A Climatological Study of Tropical Cyclone Rainfall in Vietnam

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Abstract

This study investigated the characteristics of the rainfall associated with tropical cyclones (TCs), using the TC best-track data and daily rainfall data from 15 meteorological stations for the period 1961−2008 for the coastal region of Vietnam. In addition to investigating the TC rainfall amount, we estimated the TC rain ratio and the ratio of TC heavy rainfall days (TC_R50) and interpreted these parameters for El Niño and La Niña years. Our results show that the maximum TC rainfall occurs from July to September in the northern region, whereas the total rainfall at southern stations is mainly composed of non-TC rainfall. The TC rainfall amount is concentrated in the central region, with a peak in October-November. The TC rain ratio varies from 0 to ~25%, showing a maximum value in the region of 16°N−18°N in September. The mid-central region of Vietnam has maximum TC_R50 ratio in September-October corresponding to its highest TC frequency in the same period. During El Niño (La Niña) years, the TC rain ratio and TC_R50 ratio in the central region show a significant decrease (increase) in October-November. The La Niña phases more strongly affect TC rainfall than the El Niño phases, particularly in central Vietnam.

1. Introduction

Tropical cyclones (TCs) regularly threaten many countries, bringing dangers such as disastrously heavy rainfall and flooding. Several studies have examined the rainfall associated with TCs (hereafter called TC rainfall). For example, Rodgers et al. (2000) estimated TC rainfall in the North Pacific using Special Sensor Microwave Imager (SSM/I) observations for an 11-year period. They found that TCs contributed 12% of the climatological rainfall over the western North Pacific (WNP) from June to November. They also showed that TC rainfall increased from 12 to 18% during El Niño events. Englehart and Douglas (2001) investigated the role of tropical storms over the eastern North Pacific in the rainfall climatology of western Mexico and showed that tropical storm-associated rainfall normally constitutes 20 to 60% of rainfall along Mexico's Pacific coast. In more extreme cases, they found that such rainfall can contribute as much as 25 to 30% to seasonal rainfall totals in western interior locations. Gleason (2006) estimated the characteristics of TC rainfall in the United States between 1950 and 2004. They found that coastal and near-coastal regions received 8 to 16% and 4 to 12% of the precipitation by TCs, respectively. Ren et al. (2006) reported that the ratio of annual TC precipitation to total annual rainfall is 20 to 30% in most of Taiwan and along the coast of China south of 25°N, using rain gauge data over China during 1971−2004. Kubota and Wang (2009) investigated the effect of TCs on seasonal and inter-annual rainfall variability over the WNP by analyzing rainfall data at 22 rain gauge stations. They showed that along 125°E and between 18°N and 26°N, TC rain accounts for 50 to 60% of the total rainfall during the TC season from July to October. In addition, they described some characteristics of TC rainfall during the developing phases of El Niño and La Niña. Recently, Sugino and Satomura (2010) mapped precipitation due to typhoons in the period 1998−2004 over Indochina, based on Tropical Rainfall Measuring Mission (TRMM)-3B42 data. They showed that the maximum precipitation occurs along the eastern coast of Indochina, with the precipitation amount over land decreasing as distance from the coast increases.

Vietnam is located along the eastern coast of the Indochina Peninsula. It is separated from other parts of the peninsula by the Truong Son range, which runs parallel to the coast (Yokoi and Matsumoto 2008). Every year, TCs that originate within the South China Sea (SCS) and the WNP strongly affect Vietnam, with high frequency in the northern and central regions and low frequency in the southern region. According to Garcia (2002), Vietnam is struck by an average of four to six typhoons per year. Some previous studies have examined the link between rainfall and TC activity, between rainfall and El Niño/La Niña-Southern Oscillation (ENSO) for Vietnam. For example, Takahashi et al. (2009) used a 30-year simulation for September from 1966 to 1995 and found a weakening TC activity over the region, which caused the observed long-term decrease in September rainfall along the eastern coast of Vietnam. Yen et al. (2010) analyzed the observational based data in Vietnam and concluded that central Vietnam has more (less) rainfall in the La Niña (El Niño) years. However, little has been known about the TC rainfall in Vietnam and its relationship with some large scale oscillations. Therefore, this study aims to explore the characteristics of the climatological seasonal TC rainfall in Vietnam, including the amount, the TC rainfall ratio, and heavy rainfall events. We also investigated the differences in these parameters during ENSO years for the coastal region of Vietnam.

2. Data used and method

2.1 Data used

The SCS is part of the WNP, defined here as the ocean body between 0°N and 25°N and 100°E and 120°E (Goh and Chan 2010). TCs in the SCS are formed in two ways. Some originate within the region, while others enter from the WNP. To investigate TCs and associated rainfall in this region, two main data sources have been used: (1) TC best-track data from the UNISYS website (http://weather.unisys.com) provided through the Joint Typhoon Warning Center and (2) daily rainfall observed at 15 meteorological stations operated by the Vietnamese National Hydro-Meteorological Service (Supplementary Table 1). The reason to choose UNISYS over different available best track datasets such as Regional Specialized Meteorological Center (RSMC) Tokyo, International Best Track Archive for Climate Stewardship (IBTrACS) and the Shanghai Typhoon Institute (STI) is simply based on our familiarity with the data. Song et al. (2010) mentioned that differences in TC tracks among these data sets are negligibly small, while TC intensities could be relatively different. Therefore, which best track data sets to use is not a challenging problem because only TC tracks information is required in this study.

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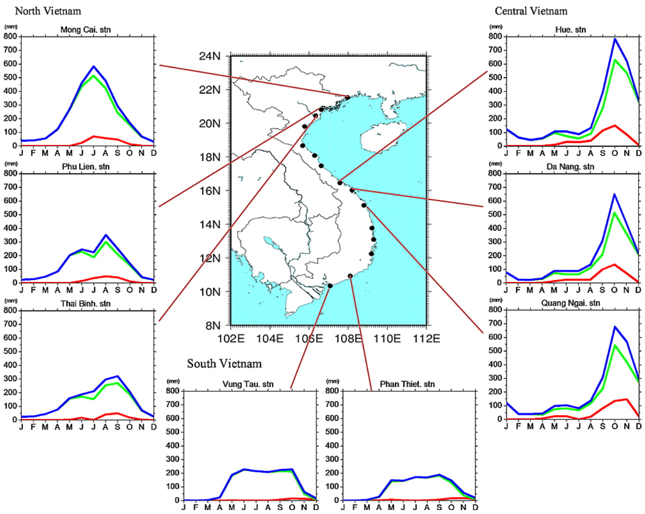

Fig. 1. Monthly climatological distribution of the total rainfall (blue), TC rainfall (red), and non-TC rainfall (green) of eight weather stations located in three Vietnam coastal regions (units are in mm). The dots show the locations of the stations.

Figure 1 shows these stations and rainfall information. We selected TC best-track and daily rainfall data for the same period (1961−2008) and obtained information on El Niño-Southern Oscillation (ENSO) years from Kubota and Wang (2009) (Supplementary Table 2).

2.2 Method

Previous study used different distances from the TC center to define TC-induced rainfall. Englehart and Douglas (2001) found that in 90% of cases over western Mexico, TC rainfall occurs within 600 km from the center of the TC. Gleason (2006) estimated the characteristics of TC rainfall in the United States based on a simple partition method to consider rainfall associated with TCs. He treated any rainfall less than or equal to 600 km from the center of the storm as TC rainfall. Kubota and Wang (2009) assumed that the daily rainfall as a function of the distance between the TC center and stations and TC-induced rainfall could be estimated from station data when a TC was located within the radius of influence (1000 km). Hattori et al. (2010) showed the contribution of TCs to the seasonal change patterns of rainfall in the WNP, based on the Japanese 25-year Reanalysis (JRA-25) and Japan Meteorology Agency Climate Data Assimilation System (JRA-25/JCDAS) dataset (Onogi et al. 2007). In their study, TC rainfall was defined as the rainfall within 500 km of the center of the TC.

In this study, we used the distance of 600 km from the TC center to the station to investigate the TC rainfall contribution to the total rainfall (same as in Gleason 2006). The individual TC rainfall values were summed for each month at selected stations. The non-TC rainfall was defined as the difference between the total rainfall and the TC rainfall, while the TC rain ratio was defined as the TC rainfall divided by the total rainfall. In addition, heavy rainfall events caused by TCs were defined as days in which the daily rainfall amount exceeded 50 mm day^{-1} (TC_R50). In fact, 50 mm day^{-1} is the heavy rainfall threshold currently used by the forecasters of the National Center for Hydro-Meteorological Forecasting of Vietnam, similar to the criteria of the Central Weather Bureau of Taiwan (Chen et al. 2007). TC_R50 ratio was defined as TC_R50 divided by the total heavy rainfall days (the sum of TC_R50 and non TC_R50). Finally, the TC frequency was defined as the number of TCs that approached the station within the 600 km distance from the TC center.

In order to study the linkages of TC rainfall with ENSO years (Section 3.2), we used the bootstrapping technique detailed by Efron and Tibshirani (1993). In this study, 1000 bootstrap replication of size $n_{\text{El Niño}} = 18$ and $n_{\text{La Niña}} = 13$ were generated to estimate anomalies during El Niño and La Niña years, respectively. The confidence intervals for bootstrap estimates were obtained using the percentile method.

3. Results

3.1 Climatological seasonality of TC rainfall
a. TC rainfall amount

Figure 1 shows the mean distribution of TC rainfall, non-TC rainfall, and total rainfall amounts for each month at eight selected stations in three Vietnam coastal regions: north, central, and south. At most stations, TC rainfall is zero from December to May. In the northern part of Vietnam (from 20°N northward), the maximum TC rainfall occurs from July to September. In the central region (approximately from 12°N to 20°N), the stations (includes the ones not shown in Fig. 1) have two total rainfall peaks. The first peak, which occurs in May, coincides with the active south-west monsoon period in the region. The second highest peak total rainfall appears in October-November, coinciding with the TC rainfall peak. In the central region, the non-TC rainfall amount contributes significantly to the total rainfall. This suggests that in addition to TC activity, other weather systems such as inter-tropical convergence zone (ITCZ) displacement, boreal summer and winter monsoon play an important role in this region (e.g., Chen et al. 2012; Yokoi and Matsumoto 2008). For the mid-central region (located between 15°N and 17°N), Hue is the most typical station and has the highest TC rainfall (152 mm) in October among all analyzed stations in Vietnam. This result for the TC rainfall amount in the central region is close to the satellite data analyses by Jiang and Zipser (2010). However, in the southern part (from 12°N southward), the total rainfall is due mostly to non-TC rainfall. This region has both the minimum TC rainfall and minimum total rainfall in all of Vietnam. There, the rainy season coincides with the southwest monsoon season from May to October.

b. TC rain ratio and TC_R50 ratio

The time-latitude sections of the monthly mean TC frequency and TC rain ratio are presented in Figs. 2a and 2b. The distribution of these factors is different from region to region and month to month. As indicated in Fig. 2a, the TC season starts from May−June. High TC frequency occurs in the central region from September to November, with a peak in October. From Fig. 2b, it can be seen that TC rain ratio contributes from 0 to 25%, with the highest value found in the region of 16°N to 18°N in September. At three stations located in the mid-central region, the TC frequency reaches the maximum value in October, but the TC rain ratio in October is smaller than that in September because the total rainfall in October becomes maximum (Fig. 1). From 18°N northward, even though the TC frequency has a maximum value in September, the maximum TC rain ratio shifts to July, while the stations located south of 16°N have maximum ratios in November. In addition, the TC rain ratio south of 16°N reaches a maximum value in November due to both the high TC frequency and the low total rainfall.

Heavy rainfall events that can cause flooding and extensive damage, occur frequently during the rainy season in central Vietnam (Yokoi and Matsumoto 2008). To what extent do TCs contribute to these events? Figure 2c shows the time-latitude section of the monthly mean TC_R50 ratio. The value of TC_R50 ratio varies from north to south along the coastal line. TC_R50 ratio starts to increase in May, becoming greater during July-November. The northern region receives a maximum TC_R50 ratio value up to 20% from July to October, whereas the southern region receives a low TC_R50 ratio value throughout the year. The maximum value of TC_R50 ratio occurs in September, October in the mid-central region. This area also has the highest TC frequency (Fig. 2a) in the same period. Hence, TCs play an important role both in rainfall and heavy rainfall events in that region.

During the TC season in Vietnam (from June to December,

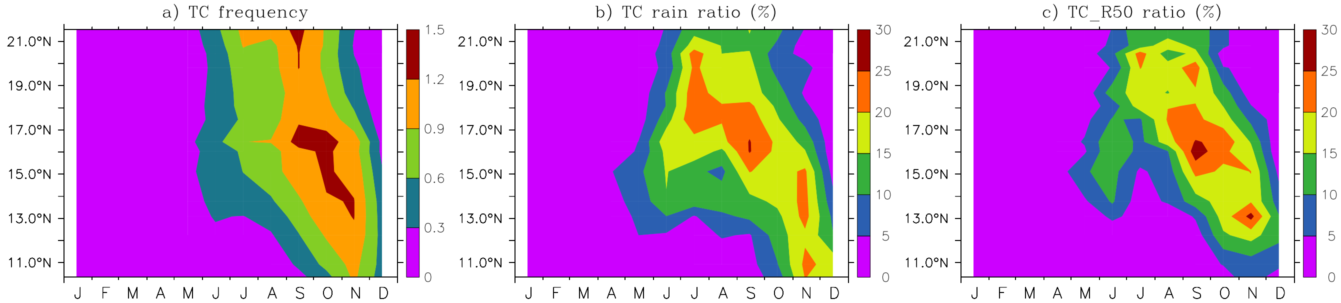

Fig. 2. Time-latitude sections of (a) TC frequency, (b) TC rain ratio, and (c) TC_R50 ratio along the Vietnam coast.

not shown), the mid-central region receives the maximum TC frequency (six cases), TC rain ratio (~26%), and TC_R50 ratio (~26%). These values decrease northward and southward along the Vietnamese coast.

3.2 Linkages with ENSO years

The association between ENSO and TC activity over the SCS/WNP is well documented. Wang and Chan (2002) noted that the interannual variability of TC formation in the WNP is strongly affected by ENSO phases. Goh and Chan (2010) showed that the total number of TCs entering the SCS from the WNP is below normal during El Niño events but above normal during La Niña events. Kubota and Wang (2009) also reported that the seasonal TC rain ratio differs between El Niño and La Niña years.

In Figs. 3 and 4, we examined the anomalies of TC frequency, TC rain ratio, and TC_R50 ratio during El Niño and La Niña years, respectively. The contour shows the mean bootstrap value of the anomalies while color shading shows areas where the anomalies is positively (negatively) significant at the 90% confidence level.

Figure 3a (Fig. 4a) shows that during El Niño (La Niña) years, TCs are significantly less (more) frequent than the climatology in October and November across all regions, which is in agreement with previous studies (Goh and Chan 2010; Wu et al. 2004). The decrease (increase) in TC frequency leads to a significant decrease (increase) of up to 20% in the TC rain ratio in October and November from 13°N northward (Figs. 3b and 4b). During El Niño years, a significantly positive TC rain ratio anomaly appears in the mid-central region in September while negative TC rain ratio anomalies appear in July. Similar to TC rain ratio, an increase in TC_R50 ratio also occurs in mid-central region in September (Fig. 3c). Significant negative (positive) TC_R50 ratio values are also found in the central region during late autumn in El Niño (La Niña) years (Figs. 3c and 4c).

Compared to the TC season (June to December) total distribution (not shown), less (more) TC frequency can be seen in all the coastal regions in Vietnam during El Niño (La Niña) years. The TC rain ratio and TC_R50 ratio also decreases (increases) during El Niño (La Niña) years, except at stations located in the northern region. Anomalies in the TC rain ratio and TC_R50 ratio in La Niña years are higher than those in El Niño years in the central region. The La Niña phases strongly affect TC rainfall, particularly in central Vietnam.

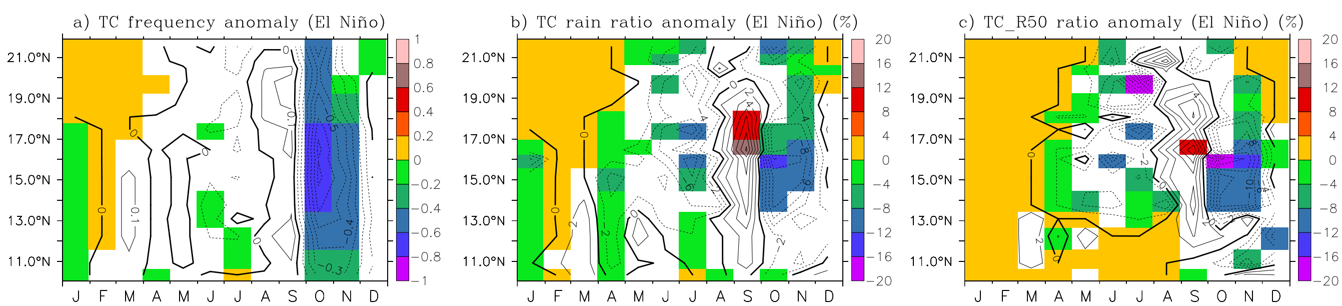

Fig. 3. Time-latitude sections of the bootstrap means (contour) of (a) TC frequency anomaly, (b) TC rain ratio anomaly, and (c) TC_R50 ratio anomaly in El Niño years. Color shading shows areas where the anomalies is positively (negatively) significant at the 90% confidence level and the color levels also indicate the bootstrap means of each anomaly.

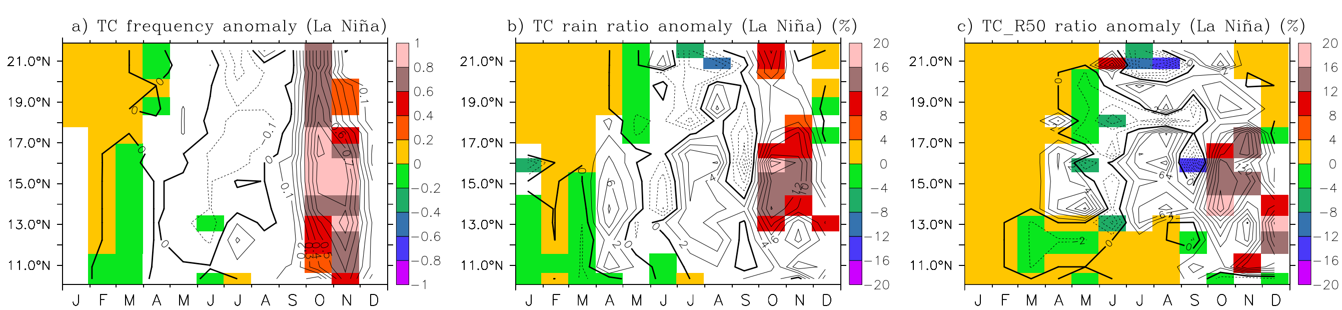

Fig. 4. Same as Fig. 3, but for La Niña years.

4. Conclusions

By analyzing the TC best-track data from the UNISYS website archive and the daily rainfall data from 15 meteorological stations in the period 1961−2008, we explored the role of TCs in the rainfall climatology of the Vietnam coastal region. The distribution of TC rainfall, TC rain ratio, and the ratio of heavy rain days varies spatially and temporally. The TC rainfall amount in the central region is higher than that in other regions, with a peak in October−November. The northern region has maximum TC rainfall from July to September, whereas the total rainfall in the south is due mainly to non-TC rainfall. The TC rain ratio varies from 0 to ~25% with a maximum value occurring from 16°N to 18°N in September. The mid-central region of Vietnam receives the maximum TC_R50 ratio in September−October and also has the highest TC frequency in the same period.

Distinct differences in El Niño and La Niña phases were found for both the TC rain ratio and TC_R50 ratio. During El Niño (La Niña) years, the TC rain ratio and TC_R50 ratio significantly decrease (increase) in October−November in the central region, particularly the 15°N to 17°N region. Our results also emphasize that the La Niña phases more strongly affect TC rainfall than the El Niño phases, particularly in central Vietnam.

This study has not addressed the long-term change in TC-induced rainfall and changes in the atmospheric circulation forced by ENSO events. Further studies are needed to investigate these problems, to identify variations in TC rainfall, and to explain the differences between ENSO phases described here.

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Supplements

Supplement 1 is list of stations used in this study.
Supplement 2 is list of ENSO years used in this study.

References

Chen, T.-C., J.-D. Tsay, M.-C. Yen, and J. Matsumoto, 2012: Interannual variation of the late fall rainfall in central Vietnam. *J. Climate*, **25**, 392−413.

Chen, C.-S., Y.-L. Chen, C.-L. Liu, P.-L. Lin, and W.-C. Chen, 2007: Statistics of heavy rainfall occurrences in Taiwan. *Wea. Forecasting*, **22**, 981−1002.

Efron, B., and R. J. Tibshirani, 1993: *An Introduction to the Bootstrap*. Chapman and Hall, 436 pp.

Englenhart, P. J., and A. V. Douglas, 2001: The role of eastern North Pacific tropical storms in the rainfall climatology of western Mexico. *Int. J. Climatol.*, **21**, 1357−1370.

Garcia, L., 2002: *Overview of Early Warning Systems for Hydro-Meteorological Hazards in Selected Countries in Southeast Asia*. Asian Disaster Preparedness Center, Thailand, 51.

Gleason, B., 2006: Characteristics of tropical cyclone rainfall in the United States. *27th Conference on Hurricanes and Tropical Meteorology*, Session 16C, Tropical Cyclones and Climate V-Atlantic Basin.

Goh, A. Z. C., and J. C. L. Chan, 2010: Interannual and interdecadal variations of tropical cyclone activity in the South China Sea. *Int. J. Climatol.*, **30**, 827−843.

Hattori, M., K. Tsuboki, and S. Mori, 2010: Contribution of tropical cyclones to the seasonal change patterns of precipitation in the western North Pacific: Estimation based on JRA-25/JCDAS. *SOLA*, **6**, 101−104.

Jiang, H., and E. J. Zipser, 2010: Contribution of tropical cyclones to the global precipitation from eight seasons of TRMM data: regional, seasonal, and interannual variations. *J. Climate*, **23**, 1526−1543.

Kubota, H., and B. Wang, 2009: How much do tropical cyclones affect seasonal and interannual rainfall variability over the western North Pacific? *J. Climate*, **22**, 5495−5510.

Onogi, K., J. Tsutsui, H. Koide, M. Sakamoto, S. Kobayashi, H. Hatsushika, T. Matsumoto, N. Yamazaki, H. Kamahori, K. Takahashi, S. Kadokura, K. Wada, K. Kato, R. Oyama, T. Ose, N. Mannoji, and R. Taira, 2007: The JRA-25 reanalysis. *J. Meteor. Soc. Japan*, **85**, 369−432.

Ren, F., G. Wu, W. Dong, X. Wang, Y. Wang, W. Ai, and W. Li, 2006: Changes in tropical cyclone precipitation over China. *Geophys. Res. Lett.*, **33**, L20702, doi:10.1029/2006GL027951.

Rodgers, E. B., R. F. Adler, and H. F. Pierce, 2000: Contribution of tropical cyclones to the North Pacific climatological rainfall as observed from satellites. *J. Appl. Meteor.*, **39**, 1658−1678.

Song, J.-J., Y. Wang, and L. Wu, 2010: Trend discrepancies among three best track data sets of western North Pacific tropical cyclones. *J. Geophys. Res.*, **115**, D12128, doi:10.1029/2009JD013058

Sugino, M., and T. Satomura, 2010: Long-lived typhoons over Indochina. *Journal of Research in Engineering and Technology*, **7**, 97−104.

Takahashi, H. G., T. Yoshikane, M. Hara, and T. Yasunari, 2009: High-resolution regional climate simulations of the long-term decrease in September rainfall over Indochina. *Atmos. Sci. Let.*, **10**, 14−18, doi:10.1002/asl.203.

Wang, B., and J. C. L. Chan, 2002: How strong ENSO events affect tropical storm activity over the western North Pacific. *J. Climate*, **15**, 1643−1658.

Wu, M. C., W. L. Chang, and W. M. Leung, 2004: Impacts of El Niño-Southern oscillation events on tropical cyclone landfalling activity in the western North Pacific. *J. Climate*, **17**, 1419−1428.

Yen, M. C., T. C. Chen, H. L. Hu, R. Y. Tzeng, D. T. Dinh, T. T. T. Nguyen, and C. J. Wong, 2010: Interannual variation of the fall rainfall in Central Vietnam. *J. Meteor. Soc. Japan*, **89A**, 259−270, doi:10.2151/jmsj.2011-A16.

Yokoi, S., and J. Matsumoto, 2008: Collaborative effects of cold surge and tropical depression-type disturbance on heavy rainfall in central Vietnam. *Mon. Wea. Rev.*, **136**, 3275−3287.

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SOLA: http://www.jstage.jst.go.jp/browse/sola