Investigation of XBT and XCTD biases in the seas around India

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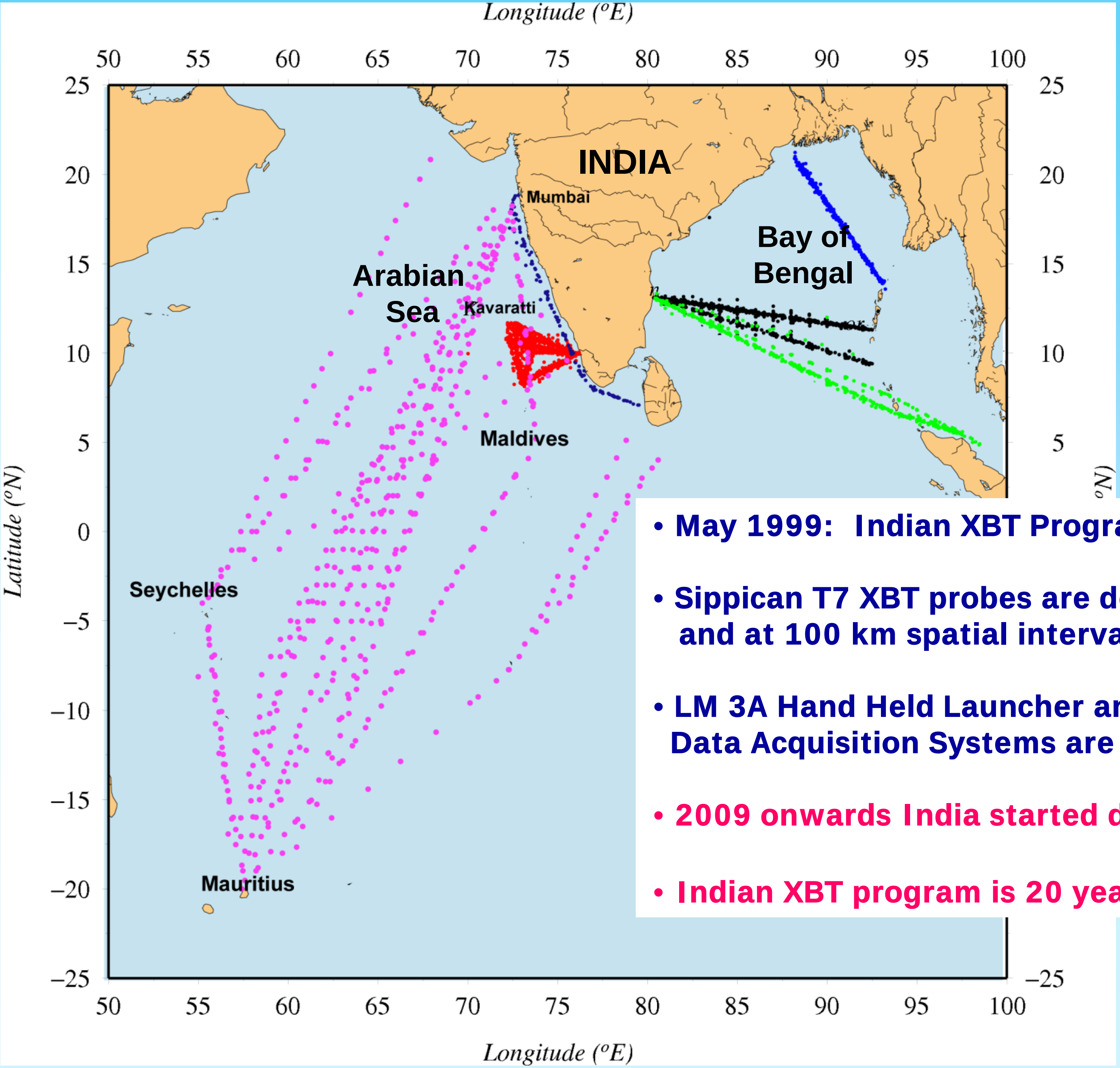
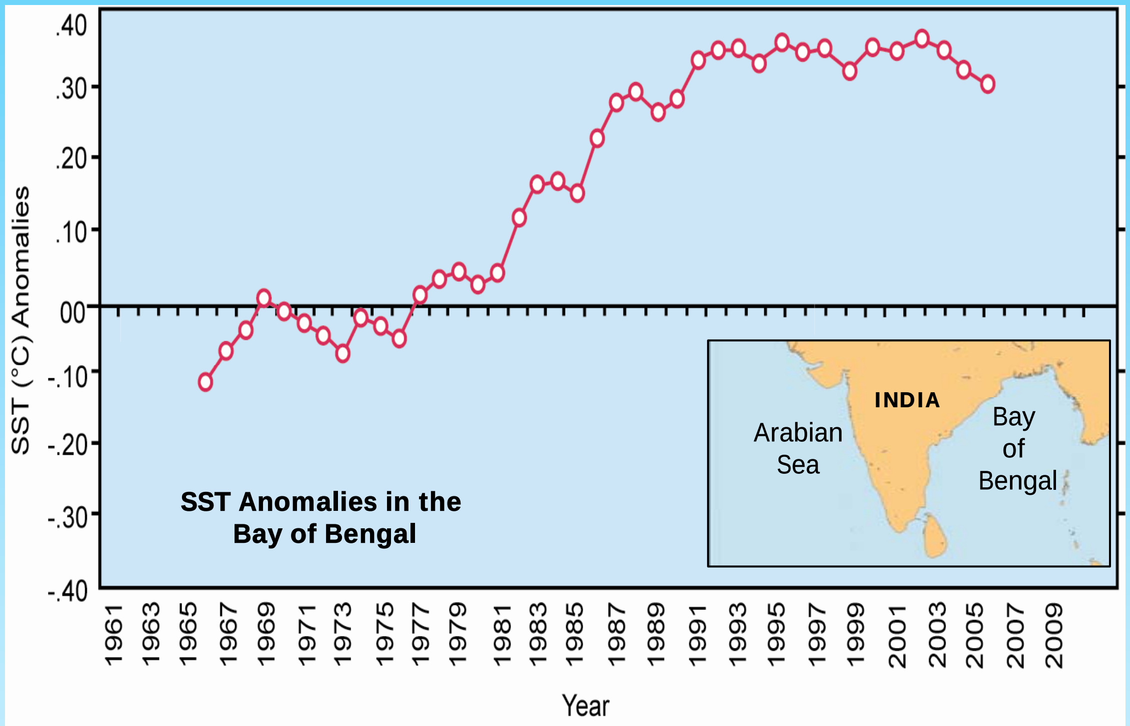
1: N O D C, USA 2: N I O, India 3: E N E A, Italy

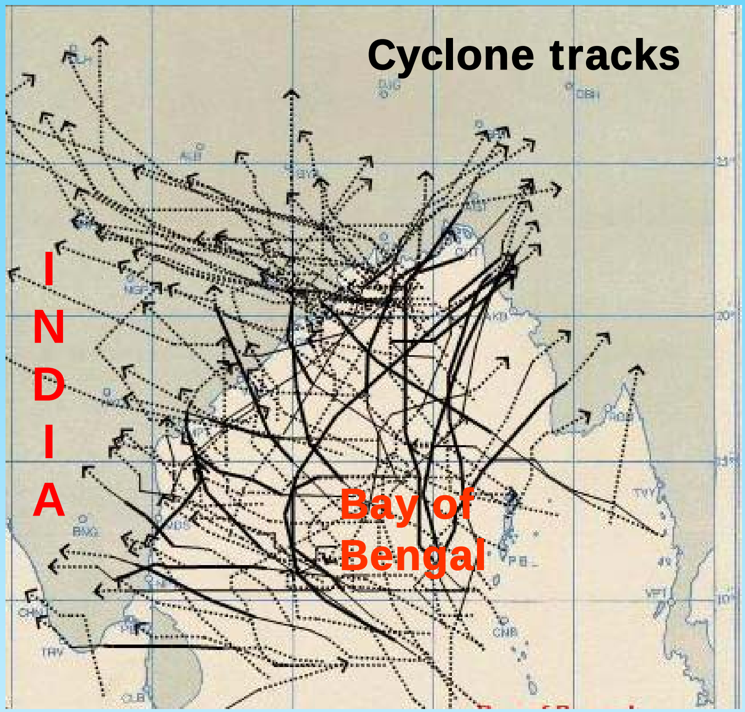
Ongoing Indian XBT Transects



- **May 1999: Indian XBT Program was initiated.**
- **Sippican T7 XBT probes are deployed at monthly and at 100 km spatial intervals.**
- **LM 3A Hand Held Launcher and MK - 21 / MK – 150 Data Acquisition Systems are used.**
- **2009 onwards India started deploying TSK XCTD3's.**
- **Indian XBT program is 20 years old**

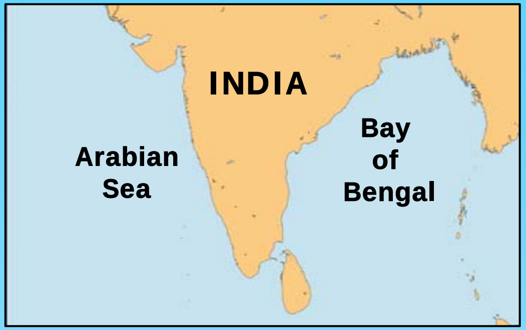
SST Anomalies and Cyclone tracks in the Bay of Bengal





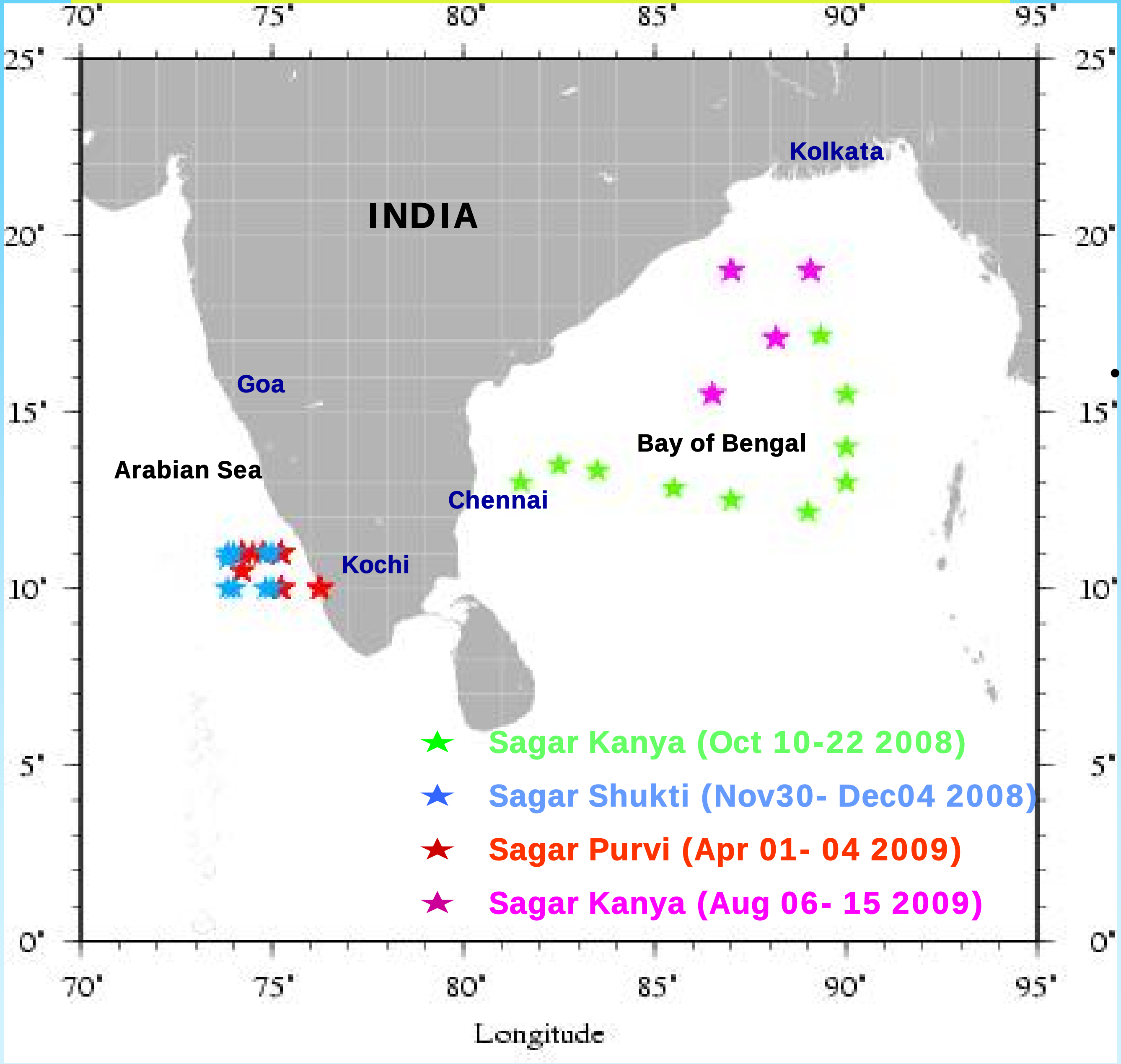
- SSTs in the Bay of Bengal & in the North Indian Ocean have been showing an increasing trends
- However, sub-surface heat contents does not show such increasing trends
- Bay of Bengal experiences devastating cyclonic storms during pre & post monsoon seasons.
- 20 years time series XBT data is very valuable for examining the Climate Variability Studies.

Critical issues to be resolved.



- **Can we apply a Uniform bias correction for Arabian Sea & Bay of Bengal?**
- **Is it necessary to consider these basins separately ??**
- **How large would be the error with an uniform bias correction ??**
- **If we do not apply corrections, are the temperature bias errors are small enough to examine long term temperature change signals ??**

XBT/XCTD/CTD comparison tests in the Bay of Bengal and Arabian Sea



- Conducted 4 special cruises
  Two in the Bay of Bengal
  & two in the Arabian Sea

- Deployed XBTs & XCTDs
  within 15 minutes of the
  start time of the CTD cast

Details on cruises conducted & CTDs used in the present study

Area of Operation	Ship Name	Cruise Period	Winch Speed (m/min)	Height of Operation From Sea Surface (m)	Type of CTD Used	Local Weather
Bay of Bengal (BB) 2008	Sagar Kanya	10 – 22 October 2008	30-35	10	Idronaut	Moderate
Arabian Sea (AS) 2008	Sagar Shukti	Nov 30 – Dec 04, 2008	30-35	2	Seabird	Calm
Arabian Sea (AS) 2009	Sagar Purvi	01 – 04 April , 2009	35-40	4	Seabird	Calm
Bay of Bengal (BB) 2009	Sagar Kanya	06 – 15 August 2009	30-35	10	Seabird	Rough

Details on XCTDs & XBTs used in the present study

Cruise	XBT Manufacturer and Type	XCTD Manufacturer and Type	XBT Date of Manufacture	XCTD Date of Manufacture	XBT/XCTD Data Acquisition System
BB08	Sippican T7	TSK XCTD-3	Aug, 2008	Feb, 2008	MK-130
AS08	Sippican T7	TSK XCTD-3	Aug, 2008	Feb, 2008	MK-130
AS09	Sippican T7	TSK XCTD-3	Aug, 2008	Aug, 2008	MK-130
BB09	Sippican T7	TSK XCTD-3	May, 2009	Aug, 2008	MK-130

In 3 cruises SESCAT CTD Profiler & in 1 cruise Idronaut CTD.

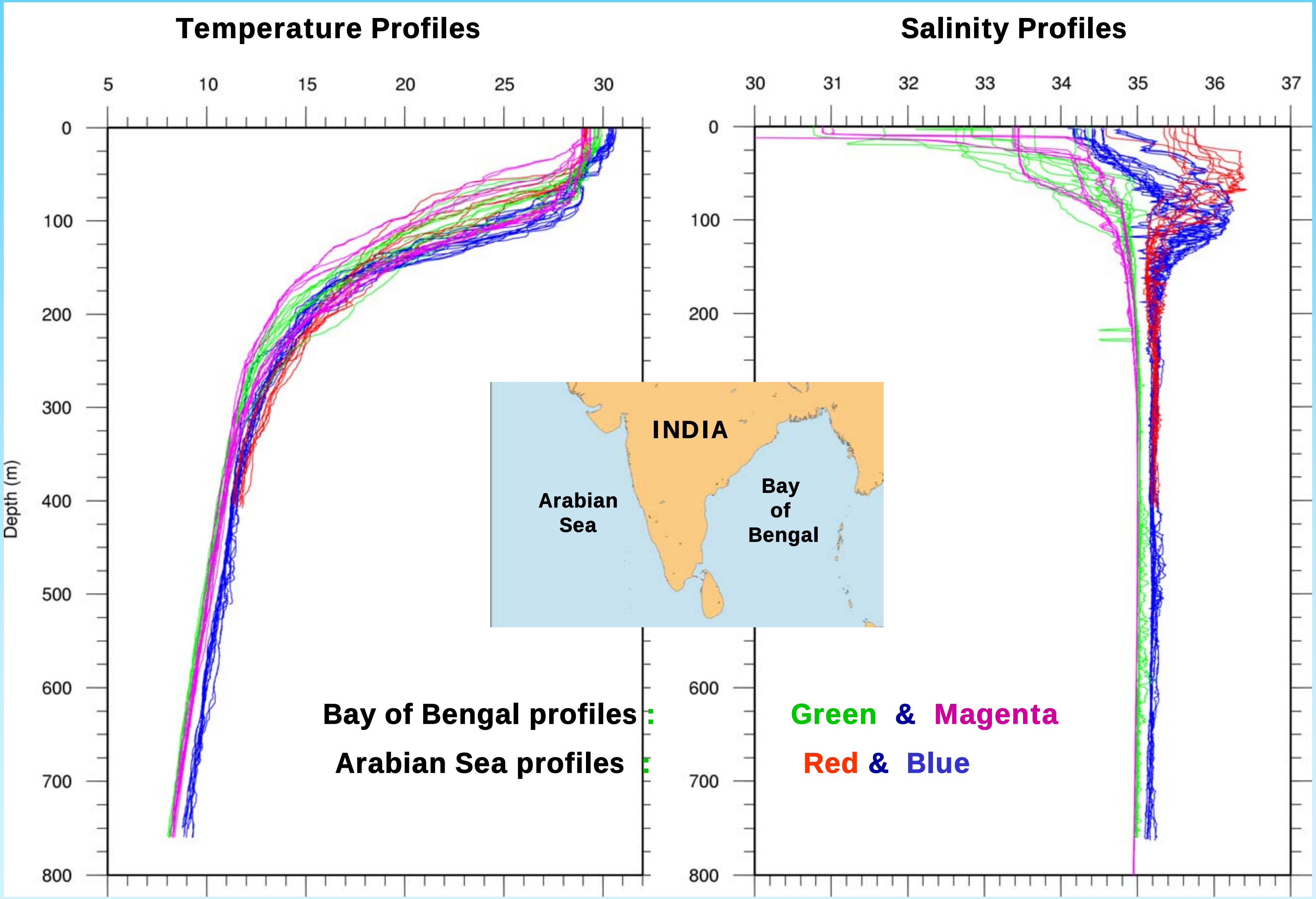
SEACAT sampling rate is 4 Hz
0.005^0C & 0.0005 Sm^{-1}

SEACAT CTD was calibrated prior to each cruise

Idronaut sampling rate is 40 Hz, 0.001^0C & 0.0001 Sm^{-1}

XCTD Accuracies
0. 02^oC, 0. 003Sm^{-1}

CTD Temperature & Salinity profiles in the Bay of Bengal & Arabian Sea



Methodology

• Procedures of Hanawa 1995 (H95) for obtaining FRE coefficients was used as the basis for the methodology used in the present study

• XBT / XCTD depths are calculated using the FRE

$$Z = at - bt^2$$

a = initial velocity, b = probe acceleration &
t = time elapsed (seconds)

XBT depths : calculated initially using H95 FRE constants
XCTD depths : using TSK FRE coefficients

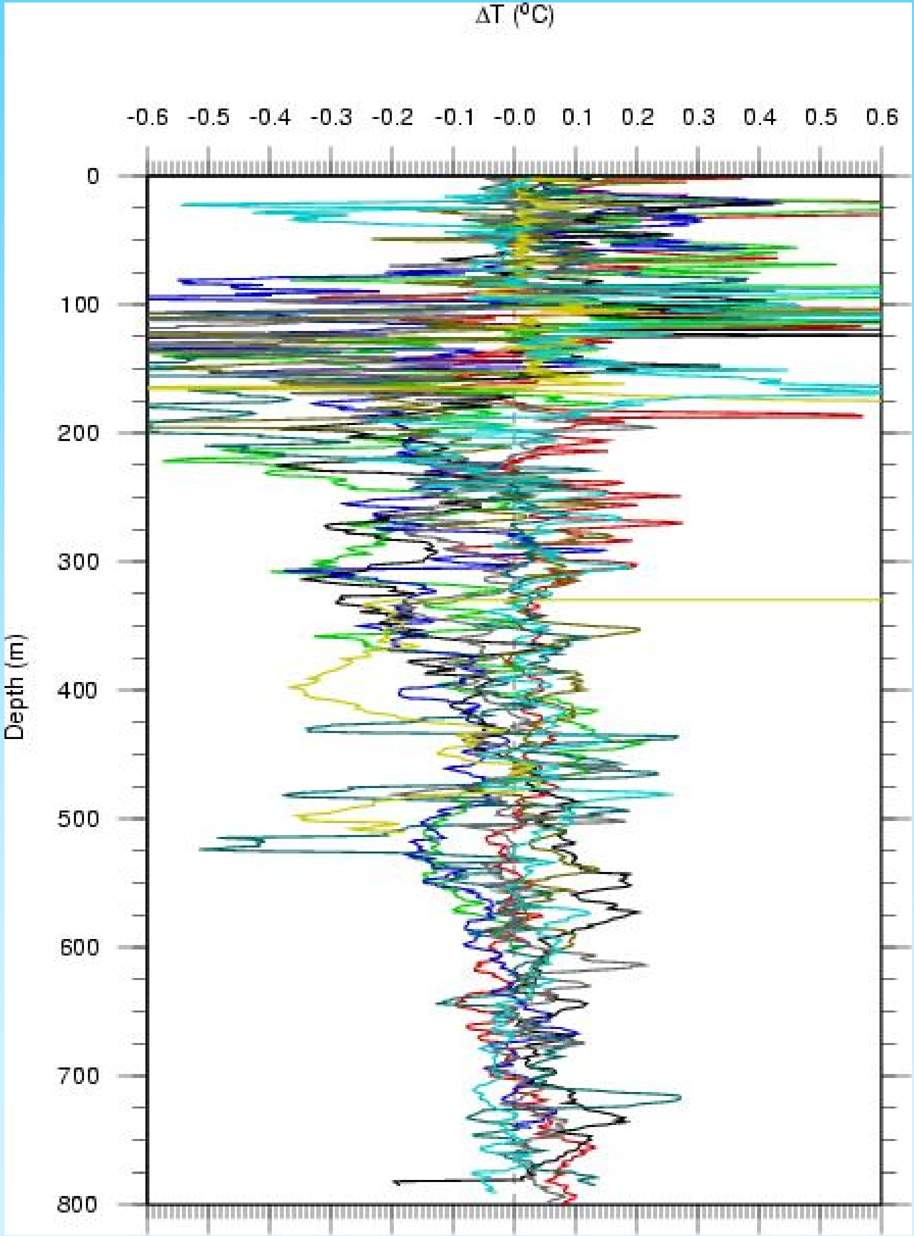
• XBT & CTD Depths were interpolated at 1m intervals.

• Vertical temperature gradients between 1m depths are calculated

• Time is back calculated from FRE.

• HN95 method was slightly modified by summing all vertical temperature gradient differences between XBT & XCTD, thus providing larger pool of values than H95.

Temperature differences between first & second CTD casts at each station in the Arabian Sea

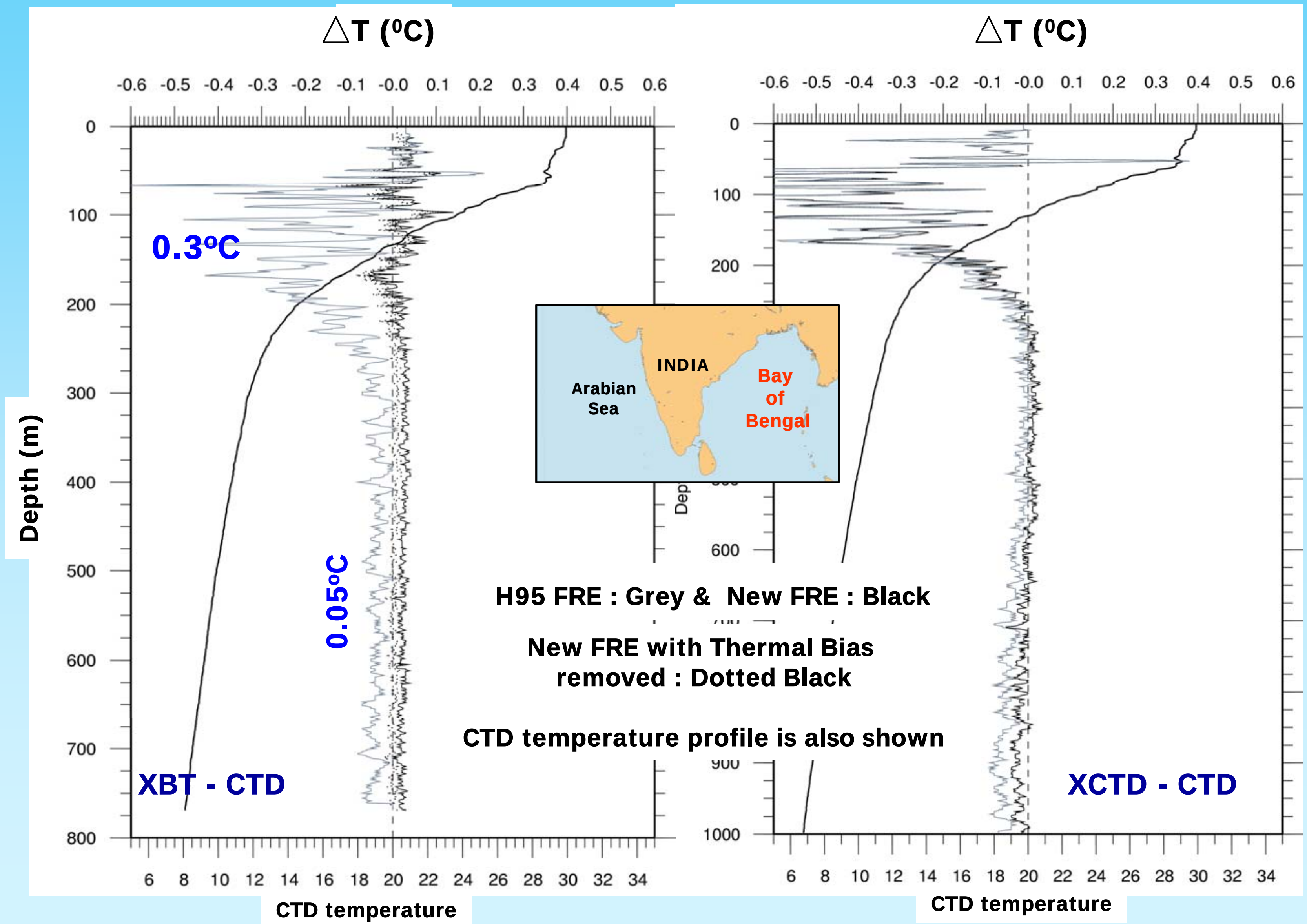


- Consecutive CTD casts have start times within 45 to 75 minutes of each other.
- Same CTD was lowered twice.
CTD was lowered with the same winch speed
- Internal waves & ship drift must have caused the observed temperature differences
- These differences are of the same order as temperature differences between CTDs and XBTs (XCTDs).
- This complicates estimation of XBT (XCTD) FRE by comparing with CTD cast.

Examples with individual XBT & XCTD cases from the Bay of Bengal

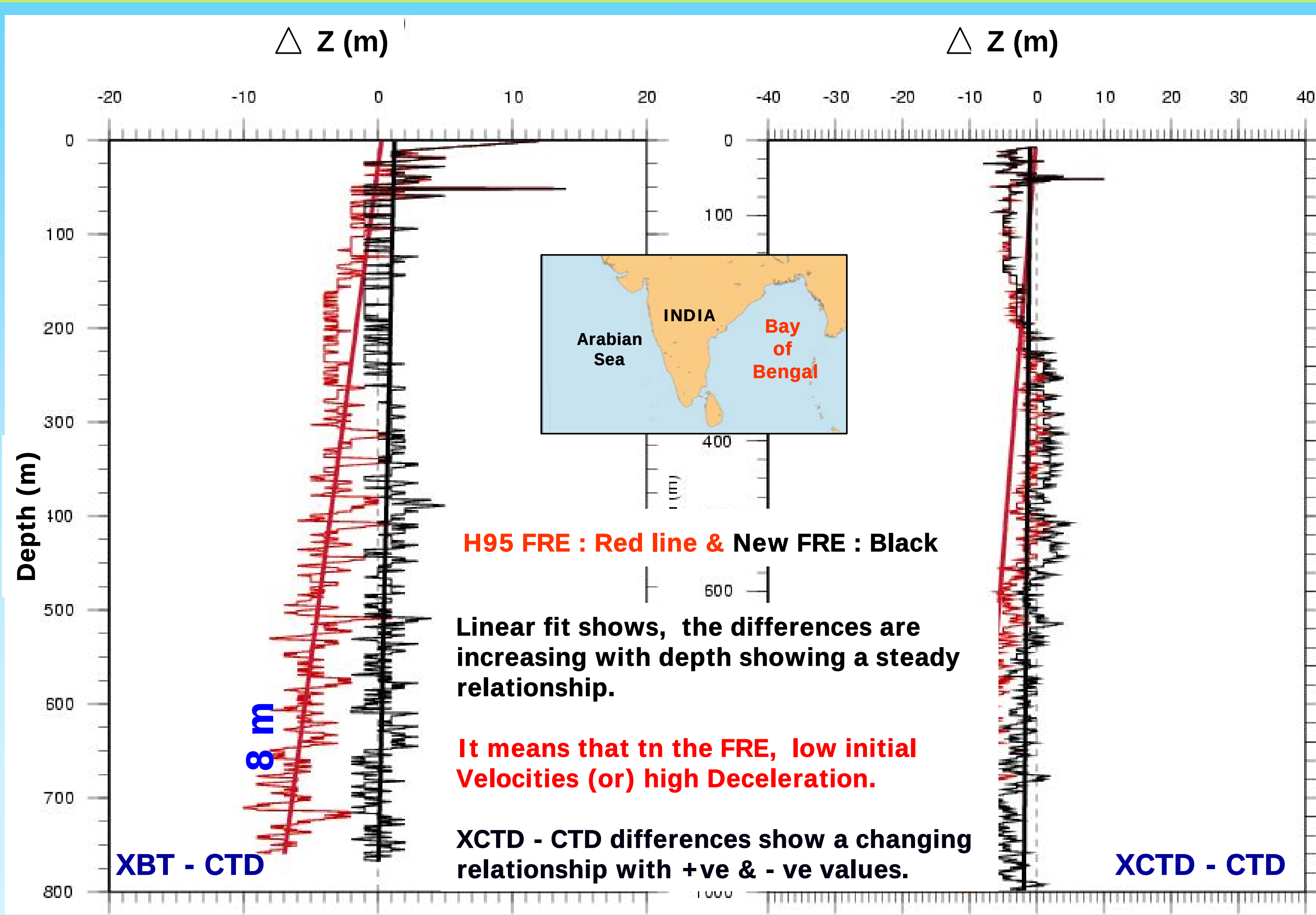
XBT – concurrent CTD Temperature differences at the same depth in the Bay of Bengal

XCTD – concurrent CTD Temperature differences at the same depth in the Bay of Bengal



XBT – concurrent CTD depth differences for the same temperature in the Bay of Bengal

XCTD – concurrent CTD depth differences for the same temperature in the Bay of Bengal



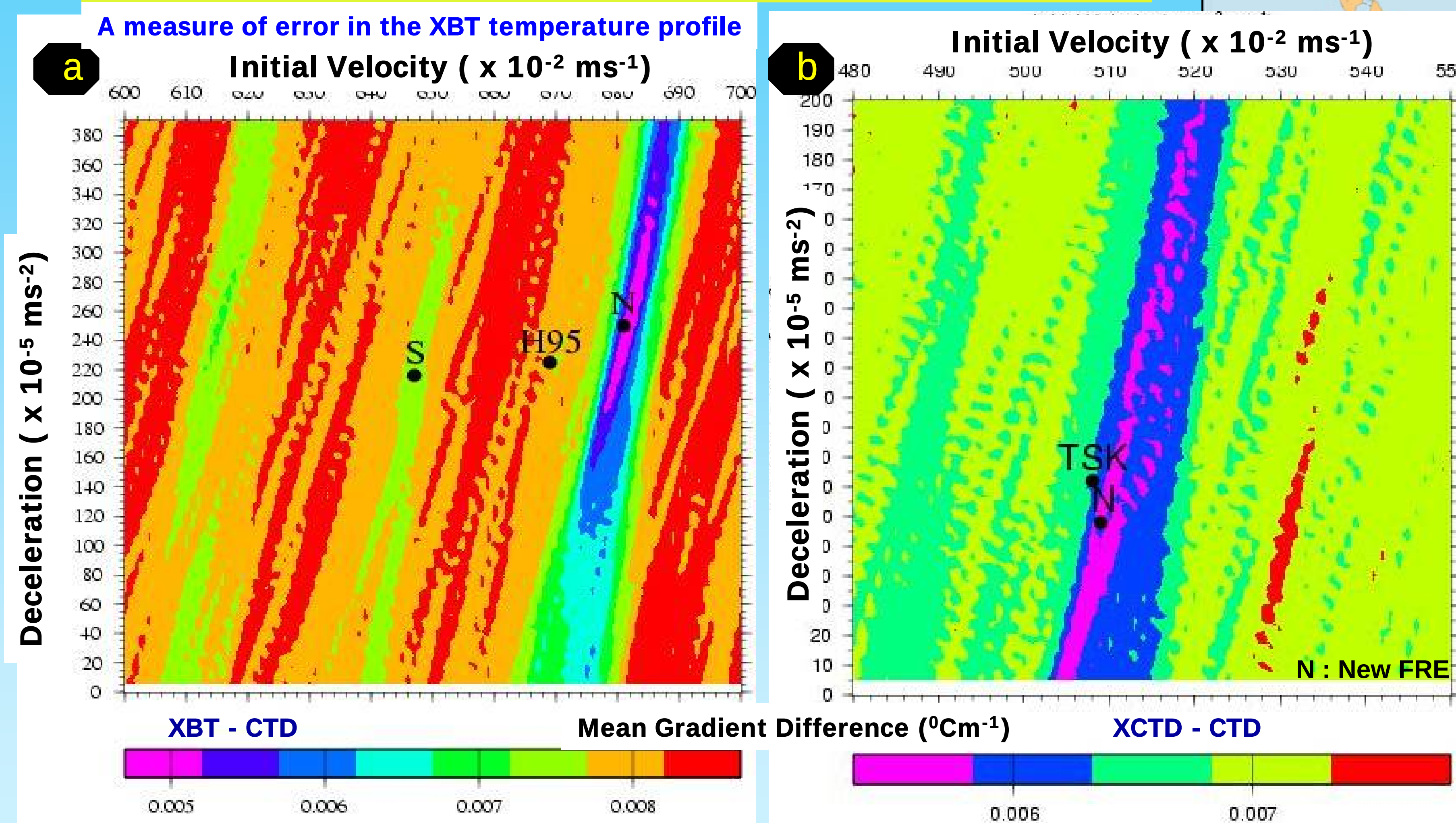
H95 FRE : Red line & New FRE : Black

Linear fit shows, the differences are increasing with depth showing a steady relationship.

It means that tn the FRE, low initial Velocities (or) high Deceleration.

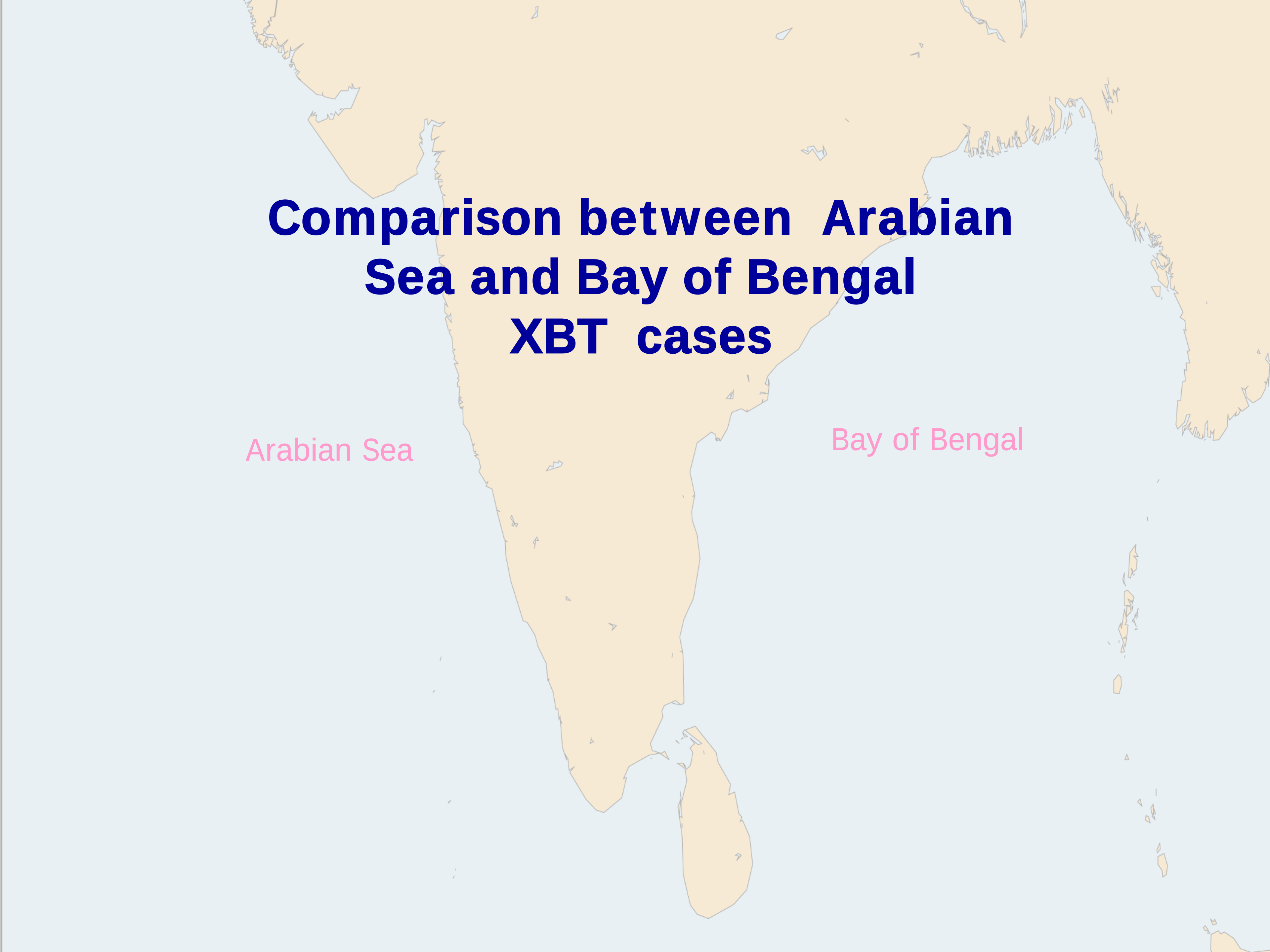
XCTD - CTD differences show a changing relationship with +ve & - ve values.

Mean vertical temperature gradient differences between (a) XBT & CTD & (b) XCTD & CTD in the Bay of Bengal for each Initial Velocity and Deceleration



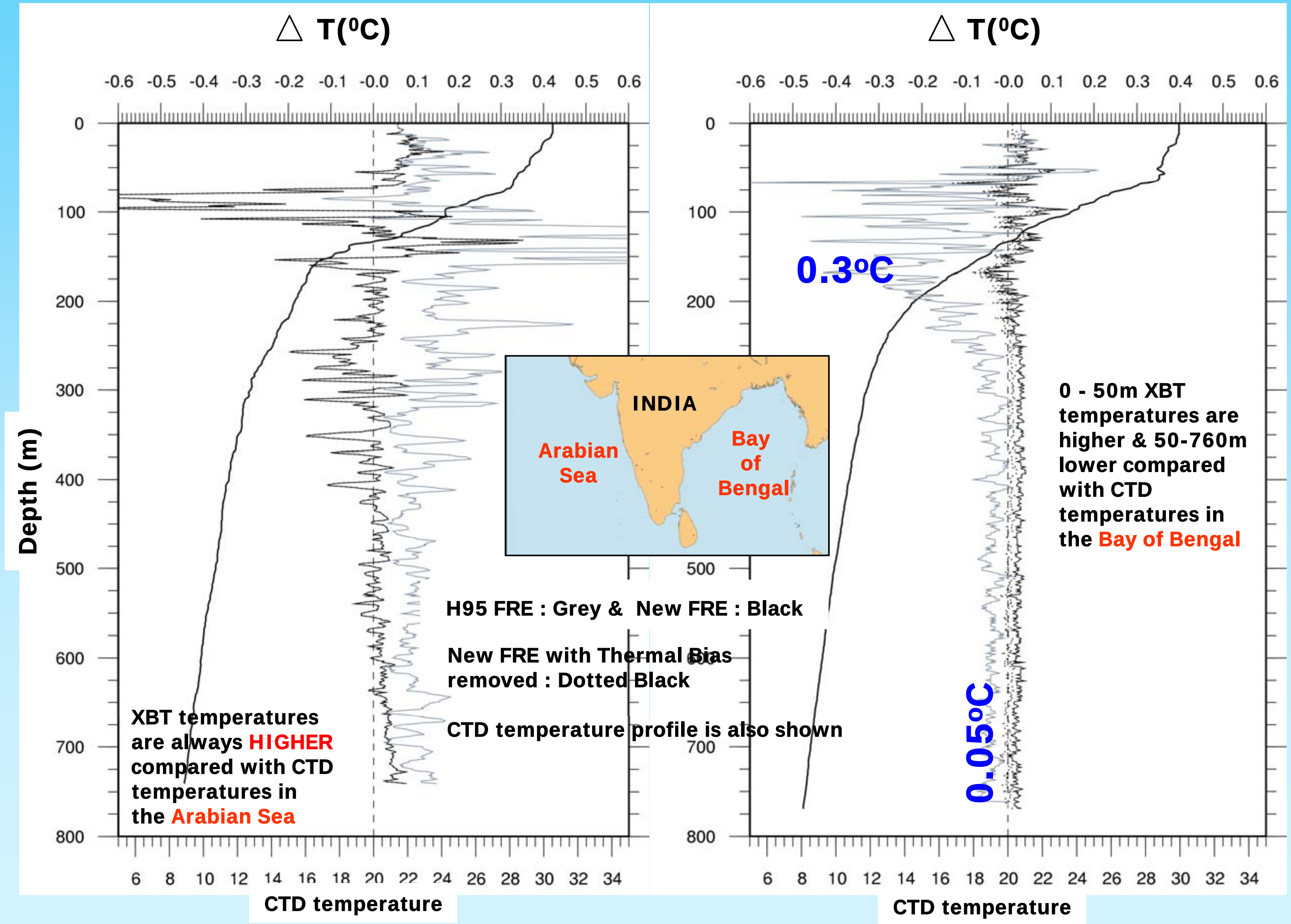
Yellow / Red : FRE resulting in larger differences between XBT & CTD profiles, Blue / Magenta represent smaller differences. Magenta area represent True FRE. Blue / Magenta area occupied narrower range in Fig a than in Fig. b. Strong linear relation between initial velocity & Deceleration with in the Magenta area in Fig. a & no such relation in Fig. b.

Comparison between Arabian Sea and Bay of Bengal XBT cases



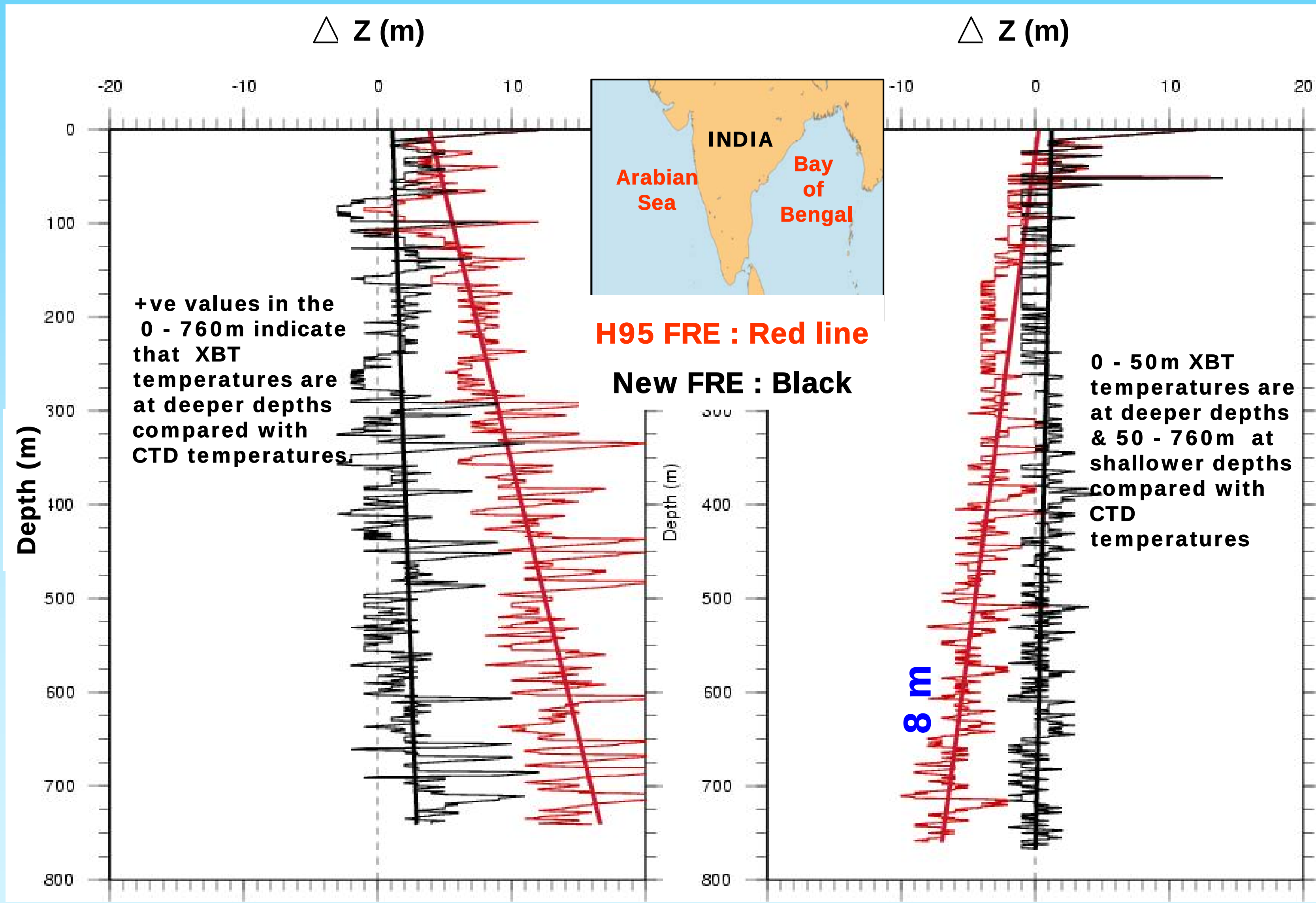
XBT – concurrent CTD Temperature differences at the same depth in the Arabian Sea

XBT – concurrent CTD Temperature differences at the same depth in the Bay of Bengal



XBT – concurrent CTD depth differences for the same temperature in the Arabian Sea

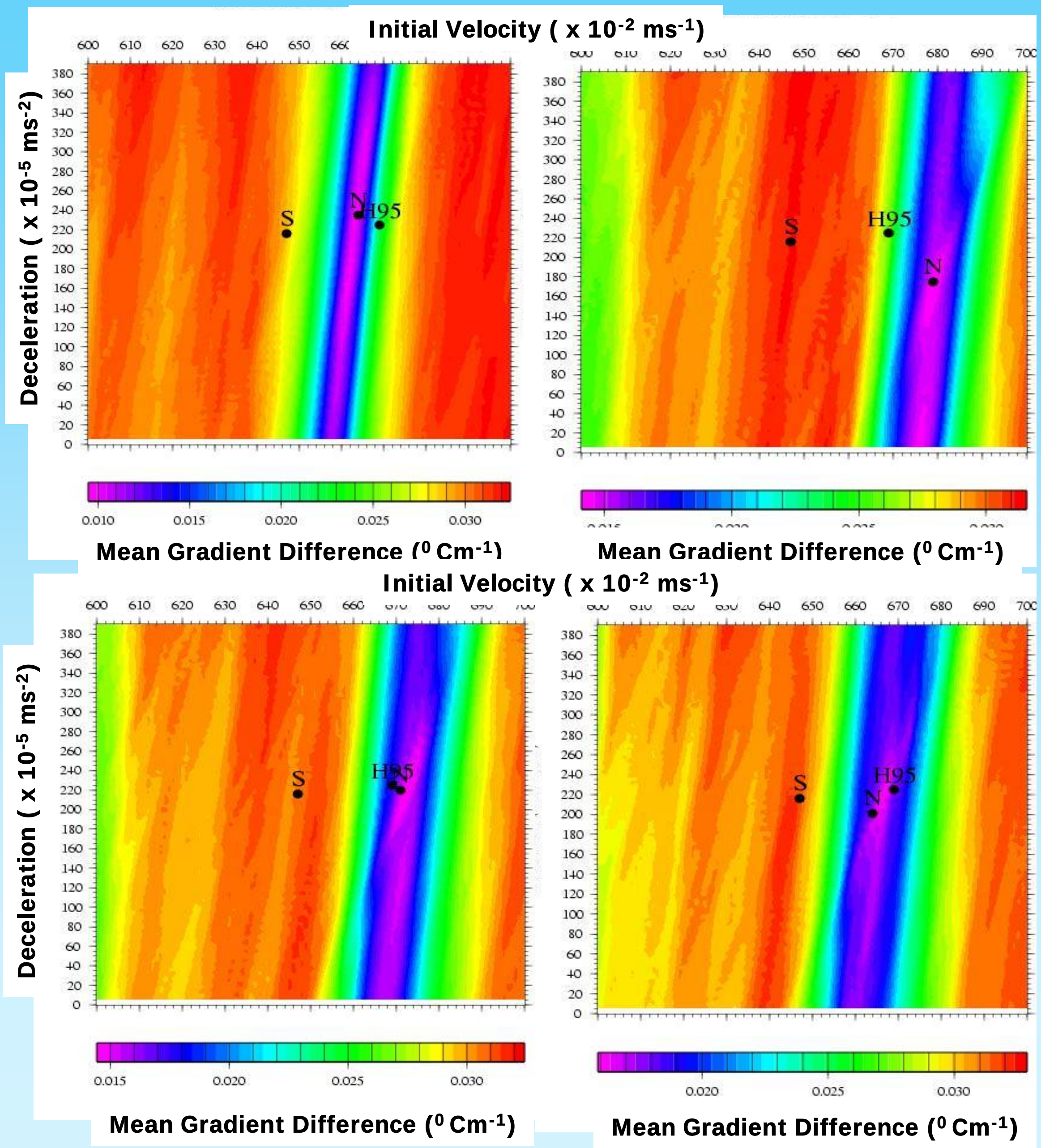
XBT – concurrent CTD depth differences for the same temperature in the Bay of Bengal



Comparison of multiple XBT drops to the same CTD cast in the Arabian Sea

- In order to examine the consistency of the XBT / CTD comparisons, 4 XBTs & 2CTD casts were done at the same location
- All XBTs were dropped within 15 minutes of CTD start time and completed while the CTD cast was still underway.
- It is expected that, this procedure minimizes the Natural Variability, but does not eliminate.

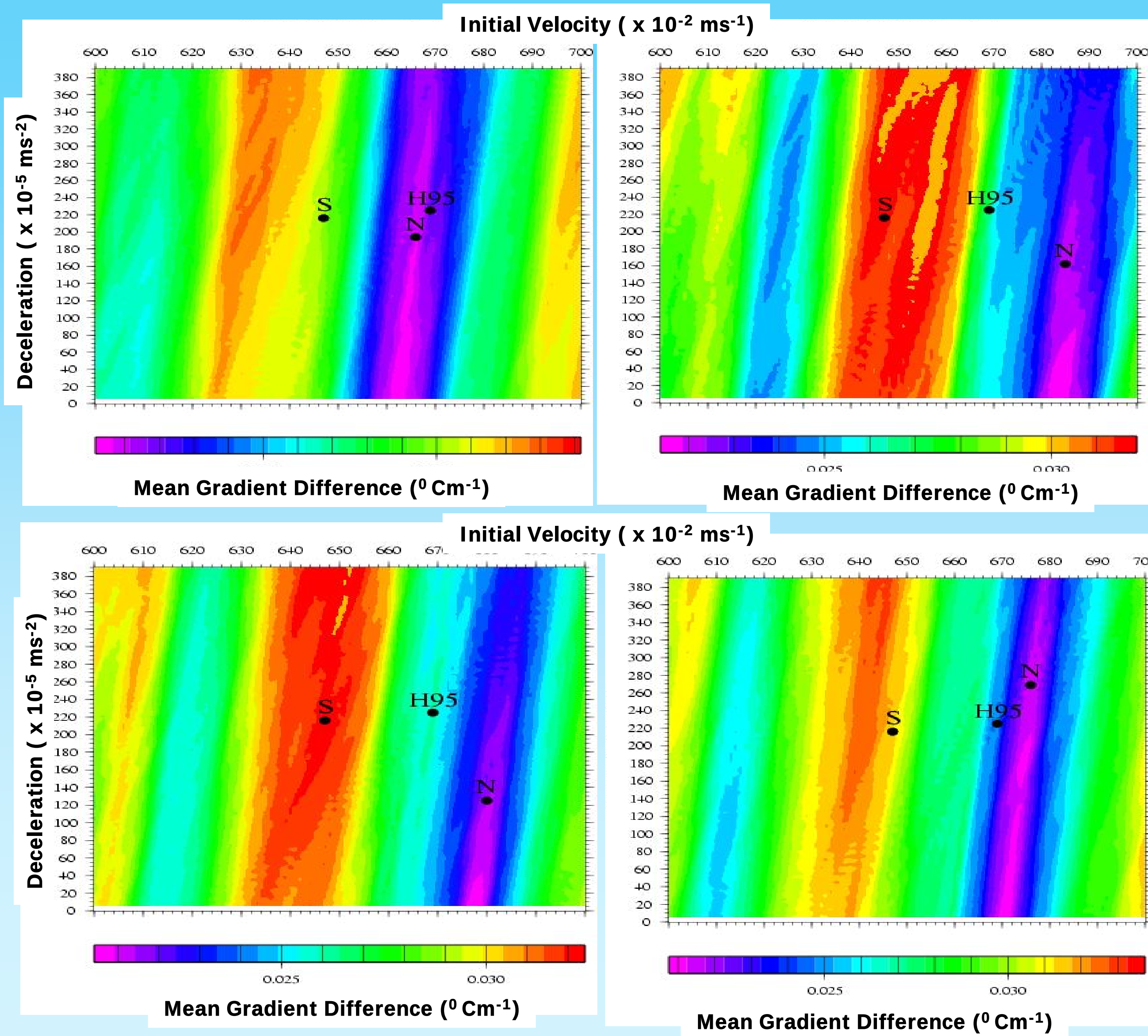
Vertical temperature gradient differences in the Arabian Sea for each set of (a , b) coefficients for 4 XBTs against 1st CTD cast

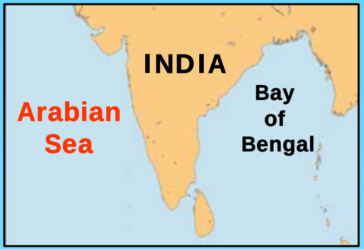


- **Comparing multiple XBT drops with 1st CTD cast.**

- **The areas covered by Blue / Magenta (minimum areas) are different in these 4 XBT drops indicating large Probe to Probe Variability.**

Temperature gradient differences between 4 XBTs & 2nd CTD cast in the Arabian Sea





The areas covered by Blue / Magenta (minimum areas) is wider compared with first CTD cast

Natural Variability is occurring with time & space

This complicates calculating new FRE.

XBTs should be dropped close to the CTD cast time

Recalculated XBT mean FRE coefficients and temperature biases

Cruise	Initial Velocity (a coefficient ms^{-1})	Deceleration (b coefficient 10^{-3} ms^{-2})	Thermal Bias (°C)
H95	6.691	2.25	-
BB08	6.79 ± 0.14	2.54 ± 0.79	0.01 ± 0.02
AS08	6.56 ± 0.14	1.32 ± 0.93	-0.01 ± 0.04
AS09	6.65 ± 0.17	1.83 ± 1.20	0.0 ± 0.03
BB09	6.59 ± 0.11	1.85 ± 1.14	0.01 ± 0.03

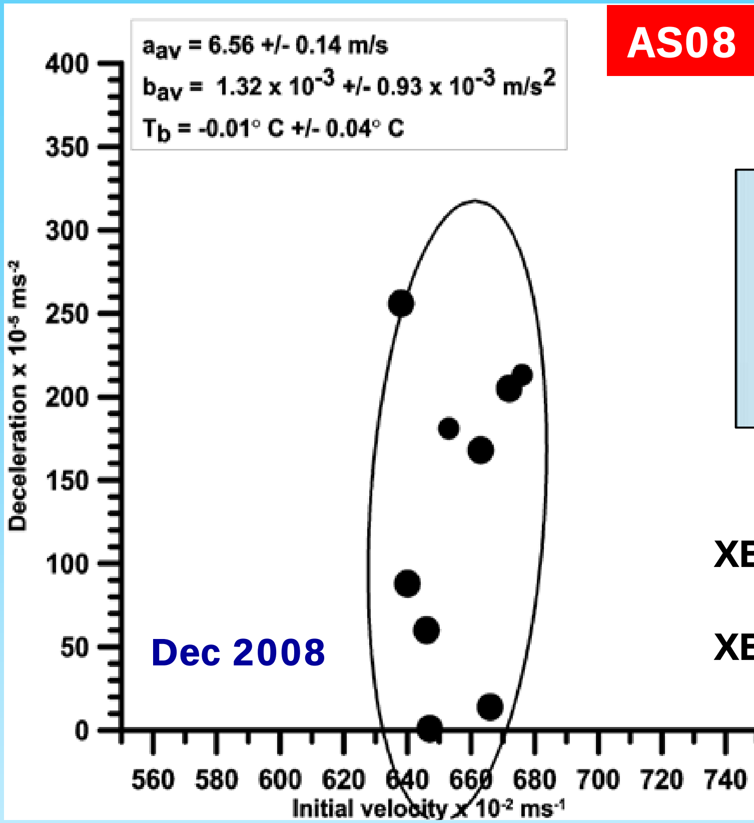
Recalculated XCTD mean FRE coefficients and temperature biases

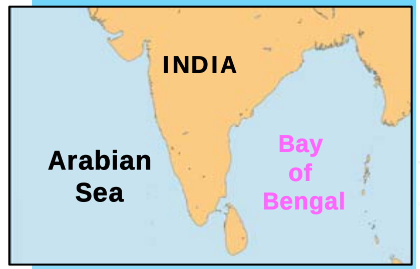
Cruise	Initial Velocity (a coefficient ms^{-1})	Deceleration (b coefficient 10^{-3} ms^{-2})	Thermal Bias (°C)
TSK	5.076	0.72	-
BB08	5.19 ± 0.11	0.87 ± 0.56	0.00 ± 0.00
AS08	5.23 ± 0.10	1.14 ± 0.61	0.01 ± 0.01
AS09	5.26 ± 0.11	1.40 ± 0.47	0.01 ± 0.01
BB09	5.18 ± 0.10	0.75 ± 0.47	0.00 ± 0.00

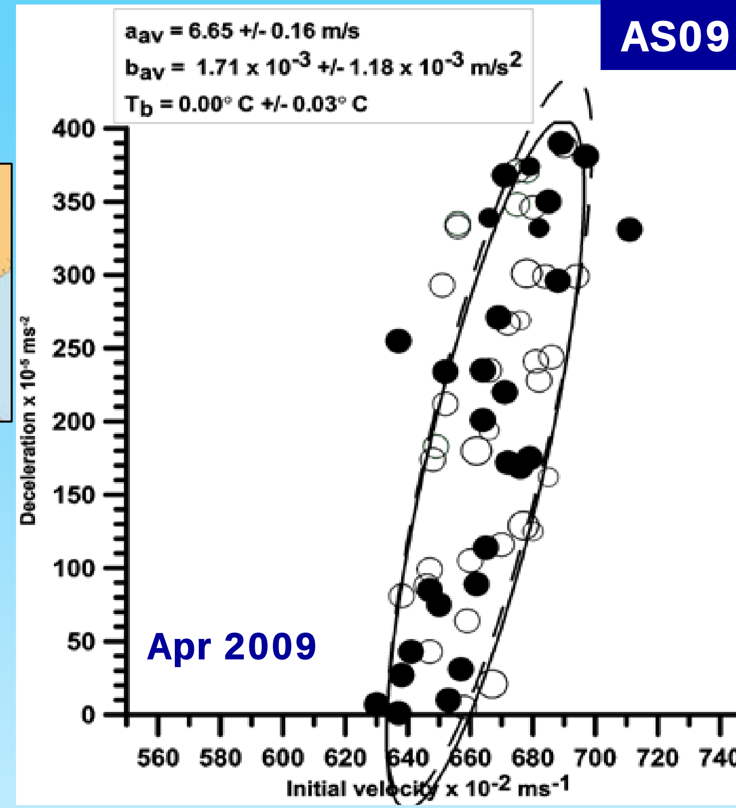
Summary of mean calculated FRE Coefficients & Thermal bias for XBTs and XCTDs for individual cruises.

It is better to examine each cruise in detail

Recalculated FRE coefficients for all XBT/CTD pairs in the Arabian Sea cruises







XBT vs 1st CTD ●

XBT vs 2nd CTD ○

Ellipses represent 95% confidence interval
(Two standard deviations from mean)

(AS09) Large spread of points resulting in mean IV identical to H95 & lower Deceleration with large SDs

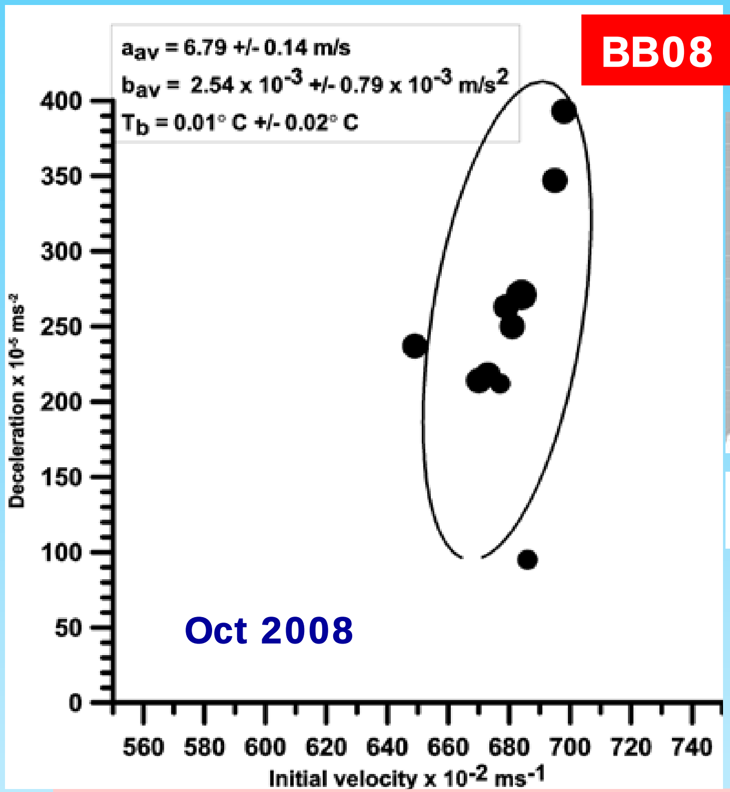
(AS08) Mean Initial Velocities & Deceleration are lower than H95 with large Standard Deviations.

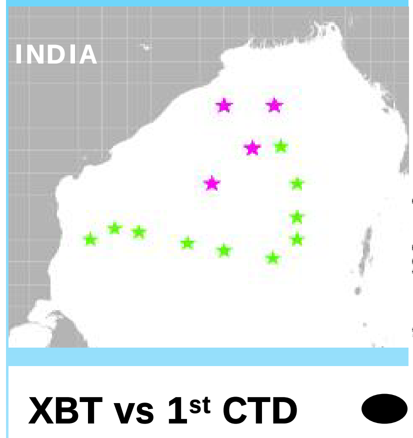
Mean FREs for two Arabian Sea cruises are very different

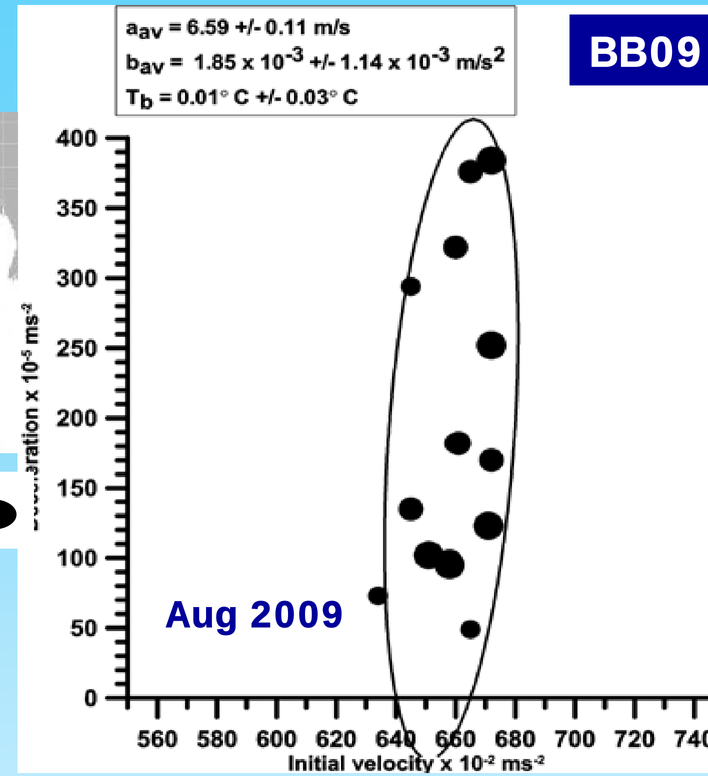
Same batch of XBTs are used in both cruises. Batch to batch variability is not a factor (August 2008)

Variations in the XBTs Spin Rate Value may be the main reason for these large differences in the FRE.

Recalculated FRE coefficients for all XBT/CTD pairs for the Bay of Bengal cruises







Ellipses represent 95% confidence interval
(Two standard deviations from mean)

(BB08) : Mean Initial Velocity & Deceleration values are Significantly higher than H95.

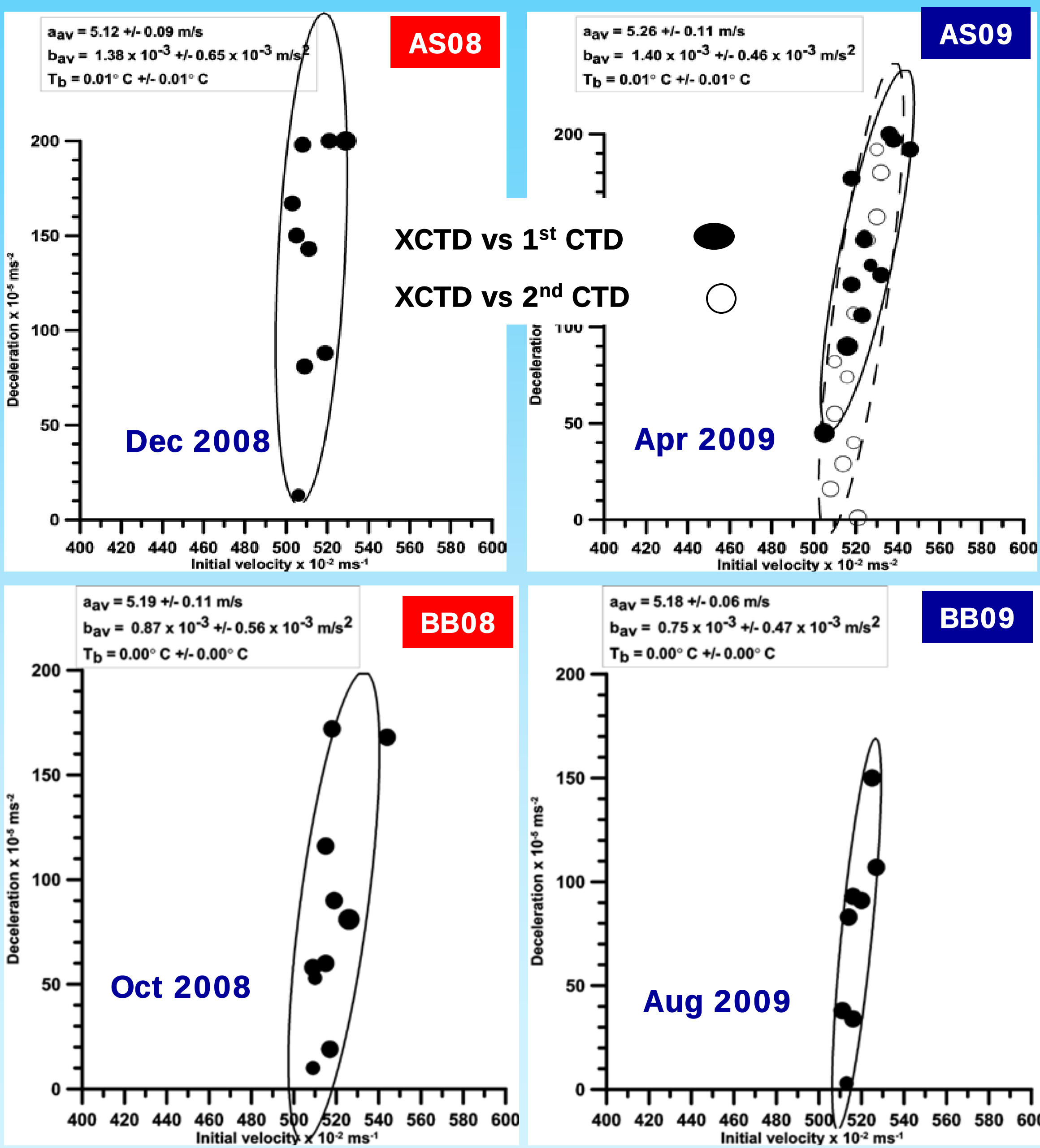
(BB09) : Here the mean Initial Velocity & Deceleration values are lower than BB08.

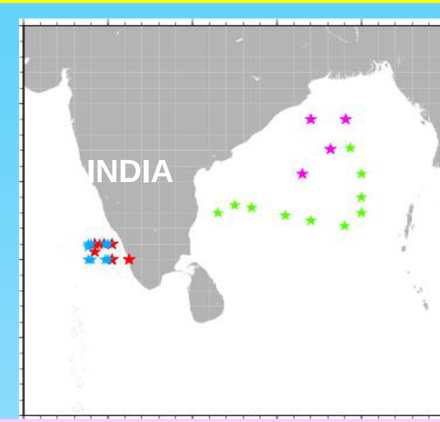
BB08 cruise is in the southern Bay of Bengal & during South West Monsoon season

BB09 : in the Northern Bay of Bengal & after South West Monsoon season – lower salinities.

Different environmental conditions have contributed for the variations in the FRE in the BoB.

Recalculated FRE Coefficients for all XCTD/CTD for the Arabian Sea & Bay of Bengal cruises





Ellipses represent 95% confidence interval (Two standard deviations)

Similar to XBTs the XCTD Mean FRE coefficients for the Arabian Sea are very different between the Two cruises.

However the XCTD FRE Coefficients for the Bay of Bengal cruises are very close to each other

Calculated XCTD FRE coefficients are higher than Manufacturers.

Kizu et al 2008 coefficients for the Northern Pacific are lower than Manufacturers.

♥Two questions may be addressed with our present data.

♥In spite of the observed large probe to probe variability
is it possible to calculate cruise specific FRE coefficients **???**.

♥In the absence of a reliable set of recalculated FRE coefficients,
are the errors involved in using H95 coefficients are small enough
to use the XBT data for Climate Studies **???.**

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To find answers to these questions, we looked at average temperature anomalies at standard depths.

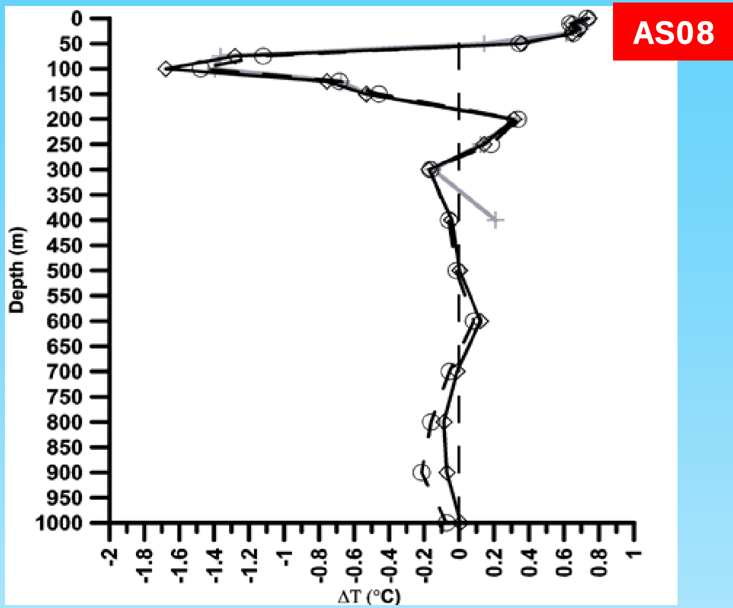
The recalculated FRE temp anomalies show considerable improvement over H95 FRE temperature anomalies in comparison with CTD anomalies.

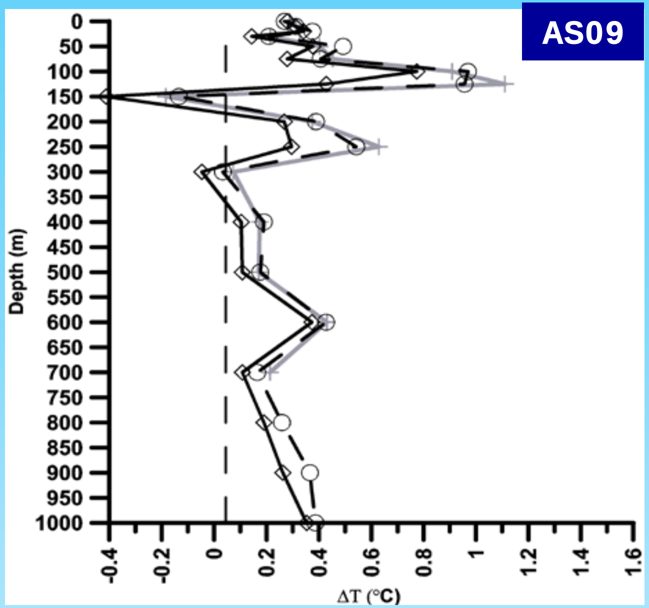
Summary

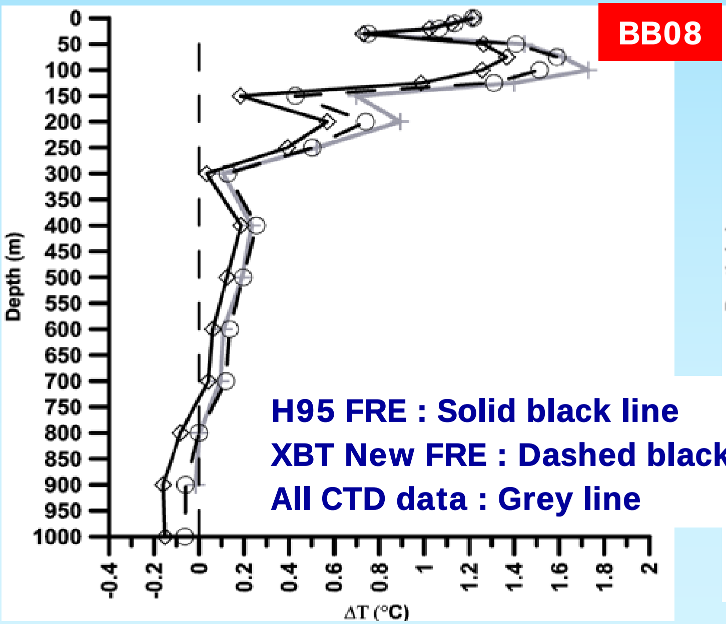
- It is not possible to assign any unique & definitive FRE to the XBT data for the Arabian Sea (or) Bay of Bengal.
- Observed significant probe to probe FRE velocity & deceleration coefficient variability in the XBT data within a cruise & also among the cruises.
- Observed small ($0.01^{0}C$) thermal bias for our XBT data.
- H95 FRE showed larger errors in the 75 - 200m & minimum errors below 200m when compared with new FRE.
- Further side-by-side tests in the Arabian Sea & Bay of Bengal are essential to overcome the observed probe to probe variability problems & to propose a new FRE.
- XCTD FRE velocity coefficients are higher than TSK coefficients probably due to the influence of temperature on XCTD FRE.
- Probe to probe FRE variability in the XCTDs is minimum compared with XBTs.

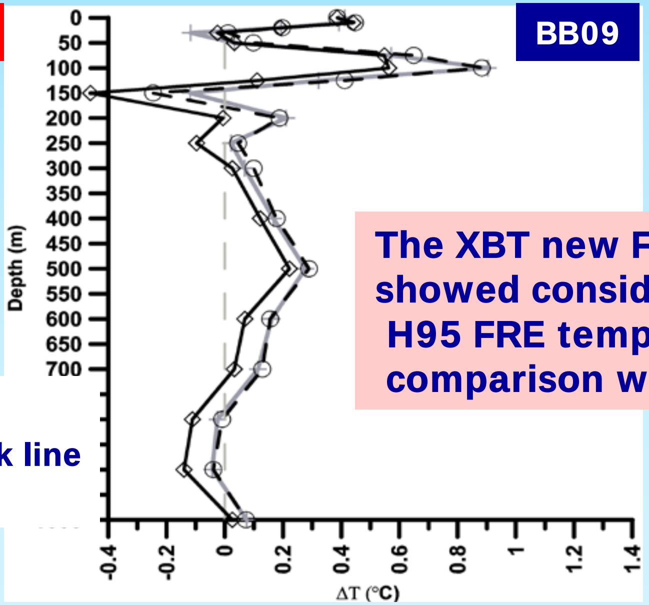

Thank You

Mean temperature anomalies from all XBT data w.r.t WOA 2005





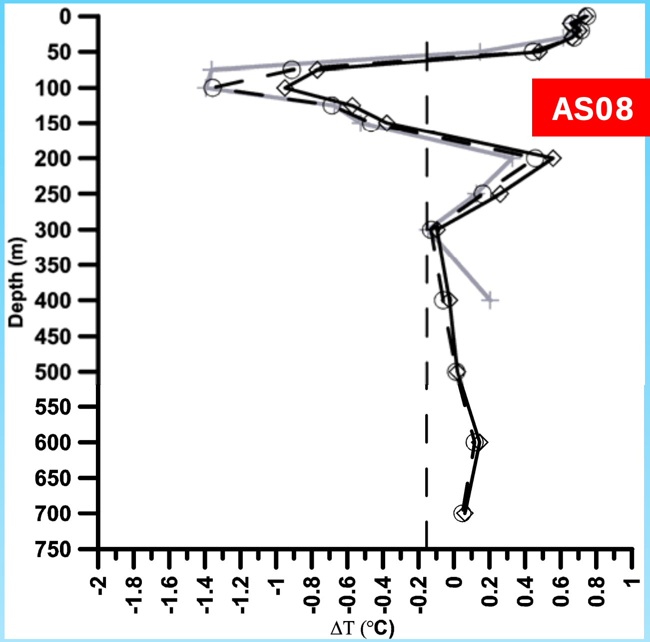


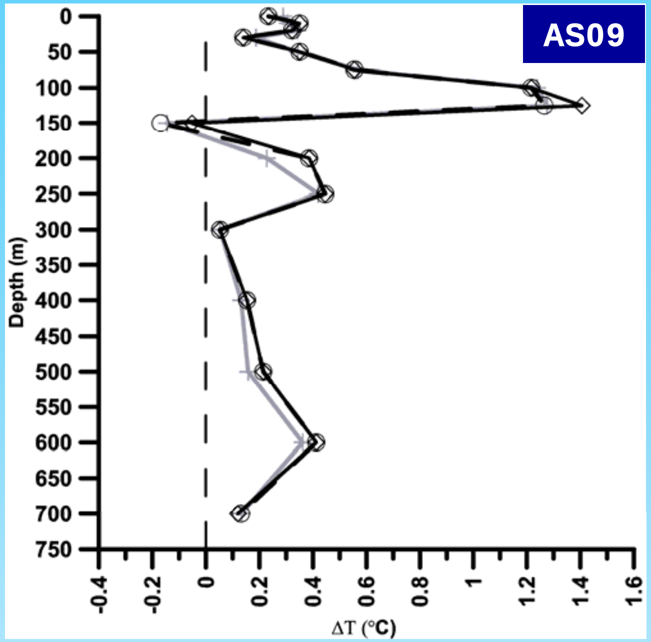


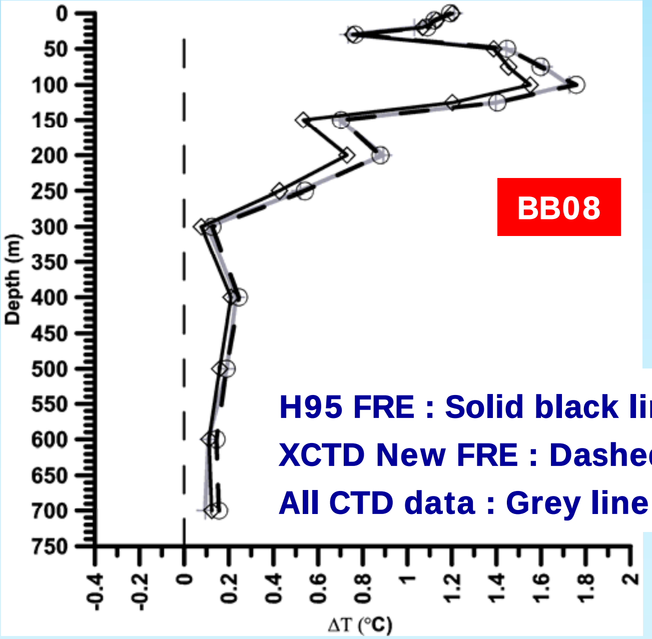
H95 FRE : Solid black line
XBT New FRE : Dashed black line
All CTD data : Grey line

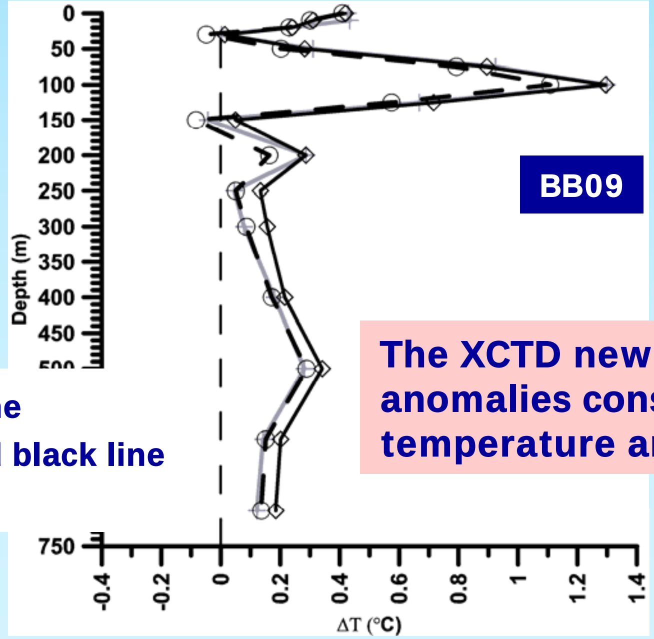
The XBT new FRE temperature anomalies showed considerable improvement over H95 FRE temperature anomalies in comparison with CTD anomalies.

Mean temperature anomalies from all XCTD data w.r.t WOA 2005









H95 FRE : Solid black line

XCTD New FRE : Dashed black line

All CTD data : Grey line

The XCTD new FRE brought temperature anomalies considerably closer to the CTD temperature anomalies.