Decadal Variability of Tropical Cyclone Activity over the Western North Pacific

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Abstract

Time series of tropical cyclone (TC) counts over the Western North Pacific (WNP) from 1965 to 2001 were analyzed by a statistical change-point analysis. Results reveal two major epochs of activity. The epoch during 1989-1997 is marked by high activity in contrast to the low activity during 1968-1988.

Relative to the inactive epoch, a warmer ocean surface over the region where TCs are generally formed is found in the active epoch, although this warming is rather small (0.1°C). Anomalous low-level cyclonic vorticity and a huge, anomalous cyclonic circulation gyre over the Philippine Sea are noted when the inactive period is subtracted from the active period. Weaker vertical wind shears, stronger ascending motion, and increased precipitable water over the major genesis area are found during the active epoch as opposed to the inactive epoch. These changes in environmental conditions collectively favor higher cyclone activity for the recent epoch.

Key words: Tropical cyclone; Decadal variability; Monsoon trough; Vorticity; Vertical wind shear; Sea surface temperature

1. Introduction

Tropical cyclones (TCs) are perhaps the most devastating phenomenon of natural disasters because of the loss of human life they cause and the large economic losses they inflict. The WNP stands out as an active region for TC formation and is particularly noted for the occurrence of large and intense TCs (McBride, 1995).

Chan and Shi (1996) noted that the annual numbers of TCs in the WNP were high in the 1960s, decreased in the 1970s, and then gradually increased until the early 1990s. Yumoto and Matsuura (2001) found interdecadal variability of TC activity in the WNP. Ho et. al. (2003) showed a interdecadal changes in summertime typhoon tracks in the WNP. Lin and Wu (2001) also found a change of TC formation in the WNP before and after the 1975/76 climate shift. Based on a change-point model used for the central North Pacific (Chu, 2002) and the North Atlantic (Elsner et al., 2000), a statistical analysis is here applied to objectively identify the timing of change-point years in TC series over the WNP. As will be seen later, two major epochs in the TC time series over the WNP are identified. Large-scale environmental conditions instrumental for TC incidences during the peak typhoon season between these two epochs are then investigated.

2. Data and Methodology

The historical record of TC activity in the WNP was obtained from the annual tropical cyclone reports issued by the Joint Typhoon Warning Center (JTWC) in Guam (e.g. JTWC 2001). Here TCs refer to tropical storms and typhoons. The period of analysis is from 1965 to 2001. The following data are also used: the monthly NCEP-NCAR reanalysis dataset for the period 1965-2001 (Kalnay et al. 1996), and the extended reconstruction sea surface temperature (SST) produced by the National Climatic Data Center (NCDC) (Smith and Reynolds 2003).

Using a step function as an independent variable and taking a logarithmic transformation of the annual TC counts as a dependent variable, Elsner et al. (2000) and

Chu (2002) developed a regression model to help identify the exact time of decadal changes in the tropical cyclone frequency over the North Atlantic and the central North Pacific, respectively. The same model is here applied for detecting change-points in the WNP cyclone series. The null hypothesis (i.e., slope being zero) is rejected at the 95% confidence level if the estimated slope is at least twice as large as its standard error at a point in the TC series. The differences in the large-scale circulation between active and inactive epochs are evaluated by a nonparametric Mann-Whitney rank-sum test (Chu, 2002). In the following analysis, the seasonal mean circulation refers to the entire period from 1965 to 2001.

3. Results

The historical records show that the TCs over the WNP occurred in every single month of the calendar year. In the mean, the peak TC season over the WNP runs from July to October with almost 70% of TCs observed during this peak season.

Figure 1 shows the time series of the annual number of TCs in the WNP from 1965-2001.The statistical analysis objectively identifies three significant change-points (1968, 1989, and 1998) with four periods in the TC series. The four periods are 1965-1967, 1968-1988, 1989-1997, and 1998-2001. Because the first and last periods are short, we will focus on the two middle epochs (1968-1988 and 1989-1997). The epoch during 1989-1997 is marked by high activity in contrast to the low activity during 1968-1988. For the active epoch, the average is 31.1 TCs per year and for the inactive epoch the mean value is only 25.4 TCs per year. To determine whether the decadal difference in TC is significant, a two-sample t-test is applied to the periods of 1968-1988 and 1989-1997. Under the assumption of independence, the mean difference between these two epochs is significant at the 95% level.

Having established that TC activity has undergone decadal variations, our next goal is to illustrate the large-scale circulation features during the peak season between the two epochs. Compared to the inactive epoch, a positive and statistically significant difference in SST is noted over the equatorial central Pacific and to the southeast of Japan during the active TC epoch (Fig. 2). Differences in SST are small (~0.1°C) over the Major Genesis Area (MGA), a region between 10°N-20°N and 130°E-160°E (Chia and Ropelewski, 2002). Warm SSTs (≥29°C) generally characterize the WNP during the peak season (not shown). That is, the background SSTs are already favorable for TC formation and a slight warming of ocean surface in the recent epoch may only play a marginal factor for the decadal TC variations.

The favorable locations for TC genesis are in, or just poleward of, a monsoon trough (Gray 1968; Ramage 1974). Climatologically, a band of low-level cyclonic vorticity extends eastward from the South China Sea through the Philippine Sea to 180°E, coinciding approximately with the location of the monsoon trough (Fig. 3a). For the difference map (Fig. 3b), anomalous cyclonic vorticity as large as $2\times10^{-6}\ s^{-1}$ is observed over the eastern MGA during the active epoch relative to the inactive epoch. This is the region where the difference in relative vorticity is statistically significant. To understand why there is anomalous cyclonic vorticity over the eastern half of the MGA, Fig. 4 displays the difference map of the streamlines at 850-hPa between the two epochs. Interestingly, a large and anomalous cyclonic cell, similar to the monsoon gyre (Lander, 1994), dominates over the Philippine Sea. To the north of this cyclonic cell is an anomalously anticyclonic cell over the North Pacific Ocean. A band of enhanced westerly anomalies prevails over the MGA, where appeared to be related to tropical central Pacific heating anomalies (Fig. 2).

Easterly anomalies prevail to the north of the MGA (Fig. 4). This wind pattern is conducive to cyclonic shear anomalies observed over the MGA in the recent epoch (Fig. 3b). Another notable feature in Fig. 3b is a wave train structure emanating from the heat source region near the tropical central Pacific Ocean to the North Pacific Ocean. The lower tropospheric response as seen in Figs. 3b and 4 is similar to the steady response to tropical heating (Fig. 2) in Gill (1980).

The vertical wind shear (VWS) is defined as the sum of the squared difference of the zonal and meridional wind components between 200-hPa and 850-hPa levels. Weak VWS allows the condensation heating to concentrate in a vertical column, enhancing the surface pressure fall. This effect favors tropical cyclogenesis and possibly typhoon development. The difference in VWS between the two epochs is shown in Fig. 5. A small decrease in VWS is found in the northern portion of the MGA and a small increase in the southern part of MGA in the recent epoch. However, none of the change in VWS over the MGA is statistically significant.

As noted by Frank (1987), the mean upward vertical motion is essential to the TC formation. The low-level (850-hPa) and high-level (200-hPa) vertical velocity difference maps (Figs. 6a and b) show a significant increase in the ascending motion over a large portion of the MGA in the recent epoch.

The importance of the atmospheric moisture for TC development is discussed in Knaff (1999). Fig. 7 displays the total precipitable water (TPW) difference between the two epochs. An increase in TPW is noted over the MGA. Less subsidence drying, suggested by an increase in upward motion (Fig. 6), which could bring more water from the lower troposphere, may account for the increased moist layer depth over the MGA in the recent epoch.

4. Summary

A statistical change-point analysis is applied to detect and quantify decadal shifts in the rates of tropical cyclones over the WNP. During 1965-2001, three significant shifts (1968, 1989, and 1998) are noted in the TC time series, and this study focuses on two major epochs: the inactive (1968-1988) and active (1989-1997) epochs.

Relative to the inactive epoch, slightly warmer sea surface temperatures, stronger low-level anomalous cyclonic vorticity, slightly weaker vertical wind shear, slightly increased tropospheric precipitable water, and stronger ascending motions are observed over the major genesis area in the recent epoch. Although some of the aforementioned changes are small (e.g., vertical wind shears), variations in each individual environmental condition work in the proper sense and collectively favor more cyclone incidences observed over the Western North Pacific during the recent epoch.

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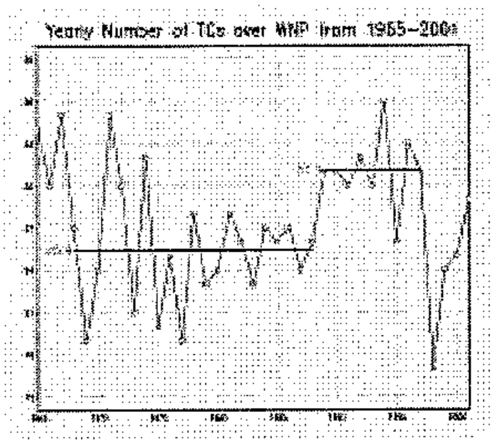

Fig. 1 The yearly number of tropical cyclones over the western North Pacific from 1965 to 2001. The thick, horizontal line represents the average of tropical cyclones from 1968 to 1988, and the average from 1989 to 1997.

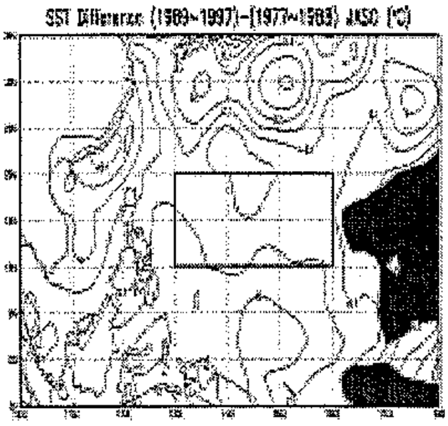

Fig. 2 Sea surface temperature (SST) difference between 1989-1997 and 1968-1988. The contour interval is 0.05℃. Areas where the nonparametric test indicates significant differences at the 95% level or above are shaded. The box between 10°N-20°N and 130°E-160°E is referred to as the major genesis area (MGA).

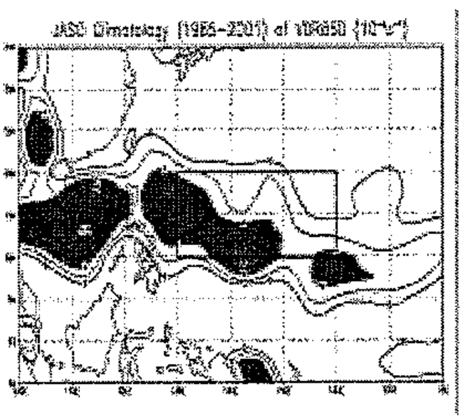

Fig. 3 (a) Climatological (July to October) mean low-level (850-hPa) vorticity ($10^{-6}s^{-1}$) pattern. Shading areas indicate regions where the vorticity is larger than $4x10^{-6}$ s^{-1}. Only positive values are contoured.

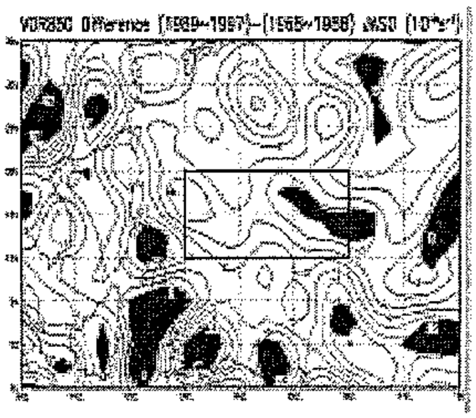

Fig. 3(b) Same as Fig. 2, but for the vorticity difference at 850-hPa. The contour interval is $1x10^{-6}$ s^{-1}.

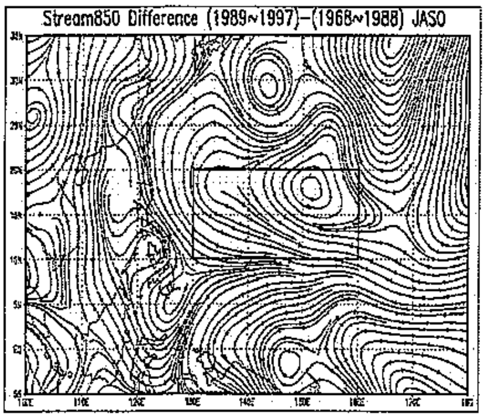

Fig. 4 Same as Fig. 2, but for the streamline difference at 850-hPa.

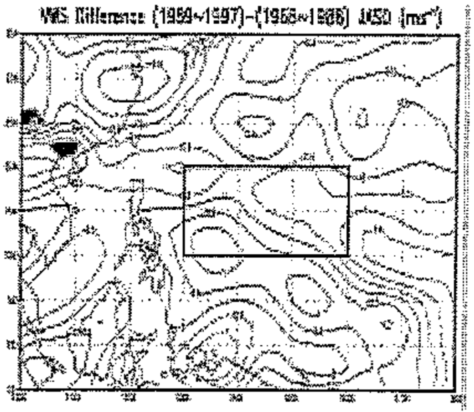

Fig. 5 Same as Fig. 2, but for the vertical wind shear difference. The contour interval is 0.5 m s^{-1}.

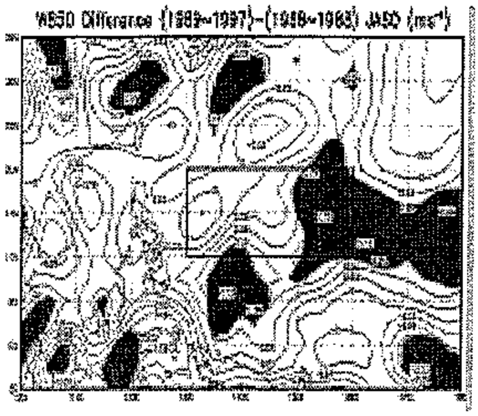

Fig. 6a Same as Fig. 2, but for the vertical velocity difference at 850-hPa. The contour interval is 0.03 m s^{-1}.

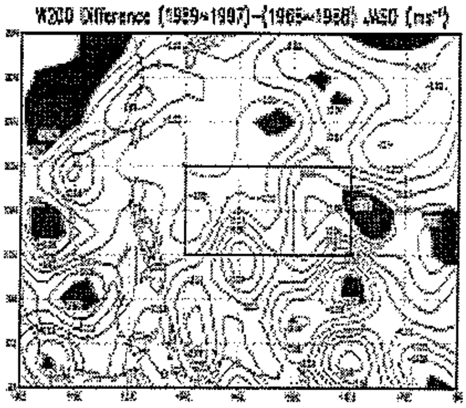

Fig. 6a Same as Fig. 2, but for the vertical velocity difference at 200-hPa. The contour interval is 0.03 m s^{-1}.

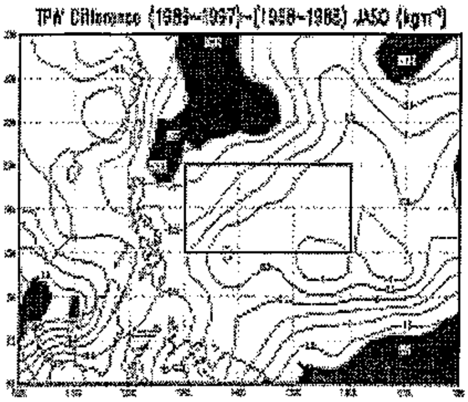

Fig. 7 Same as Fig. 2, but for the total precipitable water (TPW) difference. The contour interval is 0.5 kg m^{-2}.