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Remote Sensing Analysis of Impact of Typhoon on Environment in the Sea Area South of Hainan Island

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Abstract

MODIS derived Chlorophyll a concentration (Chl-a)， Particulate Organic Carbon (POC) and Sea Surface Temperature (SST) as well as QuickScat wind and TRMM derived accumulated rainfall data were analyzed to investigate the Chl-a and POC increase in tongue feature in the sea area south of Hainan Island. Results showed that the high Chl-a concentration area in tongue feature appeared after the passage of typhoon Washi over the middle of Hainan Island from east to west on July 30 2005. The high Chl-a and POC area stretched along 18° N to the deep interior of the SCS was detected on August 1 2005, and lasted for about one week. The formation of the Chl-a in tongue feature is caused mainly by increased load of terrestrial nutrient which was with the increased rainwater runoff during typhoon. Second the Ekman transport generated by the strong wind during typhoon. In addition, the changes of sea surface currents contributed to the stretch of the high Chl-a to the SCS. The large increases of POC after passage of typhoon indicates that typhoon play an active role on global carbon cycle. Typhoon is important for the mitigation of increasingly prominent greenhouse effect.

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Keywords: *sea* area south of Hainan Island; south western monsoon; Chlorophyll a; remote sensing

Introduction

Phytoplankton is the basis of marine food chain, which plays an important part in marine ecosystem material circulation and energy transformation process [1]. Chlorophyll a is the main pigment of phytoplankton, and often used as an indicator of phytoplankton biomass [2].Particulate organic carbon (POC)

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generally refers to particles with diameter more than 0.2 ~ 1.0 μm, including organic debris, and Micro-(20 ~ 200 μm), Nano-(3 ~ 20 μm), Pico-(0.2 ~ 3 μm) and other types of marine micro-organisms, it is marine food chain ecosystems foundation and closely related with biological life processes and primary productivity, mean while it is the main forms of sea water carbon sequestration and migration [3-5]. Rapid increase of global warming caused by carbon dioxide and other greenhouse gases is one of major global environmental problems, while marine plays a very important regulatory role. POC output means "biological pump process" which determines within a short term (quarter ~ decades) ocean regulates atmospheric carbon dioxide. Therefore studies of chlorophyll a as well as particulate organic carbon distribution and change are significant [6-9].

South of Hainan Island linking North Bay and north area of South China Sea is affected by interaction among the South China Sea outside currents, Hainan Island coastal current and Vietnamese coastal all year round, its hydrodynamic condition is very complex. [2, 10, 11]. Studies suggest that coastal continental runoff and upward current caused by a variety of physical processes are common source of nutrient input, which provide near shore with high concentration of chlorophyll a[12-15], but the waters in the south of Hainan Island are low with chlorophyll a concentration during summer[16].Hainan Island is higher at the center and low around the edge, which is easy to speed up rivers flow, there are 38 rivers of the entire island, including six ones access to the sea from south, its total drainage area is 4141km^2 , takes about 12% of the total area of Hainan Island. With heavy rainfall influence caused by typhoon, algal blooms may outbreak at the south waters of Hainan Island [9]. When typhoon sweeps over the sea, it can effectively promote one kind of marine life - the growth of marine phytoplankton [17]. Thereby enhance Chlorophyll a concentration and marine primary biological productivity, while marine primary productivity plays an important role in the Earth's circulatory system, about 40% of the oxygen is also provided by the phytoplankton, like all plants, phytoplankton use carbon dioxide, sunlight and other nutrients for photosynthesis and reproduction, which become the basis of the marine food chain. In 2005 typhoon Katrina landed in the region of Gulf of Mexico , it made chlorophyll a concentration rose from about 0．3 mg m^{-3}, to about 1．5 mg·m^{-3}[18]. Tropical Storm Kai Tak caused sea surface chlorophyll a concentration increasing by nearly 30 times [19]. The important Sanya fishing grounds are at south waters of Hainan Island with great economic and ecological significance[20] , But there are no relevant studies on chlorophyll a distribution at South waters of Hainan Island[8, 20, 21], and no reports about typhoon influencing particulate organic carbon distribution of. Study found that in July 30, 2005 typhoon "Washi" went from east to west across Hainan Island, August 1st it was detected at south waters of Hainan Island, a high concentration of tongue-shape strap and particulate organic carbon about a 2 ° long and 0.5 °wide and there are still no studies about this. This paper aims to analyze the influence of environmental factors on the typhoon, and further understand of the response mechanism about ecological processes of this economic zone (Figure 1) on tropical cyclone [20]. With a clear understanding of the significance of economic zone environment protection is very important, and provide data accumulation for studying the impact of typhoons on ecological environment.

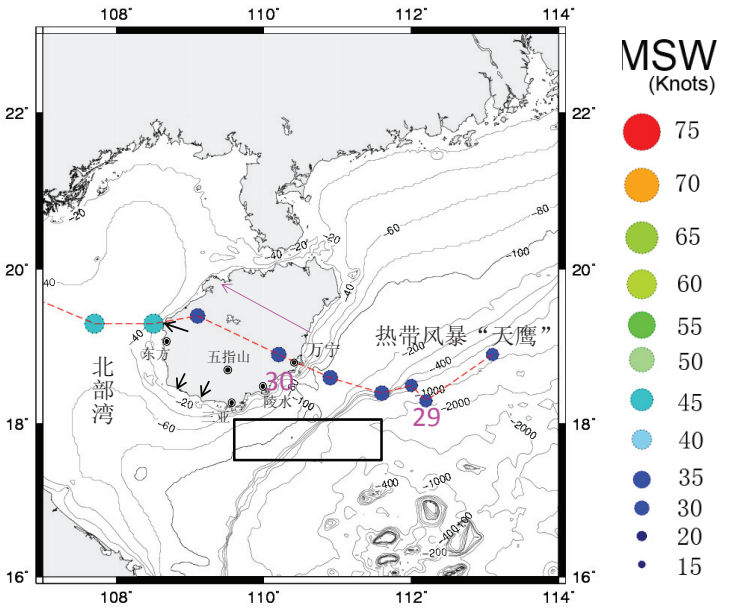

Fig1 Track of tropical storm Washi and the bathymetry of the study area, pink dates show 00:00 of each day, arrow indicates the moving direction, center positions every 6 h are indicated by colored circles, circle color: maximum sustained wind speeds [MSW, knots, 1 knot = 0.514 m/s]. All dates and times are Coordinated Universal Time (UTC). Black arrows indicate river estuaries; black box is the sampling area

Materials and methods

Taking use of GMT (Generic Mapping Tools) to generate studied area terrain map and the typhoon route [22]. Typhoon route data comes from Unisys Weather Western Pacific typhoon database. The data is graded by “Saffir-Simpson Scale", the typhoon "Washi" is a tropical storm. Typhoon route is shown in red dotted lines. Typhoon center data interval is 6 hours, sustained winds of the typhoon center is displayed in color dots (Figure 1).

Chlorophyll a concentration, particulate organic carbon and sea surface temperature data from the MODIS (Moderate-resolution imaging Spectroradiometer) are secondary products from daily data, all data come from NASA Goddard Space Flight Center Distributed Active Archive (GSFC DAAC), spatial resolution is 1km × 1km, time is August 2005.

Rainfall data is from tropical Rainfall Measuring satellite TRMM (Tropical Rainfall Measuring Mission) daily accumulated data. TRMM experimental program is cooperated by the United States and Japan called the tropical rainfall measurement programs. The key equipment of TRMM satellite onboard - Rainfall TRMM radar is an active microwave radiometer on mounted on TRMM experimental satellite. The level 3 data from TRMM 3B42 V6 is used to estimate rainfall. The satellite collects global tropical rainfall data every three hours, the daily data is from 8 times average when passing this area, its spatial resolution is 0.25 ° × 0.25 °. Relevant data can be downloaded from NASA Website (http://disc2.nascom.nasa.gov).

Level 3 ocean surface wind data of QuickScat is provided by NASA (www.remss.com). Spatial resolution is 0.25 ° × 0.25 °. QuikScat marine wind data is processed with remote sensing system, which is sponsored by the marine wind farms investigation group of NASA(available at www.remss.com).

JASON-1/-2, TOPEX, ERS-2, ENVISAT and GFO Sea surface height anomaly (SHA) and significant wave height data are handled by the Stennis Center (NRL site at the Stennis Space Center), the data is interpolated from sea surface height anomaly (SHA). Geotropic flow data is acquired the calculation of sea surface height anomalies and climate means dynamic height [23].

Result

Distribution characteristics of chlorophyll a. This paper takes use of data of July 26 to show the front-end chlorophyll a distribution. Data show that chlorophyll a high value is manly concentrated in south coast of Hainan Island(Figure 2a), while concentration is low in open seas, sample regional average concentration is 0.107 mg m^{-3}. Typhoon "Washi" landed on Hainan Island in the early morning of July 30, 2005, and its maximum wind power is about 17.99 m s^{-1}. After "Washi" went by (August 1), it was detected a tongue-shape high values of chlorophyll a concentrations (Figure 2b), the maximum concentration is 0.898 mg m^{-3}, which was 3.84 times before the typhoon. The average chlorophyll a concentration in the sampling area was 0.395 mg m^{-3}, which is 3.69 times of the first typhoon. Tongue-shape chlorophyll a (> 0.2 mg m^{-3}) high concentration area is 9000 km^2 which went eastward up to 112 ° E, southward up to 17.5 ° N. data analysis of August 1 revealed that the tongue-shape chlorophyll a high concentration status would last for a week or so.

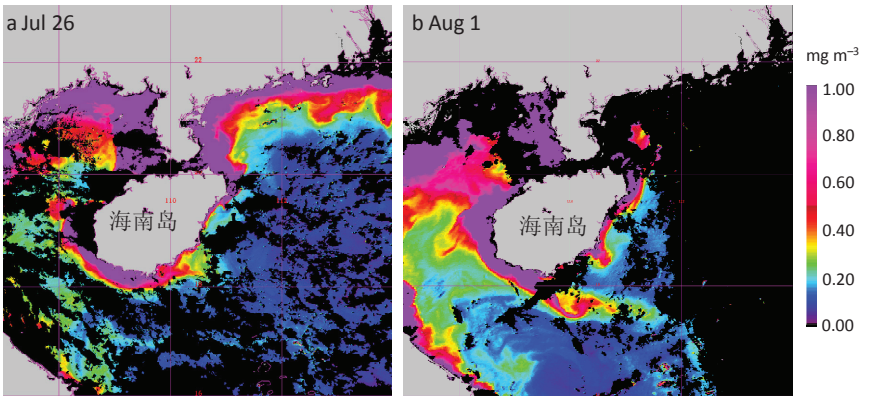

Fig2 MODIS derived sea surface Chlorophyll a concentration distribution before and after the passage of typhoon a before the passage of typhoon; b after the passage of typhoon

Temperature features in South waters of Hainan Island. South waters of Hainan Island belongs to northwestern South China Sea, summer sea surface temperature is relatively high. Sea surface temperature data show that the temperature is slightly low (27 ℃) before tycoon, most waters are above 28 ℃ (Figure 3a). Sea surface temperature, of August 1, 2005 showed there was a correspondence between one low temperature area with tongue-shape chlorophyll a high value area (Figure 2b and Figure 3b). Low-temperature region is at the southeast waters of Hainan Island, temperature in open sea is relatively low. With temperature gradually decreased, sea surface temperature returned to normal.

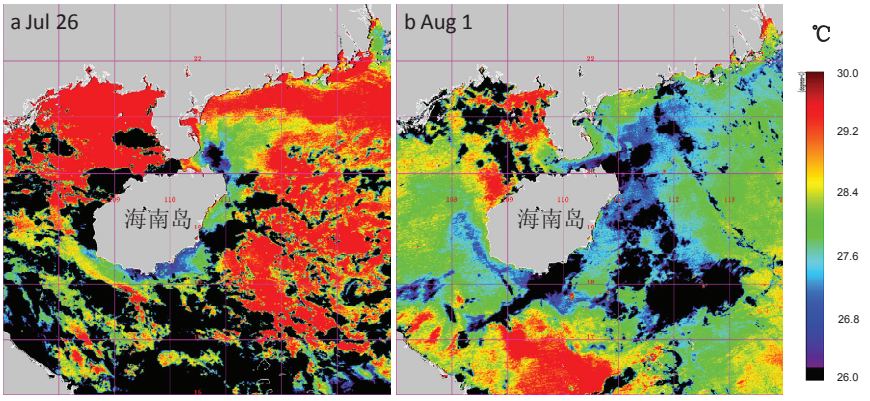

Fig3 MODIS derived sea surface temperature distribution before and after the passage of typhoon a before the passage of typhoon; b after the passage of typhoon

Particulate organic carbon concentration distribution features. Particulate organic carbon plays a key role in global carbon cycle and ocean carbon flux [17, 18]. Comparison of before and after typhoon found that: particulate organic carbon concentration has greatly increased after typhoon, and the high values area is similar with chlorophyll a distribution high value areas. Before typhoon the average concentration of particulate organic carbon was41.38 mg m^{-3} (Figure 4a) at south waters of Hainan Island; during typhoon it reached the maximum of 182 mg m^{-3} (Figure 4b). After typhoon, the average concentration was 74.731, which was 1.81 times before the typhoon. High particulate organic carbon concentration (>80 mg m^{-3}) area reached 8800 km^2.

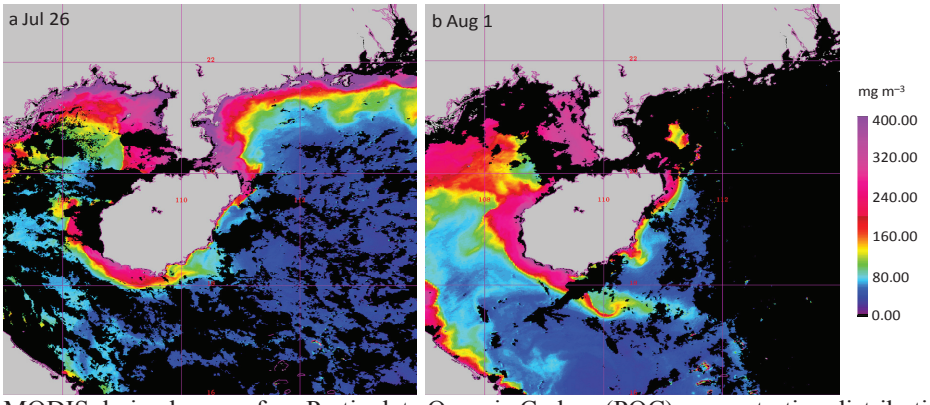

Fig4 MODIS derived sea surface Particulate Organic Carbon (POC) concentration distribution before and after the passage of typhoon a before the passage of typhoon; b after the passage of typhoon

Other marine elements. QuickScat wind data indicates that wind speed is relatively low, which is below 10 m s^{-1} at the south waters of Hainan Island and the direction is roughly NE - SW (Figure 5a). Typhoon "Washi" landed on Hainan Island in July 30, 2005 morning. Data of July 29 south waters of Hainan Island shows that wind speed increased, reaching to more than20 m s^{-1}; and strong wind direction paralleled to that of coastline southeast of Hainan Island (Fig. 5b), which is conducive to the formation of lateral Ekman transport .

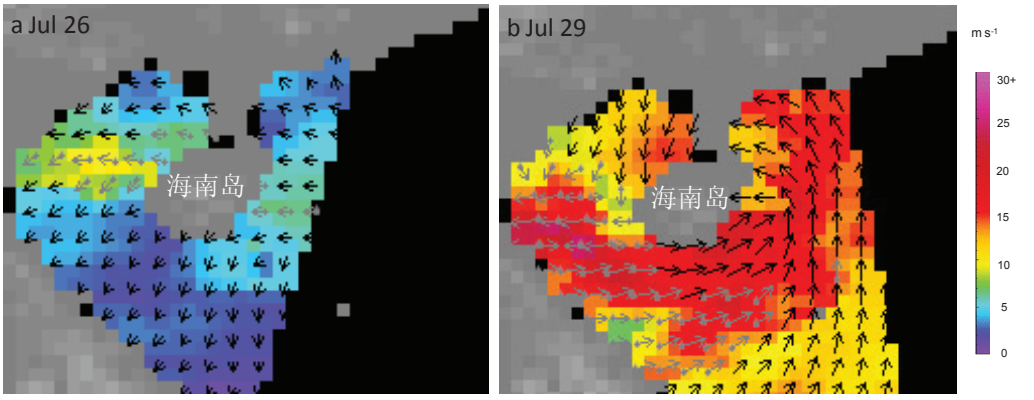

Fig5 sea surface wind before and during the passage of typhoon a before the passage of typhoon; b during the passage of typhoon

Accumulated rainfall data obtained from TRMM shows: before typhoon the rainfall is small, averagely in 20 mm or less (Figure 6a). it sweep across Hainan middle area in July 30, 2005, most of the Beibu Gulf waters and Hainan have strong rainfall in 2005 July 28 to 30, among which rainfall occurred in south half of Hainan Island(Figure 6b). 28-30 cumulative rainfall data shows: in the southern tip of Hainan Island as well as south waters, the accumulated rainfall is up to 200 mm. Hainan Provincial Meteorological Observatory monitored data also confirmed: 28 to 29, Wanning, Lingshui and other places are heavy rains, and rainfall concentrated in the central and southern area, among which during 29th , from 8 am to 2 pm, Wu Zhishan 45 mm of rainfall, Lingshui 46 mm, Dongfang 41 mm, and Sanya 32 mm.

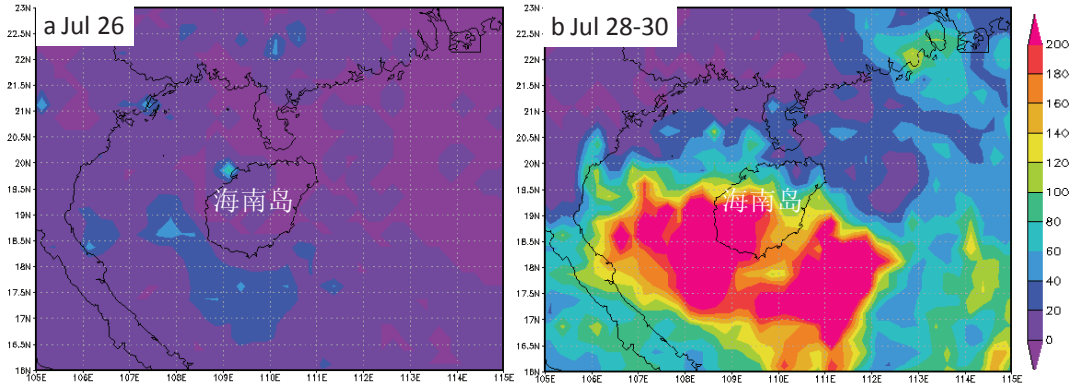

Fig6 TRRM derived daily accumulated rainfall before and during typhoon a before the passage of typhoon (Jul 26); b three day composite during typhoon

Figure 7 shows the sea surface flow changes before and after typhoon "Washi". Before typhoon the flow was roughly southwest - northeast (Figure 7a white arrow). After typhoon the west sea surface flow field of east longitude 110 degrees remained as the flow before typhoon; the flow of east longitude 110 degrees east changed into northwest - southeast direction (Figure 7b white arrow), which is the same with tongue-shape high chlorophyll a concentration area extension direction.

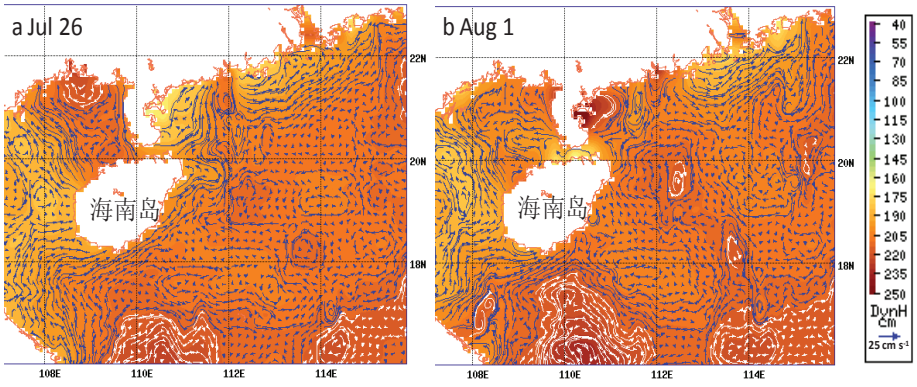

Fig7 sea surface current changes before and after the passage of typhoon a before the passage of typhoon; b after the passage of typhoon

Discussion

Change of particulate organic carbon. Studies show that ocean uptakes about 1 / 3 carbon dioxide of total human emissions [24, 25]. This study takes a weak typhoon as research object and found that the average concentration of particulate organic carbon is 74.731 which are 1.81 times than before. High particulate organic carbon concentration (>80 mg m^{-3})area reached to 9000 km^2. Violent typhoon or super typhoon will have a stronger effect on the increase of Particulate organic carbon. Typhoon can promote ocean chlorophyll a and particulate organic carbon concentrations increase and the growth of primary productivity, which would enhance the capacity of oceans to absorb carbon dioxide, thus contributing to reduce global carbon dioxide mitigation of greenhouse effect. Statistics show that from 1945 to 2010 there is a total of 1861 typhoon generated in Northwest Pacific, 1366 of which went through and affect the South China Sea, 321 affect waters around Hainan Island. An annual average of 4.86 typhoons goes through Hainan Island. It is estimated that Typhoon plays an important role in global carbon dioxide regulation, but how much it effect the regulation of carbon dioxide remains to be further studied.

Chlorophyll changes

Typhoon "Washi" sweep across Hainan Island in July 30, 2005, August 1 it is detected a tongue-shape high chlorophyll a values area extending to South China Sea (Fig. 2b). The chlorophyll a concentration is relatively low compared with it before the typhoon (Figure 2a), while during typhoon “Washi”(28-31,July), the southern part of Hainan Island and most of the Beibu Gulf waters have great rainfall (Figure 6b), up to 200 mm. Hainan Island terrain is high in the center and lower around the edge, by which river flow easily speed up, there are 38 rivers on the entire island, including six access into sea from the south, its total drainage area took about 4141km^2 and about 12% of the total area of Hainan Island [9], terrestrial nutrient salt is conductive the formation of tongue-shape high value chlorophyll a concentration at the southern tip of Hainan Island [26,27].During typhoon "Washi" passing by, 28 to 30, 2005, there was strong rainfall over the entire Beibu Gulf waters and south waters of Hainan Island (Figure 6b). Surface runoff increase after the storm promotes the reduction of sea water temperature, which shows in sea surface temperature changes on tongue-shape strap (Fig. 3b). A large tongue-shape high chlorophyll a after typhoon shows: Typhoon has

a positive impact on phytoplankton and primary productivity of the sea. High primary productivity provides energy for the entire eco-system and accelerates material circulation and ocean energy conversion process.

Other marine factors. QuickScat wind site data of July 29, 2005 also shows that wind speed is high at south waters of Hainan Island, and the direction is parallel to the south coastline of the Island. Because of topography , this kind of wind distribution is conducive to the Ekman transport which causes lower water upwelling [4] and bring nutrition for high value chlorophyll a strap (Figure 2b).

Hainan Island is one of the most severely regions affected by typhoon, total annual rainfall is between 1500-2000 mm, and over 20% is brought by typhoon[28]. August 28-31,2005 typhoon "Washi" brought 200 mm rainfalls(Fig. 6b), in September, Rapid precipitation of typhoon "David" caused a rapid increase of chlorophyll which shows the vortex shape, and this study found a long tongue-shape strap which was speculated have some relevance with rainfalls. Daily rainfalls during the typhoon, "David," had reached 300 mm [9]. Typhoon "Washi" caused rainfall mainly concentrated in the southwest Hainan Island and adjacent waters, while "David" caused rainfall mainly in the southeast of Hainan Island and nearby waters.

Conclusion

This paper studies MODIS chlorophyll a, particulate organic carbon, SST data, sea surface wind field from satellite QuikSCAT remote sensing data and accumulated rainfall TRRM and finds that on August 1 after the typhoon, it was detected a high tongue-shape concentration area with chlorophyll a and particulate organic carbon at south waters of Hainan Island, along 18 ° N and extended to the South China Sea, its main causes are: 1. Rainfalls during typhoon increase of terrigenous nutrient salt, 2. The Ekman transport caused by strong typhoon at the southern tip of Hainan Island; 3. Sea surface flow change is good for the formation of high value tongue-shape chlorophyll a area.

Large amount of chlorophyll a and particulate organic carbon after typhoon show that typhoon is conducive to the oceans absorb and fix carbon dioxide in the atmosphere, accelerate marine nutrient cycling and energy transformation process. It has become increasingly prominent to alleviate the current impact of global warming.

Acknowledgement

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