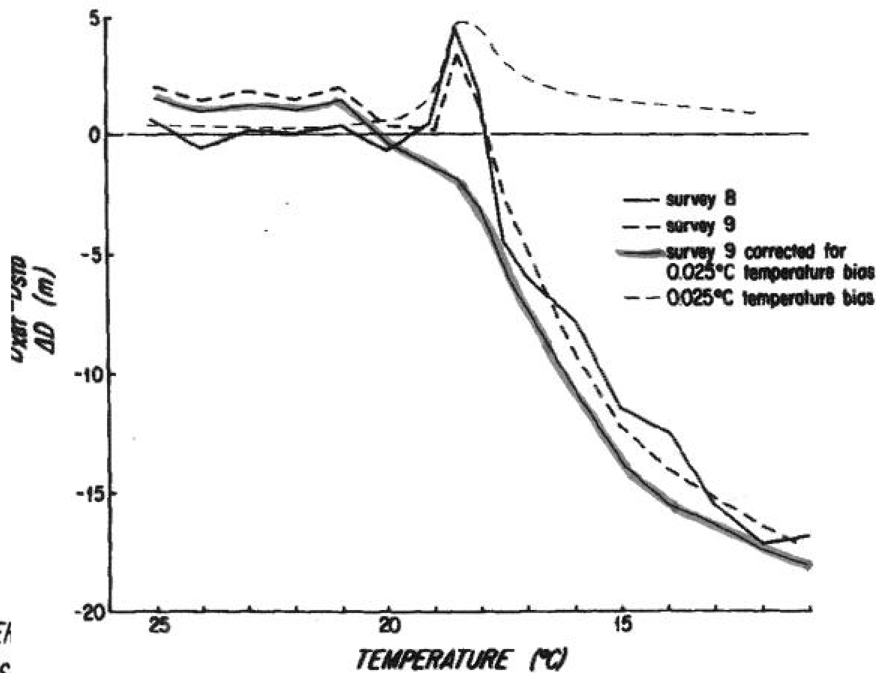

FIG. 5. XBT mean depth error vs temperature for the T-7 probe.

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Heinmiller et al. 1983. Systematic T- and depth errors studied

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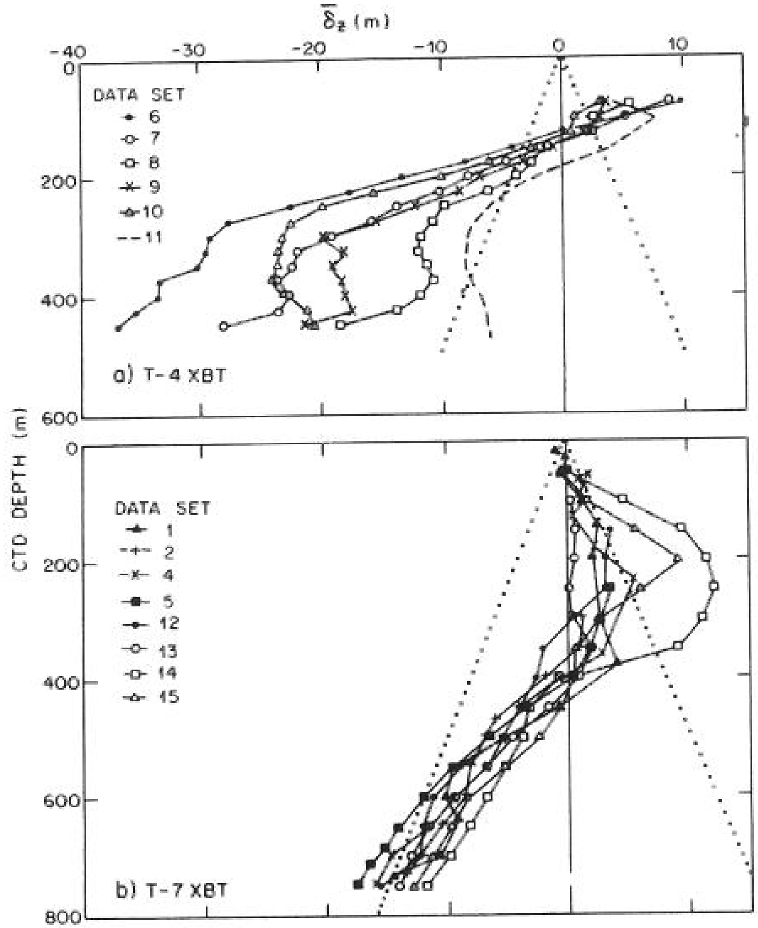

rtical profiles of mean XBT–CTD depth differences ($\bar{\delta}_z$) for T-4 (a) a
d lines represent 0.02 times CTD depth. Numbers denote data sets (Tab

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

Szabados and Wright (1989). Study of T- and depth biases. Different acquisition systems compared

Table 4. MEAN TEMPERATURE DIFFERENCES BETWEEN THE XBT AND CTD IN THE MIXED LAYERS (DEGREES CELSIUS)

SYSTEM	MEAN	STANDARD DEVIATION
MK-9	.029	.046
BATHY	.106	.064
OSU	-.074	.083
ARGOS	.016	.055

Bartz 1992

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SEA TECH INC. FAX 503-757-7027 TELEX 258519 CTEK
P.O. Box 779 • Corvallis, Oregon 97339 • 503-757-9716

PROGRESS REPORT
TO
OFFICE OF NAVAL RESEARCH

FOR CONTRACT NO: N00014-90-C-0123

TITLE: Development of an Expendable Particle Sensor

ITEM NO: 0001AG

DATE: 30 November 92

Robert Bartz
Robert Bartz
Principal Investigator

1

The following table lists data for the first expendable probe drop test on Sunday, September 13, 1992. The first four probes were not video taped, they were on the bottom when the video data starts at 11:13.34. This was our first test using a flash strobe to provide accurate probe launch time. Viewing the video data, it is obvious that the probes were dropped too fast for the photographer to keep up, consequently data is incomplete for several probe deployments during this first test.

Table 1 First expendable probe drop test on Sunday

Probe ID	Type/Mod	Wire (Y/N)	Weight (gm)	C of G inches	Start seconds	Stop seconds	Spin RPM	Drop Rate meters/sec	
H	no video							4 probes	
S	no video							are	
16	no video							on	
13	no video							bottom	
12	XBT-5	Y	980	2.85	no flash	7.59	360		
15	XBT-5	N	720	2.19	19.37	23.35	360	4.84	
14	XBT-5/M2	N	716	2.19	33.19 ?	37.24	360	4.70	
2	XOTD/M1	Y	784	3.40	46.36 ?	51.46	N/A	3.72	
17	XBT-5	N	717	2.18	57.45 ?	64.26	214	2.87	
4	XBT-4	Y	719	1.90	83.10	missed			
18	XBT-4/M1	Y	719	2.05	no flash	90.01	360		
6	XBT-4	N	608	1.65	97.17	missed			
19	XBT-4/M2	Y	715	2.00	no flash	104.28			
8	XBT-7	Y	717	2.10	no flash	109.29			
9	XBT-7	Y	719	2.10	118.31	121.52	450	5.73	1)
5	XBT-4	Y	715	2.05	131.16	134.25	400	6.10	2)
22	AXBT	N	702	0.75	144.23	157.52	N/A	1.42	
20	AXBT	Y	839	1.03	no flash	168.12	N/A		
23	AXBT	N	699	0.77	no flash	181.50	N/A		
21	AXBT	Y	845	1.05	no flash	197.56	N/A		

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

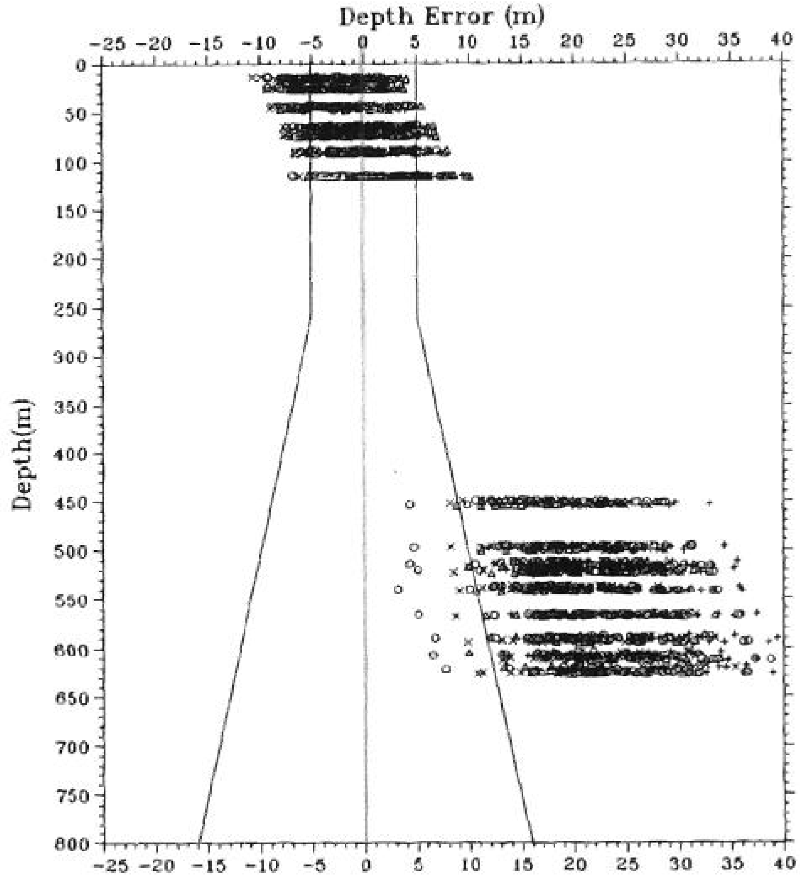

FIG. 4. Depth error ($Z_{CTD} - Z_{XBT}$) for selected features. XBT depths calculated with the Sippican FRE. Different symbols denote different LAS's.

Budeus and Krause (1993) On board calibration method

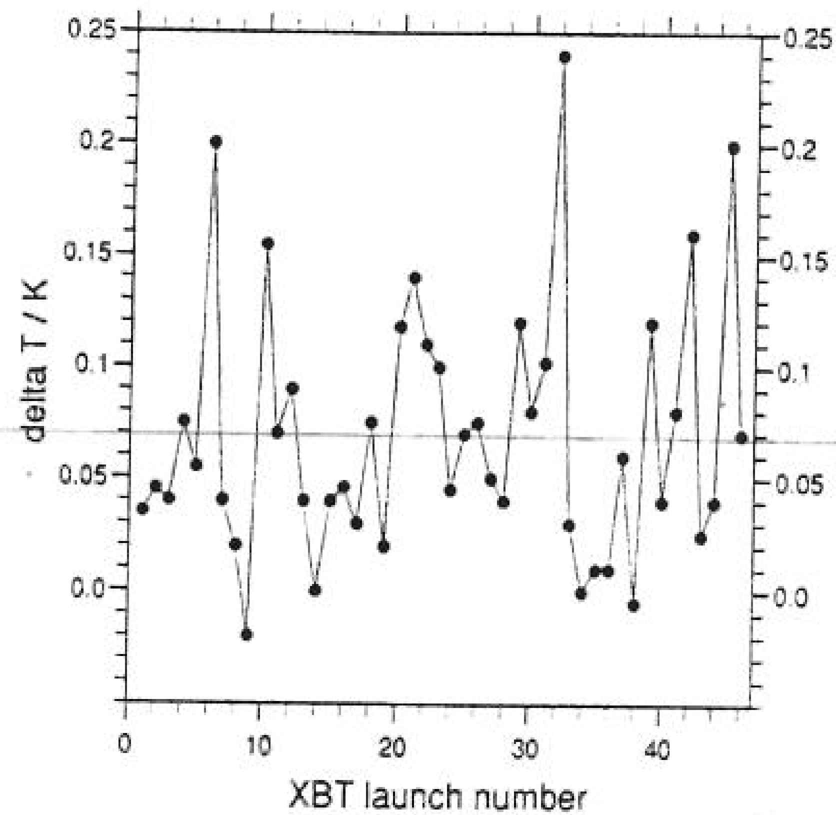

Fig. 2. Temperature difference between the reference thermometer and a number of XBT probes, measured during *Polarstern* cruise ARK 7/2.

Kezele and Friesen, 1993. Analysis of the concurrent XBT and CTD tests. Potential errors identified

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XBT Test Data Comparison and Analysis

Concurrent XBT and CTD Tests Yield Basis for Analysis of Errors—Source of Discrepancies Potentially Identified

By Dusko B. Kezele
Hydrodynamics Engineer
and
Gary Friesen
Program Manager
Sparton of Canada Ltd.

With the end of the Cold War approaching, Sparton of Canada Ltd. (SOC)—a division of Sparton Corp. (Jackson, Michigan)—was brought to the oceanographic community with a focus towards a diversified product line and a broader customer base. The expendable bathythermograph (XBT) was a logical first undertaking given SOC's history in the production of the AN/SSQ-36 (air-launched XBT).

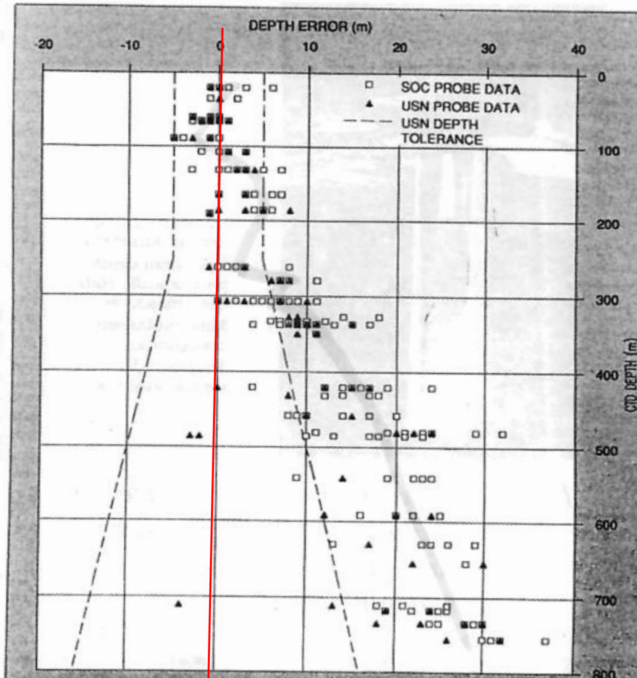
The existing XBT design, accepted as a standard within the community, had long been the only practical technology available that could provide a vertical temperature profile to a vessel underway. However, much of the product implementation effort confirmed that the concept (a fine bifilar wire despooling from a spinning probe as it falls through the water column) is effective but may need to be improved.

Predicting the depth of the probe from elapsed time via a fall rate equation has been the focus of controversy and is a topic worthy of discussion.

First developed in the early 1960s for the U.S. Navy as a temperature survey tool, the XBT's primary function was (and still is) to locate the seasonal thermocline with an accuracy of ±0.1°C and ±2 percent in depth without the need to slow ship speed. However, the XBT has also come to be extensively used in the oceanographic community as a research tool. This application spurred a need for improved XBT accuracy, particularly in depth.

Recently, Sparton of Canada was granted a qualification as an XBT supplier to the Navy as a result of extensive at-sea tests and a comprehensive facility evaluation by Navy personnel. Initial tests were conducted December 1991 through January 1992

(Continued on page 18)



The depth errors for both SOC and USN probes, shown superimposed on USN-specified tolerance limits (the greater of 5 meters or ±percent) indicate that both probes fall faster than specified and that systematic depth errors exist for the XBT-7.

Depth errors should be completely decoupled from any analysis of T-accuracy

236 depth-error data points

Both Sparton and Sippican probes Fall faster than Sippican FRE

Z_{spar}=6,609t – 0.0016 t2

Z_{Sip}=6,573t-0.0018t2

The variybility of fluid properties can affect the XVBT drag coeff.

The precise „C_D versus Re“ curve remains unknown for XBTs

FRE is not valid above ~10m

No globally applicable FR model can be developed without detailed hydrodynamic drag data

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Boyd and Linzell (1993). Thermal bias estimates for T-5. New T-5 FRE

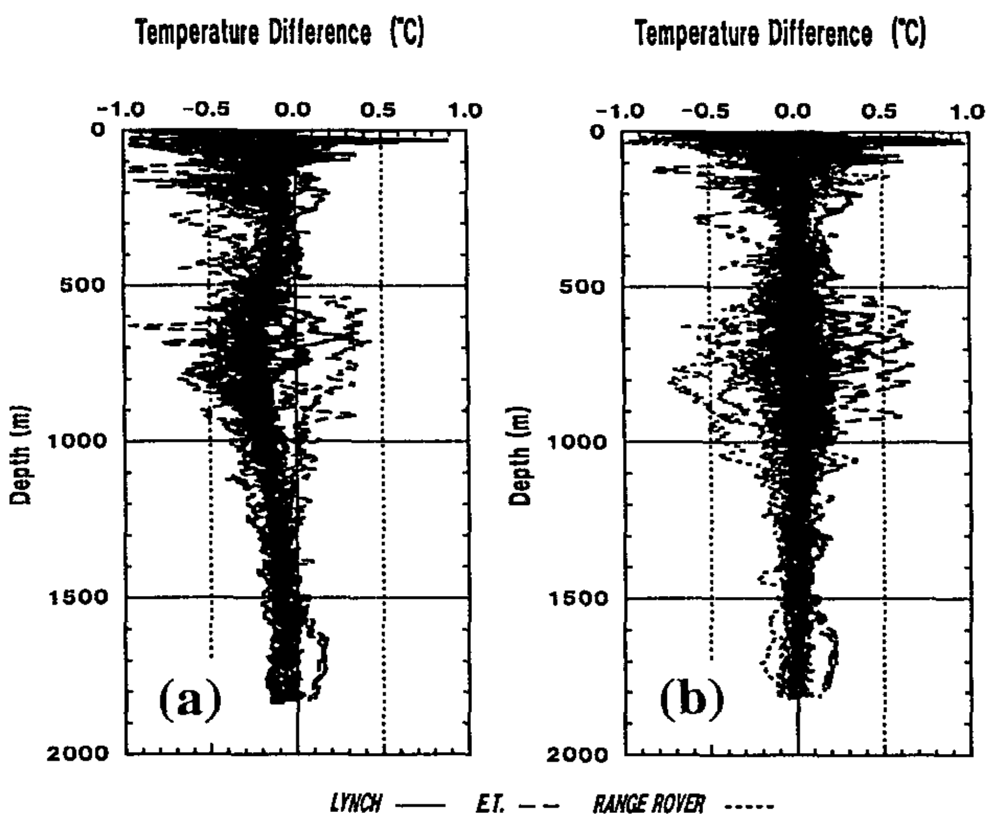

FIG. 6. Mean temperature difference versus depth for the CTD–XBT profile pairs in this study. Panel (a) was computed using uncorrected temperatures and the manufacturer's fall-rate equation. Panel (b) was computed using the temperature corrections and cubic fall-rate equation from this study.

Hanawa, Rual, Bailey, Sy, Szabados (1994, 1995). A comprehensice depth-error study. New FRE for T4,T6 and T7. Data from nine geographical regions

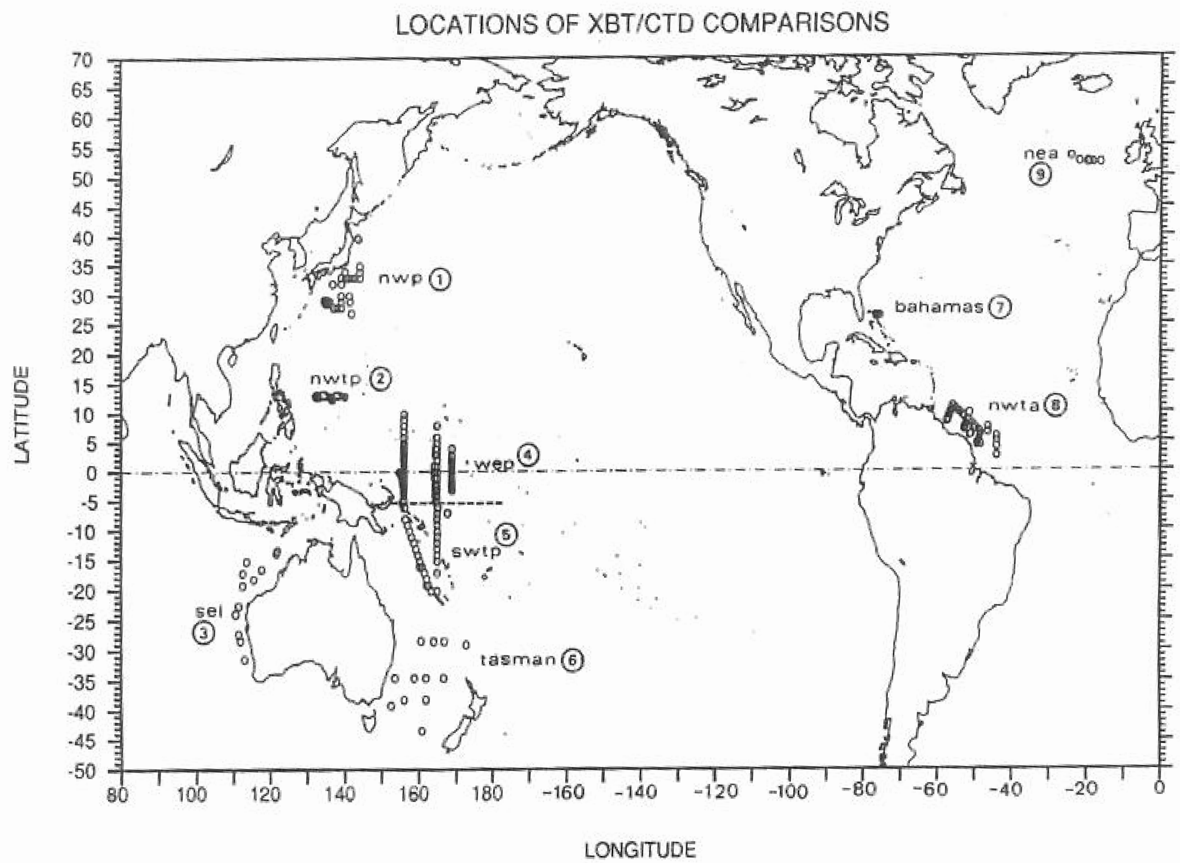

Fig. 1. Locations where the XBT/CTD comparison experiments were conducted (see also Table 1). The dashed line at 5°S in the western Pacific shows the limit between the wep and swtp data sets.

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Hanawa et al. 1995. Indication of possible diffrent FR for Sippican and TSK probes

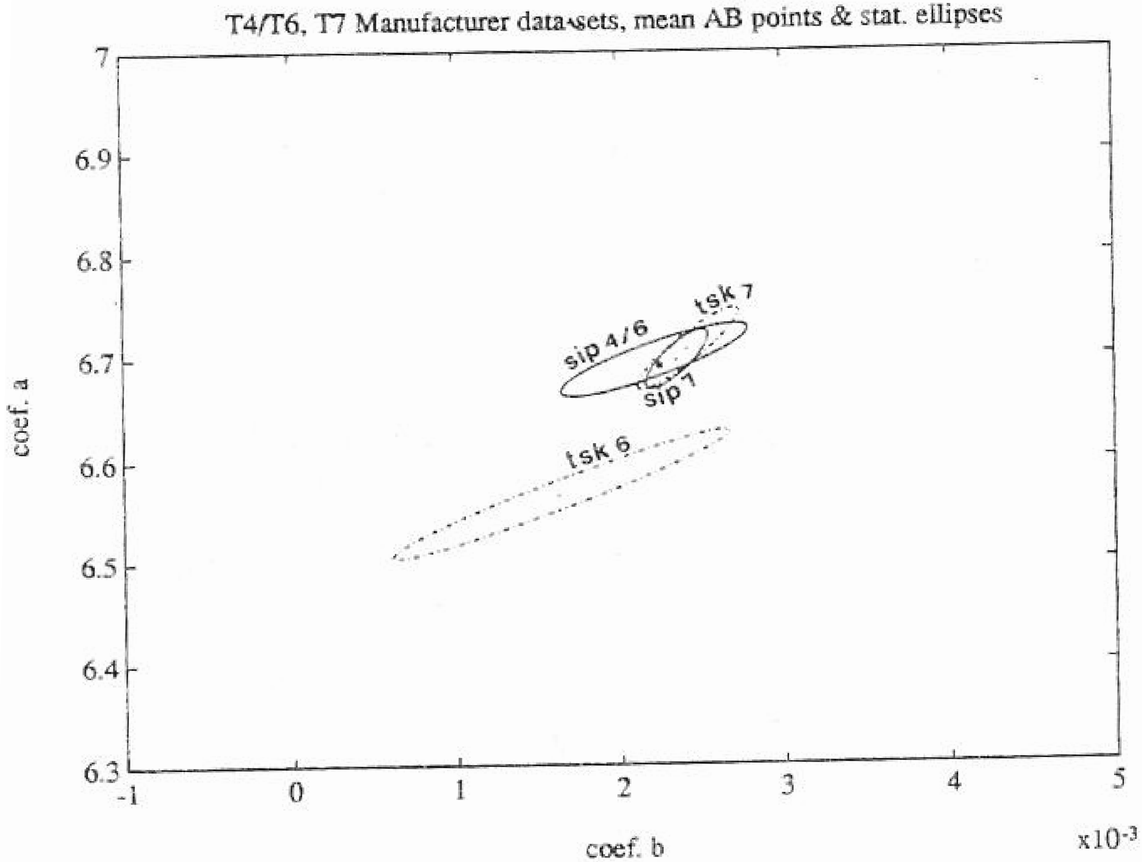


Fig. 10. Mean Sippican, and TSK, T-7 and T-4/T-6 AB points and their two-standard-error-of-the-mean ellipses on the a–b plane (same scales as Fig. 8, see Table 1 for detailed information).

Thadathil et al 2002

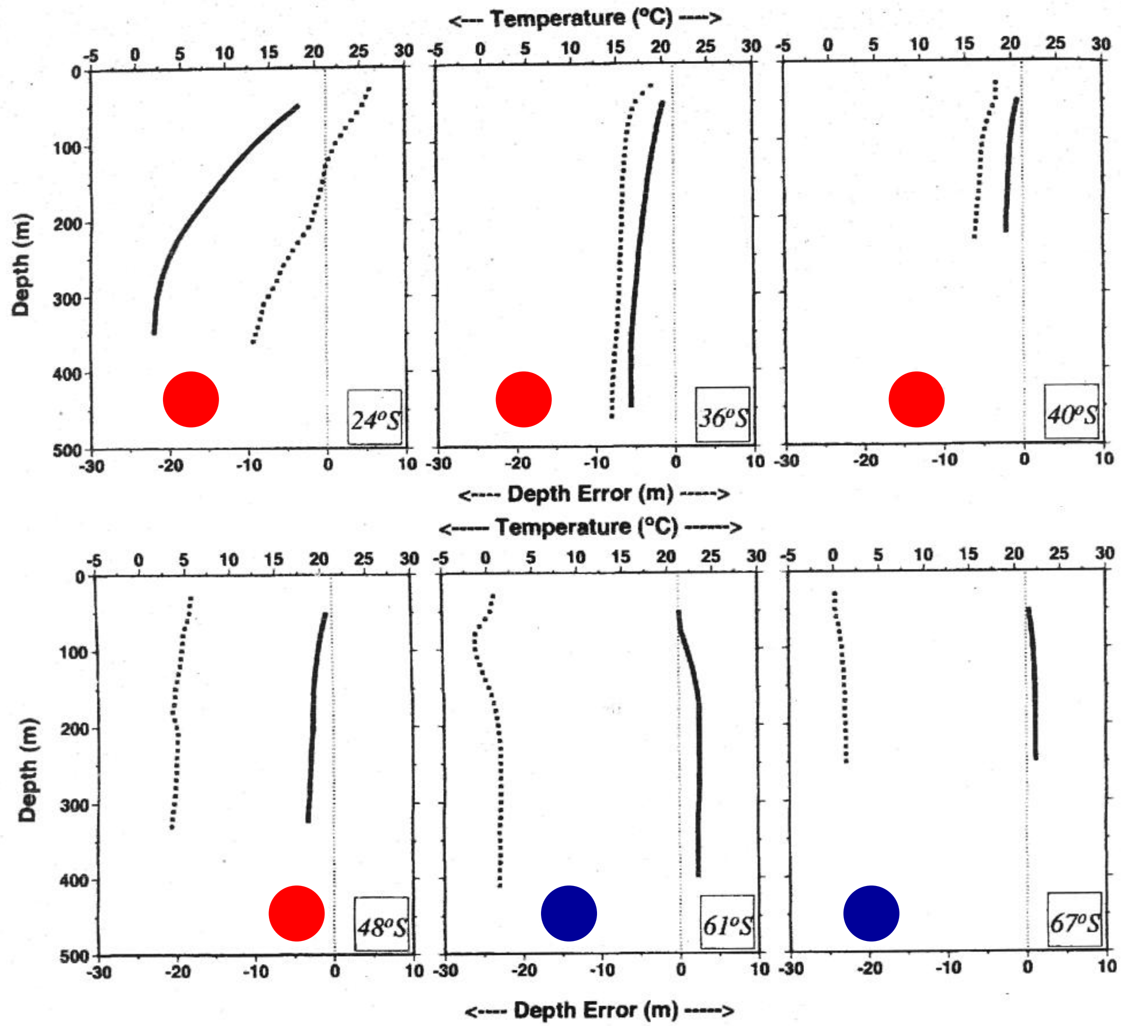
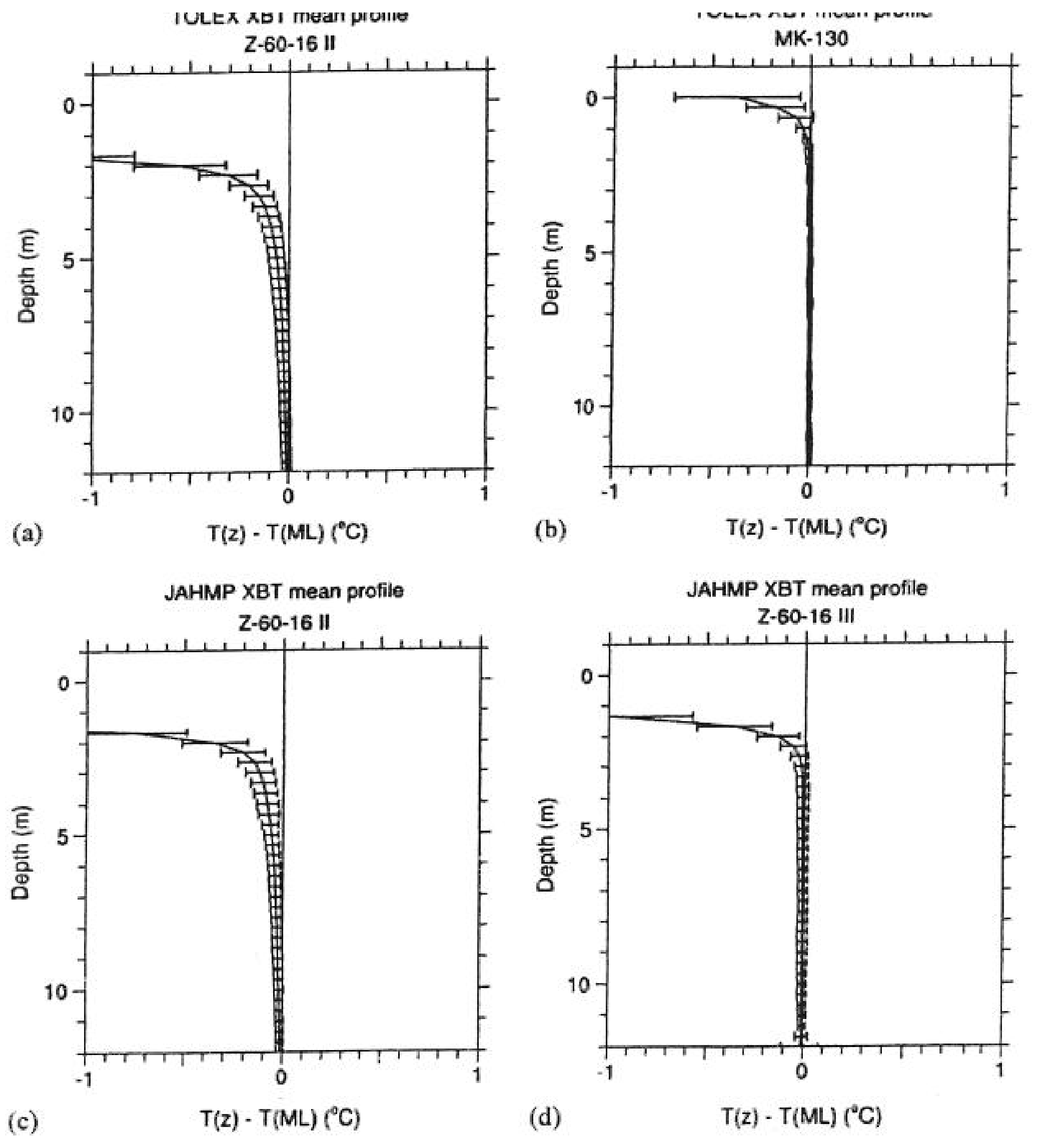


FIG. 9. Analytical depth errors for different latitudes from the tropical to polar regions along with the corresponding temperature profiles. Solid lines represent depth error and dashed lines represent temperature.

Kizu and Hanawa (2002). Estimates of the near-surface layer thickness where transient effects are importent



Reseghetti, Borghini and Manzella (2007). A new data correction method including both temperature and depth corrections. Importance of system response time demonstrated

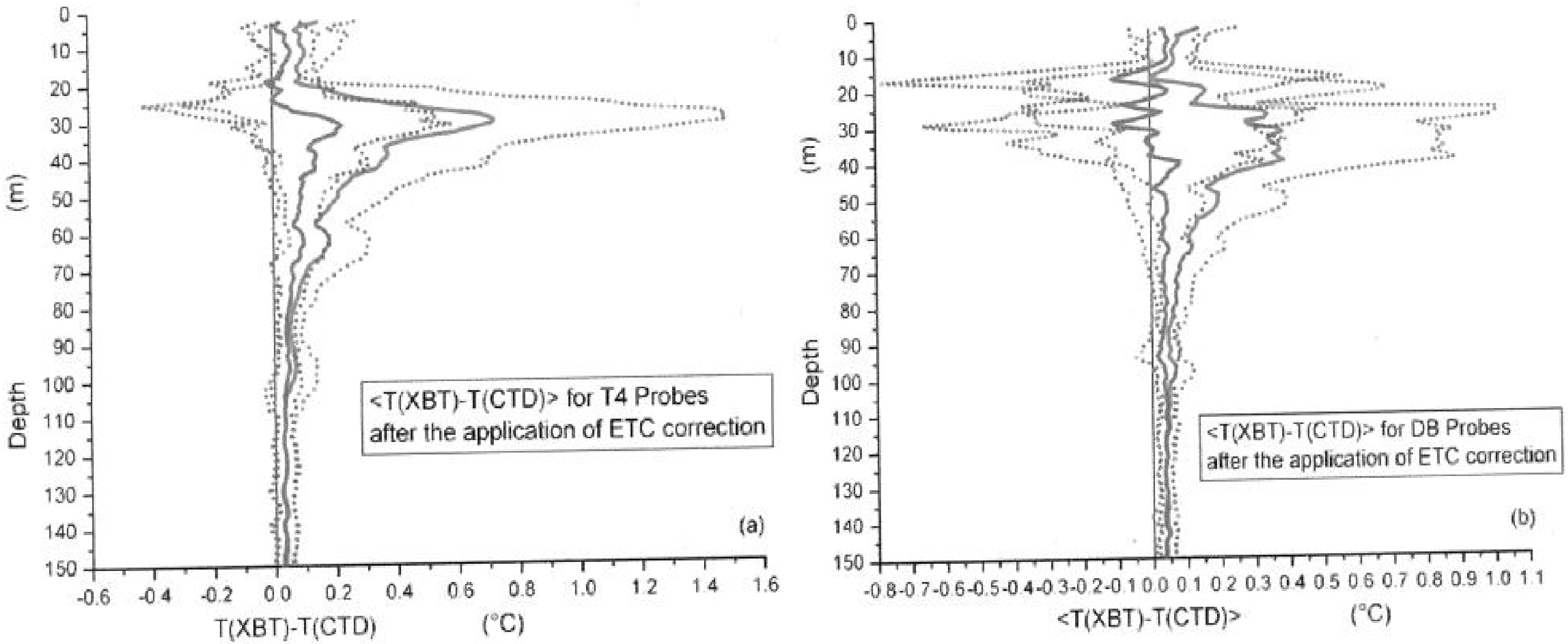
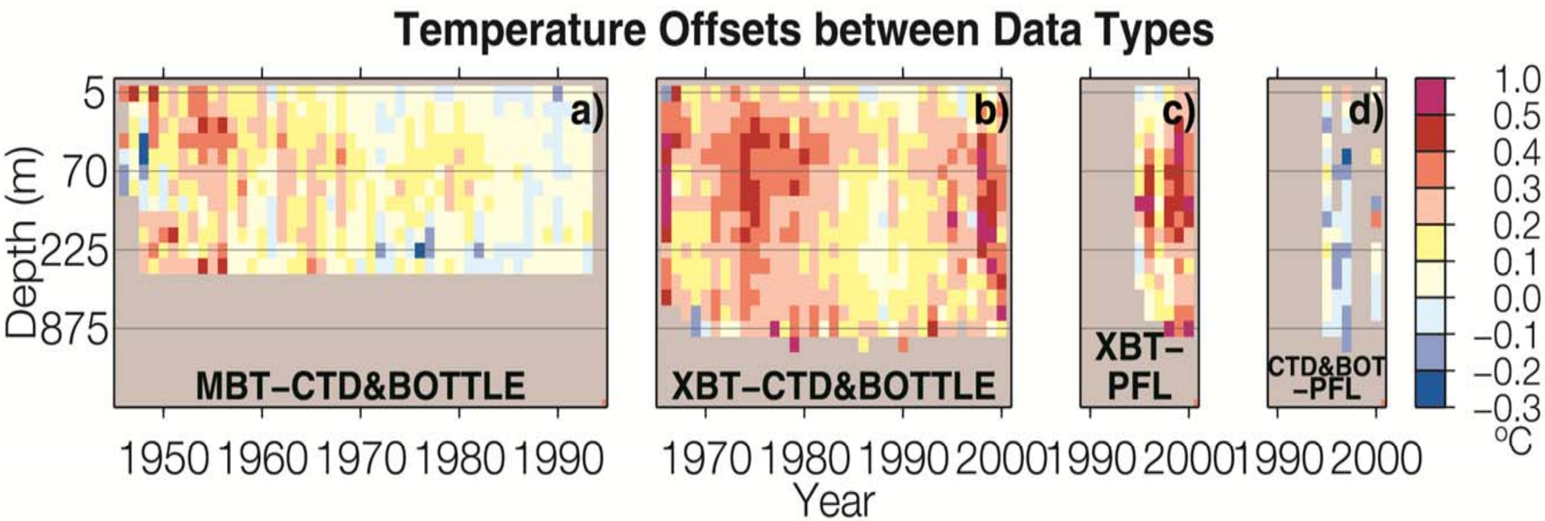


Fig. 6. Comparison between mean temperature difference (with one standard deviation) with data processing as in Manzella et al. (2003), i red, and after the application of ETC correction, in blue: in **(a)** T4 probes, and in **(b)** DB probes. The plots have different scales.

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



From Gouretski&Koltermann, 2007

Wijffels et al., 2008 confirmed G&K2007 results and suggested corrections. Bias is attributed solely to the fall-rate time-variations

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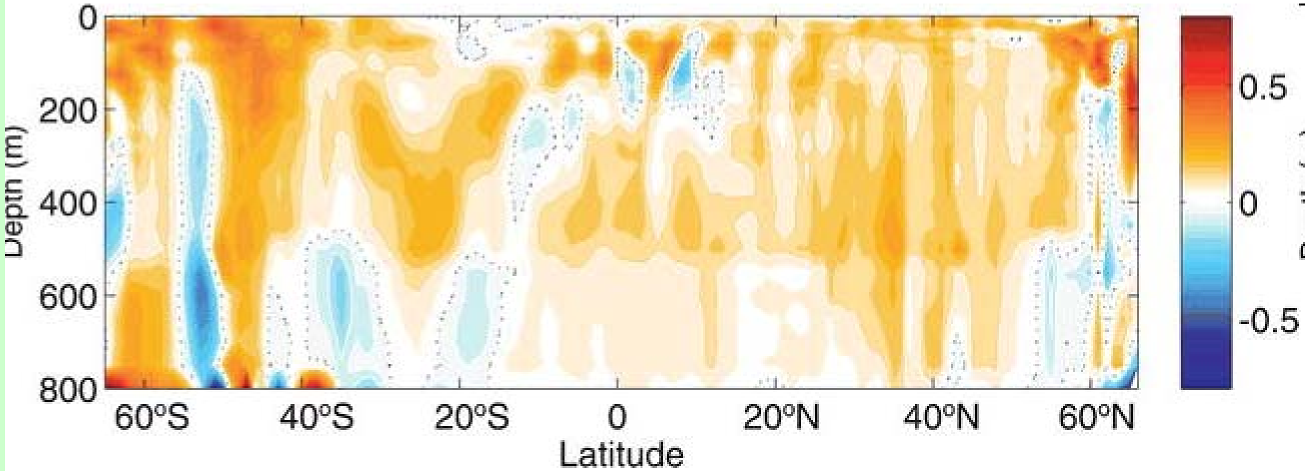

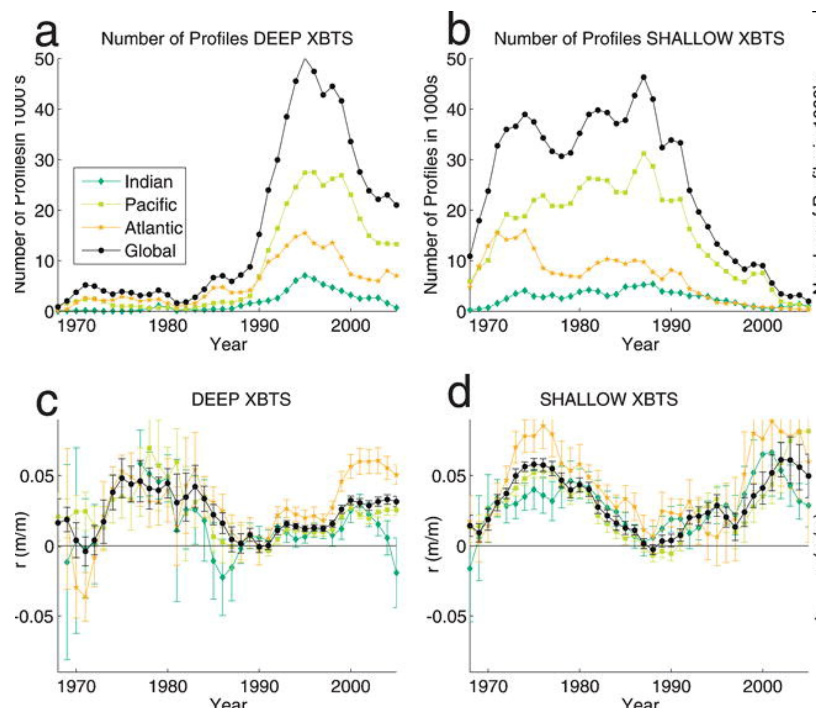

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Reverdin et al (2009)

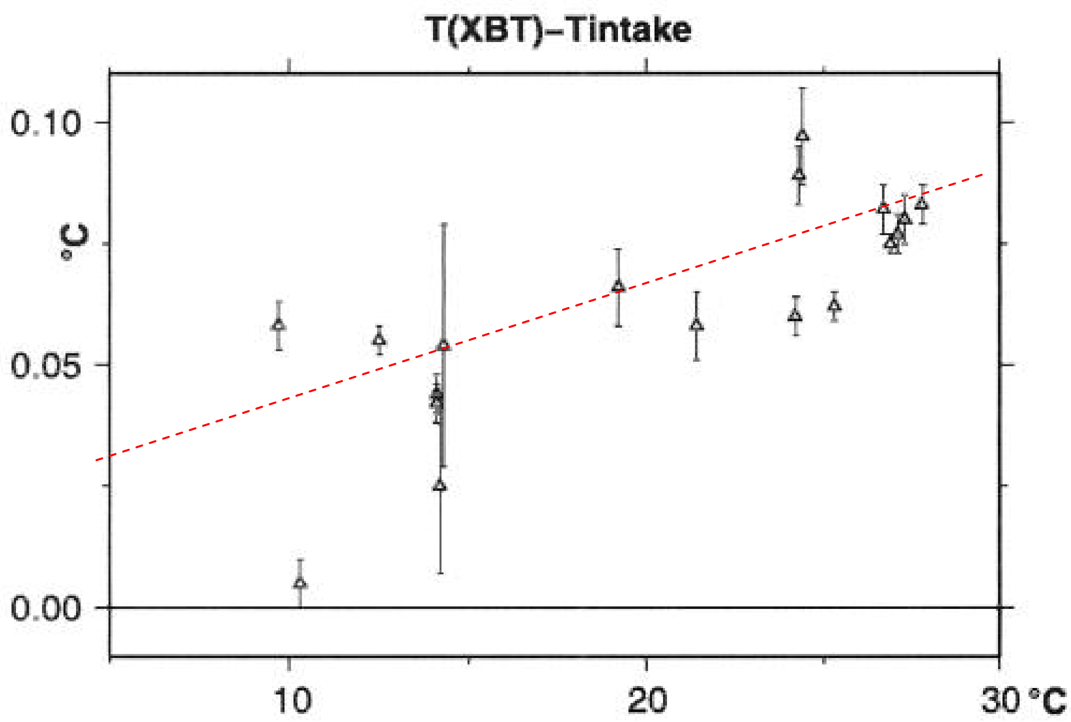
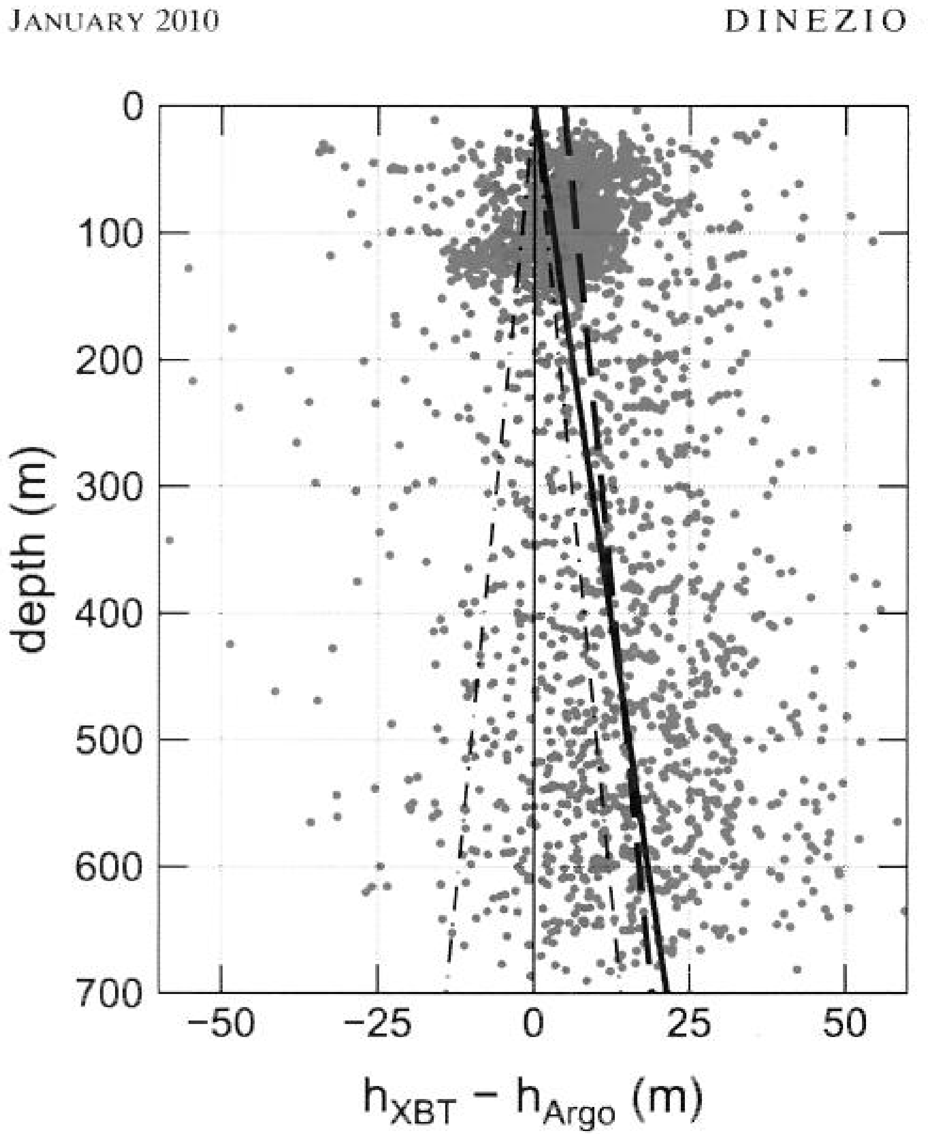
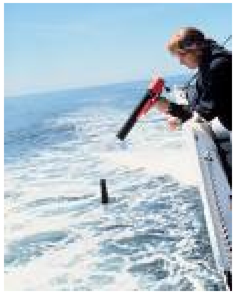


FIG. 2. Comparison of near-surface temperature from XBTs with corrected intake temperatures. For each cruise, the average difference and its associated error are indicated as a function of average intake temperature (see Tables 1 and 2). Notice that for the two "coldest" cruises Ovide2002 and Ovide2004, the intake temperature was corrected based on comparison with nonsimultaneous CTD measurements. The values for the two 2007 cruises Egee5 and Egee6, which exhibit smaller differences, have not been plotted.

DiNezio and Goni (2009). XBT vs Argo comparison. Hanawa et al. FRE no more actual for the period 2000-07.



XBT Bias sources:



- **Fall rate equation : $Z_{xbt} = at - bt^2$**

  (uncertainty in coefficients, overall validity questionable)

- **Probe characteristics (slight manufacturing differences in thermistor, probe weight, probe shape/size)**

- **Wire (different type of insulation)**

- **Acqusition system (strip-chart/digital recorders,ETC,...)**

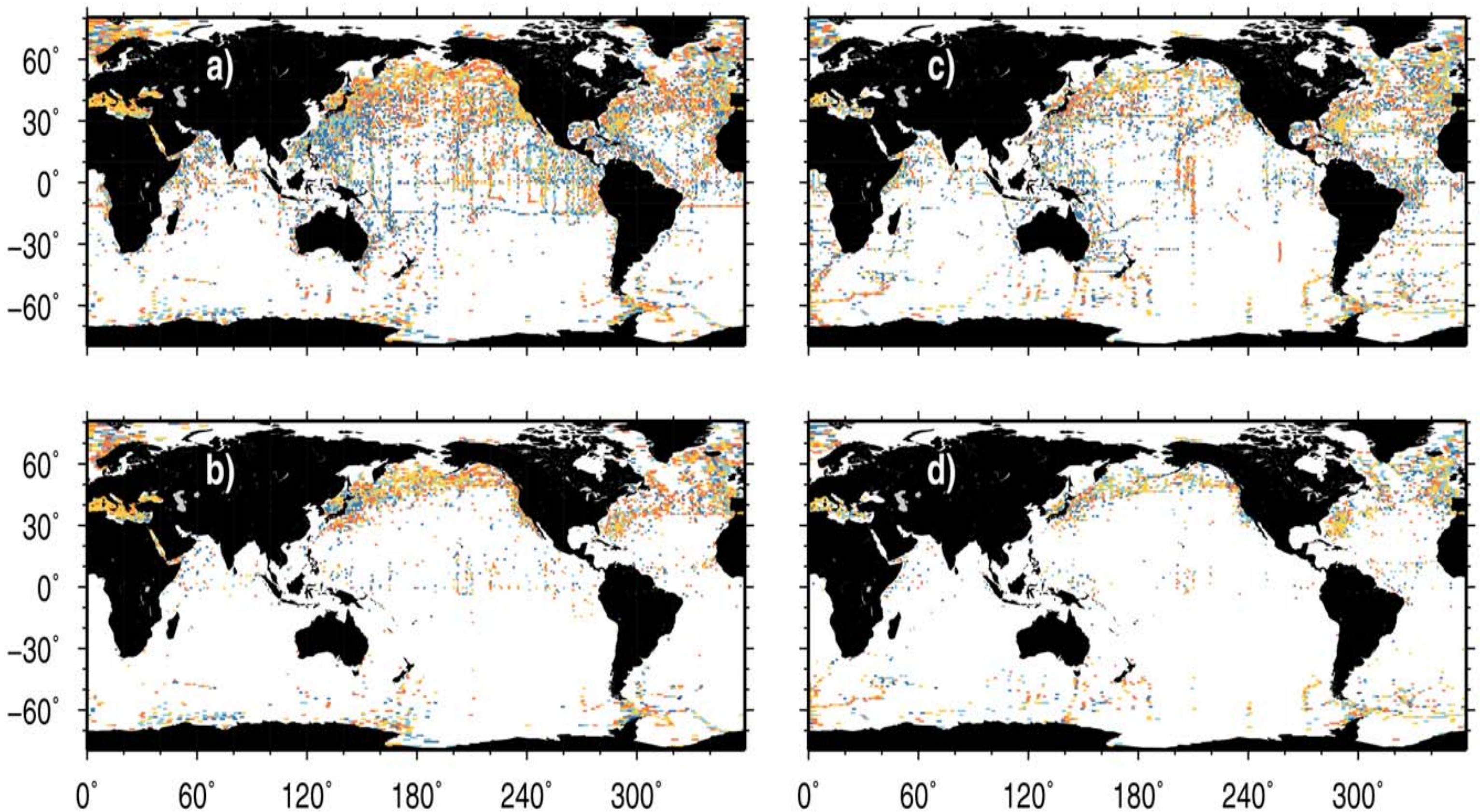
- **Launch conditions (height, air temperature, sea-ice, ship-wake ...)**

- **Ambient conditions during the fall (viscosity~water temperature)**

Comparison of binned XBT and CTD data
BINNING OF THE ORIGINAL T-PROFILES: 111kim x 111km x 1month

- **Prevailing positive bias in weakly stratified waters (b,d)**
- **Negative biases in the tropics (strong thermocline) (a,c)**

Total T-bias at 300 m level /T_{XBT} - T_{CTD}



(from Gouretski&Reseghetti, 2010)

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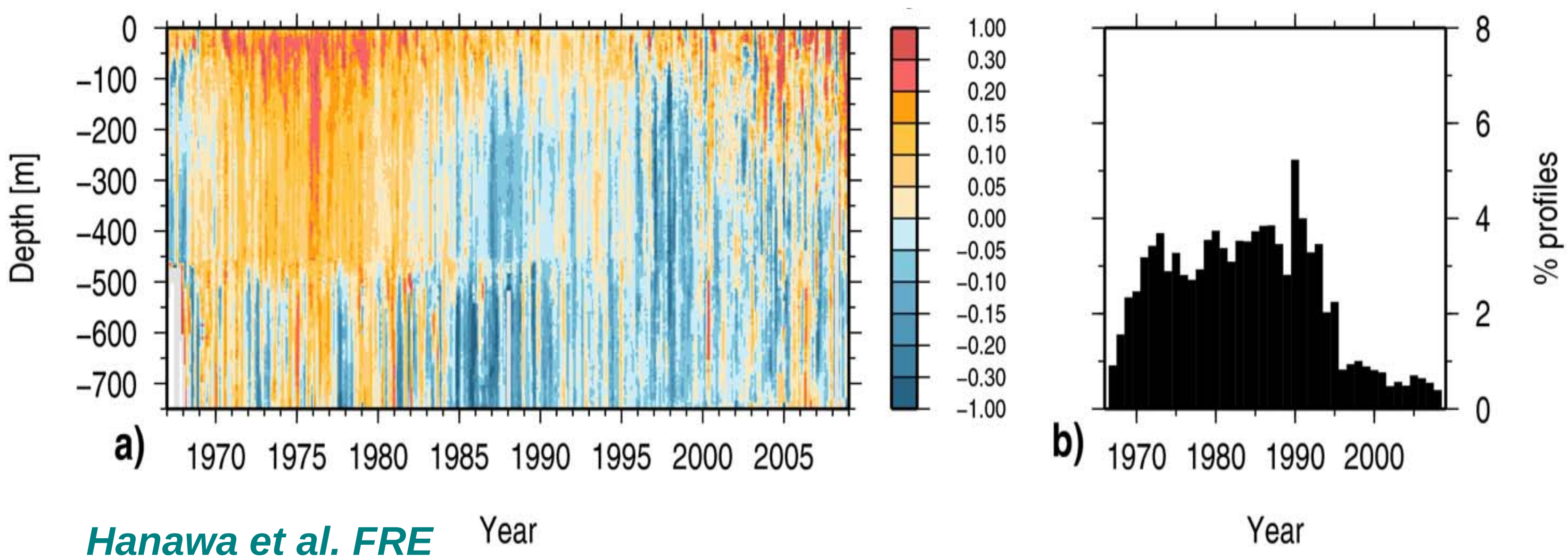
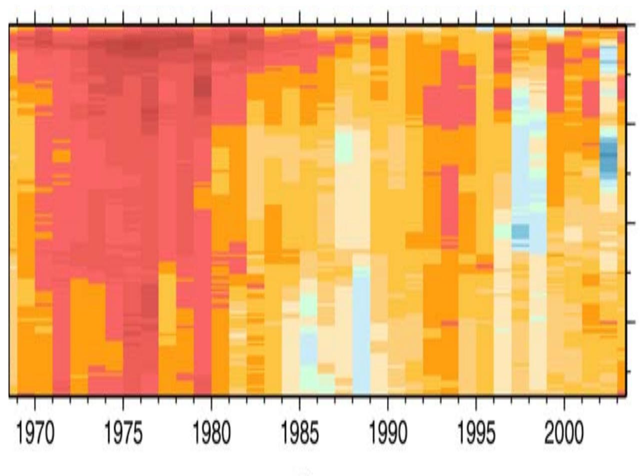
Globally-averaged T-bias plotted vs depth and time

Original Sippican FRE



Hanawa et al. FRE



(Gouretski&Reseghetti, 2010)

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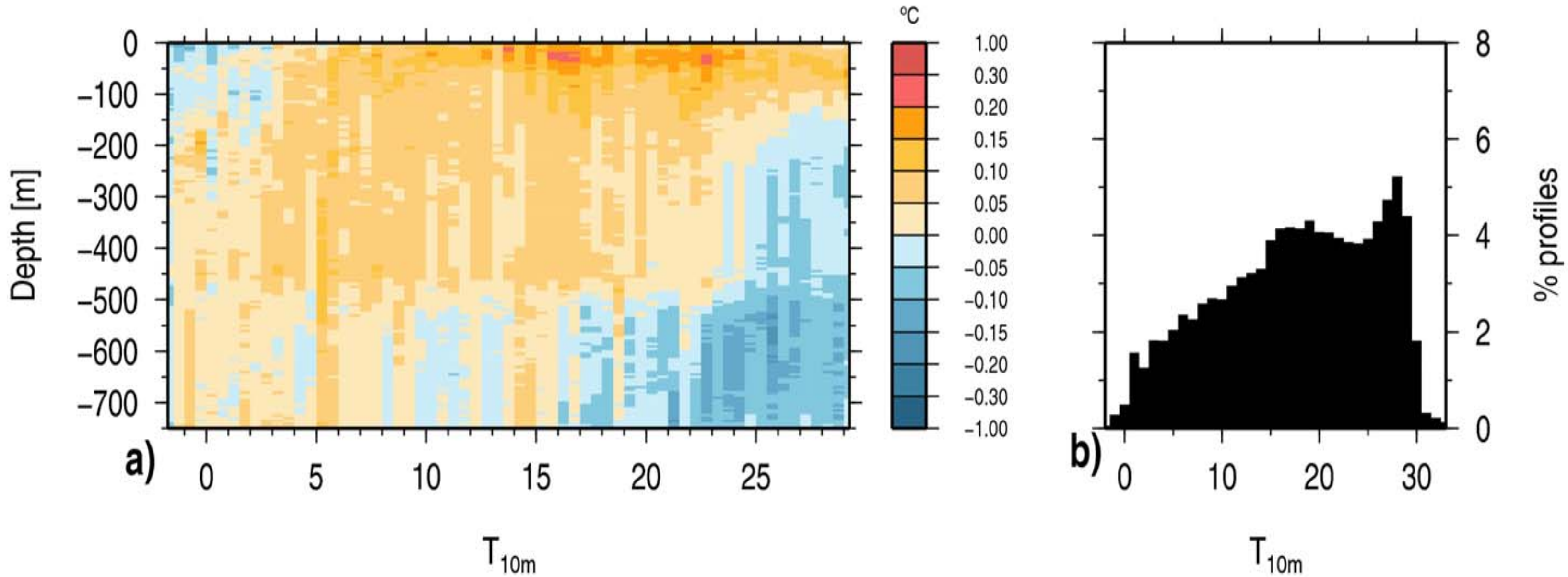
Time-averaged T-bias plotted vs depth and temperature at 10 m



(from Gouretski&Reseghetti, 2010)

Time-averaged T-bias plotted vs depth and latitude

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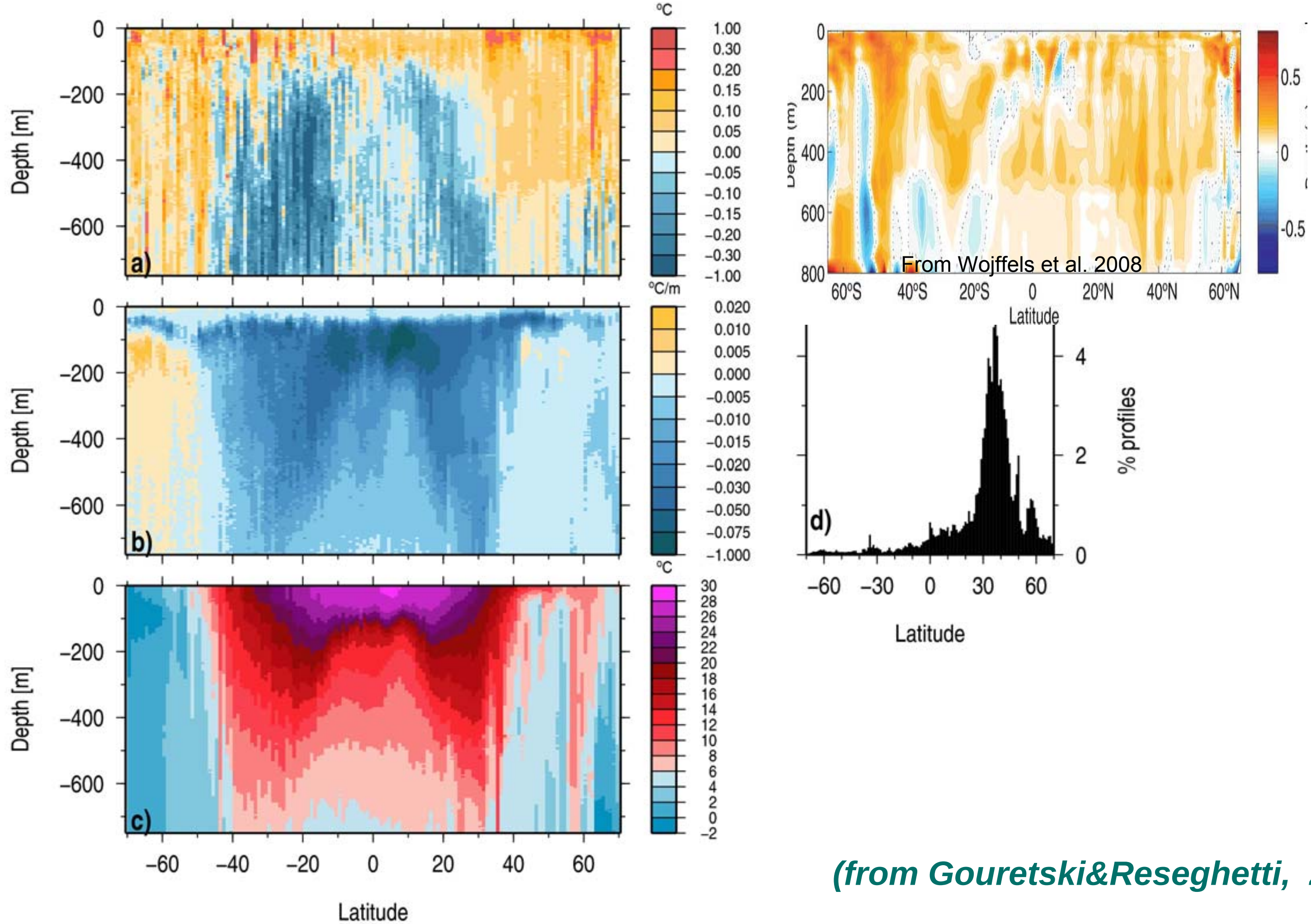
- ***Common geographic pattern: correlation with vertical temperature gradient***

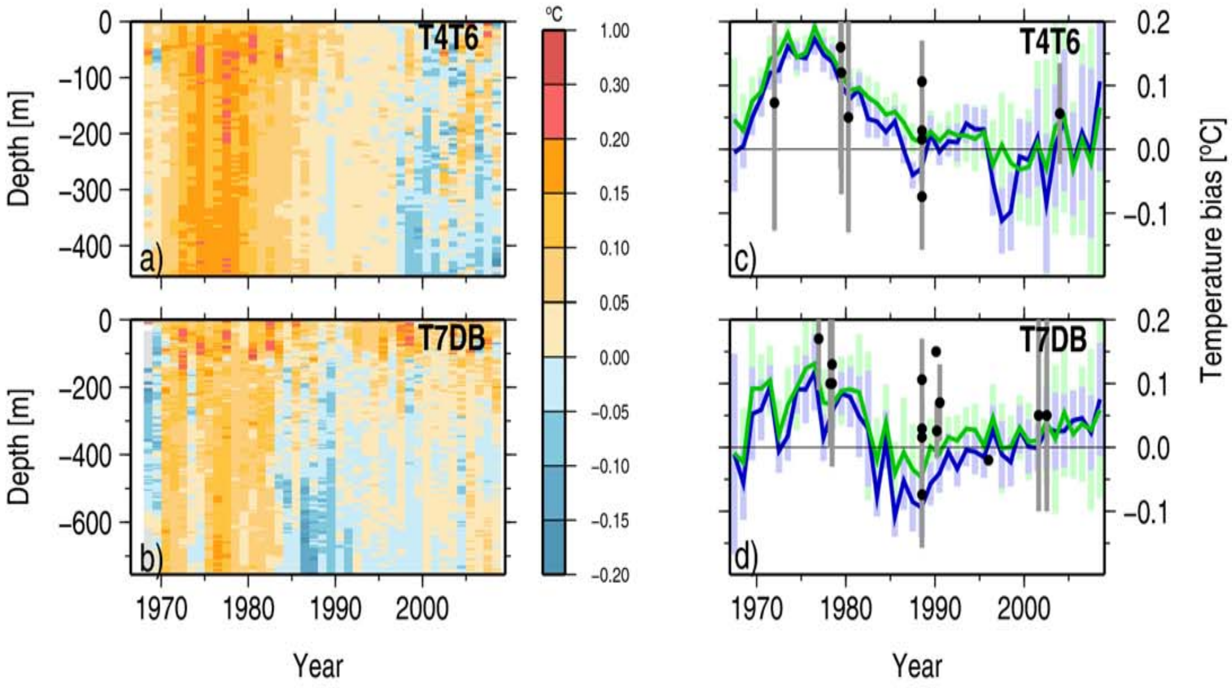


(from Gouretski&Reseghetti, 2010)

THERMAL BIAS PROBLEM

- **Total T-bias for bins with |dT/dz|<0.005 °C/m**

Versus Depth and time ***Depth-averaged***



(from Gouretski&Reseghetti, 2010)

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BIAS MODEL

Bias ($T_{XBT} - T_{ref}$) of the individual XBT binned profile:

$$b(x,y,z,t) = b_T(x,y,t) + \zeta(z,t) \cdot \gamma(x,y,z,t) + \varepsilon(x,y,z,t).$$

- **Spatially averaged total T-bias:** $B(z,t) = B_T(t) + \zeta(z,t) \cdot G(z,t)$,

  z – actual depth

  t – time

  $B_T(t)$ – thermal bias

  γ,G – vertical T-gradient

  ζ – depth error

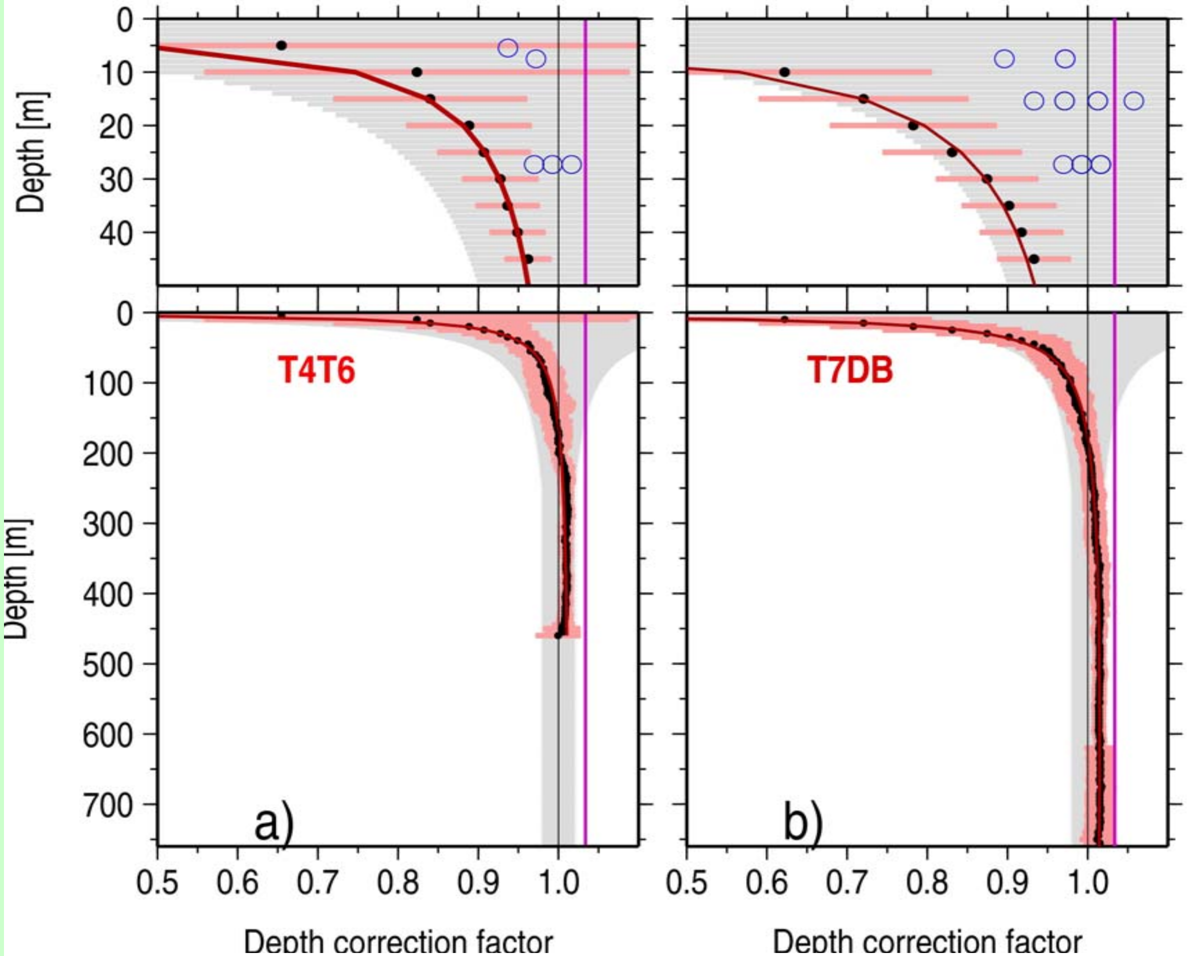
- **Depth correction factor:** $s(z,t) = z/z_x(z,t)$

  z_x – XBT depth

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

Optimal depth correction factor

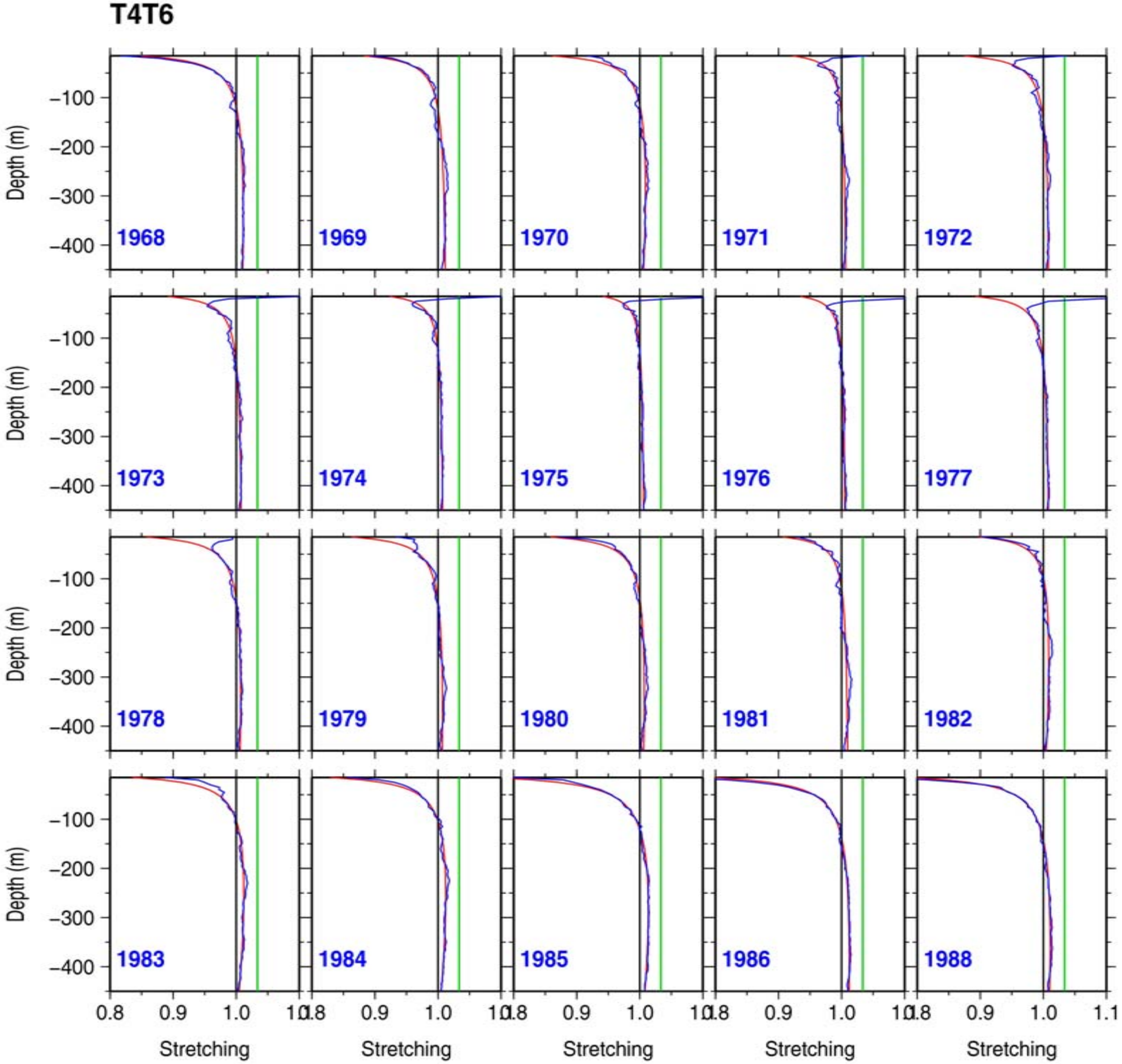
Time-mean depth correction factor for T4/T6 and T7/DeepBlue XBT probes



Correction factor varies with depth!

(Gouretski&Reseghetti, 2010)

Changes of the depth correction factor with time



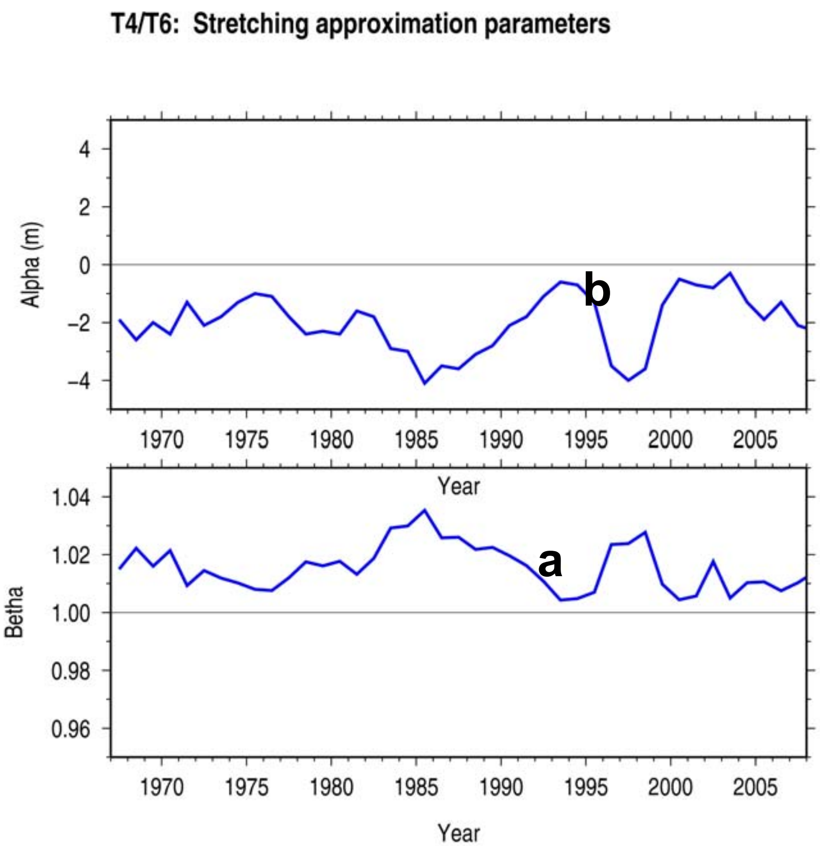
Analytical approximation for the depth correction factor

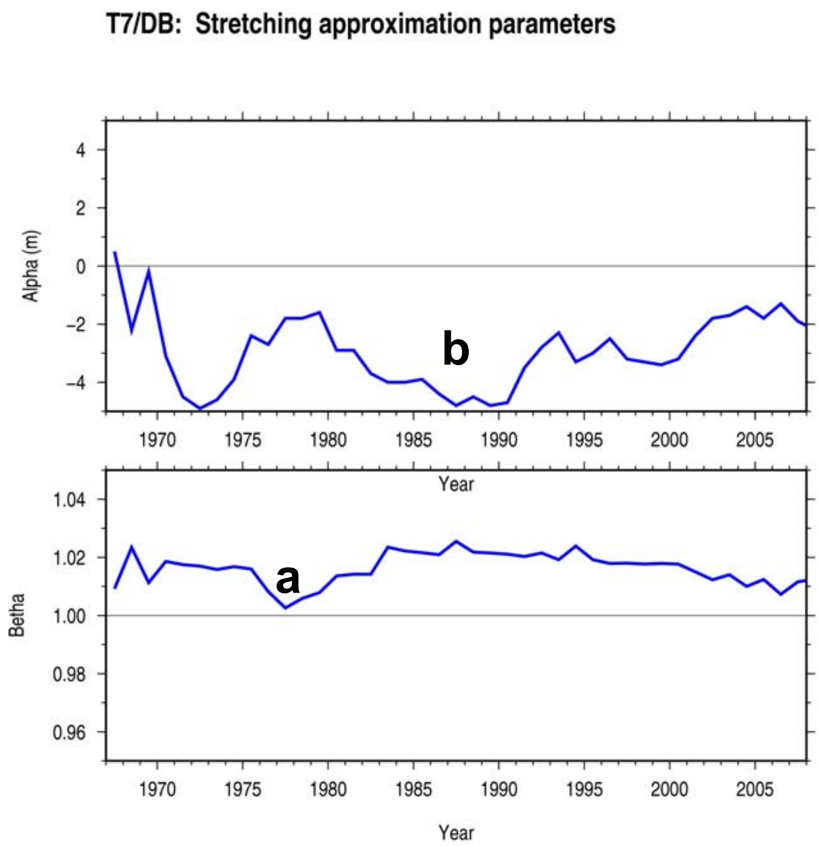
$$S(z_x) = a - b/z_x - c\,z_x^2$$

	T4/T6	T7/DB
a =	1.0164	1.0261
b =	2.7 m	4.6 m
c =	0	$1*10^{-8}m^{-2}$

Stretching approximation parameters vs time

$$S(z) = a - b/z - c\,z^2$$





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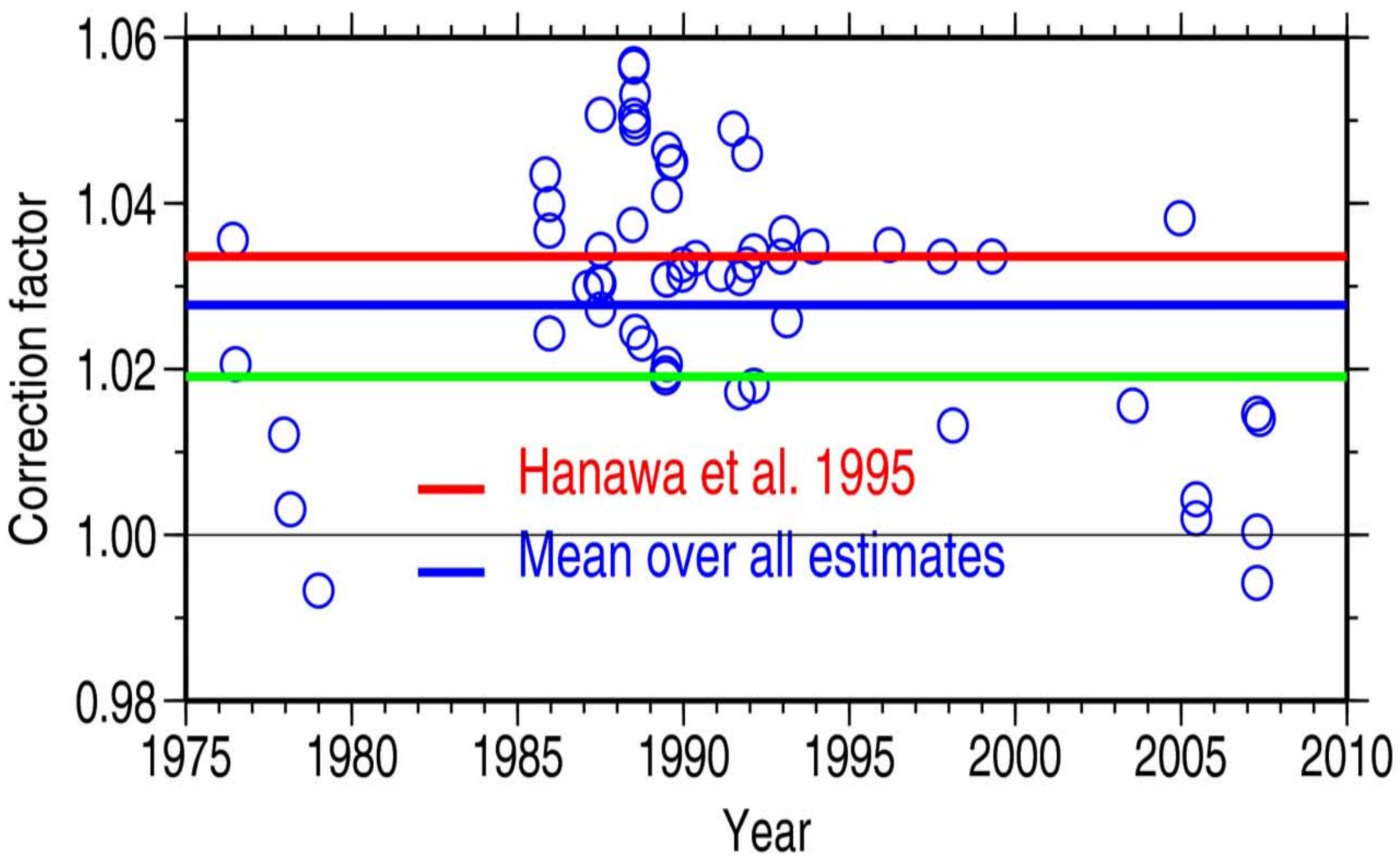
Fall-rate uncertainty problem: side by side XBT vs CTD intercomparisons

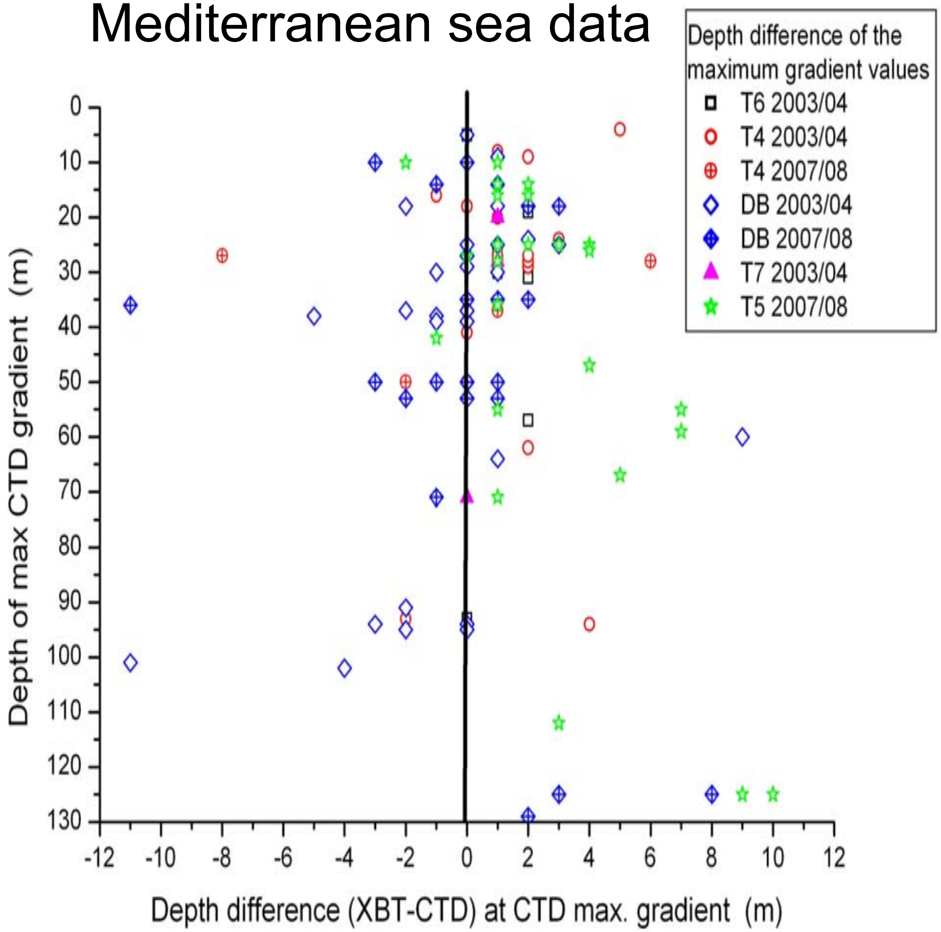


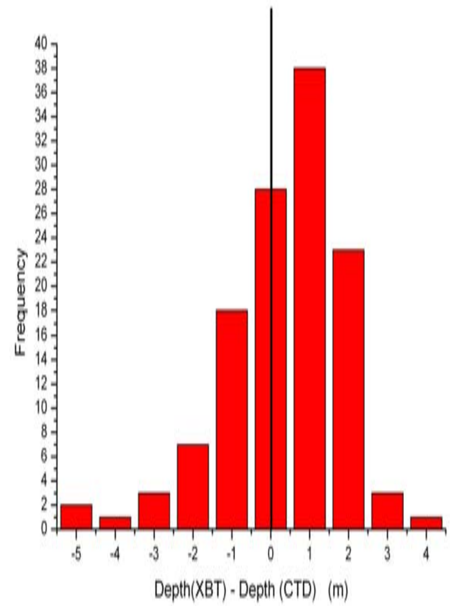
64 side-by-side intercomparisons available from the literature

Depth overestimation in the upper layer has been observed

XBT vs CTD intercomparisons,

Mediterranean sea data

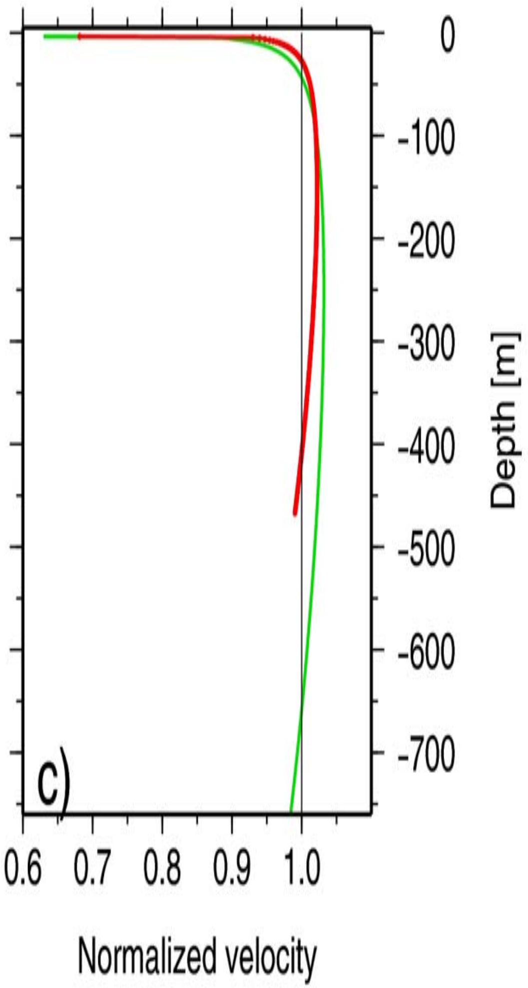




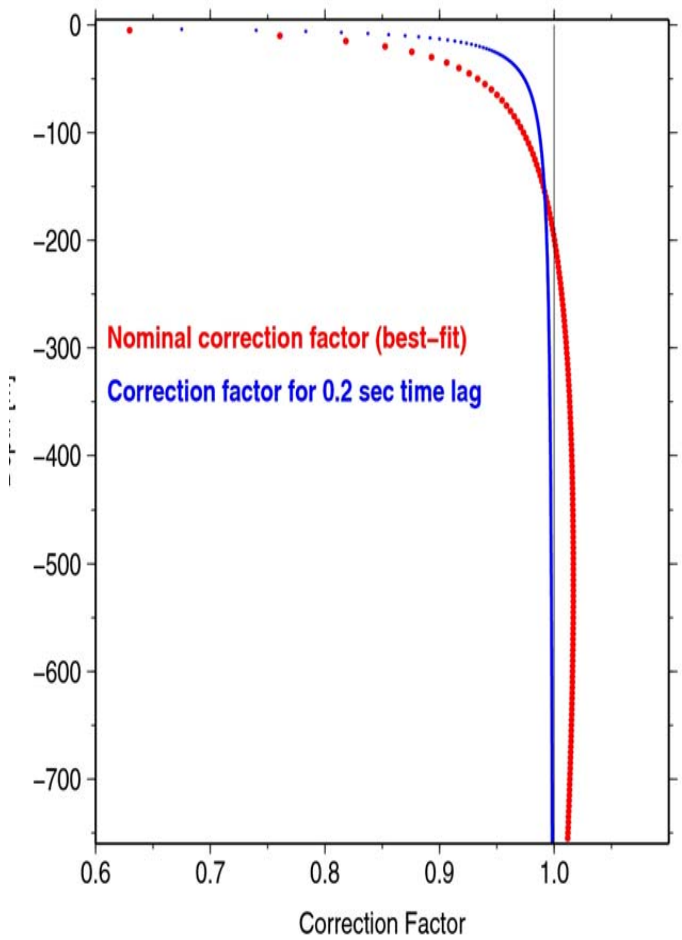
(from Gouretski&Reseghetti, 2010)

Why depth is overestimated near the surface?

1) Velocity is slower then the nominal fall velocity



2) There is a time lag in the whole XBT system (response time + thermal adjustment)



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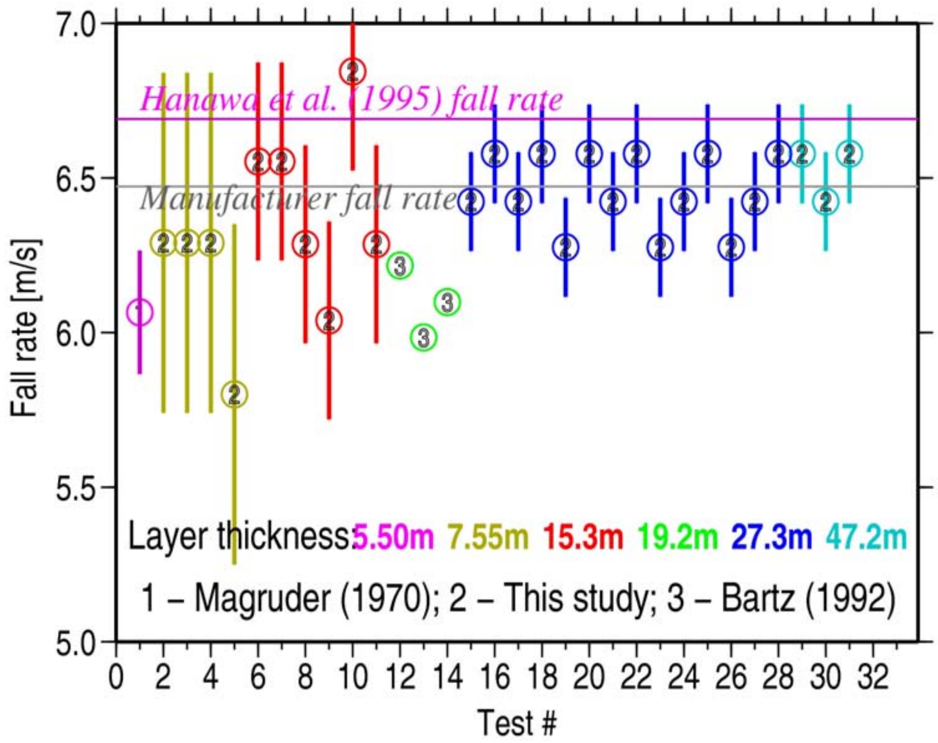
Direct measurements of the XBT fall velocity



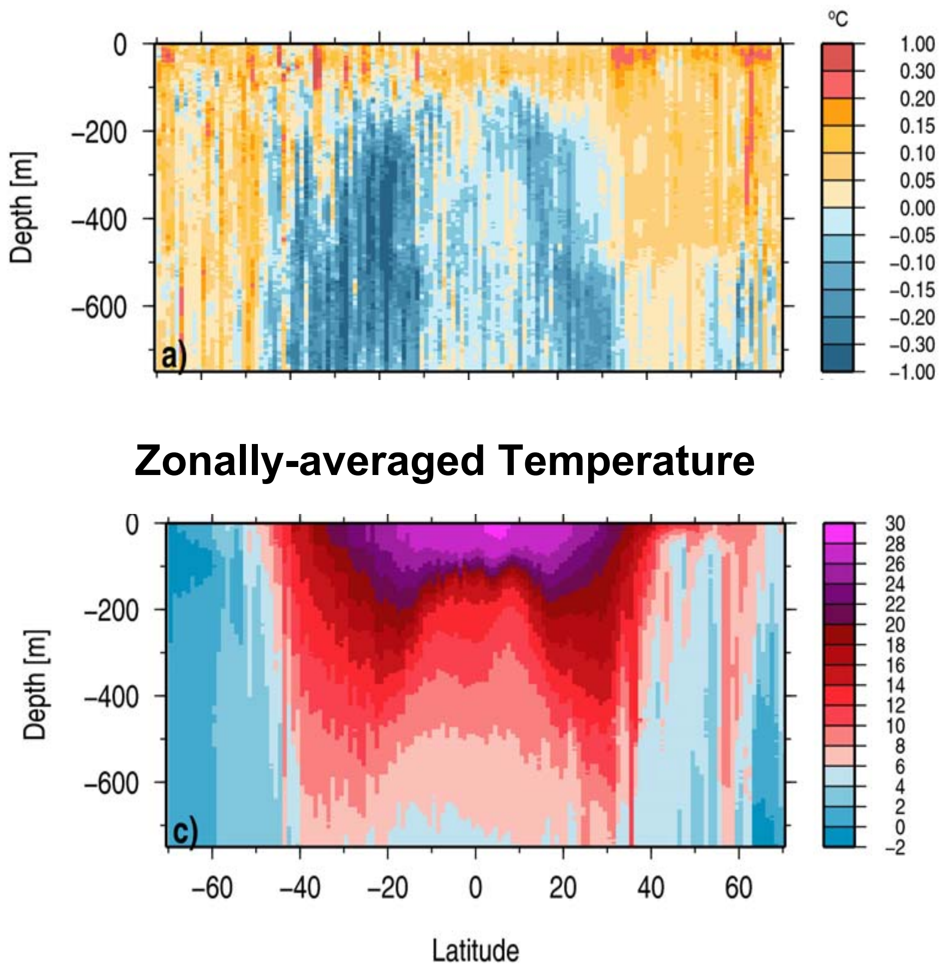
(from Gouretski&Reseghetti, 2010)

Conclusion: Fall rate reduction is not enough to explain the apparent depth underestimation in the upper layers ! Further tests needed to improve statistics

FALL-RATE DEPENDENCE ON TEMPERATURE

Zonally-averaged T-bias

Zonally-averaged Temperature



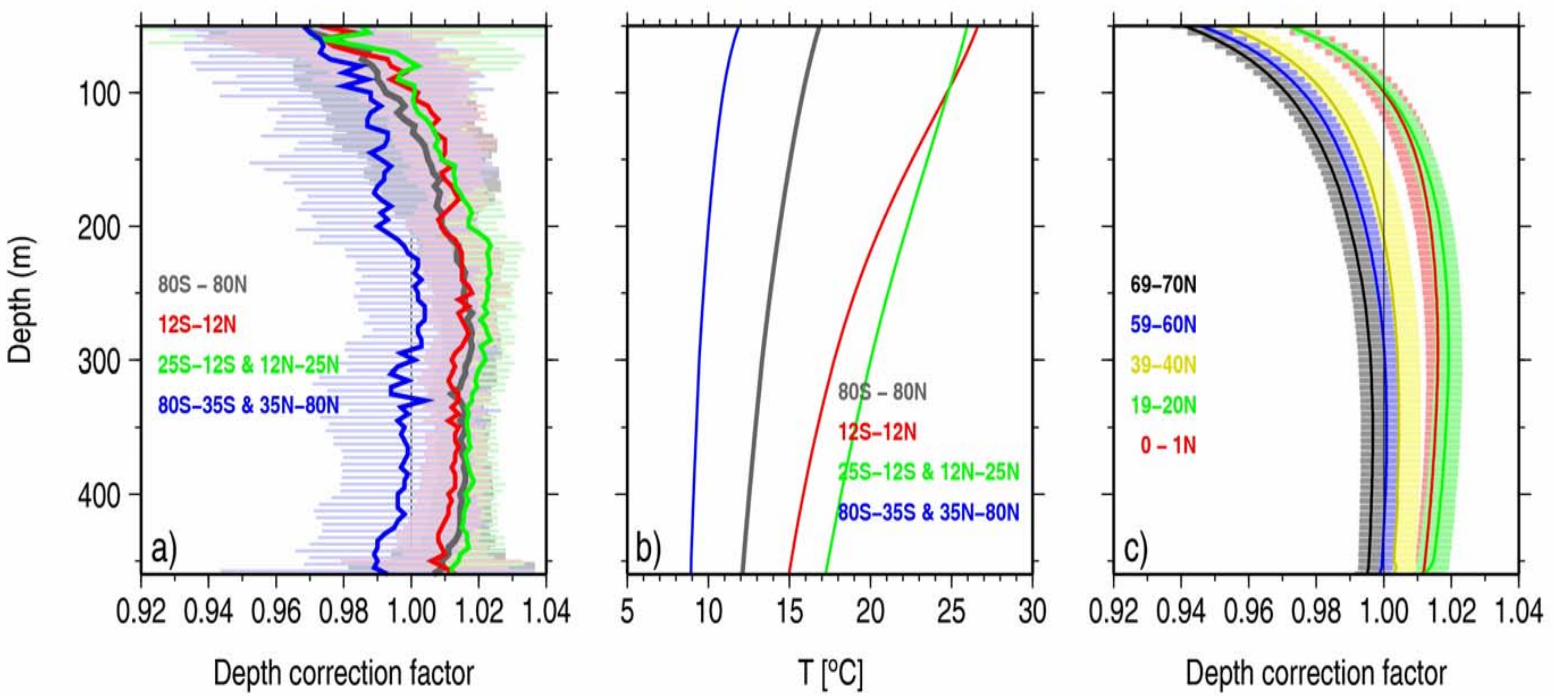
(from Gouretski&Reseghetti, 2010)

FALL RATE DEPENDENCE ON TEMPERATURE

Depth correction factor in selected latitude belts (optimal fit)

Profiles of T averaged between 0 and Z meters

Depth correction factor in selected latitude belts (analytical representation)



(from Gouretski&Reseghetti, 2010)

PARAMETERIZATION OF THE TEMPERATURE (viscosity) EFFECT

- **We suggest to parameterize temperature(viscosity) effect through a T-dependent correction factor:**

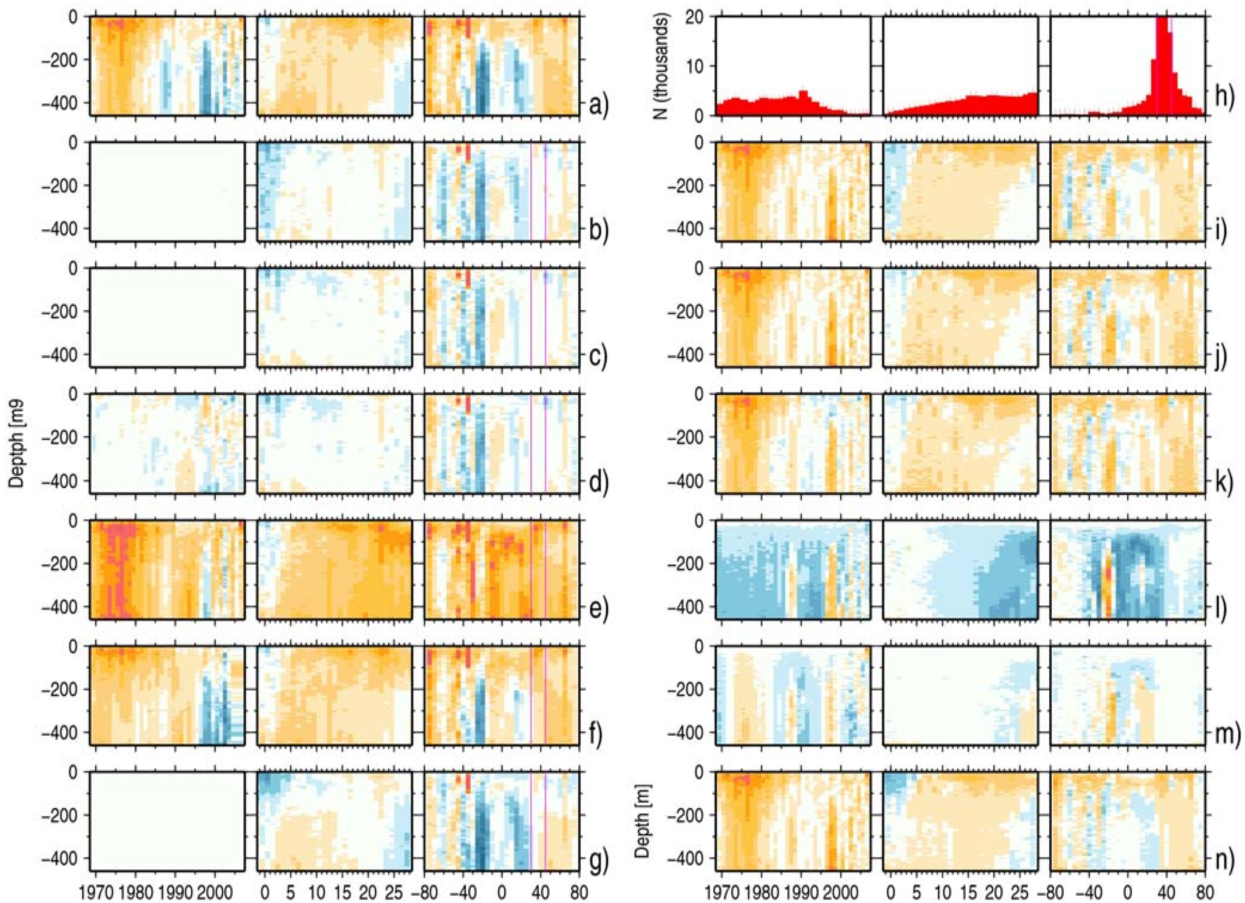
$$\mathbf{s = s_o + k\Delta\check{T},}$$

- **Where $\Delta T = \check{T} - \check{T}_o$ and $\check{T}_o$ and $\check{T}$ are global mean and observed temperature averaged between the surface and level z: $\check{T} = 1/z \int T dz$**

Original and residual bias for different bias models: T-4/T-6

Total T-bias

Bias reduction



Original

S=s(z,t)

S=s(z,t,ΔŤ)

$S=s_o(z, \Delta Ť)$

S=1.0336

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

S=1.0

$C_T=C_T\ (z,t)$

(from Gouretski&Reseghetti, s2010)

Original and residual bias for different bias model: T-7/DB

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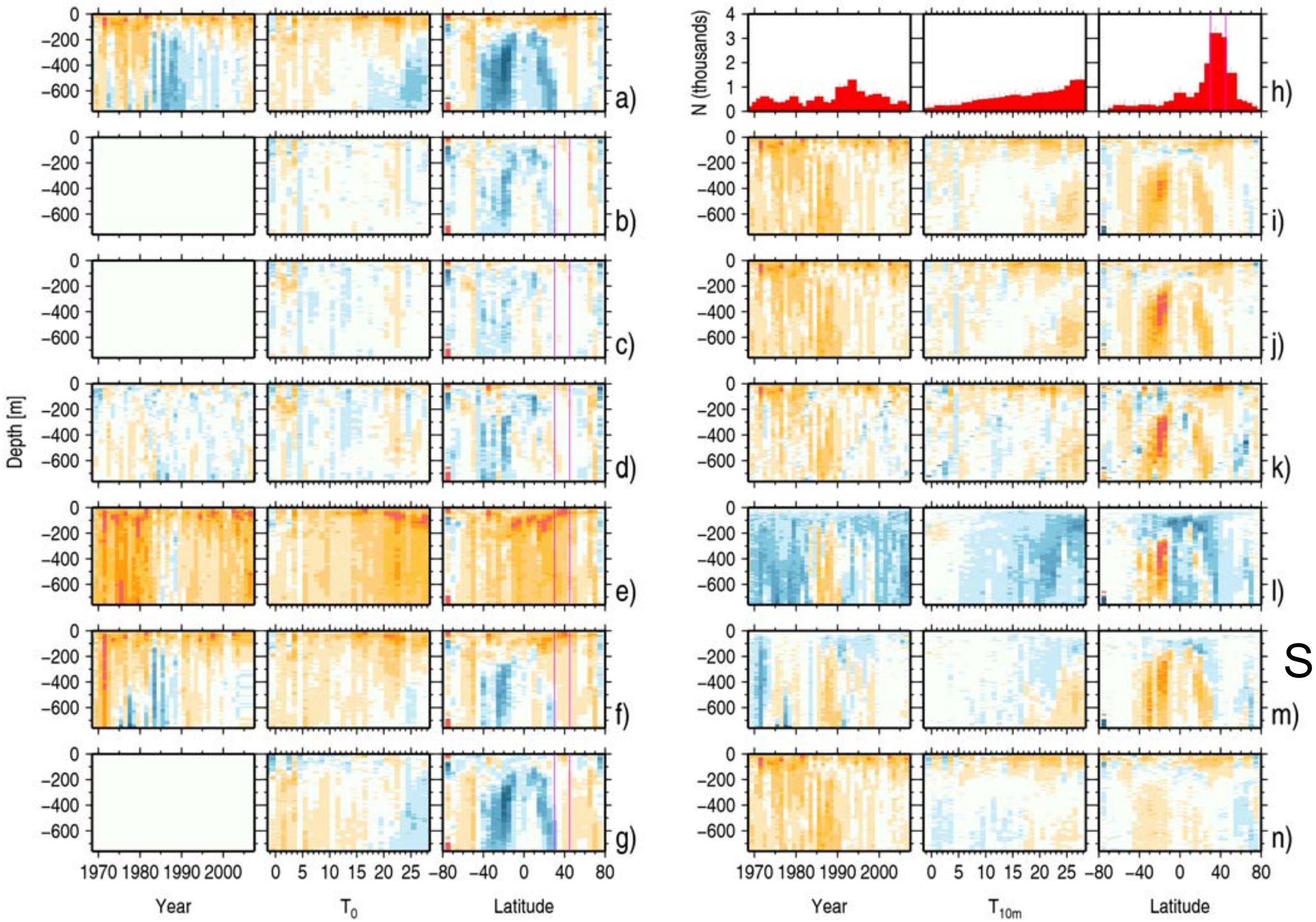
Total T-bias ***Bias reduction***



Original

S=s(z,t)

S=s(z,t,ΔŤ)

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

S=1.0336

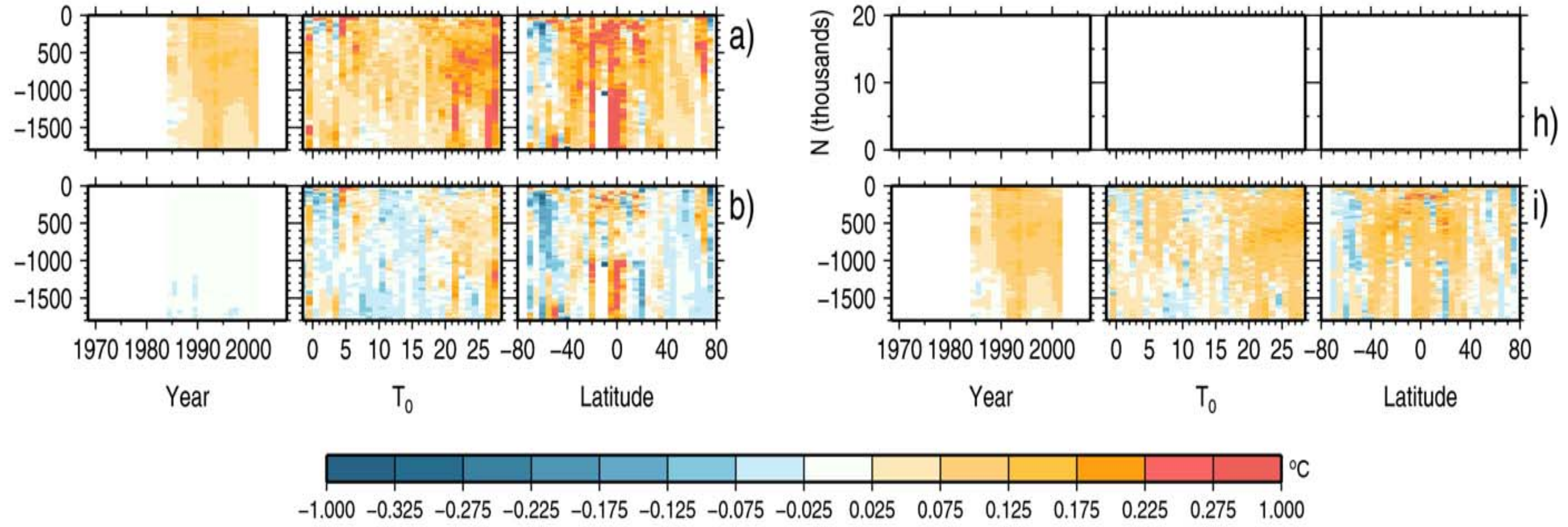
S=s(t) **(Wijffels et al.2008)**

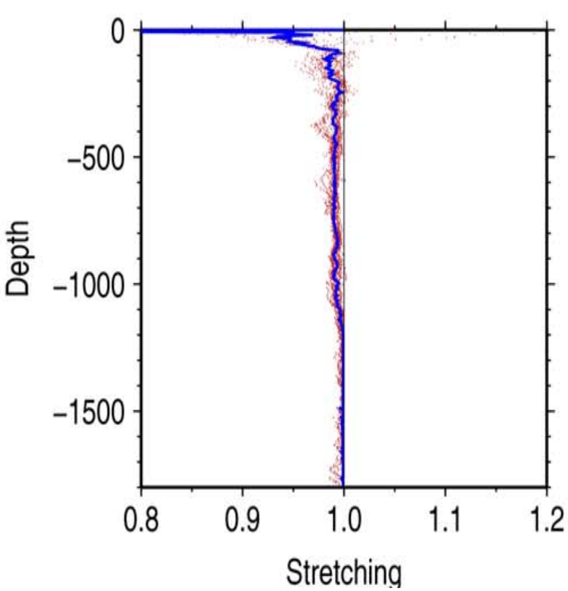
S=1.0

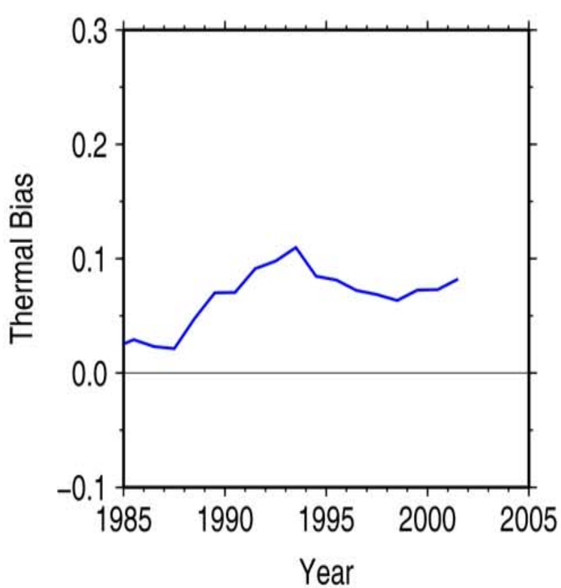
$C_T=C_T(z,t)$

(from Gouretski&Reseghetti, 2010)

Optimal stretching and T-bias fo T5 probes: preliminary results







S(z)=0.9954-0.4/z

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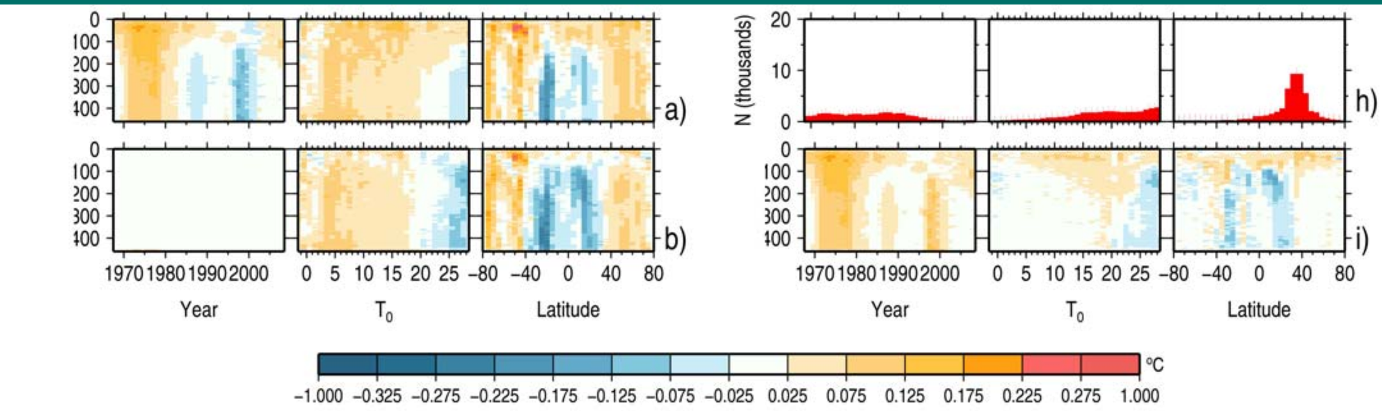
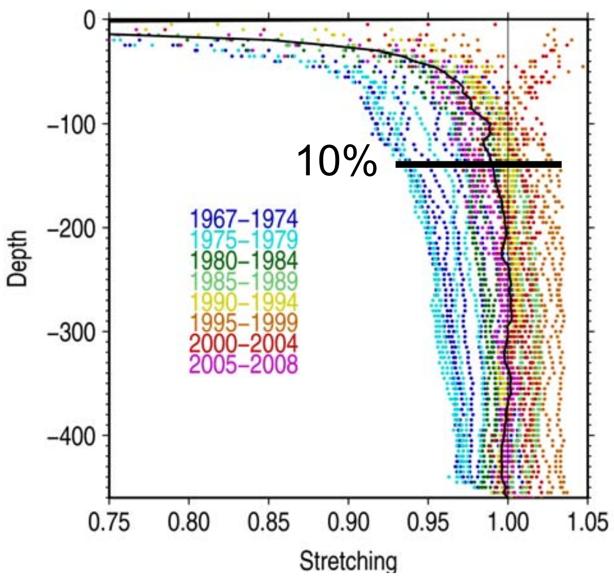
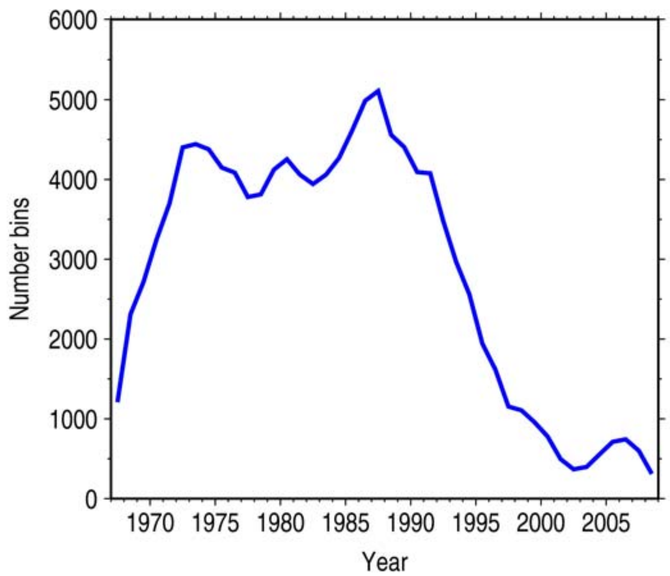
Zero thermal bias, optimal depth correction for T-4/t-6







Scattering of the stretching coefficient obviously unrealistically large

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BIASES IN THE MBT DATA

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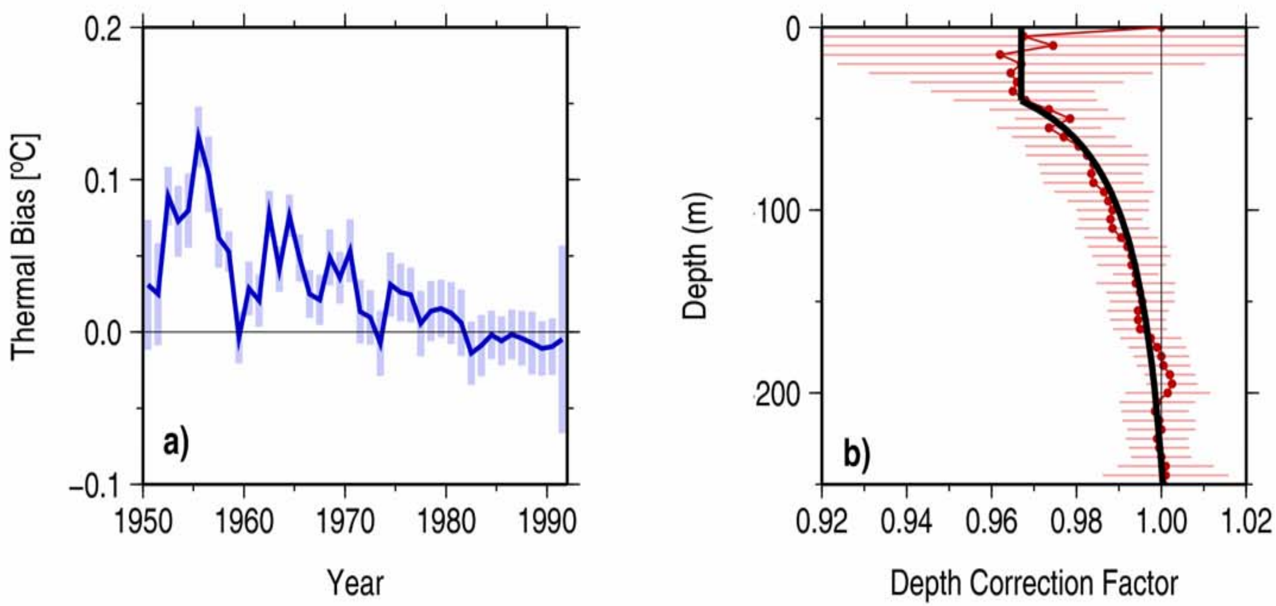
Thermal bias

Depth correction factor



(Gouretski&Reseghetti, 2010)

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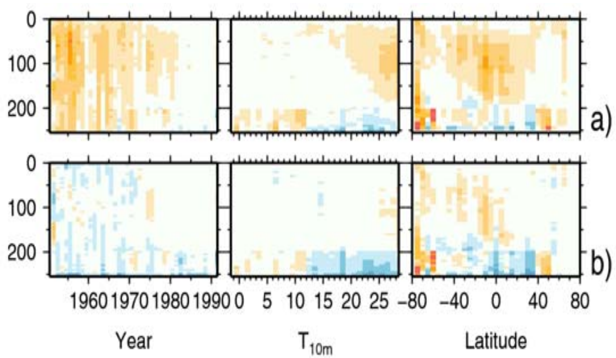
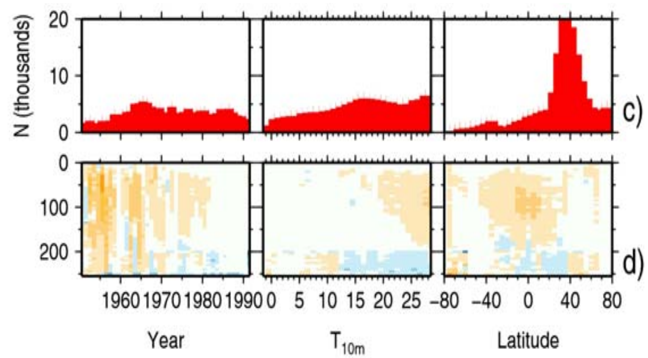
Total T-bias in MBT Data

Total T-bias



Bias reduction



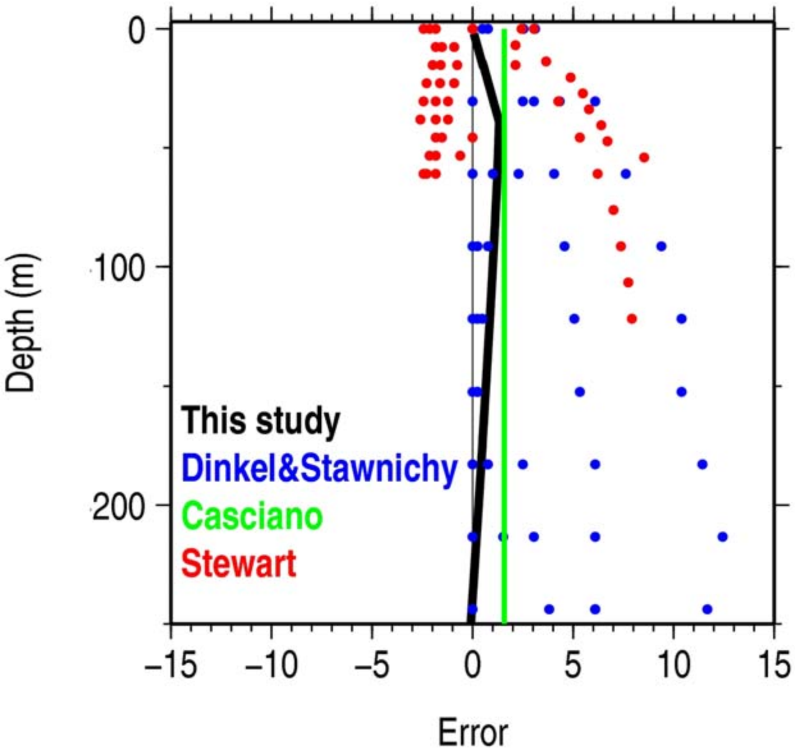
Original data

Corrected data

(Gouretski&Reseghetti, 2010)

MBT laboratory calibrations

MBT depth bias from laboratory calibrations



(Gouretski&Reseghetti, 2010)

Consistency of the CTD&Botlle Dataset

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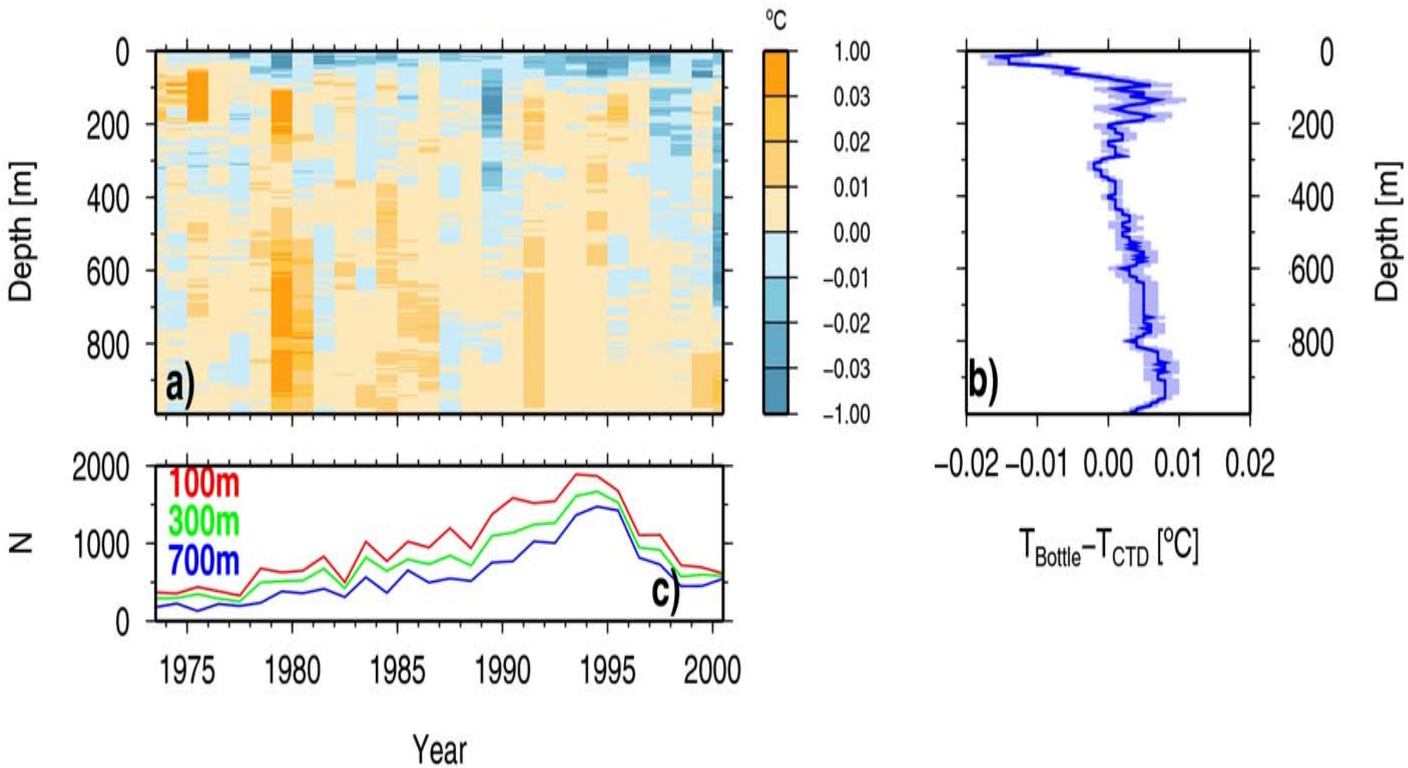
Yearly T-difference (Bottle – CTD) as the median of all collocated bins



(Gouretski&Reseghetti, 2010)

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Summary-1

- **Consensus (probably) exists on:**
- **1) XBT data may have both depth- and thermal bias**
- **2) Sippican FRE for T-4, T-6, T-7 and DB underestimates the fall rate below the near- surface layer, depth overestimation for T-5 probes**
- **3) Thermal bias is not-negligible and can explain part of time variations in the total T-bias. This bias varies with time.**
- **4) Depth-varying depth-correction factor required**
- **5) Fall-rate is dependent on the ambient water temperature**
- **6) Fall-rate is time dependent**
- **7) Biases may depend on acqusition system**
- **......?**

Summary -2

Open questions:

1) How variable were the fall-rate characteristics since 1967?
2) Is thermal bias temperature-dependent?
3) Do Sippican and TSK probes have different FREs?
4) Performance of strip-chart recorders essentially unknown
5) Fall-rate dependence on small manufacturing differences (probe weight, size, thermistor, ...) to be confirmed
6) Fall rate dependence on launch height still unclear
7) Ship-wake & ocean current influence on the fall rate unknown
8) Better parameterization for the fall-rate dependance on ambient temperature needed

.........?

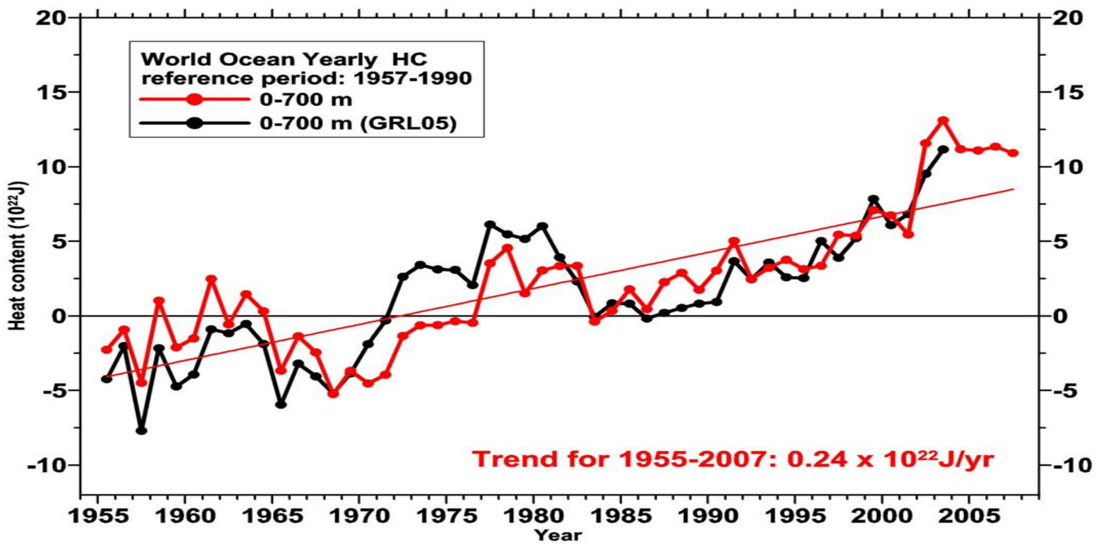
Summary-3

- Can we develop (agree upon) a new FRE(s) which we can recommend to use instead of Hanawa et. al. 1994,1995 FRE?
- Is it possible to provide a single new FRE, or do we have to treat strip-chart recoreded and digitally-recorded data separately?
- Can we agree upon a correction method for the XBT data?

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.**



From Levitus et al., 2009

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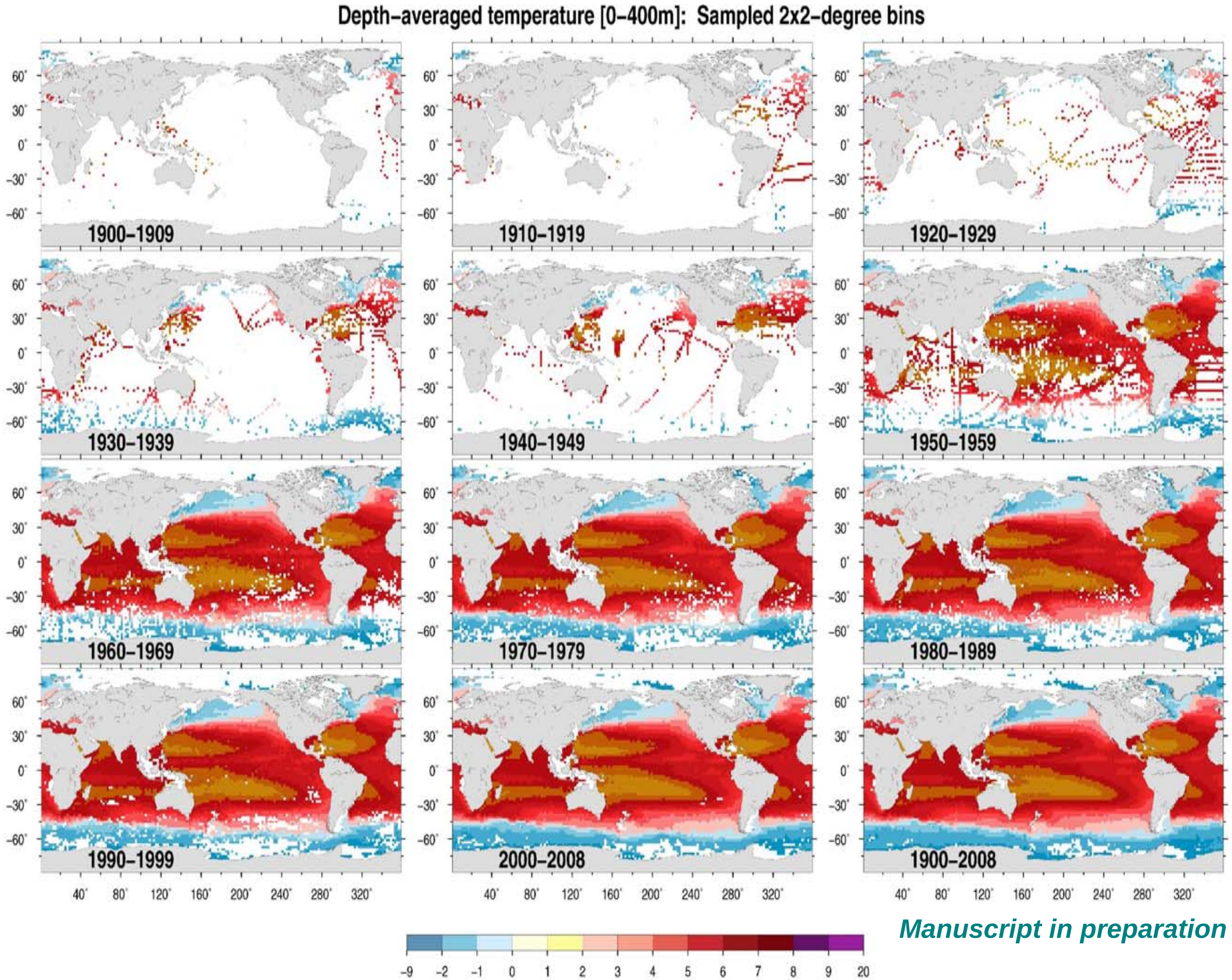
Sampled 2x2-degree boxes



Manuscript in preparation

Layer mean global T-anomaly

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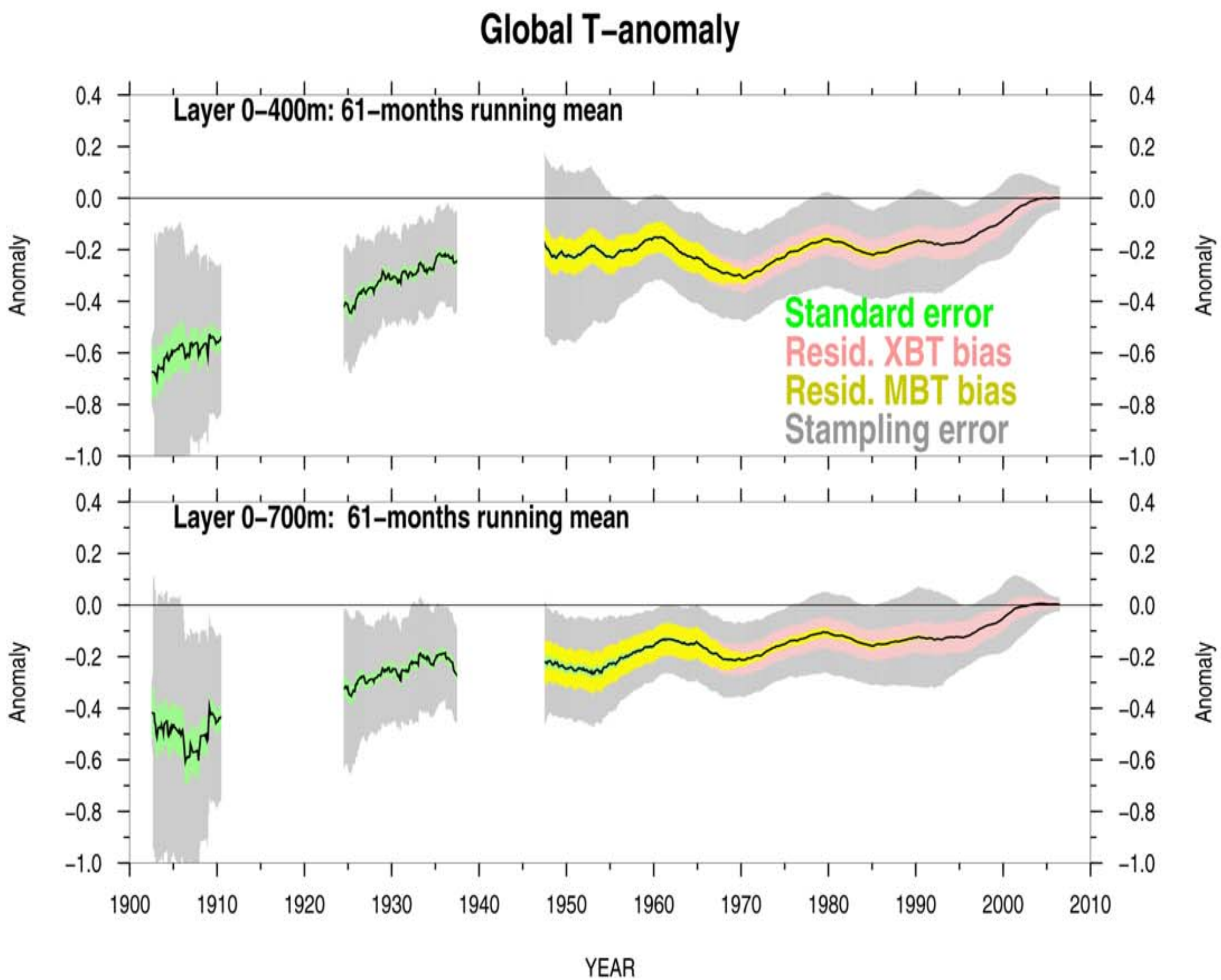

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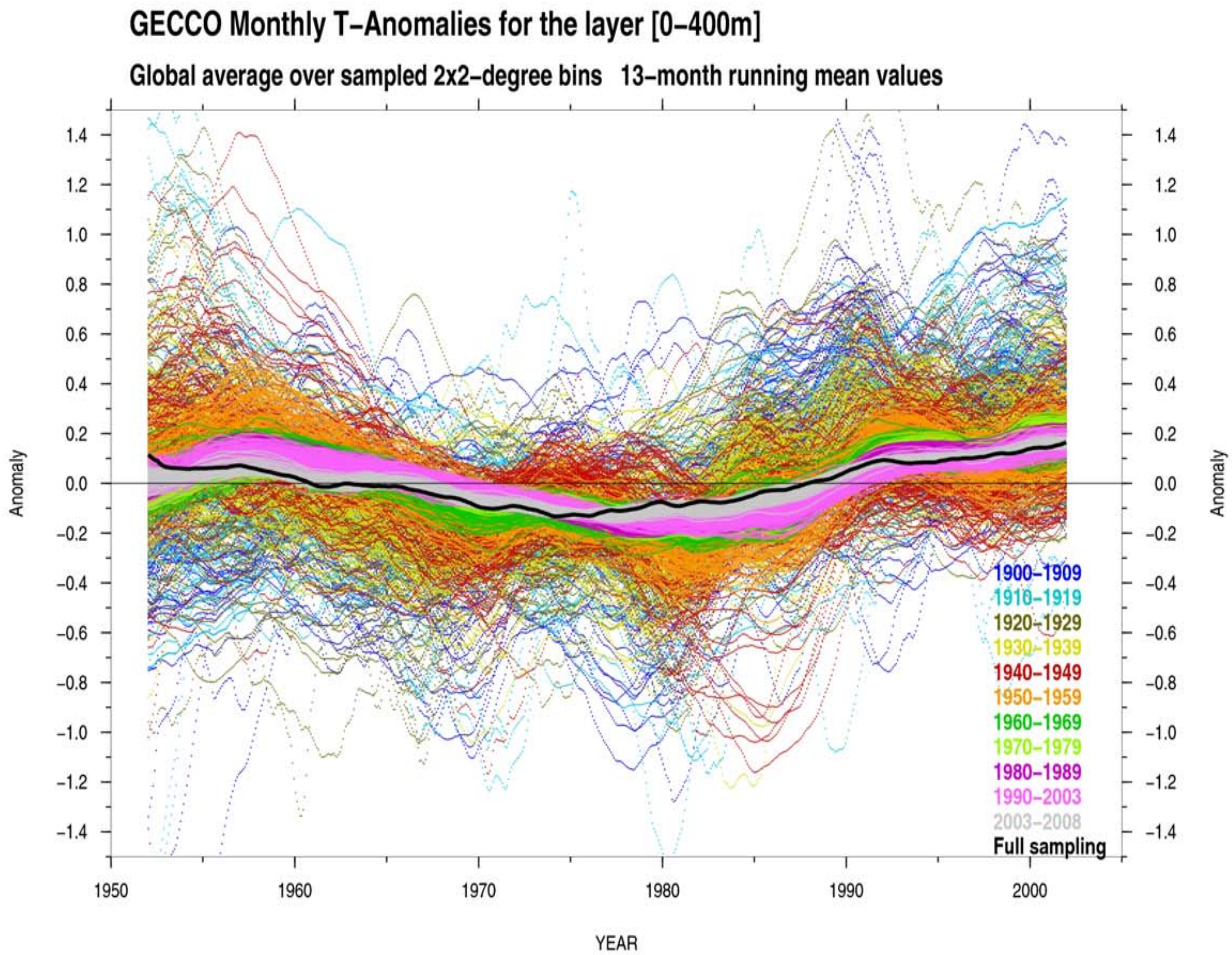
Estimating sampling error from GECCO reanalysis



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Estimates of the residual bias

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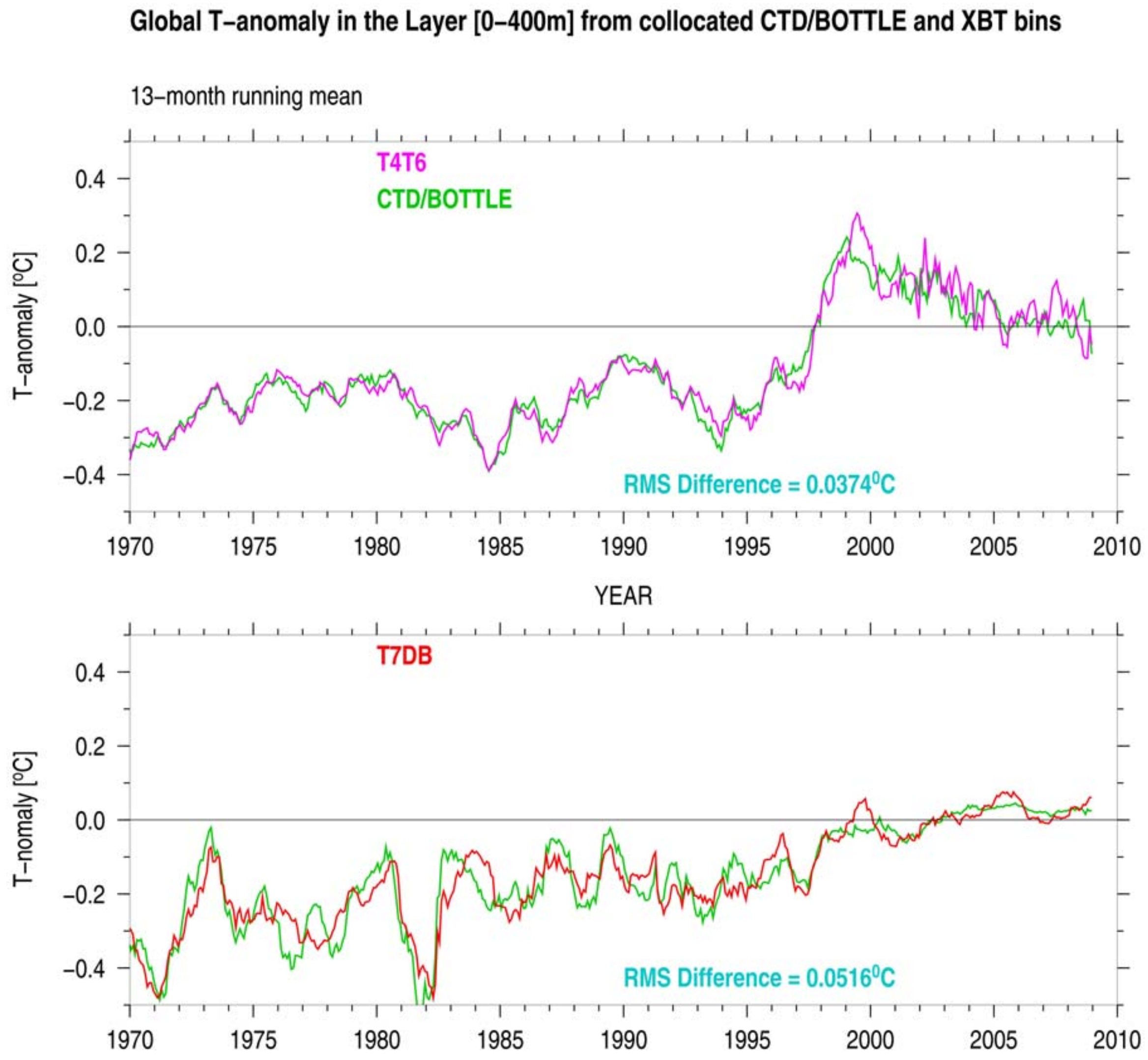

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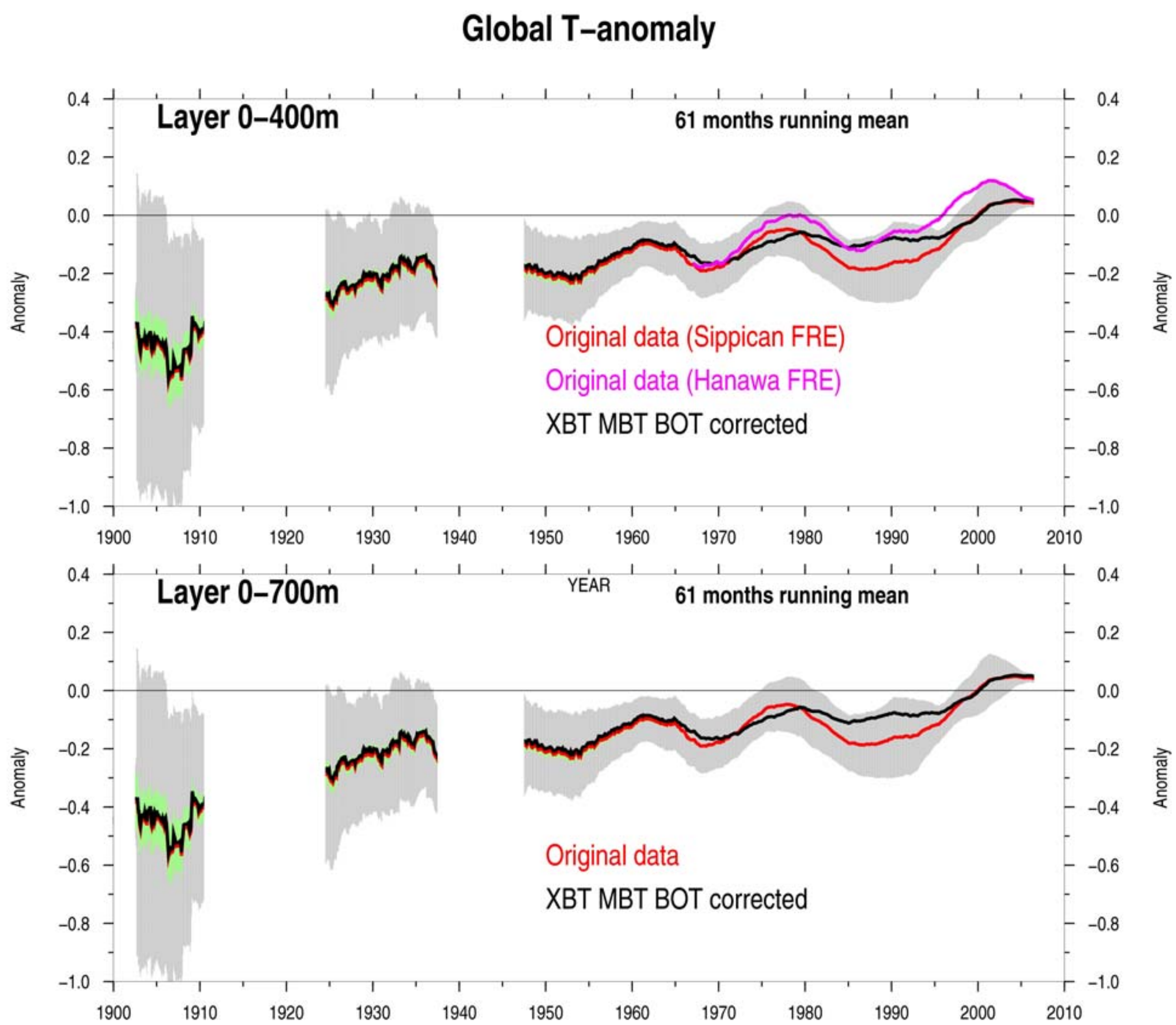
Global T-anomaly: Original vs corrected data



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CONCLUSIONS

- **Research quality profile data set is needed to reduce uncertainties in the 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 both the metadata for the historical collection and dedicated tests and CTD/XBT inter-copmparisons needed**
- **Further close cooperation between research groups important to estimate the effect of methodological differences**


Thank you!