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Long-term trends in tropical cyclone rainfall in Vietnam

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Abstract: This paper investigated the long-term trends in rainfall occurring during tropical cyclone (TC) in Vietnam region using the TCs best-track data provided through the Joint Typhoon Warning Center and daily rainfall data of 58 meteorological stations recorded by Vietnamese National Hydro-Meteorological Service for the years from 1961 through 2008. Significant increasing trend with 90% and 95% confidence levels of TC rainfall amount (TCRA) and TC heavy rainfall days (TC_R50) were observed at most stations in central coastline during the study period. As regards to regional contexts, no significant trends were detected in the north of 20^{o}N (REG1), 17^{o}-20^{o}N (REG2) and south of 12^{o}N (REG4); while the significant increasing was found in 12^{o}-17^{o}N region (REG3) for both of TCRA and TC_R50. The contrastive long-term trend of heavy rainfall occurrences in REG1 and REG3 was noted in the previous study. The results suggest that cause of the increasing trend in REG3 can be explained partly by TC rainfall, while the decreasing trend in REG1 is due to Non-TC rainfall. A significant increase of TC rainfall was revealed during the 1990s in REG3.
Key words: Vietnam, tropical cyclone rainfall, long-term trends, Mann-Kendal.

Introduction

The tropical cyclones (TCs) are one of the most destructive natural disasters, bringing dangers such as disastrously heavy rainfall and flooding. These effects can cause overtopping and erosion of dikes and sand dunes and lead to saltwater intrusion of farmland with water masses destroying the crop. Therefore, understanding the effects of TCs or typhoons is the great interest in order to develop protection methods for preventing such damage. Over the last decade, the rainfall associated with TC has received considerable attentions by many scientists. Rodgers *et al*. (2000) estimated TC rainfall in the North Pacific using Special Sensor Microwave Imager (SSM/I) observations for an 11-year period. Englehart and Douglas (2001) investigated the role of tropical storms over the eastern North Pacific in the rainfall climatology of western Mexico. Gleason (2006) estimated characteristics of TC rainfall in the United States between 1950 and 2004. Kubota and Wang (2009) investigated the effect of TCs on seasonal and inter-annual rainfall variability over the Western North Pacific (WNP) and found that along 125^{o}E and between18^{o}N and 26^{o}N, the TC rain accounts for 50-60% of the total rainfall during the TC season from July to October. 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 and reported that the maximum precipitation occurs along the eastern coast of Indochina, with the precipitation amount over land decreasing as distance from the coast increases. In addition, the variation in TC activity in the WNP/the South China Sea (SCS) has also received attention of many researchers (Emanuel, 2005, Websters *et al*., 2005, Goh and Chan, 2010). Some recent studies have also examined the variation of TC activity and rainfall-related TCs. Lee *et al.* (2012) depicted a decrease in the TC frequency in the SCS from 1961 to 2010 based on the best track data of four main weather agencies, but that trend was not statistically significant at 5% level for most datasets. They mentioned that large differences in datasets do not allow for detecting the long-term trend of TC intensity in the SCS. Apart from the long-term trend of TC frequency, their results showed that no significant trend on the TC-induced extreme rainfall is found in Hong Kong area. Liu and Chan (2012) examined the interdecadal variation of the TC activity over the WNP and found that the inactive of TC activity after 1998. The reason for that is the strong vertical wind shear and strong subtropical high observed together apparently lead to unfavorable atmospheric conditions for TC genesis. Chang *et al*. (2012) showed the trends of TC rainfall and monsoon rainfall over the China summer monsoon region from 1958 through 2010 have been distorted by WNP typhoons, which bring rainfall with decreasing frequency and increasing intensity.

Located along the east coast of the Indochina Peninsula with a substantial latitudinal extent from 8^{o}N to 22^{o}N on the north-western Pacific Ocean, Vietnam is one of the countries strongly affected by the TCs which are originated within the SCS or coming from the WNP with high frequency in the northern and central region and low frequency in the southern region. According to Garcia (2002), Vietnam is struck by an average of four to six typhoons per year. Luong *et al*. (2011) showed that 7 % of deaths and 36% of destroyed and damaged houses in Vietnam over the period 1989-2010 were caused by storms. Nguyen-Thi *et al*. (2012) investigated the seasonal and regional characteristics of the climatological rainfall associated with TCs in the coastal region of Vietnam and presented the differences of these characteristics in the El Niño and La Niña years. The results showed that TC rainfall varies from 0 to ~25% of total rainfall, in which the mid-central region of Vietnam receives the maximum value and also has the highest TC frequency. In recent years, the trend of rainfall in Vietnam was noted in some previous studies (Manton *et al*., 2001; Endo *et al*., 2009). However, they did not mention about the role of rainfall from TCs to that trend. The current study, therefore, aims to assess the long-term trends in TC rainfall from 1961 to 2008 in the whole and some sub-regions of Vietnam in order to provide some helpful understanding and basic references for further climatological studies in Vietnam.

Materials and Methods

In this study, we use TC best-track data from the UNISYS website (http://weather.unisys.com) provided through the Joint Typhoon Warning Center (JTWC) and daily rainfall data of 58 meteorological stations operated by the Vietnamese National Hydro-Meteorological Service covering the period from 1961-2008 to investigate the variations of TC rainfall for Vietnam. Fig. 1 shows the location of these stations and the climatology of annual total rainfall induced by TC during 48 years.

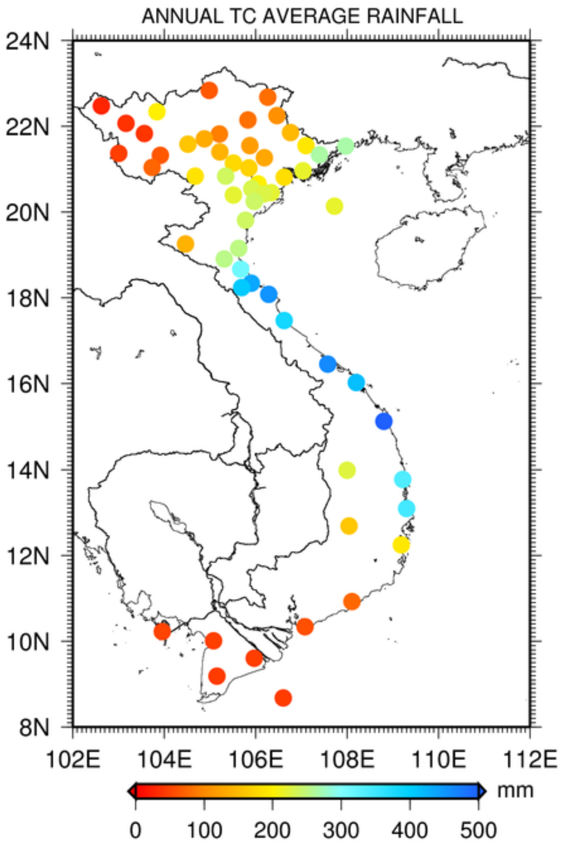

Fig. 1. Annual TC average rainfall of 58 meteorological stations considered in this study

Some 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). In this study, we used the distance of 600 km from the TC center to the station to identify TC rainfall as carried out in Nguyen-Thi *et al.* (2012). Four sub-regions namely REG1, REG2, REG3, and REG4 are defined as the location of the stations at the north of 20^{o}N, 17^{o}-20^{o}N, 12^{o}-17^{o}N, and south of 12^{o}N, respectively. The regional definition is based on the similarity of TC rainfall climatology and the trend of that (as shown in Figs. 1 and 2). Eight TC rainfall indices described in Table 1 were calculated for each station for annual timescale. In order to explore the role of TCs formed in the SCS/WNP on the trends of some indices, TCRA and TC_R50 were calculated separately for each station and each basin. In this study, the SCS is defined as part of the WNP between 0° and 25°N and 100° and 120°E (Goh and Chan, 2010). To obtain the regional indices, the annual indices were averaged over the meteorological stations in each of four sub-regions. The significance of the trend was calculated by using the non-parametric Mann-Kendall method and the slope of trends were estimated by applying Sen's estimator (Hirsch *et al.*, 1982, Helse and Hirsch, 2002). The statistical significance levels at 90% and 95% were used for the trend analysis.

Table 1. TC rainfall indices used in this study

Index	Description	Unit
TCRA	Annual TC rainfall amount	mm
TC_R50	Number of days with TC daily rainfall ≥50 mm	days
TCRA_SCS	Annual TC rainfall amount when TC formed in the SCS	mm
TC_R50_SCS	Number of days with TC daily rainfall ≥50 mm when TC formed in the SCS	days
TCRA_WNP	Annual TC rainfall amount when TC formed in the WNP	mm
TC_R50_WNP	Number of days with TC daily rainfall ≥50 mm when TC formed in the WNP	days
Non-TCRA	The difference between total rainfall and TCRA	mm
Non-TC_R50	The difference between total number of days with daily rainfall ≥50 mm and TC_R50	days

Results and Discussion

Temporal trends in TC rainfall in whole region: Fig. 2 shows the temporal trends of annual TC rainfall amount (TCRA) and TC heavy rainfall days (TC_R50) over the whole Vietnam for the 48 years period using the non-parametric Mann- Kendall test. For the contribution of TCs to the annual rainfall (TCRA), most of the stations located along the coastline show the increasing trend, but there is only 6 of 58 stations have significant increasing trend in mid- and south-central area (Fig. 2a). Over much of north-Vietnam and south there is little change in TCRA with some areas showing increasing or decreasing trend (not significant at the 90% and 95% levels). For TC_R50, the positive significant trend at 90% and 95% confident levels of some stations is also found in the same region with TCRA, but no trend is detected at all stations in the south of 12^{o}N and in the north of 20^{o}N (Fig. 2b).

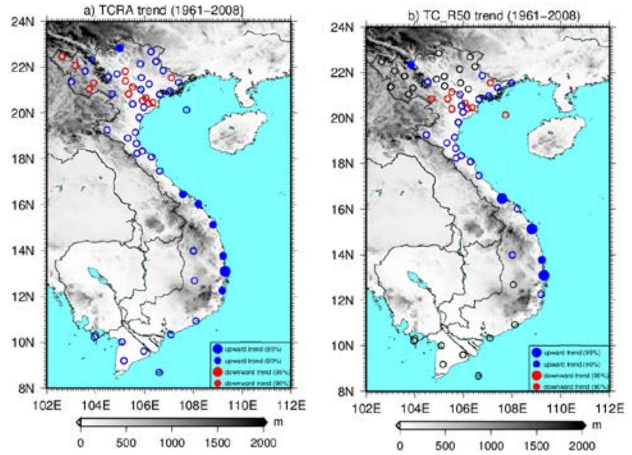

Fig. 2. Trends of (a) TCRA and (b) TC_R50 for 58 stations in Vietnam, 1961-2008. Blue (red) symbol indicates increasing (decreasing) trend where small (big) filled circles are statistically significant at 90% (95%) confidence level, open circles are not significant in any of the these levels. Black open circles represent stations with no trend.

Temporal trends in TC rainfall in four sub-regions:
Table 2 shows the annual trends of the eight rainfall indices for four sub-regions: REG1 (north of 20^{o}N), REG2 (17^o-20^{o}N), REG3 (12^o-17^{o}N), and REG4 (south of 12^{o}N) at 90% and 95% confident levels.

Table 2. Slope trends of eight rainfall indices over four sub-regions in Vietnam during 1961-2008

Index/Region	REG 1	REG 2	REG 3	REG 4
TCRA	0.64	1.74	4.64**	0.43
TC_R50	0.00	0.01	0.03*	0.00
TCRA_SCS	0.00	1.46	1.8	0.00
TC_R50_SCS	0.00	0.01	0.01	0.00
TCRA_WNP	-0.08	0.00	1.62*	0.16**
TC_R50_WNP	0.00	0.00	0.01*	0.00
Non-TCRA	-5.1**	-3.51	3.35	1.19
Non-TC_R50	-0.05*	-0.02	0.05*	0.00

The indices that do not show any significant trends are rainfall and heavy rainfall accumulated form TCs formed in the SCS (TCRA_SCS and TC_R50_SCS), while rainfall derived from TCs formed in the WNP (TCRA_WNP) has increased significantly in REG3 and REG4 (1.62 mm/year and 0.16 mm/year, respectively). REG1 is the region received the significant negative trend for Non-TC rainfall indices with slope trend of 5.1 mm/year and 0.05 days/year for Non-TCRA and Non-TC_R50 index, respectively. Figures 3a and 3b show the annual time series anomalies of Non-TCRA and Non-TC_R50 in REG1; the linear trends show a significant decrease during 1961-2008. TCRA in REG1 also shows an increase with slope trend about 0.64 mm/year but not significant. REG2 does not show any significant trend in all indices. REG3 is the region with the largest number of significant positive trends for both TC rainfall and Non-TC rainfall. To complement these results of TC rainfall, Figures 4a and 4b show the time series of TCRA and TC_R50 anomaly in REG3 during the 1961-2008 period; the significant increase of these indices are indicated by linear trends. There is a significant positive correlation between TCRA and TC_R50 (r=0.98, approximately) at 95% confidence level. It means that the increase of TC rainfall amount is mainly contributed from heavy rainfall days caused by TCs in REG3. In Table 2 also shows that rainfall comes from the contribution of TCs formed inside the SCS does not show any trend, while a significant increasing trend is found with the contribution of TCs entering the SCS in this region.

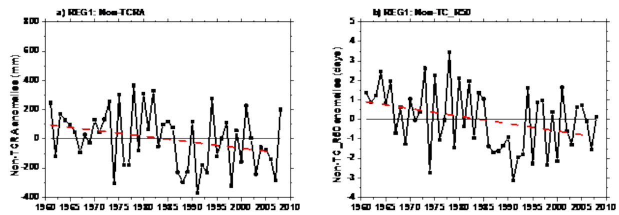

Fig. 3. Annual time series anomalies and linear trends (dash lines) of (a) Non-TCRA and (b) Non-TC_R50 in REG1.

Since TCRA_SCS/TC_WNP is one component of TCRA (similar with TC_R50), overall, it can be concluded that TCs formed in the WNP contributed more than TCs inside the SCS to that trend during the study period. Endo *et al.* (2009) noted that the contrastive long-term trend of heavy rainfall occurrences in Vietnam with the decrease (increase) occurs in the north (south) regions (similar to the location of REG1 and REG3). However, he did not separate the trend of TC rainfall from non-TC rainfall and the reason for that feature was unknown. These results suggest that the cause of the increasing trend in REG3 can be explained partly by TC rainfall, while the decreasing trend in REG1 is due to non-TC rainfall. A larger frequency of negative anomaly of TCRA and TC_R50 indices is seen in the mid-1970s and before 1983 in REG3. On the other hand, a larger frequency of positive anomaly of those indices is seen after 1983, in particular, during the 1990s decade with a peak in 1990. As documented by Goh and Chan (2010), the number of TCs entering and formed in the SCS during the warm Pacific Decadal Oscillation (PDO) and El Niño phase tends to be below normal and above normal during the negative PDO and La Niña phases. This period (after 1983 to 2000) is known as the period which has more negative PDO and La Niña events than other periods. Does it make more TC frequency leads to more rainfall in this period? Leung *et al.* (2005) and Goh and Chan (2010) indicated that the decline of TC activity in the SCS is likely due to the decrease of TCs entering the SCS from the WNP, in particular after the mid-1990s. The increase of TC rainfall in REG3 during the 1990s could be directly linked to the changes in TC characteristics in not only frequency but also tracks and intensity. The inter-decadal variability of TC rainfall during this period should be addressed in the next study.

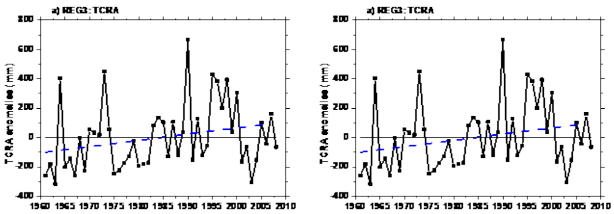

Fig. 4. Annual time series anomalies and linear trends (dash lines) of (a) TCRA and (b) TC_R50 in REG3.

Conclusions

We investigated the long-term trends in TC rainfall in the whole Vietnam and four sub-regions, namely REG1 (north of 20^{o}N), REG2 (17^o-20^{o}N), REG3 (12^o-17^{o}N), and REG4 (south of 12^{o}N) using the TCs best-track data provided through JTWC and daily rainfall records of 58 meteorological stations observed by Vietnamese National Hydro-Meteorological Service for the years from 1961 through 2008. A significant increasing trend with 90% and 95% confidence levels of TC rainfall amount (TCRA) and TC heavy rainfall days (TC_R50) indices is observed clearly at most stations in central coastline during the study period. For regional trends, little significant trends are detected in REG1, REG2, and REG4, while the significant increase is found in REG3 for both of TCRA and TC_R50. The increase of TC rainfall amount is mainly contributed from heavy rainfall days caused by TCs in REG3. The contrastive long-term trend of heavy rainfall occurrences in REG1 and REG3 was noted in Endo *et al*. (2009). These results suggest that the cause of the increasing trend of heavy rainfall in REG3 can be explained partly by TC rainfall, while the decreasing trend in REG1 is due to Non-TC rainfall. A larger frequency of positive anomaly of TCRA/TC_R50 is seen during the 1990s in the mid- and south-central regions in Vietnam.
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