

A new view of biases in historical expendable bathythermograph data based on side-by-side comparisons

Wealth from Oceans Flagship

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XBTs: the thermal bias

Previous studies:

- Global datasets, pseudo buddies require massive averaging
- Side-by-side comparisons with CTDs

This study compiles all the available existing side-by-side XBT/CTD comparisons into one dataset

- this allows us to use ocean fine scale structure to separate out the depth bias from temperature bias

The focus

Sippican T7 and Deep Blue probes – the most broadly used since the late 1980's

After correcting the XBT data to Hanawa's 1995 depth equation:

- Is there still a depth error?
 - Does it vary with time, temperature, recorder type?
 - Is the slope of the depth error linear?
- Is there a temperature bias?
 - Does it vary with time, temperature, recorder type?

How many XBT/CTD pairs?

The data

NODC website

Archived data at CSIRO Marine and Atmospheric
Research and Antarctic Division

Non-archived data at CSIRO

More data to be included

ALL data high resolution

Currently have a total of ~1540 good pairs.

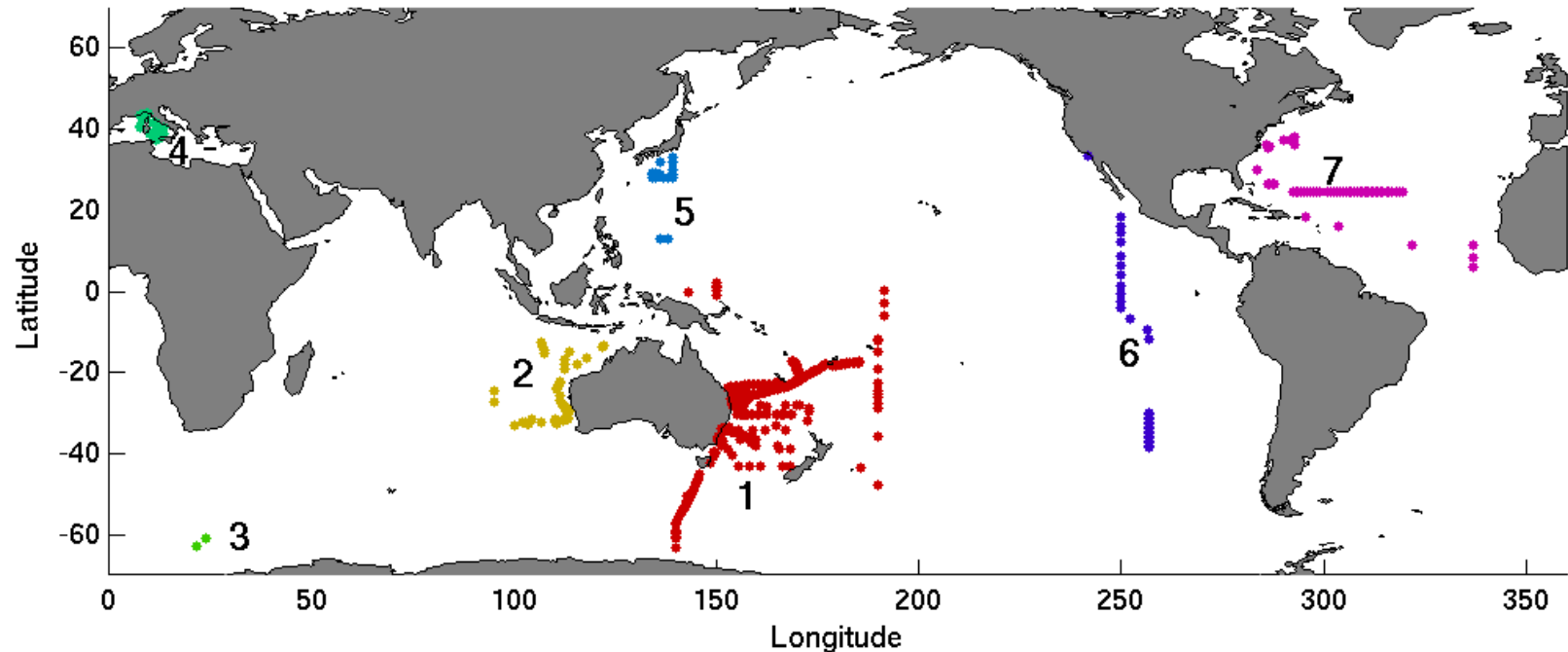
The Metadata

Probe type and recorder type information

Probe serial numbers

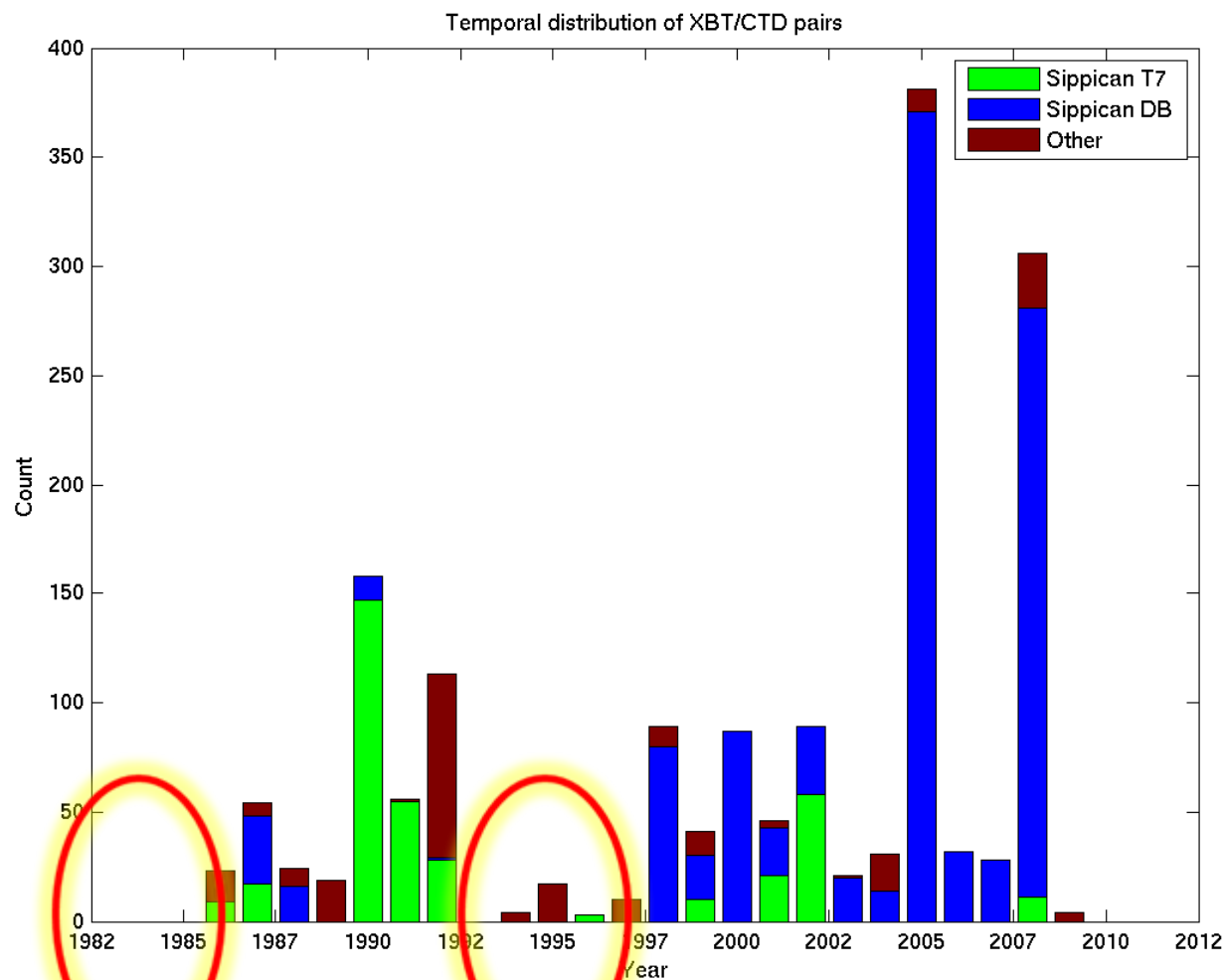
Date of manufacture

Where are the pairs?



1. Australian (*Franklin*, *Aurora Australis*, *Southern Surveyor*)
2. Australian (*Franklin*)
3. Indian (*Polar Bird*)
4. Italian (*Urania*)
5. Japanese (*Hakuho Maru*, *Tansei Maru*)
6. American (*Yellowfin*, *Ron Brown*)
7. American (*Nancy Foster*, *Ron Brown*, *USN Bartlett*, *Oceanus*)

Temporal distribution of pairs



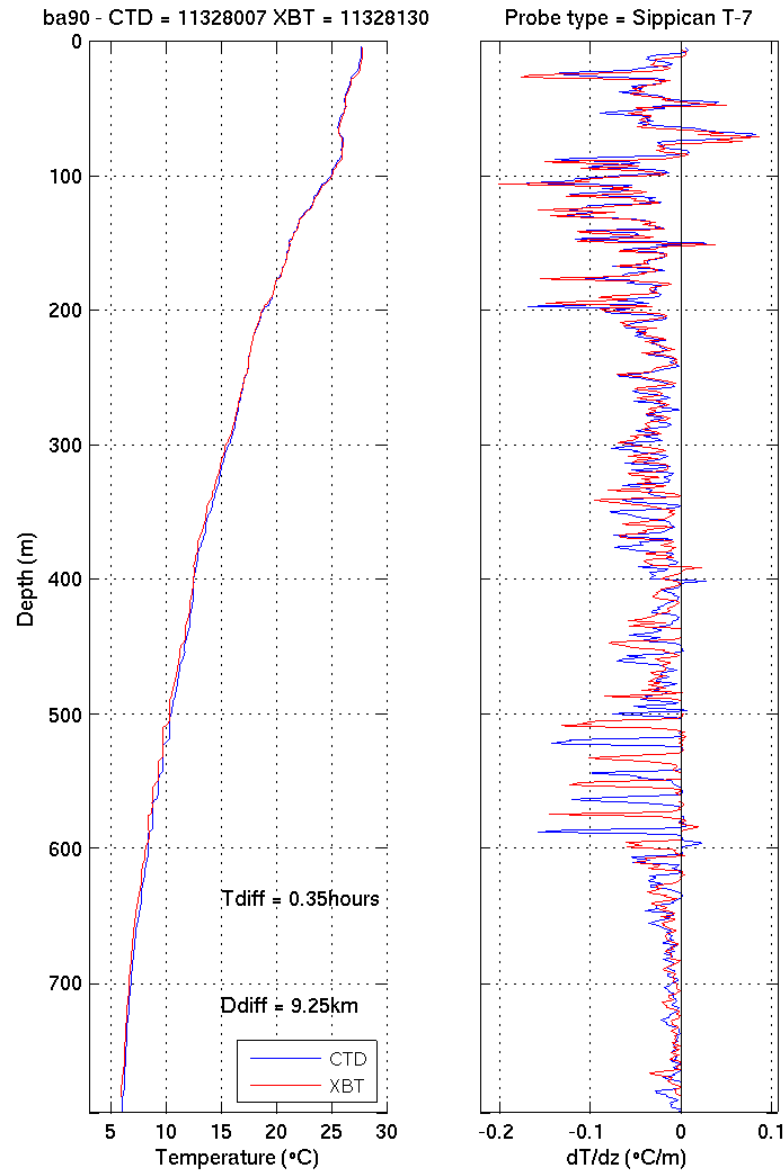
Pair identification

- Data collated and reformatted into netcdf
- Each XBT was depth corrected to Hanawa 1995
- All data was QC'd to CSIRO Cookbook standards using 'MQuEST'
- Possible XBT/CTD pairs were identified by looking in a location, date/time box which varied to suit the dataset, but was usually within 3hours and 3km.

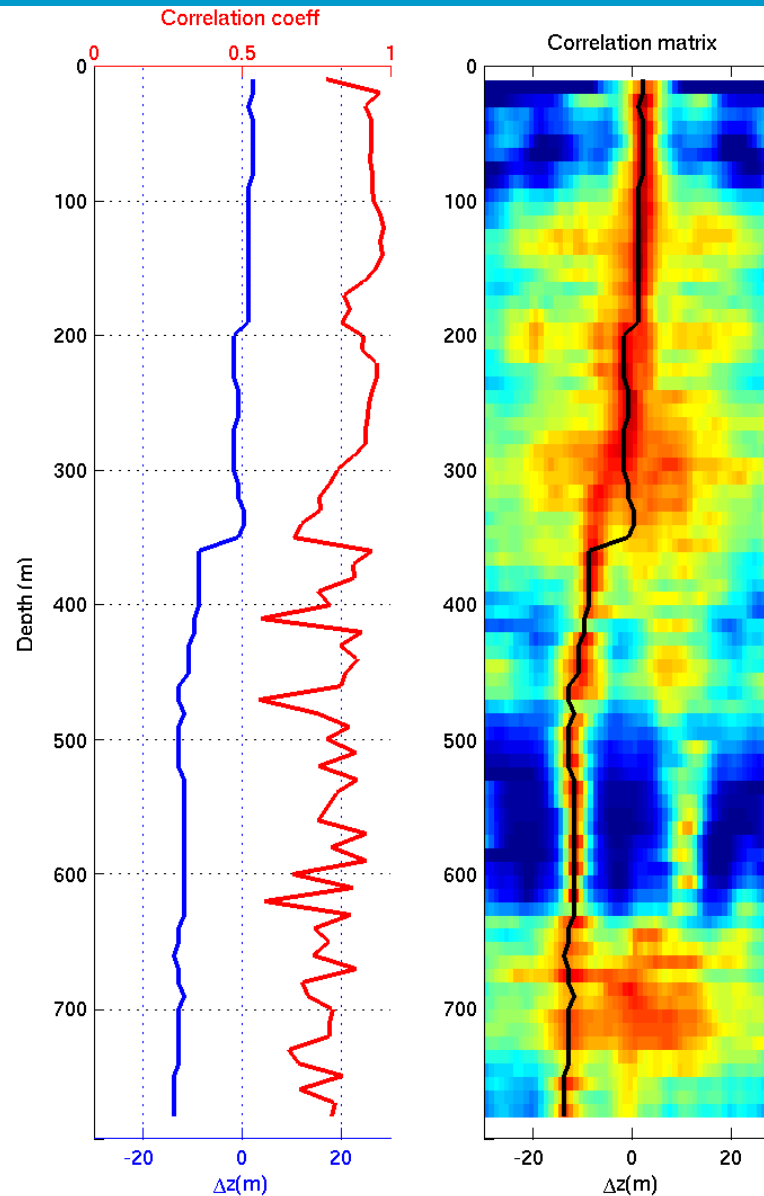
Depth error (lag) determination

- For each possible CTD match with an XBT:
 - Raw XBT and CTD data was filtered if necessary
 - XBT and CTD both interpolated onto a 1m depth grid
 - Gradients were calculated (dT/dz)
 - At each 10m depth, a cross-correlation was performed on the gradient data (XBT vs CTD), with a range of $\pm 40m$
 - The best depth error (lag) for each depth bin was selected based on a combination of highest correlation and closest match to the previous depth bin lag
- More than one matching CTD: the CTD which gave the highest overall correlation with the XBT was selected.
- Non-matching pairs discarded from the dataset.

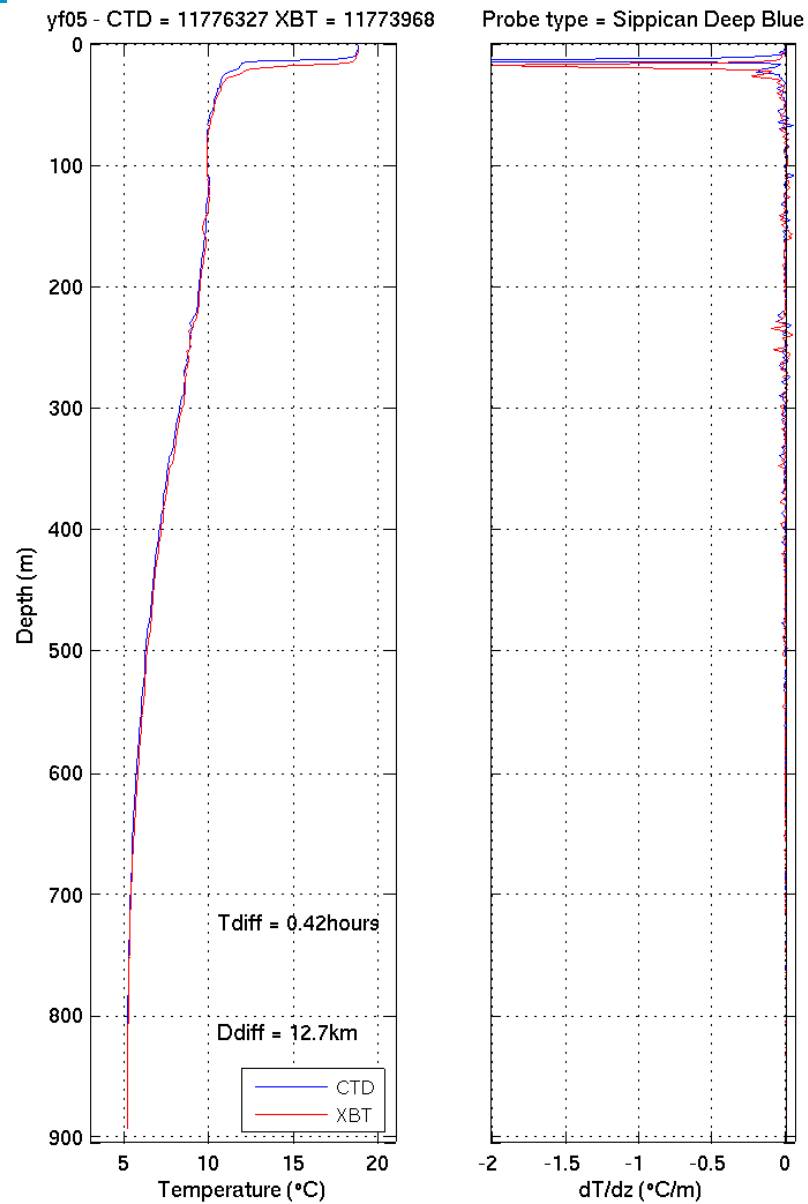
Results from an area of high temperature gradients



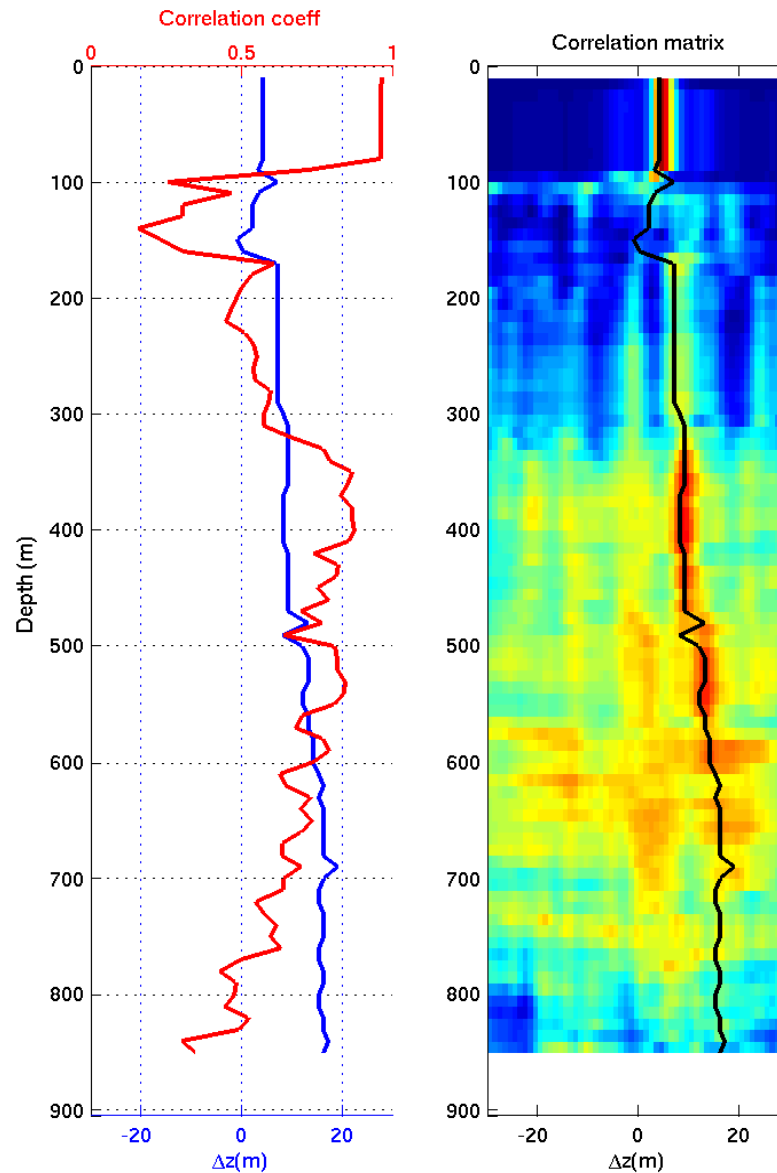
Results from an area of high temperature gradients



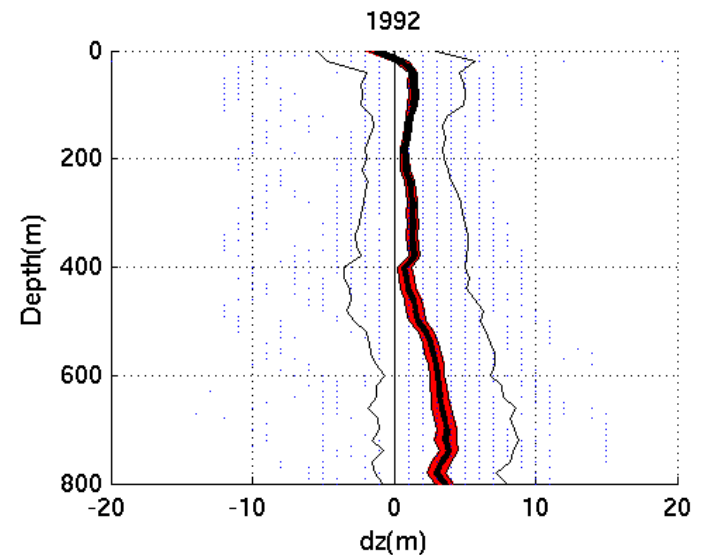
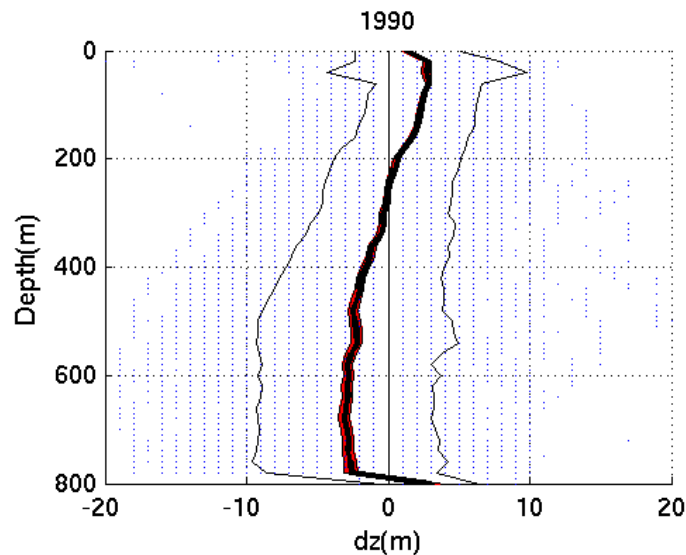
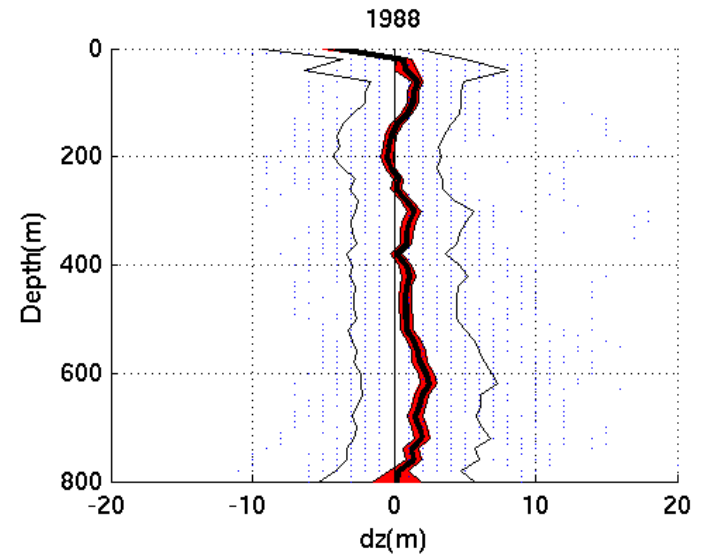
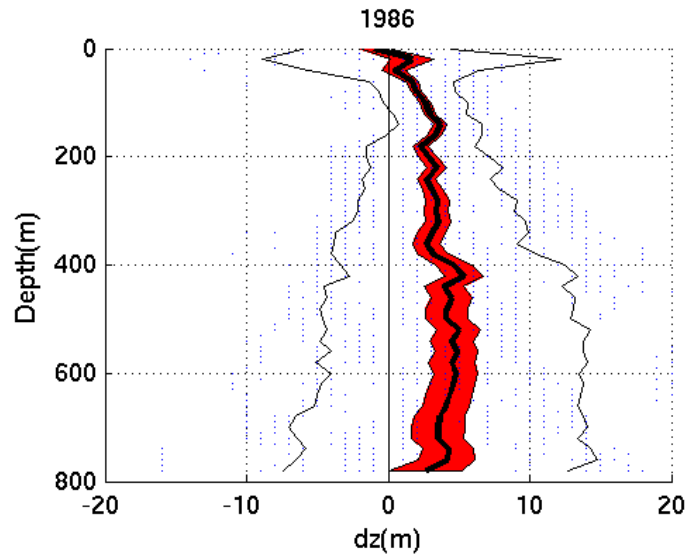
Results from an area of low temperature gradients



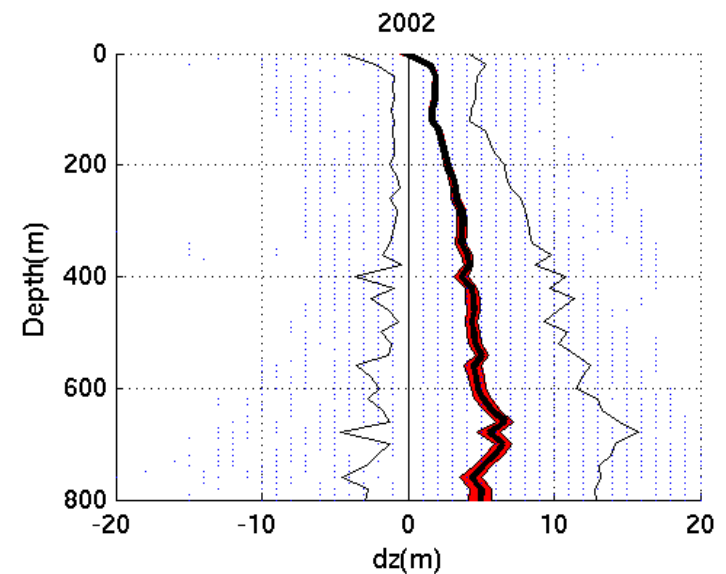
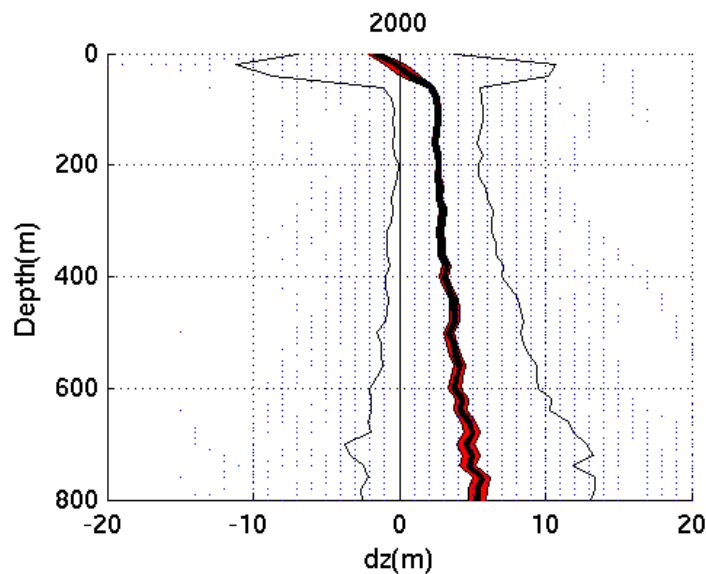
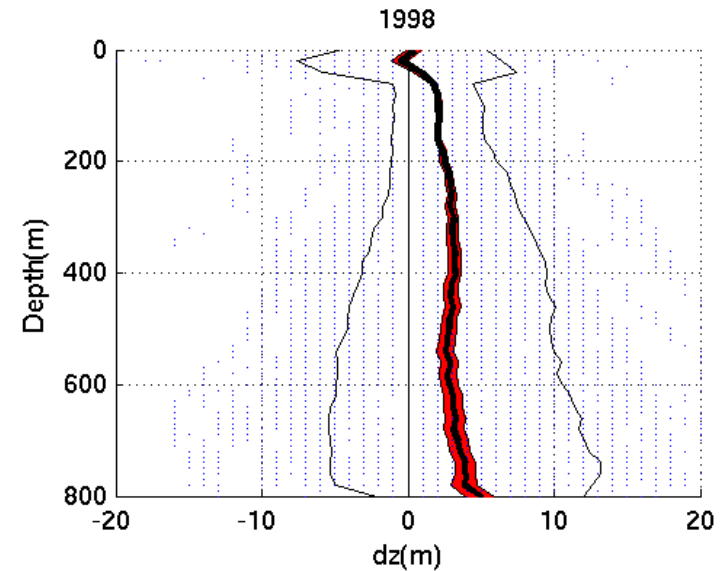
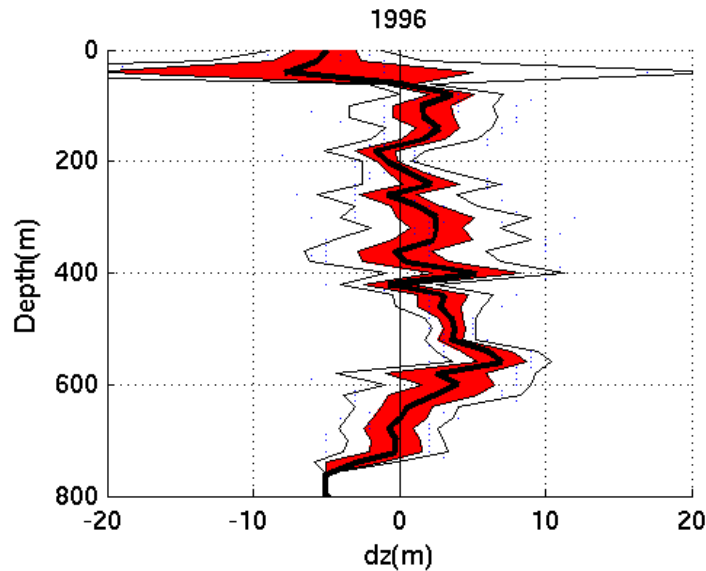
Results from an area of low temperature gradients



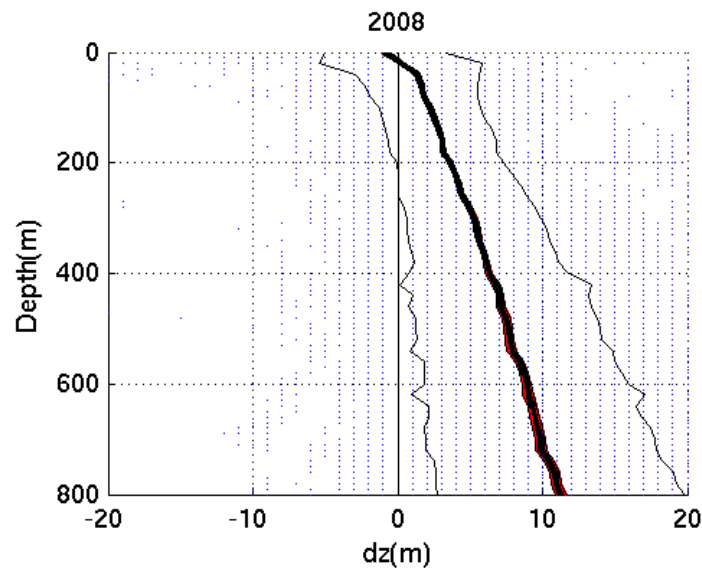
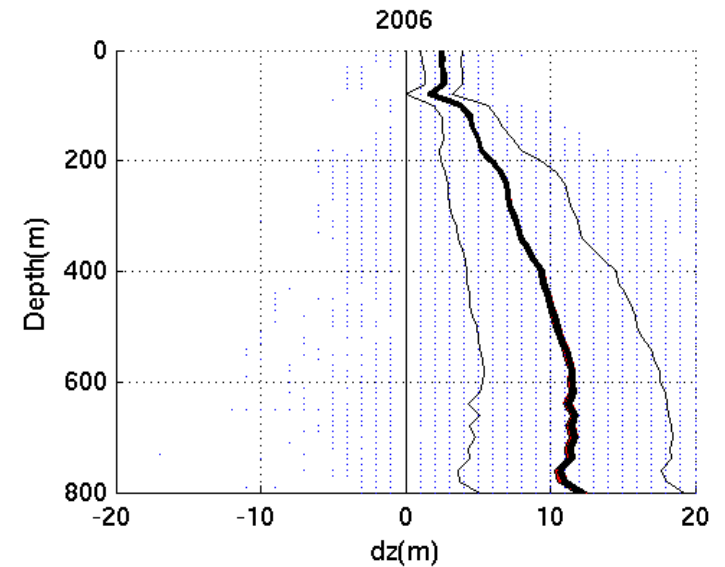
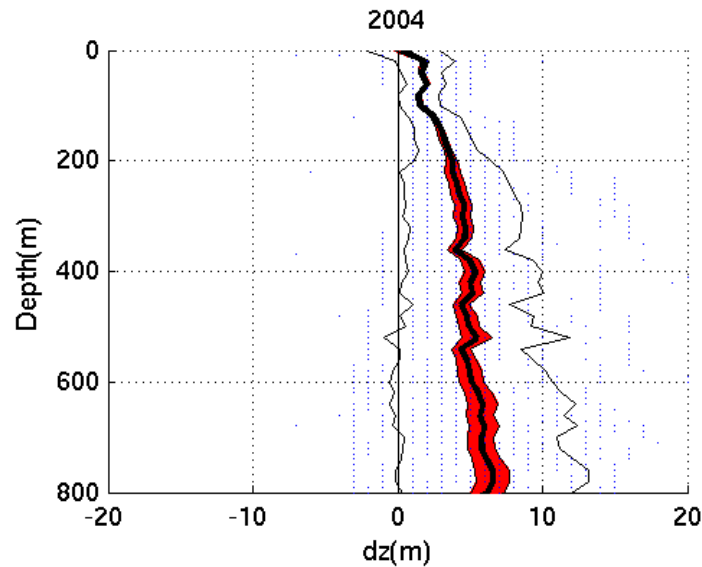
Depth errors over time - Late 80's to early 90's



Depth errors over time - Late 90's to early 2000's



Depth errors over time - Late 2000's to early 2010's



Breaking down the bias.

Correct the depth of each XBT using a weighted linear fit to the lags.

The result:

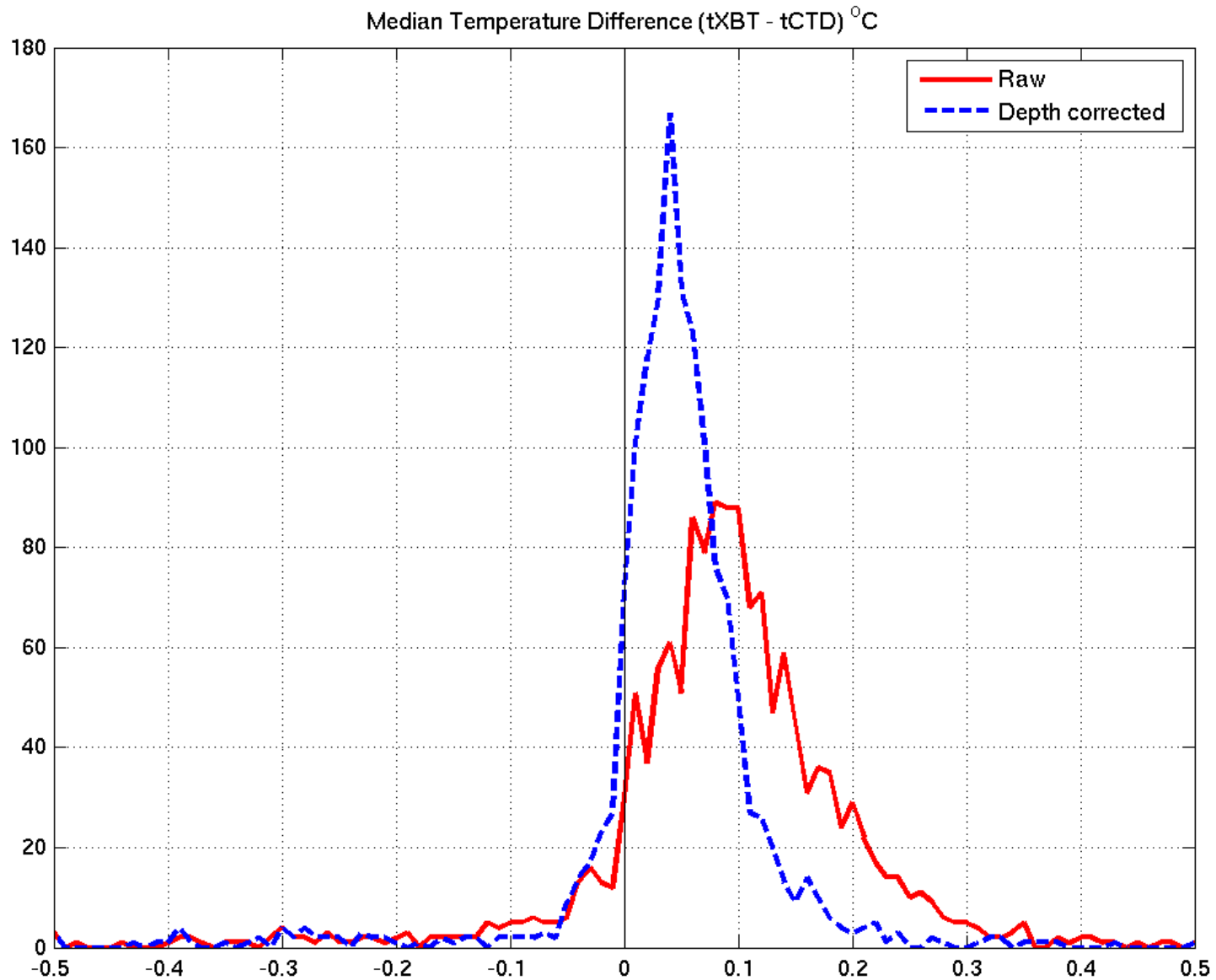
- Depth error slope
- Surface intercept value

$$\text{depth error} = \text{intercept} + \text{slope} * \text{depth}(\text{xbt})$$

After correcting for the depth error:

- Temperature bias

Temperature bias after depth correction

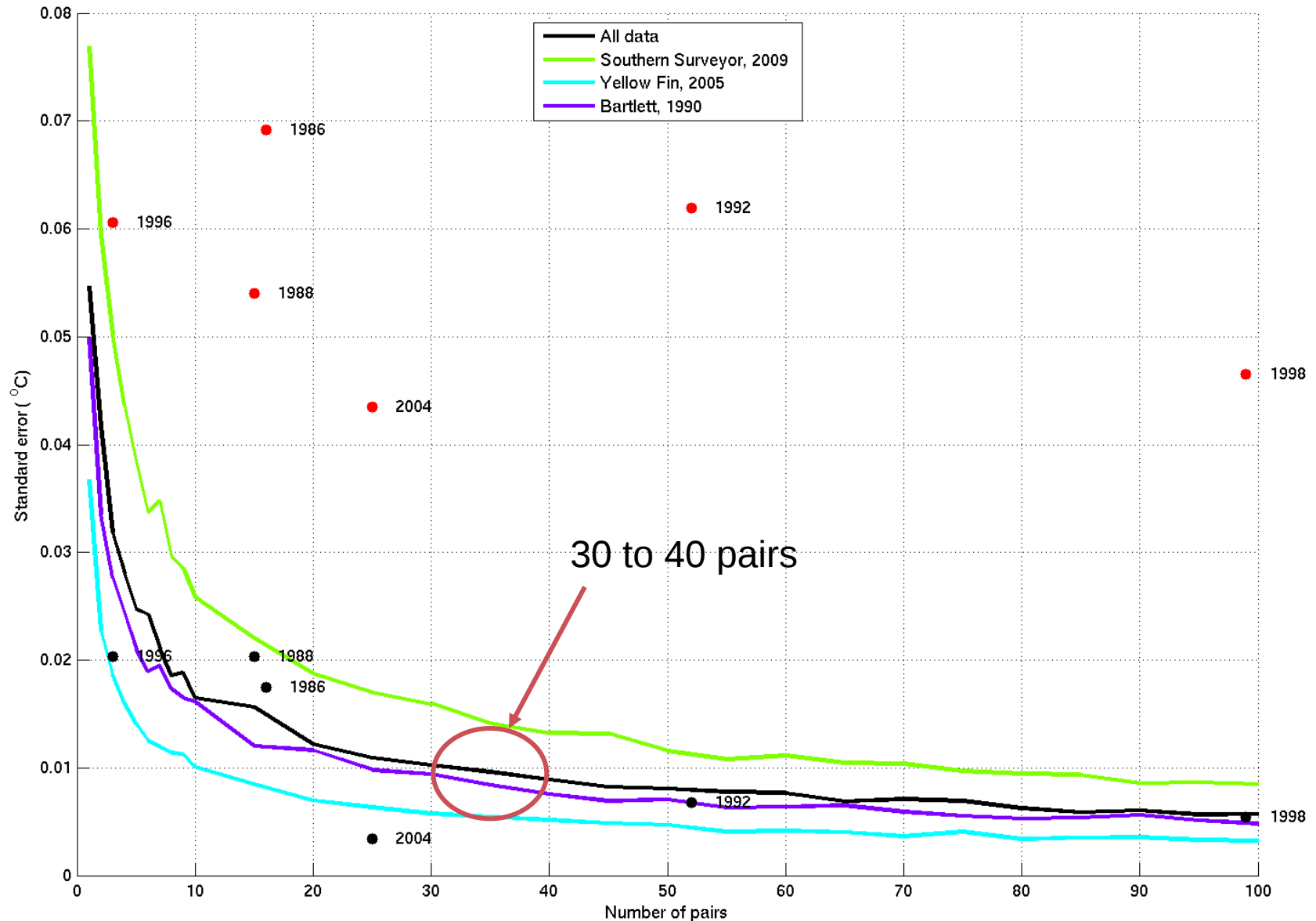


How many pairs do we need?

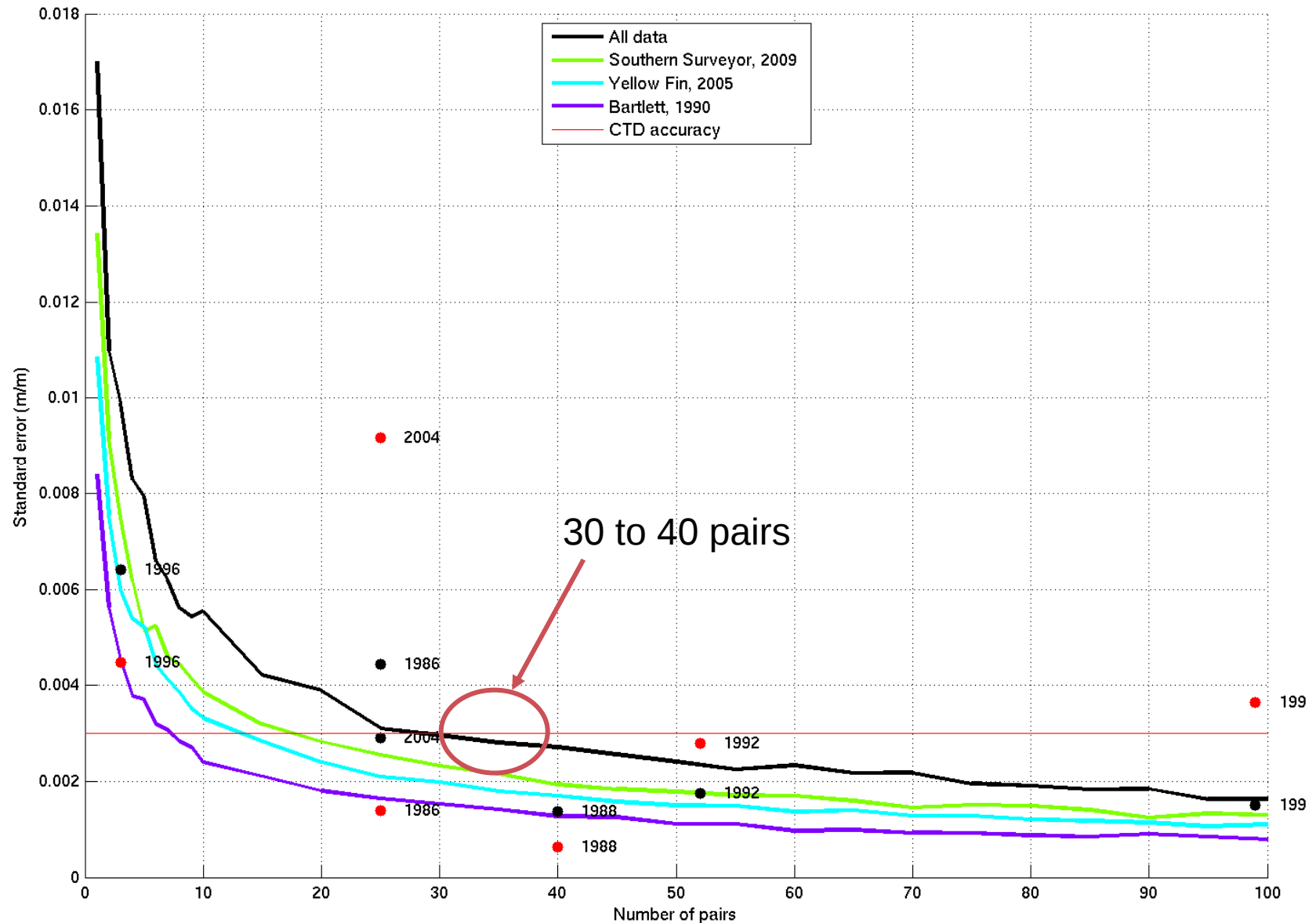
To estimate the size of the error for any number of pairs

- Perform a bootstrap analysis of:
 - The temperature bias
 - The depth error slope
- Take a random subsample of the dataset for each number of pairs (1 to 400 pairs)
- Mean result of each subsample was recorded.
- Repeated 500 times.
- Calculate the standard deviation of the 500 results

Noise in temperature bias



Noise in depth error slope

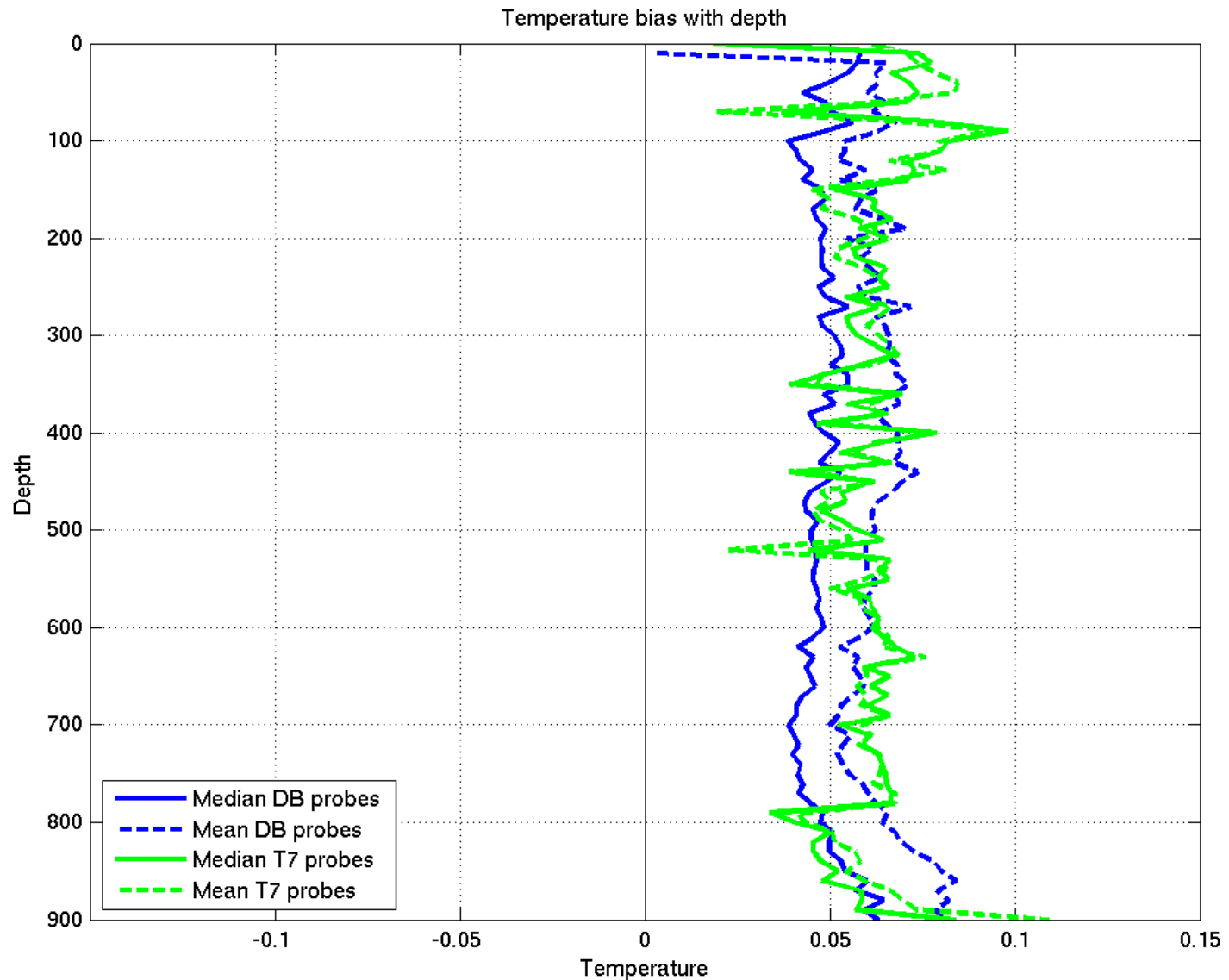


Temperature bias characteristics

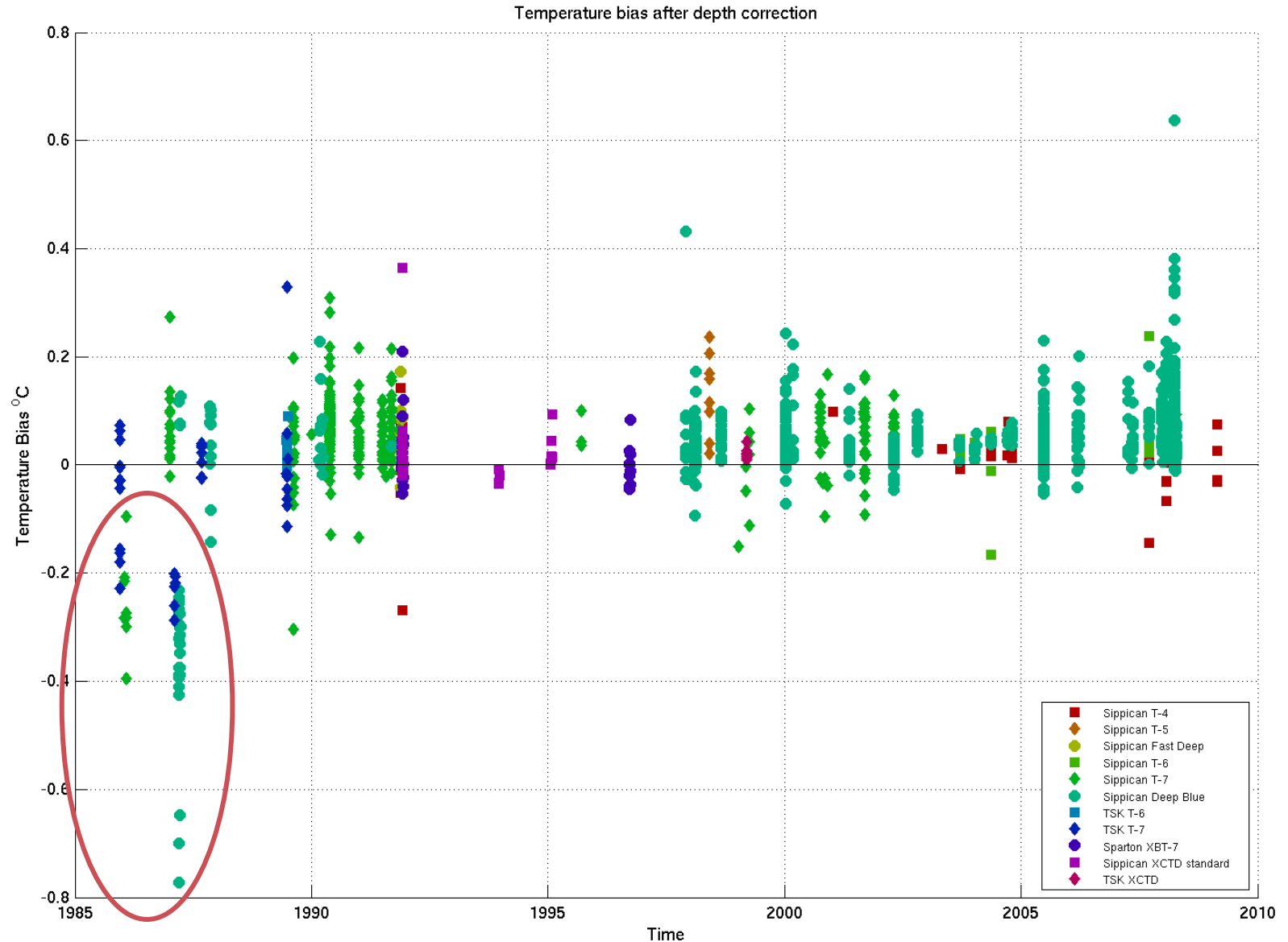
The temperature bias

- Does it change with depth?
- Does it change over time?
- Does it change with temperature?
- Is there a system issue that contributes to the bias?

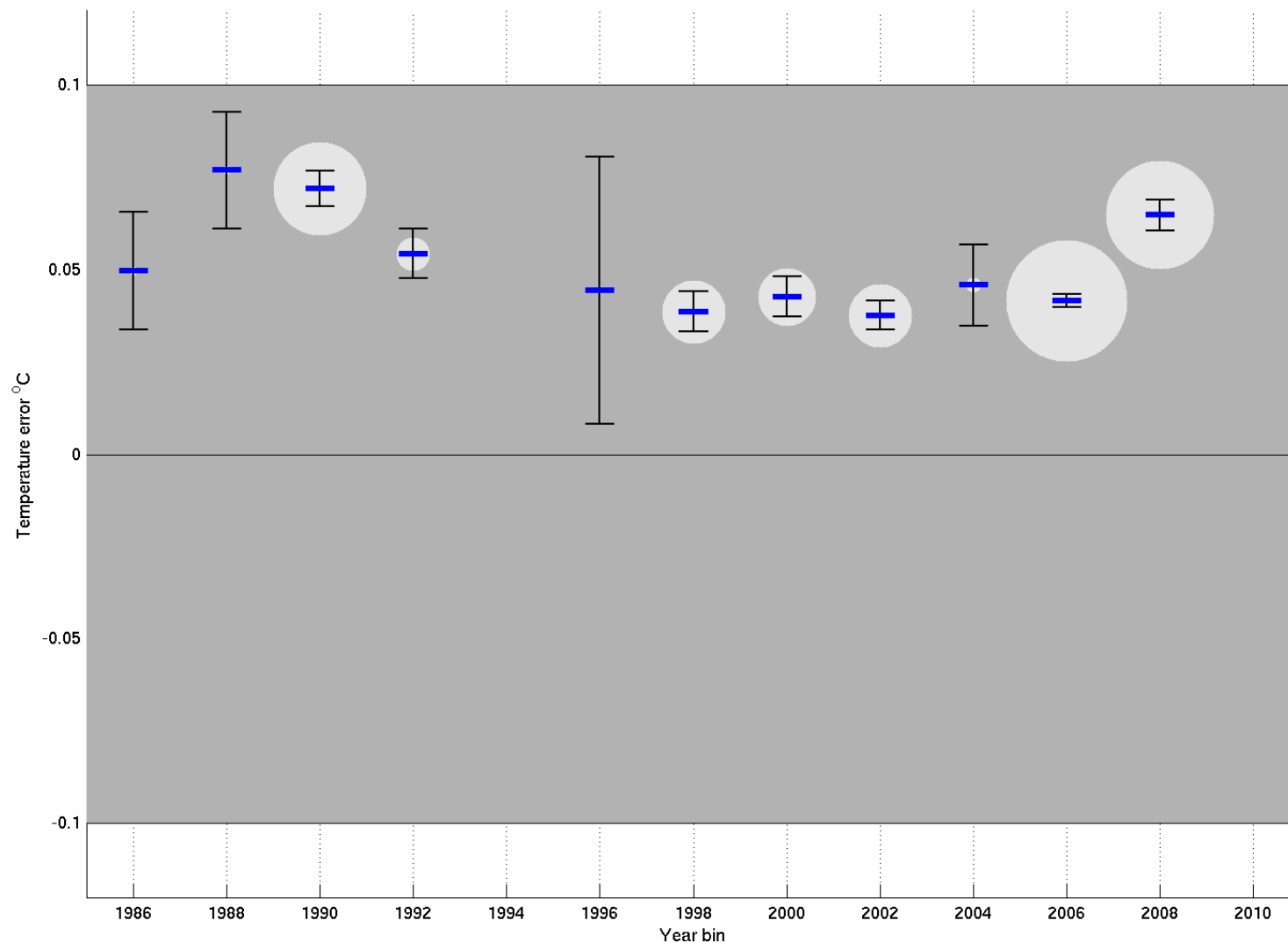
Temperature bias with depth: constant!



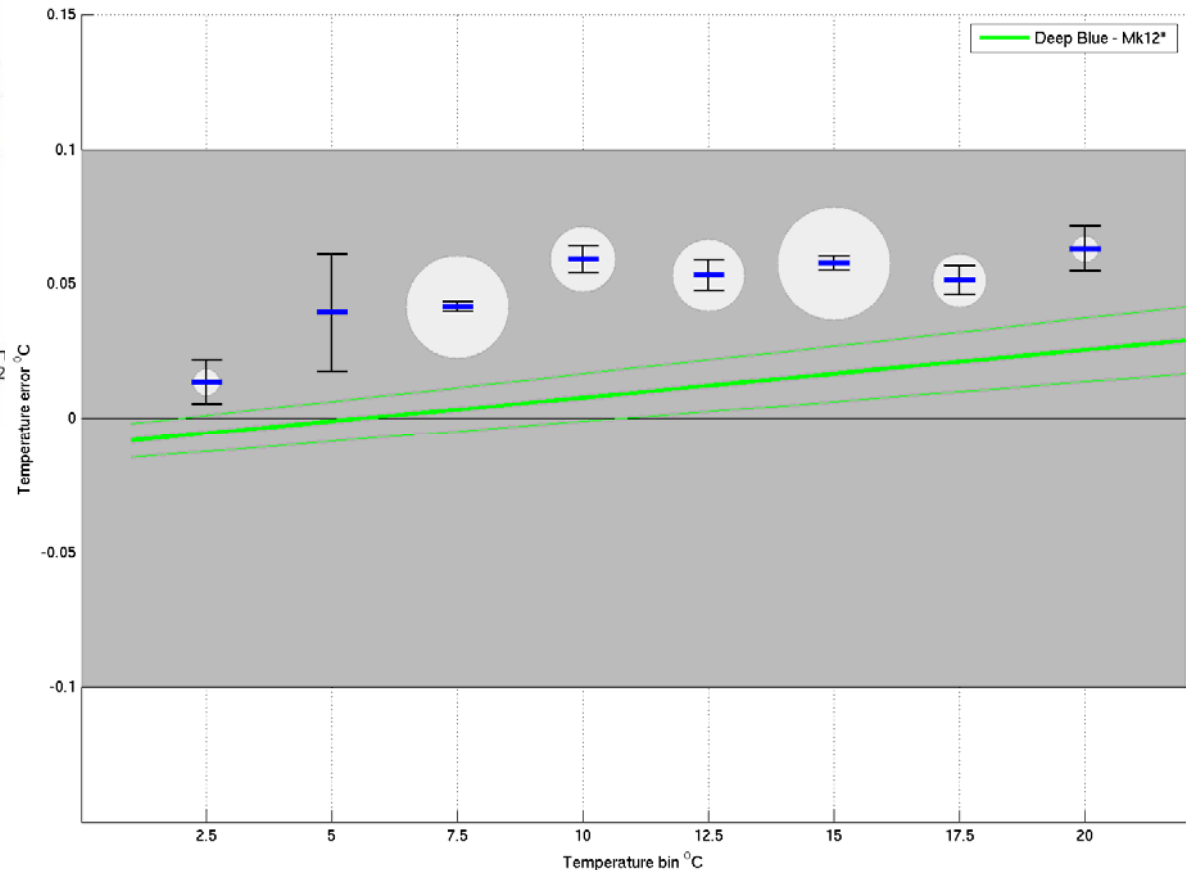
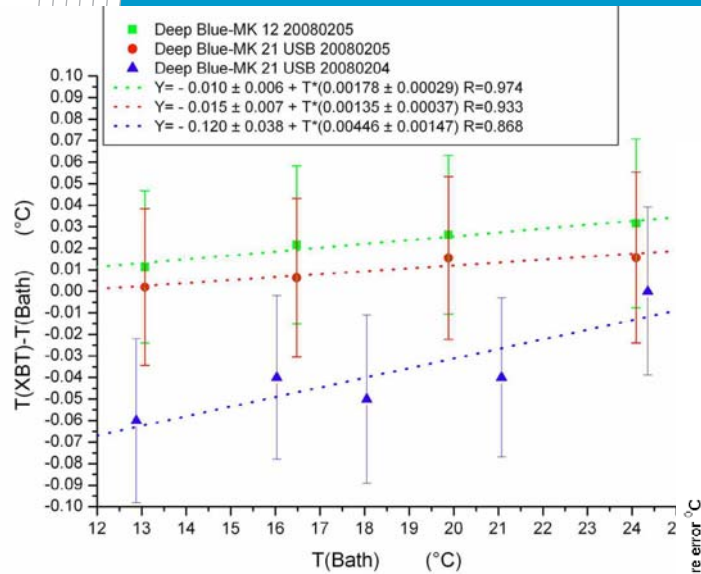
Temperature bias: time dependence?



Temperature bias: time dependence (T7/DB)

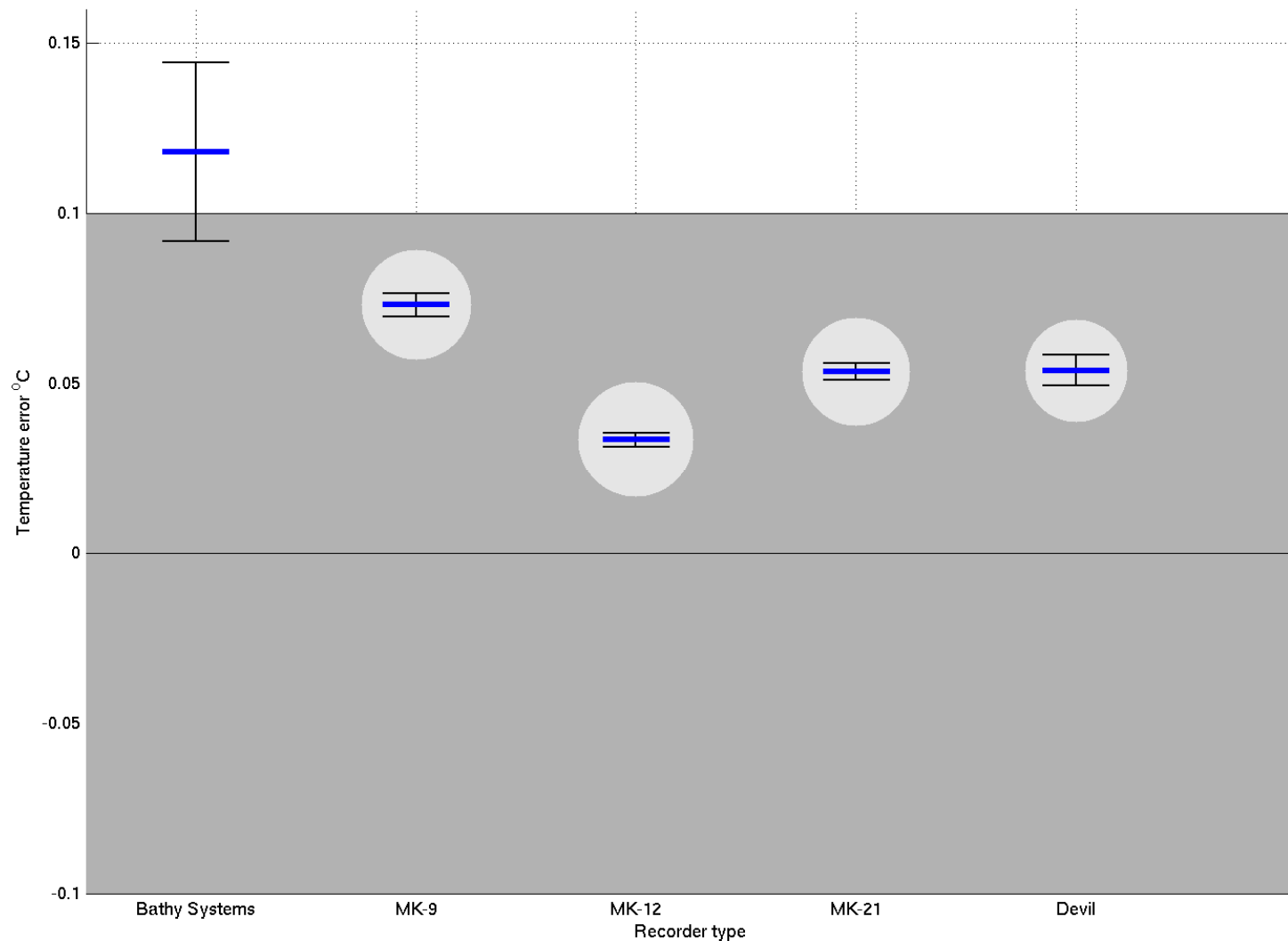


Temperature bias: temperature dependence?



*From figure 4 in: Viktor Gouretski and Franco Reseghetti, On depth and temperature biases in bathythermograph data: Development of a new correction scheme based on analysis of a global ocean database, Deep-Sea Research I, doi:10.1016/j.dsr.2010.03.011

Temperature bias: system dependence?

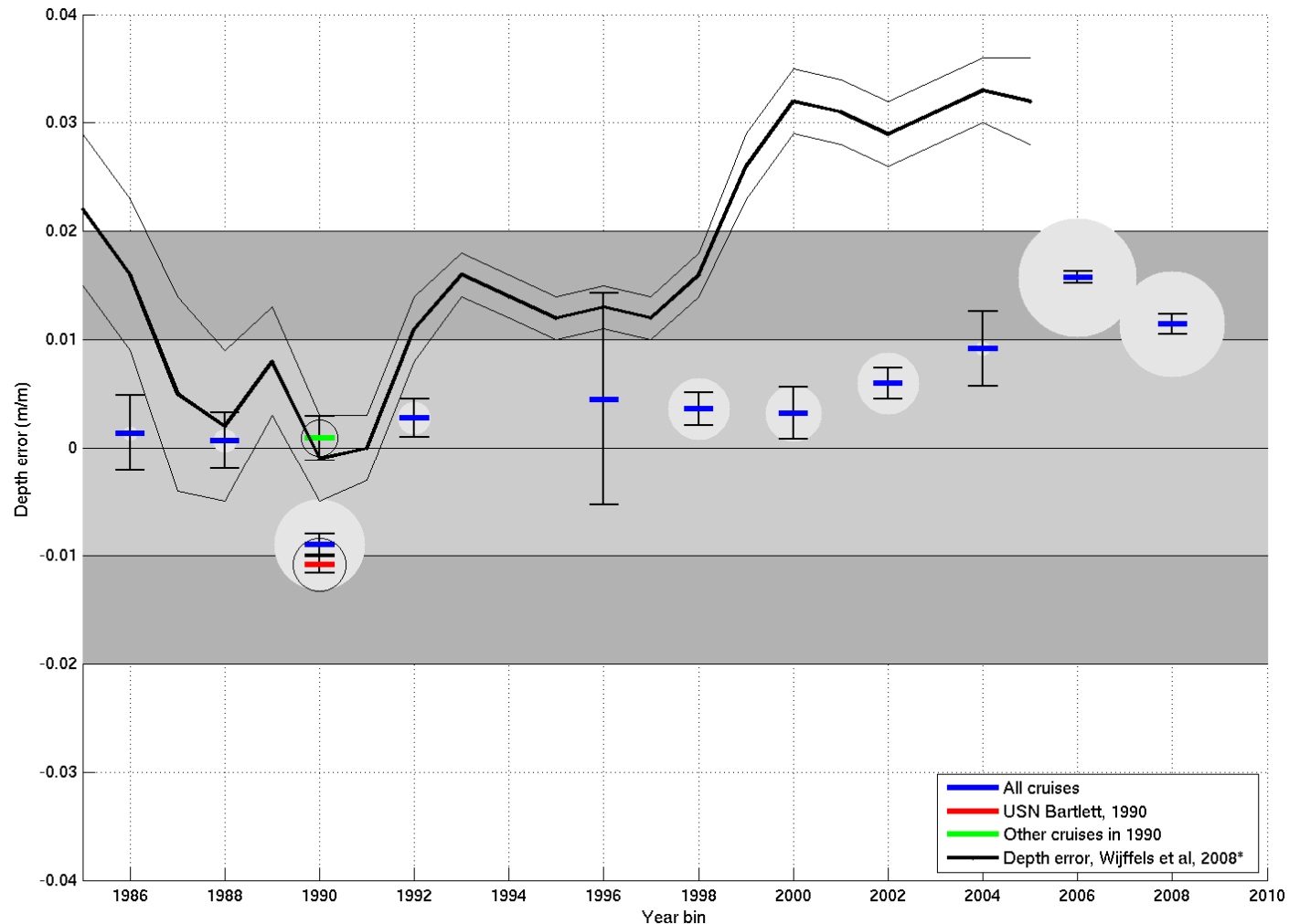


Depth error characteristics

The slope of the depth error

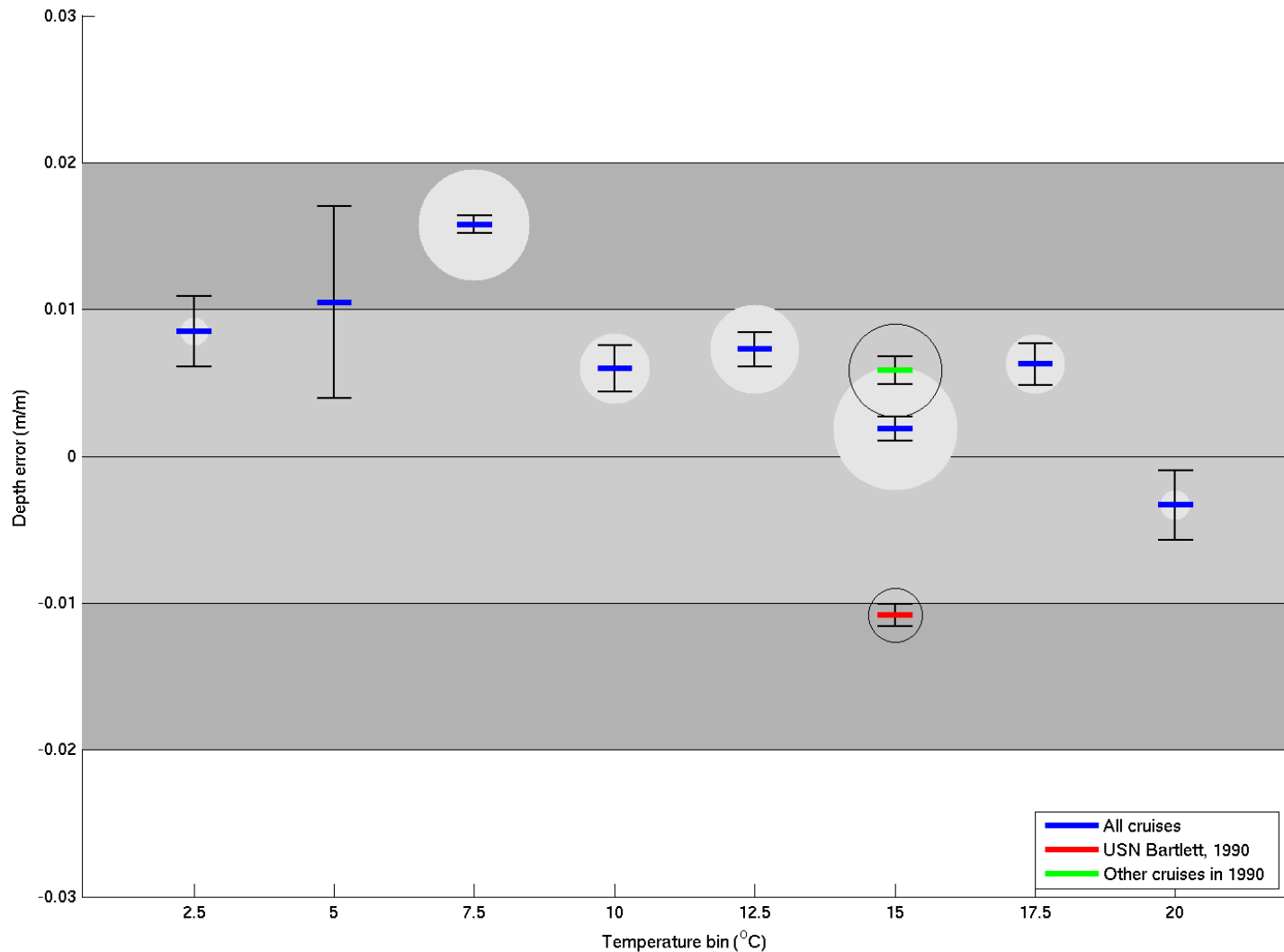
- Does it change over time?
- Does it change with temperature?
- Is there system issue that contributes to the slope?

Depth error slope: time dependence?

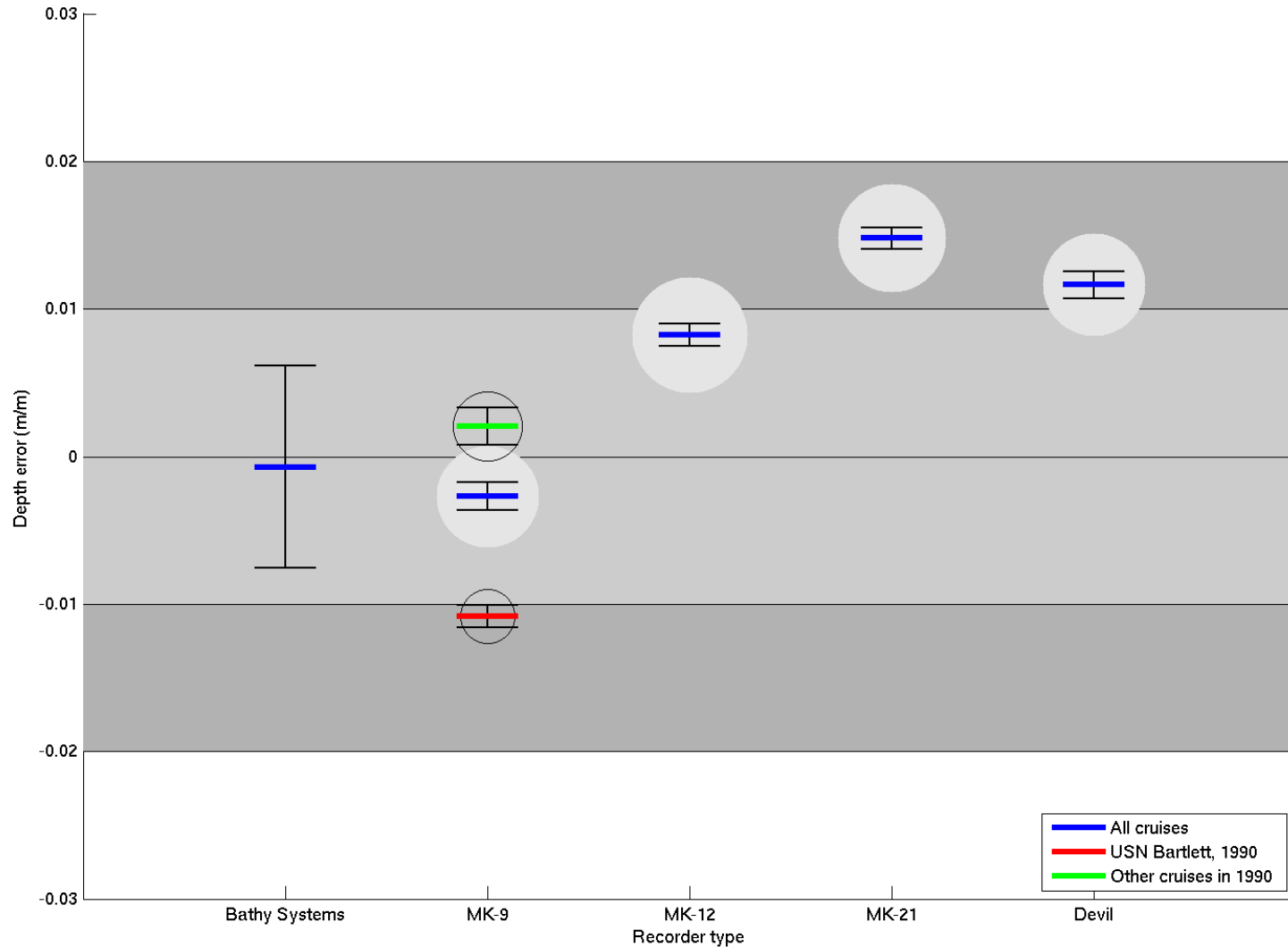


*From figure 12 in: Wijffels et al, Changing Expendable Bathythermograph Fall Rates and Their Impact on Estimates of Thermosteric Sea Level Rise, Journal of Climate, 21,5657:5672.

Depth error slope: temperature dependence?



Depth error slope: system dependence?

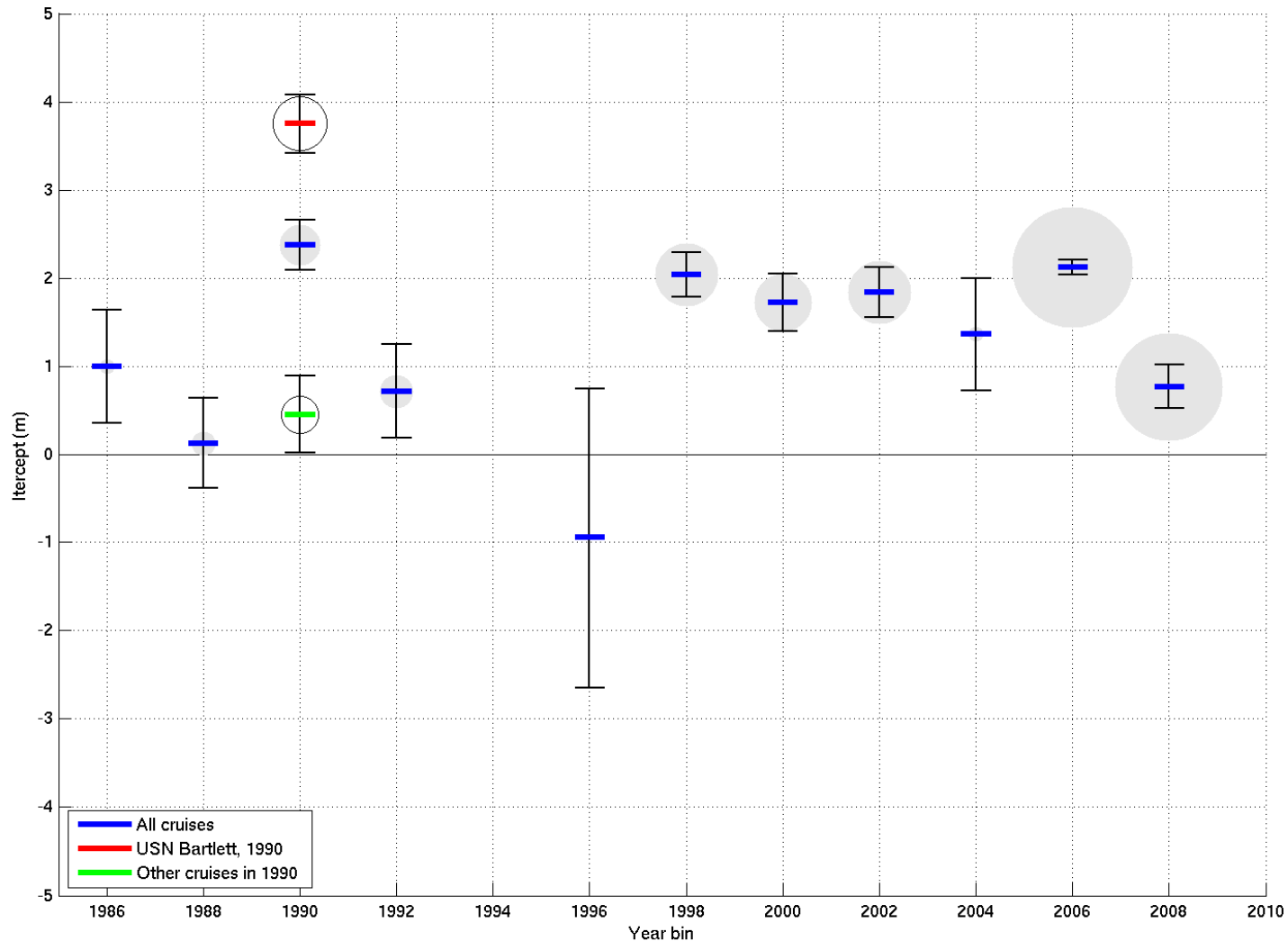


Depth error: Surface intercept characteristics

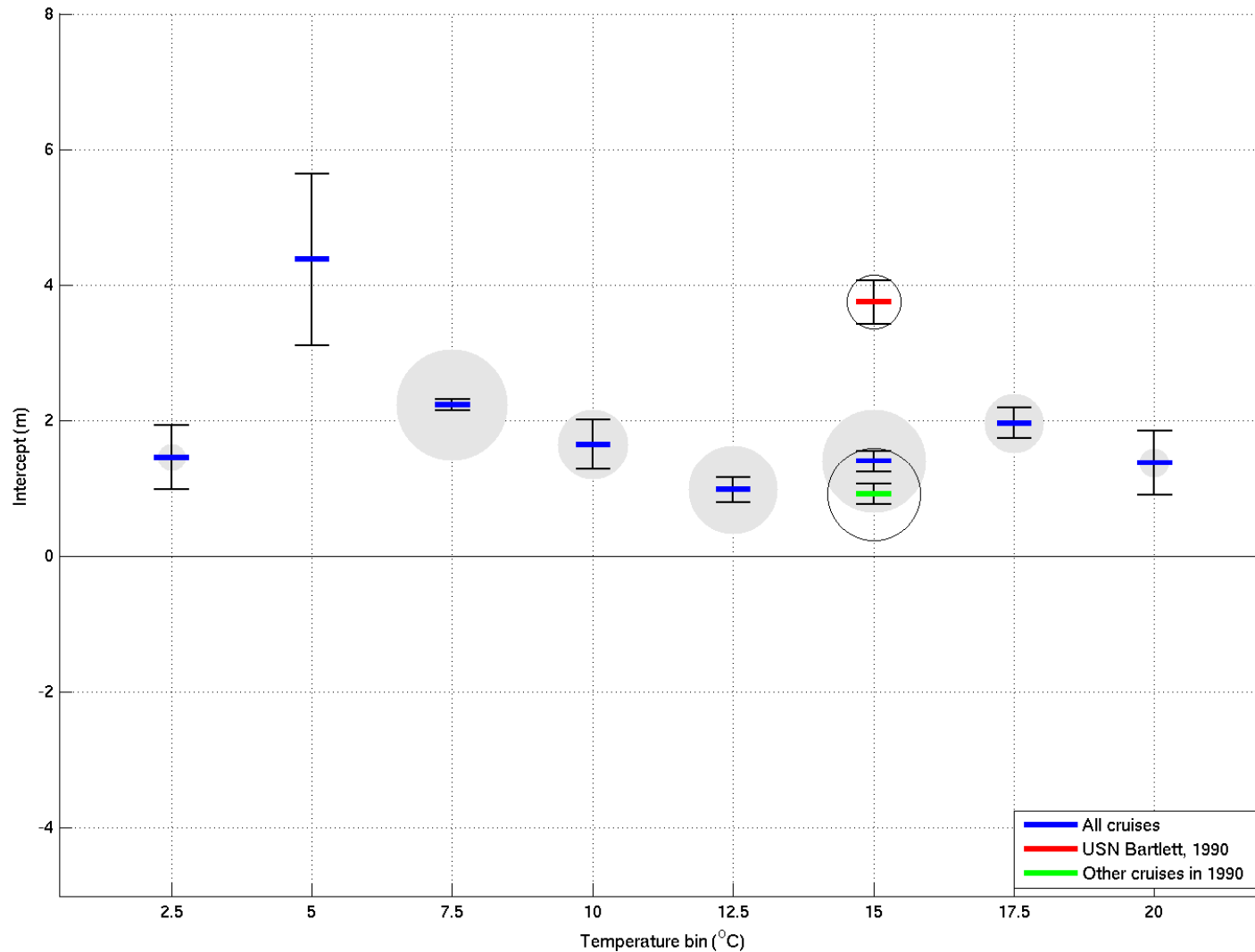
The intercept

- Does it change over time?
- Does mean profile temperature effect the intercept?
- Is there a system issue that contributes to the intercept?

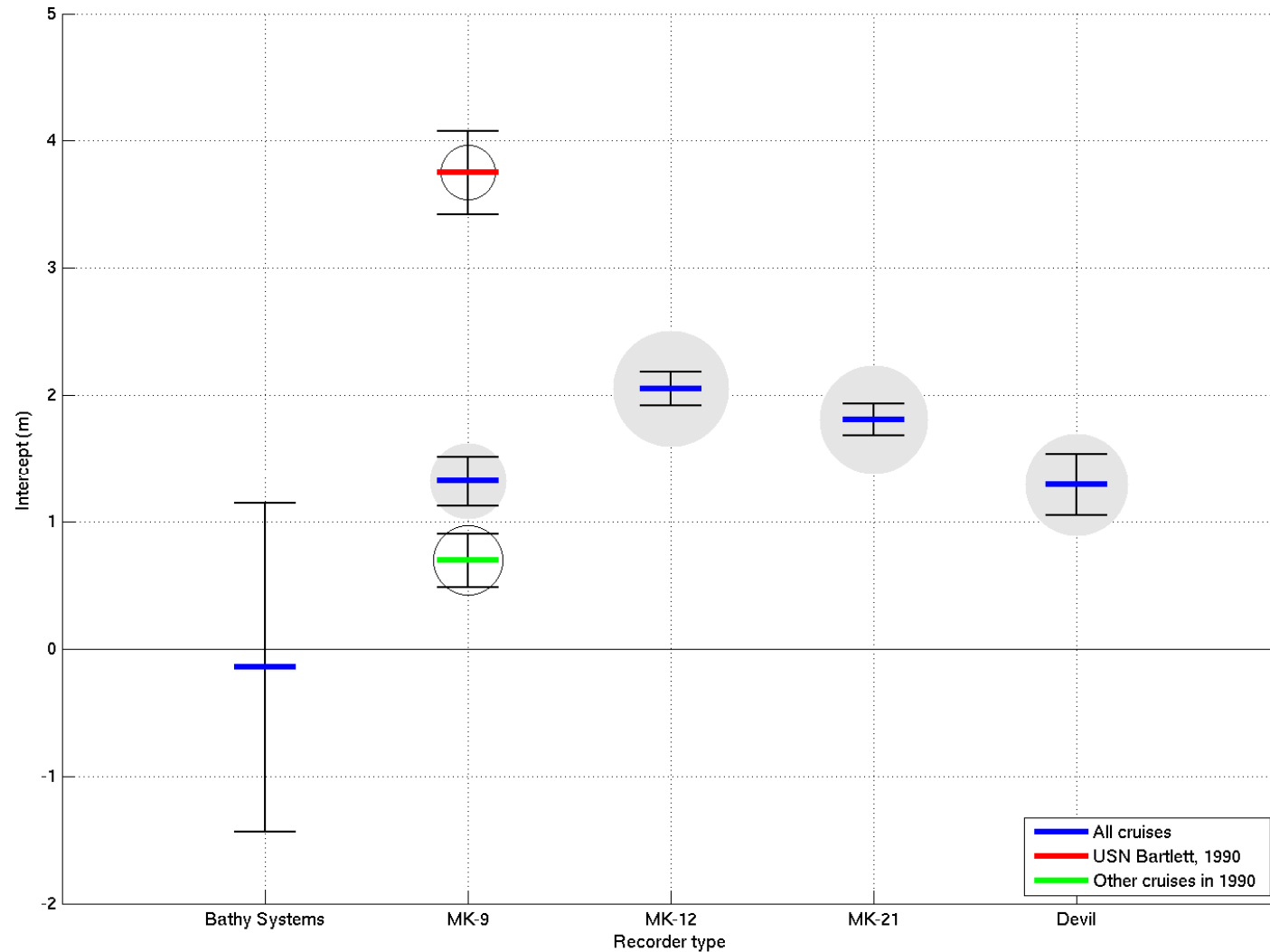
Surface intercept: time dependence?



Surface intercept: temperature dependence?



Surface intercept: system dependence?



Conclusions: Good news

A simple weighted linear depth correction reduces the XBT temperature bias

Temperature bias is positive, and consistent over time and recorder types.

There is a time dependant depth error remaining after correction to Hanawa 1995. It is within $\pm 2\%$

The depth error intercept is positive ($\sim 2\text{m}$), independent of time, profile temperature and recorder types.

Conclusions: Not-so-good news

May be a recorder type dependency in the depth error slope.

May be a temperature dependency in the temperature bias

Possibly a temperature dependency in the depth error slope.

Some outlier cruises

Future Work?

- Reanalyse the archives:
 - Account for a fixed depth offset (intercept) and temperature offset, and then examine the resulting implied depth biases
 - As above using pseudo-profiles based on altimetry?
- Fill in the holes:
 - Try to find pairs from lean years
 - Look at other probe types
- Bath experiments with XBT systems:
 - Can the temperature bias can be reproduced in the laboratory
- Form of depth bias:
 - slope and offset model does not work in the upper 50-80m
- Derive correction scheme and re-analyse for history of GOHC

Thank you

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