Mesoscale eddies cases study at Xisha waters in the South China Sea in 2009/2010

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Abstract Analyzing the observed currents at Xisha (110.3899°E, 17.1038°N) during May 2009 to May 2010, it is found that the kinetic energy has significant mesoscale variability, and each peak responds to large positive/negative ocean surface current curl caused by mesoscale eddies. Compared the kinetic energy with the wind stress work and the pressure work, it is also found that the barotropic pressure work which is mainly contributed by the sea surface height (SSH) corresponding to the mesoscale eddies behaves like the kinetic energy. The contribution of the mesoscale eddies to the kinetic energy can be up to 90% sometimes and reach deep level every time. Using the satellite altimeter data, the paths of mesoscale eddies contributing to the kinetic energy variability are traced back. In the winter half of the year, the mesoscale eddies propagating along the northern South China Sea shelf or across the basin from the west of the Philippines toward Xisha arrive at Xisha, influencing the kinetic energy. In the summer half of the year, the mesoscale eddies are mainly from the south, which were shed from the Vietnam coast current. And the cause for eddy shedding may be related to the relaxation of the Ekman transport anomalies.

1. Introduction

The South China Sea (SCS) is a semienclosed marginal sea in the western Pacific Ocean, with a broad shelf and slope in its northern part. The continental shelf in the northern SCS (NSCS) is ENE-WSW oriented and 150–250 km wide, with the Dongsha Islands located about 200 km offshore over the upper continental slope. The large-scale circulation in the SCS is driven mainly by Asian monsoons and the lateral influxes that intrude through the Luzon Strait and the Taiwan Strait in the NSCS and through the Karimata Strait in the southwestern SCS [Qu, 2001; Dong et al., 2010; Shu et al., 2011; Wang et al., 2011, 2013]. Driven by the prevailing northeasterly (southwesterly) monsoon in winter (summer), the basin-scale cyclonic (anticyclonic) circulation typically moves around the continental margin in the SCS [Wyrtki, 1961; Fang et al., 2002; Yang et al., 2002; Gan et al., 2006]. Active summer monsoon is well correlated with positive and negative phases of the intraseasonal variability of latent-heat fluxes in the SCS [Zeng and Wang, 2009; Zeng et al., 2009].

Mesoscale eddies are an important component of dynamical oceanography across the range of scales [Wunsch, 1999; Qiu and Chen, 2005]. The signals of 20–150 days and 50–500 km dominate the oceanic variability [Wyrtki et al., 1976; Richman et al., 1977], and the mesoscale eddies contribute largely to these signals [Chelton et al., 2007]. In the SCS, many eddies are observed from hydrographic data sets [Xu et al., 1982; Chu et al., 1998; Li et al., 1998] and satellite sea level anomalies data [Li et al., 2002; Su et al., 2002; Yuan et al., 2007; Chow et al., 2008; Wang et al., 2008]. Wang et al. [2003] counted the SCS mesoscale eddies using a merged satellite altimeter data set and found that eddies can be mainly grouped into four geographic zones in the SCS. Xu et al. [2010] used model output and found that about 32.9 ± 2.4 eddies predicted each year and the radii of these eddies range from about 46.5–223.5 km, with a mean value of 87.4 km, in the SCS. Chen et al. [2011] investigated mean properties of eddies in the SCS by analyzing 17 years of satellite altimetry data, and found that the mean radius and lifetime of eddies are 132 km and 8.8 weeks, respectively, both depending on where the eddies were formed. Zhuang et al. [2010] analyzed the strong intraseasonal variability (associated with the mesoscale eddy energy) regions: on the northern continental shelf, in the Gulf of Thailand, and along two bands in the deep basin with the northern band located west of the Luzon Strait and the southern one southeast of Vietnam.
The causes of mesoscale eddies may be revealed to the bathymetry anomaly [Sangrà et al., 2005] or shedding from strong currents such as the Gulf Stream and the Kuroshio [Hurlburt and Thompson, 1980; Li et al., 1998; Hetland et al., 1999]. The Kuroshio is the western boundary current of the North Pacific Ocean, and penetrates into the SCS when flowing over the Luzon Strait [Shaw, 1989; Qu, 2000]. Sometimes, a meander will form in the northern strait [Li and Wu, 1989], and mesoscale anticyclonic eddies may be shed from the unstable meander and then propagate westward into the SCS [Li et al., 1998; Wang et al., 2000; Yang et al., 2000; Li et al., 2002; Su et al., 2002; Jia and Liu, 2004; Yuan et al., 2006]. Yuan et al. [2006] concluded that the anticyclonic eddies shed from the Kuroshio can occur all year round; however, they are more frequent in winter. Jia et al. [2005] investigated the mechanisms of eddy shedding from the Kuroshio, and identified a relationship between eddy shedding and Kuroshio intrusion under different zonal wind speeds. Yang and Liu [2003] found that there are forced Rossby waves in the NSCS, originating from the northwest off Luzon Island, actually propagating west-northwestward toward the Guangdong coast.

Xisha connects the southwest-northeast NSCS continental shelf and the southward Vietnam continent shelf (Figure 1), and is the place where many eddies passed by or ended [Wang et al., 2003, 2008; Xu et al., 2010; Zhuang et al., 2010; Chen et al., 2011]. In this paper, we mainly focus on the mesoscale variability of the kinetic energy based on the ADCP observation, and trace back each mesoscale eddy in 2009/2010, trying to find the relationship between the Xisha kinetic energy variability and the mesoscale eddies.

The paper is organized as follows. section 2 describes the data used in this study. Section 3 gives the mesoscale variability of the observed kinetic energy. Section 4 discusses the path of each mesoscale eddy. In section 5, discussion and conclusion will be given.

2. Data

The merged sea surface height (SSH) and anomalies (SSHA) are from TOPEX/Poseidon, Jason 1, and ERS (European Research Satellite), provided by the French Archiving, Validation Interpretation of Satellite...
Figure 2. (a) The average vertical integrated kinetic energy (red line; multiplied by $1.0 \times 10^3$) and the velocity (arrow); (b) the vertical distribution of the kinetic energy (shaded) and the velocity direction (arrow); and (c) the vertical distribution of the time averaged kinetic energy (multiplied by $1.0 \times 10^3$) and the velocity.

Figure 3. (a) The period that the eddy touches the ADCP station (the outermost closed SSHA isoline includes the ADCP station), blue line denotes the cold eddy and red line denotes the warm eddy. (b) The distance between the eddies’ center and the Xisha station (Distance, cyan line), the average vertical integrated kinetic energy (KE, red line), the variation of the KE (KEV, blue line), the peak of the KEV (Max KEV, purple line), and the valley of the KEV (Min KEV, black line) (the KE has been dealt with another twice 11 days running mean and all the variables have been normalized by each maximum value). (c) The vertical distribution of the variation of the KE (unit: m$^2$/s$^2$), the purple line is the Max KEV, the black line is the Min KEV, and the green dot is the location that is the closest to the zero KEV between each eddy.
Oceanographic Data (AVISO) project. The data are a grid with 1/3° resolution and averaged over 7 days (weekly). They are used to identify the positions of eddies in this study.

The ocean surface current is from the Ocean Surface Currents Analyses Real-time (OSCAR) [Bonjean and Lagerloef, 2002], which is a project to calculate ocean surface velocities from satellite fields. It contains near-surface ocean current estimates, derived using quasilinear and steady flow momentum equations.

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*C denotes cyclonic eddy and A denotes anticyclonic eddy.

Oceanographic Data (AVISO) project. The data are a grid with 1/3° resolution and averaged over 7 days (weekly). They are used to identify the positions of eddies in this study.

The ocean surface current is from the Ocean Surface Currents Analyses Real-time (OSCAR) [Bonjean and Lagerloef, 2002], which is a project to calculate ocean surface velocities from satellite fields. It contains near-surface ocean current estimates, derived using quasilinear and steady flow momentum equations.

Figure 4. (a) The average vertical integrated kinetic energy (multiplied by $1.0 \times 10^3$), barotropic pressure work (multiplied by $2.0 \times 10^7$), wind stress work (multiplied by $4.0 \times 10^8$), and vertical mean of velocity speed vertical shear anomalies (unit: $s^{-1}$, multiplied by $2.0 \times 10^3$). (b) The average vertical integrated kinetic energy, the mean time kinetic energy, and the standard deviation (all multiplied by $1.0 \times 10^3$) and the SSHA. (c) The vertical distribution of the kinetic energy (multiplied by $1.0 \times 10^3$), the value larger than the mean plus standard deviation of the kinetic is shown and the blue line denotes the mean kinetic energy and the velocity vector (Up North).
horizontal velocity is estimated from SSH, surface wind, and sea surface temperature; these data were collected from various satellites and in situ instruments. The model formulation combines geostrophic, Ekman and Stommel shear dynamics, and a complementary term from the surface buoyancy gradient. Surface currents are provided on global 1/3° grid with a 5 day resolution dating from 1992 to present. Compared with the satellite sea surface geostrophic current, the OSCAR contains more dynamic process and closer to the real ocean current.

The mooring station is located at (110.3899° E, 17.1038° N) in Xisha (Figure 1), and the water depth is 1412 m. A Long Ranger ADCP is set at the 500 m depth, and the sampling time is 30 min. The velocity data above 450 m have been collected from 4 May 2009 to 4 May 2010, which has already been used to analyze the near-inertial kinetic variability [Chen et al., 2013]. The velocity has been averaged over 24 h (daily), and 11 day running mean has been used to remove high frequency signals.

3. Variability of Kinetic Energy

3.1. Variability of the Observed Kinetic Energy

The observation velocity from the ADCP has been shown in Figure 2. Figure 2a is the average vertically integrated velocity and kinetic energy, and it can be found that the direction of the velocity is mainly south-west except the August in which month the direction of the velocity turns north-east. There are six peaks of the kinetic energy and each peak maintains 1 month or so. Figure 2c shows average time-integrated velocity and kinetic energy. It can be found that the direction of the velocity is almost the same (south-west) from the upper to the deep and the kinetic energy reduces from top down. Figure 2b is the time-depth
distribution of the kinetic energy and the velocity direction. There are several large kinetic energy centers with different vertical structures. The first two large kinetic energy centers extend to the bottom from the top with the maximum center locating at the middle depth (about 300 m). However, from the September to December, the large kinetic energy center mainly locates at the upper levels. During the January to March in the following year, the kinetic energy behaves larger and extends more deep.

The observed velocity behaves obvious mesoscale variability, and the variation of the kinetic energy has been shown in Figure 3. In Figure 3a, the eddies arriving information have been shown, marked the period that the eddy touches the ADCP station (the outermost closed SSHA isoline includes the ADCP station). In Figure 3b, the average vertically integrated kinetic energy and its variation have been shown and the variation is calculated using the central difference. The maximum and minimum points of the variation have been marked which are used to identify the most significant mesoscale variability period. In order to get the maximum and minimum points, the variation is calculated from the kinetic energy with another twice 11 day running means. During the observation period, seven mesoscale eddies have been found which directly influenced the Xisha waters, and the distances between the eddy center and the Xisha station have been calculated (the detail information can be found in Table 1). It can be found that each kinetic energy peak is associated with the mesoscale eddies. Based on the mesoscale eddies’ characters which will be discussed in section 3.2, four periods have been defined and the boundaries are used of the variation maximum and minimum points. Figure 3c is the vertical distribution of the kinetic energy variation and the green dots are the points that are most close to the zero variation between each eddy process.

From the above discussion, it can be found that Xisha water locates at the northwest corner of the SCS and the kinetic energy has strong response to the mesoscale eddies passed by. From the results of Chen et al. [2011] and Wang et al. [2003], it also can be found that the Xisha water is an important intersection position.
for the west propagation eddies. And Zhuang et al. [2010] pointed that strong intraseasonal variability exist on the NSCS continent shelf, include Xisha water. Maybe the strong intraseasonal variability due to these mesoscale eddies.

### 3.2. Impact Factors on the Variability of Kinetic Energy

The kinetic energy and velocity are calculated again in Figure 4; however, it mainly shows the value that larger than the mean time kinetic energy. The first two periods have relatively deep structures, and the duration is \(<1\) month. The third period lasts \(>3\) months; however, its impact is very shallow. The fourth period lasts \(>2\) months, and the vertical structure various with time, which quickly deepens and then becomes shallow, and beyond the observed depth limit finally. The sea surface height anomalies (SSHA) have been overlay with the kinetic energy, and it can be found that each period is corresponding to cyclonic or anticyclonic eddies process. The SSHA used here was the local SSHA minus the corresponding space mean (extend 0.5° toward four directions from the Xisha station), which was able to show the eddies information more clear.

In order to investigate the influences of wind stress and barotropic pressure on the kinetic energy variability, we utilize the following formula, which omits the advection, diffusion, and baroclinic structure:

\[
\frac{1}{2} \frac{\partial \mathbf{u}^2}{\partial t} = -g \cdot \nabla \eta + \frac{\mathbf{u} \cdot \tau}{\rho_o H}
\]

where \(\mathbf{u} = \int_{-H}^{0} u dz\) is the vertically integrated velocity, \(g = 9.8 \text{ m/s}^2\) is the earth gravity, \(\eta\) is the SSH, and \(\tau\) is the sea surface wind stress. \(\rho_o\) is the mean ocean density, and is set as 1024 kg/m³ in this paper. \(H\) is the water depth, and is set as the observation maximum depth of 450 m.
The first term of the r.h.s. of (1) is the barotropic pressure work, which is contributed by the SSH gradient, and the second term of the r.h.s. of (1) is the wind stress work. The wind stress work is the direct local effect, while the SSH also includes the indirect wind stress contribution, such as the Ekman Pumping which contributes to the SSH accumulation. The Ekman Pumping is directly related with the wind stress curl, and then the wind stress curl will be also analyzed in the following sections.

Comparing the kinetic energy with the pressure work and the wind stress work, it can be found that the pressure work resembles the kinetic energy better. Each kinetic energy peak corresponds to the peak of the pressure work, and the value of the pressure work is also much larger than that of the wind stress work, which indicates that the SSH variability is the main contribution to the kinetic energy variability. However, there are relatively large mismatches between the pressure work and the kinetic energy from later third period. The above analysis omits the baroclinic effects, which may have large contributions. In order to qualitatively estimate the baroclinic effect, the vertical averaged velocity speed vertical shear anomalies (hereafter vertical shear) has been calculated. It can be found the mismatch is large when the vertical shear is large. The large vertical shear denotes strong baroclinic effects in some extents, and the mismatch maybe due to the lack of the baroclinic pressure work.

Mesoscale eddy energy has an important contribution to the SSH variability [Zhuang et al., 2010], and the resemblance between the pressure work and the kinetic energy indicates the mesoscale eddies play an important role in the SSH variability.
important role in the kinetic energy variability. The ocean surface current curl is more clear to reflect the eddy information, and the comparison between the kinetic energy with the wind stress curl (calculated from the Daily Advanced Scatterometer (ASCAT) Surface Wind Fields) (Bentamy and Denis, 2012) and sea surface current curl (calculated from the OSCAR) confirms that the mesoscale eddies are the main contribution to the variability of the kinetic energy (Figure 5b). The Ekman depth (calculated from ASCAT) indicates the depth that the wind stress effect can reach, and there is no obvious relationship between the Ekman depth and the kinetic energy. However, the Ekman depth and the vertical shear resemble each other (Figure 5c), which indicate the baroclinic structure maybe affect by the local wind stress. During 28 October to 30 December, the peaks of Ekman depth and vertical shear are related with the large mismatch between the pressure work and the kinetic energy from third period mentioned above. During this period, although the wind stress curl and the wind stress work do not work effective to affect the local kinetic energy, the wind stress can stir the ocean and enhance the baroclinic effect to strengthen the local kinetic energy. The comparison between OSCAR and the ADCP is shown in Figure 5a, and this two databases resemble each other.

The first and third periods responded to the cyclone eddies and the second period responded to an anticyclone eddy. During the fourth period, the anticyclone and cyclone eddies alternative influenced the current at Xisha.

The vertical structure of the kinetic energy indicates that the influence of cyclone eddies maybe shallower than the anticyclone. The third and the middle fourth periods are influenced by the cyclonic eddies, and the kinetic energy increasement mainly occurs at the upper ocean. The first period is also associated with a cyclonic eddy; however, the depth of the kinetic energy increasement behaves like the anticyclone process. The sample is not sufficient enough to give a statistical conclusion, while there may be some hypothesis. The influence of the anticyclone eddies on the kinetic energy may reach deeper water level than the cyclone.

Figure 9. Mesoscale eddy propagation. (left) The shaded is the sea surface height anomalies (SSHA, unit: cm) from 1 July to 15 July, and the blue triangle represents the cyclone eddy center shedding from the Vietnam coast current. (center) Mesoscale propagation path, and the blue triangle represents the cyclone eddy center; the shaded represents the SSHA at 9 September. (right) The distribution of SSHA representing the cyclone eddy. The red star represents the ADCP location. The SSHA contour interval is 2 cm.
eddies; however, the influence depths of the cyclonic eddies may change with seasons, i.e., deep in the summer and shallow in the winter half year, or may be related to the monsoon conversion.

3.3. Estimation of the Mesoscale Eddies’ Contribution to the Kinetic Energy

In Figure 6, the contributions of the mesoscale eddies to the kinetic energy have been estimated. The estimated method is as follows: the most close to the zero kinetic energy variation points between two eddies have been selected (have been shown in Figure 3b) and each eddy is bounded by such two points. The linear interpolated kinetic energy by the local kinetic energy from such two points is considered as the large-scale kinetic energy without mesoscale eddy influence. That the difference between the real and the linear interpolated kinetic energy is divided by the real kinetic energy is the estimated value of the mesoscale eddies’ contribution to the local kinetic energy. From the distribution, it can be found that the mesoscale eddies are the mainly contribution to the kinetic energy during its pass by. During the third period, although the kinetic energy is very small in the deep level, the mesoscale eddies still are the mainly contribution to the kinetic energy variability.

4. Tracing Back Each Eddy

In order to investigate the path of mesoscale eddies, we trace back each eddy based on the satellite altimeter data, i.e., SSH anomalies (SSHA). During the observation period, seven eddies were found to pass by the observation station and influence the kinetic energy. The first cyclone eddy originated from the southeast to the Dongsha Islands and propagated along the NSCS continent shelf toward southwest (Figure 7). This cyclonic eddy lasted for about 6 months to arrive at
the Xisha area and the eddy center reached Xisha station on 24 June, and then turned southward, leaving the observation station.

The second eddy is the combination of three anticyclonic eddies (Figure 8). The north eddy originated from west of the Luzon Strait on 28 January and propagated along the NSCS continental shelf toward southwest. Another eddy originated from the west of the Philippines and propagated westward. On 8 July, these two anticyclonic eddies merged as one eddy at the outer edge of the continental shelf, and then continued southwestward. On 18 March, an anticyclonic eddy occurred at the central basin and propagated westward. This eddy arrived at the south of the Xisha station and remained there for 2 months until 15 July, after which it propagated northeastward toward the Xisha station. On 5 August, three eddies merged into one east of the Xisha station, and influenced the local kinetic energy variability.

The third cyclonic eddy originated from the south, which was shed from the Vietnam coast current (Figure 9). From the 1 July, the current along the Vietnam coast extended outward gradually, and shed a cyclonic eddy on 15 July. The shed eddy propagated northwestward and arrived at Xisha station on 9 September, influencing the local current.

The fourth cyclonic eddy (Figure 10) is similar to the third one, which was also shed from the Vietnam coast current but was about 1 month later than the third one. After the eddy shed from the coast current, part of its energy propagated northeastward and developed into a cyclonic eddy with the center at about 114°E. The cyclonic eddy turned to northwest, and was close to the third eddy (shown in Figure 9) at about 21 October. The fourth eddy merged with the third one and became a large cyclonic eddy. Its north edge continued to influence the Xisha station in place of the third eddy.
The last three eddies were associated with the fourth period. The first anticyclonic eddy propagated from Dongsha Island along the continental shelf toward the Xisha station from 19 September 2009 to 27 January 2010, and arrived at the Xisha station at 13 January 2010 (Figure 11). The second cyclonic eddy originated from the west to the Philippines (Figure 12). In late December, the cyclonic eddy was located at the west of the Philippines, and the center of this eddy almost did not move. However, the west edge of the eddy extended toward the west gradually, and reached the continental shelf in early January 2010. Finally, a cyclonic eddy was generated at the continental shelf, which may result from the interaction between the eddy and the topography. And then this cyclonic eddy arrived at the Xisha station at about 10 February 2010 and influenced the local current. The third anticyclonic eddy propagated along the NSCS continental shelf to Xisha station and arrived at about 3 March (Figure 13). During this process, just the west edge of the anticyclonic eddy arrived at the Xisha station.

From the above discussion, there are three paths by which the eddies can arrive at the Xisha station during the observation period which is consistent with the results from Wang et al. [2003]. However, the cases study indicates that there are more long life eddies on the NSCS shelf and can arrive at the Xisha waters through the NSCS continent shelf. During the propagation, the merge and separation may occur. The most frequent path is the NSCS continental shelf; many eddies propagated along the shelf are associated with the topography Rossby wave or the southwestern boundary current. Another path is from the central basin toward the northwest. This path may be associated with the summer monsoon, which generates larger scale anticyclonic

Figure 12. Mesoscale eddy propagation. (left) The shaded is the sea surface height anomalies (SSHA, unit: cm) from 23 December 2009 to 20 January 2010; the red triangle represents the eddy center. (right) The distribution of SSHA representing the anticyclone eddy. The red star represents the ADCP location. The SSHA contour interval is 1 cm.
The eddies shed from the Vietnam coast current play an important role along this path, and the shedding process may be related to the Vietnam summer offshore jet. The third path is from the west of the Philippines toward west. This path will be blocked by the NSCS continental shelf and the interaction between topography and eddy may contribute significantly to the eddy generation and separation.

The generation and propagation mechanisms and the interaction between topography and eddy are important and complex issues; however, we do not discuss them in this paper since they are our ongoing research.

5. Discussion and Conclusions

This paper describes some characters of kinetic energy mesoscale variability at the Xisha station. In this section, we want to briefly discuss some possible relationship between the eddy shedding and the Ekman transport at the Vietnam coast, and then draw some conclusions.

During the observation period, there were two cyclonic eddies shedding from the Vietnam coast current in July and August, respectively, influencing the Xisha kinetic energy. During the eddy shedding period, the summer monsoon prevailed, and the western boundary current flowed northward along the Vietnam coast, with an offshore current located at about 12°N [Gan and Qu, 2008]. Comparing the Ekman transport anomalies and the isoline of the SSHA, the Ekman transport anomalies may swing or extend eastward the offshore current’s axis, and then the relaxation of the Ekman transport anomalies cause eddy shedding. In this paper, the meridional and zonal Ekman transport are estimated, respectively, using the Daily Advanced Scatterometer (ASCAT) Surface Wind Fields [Bentamy and Denis, 2012]. The zonal mean Ekman transports between 500 and 1500 m isobaths have been analyzed. In order to show the complete evolution of the Ekman transports.

**Figure 13.** Mesoscale eddy propagation. (top) Contour lines represent the 500 and 2000 m isolines, and the red triangle represents the anticyclone eddy center from 14 October 2009 to 17 February 2010; the shaded is the sea surface height anomalies (SSHA, unit: cm) at 17 February 2010. (bottom) The distribution of SSHA representing the cyclone eddy. The red star represents the ADCP location. The SSHA contour interval is 1 cm.
during the development of the cyclonic eddies, the lengths of Ekman transport evolution time taken to analyzed are slightly longer than that of cyclonic eddies. The Ekman transport anomalies, which are the Ekman transport minus the corresponding time mean, are utilized to explain the possible reason of these eddies shedding.

Figure 14a shows the 10 cm isoline of SSHA, indicating the eddy shedding process. The isoline gradually shift northward from 3 June to 15 July, and an enclosed isoline separated from the low SSHA tongue finally. The time mean meridian Ekman transport, which is averaged between the 500 and 1500 m isobaths, is given in Figure 14b, showing southward transport. The upper ocean large-scale current was anticyclonic and the northward boundary current may advect the Vietnam coast low SSHA tongue northward; however, the southward Ekman transport was against the large-scale boundary current and suppressed the low tongue northward. During late June to early July, large positive anomalies occurred, and the low SSHA tongue was lifted northward. After the positive anomalies suddenly disappeared, the low SSHA tongue turned back to the south, leaving an enclosed SSHA center. This process behaved like the competition between the large-scale anticyclonic current and the local southward Ekman transport. Strong Ekman transport blocked the low SSHA tongue northward, while the positive anomalies weakened the southward transport and the low SSHA tongue was advected northward by the large-scale current. The sudden relaxation of the positive Ekman transport anomalies will cause the low SSHA tongue to retreat to the south; however, the tip of the low SSHA was shed from the main body and developed as a cyclonic eddy.

Figure 15 shows a similar process as Figure 14, while the eddy shedding is related to the zonal Ekman transport anomalies relaxation. From 22 July to 19 August, the isoline of SSHA extended toward east gradually, which was related to the positive Ekman transport anomalies and suddenly retreated back to the Vietnam coast, leaving an enclosed low SSHA center after the positive anomalies relaxation.

In this paper, we focus on the variability of kinetic energy at Xisha station, which is mainly influenced by mesoscale eddies. The contribution of mesoscale eddy to local kinetic energy is huge when passing by, and
it can reach >90%. In the late third period, although the mesoscale eddy has passed by, the kinetic energy still maintained large which may due to the strong baroclinic effect result from the wind stress. The influence depth of anticyclonic and cyclonic eddies may be different and the anticyclonic eddies may have deeper influence. There are three paths that the eddies propagated to the Xisha. One is the NSCS continental shelf, and another is cross the midbasin from the Philippines westward to the Xisha. These two paths mainly occurred in the winter half of the year. The third path is from the south basin toward northwest, and the eddy was shed from the Vietnam coast current. Comparison of the Ekman transport anomalies with the isoline development suggests that the eddy shedding may be related to the Ekman transport anomalies relaxation.

References


