List of Changes and Responses for Ocean Science Discussion (OS-2020-91)

Interactive comment on
"Simulated Zonal Current Characteristics in the Southeastern Tropical Indian Ocean (SETIO)"

Thank you for your time and effort in reviewing our paper, and for providing the valuable suggestions, comments, and corrections, which helped make our manuscript stronger. We have modified the manuscript based on the Reviewer's suggestions and hope that the revision adequately addressed the Reviewer's concerns, so that the revised manuscript will be suitable for publication.

Anonymous Referee #1
Submitted on 11 Mar 2021

I am grateful to the authors for their efforts in improving the manuscript. Most of my previous concerns have been addressed. But I have some further comments for your reference. I agree with another anonymous review that this manuscript failed to specify clearly what the novelty of this work is for the scientific community. The authors presented plenty of analysis and estimates based on their simulations, which I think is a good contribution to the community. But unfortunately, it seems that the poor writing and cumbersome structure of the present version make the manuscript a hard read. I suggest the authors further to revise and refine the article carefully. My comments are listed below.

Major comments:

1. Abstract: The authors may clarify clearly what is new relative to previous studies. Remove less important or uninspiring conclusions from the Abstract and add important or novel conclusions to it. For example, the readers may don't care about the power density of each time scale in the Abstract.

We thank the reviewer for the thoughtful suggestions and comments towards improving our manuscript. In the revised manuscript, we have revised the Abstract (Lines 9-37) and refined the article as well. Less important or uninspiring conclusions has been removed from the Abstract and important or novel conclusions has been added to it.

2. Lines 190-205: I feel confused about this paragraph. The authors claimed that the SJC and SJUC are caused by downwelling Kelvin waves, but you concluded that the SJC and SJUC are induced by local eastward wind as well and called the downwelling Kelvin waves a minor addition. Then, who is the real cause of the currents? Meanwhile, I don't understand how can a non-stationarity wave forms a steady mean flow?

We would like to thank the reviewer for the insightful and careful review of our manuscript. The SJC and SJUC are caused by local eastward wind. During the NW monsoon (DJF), the dominant eastward current at A_{EJ}, particularly that at depth beneath 100 m, strengthens and occurs up to ~800 m, coinciding with the arrival of a seasonal downwelling Kelvin wave originating in the equatorial Indian Ocean during the transitional monsoons (SON). To make it more obvious and easier to understand the description, we have modified and refined the paragraph in Lines 213-232, as follows:

3.2.1 Vertical Structure of Zonal Current along Meridional Section EJ (A_{EJ}-B_{EJ}-C_{EJ})

Different zonal current system along the meridional transect East Java (EJ; A_{EJ}-B_{EJ}-C_{EJ}) can clearly be seen in Figs. 6a-f. On average, for the period 1950 through 2013, zonal climatological current at A_{EJ} (nearshore area) generally flows eastward from the sea surface to 100 m depth (Figs. 6a and 6d) and reaches its maximum value of about 0.16 m s^{-1}. It is suggested that the average zonal current at this point is mainly attributed to SJC and it shows seasonal variations. During the SE monsoon (JJA), the strength of climatological eastward SJC at this point in upper 10 m depth reduces (Fig. 6d). Meanwhile, during the NW monsoon (DJF), the current in the upper 10 m (Fig. 6d) flows more eastward in response to the prevailing northwesterly winds (Fig. 7). In general, the mean eastward current at A_{EJ}, during DJF was attributed to local winds. Interestingly, during this monsoon period (DJF), the eastward current at A_{EJ}, particularly that at depth beneath 100 m, strengthens and occurs up to ~800 m. Other physical processes may account for the enhanced eastward current at this point. The SJC and SJUC, which are seasonally varying currents and predominantly eastward, are defined as the surface current in the upper 150 m and the subsurface current beneath 150 m down to 1000 m, respectively (Iskandar et al., 2006). The eastward-flowing SJC and SJUC are intensified, coinciding with the arrival of a seasonal downwelling Kelvin wave along the south coast of Java (e.g., Sprintall et al., 1999, 2000; Iskandar et al., 2006). Downwelling Kelvin waves originating in the equatorial Indian Ocean during the transitional monsoons propagate along the coasts of western Sumatra and southern Java with phase speeds ranging from 1.5 to 2.9 m s^{-1} (e.g., Sprintall et al., 2000; Syamsudin et al., 2004; Iskandar et al., 2005). These phase speeds indicate that the downwelling Kelvin waves will arrive at A_{EJ} in 21 – 41 days. In this case, downwelling Kelvin waves generated during the monsoon transition period in November may arrive at A_{EJ} in December/January. Therefore, in addition to the local eastward winds, the downwelling Kelvin waves may also contribute to strengthen the eastward currents at A_{EJ} during the NW monsoon, including those at depth beneath 100 m.

Minor comments:

1. Line 44: simulated data -> simulations

Thank you very much for your correction. In the revised manuscript, we have changed "simulated data" to "simulations" (Line 55).

2. Line 50: delete "by previous investigators"

Thank you for your correction. In the revised manuscript, we have deleted "by previous investigators" (Line 62).

3. Line 61: interannual variability of what?

We thank the reviewer for the correction. In the revised manuscript, we have modified "interannual variability" to "interannual variability of ENSO" (Line 71).

4. Line 63: delete "event"

Thank you very much for your correction. In the revised manuscript, we have deleted "event" (Line 73).

5. Line 75: with -> on a

Thank you for your correction. In the revised manuscript, we have changed "with" to "on a" (Line 83).

6. Lines 79-80: The statement is too absolute to say "no information concerning". You may rephrase this sentence, for example: "However, the seasonal and interannual variations of SEC in the SETIO is unclear yet."

Thank you very much for your suggestion. In the revised manuscript, we have rephrased "no information concerning" to "However, the seasonal and interannual variations of SEC in the SETIO are unclear yet" (Line 89-90).

7. Line 82: all previous investigations -> previous studies

Thank you for your suggestion. In the revised manuscript, we have changed "all previous investigations" to "previous studies" (Line 92).

8. Line 185: seasonal depth profiles -> seasonal mean profiles

Thank you very much for your correction. In the revised manuscript, we have changed "seasonal depth profiles" to "seasonal mean profiles" (Line 208).

9. Line 187: at the nine observation points -> at each point

Thank you for your correction. In the revised manuscript, we have changed "at the nine observation points" to "at each point" (Line 210).

10. Line 188 and elsewhere: used too many "distinctive"

Thank you for your valuable suggestions. In the revised manuscript, we have reduced the use of "distinctive" in Line 210 and elsewhere.

11. Figure 4: add unit of longitudes

We thank the reviewer for the suggestions. In the revised manuscript, we have added unit of longitudes (Figure 4).

12. Figures 5 and 9: add unit of latitudes

Thank you for your suggestions. We have added unit of latitudes (Figure 5 and 9) in the revised manuscript

13. Figures 10-12: could you estimate the proportion of contribution of each EEMD mode to the EOF1? For example, standard deviation of each EEMD mode relative to the total variance of PC1?

Thank you for your valuable suggestions. As suggested by the reviewer, we have estimated the proportion of contribution of each EEMD mode to the EOF1 by calculating standard deviation of each EEMD mode relative to the total variance of PC1. In Section 3.3 (Line 387-394), we have added description of the proportion of contribution of each EEMD mode to the EOF1, as follows:

Moreover, the proportion of contribution of each EEMD mode to the EOF1 is estimated by calculating standard deviation of each EEMD mode relative to the total variance of PC1 (Figs. 10-12). In general, the contributions of each EEMD mode to the EOF1 at A_{WJ} and B_{SM}, from largest to smallest, are intraseasonal, semiannual, annual, interannual, and long-term (Figs. 10 and 11). Intriguingly, however, the contribution of long-term signal (19.2 %) at C_{EJ} is larger than the interannual (16.3%) and annual (14.7%) signals (Fig. 12). For the scope of this paper, we only focused on the analysis of the EOF1 of zonal current from intraseasonal to interannual timescales. The interesting results concerning the existence of pronounced contribution of long-term variation to the EOF1 at C_{EJ} will be investigated in a future study.

Anonymous Referee #2

Submitted on 06 Mar 2021

This study investigates the variability of zonal current within the region that involves multiple currents system, i.e., the South Java Current, the Indonesian Throughflow, the South Equatorial Current, and the coastal upwelling. Due to interactions among these currents, the variability in this region is very complex. Using EOF and EEMD, the authors have discussed the intraseasonal, seasonal, and interannual variations of the zonal currents in the southeastern tropical Indian Ocean. The authors have improved their manuscript, the results are reasonable and the text are generally easy to follow. I think this study basically meets the goals of the Journal, and thus should be accepted after some major revision, as listed below.

Major comments:

1. Although the authors explained why they have done EEMD after EOF, there are some issues need to be further clarified. First, what are the physical mean of the EOF1? In other words, the EOF1 spatial mode is subject to multi-time scale variations, making it confusing that which dynamical processes are dominant.

We thank the reviewer for the thoughtful comments towards improving our manuscript. We would like to clarify it.

EOF via singular value decomposition matrix of data decomposes into three new matrices which may be used to form the eigenvalues, eigenvectors, and eigenfunctions. The resulting eigenfunctions display the spatial patterns (in our case, the vertical patterns for mode-1 shown in Figs. 10a, 11a, 12a), while the eigenvectors (eigenperiod) show time varying amplitude for each mode (in our case, the eigenperiod for mode-1 shown in Figs. 10b, 11b, and 12b). The eigenvalues demonstrate the strength of each mode, with the first mode defines as being the mode associated with the largest eigenvalue, and hence the largest percent of the variance (Table 2).

In our case, the physical mean of the EOF1 demonstrates the dominant vertical mode structure (Figs. 10a, 11a, 12a) and its temporal model variability (Figs 10b, 11b, and 12b) relative to the mean flow. Temporal mode variability displays the time-varying element of the vertical mode structure, which enables us to calculate the velocity variability relative to the mean flow (by multiplying the vertical mode structures (Figs. 10a, 11a, 12a) and the temporal variability (Figs 10b, 11b, and 12b).

Dominant dynamical processes are obtained by analyzing the velocity variability relative to the mean flow and by finding out dominant frequencies in the eigenperiod of mode-1. In this case, one can apply Fourier transform of these time series (Figs. 10b, 11b, and 12b) by assuming that the time varying signal is linear and periodic. In here, we use time series analysis technique (EEMD) which is using Hilbert transform, that suitable not only for linear periodic time series, but also suitable for nonlinear and nonperiodic signals. For detailed technique, please refer to Huang et al., 1998. Our results are shown in Figs. 10d-h, 11d-h, and 12d-h.

We do hope this could clarify it. Thank you.

2. The mesoscale eddies are very active in the study area, I think it should be important for the zonal current variations at intraseasonal to semi-annual time scale. Can the EOF analysis able to resolve the contribution of eddies? I strongly encourage the authors to discussion focus on this point of view in detail.

We would like to thank the reviewer for the insightful review of our manuscript. According to previous studies (e.g., Chelton et al., 2007; Yang et al., 2015), lifetime of mesoscale eddies in the SETIO is relatively short, approximately 50 days for cyclonic eddy and 46 days for anticyclonic eddy. In our present study, the time interval of the HYCOM data that used for the analysis is monthly mean. Hence, the highest (Nyquist) frequency resolved by the sample series is 0.5 cycles per month (periods ≥ 2 months). In here, we only focused on the analysis of the EOF1 of zonal current on timescale ≥ 2 months. Therefore, in this present study, the contribution of eddies could not be resolved yet.

Thank you for your insightful and encouraging suggestions. We really appreciate the suggestions. We would investigate this important topic concerning the contribution of eddies in the next study.

3. The relationship between IOD and zonal currents lies in two aspects: 1) the IOD SST anomaly induces surface wind anomalies, together with SSH gradient, resulting in zonal currents anomalies; and 2) Oceanic long waves dynamics (i.e., the Kelvin and Rossby waves) propagation may induce zonal currents anomalies and SSH anomalies in the southeastern tropical Indian Ocean, thereby resulting in IOD events. In addition, since the IOD tend to co-occur with ENSO, partial correlation is recommended to use, rather than correlation analysis.

We thank the referee for valuable recommendations. In the revised manuscript, we have calculated partial correlation (Table 7) and added additional descriptions as well (Lines 474-484), as follows:

In addition to the lagged correlation analysis (Table 4), partial correlation analysis was also conducted since the IOD tend to co-occur with ENSO. Table 7 shows the partial correlation coefficients between zonal currents at 30 m on interannual timescale and the ONI and DMI. As for the ONI, the currents revealed significant positive correlations at C_{EJ} during all monsoon seasons. This positive correlation suggests that El Niño (La Niña) events caused an eastward (westward) anomaly of currents at this point. Meanwhile, the partial correlation between the currents and the DMI showed significant negative correlation at B_{SM}, in which it occurred only during the SE monsoon (JJA), as shown in Table 7. This negative correlation indicates that an eastward (westward) anomaly of the currents was induced by negative (positive) IOD. The results of the partial correlation analysis confirm and complement the previous findings in Table 4 that ENSO mainly contributed to the zonal current variability at C_{EJ} in DJF, MAM, JJA, and SON, whereas the IOD had a significant influence on the variability of current at B_{SM} and only in JJA. In this present study, however, what are the causes of the influence of IOD on the current variability at B_{SM} only in JJA are still unresolved. Further research is necessary to explain the dynamical links of this matter.

Table 7. Partial correlation coefficients between zonal currents at 30 m on interannual timescale and each ONI and DMI. Only values above 95% confidence level are shown.

Points	ONI – *U* (no DMI)				DMI – *U* (no ONI)			
	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON
A_{WJ}	-	-	-	-	-	-	-	-
B_{SM}	-	-	-	-	-	-	-0.76	-
C_{EJ}	0.46	0.28	0.47	0.43	-	-	-	-
The 95% significance level	±0.19	±0.25	±0.26	±0.23	±0.63	±0.49	±0.35	±0.41

4. It is interesting that the zonal currents are correlated with remote winds in both equatorial Indian and Pacific oceans, but the explanation for the dynamical links are weak. Why the zonal currents lag the Pacific winds by 4 months? What is the pathways for the Pacific signal?

We would like to thank the reviewer for the thoughtful and insightful comments towards improving our manuscript. In the revised manuscript, we have provided additional explanation concerning this matter (Lines 525-539), as follows:

Previous study conducted by Wijffels and Meyers (2004) shows that the variability in the ITF region associated with Kelvin and Rossby waves originating in the Indian and Pacific Oceans, respectively. They have revealed the pathways for equatorial Pacific wind energy traveling down the Papuan/Australian shelf break and radiating westward-propagating Rossby Waves into the Banda Sea and southeast Indian Ocean (their Fig. 20). Hence, there is a contribution of the westward-propagating Rossby Waves to the ITF variability inside the Indonesian seas or at the ITF exit regions (Ombai and Lombok Straits, and Timor Passage), which lead into the SETIO as well as the western coast of Sumatra and the southern coast of Java. Our simulation (Fig. 2) clearly shows that ITF flowing from the exit passages of Indonesian seas (Lombok, Ombai, and Timor passages) feeds into the SETIO region. Moreover, Wijffels and Meyers (2004) have computed the remotely driven Pacific Rossby wave speeds as a function of latitude. The phase speeds have been compared with the theoretical Rossby wave speeds based on atlas of Chelton et al. (1998). In this study, we have estimated the travel time of the westward-propagating Rossby waves excited by the wind anomalies in the central and western Pacific to the SETIO, especially at point C_{EJ}, based on the pathways for the Pacific signals introduced by Wijffels and Meyers (2004). In general, it was found that the equatorial Pacific signals around 130° W took approximately 3.01 months to the C_{EJ} based on the mean phase speed of about 0.2 cm s^{-1} taken from Wijffels and Meyers (2004). This travel time estimation was within the range of the 4-month lags between the flows at C_{EJ} and the Pacific winds derived from the lagged correlation analysis in Fig. 17.

Specific comments:

1. In section 2, Line 100-105, it should better be 'Data and Methods', instead of 'Material and Methods'

Thank you very much for your correction. In the revised manuscript, we have changed "Material and Methods" to "Data and Methods" (Line 127).

2. For the validation of the HYCOM data, it is better to calculate the root mean square errors as well.

We thank the referee for valuable suggestions. In the revised manuscript, we have calculated the root mean square errors as well (Figure 1 and Lines 140-143).

3. I think it is necessary to introduce the time interval of the HYCOM data that used for the analysis, is it daily or monthly mean? If it is daily averaged, it may hard to resolve intraseasonal signal.

Thank you very much for your comments and suggestions. The time interval of the HYCOM data that used for the analysis is monthly mean. Based on the Nyquist sampling theorem, the highest frequency resolved by the sample series is 0.5 cycles per month. Therefore, intraseasonal signals with a minimum period of about 2 months can still be resolved. In the revised manuscript, we have introduced the time interval of the HYCOM data that used for the analysis (Line 129).

4. Line 134, since the EOF has been introduced in Introduction, so it does not necessary to repeat the full name ‘Empirical Orthogonal Function’ here.

Thank you for the reviewer’s correction. The repetition of the full name ‘Empirical Orthogonal Function’ has been deleted (Line 153).

5. It should also introduce the method for calculating the power spectrum.

Thank you for your suggestion. In the revised manuscript, we have introduced the method for calculating the power spectrum (Lines 158 - 163), as follows:

Furthermore, a power spectral analysis (Emery and Thomson, 2001) was applied to the EEMD results to identify dominant periods of the zonal current variability in the study area. The power spectral analysis is computed from a measured time series by cutting the time series into several segments and applying Fourier analysis to these segments. The contribution from individual Fourier harmonics was subsequently summed to derive total energy of time series. In addition, 95% confidence red noise level in power spectrum, specified to acquire accurate confidence thresholds for true periodic signatures, was calculated based on number of degrees of freedom in each frequency band (Mann and Lees, 1996).