Validation of Multi-Scale Ultra-High Resolution (MUR) Sea Surface Temperature with Coastal Buoys Observations and Applications for Coastal Fronts in the Bay of Bengal

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Abstract

The high-resolution sea surface temperature (SST) is very useful for its coverage near to coast to study the fine scale processes and its impact on multi-scale atmospheric process. The work presents the validation of Multiscale Ultra High Resolution (MUR) SST products with three coastal buoy and three open ocean buoy observations in the Bay of Bengal (BoB). The comparisons show the correlation coefficient (R) more than 0.80 with coastal buoys and root mean square error (RMSE) less than 0.1°C. In the open ocean, the value of R is higher and RMSE is lesser compared to the coastal observation. This is first of kind validation of the SST data with coastal buoys. The results provided the usefulness of the MUR SST in the BoB region. The front detection method is applied on December SST. A strong SST gradient of value 0.1 $℃.km^{-1}$ is observed in the head and western BoB. We conclude that the MUR SST is good in quality in the coastal and open ocean to study the small scale feature in the BoB.

1. Introduction

The Sea Surface Temperature (SST) in the Bay of Bengal (BoB) is very important for the multipurpose meteorology and oceanography applications. From monsoon depressions to cyclones formations are controlled by the SST in this basin. The SST is the indicator for the upwelling zone, warm and cold eddies etc. The sea surface is the region where the air-sea interactions take place in the exchange of heat, momentum and gases between atmosphere and ocean. The SST distribution and characteristics are critical for physical, chemical, and biological characteristics of ocean and drives the weather (*Yanling et al., 2017*).
In last three decades, the satellites with Infrared (IR) and microwave (MW) are sensors measuring the SST efficiently and proving the near real time data with global coverage. The MW sensors provide typically coarser resolutions (~ 25 km) compared to IR sensors, which provide finer resolution to 1-km scales. But, IR-based measurements are uncertain under cloud, where the MWS can measure the SST through no-precipitable cloud. Jet Propulsion Laboratory (JPL) combines the SST data from multi-satellites and provide a global daily analysis gridded at a 0.01°×0.01° horizontal resolution Multi-Scale Ultra-High Resolution (MUR) SST (*Chin et al., 2017*). The details of this data are given in section 2.
The high-resolution SST is crucial for studying the coastal processes e.g. upwelling, fronts etc., which controls marine eco-system. The BoB is one of the large marine ecosystem of the global oceans (Belkin et al., 2009). In this work, we have validated in MUR SST with SST observation from coastal wave rider buoys (source: INCOIS, India) and Research Moored Array for African-Asian-Australian Monsoon Analysis (RAMA) observations for open ocean (see section 2). The western BoB is the very dynamical due to the reversal of the costal currents. It carries warm and saline water northward during the February to May and cold and fresh water southward during October to December (Shenoi, 2009). It creates the strong the salinity and temperature gradient on the western side of the BoB (Hareesh Kumar et al., 2013). The high-resolution SST is used here to detect the thermal fronts.

The paper is organized as follows: Section 2 describes the data and methodology, section 3 describes the validations and thermal front detection. The section 4 summarizes the results obtained from this study.

2. Data and Methods

This section briefly describes the SST datasets used in this study in section 2.1 and statistical formulations in section 2.2.

2.1 SST datasets

The MUR SST, described in section 2.1, is validated with *in-situ* observations with coastal buoys along the west coast of the BoB and the open ocean with RAMA. The description of the *in-situ* observations are given in section 2.1.2.

2.1.1 SST observations

The daily MUR SST is provided by Jet Propulsion Laboratory(JPL) on a global 0.01°×0.01° grid (source: https://www.mur.jpl.noaa.gov). MURSST is available from 2002 to till now. In this data, data fusion and interpolation method is used to combine the various satellite datasets (MODIS Terra, MODIS Aqua, Pathfinder Night, Pathfinder Day, NOAA-18 GAC, NOAA-19 GAC, MetOp-A GAC, AMSR-E, WindSat, AMSR2) and in-situ data(iQuam) and finally the ice fraction is taken from OSI-409/401 (*Armstrong et al., 2012, Chin et al., 2017*).

Table 1. Satellite Instruments used for MUR JPL and their resolution including errors

Instrument	Resolution(km)	Errors
MODIS	1	0.6°C
AVHRR	9	0.4°C
AMSR-E	25	0.5°C
$AMSR_2$	25	0.5°C
WindSat	25	0.5°C

The Multi-Resolution Variational Analysis (MRVA) method is used to prepare this SST (*Chin et al. 2017*). Due to its high accuracy and daily availability of data with global fine resolution of 1km JPL SST is also can be used for detection of fronts and frontal eddies.

2.1.2 *In-situ* observations

The MURSST in the coastal BoB is assessed with observations from coastal wave buoy deployed at Digha, Pondicherry and Visakhapatnam (Figure 1). Observations is available from May 2016 to April 2017 of a very high temporal resolution of approximately 30 mins (source: INCOIS, India). This data is post processed and averaged to daily data to compare with MURSST. In the open ocean, RAMA (source: https://www.pmel.noaa.gov/gtmba/pmel-theme/indian-ocean-rama) buoy datasets along 90°E are also used to compare. RAMA buoys at 08°N, 12°N and 15°N have a continues data of 365 days in 2015, hence that year is considered for the validation. Locations and durations of data from wave and RAMA buoy is shown in the following table 2 and locations in figure 1.

Table 2. Wave and RAMA buoy data used for SST validation with duration

State	Radar Location	Data period
Wave Buoy	87.65°E, 21.29°N (Digha)	1-05-2016 to 31-04-2017
	79.85°E, 11.92°N (Pondicherry)	
	83.26°N, 17.63°E (Visakhapatnam)	
RAMA Buoy	90°E, 08°N	1-01-2015 to 31-12-2015
	90°E, 12°N	
	90°E,15°N	

Study area and *in-situ* observations locations are shown in the figure 1, showing the usage of high resolution SST in calculating the SST gradient magnitude and analyzing its influence over the coastal waters.

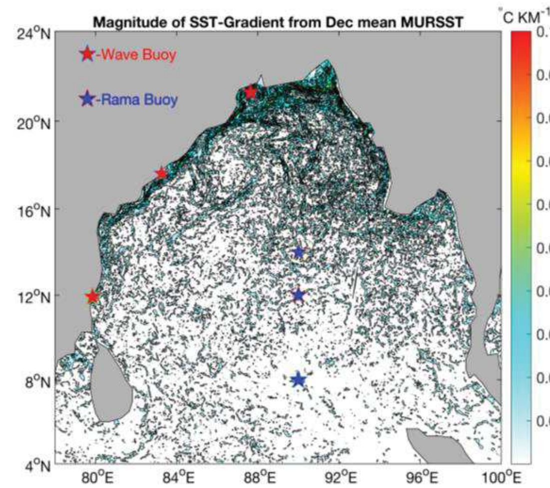

Figure 1. Study area - SST Gradient magnitude calculated using Belkin and O'Reilly (2009) Algorithm for 2010 December Mean MURSST. *In-situ* observations locations are marked and listed in top left corner of figure.

2.2 Methodology

The Correlation, Root Mean Square Error (RMSE) and Bias were calculated for the MURSST and *insitu* SST observations using the following formula.
The correlation coefficient of two random variables is a measure of their linear dependence. If each variable has N scalar observations, then the Pearson correlation coefficient is defined as

$$\rho(A,B) = \frac{1}{N-1}\sum_{i=1}^{N}\left(\frac{\overline{A_i - \mu_A}}{\sigma_A}\right)\left(\frac{B_i - \mu_B}{\sigma_B}\right) \quad (1).$$

where μ_A and σ_A are the mean and standard deviation of A, respectively, and μ_B and σ_B are the mean and standard deviation of B. Here is N is 365. Some suspicious data points are remover, but they are very few. The data from the closest grid point of MUR SST is considered for comparison.
Bias of a data is calculated using

$$Bias = \frac{\sum_{i=1}^{N}(\epsilon_i)}{N} \quad (2).$$

Where ϵ is the error and calculated by using following formula

$$Error(\epsilon) = insitu - \text{MURSST} \quad (3).$$

RMSE is calculated using equation (4)

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(\epsilon_i)^2}{N}} \quad (4).$$

3. Results

This section described the validation of MUR SST in section 3.1 and its applications for thermal fronts in section 3.2.

3.1 Validation of MURSST

In coastal waters, the time series of MURSSTs at three locations show daily and intra-seasonal variations very close to the observed variability (Figure 3). The in-situ observations are in three parts of the western BoB. The southernmost observations at Pondicherry shows highest correlation and less error compared to the other northern locations Visakhapatnam and Digha. However, at all locations the correlations are higher than 0.84 and the RMSE is less 1.5°C. In open sea, MURSST is showing a strong correlation with the RAMA buoy data and relatively less RMSE (Figure 4). The Correlation, Bias and RMSE of the *in-situ* buoy SST and MURSST is shown in Table 3.

Table 3. statistical validation of MURSST with *in-situ* observations

Stations	Correlation	Bias	RMSE
Digha	0.86	-0.13	1.42
Visakhapatnam	0.84	0.13	1.03
Pondicherry	0.87	-0.10	0.57
Latitude 08°N	0.86	0.07	0.33
Latitude 12°N	0.91	0.15	0.40
Latitude 15°N	0.95	0.15	0.36

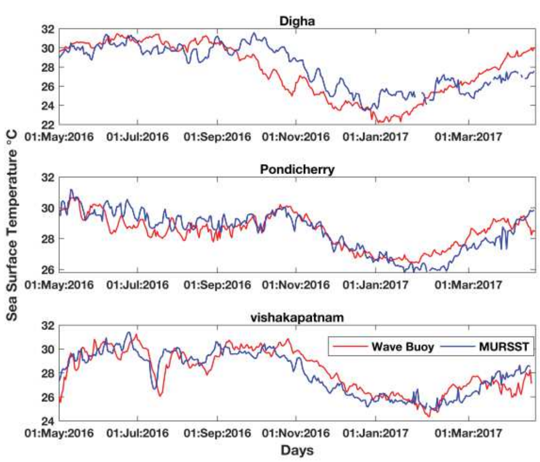

Figure 3. Temporal variation of MURSST (blue) with *insitu* wave buoy SST (red) at (a) Digha (b) Pondicherry and (c) Visakhapatnam.

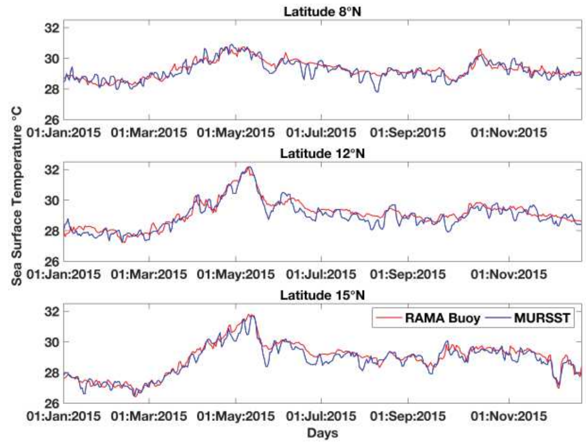

Figure 4. Temporal variation of MURSST (blue) with *in-situ* RAMA buoy SST (red) at (a) Latitude 8°N (b) Latitude 12°N and (c) Latitude 15°N along the 90°N longitude.

3.2 Thermal Fronts

The validation shows the good agreement with the observations in the BoB basin. The thermal fronts are detected using the Belkin and O'Reilly (2009) algorithm. A strong gradient of 0.1°C.km^{-1} is observed in the north and wester BoB (Figure 1). During December, the norther and southward coastal current along the western BoB is dominated by the fresh water. But the fronts are also evident from the high-resolution SST map.

4. Summary

Remote sensing is the fore most and at present primary way of collecting the large spatial resolution ocean observations by understanding the retrievals and interpolation methods of SST. Validation of the MURSST is efficiently done with the available *in-situ* SST observations focusing at coastal waters. Frequent validation of MURSST with several other data is required with the better understanding the MRVA method of JPL. For the first time MURSST is validated over the Bay of Bengal and specially in the perspective of coastal waters. Validation of the high resolution MURSST will help the users to utilize this data for different ocean and meteorological applications in the BoB.

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