Low-Level Wind Variability over the Indochina Peninsular during Boreal Winter

Sirapong Sooktawee, Usa Humphries, Atsamon Limsakul, and Prungchan Wongwises

***Abstract*—Low-level wind can be used to represent winter monsoon as an index constructed from 850 hPa wind. The vector empirical orthogonal function (VEOF) method is used to decompose variability of the low-level wind from JRA-25 reanalysis data during the boreal winter (December to February) over the Indochina peninsular. The first VEOF mode exhibits tropical anomalous easterlies over the southern region and anomalous southeasterlies over the central of region. A spatial pattern in positive phase of the first mode exhibits anomalous northeasterlies, and the pattern of negative phase reveals anomalous southwesterlies over the interior of the region. The variability of winter monsoon over the Indochina peninsular shows interannual variation, and long term variability is of interest. The relationship of winter monsoon over the Indochina peninsular to the East Asian winter monsoon (EAWM), which is a major climate feature during boreal winter, is investigated and discussed.**

***Index Terms*— Indochina peninsular, variability, vector empirical orthogonal function, winter monsoon.**

I. Introduction

Winter monsoon is a one of major climate features over the Indochina peninsular region consisting of Cambodia, Laos, Myanmar, Singapore, Thailand, Viet Nam, and some territory of Malaysia, that locates between the Indian Ocean and the Pacific Ocean. Climate of the Indochina peninsular has been affected by the Indian monsoon and the East Asian monsoon. During summer season, the Indian summer monsoon is stronger than the monsoon in the East Asian region, but the EAWM is dominant during winter season with less influence from the Indian summer monsoon [1]. Most of the studies over the Indochina peninsular focus on the Asian summer monsoon or during wet season [2]-[5].

Nevertheless, the EAWM related to Siberian high that is an important factor of climate variation and wind circulation during winter season [6]. There are two principal properties of EAWM consisting of its intensity and trough axis that influence climate on parts of the Indochina peninsular. Its intensity and trough positioning are described by the trough intensity index (TII) and the trough axis index (TAI) [7].

In generally, low-level wind flows over the Eurasian continent during winter season is split into two branches; the first branch travels eastward to subtropical western Pacific, and the second branch turns along the coasts of East Asia, penetrates to the South China Sea, and influences on the tropical regions [8]. To measure the strength of EAWM, an index of low-level wind at 850 hPa can be used [9]. At lower levels, wind driven by pressure gradient force resulted from difference of high and low pressures, Coriolis force, and more effect from the Earth surface exert friction on the air movement.

Variability of wind can be characterized by the VEOF method. This method succeeds to decompose surface wind from observation representing mesoscale region, in terms of space and time. Eigenvector exhibits corresponding wind field, and principal component presents its variability in terms of time series that is relative to wind speed [10]. It is applied for monsoon analysis as well [11], [12]. Variability of wind over the Indochina peninsular, which is regional scale, is of interest to determine major modes during winter season influenced by the EAWM.

This work aims to determine modes of the winter monsoon variability by apply VEOF method to anomalies of wind at 850 hPa level (here after referred to low-level wind) over the Indochina peninsular. Occurrences of principal modes are classified into positive and negative phases. Their relationships to EAWM indices are investigated by correlation coefficients that aim to exhibit possibility of their linkages. It will give more understanding of the EAWM influences on climate and environmental impacts over the Indochina peninsular.

II. Data and Methods

In this study, the monthly mean data set of zonal wind, meridional wind, seal level pressure, and geopotential height of Japanese 25-year reanalysis (JRA-25) long-term reanalysis cooperative research project [13] carried out by the Japan Meteorological Agency (JMA) and the Central Research Institute of Electric Power Industry (CRIEPI) from 1979 to 2010 are used for analysis. This dataset has 1.25° × 1.25° horizontal resolution, whereas the famous data set the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCAR/NCEP) reanalysis

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dataset that having 2.5° × 2.5° horizontal resolution [14] is used for climatic representative comparison. The vertical resolution of JRA-25 data set extends from 1000 to 1 hPa with 23 vertical pressure levels including a level at 850 hPa. The study period (32 years of 1979-2010) is long enough for climatic representation. The study area representing Indochina peninsular is a domain of 5-30°N, 90-110°E as shown in Fig. 1.

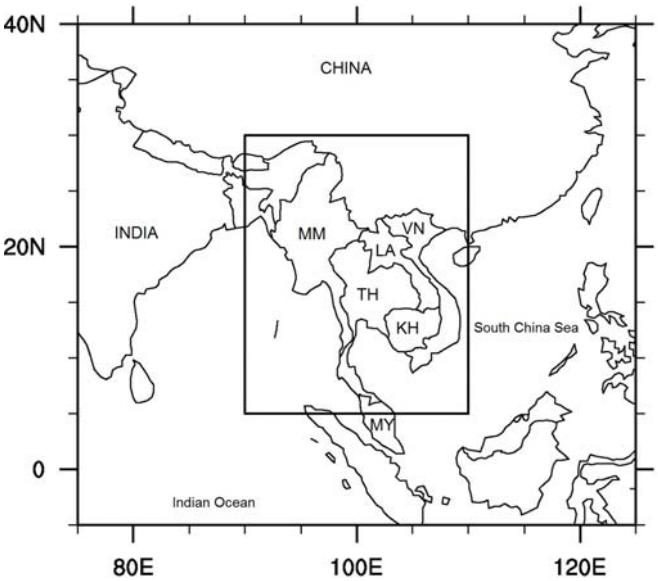

Fig. 1. The study domain (a rectangular box) representing the Indochina peninsular. KH is Cambodia, LA is Laos, MM is Myanmar, MY is Malaysia, TH is Thailand, and VN is Viet Nam.

To decompose mode of wind anomalies, the method of Empirical Orthogonal Function for vector is utilized. Zonal and meridional winds are ingredient of wind vector. Before analysis, their anomalies are formed in complex number format. The form represents anomaly in terms of wind speed and wind direction, presenting as

$$W' = WS' e^{iWD'}, \tag{1}$$

where WS' is an magnitude related to zonal and meridional anomalies, WD' is a direction corresponding to WS', and W' is a component forming from WS' and WD'. The direction of WD' is measured from the East in counterclockwise direction that differs from general definition in the meteorological wind direction measuring from the North in clockwise direction [15]. In addition, the complex form for the analysis is an exponential form of a complex number. It can be converted to a rectangular form as well. A matrix S of complex numbers, W', is used to determine a Hermitian matrix as follows:

$$\mathrm{H} = \frac{1}{\mathrm{M}} \mathrm{SS}^{\dagger}, \tag{2}$$

where H is a Hermitian matrix, S is a matrix of complete W' components that represented by N × M rectangular matrix, $\mathrm{S}^{\dagger}$ is the complex conjugate transpose of S. Thus all eigenvalues of Hermitian are given by

$$\mathrm{H}\hat{\mathrm{E}}_{\mathrm{j}} = \lambda_{\mathrm{j}} \hat{\mathrm{E}}_{\mathrm{j}}\ ; \qquad \mathrm{j} = 1,\mathrm{N}, \tag{3}$$

where $\hat{\mathrm{E}}_{\mathrm{j}}$ is the jth eigenvector and λ_{j} is the jth eigenvalue.

Whereas, weighting coefficient (c_{m}) corresponding to the mth vector of the S matrix (S_{m}) is determined by

$$c_{\mathrm{m}} = \hat{\mathrm{E}}^{\dagger} \mathrm{S}_{\mathrm{m}}, \tag{4}$$

where $\hat{\mathrm{E}}^{\dagger}$ is the complex conjugate transpose of eigenvectors.

The spatial mode (VEOF) is represented by eigenvector presenting in terms of anomalous direction and relative anomalous magnitude for each grid point. Temporal variation is spanned by utilization of the coefficient expansion as present in equation (4), which known as the principal component (PC). Time series plot of the coefficient magnitudes represents scaling of the anomalous magnitude of each mode for whole grid cells, and that consists of real and imaginary parts. The correlations of temporal variations of corresponding spatial pattern VEOFs to others EAWM indices are determined by Pearson correlation method, leading to exhibit relationship of them. Indices of EAWM given by Wang et al. consist of a trough intensity index and a trough axis index [7] that is used for this purpose.

III. Low-Level Wind Variability

Before decompose modes of low-level wind, climatic circulation patterns of JRA-25 and NCEP/NCAR over the Indochina peninsular domain are compared to ensure representative of JRA-25. Both of them agree with similar circulation to capture low-level wind circulation during the boreal winter over the Indochina peninsular domain (Fig. 2). A wider domain covering most of Asia given by JRA-25 data exhibits low-level circulation, sea level pressure distribution, and geopotential high contour as shown in Fig. 3, respectively. They present easterlies over the equator of the ICP region (Fig. 2.) that link to tropical easterlies connecting to the Australian summer monsoon by cross-equatorial flow over the South China Sea and Celebes Sea [1]. Convergent exhibits over the East Indian Ocean near Sumatra Island. Westerlies dominate over mid-latitude of Eurasia continent, and turn below 50°N in the North Pacific Ocean due to influences of Siberian high and Aleutien low (Fig. 3).

Decomposition of low-level wind anomalies results the first eigenvector (VEOF1) and the second eigenvector (VEOF2) (Fig. 4) accounting for 46.58% and 13.77%, respectively, that is 60.35% of the total. The eigenvector spatial pattern consists of plenty of vectors. A particular vector shows the direction of low-level wind anomaly that represents for a corresponding grid cell. The magnitude of a vector represents to the relative magnitude of wind anomaly at the grid cell. A spatial pattern of VEOF1 (Fig. 4a) shows anomalous wind blows to the continent and splits into two pathways consisting of northward and westward. Moist air from the South China Sea travels more to the Indochina peninsular by the anomalous wind, resulting to rain during winter season over some parts of the region. Anomalous

southerlies and southeasterlies over the northern Indochina peninsular move northward due to low pressure centering at 30°N, 102°E (Fig. 3).

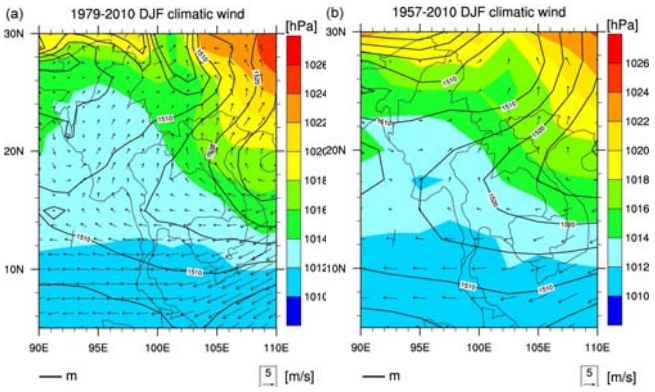

Fig. 2. Boreal winter climatologies of low-level wind (vector), sea level pressure (shaded contour), and geopotential height at 850 hPa (contour line) over the Indochina peninsular given by (a) the JRA-25 and (b) NCEP/NCAR data of 1979-2010 and 1957-2010, respectively.

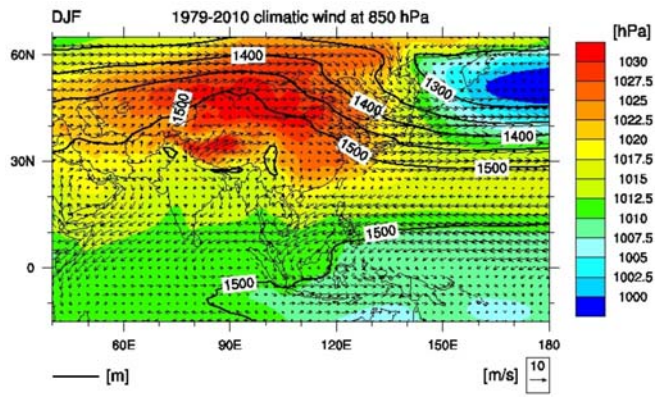

Fig. 3. Boreal winter climatology of low-level wind (vector), mean sea level (shaded contour), and geopotential height at 850 hPa (contour line) of a period 1979-2010.

On the other hand, anomalous northerlies on the northern part of Indochina peninsular move southward as shown in the second mode. The anomalous northerlies turn along the coast of Viet Nam and then connect to easterlies on southern part of the region (Fig. 4b) with less contribution of the second mode to low-level wind variability than the first, but it embeds in the variability of wind over the region also.

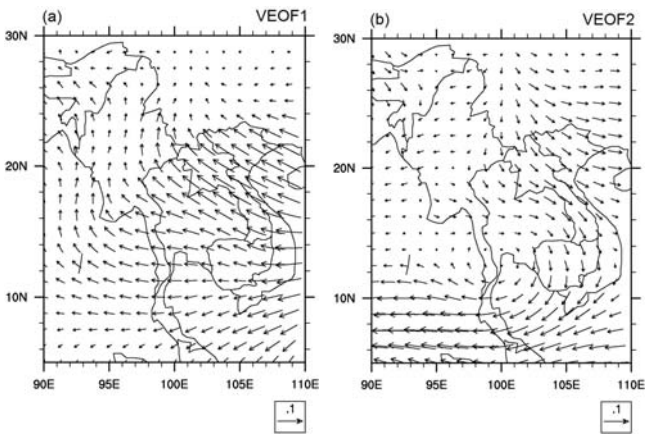

Fig. 4. (a) The first VEOF mode of low-level wind for a period of years 1979-2010, and (b) the second VEOF with the similar level and period.

Whereas temporal variation exhibits the winter monsoon variability defined by relative magnitude to wind anomaly departs from mean, representing for whole region (Fig. 5). According to the rectangular form of complex number, the PCs show changes of real and imaginary parts that imply to zonal and meridional anomalies corresponding to VEOF1 (Figs. 5a and 5b) and VEOF2 (not present here). To confirm the existences of positive and negative phases, circulations in 1998 and 1999 representing negative and positive phases of both zonal and meridional anomalies are investigated as present in Fig. 6. A criterion is used to classify them into positive and negative phases of anomalous zonal and meridional PC1s, which is a normalized value exceeding a range ± 1 time of standard deviation.

The circulation during boreal winter in 1998 (Fig. 6b) represents negative phases of anomalous zonal and meridional PC1. The circulation exhibits stronger southwesterlies over northern part of Thailand, Laos, and Viet Nam than the circulation positive phases in 1999 (Fig. 6a). It implies to less influence of EAWM, thus southwesterlies prevail over northern part of these countries. Whereas easterlies prevail over southern part of the Indochina region, and extend to cover the interior of the region when positive phases of both presenting.

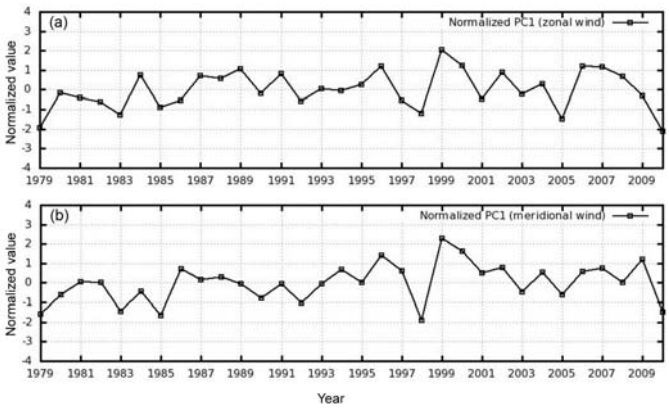

Fig. 5. Temporal variations of (a) real part and (b) imaginary part of the normalized principal component corresponding to VEOF1 (PC1).

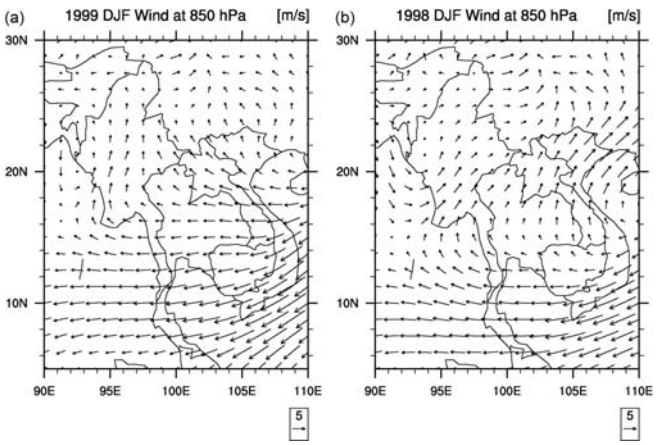

Fig. 6. Mean low-level wind fields of (a) a positive phase year (1999) and (b) a negative phase year (1998) during boreal winter.

However, the spatial patterns of VEOFs do not present information in details of positive and negative spatial patterns. Apparent of strong southwesterlies over northern part of the countries during negative phase (Fig. 6b), and apparent of easterlies extending from southern part to cover the interior of Indochina peninsular during positive phases (Fig. 6a) are of interest. It is important to exhibit spatial patterns corresponding to changes of anomalous zonal and meridional PC time series. Because of more contribution of VEOF1, composite analysis is used to depict spatial patterns of positive and negative phases of PC1 only. Selected years for composite analysis present in Table I.

TABLE I: CASES FOR COMPOSITE ANALYSIS OF ANOMALOUS ZONAL AND MERIDIONAL PRINCIPAL COMPONENTS OF THE FIRST MODE.

Positive		Negative	
Zonal	Meridional	Zonal	Meridional
1989	1996	1979	1979
1996	1999	1983	1983
1999	2000	1998	1985
2000	2009	2005	1992
2006		2010	1998
2007			2010

Composite anomalous circulation of positive PC1 exhibits strong anomalous northeasterlies over southern Myanmar, Thailand, Cambodia, Laos, and Viet Nam, which corresponds to characteristic of EAWM (Fig. 7a). This is a cause of easterlies apparent extending from southern part to cover interior of the Indochina peninsular in 1999 (Fig. 6a). It can imply to easterlies over southern part of the Indochina peninsular (Fig. 2) are strengthened by weakening of southeasterlies caused from dominant northeasterlies of positive phase (Fig. 7a). Unlike composite of positive PC1, the anomalous circulation of negative phase (Fig. 7b) presents dominant anomalous wind travels northeastward from the Andaman Sea and the Gulf of Thailand to Thailand, Cambodia, Laos, and Viet Nam, resulting in weakening of easterlies on the interior of the Indochina peninsular. This pattern implies to weak influence of EAWM. In addition, easterlies near equator are enhanced due to weak circulation over the area 90-102°E, 5-10° N (Fig. 7b) that implies to weak influence of EAWM enhances tropical easterlies. This is consistent with the study [16].

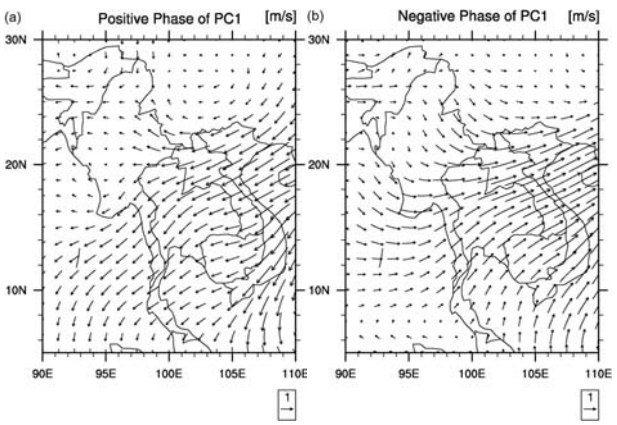

Fig. 7. Composite low-level wind anomalies of PC1 (a) positive and (b) negative phases, respectively.

Thus, dominant positive (negative) phase of anomalous zonal and meridional wind perhaps imply to more (less) influence of EAWM on the Indochina peninsular. Thus, it is of interest to examine relationship of variability over the Indochina peninsular representing by PCs to EAWM features consisting of its intensity and trough behavior.

IV. RELATIONSHIP TO EAWM

To examine the relationship, comparisons of anomalous real and imaginary PC1 time series to EAWM features representing by TII and TAI are used. Pearson correlation method is used to determine the correlation coefficients of them. Result shows small values of correlation coefficients. Possibility is the Indochina peninsular locates at area influenced by the Indian tropical monsoon, the Western North Pacific monsoon, and the East Asian subtropical monsoon [4]. In detail, correlations between temporal variations of normalized real part PC1 to TII and TAI are 0.12 and 0.09, respectively, as present in Table II. They show weak correlations to EAWM indices, which imply less effect of EAWM on anomalous zonal wind over the region. However, small positive values mean that zonal anomalies are a little strengthened by EAWM, which agree with the extending of easterlies in the positive phase. Correlation coefficients of normalized imaginary PC1 to TII and TAI are 0.06 and 0.18, respectively. They also show weak correlations to EAWM indices, but normalized imaginary PC1 implying to meridional anomalies are related to trough positioning more than trough intensity. On the other hand, EAWM intensity quite more relate to zonal anomalies than meridional anomalies. For trough positioning, meridional anomalies have better correlate to TAI than zonal anomalies to it.

In terms of variability, temporal PC1 time series show interannual change. Since correlations of them are small, temporal variations of anomalous zonal and meridional PC1 to EAWM indices present in Fig. 8a-8d. Time series of them show some good correlation such as during 2005-2009. Zonal anomaly is weak in 2005, and gets stronger in next three consecutive years, after that backs to neutral condition (Fig. 8a). Its variability perhaps is long-term change that will possibly more relate to EAWM.

On the other hand, three consecutive events of positive Indian Ocean dipole (IOD) appear in the years 2006 to 2008 [17]. Whereas normalized PC1 of zonal anomalies in 2006 and 2007 exceed the criterion, but the value of 2008 is under the criterion, and also closes to exceed the criterion (Fig. 8a). In this case, three consecutive events of positive anomalous zonal PC1 in 2006-2008 present at the same time of three consecutive positive IOD events with high TII.

TABLE II: CORRELATION COEFICIENTS OF PC1S TO TII AND TAI

EAWM indices	Anomalous of PC1	
	Zonal	Meridional
TII	0.12	0.06
TAI	0.09	0.18

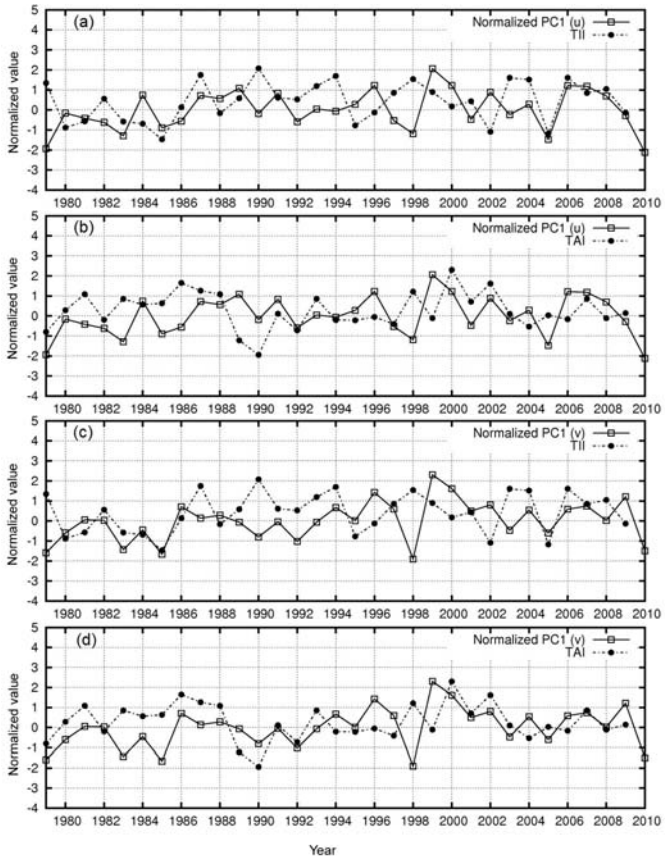

Fig. 8. Time series of normalized PC1s of zonal anomalies (u) with (a) TII and (b) TAI, and meridional anomalies (v) with (c) TII and (d) TAI, respectively.

V. Conclusion

This study uses the VEOF method to decompose low-level wind over the Indochina peninsular into spatial modes and corresponding temporal variations. The first mode (VEOF1) explains 46.58% of the total variance. In addition to positive and negative phases of PC1, southwesterlies prevail over northern part of Thailand, Laos, and Viet Nam in 1998 with appearance of negative phase. Whereas easterlies prevail over southern part of the Indochina region, and extend to cover the interior of the region when the positive phase exhibits in 1999. It implies to low-level wind variability over the Indochina peninsular gets more (less) influence of northeasterlies during appearance of positive (negative) phase during the boreal winter.

Composite analysis shows positive and negative phases of anomalous zonal and meridional PC1s. The composite positive pattern of low-level wind anomalies shows enhancement of northeasterlies over southern part of Myanmar, Thailand, Cambodia, Laos, and Viet Nam. This spatial pattern is consistent with characteristic of EAWM. For negative phase of winter monsoon over the Indochina region, anomalous southwesterlies dominate that oppose to the characteristic of EAWM. Therefore, positive (negative) phase of anomalous zonal and meridional wind perhaps implies to more (less) influence of EAWM on the Indochina peninsular.

Relationships of winter monsoon over the Indochina peninsular to EAWM features show weak correlations to EAWM. But correlation of the real part PC1 to TII shows some good correlation during 2005-2009. Its variability is possibly long-term change that will perhaps more relate to EAWM. On the other hand, three consecutive events of positive IOD appear in the years 2006 to 2008 [17] presenting at the same period of three consecutive high real part PC1 events during 2006-2008 with high TII events. Influences of more climate modes on the Indochina peninsular and underlie mechanism are required to investigate further.

Acknowledgments

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