Rapid assessment of SST and Chlorophyll concentration variability due to cyclone Bulbul in the Bay of Bengal using remotely sensed satellite image data

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Key Points:

- Tropical cyclone, chlorophyll-a, sea surface temperature

Abstract

An assessment on the changes in some biological and physical properties of Bay of Bengal because of tropical cyclone BULBUL (landfall on 9 November 2019) was studied using ocean color remote sensing technique. The attempt involved the use of the Moderate Resolution Imaging Spectro-radiometer (MODIS), the Visible and Infrared Imager/Radiometer Suite (VIIRS) of the Joint Polar Satellite System (JPSS) and the Suomi National Polar-orbiting Partnership (S-NPP) sensor data in mapping of the quick variation in the chlorophyll-a concentration and Sea Surface Temperature (SST) in the upper water body. The study revealed an upward trend in chlorophyll concentration and the maximum value was of 18.21 mgm^{-3} on 15 November at 21°03’45’’N and 86°58’45’’E and the lowest temperature was 25.1°C on 11 November near 21.2°N and 88.1°E and showed a slight increase in SST in the post cyclonic period. The study also revealed a linear relationship between the chlorophyll concentration and SST.

1. Introduction

Bay of Bengal, a semi enclosed tropical marine ecosystem of northern Indian ocean is located between latitudes 5°N and 22°N and longitudes 80°E and 100°E (Vinayachandran, 2003). The bay is bounded by Bangladesh on the North and by Myanmar and the Andaman and South of India and Myanmar and the Nicobar Islands of India on the East and by India on the East. Sri Lanka and the north westernmost point of Sumatra (Indonesia) is its southern limit. It occupies an area of 2,172,000 sq. km. A number of large rivers flow into the Bay of Bengal, such the Ganges, the Meghna, the Brahmaputra, the Irrawaddy, the Godavari, the Mahanadi, the Brahmani, the Baitarani, the Krishna and the Kaveri (Map of Bay of Bengal- World Seas, 2019). The bay and its adjacent land areas are influenced by some of the fascinating meteorological conditions like monsoon bringing huge rainfall and wide variation of physical and chemical properties of water which makes it a more complex and intriguing than that of any other similar body of water. Tropical cyclones are an intense circular storm that originates over warm tropical oceans. It is characterized by the strong winds and heavy rainfall. Tropical cyclones are a major hazard in tropical coastal regions, both in terms of loss of life and economic damage. The extensive coastal belt of India and Bangladesh is very vulnerable to these tropical cyclones (Venkateswrlu, 2004). Such cyclones originate in the Bay of Bengal during the spring (April–May) and fall (October–November) intermonsoons (Subrahmanyam, 2002). The Bay of Bengal and its coastal states are vulnerable to such tropical cyclones which originate from the equatorial region during the winter (November-December) and spring (April-May). During the winter monsoon, a cyclonic gyre generally prevails in the bay which forms an equatorward western boundary current along the east coast of India. These cyclonic disturbances assisted with heavy winds and rainfall has profound impacts on the physical, chemical and biological characteristics of the water, thus affecting the abundance and production of phytoplankton. These cyclones induced upwelling, vertical mixing and the cooling of the surface temperature creates a huge episodic contrast in the chlorophyll concentration between the before and after situation (Chavez, 2009). Satellite ocean color for chlorophyll concentrations is a new approach for understanding the influence of tropical cyclone on biology, such as phytoplankton blooms, and oceanic physical processes, such as eddies (Subrahmanyam, 2002). For most regions of the world, the color of the ocean is determined primarily by the abundance of phytoplankton and its associated photosynthetic pigments (Hiroshi Kawamura, 2001). As the concentration of phytoplankton pigments increases, ocean color shifts from blue to green ("The Color of Disease |

Earthdata", 2019). The satellite observations are quite a good tool for monitoring ocean color because of their repeated coverage with high spatial resolution. Long-term time series of satellite ocean color measurements are important for understanding the marine biology, oceanic physical processes and coastal environment changes (Benway et al., 2019). Satellite remote sensing provides information on chlorophyll-a concentration. In this paper, we studied the very recent cyclonic storm BULBUL happened on 2019 and investigated the impact of this cyclone on Chlorophyll-a in the north western part of the Bay of Bengal using satellite. Recent Cyclone Bulbul was a strong tropical cyclone which streaked in the West Bengal of Indian state as well as Bangladesh in November 2019, heavy rains, causing storm surge, and flash floods across the areas. After crossing the Indochinese Peninsula, the Tropical Storm Matmo's remnants entered the Andaman Sea. It began to re-organize in the southern Bay of Bengal in early of November, then it slowly grew up into a cyclone as it moved north. It is one of the fourth tropical cyclone which ever recorded to regenerate in the Andaman Sea, and only the second to make it to hurricane strength crossing Southeast Asia overland, and the first being in 1960 (Aljazeera.com, 2019).

1.1. Description of Cyclone BULBUL

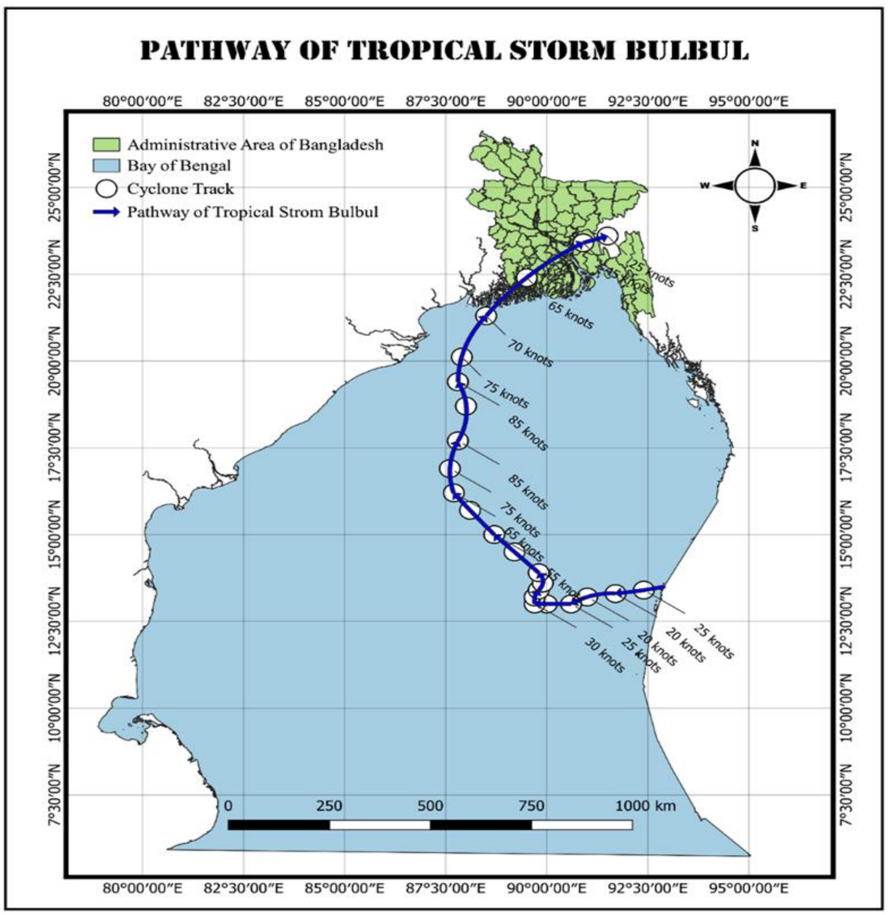


Figure 1. Pathway of tropical storm BULBUL

The path of cyclone BULBUL is shown in Figure 1 and according to the Bangladesh Meteorological Department (BMD) and the Indian Meteorological Department, the cyclone BULBUL led by the remnant of tropical Storm MATMO (28th October - 2nd November 2019) over west Pacific Ocean that emerged into north Andaman Sea. It is originated as a low pressure zone over north Andaman Sea in the early morning of 04th November. It Moved west-northwestwards having favorable environmental conditions and emerged as a depression (D) over east central and adjoining southeast Bay of Bengal in the early morning of 05th November. As it moved west-northwestwards, it amplified into a deep depression (DD) over east central and adjoining southeast area of the bay in the early morning of 06th November. By moving furthermore in the north- northwestward direction, BULBUL intensified into a cyclonic storm in the late night of 06th November over east central and adjoining southeast area. It turned into a severe cyclonic storm (SCS) in the evening of 07th November over west central and adjoining east central Bay of Bengal while continuing to move north-northwestwards. Moving nearly northwards, it further intensified into a very severe cyclonic storm (VSCS) in the early morning (0000 UTC) of 08th November over west central and adjoining east central Bay. It continued to move nearly northwards until the afternoon (0900 UTC) of 09th November and then started to re-curve northeastwards from the evening (1200 UTC) of the same day. Subsequently, it weakened into a SCS and crossed West Bengal coast, close to Sundarbans Dhanchi Forest near 21.55°N/88.5°E during the night (1500 to 1800 UTC) of 09th November as a Severe Cyclonic Storm with maximum sustained surface wind speed of 110-120 kmph gusting to 135 kmph.

2. Materials and Methods

In this study, the cyclone data of tracking points with latitude and longitude are taken from the Bangladesh Meteorology Department (BMD) and Indian Meteorological Department (IMD) and a significant portion of points have been selected from the list on the basis of data availability. As It is very tough to carry out the in-situ observations of different parameters during the cyclonic period, remotely observed data of level 2 and level 3A and 3B from different satellite sensors like The Moderate Resolution Imaging Spectro-radiometer (MODIS), The Visible and Infrared Imager/Radiometer Suite (VIIRS) of the Joint Polar Satellite System (JPSS) and the Suomi National Polar-orbiting Partnership (S-NPP) have been used. Aqua MODIS view the entire Earth's surface every 2 days in 36 spectral bands ranging in wavelength from 0.4 to 14.4 µm and chlorophyll-a concentration data of level 3B with native resolution of 4.63×4.63 km and 9×9 km are acquired from this sensor. These data are processed and analyzed for time series plotting, bloom detection etc. in SEADAS and SATCO2 environment. The SST data of 11 µm during the daytime of native resolution 4.63×4.63 km of both level 2 and level 3 are acquired from the VIIRS-SNPP sensor and processed in SEADAS environment. The daily coverage data for Both the chlorophyll concentration and SST have been used in this study.

3. Track Point Data

Suitable tracking points along the pathway of Tropical Cyclone Bulbul in Table 1 (on the basis

Date	**Time (UTC)**	**Tracking Point**	**Centre lat.0 N/ long. 0 E**		**Estimated Maximum Sustained Surface Wind (kt)**	**Grade**
05/11/2019	1800	01	13.3	89.8	25	D
06/11/2019	0000	02	13.4	89.7	30	DD
	1800	03	13.8	89.3	35	CS
07/11/2019	0600	04	15.3	88.7	40	CS
08/11/2019	0300	05	17.2	87.6	65	VSCS
	0900	06	18.1	87.6	70	VSCS
	1800	07	19.3	87.6	75	VSCS
	2100	08	19.6	87.7	75	VSCS
09/11/2019	0000	09	20.0	87.6	75	VSCS
	0300	10	20.4	87.6	70	VSCS
	0600	11	20.6	87.8	70	VSCS
	0900	12	20.9	87.9	70	VSCS
	1200	13	21.2	88.1	70	VSCS
	1500	14	21.4	88.3	60	SCS
10/11/2019	0000	15	22.1	89.5	45	CS
	1200	16	22.5	90.4	30	DD
11/11/2019	0000	17	23.1	91.9	20	D

of the availability of satellite data):

Table 1.
*D- Depression
*DD- Deep Depression
*SCS- Severe Cyclonic Storm
*VSCS- Very Severe Cyclonic Storm
*kt- Knots

4. Results and Discussion

4.1. Variation of Sea Surface Temperature

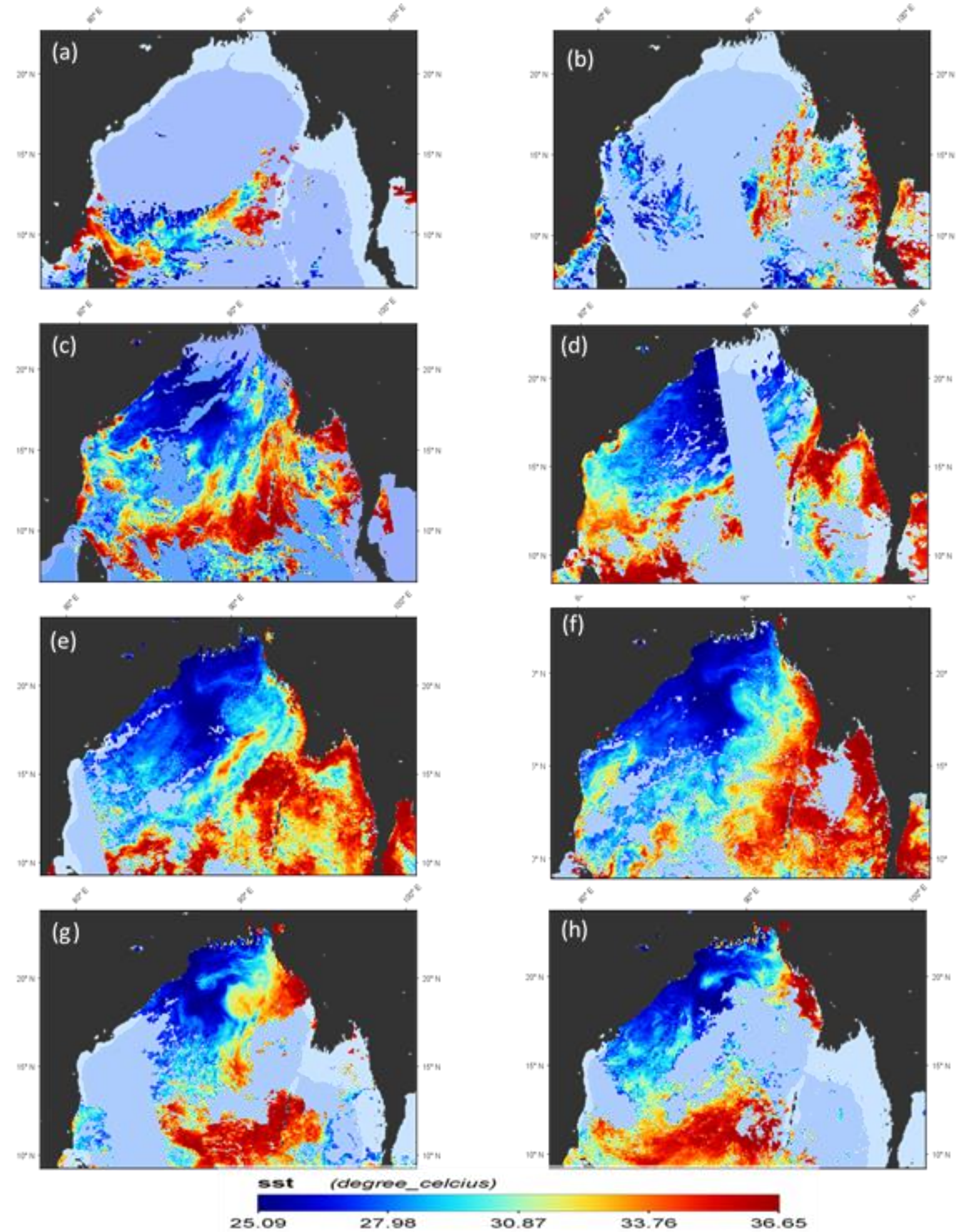


Figure 2. SNPP-VIIRS daily composite of SST (11 µm) during daytime-(a)08 November 2019, (b)09 November 2019, (c)10 November 2019, (d)11 November 2019, (e)12 November 2019, (f)13 Nov 2019, (g)14 November 2019, (h)15 November 2019

To understand the change in the sea surface temperature and its effect to other processes during and after the cyclone, the daily coverage daytime SST data obtained from satellite sensors are analyzed and presented in Figure 2(a-h). During the storm, data of four days from 8th-11th November are taken into account and the temperature of this period ranged from 26.24°C to 29.5°C along the pathway of cyclone shown in Figure 2(a-d). The lowest temperature in this 4 days' range is found to be 25.1°C on 11th November near 21.2°N and 88.1°E. The post cyclonic period data from 12th-15th November are presented in Figure 2(e-h) which shows a change between 26.8°C and 29.6°C along the pathway. The lowest temperature in this period is found to be 25.6°C on 12th November near the track point 14 at 21.6°N and 88.02°E.

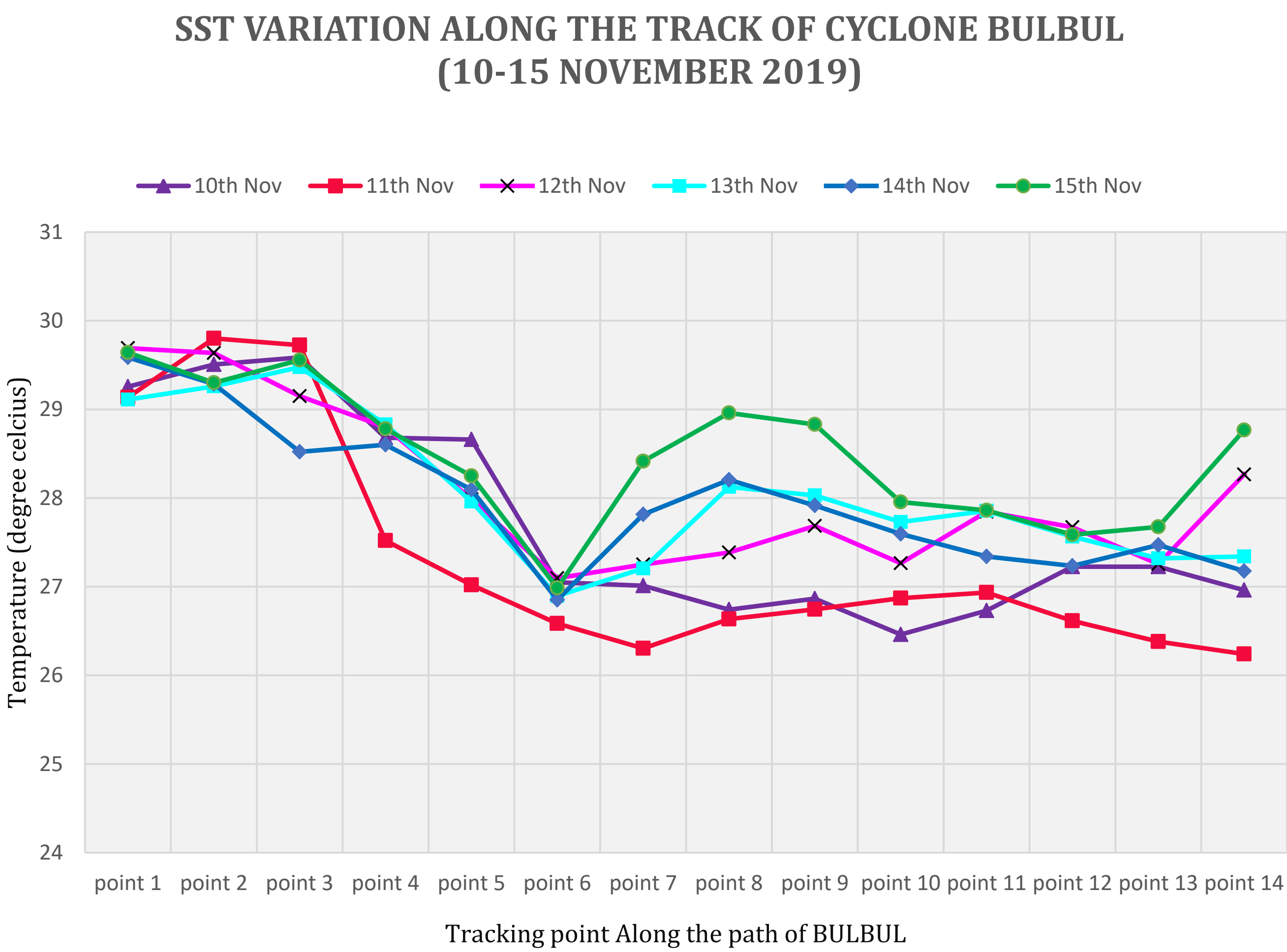
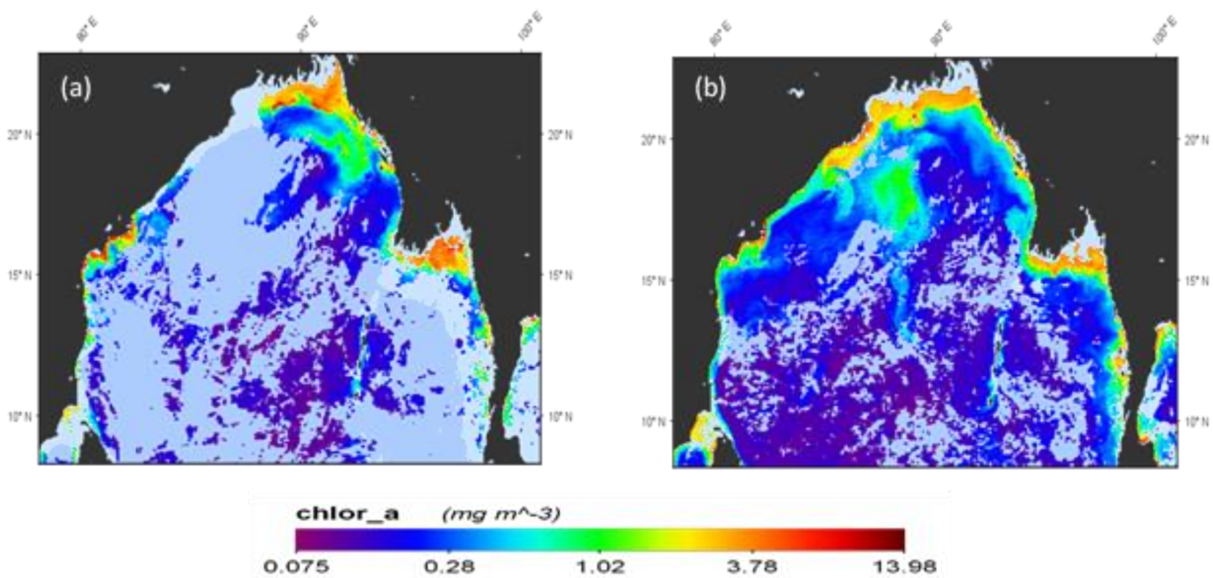


Figure 3. Variation of SST during daytime along the tracking point during and after cyclone BULBUL

4.2. Variation in Chlorophyll concentration

Figure 4. SNPP-VIIRS 8-day coverage of chl-a concentration-(a)01-08 Nov 2019, (b)09-16 Nov 2019



The response of phytoplankton community is observed by analyzing the chlorophyll concentration data derived from MODIS. Satellite observation of chlorophyll concentration shows the scenario during and after the super cyclonic episode was shown in Figure 4. Daily and eight-day composite data of chlorophyll from 01-16 November from both MODIS and SNPP-VIIRS are used for analysis due to the unavailability of the hourly data and immense cloud coverage over the bay. After the landfall of BULBUL on 10 November 2019, the chlorophyll concentration has increased to 5.25 mgm^{-3} on 11 November 2019 at 19°8’45’’N latitude and

85°11’15’’E longitude, 7.98 mgm^{-3} on 12 November at 20°53’45’’N and 88°21’15’’E, 3.04 mgm^{-3} on 13 November at 19°03’45’’E and 84°58’45’’E and reached to a maximum value of 18.21 mgm^{-3} on 15 November at 21°03’45’’N and 86°58’45’’E.

The observation indicates to an increase in the chlorophyll-a concentration during and after the storm. This complies to the post eight days of cyclone BULBUL from 09-16 November 2019. As, chlorophyll concentration is very important for the biological processes of the upper ocean and this study conceptualizes that it can be altered by the tropical storms like BULBUL and can play a considerable role in the transformation of phytoplankton behavior and other biogeochemical processes like primary productivity.

Besides, an attempt is made to study the relationship between the sea surface temperature and the chlorophyll-a concentration during and after the tropical cyclone BULBUL in Figure 6. The chlorophyll-a concentration along the cyclone pathways, from 08 November 2019 to 16

November 2019 are used here to show a marginal relationship. The cyclone was examined with SST along cyclone pathway values as shown in Figure 3 and Chlorophyll-a concentration values as shown in Figure 5. From the analysis, a positive relationship between the cyclone intensity and chlorophyll-a concentration has been observed. This result conforms that as the intensity/strength of the cyclone increases (black solid line) the chlorophyll concentration also increases. The study also reveals the greater biological response to the cyclones and the magnitude of response depends on the strength of the cyclones.

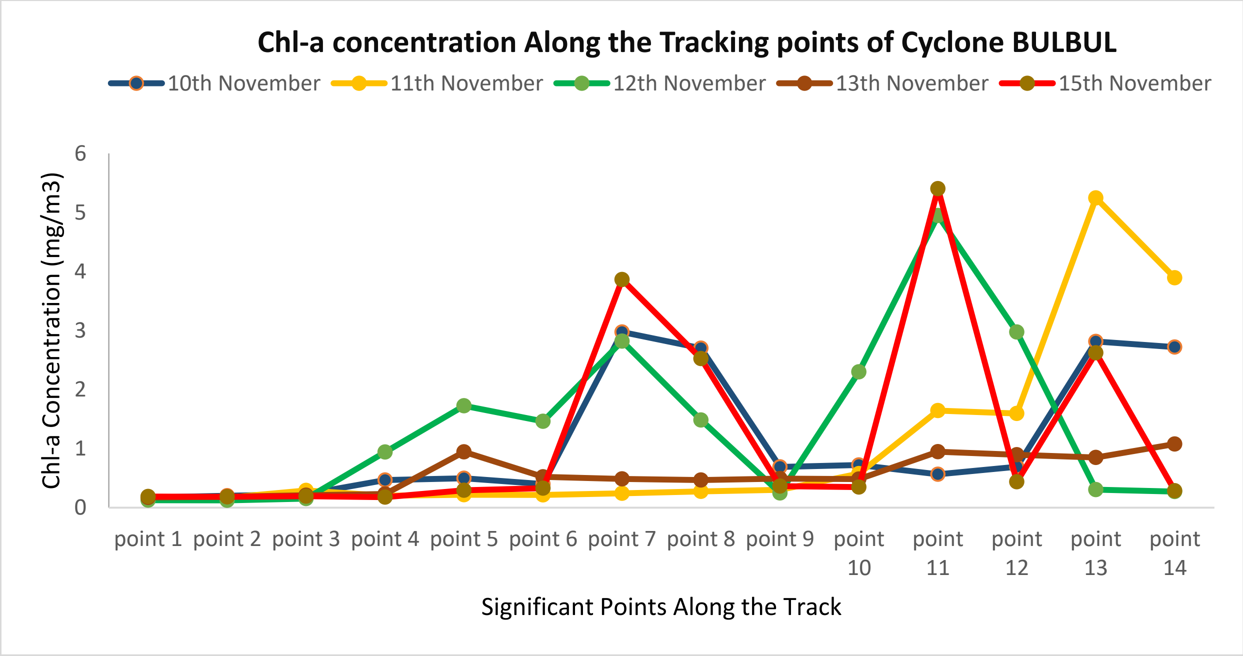


Figure 5. Variation in concentration of chlorophyll concentration due to cyclone BULBUL (10-15 November)

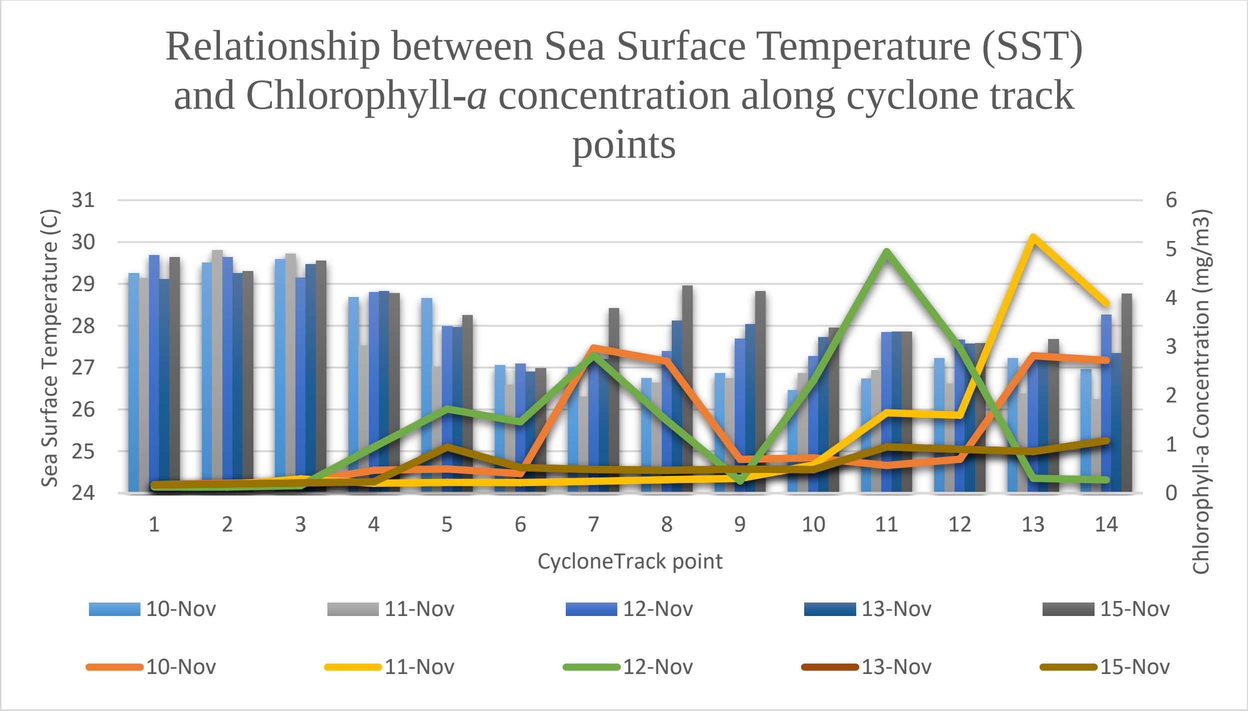


Figure 6. Relationship graph between the SST and the chlorophyll concentration along the pathway of cyclone BULBUL

5. Conclusions

This study has shown the usefulness of satellite data in measuring the physical and biological properties during and after severe tropical episodes like cyclones and to understand the changes in the patches. The maximum increase in the concentration of chlorophyll is observed with a time lag of 4 days immediately after the cyclone. This lag can be attributed to the time taken for the upwelling process and injection of nutrients to the euphotic zone and for the photosynthesis reaction to enhance the chlorophyll concentration. This enhancement and persistence of chlorophyll is also evident from the 8-day composites of SNPP-VIIRS chlorophyll imagery. But due to the lack of the cloud free data of other parameters, it wasn't possible to find out reasons behind the sudden change in chlorophyll concentration and its relation to primary production and other biogeochemical processes.

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