**International Journal of Geosciences, 2015, 6, 473-480**
Published Online May 2015 in SciRes. http://www.scirp.org/journal/ijg
http://dx.doi.org/10.4236/ijg.2015.65037

# Impact of Cyclone PHAILIN on Chlorophyll-*a* Concentration and Productivity in the Bay of Bengal

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Received 24 March 2015; accepted 10 May 2015; published 13 May 2015



## Abstract

**Ocean colour remote sensing is one of the conventional methods in satellite oceanography used to study the biological response of the upper ocean to the tropical cyclones. This paper aims to study the impact of the Very Severe Cyclonic storm PHAILIN, and its consequence on the surface chlorophyll-*a* concentration distribution in the Bay of Bengal using Oceansat-2 Ocean Colour Monitor (OCM). The impact of this cyclone on ocean primary productivity has been studied using MODIS-A data. Sea surface temperature (SST) plays an important role in the generation of primary productivity along with the other oceanographic parameters; SST patterns in the Bay of Bengal during the cyclone period were studied. From the analysis, it is observed that the chlorophyll-*a* concentration has increased from 1.08 (before) to 7.06 mg/m$^3$ after the cyclone with an SST drop of ~3˚C (29.19˚C to 26˚C). The primary productivity has increased from 410.0506 to 779.9814 mg/C/m$^2$/day after the cyclone. In addition to the above analysis, an attempt has also been made to study the impact of cyclone intensity on the chlorophyll concentration. The study shows that the comparison between cyclone intensity (CI) and chlorophyll concentration shows a positive relationship.**

## Keywords

**Oceansat-2 OCM, Cyclone, Chlorophyll-*a*, Primary Productivity, Cyclone Intensity, SST**

## 1. Introduction

Tropical cyclones are one of the episodic disturbances which influences on both the abundance and production

**How to cite this paper:** Preethi Latha, T., Rao, K.H., Nagamani, P.V., Amminedu, E., Choudhury, S.B., Dutt, C.B.S. and Dadhwal, V.K. (2015) Impact of Cyclone PHAILIN on Chlorophyll-*a* Concentration and Productivity in the Bay of Bengal. *International Journal of Geosciences*, **6**, 473-480. http://dx.doi.org/10.4236/ijg.2015.65037

of marine phytoplankton [1] which also affects the physical and biological oceanographic parameters. These cyclonic disturbances also show the strong winds and heavy rainfall. In terms of biological consequences, the cyclone wind field causes local mixing which results in the injection of nutrients into the upper layer of the ocean and triggering phytoplankton blooms [2] [3]. The upper ocean response to a moving cyclone has been studied by many researchers [4]. Cyclone induced upwelling and enhanced vertical mixing causes the injection of nutrients to the euphotic zone and availability of sufficient light conditions for photosynthesis at surface [3] [5]-[8] which favors the condition of Chlorophyll-*a* concentration enhancement [9]-[13]. The studies on the phytoplankton blooms caused by tropical storms are crucial in understanding the mixing and biogeochemical processes in the oceans. The strong cyclonic winds often result in the decrease of Sea Surface Temperature (SST) which plays a major role in the generation of Primary Productivity thus enhancing the productivity of the water column after the cyclone. Satellite remote sensing provides information on several parameters such as sea surface temperature, wind speed and ocean color datasets like chlorophyll-*a* concentration and primary productivity to study the phenomena of cyclones. Remote sensing satellites with radiometers at visible, infra-red and microwave frequencies provide near real time data to diagnose cyclone development and its track/path. Optical remote sensing limits in capturing the entire cyclone event as the sensors obscured by the clouds.

In this paper, we studied the very severe cyclonic storm PHAILIN (*now onwards cyclone PHAILIN*), happened after the 1999 Odisha Super cyclone and investigated the impact of this cyclone on Chlorophyll-*a*, SST and productivity in the central western part of the Bay of Bengal using satellite observations. In addition to that, the impact of cyclone intensity on chlorophyll concentration has been studied.

## Development Stages of PHAILIN

As per the IMD report (Very Severe Cyclonic Storm, PHAILIN over the Bay of Bengal (08-14 October 2013): A Report) [14] on the genesis of the cyclone PHAILIN was reported on 08 of October 2013 (total duration 08-16 October 2013) over the Bay of Bengal and the track of the cyclone is shown in **Figure 1**. For this cyclone, a low depression system was initially formed over the (12˚N & 96˚E lat/long) on 8 October 2013 on the eastern side of Andaman and developed into a deep depression on 09 October and then to a severe cyclonic storm on 10 October and moved towards northern Bay of Bengal and crossed the Odisha coast on 12 October causing a large destruction. The maximum sustained surface wind speed was 115 Kt during the severe cyclonic storm conditions and the pressure drop during the land fall point was 66 h·Pa.

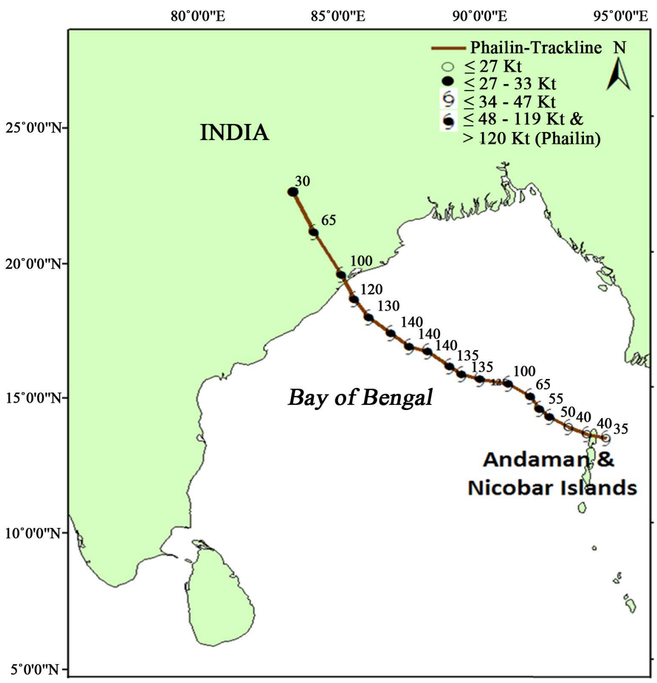


**Figure 1.** Cyclone track of cyclone PHAILIN.

## 2. Materials and Methods

It is very difficult to carry out the *in-situ* observations during the cyclone period. In this present study, the cyclone data of track points with latitude and longitude including cyclone intensity, pressure, and wind and cyclone stage was taken from the Indian Meteorological Department (IMD) [15]. The chlorophyll-*a* concentration data derived from OCM-2 with a native resolution of 360 m using OC-4 algorithm in the SeaDAS environment has been used. Since OCM-2 has two day repetivity and covers the Bay of Bengal region in two paths of 10 and 11 covering from the rows 13, 14 and 15, compositing the two day passes covering the Bay of Bengal has been done. In order to compute the chlorophyll concentration along the cyclone track, the data was gridded in a 2 × 2 degree box for each track point, SST data along the track was taken from NOAA AVHRR with a resolution of 0.25 × 0.25, and 8-day composites of primary productivity data of MODIS-A derived from Vertically GPM [16] model with a resolution of 4 km has been used in the study.

## 3. Results

### 3.1. SST Response

During the cyclone due to strong winds and anti-cyclonic conditions divergence takes place which brings the nutrient rich cooler water to the surface and makes the ocean surface cooler [4] [17]-[19]. As the SST has increased from 28˚C to 29.16˚C ocean thermal condition was well favored for the genesis of the cyclone PHAILIN in the Bay of Bengal [17]. To understand the thermal response of the upper ocean to the passage of PHAILIN, SST along the cyclone track before and after the cyclone has been analyzed. Along the track, the SST was examined for the periods: before (5-7 October 2013), during (8-12 October 2013) and after (13-16 October 2013) the passage of the cyclone (**Figure 2**). Before the passage of the cyclone PHAILIN, SST along the cyclone track varied from 28˚C to 29.19˚C (black solid dots line in **Figure 2**) at the cyclogenesis point. SST during depression or at the cyclogenesis was 29.16˚C and during the severe cyclonic storm conditions SST was reduced to 27.14˚C. From this analysis SST drop of 2˚C is evident for cyclone PHAILIN. Immediate after the passage of the PHAILIN cyclone the cooling was observed up to a period of four days with a value of 26.5˚C near to the land fall point.

### 3.2. Biological Response

#### 3.2.1. Chlorophyll-*a*

Biological response of the PHAILIN cyclone has been explored (before and after) by analyzing chlorophyll-*a*

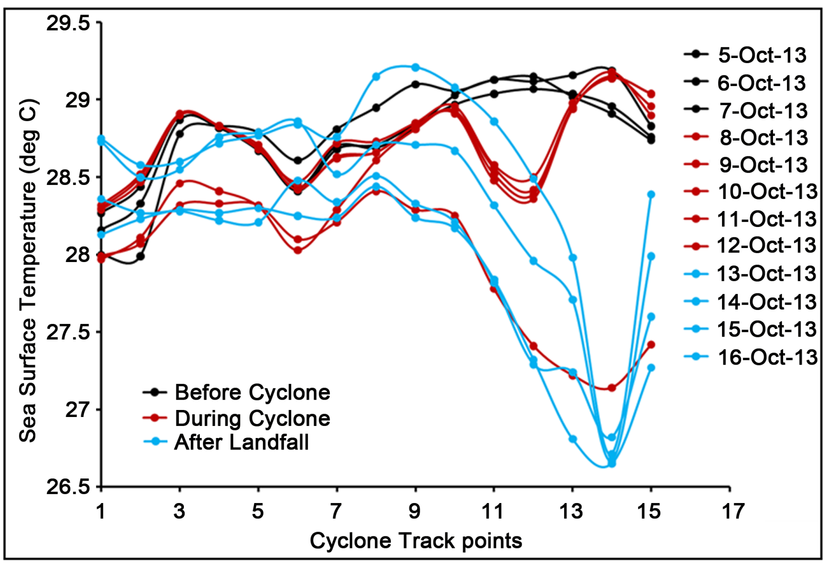


**Figure 2.** The sea surface temperature response along the cyclone track points of PHAILIN.

concentration from Oceansat-2. Two day composites of OCM-2 chlorophyll imagery were used for this cyclone and the concentration values along the cyclone track points were examined as shown in **Figure 3**. The chlorophyll-*a* concentration in the Bay of Bengal at the cyclogenesis point of PHAILIN was 1.8 mg/m$^3$.

After the landfall of the cyclone on 12Oct 2013, the chlorophyll concentration has increased to 4.94 mg/m$^3$ on 13 & 14 October 2013 (light blue colour solid line in **Figure 3**) at 16.1˚N latitude 88.4˚E longitude and reached to a maximum value of 7.06 mg/m$^3$ on 15 & 16 October 2013 (pink colour solid line in **Figure 3**) at 16.7˚N latitude 87.7˚E longitude. 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 OCM-2 chlorophyll imagery as shown in **Figure 4**. From the observations of [20], the increase in Chlorophyll-*a* anomaly was 4.35 mg/m$^3$ and SST of 2.5˚C respectively during entire event. From the recent study [21] also showed the increase in biological response of the Bay of Bengal to the cyclone PHAILIN.

### 3.2.2. Primary Productivity

Satellite based remote sensing is the most powerful tool in explaining the enhanced biological response due to the passage of the tropical cyclones [3] [5]. In this present study, the effect of PHAILIN cyclone on primary productivity has been studied using the weekly composites of primary productivity products (4 Km) from MODIS-A. Weekly composite of Primary Productivity (VGPM derived) from MODIS-A were analysed as shown in **Figure 5** before, during and after the super cyclone PHAILIN. From the analysis it is clearly observed that before the cyclone *i.e.*, from 24-30 September 2013, along the cyclone track there is very low productivity with a mean value of 410.0506 mg/C/m$^2$/day. The productivity values are very low in the Central Bay of Bengal and even near the Andaman coast. During the cyclone period *i.e.* from 9-16 October 2013, the mean PP value observed along the track was 779.9814 mg/C/m$^2$/day, And after the cyclone period *i.e.*, from 17-24 October 2013, the mean PP value was ~347.9945 mg/C/m$^2$/day all along the track which indicates not much variability in the primary productivity value even after the passage of the cyclone. From this analysis, it is clearly observed that increase in the chlorophyll concentration is not proportionate to Primary Productivity as shown in **Figure 5**. This can be attributed to the dependency of PP to the other parameters like nutrients, light availability and SST apart from chlorophyll concentration.

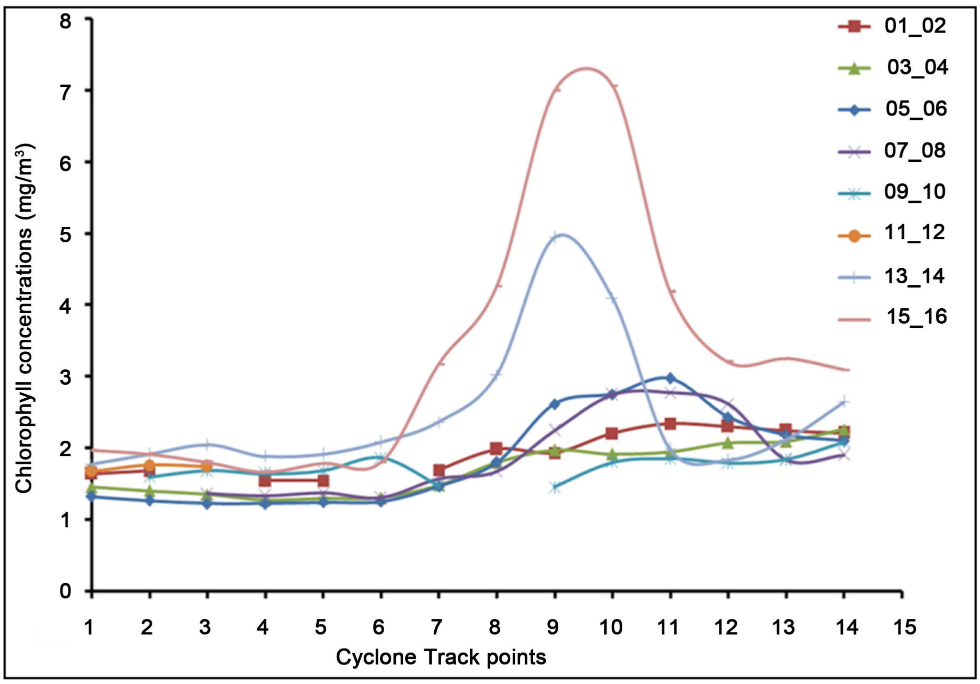


**Figure 3.** The response of chlorophyll-*a* concentration along the cyclone track points of PHAILIN.

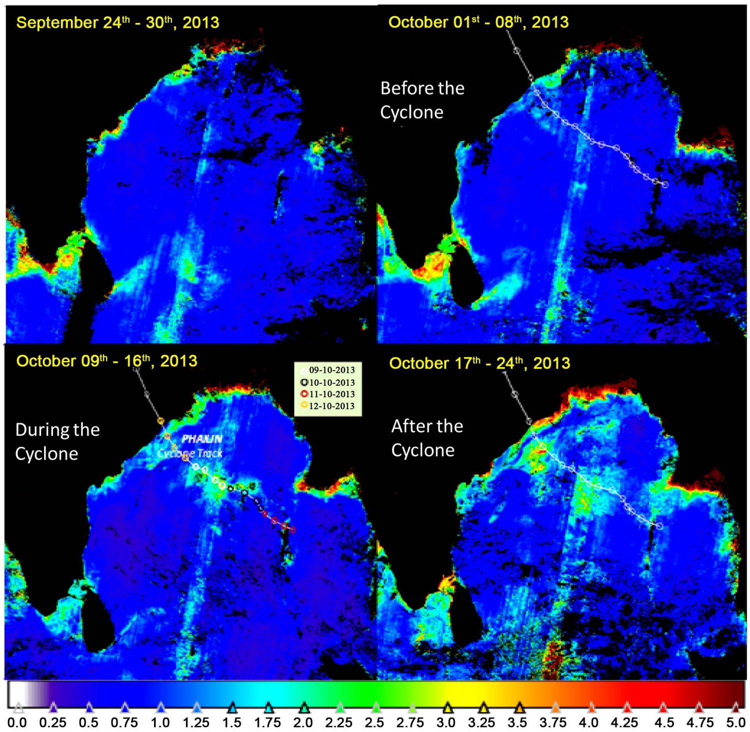


**Figure 4.** Weekly composites showing the distribution of chlorophyll-*a* concentration in the Bay of Bengal before, during and after the cyclone PHAILIN.

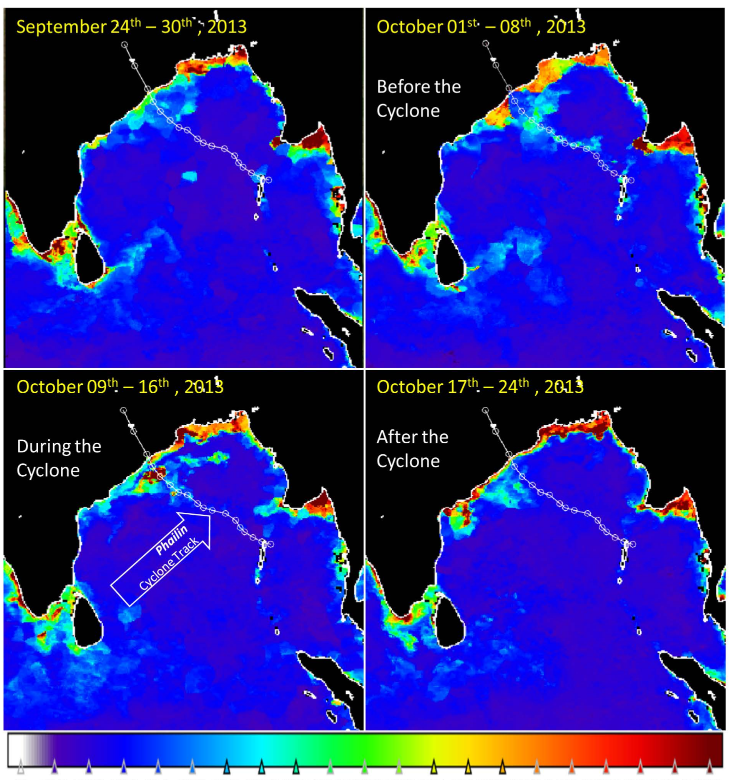


**Figure 5.** Weekly composites of MODIS-A showing the distribution of primary productivity in the Bay of Bengal before, during and after the cyclone PHAILIN.

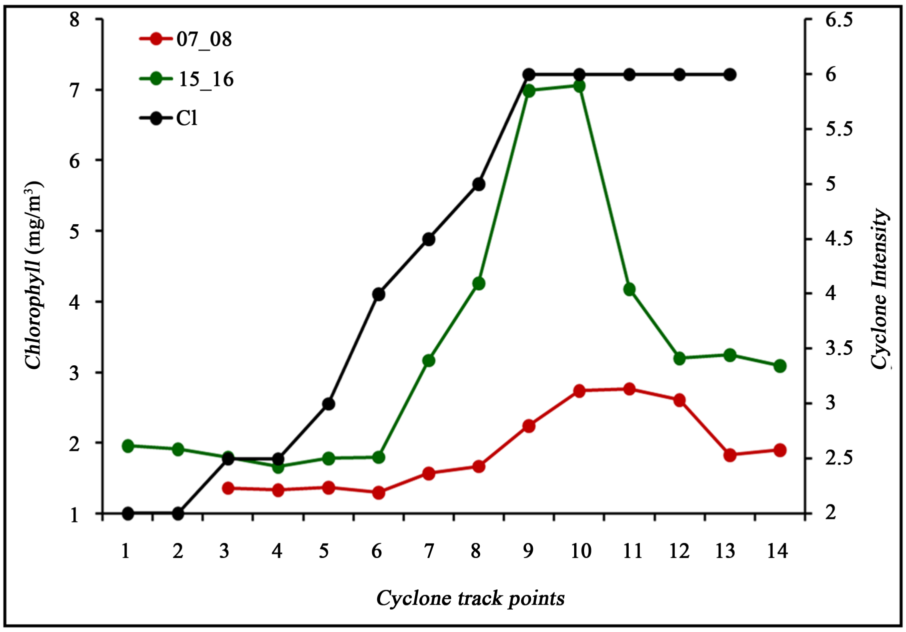


**Figure 6.** Relationship between cyclone intensity (CI) and Chlorophyll-*a* concentration for before (solid red dotted line) and after the cyclone PHAILIN dates (solid green dotted line). The solid black dotted line indicated the cyclone intensity along the track of cyclone PHAILIN.

The analysis shows that an increase in the chlorophyll-*a* concentration is very clear before and after the cyclone. However, the same enhancement in the PP value is not clear; this can be observed from the satellite images as well. This can be conformed from the last week of the chlorophyll and PP images, *i.e.*, from 17-24 October 2013, though there is an increase and persistence of the chlorophyll concentration (>5 mg/m$^3$) this didn't influence the PP increase. This infers that, though chlorophyll plays an important role in the PP or to the biological response of the upper ocean due to cyclones there are other parameters/conditions of the ocean might have played a role, which resulted in the marginal PP increment due to cyclone PHAILIN.

### 3.3. Impact of Cyclone Intensity on Chlorophyll-*a* Concentration

An attempt is made to study the relationship between the cyclone intensity and the chlorophyll-*a* concentration. The chlorophyll-*a* concentration along the cyclone track points, one day before *i.e.*, on 07 & 08 October 2013 and after *i.e.*, 15 & 16 October 2013 the cyclone were examined with cyclone intensity values as shown in **Figure 6**. 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.

## 4. Conclusion

From the present study, due to PHAILIN cyclone, the sea surface temperature dropped from 29.19˚C to 26.5˚C. This reveals that a threefold increase in the chlorophyll-*a* concentration from 1.08 to 7.06 mg/m$^3$ and an increase in the primary productivity from 410.0506 to 779.9814 mg/C/m$^2$/day are observed. A positive relationship with the cyclone intensity and chlorophyll-*a* concentration is observed. The increase in the magnitude of chlorophyll-*a* concentration also depends on the intensity of the cyclone along with the other physical parameters contributing to the biological response of the upper ocean column to the tropical cyclones.

## Acknowledgements

We are thankful to India Meteorological Department, New Delhi for providing the cyclone track data and report.The authors would like to express their sincere thanks to SeaDAS software package developed by NASA OBPG.

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