SOME FEATURES OF SEVERE TROPICAL CYCLONE CHANGE IN THE COOL AND WARM SUMMER OVER EAST CHINA SEA①

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ABSTRACT

Based on the definition of cool summer and warm summer, statistical characteristics of severe tropical cyclones are studied over East China Sea using 1951—1994 typhoon and temperature data. It is found that the frequency, tracks, intensity and moving speed of the tropical cyclone between cold summer and warm summer were much different. The background features of the difference were also discussed in contrast.

Key words: cool summer year, warm summer year, severe tropical cyclone, eastern offshore waters of China

I. INTRODUCTION

Whenever the northern summer comes, it is possible for the coastal regions in the east of China to be exposed to the attack or influence of tropical cyclones from the western Pacific in a sequence from south to north. Due to hazardous weather and enormous calamities they usually inflict upon along the path, much research has been performed on it by Chinese meteorologists, and a number of important achievements and progress have been obtained in recent years in regard of the analysis of evolution of the intensity and track, and its synoptic and climatic background, of the tropical cyclone offshore (Chen and Ding, 1979, project team, 1995, Yan, Chen and Zhang, 1993 and Yan, Zhang and Chen, 1995). In consistence with relevant key research project in the national "8th & 9th five-year" development plan, intensive study has been done on the tropical cyclone off the coast of China, with the disclosure of considerable difference in the frequency of occurrence, track of motion, intensity and moving speed, in addition to significant interannual variability, with respect to severe tropical cyclone offshore, particularly in the eastern coastal area. Reviewing its cause, it is found to be in a constituent way related to the difference in the thermodynamic field of ground surface in the specific eastern continent as well as the role of the general circulation. Study used to be less in this regard. With reference to the *Typhoon Yearly Books* for 1951—1994 and temperature information and on the basis of standards dividing cool and warm summer for the east of China, a number of characteristics concerning the variations of offshore tropical cyclone are statistically analyzed to yield results that tell. It is surely significant that it helps reduce disaster and broaden our way of thought in forecasting.

II. SELECTION OF DATA AND DIVISION OF COOL AND WARM SUMMER

Mean temperature $\overline{T}_{Jul-Aug}$ in July—August from 1951 to 1994 selected from obser-

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vation stations in Hankou, Yichang, Yueyang, Changsha, Jiujiang, Anqing, Hefei, Chuxian, Nanjing, Changzhou, Wuhu, Liu'an, Nantong, Shanghai, Hanzhou, Ningbo, Jingdezhen, Nanchang, Guixi and Dunxi are used to represent the air temperature in summer for the central and eastern China. Through analyses of the anomaly field with the method of empirical orthogonal function (EOF), it is found that the first eigenvector field EOF takes up 85% of the total variance (figure omitted). The eigenvectors are all positive in the expanded region, suggesting significant consistence in the spatial distribution of summertime temperature in this area. The maxima of characteristic eigenvectors are mainly located in Wuhu, Nanjing, Hanzhou and Jingdezhen. The correlation is above 0.80 between the temporal coefficient T_1 and all stations, and above 0.95 for those in Wuhu, Nanjing, Hanzhou and Jingdezhen, with respect to the summer air temperature EOF1 for that area. As EOF1 is reflecting the general tendency of relevant temperature variations, the standard deviation of July—August temperature at these stations that is larger than 1.0 is made the index of criterion in order to quantitatively describe the basic features of cool and warm of summer (the stations so selected that the application is convenient). In other words, it is defined as a

cool summer year when $-1.0°C<\Delta T\leqslant -0.5°C$;

highly cool summer year when $\Delta T\leqslant -1.0°C$;

warm summer year when $1.0°C>\Delta T\geqslant 0.5°C$;

highly warm summer year when $\Delta T\geqslant 1.0°C$.

As a result, thirteen years are defined as cool summer, namely, 1952, 1954, 1965, 1968, 1972, 1974, 1980, 1982, 1986, 1987, 1989, 1991 and 1993 and eleven years as warm summer, i.e. 1953, 1959, 1961, 1964, 1966, 1967, 1971, 1973, 1978, 1990 and 1994, over the period from 1951 to 1994. For the purpose of comparison and analysis, the eastern "offshore waters" contains the areas bounded by 125°E and the coastline, i.e. the East China Sea, Yellow Sea and Bohai Sea, according to the specifications by the expert team for key typhoon research project in the national "8th five-year" plan; the grades of intensity variations in tropical cyclone are the changes within 12 h after the tropical cyclone migrates into the offshore waters of eastern China, i.e. a storm with $\Delta V_{12}\geqslant 10$ m $\cdot$ s^{-1} is classified as abrupt intensifying or weakening, one that is accompanied by 5 m $\cdot$ s$^{-1}\leqslant V_{12}\leqslant 9$ m $\cdot$ s^{-1} is identified as gradually intensifying or weakening, and one that is marked with $V_{12}<5$ m $\cdot$ s^{-1} is denoted as largely stable or unchanged; variations in moving speed means the acceleration or deceleration for a period from 12 h before to 18 h after migration into the offshore waters, or, it moves with $\Delta V\geqslant 5$ km/h regardless of acceleration or deceleration. If $\Delta V<5$ km/h, the tropical cyclone is said to have little or no changes in the speed of movement.

Ⅲ. COOL AND WARM SUMMER AND OCCURRENCE OF SEVERE OFFSHORE TROPICAL CYCLONE AND INTENSITY VARIATIONS

Table 1 gives the number of occurrence of severe tropical cyclone off the East China coastline from June to September. Sharp difference exists between the cool and warm summer year with respect to the tropical cyclone migrating into the offshore waters from the West Pacific. There are 28 severe tropical cyclones in the cool summer (13 years in all) averaging at 2.2 per year; the annual occurrence is generally 1—2 with 1989 on the more-than-usual side and 1993 on the lowest (0). On the other hand, there are 46 such storms in the warm summer (11 years in all) averaging at 4.2 per year, almost twice as much as in the cool summer years; the annual occurrence is normally 3—6 with 1994

Table 1. Statistical features for the frequency of tropical cyclone in cool and warm summer over East China Sea.

Cool S.	Year	1952	1954	1965	1968	1972	1974	1980	1982	1986	1987	1989	1991	1993	tot.	M.
	Num.	2	1	2	1	3	3	1	2	3	3	5	2	0	28	2.2
Warm S.	Year	1953	1959	1961	1964	1966	1967	1971	1973	1978	1990	1994	tot.	M.		
	Num.	4	4	2	3	5	3	2	4	6	6	7	46	4.2		

having the most (7) and 1965 and 1971 having the least (2 for each).

Apart from the difference in the annual variations of tropical cyclone migrating into the offshore waters between the cool and warm summer year, similar trend also exists in the change in intensity. Tables 2 and 3 present the statistic results in this regard. It is shown that the cool summer is usually marked by the intensity of tropical storm (18, including severe tropical cyclone), taking up 64% of the total, with minority in the group of typhoon (10) taking up 36% of the total. In addition, the tropical cyclone migrating into offshore waters and generally weakening takes up about 54%, in which 25%, 29%, 18%, and 7% are for storms of abrupt weakening, gradual weakening, intensifying and abrupt intensifying, respectively. The rest is largely with little or no change in intensity.

Table 2. Statistical features of the variations of the strong tropical cyclones in cool summer. ①

Trends Names	INTST level	INTST Var.	V. Var.	Track type	Trends Names	INTST level	INTST Var.	V. Var.	Track type	
Gilda	T.S.	↑	0	1	Cecil	T	↗	—	3	
Mary	T.S.	↑	+	1	Nancy	T.S.	↑	+	3	
54(11)	T.S.	→	—	4	Vera	T	↗	0	3	
5606	T.S.	↗	+	3	Abby	T.S.	↑	+	3	
Harriet	T	↑	0	1	Vernon	T.S.	↑	—	4	
Polly	T	↘	—	5	Alex	T	→	—	1	
Winnie	T.S.	→	—	1	Thelma	T	↘	0	3	
Rita	T.S.	↗	+	2	Hope	T.S.	→	—	1	
Betty	T.S.	↗	—	1	Ken,Lora	T.S.	→	0	2	
Jean	T.S.	↗	+	4	8918	T.S.	↘	—	1	
Lorna	T.S.	↓	0	2	Vera	T.S.	→	0	1	
Mary	T	→	—	1	Sarah	T	→	—	1	
Norris	T	↓	—	1	Ellie	T.S.	↗	—	4	
Andy	T.S.	↑	—	1	Gladys	T.S.	↗	—	4	
Item	TC	T	TS	↓	↘	→	↗	↑	+	0	—
Total	28	10	18	2	3	8	8	7	6	7	15
13 Yr M.	2.2	0.8	1.4	0.2	0.2	0.6	0.6	0.5	0.5	0.5	1.2
P. (%)		36	64	7	11	29	29	25	21	25	54

① The figures inside the brackets denote the serial number of tropical cyclone; ↓, ↘, →, ↗and ↑ stand for severe tropical cyclone migrated into the eastern offshore waters that abruptly intensifies, slowly intensifies, changes little, gradually weakens and abruptly weakens, respectively; +, 0 and — are for accelerating, stationary and decelerating tropical cyclone; 1, 2, 3, 4 and 5 are for tropical cyclone making landfall south, north of the Changjiang River Mouth, recurving to the north or changing directions, decaying and dissipating offshore, and looping offshore, respectively.

Table 3. Statistical features of the variation of the severe tropical cyclones in the warm summer. ①

Trends Names	INTST level	INTST Var.	V. Var.	Track type	Trends Names	INTST level	INTST Var.	V. Var.	Track type
Dinah	T.S.	→	+	3	Wilda	T	↓	+	1
53(05)	T	↑	+	1	Billie	T	↑	+	2
Jeanne	T	↑	+	1	Iris	T.S.	→	+	3
53(14)	T	↗	+	1	Marge	T.S.	↓	+	1
Ophelia	T	→	—	1	Trix	T	↓	+	1
5904	T	↓	—	1	Carmen	T	→	—	5
Rita	T	↓	—	1	Della	T.S.	↘	+	1
59(19)	T	→	0	3	Irma	T.S.	↓	0	3
Betty	T.S.	→	+	1	Ora	T.S.	↘	0	3
Tilda	T	↗	+	1	Wendy	T.S.	→	—	3
Flossie	T	↘	+	3	Percy	T	→	0	1
Betty	T	↘	0	4	Ofelia	T	↑	+	3
Helen	T	↑	0	2	Robyn	T.S.	↘	0	3
Nina	T.S.	↗	+	4	Abe	T	→	0	3
Tess	T	↓	+	1	Yancy	T	↘	+	1
Cora	T	↑	+	1	Cecil	T.S.	↓	0	1
Alice	T	→	0	1	Tim	T	↑	+	1
Elsie	T	→	+	3	Caitlin	T.S.	↓	0	1
Clara	T	↓	+	1	Doug	T	↗	0	1
Dot	T.S.	↗	0	2	Ellie	T	↗	0	2
6708	T.S.	↓	0	1	Fred	T	→	+	1
Polly	T.S.	→	0	3	Li	T	↘	0	1
Bess	T	→	0	1	Seth	T	↗	+	3

Item	TC	T	TS	↓	↘	→	↗	↑	+	0	—
Total	46	31	15	11	7	14	7	7	23	18	5
13 Yr M.	4.2	2.8	1.4	1.0	0.8	1.3	0.8	0.8	2.1	1.6	0.5
P. (%)		64	33	23	15	30	15	15	50	39	11

On the contrary, the warm summer year is characteristic of tropical cyclone on the level of typhoon (31) after migration into the waters off the east China coast. They account for 67% or more of the total storm and only fifteen of them are tropical storm, sharing 32% of the total. Around the time close to the offshore waters, there are more tropical cyclones that continuously intensify than those that continuously weaken, specifically, 18 of them being the former (38%) and 11 abruptly (23%), and 14 of them being the latter (30%) in which those of abrupt weakening by 15%. The remaining 30% is shared by the group with little or no change.

① The denotations are the same as in Table 2.

IV. COOL AND WARM SUMMER AND SPEED VARIATIONS OF SEVERE OFFSHORE TROPICAL CYCLONE

It is known from Tables 2 and 3 that there exists sharp difference in the speed of motion between the cool and warm summer years around the time of migration into the offshore waters. For the cool summer, about 54% of the tropical cyclone tend to decelerate, 21% tend to accelerate and 25% remain virtually unchanged. Only 11% tend to decelerate (Table 3).

V. COOL AND WARM SUMMER AND OFFSHORE TRACKS

Fig. 1a and b give distribution of occurring frequency in a 1°×1° mesh and main tracks on a multi-yearly basis for the tropical cyclone migrating into the waters off the eastern coast of China in both cool and warm summer (June—September). It is found that the difference not only exists in the number of occurrence but also in the track principally followed with regard to the migrating tropical cyclones that hit or influence the eastern waters. In the cool summer, there are fewer occurrences of tropical cyclone offshore, more of recurving track, less of making landfalls, and more of turning to the east for the track and influence range (being confined to area east of 117°E). On the other hand, the warm summer year is featured by higher frequency of occurrence, especially

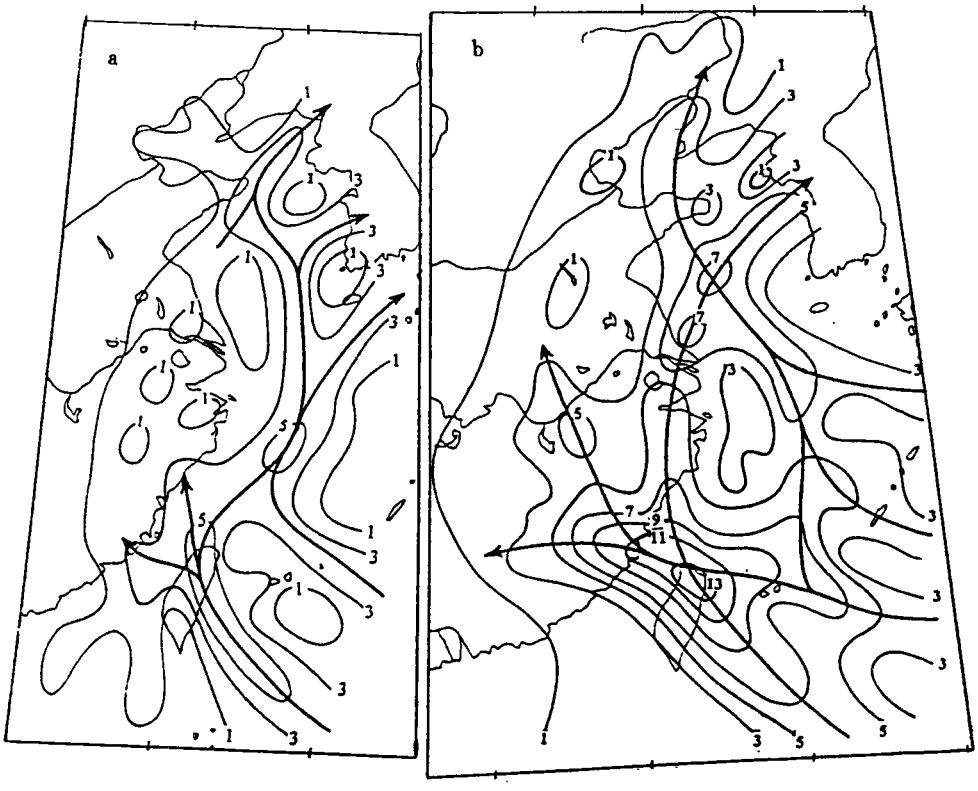

Fig. 1. Frequency and the main track of tropical cyclone in the cool and warm summer.

over the southern waters of the East China Sea, more of westward-landfalling track, more extensive range of influence as far west as 112°E , and more-to-the-north/west point of recurvature offshore. These are well indicated in Tables 2 and 3.

VI. CIRCULATION BACKGROUND OF COOL AND WARM SUMMER AND ANALYSIS OF SST FIELD

It is inferred from the analysis above that there is large difference in the frequency of occurrence, track, intensity and moving speed between the cool and warm summer with respect to severe tropical cyclone offshore. The cause behind it is, above all, related with the particular surface thermodynamics in the east of China, then, with the accountable significant difference between the ocean and atmosphere.

1. *The factor of northwest Pacific subtropical high*

The northwest Pacific subtropical high is one of the important systems that influence the east of China. The index is a good, critical indicator of the background of general circulation. Figs. 2a and b give the evolutionary curves of the index in both cool and warm summer. It is known from Fig. 2a that the latitude on which the ridge of the subtropical high sits is more southward in the cool summer than usual, being 2 degrees on average more to the south in July and August, while it is more northward in the warm summer than usual and by 2 degrees of latitude in August, especially. It is apparent that the anomalously northward location of the subtropical high is favourable for a formed tropical storm to move northward and westward along the extended easterly, as well as a northward position of ITCZ to its south and more likely trigger-off of tropical storm. It is seen in Fig. 2a that apart from a more westward position in June, the northwest Pacific subtropical high in the cool summer is obviously more to the east in terms of the west-

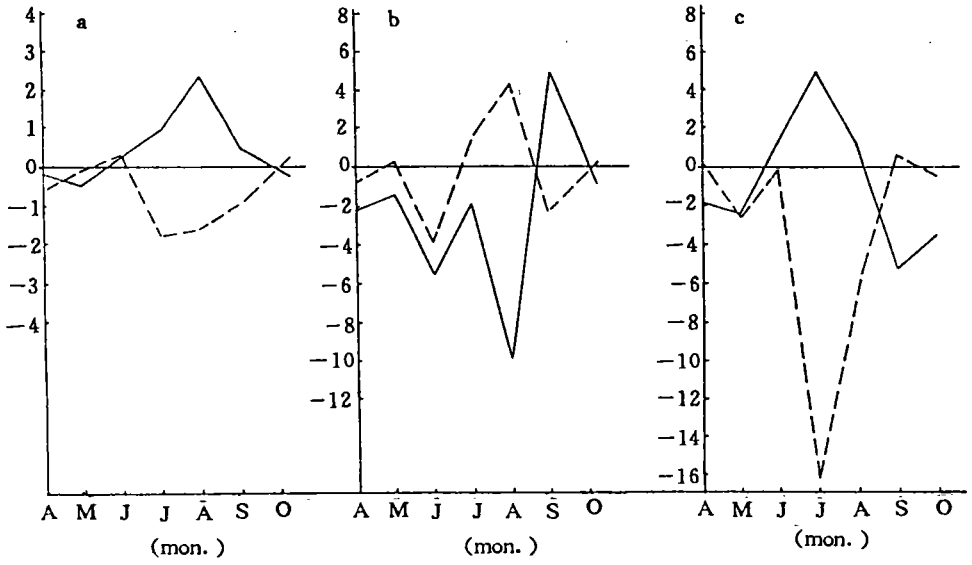

Fig. 2. Anomaly index of West Pacific subtropical high position (a), anomaly of westward extending ridge (b) and anomaly index for polar vortex (c) (60—180°E) in the cool and warm summer.
– – – –cool summer, ——warm summer.

ward point of extension in the prime season of July—August, being favourable for eastward track and recurvature of the tropical cyclone offshore. In the warm summer, however, the high is anomalously westward and by over 10 degrees of latitude in August, especially. It accounts for the dominance of westward track and further, the induction of the tropical cyclone deep inland and extension of influence towards the west and north.

2. *The factor of northern poleward vortex*

The index variations of the area of vortex in 60°E—180°E region for the northern hemisphere can be used to describe how actively the polar vortex in summer and what influence it poses on the weather in China. It is clear in Fig. 2a that the vortex is anomalously strong (weak) in the cool (warm) summer versus lower (significantly higher) temperature over eastern continent of China. Previous studies have shown that the tropical cyclone tends to move towards the warm rather than cold sector (Fisher, 1958; Penlroth, 1962), due to the environment provided by the very temperature field over land that is warmer in the warm summer. In contrast, the tropical storm is less likely to be "attracted" to land in the cool summer and instead, a tendency for slow-down, weakening, dissipation or recurvature is more obvious.

3. *The factor of offshore SST field*

Sharp difference also exists in the relevant field of SST between the cool and warm summer, especially apparent in the year of extremes. Fig. 3 is the distributions of SSTA in typical cool and warm summer in the east of China (to be denoted by July). It is shown that the distribution is almost exactly reversed for the two. In the strong cool summer (Fig. 3a), SST is anomalously colder by 1 — 2 °C while it is anomalously warmer (by 0.5—1.5°C in most area of waters) than usual. It is obvious that the distribution of such SSTA also accounts for whether there will be frequent activity of tropical cyclone and whether it will take a consistent westward or recurving track over the waters off the

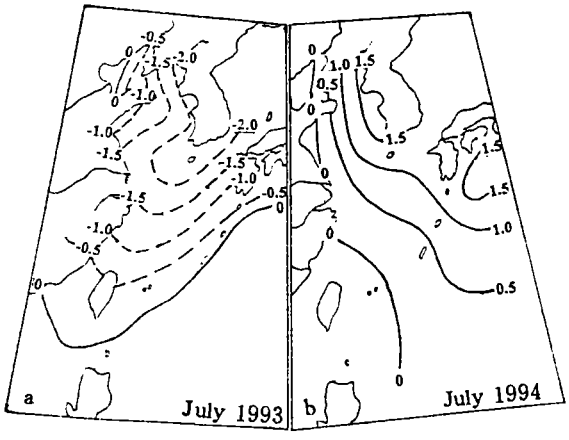

Fig. 3. Distribution of SSTA in highly cool summer (a) and highly warm summer (b) over East China Sea.

eoast of China.

Ⅶ. SUMMARY AND CONCLUSIONS

In the eastern continent of China, the year is divided into the cool and warm summer to which vastly different activity of severe offshore tropical cyclone corresponds. For the cool summer year, the tropical cyclone is less active, acquires weaker intensity, moves more slowly and recurves more frequently offshore. For the warm summer year, it has higher occurrence and intensity, takes more westward track at faster speed, and makes landfalls over relatively concentrated zone (the section from Zhejiang to Fujian is mostly preferred) with the point of recurvature being anomalously westward and northward, increasing the possibility for the eastern area of China to be subject to hazardous weather with growing consequences. It is just the discrepances in the structure of the continental temperature and pressure fields, offshore SST, northern polar vortex, and behaviour of the subtropical high that have led to such sharp differences. The finding is of essential implication for the improvement of conceptual frame for prediction of severe offshore tropical cyclone and the prevention and reduction of disaster.

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