Definition of new summer monsoon index for Vietnam region

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Received 20 September 2017; accepted 12 February 2018

Abstract:

In this study, we define a new summer monsoon index for Vietnam region (VSMI) by averaging 850hPa zonal wind (U850hPa) over the area of 5-15°N and 100-110°E using the 1981-2010 CFSR reanalysis data. The evaluation results show that VSMI index can reflect well the interannual variability of both low and high broad-scale circulation of the summer monsoon. On the intraseasonal timescale, the pentad-to-pentad VSMI index has a close relationship to the local summer monsoon rainfall observed. The correlation coefficients between VSMI index and rainfall are at 95% confidence level and show clearly effects of summer monsoon on the local rainfall due to terrain. The comparison results among three indices show that the VSMI index is the most suitable index in the term of describing summer monsoon for Vietnam region. In addition, features of summer monsoon as intensity, onset and withdrawal date as well as break event can be defined by the VSMI index.

Keywords: ***OLR, U850hPa, rainfall, summer monsoon, VSMI***

Classification number: ***6.2***

Introduction

Vietnam is located in the affected area of the Asian monsoon system, collided by a lot of monsoon systems, like Southern Asia, Eastern Asia as well as North-Western Pacific monsoons. Besides, monsoon circulations are also significantly influenced by topography, specifically Truong Son Mountains, lying along Vietnam and Laos' boundary [1]. Therefore, it is hard to predict the seasonal monsoons over Vietnam due to typical and immensely complex.

On the other hand, Vietnam has high mountains in the North-eastern zone and high-narrow Truong Son Mountains along the border of Vietnam-Laos. On the side adjacent to the sea, a fertile and narrow coastal lowland extends south from the Red River Delta to the Mekong Delta (Fig. 1). Therefore, climate regimes in Vietnam are strongly affected by both monsoon systems and local factors. Due to its terrain, Vietnam's climate varies greatly from north to south with seven climatic regions.

This mountainous system intercepts the south-western monsoon during the period of summer monsoon leading to the Foehn effect-well-known as hot and dry downslope wind. This wind often occurs in the North, North Central and South Central of Vietnam during summer. Additionally, due to topographical influence, a depression is formed above Indochinese Peninsula's northern part. This depression plays the role of a convergent zone, which changes zonal wind's direction from south-west to south-east before moving forward to the Gulf of Tonkin and the North of Vietnam (frequently observed in the North-East and North Delta regions). In other words, due to geographical and topographical features, the monsoon circulation in Vietnam is typical, complex and difficult to forecast.

Weather patterns in Vietnam during summer strongly depend on monsoon circulation, specifically the south-western monsoon blowing from the Bay of Bengal giving extreme humidity. For instance, hot and wet weather in the South of Vietnam and dry and hot weather in Central of Vietnam in the summer can be attributed to the Foehn effect. Besides, the weather during the summer is also controlled by the tropical Pacific Ocean air, originally coming from the North Pacific Subtropical High.

Be aware of the important relationship between the weather in Vietnam and summer monsoon; many studies have been conducted to propose indices for the purpose of determining and monitoring summer monsoon activity over several sub-regions, including the Central Highlands and the South of Vietnam [2-4] and Vietnam East Sea [5]. However, these studies have remained deficient in characterizing the activities of summer monsoon in Vietnam, especially its retreat. Moreover, previous studies mainly focus on the qualitative analysis, proposing the summer monsoon onset date. Based on the general definition of the summer monsoon index and the aim of the index proposed [5, 6], this study introduces our investigations of proposing a new summer monsoon index to

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describe summer monsoon for Vietnam region.

In general, most of the previous summer monsoon indices were essentially constructed from zonal wind at 850hPa (U850hPa) or combination of U850hPa and U200hPa or combination of U850hPa and rainfall. P.T.T. Huong, et al. (1999) used five-day running mean of rainfall and U850hPa to determine the summer monsoon onset over the Central Highlands and the South of Vietnam. The onset date was triggered following these criteria: i) five-day running mean of rainfall exceeds 25 mm and ii) U850hPa cease to blow from the east [2]. N.T.H. Thuan (2007) indicated that the differences in U850hPa between the region (2.5^0N-12.5^0N; 95^0E-115^0E and 20^0N-27.5^0N; 105^0E-120^0E) can be used to evaluate the variability of summer monsoon over the South region of Vietnam in ENSO phases [3]. From the simulations from RAM model for the years 1998, 2001, 2004 and 2010, N.M. Truong, et al. (2012) compared the ability of U850hPa, rainfall and upper-level temperature gradient indices in determining onset of summer monsoon over the South region of Vietnam. The results showed that the western wind index defined by the U850hPa is the most optimal, because it reflects correctly broad-scale circulation and correlates well with rainfall [4]. N.D. Mau, et al. (2016) determined monsoon onset over sub-regions of Vietnam using the five-day running means of U850hPa. Commonly, zonal wind at 850hPa plays an important role in those mentioned studies [7].

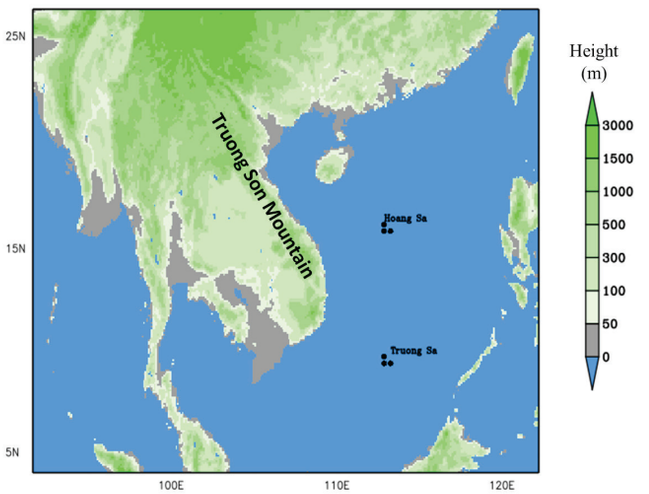

Fig. 1. The terrain map of Vietnam and neighboring countries [8].

Data and methods

The 30-yr (1981-2010) circulation data of CFSR (Climate Forecast System Reanalysis) used in this study are derived from National Center for Environmental Prediction - National Centers for Atmospheric Research (NCEP-NCAR). Daily mean wind data on 25x25 km resolution and in 850hPa, 700hPa, 500hPa and 300hPa layers of atmosphere are used. Additionally, the Outgoing Longwave Radiation (OLR) of CFSR data during 1981-2010 is employed.

To evaluate the performance of the summer monsoon index in describing summer monsoon rainfall, we use the daily mean rainfall observation data at 70 stations over Vietnam (Fig. 2). This 30-yr (1981-2010) daily mean rainfall is derived from National Hyro-Meteorological Service (NHMS).

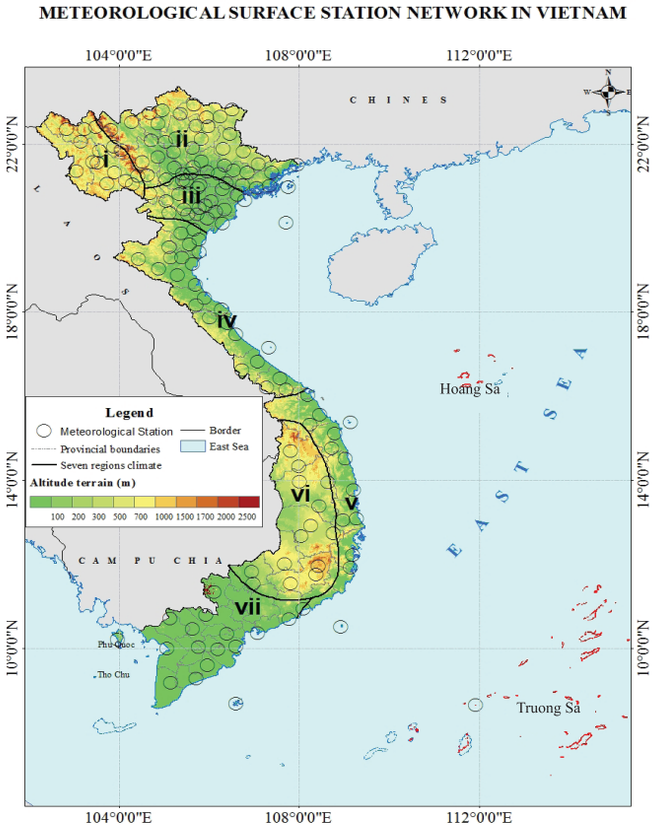

Fig. 2. The position of 70 meteorological stations was used in the study.

We define the new summer monsoon index based on the definition and physical characteristics of summer monsoon in Vietnam. The summer monsoon in Vietnam is the broad-scale circulation of Southwest monsoon, normally from May to September in each year [1]. The zonal wind in the 850hPa layer is employed as the representation of the Southwest monsoon. Results of analyzing winds in the 850hPa layer are the initial information for definition of the VSMI. The Empirical Orthogonal Function (EOF) Analysis for U850hPa is used in determining the principal waves/signals (major mode) during the summer.

The approach for definition of the VSMI can be followed by two steps:

(1) Choice of the variable and domain for defining the VSMI.

(2) Evaluating the performance of the VSMI in describing the activity of summer monsoon and summer monsoon

rainfall. Basically, the VSMI is defined the good summer monsoon index as it performs well the broad-scale circulation as well as summer monsoon rainfall. In this study, we evaluate the performance of newly defined VSMI in describing the broad-scale circulation based on the correlation coefficients with zonal wind in atmospheric layers (U850hPa, U700hPa and U300hPa). Referring the evaluation of performance in describing in local rainfall, we compare the ability of this VSMI index with the ability of two indices as SCSSM [5] and CSHL [3] based on the correlation coefficients maps.

Results and discussion

Choice of the variable and domain for defining the VSMI index.

The onset of Asian summer monsoon is characterized by reversal of broad-scale wind associated with sudden change from dry to rainy season. To be more specific, the onset of summer monsoon can be determined when eastern wind at 850hPa changes into western and rainfall occurs in large spatial scale, simultaneously. However, in some areas, rainfall sometimes occurs later or earlier than the change in direction of zonal wind, because of the effect of local factors or tropical turbulence. Especially, the correlation between zonal wind and rainfall is trivial in complicated topography areas or colliding zone of monsoon systems. Wang and Fan (1999) [6] employed OLR to define the onset of summer monsoon, because it reflects effectively the occurrence of broad-scale convection, representing activities of Inter-tropical Convergence Zone (ITCZ). Additionally, ITCZ is not significantly affected by local factors. In summary, 850hPa zonal winds and OLR can play an important role in defining the onset date of summer monsoon in Vietnam.

Figure 3 shows the U850hPa and OLR averaged over longitudes 100°E-110°E during the period 1981-2010. It is clearly illustrated that western winds and deep convection (OLR value less than 220 W/m^2) dominate during the onset of summer monsoon. From May to October, western winds (positive value) and deep convection are maintained. From mid-October, over most Vietnam, although western winds are replaced by eastern winds, showing the withdrawal of summer monsoon, low ORL values remain until the end of December. It can be inferred that developments of the western winds and OLR are homogeneous during the activity of summer monsoon, but it ceases with the retreat of summer monsoon. Therefore, it is necessary to use both zonal wind and OLR for defining the onset of summer monsoon; however, the withdrawal of summer monsoon is defined only by zonal wind.

The duration of summer monsoon onset is shorter than that of withdrawal. In early summer, the duration of onset is very short with the sudden reversal of wind direction from easterly to westerly and the appearance of low OLR values. Figure 3 shows that the declination angles of zonal wind at 850hPa and OLR in the onset of summer monsoon are large with approximately 90°E and much larger than that of summer monsoon withdrawal. The reason is that the rapidly northward movement of ITCZ causes rainy season in Vietnam in early summer, but the southward movement of ITCZ in late summer is slower. The activity of the ITCZ makes the Asian summer monsoon more typical and complicated to define the withdrawal date.

For Vietnam, in mid-May, easterly winds are replaced by westerly winds and the deep convection occurs (Fig. 4). In late summer (about mid-October), the values of zonal wind change from positive to negative, indicating the withdrawal of summer monsoon. However, the low values of ORL occur from mid-May to December. Besides, during summer monsoon activity, the values of zonal wind maximize in June and August and minimize in September. In other words, the correlation between zonal wind and OLR is low during the duration of summer monsoon.

The calculated result of circulation at 850hPa in the summer (Fig. 5) shows that the tropical jet stream blows

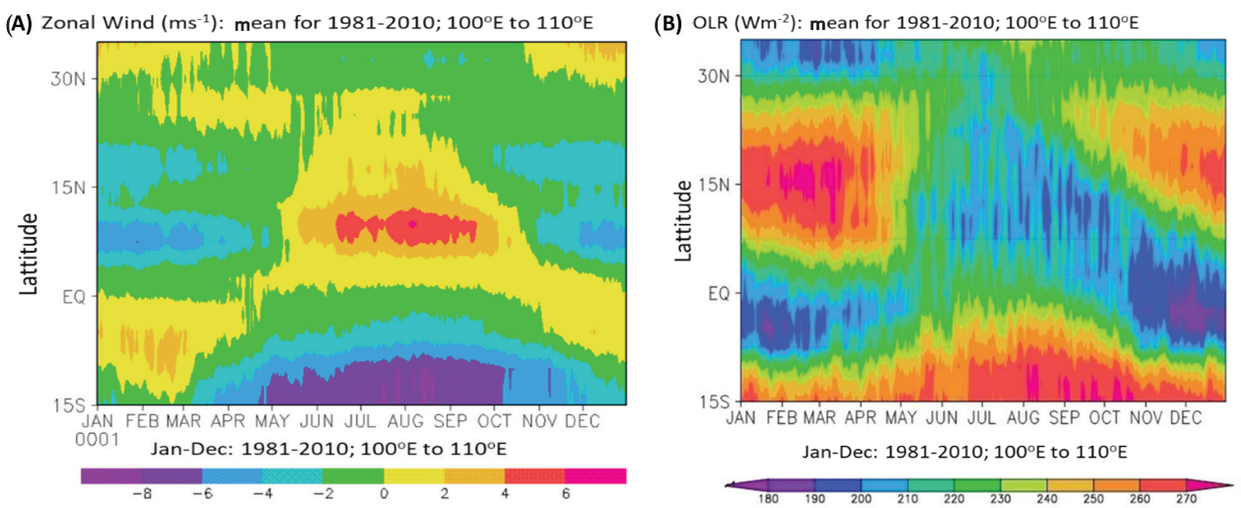

Fig. 3. Hovmöller diagram for composite mean for 1981-2010 and 100°E-110°E. (A) U850hPa (ms^{-1}), **(B)** OLR (Wm^{-2}).

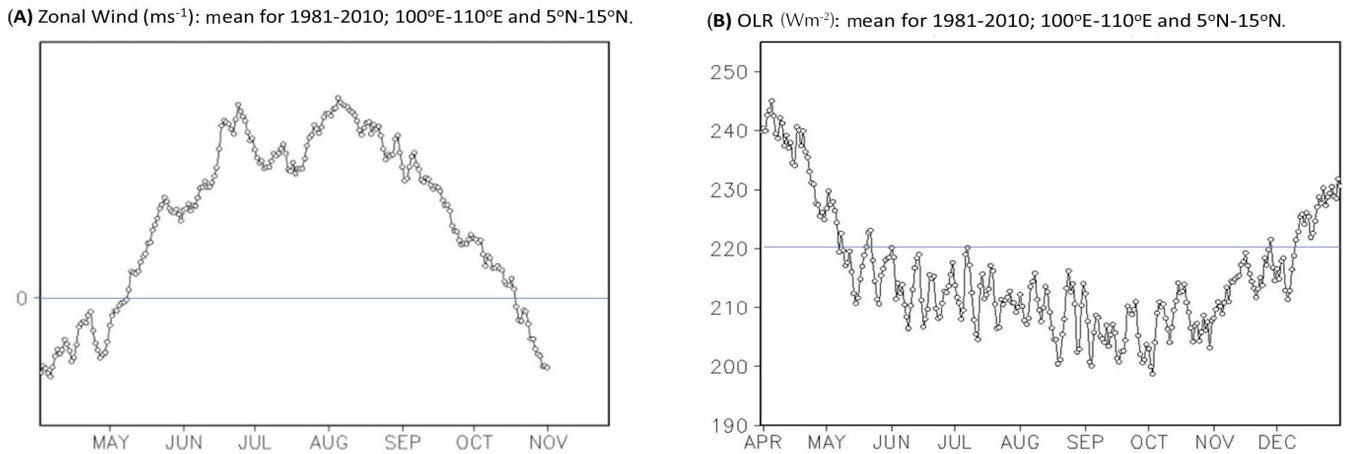

Fig. 4. Composite mean for 1981-2010; 100°E-110°E; 5°N-15°N. (A) U850hPa (ms^{-1})**, (B)** OLR (Wm^{-2}).

from the Southern hemisphere to the Northern hemisphere (also known as Somali jet stream). This jet stream acts as a connecting factor of tropical atmosphere between hemispheres. Somali jet stream has a horizontal scale of 20 latitude, covering regions of East Africa, Arabian Sea, India and Indochinese Peninsula. This jet stream is weak over Philippine region, thereafter combining with the above part of the North Pacific Subtropical High to form extra-tropical circulation (Fig. 5). The strengthening or weakening of this jet stream is closely related to the occurrence of broad-scale convection from India, Bay of Bengal to Vietnam. By dint of broad-scale, Somali jet stream can describe Asian summer monsoon activities very well.

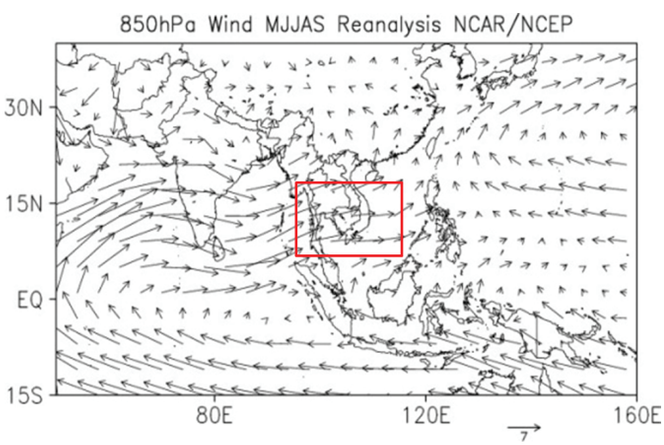

Fig. 5. MJJAS 850hPa winds for 1981-2010.

As Vietnam's territory stretches from 8°N to 23°N latitude and is located in transitional zone between westerly winds and trade wind, the influence of westerly winds on Vietnam is significantly different among areas. Central, Central Highlands and South regions are strongly affected by westerly winds, while the influence of westerly winds on the northern regions is not clear. In northern region, the main wind direction in summer is south-west, south, and south-east. In the South, in addition to the impact of westerly winds, the region is also affected by winds from North Australia. However, the influence of winds from North Australia is significantly weaker than westerly winds.

In the typical monsoon areas, such as India or East Asia, the strengthening or weakening of summer monsoon activities are often exhibited by heavy rain in several days. However, because Vietnam is affected by some monsoon systems, summer monsoon in Vietnam isn't absolutely typical. It belongs to the transition zone of monsoon sub-systems. Besides, rainfall in Vietnam is dominated by many factors, thus wind index is more suitable than rainfall index in describing summer monsoon activities. Moreover, the zonal wind index also has more advantages than other indices in describing summer monsoon thanks to stable characteristics, the non-significant influence of local factors and describing broad-scale circulation characteristics well. Overall, the zonal wind index is the most suitable index to define summer monsoon in Vietnam.

Averaging from May to September, the results of the EOF analysis for the U850hPa show that Vietnam is affected by two components of EOF: Mode 1 and Mode 2. According to Fourier analysis of time series, Mode 1 and Mode 2 represent alternately the tropical westerlies from southern hemisphere, and easterly wind turbulences from the southern edge of the North Pacific Subtropical High, respectively. In which, Mode 1 holds 65.9% of the total variation of atmospheric waves with pattern from East African Coast to Philippine; Mode 2 accounts for 6.3% of the total variation with Pattern from west Pacific Ocean to Indochinese Peninsula (Fig. 6). Although the information of Mode 1 is significantly greater than that of Mode 2, it is necessary to assess the influence of Mode 2. In other words, not only is summer monsoon in Vietnam affected by Indian monsoon, but it is also affected by the North Pacific High.

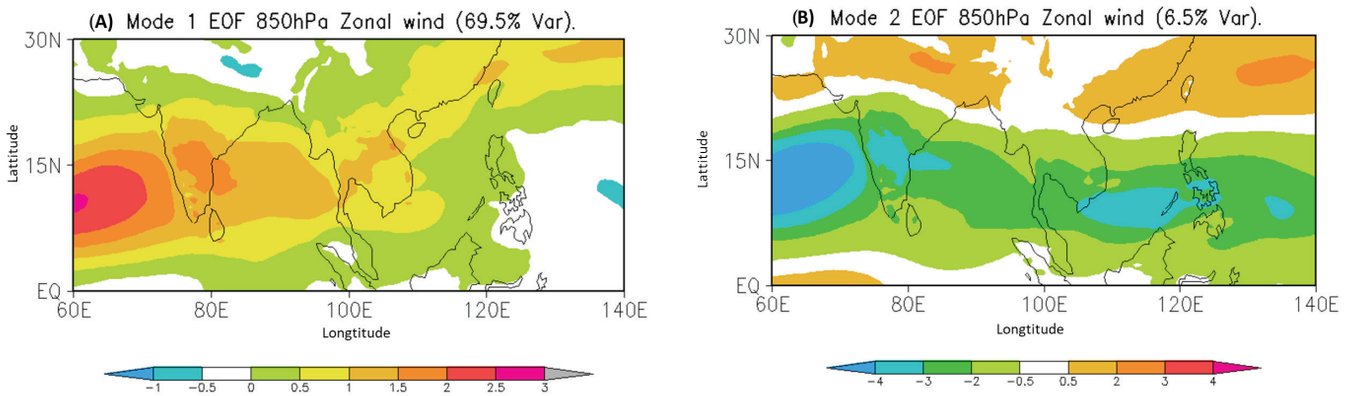

Fig. 6. EOF Mode 1 and EOF Mode 2 for 850hPa zonal wind of CFSR in summer between 1981 and 2010.

Based on the results, it is possible to use Mode 1 as an index to characterize summer monsoon activities in Vietnam. These above figures (Figs. 3-6) indicate that the zonal wind over the area (5°N-15°N, 100°E-110°E) can be the VSMI. Therefore, this study proposes a VSMI, which can be defined as the zonal wind at 850hPa averaged over the area (5°N-15°N, 100°E-110°E), namely VSMI.

The equation for calculating VSMI:

VSMI = U850hPa (5°N - 15°N; 100°E - 110°E)

As the VSMI belongs to Mode 1, VSMI can reflect the broad-scale circulation and local variability of westerly winds in Vietnam. The domain defining VSMI is not too large to separate from other summer monsoon systems as Indian monsoon or Northwest Pacific monsoon. This index is reliable to reflect well the strengthening and weakening of summer monsoon in Vietnam, because it is not affected by local factors and small-scale turbulences.

Performance of the VSMI in describing the broad-scale circulation

The broad-scale circulation is one of the most important features of the summer monsoon. The circulation of summer monsoon is featured by the westly wind in the low layers (850hPa, 700hPa) and eastly wind in the high layers (300hPa, 200hPa). To investigate the ability of the VSMI in describing these circulations, we calculate the correlation coefficients between the VSMI index with zonal wind in both low layers (U850hPa, U700hPa) and high layer (U300hPa). The VSMI and zonal winds are defined by averaging seasonal data from May to September for the for the period 1981-2010.

To establish the relationship between VSMI with low zonal winds, Figs. 7-8 show the correlation maps of VSMI with U850hPa and U700hPa, respectively. Significant correlations can be found over the Southwest monsoon region. Fig. 7 shows the shaded areas with correlation coefficients higher than 0.35 (or smaller than -0.35) and reaching the 95% confidence level. The positive correlation coefficients cover a broad-scale region from 5°N to 25°N and from the tropical Indian Ocean to over Philippine. In the 700hPa, the positive correlation region is higher than 0.35 and similar to the region of the 850hPa as well as significant at the 95% confidence level. These results show that VSMI can reflects well the activity of the broad-scale circulation of summer monsoon in the lower layers.

In the high layer, Fig. 9 shows the correlation coefficients map of VSMI with U300hPa. In this layer, the direction of the wind is opposite direction with the lower layers. It means that the eastly wind is popular in the high layers. Therefore, the map shows negative correlation is lower than -0.35 over the North and a part of the South of the map. The correlation between VSMI with U300hPa is significant at the 95% confidence level, except for the center of the map.

Synthesis of above results, the correlations between VSMI with various layers of atmosphere are close to the broad-scale circulation of the summer monsoon and at the 95% confidence level. Clearly, the VSMI can well reflect both low and high broad-scale circulation during summer monsoon.

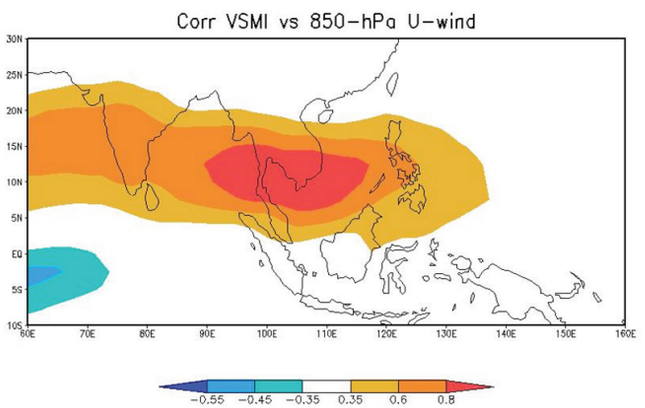

Fig. 7. Map of correlation coefficients of VSMI with U850hPa during summer (May-September). The shaded areas denote correlation coefficients at the 95% confidence level.

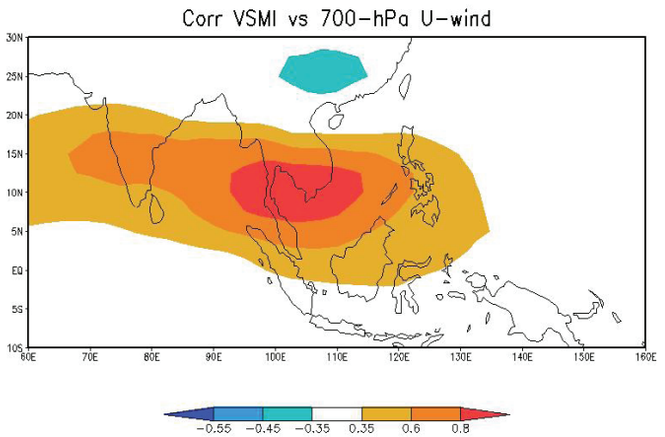

Fig. 8. Map of correlation coefficients of VSMI with U700hPa during summer (May-September). The shaded areas denote correlation coefficients at the 95% confidence level.

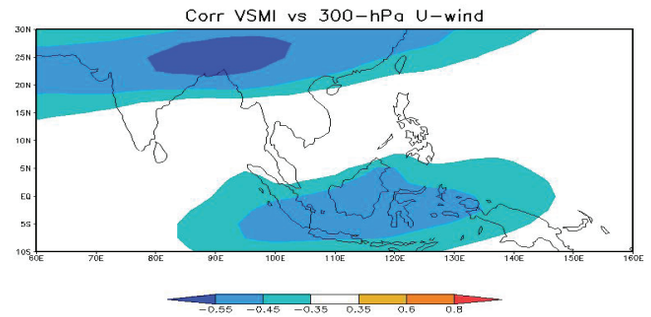

Fig. 9. Map of correlation coefficients of VSMI with U300hPa during summer (May-September). The shaded areas denote correlation coefficients at the 95% confidence level.

Performance of the VSMI in describing summer monsoon rainfall

Rainfall is one of the most important feature of summer monsoon as well as the consequence of its. The intraseasonal oscillation of summer monsoon rainfall is depend on the activity of the summer monsoon. In this section, we evaluate the performance of the VSMI in describing the summer monsoon rainfall in Vietnam. To investigate the performance, we calculate the correlation coefficients between various indices (VSMI, SCSSM, CSHL) with rainfall. The summer monsoon indices and rainfall are calculated by averaging the pentad mean data from the 25th (1 May) to the 54th pentad (30 September) for the period 1981-2010. Because of the terrain distribution in Vietnam, the correlation of the summer monsoon with rainfall is positive in the North, Central Highlands as well as the South. Oppositely, the negative correlation is on the Central regions due to the effects of Foehn winds [1].

Figures 10-12 present the correlation coefficients maps between various indices (VSMI, SCSSM, CSHL) with summer monsoon rainfall, respectively. The correlation coefficients maps are above 0.13 in a part of the North, Central Highlands as well as the South. These correlations are at the 95% confidence level. The VSMI shows the higher correlation coefficient with rainfall than SCSSM and CSHL in these summer monsoon rainfall regions. Both the VSMI and SCSSM indices show the effects of terrain on the distribution of the summer monsoon rainfall in Vietnam. This is the positive correlations in the North, Central Highlands and South; the negative correlations in the Central. However, the VSMI shows the clearer effects of the terrain than the SCSSM, especially in the South and Central regions. In while, the CSHL shows the positive correlations in over most regions of Vietnam. It means that the CSHL is the index can perform the rainfall event during summer. However, this is not true the summer monsoon rainfall and also including rainfall from other factors, especially in the Central region and the east side of the Hoang Lien Son mountain in the North.

The comparison of three indices reveals that there are significant correlations with the summer monsoon rainfall in the Central Highlands and the South. Clearly, the VSMI shows the higher correlation coefficients than other indices. In addition, the clear negative correlation in the Central region shows that the VSMI can describe well the distribution of the summer monsoon rainfall in Vietnam.

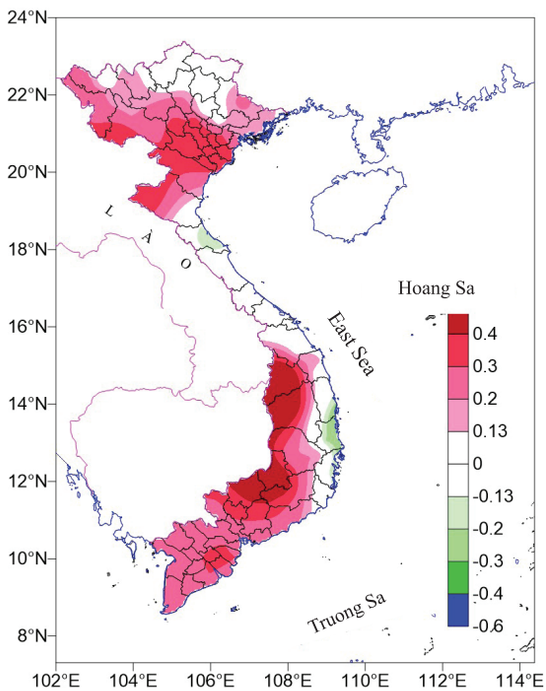

Fig. 10. Map of correlation coefficients of VSMI with rainfall (in pentad scale) during summer (May-September). The shaded areas denote correlation coefficients at the 95% confidence level.

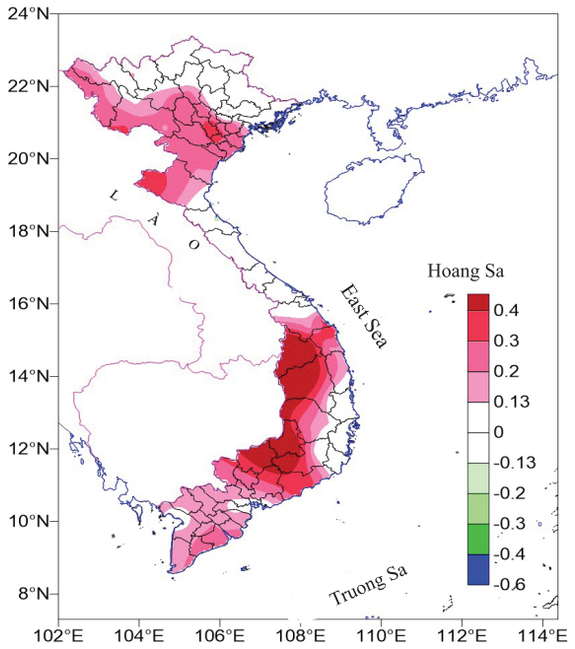

Fig. 11. Map of correlation coefficients of SCSSM with rainfall (in pentad scale) during summer (May-September). The shaded areas denote correlation coefficients at the 95% confidence level.

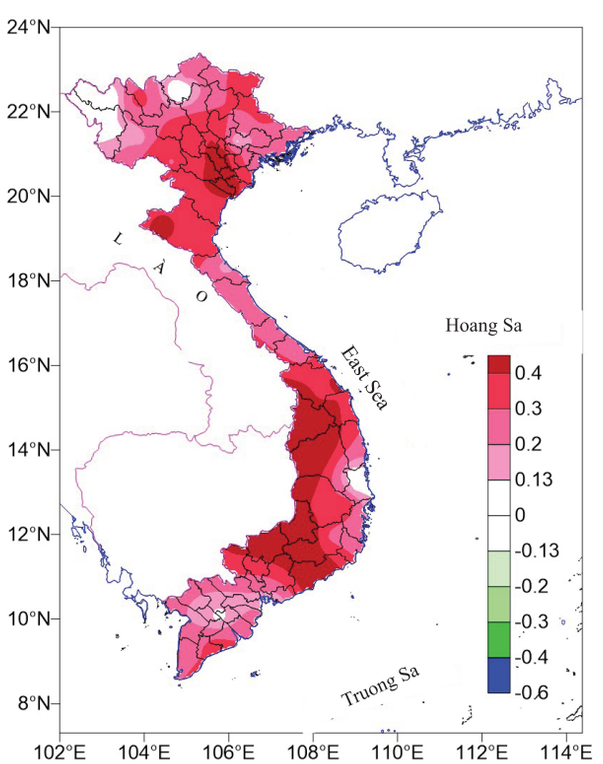

Fig. 12. Map of correlation coefficients of CSHL with rainfall (in pentad scale) during summer (May-September). The shaded areas denote correlation coefficients at the 95% confidence level.

Conclusions

We define the new summer monsoon index by averaging zonal wind in the 850hPa over the South of Vietnam (5°N-15°N; 100°E-110°E), the name of index is VSMI. The VSMI shows clearly the activity of summer monsoon. Based on the VSMI, most of important features of the summer monsoon can be found including intensity, onset and withdrawal date as well break period.

The new summer monsoon index is highly correlated with the broad-scale summer monsoon in low and high layers on the interannual timescales. During 1981-2010, the correlations between VSMI with U850hPa and U700hPa are higher than 0.35 in the Southwest monsoon region. The correlation coefficients are at the 95% confidence level. In the 300hPa, the correlation between the VSMI with U300hPa is smaller than -0.35 and at the 95% confidence level. This suggests that the VSMI can reflect the interannual variations of broad-scale summer monsoon circulations in layers of atmosphere.

The VSMI, SCSSM and CSHL indices are significantly correlated with rainfall in the Central Highlands and the South of Vietnam. However, the summer monsoon rainfall in Vietnam is reflected more clearly by the VSMI and SCSSM indices than the CSHL. In while, the CSHL tend to describe the positive correlations with rainfall which is not only rainfall from summer monsoon. Comparison of three indices, the VSMI reflect more clearly summer monsoon rainfall than other two indices.

Based on these above analyzes, the new VSMI is the good summer monsoon index for Vietnam region. This index can reflect well the broad-scale circulation and also the summer moon soon rainfall in Vietnam. This index is calculated by U850hPa and easily can be applied to operational monitoring and forecasting of summer monsoon in Vietnam.

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