Impact of systematic errors in hydrographic data on estimates of ocean warming

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in der Helmholtz-Gemeinschaft

6-9 Mai 2008 Gdynia, Poland

Main Questions:

- How large are systematic temperature errors?
- What is their origin?
- Can we correct the data properly?
- What effect could these errors have on the calculations of the global temperature/heat content anomaly?

Studies of systematic errors in Hydrographic data

- *Wyrtki (1971)* – nutrient data
- *Gordon & Molinelli (1982)* – salinity, oxygen, nut‘s
- *A.Mantyla (1980,1987,1994)* – salinity
- *Aoyama et al. (1998)* – offsets in IAPSO standard water
- *Johnson, Robbins&Hufford (2001)* – salinity, oxygen, nuts‘s (WOCE Pacific dataset)
- *Gouretski&Jancke (2001)* – salinity,oxygen,nut‘s (global WOCE & historical data)

Cruise property biases (from Gouretski&Koltermann, 2004)

V.V. Gouretski, K. Jancke / Progress in Oceanography 48 (2001) 337–402 345

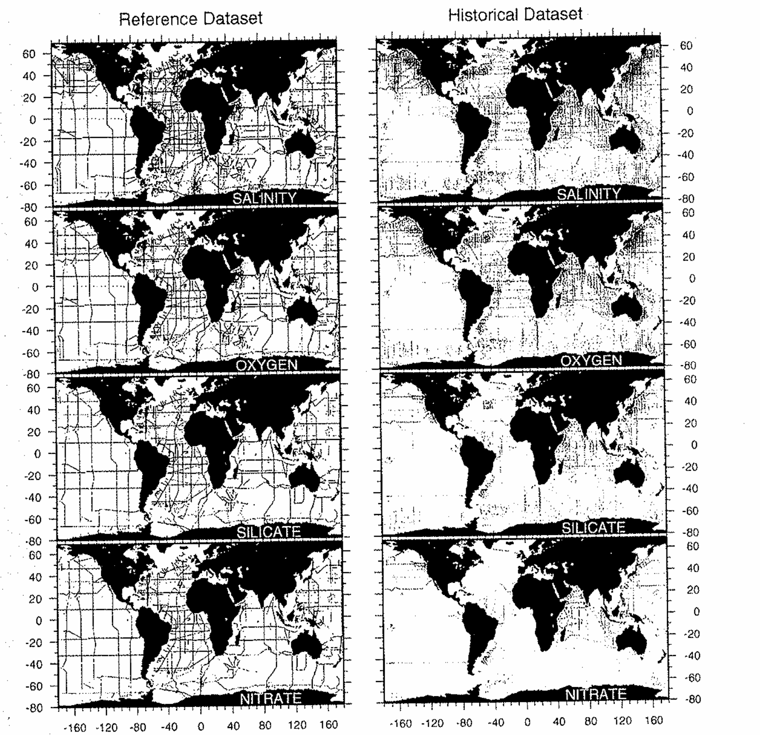


Fig. 2. Station distribution for the reference and historical datasets. WOCE cruises are shown in red.

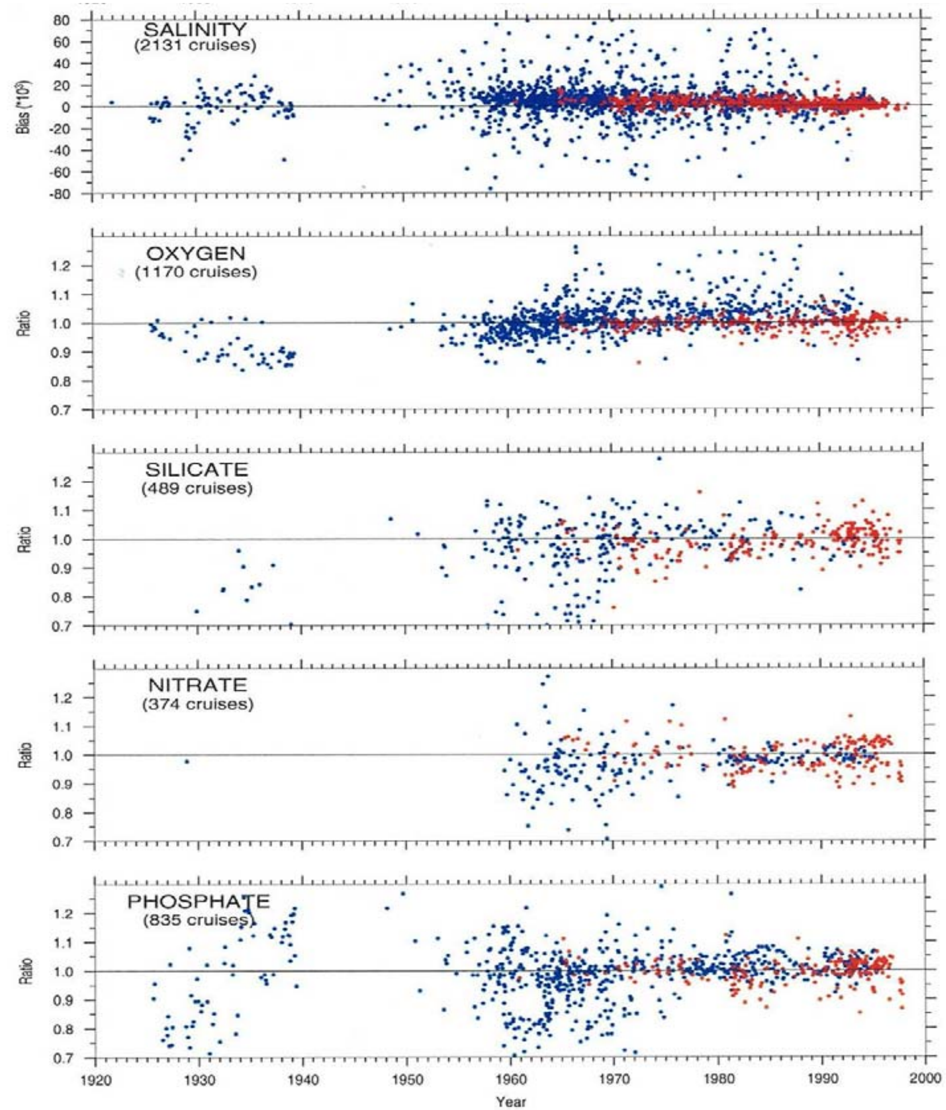
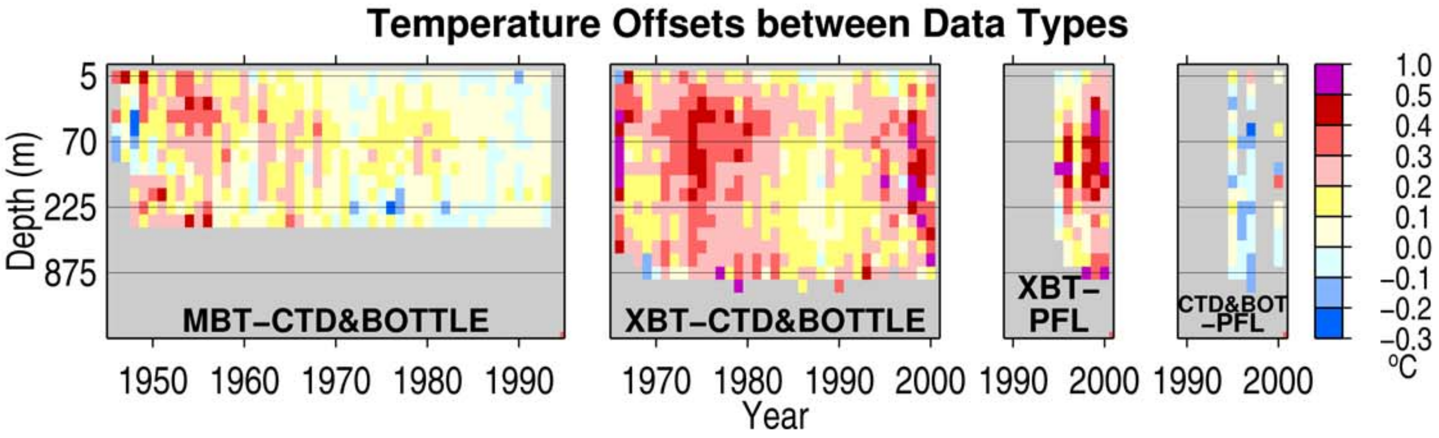


Fig. 11 Cruise biases versus time (red – reference cruises, blue – historical cruises).



(Gouretski & Koltermann, 2007)

Oceanographic instruments to measure temperature

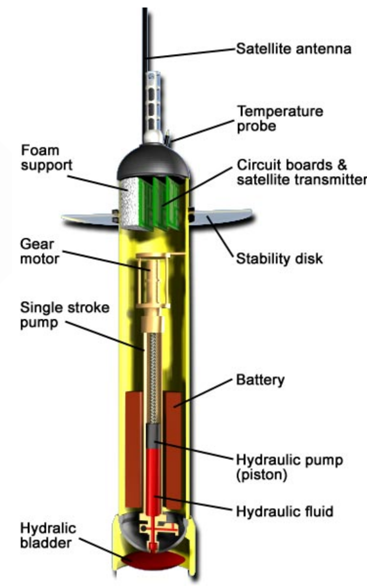
Nansen Bottles with reversing thermometers

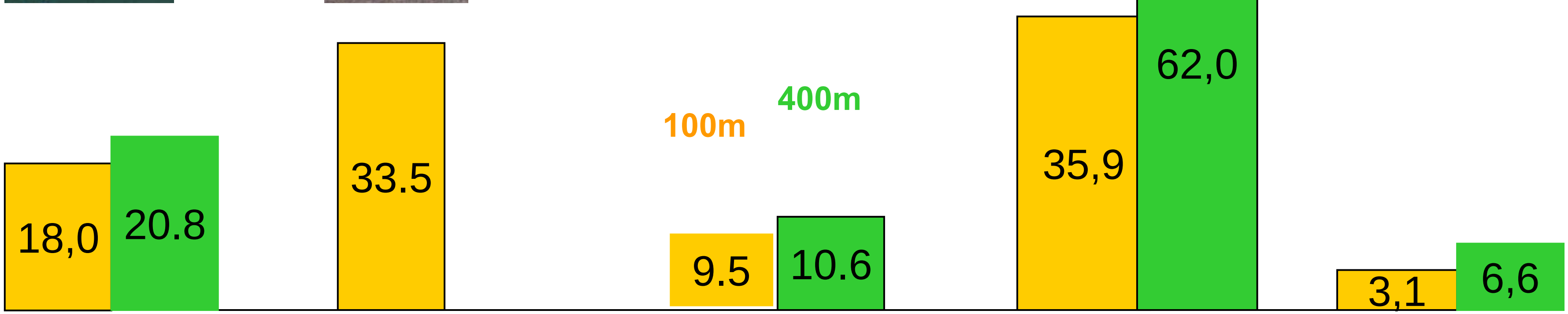
Mechanical Bathithermograph

CTD

XBT

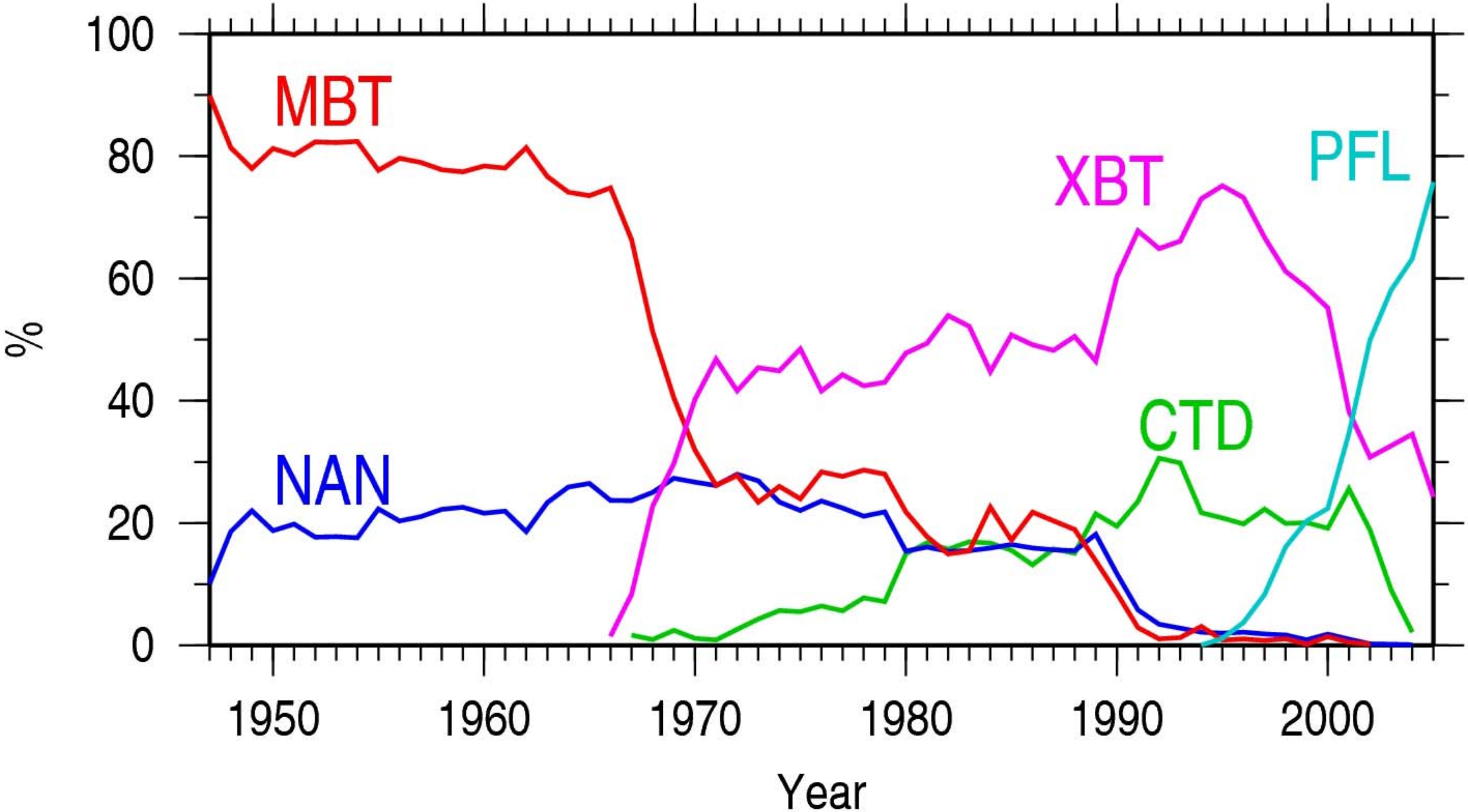
Profiling float



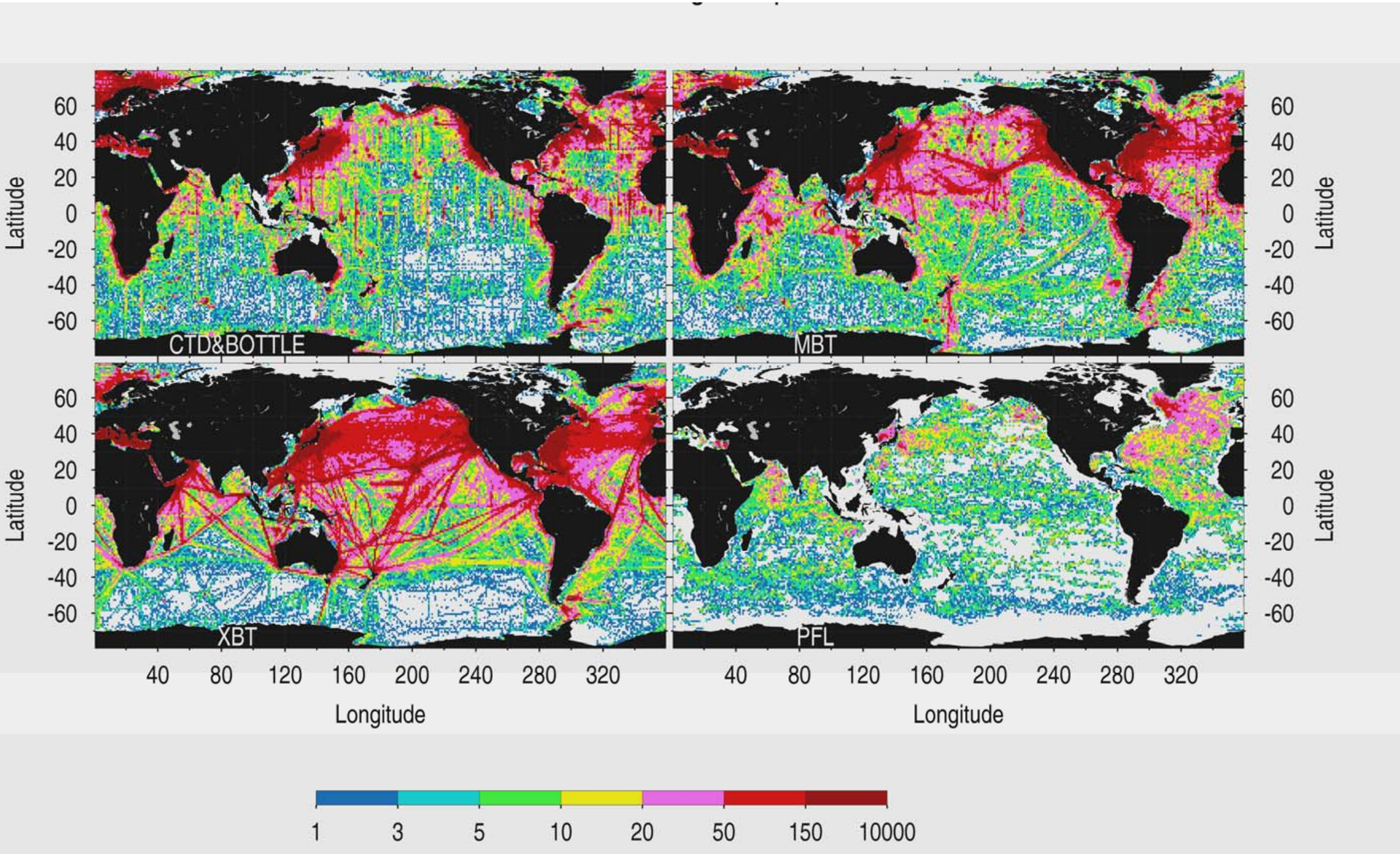


Time period: 1947 - 2006

Datatype percentage at 100 meter depth



Total Number of T-Profiles in 1x1-degree squares for different datatypes



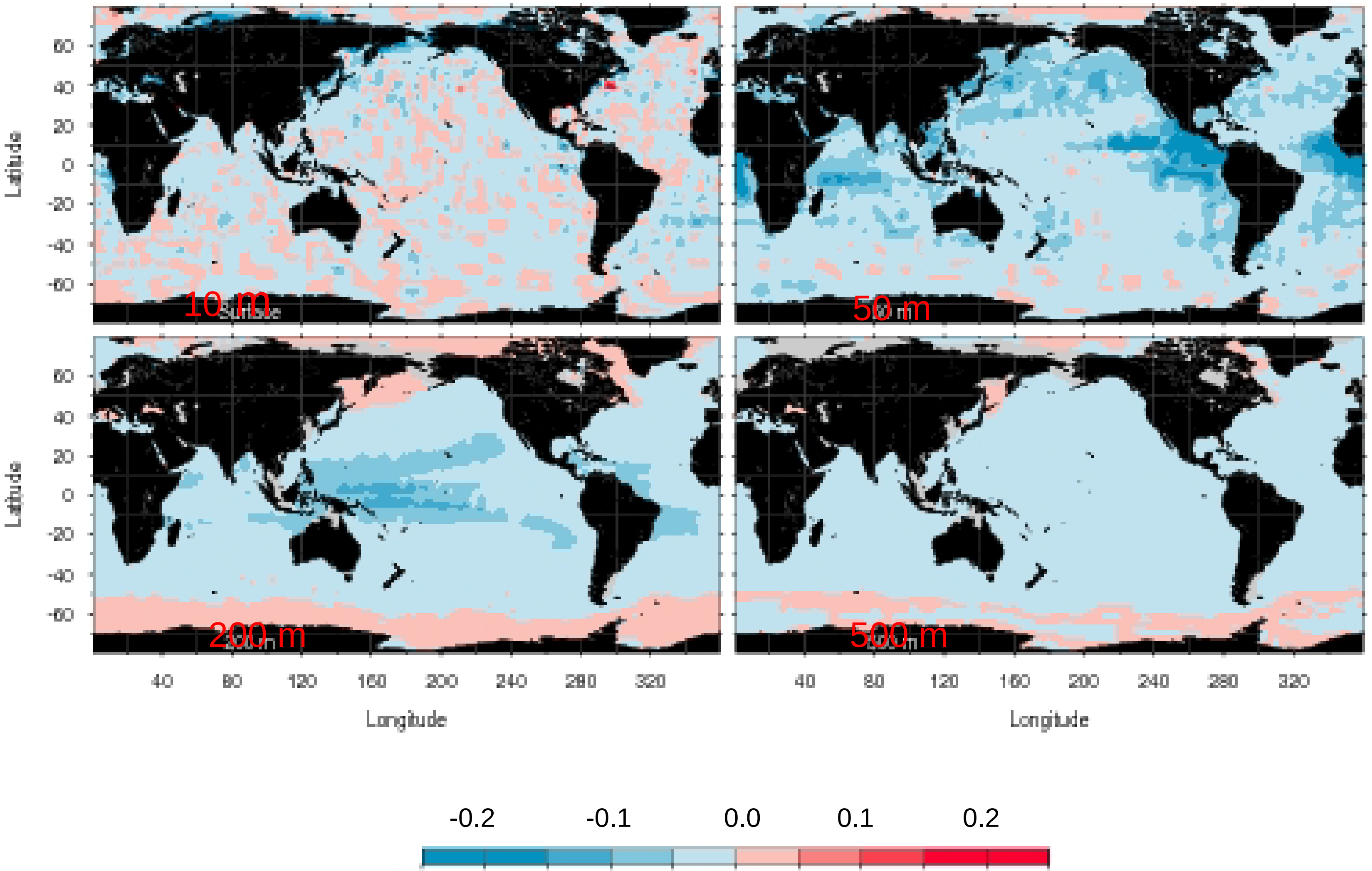
Origin of Systematic Temperature Errors:

- Pure temperature error

- Sample depth error: translates into T-error if $|DT/Dz| > 0$

(In case of XBT casts: difficult to identify the two error types as pressure/depth is not measured)

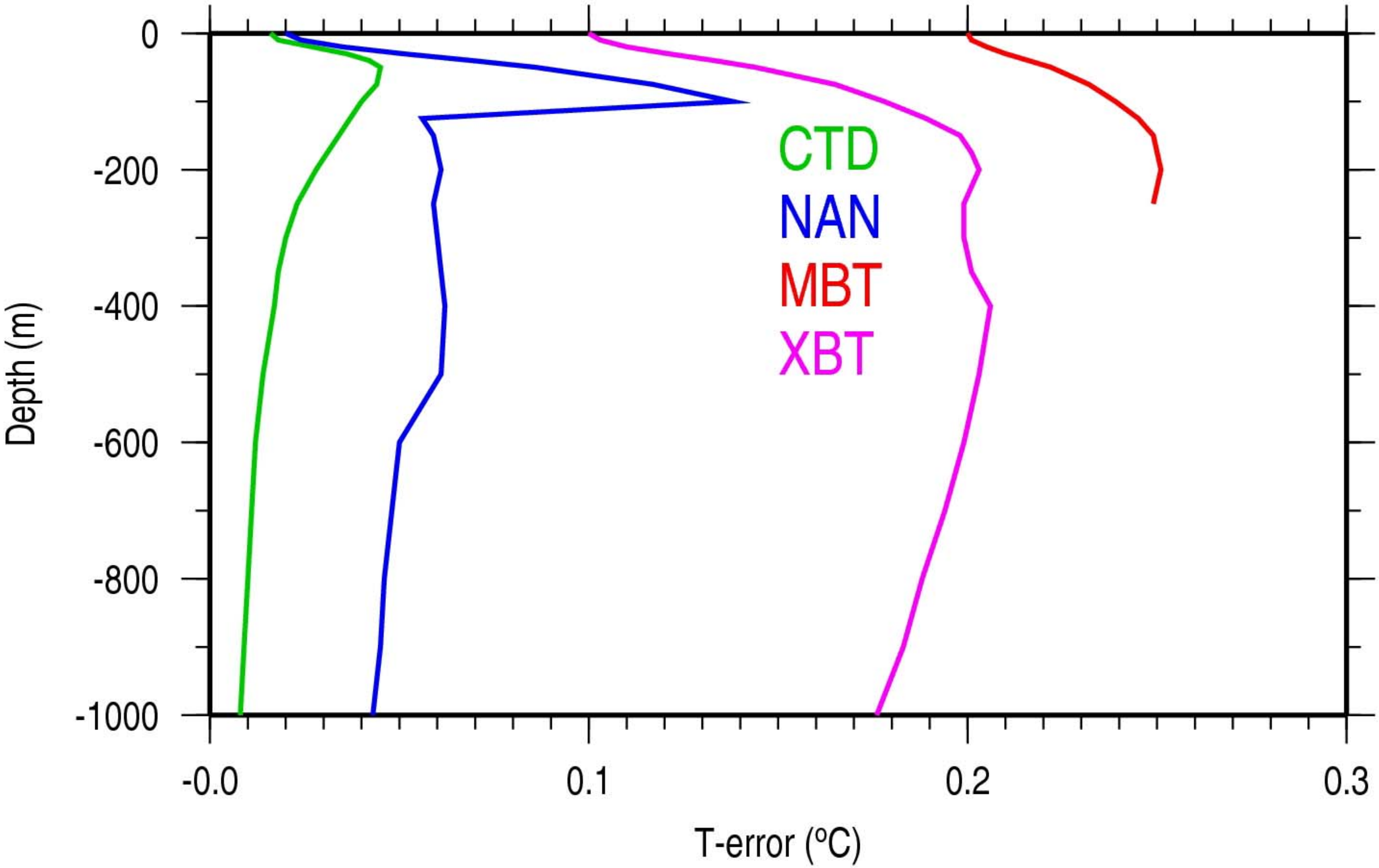
Vertical Temperature Gradient [°C · m^{-1}] at depths (annual WGHC Climatology)



Depth ranges and mesurement precisions of main oceanographic instruments

	CTD	Nansen Bottles	MBT	XBT	PFL
Precision of Temperature, °C	0.005	0.02	0.2	0.1	0.005
Precision of depth, meters	0.015% FS	≤ 3% Z (Z<200m) ≤1,0% Z (Z>1000m)	1% FS	$0.02 \cdot Z$	<2.4

Estimates of the total temperature error based on instrument precision specifications and the mean vertical temperature gradient



Calculation of T-biases:

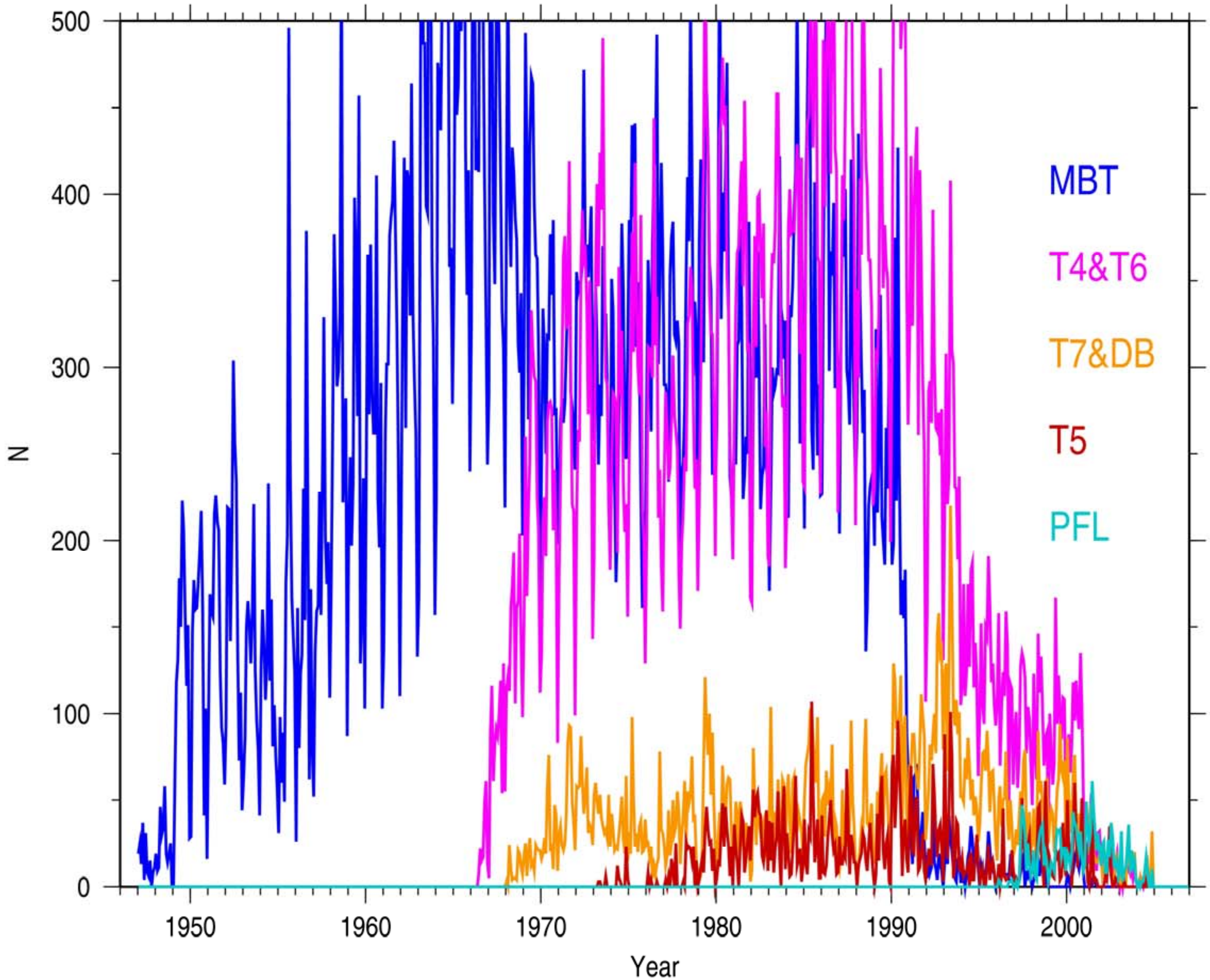
1) Building super-observations:
- Time binning: monthly
- Spatial binning: 111x111km
- Binned temperature for each instrument type separately between 1947 and 2006

2) Comparing data-type mean temperatures with CTD/Bottle temperatures in collocated boxes:

Box-averaged bias: $B = \langle T_{DataType} \rangle - \langle T_{BOT/CTD} \rangle$

- Area-averaged box-values are used to produce bias time-series at each level

Number of overlapping boxes (Datatype/CTD&BOTTLE)

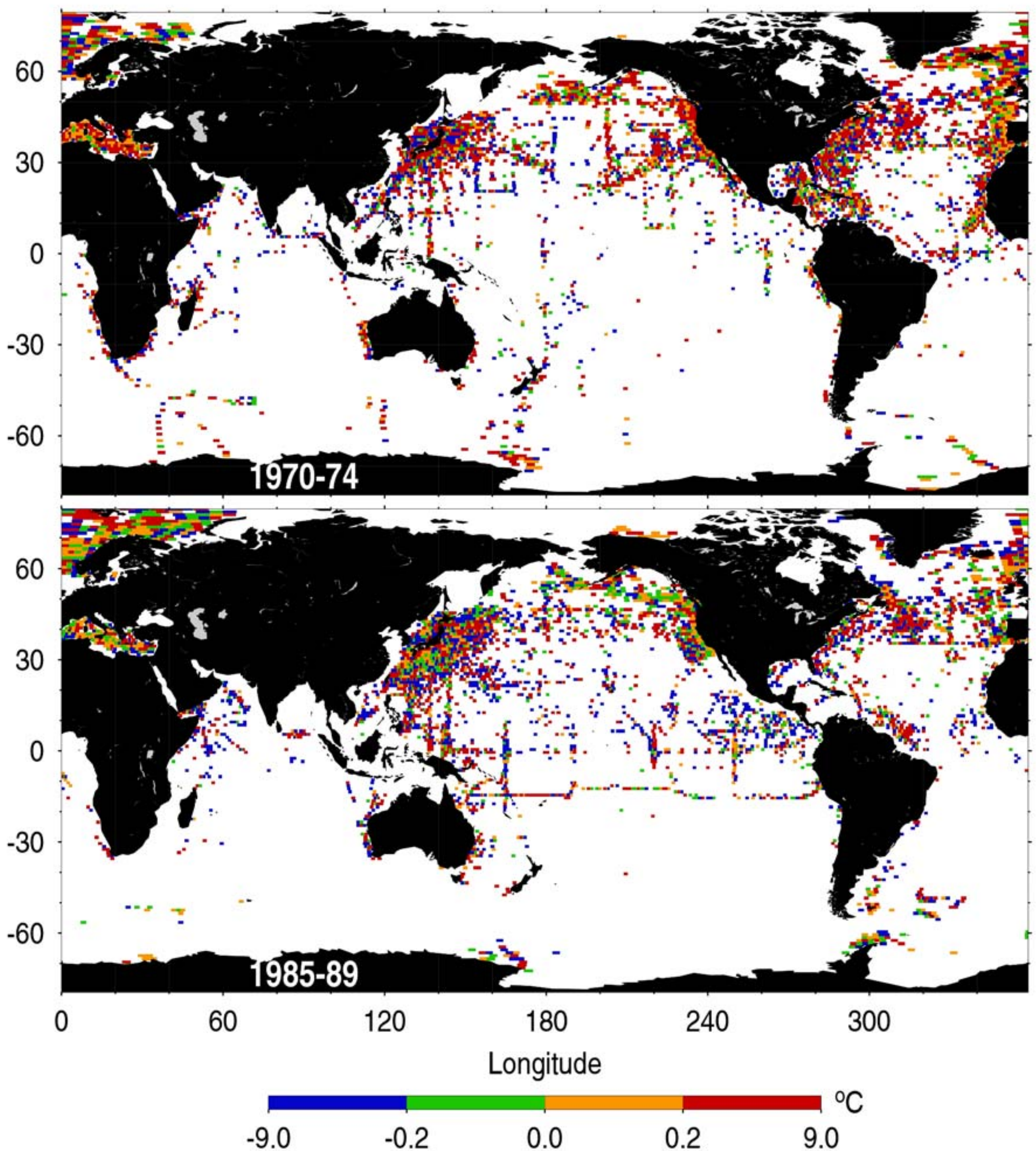


XBTs: main T-data source since 1967

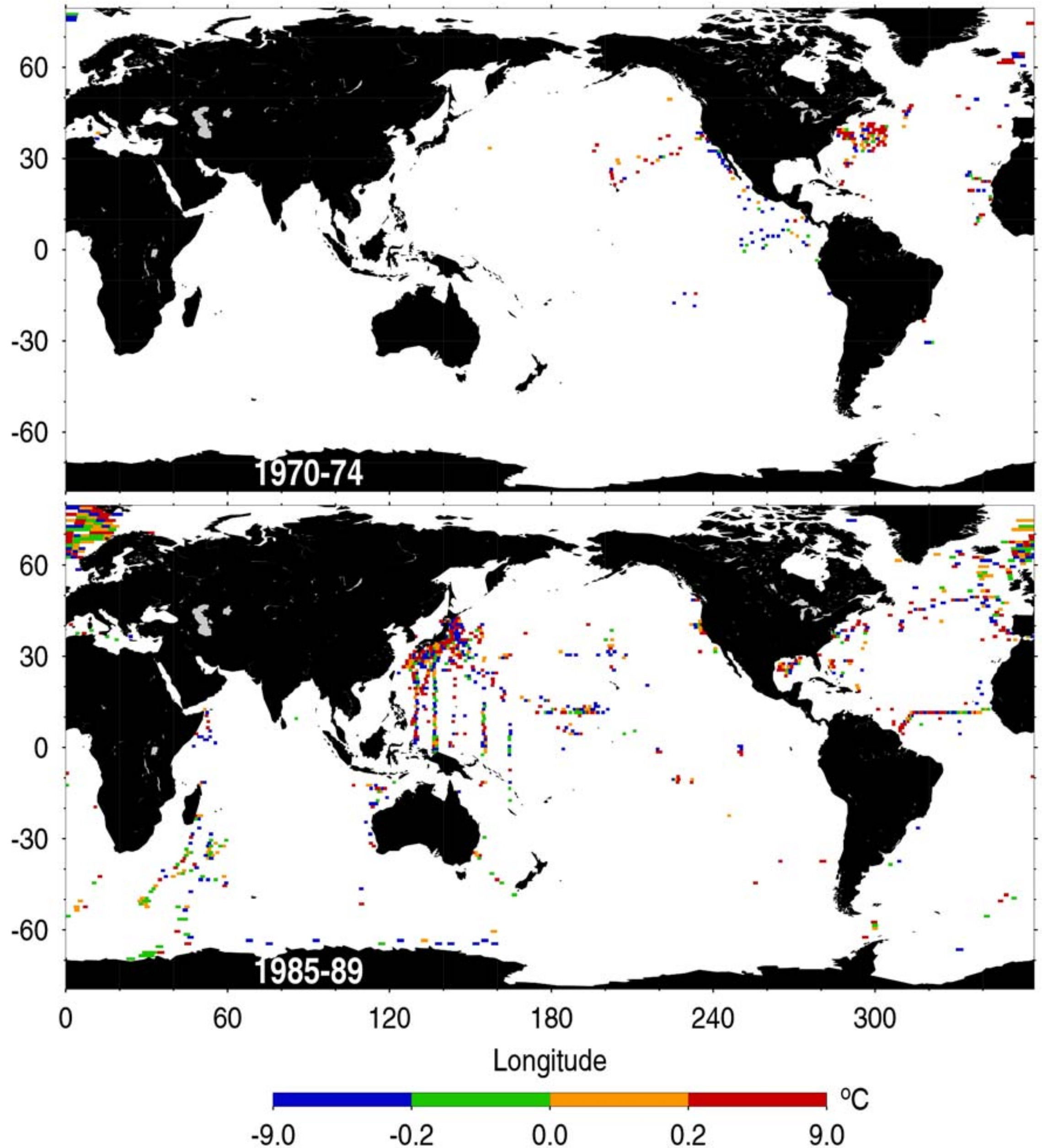
Type	Max Depth	Rated ship speed	Application
T-4	460	30	Standard NAVY
T-6	460	15	Standard oceanographic
T-7	760	15	NAVY & Oceanographic
Deep Blue	760	20	NAVY & Oceanographic
T-5	1830	6	NAVY & Oceanographic

T4&T6: 71.6% **T7&DB 19.6%** **T5: 8.8%**

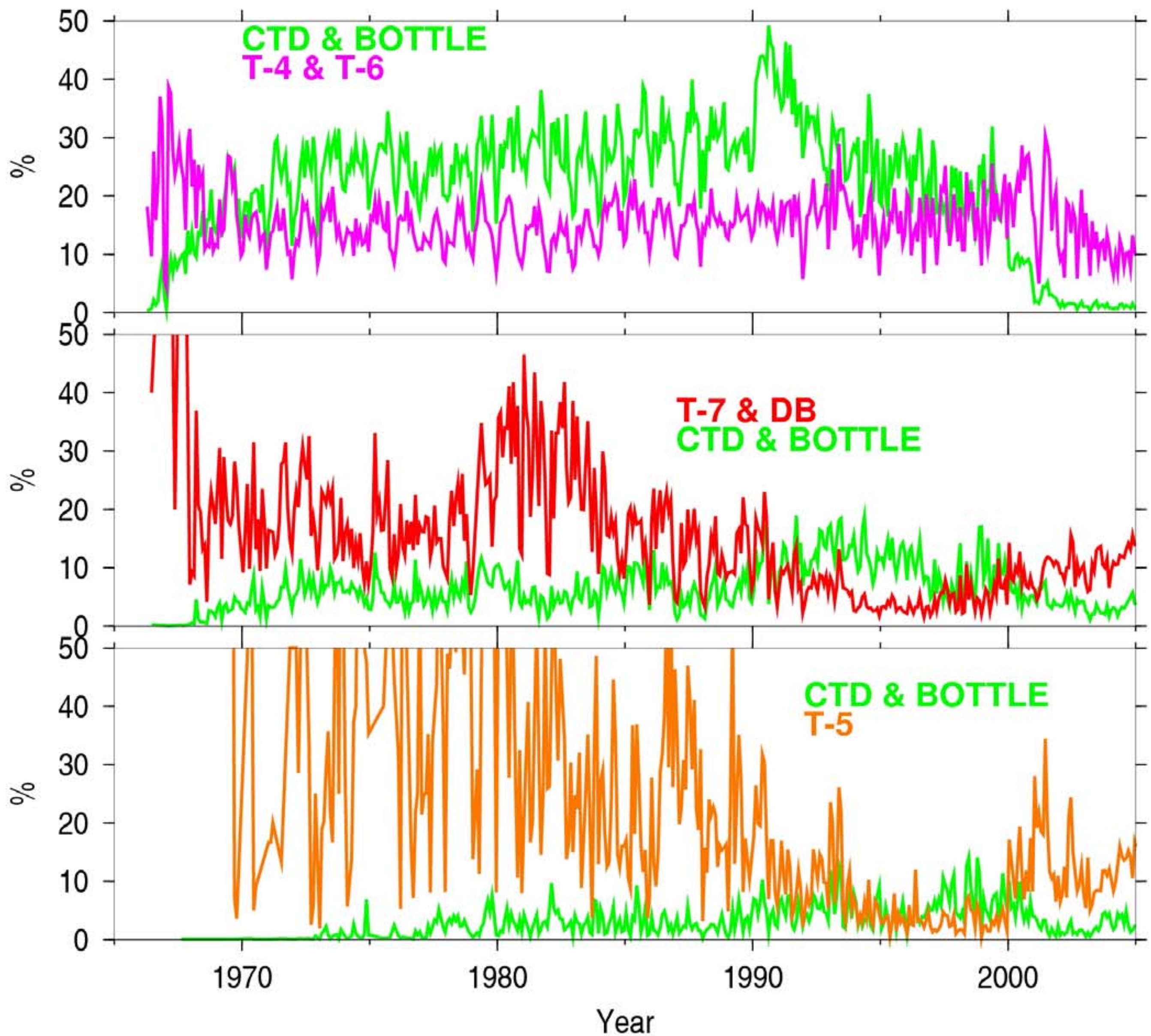
Temperature offset for T-4 & T-6 (100 m level)



Temperature offset for T5 (100 m level)



Percentage of overlapping 111x111km boxes (at 100 m level)



XBT Fall-rate Equation

$$Z_{xbt} = at - bt^2$$

(t is time (in sec) elapsed from the probe entry into the water)

For XBT-types T-4/T-6/T-7

a=6.472 **b=0.00216**	Sippican Ocean Systems (manufacturer)
a=6.691 **b=0.00225**	New recommended coefficients (Hanawa et al., 1994, 1995)

XBT's fall rate is underestimated by the manufacturer!

Hanawa et al. (1994) linear depth correction factor : $Z_{true} = 1.0336 * Z_{XBT}$

T-biases for T4 & T6

BLUE - original data   MAGENTA - corrected data (Hanawa et al. (1994) fall-rate corrections)

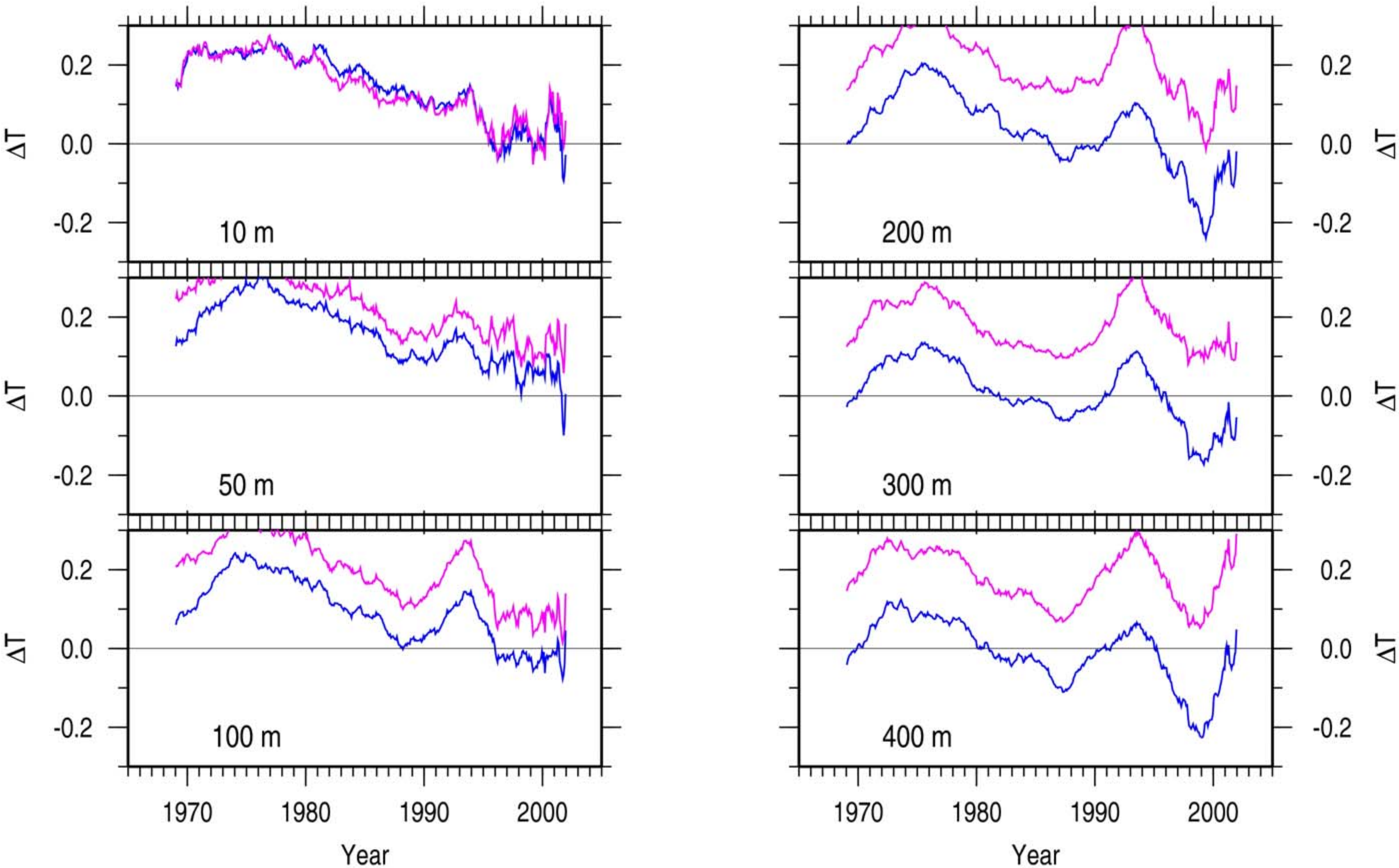
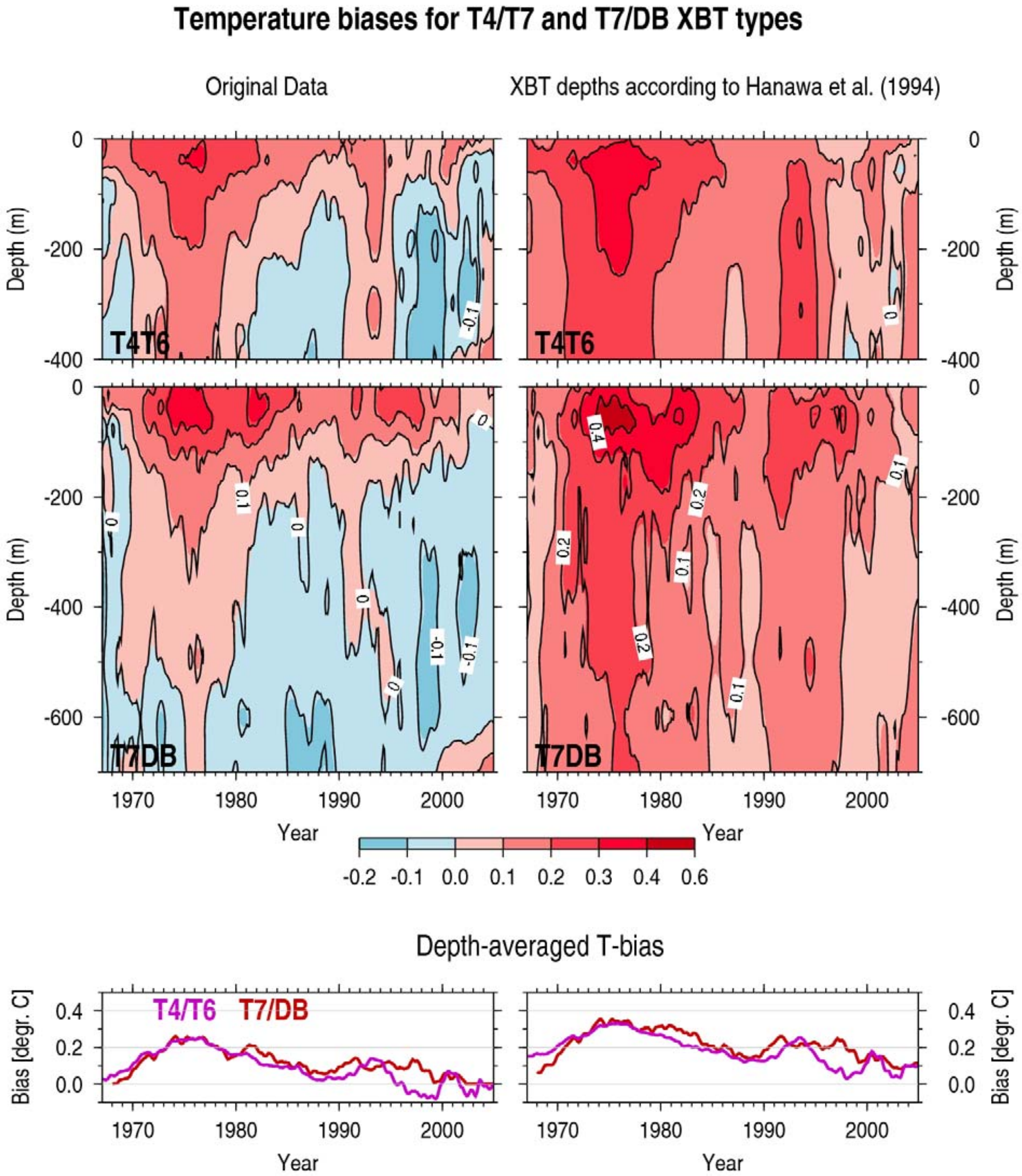


Table 1. XBT temperature biases from XBT/CTD inter-comparison experiments (from Gouretski&Koltermann, 2007)

Author	Time of data acquisition	Temperature Offset, ºC
Wood, 1976	?	Positive offset
Heinmiller et al., 1983	1973-79	0.13-0.19
Bailey et. al., 1989	Historical archive	Positive T-drift with depth
Wright and Szabados, 1989	?	0.11-0.24
Boyd and Linzell, 1991	1991	0.07
Hallock and Teague, 1992	1990	0.1
Schmeiser, 2000	2000	0.15
Roth, 2001	2001	0.08
Boedecker, 2001	2001	0.09
Fang, 2002	2002	0.025-0.107
Kizu and Hanawa, 2002	1985-2001	up to 1
Dixon, 2003	2003	0.13
Laird, 2006	2006	0.04
Reseghetti et al., 2006	2004	O(0.05) below400 m 0.2-2.8 in the thermocline


Temperature biases for T4/T7 and T7/DB XBT types
Original Data
XBT depths according to Hanawa et al. (1994)
Depth (m)
T4T6
T7DB
0
-200
-400
-600
1970
1980
1990
2000
Year
-0.2
-0.1
0.0
0.1
0.2
0.3
0.4
0.6
Depth-averaged T-bias
Bias [degr. C]
T4/T6
T7/DB

Hanawa et al. (1994) depth corrections do not eliminate the total warm temperature bias:

The corrected XBT data are „getting warmer“

What is wrong?

Bias decomposition (for box-averaged values) :

$$\langle b(z)\rangle = \langle\Delta\rangle + \langle\gamma(z)\rangle \cdot \zeta(z) + \varepsilon \,,$$

where

$\langle\Delta\rangle$	(pure) temperature bias, depth independent
$\zeta(z) = Z_{XBT} - Z_{TRUE}$	sample depth bias, depth dependent
$\gamma(z)$	vertical temperature gradient

Spatial averaging {…} over N boxes gives

$$\{\langle b\rangle\} \approx \{\langle\Delta\rangle\} + \{\langle\gamma(z)\rangle\} \cdot \zeta(z)$$

Since the depth-error at the surface is zero (ζ = 0 for z=0),

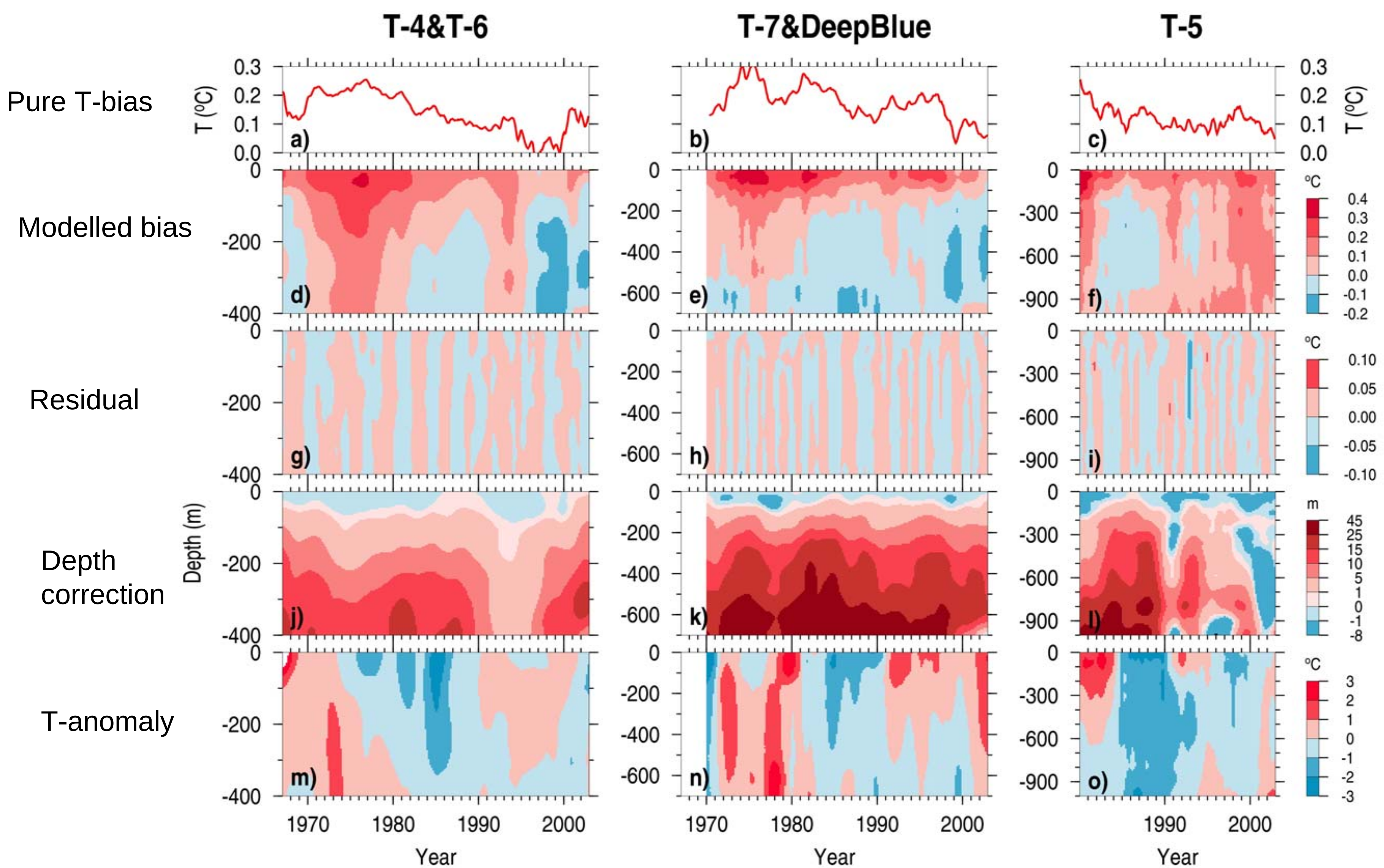
the depth-independent T-bias is: $\{\langle\Delta\rangle\} = \{\langle b(0)\rangle\}$

Depth correction at an arbitrary level Z is given by

$$\zeta(z) \approx \frac{\{\langle b(z)\rangle\} - \{\langle b(0)\rangle\}}{\{\langle\gamma(z)\rangle\}}$$

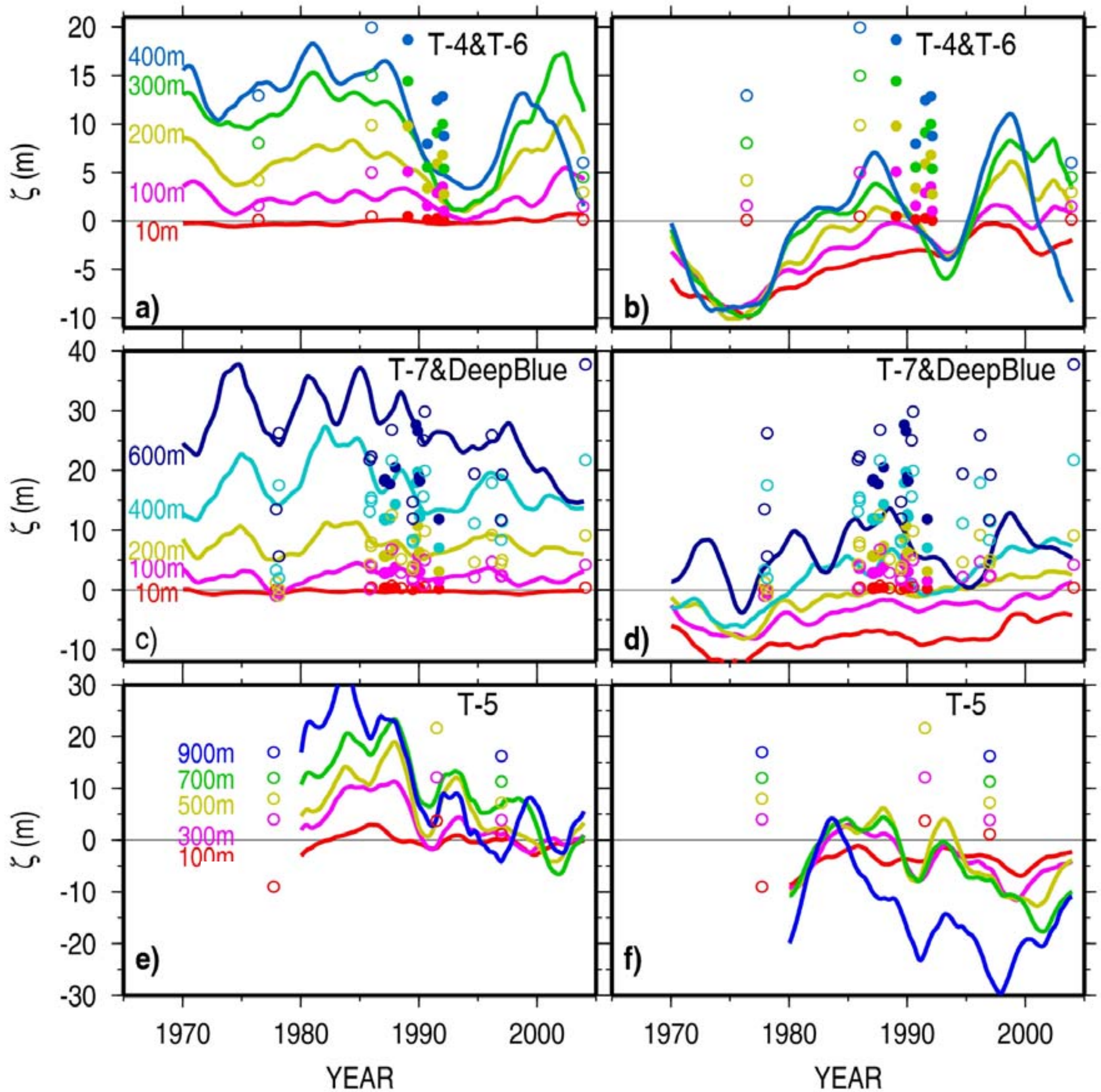
Corrections ζ can be compared with *independent* in-situ XBT vs CTD inter-comparisons

Application of the bias model to different XBT types

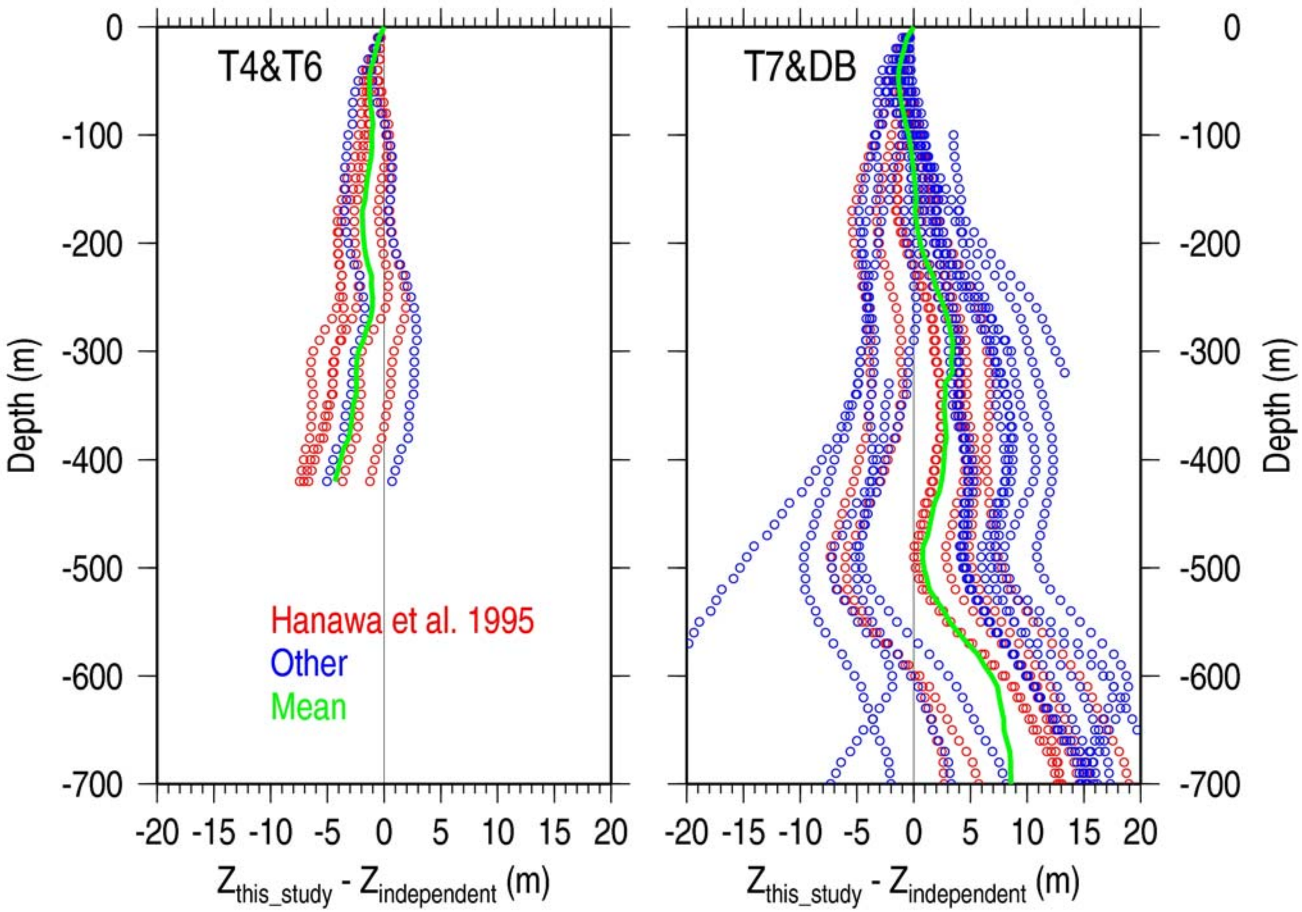


Comparison of XBT depth corrections (ζ) with independent experiments (circles)

Bias Model => $\mathbf{b(z)} = \Delta + \gamma(\mathbf{z}) \cdot \zeta(\mathbf{z})$ $\mathbf{b(z)} = \gamma(\mathbf{z}) \cdot \zeta(\mathbf{z})$



Comparison of modelled depth corrections with independent results



Modelling MBT biases

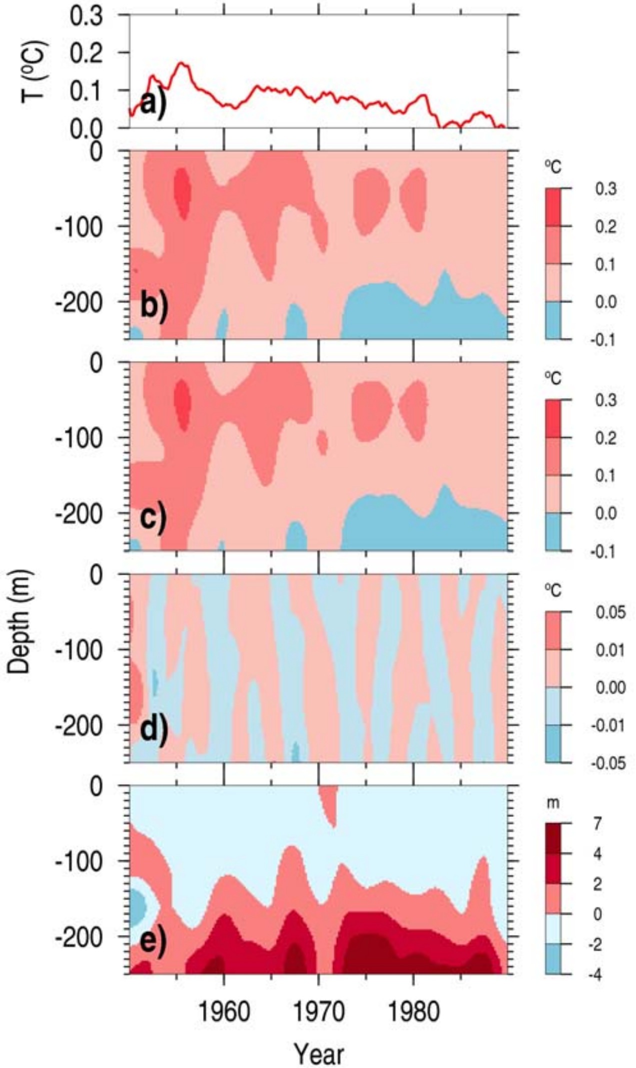
Pure T-bias

Observed bias

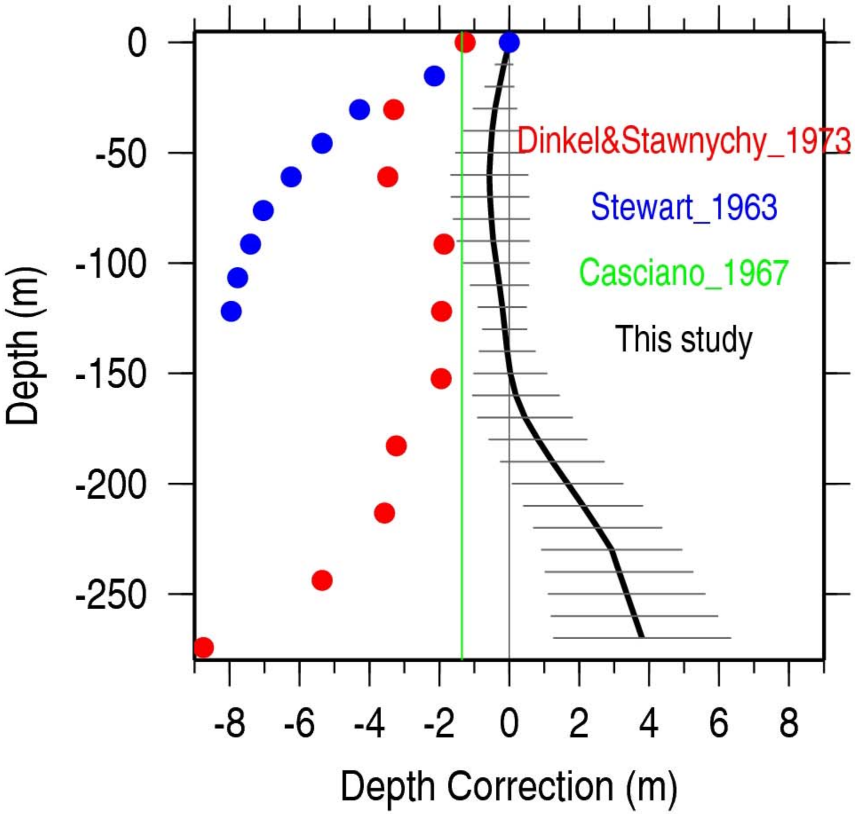
Modelled bias

Residuals

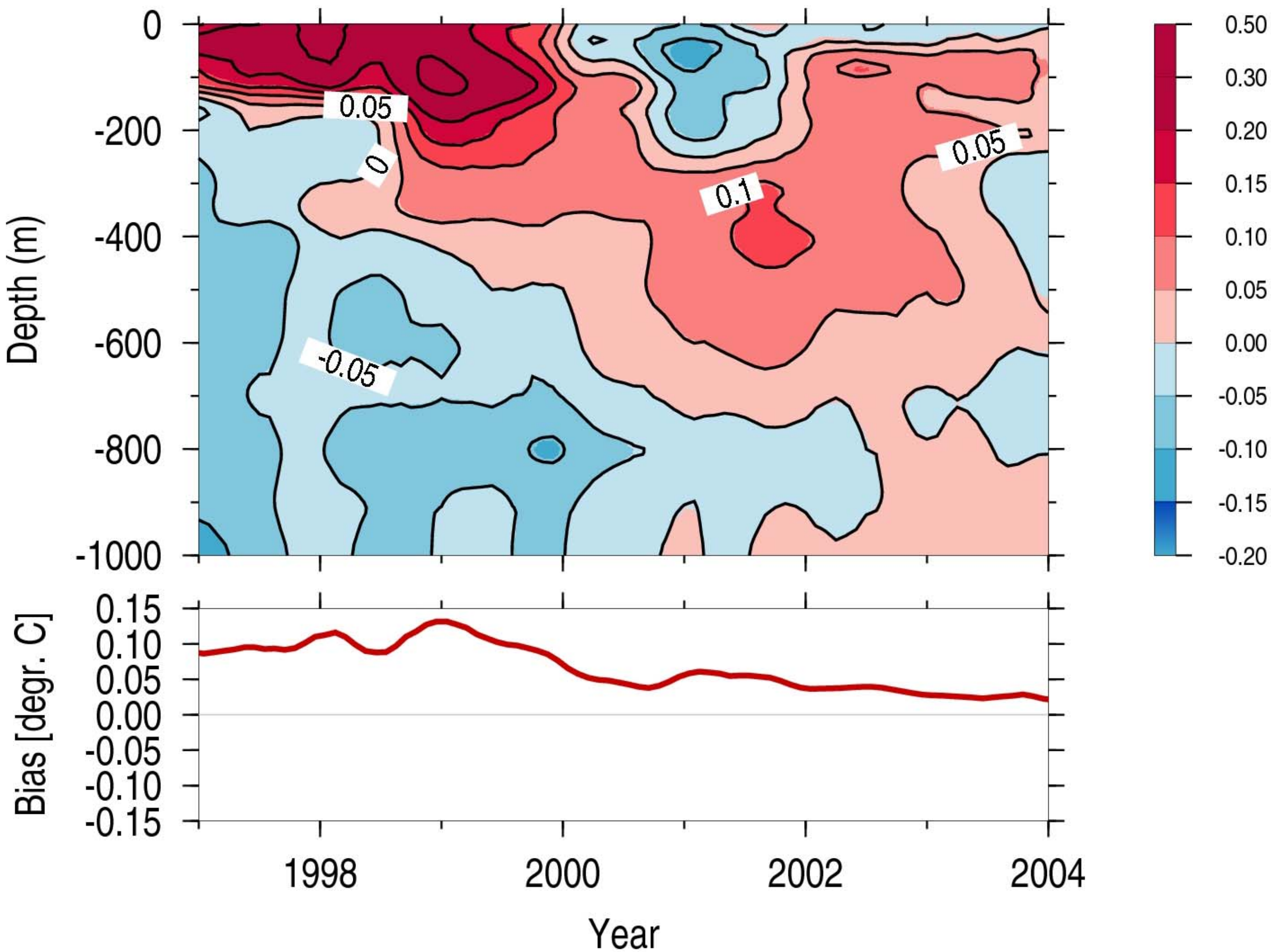
Depth correction



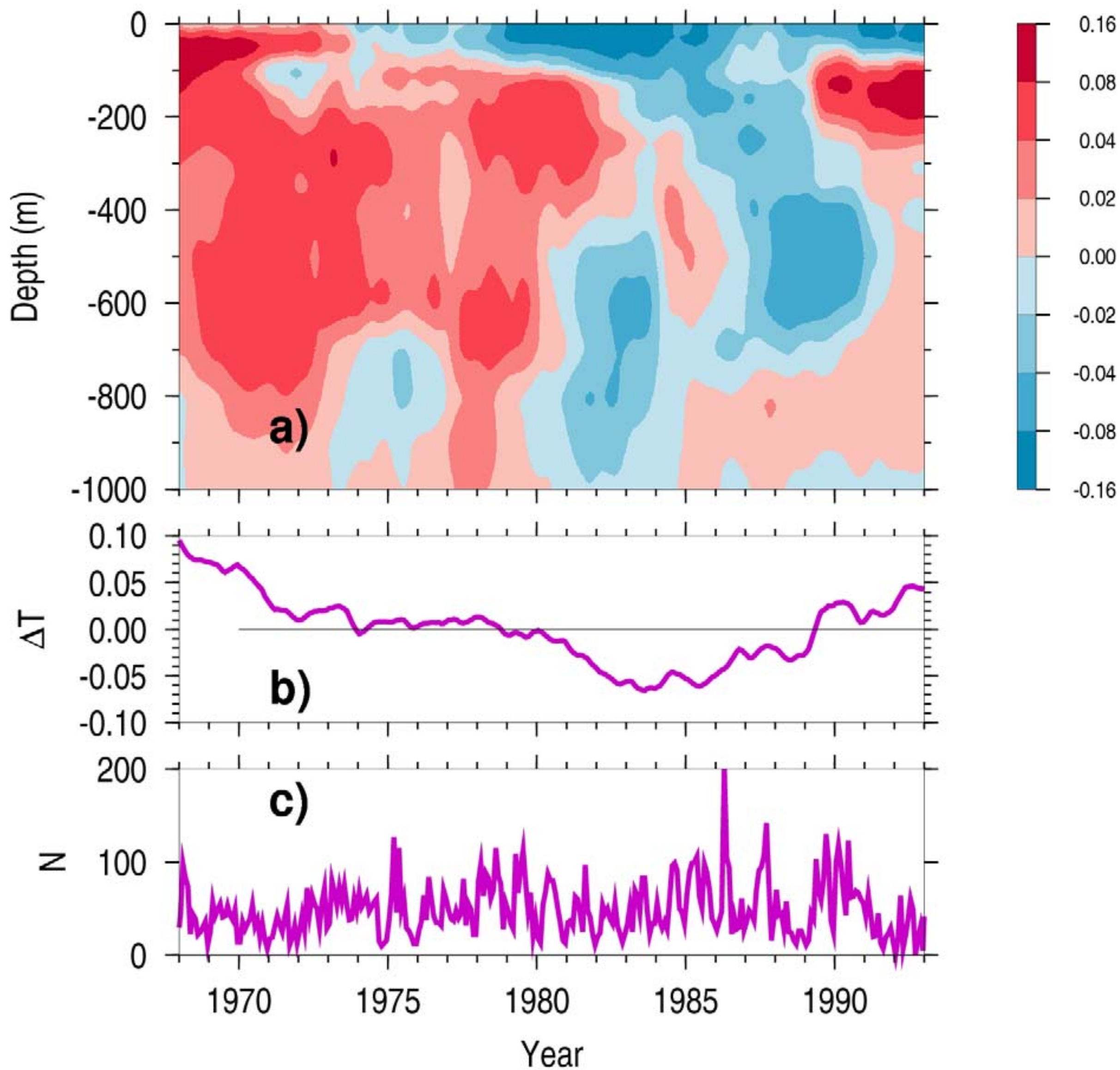
Estimated MBT biases vs calibration results



Profiling floats vs CTD



BOTTLE vs CTD



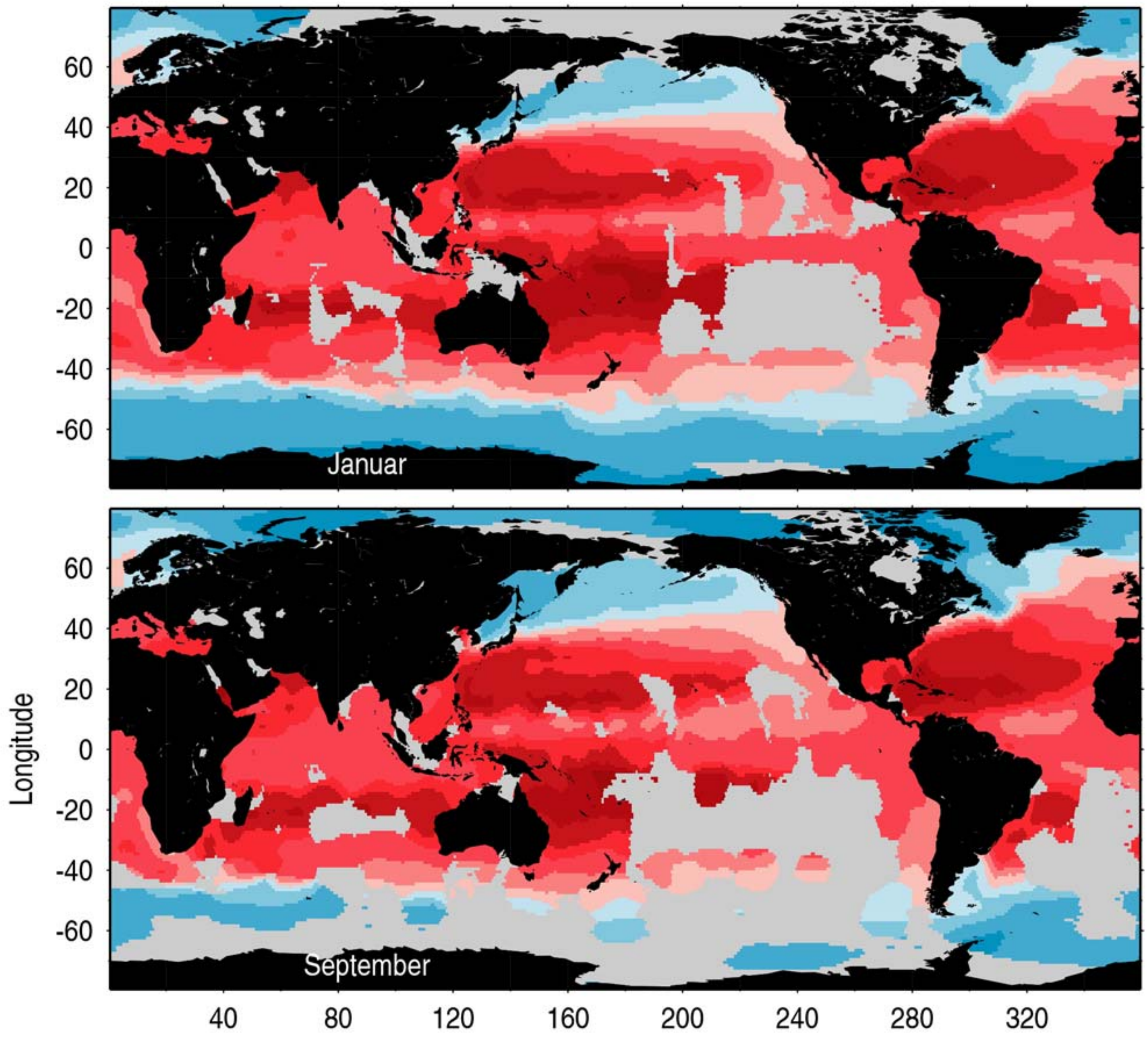
What effect observed temperature biases could have on the estimates of the global temperature/heat content anomalies?

T-Anomaly caclulation

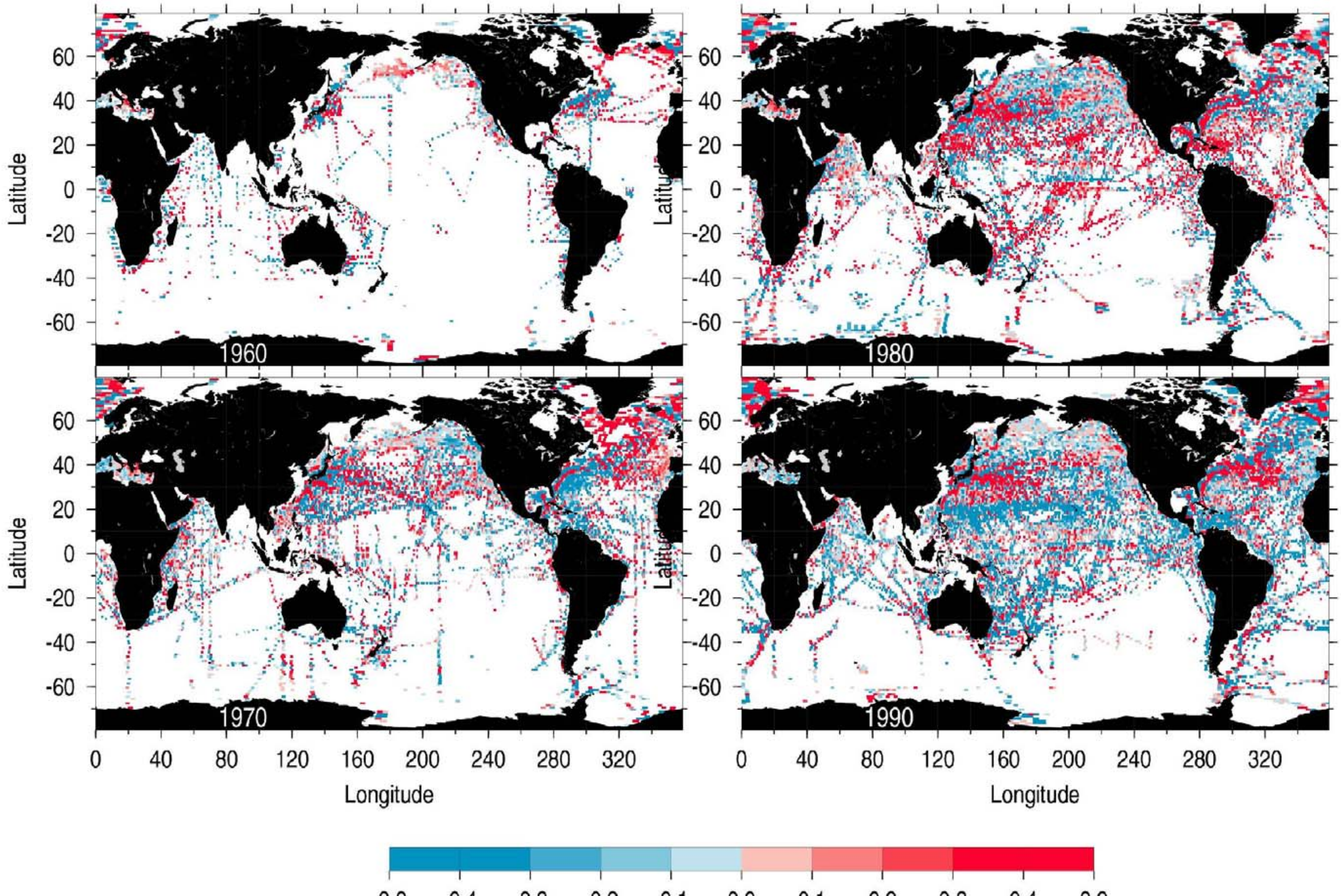
Reference climatology:

- Base period: 1971-1995
- Datatypes: CTD & Bottle Data
- Grid: 111x111km
- Above 400m: monthly
- Below 400m: annual

Reference Climatology (100 m level)

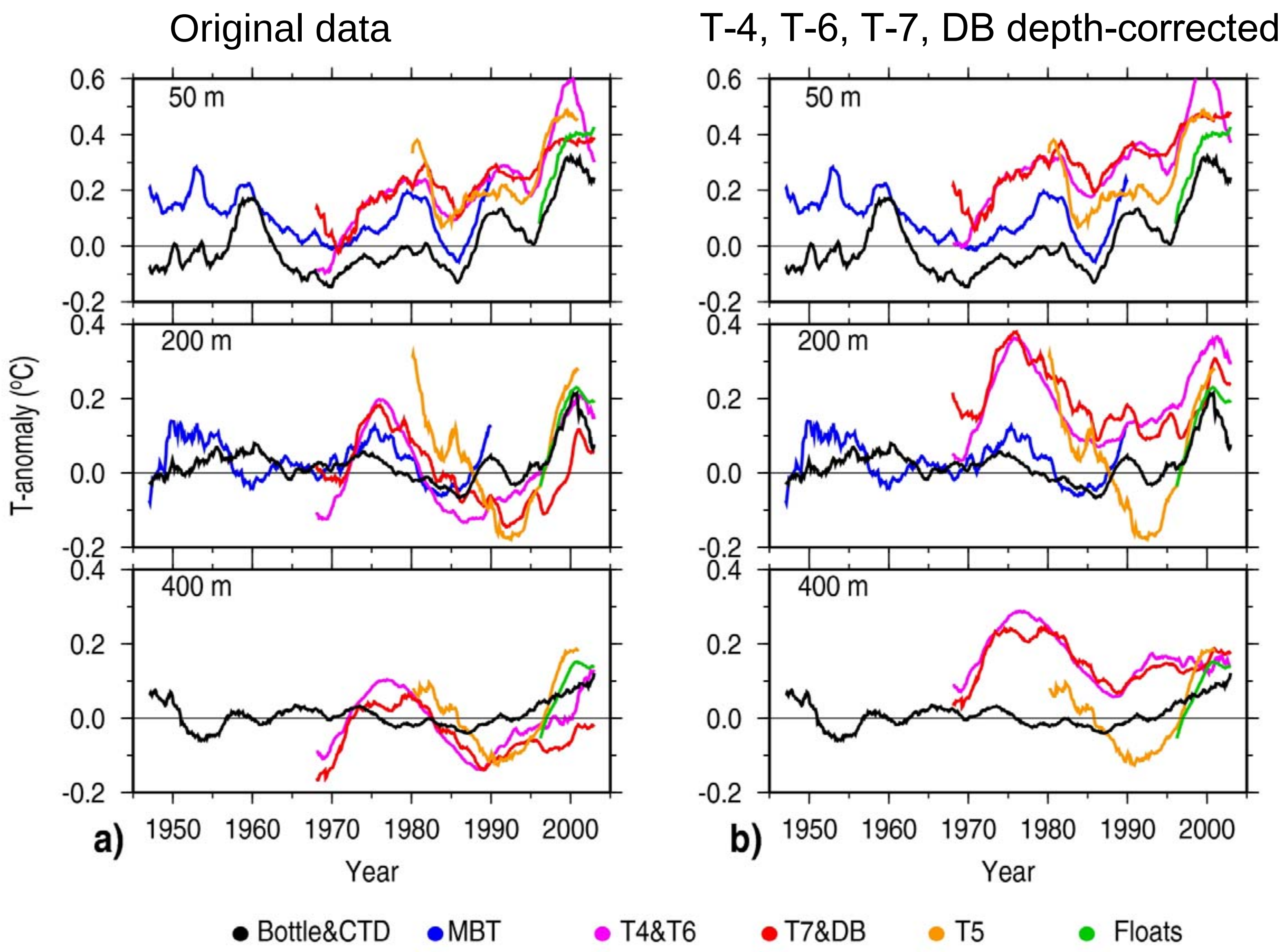


Box-averaged T-anomalies for selected years at 400 m



Global T-anomalies at selected levels :

Data-type dependence (Systematic errors + different sampling)



- For the composite dataset global anomalies were calculated based on:

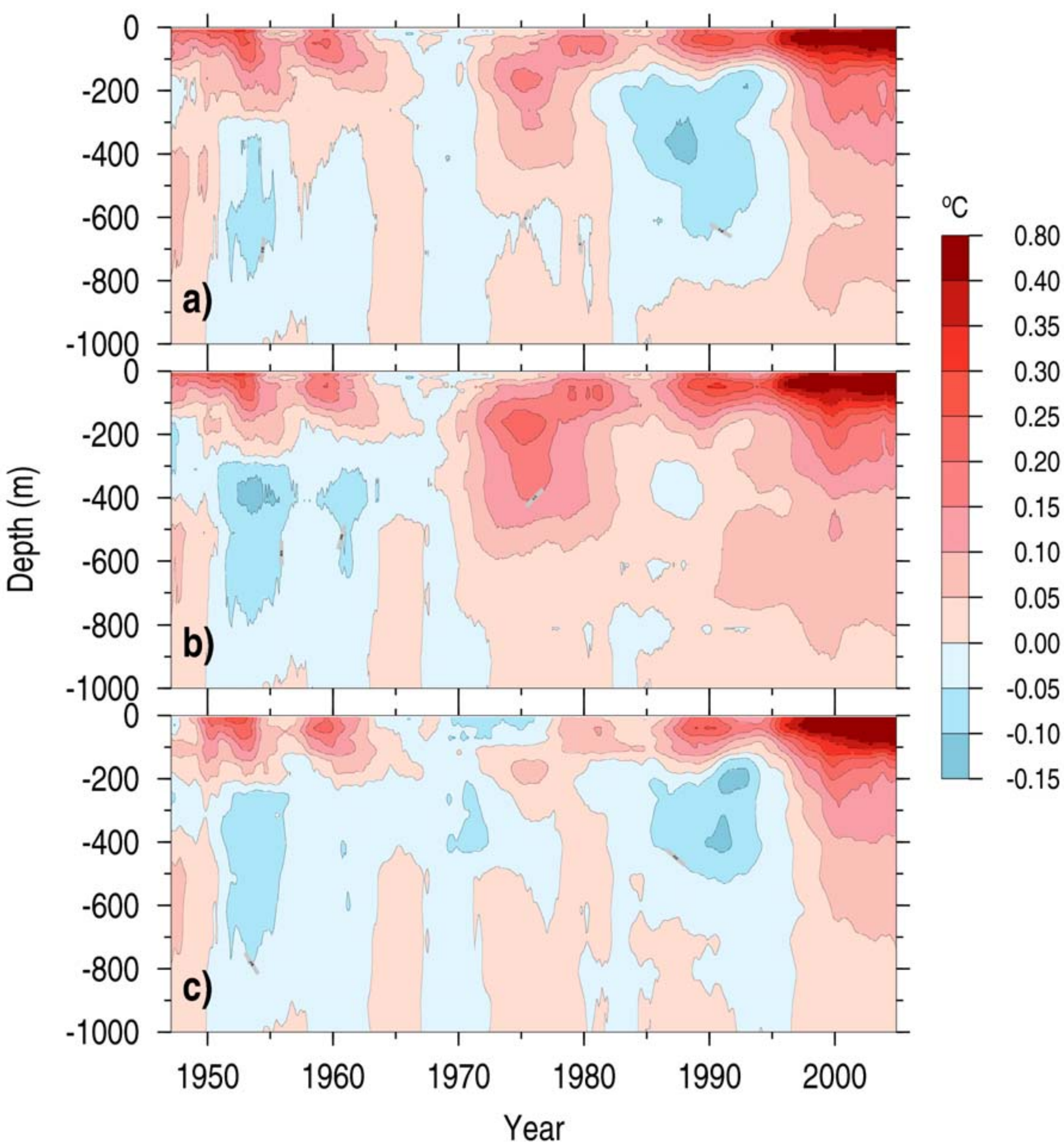
1) Original data for all types

2) XBT data corrected using Hanawa et al. (1994) fall-rate corrections, original data for all other data types

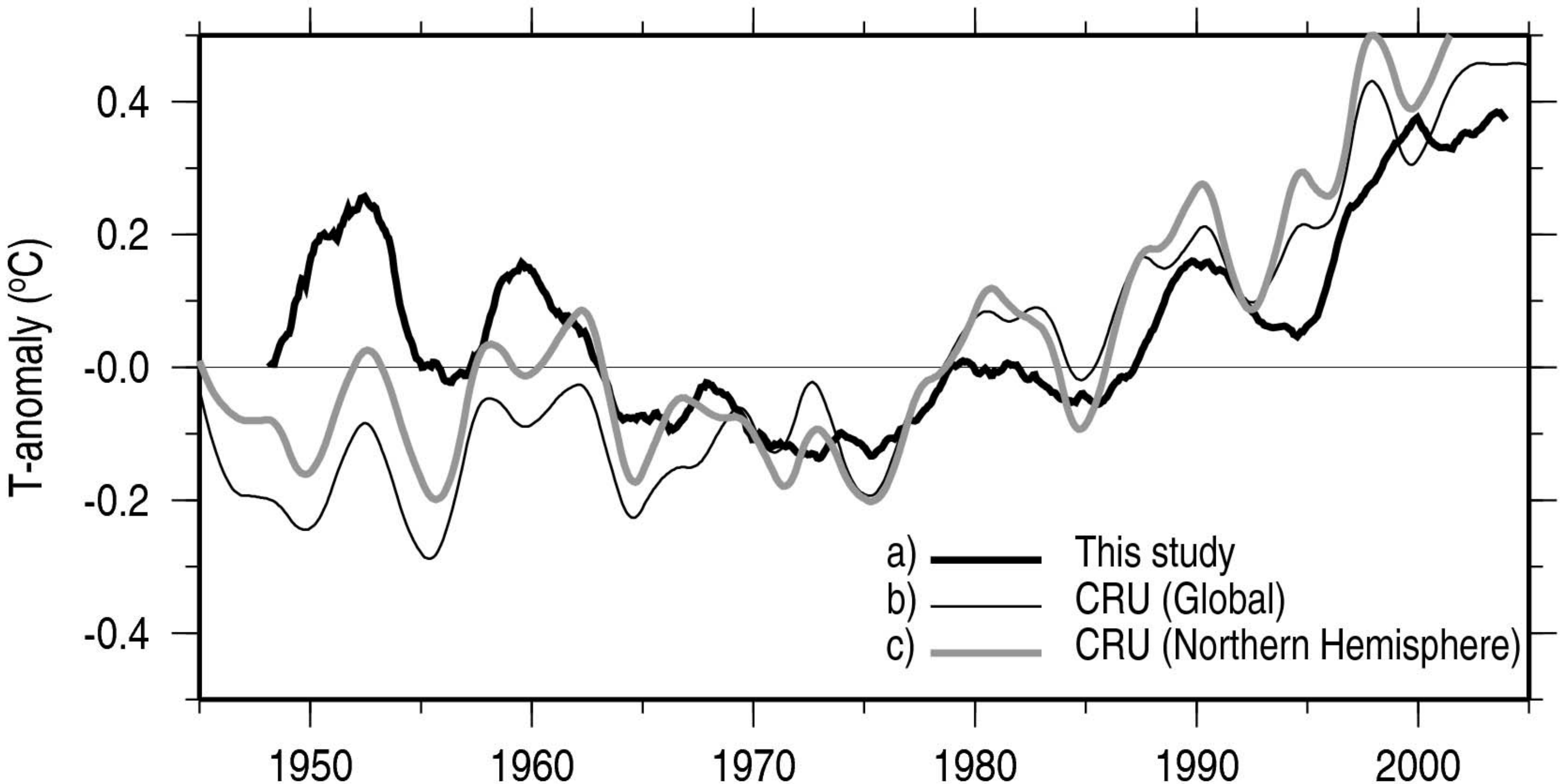
3) XBT & MBT data corrected for both T- and Z-bias, original data for all other data types

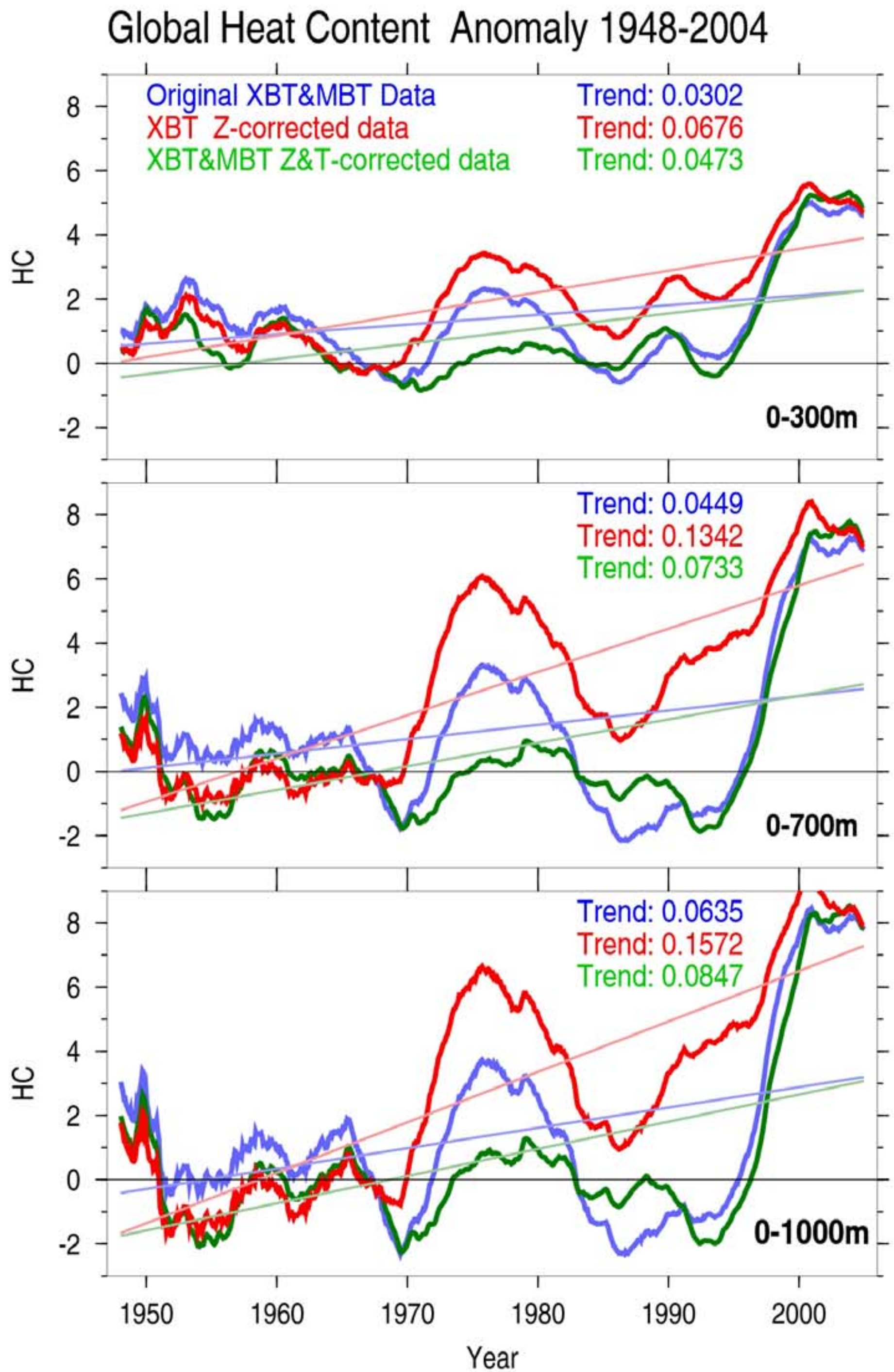
Global Temperature Anomaly:

a) original data; b)Hanawa et al. (1994) depth corrected; c) depth and T-corrected data



Global surface temperature anomaly



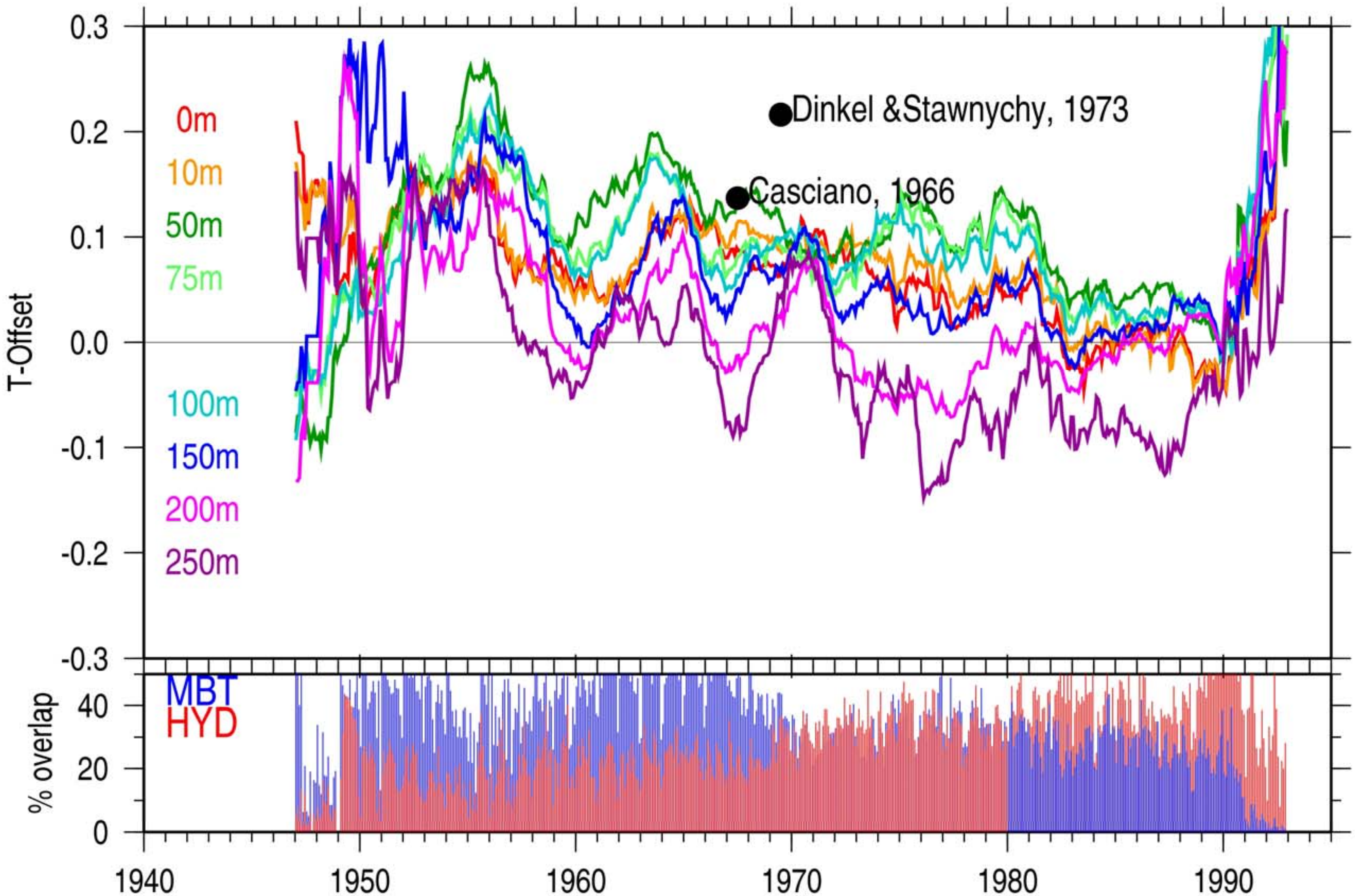


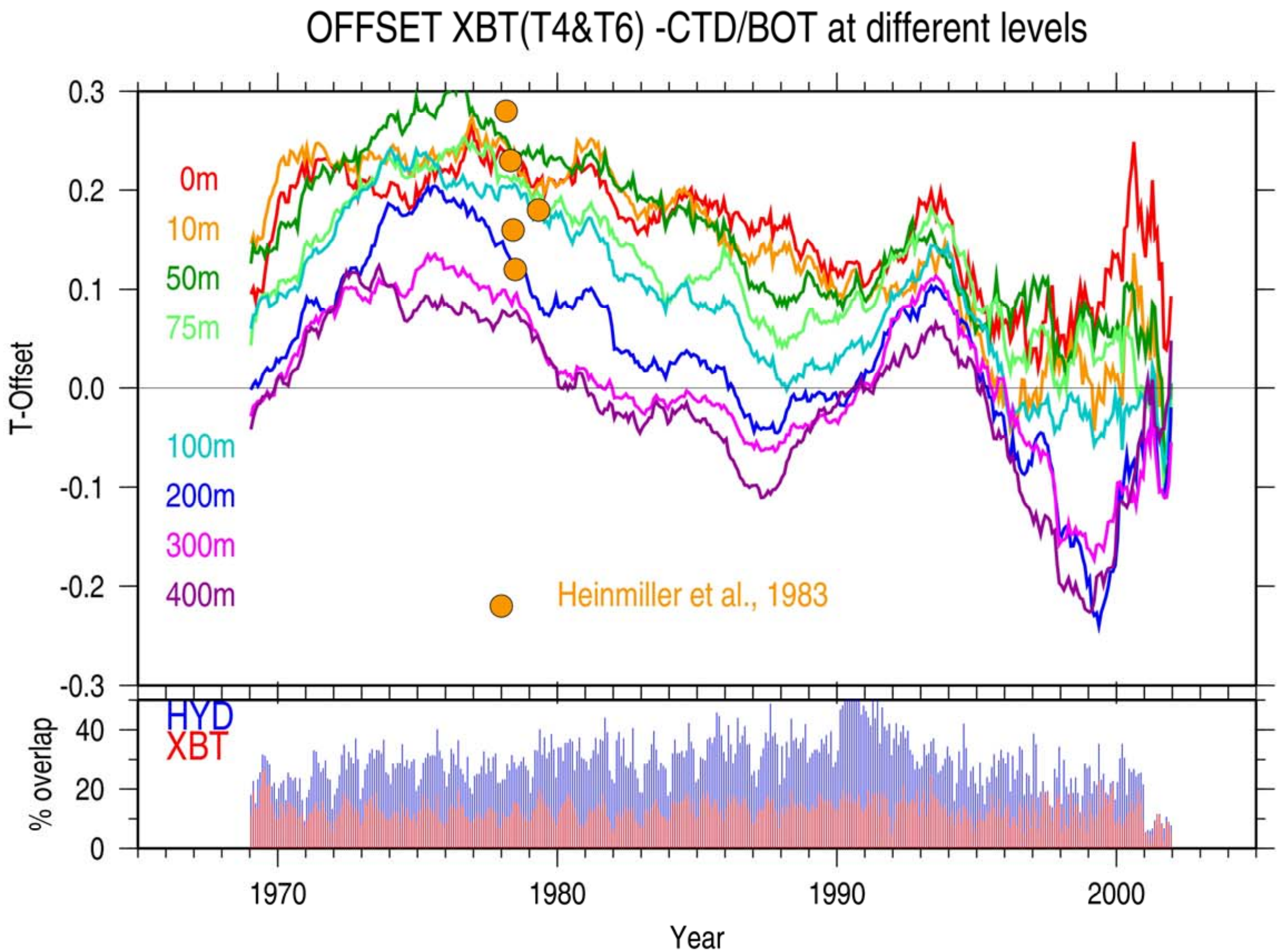
Global Heat Content Anomaly 1948-2004
Original XBT&MBT Data
XBT Z-corrected data
XBT&MBT Z&T-corrected data
Trend: 0.0302
Trend: 0.0676
Trend: 0.0473
0-300m
Trend: 0.0449
Trend: 0.1342
Trend: 0.0733
0-700m
Trend: 0.0635
Trend: 0.1572
Trend: 0.0847
0-1000m
HC
Year
1950
1960
1970
1980
1990
2000

Conclusions

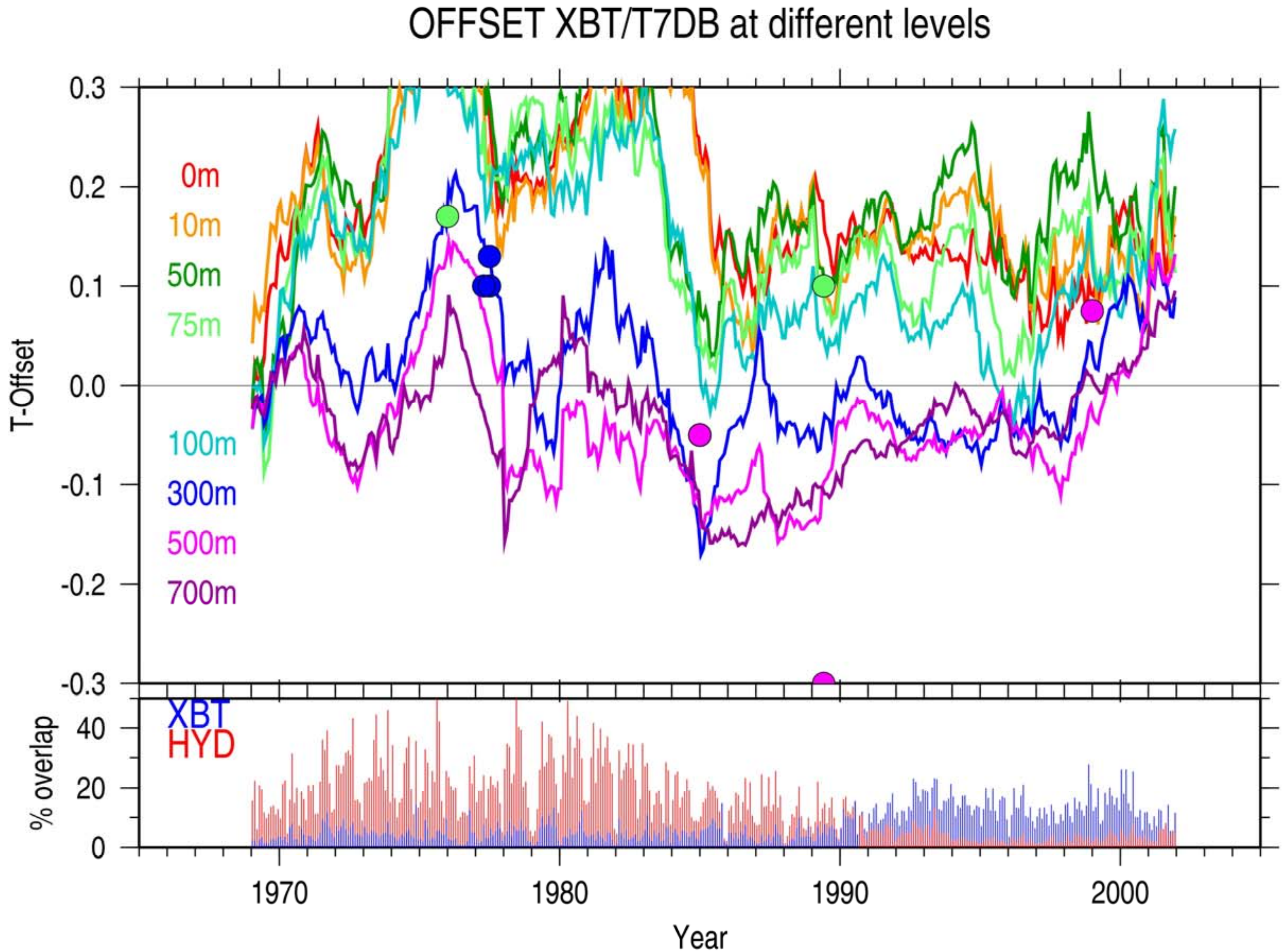
- Temperature subsurface measurements are subject to significant systematic errors
- Comparison with co-located CTD/Bottle data allows estimates of systematic errors in XBT and MBT data
- XBT data are both temperature- and depth-biased
- The validity of depth-corrections determined by Hanawa et al. (1994) is confirmed. However, account for temperature biases is nesessary, as application of the depth-corrections only introduces an additional positive temperature bias
- The magnitude of instrument-dependent temperature biases is not negligible for climatic studies
- Corrections for depth and temperature biases reduce estimates of the Global Ocean warming between 1950s-1990s

Offset MBT-CTD/BOT at Different Levels

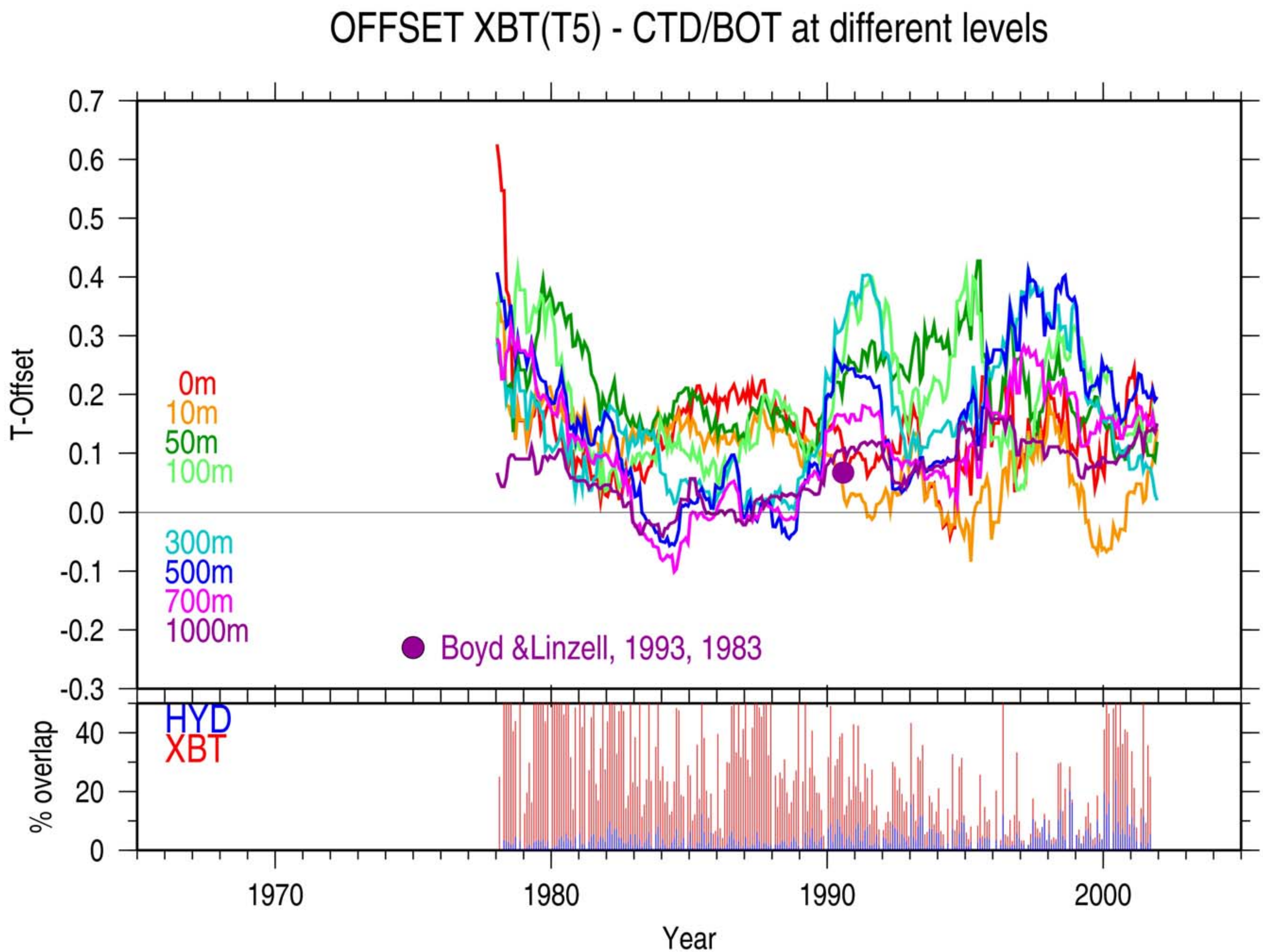




OFFSET XBT(T4&T6) -CTD/BOT at different levels
T-Offset
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
0m
10m
50m
75m
100m
200m
300m
400m
Heinmiller et al., 1983
HYD
XBT
% overlap
40
20
0
1970
1980
1990
2000
Year



OFFSET XBT/T7DB at different levels
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
T-Offset
0m
10m
50m
75m
100m
300m
500m
700m
XBT
HYD
40
20
0
% overlap
1970
1980
1990
2000
Year

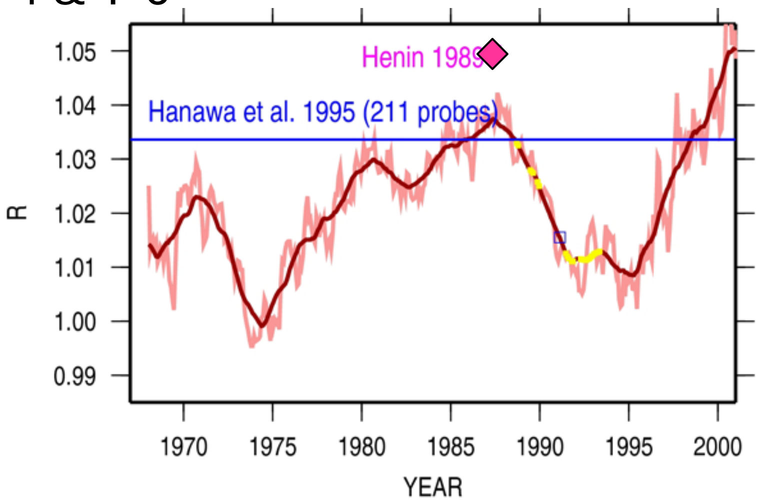


OFFSET XBT(T5) - CTD/BOT at different levels
T-Offset
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
0m
10m
50m
100m
300m
500m
700m
1000m
Boyd &Linzell, 1993, 1983
HYD
XBT
% overlap
40
20
0
1970
1980
1990
2000
Year

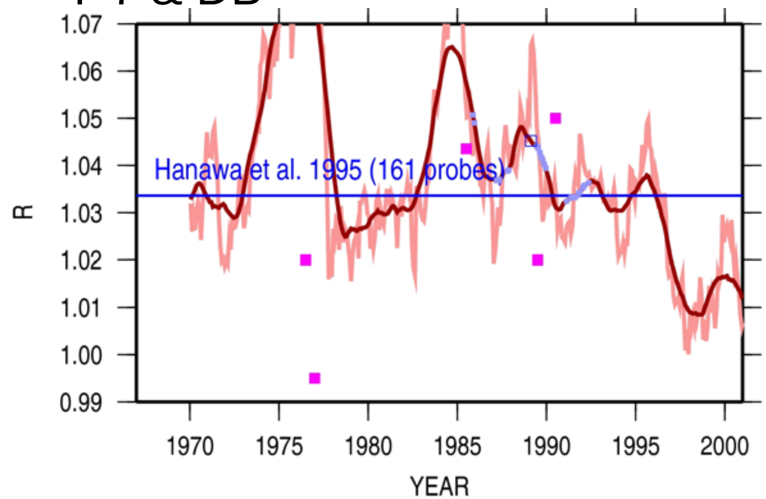
Depth-averaged linear correction factor for original XBT data:

$$Z_{TRUE} = R * Z_{XBT}$$

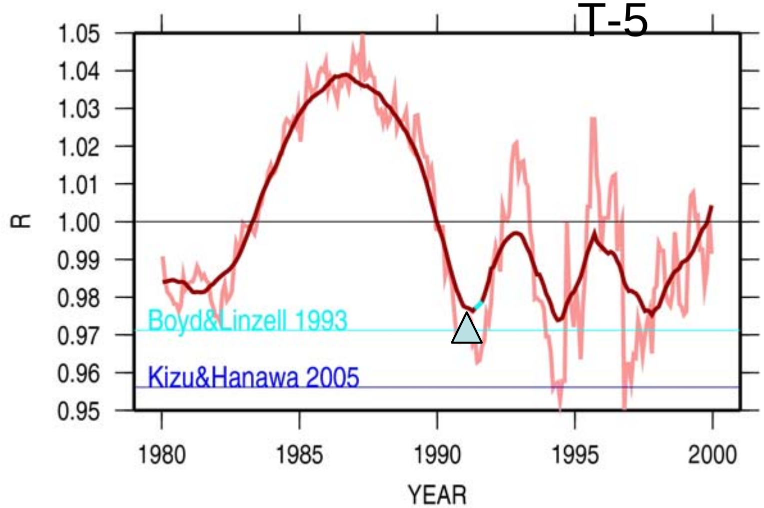
T-4 & T-6



T-7 & DB



T-5



Nansen Bottles

Temperature **is measured** with thermometers

Depth derived from:

1) the T-difference between protected and unprotected thermometers

or

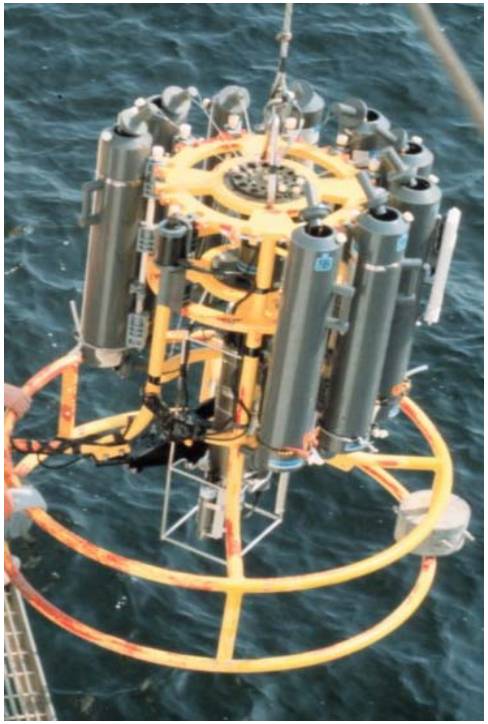
2) length of the wire out and wire angle at the deck height

Thermometers calibrated regularly

MBT

- T is scribed on a coated slide.
- The thermal element contains a tube, filled with xylene that expands and contracts with T.
- The depth element consists of a spring loaded piston enclosed in a flexible envelope made of metal bellows.
- Calibrated regularly (?)
- There were about 5000 MBTs in the USA in use in 1967

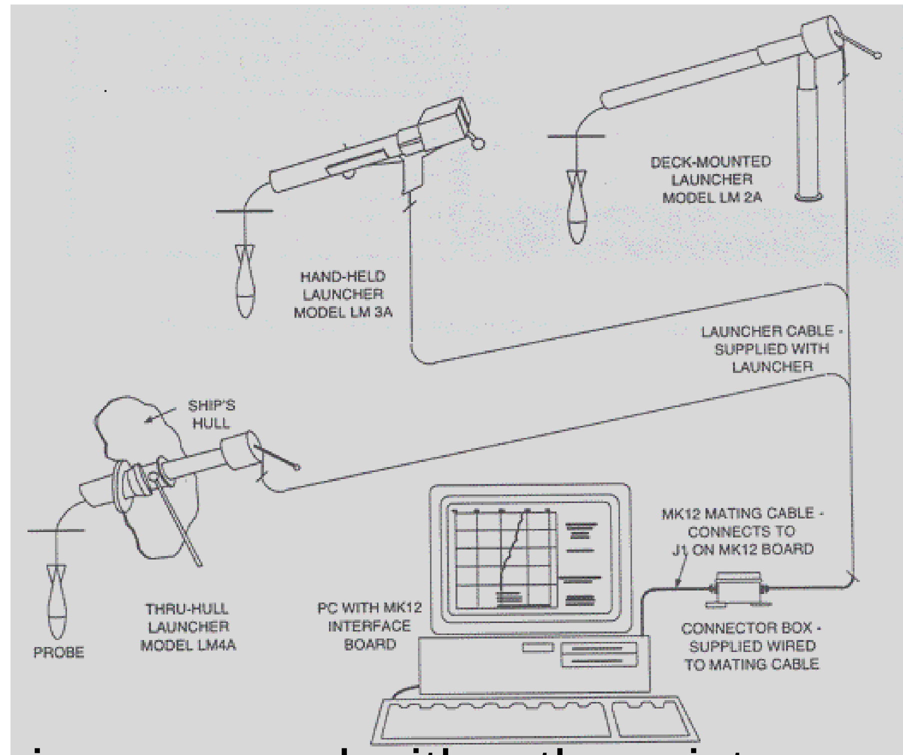
CTD

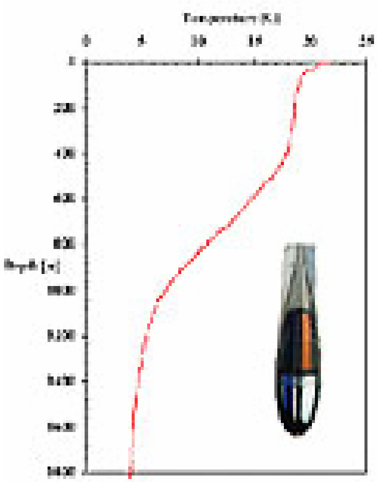


Instrument is electrically connected with recording device in the lab

- Both Temperature and Pressure are measured with high-precision sensors
- Depth is calculated from pressure, T and S
- Sensors regularly calibrated

Expendable Bathythermograph (XBT)



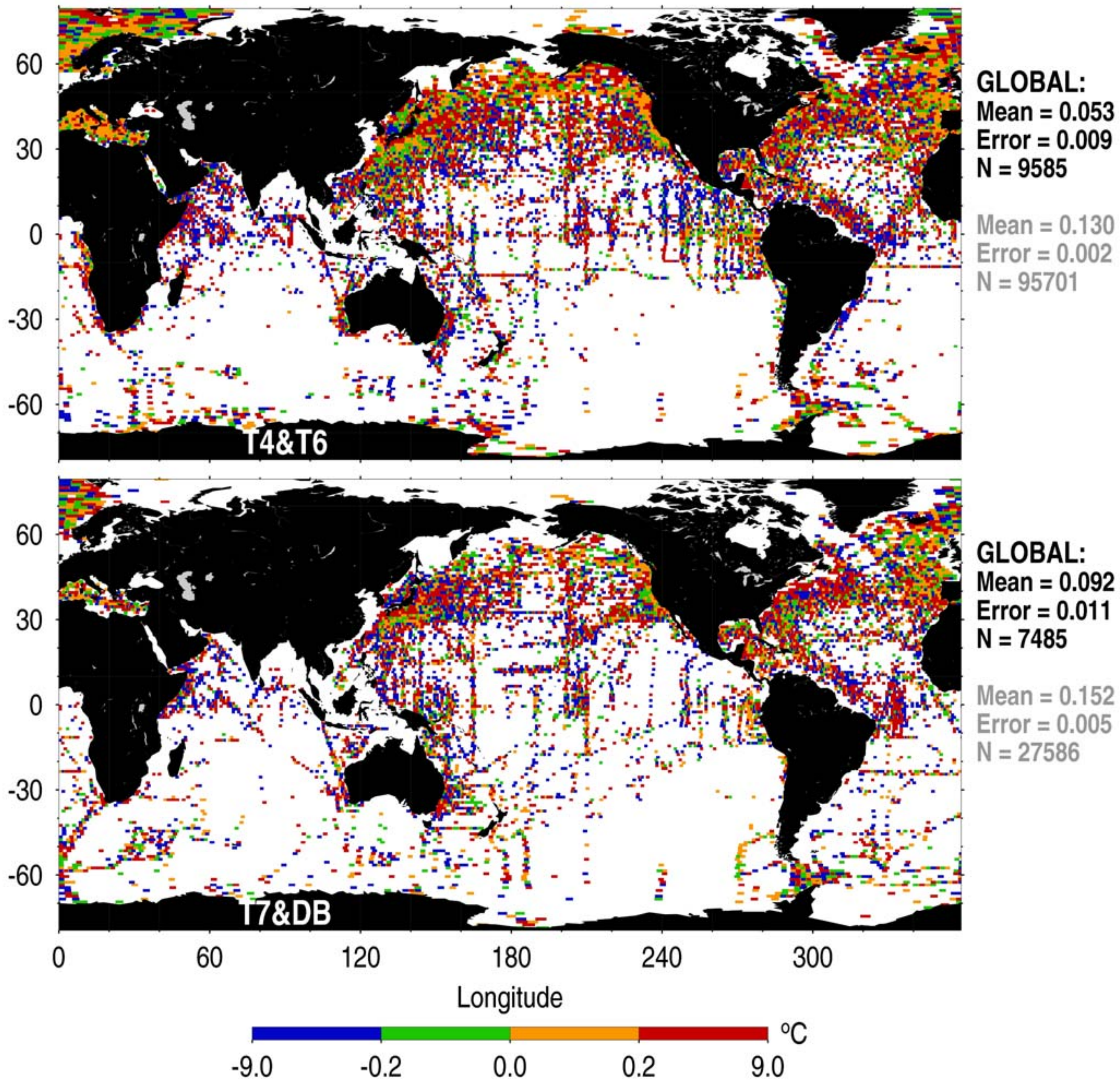


Temperature is measured with a thermistor

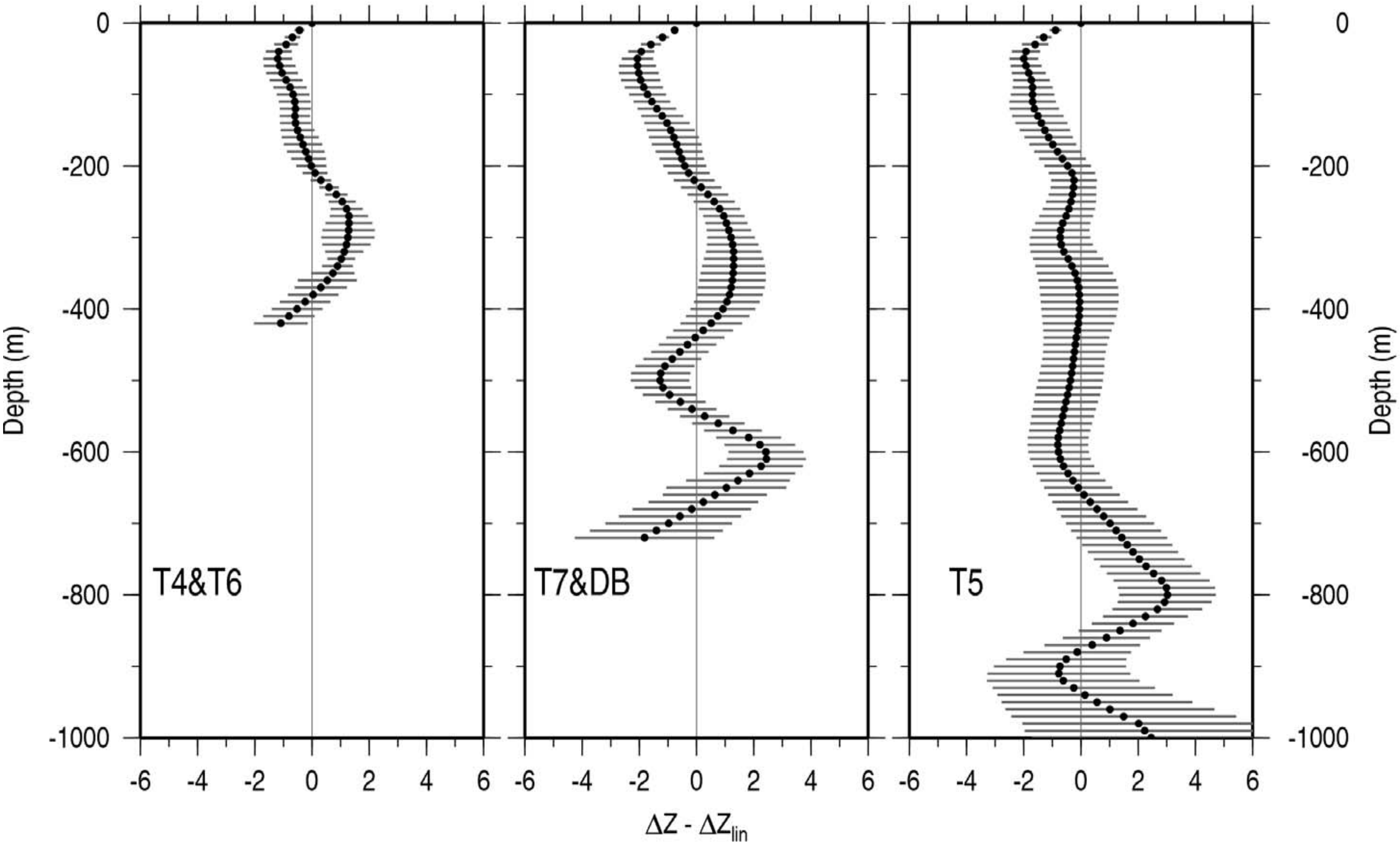
Depth is calculated from the assumed probe fall rate

Post-calibration not possible: the probe is lost!

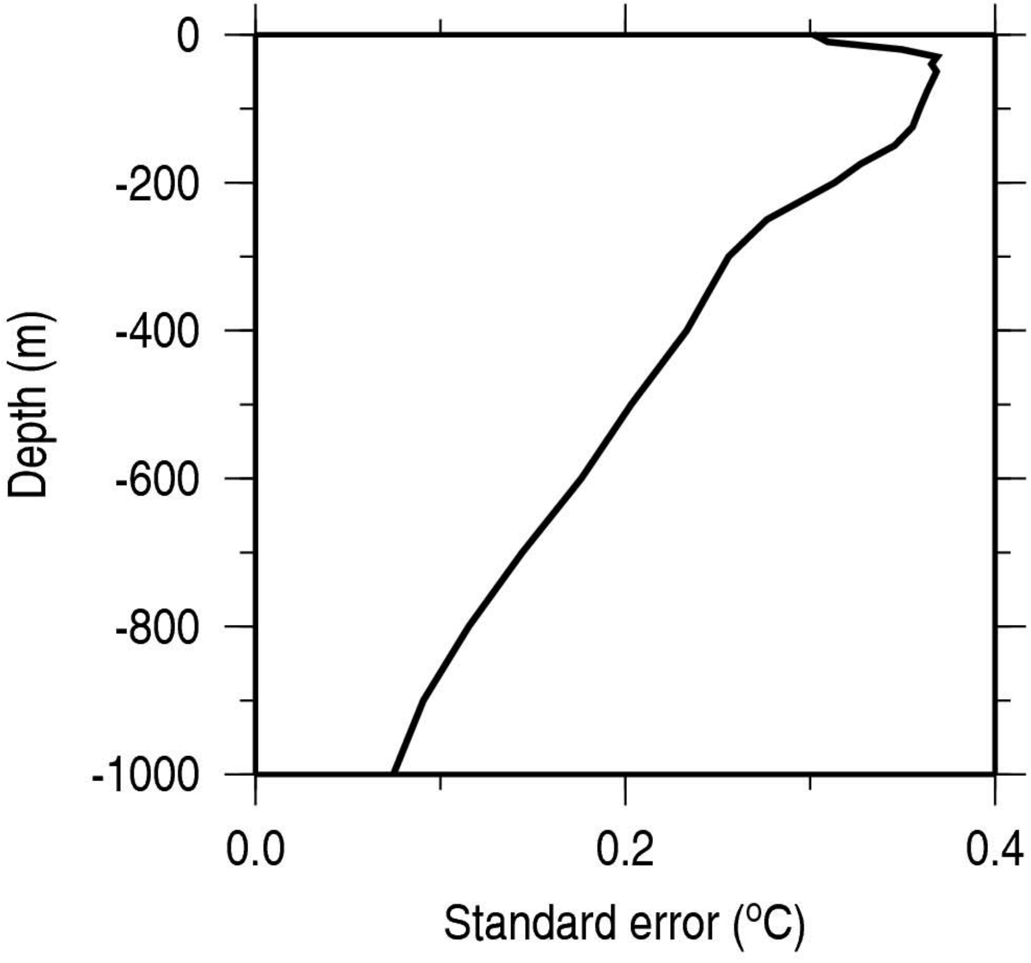
Time-mean box-average temperature biases at 100 m level



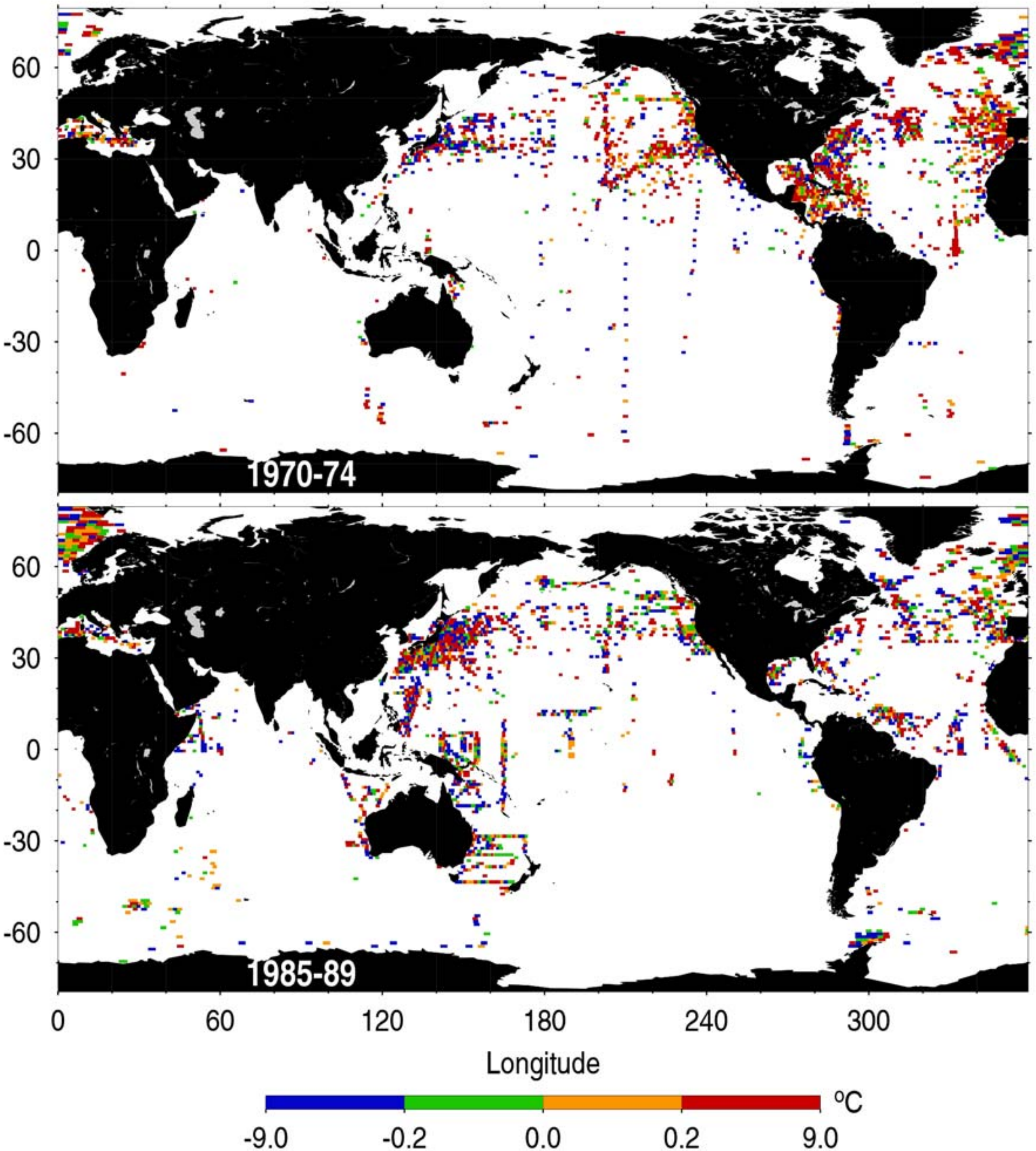
XBT depth-correction Differences: $DZ_{estimated} - DZ_{linear}$



Mean within-box temperature standard error

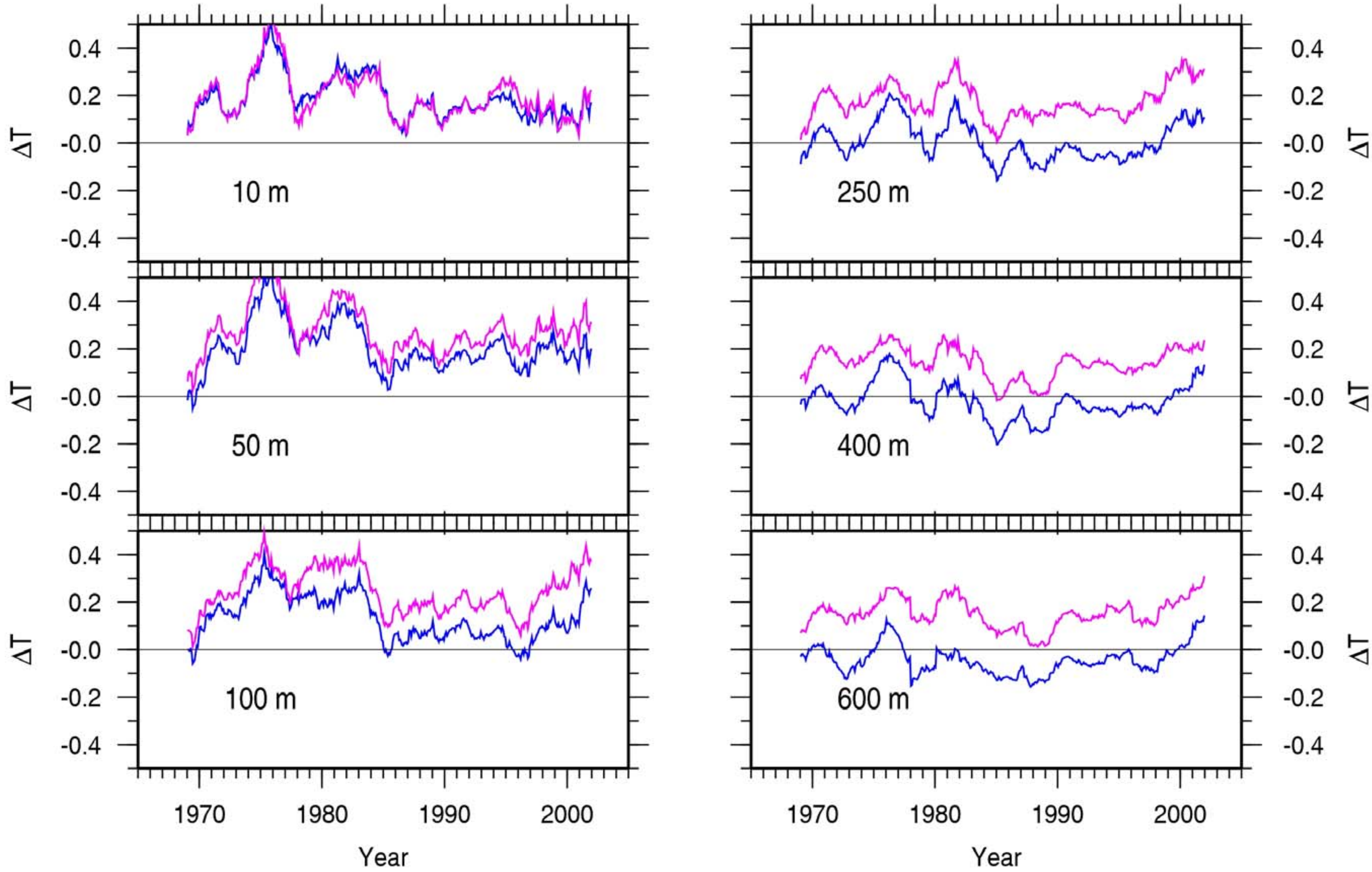


Temperature offset for T-7 & Deep Blue (100 m level)



T-biases for T7 & DB

BLUE - original data MAGENTA - corrected data (Hanawa et al.(1994) fall-rate corrections)



XBT bias model

A true box-averaged <…> temperature bias is:

$$\langle B \rangle \equiv \langle T_{XBT} \rangle - \langle T_{TRUE} \rangle$$

(True T-values collocated and simultaneous)

An observed bias is:

$$\langle b \rangle = \langle T_{XBT} \rangle - \langle T_{CTD} \rangle = \langle B \rangle + \varepsilon$$

(ε – error due to CTD profiles being not strictly collocated, magnitude determined by the synoptic variability)