



Phytoplankton Blooms Triggered by Anticyclonic Eddy and Cyclonic Eddy during Tropical Cyclone Nada

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ABSTRACT

Tropical cyclone (TC) Nada occurred in the southwestern Bay of Bengal (BOB) in the winter of 2016. With high photosynthetically available radiation (PAR) and minimal precipitation, phytoplankton blooms occurred from offshore to nearshore respectively. In this study, there was an pre-existed ocean eddy pair on the left and right sides of Nada's path before its passage, we studied the different mechanisms of phytoplankton blooms caused by TC Nada and the ocean eddy pair with satellite observation, multisource reanalysis products, and Argo float data. An anticyclonic eddy near Sri Lanka was weakened during Nada and horizontal transport of chlorophyll-a (Chl-a) balanced the inhibition effect of anticyclone on Chl-a. Near the anticyclonic eddy's periphery, an upwelling above the thermocline was enhanced by Nada which promoted the uplift of nutrient-rich deep-water. Meanwhile, the large cyclonic eddy in the northern Bay of Bengal was strengthened by Nada, with the vorticity increasing from 0.19 s^{-1} to 0.28 s^{-1} . Significant inertial oscillation (~ 2 days period) happened in the subsurface layer, leading to strong vertical mixing and upwelling and subsequently causing the offshore surface Chl-a bloom. This study provides new insights to evaluate typhoons and ocean eddies that induce biological responses in the future.

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1 INTRODUCTION

Chlorophyll-a (Chl-a) concentrations play an important role in marine photoautotrophs, which is not only marine primary producers but also fundamental links in the biological chain (Falkowski, 1994; Behrenfeld and Falkowski, 1997; Zhao et al., 2015). A tropical cyclone (TC) is a strong interaction between the atmosphere and the ocean. Generally, surface Chl-a concentration often increases when TCs pass over a sea (Zhao et al., 2015). Strong winds, rainstorms, and storm tide frequently occurred during a TC landfalling, causing serious damage to human life and property.

Many scholars have made great progress in analyzing the characteristics and climate drivers of cyclones in the North Indian Ocean (Singh et al., 2000; Krishna, 2009; Evan and Camargo, 2011; Ng and Chan, 2012; Sugi et al., 2014). For example, 80% of the world's deadliest cyclones formed in the Bay of Bengal (BOB), even though no more than 7% of global TCs occurred in the bay (Bhardwaj and Singh, 2020; Liu et al., 2021). Some studies found that the chlorophyll blooms in the BOB were mainly caused by strong Ekman pumping induced by TCs (Vinayachandran and Mathew, 2003; Madhu et al., 2006). Moreover, some scholars believed that the dominant reason for the blooms is that the ocean currents and eddies related to cyclones are strong enough to erode stratification (Gomes et al., 2000). Some early studies confirmed that cyclonic mesoscale eddy current could make nutrients upwelling to supply nutrient-rich water into the upper ocean (McGillicuddy Jr and Robinson, 1997; Oschlies and Garcon, 1998). The vertical changes of Chl-a, nitrate, temperature and mixed layer depth (MLD) effectively indicate that the cyclonic eddy transports nutritional water up to the upper layer, causing the surface Chl-a to burst (Iskandar et al., 2010).

The BOB region is influenced by many TCs before and after the monsoon when various vortices are produced in the Midwest Gulf (Anandh et al., 2020). It is crucial to analyze the evolution of a cyclone by studying the upper ocean characteristics and the oceanic feedback to the cyclone (Lin et al., 2009; Kaplan et al., 2010; Wang et al., 2018; Ning et al., 2019). Hence, it is significant to analyze the response of the BOB's upper layer to TCs.

In this study, TC Nada was formed in the south-central part of the BOB on November 29, 2016, and moved northwestward. It was a fast-moving and weak cyclone that made landfall on the southeastern coast of the Indian Peninsula on December 2, 2016. From December 1 to December 7, there was a continuous enhancement in chlorophyll-a concentration in the sea surface. We chose the region near the starting position of Nada marked as box A (6.5°N–8°N, 87.5°E–89°E). In addition, based on the locations of Chl-a enhancement, we chose two regions (Figure 1) named as box B (8°N–9.5°N, 81.5°E–83°E) and box C (11.3°N–12.8°N, 81.5°E–83°E), where appeared the anticyclonic and cyclonic eddies (Figure 4).

This paper mainly focuses on investigating the different mechanisms of Chl-a blooms in boxes B and C after the passage of Nada. In addition, we analyzed the effects of the vorticity from the anticyclonic and cyclonic eddies on phytoplankton blooms, when an inertial oscillation occurred. Section 2 introduces the data and methods, which are followed by the results in Section 3. The discussion is presented in Section 4. Finally, Section 5 summarizes the conclusions.

2 DATA AND METHODOLOGY

2.1 DATA

The daily Chl-a concentration dataset and photosynthetically available radiation (PAR) data used in this study are obtained from the GlobColour project which provided continuously combined L3 marine color products, and the spatial resolution is 4 km (available at <http://hermes.acri.fr/index.php?class=archive>). Daily microwave and infrared optimally interpolated sea surface temperature (SST) data with a spatial resolution of 9 km are obtained from the Remote Sensing System (<https://data.remss.com/>).

The dataset of seawater current velocity, sea surface height (SSH), seawater temperature, and salinity with a resolution of $(1/12)^\circ \times (1/12)^\circ$ and subsurface daily Chl-a concentration data with resolutions of $(0.25)^\circ \times (0.25)^\circ$ are acquired from global ocean Copernicus Marine Environmental Monitoring Service (CMEMS) merged and gridded products (available at <https://resources.marine.copernicus.eu/>), providing timely and systemic reliable messages on the physical and biogeochemical ocean.

The daily gridded surface vector winds data with a high spatial resolution of $(0.25)^\circ \times (0.25)^\circ$ are derived from the Cross-Calibrated Multi-Platform (CCMP, from <http://www.remss.com/measurements/ccmp>). L3 wind analysis datasets have appropriate spatial and temporal resolutions for scientific researches, which contains 4 daily maps of 0.25° gridded vector winds.

Cumulative daily precipitation data with spatial resolutions of $(0.25)^\circ \times (0.25)^\circ$ are provided by tropical rainfall measuring mission (TRMM, <https://daac.gsfc.nasa.gov/>), which are produced from the research-quality 3-hourly TRMM multi-satellite precipitation analysis (TMPA). TRMM covers tropical and subtropical areas of the earth and provides important information on the variability of precipitation.

The vertical profiles of temperature and salinity data are provided by the argo program (<http://www.argodatamgt.org/>). The argo platform numbers are 2901896 and 2902190. The Argo profiles are located in box B and box C in Figure 1, respectively. They can provide situ data of temperature and salinity at different ocean depths before and after the passage of TC Nada.

The Joint Typhoon Warning Center (JTWC) provides the best track data of Nada that can be accessed at <https://www.metoc.navy.mil/jtwc/jtwc.html>. The time, maximum wind speed, and TC center position at 6-h intervals can be found in the dataset.

2.2 METHODOLOGY

Vorticity is a vector measure of local rotation in a fluid flow, defined mathematically as the curl of the velocity vector. In meteorology, ‘the vorticity’ usually refers to the vertical component of the vorticity. Eq (1) is used to calculate the curl of the ocean current vector.

$$\text{curl}_z = dv/dx - du/dy \quad (1)$$

where u and v represent the components of velocity along the x and y axes respectively.

Ekman transport is an important index to measure the balance between wind stress and Coriolis force on the horizontal plane and it results in the convergence and divergence of seawater at the Ekman pumping velocity (EPV). EPV can be calculated according to the following formula:

$$\omega_E = 1/\rho f \times (\nabla \times \tau) \quad (2)$$

where ω_E indicates the EPV, $\rho = 1024 \text{ kg}\cdot\text{m}^{-3}$ represents the sea water density, f is the Coriolis parameter, τ and indicates the wind stress. The curl of the wind stress can be gained by Eq (3) (Enriquez and Friehe, 1995; Lü et al., 2020b):

$$\nabla \times \tau = 1/R \cos \varphi \times [\partial \tau_y / \partial \lambda - \partial / \partial \varphi \times (\tau_x \cos \varphi)] \quad (3)$$

where R is the radius of the Earth φ , λ , represent the geographic latitude and longitude respectively; τ_x and τ_y indicate the zonal and meridional components of wind stress respectively.

3 RESULTS

3.1 TRACK AND INTENSITY OF NADA

At 18:00 UTC on November 29, Nada intensified as a tropical storm with a maximum wind speed of $23 \text{ m}\cdot\text{s}^{-1}$ and then weakened as a tropical depression. Nada moved northwestward and made landfall on the southeastern coast of the Indian Peninsula at 00:00 UTC on December 2. Figure 1 shows the TC track, wind speed, study area (Box A, Box B and Box C), and Argo positions. The Argo platform numbers were 2901896 and 2902190 marked as diamonds and hexagons respectively. The central

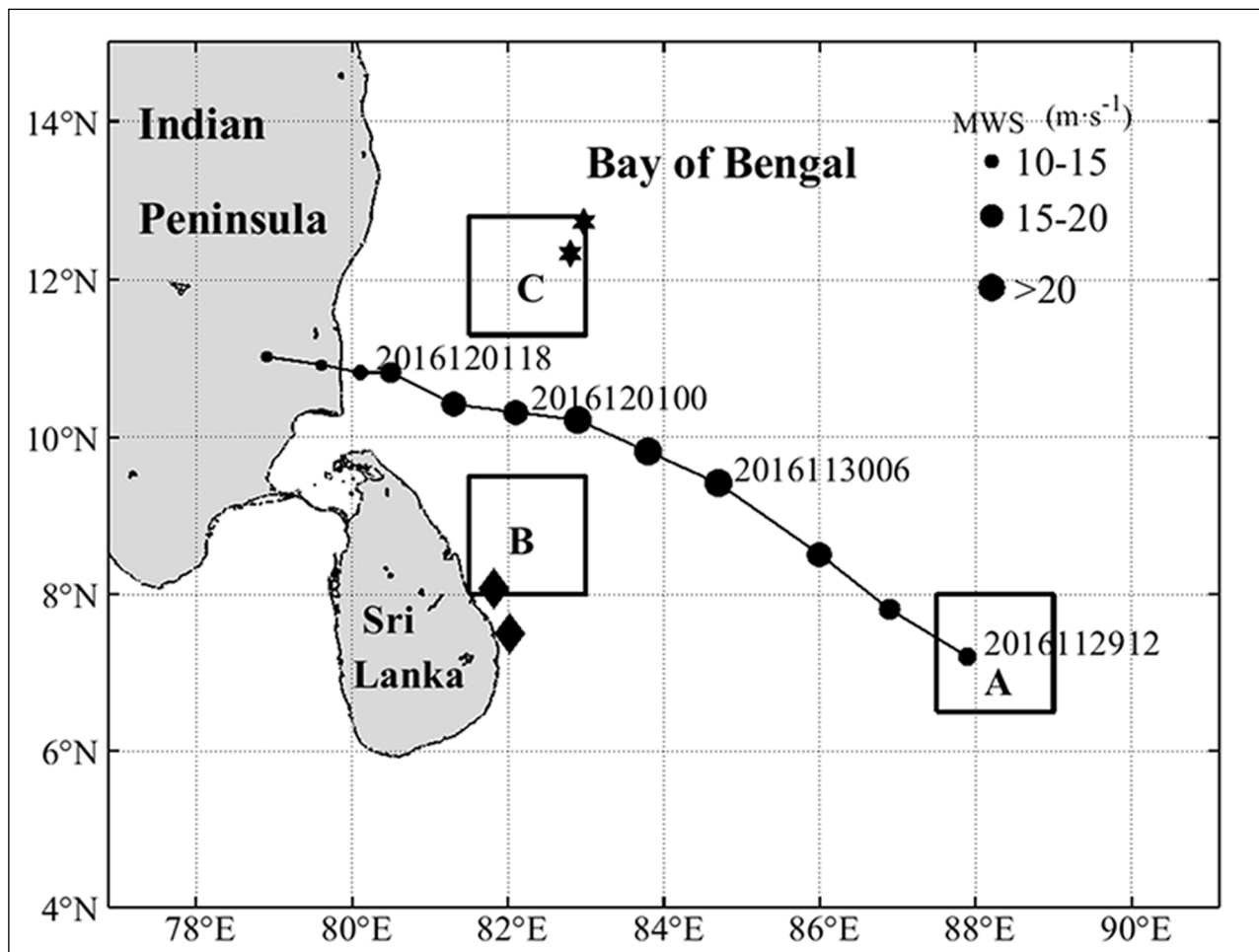


Figure 1 Trajectory of Nada.

positions of Nada every 6 h are represented with black circles, and the circle size indicates TC intensity. The three solid black squares indicate the studied boxes, namely box A (6.5°N–8°N, 87.5°E–89°E), box B (8°N–9.5°N, 81.5°E–83°E), and box C (11.3°N–12.8°N, 81.5°E–83°E).

3.2 RESPONSE OF CHL-A AND SST

To avoid the influence of clouds when Nada passed, the Chl-a concentration data for 9 consecutive days (i.e. before Nada: November 20 to November 28, during and after Nada: November 29 to December 7) were averaged according to Chacko and Jayaram (2021). In Figure 2, the Chl-a concentrations before (a), during and after (b) the passage of Nada are provided. There was a high concentration of Chl-a that appeared continuously after the passage of Nada. The Chl-a maps clearly show the phenomenon of strong phytoplankton blooms from November 29 to December 7. In response to the passage of a TC, different variables may change in a dissimilar manner over time and at different locations, with different impacts (Liu et al., 2020). Another important oceanic response to a typhoon is the cooling of SST, which is affected by typhoon strength, translation speed, and other factors (Zhao et al., 2015). Figure 2c–d shows that the 9-day averaged SST for the same period as Chl-a. Before the passage of Nada, warmer water with more than 28 °C

locates in the southeast of BOB (Figure 2c). The SST cooled significantly ($>1^{\circ}\text{C}$) after the passage of Nada (Figure 2d). Figure 2d shows the location of SST cooling coincided with the offshore phytoplankton bloom patches.

To overcome the limited coverage of satellite-acquired chlorophyll data due to cloud covers, Xia et al. (2022) used 2-day averaged observations over time to show the enhancement of Chl-a. In this study, the changes of 3-day averaged Chl-a concentrations for the three boxes are presented in Figure 3. In box A, the Chl-a concentration changed a little, where no Chl-a bloom appeared. The concentration of Chl-a in box B (box C) increased on November 29 to a maximum of 0.43 (0.47) $\text{mg}\cdot\text{m}^{-3}$ on December 6 and then decreased to the pre-Nada level after December 7, sharply. Chl-a increased from offshore (box A) to the nearshore (boxes B and C) after the passage of Nada. Zhao et al. (2017) found a similar phenomenon that the increase in the Chl-a concentration was much larger nearshore than offshore during the fast-moving tropical storm Washi in the South China Sea (SCS). Interestingly, phytoplankton erupted almost simultaneously in boxes B and C in the nearshore waters, and the phytoplankton blooms continued to increase for 6 days after Nada. The possible driving mechanisms of the phytoplankton blooms in boxes B and C are analyzed in the next section.

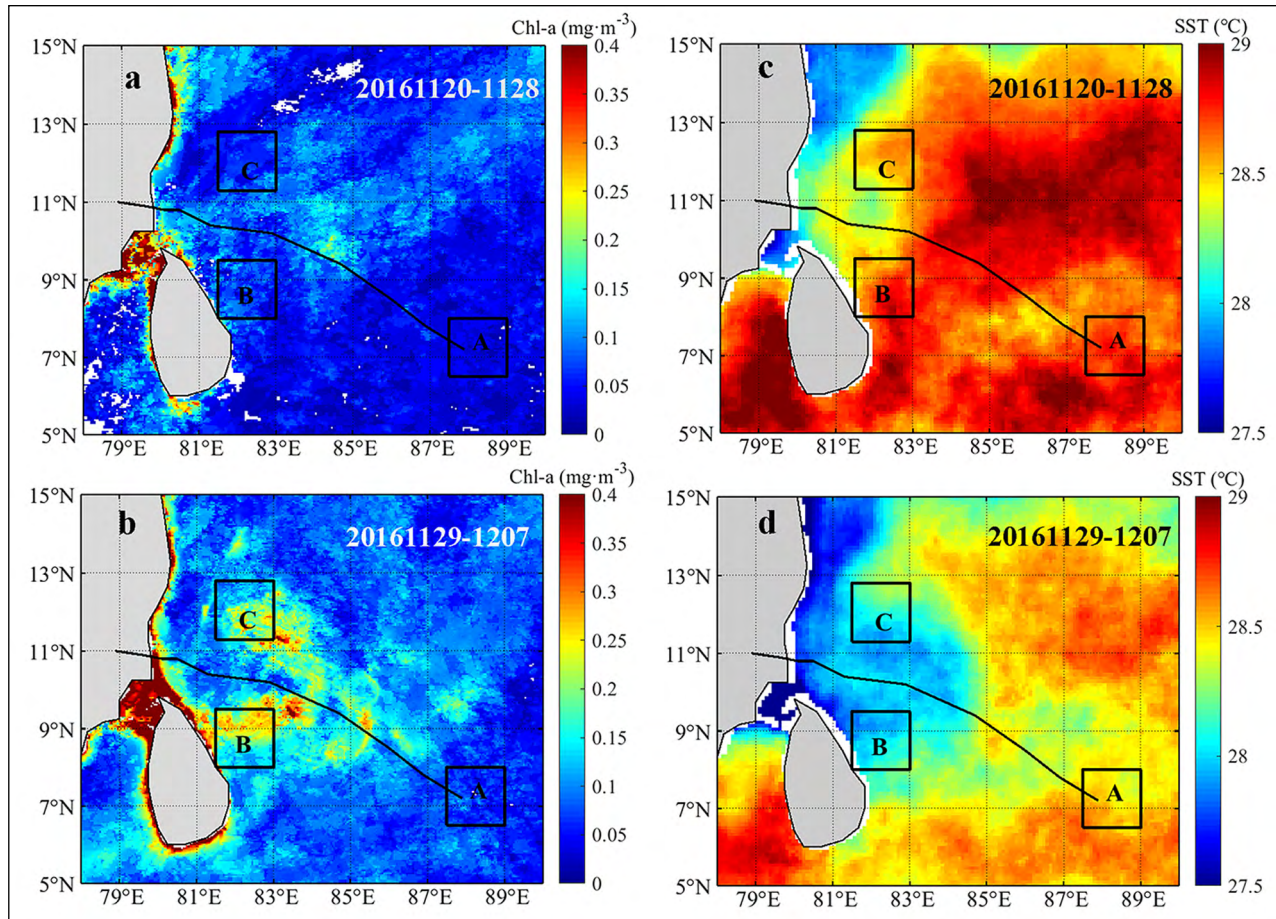


Figure 2 The responses of 9-day averaged surface Chl-a concentration (a, b) and SST (c, d) before (a, c, November 20–28), during and after (b, d, November 29 to December 7) the passage of Nada.

3.3 OCEAN EDDIES AND SEA CURRENT FIELD

The sea surface height (SSH) and sea surface current field are presented in Figure 4. Before Nada arrived, an anticyclonic (warm) eddy appeared at 81.5°E to 82.5°E longitude and 9°N to 9.5°N latitude (Figure 4a) near box B, and a cyclonic (cold) eddy occurred along 82°E longitude and 11°N to 13°N latitude before Nada (Figure 4a) in box C. Figure 4b-d shows that the sea current velocity increased during and after Nada passed through

the cyclonic eddy, which might lead to the enhancement of the eddy. A southward coastal current along the eastern coast of the Indian peninsula, which increased in velocity after Nada and flowed through the periphery of the anticyclonic eddy, might contributed to the strengthening of the anticyclonic eddy.

Time series of SST anomalies for the different boxes from November 20 to December 11 are presented in Figure 5. The SST anomaly was obtained by the difference

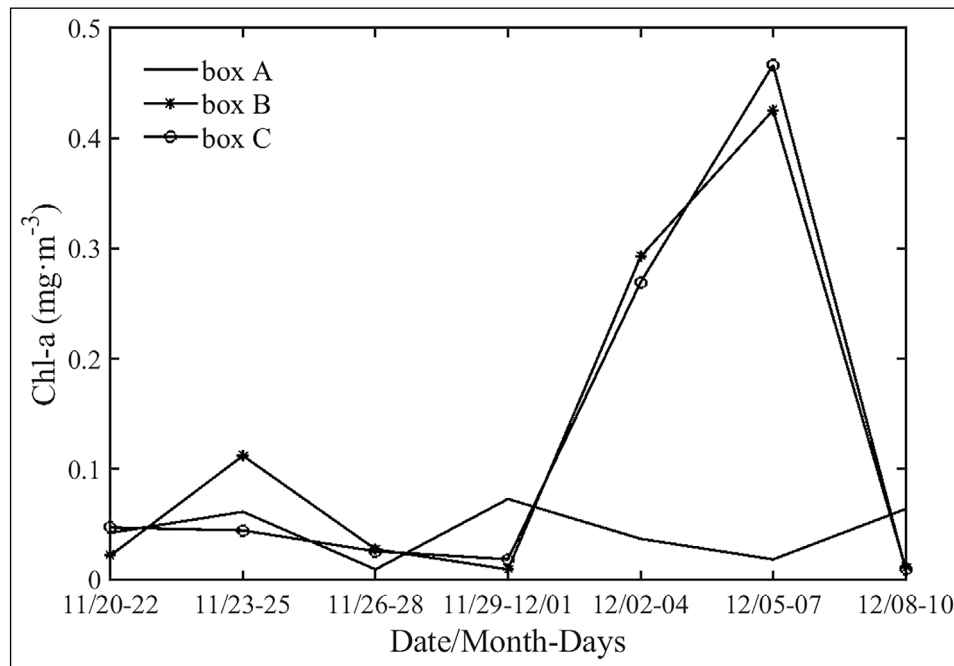


Figure 3 The time series of 3-day averaged Chl-a concentrations in boxes A, B, and C from November 20 to December 10.

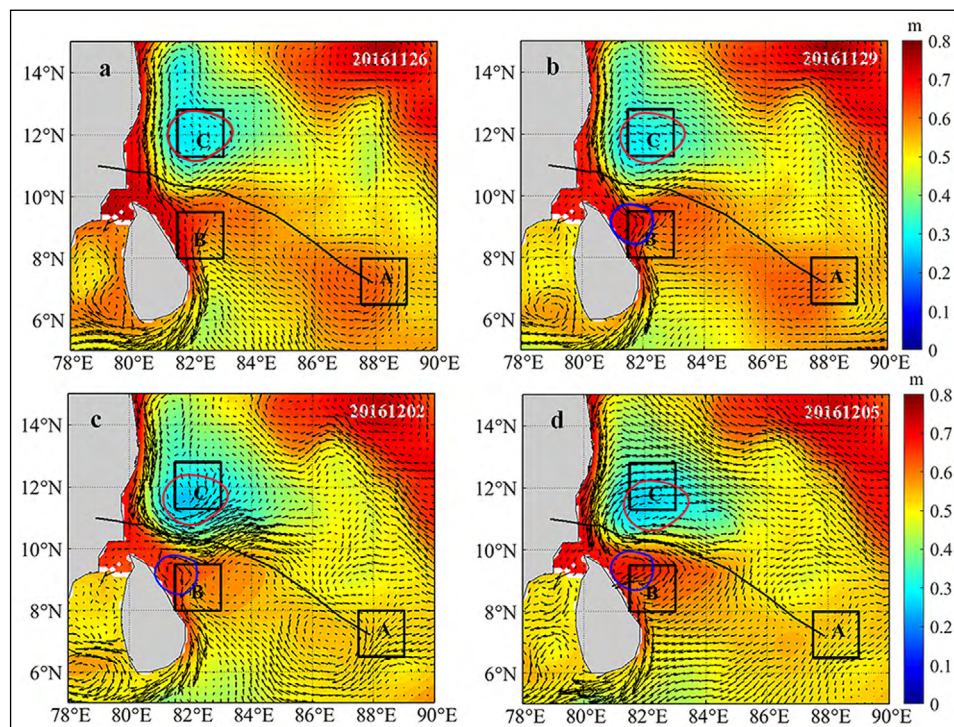


Figure 4 SSH (colors, m) and sea surface current field (arrows, m·s⁻¹) before (a), during (b) and after (c, d) the passage of TC Nada. The red (blue) ring marks the location of the cyclonic (anticyclonic) eddy.

between the daily SST and the averaged SST during this period. It can be seen that during and after the passage of Nada, the SST of the three boxes has decreased compared with that before Nada. SST decreased by 0.9°C on average from November 29 to December 1 in box B. Before, during and after the passage of Nada, box C was always within the range of the cyclonic eddy, the SST of box C was always cooling, and gradually rose after the TC landed, but still lower than that before Nada, generally.

3.4 PRECIPITATION AND PHOTOSYNTHETICALLY AVAILABLE RADIATION (PAR)

The time series of daily averaged precipitation and PAR for boxes B and C are presented in Figure 6. During the passage of Nada, the TC brought abundant rainfall and an obvious decrease in PAR near its path. As Nada moved to the west, the precipitation in box B (box C) began to increase on November 28 (November 29), reaching a maximum of $63.05\text{ mm}\cdot\text{day}^{-1}$ ($18.95\text{ mm}\cdot\text{day}^{-1}$) on

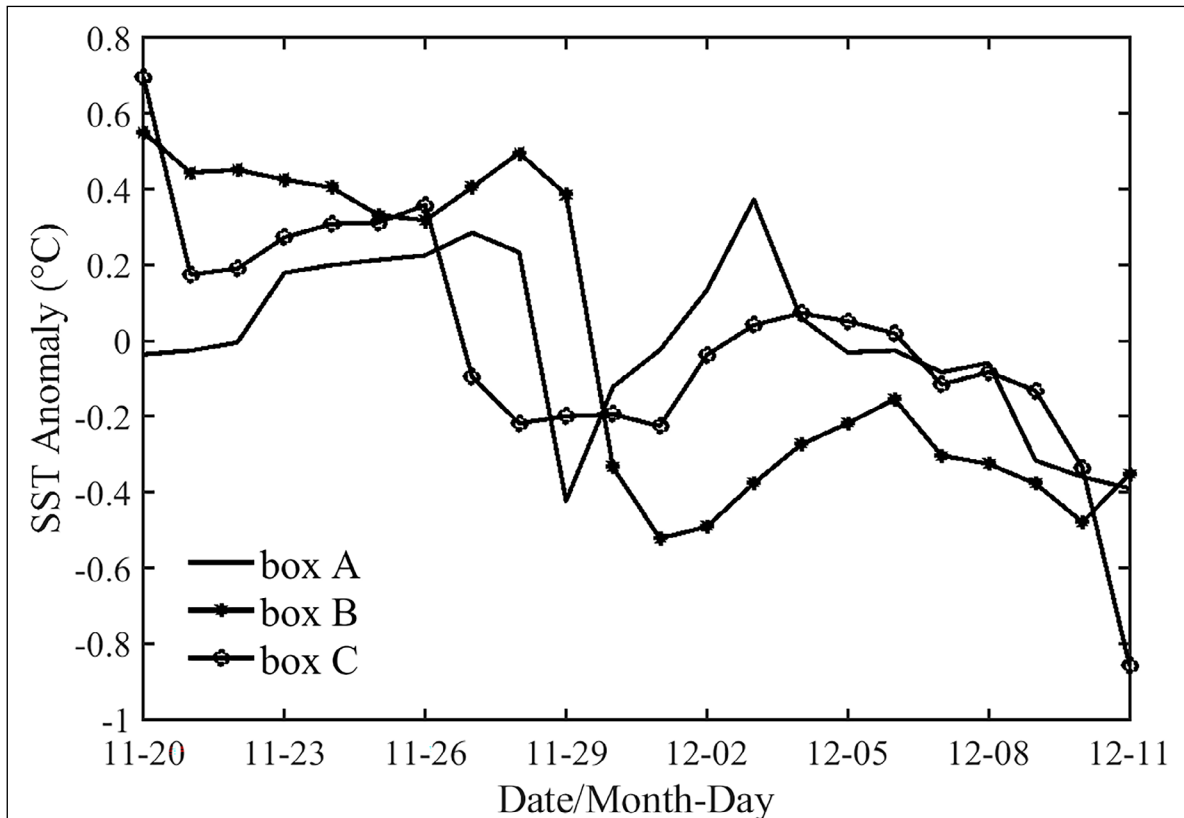


Figure 5 Spatially averaged SST anomaly in boxes A, B, and C from November 20 to December 11.

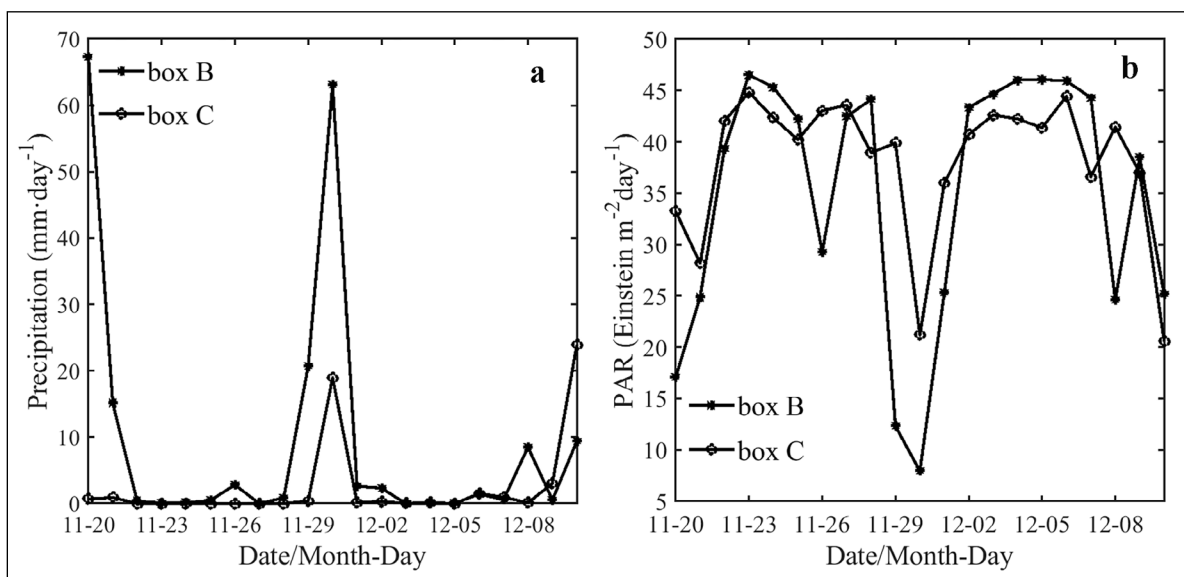


Figure 6 Time series of spatially averaged precipitation (a) and PAR (b) in boxes B and C from November 20 to December 10.

November 30, and then significantly decreased after December 1 (Figure 6a). Heavy rainfall can cause strong stratification and weaken turbulence (Turner, 1979). There was less precipitation from December 1 to 7 in boxes B and C, which was beneficial for the vertical transport of nutrients. The PARs reached a minimum on November 30 and recovered to a steady state on December 3, which provided plenty of sunshine for the phytoplankton bloom events in boxes B and C from December 3 to December 6.

3.5 VERTICAL MIXING AND UPWELLING

Figure 7 shows the time series of Chl-a fluxes on box B's four sides from November 20 to December 10. The Chl-a concentrations on the southern and northern sides multiplied by v are their Chl-a fluxes, and the Chl-a concentrations on the eastern and western sides multiplied by u . On the southern and western (northern and eastern) sides, positive flux values represent flow-in (flow-out) and negative values represent flow-out (flow-in). In Figure 7, we can see that Chl-a flowed in box B from the western and northern sides, and flowed out from the

eastern and southern sides. The western sea surface Chl-a flux on December 1 was $0.113 \text{ mg} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$, and Chl-a upwelled maintained for 4 days from November 30 to December 3. This coincides with the eastward Chl-a transport around box B in Figure 2b. Temporal variation of the vertical integral of Chl-a concentration above 20 m along box B's western boundary is shown in Figure 8. From December 1 to December 4, high Chl-a concentrations were concentrated at $8.8\text{--}9.1^\circ\text{N}$ around the anticyclonic eddy's periphery (Figure 4).

Figure 9 shows the time series of the averaged Chl-a concentrations with depth in box B. Above the depth of 50 m near the thermocline, Chl-a rose to the upper layer with upwellings after the passage of Nada. Furthermore, the Chl-a flowed from the coast to box B (Figure 6), which caused a phytoplankton bloom.

Time series of the averaged Chl-a of box C from November 20 to December 8 is presented in Figure 10. Liu et al. (2009) suggested that after a typhoon passed, the originally existing cyclonic eddy may aggravate the dynamic response of the upper ocean and significantly

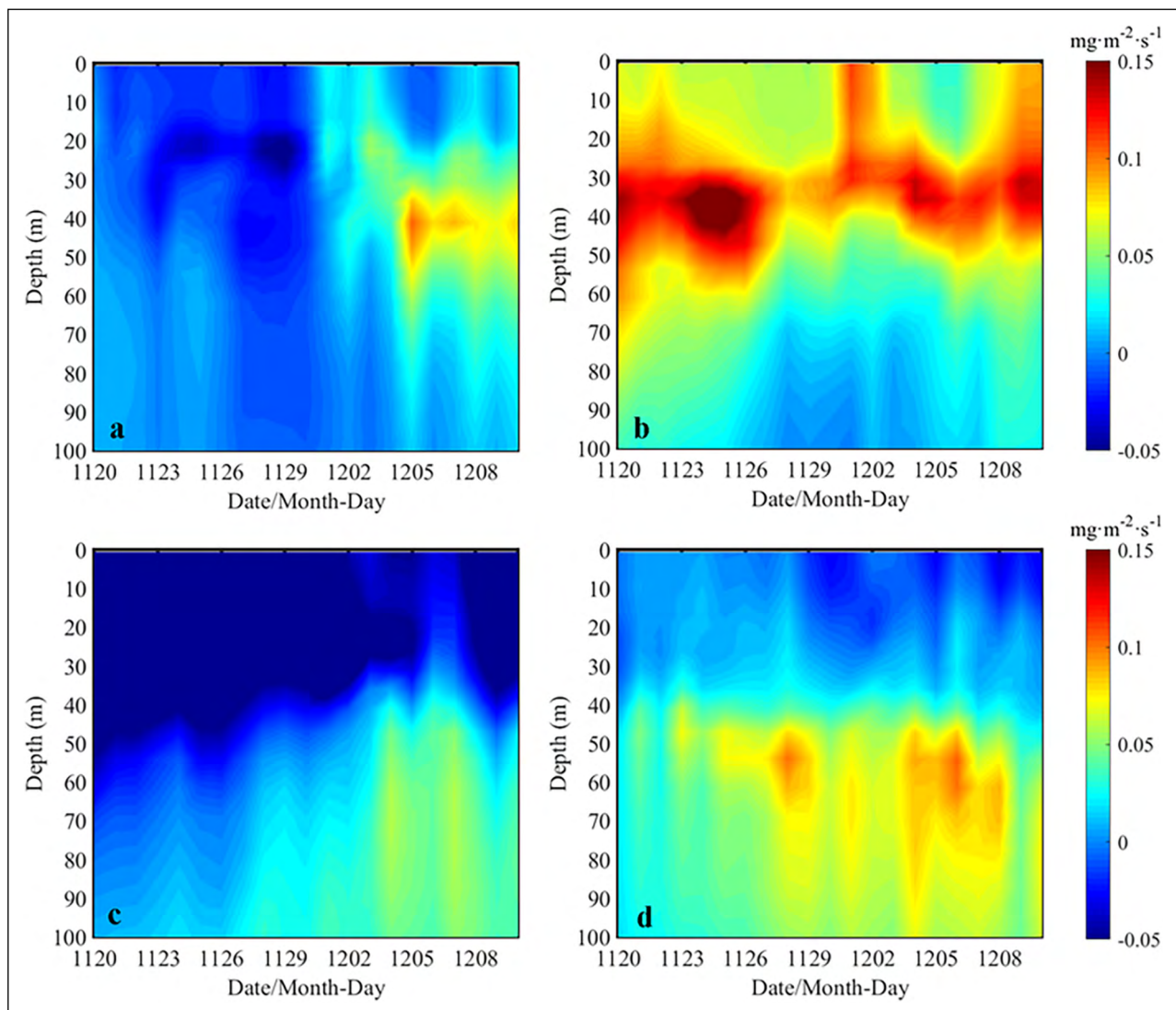


Figure 7 Time series of lateral Chl-a fluxes for box B (east boundary (a), west boundary (b), south boundary (c), and north boundary (d)).

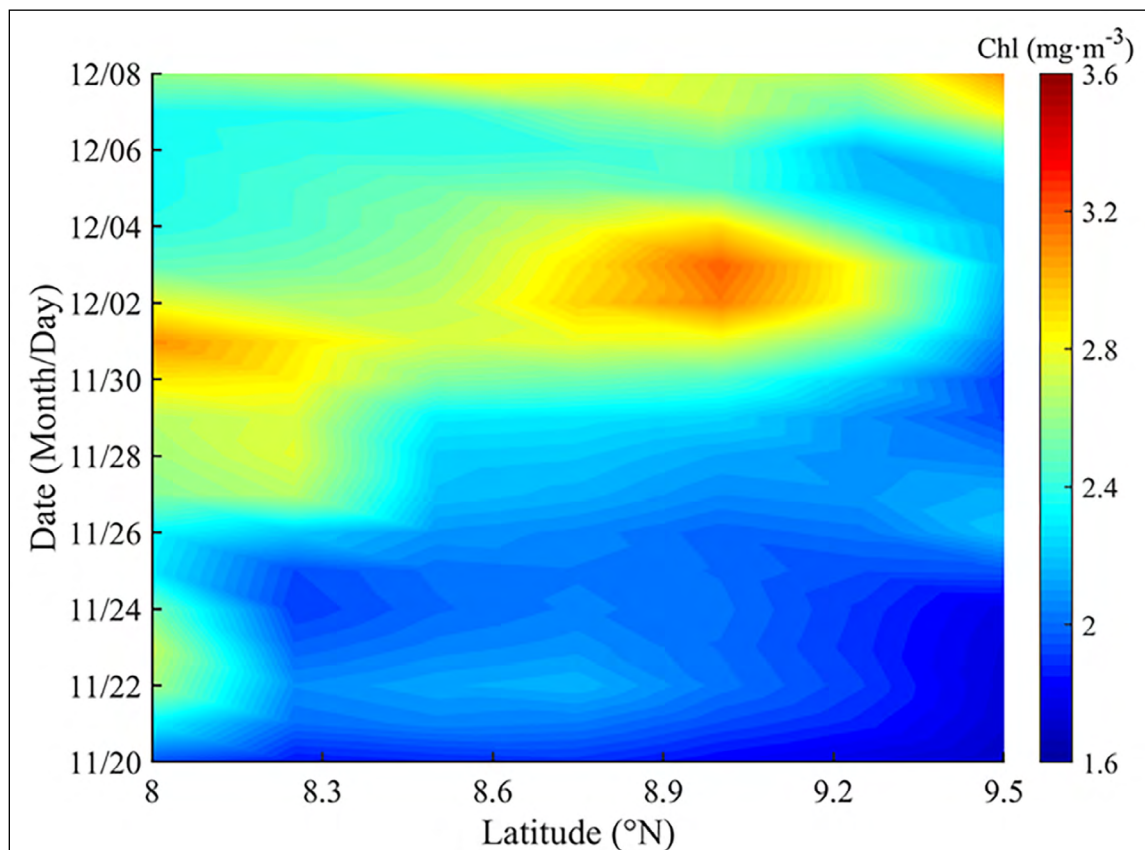


Figure 8 Time series of vertical integration of Chl-a concentration in the upper layer (0–20 m) along the western side of box B from November 20 to December 8.

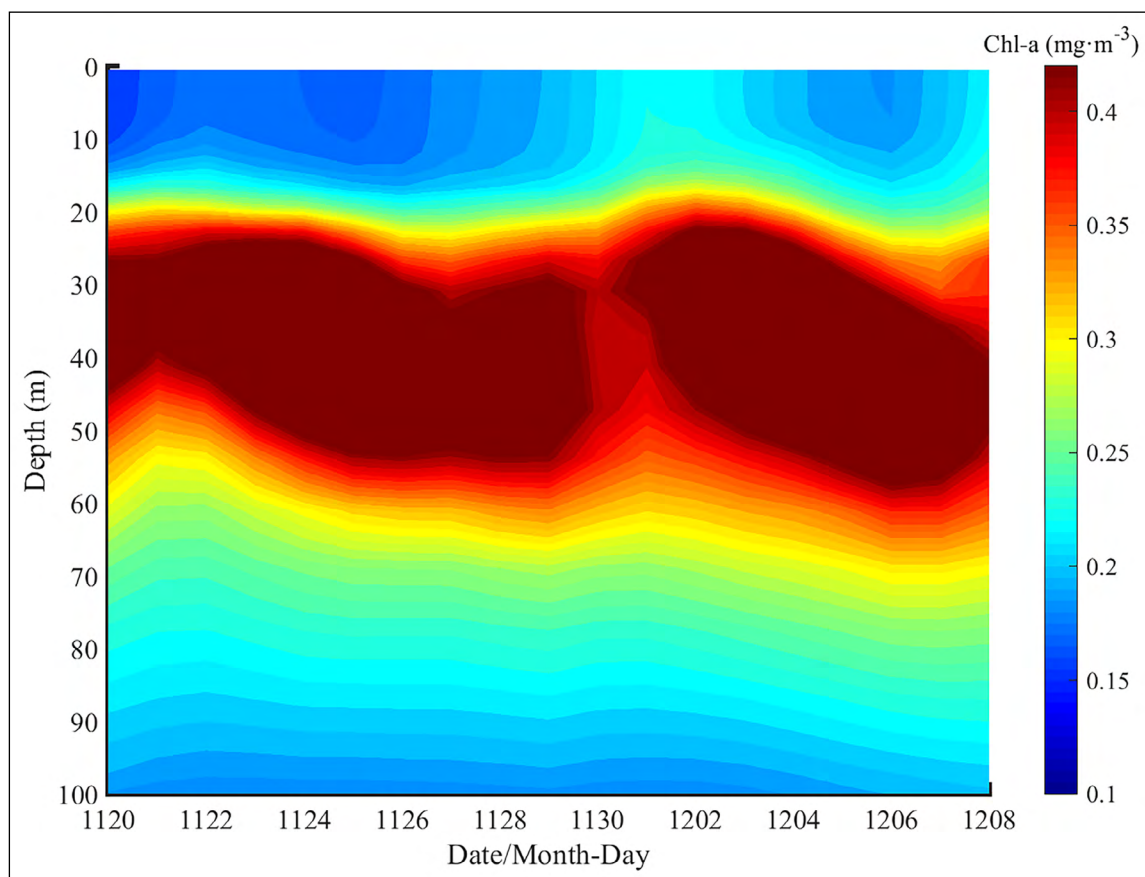


Figure 9 Time series of the domain averaged Chl-a concentration with depth in box B.

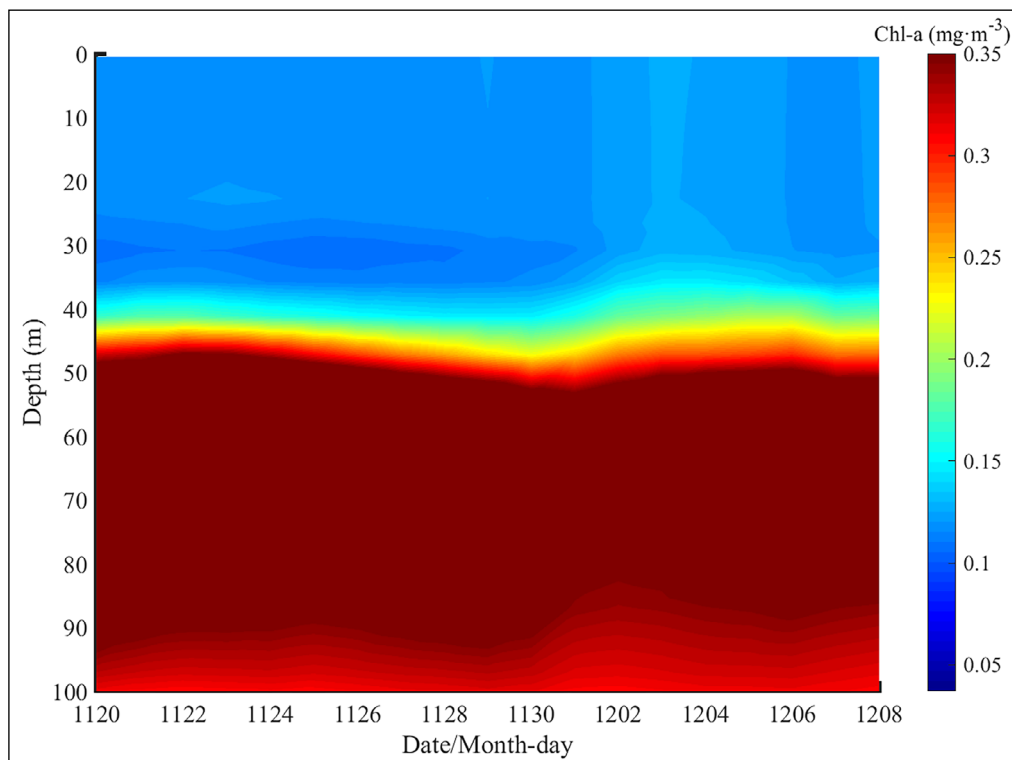


Figure 10 Time series of the averaged Chl-a concentrations with depth in box C.

enhance nutrients. A cyclonic eddy has a relatively unstable thermodynamic structure and cold water pumping, which significantly influence the stratification structure of seawater (Walker et al., 2014; Ma et al., 2018). Subsurface Chl-a intrudes upward to surface caused by upwelling and vertical mixing from December 1 to December 6, which triggered a phytoplankton bloom.

4 DISCUSSION

4.1 VARIATION OF STRATIFICATION

Previous studies have principally focused on the impacts of a few strong TCs about their impacts on phytoplankton and primary productivity in the deep ocean (i.e., a water depth > 200 m), for instance, those in the western Pacific and the SCS far from the continental shelf (Lin et al., 2003; Zheng and Tang, 2007; Zhao et al., 2008; Sun et al., 2010; Lin, 2012). However, TC Nada was a typical fast-moving and weak cyclone that influenced surface phytoplankton in the coastal waters of BOB. Figure 11a shows the vertical profiles of the buoyancy frequency from the Argo buoys in box B. The same Argo float remained in box B for more than 20 days, which helped analyze the eddy dynamics. Before (after) the passage of Nada, the thermocline was located at a depth of 38.8 m (53.7 m) on November 25 (December 10), where the maximum buoyancy frequency was $N = 0.067 \text{ s}^{-1}$ (0.041 s^{-1}). The mixed layer deepened and stratification weakened can promote the uplift of Chl-a in the water column (Niu et al., 2016; Lü et al., 2020a). The vertical

profiles of buoyancy frequency from the Argo floats in box C are shown in Figure 11b. Before (after) the passage of TC Nada, the thermocline was located at a depth of 33.7 m (35.6 m) on November 25 (December 5), where the maximum buoyancy frequency was $N = 0.032 \text{ s}^{-1}$ (0.026 s^{-1}). The stratification in the upper ocean weakened and promoted the accumulation of phytoplankton in box C, which was within the enhanced ocean cyclonic eddy.

4.2 ROLES OF THE TC AND EDDIES

The Ekman pumping velocity (EPV) during the passage of Nada is calculated based on Eqs (2) and (3) and presented in Figure 12. The upwelling within the vicinity of box A was apparently stronger ($> 2 \times 10^{-4} \text{ m}\cdot\text{s}^{-1}$) at 6:00 UTC on November 29, 2016 than other times. Strong upwellings only occurred in a small area near the center of the TC, and large compensatory downwellings appeared outside upwelled areas (Jaimes and Shay, 2015; Xia et al., 2022). Vinayachandran (2009) established that during the northeast monsoon (November, December), phytoplankton blooms first occurred in the subsurface, and then erupted at the sea surface with sufficiently strong Ekman pumping, which is also a factor in phytoplankton blooms around Sri Lanka. Figure 12c shows that the TC passed through boxes B and C on December 1 and produced an EPV with about $1 \times 10^{-4} \text{ m}\cdot\text{s}^{-1}$ near Nada's path. For box B, Nada strengthened the upwelling near the anticyclonic eddy's periphery, causing the subsurface Chl-a to be uplifted to the surface (Figure 9). For box C, Nada enhanced the cyclonic eddy and caused inertial oscillations with a 2-day period, leading to strong vertical

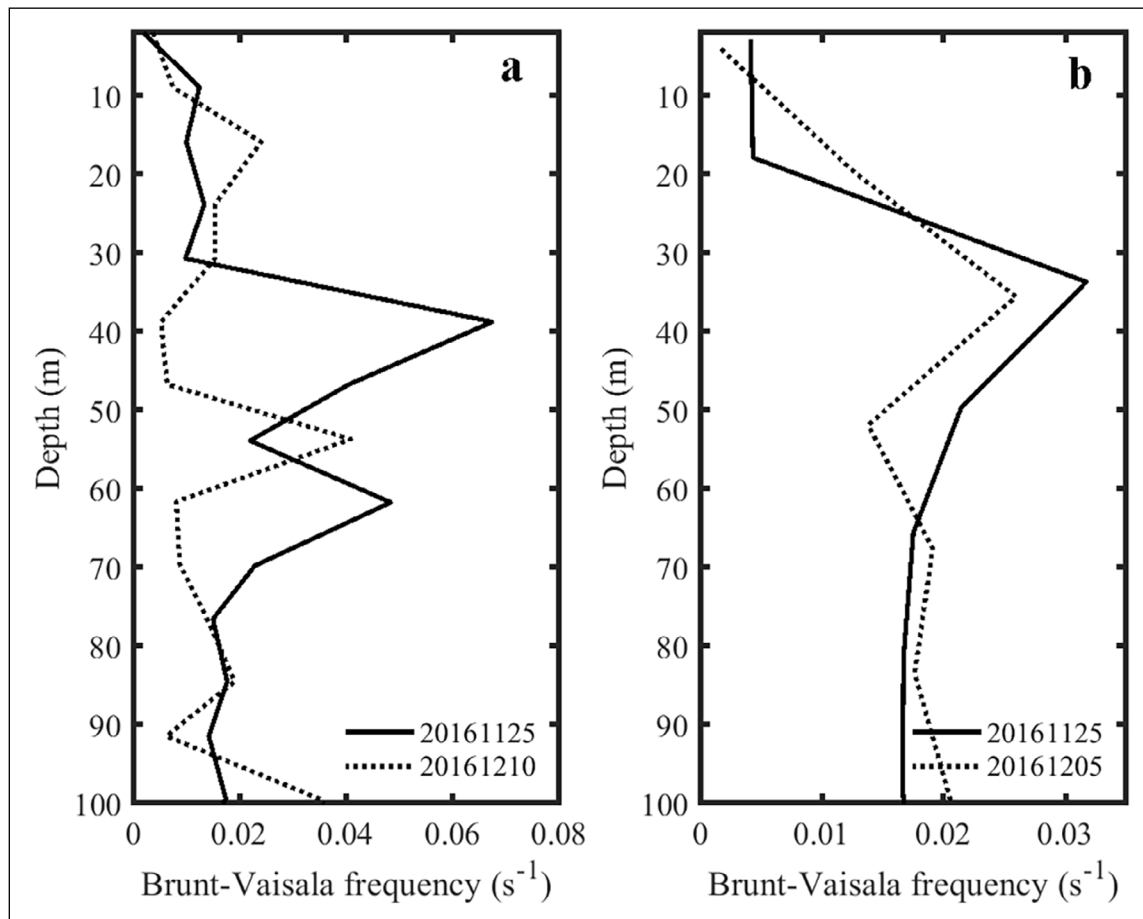


Figure 11 The buoyancy frequency of the Argo profiles in boxes B (a) and C (b) before and after the passage of Nada.

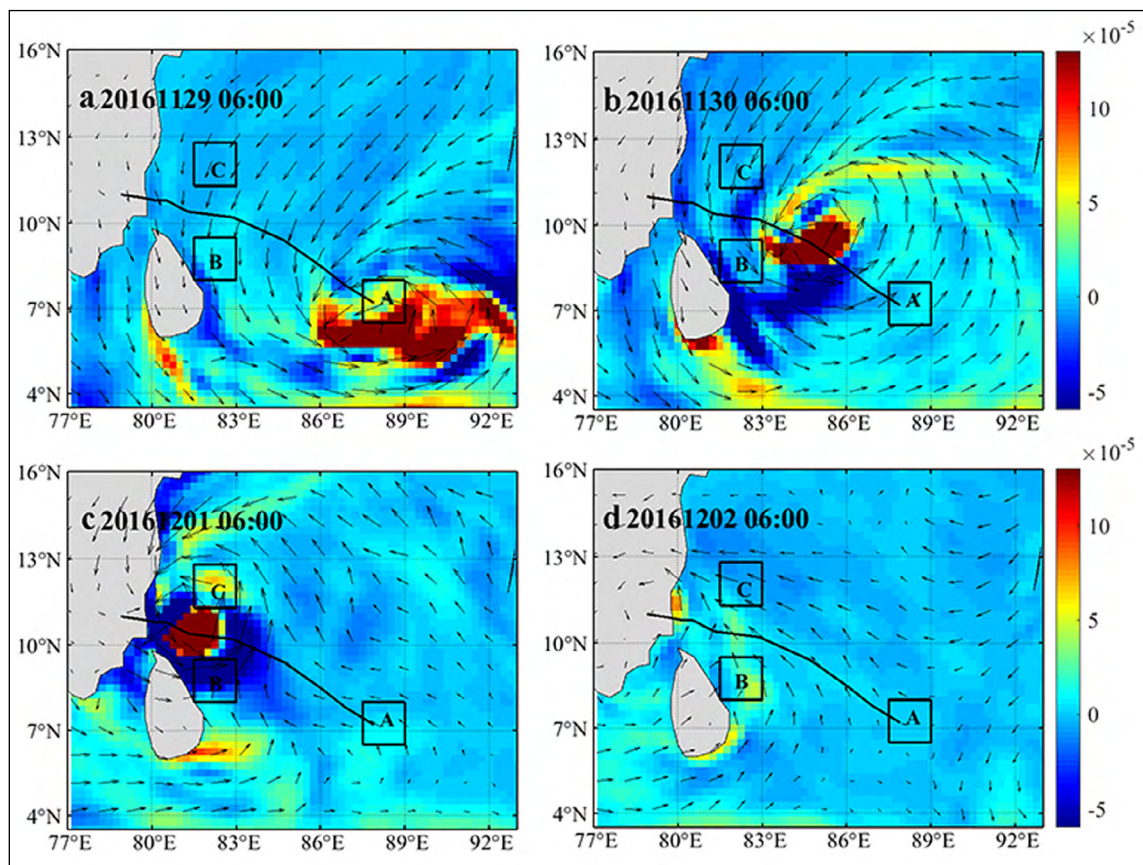


Figure 12 The sea surface wind speed (arrows) and EPV (colors) during TC Nada passage.

mixing in box C (Figure 14). It can be seen from the current field that the coastal current is equatorward through the cold eddy and carries cold current to the western boundary of box B (Figure 4), which cooperated with the Ekman pumping caused by Nada, the average negative anomaly SST in box B is larger than boxes A and C (Figure 5).

The vorticity calculated by Eq (1) was used to measure the strength of the eddies (Lü et al., 2020b). Positive vorticity indicates cyclonic eddies and negative vorticity means anticyclonic eddies. Figure 13 shows time series of spatially averaged negative vorticity of the anticyclonic eddy from November 24 to December 10 in box B. The vorticity experienced two enhancements before (November 26 to 29) and after (December 2 to 5) Nada. The surface vorticity was -0.65 s^{-1} before the arrival of Nada on November 29 and decreased to -0.31 s^{-1} during the passage of Nada from November 30 to December 2. It can be seen that the decreased vorticity of the original anticyclone and the eastward and southward transport of Chl-a (Figures 7 and 8) balanced the inhibition of

anticyclonic eddy on Chl-a. The surface vorticity began to increase on December 2 and increased to -0.62 s^{-1} on December 5 (Figure 13b), which enhanced downwellings after Nada and then inhibited the rise of Chl-a. The increase of sea surface Chl-a was triggered by the upward of higher Chl-a in the subsurface (Figure 9) during the passage of Nada. A similar phenomenon caused by the upward of subsurface higher Chl-a after TC ARB 01 enhanced the pre-existed anticyclone was observed in the southwest Indian peninsula by Tan et al. (2022).

Liu et al. (2020) found that a cyclonic eddy intensified during the passage of Typhoon Talim, which promoted a 10-fold increase in the concentration of Chl-a. The time series of spatially averaged positive vorticity of the cyclonic from November 24 to December 10 in box C is shown in Figure 14. As Nada passed on November 30, inertial oscillations with a period of 2 days were generated at 35 m which was below the mixed layer (Figure 14a). The surface vorticity was 0.19 s^{-1} on November 29 before the arrival of Nada, and increased to 0.27 s^{-1} on

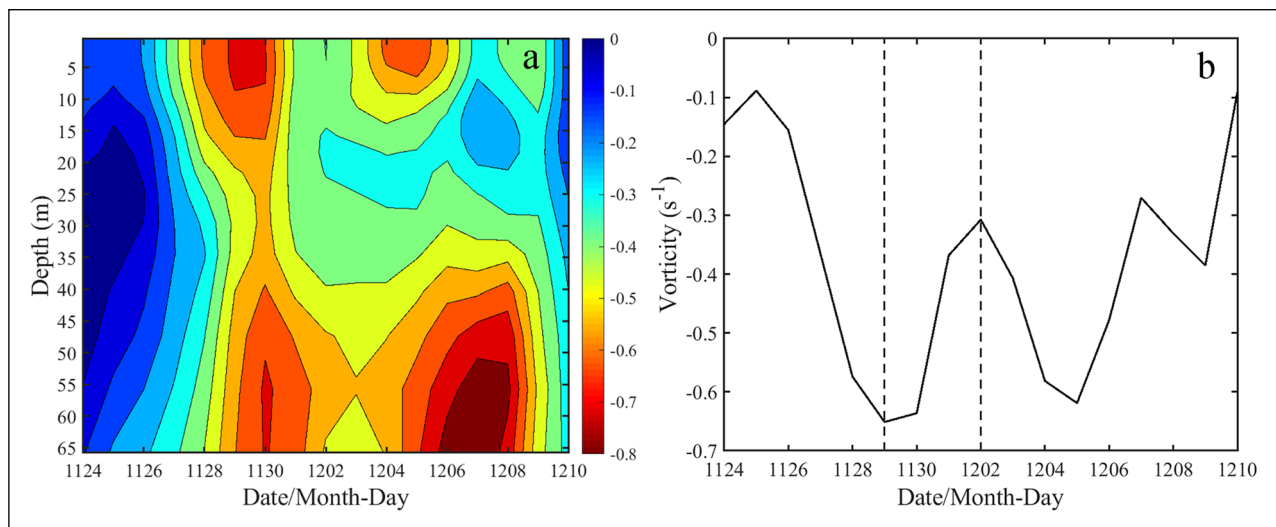


Figure 13 Time series of the averaged vorticity at different depths (a) and at the sea surface (b) of the anticyclonic eddy in box B. Dashed lines present the passage of Nada.

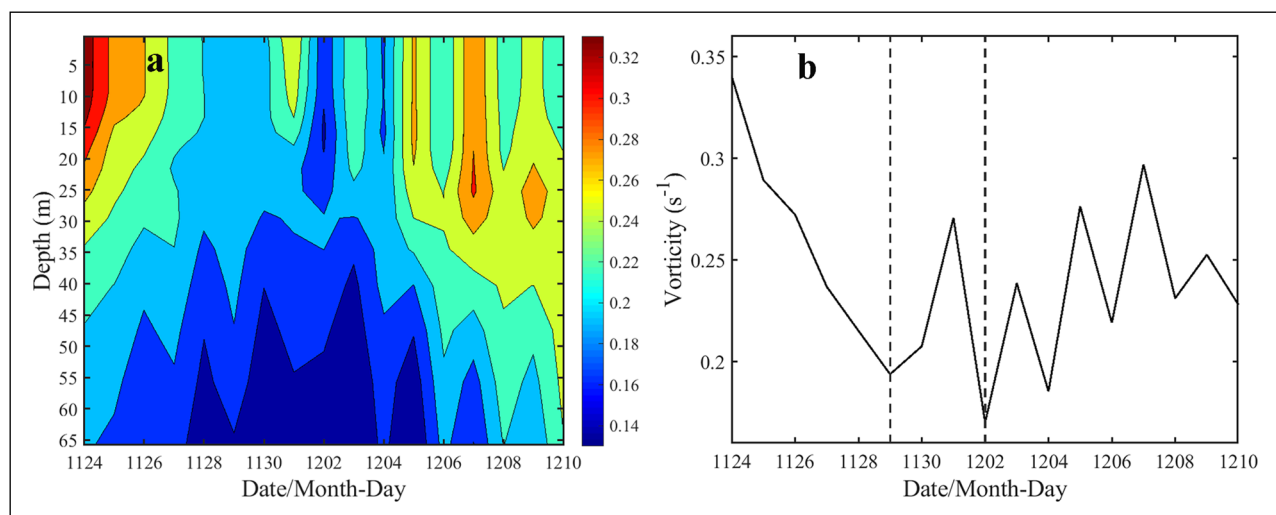


Figure 14 Time series of the averaged vorticity at different depths (a) and at the sea surface (b) of the cyclonic eddy in box C. Dashed lines present the passage of Nada.

December 1 during the passage of Nada (Figure 14b). Strong vertical mixing occurred on December 1. After the passage of Nada, the vorticity of the cyclonic eddy was enhanced, especially from December 4 to December 7, the maximum vorticity below the mixed layer was more than 0.28 s^{-1} (Figure 14a). Therefore, a TC can intensify a pre-existing oceanic cyclone, produce enhanced upwelling and vertical mixing, and trigger the bursts of surface Chl-a with high PARs and minimal rainfall (Figure 6). Similar phenomena have been found in many areas, such as the western North Pacific and the southeastern Arabian Sea (Zheng et al., 2008; Sun et al., 2009; Lee et al., 2020; Lü et al., 2020b).

5 CONCLUSIONS

In this study, we analyzed the Chl-a variation and associated oceanic conditions in the BOB during the passage of TC Nada in 2016. Multisource reanalysis products and Argo float data were used to investigate the upper ocean responses to the TC Nada. The following conclusions were drawn:

1. Along the TC's path, phytoplankton blooms gradually occurred from offshore to nearshore to the east of Sri Lanka. The Chl-a concentration increased progressively in box B on December 3, with a maximum of $0.43 \text{ mg} \cdot \text{m}^{-3}$. The Chl-a concentration in box C changed from $0.02 \text{ mg} \cdot \text{m}^{-3}$ on December 2 to $0.47 \text{ mg} \cdot \text{m}^{-3}$ on December 6, and this Chl-a bloom sustained for 4 days after the passage of Nada.
2. In box B, the vorticity of the pre-existed anticyclone was weakened from -0.65 s^{-1} to -0.31 s^{-1} during the passage of Nada, when the eastward and southward transport of Chl-a can balance the inhibition effect of anticyclonic eddy on Chl-a blooms. Besides, the mixed layer near the anticyclonic eddy's periphery has deepened from 38.8 m to 53.7 m and the stratification of the upper ocean weakened, which can promote the uplift of nutrient-rich deep water. The higher Chl-a water in the mixed layer was uplifted by upwelling resulting in the sea-surface phytoplankton bloom.
3. In box C, Nada enhanced the vorticity of the cyclonic eddy and caused inertial oscillations with a 2-day period, leading to strong vertical mixing and upwelling, which changed the vertical stratification of the upper ocean. Vertical mixing and upwelling triggered the sea-surface phytoplankton bloom.

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COMPETING INTERESTS

The authors have no competing interests to declare.

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