Article ID: 1006-8775(2010) 02-0189-06

STUDIES ON RELATIONSHIPS BETWEEN ENSO AND LANDFALLING TROPICAL CYCLONES IN CHINA

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Abstract: The data of landfalling tropical cyclones (TCs) in China and ENSO events and the NinoZ index during 1951 to 2005 were used to study the relationships between ENSO and landfalling TCs in China. ENSO events from July to September have obvious effects on landfalling TCs in China. When El Niño persists throughout the months, the frequency of landfalling TCs is less than normal, the season of landfalling TCs is shorter, the annually first landfall is later, the annually last landfall is earlier, and the mean intensity is stronger and more landfalling TCs achieve the intensity of typhoon. Otherwise is true for La Niña. That is to say, ENSO events evolving from July to September show strong prediction signals for landfalling TCs in China. When ENSO ends or starts in a year while the NinoZ index remains neutral in July through September, landfalling TCs also have some impacts of ENSO. El Niño events have more significant effects on landfalling TCs than La Niña events.

Key words: ENSO; landfalling TCs; NinoZ index

CLC number: P732 **Document code:** A **doi:** 10.3969/j.issn.1006-8775.2010.02.011

1 INTRODUCTION

ENSO is an important factor in annual climate variability and has significant effect on global climate. Studies showed that there are fewer TCs in the western North Pacific in El Niño years while more in La Niña years[1-5], and landfalling TCs in China have a close relationship with ENSO events. In El Niño years, the frequency of landfalling TCs is less, the intensity is stronger, the annually first landfall occurs later and the last one occurs earlier than those in La Niña years. Now, ENSO events can be predicted well, providing reliable base for seasonal prediction. According to the growing need of operational prediction and policy services in National Climate Center, the prediction services for landfalling TCs in China require much more than just prediction of landfalling frequency. Since tropical cyclone activity is closely correlated with the stage of ENSO events, in this paper, based on the seasonal stage of ENSO events, relations between ENSO events and frequency of landfalling TCs, the annually first landfall and last landfall and landfalling intensity are discussed to provide a statistical model for landfalling TCs' seasonal prediction.

2 DATA AND METHODOLOGY

ENSO events from 1951 to 2003 are referred to the definition of Li et al.[9] and those from 2004 to 2005 are from the operational monitoring in National Climate Center (NCC). The duration of each ENSO event is shown in Table 1. The NinoZ indices in 1951 to 2005 are from NCC. The data of landfalling TCs in China from 1951 to 2005 are also from NCC[10], including the maximum surface wind and location at landing moment. The monthly mean outgoing long wave radiation (OLR) dataset is from http://www.ncdc.noaa.gov/ covering the period from June 1974 to December 2005.

According to Ren et al.[11], the annually first landfalling TC is, within the course of a year, the first tropical cyclone landing in China and the last landfalling TC is the last one. The annually first landfall date is the date when the annually first landfall takes place in China and the last landfall date is the date when the last one occurs. In this study, the season of landfalling TCs is defined as the number of days between the annually first landfall date and the last

Received date: 2009-12-21; **revised date:** 2010-03-26

Foundation item: project of the Ministry of Sciences and Technology of the People's Republic of China (GYHY200806009); projects of National Natural Science Foundation of China (40775046)

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date. The mean intensity of landfalling TCs is the mean value of the maximum surface wind at the landing moment. TC represents all the landfalling TCs including tropical depressions, and TS stands for the landfalling TCs whose intensities exceed tropical storm intensity (17.2 m/s) at the landing moment while TY refers to those whose intensities surpass typhoon intensity (32.7 m/s). The climate mean values are based on the time from 1971 to 2000.

Table 1 Duration of ENSO events from 1951 to 2005.

	Serial number	Duration		Serial number	Duration
	1	Jul. 1951—Dec. 1951		1	Apr. 1954—Jan. 1957
	2	Apr. 1957—Apr. 1958		2	Oct. 1962—Feb. 1963
	3	Jul. 1963—Dec. 1963		3	Mar. 1964—Jan. 1965
	4	Jun. 1965—Feb. 1966		4	Aug. 1967—May 1968
	5	Nov. 1968—Jan. 1970		5	Jun. 1970—Jan 1972
El Niño	6	Apr. 1972—Feb. 1973	La Nina	6	May 1973—May 1974
	7	May 1982—Aug. 1983		7	Sept. 1974—Mar. 1976
	8	Sept. 1986—Jan. 1988		8	Oct. 1984—Oct. 1985
	9	May 1991—Jun. 1992		9	Apr. 1988—Jun. 1989
	10	Oct. 1994—Feb. 1995		10	Sept. 1995—May 1996
	11	Apr. 1997—May 1998		11	Sept. 1998—Jul. 2000
	12	May 2002—Feb. 2003			

3 VARIATIONS IN LANDFALLING TCs

Figure 1 shows the time series of frequency, mean intensity and season of landfalling tropical cyclone (TC) and tropical storm (TS) in 1951 through 2005. A significant decreasing trend can be seen in the frequency of landfalling TCs while there is no obvious trend in the frequency of landfalling TSs (Fig. 1a). There are more landfalling TCs while less landfalling TSs in 1950s and the two mean frequencies during the years 1996 through 2005 are below average. A 4-year cycle oscillation is observed in the frequency of landfalling TCs using power spectrum analysis. As shown in Fig. 1b, the mean intensity of landfalling TCs does not show any decreasing or increasing trend while decreasing trends are observed in the mean intensity of landfalling TSs. Note, the mean intensity of landfalling TCs in 2005 reaches the highest level and the mean intensity of landfalling TSs ranks the second place since 1991. Both the seasons of landfalling TCs and TSs show decreasing trends (Fig. 1c). The annually first landfall dates of TCs and TSs has the tendency of becoming later and later while the annually last landfall dates do not show any trend. Figure 1 also illustrates the jumping character first discovered by Chen in the mid-1970s [12]. There are more positive anomalies before 1976 while more negative anomalies since then. Moreover, there are short-term oscillations in landfalling activity and the active period is alternated with the inactive one but their durations differ from each other.

4 RELATIONSHIPS BETWEEN ENSO EVENTS AND LANDFALLING TCs

Landfalling TCs in China usually occur from July to September. Does the abnormality of the tropical Pacific Ocean during these months have obvious effects on landfalling TCs? How are the effects working? Next, the effects on landfalling TCs of the tropical Pacific Ocean in July through September are discussed.

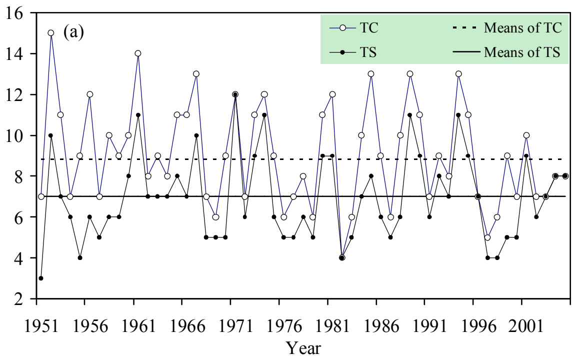
4.1 *Characteristics of ENSO events persisting July through September*

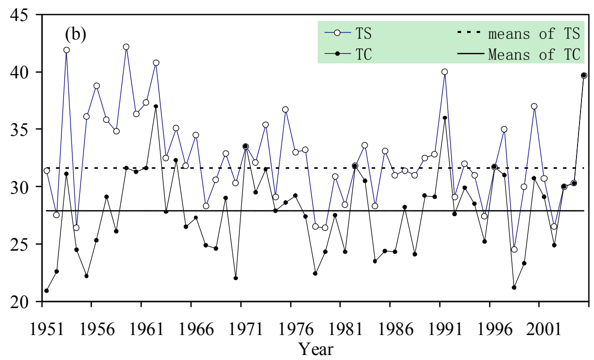
Here, the samples for ENSO events persisting July through September are those years in which at least 2 continuous months belong to the durations of El Niño or La Niña events. Accordingly, the samples are divided to warm and cold years.

4.1.1 WARM YEARS

Table 2 shows the characteristics of landfalling TCs in the 12 warm years (1951, 1957, 1963, 1965, 1969, 1972, 1982, 1983, 1987, 1991, 1997, and 2002).

Relatively consistent trends are observed. The frequencies of landfalling TCs tend to be less than normal, the annually first landfall date is prone to be later while the last landfall date is earlier than normal, the seasons of landfalling TCs are shorter, the mean intensities are near normal or stronger, and the frequencies of landfalling TYs are less than normal. According to Chen and Liu[13], although typhoon activity in western Pacific becomes strong in El Niño years, this is not in favor of more landfalling TYs in China.





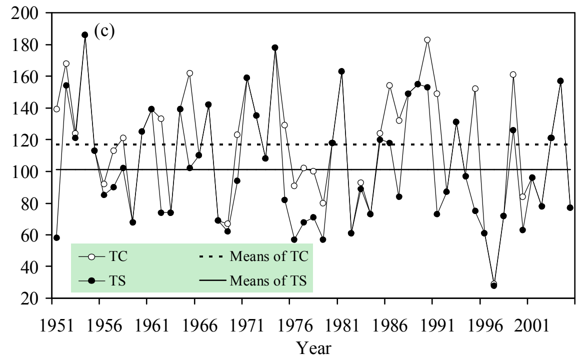


Fig.1 Time series for frequency (a), mean intensity (b, m/s) and season (c, days) of landfalling tropical cyclones (TCs) and tropical storms (TSs) during 1951 to 2005.

Table 2 Characteristics of landfalling TCs in warm years.

Number of sample years	frequency		First date		Last date		season		Mean intensity		Frequency of TY
	TC	TS	TC	TS	TC	TS	TC	TS	TC	TS	
12	10B	10B	3E	2E	7E	7E	6S	7S	2B	1B	6B
	1A	1A	7L	7L	3L	1L	4lL	1L	5A	4A	3A
	1N	1N	2N	3N	2N	4N	2N	4N	5N	7N	3N

*B: below normal; A: above normal and N for normal
*E: earlier than normal; L: later than normal
*S: shorter than normal; L: longer than normal

4.1.2 Cold years

Table 3 shows the characteristics of landfalling TCs in the 12 cold years (1954, 1955, 1956, 1964, 1967, 1970, 1971, 1973, 1975, 1985, 1988, and 1999). In general, the frequency of landfalling TCs inclines to be above normal while that of landfalling TSs tends to be below normal. The annually first landfall date is prone to be earlier while the last date is likely to be later than normal, the seasons of landfalling TCs and TSs are longer than normal, the mean intensity of landfalling TCs is weaker while that of landfalling TSs is stronger than normal, and there are more chances for more landfalling TYs. On the whole, the characteristics in cold years are opposite to those in warm years. Both the frequencies of very weak and very strong landfalling TCs have increased. In comparison with Table 2, the characteristics in cold years are not as consistent with each other as those in warm years.

The aforementioned analyses indicate that, during the main season of tropical cyclones landing in China, when the tropical Pacific Ocean persists in warm (cold) events, there are relatively consistent variations in landfalling TCs. ENSO events persisting in July through September show great signal on prediction of landfalling TCs.

4.2 *Neutral condition in July–September*

Do the ENSO events which end before or begin after the main landfalling season have significant effects on landfalling TCs? The characteristics of landfalling TCs are discussed for the years when ENSO events end in preceding winter or spring or begin in the successive autumn and the tropical Pacific Ocean keeps neutral in July through September. The neutral conditions are divided into neutral-warm and neutral-cold ones according to the positively or negatively accumulated NinoZ index for July through September.

Table 3 Characteristics of landfalling TCs in cold years.

Number of sample years	frequency		First date		Last date		Season		Mean intensity		Frequency
	TC	TS	TC	TS	TC	TS	TC	TS	TC	TS	of TY
	1B	7B	6E	7E	2E	2E	1S	1S	8B	3B	4B
12	6A	4A	3L	3L	5L	8L	6L	7L	3A	7A	7A
	5N	1N	3N	2N	5N	2N	5N	4N	1N	2N	1N

4.2.1 NEUTRAL-WARM CONDITION

There are 7 neutral-warm years (1958, 1968, 1976, 1986, 1992, 1994, and 2003) and the characteristics of landfalling TCs are shown in Table 4. In general, the frequency is likely to be below normal, the annually first landfall date is prone to be later and the last date is earlier, the season is likely to be shorter, the mean intensity is below or near normal, and the frequency of landfalling TYs is prone to be less than normal. The basic variations are similar with those in warm years, but the consistence is not as good as that in warm years. When the accumulated NinoZ index exceeds 1.0°C (1.26°C in 1976), all of the characteristics are just like those in warm years.

4.2.2 NEUTRAL-COLD CONDITION

Table 5 shows the characteristics of landfalling TCs in the 10 neutral-cold years (1952, 1962, 1966, 1974, 1984, 1989, 1995, 1996, 1998, and 2000). When the tropical Pacific Ocean keeps neutral-cold, there is no obvious consistence in the variations of landfalling TCs. The frequency is more likely to be above normal, the annually last landfall date is prone to be earlier, the season is likely shorter, and the mean intensity is weaker. For the 5 years in which the accumulated NinoZ index is below –1.0°C (1974, 1984, 1989, 1998, and 2000), the characteristics in 1974 when a La Niña event ended in June and a new La Niña event came into being in September are like those in cold years; but in 1998 and 2000, the landfalling TCs show the characteristics of warm years. This probably is due to the fact that 1998 and 2000 belong to the period of weak tropical cyclone activity. Therefore, the lanfalling TCs in the two years do not show the characteristics of cold years.

From the aforementioned analysis, we conclude that maintaining neutral-warm condition, the tropical Pacific Ocean has some effect on landfalling TCs, which mainly have the characteristics of warm years and the effect is more significant when the neutral-warm condition is stronger. Landfalling TCs do not show obvious consistent variations in neutral-cold years. However, when the neutral-cold condition becomes stronger, characteristics of cold years may occur. Table 4 and Table 5 do not have significant results as Table 2 and Table 3. This also illustrates that neutral condition in the tropical Pacific Ocean in July through September does not have significant effects on landfalling TCs although there are endings or beginnings of ENSO events in the years.

Table 4 Characteristics of landfalling TCs in neutral-warm years.

Number of sample years	frequency		First date		Last date		season		Mean intensity		Frequency
	TC	TS	TC	TS	TC	TS	TC	TS	TC	TS	of TY
	3B	4B	2E	2E	3E	4E	4S	2S	3B	2B	3B
7	2A	2A	3L	3L	1L	2L	1L	2L	1A	1A	2A
	2N	1N	2N	2N	3N	1N	2N	3N	3N	4N	2N

5 ATMOSPHERIC CIRCULATION AND TROPICAL CONVECTION

The above-mentioned analysis disclosed that the tropical Pacific Ocean that maintains ENSO events in July through September has significant effects on landfalling TCs. Researches have indicated that TC activities are strong when tropical convection is strong over the West Pacific and it is also true for weak TC activities with weak tropical convection[14]. Whether or not TCs land in China is closely correlated with atmospheric circulations. Next, characteristics of tropical convection and geopotential height at 500 hPa from July to September in warm and cold years will be discussed. Figure 2 shows the composite of OLR anomalies in warm and cold years. In warm years, positive anomalies of more than 5 W/m^2 control the tropical Pacific Ocean west of 140°E, indicating that the tropical convection is suppressed and the Walker circulation weakens, which is to the disadvantage of TCs. In cold years, however, opposite characteristics are observed. Negative anomalies of less than –5 W/m^2 control the tropical Pacific Ocean west of 140°E, indicating active tropical convection and strong Walker circulation and this is to the benefit of TCs. The composite of geopotential height at 500 hPa during the months shows that anomalous distribution of "+, –, +" covers the region from East Asia to the western North Pacific and the subtropical high over the western North Pacific is stronger and its position is southward and westward than normal and this is not in the favor of landfalling TCs. While in cold years, the geopotential height anomalies are "–, +, –" and the subtropical high is weaker and its position is northward and eastward than normal and this is in the favor of landfalling TCs. However, the relationships between landfalling TCs and the subtropical high are complicated. If the subtropical high is unusually eastward than its normal position, TCs would turn direction along the guiding airflow west of the subtropical high and could not land in China. In this discussion, only warm and cold years are analyzed and the results are somewhat with limitation.

Table 5 Characteristics of landfalling TCs in neutral-cold years.

Number of sample years	Frequency		First date		Last date		season		Mean intensity		Frequency of TY
	TC	TS	TC	TS	TC	TS	TC	TS	TC	TS	
	3B	3B	4E	4E	5E	5E	4S	6S	5B	4B	3B
10	6A	4A	2L	4L	4L	3L	4L	3L	3A	3A	3A
	1N	3N	4N	2N	1N	2N	2N	1N	2N	3N	4N

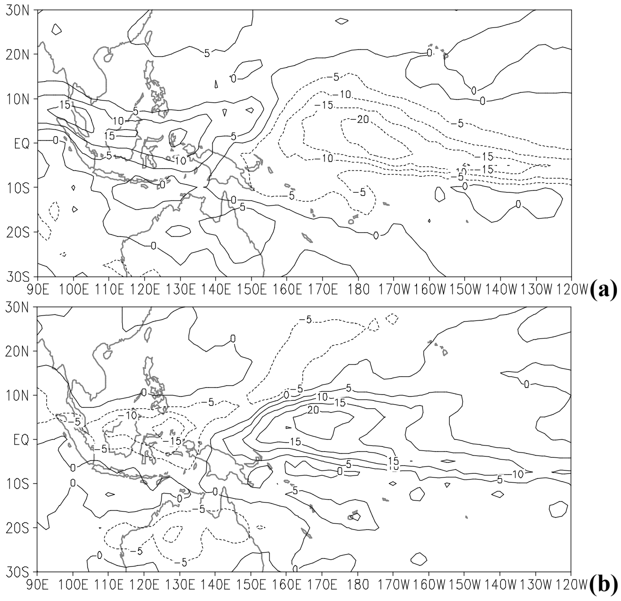


Fig.2 Composite of Outgoing Long-wave Radiation (OLR) anomalies in warm (a) and cold (b) years.

6 CONCLUSIONS AND DISCUSSIONS

(1) The tropical Pacific Ocean maintaining ENSO events in July to September has significant effects on landfalling TCs. In warm (cold) years, the frequency of landfalling TCs is below (above) normal, the annually first landfall date is later (earlier) and the last date is earlier (later), the season of landfalling TCs is shorter (longer), the mean intensity is stronger (weaker), and the frequency of landfalling TYs is less (more) than normal. ENSO events persisting July through September shows strong signal on prediction of landfalling TCs.

(2) In years when there is ending or beginning of ENSO events but the tropical Pacific Ocean keeps neutral-warm, landfalling TCs show characteristics of those in warm years and the effect is more significant when the neutral-warm condition is stronger. Landfalling TCs do not show significantly consistent variations in neutral-cold years. However, when the neutral-cold condition becomes stronger, characteristics of cold years could occur.

(3) Warm events have more significant effects on landfalling TCs than cold events.

Due to the limited size of samples, our conclusions are somewhat with limitation. The characteristics of landfalling TCs do not correspond to the ENSO events one by one. Although significant, the ENSO events is not the only one decisive factor for landfalling TCs. Snow cover, soil humidity and air circulations in winter all affect on landfalling TCs in the coming summer[15]. Not only ENSO events have effects on tropical cyclones, but also tropical cyclones influence ENSO events. In warm years, TC activities over the western North Pacific are stronger and their lifetime is longer than in cold years[16], and active TC activities are of benefit to the development of ENSO events[17].

Whether or not TC is active is closely correlated to tropical convection in the corresponding period. Landfalling TCs in China are confined by atmospheric circulations at the same period. Furthermore, there are significant correlations between landfalling TCs and other circumstances[18]. Therefore, correlations between other factors and landfalling TCs need also to be considered in the operational prediction.

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Citation: WANG Xiao-ling and SONG Wen-ling. Studies on relationships between ENSO and landfalling tropical cyclones in China. *J. Trop. Meteor.*, 2010, 16(2): 189-194.