Effects of ENSO on the intraseasonal oscillations of sea surface temperature and wind speed along Vietnam's coastal areas

Quoc Huy Le[1], Thuc Tran[1], Xuan Hien Nguyen[1*], Van Uu Dinh[2]

[1]*Vietnam Institute of Meteorology, Hydrology and Climate Change*

[2] *University of Science, Vietnam National University, Hanoi*

Received 25 May 2017; accepted 1 September 2017

Abstract:

Our study applied the Ensemble Empirical Mode Decomposition (EEMD) method to analyze intraseasonal variability (ISV) of sea surface temperature (SST) and wind speed using a 22-year monitoring data set from 10 coastal stations. Results show that the El Niño and Southern Oscillation (ENSO) significantly affected the ISO Quasi-Biennial Oscillation (QBWO) 10-20 day periods and Madden-Julian Oscillation (MJO) 30-60 day periods of SST and wind speed at the coastal stations. As seen with MJO, the effects of ENSO on SST tend to increase from the north to south, whereas its impact on wind speed decreases from the north to south of Vietnam's coastal areas. In contrast, with QBWO, the effect of ENSO on SST reduces moving from the north to south, whereas its impact on wind speed increases from the north to south of Vietnam's coastal areas.

Keywords: *EEMD, El Niño, ENSO, ISV, SST.*

Classification number: *6.2*

Introduction

The hydro-meteorological time series data collected around the world and most specifically collected at the South China Sea particularly contains the high to low-frequency signals, or from synop to interannual periods. These oscillation signals are due to the influences of processes varying from a planetary to regional scale, including: Seasonal oscillation with the monsoon (3-6 months), QBO (20-30 months), ENSO (3-5 years), Pacific Decadal Oscillation (PDO) (10-11 years), and others. ISO is the bridge between the synop scale and the seasonal scale, and directly affects the weather and climate in the region. Previous studies have shown that the South China Sea has two local ISOs including a 10-20-day period QBWO and a 30-60 day period MJO [1-5].

The ENSO is an oscillation phenomenon found on a global scale covering a period of 3-5 years. This oscillation significantly affects the large-scale circulations and others that are smaller scale, such as ISV, and seasonal oscillation; which, in turn, affects climate and weather in the region, including in the South China Sea. So far, the effect of ENSO on ISV is still an ongoing debate. Some studies suggested that the phases of ISV or MJO are strongly related to the warm phases of ENSO (El Niño) [6, 7], but other studies have found no significant relationship between MJO and ENSO [8, 9]. However, most of the studies show a common agreement that the main effect of ENSO on ISV is limited to areas of the Pacific Ocean, while MJO tends to operate in the Central Pacific and does not operate in the Western Pacific Ocean during the warm phases of the ENSO [10, 11]. D.E. Waliser, et al. (1999) suggested that ISV is very sensitive to small changes from SST and the author also suggested that ISO may be related to ENSO [9]. Wen Zhou, et al. (2005) suggested that in the warm phase of ENSO, MJO switches to activate in the Central and Eastern Pacific, and is not active in the Indian Ocean nor the South China Sea. In the cold phases of ENSO, MJO is active in the South China Sea, but the author also noted that this hypothesis needs further study [12].

Thus, although a lot of studies on the ISV and its interactions with large-scale global oscillations have been conducted, the study of ISV in coastal areas of Vietnam is still very limited, especially studies using measured data from coastal stations.

This paper aims to study the ISV of marine hydro meteorological factors and its interaction with ENSO. To do that,

*Corresponding author: Email: nguyenxuanhien79@gmail.com

we applied EEMD method to analyze ISV of SST and wind speed in Vietnam's coastal areas using a 22-year data set from ten coastal stations.

Method and data

Empirical Mode Decomposition (EMD) is a new and useful method used to separate and analyze a time series of data, particularly non-linear and non-stationary data. EMD decomposes data into different frequencies (from high to low) and different amplitudes. The data is analyzed based on characteristics of the data itself (adaptive analysis), which does not depend on the choices of the user [13].

From a time series X(t), through the filtering process (sifting process), EMD decomposes X(t) into a finite number of intrinsic mode functions (IMFs):

$$X(t) = \sum_{i=1}^{n} IMF_i + r \qquad (1)$$

where: IMF_i represents mode i^{th}, and r is the residual of the data X(t), which is then referred to the trend of data, and n is the number of IMFs, which depends on the length of data.

In order to apply EMD for decomposing data, the input data has to satisfy three conditions: (i) The signal must have at least two extremes, including one maximum and one minimum; (ii) The time scales must be determined for the time interval between two extreme points; and (iii) If the data does not have extreme values, only the bending point is recorded for the extreme values to be determined by taking their derivatives. The major steps of the EMD method are as follows:

1) Identify all extremes, connecting the high peak points by an upper boundary and the low peak points by a lower boundary, and then calculate the mean values of the upper and lower boundaries to get an average of $m_1(t)$.

2) Subtract the original data from $m_1(t)$, we get the first component of the sifting process $h_1(t)$:

$$h_1(t) = X(t) - m_1(t) \qquad (2)$$

3) Assign $h_1(t)$ to a new time series, and step 1, step 2 is repeated:

$$h_2(t) = h_1(t) - m_2(t)$$

...

$$h_k(t) = h_{k-1}(t) - m_k(t)$$

The iteraction process only stops when the Cauchy Convergence Criterion is satisfied [14]:

$$SD_k = \frac{\sum_{t=0}^{T} |h_{k-1}(t) - h_1(t)|^2}{\sum_{i=1}^{n} h_{k-1}^2} \qquad (3)$$

In which, h_k is the sifting result in the k^{th} interaction, if SD_k is smaller than a given value (usually about 0.2-0.3), thus the filtering process can be stopped because the IMF has brought full physical meaning. The highest frequency of the $c_1(t)$-component will be assigned using $h_k(t)$:

$$c_1(t) = h_k(t) \qquad (4)$$

4) After the IMF component has the highest frequency value extracted-$c_1(t)$, the rest of the data is then determined:

$$r_1(t) = X(t) - c_1(t) \qquad (5)$$

5) The remaining data-$r_1(t)$ continues to be used to extract IMF components with lower frequencies. When $r_i(t)$ becomes a monotonic function, or a function that has only one extreme, no IMF component is extracted further, and the decomposition stops. Finally the data is decomposed into the form (1).

However, the EMD method has a limitation that is the mixed frequencies problem (or mode mixing). That is, there is more than one frequency that exists in an IMF, or a frequency is present in two different IMF functions. This will lead to false results for the physical nature of each IMF received.

The EEMD method was improved by Z.H. Wu and N.E. Huang (2009) using EMD to rectify the mode-mixing problem. Accordingly, the original data was added to a white noise series (Gaussian noise) with finite amplitude. Then, the data is decomposed into IMFs using the EMD method for new time series. The IMFs received from the EEMD method significantly reduced the mode-mixing phenomena [14]. Usually, the amplitude of white noise at 0.2-0.4 times the standard deviation of the original data and number of repetitions of the filtering process is several hundred times.

The steps of the EEMD method are as follows:

i) Add a white noise series to the original data

ii) Decompose the data with added white noise into IMFs by EMD

iii) Repeat steps 1 and 2 as many times as is required until the envelopes are symmetric with respect to zero (note that each time a different white noise series is added)

iv) Obtain the ensemble means of the corresponding IMFs of the decompositions as the final result.

To determine the average period of each IMF, the following formula is proposed [1]:

$$AC_k = n/Peaks_k$$

In which, Ac_k is the average period of k^{th} IMF, n is the sample size or the length of original data. $Peaks_k$ is the number of local extreme peak values of the k^{th} IMF.

SST and wind speed data have been measured at Vietnamese coastal stations from since the mid-20th century. However, until 1993, data measured synchronization was continuous and comprehensive. After analysis and quality assessment of data, SST and wind speed observed from 1993 to 2015 at 10 stations are used in the study, including: Bai Chay, Hon Dau, Hon Ngu, Con Co, Son Tra, Quy Nhon, Phu Quy, Vung Tau, Con Dao, and Phu Quoc.

Oceanic Niño Index (ONI) is obtained from the National Oceanic and Atmospheric Administration (NOAA) [15]. ONI is running 3-month means of the SST anomaly across the Niño 3.4 area (5°N-5°S, 120°E-170°W). It is a standard that NOAA uses to determine the El Niño (warm phase) and La Nina (cold phase) in the tropical Pacific region.

Result and discussion

Determine ENSO winter events

The El Niño and La Nina events are determined from the ONI. A ENSO event occurs when ONI exceeds or equals the threshold of ± 0.5 in five consecutive months. The years in which ONI is greater than or equal to 0.5 is an El Niño year, and the years in which ONI is less than or equal to -0.5 is a La Nina year. ENSO winters are the years that ENSO occurs in winter (months 12, 1, and 2). December is the month of the previous year and January and February are the months of the following year. The neutral years are the years that ENSO does not occur throughout the year (Table 1).

There are seven El Niño winter events, seven La Nina winter events and nine neutral years.

Decompose SST and wind speed data of coastal stations

Decomposition by EEMD shows that, there are 13 components decomposed, in which intraseasonal oscillations is IMF4, IMF5 and IMF6 components (Table 2). IMF4 component is QBWD oscillation (10-20 days period). IMFs components have frequencies close together is IMF5 and IMF6 be combined into a single component to make sure of the physical meaning of the oscillation [14]. Taking the average of the IMF5 and IMF6, we obtained a 30-60 days period oscillation, called an MJO.

Table 1. The ENSO years and neutral years.

No	El Niño	La Nina	ENSO Winter		Neutral
			El Niño	*La Nina*	
1	1994	1995	1994	1995	1993
2	1997	1998	1997	1998	1996
3	2002	1999	2002	1999	2001
4	2004	2000	2004	2000	2003
5	2006	2007	2006	2007	2005
6	2009	2010	2009	2010	2008
7	2015	2011	2015	2011	2012
8					2013
9					2014
Total	**7**	**7**	**7**	**7**	**9**

Table 2. ISV of SST and wind speed (ws).

Station/IMF	IMF4		IMF5		IMF6	
	ws	*SST*	*ws*	*SST*	*ws*	*SST*
Bai Chay	14	16	27	30	41	67
Hon Dau	14	15	27	31	50	65
Hon Ngu	14	16	29	31	55	47
Con Co	15	15	29	32	48	53
Son Tra	14	16	27	31	56	70
Quy Nhon	14	17	23	32	48	63
Phu Quy	17	16	33	33	57	55
Vung Tau	14	16	30	35	49	68
Con Đao	16	16	33	32	66	48
Phu Quoc	15	16	21	34	53	38

Unit: days.

From here, ISV of SST in 10-20 days period is presented as SST QBWO; ISV of SST in 30-60 days period is presented as SST MJO; similarly for wind speed is WS QBWO and WS MJO.

Assessing the effect of ENSO to ISV

Correlation between ENSO and ISV:

Using lead/lag correlation analysis (SST Niño had a 3.4 lead of 60 months longer than ISV) between interannual variation (IAV) of SST Niño 3.4 and interannual variation of ISV, results show that at the time of ENSO activity (zero time), the effects of ENSO on ISV were not significant in most stations with low correlation coefficients (from -0.2 to 0.3). However, at the time of SST Niño 3.4 lead 40-50 months than ISV, the correlation between SST Niño 3.4 and ISV is significant at most stations (Fig. 1A, 1B, 1C, 1D, and Table 3):

- The IAV of SST Niño 3.4 has a negative correlation with the IAV of SST-QBWO (from -0.1 to -0.6) and have a positive correlation with IAV of SST-MJO (from 0.2 to 0.7) in at most of the stations.

- IAV of SST Niño 3.4 has a negative correlation with IAV of WS-QBWO (from -0.3 to -0.6) and has a negative correlation with IAV of WS-MJO (from -0.4 to -0.7) at most of the stations.

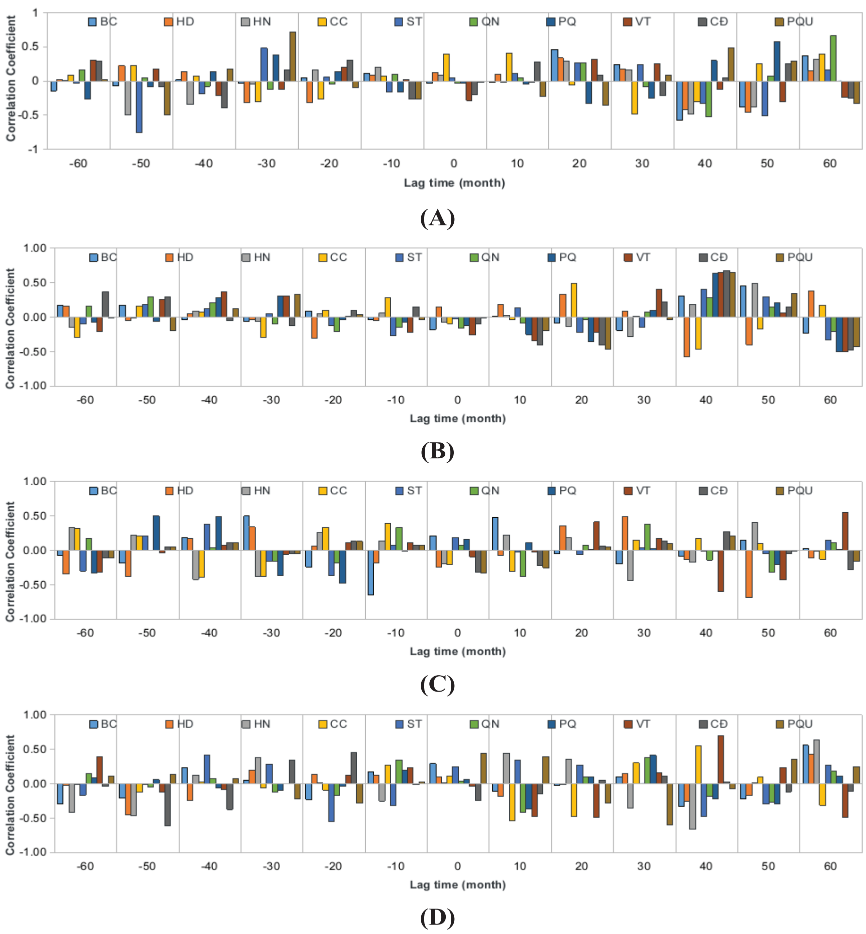

Fig. 1. The lead/lag correlation coefficient between the IAV of SST Niño 3.4 and the IAV of ISV. (A) IAV of SST Niño 3.4 and SST-QBWO; **(B)** IAV of SST Niño 3.4 and SST-MJO; **(C)** IAV of SST Niño 3.4 and wind speeds QBWO; **(D)** IAV of SST Niño 3.4 and WS-MJO.

Table 3. The correlation coefficient between the IAV of SST Niño 3.4 and the IAV of ISV at the time of SST Niño 3.4 lead 40-50 months than ISV (the 95% statistically significant correlation coefficient is marked by*).

Stations	Periods			
	10-25 days		30-60 days	
	SST	*WS*	*SST*	*WS*
Bai Chay	-0.58*	-0.09	0.31*	-0.33*
Hon Dau	-0.42*	-0.14*	-0.57*	-0.25*
Hon Ngu	-0.48*	-0.17*	0.19*	-0.66*
Con Co	-0.3*	0.18*	-0.47*	0.56*
Son Tra	-0.33*	-0.01	0.41*	-0.47*
Quy Nhon	-0.52*	-0.14*	0.28*	-0.18*
Phu Quy	0.3*	-0.01	0.64*	-0.22*
Vung Tau	-0.12	-0.6*	0.65*	0.70*
Con Đao	0.04	0.27*	0.68*	0.03
Phu Quoc	0.49*	0.21*	0.65*	-0.08

The average of the absolute value of the correlation coefficient between IAV of SST Niño 3.4 and IAV of ISV was calculated and presented in Table 4.

Table 4. The average of the absolute value of the correlation coefficient between IAV of SST Niño 3.4 and IAV of ISV.

IAV of ISO/ stations	Northern stations	Central stations	Southern stations
SST-QBWO	0.49	0.36	0.21
WS-QBWO	0.13	0.08	0.36
SST-MJO	0.35	0.45	0.66
WS-MJO	0.41	0.35	0.27

From Table 4, we could see that the effects of ENSO on SST-QBWO decrease from north to south, while the effects of ENSO on WS-QBWO at southern stations are higher than northern stations. In contrast, the effects of ENSO on SST-MJO increase from north to south, and the effects of ENSO on WS-MJO decrease from north to south, and this may be due to the influence of terrain and shoreline shape. In the following section, we assess the different levels of effect of ENSO to ISO from SST and wind speed in the El Niño and La Nina phases.

Effects of ENSO to ISV of SST and wind speed in El Niño and La Nina:

In order to research the changes of ISV on El Niño and La Nina conditions, multi-year monthly means of ISV over all stations were calculated over a full time period of 1993-2015 and for the El Niño and La Nina years. The result showed that SST-QBWO had phase transitions in mid-October when winter monsoons prevailed in the South China Sea. In the La Nina condition, SST-QBWO obtained positive values for the winter, with a peak in December; and negative values in the spring and fall, with a peak in July and an increasing trend held until the end of October (phase two). Under El Niño conditions, SST-QBWO changed the opposite with low

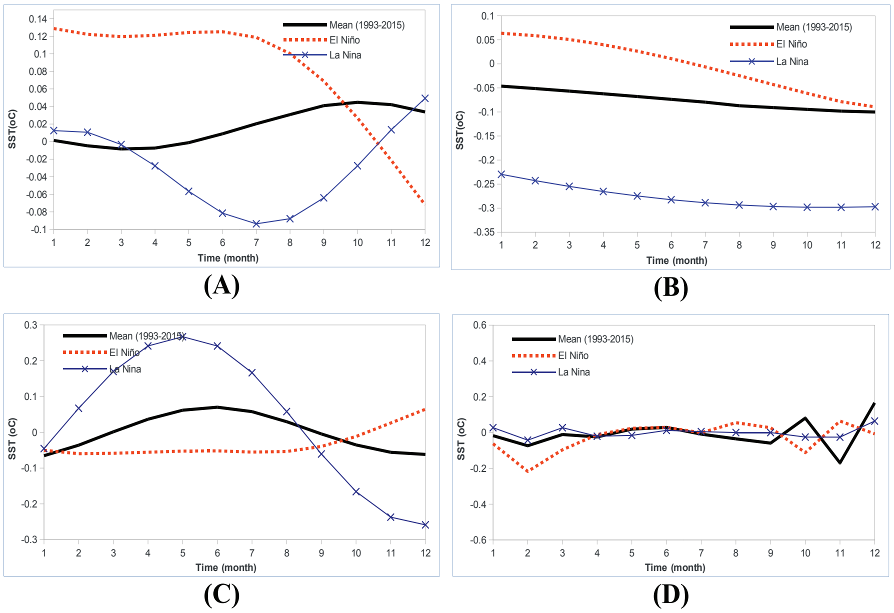

Fig. 2. Fluctuation of multi year monthly mean of ISV across all stations in a full time period 1993-2015 and El Niño, La Nina years. (A) SST QBWO, **(B)** SST MJO, **(C)** WS QBWO, **(D)** WS MJO.

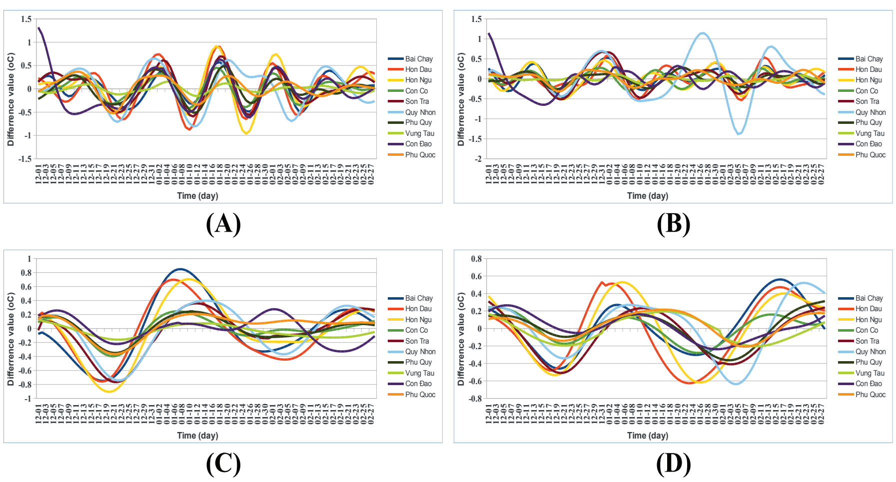

Fig. 3. Fluctuation difference value of SST ISO between ENSO winter and neutral winter at each stations. (A) SST QBWO between El Niño and neutral winter years, **(B)** SST QBWO between La Nina and neutral winter years, **(C)** SST MJO between El Niño and neutral winter years, **(D)** SST MJO between La Nina and neutral winter years.

peaks in December and was enhanced from January to September (Fig. 2A). WS-QBWO had phase transitions in February and September, when winter and summer monsoons began reducing. In La Nina condition, WS-QBWO obtained positive values in spring and summer with the high peak in May, and the obtained negative values in fall and winter at a low peak in December. In El Niño condition, WS-QBWO changed opposite with negative values from January to October. The amplitude of WS-QBWO in the winter less than in summer and in El Niño condition less than La Nina condition (Fig. 2C).

In Neutral and La Nina conditions, SST-MJO obtained negative values across a full year. In all conditions, SST-MJO has a decreasing trend throughout the year. The SST-MJO value for La Nina was strong, and more steadily decreasing than El Niño and Neutral conditions (Fig. 2B). ENSO has not significant effect to WS-MJO from January to the end June when WS-MJO-less change. WS-MJO only changes from July to December. The amplitude of WS-MJO in El Niño condition is less than La Nina condition (Fig. 2D).

Thus, ENSO's effect on SST-ISV was more significant than WS-ISV. There is the opposite phase of the effect of ENSO to SST-QBWO and WS-QBWO during El Niño and La Nina conditions.

The effect of ENSO to ISV from SST and wind speed in ENSO winter years:

Calculation was conducted to find the difference of ISV values between ENSO winter and neutral winter months at each station. Fluctuation of this difference showed that, there were four QBWO and two MJO occurrences in the three months of winter (Fig. 3). The next step was to calculate the standard deviation of the above differences. This standard deviation values reflect the amplitude of ISV during ENSO winter years. The standard deviation of the difference of SST-QBWO obtained high values at Hon Dau, Con Dao, Quy Nhon, and the lowest at Vung Tau (Fig. 4A). The standard deviation of the differences of SST-MJO decrease from northern stations to southern stations. Almost all stations had fluctuations of SST-MJO in La Nina winter months greater than in El Niño winter months (Fig. 4B). The standard deviation values of WS-QBWO at Son Tra, Quy Nhon, and Vung Tau stations were lower than the remain stations. Specially, Phu Quy station had the highest value (Fig. 4C). The standard deviation value of WS-MJO was highest at Phu Quy too (Fig. 4D). This due to Phu Quy Island is located in the sea area with strong winds stress compared to other stations.

Conclusions

ENSO's effects are significant to the

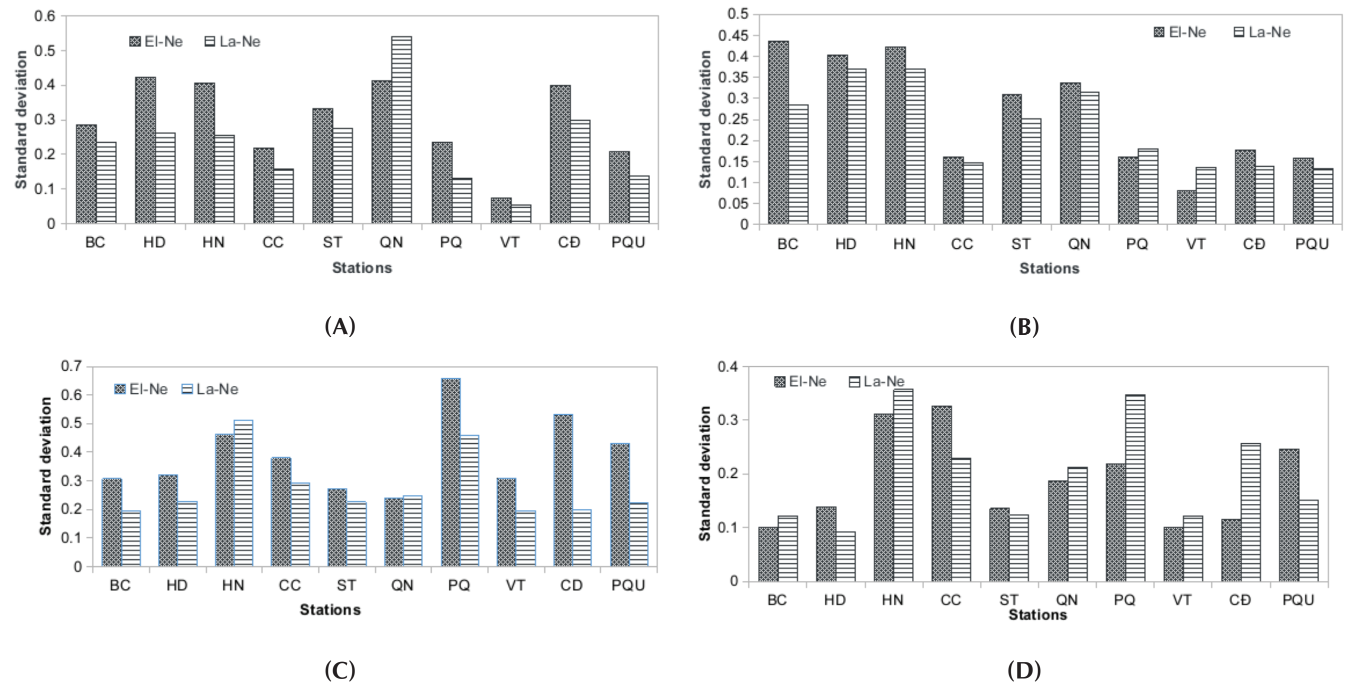

Fig. 4. The standard deviation of difference between SST ISV, WS ISV in ENSO winter and neutral winter at each stations. (A) SST QBWO in El Niño winter year, **(B)** SST MJO in La Nina winter year, **(C)** WS QBWO in El Niño winter year, **(D)** WS MJO; El-Ne is difference between El Niño and neutral year; La-Ne is difference between La Nina and neutral year.

intra-seasonal oscillation of SST and wind speed at the coastal stations in both the QBWO and the MJO. The effect of ENSO on SST-MJO tends to increase from north to south, while the effect of ENSO on WS-MJO tends to decrease from north to south. The effect of ENSO on SST-QBWO decreases from north to south, and the effect of ENSO on WS-QBWO at the southern stations are higher than that of the northern stations. ENSO effects aresignificant to SST-ISO than WS-ISO. There are the opposite phases of the effect of ENSO on SST-QBWO and WS-QBWO during El Niño and La Nina conditions. There are four QBWO and two MJO occurrences in the three months of winter every year.

REFERENCES

[1] Johnny C.L. Chan, W. Ai, J. Xu (2002), "Mechanisms responsible for the maintenance of the 1998 South China Sea summer monsoon", *Journal of the Meteorological Society of Japan*, **80(5)**, pp.1103-1113.

[2] Tsing-Chang Chen, Jau-Ming Chen (1993), "The 10-20-day mode of the 1979 Indian monsoon: Its relation with the time variation of monsoon rainfall", *Mon. Wea. Rev.*, **121**, pp.2465-2482.

[3] T-C Chen, J-M. Chen (1995), "An observational study of the South China Sea monsoon during the 1979 summer: onset and life cycle", *Mon. Wea. Rev.*, **123**, pp.2295-2318.

[4] T-C. Chen, M-C. Yen, S-P. Weng (2000), "Interaction between the summer monsoon in East Asia and the South China Sea: Intra-seasonal monsoon modes", *J. Atmos. Sci.*, **57**, pp.1373-1392.

[5] K-M. Lau, G-J. Yang, S-H. Shen (1988), "Seasonal and intraseasonal climatology of summer monsoon rainfall over East Asia", *Mon. Wea. Rev.*, **116**, pp.18-37.

[6] W.S. Kessler, M.J. McPhaden (1995), "Oceanic equatorial waves and the 1991-1993 El Niño", *Journal of Climate*, **8(7)**, pp.1757-1774.

[7] J.M. Slingo, D.P. Rowell, K.R. Sperber, F. Nortley (1999), "On the predictability of the interannual behavior of the Madden-Julian oscillation and its relationship with El Niño", *Quarterly Journal of the Royal Meteorological Society*, **125**, pp.583-609.

[8] H.H. Hendon, C. Zhang, J.D. Glick (1999), "Interannual variation of the Madden-Julian oscillation during austral summer", *Journal of Climate*, **12**, pp.2538-2550.

[9] D.E. Waliser, K-M. Lau, J.H. Kim (1999), "The influence of coupled sea surface temperature on the Madden-Julian Oscillation: A model perturbation experiment", *Journal of the Atmospheric Sciences*, **56**, pp.333-358.

[10] A. Fink, P. Speth (1997), "Some potential forcing mechanisms of the year-to-year variability of the tropical convection and its intraseasonal (25-70-day) variability", *International Journal of Climatology*, **17(4)**, pp.1513-1534.

[11] D.S. Gutzler (1991), "Interannual fluctuations of intraseasonal variance of near-equatorial zonal winds", *Journal of Geophysical Research*, **96**, pp.3173-3185.

[12] Wen Zhou, Johnny C.L. Chan (2005), "Intraseasonal Oscillations and the South China Sea summer monsoon onset", *Int. J. Climatol.*, **25**, pp.1585-1609.

[13] N.E. Huang, Z. Shen, S.R. Long, M.C. Wu, H.H. Shih, Q. Zheng, N-C. Yen, C.C. Tung, H.H. Liu (1998), "The empirical mode decomposition and the Hilbert spectrum for nonlinear and nonstationary time series analysis", *Proc. R. Soc. London*, **Ser. A**, **454**, 903-993.

[14] Z.H. Wu, N.E. Huang (2009), "Ensemble empirical mode decomposition: A noise-assisted data analysis method", *Adv. Adapt. Data. Anal.*, **1(1)**, pp.1-41.

[15] http://ggweather.com/enso/oni.htm.