CHARACTERIZING EFFECTS OF DIFFERENT ENSO PHASES ON SEA SURFACE TEMPERATURE IN THE VIET NAM EAST SEA

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Abstract: *The effect of different ENSO phases on Sea Surface Temperature (SST) has been an intensive effort to find the link between this basin-scale climate pattern and one of the most critical marine parameters. This issue, however, has not been well-studied in the Viet Nam East Sea (VES). This study examined the effect of different ENSO phases on SST in the VES by applying a series of statistical techniques on both satellite data and observed data from coastal stations. We find a significant correlation between ENSO and satellite-based SST data in the winter season (r = 0.56). We recognize a stronger relationship of ENSO-SST in the southern stations (with r varies from 0.47 - 0.83). We then compared the impact of different ENSO phases for the period of 1990 - 2019. Our results reveal that the extreme El Nino event 1997/98 had impacted SST strongly than any other event. In addition, we find that the response of SST to ENSO phases does not depend on intensity. The outcomes of this work may significantly contribute to the understanding of the effects of ENSO on marine parameters in the VES.*

Keywords: *ENSO, SST, EEMD, EOF.*

1. Introduction

ENSO (El Niño - Southern Oscillation) is a large-scale climate pattern in the tropical Pacific region but has global impacts. ENSO occurs every 2 - 7 years and includes two opposite phases: El Nino (warm phase) and La Nina (cold phase), with a significant change of atmospheric circulation [1]. This change, in turn, strongly impacts many weather parameters such as temperature, rainfall, etc.… Those impacts have been intensively reported and studied in many works, but a large portion of them has focused on land. In contrast, the effects of ENSO on sea surface parameters have been less well-studied. The sea surface temperature (SST) is the most crucial parameter since it has been used as a monitoring indicator of ENSO via several ENSO indices (e.g., NINO3.4, Multivariate ENSO Index - MEI). However, the response of SST to different ENSO phases (i.e., El Nino and La Nina) varies in each event. In a recent paper [9], Rao and Ren (2017) compared the impacts of different ENSO extreme events on SST and other parameters in the tropical Pacific region. Their results reveal distinctive effects of El Nino 1982/83, 1997/98, and 2015/16 on SST. This study suggests a different mechanism of each El Nino will have a distinct influence on various parameters. The work of Rao and Ren (2017) has led to an interesting research question: Do different ENSO events (both El Nino and La Nina) have the same impacts on SST in a small-scale ocean basin such as the Viet Nam East Sea? If they do differently, can we compare their effects?

The Viet Nam East Sea (VES) is one of the largest marginal seas in the world. There is a complex air-sea coupled system in this region, including unique climatic-oceanic related phenomena: Monsoons, ENSO, and ocean currents. The link between ENSO and SST

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has been discovered in several studies [8, 10]. They used EOF analysis to find the main pattern of SST in the VES and found a significant correlation between ENSO and SST. However, they did not compare in more detail the effects of each ENSO event on SST. In Viet Nam, the impact of ENSO on SST has been investigated in numerous studies [5, 6, 7, 11, 12, 13], but very few works paid attention to sea surface parameters.

In this study, we present detailed research for the first time on the comparison of different ENSO phases on SST in the VES. We used both satellite data (from 1993 - 2020) and obverses data from coastal and island stations (from 1990 - 2019) for this study. The data and methods will be presented in section 2; results and discussions will appear in section 3, and finally, we conclude some key findings in section 4.

2. Data and Methodology

2.1. Data sets

We collected monthly satellite SST data sets from CMEMS (1993 - 2020) with a 0.25° x 0.25° degree spatial resolution. The data cover the area from 0 - 25°N to 99 - 121°E in the western tropical Pacific. The monthly observed data from coastal and offshore stations came from 07 stations expanding from the North to the South of Viet Nam: Cua Ong, Bai Chay, Son Tra, Quy Nhon, Phu Quy (island), Truong Sa (island), and Vung Tau. We processed observed SST data sets to make sure that they meet the quality and have a common period. We chose a period of 1990 - 2019 for all seven stations so that the correlation analysis will be comparable between them.

There are several ENSO indices such as: Nino3.4, MEI, or SOI, but in this study we used Nino3 index to present the evolution of ENSO phases. Nino3 index is considered as the best index to capture El Nino extreme events since it uses the maximum SST anomalies that are in the same region (5°S - 5°N, 150°E - 90°W) [9]. The monthly time series of Nino3 will be used in analysis along with data of SST in this study.

2.2. Methodology

2.2.1. Link with ENSO

For satellite data, we applied Empirical Orthogonal Function (EOF) analysis to determine the spatial and temporal patterns of SST in the VES. We then selected only the first principal component (PC1) time series of SST from EOF analysis to examine the relationship between SST and ENSO via the Nino3 index. Before applying EOF, we had removed the trend and seasonal signals from the data set so that EOF only analyzed the SST anomalies (SSTA). This is necessary as Nino3 is calculated by using SSTA in region of 5°S - 5°N, 150° - 90°W. The two time series (PC1-SST and Nino3) are analyzed by cross correlation analysis. We then further explore the co-variations of both SST and Nino3 by using coherence-wavelet analysis [Grinsted et al., 2004]. This step aims to find out the common period that two time series co-vary throughout the length of data sets.

For SST data from stations, we used Ensemble Empirical Mode Decomposition (EEMD) method to obtain the 2 - 7 year signals (the ENSO re-occurrence) from monthly SST data and Nino3. EEMD is an adaptive and data-driven method to decompose a raw time series to different modes with their amplitudes and frequencies [14]. This method has been recently used in a work led by Le et al., 2017 to analyze SST for coastal stations along Viet Nam's coastlines.

2.2.2. Comparison of different ENSO phases on SST

To compare the effects of different ENSO phases on SST in the VES we mainly focus on the difference between El Nino events (warm phase) and La Nina events (cold phase). We also measure the power of some extreme events [e.g., El Nino 1997/98 and 2015/16 events] against other events from 1990 - 2019. To do that, we used the Hovmoller diagram and other statistical plots to characterize the strength of events and their impacts on SST.

3. Results and Discussions

3.1. Impacts of ENSO on SST

The results of EOF analysis are presented in Fig. 1. We chose to present the first three EOFs and PCs because they account for about 82% of total variance of SST in the VES from 1993 - 2020. Here, we focus on the first EOF and PC. The EOF1 (62%) increases of SST for the entire study area with the maximum increasing SST ~ 2ºC. It can be seen from Fig. 1 that; the coastal and offshore Southern Central and Southern coasts of Viet Nam are warmest regions. Results from Fig. 1 indicates a rising trend of SST recently in the VES, which has also been reported in other studies.

The correlation coefficient of monthly PC1-Nino3 is *r = 0.3* but that increases to *r = 0.56* when we average values of three months: 12, 1 and 2 - DJF (Fig. 2). This result proves the effect of ENSO on SST in the winter when ENSO is in its mature phase. In addition, the result also shows the positive correlation between SST and ENSO: SST increases/decreases in warm/cold phase of ENSO. Our results agree well with other studies (e.g.,) but we further prove the effect of ENSO on SST by using the winter-averaged SSTA and Nino3. Results form coherence-wavelet analysis also reveal that PC1-SST and Nino3 co-vary in a high power period of 4 - 6 years during 1993 - 2005 (Fig. 3). The high power is strongest in the extreme El Nino 1997/98 event compared to other events. After 2005, Nino3 and PC1-SST show high correlation in the 2 - 4 year band indicating another process dominates variations of SST in the VES (Fig. 3).

ENSO also shows the effect on SST from coastal and island stations. The ENSO-related signals from each data set after using EEMD were analyzed with Nino3 (note that, the trend in each data had been removed in EEMD analysis). The correlation coefficients vary from 0.4 - 0.66 for monthly data and from 0.36 - 0.83 for winter-averaged data (Table 1).

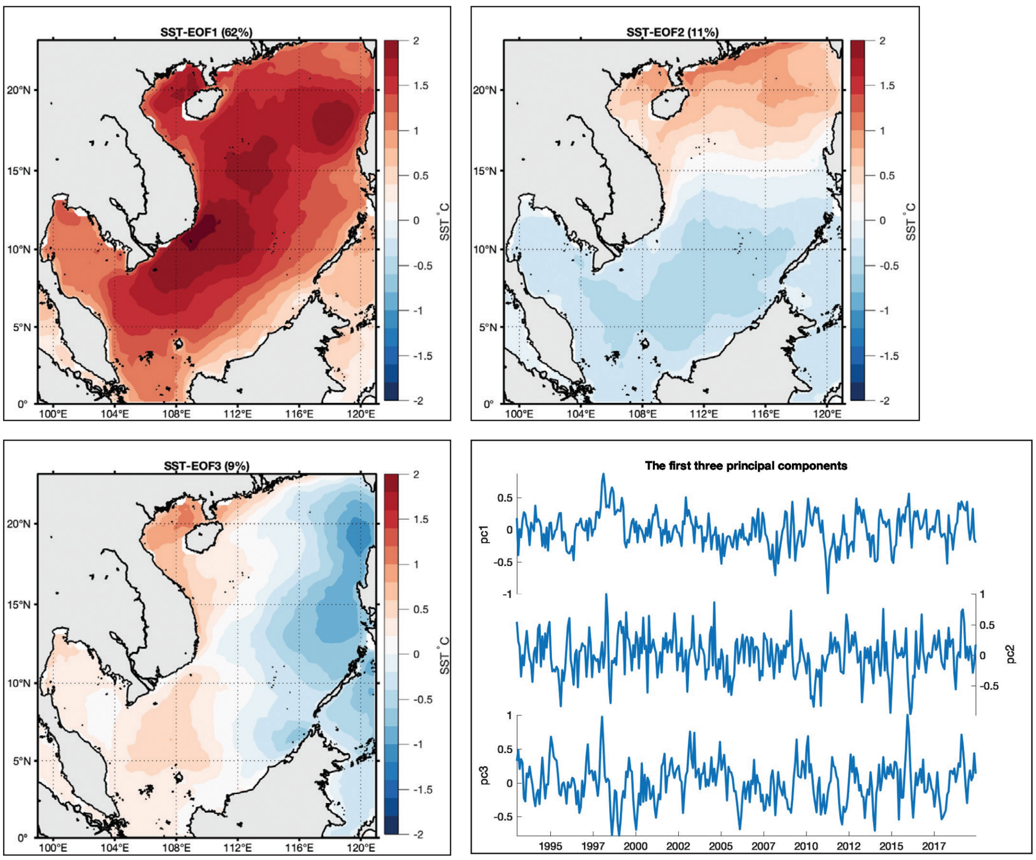

Figure 1. The three first EOF and PCs of SST from EOF analysis

Unlike moderate correlations between Northern stations and Nino3, Southern stations show higher correlations with ENSO, particularly in the mature phase. This indicates that the imprint of ENSO is more clear and more increased of south VES, which agrees with the results from EOF analysis above. Phu Quy and Truong Sa have the highest correlations with r = 0.83 and r = 0.71, respectively (Fig. 4). Table 1 also reveals that the El Nino 1997/98 strongly impacted on SST in 4 stations (Son Tra, Quy Nhon, Phu Quy and Truong Sa) with the largest change in Quy Nhon station (0.8°C). Nevertheless, La Nina events also show remarkable impact on SST in Cua Ong, Bay Chay and Quy Nhon. Interestingly, the extreme El Nino 2015/16 event does not significantly impact SST, although 2015/16 is considered a powerful event after 1997/98 and 1982/83 events.

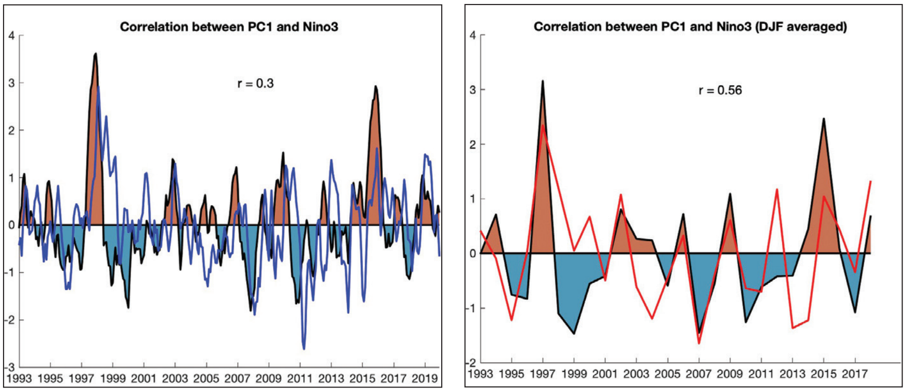

Figure 2. Cross-correlation analysis between PC1-SST and Nino3 in: monthly data (left) and winter-averaged data - DJF (right). The shaded anomaly graph shows Nino3 data

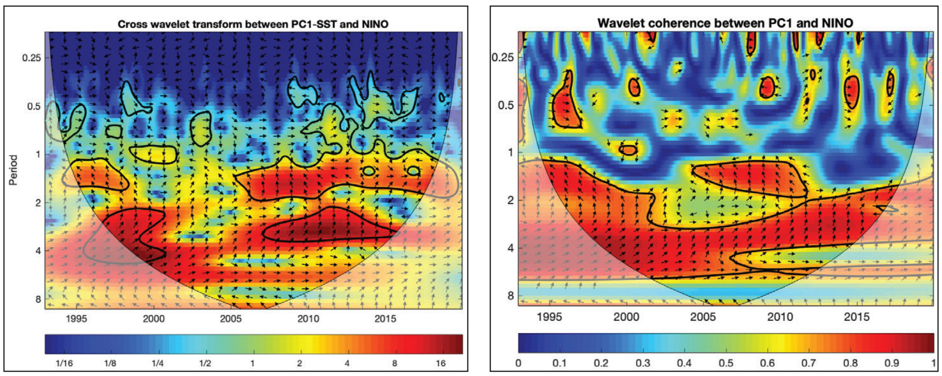

Figure 3. Coherence wavelet analysis for PC1-SST and Nino3 during 1993-2020

Table 1. Correlation coefficients between SST-Nino3 at 07 stations

Station	**Length of Data**	$r_{SST-Nino3}$	$r_{SST-Nino3-DJF}$	**The changes in ENSO phases (°C)**
Cua Ong	1990 - 2019	0.40	0.36	-0.75(2007)**
Bai Chay	1990 - 2019	0.41	0.42	-0.92(2010)**
Son Tra	1990 - 2019	0.40	0.42	0.62(1997)*
Quy Nhon	1990 - 2019	0.42	0.47	0.8 (1997)*, -0.8 (2011)**
Phu Quy	1990 - 2019	0.66	0.83	0.72(1997)*
Truong Sa	1990 - 2019	0.56	0.71	0.67(1997)*
Vung Tau	1990 - 2019	0.44	0.60	0.58(2015)*

**: El Nino events; **: La Nina events*

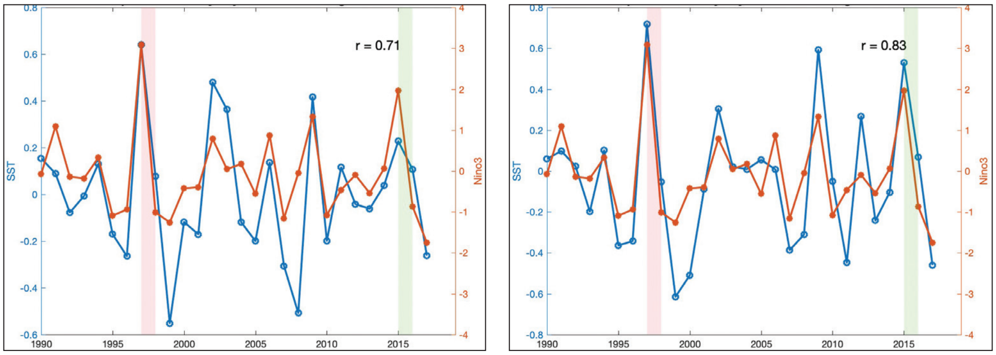

Figure 4. Correlations between SST and Nino3 using winter mean at Truong Sa (left) and Phu Quy (right). The shaded band shows El Nino 1997/98 (pink) and El Nino 2015/16 (green) phase.

3.2. Comparison of different ENSO phases

This section defines intense/extreme El Nino events as 1997/98 and 2015/16; strong La Nina events are 1998/99, 1999/00, 2007/08, and 2010/11. Other events will be considered as weak events (for both El Nino and La Nina phases).

First, we used Hovmoller to present the evolution of SST in the time-longitude dimension. We averaged along latitudes monthly SSTA and in DJF period to truly see the mature phase of ENSO. To focus on the coastal regions of Viet Nam, we only plot Hovmoller diagram for an area from 104°E to 112°E (Fig. 5). Fig. 5 shows that SSTA in the El Nino 1997/98 event increased up to more than 1°C, highest among other events indicating the most powerful El Nino event in history. The increase of SSTA in the El Nino 1997/98 expanded from the center of the VES to coastal regions of Viet Nam (104°E - 105°E, Fig. 6). The 2015/16 event also made an increase of SSTA but with lower values. Overall, SSTA increased and was warmer than normal conditions in El Nino events, except for the 2004/05 event (a decrease of -0.2 ÷ -0.3°C). Conversely, La Nina reduced SST anomalies, except for the 1998/99 event (an increase of 0.1 - 0.2°C). This contrast is clearly shown in Fig. 5 and Fig. 6.

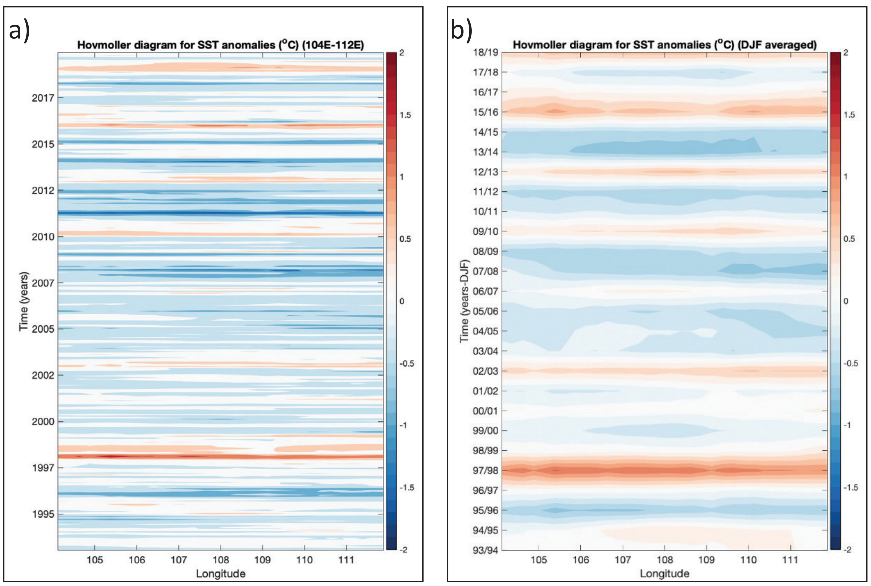

Figure 5.Hovmoller diagram of SST for: monthly data (a) and winter mean data (b)

To further certify the differences between ENSO phases, we show in Fig. 7 the normalized values of PC1-SST from EOF analysis and Fig. 8 the scatter plot between PC1-SST and Nino3 index for each winter year. In these Figs, we used standard deviations as an indicator to measure the strength of each event. It shows that not many El Nino and La Nina events strongly impact SST anomalies in the VES regions, but we still observe some significant features.

Firstly, among El Nino events outside the ±1σ area, the extreme El Nino 1997/98 event has strongest impact on SST anomalies as all its statistical values surpass other events (Figs 7 and 8). The 2015/16 and 2002/03 events have little impacts on SST anomalies whereas the 2004/05 event shows "strange" behavior with negative sign on SST anomalies.

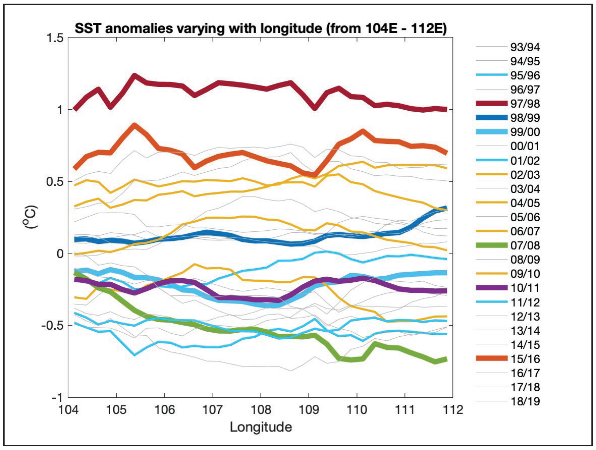

Figure 6. Evolution of SST anomalies with longitude using DJF data. The grey lines show neutral phases

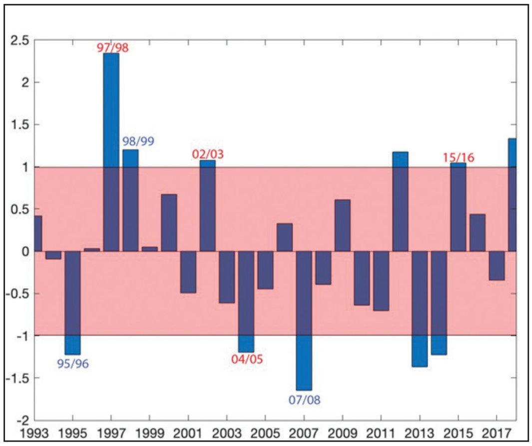

Figure 7.The normalized PC1-SST values from EOF analysis for each winter year. The shaded area indicates the area of ± 1σ

Secondly, only two La Nina events have significant impacts on SST anomalies: 1995/96 and 2007/08 cases but the latter event has much more influence. Meanwhile, the strong 1998/99, 1999/00 and 2010/11 cases do not show their effects and the 1998/99 case even observes a positive sign of SST anomalies (Figs 7 and 8).

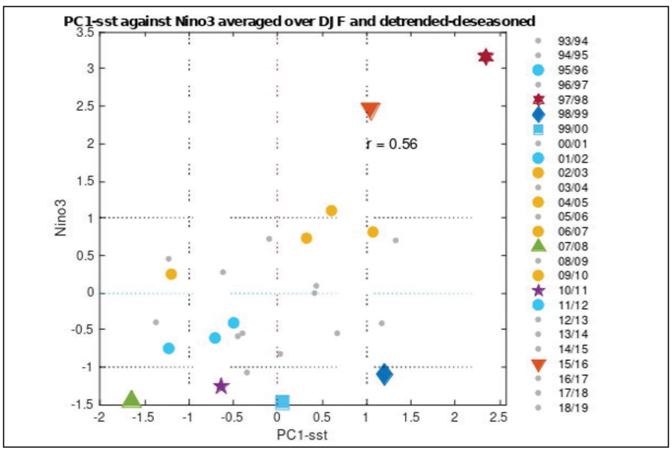

Figure 8. Scatter plot between PC1-SST and Nino3 index for each winter year. The dash lines show area of ±1σ

The difference between ENSO phases in this study agrees well with other studies and suggests a debate on different underlying mechanisms between ENSO events. There have been several studies trying to reveal how El Nino events differ from each other in terms of influence on SST anomalies [4, 9]. For example, Paek [4] discussed that the two extreme El Nino events 1997/98 and 2015/16 have distinct underlying dynamics and climate impacts. They suggested that the maximum SST anomalies in the 2015/16 event did not propagate westward as far as to the 1997/98 events. By looking at the peak magnitude of the westerly wind anomalies in the two events, the authors found that the wind in the latter event was 35% smaller than during the 1997/98 event. This might be why the maximum SST anomalies in the VES were much higher during the 1997/98 event in our study. Paek [4] also discussed that the type of the two events was not the same leading to the different behavior in the mature phase. While the 1997/98 event was pure eastern Pacific (EP) ENSO, the 2015/16 even showed a mixture of both the EP and central Pacific (CP) ENSO, causing the departure of the 1997/98 event.

4. Conclusions

Impacts of ENSO have been reported in other studies but here we present the first work of combining satellite data and observed data from coastal stations to study the imprints of ENSO in the VES. We also introduce the first study of comparison of different ENSO phases from 1993 - 2020. Our results show that ENSO has stronger impacts on SST in the south central to southern Viet Nam coastline than the North. These imprints are more prominent in the mature phase of ENSO (i.e., wintertime) when the correlation between Nino3 index and PC1-SST is $r = 0.56$.

Our findings reveal that the extreme 1997/98 El Nino event was the most powerful event and has most impact on SST anomalies in the VES. The second extreme El Nino 2015/16 did not produce the effect as strong as the 1997/98 event. This difference might be due to the variance of underlying dynamics (e.g., the westerly wind intensity). But to fully explain this matter, there is a need for a detailed study in the future.

It should be noted that, the response of SST to ENSO is not related to the intensity of each event. A weak ENSO case could show a remarkable effect on SST while a strong one could not. This might be an important insight for the following research to studyon the impact of ENSO in the VES.

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