

# The Thermal Response of the Upper Ocean to Very Severe Cyclones over the Bay of Bengal during 1981-2021

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## Abstract

Tropical cyclones are one of the most devastating natural disasters, and the frequency with which they form is closely tied to environmental factors. One of the characteristics known to enhance tropical cyclone (TC) generation is a warm sea surface temperature (SST). The rapid down-gradation in sea surface temperature due to the tropical cyclone has been shown in recent studies on different basins throughout the world rather than the Bay of Bengal (BoB). This reduced SST takes time to recover. Many researchers are studying to determine the recovery period and use it in predicting TCs intensity as it is shown that SST is related to intensity. Recently, many studies are also done to classify the cyclones regarding their recovery time. This study uses GrADS to plot SST of BoB to find out the lowest SST during severe cyclones. Then use that spot to find the recovery time. With respect to this recovery time, we classified those cyclones in three classes. By this methodology, it is concluded that SST in BoB can recover within about 27 days, and 56% of cyclones recover within 30 days.

**Keywords:** Tropical cyclone, temperature, Bay of Bengal, Sea Surface Temperature

## 1. Introduction

Bangladesh has been intrinsically associated with severe tropical cyclones. As we have the phenomenon of re-circulation of tropical cyclones (TCs) in the Bay of Bengal, shallow continental shelf, triangular shape at the North of Bay of Bengal, almost sea-level orography of the Bangladesh coastal land, and approximately 580 km of exposed coastline along the Bay of Bengal [1]. Tropical cyclones are one of the foremost dangerous natural disasters. They need to be detected and observed over the 20th century with improvement from observing technologies, like satellite remote sensing, which allows more accuracy in their surveillance. Within the current climate, about 80 cyclones develop every year within the different ocean basins all over the world, mostly in summer or in early autumn. Storms develop over tropical ocean water and move toward higher latitudes until they decay over land or cold water [2].

In this work, we have taken the change of Sea surface temperature anomaly (SSTA) and Sea surface temperature (SST) with cyclone as the thermal response of sea surface. To TC's occurrence generally, SST rises to boost up the convection force. As soon as it takes place, we face a rapid fall of SST. It is the strong winds that associated with tropical cyclones, causes the fall of SST beneath the storm. At first an SST reduction is small in spatial scale, can also spread to larger scales over time. Fisher (1958); Brand (1971); Jansen et al. (2010); all in their research stated that tropical cyclones (TCs) induce reductions in the sea surface temperature (SST) beneath the storm due to associated strong winds [3-5].

Within the wake, SST decreasing range from less than 1°C (Cione et al. 2000), 4°C (Price et al. 2008), 6°C (Berg 2002), 7°C (Walker et al. 2005), and 9°C (Lin et al. 2003) [6-10]. Generally, in the Northern Hemisphere the greatest fall in SST are found to the right of the TC's track (Nelson 1996), whereas it is found to the left of the track within the Southern hemisphere (Berg 2002) [8, 11].

Many of the values of SST reduction reported within the literature ask the utmost cooling observed within the wake to the rear of the TC and adjacent to its track. Cooling of the ocean surface also occurs within the neighborhood of the eye wall, although SST reductions are generally smaller than those within the adjacent wake. Consideration of the TC-induced change in SST near the eyewall is vital because reduced SSTs mean reduced fluxes of warmth from the ocean to the storm. The reduced surface fluxes beneath the eyewall, instead of a change in surface flux at some distance from the TC's center, have the potential to impact the storm's intensity.

Willoughby in 2007; Wang and Wu in 2004; Schrope in 2005 found that accurate prediction of cyclone intensity change had become a great challenge for the meteorological community [12-14]. Pattnaik, S.; English, C.; Krishnamurti, T. N. in 2011 found that cyclone intensity change depends on many internal as well as external factors. SST is one of them [15].

Crnivec et al. (2016) investigated the effects of modifying the SST and latitude and found that when the SST is around 26°C, the TC intensification rate is substantially dependent on latitude, but this dependence decreases as the SST rises. The rate of TC intensification increases with SST at a particular latitude [16].

Sanabia, E., B. Barrett, P.G. Black, S. Chen, J.A. Cummings in 2013 researched over the Atlantic basin and found that updating SST through an ocean coupled model improves the forecast of TC intensity [17]. Similar result found by Yablonsky *et al.* in 2015 [18].

Similarly Sandery, P.A., G.B. Brassington, A. Craig, and T. Pugh in 2010 [19] and Jullien, S., P. Marchesiello, C. Menkes, Jérôme Lefevre, N. Jourdain, G. Samson, M. Lengaigne in 2014 researched over over Pacific Ocean basin [20]. But none of them were done over BoB basin.

However, BoB is a warm ocean all year as SST is almost always greater than 27°C which is researched by Bhat *et al.* in 2004. This SST is required for TC generation and evolution. Even after meeting the warm water criterion, some TCs intensify while others fade away over the BoB [21].

As a result of this research, we can infer that TC evolution is influenced by SST variations throughout a TC's life cycle, and that incorporating realistic SST changes into the life cycle of a TC can enhance the prediction of TC physical parameters (track, intensity, and structure). SST not only necessary for genesis of cyclone but also intensify TC. For anticipating the quick intensification phase of a cyclone, Bender and Ginis (2000) demonstrated the necessity of accurate coupling of sea surface temperature (SST) in the Geophysical Fluid Dynamics Laboratory (GFDL) model [22].

The number of days needed for the SST to recover is called recovery time and it varies from cyclone to cyclone, with time periods starting from days to weeks. Hazelworth (1968) found a variety from 1 to 36 days, with a mean period of about 20 days in the Gulf of Mexico, while along the geographical region of the United States; the mean was approximately 10 days [23]. Nelson (1996) found that cooling of the ocean surface was still cold nearly one month after the storm's passage, [11] and Emanuel (2001) noted a restoration of SSTA over a period of weeks. [24]. By utilizing a large database of storm tracks and SSTs, Hart *et al.* (2007) found that SST returned to normal anomaly approximately 35-40 days after the TC's departure [25].

The classification of TC with respect to recovery time which was noted by defined by Hart *et al.* in 2007 [26] is written below:

**Table 1:** Classification TC with respect to recovery time

Cyclone class No.	Recovery Time(days)
1	1 – 5
2	6 – 30
3	> 30

## 2. Data Used and Methodology

### 2.1. Data used

The NOAA 1/4° Daily Optimum Interpolation Sea Surface Temperature (OISST) is a long-term Climate Data Record that combines measurements from many platforms (satellites, ships, buoys, and Argo floats) into a consistent global grid. To build a geographically complete map of sea surface temperature, the dataset is interpolated to cover gaps in the grid. To account for platform differences and sensor biases, satellite and ship observations are compared to buoys. [27]

These used data are provided at NOAA/NCEI (Data Access - OISST | National Centers for Environmental Information (NCEI) formerly known as National Climatic Data Center (NCDC); access date: June 19, 2021).

### 2.2. Methodology

With all those data discussed before, we have gone through some steps to turn them into useful information. At first, we do visualization in GrADS and numerical calculation and presentation in Microsoft Excel.

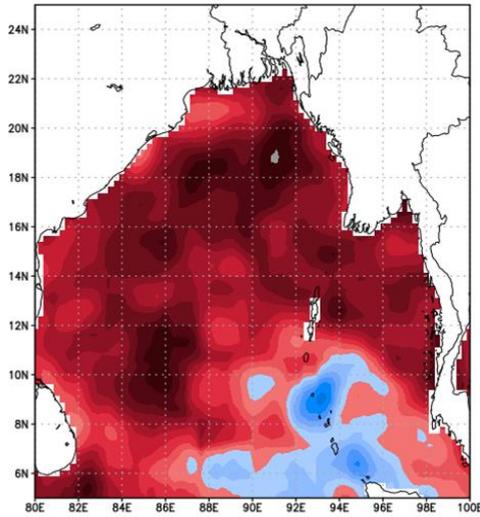
In this work, we use GrADS to visualize SST of BoB for some continuous days during the occurrence of each severe cyclones considered. For example,

Step 1: We choose a cyclone AMPHAN and load provided data on GrADS.

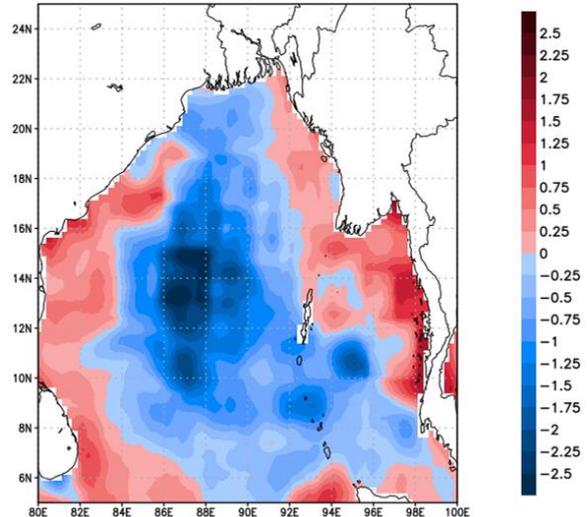
Step 2: We start visualization over Bay of Bengal latitude 5°-25°N, longitude 80°-100°E.

Step 3: We look for the highest and lowest temperature before and during the cyclone as shown in Fig. 1 and Fig. 2 respectively.

Step 4: From step three we found that there's a sudden fall of SST due to AMPHAN. Here's SST fall suddenly within only 6 days.



**Fig. 1:** SST plot of BoB on 15 May before AMPHAN



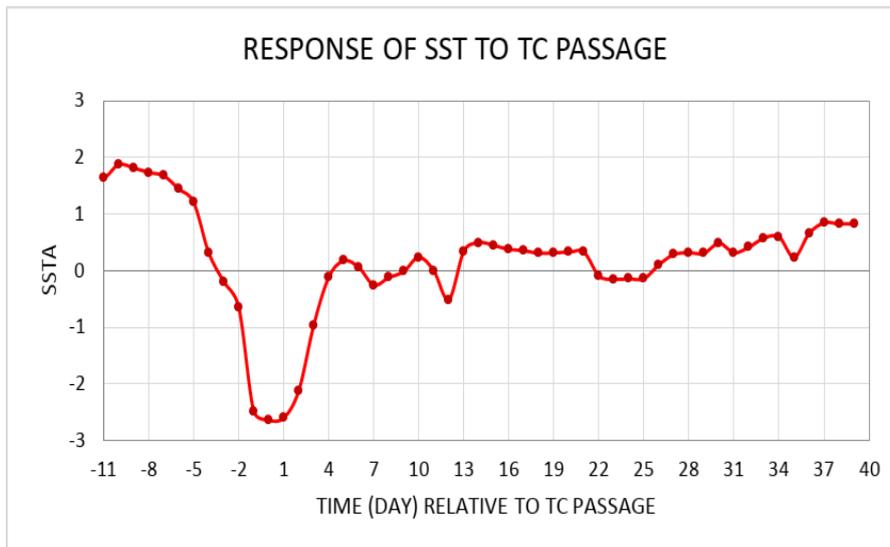
**Fig. 2:** SST plot of BoB on 20 May during AMPHAN

Step 5: From Fig. 2 we see that the lowest value of sea surface temperature was found near latitude 13.5°N and longitude 87°E on 20 May.

By those steps using GrADS we found the location of highest SST drop.

**Calculating Recovery Time**

Now, we use EXCEL to create numerical presentation of the SSTA on that specific location. From the provided data we use the SSTA of latitude 13.5°N and longitude 87°E on 20 May and get the Fig. 3.



**Fig 3:** SSTA change with respect to AMPHAN passage

From the figure we see it didn't get the previous SST for several days. So, we estimate the recovery time by our available data that is 39 days.

**3. RESULTS AND DISCUSSION**

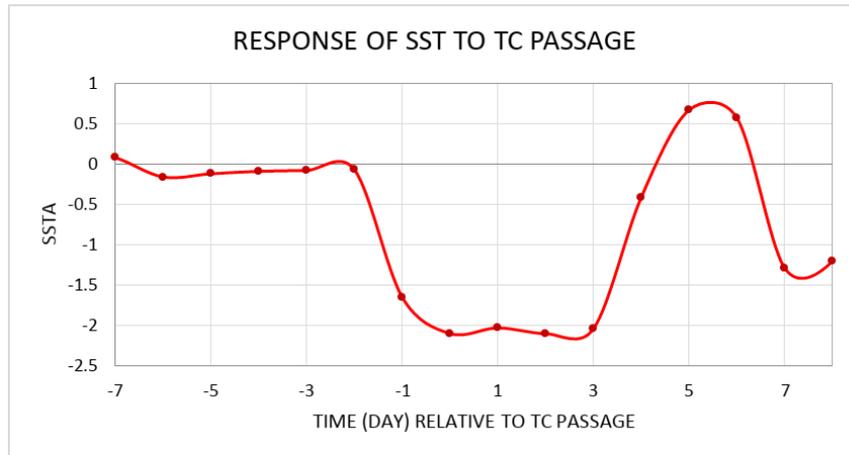
By using the methodology described previously, and using **Table-1**, we found the recovery time and classify the severe cyclones on BoB.

**Classification**

We classify the cyclone over BoB in three classes with respect to their recovery time.

**Class 1:** Cyclones which recover immediately usually within 1 to 5 days.

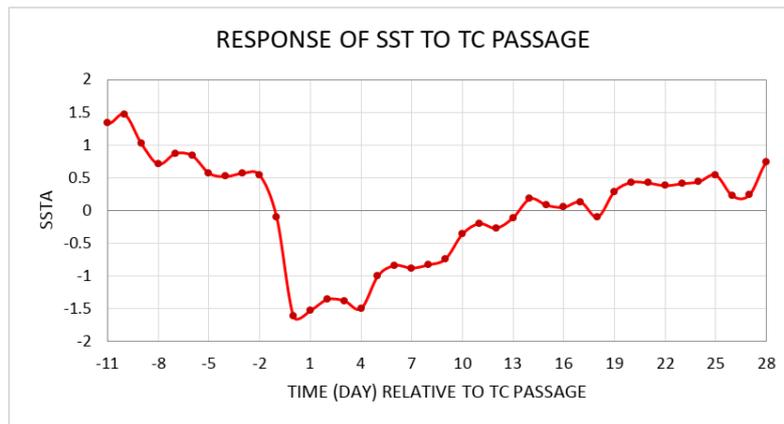
Example: Cyclone of 1991 recovers in 5 days.



**Fig 4:** SSTA change with respect to Class 1 cyclone passage

**Class 2:** Cyclones which takes some time to recover usually within 6 to 30 days.

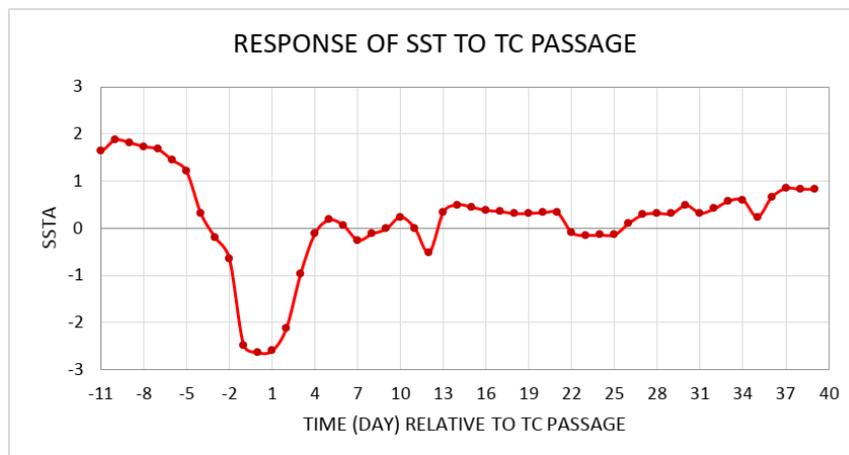
Example: FANI recovers in 28 days.



**Fig 5:** SSTA change with respect to Class 2 cyclone passage

**Class 3:** Cyclones which never recover or recover very lately usually more than 30 days.

Example: AMPHAN recovers in 39 days.



**Fig 6:** SSTA change with respect to Class 3 cyclone passage

**Percentage of cyclone class**

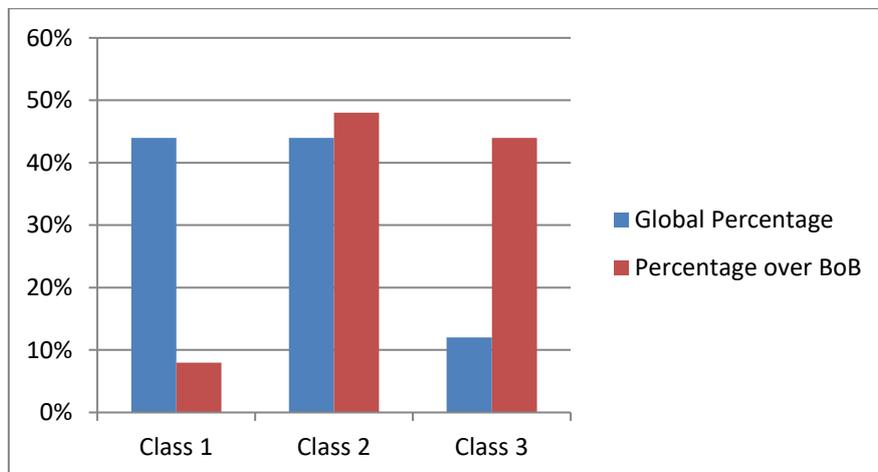
We calculated 25 severe cyclone over BoB as sample to find the class percentage of occurrence.

**Table 2:** Class percentage of occurrence

Class percentage		
Class	Number of cyclones	Percentage
Class 1	2	8
Class 2	12	48
Class 3	11	44

Finally, we get the average fall time = **3.16** days and average recovery time = **26.88**days over Bay of Bengal and we have **44%** of class 3, **48%** of class 2 and **8%** of class 1.

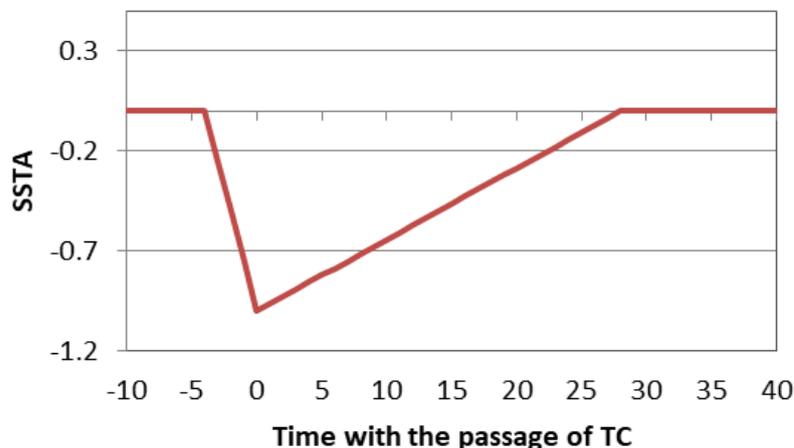
Now if we compare this percentage with global percentage found by Dare et al. [8], we get class 2 shows similarity with the global percentage but other classes show dissimilarity.



**Fig 7:** Comparison between the percentage of TC class occurrence Global and BoB

**4. Conclusion**

As Bangladesh frequently affected by tropical cyclones, there’s many research have been done on cyclones. In spite of these many works done, thermal response of sea surface towards cyclone over Bay of Bengal is a new approach. Previously, Hazelworth found a variety from 1 to 36 days, with a mean period of about 20 days in the Gulf of Mexico, while along the geographical region of the United States, the mean was approximately 10 days [23]. Nelson found that cooling of the ocean surface was still cold nearly one month after the storm’s passage, [11]



**Fig 8:** SSTA change with respect to time with passage of TC on average

and Emanuel noted a restoration of SSTA over a period of weeks [24]. By utilizing a large database of storm tracks and SSTs, Hart et al. found that SST returned to normal anomaly approximately 35-40 days after the TC’s departure

[26]. All of these works are done in different basins all around the world but not in BoB. All previous studies show that recovery time changes from basin to basin.

In this work, we specifically chose the basin of Bay of Bengal. To occur a cyclone, it needs sea surface temperature above 26°C. When it passes by sea surface temperature falls suddenly and it takes some time to recover, usually much more than its fall time. In our work, we conclude with the result that the cyclones in BoB in average have the fall time of **3.16** days and it takes **26.88** days recovery.

We also classify the cyclones over BoB on the basis of study of Hart et al. [26] and found that we have 48% of class 2 cyclone, 44% of Class 3 cyclone and 8% of class 1 cyclone.

So, we can conclude this study with the result of average recovery time 26.88  $\approx$  27 days and most of the cyclones over BoB recover within 30 days.

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