

Enhancement of near-inertial waves by cyclonic eddy in the northwestern South China Sea during spring 2022

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Abstract. By analyzing dataset derived from four moorings during spring 2022, this study provides direct evidence that near-inertial waves (NIWs) can be largely enhanced by a passing cyclonic eddy (CE) in the northwestern South China Sea. Results show that the enhancement of NIWs mainly occurred at north side of the CE due to asymmetry of eddy structure. In vertical, the enhancement concentrated at above 200 m and reached peaks at around 100 m. Significant energy transfer rates between the CE and NIWs appeared at the same depth of the enhancement can reach up to 6×10^{-10} m^2/s^3 at the CE's edge. Under the impact of the CE, power of the first five NIWs modes was promoted significantly and dominated by the second and third modes. Overall, the CE transferred energy to NIWs before near-inertial kinetic energy reaching its peaks, while NIWs gave energy back to the CE after the peaks.

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1 Introduction

Near-inertial waves (NIWs) are ubiquitous features throughout the global ocean with frequencies near the Coriolis frequency f (Garrett, 2001). As dominant modes of high-frequency variability in oceans, they contain half of the kinetic energy in internal wave fields (Alford, 2003; Alford et al., 2016;

32 Ferrari and Wunsch, 2009). NIWs transfer energy from mixed layer to interior and ultimately dissipate
33 into microscale turbulence, providing an energy source for abyssal diapycnal mixing (Chen et al., 2017;
34 Ferrari and Wunsch, 2009). Therefore, NIWs are of vital importance for energy cascade among
35 multiscale dynamic processes.

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36 Due to horizontal spatial scales of 10–100 km and slow group speed of NIWs, they are likely to
37 interact strongly with mesoscale eddy in oceans (Alford et al., 2016). Besides resonant frequency
38 shifting from local f to the effective inertial frequency caused by mesoscale vorticity (Klein et al., 2003;
39 Kunze, 1985; Weller, 1982), energy exchange between eddy and NIWs also plays an important role in
40 oceanic energy cascade (Ferrari and Wunsch, 2009; Thomas, 2017). Researchers have stated that the
41 NIWs can extract energy from eddy and affect the vertical material transport (Barkan et al., 2021;
42 Esposito et al., 2023). Moreover, energy transfer from mean flows can balance the dissipation of near-
43 inertial energy near the critical layer, thereby conserving near-inertial energy during eddy migration,
44 (Xu et al., 2022b).

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45 Jing et al. (2017) and Jing et al. (2018) suggested that there is a permanent energy transfer from
46 eddies to NIWs under a positive Okubo–Weiss parameter condition. Furthermore, Yu et al. (2022)
47 revealed that enhanced near-inertial kinetic energy (NIKE) is found preferentially in regions of
48 anticyclonic vorticity. Using surface drifter dataset, Liu et al. (2023) indicated that bidirectional energy
49 transfer exists between eddy and NIWs in the global oceans. Above studies all emphasized role of eddy
50 on affecting frequencies of NIWs, NIKE as well.

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51 As the largest semi-enclosed marginal sea in the northwestern Pacific Ocean, the South China Sea
52 (SCS) has frequent eddy activities (Wang et al., 2003; Wang et al., 2008; Chen et al., 2011; Nan et al.,
53 2011; Chu et al., 2014). Early studies, by using various eddy detection algorithms, have statistically
54 characterized the mean properties of eddies, identifying peak occurrences along western boundary
55 currents and shelf break regions (Wang et al., 2003; Lin et al., 2007; Xiu et al., 2010). Specifically,
56 Chen et al. (2011) indicated that eddies occur 35%–60% of the time in the northern SCS, underscoring
57 their critical role in regional oceanography. Recent advancements in remote sensing and in-situ
58 observational technologies have enabled significant insights into eddy formation and their three-
59 dimensional structures (Nan et al., 2011; Zhang et al., 2016; He et al., 2018; Chu et al., 2022; Wang et
60 al., 2023). Due to their unique three-dimensional structures and spatiotemporal scales, eddies mediate
61 significant material transport (Zhang et al., 2015; He et al., 2018; Zhang et al., 2019) and substantial

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energy exchanges with internal waves and western boundary currents (Chu et al., 2014; Huang et al., 2018; Xu et al., 2022; Liu et al., 2023; Zhang et al., 2023; Zhao et al., 2023; Fan et al., 2024).

In the northwestern SCS, large portion of eddy propagate westward and terminate near Xisha Trough (Fig. 1a(Wang et al., 2003; Zhai et al., 2010), making this place as an ideal area for investigating NIWs and its interaction with eddy. However, interaction and energy exchange processes between them remain to be investigated in this area. In this study, four moorings, each equipped with a Teledyne RD Acoustic Doppler Current Profiler (ADCP), were deployed in the Xisha Trough of the northwestern SCS (Fig. 1a). During spring 2022, a cyclonic eddy (CE) propagated westward across the mooring array, giving an opportunity to study energy transfer between NIWs and the CE in this area. We introduce data and methods in Section 2, present the observation results in Section 3, discuss energy transfer between NIWs and the CE in Section 4, and give a conclusion in Section 5.

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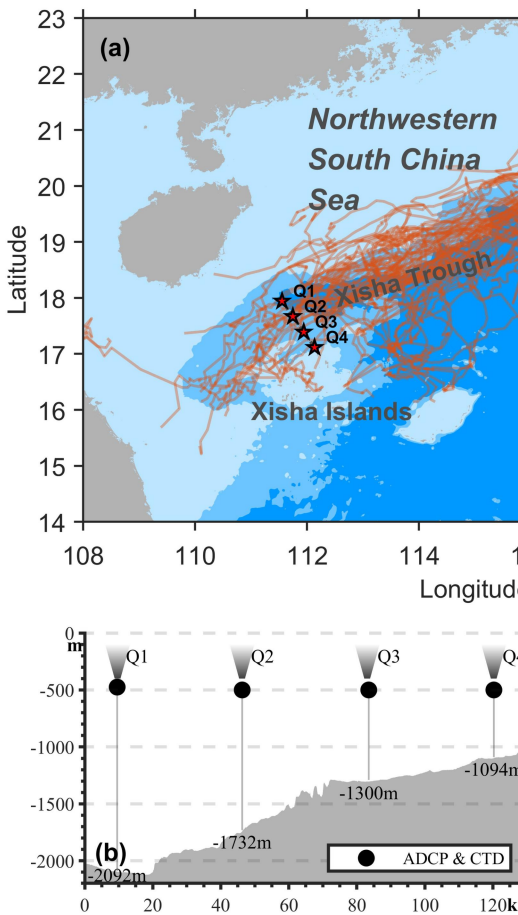
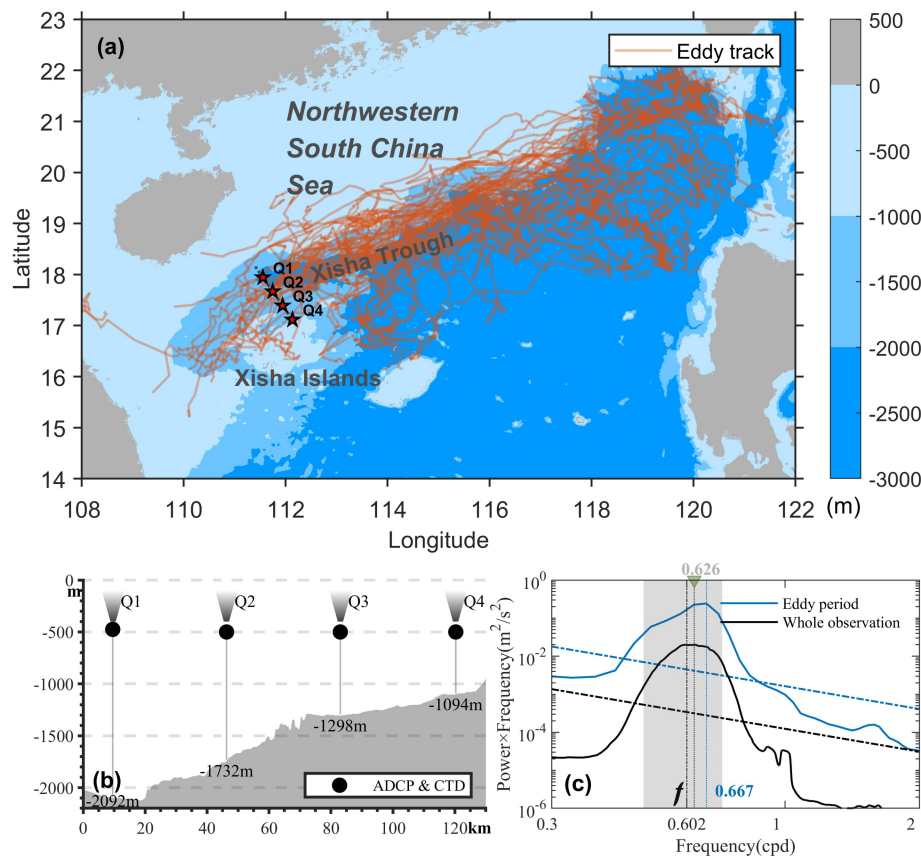


Figure 1: (a) Location of four moorings (Q1-Q4) in the northwestern SCS. The shaded background color represents topography. Orange lines indicate tracks of long-lasting eddy propagating from the Luzon area to the Xisha Trough from 1993 to 2023. (b) Structure of upward-looking ADCP mooring along the slope of topography. (c) The power spectra during eddy period (blue line) and whole observation period (black line). The spectra are

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79 averaged above 200 m.

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80 2 Methodology

81 2.1 Data

82 The four moorings (Q1-Q4) were deployed in the study area on August 21-23, 2021. One up-
83 looking 75-kHz ADCP along with a CTD (SBE 37sm) was fixed at approximately 480 m depth and
84 continuously monitored current velocity for each mooring (Fig. 1b). The ADCPs were set to have 30
85 bins with 16 m of vertical interval and 30 minutes of temporal interval, enabling extraction of NIWs of
86 the upper ocean. The moorings were recovered on November 13-15, 2022. Several ADCP bins near the
87 sea surface were omitted due to large fluctuations, and the remaining were vertically linearly
88 interpolated to 1m resolution. Due to the significant vertical fluctuations based on CTD data in certain
89 periods, flow velocity compensation correction was applied to ADCP data, which was calculated based
90 on depth change and flow direction.

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91 The Copernicus Marine Environment Monitoring Service (CMEMS) provides daily geostrophic
92 current and sea level anomaly (SLA) data with a resolution of $0.25^\circ \times 0.25^\circ$, which were used to detect
93 eddy during the observation period. The $1/12^\circ$ three-dimensional products were obtained from
94 CMEMS to calculate energy transfer rate between eddy and NIWs. The eddy dataset from Archiving,
95 Validation, and Interpretation of Satellite Oceanographic (AVISO) was used to provide the trajectories
96 and edges of the eddy. World Ocean Atlas (WOA18) data was used to extract temperature and salinity
97 data. The European Centre for Medium-Range Weather Forecasts (ECMWF) Reanalysis V5 (ERA-5)
98 data, which has hourly temporal and 0.25° spatial resolutions, was used to calculate near-inertial energy
99 input from the wind field.

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100 2.2 Method

101 The method for ADCP velocity flow velocity compensation correction is as follows:

$$102 \quad \vec{V}_{\text{true}}(t) = \vec{V}_{\text{measured}}(t) + \vec{V}_{\text{platform}}(t). \quad (1)$$

$$103 \quad \vec{V}_{\text{platform}}(t) = \frac{\Delta x}{\Delta t} \vec{i} + \frac{\Delta y}{\Delta t} \vec{j}. \quad (2)$$

$$104 \quad (x, y) = (pcos\theta, psin\theta). \quad (3)$$

105 $(\rho, \theta) = (\sqrt{L^2 - z_{\text{top}}^2}, \alpha),$ (4)

106 where $\vec{V}_{\text{true}}$, $\vec{V}_{\text{measured}}$ and $\vec{V}_{\text{platform}}$ are the true velocity, observed velocity and the platform movement
 107 velocity, respectively. (ρ, θ) is the polar coordinate position of the ADCP with the initial position as the
 108 origin. L , z_{top} and α are the length of the rope at the position of the ADCP, the depth of the ADCP and
 109 the direction angle of the horizontal projection.

110
 111 The eddy-NIW energy transfer rate ε , where a positive value indicates energy transfer from eddies
 112 to NIWs and a negative value denotes the reverse, can be quantitatively calculated following Jing et al.
 113 (2018):

114 $\varepsilon = -(\langle u_i u_i \rangle - \langle v_i v_i \rangle) \frac{S_n}{2} - \langle u_i v_i \rangle S_s,$ (5)

115 where $S_n = \frac{\partial u_g}{\partial x} - \frac{\partial v_g}{\partial y}$ and $S_s = \frac{\partial u_g}{\partial y} + \frac{\partial v_g}{\partial x}$ are the normal strain and shear strain of the geostrophic
 116 velocity u_g and v_g , which is obtained from the CMEMS three-dimensional reanalysis data (Chen et al.,
 117 2023). We used fourth-order Butterworth band-pass filter with the cutoff frequency (0.8f-1.2f) to
 118 separate near-inertial velocity u_i and v_i from the ADCP data. The $\langle \cdot \rangle$ represents a moving average of 3
 119 internal wave periods.

120 Near-inertial wind work was estimated as (Alford, 2001; Dasaro, 1985):

121 $W = \vec{\tau} \cdot \vec{u}_i,$ (6)

122 where $\vec{u}_i$ is near-inertial velocity at sea surface derived from CMEMS products and $\vec{\tau}$ is wind stress
 123 calculated as (Alford, 2020; Liu et al., 2019):

124 $\vec{\tau} = \rho_a C_D |\vec{U}_{10} - \vec{u}_c| (\vec{U}_{10} - \vec{u}_c),$ (7)

125 where $\rho_a = 1.3 \text{ kg/m}^3$ is density of air, $\vec{U}_{10}$ is 10-m wind velocity vector derived from ERA5 data, $\vec{u}_c$ is
 126 ocean current vector derived from CMEMS data, C_D is drag coefficient (Oey et al., 2006).

127 We used the Okubo-Weiss parameter (OW) (Provenzale, 1999) method to detect the CE. The OW
 128 parameter was computed from the horizontal velocity field as follows:

129 $\sigma = S_{\text{sh}}^2 + S_{\text{st}}^2 - \zeta^2,$ (8)

130 where $S_{\text{sh}} \equiv \frac{\partial u}{\partial y} \pm \frac{\partial v}{\partial x}$ and $S_{\text{st}} \equiv \frac{\partial u}{\partial x} - \frac{\partial v}{\partial y}$ are the shear and strain deformation, respectively, and ζ is the
 131 relative vorticity.

删除: Eddy-NIW energy transfer rate ε can be qualitatively calculated as (Jing et al., 2018):

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132 **3 Results**

133 **3.1 Near-inertial frequency and NIKE**

134 The snapshots of SLA and surface geostrophic velocity fields show that the CE approached the
135 mooring array on February 1 (Fig. 2). Its center passed through Q3 around February 26 and it left the
136 mooring array on March 9. During the entire observation period, NIWs exhibit a small blue shift of
137 near-inertial frequency with a peak value of 0.616 cycles per day (cpd) (Fig. 1c), while a significant
138 blue shift occurred during the eddy period (February 1 - March 9) due to the background positive
139 vorticity of the CE. The peak of spectral frequency (ω_p) reached 0.667cpd, with a relative frequency
140 shift ($\frac{\omega_p - f}{f}$, RFS) of about 10.8% in this area. It is significantly larger than the global RFS (Guo et al.,
141 2021), suggesting significant impact of the CE on local near-inertial frequencies.

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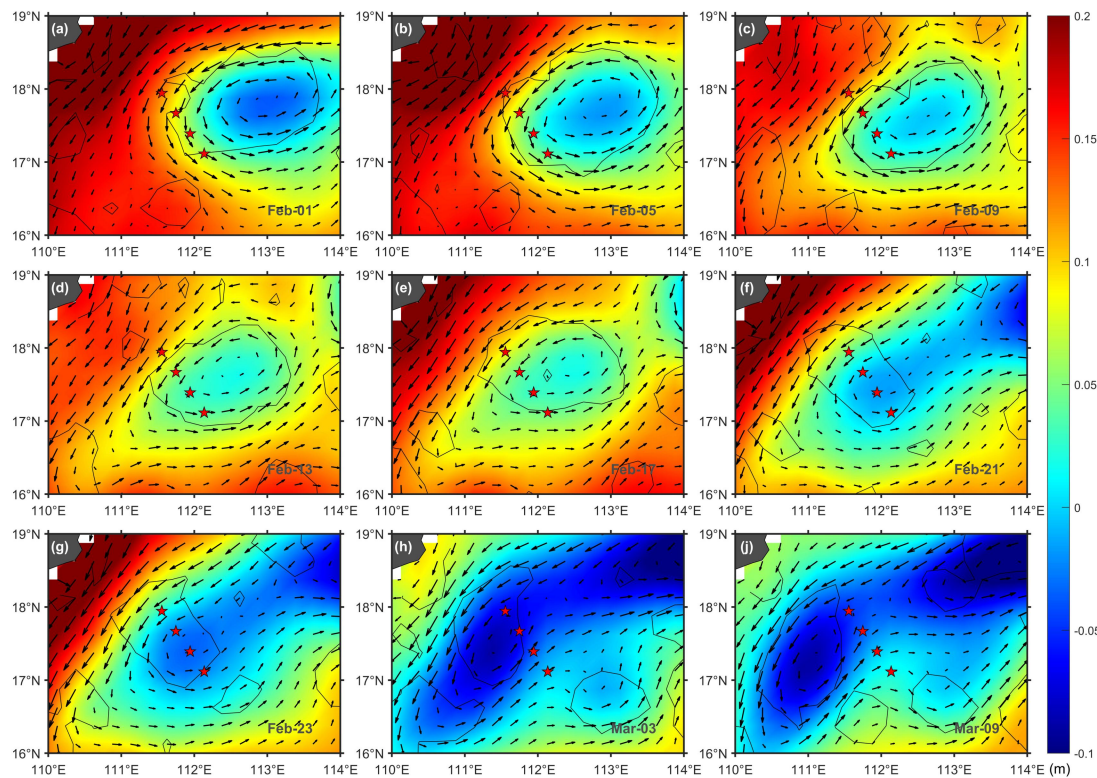
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142 **Figure 2: (a-j)** The snapshot of sea level anomaly and geostrophic current vector during February 1-March 9. The
143 black line indicates the Okubo-Weiss parameters.
144

145 Meridional velocity wavelet power spectra show that strong power of NIWs occurred during eddy
146 period but with large variations at different eddy stages (Figs. 3a-d). To quantify NIKE at different
147 stages of the CE, we defined two time periods named as Period1 (February 16-26) and Period2

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(February 26-March 8), covering 10 days before and after the eddy's center passed through the mooring array. In addition, no eddy period with calm wind during June 1-20 was chosen for extra comparison. Figs. 3e-h show temporal and vertical variations of NIKE at the four moorings during eddy period. The [missing data](#) of NIKE at surface layers are due to mooring swing caused by strong currents. It can be seen that NIKes were enhanced largely at above 200 m during Period2. And peak values of NIKE concentrated at around 100 m. The time-averaged NIKes during Period2 have almost one order larger than that during no eddy period (Figs. 3i-l), suggesting significant impact of the CE on local NIKE. Moreover, NIKes illustrate asymmetry in [space](#) during eddy period (Figs. 3e-l). At north side of the CE (Q1-Q2), NIKes became much stronger than that at south side of the CE (Q3 and Q4), especially at Q2 with a maximum value up to 12.0 J/m³ (Fig. 3f), which has the same magnitude as the result observed by Xu et al. (2022b).

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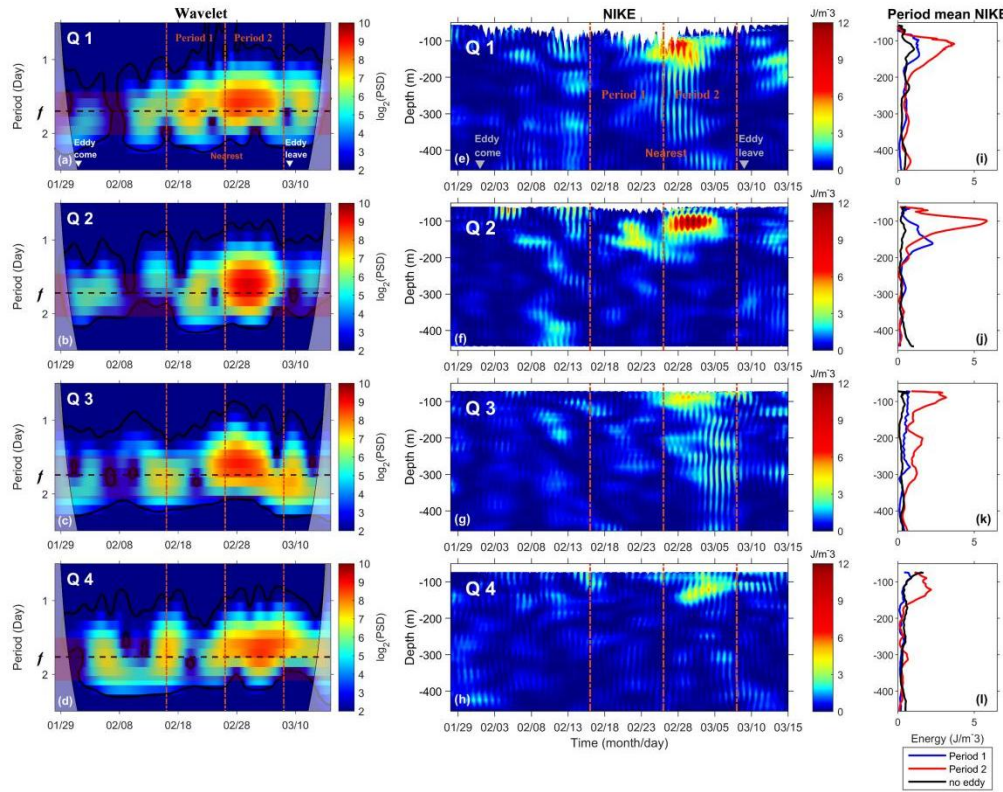


Figure 3: (a-d) 100 m-depth meridional velocity wavelet power spectra at Q1-Q4 during eddy period. (e-h) Vertical distribution of NIKE at Q1-Q4. The gray triangles indicate the time when the CE edge contacts and leaves the mooring array. (i-l) Vertical distribution of time-averaged NIKE during 'no eddy period' (black line), 'Period 1' (blue line), and 'Period 2' (red line) at Q1-Q4. The red dashed lines mark two periods of the CE.

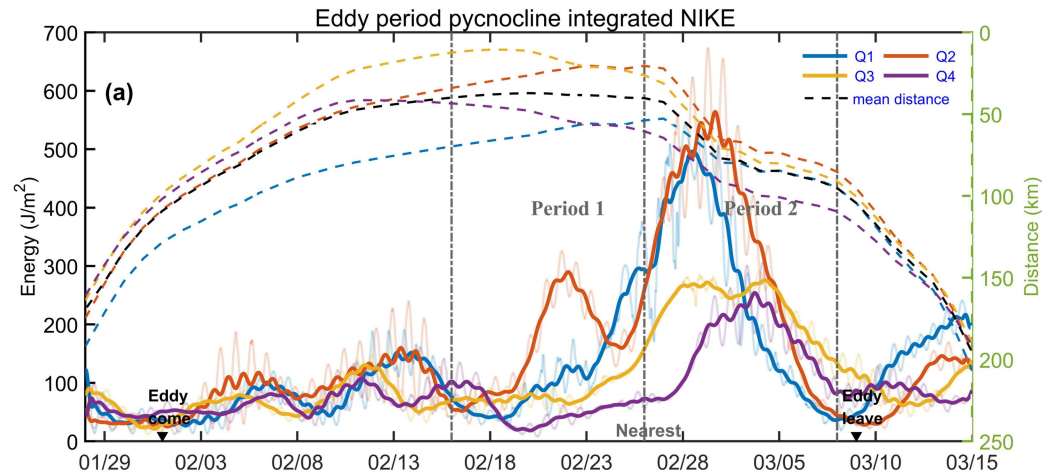
3.2 Impact of eddy on NIWs

To ensure the fact that the CE could largely enhance NIWs in the northwestern SCS, we compared

166 time series of vertical-integrated (above 200m) NIKE at each mooring with mooring-eddy distance,
 167 wind-input NIKE and eddy kinetic energy (EKE) in the study area (Fig. 4 and Fig. 5). NIWs were
 168 enhanced gradually accompanied by weakening EKE during Period1 when wind-input NIKE were
 169 relatively stable and minor. The percentage changes in the averages of NIKE and EKE for two time
 170 periods, before February 16th and from February 16th to March 8th, were 115.2% and -71.6%,
 171 respectively. Results suggest a vivid energy transfer from Eddy to NIWs during this period that will be
 172 quantified and discussed in Section 4. After passing of the CE's center, the CE enhanced NIWs faster,
 173 indicating more energy transfer from eddy to NIWs during Period2 than that during Period1. The slight
 174 increase of EKE during Period2 was contributed by background western boundary current velocity
 175 input (Fig. 2).

删除: Results suggest a vivid energy transfer from eddy to NIWs during this period that will be qualified quantified and discussed in Section 4.

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176 **Figure 4:** Time series of raw (thin lines) and daily-smoothed (thick lines) depth-integrated (above 200 m) NIKE at
 177 Q1-Q4 (solid lines) accompanying with distance between the CE's center and each mooring (dashed lines) during
 178 eddy period. The black dashed line represents the mean distance between the CE's center and four moorings. The
 179 triangles mark the time when the eddy edge contacts and leaves the mooring array.

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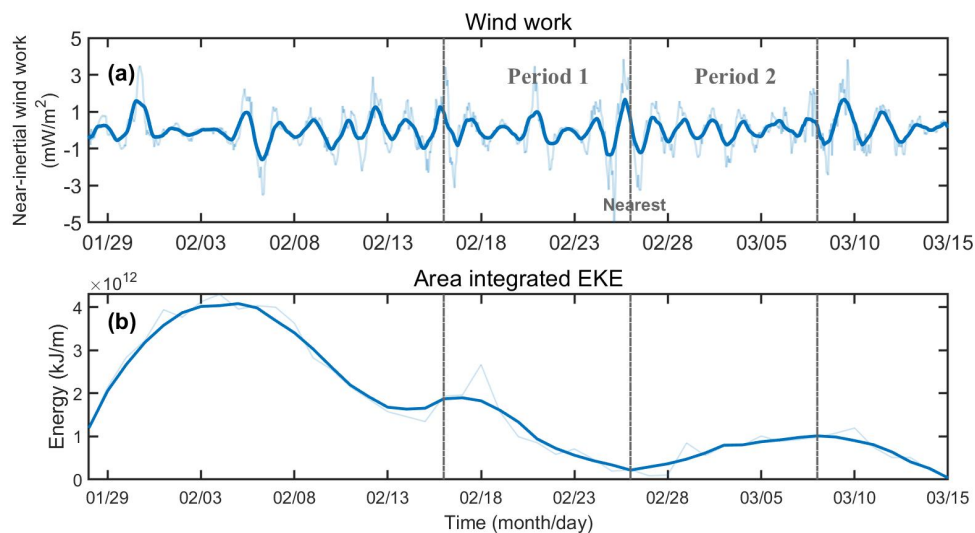
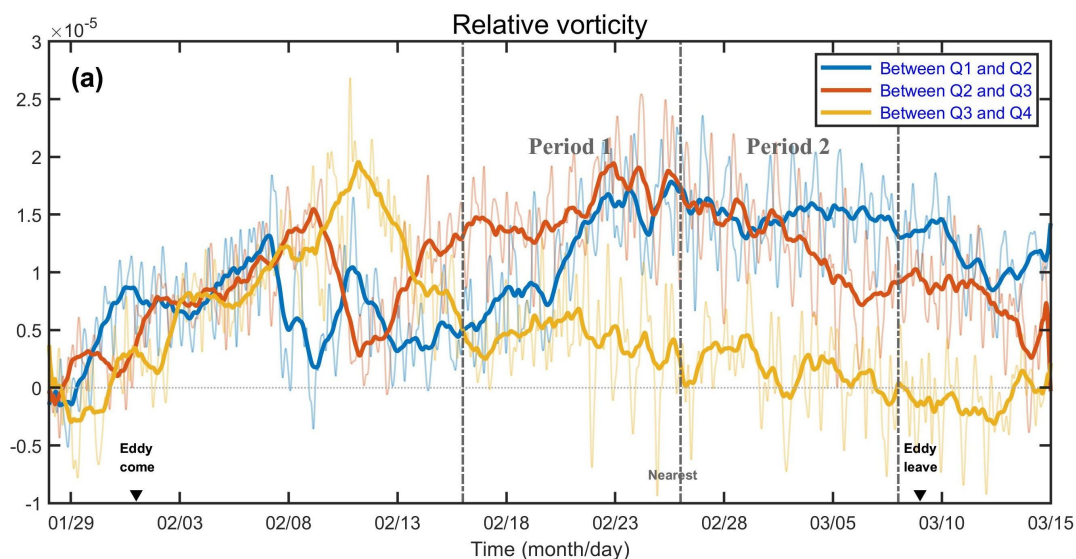


Figure 5: (a) Time series of raw (thin lines) and daily-smoothed (thick lines) averaged wind-input NIKE at Q1-Q4. (b) Time series of raw (thin lines) and daily-smoothed (thick lines) area integrated EKE.

In space, NIWs intensity reached 600 J/m^2 at Q2, whereas values at Q3 and Q4 were approximately 300 J/m^2 . This difference may be associated with the CE's vorticity distribution, where relative vorticities observed north of the CE (between Q1-Q2) were notably stronger than those measured south of the CE (between Q3-Q4) (Fig. 6). Zhao et al. (2021) and Zhao et al. (2023) pointed out that NIWs generation is significantly influenced by the eddy structure in which eddy with stronger shears tend to generate more powerful NIWs. In our case, Fig. 2 shows that the north side of the CE exhibited spatial overlap with the western boundary current of the northwestern SCS (Fig. 2) where strong shear could enhance NIWs largely at this side (Zhao et al., 2021, 2023).



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删除: In spatial, intensity of NIWs reached 600 J/m^2 at Q2, while they merely had 300 J/m^2 at Q3 and Q4 due to vorticity asymmetry of the CE in which relative vorticities at north side (between Q1 and Q2) were much larger than those at south side (between Q3 and Q4) (Fig. 6).

删除: In our case, the north side of the CE exhibited spatial overlap with the western boundary current of the northwestern SCS (Fig. 2) where strong shear is generated and could have enhanced NIWs largely at this side according to Zhao et al. (2021, 2023)

删除: In our case, the north side of the CE was merged with the western boundary current of the northwestern SCS (Fig. 1a) that generated strong shear and enhanced NIWs largely at this side.

195 **Figure 6:** Time series of raw (thin lines) and daily-smoothed (thick lines) relative vorticity among four moorings.
196 Vertical gray dashed lines mark two periods of the CE.

197 **3.3 Impact of eddy on near-inertial modes**

198 The CE not only affected frequency and energy of NIWs, but also their modes in the study area.
199 Here, we calculated vertical-averaged energy (above 200 m) of the first five modes of near-inertial
200 velocity during eddy period (Figs. 7a-d). All five modes grew since Period1 and reached peak values at
201 Period2. But the CE has different influence on different modes with low modes (mainly the second and
202 third modes) being significantly enhanced, especially near the CE's center. Low modes rose from 46%
203 (Q2) and 54.4% (Q3) [of total energy](#) during Period1 to 87.6% (Q2) and 79.5% (Q3) during Period2,
204 respectively (Figs 7e-f). The first mode has longer vertical wavelength and propagates faster than other
205 modes that make it easy escape from eddy's influence (Chen et al., 2013). Overall, energy proportion of
206 the first five modes were promoted from 81.5%, 66.8%, 69%, and 78.5% during Period1 to 90.8%,
207 88.8%, 87.7%, 94% at Q1-Q4, respectively (Figs. 7e-f). [In conclusion, the cyclonic eddy has a](#)
208 [prominent influence on diferent modes of NIWs, resulting in the intensification of lower-mode energy](#)
209 [within its core region, especially for modes 2 and 3.](#)

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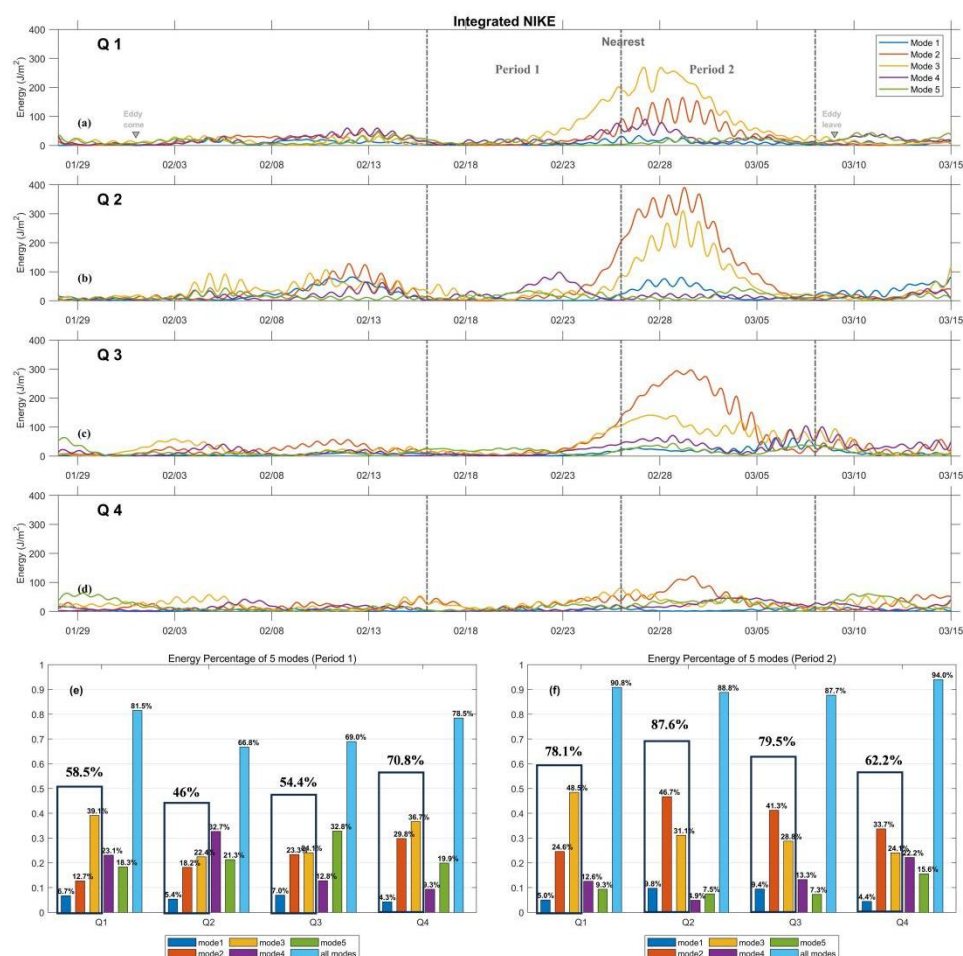


Figure 7: (a-d) Time series of NIKE for the first five modes at Q1-Q4 during eddy period. (e-f) The time-averaged proportions of each mode and all five modes during period 1 and period 2 at Q1-Q4. Black border indicates proportion sum of the first three modes.

4 Discussion

Energy exchange between eddy and NIWs is one of the most important processes in oceanic energy cascade (Alford et al., 2016; Ferrari and Wunsch, 2009; Thomas, 2017). By simulations, Jing et al. (2017) found that the energy transfer efficiency from eddies to near-inertial waves is about 2% of the near-inertial energy input by the wind in the Kuroshio Extension region. Based on surface drifter dataset, Liu et al. (2023) stated that energy transfer efficiency can reach about 13%, indicating previous underestimation of eddy impact on NIWs. For obtaining precise result, direct ocean current measurement by long-term mooring is essential (Jing et al., 2018). In this section, eddy-NIW's energy transfer rate during eddy period in the study area is qualified and discussed (Fig. 8). Corresponding to the layer of NIKE enhancement (Fig. 3), large energy transfer rates occurred at above 200 m with the peak values at around 100 m during eddy period, rather than surface and mixing layers (Jing et al.,

删除: By simulations, Jing et al. (2017) found that eddy-NIW's energy transfer efficiency is about 2% in Kuroshio Extension region

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225 2017; Liu et al., 2023). Both positive and negative transfer rates can reach a magnitude of $6 \times 10^{-10} \text{ m}^2/\text{s}^3$
226 in the study area, in which they are several times larger than the result of Jing et al. (2018) in the Gulf
227 of Mexico, but they are smaller than the result of Chen et al. (2023) in the Northwestern Pacific Ocean.
228 The differences may be attributed to the strength of eddies, their rotation direction and the intensity of
229 NIWs. Previous studies have shown that eddy rotation plays a critical role in energy transfer and NIWs
230 propagation due to differences in vorticity input and stratification modulation (Alford et al., 2016; Jing
231 et al., 2017). In addition, eddy-NIWs energy transfer is largely dependent on eddy structure in which
232 high rate can be caused by strong eddy shear (Zhao et al., 2023). It can be found that energy transfer at
233 Q1 and Q4 were more active than that Q3 due to occurrence of large shear strain at CE's edge (Figs.
234 9a-9b). Although NIKEs at Q4 were relative weak, the strong shear strains of the low frequency flow
235 promoted local transfer rates at this area. Thomas and Daniel (2020) and Li et al. (2022) both stated
236 that NIWs draw energy from the background flow when the energy ratio between them is small, and
237 vice versa. Similarly, our results show that positive/negative energy transfers from the CE to NIWs
238 dominated 'Before Strongest'/'After Strongest' periods at most mooring stations (Fig. 9c), indicating
239 an inhomogeneous and bidirectional energy transfer between eddy and NIWs during different periods
240 in the northwestern SCS.

删除: , but they are smaller than Chen et al. (2023)'s result.

删除: It can be found that energy transfer at the CE's edge (Q1 and Q4) was more active than at the CE's center (Q3). The higher energy transfer rate at Q1 generated stronger NIWs in this region, whereas Q4 exhibited a paradoxical pattern with strong transfer rates yet relatively weak NIKE. This discrepancy arises because the strong low-frequency flow strains (Figs. 9a-b) promoted the energy transfer rate but the net energy transfer rate remained low (Figs. 9c), resulting in weaker NIKE at Q4.

删除: It can be found that energy transfer at the CE's edge (Q1 and Q4) was more active than that at the CE's center (Q3). Although NIWs at Q4 were relative weak, the strong strains of the low frequency flow promoted local transfer rates at this area (Figs. 9a-b).

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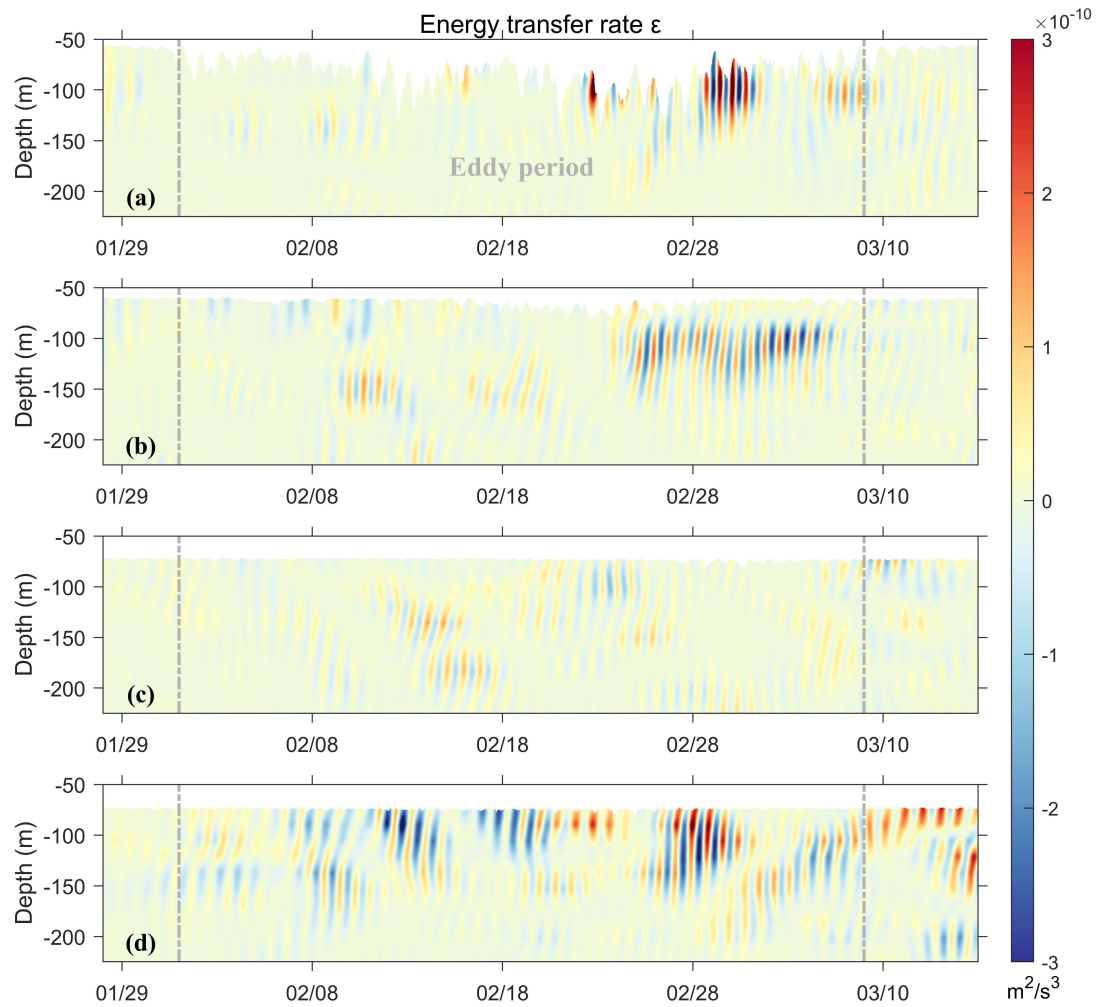
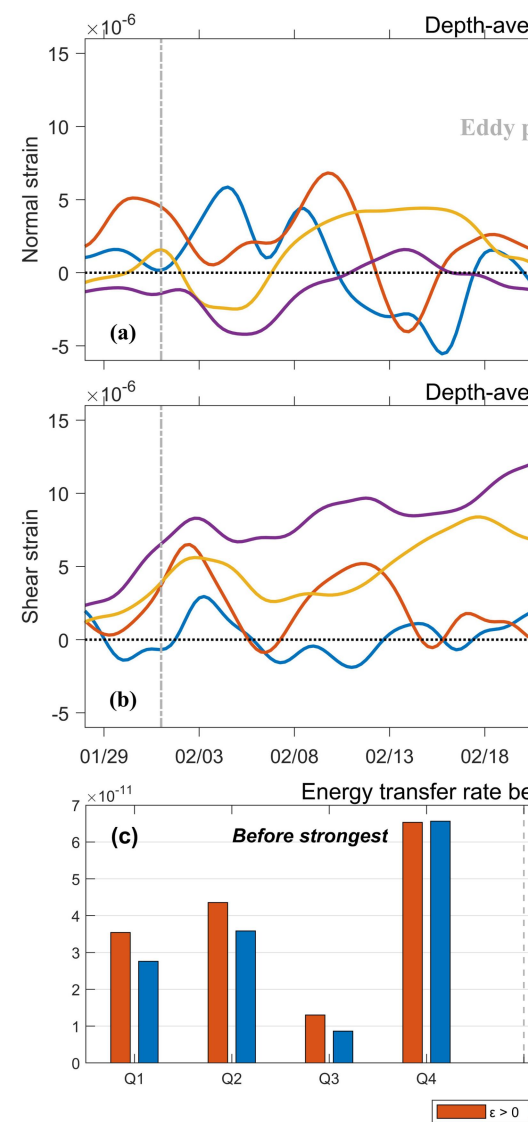


Figure 8: (a-d) Vertical distribution of energy transfer rate between the CE and NIWs at Q1-Q4 during eddy period.



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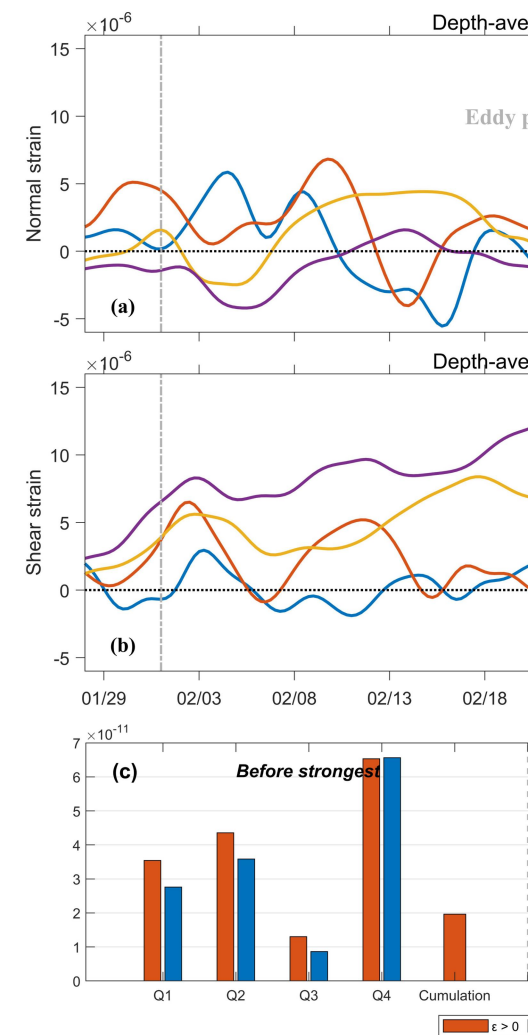
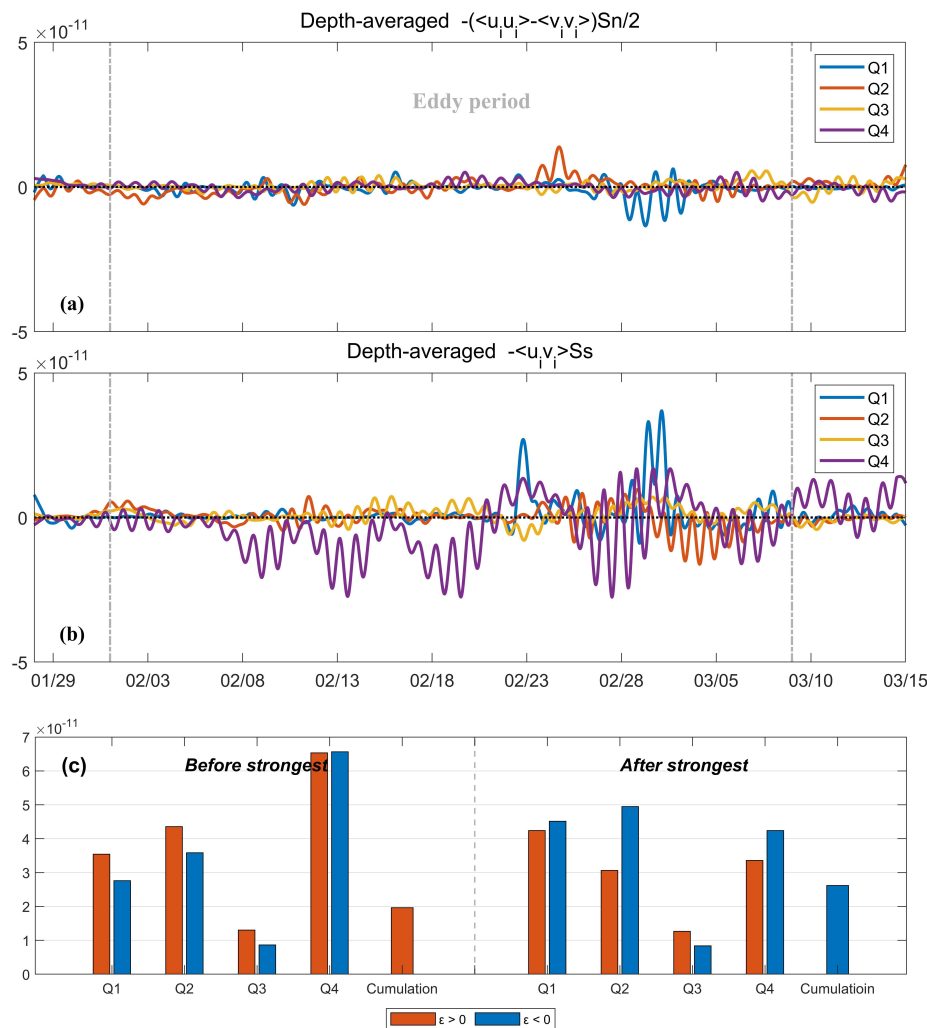


Figure 9: (a) Time series of depth-averaged (above 200 m) normal strain $-\langle u_i u_j \rangle - \langle v_i v_j \rangle \frac{S_n}{2}$ of the CE for each mooring. (b) Time-series of depth-averaged (above 200 m) shear strain $-\langle u_i v_j \rangle S_s$ of the CE for each mooring. (c) Time- (7 days) and depth-averaged (above 200 m) positive (red) and negative (blue) energy transfer rates before and after the NIKE reaching its peak at Q1-Q4. Cumulation bar represents sum of positive rates minus negative rates at Q1-Q4.

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删除: (a) Time series of depth-averaged (above 200 m) normal strain of the CE for each mooring. (b) Time-series of depth-averaged (above 200 m) shear strain of the CE for each mooring.

5 Conclusion

During spring 2022, the CE passed through the northwestern SCS. Our four long-term moorings with ADCP instruments captured the interaction and energy exchange processes between eddy and local NIWs for the first time in this area. We found that NIWs can be largely enhanced by the passing CE. Horizontally, the CE transferred more energy to NIWs at the north side than that at the south side of the CE. This disparity may be attributed to the eddy asymmetry with stronger relative vorticity and shear in the northern region, which can significantly amplify NIWs generation (Zhao et al., 2021, 2023). In vertical, the enhancement of NIKE occurred at above 200 m, with a maximum exceeding 12 J/m^3 at

删除: Horizontally, the CE transferred more energy to NIWs at the north side than that at the south side of the CE due to asymmetry of eddy structure and strong shear.

260 a depth of 100 m. Power comparison of different NIWs modes during eddy period indicate that the CE
261 promoted percentage of first five modes, especially the second and third modes. Overall, NIWs drew
262 energy from the CE during the enhancing period of NIKE, while they gave energy back to the CE
263 during weakening period of NIKE. This study is helpful for [understanding](#) multi-scale interaction and
264 energy cascade in the northwestern SCS.

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265 *Data availability.* The CMEMS products are available at
266 https://data.marine.copernicus.eu/product/GLOBAL_MULTIYEAR_PHY_001_030/services. The
267 ERA-5 wind data are available at <https://doi.org/10.24381/cds.adbb2d47>. The WOA2018
268 climatological monthly mean mixed layer depth data are available at
269 <https://www.ncei.noaa.gov/access/world-ocean-atlas-2018/>. The AVISO eddy data are available at
270 [https://www.aviso.altimetry.fr/en/data/products/value-added-products/global-mesoscale-eddy-](https://www.aviso.altimetry.fr/en/data/products/value-added-products/global-mesoscale-eddy-trajectory-product.html)
271 [trajectory-product.html](https://www.aviso.altimetry.fr/en/data/products/value-added-products/global-mesoscale-eddy-trajectory-product.html). The bathymetric data is from GEBCO Gridded Bathymetry Data
272 (<https://download.gebco.net>). The [data](#) used for plotting Figures for this paper [is](#) available at:
273 <https://doi.org/10.5281/zenodo.14638959>.

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281 of the analyses and generated the Figures. Q.A.C., B.H. and H.Z.X. wrote the main manuscript. D.X.W,
282 C.L.L, Z.Y.Z., H.C.J. contributed to the revision of the manuscript. H.Z.X., Z.Y.Z., H.C.J., W.S., T.L.,
283 L.W, S.M.L. and R.JC. conducted observations of the Mooring Array and participated in data analysis.

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