# VARIABILITY OF TMI DERIVED SST IN THE NORTH INDIAN OCEAN UNDER VARYING WIND REGIMES

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## ABSTRACT

Five years' Sea Surface Temperature (SST) values over the north Indian Ocean, obtained from TMI (RSS product - TMI Version 3A) were analyzed. Fortunately, several moored ocean buoys also functioned in the Arabian Sea and the Bay of Bengal during this period (1998-2002). The buoys are equipped with sensors, capable of measuring temperatures with an accuracy of ± 0.1 °C and 0.01° C resolutions. They are mounted at a depth of ~ 3m below the surface of the sea representing the bulk temperature.

Given the seasonal characteristics of the north Indian Ocean, the skin temperature (measured by TMI) displayed significant cooling with winds. ΔT ($T_{skin}$-$T_{bulk}$) dependence on wind speed magnitudes has been studied in detail over the Pacific Ocean by several authors, in which warmer skin for low wind speeds (< 6 m/s) have been reported. We find that in the case of north Indian Ocean too, skin is warmer than the water at depth (in our case, 3m) for winds < 6 m/s. The warmest skin is seen to correspond to a ΔT value of ~ 3 ºC, while the coolest skin corresponded to ~ 2.5 ºC in the North Indian Ocean. In an average sense, the skin cooling with wind speed during monsoon is found to be more dominant than other processes. Though overall nature of wind dependence in the pre-monsoon and post-monsoon seasons appear to be identical, monsoon feature is distinctly different, the processes which lead to this behavior needs examination. What is significant is the fact that the mean ΔT in the monsoon season is one order of magnitude less than during the pre-monsoon season. In all 2404 co-located match up points between $T_{skin}$ (TMI) and $T_{3m}$ (Buoy) in the Indian Ocean during 1998-2002 have been found. The correlation between $T_{skin}$ (TMI) and $T_{3m}$ (Buoy) is 0.75, the mean difference 0.11 ºC and standard deviation 0.65 ºC.

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## INTRODUCTION

The seasonal cycle of the physical parameters of the Indian Ocean is highly influenced by the reversal monsoon winds. Higher wind conditions during the monsoon period are responsible for the transfer of heat to the deep layer of the ocean by overturning and turbulent mixing. While the period of low wind condition and high solar insolation during the pre-monsoon encourage the thermal stratification in the upper ocean. Thus, ocean turbulence (momentum flux), air sea fluxes (latent and sensible heat fluxes) and solar insolation (short wave incoming radiation) in their turn, are responsible for the formation of complex and variable vertical temperature structures in the first few meters of the ocean (Schlussel et al., 1990; Wick et al. 1996; Castro et al., 2003). Besides, every ocean temperature observation also depends on the vertical position of the measurement and the time of the day of the measurement (Donlon et al., 2002; Gentemann et al., 2003).

Over the Indian Ocean, sea surface temperature displays variability over a wide range of space and time scales. This SST variability has been shown to be associated with the oscillations of a variety of weather patterns. The most pronounced oscillations in the SST are known to occur over the Bay of Bengal besides the equatorial western Pacific Ocean (Krishnamurti et al., 1988).

The cloud penetrating capabilities and insensitivity to aerosol properties allow the Microwave passive sensor like TMI (TRMM Microwave Imager) to provide SST in the tropical oceans under the influence of cloudiness and light precipitation (Wentz et al., 2000). It has further enriched the understanding of SST variabilities during the cloudy conditions (specifically during the Indian Summer Monsoon).

The present study was carried out with simultaneous, instantaneous and quality-checked SST observations made by the microwave radiometer on board the TRMM satellite and Indian Ocean Buoys for five years (1998 to 2002). The focus of the study has been to identify the impact of surface wind speed on the vertical temperature gradient in the upper-most layer (within the first few meters) of the ocean for the cases - pre-monsoon (February to May), monsoon (June to September) and post-monsoon (October to December).

## DATA USED

TMI Data: The Tropical Rainfall Measuring Mission (TRMM), a joint NASA-NASDA mission, has onboard the microwave radiometer TMI (Kummerow et al., 1998). The TMI has a full suite of channels ranging from 10.7 to 85 GHz and represents the first satellite sensor that is capable of accurate measurements of SST through clouds (Wentz et al., 1998). The rain sensitive channels onboard TMI are used to detect rain in the radiometer field of view. When rain is detected, the SST retrieval is discarded (Wentz et al., 2000). Because of its frequent repeat, non-sun synchronous orbit, the TMI SST data set provides an unprecedented look at the Indian Ocean basin scale SST variability under atmospheric convection conditions (Harrision and Vecchi., 2001). By virtue of its low altitude orbit (~ 350 Km), TMI has improved ground resolution (25 × 25 km) in comparison to other satellite missions with similar microwave sensors. For this study, daily gridded Version 3A TMI SST data (available online through Remote Sensing Systems at http://www.ssmi.com/.) were used.

In-situ Data: The in-situ sea surface temperature data are obtained from National Institute of Ocean Technology (NIOT) of Department of Ocean Development, India. Several deep sea and shallow water moored buoys have been functional in the north Indian Ocean since 1997 (Premkumar et al., 2000) under the National Data Buoy Program. All the Deep Sea buoys, representative of the north Indian Ocean data buoys were selected for this study. The SST sensor on the NIOT buoy is installed at ~ 3 m below the sea surface and wind sensor installed at 3 m above the sea surface. The reported SST is the average value of 600 samples (measurements acquired over 10 minutes with sampling speed of 1 sample/second) every three hour. The stated accuracy of SST sensor is ± 0.1 °C with 0.01 °C resolutions. Geographical information about deep-sea deployment is given in ***Table 1***. All buoys were operated during 1997-2002; no single buoy, unfortunately, acquired data over the entire time period of this study. Quality checked data of SST and Wind speed are used in this study.

**Table 1:**

| Buoy | Latitude | Longitude |
|---|---|---|
| **DS 1** | 15.5° N | 69.3° E |
| **DS 2** | 10.7° N | 72.5° E |
| **DS 3** | 13.0° N | 90.8° E |
| **DS 4** | 18.0° N | 87.6° E |
| **DS 5** | 14.0° N | 83.4° E |

## METHODOLOGY:

The main focus of the present study was primarily on the impact of seasonal change of wind speed on skin – bulk temperature difference over the north Indian Ocean. For this, TMI data within the spatial window of ± 75 km and temporal window ±1 hour with respect to the buoy location and buoy measurement time of SST and Wind speed. This was preceded by time series and statistical correlation analyses of these two data sets consisting of the original instantaneous observations. Impact of wind speed on ΔT has been analysed in both overall and seasonal (as defined earlier) scales.

A study of the dominant modes of SST variability in 3-day running mean data over the north Indian Ocean by the Wavelet analysis was carried out in a companion work by the authors (Parekh et al., 2004).

## RESULT AND DISCUSSIONS:

The sea surface temperature values obtained from TMI over the north Indian Ocean buoys were found to have a standard deviation of 0.65 °C with respect to the concurrent buoy measured values during the five years' period of 1998-2002 (figures 1(a)). One of the reasons why the results of comparison between TMI-SST and the Pacific Oceans' buoy yield better result (standard deviation ~0.57 °C), obtained by Gentemann et al (2004) could be due to the fact that the Pacific Ocean's buoys are deployed at a much shallower depth (~ 1 m), as against the north Indian Ocean's buoys being at ~ 3 m depth. Another important factor could be the presence of rain. While Gentemann et al (2004) had excluded cases of light rain within a search radius, the results presented here have so far not addressed this. There is a plan to carry out an exercise similar to Gentemann (2004).

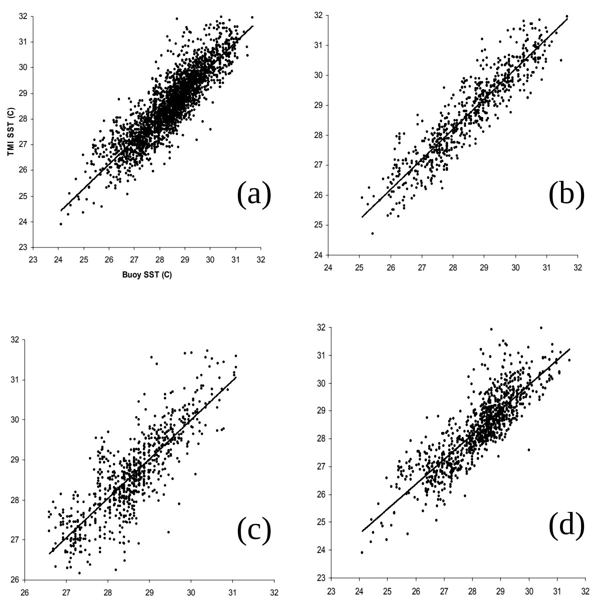


Figure 1 Comparison of TMI derived SST with those measured by north Indian Ocean buoys (1998-2002). (a) Over all, (b) Pre-monsoon, (c) Monsoon and (d) post monsoon.

The standard deviation during monsoons is almost at par or even slightly better (and the mean ΔT is least) during the monsoons because

**Table2:**

| Cases | No. of Points | Mean ΔT ° C | STD ° C |
|---|---|---|---|
| **Overall** | 2404 | 0.11 | 0.65 |
| **Pre-Monsoon** | 674 | 0.20 | 0.63 |
| **Monsoon** | 785 | 0.02 | 0.60 |
| **Post-Monsoon** | 945 | 0.12 | 0.70 |

of wind mixing. The $R^2$ value in the north Indian Ocean is found to be 0.75. The values for the standard deviations for the Pre-monsoon, Monsoon and the Post- monsoon seasons in the north Indian Ocean are respectively 0.63, 0.60 and 0.70 °C, respectively (Table 2) and the corresponding scatter analyses are represented in figures 1(b) – 1(d).

The skin temperature (measured by TMI) of the north Indian Ocean displayed significant cooling with winds. ΔT dependence on wind speed magnitudes has been studied in detail over the Pacific Ocean (Chelton et al., 2001; Donlon et al., 2002, Gentemann, 2004). For low wind speeds' (< 6 m/s) conditions in the Pacific, warmer skin have been reported by the authors. In the case of north Indian Ocean too, the skin is warmer than the water at depth (in our case, 3m) for winds less than ~ 6 m/s (figures 2 (a) to 2(d)). The warmest skin in the north Indian Ocean is found to be 3 °C (post-monsoon season) and the coolest skin is ~2.5 °C (monsoon).

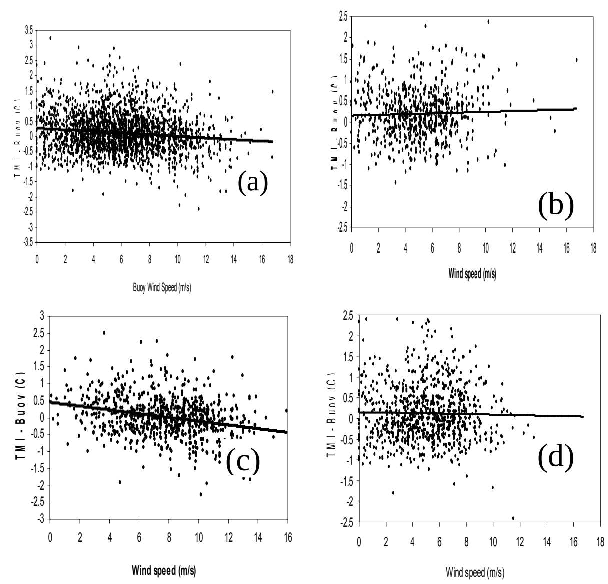


Figure 2 Variation of ΔT with wind speed for the period of 1998-2002 - (a) Over- all, (b) Pre-monsoon, (c) Monsoon and (d) post monsoon.

The figures (2(b) to 2(d)) also displayed the seasonal trends in the effect of winds on ΔT. In comparison to the Pre-/post- monsoon seasons (when mild heating/cooling trends are seen), the monsoon season ΔT shows significant cooling trend. The ΔT-SST dependence has yet not been studied in detail. Time series analysis of TMI SST shows higher variability than those measured by buoy (results not shown here). The intra-seasonal modes of the skin and the bulk

SST in the Bay of Bengal and the Arabian Sea, examined in a companion work by the authors, clearly display the 30-60 days' mode during the monsoon data (Parekh et al, 2004).

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