Interdecadal change in Western Pacific Subtropical High and climatic effects

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Abstract: Western North Pacific Subtropical High is a very important atmospheric circulation system influencing the summer climate over eastern China. Its interdecadal change is analyzed in this study. There is a significant decadal shift in about 1979/1980. Since 1980, the Western North Pacific Subtropical High has enlarged, intensified, and shifted southwestward. This change gives rise to an anti-cyclonic circulation anomaly over the region from the South China Sea to western Pacific and thus causes wet anomalies over the Yangtze River valley. During the summers of 1980-1999, the precipitation is 63.9 mm above normal, while during 1958-1979 it is 27.3 mm below normal. The difference is significant at the 99% confidence level as a t-test shown. The southwestward expanding of the Western North Pacific Subtropical High also leads to a significant warming in southern China, during 1980-1999 the summer mean temperature is 0.37oC warmer than that of the period 1958-1979. The strong warming is primarily due to the clearer skies associated with the stronger downward air motion as the Western North Pacific Subtropical High expanding to the west and controlling southern China. It is also found that the relative percentage of tropical cyclones in the regions south of 20oN is decreasing since the 1980s, but in the regions north of 20oN that is increasing at the same time. The Western North Pacific Subtropical High responds significantly to sea surface temperature of the tropical eastern Pacific with a lag of one-two seasons and simultaneously to sea surface temperature of the tropical Indian Ocean. The changes in the sea surface temperatures are mainly responsible for the interdecadal variability of the Western North Pacific Subtropical High.?

Interdecadal change in Western Pacific Subtropical High and climatic effects HE Xue-zhao1, GONG Dao-yi1,2 (1. Laboratory of Environmental Change and Natural Disaster Research, Institute of Resources Science, Beijing Normal University, Beijing 100875, China; 2. School of Earth and Environmental Sciences, Seoul National University, Seoul 151-742, Korea) The summer climate changes in eastern China are strongly influenced by East Asian summer monsoon. There are at least two circulation systems influencing or controlling East Asian summer monsoon on the large scale: one is the eastern Asian summer upper jet stream centering in the regions of 40oN; the other is the Western Pacific Subtropical High (WPSH) in the south regions. WPSH controls a broad area. It is most significant in the middle layers of troposphere and has more direct and notable effect on the surface climate. A lot of studies have paid much attention to it and its influence (Lau et al., 2000; Liu and Wu, 2000). However, these previous researches focus mainly on the interannual changes of WPSH and its influence on climate. Recently, significant interdecadal climate changes of China have been highlighted. Investigation of the responsible circulation feature in the context of the large-scale variations and of the reasons of the interdecadal climatic changes is very helpful for us to understand and forecast the interannual and interdecadal climate anomalies in East Asia. The purpose of this study is to analyze the interdecadal changes of Western Pacific Subtropical High and its influence on the climate of China. The data sets of atmospheric circulation are the reanalysis data covering the period 1958 to 1999 compiled by National Centers of Environmental Prediction/National Center of Atmospheric Research (NCEP/NCAR). The observed precipitation and temperature data sets for the period 1951-1999 are obtained from the China Meteorological Administration (CMA). To expediently analyse, we use the data only for the period 1958-1999. Figure 1 Contour lines of 5870 gpm in summer for (a) 1958-1979 and (b) 1980-1999. Shown in light green is the regions with means above 5870 gpm. Red lines show the average locations for the strongest 5 years, blue lines for the weakest 5 years. Gray squares show the key region used to define the Western Pacific Subt

ropical High index 1 Interdecadal changes of Western Pacific Subtropical High The CMA has defined a series of indices to quantify and monitor the activity of WPSH, including the area index, the intension index, the position of ridges, the west boundary, the north boundary and so on, which are updated and published in Meteorological Monthly each month and are applied widely. However, some researches indicate that the 500 hPa data used to calculate the indices have changed several times, from upper air weather maps in the 1950s to the recent model output data. There are systematic errors between these 500 hPa heights, thus, inducing discontinuities into the WPSH characteristic indices (Gong et al., 1998). It is inappropriate to investigate the interdecadal changes using these indices due to the discontinuities. To avoid this problem, we utilize the NCEP/NCAR reanalysis 500 hPa heights (Kalnay et al., 1996). WPSH is usually observed and measured by the extent of 5880 gpm contours. Since the 500 hPa heights of reanalysis data are systematically lower than the CMA data, we change the standard to 5870 gpm in this study. The regions of contour lines of 5870 gpm can directly show the intensity and position of WPSH. Checking the contour lines of 5870 gpm in summers since 1958, we find that there are distinct interdecadal changes of 5870 gpm taking place in about 1979/1980. Figures 1a and 1b show the status in 1958-1979 and 1980-1999, including the mean positions of 5870 gpm, the mean positions in the strongest 5 years and the weakest 5 years. In the first period, the strongest 5 years are 1965, 1969, 1973, 1977 and 1979, and the weakest are 1961, 1963, 1964, 1972 and 1974. In the second period, the strongest 5 years are 1980, 1983, 1987, 1995 and 1998, and the weakest are 1981, 1984, 1985, 1986 and 1997 (re. Figure 3). Obviously, in the first period the WPSH is generally weaker and located eastward and 5870 gpm lies east of Taiwan. And in the second period WPSH is stronger and its extent and extreme area are larger and extend to the equator and west. The most significant changes appear in southern China, the South China Sea and the Philippines. The 500 hPa heights have been strengthening since the 1980s. Figure 2 Correlation between the Western Pacific Subtropical High index and 500 hPa heights Table 1 The t-test for the WPSH index, rainfall along the Yangtze River valley, temperature in southern China, and the typhoon frequency. (* denotes significant at 95% confidence level) Figure 3 Time series of several parameters To quantitatively describe the notable changes of WPSH, we select the key region (125(-140(E by 20(-25(N) to calculate the mean value of 500 hPa height because this area lies at the west edge of the mean position of WPSH and is sensitive to changes in the intensity and extent of WPSH (Figure 1). The correlation at 500 hPa between the key region and the others are highly positive over the whole western Pacific. The areas with correlation coefficients higher than 0.9 cover southern China, the South China Sea and the western Pacific east of the Philippines. This shows the consistent feature of changes in association of the WPSH. Thus, height changes in the key region can describe the variations in WPSH very well. In Zhang and Lin (2000), 12 grids of 500 hPa heights in the region of 10-25oN by 90-130oN are used to monitor the activities of WPSH. In the present study, the WPSH index is represented by the mean heights of the key region. Figure 3 shows the time series of the WPSH index. In addition to the strong interannual fluctuations (the standard deviation is 10.8 gpm), there is a remarkable jump-like change in about 1979-1980. Please note that Figure 3 shows the normalized series. Statistics show that the difference in mean values of WPSH index between the 22 years prior to 1979 and the 20 years after 1980 are statistically significant. Table 1 shows that the value of t-test is 5.4, exceeding the 99% confidence level. This result is also consistent with Figure 1. 2 The influence of Western Pacific Subtropical High on rainfall Figure 4 shows correlation between the WPSH index and the summer rainfall of 160 stations. Obviously, the regions most significantly influenced by WPSH are located over the Yangtze River valley. When the WPSH index is high, there tends to be more rainfall in the regions over the valley. Because each single station´s rainfall is influenced by many local environmental factors, the regional mean would suppress the noise effectively. The mean rainfall of 32 stations in the regions east of 105(E and 27-33(N (marked by circles in Figure 4) may represent the overall condition along the Yangtze River valley in association with the subtropical high. The correlation between the 32-station mean rainfall, as well as rainfall for each station, and WPSH are calculated and shown in Figure 4. Many researches have stated that there are distinct low-frequency changes in the Yangtze River valley rainfall (Hu, 1997; Gong et al., 2000). The curves of rainfall and WPSH clearly show that their low-frequency variations are in good agreement. Figure 3b presents the time series of rainfall, during 1980-1999 the summer precipitation over the Yangtze River valley is 63.9 mm (13.3%) above normal, while during 1958-1980 the precipitation is 27.3 mm (-5.7%) below normal. The difference between the two periods is significant at the 99% confidence level as a t-test revealed. Figure 4 Correlation between the WPSH index and the summer rainfall (zero contours omitted, regions above 95 % confidence level shaded) The previous researches have revealed that when the geopotential heights at middle and lower troposphere around the key region in the western Pacific increases, there is an anomalous anticyclone with the center located over Japan and Korean Peninsula. And this kind of circulation pattern usually tends to result in more rainfall in the Yangtze River valley, through the strengthened convergence of airflow and water vapor (Lau et al., 2000; Hu, 1997; Gong et al., 200

0). As shown in Figure 1, in 1980-1999 the regions from the western Pacific to the South China Sea are surrounded by 5870 m contour lines. This implies that in association with the strengthening of the WPSH during recent two decades, the geopotential heights over these regions would increase, resulting in positive height anomalies. That would be responsible for the persistent wet condition along the Yangtze River valley during the last about 20 years. 3 The influence of the Western Pacific Subtropical High on temperature Compared to rainfall, less attention has been paid to the influence of WPSH on the temperature. In summer months, continuously high temperature usually exerts very important influence on agriculture. Extremely heat waves lead to severe drought. The correlation coefficients between stations´ temperature and WPSH indicate there are negative coefficients over the Yangtze River valley, Yellow and Huaihe river basins. This reveals that when WPSH is strong, the summer temperatures are low, which is due to the increasing of rainfall. But the negative correlations are not statistically significant. On the contrary, the summer temperatures in southern China have notable positive correlations with the subtropical high. The most distinctly positive correlations appear in the regions south of 25oN with the correlation coefficients above 0.4. The regional mean summer temperature, averaged for 17 stations over the domain east of 100oE and south of 25oN, is correlated with WPSH significantly, and the correlation coefficients are above 0.6, significant at 99% confidence level. The contribution of low-frequency changes is important to the high correlations. Figure 3c shows that the interdecadal changes of temperature are predominant: since the 1970s air temperature suddenly becomes higher and anomalously high temperature continues to present. The mean temperature for 1980-1999 is 0.22 oC higher than the annual mean over years climate and 0.37 oC higher than that in 1958-1980 (for latter period the average departure is -0.15 oC). The temperature changes over South China are concurrent with the changes of WPSH. Figures 1 and 2 show that in association with the sustained strengthening of WPSH in 1980-1999, its extent expands to the south. And its influence on southern China is correspondingly enhanced. There are also stronger sinking and divergence motion in the middle and lower troposphere over there. This would lead to less rainfall and higher temperature. Certainly, observed temperature changes especially in big cities are usually influenced by heat island effect. Since 1980 many Chinese cities have been developing rapidly. The arisen question is whether the high summer temperature over southern China in 1980-1999 is mainly due to the heat island effect. We can use reanalysis data to analyze that. Recently, Kistler et al. (2001) compared the observed temperature of Shanghai with the reanalysis data of the nearest grid (It is located over the sea). They demonstrate the two time series are tightly related: before 1980 they were nearly identical, while after 1980 because of the influence of the heat island effect the observed annual mean temperature is about 0.5 oC above the reanalysis data. The reanalyzed summer mean surface air temperatures for 9 grids over 105o-120oE, 20o-25oN (no big city is located exactly at these grid points), are indicated in Figure 3c by dashed line. Obviously, the two curves are tightly related not only at interannual variability but also the jump-like changes in 1979/1980. The influence of the heat island is not significant. Therefore, the sudden changes of summer temperature would have resulted from the enhancing and westward expanding of the WPSH. 4 The influence of the Western Pacific Subtropical High on tropical cyclone Typhoons in western Pacific also play an important role in summer climate of China. Gray (1968) has indicated there are six factors in favor of genesis of typhoon: higher sea surface temperature (SST), more powerful Coriolis force, more powerful relative vorticity at the low layer of troposphere, weaker vertical wind shear, conditional unstable air and enough water vapor. Among these factors the influence of long-term changes of SST on typhoon frequency are emphasized in the past (e.g., Yang and Shi, 1999). However, many researches have indicated that the influence of large-scale atmosphere circulation on long-term changes of typhoon should not be underestimated. Ye and Dong (1998) demonstrate typhoon activities are closely related to the WPSH and the mid-latitude westerly. In general, when WPSH is strong, there are less typhoon activities. Recently Yumoto and Matsuura (2001) have studied interdecadal changes of tropical cyclones frequency. They found that in association with the more and less typhoon activities there are notable differences in not only Pacific SSTs (0.2 (C higher in more active decade than in the less active decade) but also the large-scale atmospheric circulations including the relative vorticity at 800 hPa, divergence at 200 hPa and other elements. Statistical analysis indicates that strong typhoons often appear first in the regions east of 125oE (Chen et al., 1999). The typhoons originating from these regions account for 78% of the total typhoons over the western North Pacific. Typhoons for both the entire northwest Pacific and the regions east of 125oE show fluctuations in the order of 10-13 years. No abrupt 1979/1980 changes, as the WPSH has experienced, are found. This suggests that other factors such as sea temperature may play more important roles in the typhoon genesis than atmosphere circulation (Yumoto and Matsuura, 2001). However, further analysis indicates that interdecadal changes of WPSH have distinct influence on the relative frequency of typhoons (the ratio of typhoon numbers of each region to the total numbers). The tropical cyclone data of the past years used here are from the Japan Meteorological Administration (RSMC, 1992). The domain of 125o-160oE, south of 20oN is a high typhoon

genesis region in which the average typhoon number is 7 (accounting for 62% of the total number). The variations in 500 hPa also indicate this region has negative relations with adjacent regions in mid-latitudes; when the heights in low-latitudes increase, the heights in mid-latitudes decrease, and vice versa (Figure 2). Thus, in order to keep consistent with the 500 hPa heights, two sub-regions (one is south of 20oN and the other is north of it) are selected. The typhoon ratios in these two regions to the total numbers over the western Pacific are calculated and shown in Figures 3d and 3e, respectively. Obviously, since the late 1970s, the typhoon ratio for low-latitudes has distinctly decreased. Similar to the previous analysis, a t-test is also applied to the time series. The relative frequencies in the low-latitudes are 66.3% and 55.3% in 1958-1980 and in 1980-1999 respectively. The t value is -2.5, exceeding the 95% confidence level (Table 1). The relative frequency for mid-latitudes over the Pacific has been increasing since the end of the 1970s, but the t-test shows the changes is not statistically significant. The correlation coefficients between typhoon numbers and 500 hPa heights over the Northern Hemisphere during July to October for the period 1951-1991 display that there is high correlation in western Pacific: the significantly negative correlation appears in the regions from the South China Sea to low-latitudes over the western Pacific, and the positive correlation in the regions to the north (Chen and Chao, 1997). This pattern is similar to Figure 2. All these results suggest that when the WPSH gets stronger the genesis of typhoon tends to be reduced, whereas the WPSH is weak the typhoon activity tends to be enhanced. 5 Discussion There are many factors influencing WPSH, including the internal dynamic processes and external forces (Liu and Wu, 2000). Among all factors, the anomalous lower boundary condition may be the most important one responsible for the interdecadal changes in the WPSH. Analyses reveal that the correlation between mean SST of the western Pacific and WPSH is not significant. Thus, the signal of interdecadal changes in WPSH would originate from other regions, especially the tropical SST. Angell (1981) has indicated that when equatorial Pacific SST is high, subtropical high is strong and the center axis shifts southward. This cause-effect relationship is most notable when the SSTs leading by 1-2 seasons (Gong and Wang, 1998). However, there is no much analysis focusing on the WPSH. Table 2 shows the correlation coefficients between the WPSH index and the eastern equatorial Pacific SSTs, with the different SST leading seasons. Obviously, the influence of the Nino SST on WPSH is strong when temperature leading by 1-2 seasons. Among these areas, Nino4 temperature is simultaneously correlated with the WPSH index with strong relation. This may be due to the associated change in atmospheric circulation via both the Hadley Circulation and such wave trains as the Pacific-Japan teleconnection pattern, usually the latter mechanism carries a shorter time lags (Huang and Wu, 1989; Nitta, 1987). It is noted that Nino SST has distinct interdecadal changes. The Nino3 SST has been much higher since the 1980s and the t-test value for the two periods of 1958-1979 and 1980-1999 is 2.24, also significant at the 95% confidence level. Figure 5 (a) Nino3 SST in spring, (b) Tropical Indian Ocean (7.5oS-7.5oN, 65o-100(E) SST in summer. Both normalized. Table 2 Correlation between sea surface temperatures and 500 hPa height (20-25(N, 125-140(E), with different SST leading seasons. Data period is 1958-1999. By analyzing the global tropical SSTs, we find the correlation between the WPSH index and the tropical SSTs of the Indian Ocean as well as of tropical Pacific are remarkable. In Indian Ocean the strongest correlation appears in 7.5oN-9.5oS, 65o-100oE. Regional mean SSTs over this area is correlated with WPSH at the values of 0.76 and 0.77, when subtropical high lags by one and two seasons respectively. The interdecadal changes of the SST in this region is even more significant than the Nino SSTs, the t-value is 5.5 (exceeding the 99% confidence level). Therefore the interdecadal variations of the SSTs in tropical Pacific and tropical Indian may play very important roles in the jump-like changes of WPSH in about 1979/1980. Finally, it should be noted that the 500 hPa data in this study are reanalysis data. Kistler et al. (2001) point out that the reanalysis data have two main error resources resulted from the global observing system changes. One is the using of the high-level radiosonde data beginning from the International Geophysical Year of 1957/58. Data since 1958 is more reliable than the prior period. The other is the using of the satellite data after 1979. However, some analyses show that errors are evident in the high levels (above 200 hPa) for some parameters only. The 500 hPa geopotential height is a Class A parameter, i.e. the data quality dependents primarily on the ground observations. Class A parameter is most reliable in the whole reanalysis data sets. Thus, the system errors in reanalysis data would have no evident influence on the research and results in this study. References