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TROPICAL CYCLONE ACTIVITY OVER VIETNAM EAST SEA: CLIMATIC SHIFT AND ITS ASSOCIATED FACTORS

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ABSTRACT

This study examines the climatic shift of the tropical cyclone (TC) frequency affecting Vietnam's coastal region during the period from 1975 to 2014 (40-years). Several different TC databases in the Northwestern Pacific (WPAC) basin were used in this study included 1) the US Joint Typhoon Warning Center (JTWC), 2) the Japan Regional Specialized Meteorological Center (RSMC), and 3) the Weather Unisys. The results show that there is a consistent increase in both the number of strong TCs as well as the TC occurrences during the recent 1995-2014 period relative to the reference period from 1975-1994. For weak and moderate TCs, their total number decreases in the recent 1995-2014 period as compared to the reference period, but the change is not statistically significant. This decrease in the number of weak/moderate TCs during the recent period is consistent among all different data sources**. T**he meridional surface temperature gradient during the recent 1995-2014 period is substantially larger than that in the reference 1975-1994 period. This increase in the meridional surface temperature gradient is persistent regardless of how the gradient is defined, thus accounting for an increase in vertical wind shear and justifying why the overall number of TCs decreases during the recent period. Along with stronger vertical wind shear, it is also found that the intensity of summer monsoon in the VES decreases between the two periods**.**

Key words: Tropical cyclone frequency, climate change, extreme hazards, Vietnam, typhoons.

1. INTRODUCTION

Tropical cyclones (TCs) are major extreme hazardous weather events in the Earth's atmosphere. Among several main TC development regions, the Northwestern Pacific (WPAC) ocean basin is the most active area with an average of ~ 28-30 TCs each year, about a quarter of which are super-typhoons that have large impacts on economy and the loss of properties and life in countries with long coastlines (e.g., Feser and von Storch 2008, Cinco et al. 2016, Tan et al. 2016). In the context of the global climate change, various studies have projected that the number of intense TCs, tends to increase in the future warmer climate (Rayner et al. 2003, Bengtsson et al. 2007, Bender et al. 2010, Knutson et al 2010, 2013, Oouchi et al. 2006, Murakami et al. 2011).

Among numerous factors that can impact TC frequency sea surface temperature (SST) is often considered the first-order dominant factor that can affect the formation, intensity, as well as the frequency of storms. Many observational and modeling studies have shown that the future warmer SST in the WPAC could lead to not only more intense TCs, but also a shift in the track pattern that could directly affect the TC landfalling in this basin (Murakami et al. 2011, Wang et al. 2010).

Given the unique properties of environmental conditions in the ES that pose significant impacts on Vietnam's coastline, the main focus of this study is to 1) examine the epochal shift in the TC frequency in this area during the 40 years from 1975-2014, and 2) determine the large-scale factors that could be responsible for such a climatic shift in the TC frequency in the ES. Our

specific emphases herein are on several key environmental factors in the ES including surface temperature gradient, monsoon intensity, and vertical wind shear.

2. DATA AND METHODS

In this study, TC data analyses for a 40-year period from 1975 to 2014 are obtained from three different sources including the US Joint Typhoon Warning Center (JTWC), 2) the Japan Regional Specialized Meteorological Center (RSMC), and 3) the Weather Unisys. To focus on the TC activity over Vietnam East Sea (VES), any TC whose any part of its life cycle is inside a domain of [105^o-120^{o}E]×[5^o-20^{o}N] is selected for our analyses, regardless of where they are formed inside or elsewhere in the VES domain. In addition, the surface temperature data as well as the atmospheric data at pressure levels of the National Center for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) Reanalysis with a horizontal resolution of 2.5^o × 2.5^o were also used. The three TC datasets are divided into two 20-year epochs; one is from 1975-1994 (hereinafter referred to as a reference epcoh), and the other from 1995-2014. Two different metrics are used to quantify the change of TC activity in the VES: 1) the number of TCs, and 2) the number of TC occurrences (at an interval of 6-h) inside the VES. Furthermore, the TCs in the VES are divided into three different groups, based on their maximum 10-m sustained wind (VMAX). All TCs are categorized into a weak TC group, a moderate TC group, and a strong TC group.

The domain between the two longitudes 105^{o}E to 120^{o}E are partitioned into a pair of two latitudinal bands: the northern part and the southern part of the VES. The wind fields in the NCEP/NCAR reanalysis are used to calculate the averaged zonal wind on a given isobaric surface that can effectively characterize the summer monsoon activities in the VES. This index is defined as an average of the zonal wind component in the region (5-15°N, 110-120°E) at the 850 hPa level.

3. RESULTS AND DISCUSSION

It can be seen from Figures 1 that, the total number of TCs for all categories during the recent 1995-2014 period decreases as compared to the 1975-1994 period across all three data sources. For weak and moderate TCs, their total number decreases consistently among all different data sources in the recent 1995-2014 period as compared to the reference period. However, the average number of strong TCs during 1995-2014 increases, in both the relative percentage and absolute value, relative to the baseline period. These changes in the average number of strong TCs are very robust, regardless of how the dataset from 1975-2014 is partitioned.

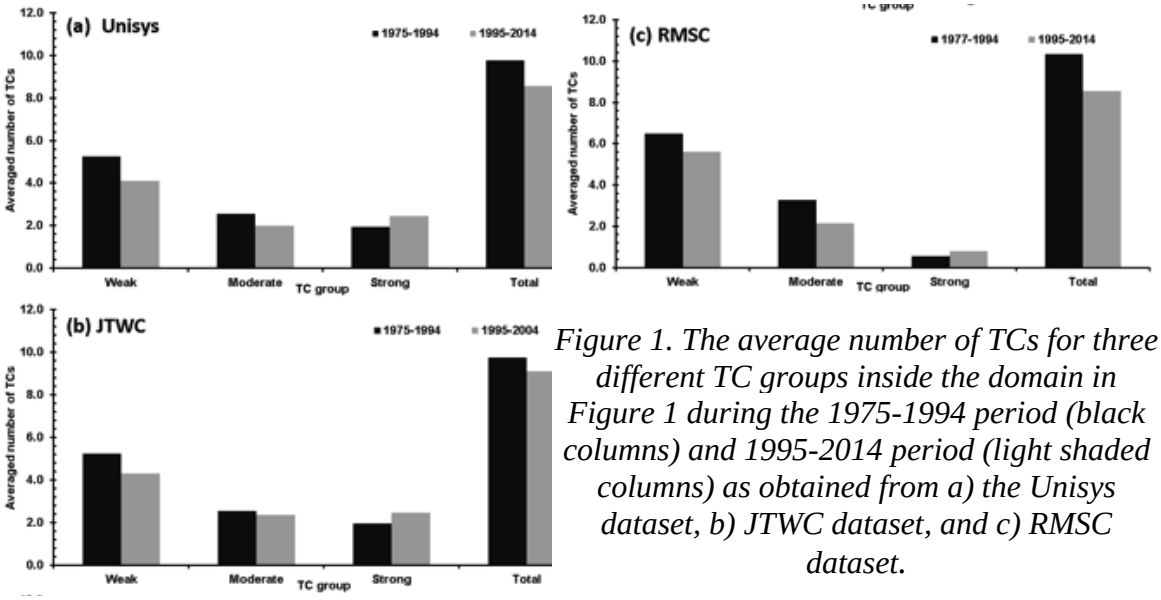

Figure 1. The average number of TCs for three different TC groups inside the domain in Figure 1 during the 1975-1994 period (black columns) and 1995-2014 period (light shaded columns) as obtained from a) the Unisys dataset, b) JTWC dataset, and c) RMSC dataset.

The overall surface temperature distributions during the reference and the 1995-2014 periods are fairly similar, with a warmer SST to the south of the VES (Figure 2). The three warmest pools of SST can be seen in the Gulf of Thailand, South of Vietnam, and South of Philippines Sea, which are apparent in both the reference and the recent periods. However, the SST in the VES is slightly warmer in the recent period than in the reference period (0.2 to 0.4 ^{o}C). The warmer trend relative to the reference period is not homogenous but appears to be more apparent in the central region of the VES with a warming of ~ 0.4-0.6 ^{o}C, whereas the warming is relatively modest in the outer region (~0.1-0.2 ^{o}C).

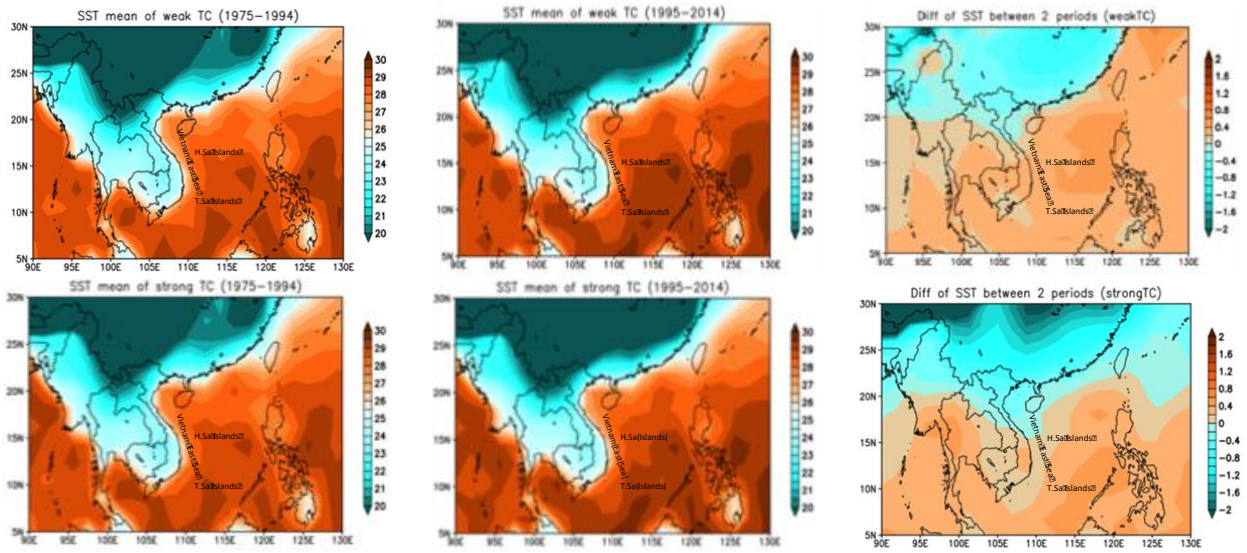

Figure 2. Distribution of the averaged surface temperature (shaded, unit ^{0}C) for the reference period from 1975-1994 (left), the recent period from 1995-2014 (middle), and the difference between the recent and the reference periods (right), and for the weak (top) and the strong (bottom) TC group.

Table 1 compares the average surface temperature of the two pairs of latitudinal bands at the north bound and south bound of the VES as a quantitative estimation of the north-south surface temperature gradient (STG) change. These gradient values are respectively -12.5^{o}C, and -9.5^{o}C for both pairs P1 and P2 for the recent 1995-2014 period, which are somewhat similar to those during the reference period. The change in the STG between the two periods is nevertheless much larger for the strong TC group. Such a pronounced change in the north-south STG indicates an important clue for the shift in the TC activities in the VES, particularly the increase of strong TCs as well as the strong TC occurrences during the 1995-2014 period as compared to the baseline period. In fact, changes in the meridional STG could indicate much more significant variations of several large-scale atmospheric conditions such as vertical wind shear, moisture content, or tropospheric stratification that TCs reside in. These large-scale factors may or may not collaborate with each other, and therefore can enhance or depress TC activities. Further investigations (not show) indicated that a larger SST gradient would promote a stronger vertical wind shear via thermal wind relationship, thus preventing the formation of the TCs. On the contrary, the same larger SST gradient could enhance the monsoon activities and enhance the barotropic instability in the lower troposphere, resulting in more TC development. Physically, weakened monsoon often implies a shift in the atmosphere mass such that the sea level pressure increases over almost the entire Pacific Ocean as well as reduction in the large-scale precipitation. The changes in the monsoonal activities can impact not only TC frequency (via barotropic instability), but also TC intensity (via change in the tropospheric stratification).

Table 1. The average temperature (^{0}C) of each latitudinal line between 1975-1994, 1995-2014, two-stage effect: (1995-2014) minus (1975-1994) Strong storms and entire periods of 20 years ago and 20 years later

	Latitudinal band	**Weak TC**		**Strong TC**		**All average SST**	
		Value	Difference	Value	Difference	Value	Difference
Time Period: 1975-1994							
Pair P1	25^0-30^0	292.3	-9.6	292.4	-9.5	288.9	-12.6
	5^0-10^0	301.9		301.9		301.5	
Pair P2	20^0-30^0	294.0	-7	294.1	-6.9	291.3	-9.4
	5^0-15^0	301.0		301.0		300.7	
Time Period: 1975-1994							
Pair P1	25^0-30^0	291.7	-10.5	291.1	-11.1	289.3	-12.5
	5^0-10^0	302.2		302.2		301.8	
Pair P2	20^0-30^0	293.6	-7.7	293.1	-8.2	291.6	-9.5
	5^0-15^0	301.3		301.3		301.1	
Difference (1995-2014)-(1975-1994)							
Pair P1	25^0-30^0	-0.58	**-0.87**	-1.39	**-1.72**	0.34	0.01
	5^0-10^0	0.29		0.33		0.34	
Pair P2	20^0-30^0	-0.41	**-0.72**	-1.03	**-1.33**	0.34	-0.04
	5^0-15^0	0.31		0.30		0.38	

4. CONCLUSIONS

It was found in this study that there is a significant shift in the TC frequency as well as the TC occurrences in the VES between a reference period from 1975-1994, and a recent period from 1995-2014. Unlike the strong TC statistics, the group of weak and moderate TCs showed a decrease in the total number of TCs in the recent 1995-2014 period as compared to the baseline period. Physically, a larger gradient of surface temperature implies a larger pressure difference between the northern and the southern parts of the VES, which allows for larger barotropic instability and more favorable conditions for TC disturbances to develop. The larger meridional surface temperature gradient could produce stronger vertical wind shear and prohibit TC development.

It was also found that the intensity of summer monsoons in the VES is smaller during the recent 1995-2014 period as compared to the baseline period. The competing effects between vertical wind shear and the horizontal instability in the VES associated with the summer monsoon may explain why the TC climatology in this region could not display a clear signal of variability. The results obtained in this study highlight the complex nature of TCs in the VES whose underlying mechanisms are still not clear due to competing effects of vertical wind shear, monsoon, and the meridional SST gradient. Therefore, more in-depth research on TCs to isolate the roles of each large-scale factor in the VES region will be needed to help better capture the future TC activities in this part of the WPAC basin.

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