Proceeding Paper

Remote Sensing Biological Pump Potential: A Plankton Spatio-Temporal Modelling in the Philippine Seas

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Abstract: This study focuses on the quantification and forecasting of the Biological Pump potential in the Philippine seas, specifically inside the Exclusive Economic Zone (EEZ). Variabilities and disturbances that might potentially influence ocean productivity such as increased sea surface temperature, and the high frequency of typhoons in the Philippines were investigated. CHL and SST spatio-temporal maps were used to provide visualization for the trends and phenomena before, during, and after typhoon occurrence for the years 2019-2021. Integrating the NASA Ocean Color data of CHL and SST with typhoon tracks, the Biological Pump potential annual estimate was generated.

Keywords: image processing; biological pump potential; environmental monitoring; remote sensing; forecasting planktons; plankton carbon sequestration

1. Introduction

In regulating the atmospheric CO2 concentration, the ocean plays a vital role in the Earth's carbon cycle [1]. There are six (6) ocean biological carbon pumps (OBCPs) that comprise the downward pumping of biogenic carbon to the deep ocean [2], estimated to be at between 5 and 14 Pg C y-1 [3-4]. These include the Mixed layer pump, the Eddy Subduction pump, the Large-scale Subduction pump, the Ekman pumping, and animal mediated pumps, and the vertical migration of zooplankton [5]. Some animals like fish and jellyfish, which are larger than zooplankton may also contribute to these animal-mediated pumps [6]. Presently, various techniques have been conducted to monitor and understand the dynamics of these processes in space and time, which is also critical in global climate processes [7].

Geographically situated in the typhoon belt of the Pacific, the Philippines receives an average of 20 typhoons per year [10]. The archipelago consisting over 7000 islands and islets is clustered into three main island groups, Luzon, Visayas and Mindanao. The Southern part of Luzon and Visayas islands are the most hard-hit in terms of typhoons, among other natural disasters experienced in the country. Given these threats, the Philippines has a high biodiversity including numerous flora and fauna endemic to the archipelago, hence the need to advance understanding in the marine environment to improve monitoring and intervention efforts in the future.

The use of remote sensing, similar to various environmental monitoring, provides an avenue to expand the understanding of the OBCPs, from traditional ship-based Net Primary Production (NPP) [8-9] point measurements, to space and time covering the entire ocean [1]. This paper presents a viable and low-cost option to estimate the NPP exploiting available remote sensing data products.

2. Materials and Methods

False color representations of satellite data were extracted from the NASA Ocean Color website. Specifically, the maps used were 8-day data of both CHL and SST from the Level 1 & 2 browser, a total of 276 images for 2019-2021. These data were produced under NASA's Earth Observing System Data and Information System (EOSDIS). NASA's CHL uses an algorithm derived from the in-situ measurements of CHL-a and remote sensing reflectances (Rrs) captured by satellite sensors using the band range 440 - 670 nm [11]. The SST was derived from long-wave infrared (LWIR) bands in MODIS and VIIRS sensors with an algorithm based on a modified nonlinear SST algorithm developed by [12] and recently by [13].

The region of interest (ROI) considered is specific to the extent of the Philippine Exclusive Economic Zone (EEZ) for data cleaning and processing. Instead of total pixel removal, cloud covers represented by black pixels were all replaced by non-black neighboring pixels.

To simplify the analysis of the CHL trends and plankton productivity, the EEZ of the archipelago was subdivided into 4 quadrants (also represented by the transect lines in Figure 1a) covering the main seas around the country: the Philippine Sea (T1&T2), West Philippine Sea (T4), and Sulu Sea (T3). Coordinates of the four (4) transect lines were used to extract the RGB data of all 75x75 px images (CHL and SST).

Image Processing and Machine Learning using Python and Matlab were utilized to generate the 75x75 Spatio-Temporal 8-day maps for the years 2019-2021. K-nearest neighbor (KNN) was used to facilitate classification of the map data and extraction of both the CHL and SST values based on NASA color scales.

Spatio-Temporal CHL abundance was compared with SST variability and typhoon occurrence (pre, during and after) to look for trends, both short- and long-term periods. CHL and SST linear relationship was also checked for possible correlations.

Using the Spatio-Temporal model, mainly considering SST and integrating possible typhoon occurrence as buffer, the forecast for the Philippine Biological Pump potential was generated.

3. Results

High productivity occurs mainly in the West Philippine Sea (Quadrant 4), and Sulu Sea (Quadrant 3) as shown in Figure 1b.

3.1. Spatio-Temporal Relationships of CHL, Typhoons and SST

The typhoon season in the Philippines usually begins by June but typhoons may occur as early as January, just like in the year 2019. However, the Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA) started detecting typhoons entering in the Philippine Area of responsibility only in the month of May for the year 2020, with high intensity typhoons occurring in the last quarter of the year and primarily in Luzon and Visayas. The opposite can be said for 2021 with typhoons both for 3rd and 4th quarter but mostly in the Visayas and Mindanao area. High intensity Typhoons occur in Luzon (2019), Luzon and Visayas (2020) and Visayas and Mindanao (2021) with as fast as over 250 kph, 315 kph, and 280 kph respectively. In fact, back in 2020, there was even a series of typhoons which hit the Bicol Region in a span of only 3 weeks, led by the infamous Super Typhoon Rolly.

It was highly evident that when typhoons Goring and Betty (2019), Marce and Carina (2020), and Kiko, Jolina, Maring, and Nando (2021) traversed near transect 1, the CHL value dropped, as shown in Figure 2. In transect 2, this is also true with Ambo (2020), but when Liwayway (2019), Bising (2021) and Odette (2021) there was no change in the CHL value, even though they are both high intensity typhoons. While it was surprising to observe that when typhoons Amang (2019) and Auring (2021) traversed near transect 2, the CHL value increased [10].

While there was minimal typhoon crossing Transect 3, except for Odette (2021) with increased CHL, Transect 4 is rather peculiar since the CHL value increased after the occurrence of Kabayan (2019), Quiel (2019), Ofel (2020), Ulysses (2020), and Vicky (2020), while dropping after Lanie (2021).
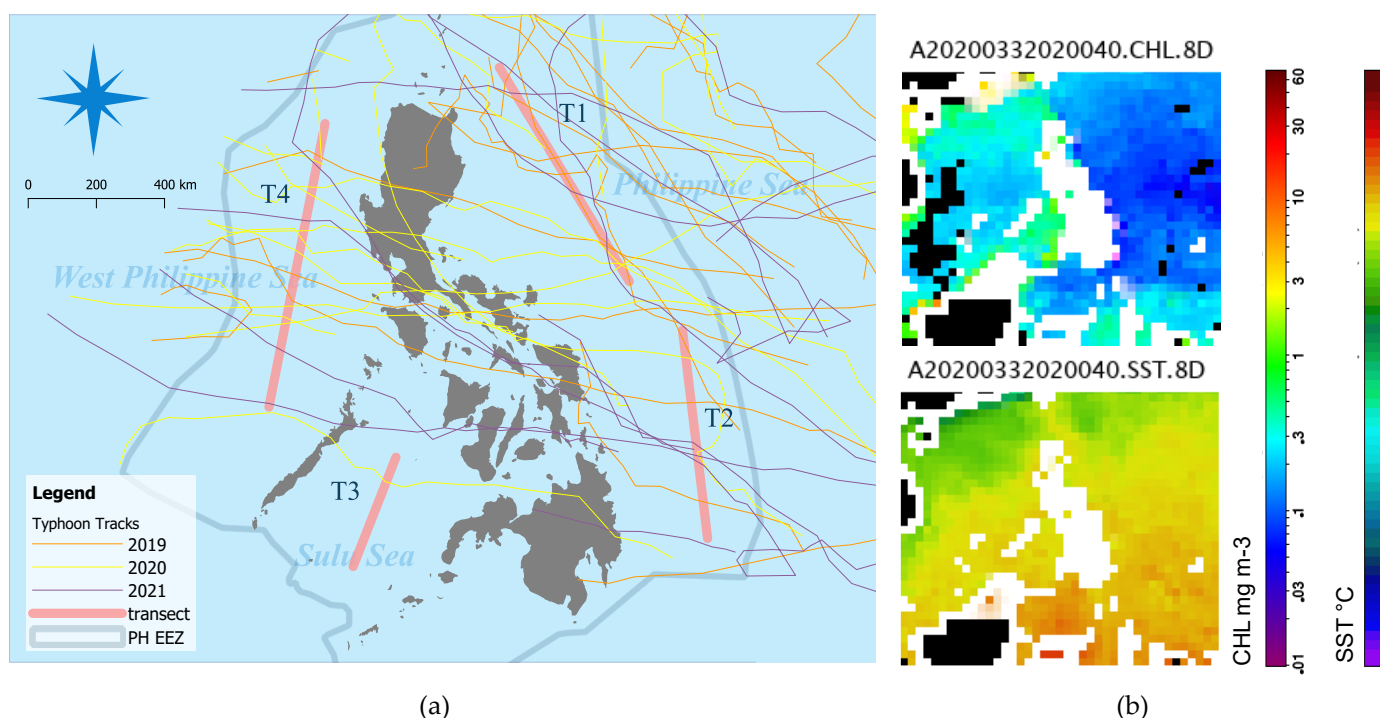

Figure 1. Visualization of the a) Philippine Tropical Cyclone tracks for the years 2019-2021, and sample NASA false colour maps for b) CHL /SST. CHL Peak month map (February 2020).

Each transect showed a different trend. In Transect 1, a steep decrease in CHL was observed with decreasing SST for January-March (2019-2021) while a steady decrease in CHL with increasing SST from April onwards for 2019-2020 and almost no change in CHL for 2021. Interestingly, in Transect 2, decreasing SST comes with increasing and decreasing CHL for February-March (2019-2020), while decreasing CHL with increasing SST for April onwards. The year 2021 has a different behavior since the decrease in SST was observed from January-June with also decreasing CHL, while on July onwards, SST increased with almost no change in the CHL.

There are 3 different trends that can be observed in Transect 4. In 2019, There was a deep decreasing CHL with decreasing SST from February-March while the opposite was observed in 2020, with CHL increasing despite the decreasing SST. It was a combination on the other hand in 2021, with increasing and decreasing CHL with decreasing SST for January-April. Though for the second threshold of the year, increasing SST and decreasing CHL go hand in hand from April/May onwards (2019-2020).

The CHL and SST regression results showed a weak linear relationship between CHL and SST using all the data from 2019-2021, and individual yearly data (true for 2019 and 2021). Yet, it was surprising that a lone high R2 ($R2_{2020}$=0.81) was observed with also the occurrence of typhoons, specifically super typhoon Rolly.
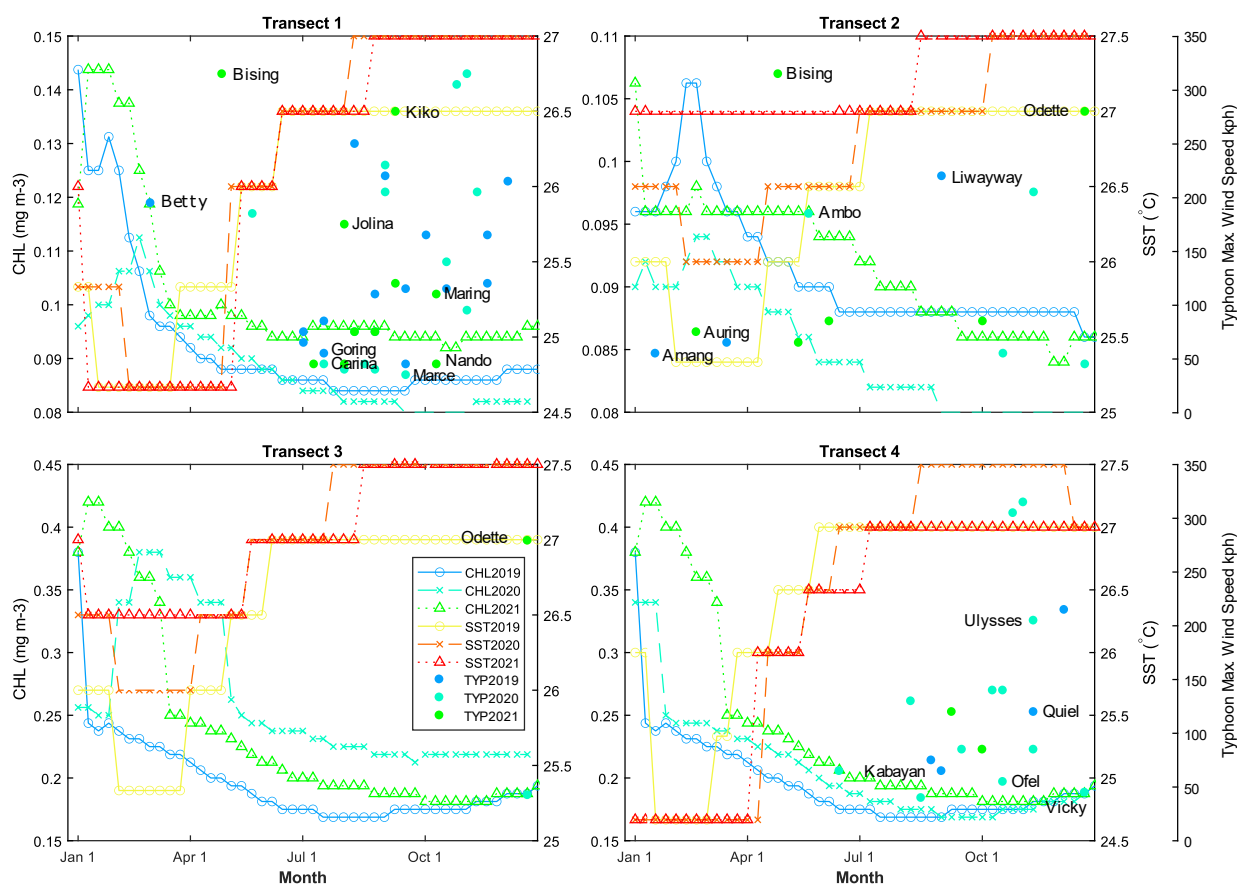
Figure 2. Time series plot of CHL, SST and Typhoons for all transect lines for 2019-2021.

Table 1. Regression Results for different data input period 2019-2021.

Year	R2	Adj R2	STD Error	Data Range Error
2019	0.497350775	0.485926929	0.010314718	0.172631256
2020	0.813471554	0.809133683	0.003874051	0.11920158
2021	0.420219238	0.407042402	0.011789143	0.227809524
2019-2021	0.423529973	0.419227958	0.010920877	0.171307876

[1] Results reflect total ungrouped data.

3.2. Ocean Net Primary Productivity (NPP) Estimation

The Vertically Generalized Production Model (VGPM), a widely used NPP model, was utilized to generate the NPP in all four quadrants of the Philippine EEZ following the transect assignment. VGPM was first described by [14], and since then, this model was utilized and further improved such with the development of carbon-based NPP [15].

The NPP model used is represented by the equation:

$$npp = chl \times pb\_opt \times day\ length \times f(irr) \times z\_eu, \tag{1}$$

which follows the convention of the original VGM model. Both the CHL and SST data were already previously generated. The f(irr) is the photosynthetically active radiation (PAR) function which was downloaded from the Ocean Color website [16] while pb_opt is a polynomial of 7th order which varies depending on the sea surface temperature.
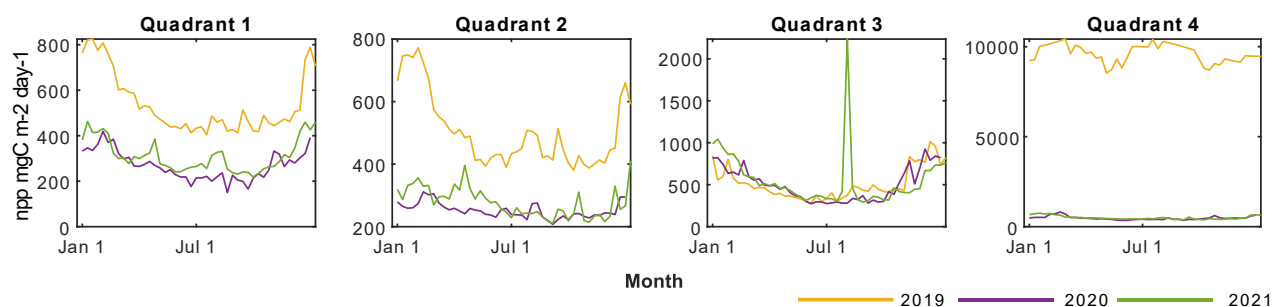
Figure 3. Net Primary Production estimate for 2019-2021.

There is general trend of the high levels of NPP during December-January (Q1-Q3), which are rainy and cold months in the Philippines. However, a peak anomaly was recorded for July of 2021 ($NPP_{Peak2021}$=2,235.5 mgC m-2 day-1). There is a single downward curve in July-August (Q1-Q3) while a double downward curve can be observed May-June, November-December (Q4). Without removing the anomaly, NPP annual for 2021 was estimated at approximately 0.34 PgC y-1.

4. Discussion and Conclusion

This study presented a low-cost methodology to provide an overview of the "where" and "when" of ocean productivity in response to typhoon occurrences in the Philippines, which is one of the hardest hit countries in the world in terms of cyclones.

It is encouraging that typhoon frequency is not heavily affecting productivity, as much as SST. In fact, there are instances that productivity increases after typhoon occurrence. A similar observation in China was recorded which may be attributed to the nutrient mixing and upwelling after typhoon passage [17].

Interestingly, a strong linear relationship between CHL and SST was observed for the year 2020. Since it is the year of the pandemic, it is possible that less anthropogenic activities might have minimized the CHL variability. The varying value of R2 considering different data groups of CHL and SST suggested that other factors may influence CHL variability, such as anthropogenic activities. Moreover, the importance of close monitoring in the Quadrant 3 (Sulu Sea), and Quadrant 4 (West Philippine Sea) should be prioritized given the relatively high productivity in these regions.

Limited to the spatial resolution of the Landsat 8 (30m swath width), the results may represent an underestimate of the actual phytoplankton productivity. Hence, it is highly recommended to explore the use of Sentinel-2 data to improve the spatial resolution in the analysis. Though typhoon occurrence poses no major threat to planktonic productivity, recent literature suggests that fast transport of organic compounds typhoon induced urban runoff could potentially make the ocean a carbon source [18]. This coupling effect of typhoons is not yet extensively understood [19] opening more research in this direction. The NPP annual estimate suggests that the PH EEZ is providing a carbon sink, however, the NPP VGM product from the ocean productivity website says otherwise (NPP_{OP2021}= -0.64 PgC y-1 based on monthly scale) despite using the same model. It would be beneficial to provide an NPP validation with ground truths, which was not present in this paper.

These uncertainties should be explored in future work including bioindicators for stress in ocean, and potentially activities in the river corridor, to better understand micro processes that influence planktonic activity both in the macro and microscale.

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