Examination of XBT Depth/Temperature Bias in the Arabian Sea and Bay of Bengal: Implications for Climate Studies

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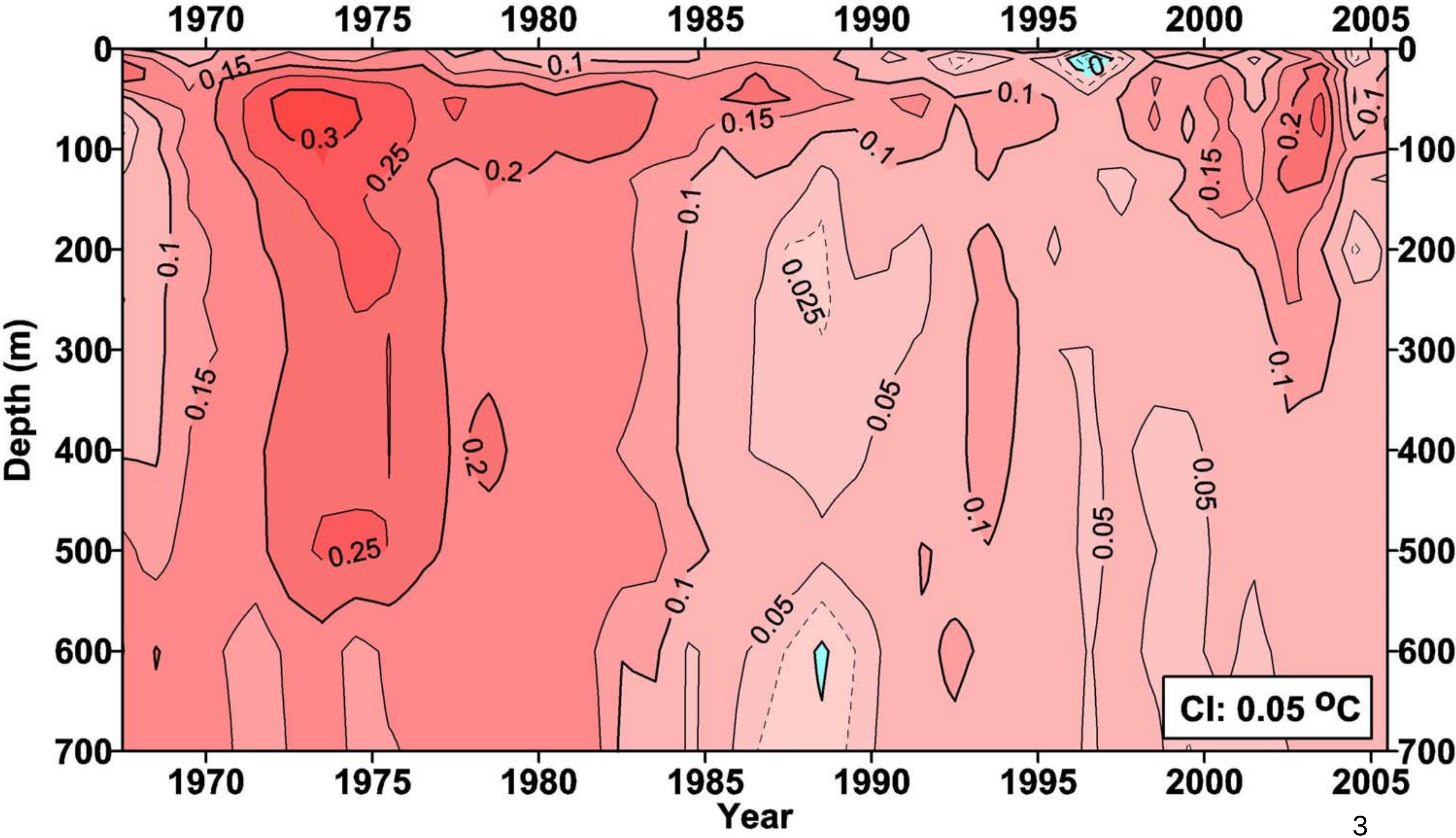
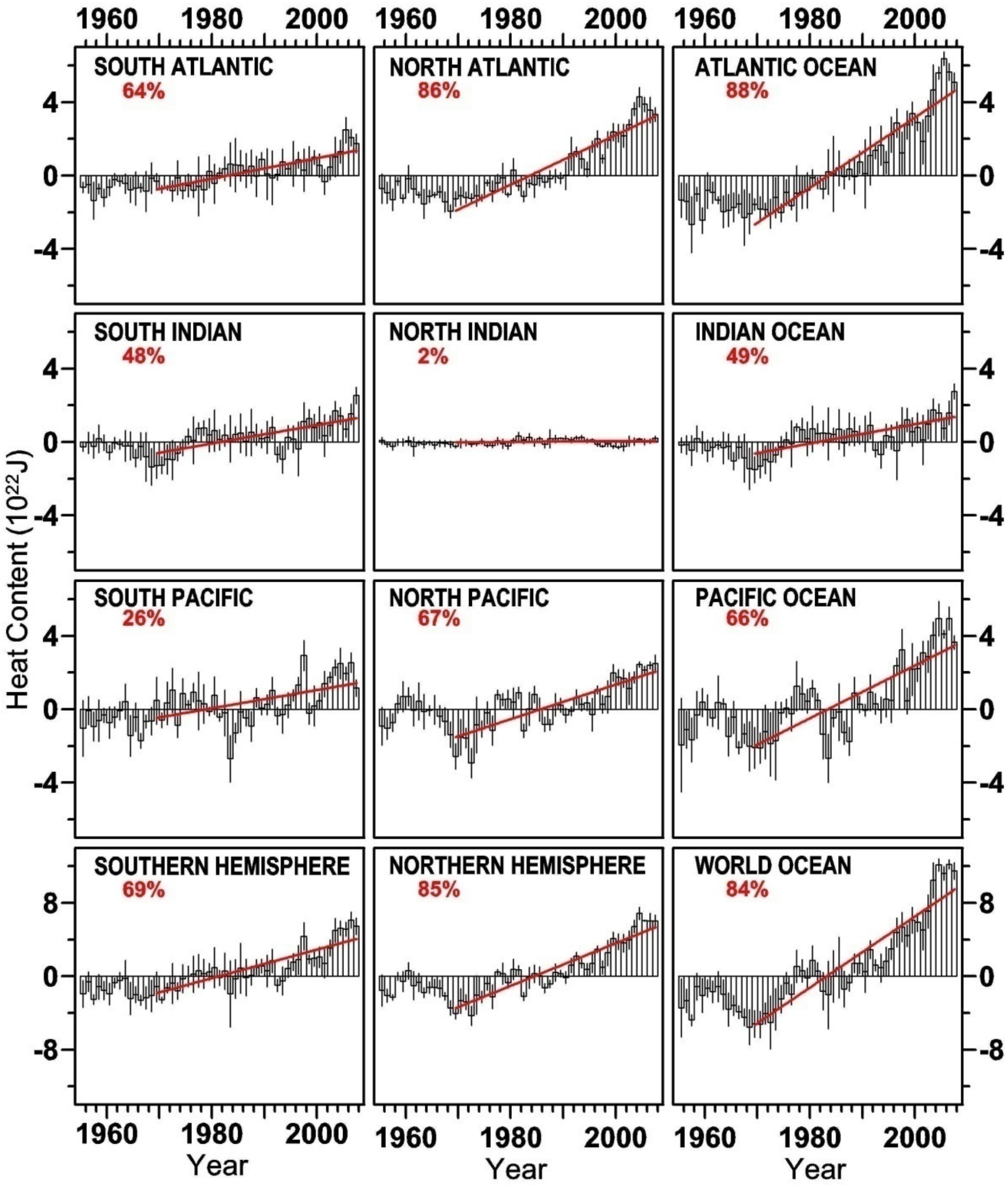
XBT Depth/Temperature Bias

- **Expendable Bathythermograph (XBT) depth calculated from time, not measured**
- **Known since early 1970s that original drop rate equation not accurate**
- **Hanawa et al. 1995 (H95) adjusted drop rate**
- **Gouretski and Koltermann 2007 show XBT error was not constant over time**

XBT Bias by Year/Depth (Levitus et al., 2009)



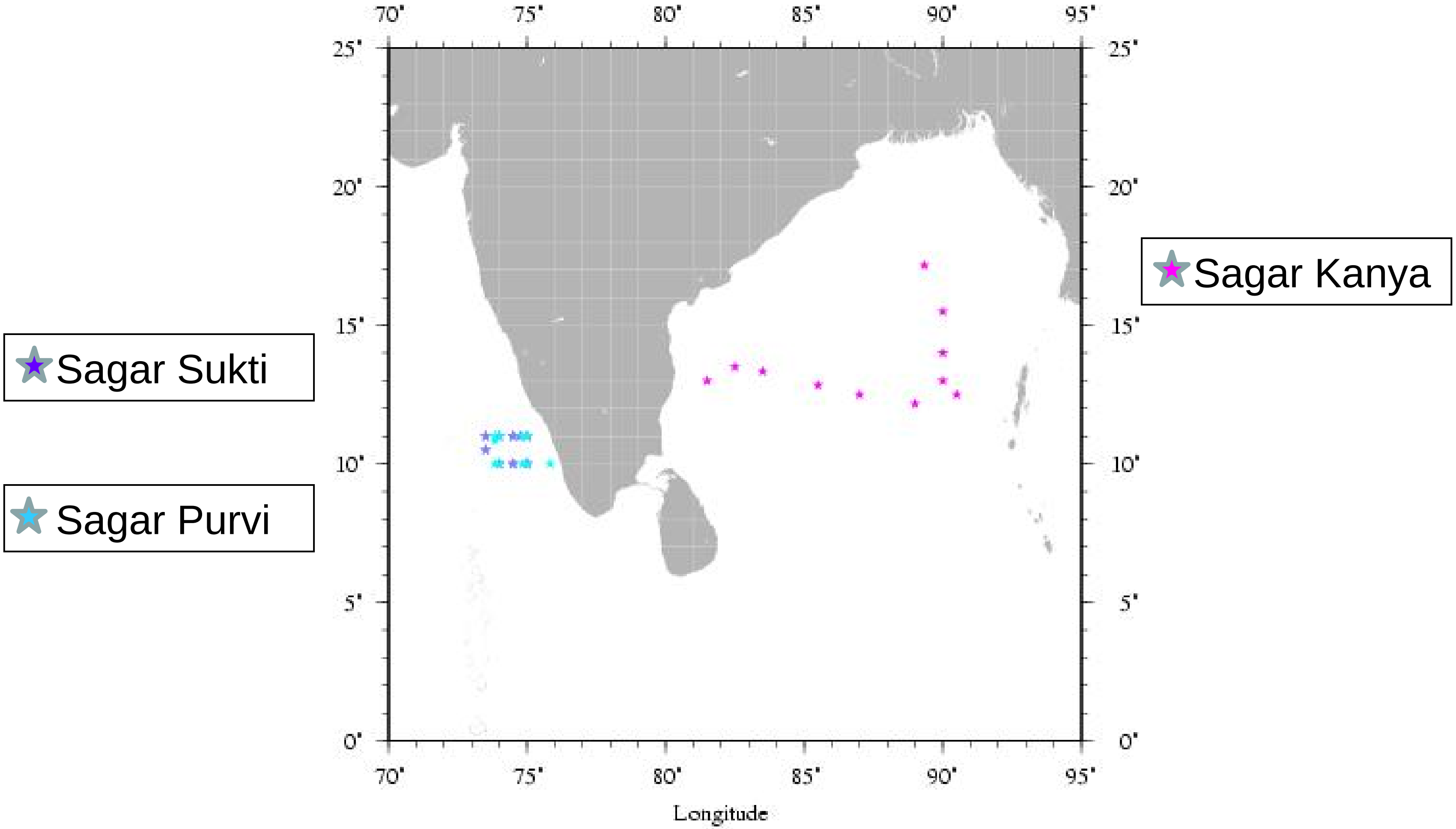
Ocean Heat Content (0-700m) by basin from Levitus et al. 2009



Implications for XBT in North Indian Ocean Climate Studies

- North Indian Ocean SST has been increasing rapidly in recent years (Jodhav and Munot, 2007), but ocean heat content has no discernable trend
- Possible geographic differences (Pankajashan et al., 2002). Arabian Sea and Bay of Bengal.
- 20 year set of time series XBT measurements (JCOMM SOT) in area. Can they be used to study problem?

Locations of Comparisons



Cruise Technical Details

Ship name	CTD used	Cruise Duration	Winch Speed	Date of Manufacture of		Type of	
				XBT	XCTD	XBT	XCTD
Sagar Kanya	Idronaut	10 Oct-22 Oct 2008	30-35 mts/min	Jun 08	2008	T7	XCTD3
*Sagar Sukti	Seabird	30 Nov - 04 Dec 2008	30-35 mts/min	Jun 08	2008	T7	XCTD3
Sagar Purvi	Seabird	01 Apr - 05 Apr 2009	35-40 mts/min	Jun 08	2008	T7	XCTD3

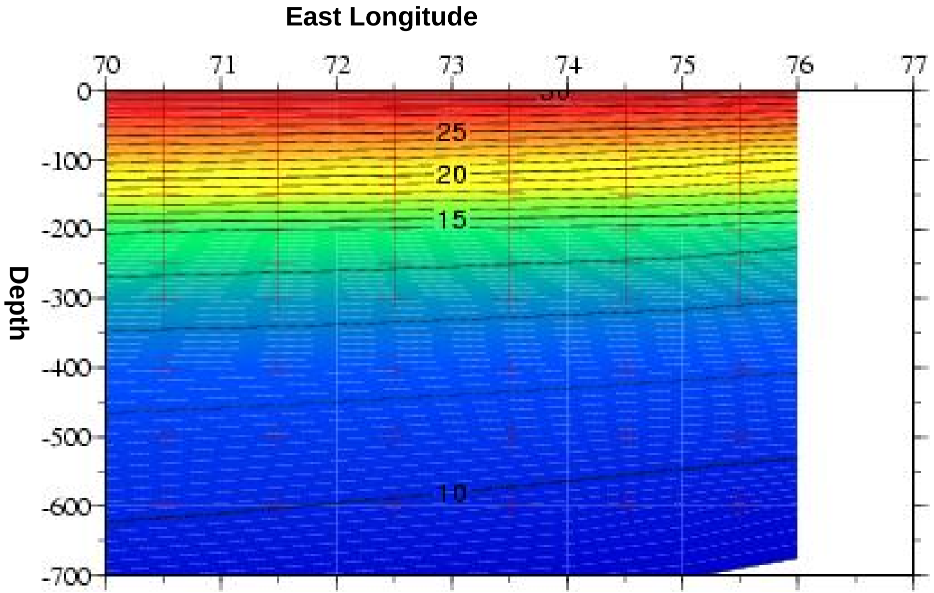
Ship Name	Type of data acquisition system used		Manufacturer of		Height of operation from sea surface	Ocean condition during the cruise
	XBT	XCTD	XBT	XCTD		
Sagar Kanya	MK-130	MK-130	Sippican ocean system	Tsurumi-Seiki Co. Ltd.	10 mts	rough weather
*Sagar Sukti	MK-130	MK-130	Sippican ocean system	Tsurumi-Seiki Co. Ltd.	2 mts	calm
Sagar Purvi	MK-130	MK-130	Sippican ocean system	Tsurumi-Seiki Co. Ltd.	4 mts	calm

*Sagar Sukti winch only allowed CTD measurements to 400 m depth

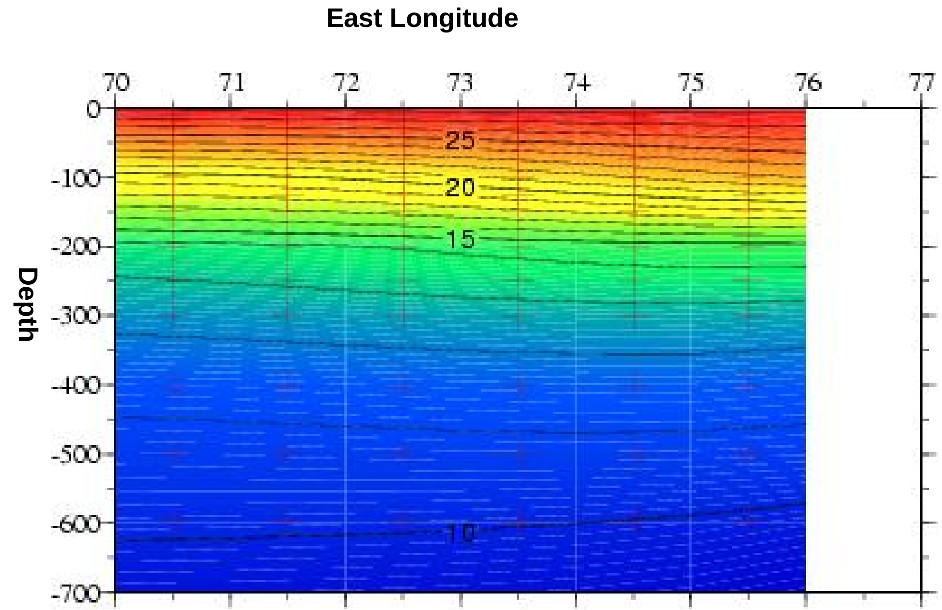
Additional Details

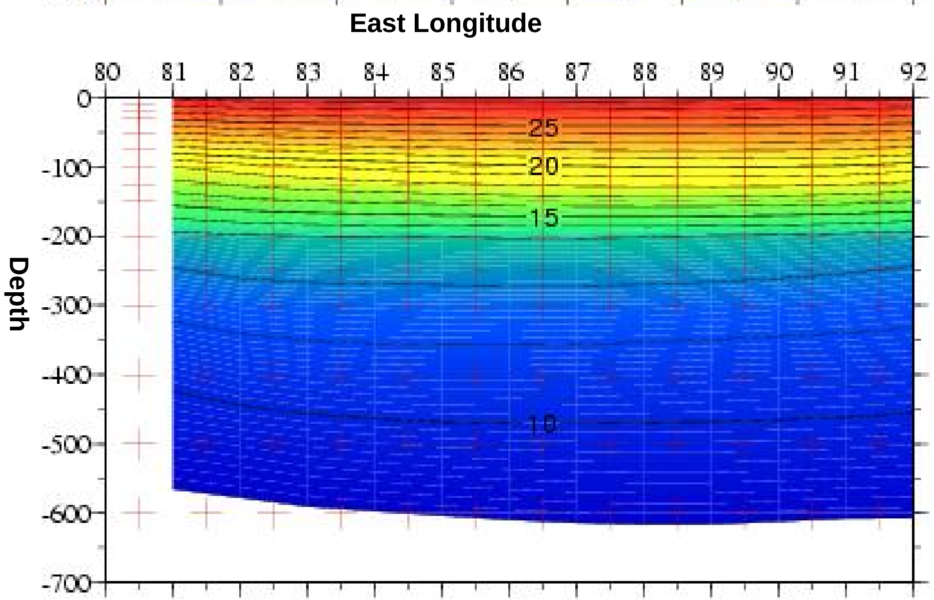
- Sagar Kanya: 11 comparisons, 1 CTD, 1 XBT, 1 XCTD.
- Sagar Sukti: 9 comparisons, 1 CTD, 1 XBT, 1 XCTD. CTD only descended to 400 m depth.
- Sagar Purvi: 9 comparisons, 2 CTD, 4 XBT, 2 XCTD.

Arabian Sea 10°N, April [Sagar Purvi]



Arabian Sea 10°N, December [Sagar Sukti]

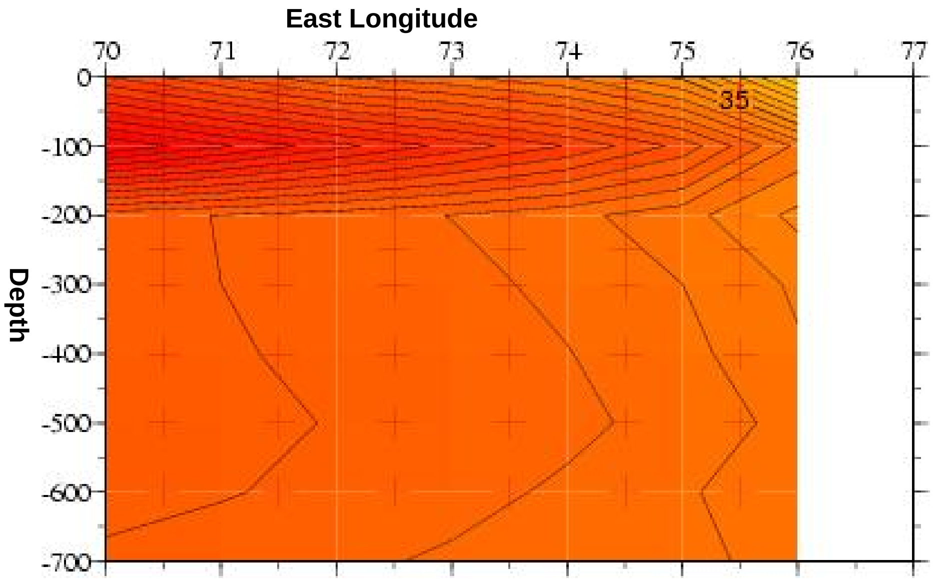




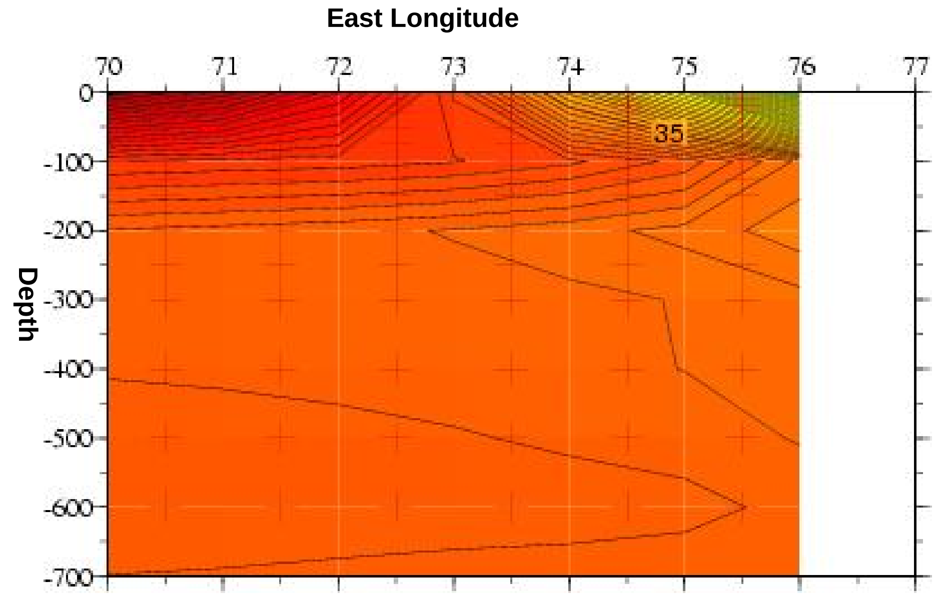
Bay of Bengal 12°N, October [Sagar Kanya]

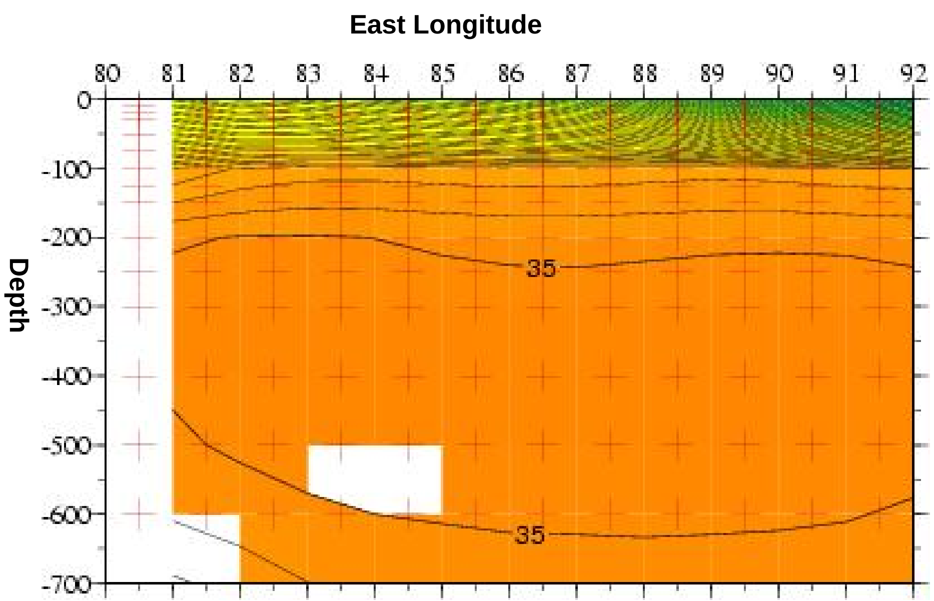
Climatological Temperature Structure
In Area/Month of 3 cruises.
Contour Interval: 1.0 °

Arabian Sea 10°N, April [Sagar Purvi]



Arabian Sea 10°N, December [Sagar Sukti]

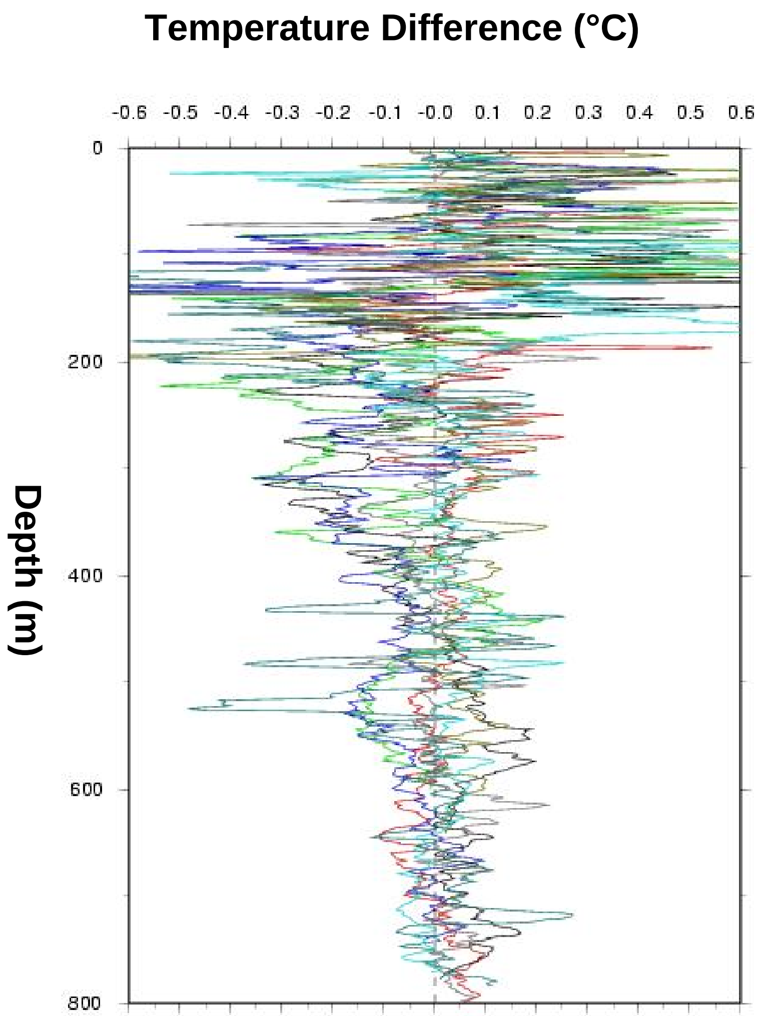




Bay of Bengal 12°N, October [Sagar Kanya]

Climatological Salinity Structure
In Area/Month of 3 cruises.
Contour Interval: 0.1

Temperature difference at same depth between CTD drops at same station within 45 minutes of each other $T(CTD_1)-T(CTD_2)$ where CTD_1 is first cast.



From Sagar Purvi cruise

Variables in XBT Bias

- Initial velocity (a coefficient)

  original Sippican = 6.47 m/s

  H95= 6.69 m/s

- Deceleration (b coefficient)

  original Sippican = 2.16×10^{-3} m/s^2

  H95= 2.25×10^{-3} m/s^2

- Thermal bias

Drop Rate/Thermal Bias Calculation Method

1. Bin XBT/CTD data into 1 meter depth increments

2. Back out time from XBT depths

3. Calculate XBT depths for all initial velocities 5.00 to 8.00 m/s (0.01 increments) and all decelerations 0.00 to 4.00 x 10^{-3} m/s^2 (0.01 x 10^{-3} increments)

4. Difference XBT - CTD temperature gradients at each 1 meter increment 200–600 meters layer, sum absolute values.

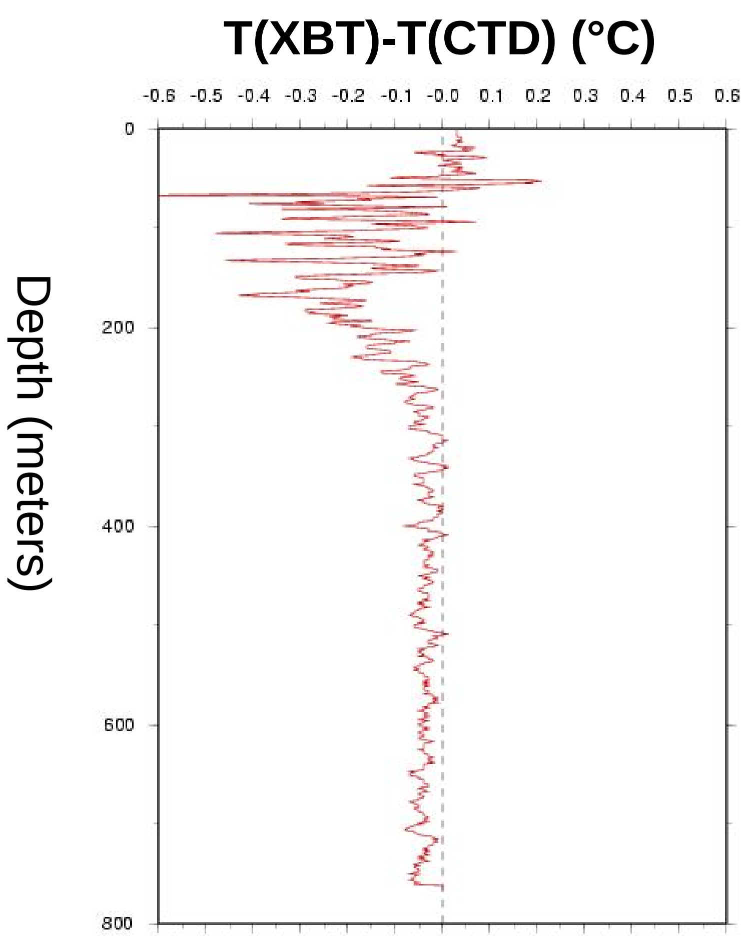
5. Minimize slope of least squares fit of difference of full temperature between XBT - CTD in the 200-600 meters layer for least 5% of step 4

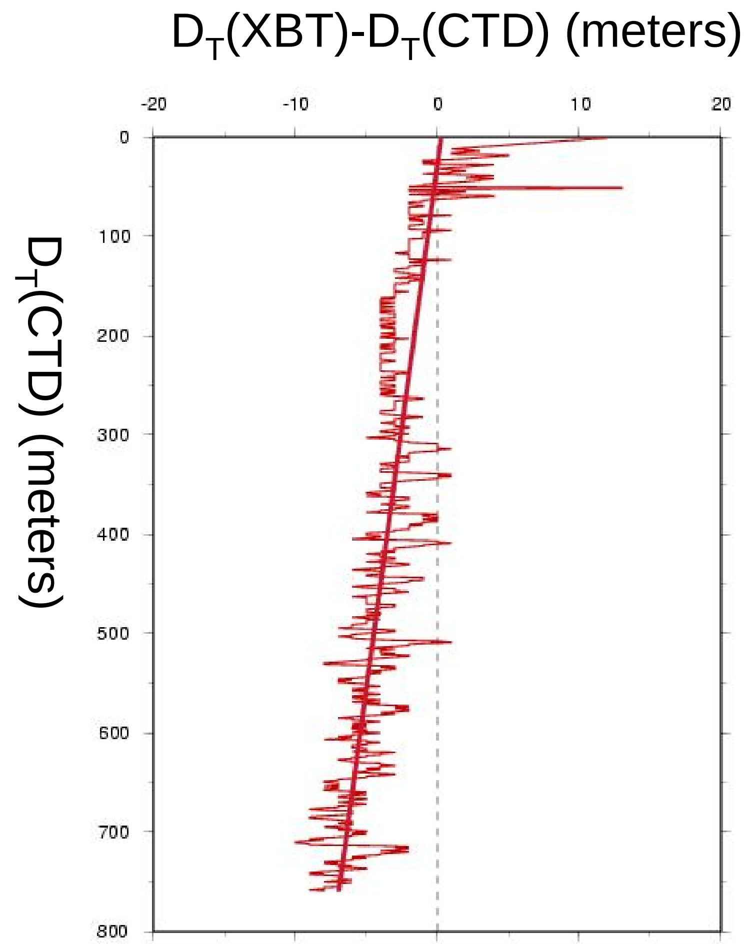
6. Residual thermal bias calculated using average difference of full XBT/CTD temperatures 200-600 meters layer after application of new drop rate

Why not use H95 Method?

- Present method is based on H95 method
- Too few points used in H95 method
- H95 method very dependent on quality control
- Deceleration not truly accounted for in H95 method

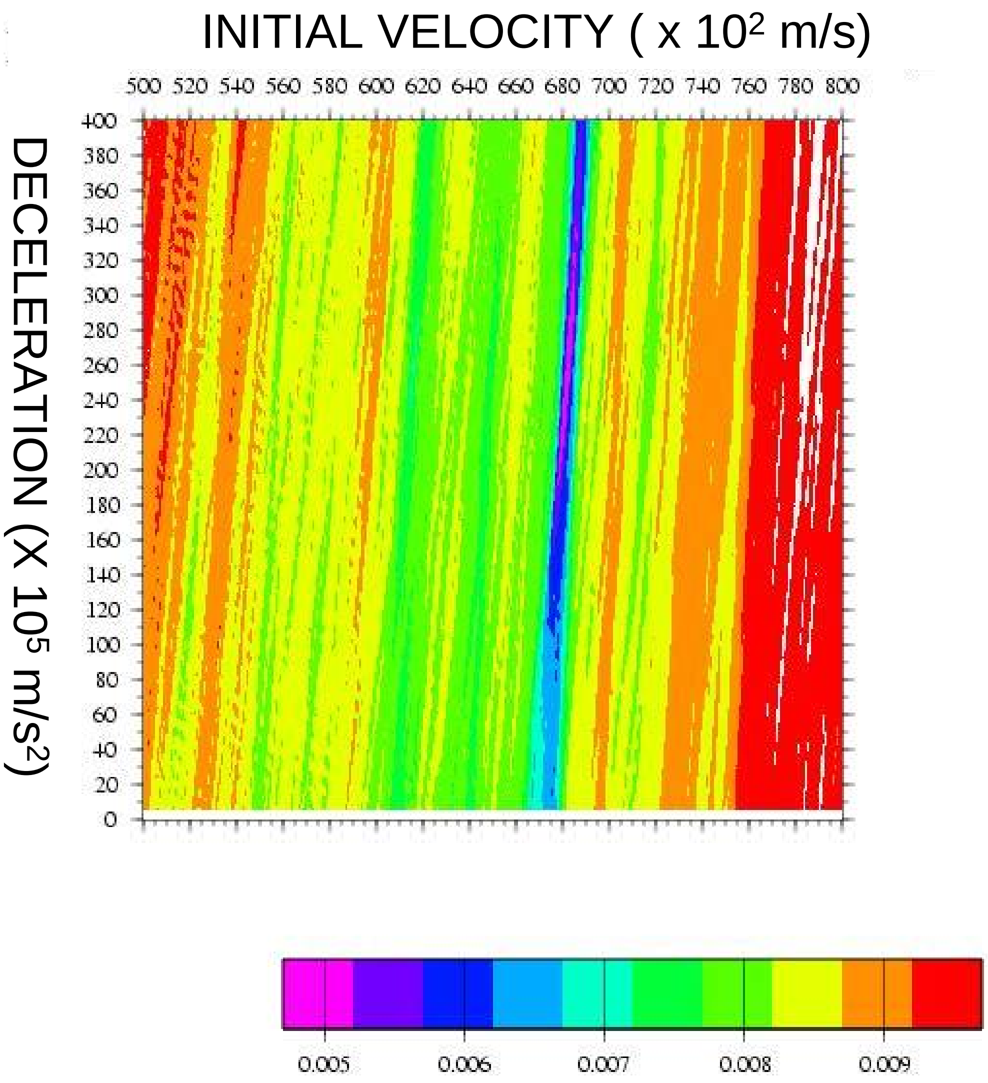
Sagar Kanya CTD-9, XBT-16
October 18, 2008 14°N, 91°E
H95 drop rate 6.69 m/s – 2.25x10^{-3} m/s^2





D$_T$=depth of a given temperature.
CTD temperature at each 1 meter interval is used as the given temperature

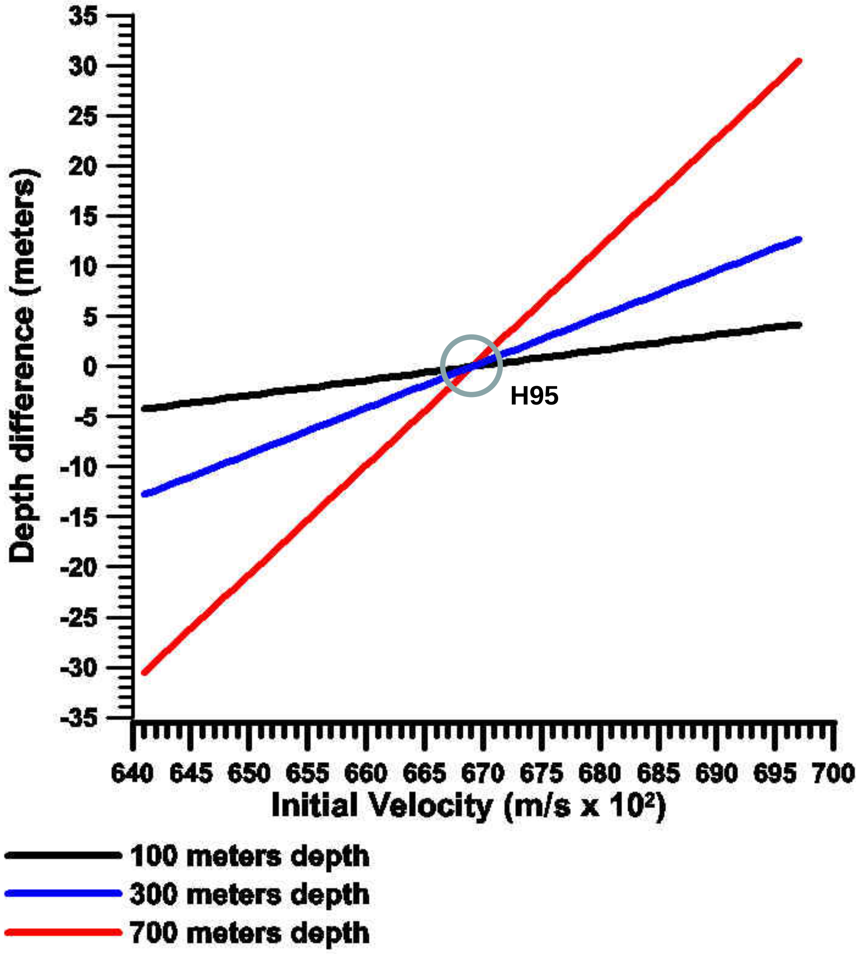
Minimizing differences using different drop rates



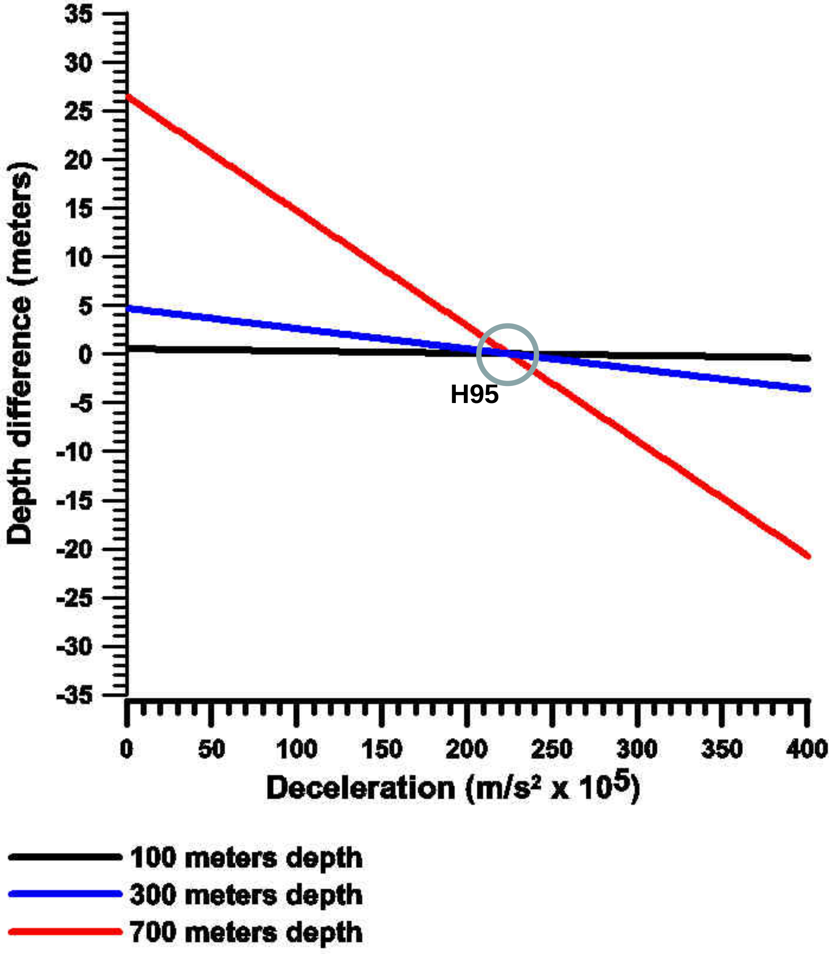
Sagar Kanya
CTD-9, XBT-16
October 18, 2008
14°N, 91°E

Sum of absolute differences between XBT and CTD gradients
For each set of initial velocities and decelerations **(°C/m)**

Depth Differences from H95 for different initial velocities (deceleration=2.25 x 10^{-3} m/s^2)



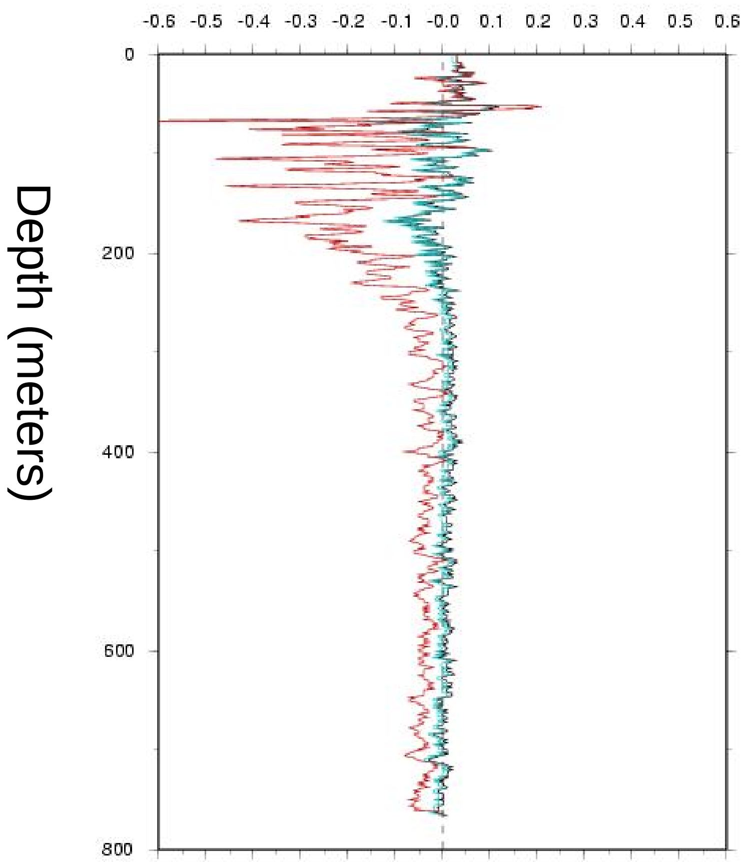
Depth Differences from H95 for different decelerations (initial velocity=6.69 m/s)



Minimizing temperature difference slope

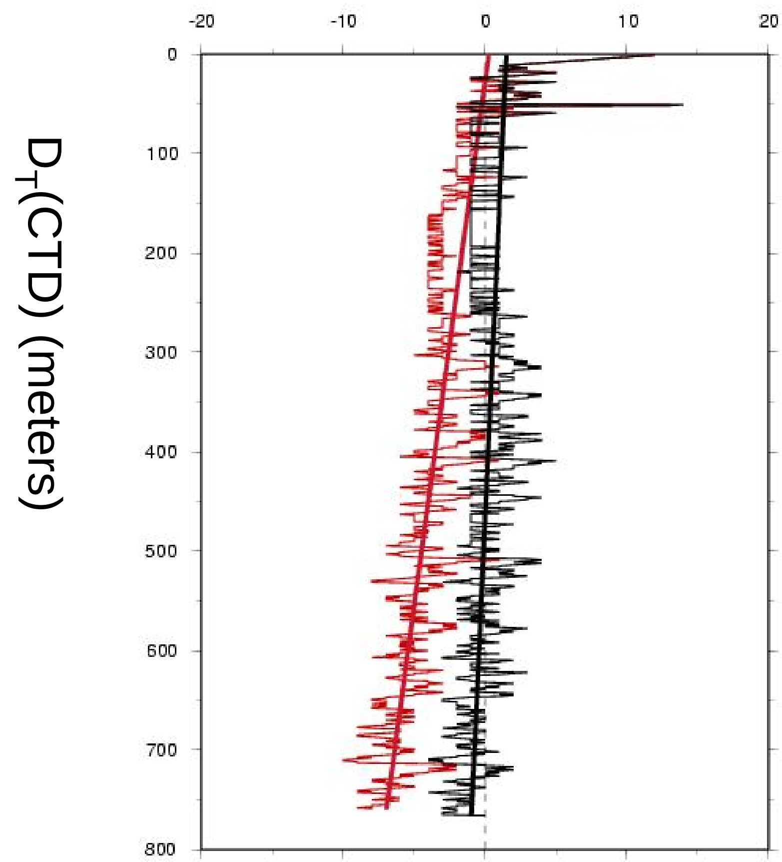
Sagar Kanya CTD-9, XBT-16
October 18, 2008 14°N, 91°E
New drop rate 6.80 m/s – 2.62×10^{-3} m/s^2
Thermal bias 0.01°C

T(XBT)-T(CTD) (°C)



Red=H95 drop rate
Black=new drop rate
Green=new drop rate – thermal bias

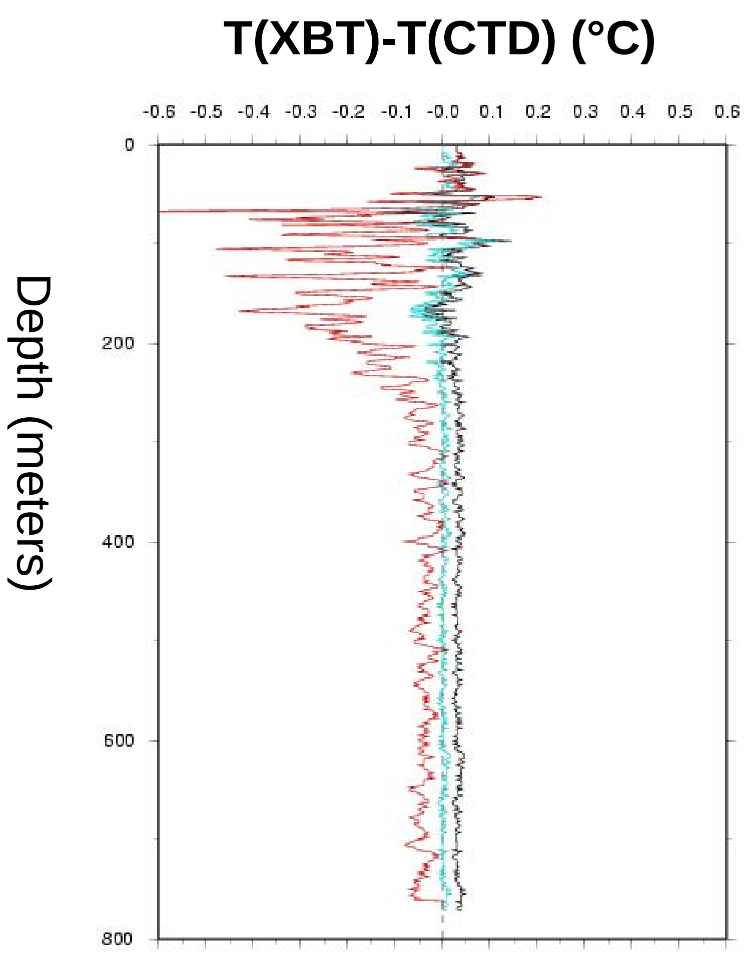
D_T(XBT)-D_T(CTD) (meters)



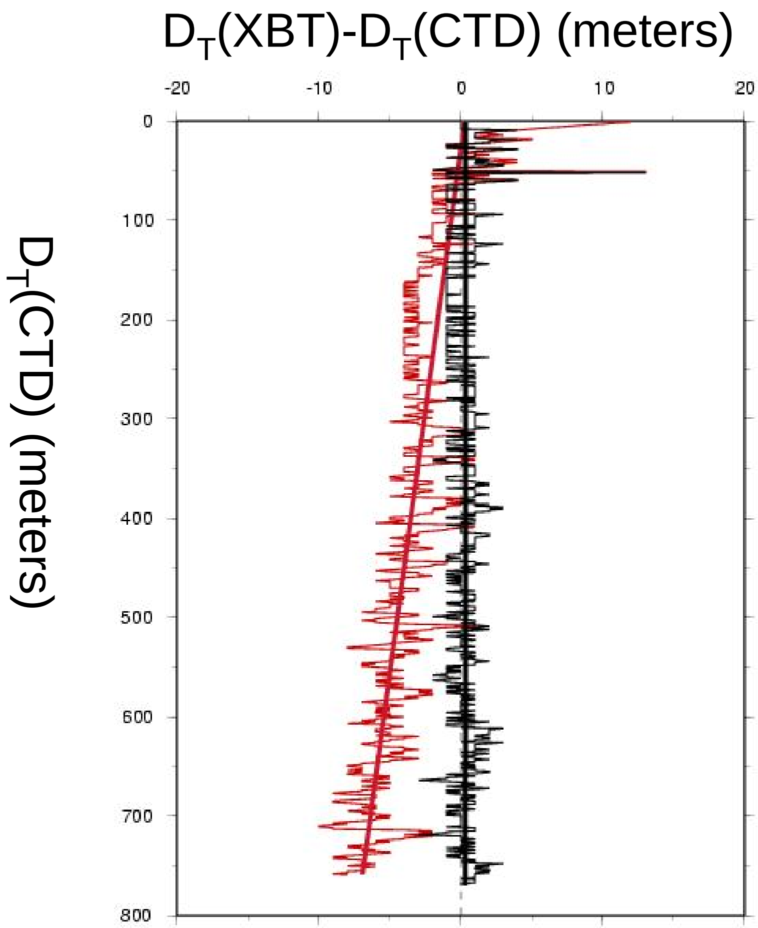
Red=H95 drop rate
Black=new drop rate – thermal bias

Minimizing depth difference slope

Sagar Kanya CTD-9, XBT-16
October 18, 2008 14°N, 91°E
New drop rate 6.81 m/s – 2.35x10^{-3} m/s^2
Thermal bias 0.03°C



Red=H95 drop rate
Black=new drop rate
Green=new drop rate – thermal bias

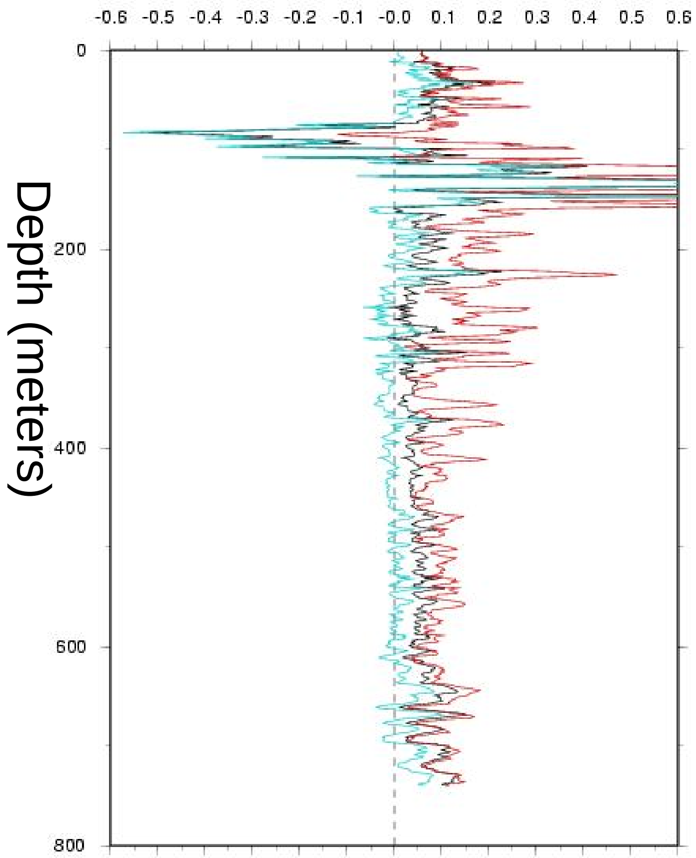


Red=H95 drop rate
Black=new drop rate – thermal bias

Minimizing temperature difference slope

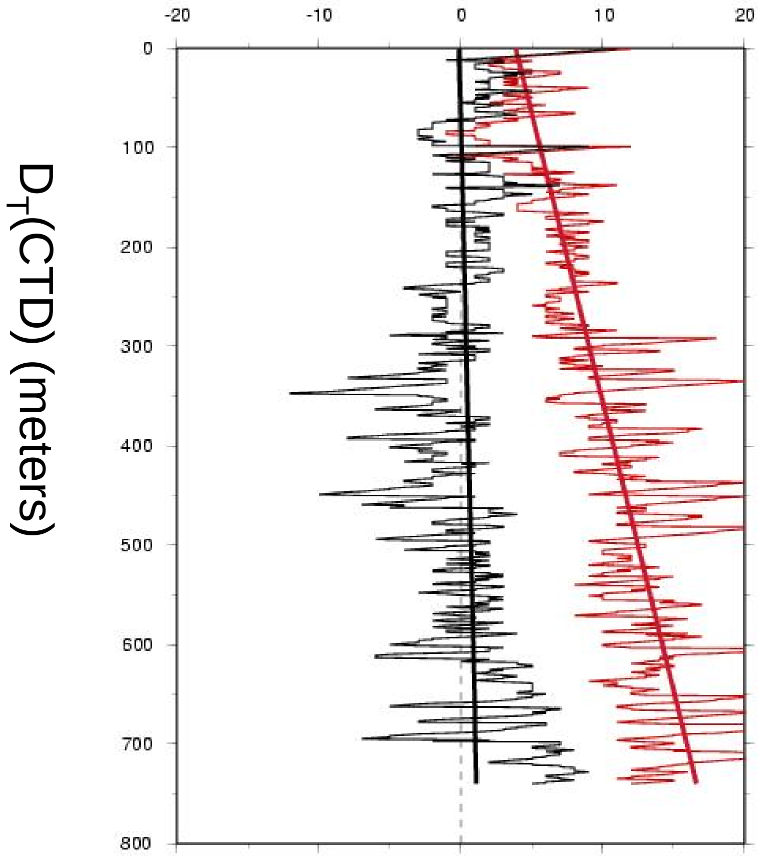
Sagar Purvi CTD-7, XBT-9
October 18, 2008 10°N, 75.23°E
New drop rate 6.51 m/s – 0.76x10^{-3} m/s^2
Thermal bias 0.05°C

T(XBT)-T(CTD) (°C)



Red=H95 drop rate
Black=new drop rate
Green=new drop rate – thermal bias

D_T(XBT)-D_T(CTD) (meters)

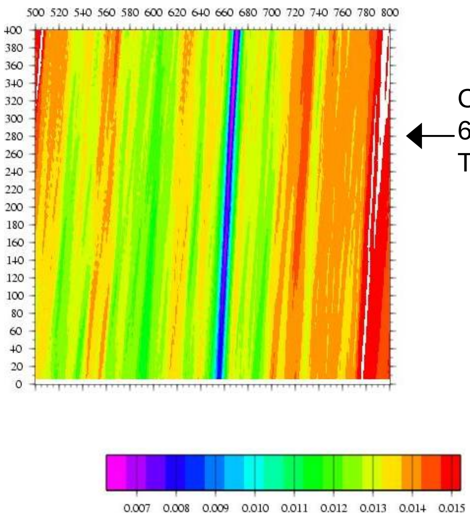


Red=H95 drop rate
Black=new drop rate – thermal bias

Sagar Purvi CTD-3, XBT 1-4, April 2,2009 10°N, 76.25°E

INITIAL VELOCITY (x 10^2 m/s)

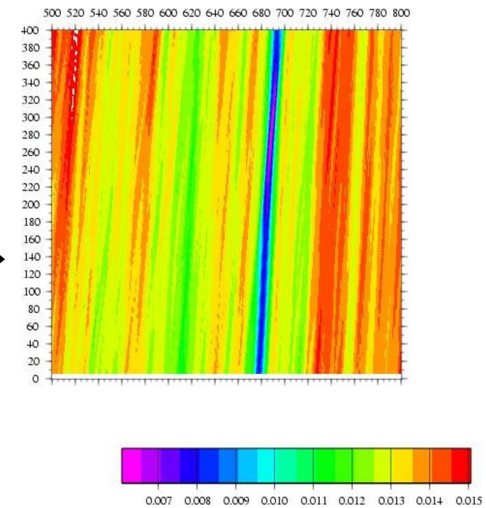
DECELERATION (X 10^5 m/s^2)



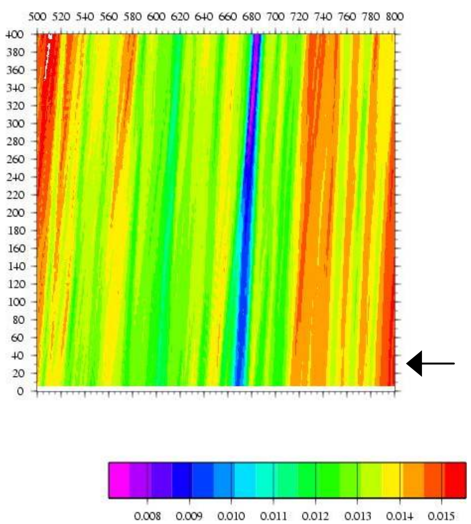
CTD-3 XBT-1
6.71 m/s – 3.26 x 10^{-3} m/s^2
Thermal bias=0.00 °C

INITIAL VELOCITY (x 10^2 m/s)

CTD-3 XBT-2
6.87 m/s – 3.60 x 10^{-3} m/s^2
Thermal bias=0.01°C

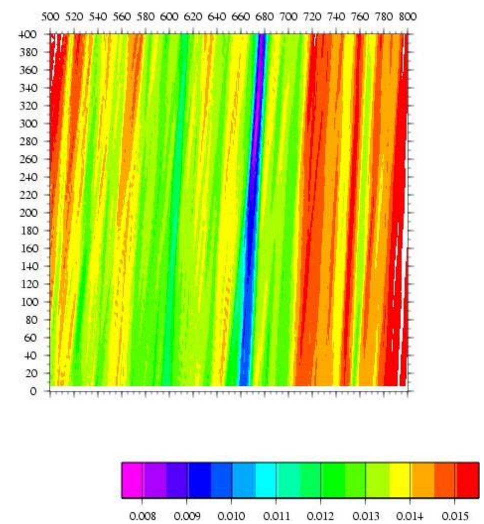


DECELERATION (X 10^5 m/s^2)



CTD-3 XBT-3
6.81 m/s – 3.71 x 10^{-3} m/s^2
Thermal bias=0.00 °C

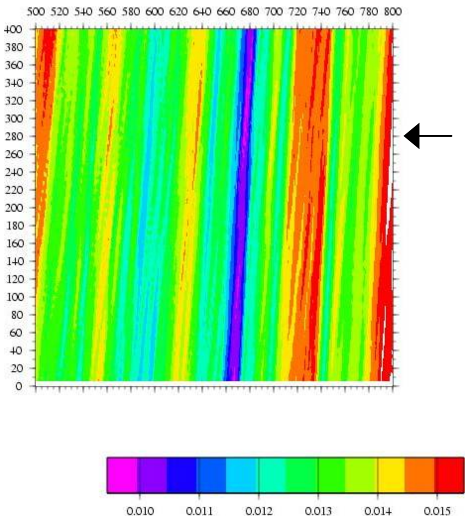
CTD-3 XBT-4
6.75 m/s – 2.42 x 10^{-3} m/s^2
Thermal bias=0.05 °C



Sagar Purvi CTD-4, XBT 1-4, April 2,2009 10°N, 76.25°E

INITIAL VELOCITY (x 10^2 m/s)

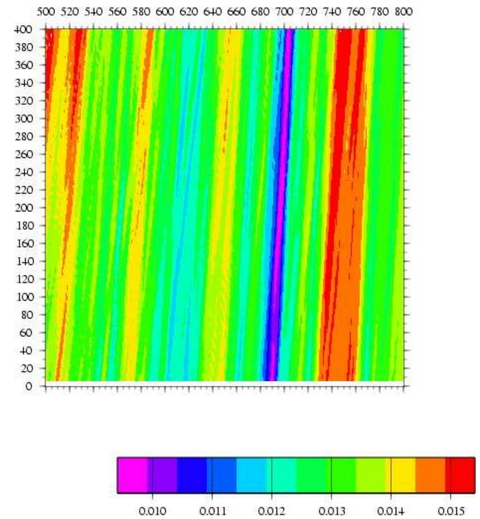
DECELERATION (X 10^5 m/s^2)



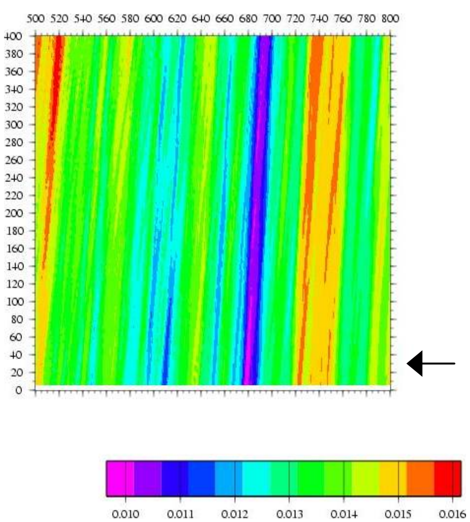
CTD-4 XBT-1
6.86 m/s – 3.74 x 10^{-3} m/s^2
Thermal bias=0.03 °C

INITIAL VELOCITY (x 10^2 m/s)

CTD-4 XBT-2
7.02 m/s – 3.89 x 10^{-3} m/s^2
Thermal bias=0.07°C

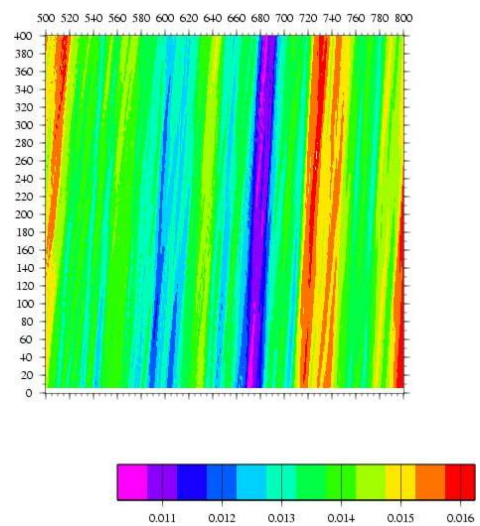


DECELERATION (X 10^5 m/s^2)



CTD-4 XBT-3
6.97 m/s – 3.99 x 10^{-3} m/s^2
Thermal bias=0.06 °C

CTD-4 XBT-4
6.88 m/s – 3.82 x 10^{-3} m/s^2
Thermal bias=0.05 °C

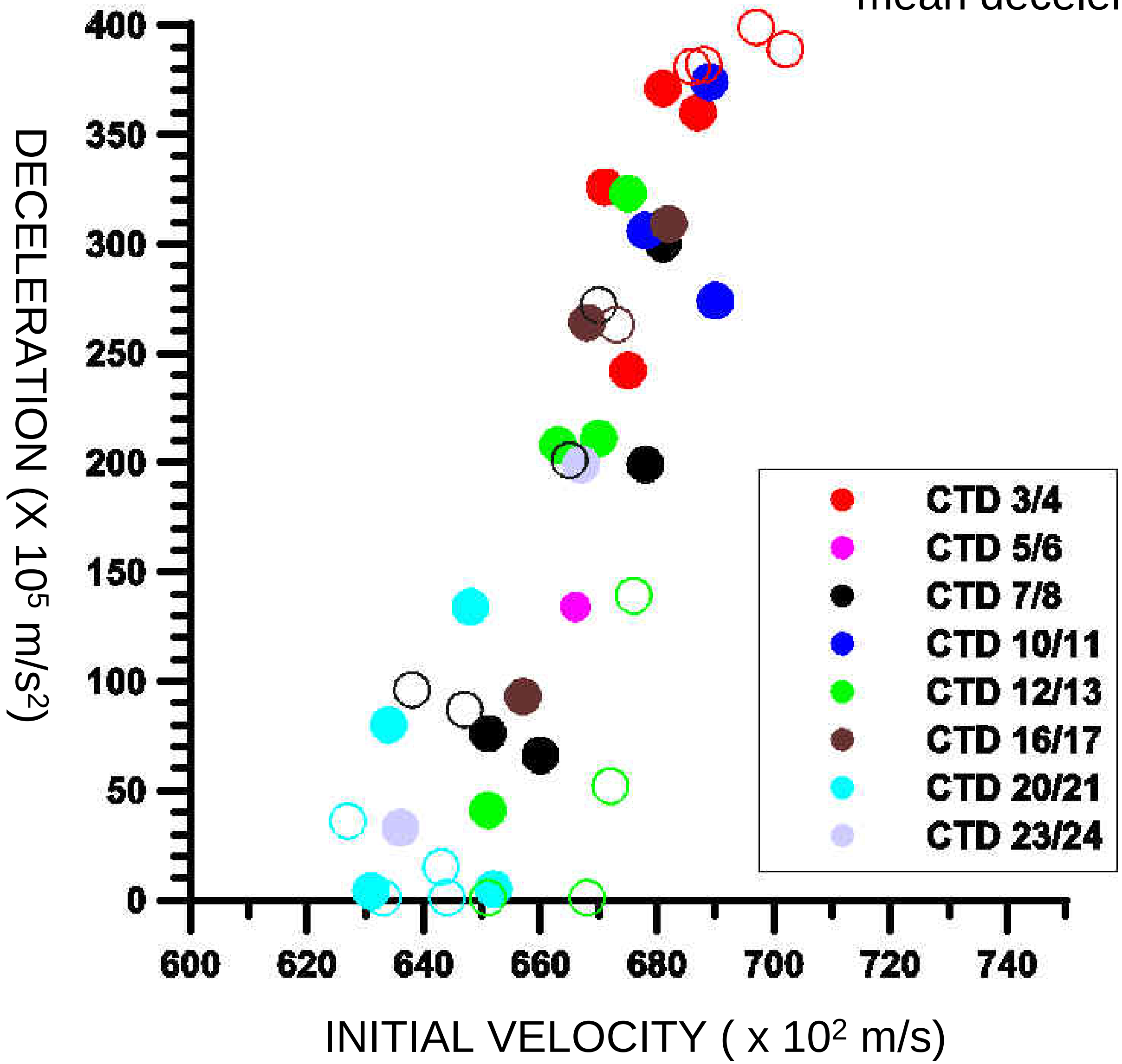


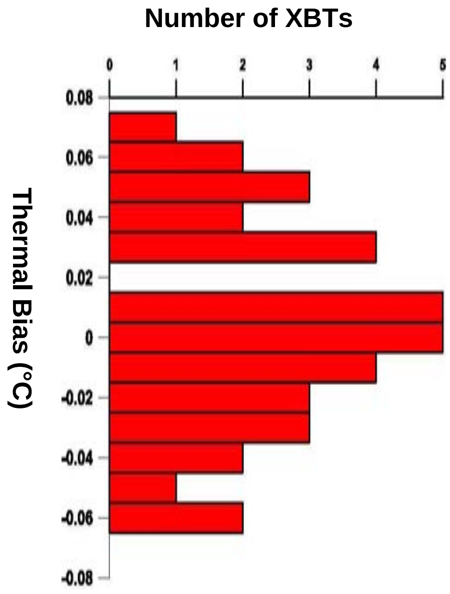
Sagar Purvi recalculated drop rates/thermal bias

Closed circle: XBT vs. CTD_1, Open Circle: XBT vs CTD_2

mean initial velocity 6.65 +/- 0.19 m/s

mean deceleration 1.82 +/- 1.36 m/s^2

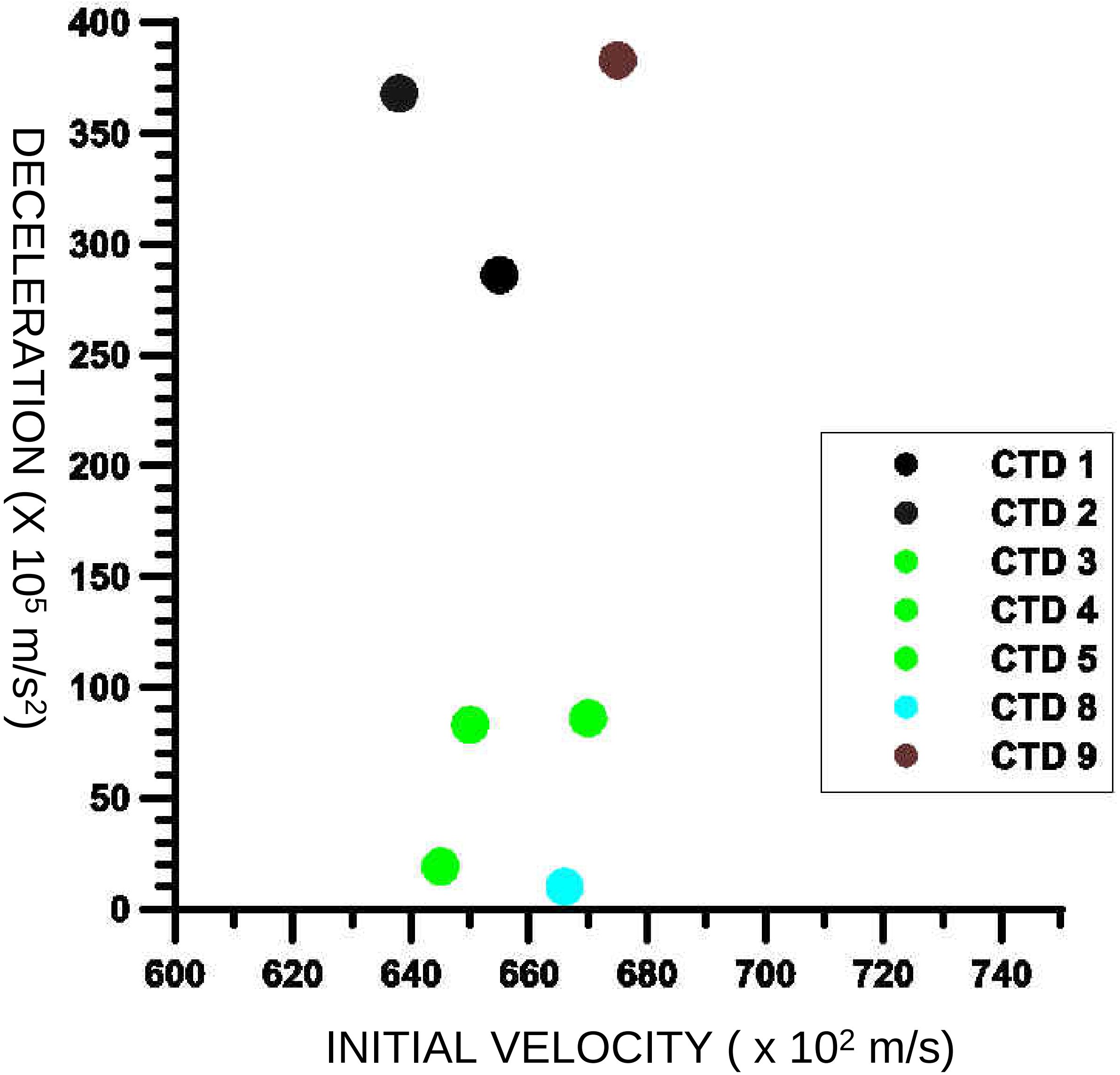


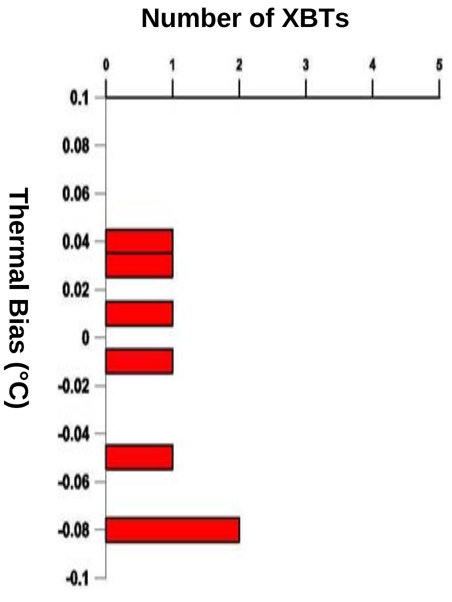


Sagar Sukti recalculated drop rates/thermal bias

mean initial velocit 6.51 +/- 0.14 m/s

mean deceleration 1.76 +/- 1.64 m/s^2

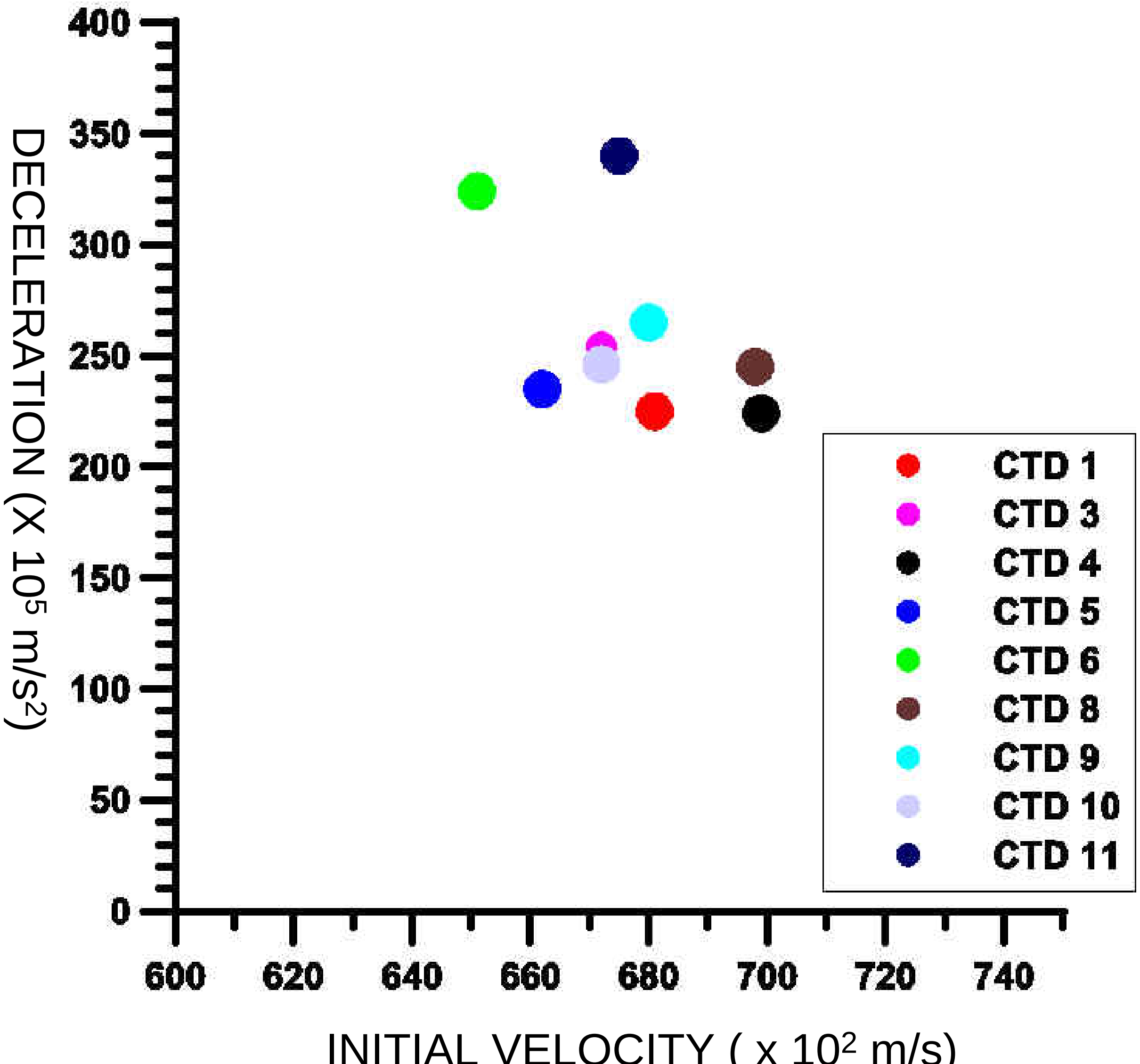


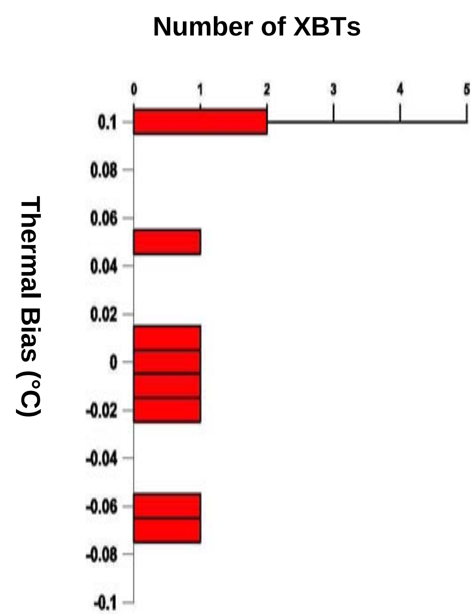


Sagar Kanya recalculated drop rates/thermal bias

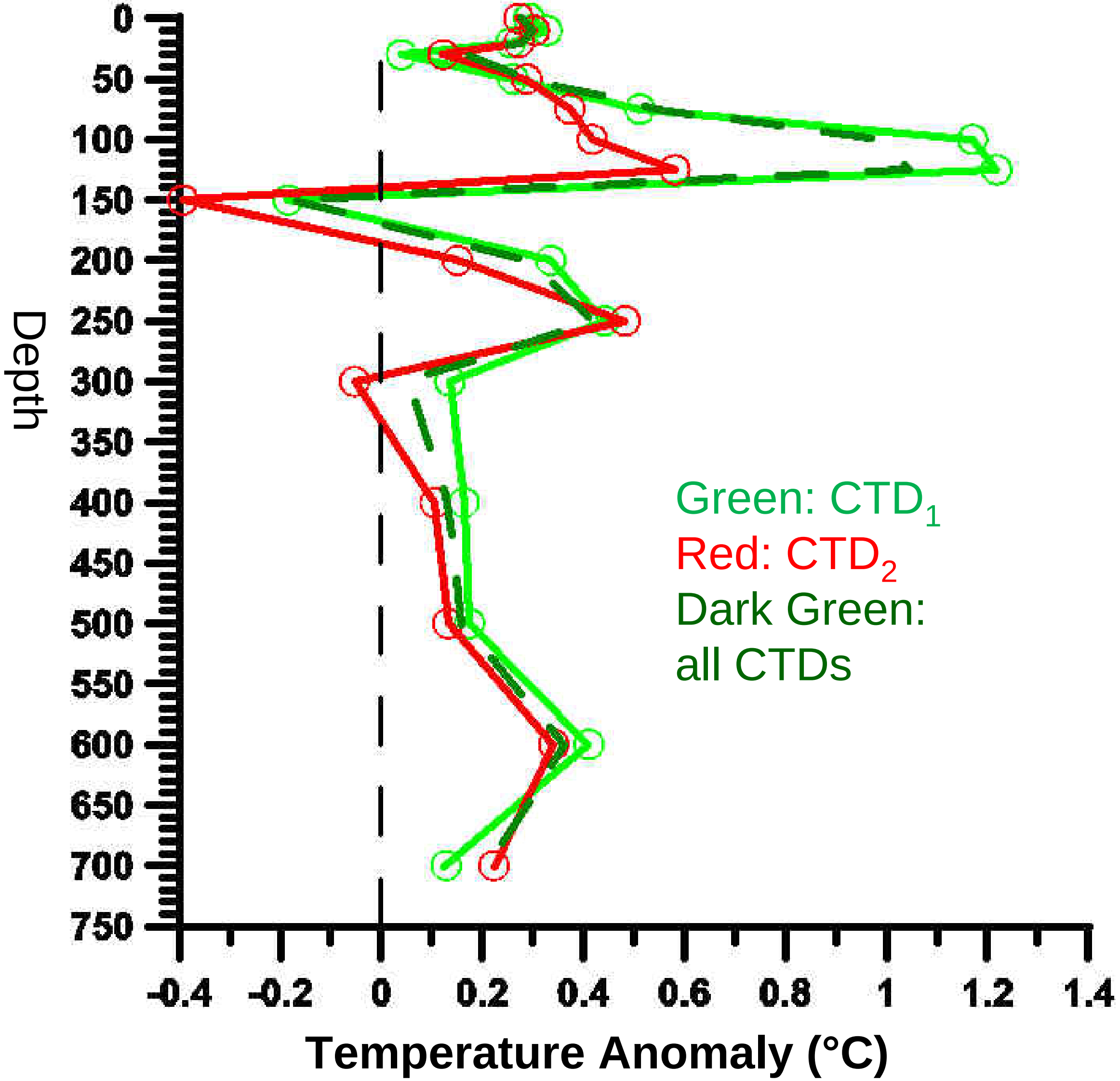
mean initial velocity 6.77 +/- 0.15 m/s

mean deceleration 2.62 +/- 0.14 m/s^2

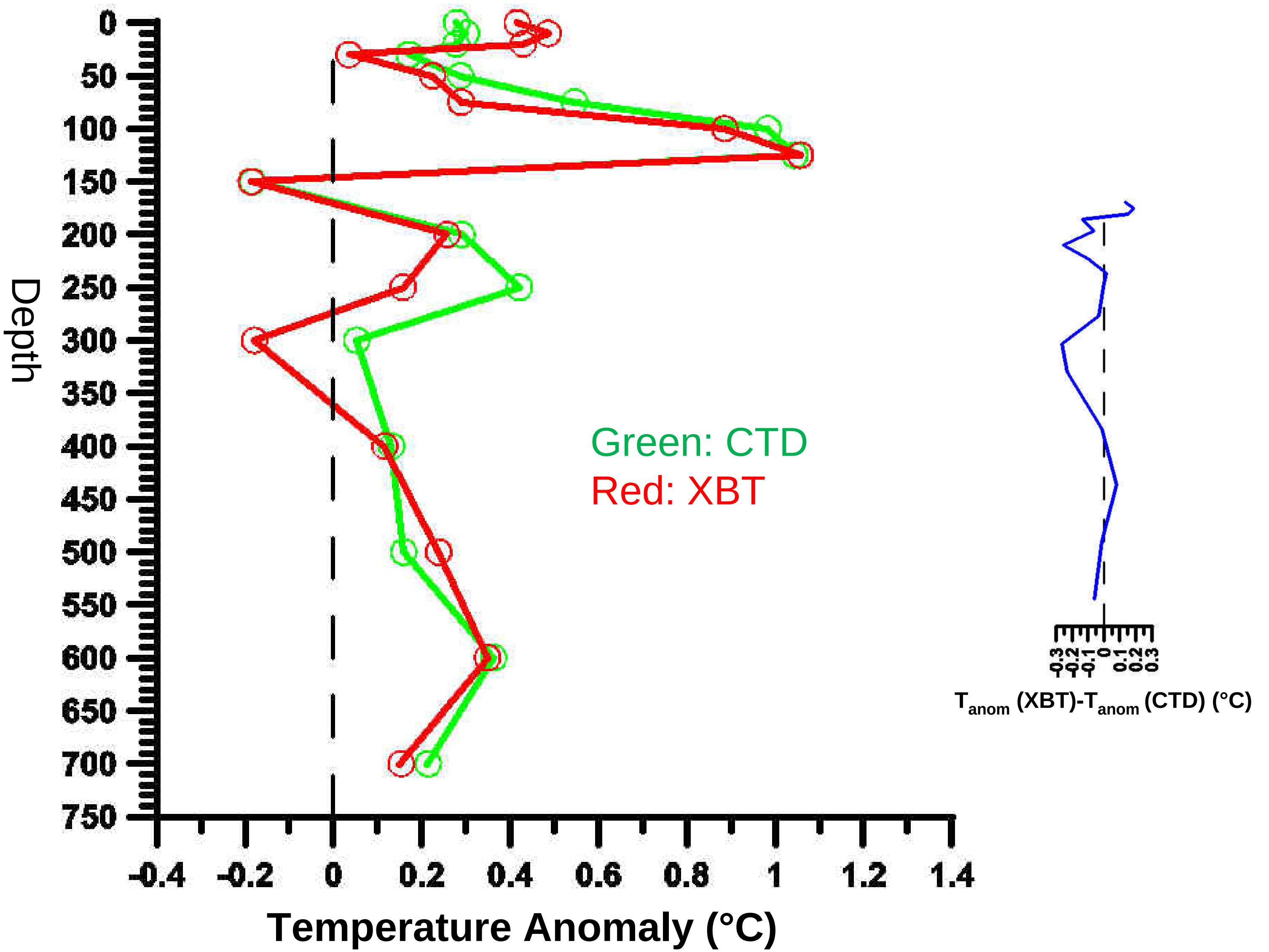




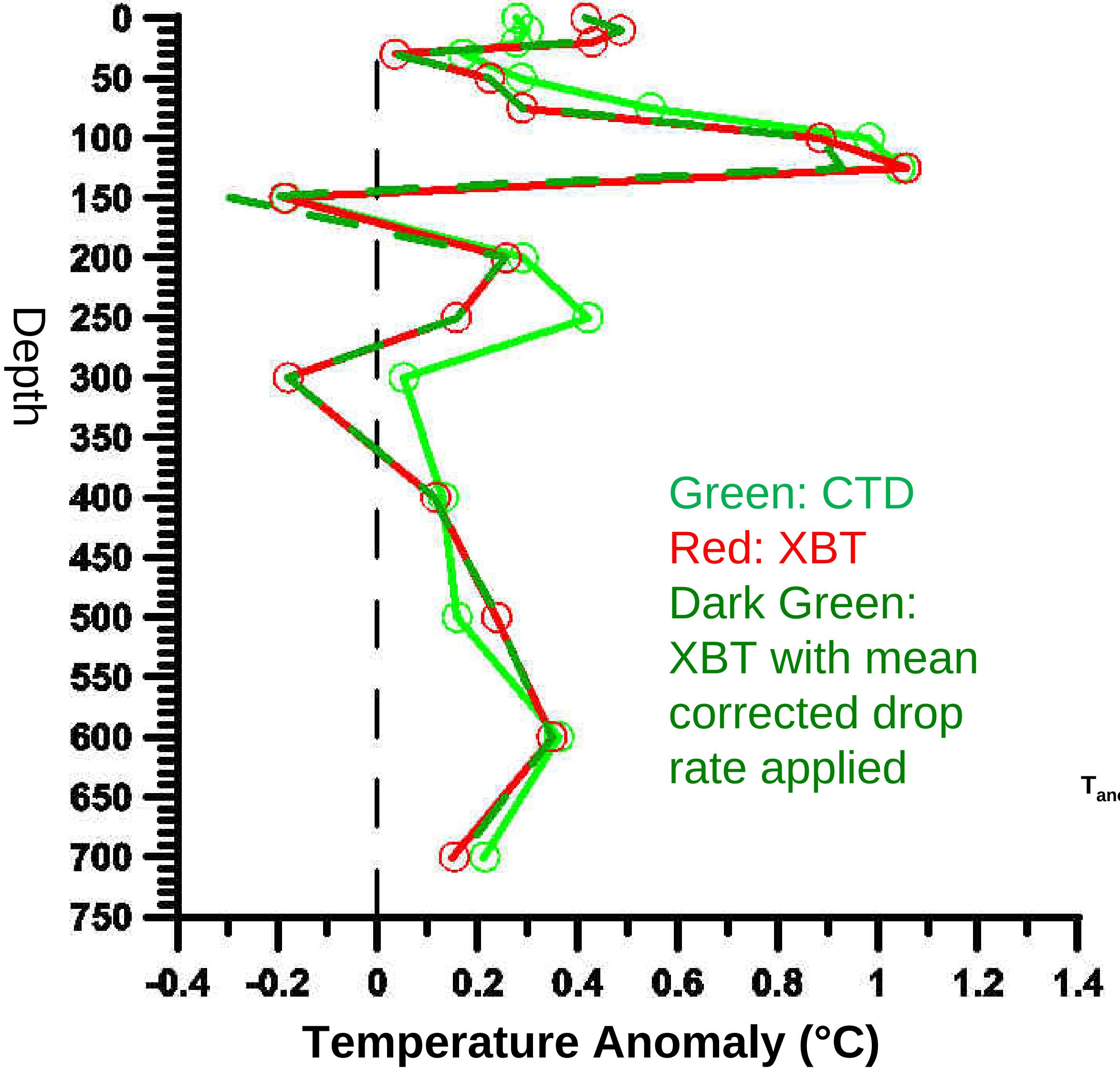
Mean Temperature Anomaly from comparison data: Sagar Purvi

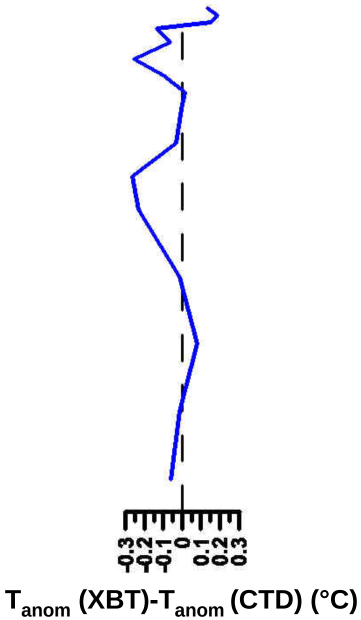


Mean Temperature Anomaly from comparison data: Sagar Purvi

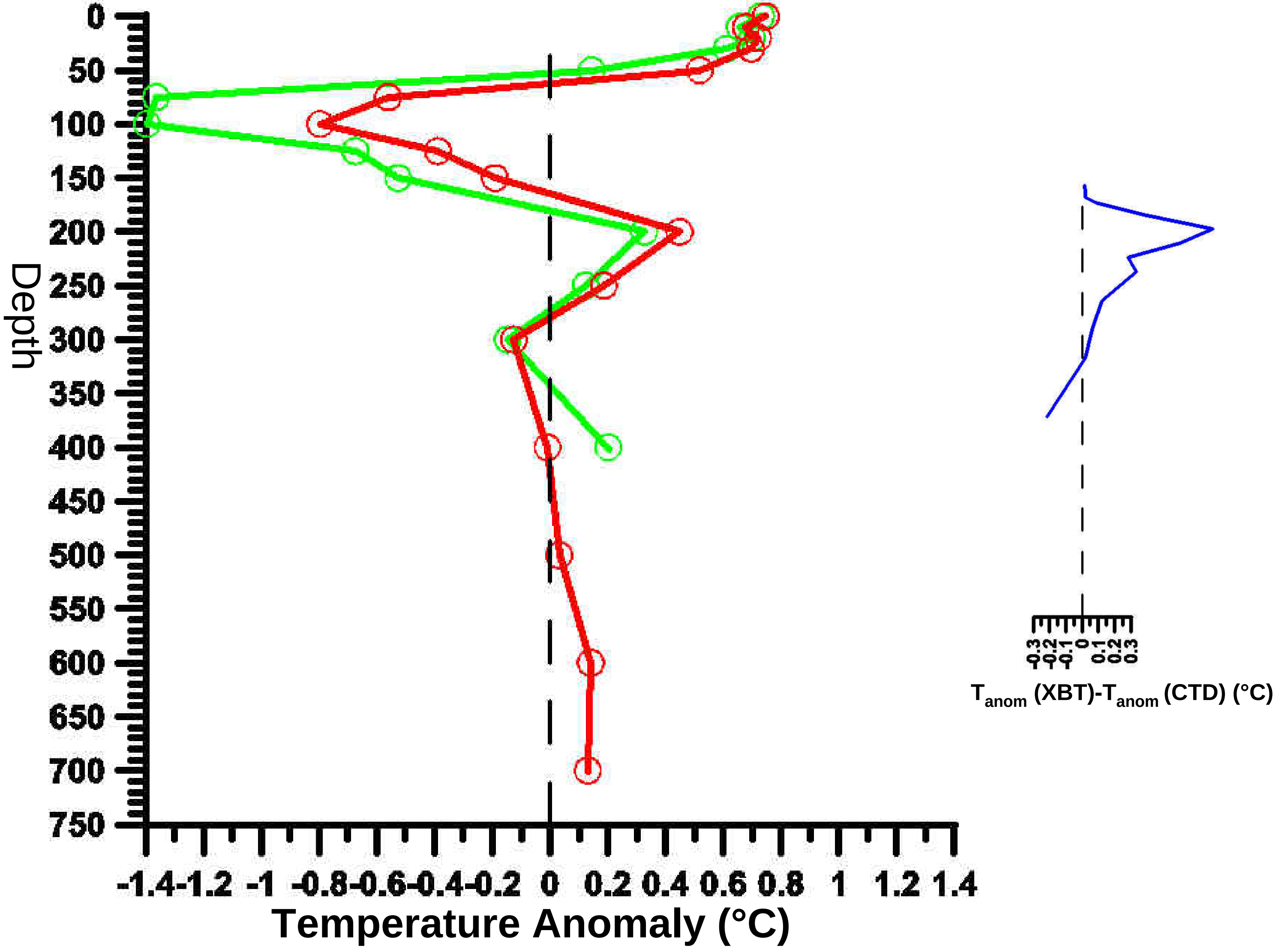


Mean Temperature Anomaly from comparison data: Sagar Purvi

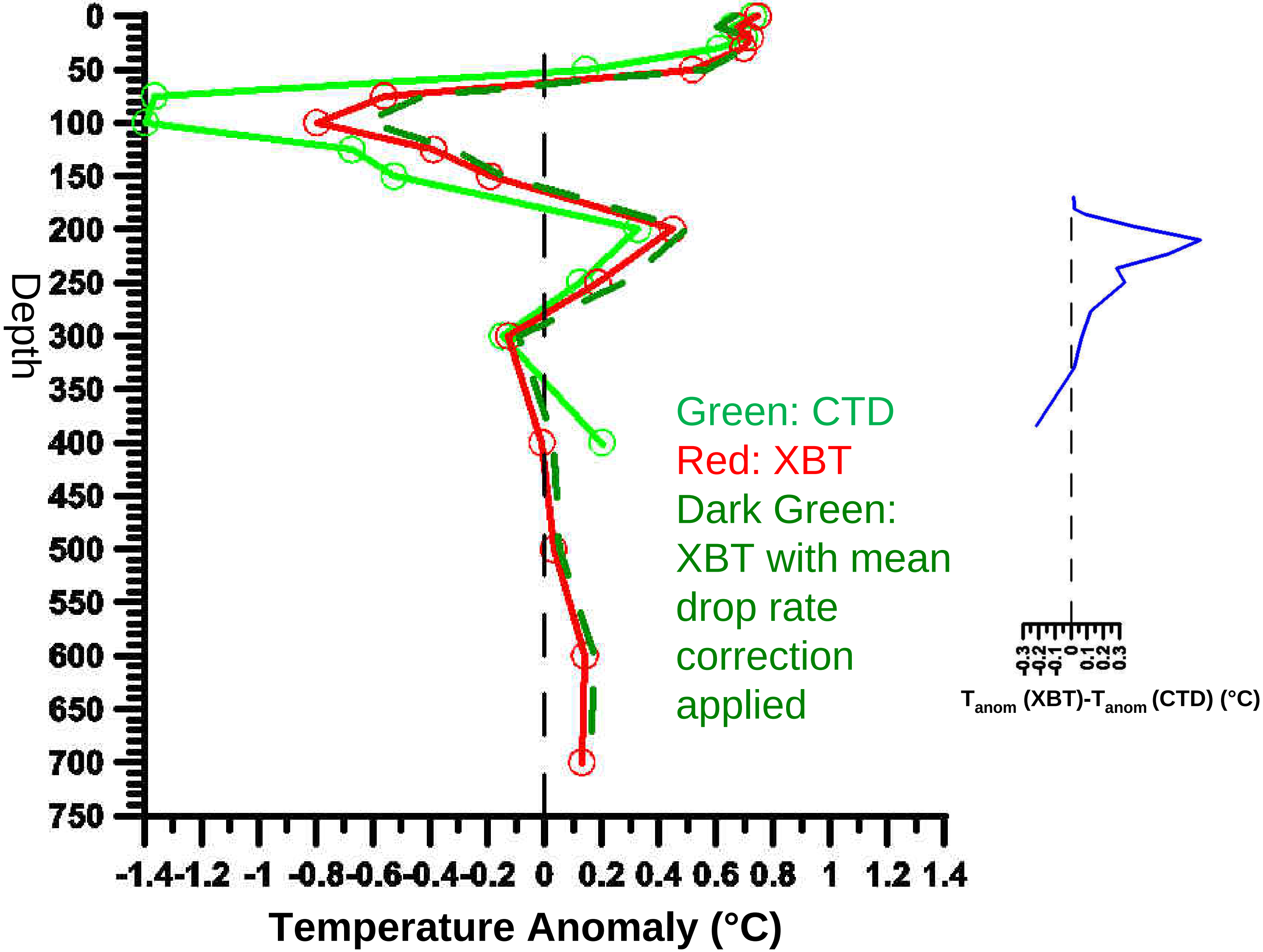




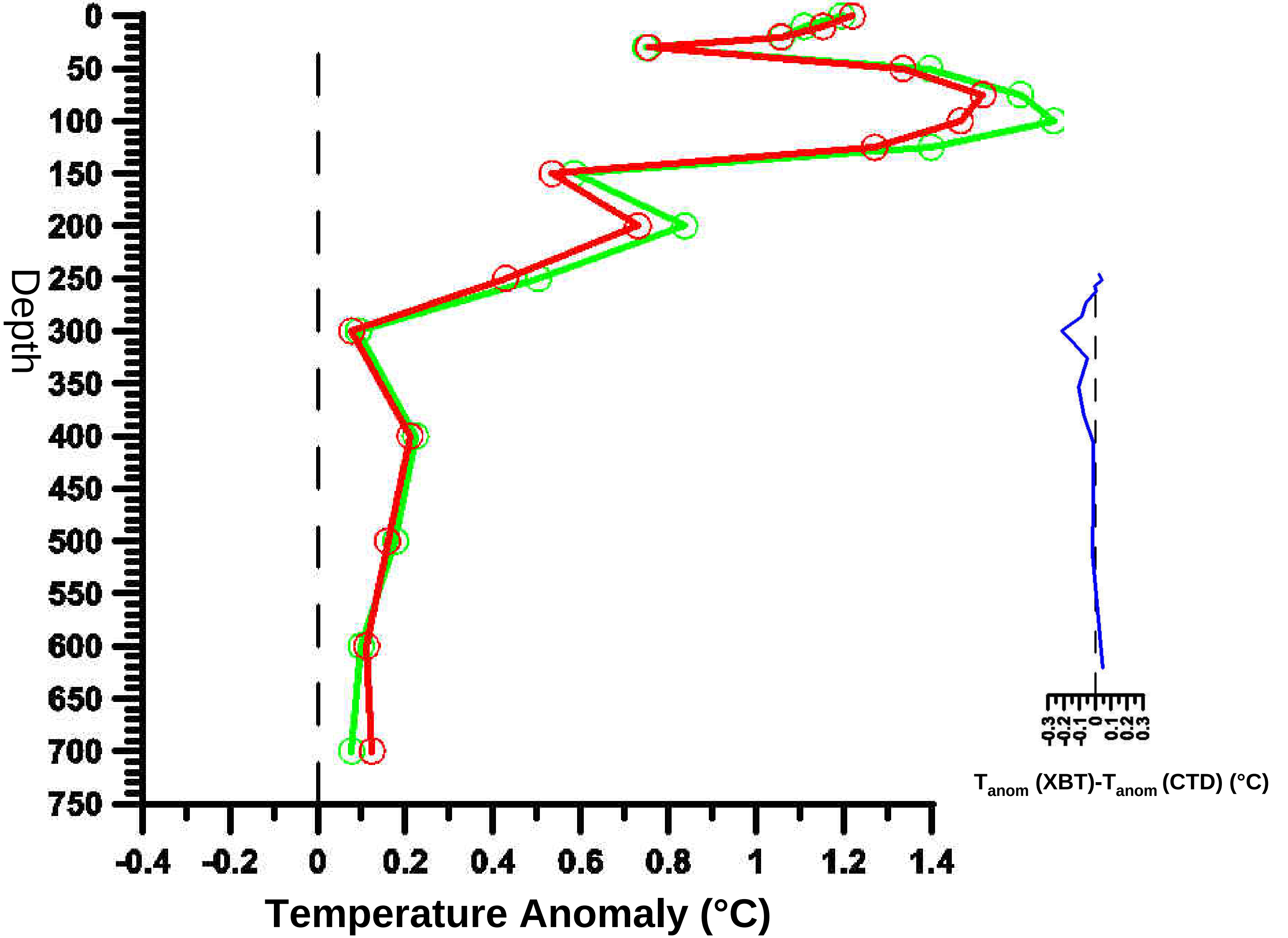
Mean Temperature Anomaly from comparison data: Sagar Sukti



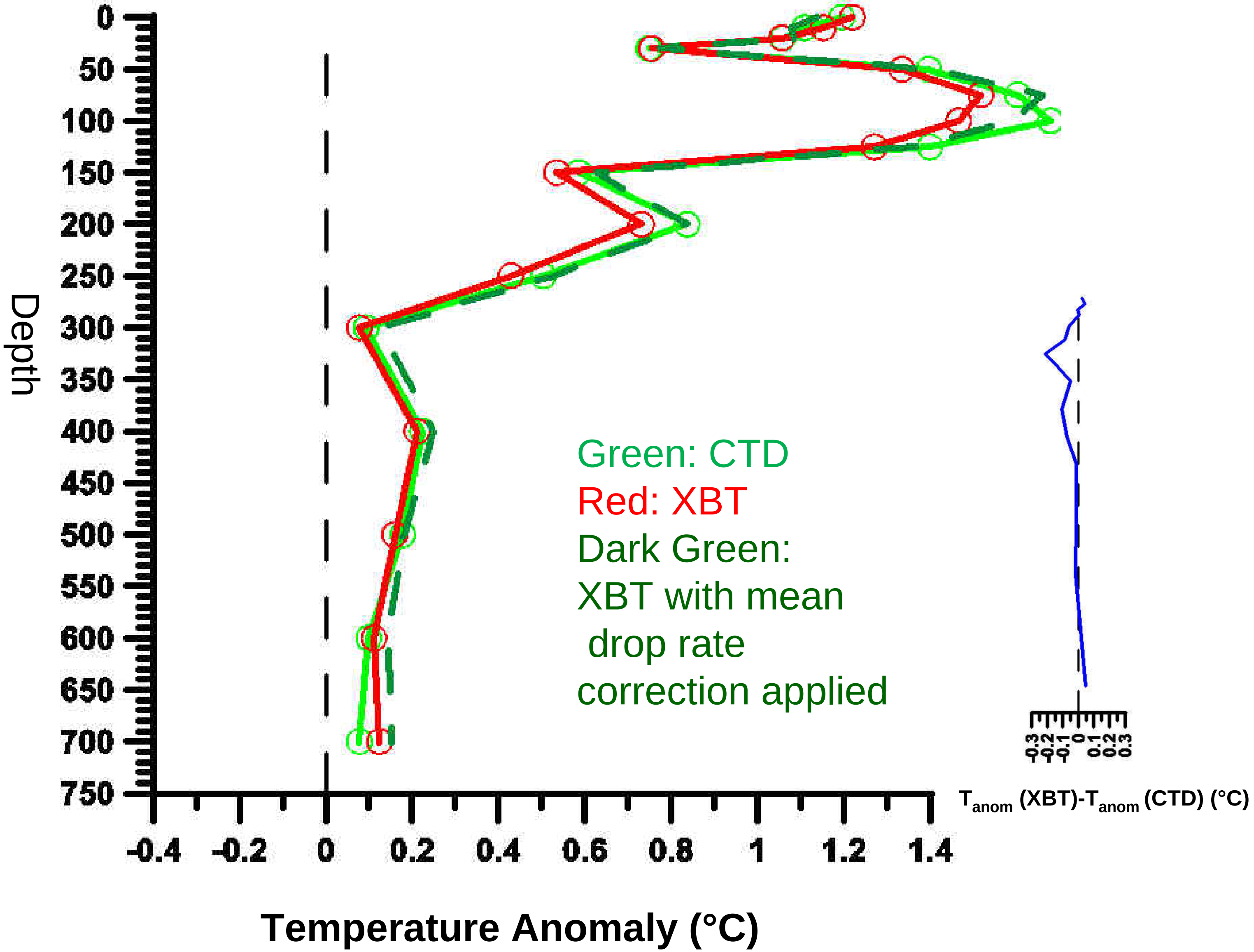
Mean Temperature Anomaly from comparison data: Sagar Sukti



Mean Temperature Anomaly from comparison data: Sagar Kanya



Mean Temperature Anomaly from comparison data: Sagar Kanya



Conclusions I: General

- There is significant variability between near-simultaneous CTD casts. This complicates comparison tests

- Minimizing XBT – CTD differences over possible drop rates shows a narrow band of legitimate initial velocities (a coefficient) over a large range of decelerations (b coefficient).

- No conclusive pattern of warm or cold bias emerges in the Arabian Sea. In the Bay of Bengal, XBT data are slightly cooler than CTD data.

- In addition to depth differences, a small thermal bias (usually < 0.08) is present in many comparision tests. The bias may equally be negative or positive.

Conclusions II: Individual Cruises

- The Sagar Kanya cruise (Bay of Bengal) yields a drop rate with slightly higher initial velocity and deceleration than H95.
- The Sagar Purvi cruise (Arabian Sea) shows a large range of drop rates, with an ellipse centered near H95
- The Sagar Sukti cruise (Arabian Sea) shows a large range of drop rates, with initial velocity less than H95. However, this is a sparse data set with disparate results.

Conclusions III: Implications for Climate Studies

- **Composited temperature anomalies using XBT data vs. CTD data give different structure vs. depth in both the Arabian Sea and Bay of Bengal.**

- **Based on these 3 cruises, this uncertainty is not reduced in the Arabian Sea using alternative drop rates, but is reduced for the Bay of Bengal.**

- **Bay of Bengal XBT record can be used for climate change studies. More tests would be helpful in the Bay. Climate change studies in the Arabian Sea with XBT data should be executed with care.**

Future Work

- Try present comparison method on historic Arabian Sea cruises (Pankajashan et al. 1998)
- Try present method on other comparison data sets (Yellowfin 2005)
- Formulate working plan for historic and future XBT drops in the Arabian Sea and Bay of Bengal with regards to climate research

Mean Temperature Anomaly from comparison data: Yellowfin