Mindanao Current/Undercurrent measured by a subsurface mooring

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Abstract The mean structure and variability of the currents east of Mindanao are investigated through 2 year mooring observations at about 8°N, 127°3′E from December 2010 to December 2012. The strong southward Mindanao Current (MC) exists in the upper 600 m with a maximum mean velocity of 73 cm/s and a standard deviation of 17 cm/s at 100 m. A northward mean flow is observed below 600 m to the depth deeper than 1000 m, which has been called the Mindanao Undercurrent (MUC) with a maximum mean velocity of about 10 cm/s at 950 m and a standard deviation of 19 cm/s. Further analysis with hydrographic data and an eddy-resolving model outputs also suggests this northward mean current to be the MUC. Intraseasonal variability with a period of 60–80 days is revealed through the whole water column from 200 m down to about 900 m. This intraseasonal variability appears to be closely related to subthermocline eddies, which translate westward and intensify near the Mindanao coast.

1. Introduction

The low-latitude western boundary currents in the north Pacific are of particular importance for ocean dynamics and climate in view of their roles in the mass/heat partition between the tropical and subtropical gyres, and in the heat budget of the warm pool [e.g., Lukas et al., 1996; Hu et al., 2011]. As two components of the low-latitude western boundary currents in the tropical north Pacific, the southward Mindanao Current (MC) in the upper layer [e.g., Nitani, 1972; Lukas, 1988; Lukas et al., 1991; Wijffels et al., 1995; Kashino et al., 2005] and the northward Mindanao Undercurrent (MUC) in the lower layer [Hu and Cui, 1989, 1991; Hu et al., 1991; Wang and Hu, 1998, 1999b; Lukas et al., 1991; Qu et al., 1998, 2012] flow along the east coast of the Mindanao Island.

Many studies have been focused on the characteristics and variability of the MC with hydrographic observations, sea level time series and numerical models. The MC is a stable coastal jet with a maximum speed of about 1 m/s [e.g., Lukas, 1988; Lukas et al., 1991; Wijffels et al., 1995]. The MC transport is believed to be related to the El Nino and Southern Oscillation (ENSO) [e.g., Kim et al., 2004; Kashino et al., 2009, 2011], and influenced by a strong, intermittent quasi-biennial signal [e.g., Lukas, 1988; Qiu and Lukas, 1996]. Recent studies also revealed existence of annual and semiannual signals in the MC transport [e.g., Tozuka et al., 2002; Qu et al., 2008]. On the basis of mooring observation from October 1999 to July 2002, Kashino et al. [2005] reported that the MC has a subsurface velocity maximum exceeding 1.3 m/s at approximately 100m depth. They also noted that the observed interannual, seasonal, and intraseasonal variations were of comparable amplitudes, and the MC was strong during boreal summer and during the onset of El Nino.

Compared with the well-known MC, the MUC is still poorly understood. Based on three CTD transects off Mindanao near 7.5°N, multiple northward velocity cores were found below 500 m and named MUC by Hu and Cui [1989, 1991]. The maximum velocity of the MUC is around 20 cm/s with a transport of 8–22 Sv [Hu et al., 1991]. This undercurrent structure was visible in the acoustic Doppler current profile (ADCP) measurements and CTD sections collected during the Western Equatorial Pacific Ocean Circulation Study (WEPOCS) [Hacker et al., 1989; Lukas et al., 1991], showing that the MUC is 20–25 km wide and 50–75 km offshore. They also appeared in recent shipboard ADCP sections along 7°N and 8°N [Kashino et al., 2009]. Several analyses of hydrographic data further suggested that, although its intensity and locality vary from time to time, the MUC is a quasi-permanent feature [e.g., Wang and Hu, 1998a, 1998b; Qu et al., 1998]. Recent studies with an eddy-resolving model also show the northward MUC within a depth range between 400 and 1000 m below the MC, though its variance is larger than the mean current [e.g., Qu et al., 2012].
However, based on seven shipboard ADCP transects in the upper 350 m between 1987 and 1990, Wijffels et al. [1995] noted that there was only a weak mean flow offshore and below the MC, and speculated that the MUC might be a transient phenomenon. Obviously, their ADCP with upper 350 m range limit could not well reach the MUC which is generally below 400 m. Using lowered and shipboard ADCP measurements from two cruises, Firing et al. [2005] observed a southward flow along the Mindanao coast and a northward flow 100–200 km offshore below 500 m, and suggested that they seemed to be subthermocline eddies. Based on current meter measurements at 700 m at 6°50′N/126°43′E during October 1999 and July 2002, Kashino et al. [2005] found that intraseasonal variability of 50–100 days was dominant and there was nearly no significant MUC at that level. They suspected that the MUC did not flow at that depth of the mooring site and it might be present in a deeper layer or further offshore.

Despite the studies listed above, several questions remain. Is the MUC a permanent current? As many studies showed large variability in the current below the MC, what are the detailed features of this variability? What is the source of this variability? Due to a lack of continuous direct measurements, there are still no definite answers to these questions.

As a part of the field experiment of the Northwestern Pacific Ocean Circulation and Climate Experiment (NPOCE) program [Hu et al., 2011], a subsurface ADCP mooring was deployed at 8°N, 127°3′E east of Mindanao Island during December 2010 to December 2012. The mooring provides 2 year velocity data between 0 and 800 m and CTD measurements at some fixed depths. With these measurements, we examined the mean structure and variability of the currents east of Mindanao in this study. The existence of the mean northward MUC is argued to be true even with large variance, and the intraseasonal variability of the MC/MUC is also illustrated. The source of this intraseasonal variability is further explored with an eddy resolving model.

2. Data

2.1. ADCP Mooring

A subsurface mooring was deployed at about 8°N, 127°3′E east of Mindanao Island to measure the MC/MUC, and the water depth is about 6100 m (Figure 1). The site of 8°N, 127°3′E was selected based on the previously calculated geostrophic velocity field from repeated hydrographic transects, generally near the inshore core of the MUC [Hu and Cui, 1989, 1991; Qu et al., 1998].

The observation period was from 1 December 2010 to 7 December 2012, with one time interval on 15–16 July 2011 for retrieval and redeployment of the mooring. An upward-looking and a downward-looking Acoustic Doppler Current Profilers (75 kHz ADCP, TRDI) were mounted on the mooring at about 400 m. There were also other instruments such as current meters and SBE 37 CTDs attached on the mooring at various depths, but we primarily focus on the 2 year ADCP measurements in this study, and CTD measurements at about 600 m are also used. The ADCP measured velocity every 1 hour in 60 bins with a bin size of 8 m,
and the sampling depth of the two ADCPs ranges from the sea surface to about 800 m. Due to the relatively
less buoyancy in the first observation period (December 2010 to July 2011), the main float which was
designed at 400 m sometimes got down to 800 m when the subsurface currents became stronger, therefore
the downward looking ADCP mounted on the main float could measure the currents at 1200 m sometimes
before July 2011, and at the same time the upward looking ADCP missed the currents in the upper 500 m.
The ADCP measured hourly velocity data were first interpolated vertically onto standard depths of 1 m verti-
cal resolution, and then were daily averaged to remove tidal signals. The SBE 37 CTD at about 600 m meas-
ures the conductivity, temperature, and pressure every 10 min. The data are first calibrated onto the fixed
depth of 600 m, and then averaged to get the daily data, which are finally used in the following analysis.

2.2. OFES Output
To investigate the source of the intraseasonal variability of the currents east of Mindanao revealed by the
mooring measurements, we also used outputs from the OGCM for the Earth Simulator (OFES). Its domain
covers a near-global region extending from 75° S to 75° N, with a horizontal resolution of 0.1° both in the
longitude and latitude. The vertical resolution varies from 5 m near the surface to 330 m near the bottom,
with a total of 54 levels. The 3 day snapshot model outputs for the period 2010–2012 are used in this study.
Detailed descriptions about this model can be found in Masumoto et al. [2004] and Sasaki et al. [2008].

3. Results
3.1. Mean Currents of MC/MUC
Figure 2a shows the vertical profile of the mean meridional velocities measured by the ADCPs during the
whole mooring period. The MC is characteristic of a strong southward flow, which is located in the upper
600 m with a mean velocity exceeding 73 cm/s at a depth of about 100 m, much weaker than the one
reported by Kashino et al. [2005]. This difference may be attributed to different locations. As Lukas et al.
[1991] showed, the MC accelerates southward along the Philippine coast. The standard deviation of the MC
at 100 m is about 17 cm/s, which is much smaller than the mean flow, indicating that the MC is a very stable
current. A northward mean flow is observed below 600 m to the depth deeper than 1000 m, which has
been called the Mindanao Undercurrent (MUC). Its maximum mean velocity is around 10 cm/s at 950 m
with a standard deviation of about 19 cm/s (Figure 2a).

It should be noted that the averaging time range in obtaining the mean velocity is different at different
depths. Figure 2c displays the number of days with effective ADCP measurements at various depths. Above
780 m, the effective measurement time range at most depths is longer than 600 days, while below 780 m it
decreases with the depth, 400 days at 800 m and 200 days at 1000 m. At 950 m, there are about 250 days
of ADCP measurements. Considering that the velocity at this depth varies with a dominant period of 60–80
days as shown in the following section, the ADCP measurements provide only about 3 degrees of freedom,
and the standard error of the mean current reaches 11 cm/s, therefore longer time series is needed to test the significance of this mean current.

The mean zonal current from the ADCP measurements is shown in Figure 2b, which is eastward in the upper 400 m with a maximum mean velocity around 5 cm/s at about 150 m. Between 400 and 1000 m, it is westward with a mean velocity of 3 cm/s at 950 m. Then the above analysis couches that the MUC is a northwestward subsurface flow, while the MC is southeastward in the upper layer. Similar to the meridional counterpart, the standard deviation of the zonal velocity is also very large, about 12 cm/s at 950 m.

Many previous studies have presented the geostrophic currents along the section of 8°N based on hydrographic observations with different values of the MC/MUC during different periods [e.g., Hu and Cui, 1989, 1991; Hacker et al., 1989; Lukas et al., 1991; Kashino et al., 1996, 2009; Qu et al., 1998; Wang and Hu, 1998a, 1998b]. To obtain a relatively reasonable velocity structure of the MC/MUC, we collected all hydrographic data available near 8°N so far from NODC, including CTD and Argo profiles, and calculated the mean geostrophic velocities in Figure 3. A strong southward MC is shown in the upper 500 m with a maximum velocity of 96 cm/s. Below the MC, a northward flow of the MUC is displayed with two cores. Obviously, the subsurface mooring is located not exactly at, but quite near the inshore core of the MUC. The axis of the inshore core is near 126.8°E centered at about 900 m, consistent with the mooring result, while its velocity is about 4 cm/s, much weaker than the mooring measured. The offshore core is located at 127.7°E with a maximum velocity of about 14 cm/s at the depth of 550 m. This multicore structure of the MUC has been reported by many previous studies based on hydrographic sections [Hu and Cui, 1989; Wang and Hu, 1998a; Qu et al., 1998] and model outputs [Qu et al., 2012].

It should be pointed out that the mean MUC measured by the mooring ADCP in Figure 2 is much weaker and deeper than the previous results provided by Hu and Cui [1989] and Wang and Hu [1998a]. One apparent reason for this difference is that Figure 2 shows the mean current during the 2 year observation period of the mooring ADCP, while previous studies were merely based on synoptic CTD sections, which were influenced strongly by subthermocline eddies as shown in the following section. In addition, different observation time may also contribute to the difference.

A 2 year time series of meridional velocities measured by the ADCP is shown in Figures 4. In the upper 400 m there is a strong and stable southward flow during the entire period. The maximum velocity is up to 100 cm/s in July 2011 at about 100 m. Below 400 m, there is a northward flow, which is strongly interfered by the intraseasonal variability. Sometimes it is very strong with a velocity over 40 cm/s, but sometimes it is weak and even reverse, which will be discussed in the next section.

3.2. Intraseasonal Variability of MC/MUC From ADCP Measurements

Power spectral density (PSD) is calculated for both meridional and zonal velocities at all depths between 0 and 800 m with the ADCP-measured data and is shown in Figure 5. Here the PSD has been normalized by...
the total velocity variance at different depths. A protruding feature of the PSD is the coherent peak with a period of 60–80 days between 200 and 800 m. In the upper 200 m, there is no peak of this period. The PSD for the zonal currents has similar features (Figure 5b). Kashino et al. [2005] and Qu et al. [2012] also mentioned the intraseasonal variability with a broader band of 50–100 days from the current meter measurements and model outputs, respectively. The intraseasonal variability is most likely attributed to the eddy activity in this region.

To better understand the intraseasonal variability of the currents, the ADCP-measured time series is filtered with a 40–100 days bandpass filter at each depth (Figure 6). The filtered time series clearly demonstrates the vertically coherent intraseasonal variability of the MC/MUC. The maximum variation takes place below 400 m with a peak-to-peak difference around 30 cm/s for the meridional component. Consistent with the spectrum analysis, the intraseasonal variability in the upper layer is relatively weaker compared with the deeper layer, indicating that the intraseasonal variability may be caused by subthermocline eddies, which are nearly invisible at the sea surface [e.g., Firing et al., 2005; Qu et al., 2012]. In addition, the intraseasonal activity appears to vary in different years, i.e., energetic in 2011 with large fluctuations and weak in 2012. The reason for this distinct and abrupt interannual change will be explored in further studies.

Such intraseasonal variability is also captured by the CTD mounted on the mooring at about 600 m (Figure 7). Because the main float of the mooring moved up and down strongly before July 2011 due to the strong
intraseasonal variability and the relative less buoyancy of the mooring system, the mooring CTD data may have large interpolation error after being calibrated onto the fixed depth. Therefore, we only show the CTD measurements during July 2011 to December 2012 (Figure 7). Both temperature and salinity measurements exhibit large intraseasonal variations with similar peak period to that of the velocity. The correlation between the velocity and temperature is 0.39, and that between the velocity and salinity is 0.32. The velocity anomalies often have warm/saline or cold/fresh characteristics. A northward velocity anomaly corresponds to warm/saline water, while a southward velocity anomaly corresponds to cold/fresh water. This probably could be understood in the following way. Since one of the water sources of the MUC’s near-shore core is the saline water from the southern hemisphere [Wang and Hu, 1998b], a northward velocity anomaly must be

![Figure 6](image.png)

**Figure 6.** Time series of 40–100 days band pass filtered meridional (a) and zonal (b) velocities from the mooring ADCP. Black contours indicate zero line of the velocity.

![Figure 7](image.png)

**Figure 7.** (a) Vertically averaged velocity vector between 600 and 800 m during July 2011 to December 2012 from the mooring ADCP. (b) and (c): temperature and salinity measurements at 600 m from the CTD mounted on the mooring.
accompanied by warm/saline water from the south. As the North Pacific Intermediate Water with cold and fresh water can reach this region off Mindanao from the north, a southward velocity anomaly must bring cold/fresh water from the north.

The gross effect of these velocity anomalies on meridional heat and salinity fluxes is estimated as \( V'T' \) and \( V'S' \) with the above time series, where \( V' \), \( T' \) and \( S' \) are anomalies of the meridional velocity, temperature and salinity, respectively. The estimated northward heat flux is about \( 4 \times 10^6 \) W/m\(^2\), and the northward salinity flux is about \( 6.7 \times 10^{-2} \) psu m/s. To further quantify these eddy effects, we calculated the ‘bolus’ velocity, which has been extensively used in prior studies [Marshall, 1997; Qu et al., 2012]. The ‘bolus’ velocity is defined as \( \langle V'S' \rangle / \Delta S \), where \( \Delta S \) represents the salinity difference between North and South Pacific waters being converged in the western tropical Pacific. According to Qu et al. [2012], the mean \( \Delta S \) here is about \( 16 \times 10^{-2} \) psu at this level. The corresponding ‘bolus’ velocity is about \( 0.42 \) m/s, much stronger than the mean current of the MUC by a factor of 4. Therefore, subthermocline eddies here play a very important role in the water exchange between North and South Pacific.

3.3. Intraseasonal Variability of MC/MUC From OFES

Although the ADCP data from the mooring at 8°N, 127°3'E illustrated the mean structure and intraseasonal variability of the MC/MUC, the mooring is only one spot in space and hence insufficient for depicting the whole picture of the MC/MUC and the source of its intraseasonal variability. Since the subthermocline intraseasonal variability is largely invisible from the sea surface, satellite altimetry is also unable to capture it. Instead, numerical model (e.g., OFES) outputs may be used to do so. The OFES outputs have been analyzed by a number of earlier studies. Dutrieux [2009] compared them with shipboard ADCP measurements and suggested that the model represents reasonably well the circulation and its variability in the western tropical Pacific. Qu et al. [2012] also noted that the simulation of OFES clearly demonstrates the circulation pattern and the variability of the low-latitude western boundary currents. Even so, we still further validated this data prior to use for this study.

3.3.1. Validation of OFES Outputs With Mooring Measurements

Figure 8 shows the mean meridional velocity along 8°N simulated by OFES. Qualitatively, the MC and MUC are well depicted, with a formidable southward flow in the upper layer overlying weaker northward flows in the layer of 400–1000m. This is in reasonable agreement with earlier observations [e.g., Hu and Cui, 1989, 1991; Lukas et al., 1991; Qu et al., 1998; Wang and Hu, 1998a].

To examine the ability of OFES in simulating the intraseasonal variability of the currents east of Mindanao we compared the OFES time series of the vertical mean meridional currents between 600 and 800 m with the mooring measurements (Figure 9a). Even though the correlation between these two time series is only 0.3, far below the 95% confidence level with about 10 degrees of freedom, both of them show obvious
intraseasonal variability and have roughly the same magnitude of variability around their means. Actually, spectrum analyses by Qu et al. [2012] have suggested the OFES-simulated currents in the 200–1000 m layer with significant intraseasonal variability of a period of 50–100 days, which is almost consistent with the mooring measurements. In general, the OFES outputs are able to duplicate the MUC and its intraseasonal variability, and can be used to explore the source of this intraseasonal variability.

### 3.3.2. Source of the MUC Intraseasonal Variability

Figures 9b and 9c show the mean EKE distribution at 605 m and along 8°N section calculated from OFES. It can be seen that eddy activities near the Philippine coast are very strong and these eddies are amassed between 200 and 1000 m with the maximum EKE at about 500 m. These eddies are suggested to be closely related to the subthermocline eddies reported by Firing et al. [2005] and play an important role in the intraseasonal variability of the subsurface currents east of Mindanao.

To seek the source of these subthermocline eddies, we have a time-longitude plot of the meridional current anomalies along 8°N during 2010–2012 derived from OFES in Figure 10, which manifests a significant westward propagation feature from the east. The signals are first formed between 140°E and 145°E with weak anomalies and then get stronger when moving westward. After passing 135°E, these anomalies become stronger and continuously move toward the Mindanao coast. It takes about 4–5 months from 135°E to the mooring site with a speed of 6–8 cm/s, which is much smaller than the westward propagation speed (>20 cm/s at 8°N) of the first-mode baroclinic Rossby wave [Chelton et al., 2011], but coincident well with the mean current advection (about 6 cm/s) in this region from the OFES data. This result hints that the westward eddy translation shown in Figure 10 is probably not due to the first-mode baroclinic Rossby wave. Qiu et al. [2013] also suggested a westward subsurface current with a speed of 1–2 cm/s in this region derived from Argo floats. The relatively coarse resolution (0.5°) of the data set used in their geostrophic calculation may underestimate the strength of the current.

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**Figure 9.** (a) Vertical mean meridional velocity between 600 and 800 m at the mooring site from ADCP (red) and OFES data (blue). Mean EKE at 605 m (b) and along 8°N (c) during 2010–2012 derived from the OFES output. The purple star in (b) and white line in (c) indicate the mooring site.
Considering that those eddies are intensified west of 130°E, it is possible that there is an energy source for subthermocline eddies near the Mindanao coast. The EKE distribution also shows locally strong eddy activity near the Mindanao coast (Figure 9). As suggested by Dutrieux [2009], most of the eddy energy might be attributed to the mixed horizontal and vertical shear instability of subthermocline currents.

In addition, the local wind stress around the mooring site is analyzed, which indicates an intraseasonal variability around 30 days (figure not shown), inconsistent with the 60–80 days variability of the subsurface currents. That means that the intraseasonal variability is not caused by local wind. This result agrees well with Firing et al. [2005] and Kashino et al. [2005], who suggested that the local wind forcing cannot be the energy source of subthermocline eddies. The subthermocline eddies probably represent energy that has propagated westward from the central Pacific and/or northward along the western boundary.

Chiang and Qu [2013] proposed that subthermocline eddies east of Mindanao are from the coast of New Guinea along a north-south dominant pathway based on the EKE analysis. The velocity vector and CTD measurements from the 8°N mooring show a little bit of meridionally moving eddies that can be seen from the rotation of the velocity vector (Figure 7). However, we only detected very few meridionally moving eddies between 3° and 8°N from the OFES data. It is possible that these meridional signals are dissipated by eddy-mean flow interactions in this region, and most of the intraseasonal signals at the mooring site comes from the east and intensifies near the Mindanao coast.

3.4. Seasonal and Interannual Variability of MC

Beside intraseasonal variability, the 2 year time series of ADCP data also help look over the seasonal and interannual variability of the MC. The meridional velocity averaged between 50 and 150 m shows obvious seasonal variation of the MC accompanied by higher frequency fluctuations (Figure 11a). During the observation period, the MC is strong in summer and weak in fall. The monthly mean velocity reaches its

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**Figure 10.** Time-longitude plot of the meridional velocity anomaly (color) at 605 m along 8°N during December 2010 to December 2012 from the OFES data. Black line indicates the mooring site.
maximum of 81 cm/s in June and minimum of 56 cm/s in October. These results are closely in agreement with the results by Kashino et al. [2005].

In addition, the MC in 2012 is weaker compared with that in 2011. Correspondingly, ENSO shifts from its cold phase in 2011 to normal phase in 2012. Such correspondence is different from the previous result of Kim et al. [2004] and Kashino et al. [2005] that the MC transport increased during El Nino. These differences indicate that the interannual variation of the MC strength does not correspond to ENSO cycle all the time. Lukas [1988] and Qiu and Lukas [1996] also suggest that interannual fluctuations of the MC are dominated by quasi-biennial oscillations based on sea level difference between Davao and Malakal and do not always correspond to ENSO, which seems to be in accordance with the present results.

4. Conclusion and Discussions

Based on 2 year ADCP measurements east of Mindanao Island, the mean structure and variability of the MC/MUC are investigated. A stable southward Mindanao Current (MC) exists in the upper 600 m with the velocity core at 100 m. A northward mean flow is observed below 600 m to the depth deeper than 1000 m, which has been called the Mindanao Undercurrent (MUC) with a maximum mean velocity of about 10 cm/s at 950 m and a standard deviation of 19 cm/s. Further analysis with hydrographic data and OFES outputs also suggest this current to be the MUC. The ADCP observation reveals significant subthermocline intraseasonal variability with a period of 60–80 days below 200 m. Analysis with OFES data indicates that they are closely related to westward translating subthermocline eddies in this region.

Through seven shipboard ADCP transects’ analysis, Wijffels et al. [1995] indicated that there was only a weak northward mean flow offshore and below the MC, and speculated that the MUC might be a transient phenomenon. However, it, seemingly, should be noted that those ADCP transects could only measure currents from the sea surface down to a depth of 350 m, unable to reach the MUC (its core is at about 950 m).

Based on seven SADCP sections along 7°N, Kashino et al. [2013] observed northward subsurface mean currents below 400 m at about 127.5°E, and suggested it was a part of an anticyclonic eddy. But both geostrophic calculations from all available hydrographic data (Figure 3) and mean velocity from OFES outputs (Figure 8) show there is a northward current west of the anticyclonic eddy, because the northward velocity is much larger and broader than the southward one. Qu et al. [2012] also shows such kind of northward current-MUC west of two anticyclonic eddies east of Mindanao (see their Figure 2a, Figure 3a and Figure 4a).
Using lowered and shipboard ADCP measurements from two cruises, Firing et al. [2005] observed a southward flow from the surface down to 2000 m along the Mindanao coast and a northward flow 100–200 km offshore between 500 and 2000 m, and then combined with diagonal shipboard ADCP sections from the second cruise to suggest that these flows were parts of cyclonic subthermocline eddies. This is somehow consistent with the strong intraseasonal variability of the currents below 200 m from the subsurface mooring measurements. As described above, the strong intraseasonal variability is from the westward translating subthermocline eddies. These strong eddies heavily interfere the MUC and sometimes can make the MUC disappear even reverse temporarily, as the case depicted by Firing et al. [2005]. Anyway, even though strongly affected by the eddy activity, the MUC as a mean flow of about 10 cm/s is still there, as shown by the ADCP measurements (Figure 2a), the multiyear hydrographic transects (Figure 3) and OFES outputs (Figure 8).

Notice that the current between 600 and 800 m became weak in 2012, and the currents below 800 m might be also weak. The reason for the weakening is speculated to be related to a zonal shift of the MUC, but not its disappearance. For instance, the northward flow could not be figured out by the mooring ADCP measurements in the upper 900 m in December 2012 (Figure 4), and then one might misunderstand it as the disappearance of the MUC, while the geostrophic velocity section calculated from the in situ CTD transect at nearly the same time clearly shows an inshore and an offshore northward cores of the MUC, which are away from the mooring site at this time (Figure 12).

In summary, the subsurface mooring at 8°N, 127°3'E east of Mindanao revealed some new features of the MC/MUC. However, it is only a single point in space and unable to capture the whole picture of the MC/MUC. As Hu and Cui [1989] mentioned, the MUC has two to three cores. The mean structure of meridional velocity at 8°N from both geostrophic calculations (Figure 3) and OFES outputs (Figure 8) also show the multicore structure of the MUC, while the offshore one is much stronger and shallower than the inshore one. In this study, the mooring site seems to be located between the inshore and offshore cores, or near the inshore one (Figures 3 and 8), therefore it may miss the major part of the MUC. For further studies on the MC/MUC, a mooring array across the current system, especially on different cores of the MUC, is really needed.

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