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THE EFFECT OF WARM POOL THERMAL STATES ON TROPICAL CYCLONES IN THE WESTERN NORTH PACIFIC

CHEN Guang-hua (陈光华), HUANG Rong-hui (黄荣辉)

(Center for Monsoon System Research, Institute of Atmospheric Physics of CAS, Beijing 100080 China)

Abstract: The influence of thermal states in the warm pool on tropical cyclones (TCs) in the western North Pacific (WNP) is investigated. There are fewer typhoons during warm years of the warm pool in which tropical storms tend to form in the northwest quadrant and move westward. Inversely, typhoons tend to recurve northeastward to the southeast of Japan and increase in number in the southeast quadrant during cold years. Based on composite analyses, circulation-induced dynamic factors rather than thermal factors are identified as being responsible for TCs activities. During the warm state, the monsoon trough retreats westwards, which leads to anomalous vorticity in low-level and divergence in high-level in the western part of west Pacific. Above-normal TCs activity is found in this area. Furthermore, wind anomalies at 500 hPa determine the main track types. On the contrary, when the warm pool is in cold state, the atmospheric circulation is responsible for the formation of more TCs in the southeast quadrant and recurving track.

Key words: west North Pacific; warm pool; tropical cyclones

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1 INTRODUCTION

Being the warmest part of global oceans, the tropical western Pacific gathers enormous amount of seawater, which provides thermodynamical drive for the general circulation on the large scale through air-sea interactions. The WNP is also the main source region of TCs. It is therefore helpful to understand the behavioral pattern of TCs and improve, as a result, the ability to predict their generation and development by studying the effect of the state of northwestern Pacific warm pool on TCs.

In previous works on the interannual variation of TC generation, ENSO, which is caused by SST in the equatorial central and eastern Pacific, is mainly focused for its effect on the number of TCs generated[1-6]. In addition, large discrepancies also exist between the conclusions drawn from them, which may be resulted from the differences in the time limit of the dataset used, indexes defined and methods employed for analysis. It is important, however, to note that the anomalies of SST and their eastward propagation in the subsurface layer of the west Pacific warm pool are having a key role in the start of the ENSO episode and as precursory signals for the latter, the thermodynamic state of the warm pool will have direct impact on the convection and atmospheric circulation above it so as to play a part in the formation and movement of TCs in WNP. It is therefore necessary to probe into the relationships between the thermodynamic state of the warm pool and the interannual variation of TCs and main physical processes that link them.

2 SOURCES OF DATA

The time for the analysis in this work is from 1959 to 2003 and the dataset used is the monthly mean sea temperature in the subsurface layer of the Pacific Ocean from the U.S. National Center for Oceanic Environment Data Analysis at a resolution of 2.5º× 2.5º. The warm pool is defined to be within 125ºE – 165ºE, 0º – 16ºN. The data of TCs for WNP (including the South China Sea) are from the Joint Typhoon Warning Center, USA. Tropical cyclones that are

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Biography: CHEN Guang-hua (1978-), male, native from Fujian province, Ph.D., mainly undertaking the study on tropical meteorology.

E-mail: cgh@mail.iap.ac.cn

studied in the work include TC (tropical depressions, tropical storms and typhoons), TSTY (tropical storms and typhoons) and TY (typhoons). Fields of physical quantities of the atmospheric circulation are taken from the 2.5º×2.5º reanalysis data of NCEP / NCAR.

3 LINKS BETWEEN THERMODYNAMIC STATE OF THE WARM POOL AND TCS

3.1 Relationships between TC number and warm pool

The mean anomalies of sea temperature in the subsurface layer of the warm pool from July to October (JASO) in 1959 – 2003 are determined. Years with the value more than 1.5ºC are defined as much warmer years and those with the value less than -1.5ºC much colder years. The much warmer years include 1970, 1975, 1978, 1998, 1999 and 2000, and the much colder years are 1972, 1982, 1987, 1991, 1993 and 1997 (Fig.1). Tab.1 presents a correlation analysis of the number of all types of TCs that formed during the JASO period over the 45 years, SST in Niño3.4, warm pool and SOI indexes defined. It is found that the confidence test is less than 95% for the correlation between the number of TCs and TSTYs and the indexes. For the two datasets, only the warm pool index and TY number reach the 95% confidence test.

Tab.1 The correlation between three types of TCs during the JASO period over the 45 years and three indexes (with the italic, bold numerals indicating confidence test more than 95%)

	TC	TSTY	TY
Niño3.4	-0.18	-0.07	0.21
Warm pool	0.12	-0.05	***-0.31***
SOI	0.09	0.0	-0.18

3.2 Difference of TSTY tracks between two types of years

To study the effect of thermodynamic condition of the warm pool on the track of TCs, the area of 100º – 180ºE, 0º – 50ºN is divided into gridpoints of 5º×5º. Track records of TSTYs available every six hours are taken into account. The number of TSTYs that move into areas ±2.5º on all sides of the gridpoint are calculated and the number of TSTYs in each of the gridpoints during the 45 years are accumulated to study the variation of TC tracks.

Differences of annual mean number of the TSTY are determined for both warm and cold years. It is found by subtracting the mean of the much warmer years from that of the much colder years that 130ºE is basically the line that divides positive and negative values (Fig.2). The pattern of distribution shows that TSTYs in the east of WNP are weaker in the much warmer years than in the much colder years and more frequent on the side closer to the continent in the much warmer years. It agrees quite well with a previous study by Lin[7]. The figure also reveals another significant characteristic: the negative area east of 130ºE aligns in a SE-NW direction south of 20ºN but becomes NE north of it. It indicates that during the much colder years the TSTYs forming in the east of WNP move northwest to the point of 130ºE, 20ºN and tend to make a northeast recurvature, increasing the chance to hit Japan.

3.3 Regional distribution of TC formation

In order to study the regional distribution of the formation of TSTYs and TYs, the WNP is divided into four domains along 150ºE and 15ºN and Domains 1, 2, 3 and 4 represent the NW, SW, SE and NE quadrants, respectively (Fig.3). Correlation is taken into account between the TSTYs / TYs forming in the four domains and the anomalies of sea temperature in the subsurface layer of the warm pool. As shown in Tab.2, the numbers of TSTYs generating in Domains 1 and 3 are significantly correlated with the warm pool and especially, the correlation coefficient is –0.7 for Region 3 while positive correlation is discovered in the NW quadrant. It is then seen that the thermodynamic state of the warm pool is almost out of phase with the number of TSTYs in the southeastern part of WNP. In other words, when the warm pool is in a warm state, less TSTYs form in the southeastern part of WNP than in the northwestern part; when the warm pool is in a cold state, otherwise is true.

Tab.2 The correlation between the four domains and the number of TSTY and TY (with the italic, bold numerals indicating confidence test more than 95%)

	Dom.1	Dom.2	Dom.3	Dom.4
TSTY	***0.41***	0.14	***-0.73***	0.24
TY	0.25	0.05	***-0.76***	0.21

4 EFFECT OF LARGE-SCALE BACKGROUND FIELD ON TCS

4.1 Effect of large-scale background field on TCs

First of all, the variation of SST is taken into account. Mean SST in WNP is all above 29ºC from July to October, with major difference in the much colder years, in which the SST contour of 29ºC is similar in morphology to the climatological mean. It is also known from composite SST anomalies made from both cold and warm years that quite a number of TCs form over the WNP in cold years and a substantial part of them are at the level of typhoon. It is then known that local SST in WNP does not correlate well with the number of TCs. Since the oceanic thermal condition is easily met for TC formation in average years, the main

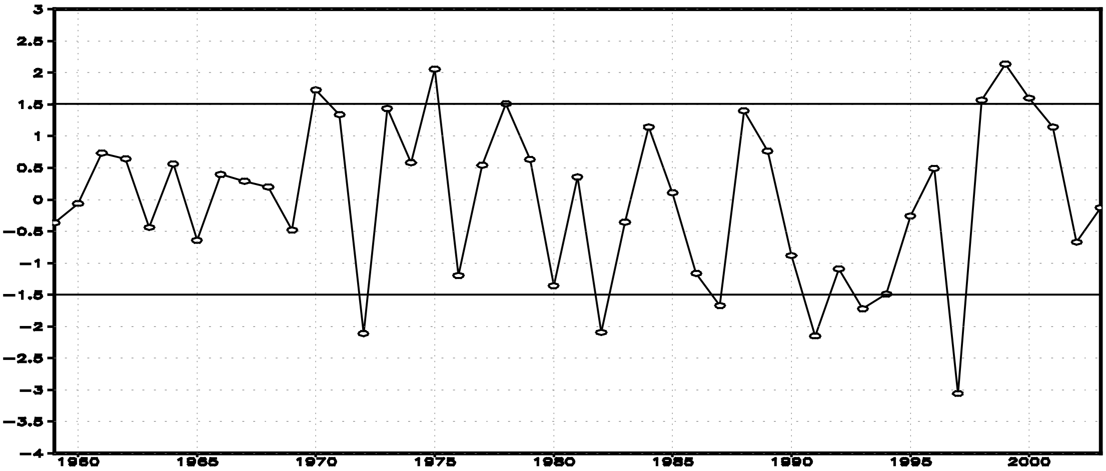


Fig.1 Time series of sea temperature of the subsurface layer of the warm pool (125160016) in the months of JASO over the 45 years. The abscissa is the year.

factors for interannual difference of TCs activity is not the local SST but the atmospheric circulation above that responds to SST.

4.2 Characteristics of atmospheric circulation

An initial disturbance is needed to form a TC. Low-level tropical circulation is used as the direct background field for it. It is known from Fig.3, which composes the 850-hPa circulation of much warmer and colder years for July – October, that the composite of two extreme years has substantially different circulation. For the composite circulation of much warmer years, the monsoon trough is near 130ºE, 15ºE, the curvature of the trough is moderate and TSTYs concentrate in the northwestern part of the WNP. The case of much colder years are just the opposite: low-latitude westerly anomalies help extend the monsoon trough eastward to areas near 180ºE and south of 10ºN, making TSTYs more likely to form over the southeastern part of the WNP. Besides, the distribution of the anomalies of vorticity and divergence on high and low levels for both cold and warm years of the warm pool are consistent with that of Fig.3.

It is known from the composite anomalies of 500-hPa wind field for the two types of years that there are differences in large-scale circulation that govern the climatological features of the TC track. In the much warmer years, significant easterly anomalies of the horizontal wind field exist in low latitudes south of 10ºN and middle latitudes north of 25ºN. Such pattern of circulation helps steer TCs to move westward to migrate into the coastal area of China and make landfalls. In the much colder years, however, the anomalous westerlies are the dominant feature in the 500-hPa wind field, especially over the region of East Asia, where a strong, stationary main trough causes southwesterly anomalies to appear in front of it and makes it easier for the TC to travel to the southeastern part of Japan before turning towards the northeast.

5 CONCLUSIONS

It is shown in the above analysis that less TYs form and more TSTYs take a westward track in the warm years of the warm pool in WNP while there are

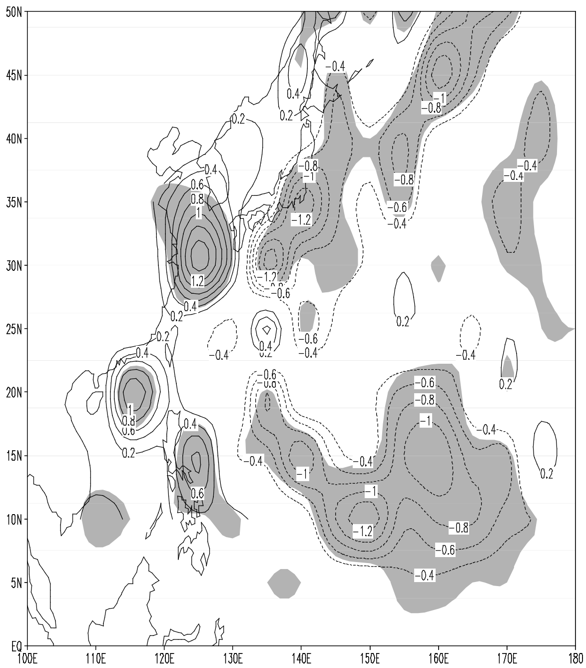
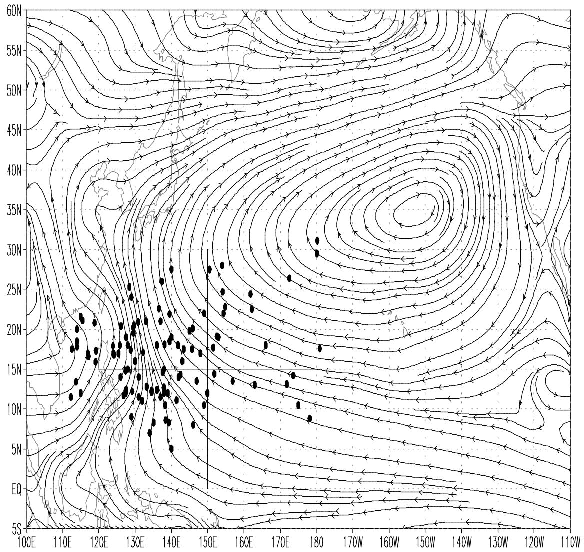
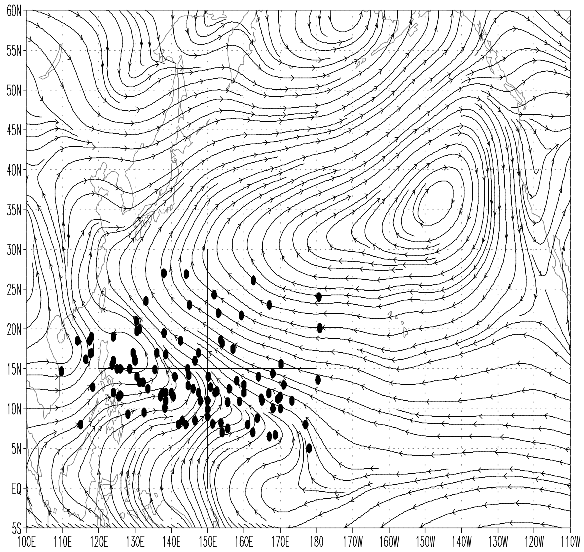


Fig.2 Mean differences of annual number of TCs between much warmer years and much colder years (by subtracting the much warmer years from the much colder years). The shaded part is where the *t* test for mean deviation is more than 90% of confidence.

more TYs in the much colder years and most of them follow tracks that lead them towards northwest till the southeastern part of Japan where they turn to the northeast. As far as the region of TSTY formation is concerned, TSTYs tend to form in the northwestern part of WNP in the warm years while they concentrate to form in the southeastern part in the cold years.



a



b

Fig.3 850-hPa flow field for the much warmer year (a) and much colder year (b). The cross explains how the domains are divided and the black spots indicate where TSTYs are formed.。

Water is as warm as 29ºC all the year round in the WNP and local SST does not have significant correlation with the number of TCs forming over it. The dynamic factor triggered by circulation in different years is the driving force for the difference in the pattern of TC activity in different states of the warm pool. In the much colder years, the westerly anomalies prevail at 850 hPa and a low-level monsoonal trough extends to the southeast to bring about positive vorticity anomalies in the southeastern part of WNP while positive anomalies of diversity appear at 200 hPa in association with anomalous ascending motion in the middle level, making it favorable for the TC to form in the southeastern part of the WNP. The pattern of circulation reverses in the much warmer years when convective, ascending motion is over the northwestern part of the WNP, making it more likely for the TC to generate in this part of the ocean.

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