INFLUENCE OF EL NINO ON WEATHER AND CLIMATE IN CHINA

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ABSTRACT

El Nino as well as the Southern Oscillation is one of the strongest signals known so far over climatic noise in interannual variations of the atmosphere and oceans. A great number of studies have shown definitely relationships between the events and climatic anomalies in China. In this review, observational results obtained in the recent several years are first summarized. Then the possible physical mechanisms on the influence of El Nino are presented and, finally, the associated problems are discussed.

Key words: El Nino, drought and floor, typhoon, cool summer, China

I. INTRODUCTION

The pioneering studies on the ocean–atmosphere interaction by Namias (1963) and Bjerknes(1966) build up scientific foundation for understanding atmospheric behavior based on oceanic situation. By 1980s, more and more researchers in atmospheric sciences started to concentrate their attention on El Nino, a phenomenon of anomalous warming on equatorial eastern as well as central Pacific Ocean. Especially, the strongest El Nino event in this century occurred during 1982–1983 and, meanwhile, our world experienced the strikingly persistent climate anomalies(WCRP,1985; Zhang et al.1985). It has stimulated greatly the efforts to seek for possible connections between El Nino and interannual climate changes on the global and regional basis.

China is located in the eastern part of Eurasian continent and on the west coast of the Pacific Ocean. The unique geographic position makes the weather and climate in China vulnerable to disturbance in thermal conditions of tropical ocean, especially in summer. A great number of studies in this regard have been carried out in recent decade. The early works, which have been summerized up in some reviews (Li et al.1979; Wang and Zhao,1984; Fu,1987; Lin and Lin,1989), placed emphasis on observational analysis of features of El Nino and their impacts. These obtained results revealed some possible relationships between El Nino on one hand and climate disasters in China, mainly droughts and floods, abnormal typhoon activities, and cool summer in Northeast China, on the other hand, it turns out from these results that the influence of El Nino might be exerted in rather complex manner. So, some in–depth analyses have been going on in the recent several years to gain a more complete insight into El Nino effect. Meanwhile,some relevant physical mechanisms have been put forward on the basis of the observational results.

In this review, the observational results on El Nino influence obtained in the recent several years are summed up first, from which it is expected to present knowledge of possible relationships between El Nino events and anomalies of atmospheric circulation in East Asia and climate disasters in China, including droughts and floods, abnormal typhoon activities and cool summer. Then the physical mechanisms associated to the influence of El Nino are discussed. And finally, some associated problems are further discussed.

II. EFFECT OF EL NINO ON THE ATMOSPHERIC CIRCULATION IN EAST ASIA

As a basic background, the atmospheric circulation in East Asia plays an important role in processes through which the tropical ocean influences weather and climate in China. The features of the circulation as well as its relation to weather and climate in China have been understood well after a few decades of research (Ye and Zhu, 1958; Ye et al., 1962; Tao et al., 1963; Chen and Ding, 1979; Tao et al., 1980). Consequently, it is a necessary and efficient way to understand the influence of El Nino and, especially, the relevant physical processes, by means of building up connection between El Nino and the circulation in East Asia. It is well–known that the subtropical high (SH) over Northwest Pacific, summer monsoon and westerlies in East Asia are major circulation systems which control large–scale climate variations in China.

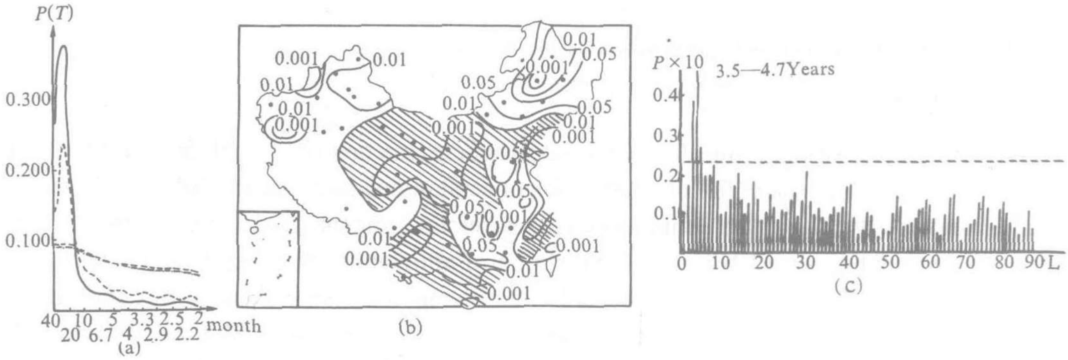
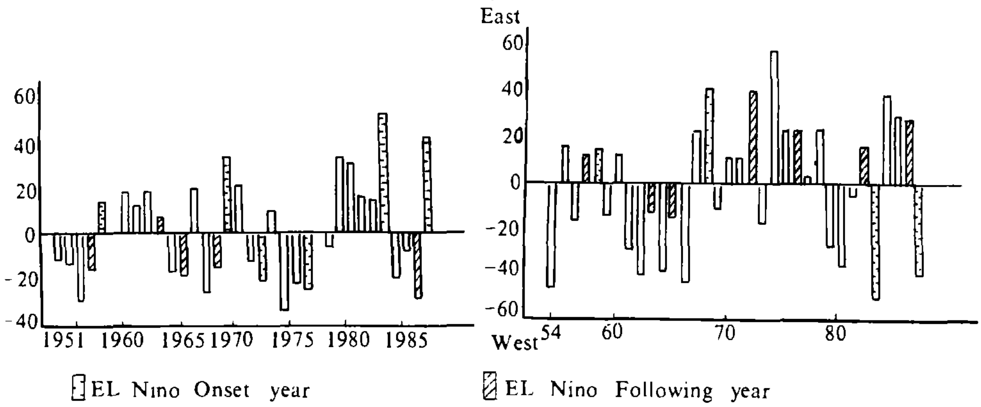


Fig. 1. Quasi–3.5 year oscillation in ocean–atmosphere system. (a) Power spectrum for SST in equatorial eastern Pacific (dashed lines) and for index of subtropical high over western Pacific (solid ones). Dot–dashed lincs are red noise (after Li et al., 1987). (b) Distribution of confidence level for quasi–3 year periodic fluctuation in rainfall (after Lu et al., 1983). (c) Power spectrum of air temperature in Heilongjiang Province (from Xu et al., 1982). L represents wavenumber.

Many studies have revealed close relationships between El Nino and interannual variations of SH. An apparent example is the coupled 3—4 year quasi–periodic oscillation between SH and El Nino with lagging time of SH by about 3—6 months (Research Group on Long– Range Weather Processes, 1977; Fu and Li, 1978; Chen, 1982, see Fig.1a for the oscillation of the SST and SH). Furthermore, the position, extension and strength of SH are remarkably different prior– and post to onset of an El Nino event. Fig.2 is annual evolution of SH intensity, defined by area index, and westward extension in summer at 500hPa during 1954—1987 (Fu and Teng, 1988). It can be seen that SH became weaker and moved to east in most of the first year (onset year) of El Nino events while stronger and to west in the following year. Zang et al. (1984) noted that violent variations in the area index and westward extension of SH follow SST anomalies in equatorial eastern Pacific and reach culmination after about three months of warming or cooling. Meridional shift of SH is also observed in El Nino year. A comparison of geopotential heights of 500hPa surface in Northwest Pacific during July to September between El Nino years and La Nina years shows strong and extensive negative anomalies in the region north of about 30°N and weak positive anomalies between 10°N and 30°N, which implies that SH would move to south in El Nino year (Li, 1987).



(a) (b)

Fig. 2. Annual evolution of intensity (a) and westward extension (b) of subtropical high over western Pacific in summer during 1954—1987 (after Fu and Teng, 1988).

There exist close relationships between El Nino and three branches of summer monsoon in East Asia, i.e. southeast monsoon in southwest of SH, southwest current from Indian subcontinent and cross–equatorial flow from the Australian high. Fig.3 displays composite airflow fields in the upper and lower troposphere in June for El Nino and La Nina years, respectively, which exhibits variations of the three monsoon air currents (Chen, 1988). It can be seen that the southeast air current becomes weaker usually due to weakening and eastward movement of SH in El Nino years. In the Indian Ocean, zonal pattern of SST anomalies appears to be mostly opposite to that in the Pacific during El Nino years. This pattern of SST anomalies (positive anomaly in the west and negative anomaly in the east), just as pointed by Chen (1988) and Deng et al. (1989), tends to fill Indian hot low and, therefore, weaken the southwest monsoon. In contrast, the cross–equatorial flow tends to intensify owing to enhancement of Australian high during El Nino year.

The features of teleconnection between El Nino and westerlies in East Asia have been analysed. Through comparing three–dimensional structure of the Hadley circulation over the Pacific and Walker circulation as well as transport of some physical quantities, Pan (1981) pointed out that warming of sea water in the equatorial eastern Pacific would increase air temperature over the sea through more upward sensible heat flux. It, in turn, results in intensification of atmospheric baroclinicity between low and middle latitudes, thus leading to enhancement of westerlies. Fu et al. (1979) pointed out that the zonal–averaged circulation over the Pacific and Walker circulation are controlled each other. The former becomes stronger while the latter weaker in response to warming of equatorial eastern Pacific Ocean. This may increase the northward transfer of momentum and heat. The similar results were gained in the diagnostic analysis for 1982— 1983 El Nino event (Yu and Li, 1989; Wu et al., 1990). The increase in both the baroclinicity and the transfer tends to make westerlies stronger.

The negative SST anomaly of tropical West Pacific, which is opposite to what happens in

East Pacific, may result in weakening and eastward movement of SH, and cause westerlies in East Asia to shift to south (Li, 1987). In addition, zonal flow prevailed in East Asia in winter of El Nino years, which means weaker winter monsoon (Zhu and Xie, 1988; Li, 1989b). The path of cold waves over East Asian continent shifts farther to the east as compared to the normal (Guo et al., 1990).

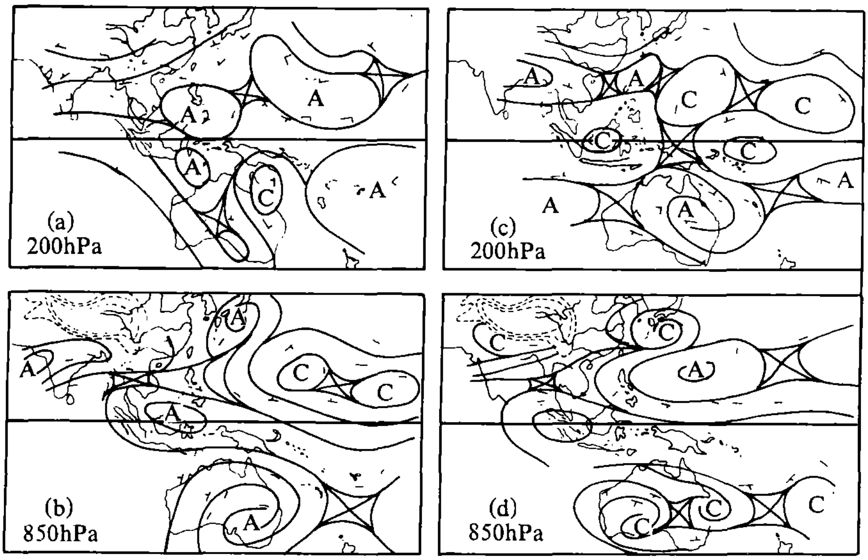


Fig. 3. Abnormal composite airflow in June for El Nino pattern (Parts a and b) and La Nina pattern (Parts c and d) of SST anomalies in the India–Pacific Ocean area(after Li, 1988).

III. EL NINO AND ITS RELATIONSHIP TO DROUGHT / FLOOD

It is shown by Lu et al. (1983), Mo (1989) and Yan (1989) that the quasi–3.5 year oscillation is also observed in rainfall field in almost all China (Fig.1b). Rainfall patterns vary tremendously in response to El Nino events (see, for example, Shi et al., 1982; Li et al., 1987; Ye, 1987). A result obtained in the previous researches is that El Nino is usually accompanied by reduction of summer monsoon rainfall in East China. Chen (1977) obtained a negative correlation relationship between SST in equatorial eastern Pacific and precipitation during flooding period in middle and lower reaches of Changjiang (Yangtze) River and the former leads the latter by about five months. Fu and Fan (1987) suggested that the common influence of El Nino exists in East China and in India, that is, precipitation would reduce in both regions in association to weakening of the summer monsoon in East Asia in El Nino year. Xu and Wu (1986) also showed that onset date of Meiyu (Plum rain) in middle and lower reaches of Changjiang River would delay and the rainfall amount would drop down under the condition of positive SST in equatorial East Pacific and negative SST in West Pacific. There is a similar variation in rainfall field in North China (Liang, 1986; Zhao,1990; Li, 1990; Wang and Li, 1990). A statistical analysis of El Nino events in the recent 500 years has indicated that spring drought in North China occurred more frequently in El Nino years (Zhao, 1990). In 13 El Nino years since 1950, rainfalls during rainy period in North China decreased for most of El Nino years (70%) with average reduction by 13.4% (Li, 1990). Recently, Wang and Li (1990) pointed out that the precipitation in semiarid region in northern China reduces generally in El Nino years. In South China where is transition belt of the summer monsoon, rainfall pattern is disturbed by many other atmospheric circulation features, so it is unlikely that there is a definite relation to El Nino events(Xu and Deng, 1989).

Some other observational results suggest that there might be varied forms of relationships between precipitation anomalies in China and El Nino events. Zhang and Zhao (1988) classified anomalous rainfall during flooding period (June—August) in East China into three patterns. For pattern I the anomalies are negative in region between Changjiang River basin and Huanghe (Yellow) River valley (Changjiang–Huanghe River area) and positive in most other parts of East China. Pattern II is almost opposite to Pattern I in the geographic distribution. Pattern III corresponds to plentiful rain in South China and deficient rain in North China. It can be seen from Table 1 that Pattern II is dominant in El Nino years. It means that deficit rainfall occurs mostly only in Changjiang–Huanghe River area while rainfall in other region might increase in El Nino years. In La Nina years Pattern I occurs with greater possibility.

Table 1. Three Patterns of Summer Rainfall in China in El Nino Years and La Nina Years (after Zhang and Zhao, 1988)

El Nino Events	Onset year	Following year	La Nina Event	Onset year	Following year
1957—1958	II	I	1955—1956	III	II
1963—1964	II	I	1964—1965	I	II
1965—1966	II	I	1967—1968	I	III
1969—1970	III	III	1970—1971	III	II
1972—1973	II	I	1973—1974	I	III
1976—1977	I	I	1975—1976	II	I
1982—1983	II	III			

Rainfall anomalies are dependent on which stage El Nino is at. According to Fu and Teng (1988), rainfall anomalies in the onset year of El Nino and the following year differ from each other. A statistics for drought / flood index since 1900 indicated that probability of positive rainfall anomalies is 2.5 times greater than that of negative one in the following year. Some other studies also showed notable differences in rainfall anomalies between these two years (Zhang and Zhao, 1988; Chen, 1990). Huang and Wu (1987) partitioned El Nino cycle into growing phase and decaying one. It is shown that rainfalls in flooding period increase in Changjiang–Huanghe River area and in Northeast China but decrease in North China and region of south to Changjiang River largely during the first phase. Almost opposite geographic distribution of rainfalls occurs during the second phase except for Northeast China (see Fig.4). Fig.5 shows the shift of abnormal rainfall belt during El Nino cycle (Yu, 1990). It can be seen that the abnormal rainfall belt moves from north to south during the first year of El Nino and moves in opposite direction during the second year.

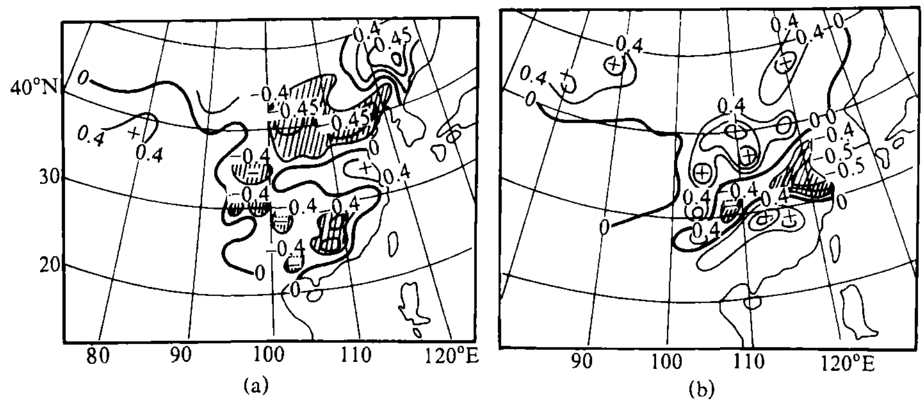


Fig. 4. Distribution of correlation coefficients between SST in equatorial eastern Pacific and rainfall in flood period in China during developing phase (a) and decaying phase (b) of El Nino (after Huang and Wu,1987).

El Nino events themselves can be classified into categories based on their strength, location, season of occurrence and persistence of warming (Wang, 1985; Fu et al., 1985; Zhao et al., 1989; Chen and Luo, 1990). Different categories of El Nino might result in distinct pattern of abnormal rainfall. Zhao et al.(1989) showed that Meiyu rain in middle and lower reaches of Changjiang River would increase if obvious warming happens in autumn or winter and decrease if the warming in spring or summer no matter which year, the onset year or the following year, it may occur in.

Furthermore, it would be more difficult to determine how the rainfall responds to El Nino if strength of anomalies of rainfall are taken into account. Tao et al. (1988) noticed that although occurrence number of negative rainfall anomalies during flooding period in Changjiang River basin during 1954—1983 is twice as many as that of positive anomalies, amplitude is much smaller for negative anomalies than for positive ones, which is opposite to the case in India.

IV. THE EFFECT OF EL NINO ON TYPHOON ACTIVITIES

The typhoons hitting China occur mainly over Northwest Pacific Ocean (about 120—140°E) and the South China Sea(about 110—120°E) between 10—20°N (Chen and Ding, 1979). El Nino can influence both frequency and track of the typhoons.

Some relationships between the typhoon frequency of occurrence and SST in the equatorial eastern Pacific have been revealed (Pan, 1982; Wang, 1983; Xie et al., 1984; Wei, 1985; Li, 1986, 1987; Yang et al., 1987; Chen and Chao, 1987; Dong, 1988; Dong and Zhong, 1989; Dong and Qi, 1990). Occurrence frequency of the typhoons is usually below–normal in El Nino year than in normal. Pan (1982) obtained negative correlation between typhoon occurrence frequency and SST in equatorial eastern Pacific with extreme value of correlation coefficient of −0.39 and SST leading by three months. A detailed observational result is listed in Table 2 (Li, 1987).

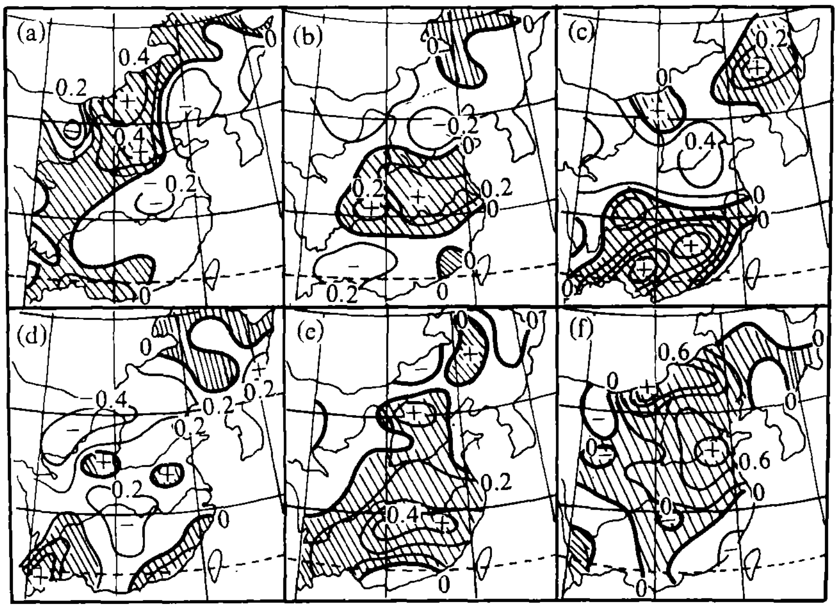


Fig. 5. Distribution of average percentage of rainfall departure in China during El Nino (a—c: April, July and October in onset year of El Nino; d—f: same as a—c except for the following year). The areas of positive values are shaded (after Yu, 1990).

However, typhoon number increases occasionally in individual El Nino years, for example, for El Nino of 1972—1973. Through comparison of typhoon frequency of different stages of El Nino cycle and in different oceans, Dong (1988) noted that the frequency in the onset year is lower and higher than that in both preceding and following adjacent years in 120—160°E and the oceanic area east of 160°E, respectively; it is much lower than that in the following year in South China Sea. The results confirm a viewpoint that the influence of El Nino reflects mainly in zonal shift of typhoon occurrence region rather than variation of total typhoon number (Wei, 1985). The regions of occurrence of typhoon move to east in El Nino years and to west in La Nina years. It also moves to south in El Nino years (Chen and Chao, 1987).

Table 2. Average Number of Typhoons Generated over Western Pacific and South China Sea and Landing on the Continent of China (after Li, 1987)

	All years	El Nino years	La Nina years
Occurrence of typhoons over western Pacific and South China Sea	24.3	21.3	26.2
Number of western Pacific typhoon entering South China Sea	6.9	4.9	8.7
Number of typhoons generated over South China Sea	3.4	2.0	4.1
Frequencies of typhoons landing on the continent of China	6.2	5.2	7.3

The track of the typhoon generating on Northwest Pacific is controlled primarily by subtropical high over the oceanic area. Since the high becomes weaker and moves to east, the typhoon turns to north before landing in China or entering South China Sea in El Nino years with higher possibility (Li, 1987). Meanwhile, there is little chance to observe unusual tracks of the typhoon usually (Lin, 1988).

V. EL NINO AND COOL SUMMER IN NORTHEAST CHINA

The cool summer in Northeast China refers to departure of air temperature near the surface in summer in the region is below a critical value, usually, −0.5°C. It is defined as heavy cool summer if the departure is below −0.8°C (Wang, 1990; Bai and Guo, 1985). The cool summer is one of major natural damages affecting the crops in this region (Ding, 1983).

The relation between the cool summer and El Nino was suggested in the late 1970s and early 1980s. The comparison of monthly air temperature in Northeast China and SST of oceanic area of 10°S−−10°N and 180—80°W during 1951—1978 showed a negative correlation (Research Group on Northeast China Cool Summer, 1979). Fu et al. (1982) and Zhang et al. (1983) analysed spatial relationships of global air surface temperature and showed pronounced negative correlation between variations of air temperature in Northeast China and SST in equatorial East Pacific, with the temperature in Northeast China lagging by several months.

Afterwards, some particular investigations on relationships between the cool summer and El Nino were further conducted. The significant sign of quasi−3.5 year oscillation has been detected in the air temperature field (Fig.1c, see Wei, 1983; Liu et al. 1983)). The long record of air temperature displays long−term coupled fluctuation between El Nino and the cool

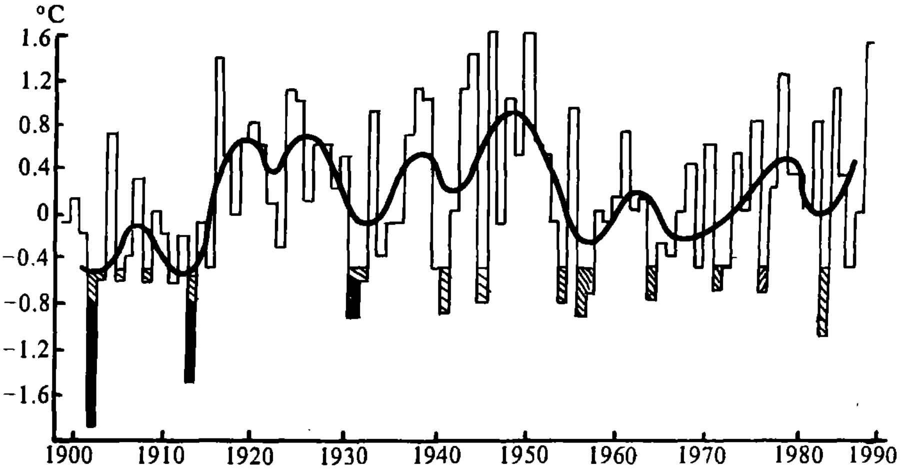


Fig. 6. Air temperature departure in East Asia (areas with declined lines and shade represent cool summer and serious cool summer, respectively) (from Wang, 1990).

summer events. Lin and Zhang (1987) showed that both of the events since 1900 can be classified into five cool and warm alternative episodes and their phases are almost opposite. The cool summer lags El Nino and their correlation reaches maximum value of 0.75 with lag time of ten years. In addition, the cool summer during cold climate episodes occurred with high frequency. Another analysis by Wang (1990) for air temperature anomalies in summer in Northeast China, Far East part of USSR, North Japan and Korea during 1899—1988 from average over 1951—1980 indicated that these regions had experienced totally 22 cool summer years, including 9 heavy cool summer years. However, the cool summer events did not occur with same frequency for different periods. For example, the frequency was high (50%) during 1902—1915 while only

6.7% during the following 15 years. It can be found further that the cool summers are associated closely with El Nino events. 13 of the 22 cool summer events occurred in El Nino years, 3 in preceding years, 6 in the following years and only one, occurring in 1908, seems to be no definite relation to El Nino (Fig.6). On the other hand, warm summers occurred in most La Nina years since 1910 (Li, 1990).

Besides Northeast China, air temperature in summer in other parts of East China has similar variations in El Nino years (Li, 1989a). In addition, individual studies show that warmer winter in East China turns out mostly in El Nino years (Li, 1989b).

VI. THE POSSIBLE MECHANISMS FOR THE EFFECT OF EL NINO EVENTS

Some possible mechanisms have been proposed to account for the observed relationships between El Nino and variations of weather and climate in China.

1. *Zonal Shift of Tropical Atmospheric Circulation Systems*

It is proposed that the interannual climate variations in China might be associated to El Nino through zonal shift of the tropical atmospheric circulation systems over western Pacific. Fu and Teng (1988) analysed entire process of 1982—1983 El Nino event and showed that the equatorial warm pool, together with the strong convective region and subtropical high over Northwest Pacific, moved to east in growing phase of the El Nino event and came back to the average positions in decaying phase. Further, the low–freqency oscillation propagated eastward first and turned back after it reached the equatorial central Pacific during the El Nino (Chen and Shao, 1990). Wang et al. (1986) showed that low pressure system, centred at Australia regularly, moves to central Pacific at the peak stage of warming (October—December) based on an analysis of El Nino events in recent 80 years.

As to the influence of the zonal shift on rainfall in China, Fu and Teng (1988) considered that the eastward movement of SH in onset year of El Nino would make southeast monsoon weaker and, correspondingly, rainfalls in the Changjiang River valley decrease. In contrast, the rainfall would increase in the following year due to westward movement of SH. However, someones argued that the monsoon rain belt would stay in the Changjiang River valley in onset year of El Nino owing to weakening and eastward movement of SH and lead to increase of rainfalls in the Changjiang River basin and decrease of rainfalls in the Huanghe River valley (Bi, 1990).

The abnormal typhoon activities might be associated to the zonal shift. In the onset year of El Nino, occurrence region of typhoon moves to east following the movement of the strong convective area and SH. It appears apparently that the occurrence frequency of typhoon decreases in the area of 120— 140°E. Meanwhile, typhoon number landing on China would reduce.

2. *Propagation of Steady Planetary Waves*

Thermal situation of sea surface ocean could influence SH through the propagation of planetary waves or teleconnection which, in turn, may influence weather and climate in China (Huang and Li, 1988; Zeng and Zhang, 1987). Huang and Li (1988) showed that the northward propagation of quasi–stationary planetary waves excited by heat sources over tropical western Pacific becomes weaker in onset year of El Nino. It would induce weakening of SH and increase of rainfalls in the Changjiang River valley.

3. *Variations of Atmospheric Circulation in Mid–Latitudes*

Li (1990) gave an account for droughts in North China in terms of variations of atmospheric circulation in East Asia related to El Nino. It is well–known that the continuous maintenance of high ridge located in 130—140°E over Japan is an important condition for heavy rain in North China in summer. In summer of El Nino year, geopotential heights on 500hPa surface in mid–latitudes in East Asia fall down. It causes the high ridge to move southward and, therefore, rainfalls in North China to decrease.

Since the troughs in westerlies deepen more frequently over Northeast China, the cool summer occurs more easily (Li, 1989a). But, winter of El Nino year is usually warmer due to weakening of winter monsoon in East Asia (Li, 1989b).

VII. DISCUSSIONS

(1) It could be drawn out from the above results that the strong signals of El Nino do exist in interannual atmospheric variations in China. However, the physical mechanisms by which El Nino events influence weather and climate in China have not yet been understood better in comparison with those in some other regions of the world, e.g. India, Australia, the United States, etc. and what have been obtained are only rather preliminary relationships and sometimes even inconsistent for different authors. It might be attributed to numerous factors, such as inherent complexity in connection between El Nino and variations of climate in China, insufficient El Nino samples and relevant oceanic and meteorological data, differences in definition and cases selected in various analysis, etc. So it should be desirable to intensify observation and corresponding analysis, just as suggested in many previous studies. In addition, similar research on El Nino′ influence has been widely carried out abroad (for example, Rasmussen and Carpenter, 1982; Pan and Oort, 1983; Shukla, 1983; Nicholls, 1984; Ropdewski and Halpert, 1987; van Heerden et al., 1988). It would be helpful to make more comparative studies on influences of El Nino on climate between in China and in other parts of the world.

(2) Some possible mechanisms on El Nino influence have been proposed. However, it is still a weak point in research of El Nino at present, which brings great difficulty to interpret the observed results, including the inconsistence among them. In addition, feedbacks of abnormal circulation in East Asia as well as abnormal weather and climate in China to formation and evolution of El Nino are much less well understood, although there have been a few individual works on this topic. Both studies of the physical mechanisms and the feedbacks are important to understand completely relationships between El Nino and variations of weather and climate in China. It is highly desirable for more simulation studies with coupled ocean–atmosphere models, especially GCMs.

(3) El Nino as well as the Southern Oscillation is one of the strongest signals known nowadays over climate noise in interannual variations of the atmosphere and oceans around the world. The previous research results suggest that it might be feasible and desirable to predict interannual climate changes by means of SST condition in equatorial eastern Pacific. A successful ten–year experiment carried out at the National Meteorological Center in Beijing since 1976 has been reported by Fu and Zeng (1988), in which the SST had been used to predict the variations of SH and rainfalls in China during summer in six–month advance and the forecasted

accuracy of 60—70% on average had been obtained for major characteristics of SH. However, it is important to keep the following two points in mind. First, the SST is only one of many factors which can cause anomalies of climate in China and it is unlikely that the correlation between SST and climate in China has reached a required degree that the satisfactory accuracy of the climate prediction can be achieved by using SST as a single predictor (Zhou, 1988). Actually, great distinction exists in El Nino influence for individual El Nino cases, partly due to perturbation resulting from the other factors. Second, the statistical correlations might change with different El Nino samples or climate episodes, which would lead to uncertainty in statistical prediction for climate variations. As to prediction of El Nino itself, some explorations have been underway for a few years. It should be significant for forecast of El Nino as well as interannual climate change in China to develop coupled ocean–atmosphere models with solid physical basis and not too complex structure as, for example, did Cane et al. (1986).

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