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Analysis on Recent Trends of Satellite Sea-surface Temperature (SST) of Bay of Bengal with Special Reference to Temperature-Salinity (T-S) Diagram

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Abstract

Bangladesh is one of the most disaster prone countries in the world and is a victim of frequent natural calamities like tropical cyclones, tornadoes, floods, storm surges and droughts. Sea surface temperature (SST) plays a vital role in determining ocean-atmosphere interaction. In this study we focused on understanding the SST variability prevailed in the region of Bay of Bengal (BoB) mainly to assume the surface temperature signature for cyclone occurrence and also assess the variations of monthly climatological T-S (Temperature-Salinity) Diagrams. For this study, the observed SST data during the years 2001-2017 were derived from MODIS (Moderate Resolution Imaging Spectroradiometer) satellite. The SST maps of BoB were produced using SAGA GIS software. Throughout the study period of Bay of Bengal the usual water averaged mean temperature ranges from 25.46°C to 28.15°C. The maximum change found in May 0.65°C and minimum in September 0.06°C of two halves of investigation period. The seasonal cycle of SST showed two warming period during April-May and October. Overall scenario of SST demonstrates an increasing trend. River run-off and rainfall causes the change of salinity distribution near the coast which changesthe monthly T-S scatter density. High scatter density of T-S observed in winter season which indicates less fresh water input. Less scatter of T-S observed in monsoon period which indicates huge freshwater input during the season. Moderate scatter observed in rest of the month indicates optimum freshwater input. Near the cost of Bangladesh, India and Mayanmar, salinity becomes less because of freshwater discharge from local land area which causes change of T-S scatter pattern.

Keywords: Bay of Bengal; Cyclone; Density; Sea Surface Temperature

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Introduction

The ocean plays an important role in earth's climate system due to its capacity of large heat storage. The energy stored in 3.5m deep water column of the ocean is approximately equal to that of entire atmosphere of the globe. The Sea Surface Temperature (SST) is a direct measure of the energy balance which drives the circulation and ultimately defines the climate. The energy transferred between the ocean and the atmosphere is to a large extent dependent on SST and functions of SST such as the sensible heat flux, latent heat flux, and radiative flux at the sea surface [1].

Sea surface temperature (SST) data are measured through satellite remote sensing using microwave (infrared) wavelength [2]. Remote sensing measurements of SST actually measure the ‘‘skin temperature”, the temperature at the top 0.1 mm of the water column, which is more strongly influenced by solar irradiance, and therefore differ somewhat from sea surface temperature [3]. SST is essential to understand the global climate [4]. SST is an important indicator of the state of the earth's climate system. Thus, appropriate assessment of SST is essential for climate monitoring, research, and prediction [5]. SST variations control meteorological and oceanographic processes such as change in current speed or the frequency of events like El Nino, monsoon depressions and subsequent floods, large-scale sea level fluctuations and formation of tropical cyclones [2]. The expected rise in SST of about 0.2–2.5^{0}C, may also cause sea level rise and other natural disasters such as an increase in storm frequency and intensity and sea water encroachment into agricultural land [6,7]. The rise of SST increases the saturation of vapor pressure which triggers water vapors and latent heat, causing the intensification of cyclones. Evan and Camargo [8] and Emanuel [9] explained the significance of SST in the increasing cyclonic intensity in addition to floods and other natural disasters. The coastal dynamics and near-shore ecosystem functions greatly dependents on the Sea surface temperature [10]. Small changes can greatly impact the sea bathymetry, destroy coral biodiversity and hamper natural ecosystems. Moreover the surface temperature has greater impacts on cyclones, swelling up of water, polar caps melting and sea level rise [11]. Increases in sea surface temperature are also expected to lengthen the growth season for certain bacteria that can contaminate seafood and cause food borne illnesses, thereby increasing the risk of health effects [12].

Sea surface temperature (SST) of the Bay of Bengal (BoB) has been linked to rainfall patterns in Bangladesh. Huge freshwater discharge from main rivers in the Bay plays an important role to shallowness of mixed layer depth of 14-49m depth and resulting low saline and high temperature water in the north and the east of the Bay [13,14]. The salinity of the ocean is a function of several factors; one major factor is temperature. Salinity and water temperature are closely related; this relationship, combined with empirical data, allows for the creation of a temperature salinity diagram. More than two thirds of the discharge comes from Ganges-Brahmaputra river system. The summer floodwaters of the Ganges and Brahmaputra rivers discharging into the Bay of Bengal plus the Irrawaddy and Salween rivers emptying into the Andaman Sea combine to influence the salinity of the surface waters over thousands of kilometers offshore [15]. These rivers carry an estimated annual of sediment load of 2.5 billion tones and get dumped to the Bay of Bengal [16]. Dumping of the huge amount of sediments causes turbidity and decrease light transparency ultimately hamper primary production. The salinity of the water of the southern part of the BOB is almost the same as in the open part of the ocean.

Therefore, careful monitoring of SST is required to assess its impacts on regional weather and climate system that in turn affects the socio-economic system. Before the 1980s the measurement practice of the SST using ships, buoys such time consuming methods but after that period most of the information about global SST has come from satellite observations. Several satellites monitoring the earth can provide thermal information about the oceanic conditions. Thematic mapper and enhanced thematic mapper onboard the Landsat, Advanced Very High Resolution Radiometer (AVHRR) onboard the National Oceanic and Atmospheric Administration (NOAA) and advanced space borne thermal emission and reflection radiometer onboard the Terra satellite are very effective for monitoring thermal patterns in the coastal oceans [17]. Though satellite derived SST climatology data length is short, nevertheless, continuous data with almost no gaps seems to give better results in performing the trend analysis.

This study analyzes the monthly variation of SST of Bay of Bengal using satellite (MODIS) derived data since January 2001 till December 2017 from aiming to take a step further to initiate a ground for regional climate and hazards monitoring.

Materials and Methods

Study Area

The Bay of Bengal is the northeastern part of the Indian Ocean, located between latitudes 5°N and 22°N and longitudes 80°E and 100°E (Figure 1), bounded on the west and northwest by India on the north by Bangladesh, and on the east by Myanmar and the Andaman and Nicobar Islands of (India). Its southern limit is a line between Sri Lanka and the north-westernmost point of Sumatra (Indonesia). It is the largest water region called a bay in the world. There are Countries dependent on the Bay of Bengal in South Asia

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and Southeast Asia. The Bay of Bengal occupies an area of 2,172,000 square km (839,000 sq mile), which is about 6% of the world ocean [18,19].

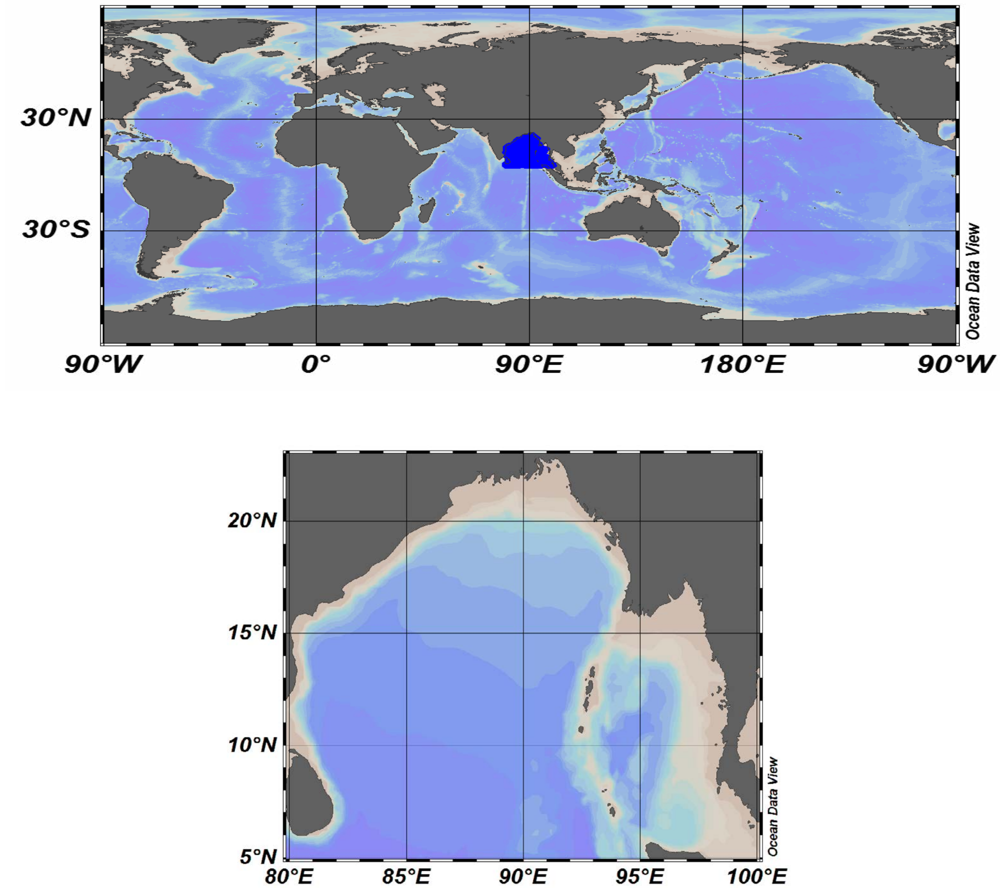

Figure1: Study domain of the Bay of Bengal.

Data Sources

The monthly averaged sea Surface temperature data set obtained from MODIS-aqua and MODIS-terra satellite and long term field data of some oceanographic variables obtained from World Ocean Database (WOD). In situ data collected by CTD(Conductivity-Temperature-Depth profiler), MBT(Mechanical Bathythermograph), MRB(Moored Buoy), OSD(Ocean Station Data), PFL(Profiling Float), SUR(Surface Only) and XBT(Expandable Bathythermograph). The following Table 1 gives the details pertaining to each of the data used in this study

Type	Parameters	Sensor/Archive	Temporal resolution of dataset	Source
Remotely Sensed	Sea Surface Temperature(SST)	MODIS-aqua MODIS-terra	2001-2017	US ocean color web NASA(level 3 browser)
In situ	All oceanographic variables available in WOD	WOD (World Ocean Database)	1967-2017	NODC (National Oceanographic Data Center)

Table 1: Data sources of the investigation area.

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MODIS Data Type	Satellite Platform	Parameter	Spectra Band	Spatial Resolution	Time Period	Day/ Night	Data format
Level-3	Aqua Satellite	Sea Surface Temperature (Global)	11µm	4 km	Monthly	Day	netCDF
	Terra satellite						

Table 2: MODIS data structure used in study (NASA).

➢ **Tools for Data Analysis and Edit**

Following software are used for mapping and analysing of data

- SAGA GIS (System for Automated Geo-scientific Analyses)
- Ocean Data View (ODV)
- Microsoft Excel 2007

Methods of Analysis

Data mapping, visualization and analysis: The data visualization was done with open source GIS software SAGA-GIS. Using this software we create map of BOB. SAGA software has so many modules, first we use TOOLS module and import SST netCDF raster file (MODIS data). We also use grid calculator and use a formula. We use projection module for define geo-references for grid where we set the cell size and coordinate, where we intersect BoB SST data from world ocean SST data by resampling tools and create monthly map of BOB from year 2001-2017. Further analysis was done using inbuilt statistical tools of the software.

The WOD data analyzed In ODV where we import Monthly CTD(Conductivity-Temperature-Depth profiler), MBT(Mechanical Bathythermograph), MRB(Moored Buoy), OSD(Ocean Station Data), PFL(Profiling Float), SUR(Surface Only) and XBT(Expandable Bathythermograph) data over 50 years(1967-2017) of Bay of Bengal and create T-S (Temperature-Salinity) diagram using Scatter Window in View option and set range of temperature and salinity at 0 to 100m depth.

In Microsoft excel we do yearly and monthly average of standard deviaton, range, minimum and maximum, monthly and half yearly average of arithmetic mean of SST and create line and bar chart to analyze Sea surface temperature of Bay of Bengal. We also create trendline to observe change in temperature.

Results and Discussions

From our study, throughout the study period of Bay of Bengal the usual water averaged mean temperature ranges from 25.46°C to 28.15°C (Figures 2 and 3). Highest temperature in April (28.15°C) and lowest in January (25.46°C) (Figures 2 and 3). Although highest temperature observed in May 29.24°C in the year 2016 (Figure 4) and lowest temperature observed in January 24.90°C in the year 2007(Figure 4). The maximum change found in May 0.65°C and minimum in September 0.06°C of two halves of investigation period (Figure 5). There was an increasing trend of peak SST from 2001-2009 and also from 2010-2017 (Figure 5). SST was showed a strong seasonal (semi-annual) cycle. The seasonal cycle of SST showed two warming period during April-May and October (Figure 2). Overall scenario of SST demonstrates an increasing trend (Figure 6).

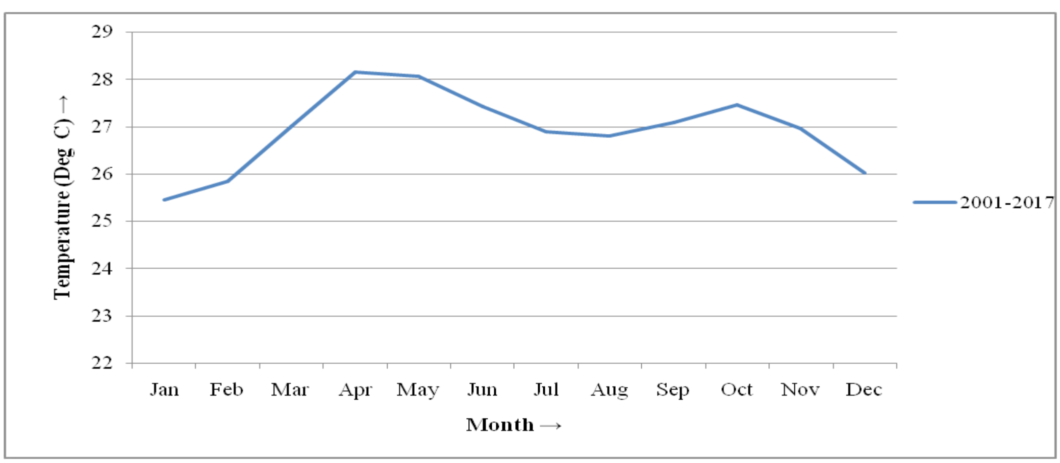

Figure 2: Monthly climatology of SST (°C).

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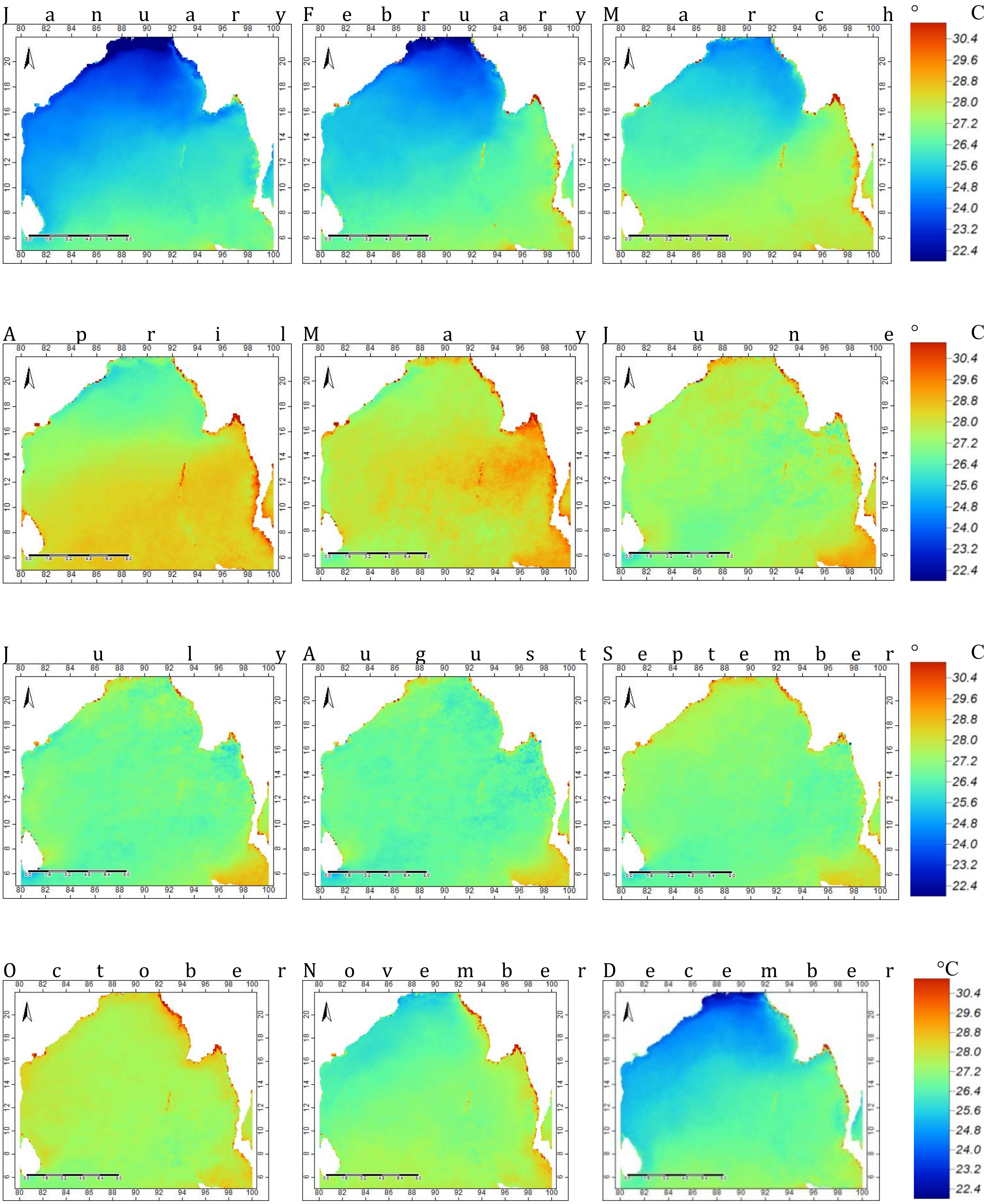

Figure 3: Monthly climatology of SST (°C) during 2001-2017.

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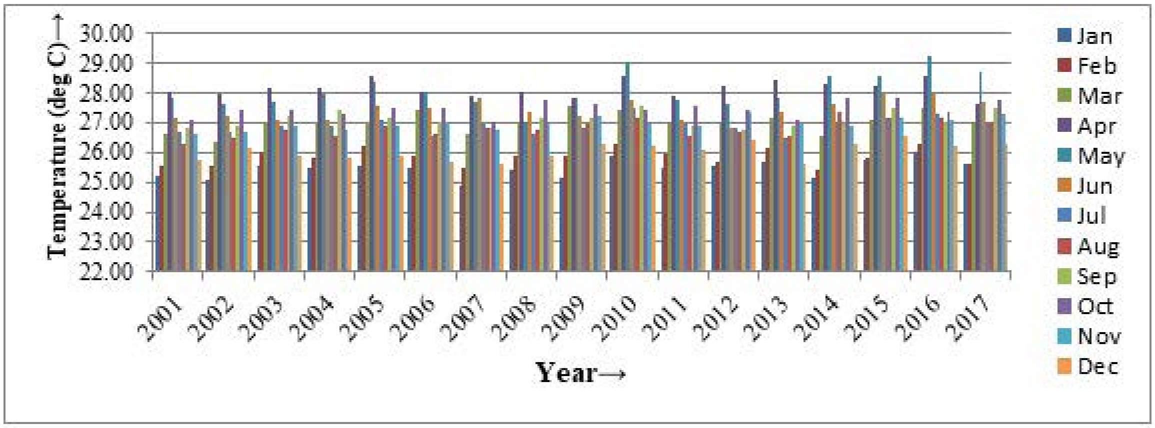

Figure 4: Time series of SST from 2001 to 2017.

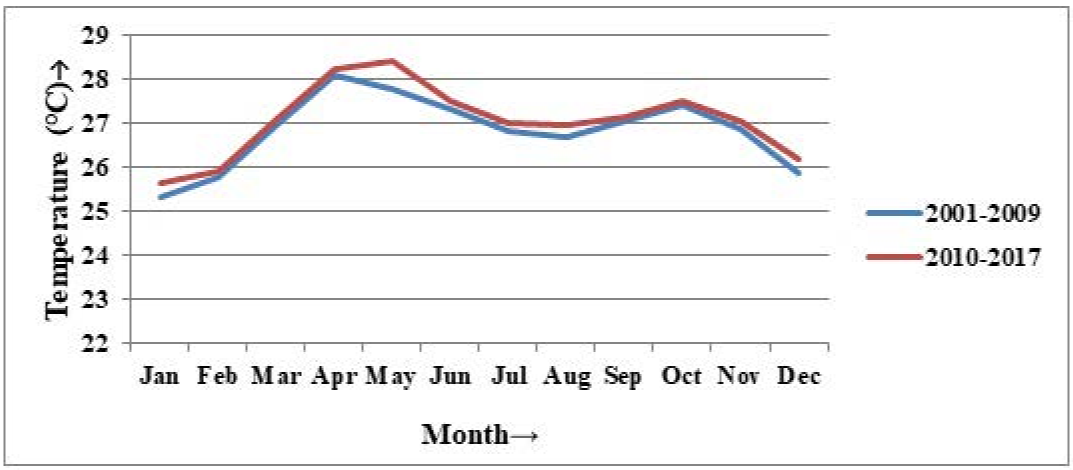

Figure 5: Line diagram of monthly SST of two halves of the investigation period.

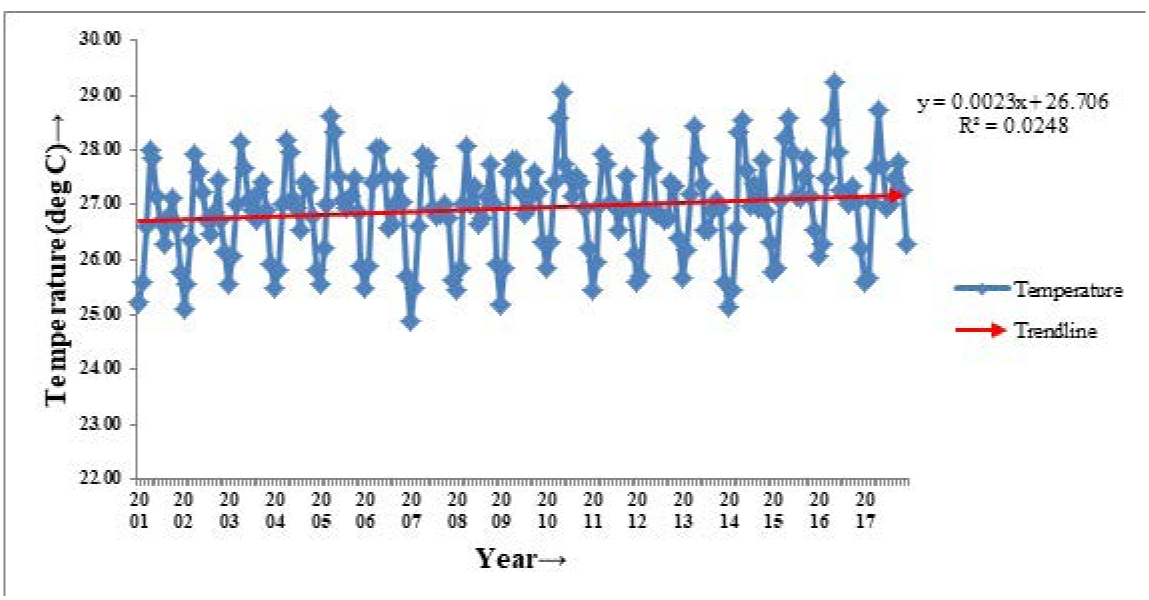

Figure 6: Time series of SST from 2001 to 2007 with trendline.

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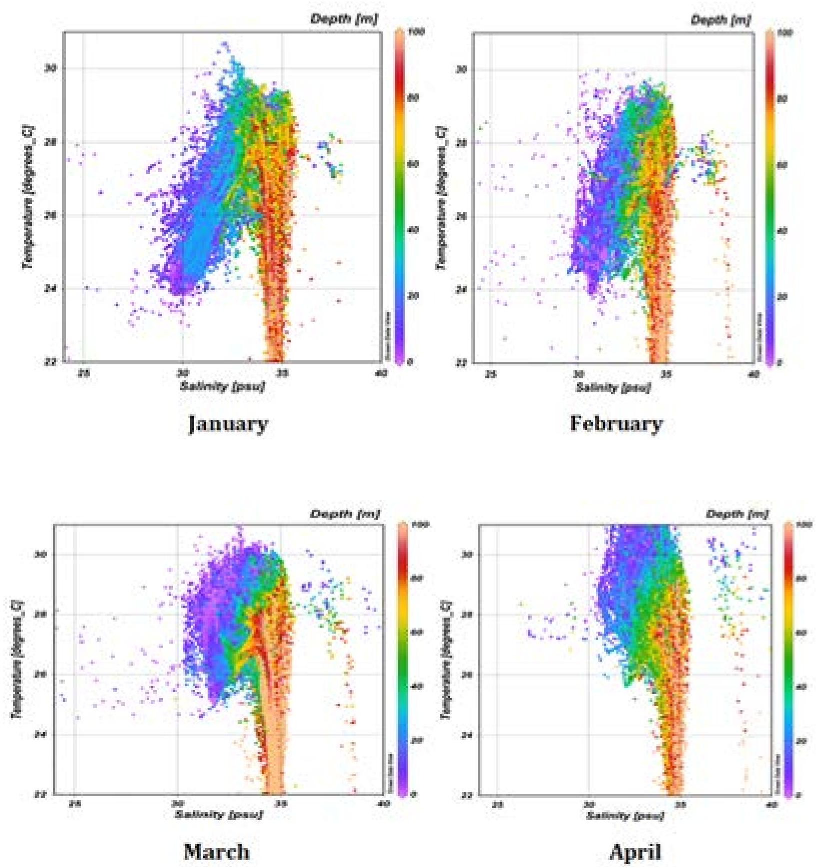
The spatial distribution of SST variation shown in (Figure 3). An interesting feature of the SST distribution in the southwestern bay was the appearance of a thermal front with a region of cold water around Sri Lanka in May. This thermal front further developed in June and peaked in August. By October, this feature was about to diminish. This must be associated with Indo-Sri Lankan upwelling system (Figure 3).

Seasonal influences are magnified by the proximity of land, which brings with it an increased annual range in atmospheric temperatures and a concentration of freshwater supply through river runoff. This makes the characterization of water masses more difficult than in the deep ocean, where most of the water is not in contact with the atmosphere. From the scatter-plot (Figure 7) of T-S of BoB over 50 years, we see that most scatter of T-S found in between 27-51m depth (Figure 7). We found high temperature in the surface where salinity is low but with increasing depth there seen decreasing of temperature and increasing salinity (Figure 7). In winter season (Dec-Feb) (Figure 7), Scatter density of T-S is high which indicates less freshwater input during the season. Scatter density of T-S indicate little amount of freshwater input in post monsoon period (Figure 7). In coastal regions of BoB evaporation is enhanced through the influence of the hot dry land; the air over the coastal ocean is very undersaturated in moisture. This can lead to a significant salinity increase in the coastal ocean during the dry season of the monsoon.

In the monsoon period (June to September), due to the huge amount of freshwater input there seen less scatter T-S density (Figure 7) compare to previous month. T-S scatter in the month of October and November (Figure 7), indicates moderate freshwater input. Actually near the cost of Bangladesh, India and Mayanmar, salinity becomes less because of freshwater discharge from local land area which causes change of T-S scatter pattern.



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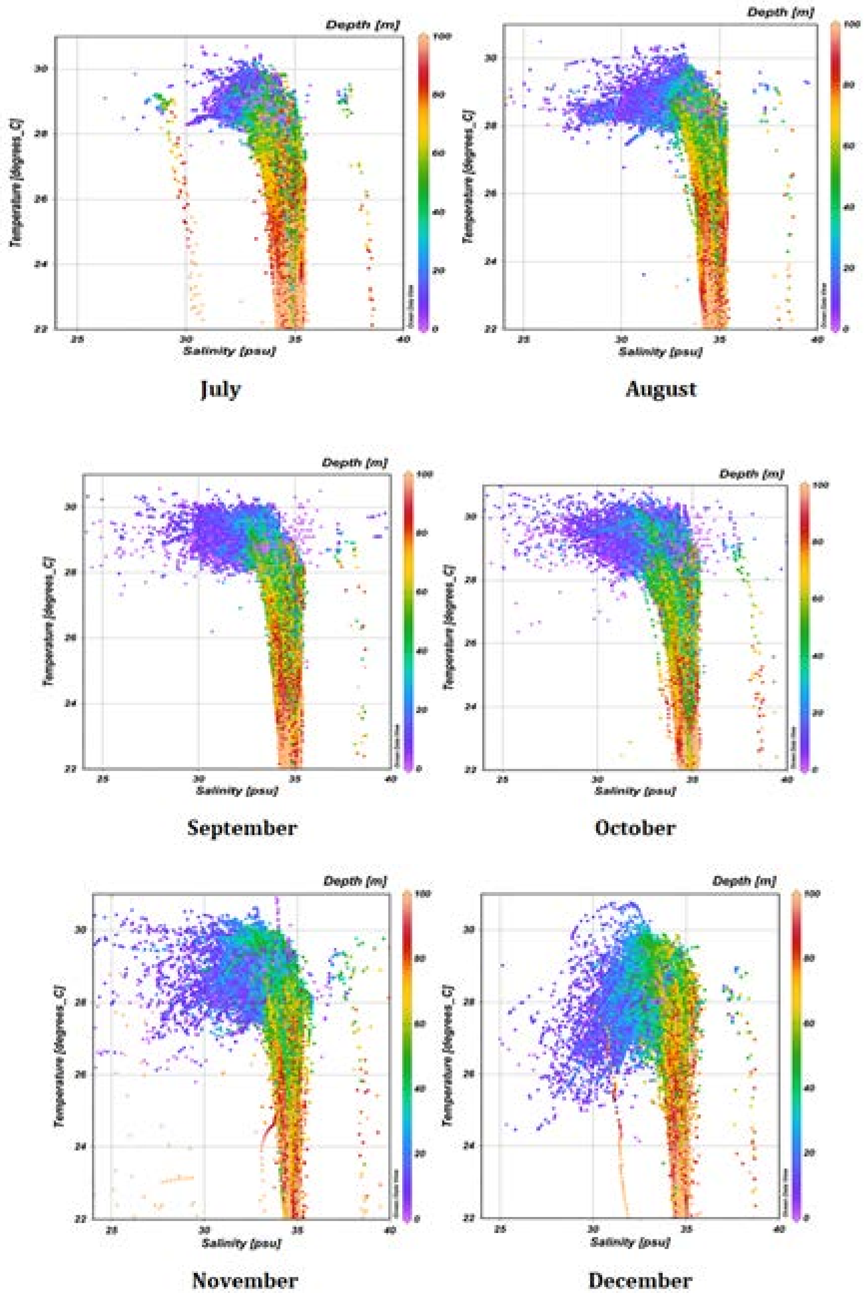

Figure 7: T-S Diagrams of Jan to Dec based on over 50 years of ocean data

Conclusion

A well interpreted SST can be utilized to detect the surface temperature signature for forecasting cyclones. Throughout the study period of Bay of Bengal the usual water averaged mean temperature ranges from 25.46°C to 28.15°C. SST was showed a strong seasonal cycle. The seasonal cycle of SST showed two warming period during April-May and October. Overall scenario of SST demonstrates an increasing trend. Freshwater discharge from local land area causes change of T-S scatter pattern. A significant change of T-S scatter density observed during winter season, pre-monsoon and post monsoon period.

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