

Temperature and depth error in the Mechanical Bathythermograph data from the Indian Ocean

Gautham. S* & Pankajakshan Thadathil

National Institute of Oceanography, Dona Paula, Goa 403 004, India

*[E-Mail: gauthams@nio.org]

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For arriving at realistic estimates of warming rate of oceans at regional and global level, it is important to understand persistent biases in observations of ocean temperature. In the present study, collocated MBT and CTD data from the Indian Ocean are used to understand the observed errors in temperature and depth of MBT data. The estimated error from the match up data shows that both temperature and depth measurement of MBT are over estimated, compared to CTD measurements. Estimated thermal bias is 0.14°C during the study period, which is significantly higher compared to earlier reports. The corrected MBT data for thermal bias and depth error shows a significant reduction in the existing error.

[**Keywords:** *mechanical bathythermograph, depth error, temperature bias, Indian Ocean*]

Introduction

Understanding long-term temperature changes in the global ocean has received growing attention during recent years as a part of the climate change issues. Since the observed warming rate of the global Ocean is small (< 0.01 °C/year)^{1,2}, it is important to understand persistent biases in observations of ocean temperature for arriving at realistic estimates of warming rate. Mechanical Bathythermograph (MBT) was introduced in 1940. They provide continuous temperature profiles versus depth presented as a trace on a smoke/gold coated slide. In the global data archives, MBT observations are available until 1992. MBT has a temperature accuracy of 0.1 °C and depth accuracy of ~ 1%. However, these accuracies were practically never achieved because of mishandling in field work, long intervals between calibrations, and instrument errors due to hysteresis, response time and shift relative to the calibration grids³. Before about 1957, a large positive bias (>0.5 °C) in the MBT temperatures was observed in the upper 30-50 meter layer and below about 150 m. The temperature and depth biases of the MBT profile were investigated by Stewart³, Casciano⁴, and Dinkel and Stawnychy⁵. All these studies reported higher temperatures and larger depths as measured by MBT compared to the reference values.

A substantial improvement occurred towards the end of 1950s, with maximum offsets at about 50-100

m depth being less than 0.3 °C. After 1980, this bias reduced further. A possible explanation for the positive bias could be a hysteresis of the diaphragm which is used in MBT instruments to sense the pressure, or a response lag in a xylene-filled copper tube which served as a temperature sensor⁶. MBT data consist of a significant share of the global temperature data archives. Therefore, understanding biases in the MBT data is a significant issue for addressing the long term warming of the ocean.

In the present study, collocated MBT and CTD data from the Indian Ocean are used to understand the observed errors in temperature and depth of MBT data. The data and method are presented in section 2. Results are provided in section 3, which is followed by discussion (section 4). A summary and conclusion is provided in section 5.

Materials and Methods

Collocated MBT and CTD data from the Indian Ocean, archived in the IODC (Indian Oceanographic Data Center) are used. Match-up pairs between CTD and MBT were extracted from the collocated stations with minimum spatial and temporal difference. Ideally, CTD-MBT data collected simultaneously (special experiment) is most appropriate to identify the MBT bias. However, at present, MBT is an obsolete instrument. Therefore, collocated MBT-CTD data available in the temperature archive has been

used for the study. When we say, ‘collocated’, the time space lag is selected as the minimum available. In this case the time lag is in the order of a few hours and space lag is practically nil (same station). Although the database shows zero time-space lag, in essence, the time lag could be of the order of a few hours (MBT is operated either before or after the CTD cast). Since the observation interval of temperature is not uniform, all data have been interpolated in a regular 5 m interval. Quality of temperature data from

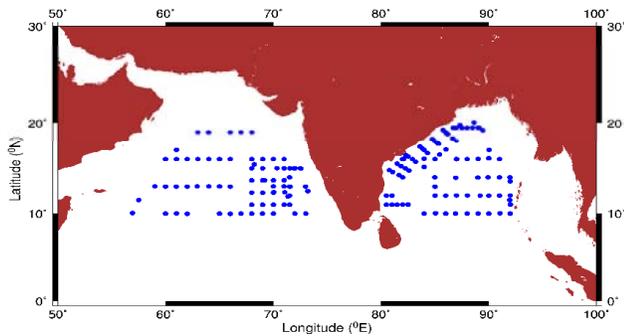


Figure 1— Location of match-up pairs between CTD and MBT

all match-up pairs have been subjected to quality check by using TS Diagram. Station coverage of 190 match-up pairs is shown in Figure 1. Details of quality checked match-up profiles used in the error analysis are given in Table 1.

MBT data has thermal bias, caused by response lag in a xylene-filled copper tube and temperature error due to depth error as reported by Gouretski and Reseghetti⁶. Thermal bias in the MBT was estimated from the mean temperature difference between MBT and CTD in the surface layer (below 25 m), as the depth error is zero when the probe comes in contact with water. Since mixed layer temperature could be represented as a proxy for SST, the mixed layer temperature bias represents the surface layer bias. The remaining temperature error after the thermal bias correction is due to the presence of depth error. CTD data in the match-up pairs were fixed as reference data to compare with MBT. Temperature difference between MBT and reference data was calculated on each vertical 5 m grid. The estimated thermal bias is removed from all MBT profiles before deriving depth error. For deriving depth error in MBT, MBT and reference data (CTD) were compared on same sigma-t surfaces. Since the salinity is not available for MBT, the sigma-t surfaces of MBT profiles were calculated

by adopting salinity from reference data. Depth error was also derived at specific theta surfaces using similar method. Using the observed mean depth error, depth correction is applied to all MBT profiles by removing the mean error from corresponding depth level for deriving the residual depth error.

Results

The Mean temperature difference between CTD and MBT is given in Figure 2(a). The figure clearly shows a positive temperature bias in the MBT data. Results show that maximum temperature error is at 100-150 m layer, is ~ 0.6 °C with a maximum positive gradient at 50-100 m layer. The observed error in the mixed layer is almost constant. A negative gradient is observed after 150 m layer depth level. Thermal bias in the MBT is calculated according to Gouretski and Reseghetti⁶ as described in the methodology section. Estimated thermal bias in the MBT is given by 0.141 °C from the surface. This result substantiates the past observation^{6,7}. Figure 2(b) shows the thermal bias corrected temperature difference.

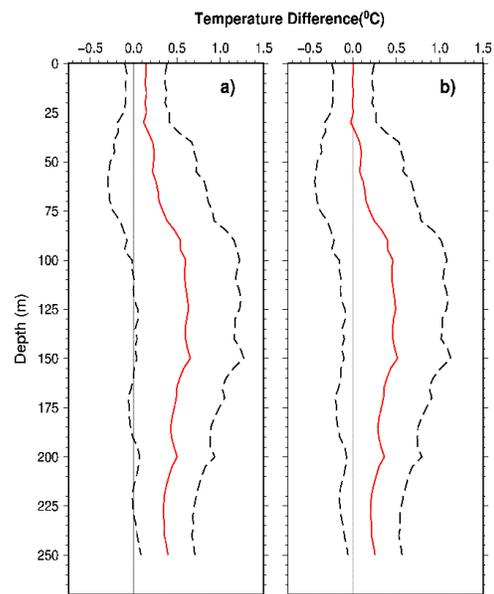


Figure 2 — (a) Observed Temperature Difference between CTD and MBT data (Continuous/Red) and standard deviation envelope (Dashed/Black) before depth and thermal bias correction. (b) Observed Temperature Difference between CTD and MBT data (Continuous/Red) and standard deviation envelope (Dashed/Black) after thermal bias correction

Table1: Details of Match-up pairs

Month and Year	Vessel	Cruise No.	No. of Match-up pairs between CTD and MBT
May 1979	R V Gaveshini	54	16
June 1979	R V Gaveshini	54	5
June 1979	R V Gaveshini	55	18
June 1979	R V Gaveshini	58	22
October 1983	O R V Sagar kanya	3	17
November 1983	O R V Sagar kanya	4	25
July 1984	O R V Sagar kanya	9	32
August 1984	O R V Sagar kanya	9	27
September 1984	O R V Sagar kanya	10	28

Depth error in the MBT data is calculated in two different ways as explained in section-2. Figure 3a and 3b showing the mean depth error and corresponding standard deviation in the MBT data from sigma-t and theta surfaces, respectively. Maximum depth error observed is 8m for depth of 200m.

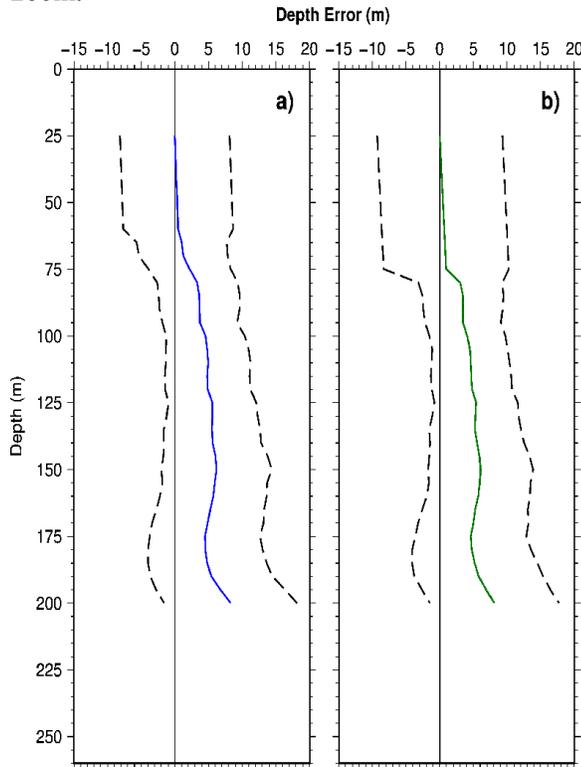


Figure 3 — (a) Mean depth error (Continuous/Blue) and standard deviation envelope (Dashed/Black) in the MBT data based on sigma-t surface (b) Mean depth error (Continuous/Green) and standard deviation envelope (Dashed/Black) in the MBT data based on theta surface.

Mean residual depth error after depth bias correction is given in figure 4a. Figure 4b is showing the residual temperature error in the MBT after depth bias correction. The result evidently shows that the temperature bias in the MBT is mainly due to the depth bias in the MBT data.

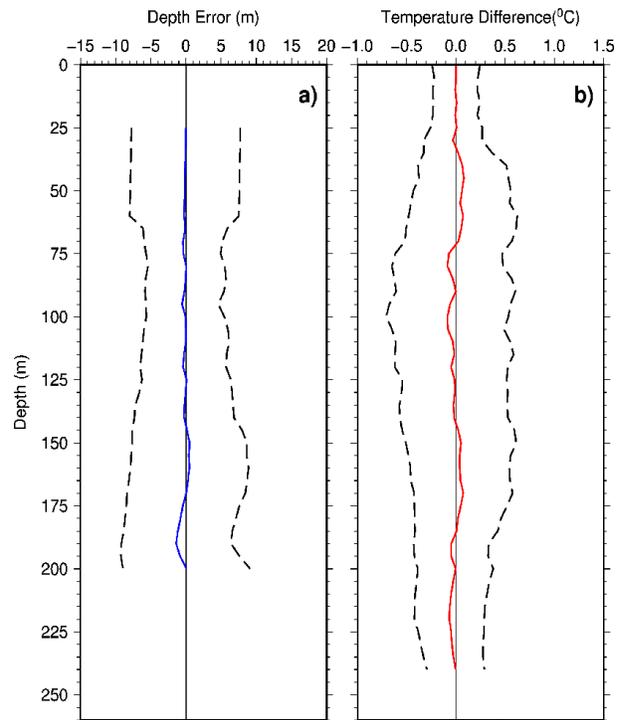


Figure 4 — (a) Observed depth error in MBT (Continuous/Blue) and standard deviation envelope (Dashed/Black) after depth correction and thermal bias correction. (b) Observed Temperature Difference between CTD and MBT (Continuous/Red) and standard deviation envelope (Dashed/Black) after depth correction and thermal bias correction.

Discussion

The estimated error from the matchup data shows that both temperature and depth measurement of MBT are overestimated with significant error, compared to CTD measurements. Gouretski and Koltermann⁷ reported similar positive temperature bias. In their study, the temperature bias is estimated from box averaged yearly mean anomaly from reference climatology. Ishii and Kimoto⁸ introduced depth bias correction in MBT to eliminate positive temperature bias from long term MBT observation and also reported overestimation of MBT depth measurements. Recent study of Gouretski and Reseghetti⁶ substantiates the overestimation of the temperature and depth measurements of MBT.

In this study, the observed mean temperature error is varying with depth. Maximum temperature error observed at depth range of 100-150 m is ~ 0.6 °C. However, the reported temperature error by Gouretski and Koltermann⁷ during the same year of our study is much lower (nearly zero) for the depth layer of 100-150 m. The observed temperature bias is decomposed to its thermal component and depth induced component as reported by Gouretski and Reseghetti⁶. In the case of observed thermal bias, Gouretski and Reseghetti⁶ reported a reduction in the thermal bias with time, with a maximum thermal bias of ~ 0.1 °C observed in 1955 and a gradual decrease to nearly zero by 1990. Our observations are during 1979-1984. The estimated thermal bias is 0.14 °C during the study period and which is significantly different and higher from that of Gouretski and Reseghetti⁶.

The observed depth error in the MBT data in our study shows an increase of error with depth as reported in the most of the earlier studies^{6,8}. From the observations of Ishii and Kimoto⁸ the mean error is minimum at 0 - 70 m layer and a maximum of ~ 9 m is observed at 250m depth level. The observed depth error in this study shows qualitatively similar trend of Ishii and Kimoto⁸.

As seen in figure-4a and 4b, the corrected MBT data for thermal bias and depth error shows a significant reduction in the error. After removing the observed thermal bias from the data, the temperature error in the mixed layer is reduced to nearly zero. However, the remaining temperature error in the MBT data after the thermal bias correction is still significant. Residual error in temperature after the depth correction (figure-4a & 4b) manifests the role of depth error in generating the observed error in

temperature. The contribution of depth error in generating the observed temperature error is much higher than that from thermal bias.

Conclusion

Understanding biases in the MBT data is a significant issue for addressing the long term warming of the ocean. Collocated MBT and CTD data (matchup) from the Indian Ocean are used to understand the observed errors in temperature and depth of MBT data. Estimated error from the matchup data shows that both temperature and depth measurements of MBT are overestimated with significant error, compared to CTD measurements. The observed thermal bias in the MBT data is 0.14 °C. The corrected MBT data for thermal bias and depth error shows a significant reduction in the error.

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