IOP Conf. Series: Materials Science and Engineering **735** (2020) 012077 doi:10.1088/1757-899X/735/1/012077

Characteristics of the Violent Typhoon Events Seriously Affecting Hainan Island and Its Relationship with PDO

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Abstract. With the typhoon cyclone data, NCEP/NCAR reanalysis datasets and PDO index data from 1949 to 2018, the characteristics of violent typhoon events seriously affecting Hainan Island (VTESAHs for short) in the past 70 years are analyzed. On this basis, the characteristics of VTESAHs in the different phases of PDO and their relationship with SST are analyzed. The results show that there is obvious inter-annual variation in the frequency of VTESAHs. The VTESAHs have good continuity in both calm and active periods, and have obvious clustering. VTESAHs are more likely to occur in the cold phase years of PDO, almost generated in the western Pacific. The source of VTESAHs in the cold phase years of PDO are mainly concentrated in the sea area of 5 ºN -15ºN and 125 ºE -150ºE,while the source of VTESAHs in the warm phase years of PDO are mainly around 10ºN. When the PDO phase is cold (warm), there is a significant negative (positive) correlation between the frequency of VTESAHs and the sea surface temperature in the western Pacific Ocean east of the Philippines at low latitudes.

1. Introduction

Typhoon is one of the main disastrous meteorological events, so the inter-annual, seasonal and monthly prediction of typhoon is great significance to disaster prevention. The relationship between typhoon activities and atmospheric and oceanic conditions has been studied extensively. It is pointed out that large-scale circulation and Pacific warm pool can affect the frequency and path of typhoon [1-3]. As a climatic variability signal, the Pacific decadal oscillation (PDO) has been used widely in the study of Pacific typhoons in recent years. According to the sea surface temperature anomaly in the northeast and tropical Pacific Ocean, Steven [4] divided PDO into cold phase and warm phase. Yang [5] summarized three kinds of views on the formation of PDO: tropical origin theory, mid-latitude origin theory and common origin theory. Wang [6], Li [7] and Gao [8] found that PDO is closely related to typhoon. The frequency of typhoons affecting China is more in the cold phase of PDO and less in the warm phase of PDO, as are the frequencies of typhoons north-going in midsummer and those affecting Shandong Province.

Violent typhoons affect Hainan Island every year from 2014 to 2016, bringing significant impacts and disasters to Hainan Island. The study on the activity characteristics and influencing factors of violent typhoons affecting Hainan Island is conducive to providing services for disaster prevention and mitigation in Hainan. Some studies [9-12] have been carried out by Hainan meteorologists. The climatic characteristics, formation mechanism and influencing factors of typhoons have been understood, which provides theoretical support for typhoon prediction. However, there is a lack of systematic understanding and application of violent typhoons due to relatively few studies. Therefore, it is necessary to study such typhoons. The characteristics of violent typhoon events seriously affecting Hainan Island (VTESAHs for short) from 1949 to 2018 are analyzed in this study. On this basis, the relationship between VTESAHs and PDO is carried out in order to provide scientific basis for violent typhoon prediction and decision support for disaster prevention and mitigation in Hainan.

2. Datasets and Methods

The typhoon cyclone data in 1949-2018 come from Typhoon Almanac compiled by China Meteorological Administration and Tropical Cyclone Best Track Dataset compiled by Shanghai Typhoon Institute. The Pacific Decadal Oscillation (PDO) Index is derived from NOAA. Sea Surface Temperature (SST) is derived from the National Centers for Environmental Prediction-National Center for Atmospheric Research (NCEP-NCAR) reanalysis data, with a horizontal resolution of 2° latitude × 2° longitude.

After entering the seriously affected area, the tropical cyclone with intensity greater than or equal to 14 grades (violent typhoon) is defined as VTESAH [13].

3. Characteristics of VTESAHs

The variation characteristics of VTESAHs from 1949 to 2018 are displayed in Figure1a. VTESAH occurred 26 times in recent 70 years with an annual average of 0.4. It occurred more frequently in the 1950s-1990s, less in the 1990s-2010s and increased significantly after 2010s. There is obvious inter-annual variation in the frequency of VTESAHs. The VTESAHs have good continuity in both calm and active periods.

It occurred four times in 1953-1956, four times in 1963-1966, five times in1970-1974, four times in 1981-1987, and none at other times before 1990s. VTESAHs occurred in 1991 and 2005 respectively in 1990s and 2000s, and after six consecutive years of calm, it occurred five times in 2011-2016. It indicates that VTESAHs have obvious clustering.

Statistics on the seasonal distribution of VTESAHs (Figure 1b), 26 VTESAHs in the past 70 years occurred in July-November, mainly concentrated in July-October. VTESAH occurred 10 times in summer, evenly distributed in July and August and none occurred in June.

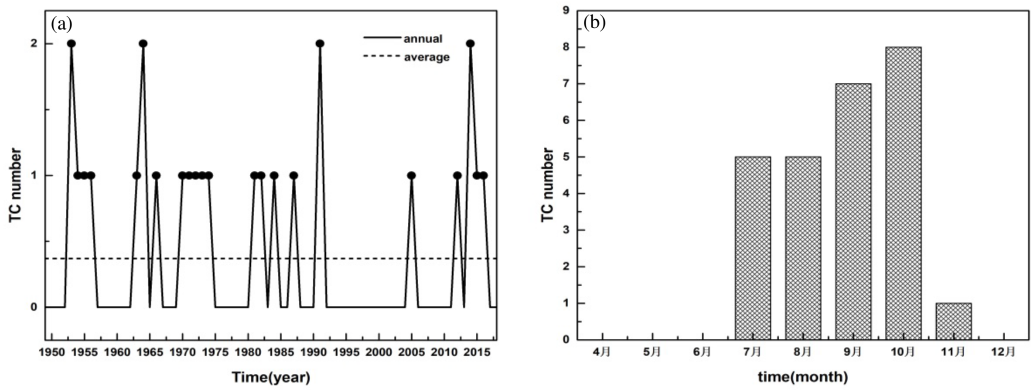

Figure 1. Inter-annual and Seasonal Distribution of VTESAHs from 1949 to 2018

4. Relationship between VTESAHs and PDO

4.1. Influence of PDO on VTESAH Frequency

The Pacific Decadal Oscillation (PDO) is the variability of the North Pacific SST on an inter-decadal time scale, which has an important impact on the inter-decadal characteristics of climate change in the Northern Hemisphere [14].The PDO index is defined as the projections of monthly mean SST anomalies onto their first EOF vectors in the North Pacific (north of 20ºN), which can be divided into cold phase and warm phase. When the index is positive (negative), it is the warm phase (cold phase) of PDO, the Central and Eastern Pacific is unusually warm (cold) at low latitudes, the North Pacific is unusually cold (warm) at mid-latitudes, and the West Bank of North America is unusually warm(cold) [5].

It can be seen from Figure2 that the cold phase year of PDO is 1949-1976 and 1999-2013, and the warm phase year of PDO is 1977-1998 and 2014-2018. 17 VTESAHs occurred in the PDO cold phase, accounting for 65.4%, and 9 occurred in the PDO warm phase. Therefore, the phases of PDO have a certain relationship with VTESAHs. VTESAHs have a good correspondence with the cold phase of PDO. It indicates that VTESAHs are more likely to occur in the cold phase years of PDO.

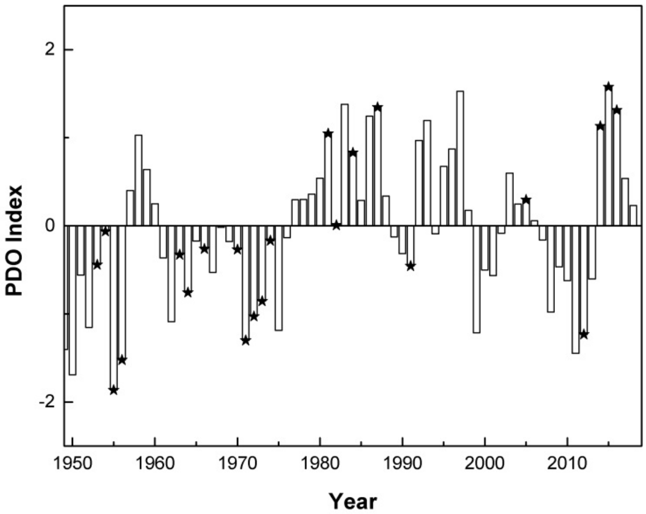

Figure 2. The Series of PDO Index from 1949 to 2018 (★Indicates that Violent Typhoon Event Occurred That Year)

4.2. Influence of PDO on the Source of VTESAHs
In the past 70 years, 25 VTESAHs were generated in the western Pacific Ocean east of the Philippines, and 1 in the South China Sea. There is a certain difference between the cold and warm phase of PDO on the source of VTESAHs (Figure3). The source of VTESAHs in the cold phase years of PDO are mainly concentrated at 5 °N -15°N and 125 °E -150°E, and the north side can be up to 16.7°N. However, the source of VTESAHs in the warm phase years of PDO are mainly around 10°N, which is more south than the cold phase.

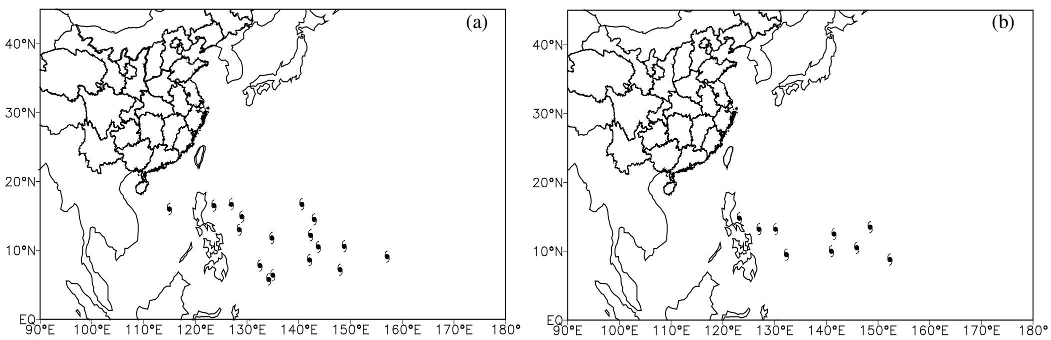

Figure 3. The Influence of PDO on the Source of VTESAHs (a: The Cold Phase of PDO, b: The Warm Phase of PDO)

4.3. Correlation between SST and the Frequency of VTESAHs
The correlation between the Pacific SST and the frequency of VTESAHs in different phases of PDO is analyzed in order to reveal the effect of PDO on VTESAHs (Figure4, Figure5). Figure4 shows the correlation between SST and the frequency of VTESAHs in the cold phase years of PDO. The SST in

the western Pacific east of the Philippines (near 140ºE-160ºE) and the frequency of VTESAHs are significantly negatively correlated at low latitudes in spring, summer, autumn and winter. It indicates that there is a negative correlation between SST in the area and the frequency of VTESAHs in the cold phase years of PDO. The cold phase of PDO usually corresponds to the positive anomaly of sea surface temperature in the western Pacific, which is beneficial to the formation and development of typhoon in the area. The SST anomaly may affect the ocean-atmosphere interaction through thermal exchange. It will have a certain impact on the frequency and intensity of the typhoon. However, more frequency of strong typhoons further strengthens the ocean mixing of the ocean surface and the subsurface, resulting in a decrease in surface sea temperature. The combined effect of sea surface temperature and strong typhoon frequency makes the sea temperature in the western Pacific Ocean and the frequency of VTESAHs negatively correlated in the cold phase of PDO. Combined with the source of VTESAHs in the cold phase years of PDO (Figure3), it can be found that the significant negative correlation area is the main source of VTESAHs.

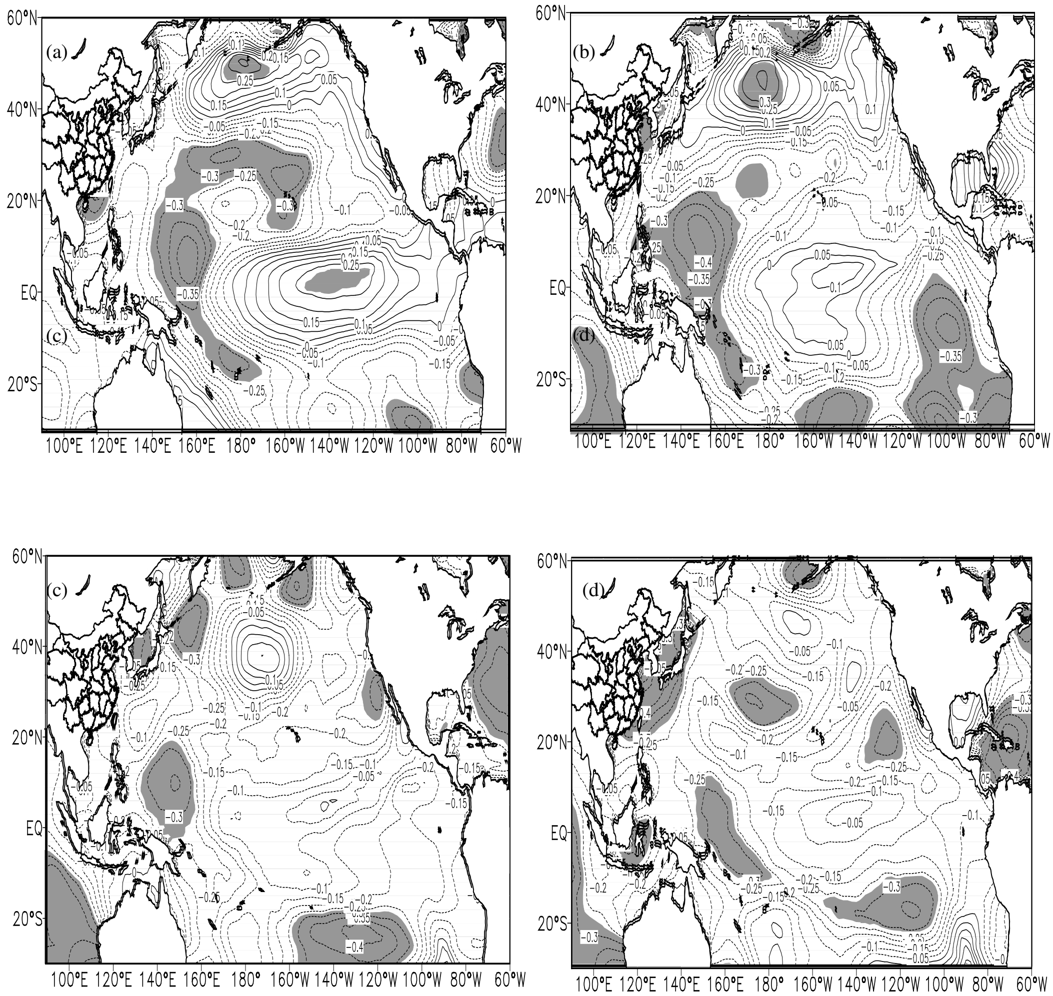

Figure 4. The Correlation between SST and the Frequency of VTESAHs in the Cold Phase Years of PDO. a: Winter, b: Spring, c: Summer, d: Autumn (Shadow Area Passed the Significance Test of 95% Level)

Figure 5 shows the correlation between SST and the frequency of VTESAHs in the warm phase years of PDO, which is quite different from the cold phase years. The Pacific SST and the frequency of VTESAHs are mainly positively correlated at low latitudes in spring, summer, autumn and winter.

The significant regions at low latitudes are mainly located in the western Pacific Ocean east of the Philippines and the Central Pacific Ocean from 160 ºE to 170 ºE. It indicates that there is a positive correlation between SST in the area and the frequency of VTESAHs in the warm phase years of PDO. The warm phase of PDO usually corresponds to the negative anomaly of the sea surface temperature in the western Pacific, which is not conducive to the occurrence of VTESAHs. It is consistent with the conclusion that the frequency of VTESAHs in the warm phase is relatively less. However, the SST anomaly affects the frequency and intensity of typhoon through ocean-atmosphere interaction. The frequency of VTESAHs is positively correlated with SST in the warm phase years of PDO. High sea temperature is also conducive to the formation and development of strong typhoon.

In summary, When the PDO phase is cold (warm), there is a significant negative (positive) correlation between the frequency of violent typhoons and the sea surface temperature in the western Pacific Ocean east of the Philippines at low latitudes.

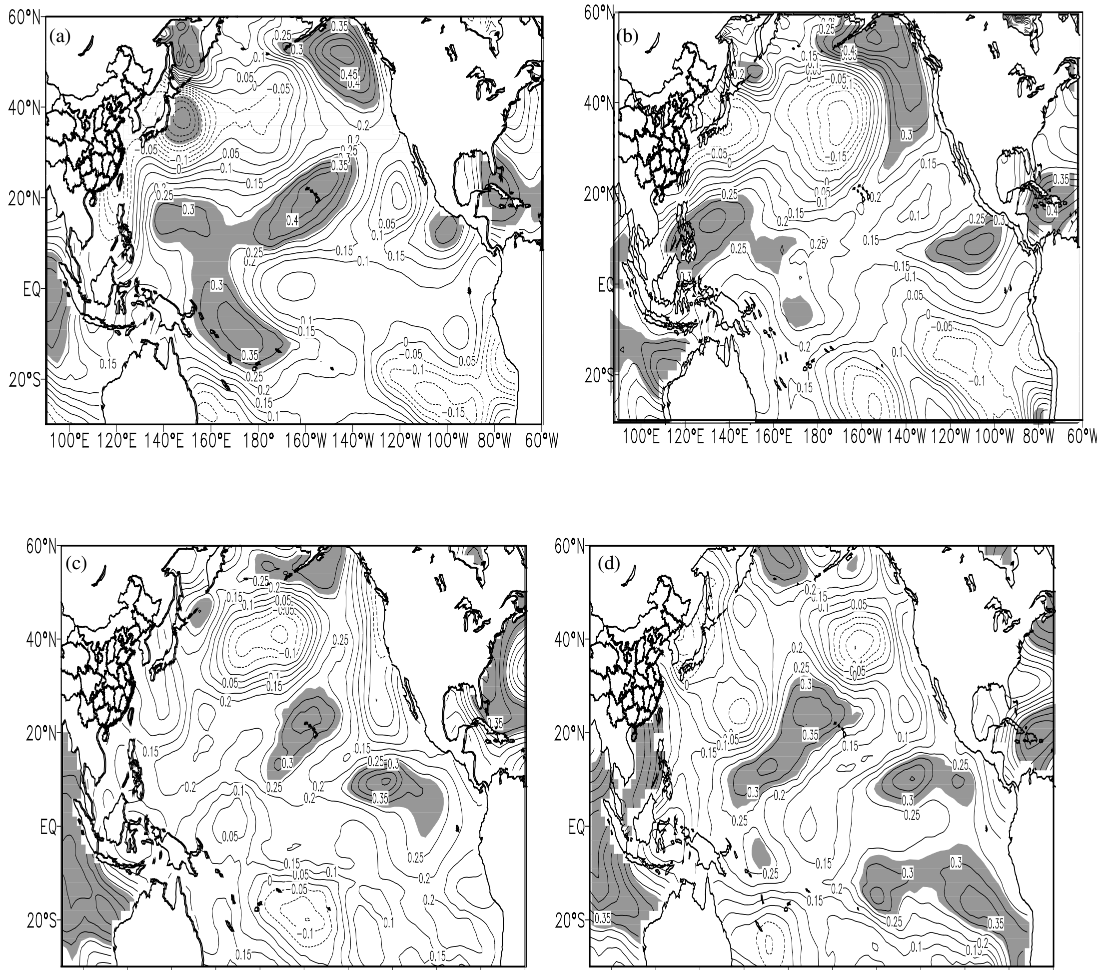

Figure 5. The Correlation between SST and the Frequency of VTESAHs in the Warm Phase Years of PDO. a: Winter, b: Spring, c: Summer, d: Autumn (Shadow Area Passed the Significance Test of 95% Level)

5. Summary

There is obvious inter-annual variation in the frequency of VTESAHs. The VTESAHs have good continuity in both calm and active periods, and have obvious clustering mainly occurring from July to October.

VTESAHs are more likely to occur in the cold phase years of PDO, almost generated in the western Pacific. The source of VTESAHs in the cold phase years of PDO are mainly concentrated in the sea area of 5 °N -15°N and 125 °E -150°E,while the source of VTESAHs in the warm phase years of PDO are mainly around 10°N.

When the PDO phase is cold (warm), there is a significant negative (positive) correlation between the frequency of VTESAHs and the sea surface temperature in the western Pacific Ocean east of the Philippines at low latitudes.

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