THE OPERATIONAL SEASONAL FORECASTING OF THE SUMMER RAINFALL IN CHINA

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ABSTRACT

The paper presents a review of the success and failure of the practical results from summer drought and flood forecasts and seasonal precipitation forecasts in the period from 1976 to 1985. An analysis is made on the anomaly of the general circulation wihch gives rise to summer precipitation and drought-flood occurrences in the country. It is proposed that the subtropical high over the West Pacific, the South Asia high and middle-latitude westerlies are the major synoptical regimes producing summer weather in China. The analysis focuses on the features of low-frequency oscillation and abnormality of the West Pacific subtropical high in the monthly 500 hPa mean charts, and on their interactions with the sea temperature of the North Pacific and the Equatorial Pacific. The result shows that there exist quasi-cycles of 3--4 years, 11 years and 19 years or so in the subtropical high with the feature of strong persistence and seasonal changes. There is a rather good correlation between the behaviour of the subtropical high and changes in the cold current area in the East Pacific, and especially during the El Nino period, there is an obvious coupling with abnormal changes of the intensity of the subtropical high. Analysis is also made on the effect of the thermal condition of the Tibetan Plateau, the Northern Hemisphere westerly circulation and the astronomical factors on the West Pacific subtropical high, the South Asia high and precipitation in the rainy season in China.

INTRODUCTION

Summer season (June-August) is a critical period of precipitation in China and a major season when severe drought and/or flood occur most frequently over a vast area. Therefore, seasonal forecasting of the summer rainfall is an important task of the operational long-range weather forecast in China. The weather forecasters from the Beijing Meteorological Center and the provincial WFOs (Weather Forecast Observatories) hold an annual meeting in spring every year to discuss the rainfall forecasts for the flood season. They analyse the characterisites of climate and atmospheric circulation at an earlier stage, especially the evolution of the West Pacific subtropical high and the South Asia high, pay special attention to the variation of various physical factors, and exchange their forecasting conclusions produced by different means of prediction. In April the Beijing Meteorological Center issues the forecast for weather trend in the flood season over the whole country, which is sent to the state government departments, other relevant organizations and all observatories in the provinces (municipalities or autonomous regions). The local WFOs and weather stations also issue the forecasts of flood-season rainfall according to their local situations. The skill of long-range weather forecasts is not perfect, but it is still of importance to relevant government departments and has been well utilized by local units.

I. REVIEW ON THE SEASONAL FORECASTS OF SUMMER RAINFALL DURING LAST TEN YEARS (1976–1985)

The major items included in the flood-season rainfall forecasts are a) the general trend of rainfall distribution over the whole country; b) the estimation of flood and drought which probably occur over a large area; c) the behaviour of typhoons which land and influence China during the flood season; and d) the forecasts for summer cold period in Northeast Region of the country. One-hundred stations over the whole country are selected to verify the forecast accuracy, which is calculated by

$$F = \frac{N + N_0 + N' + N''}{M + N' + N'} \times 100\%,$$

where F is the forecast accuracy; M = 100 is the total number of the stations selected; N is the number of the stations where the forecasted and observed anomalies have the same signs; N_0 is the number of the stations where the signs of the forecasted and observed deviations in percentage are reversed but their absolute values are less than 20%; N' and N'' are the numbers of the stations where the forecasted and observed deviations in percentage have the same sign and their absolute values range from 20 to 49% and equal to or greater than 50%, respectively. The seasonal forecast accuracy of the summer rainfall during the last ten years (1976-1985) is shown in Table 1. It is seen that the forecast skill is unstable, with a best result being 81% in 1978 and a worst one being 48% in 1983. Although in some years the forecast accuracy was not high, the flood and heavy rain in some regions were forecasted successfully. For instance, in 1981 the forecast said that there would be a flood and heavy rainfall in mid-summer in the west of Sichuan Province; this disaster did happen there and its intensity had not been seen over the last 30 years. In 1985 the forecast said that a major flood and heavy rainfall would occur in the northern part of North China and the southern part of Northeast China; the fact was that most of the North and Northeast China became rainy regions that year and the waterlogging in Northeast China was severe. These successful forecasts played an active role in taking precautions against and combating the natural calamities. Conversely, the failure of forecasts may land ourselves in a passive position to a certain extent, even result in some damages to the national economy.

 Table 1. The Operational Seasonal Forecast Accuracy of the Summer Rainfall during Last 10 Years (1976--1985)

Year	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	Average
Accuracy	68	65	81	60	54	62	71	48	71	65	64.5

The forecast and observational data for the summer-season rainfall deviations in percentage in 1978 are shown in Fig. 1, where the forecasted distribution of positive and negative deviation is in general agreement with the observations except for Northeast China. We were gratified at the success of this forecast. Fig. 2 shows another example as in Fig. 1 but for 1983, where the forecast was a failure. During the process of producing the forecast, the forecasters paid attention to the anomaly of the SST in cold water region of the equatorial eastern Pacific and the variation of the West Pacific subtropical high, which may lead to drought and flood in summer over a large area of China. But they failed to

predict the location of the subtropical high, which anomalously removed to the south from its normal position and hence the rain belt detained in the Changjiang River and Huaihe River Valleys could not move northward. Additionally, the seasonally averaged temperature on the Xizang (Tibetan) Plateau in winter and spring that year was the lowest in last







Fig. 1. The forecast map (a) and observational data (b) for the rainfall departure in percentage in June-August 1978. SCSI-South China Sea Islands.

30 years. It appears that the anomaly of thermal regime on the Xizang Plateau may be a factor which causes the anomaly of the subtropical high position. It is not clear so far for people as to the mechanism of the influence of SST and thermal regime of the Xizang Plateau on the general circulation in Asia. This is probably one of the reasons which lead to the failure of rainfall forecast for the flood season of 1983.





(b) Fig. 2. As in Fig. 1, but for 1983.

II. THE MAIN POINTS CONSIDERED FOR THE SUMMER SEASONAL FORECASTING

1. The Distribution Pattern of Summer-Season Rainfall

For the seasonal forecast we focus our attention to the main feature of rainfall distribution and the drought and flood trends over large areas of the country. The rainfall distribution in the eastern region of China (to the east of 105°E) is divided into three patterns (Fig. 3) according to different latitudinal locations of the rainy region by using the climatological summer rainfall departure percentage map.







Fig. 3. The patterns of summer-season rainfall. (a) pattern I, (b) pattern II, and (c) pattern III.

Pattern I: the major rainy region is located in and to the north of the Huanghe River Valley, and there is usually a below-normal region in the Changjiang-Huaihe River Valley, whereas in South China, it is uaually above normal.

Pattern II. the major rainy region is located between the Huanghe River and the Changjiang River; in other region it is below normal.

Pattern III: the major rainy region is along the Changjiang River and to the south of it, and the precipitation is below normal in a large area to the north of the Huaihe River.

2. The Interrelation between Rainfall Distribution Patterns and the West Pacific Subtropical High as well as the South Asia High

There are close interrelations between the above three rainfall patterns and the West Pacific subtropical high (hereinafter referred to as "the subtropical high"). The 500 hPa geopotential height departure in June—August corresponding to the three rainfall patterns is shown in Fig. 4. The height departure is positive from the Chinese mainland to the Japan Sea for pattern I. This indicates a stronger subtropical high with its location moved northward; meanwhile, the westerly in East Asia is strong with only weak waves or eddies on it, and therefore the summer seasonal rain belt is to the north of its normal location. For pattern II, the height departure is negative from the Chinese mainland to the Japan Sea, indicating a weaker subtropical high. The average location of both the subtropical high and the westerly frontal zone is to the south of that for pattern I. For pattern III, the westerly circulation in Eurasia appears as two ridges and one trough, the negative height departure from the Chinese mainland to the Japan Sea is usually larger than that for pattern II, the subtropical frontal zone is located to the south of its normal position and



Fig. 4. The mean geopotential height departure of 500 hPa in June-August for the three patterns of summer-season rainfall: (a) pattern I, (b) pattern II, and (c) pattern III.



the subtropical high ridge to the south of 25°N. Correspondingly the summer season rainfall zone is moved southward. It is seen that different rainfall distribution patterns corresponds to different subtropical high and westerly circulation, particularly for that in Chinese mainland to the Japan Sea. The location of positive height departure, which indicates the subtropical high behaviour, and its intensity variation are in accord with the rainfall distribution patterns.

Similarly the 100 hPa South Asia high has a close interrelation with the summer season rainfall in China, especially the latitudinal location and the extent of eastward extending play an important role in determining the location of major rainy zone in summer. When the South Asia high ridge in mid-summer ranging from 100° to 120°E in July is moved northward (\geq 32.5°N), the major rainy region in China is located in and to the north of the Huanghe River Valley, i. e. rainfall pattern I; otherwise, the main rainy region is located in or to the south of the Changjiang-Huaihe River Valley, i. e. rainfall pattern II or III. This interrelation is, in general, consistent with that for the 500 hPa West Pacific high.

3. The Characteristics of the Subtropical Anticyclone Circulation in the Anomalous Drought and Flood Years

An anomalous year when there occur drought and flood in a large area of China usually has direct connections with the abnomal changes of the subtropical high. In the mid-summer of the three years, 1965, 1968 and 1972, which are the severe drought years in North China, the intensity of 500 hPa subtropical high was remarkably weak. In July 1968 the subtropical high took an anomalous position southward, the monthly averaged location of the redge-line was at 20°N, which is 5 latitudes to the south of its normal location. In July 1972 the subtropical high was particularly weak and moved eastwards, its longitudinal position was 25 longitudes to the east of its normal location. In 1965 when there happened a severe drought in North China and a flood in the Huaihe River Valley the intensity of the subtropical high was fairly weak, but as its location was moved southward and westward, it resulted in the anomalous drought in North China and the Huaihe River Valley.

In the summers of 1954, 1969, 1980 and 1983 when there occurred flood and waterlogging in the wide range of the Changjiang-Huaihe River Valley, the subtropical high in these years extended westward in steadiness, the ridge-line in midsummer was obviously moved southward, and the intensity increased anomalously except in 1954. Table 2 shows the average area index of the subtropical high in the summer of the above drought and flood years, and the longitudinal position of the westward extending ridge points. A comparison of these data suggests that the difference between the drought and flood years are distinctly great.

In a word, when the intensity and location of the Northwest Pacific high and the South Asia high have abnormal changes in summer, the geographical distribution of rainfall, drought and flood in China also present different characteristics accordingly. Therefore, the analysis of the variation tendency of the Northwest Pacific and the South Asia high is a very important aspect in the seasonal forecasting of the summer precipitation.

Subtropical High Index	Area In	ndex	Westward Extending Ridge Point				
Month	June	July	Aug.	June	July	Aug.	
Drought Year Mean	17	12	15	128	136	125	
Flood Year Mean	28	28	23	105	108	116	
Climatological Mean	19	18	19	119	123	122	

Table 2. The Comparison of the Area Indexes of the Summer Subtropical High in Drought and Flood Year

Note: The area index is defined as the number of grid points where the geopotential height is greater than 5870 m between 110° and 180° E on the 500 hPa monthly average map. The westward extending ridge point is measured by the longitude of the western-most point of 5880 isopotential.

4. The Analysis of the Low Frequency Oscillation of the Long-Term Variation of the Subtropical High

The analysis shows that, in the process of the long-term variation of the subtropical anticyclone circulation, and of the intensity in particular, there exist certain quasi-periodicity and stageness. Fig. 5 shows the monthly accumulated curve of the departure of the sub-tropical high area indexes from 1951 to 1985. It is easy to see that such curves have certain low-frequency components. The spectral analysis also shows that the periods of 3

to 4 years and 11 years are significant. Thus, in a certain phase of the oscillation, the variation tendency of the subtropical high intensity is fairly persistent. The analysis also suggests, meanwhile, that the phase changes of such quasi-periodicity and persistency have strikingly seasonal characteristics, usually happening in autumn. Fig. 6 shows the variation of the correlation coefficients of the subtropical high area indexes in adjoining months. These coefficients are high for the most months, where the confidence level reaches or exceeds 0.001. The correlation coefficients decrease sharply only in autumn months, which shows that autumn is the season when the subtropical high changes easily.

The 11-year periodic variation of the subtropical high intensity may be interrelated with the solar activities. We have found that, usually to the next of the extreme years of the solar activity, the intensity of the subtropical high often has a change of reverse phase. Six extreme years of the solar activity since 1951 are indicated in Fig. 5, where the subtropical high intensity has an evident corresponding change for each case except the latest one.



Fig. 5. The monthly accumulated variation of departure of the subtropical high area indexes in 1951---1985.



Fig. 6. The mean correlation coefficients of the subtropical high area indexes in the adjoining months in Jan,—Dec,

5. The Response of the Subtropical High to the El Niño Events

The sea-surface temperature (SST) in equatorial cold water regions in the East Pacific



Fig. 7. The time-lag effect of the intensity variation of the subtropical high during El Niño events. N denotes the number of grid points with a positive departure of SST.



Fig. 8. The time-lag effect of the intensity variation of the subtropical high averaged over five anti-El Niño events. N is of the same meaning as in Fig. 7,

is fairly interrelated with the intensity of the subtropical high in the West Pacific, that is, the lower the SST, the weaker the subtropical high, and vice versa. And what is more, there exists a certain time lag. Especially in the El Niño year, the intensity of the subtropical high changes remarkably from weak to strong, and the change in the SST field in the equatorial cold water regions in the eastern Pacific is eight to nine months earlier than that of the subtropical anticyclone circulation. There are five years in Fig. 5 when the subtropical high changes from weak to strong, the turning dates are in November 1957, November 1965, March 1969, October 1972 and October 1976, respectively. The corresponding variation of SST is illustrated in Fig. 7, where altogether 50 grid points are taken, ranging from 130°W eastward and between 10°N and 10°S, in which the number of grid points of positive departure of the SST shows the variation of the SST in equatorial cold water regions in the East Pacific. It can be seen in Fig. 7 that all the changes of SST are earlier than that of the subtropical high except in 1976 with only a lead of 5 months. There is a lead of 8-9 months in all of the years. On the contrary, the changes of the subtropical high from strong to weak are also of 5 years (i. e. April 1964, November 1966, October 1970, October 1973 and June 1984). Similarly, the SST in the equatorial cold water regions of the East Pacific changes from warm to cold, which is in reverse order to El Niño event (Fig. 8 shows the average situation in these five years), but the phase lead is shorter than that in an El Niño year, usually from one month to six months. Additionally, in the ten turning points of the subtropical high mentioned above, there are seven which occurring in autumn, which is in accordance with the conclusion that it is easier for the subtropical high to change in autumn.

Besides, the SST in the Kuroshio current region of the northern Pacific also has a close correlation with the location variation of the subtropical high of the West Pacific in summer, especially in early summer. And such relationship can be traced to the previous autumn. To be exact, the SST in the Kuroshio current region in September to December of the previous year has a positive correlation with the location variation in a south-north direction of the subtropical high in June. The same is true for the westward extending ridge points of the subtropical high (i. e. the variation in the longitudinal direction), that is, if the SST in the Kuroshio current region is higher in autumn to winter and lower in winter to spring, the subtropical high of the West Pacific in the next early summer is to the north and west of its mean location; otherwise, to the south and east. Besides the Kuroshio current region, the SST of equatorial oceanic current in the East Pacific and westerly drift regions has a fairly significant correlation with the subtropical high of the West Pacific in summer. That is to say, the variation of the SST in the major current regions of the North Pacific has a time-lag effect on the activities of the subtropical high of the West Pacific in summer to a certain extent. These relationships are of very good reference to the seasonal forecasting.

6. The Analysis of the Circulation Systems in Middle and High Latitudes

The analysis of the characteristics of the westerly circulation is an important aspect in the seasonal forecasting. For instance, the different latitudinal location of the South Asia high in summer also has a certin interrelation with the variation of the westerly circulation. It is found, on the basis of correlation analysis, that in July the latitudinal variation of the location of the South Asia high has a positive correlation with the height variation of 100 hPa near Iceland in February to April, and a negative correlation with that of the geopotential height field near Aleutian Islands. Fig. 9 shows the difference value of the departures from the 100 hPa mean height in February to April between the years when the South Asia high in July is to the north of its mean location (the ridge-line \geq 32.5°N) and the years when it is to the south (the ridge-line< 32.5°N). There are three extreme regions in Fig. 9, besides the South Asia high region; the other two regions



Fig. 9. The difference value of the departure from the mean height of 100 hPa in February to April between the years when the South Asia high in July is to the north of its mean location and the year when it is to the south.

are located near Iceland low and Aleutian low, respectively. We consider the difference value of 100 hPa height departure during February to April in Iceland region (indicated by five grid points, i. e., 80°N, 10°W; 70°N, 20° W--0°; 60°N, 10°W) and Aleutian region (indicated also by five grid points, i. e. 70°N, 180°E, 60°N, 170°E-170°W; 50°N, 180°E) as the west and east oscillation indexes. Its correlation coefficient with the ridge location of the South Asia high in July is 0.53, and the associated confidence level reaches 0.01. Moreover, it is found from the analysis of summer precipitation forecasting for the major climatological regions in China that the drought, flood and summer rainfall in the Haihe River of North China has teleconnections with the oscillation in the North Atlantic in January, among which it has a positive correlation with the Iceland low pressure region and a negative correlation with Azores high pressure region, and it is also interrelated with the annual changes in Iceland low pressure areas. We choose the height departure of 500 hPa ranging from 20°-50°W, 50°-70°N in January to denote the intensity variation of Iceland low and draw a correlation scatter diagram (Fig. 10) by the above value and its annual variation with summer season rainfall in the Haihe River Valley. In the practical verification from 1977 to 1985, it shows that such teleconnection is rather steady. There are eight years out of nine true, only one year (1979) false.





The above analysis of the long-term variation of the subtropical high, the low frequency coupling oscillation of the SST and the subtropical high, the South Asia high and the westerly circulation, as well as their interrelation with the summer precipitation, drought and flood in China, is an important reference for the rainfall forecasting for summer seasons. In the routine forecasting, however, both the above analysis and the application of the analysis of various kinds of predictors and methods are required, such as physical elements, the characteristics of circulation, the variation of the climate, etc. For example, by the analysis of the thermal regime on the Xizang Plateau, it is found that the Plateau temperature in February to April has a fairly negative correlation with the longitudinal location of the subtropical high in the West Pacific. Another example: in the analysis of the climatic characteristics in the earlier stage, it is shown that the summer season rainfall in North China is interrelated with the variation of the early winter and spring temperature, which is also in accord with a popular saying of "winter warm, spring cold and summer flooding". The concern of the astronomical elements is also necessary. For instance, it is found from the statistical analysis of the interrelation of Jieqi (nodes of solar terms), which reflects the movement of the moon relative to the earth, with the climate in China, that when "slight heat" and "great heat" appear in June, there are more rainfalls in early flood period in most areas of South China than normal years; when not, there is less. In the seasonal forecasting of the summer rainfall, the forecaster first makes a comprehensive analysis and evaluates the results from every aspects, then gives a tendency forecast for the flood-season rainfall of the large areas in China and the possible disasters of drought and flood.

III. THE FUTURE DEVELOPMENT OF LONG-RANGE WEATHER FORECAST RESEARCH IN CHINA

Over the last decades the meteorologists in China have been insisting on the research and application of long-range weather forecasts. They have made certain progress in the theoretical research, routine forecasting and services, and have also yielded to a certain extent some economical and social beneficial results. However, our research and the operational work are still lag behind the practical requirements, especially when facing the rapid increase of the observational data gathering in the last ten years, which demand our further observational and theoretical research in the long-range forecasting field, and further raise our theoretical research level and operational forecasting ability of the longrange forecasts in China.

In the five years to come, we should strengthen our work in the following aspects:

(1) The theoretical research on the spatial structure of the anomaly of the general circulation, with a view to build a statistical-dynamical model for the long-range weather forecasts.

(2) The research on the physical elements which affect the long-term atmospheric process, and the diagnostical analysis of the thermal and dynamical forcing effects of the high mountain topography and the influence of the non-geophysical elements, in order to enhance the physical foundation of the long-range weather forecasting.

(3) The research on the forecasting method for the anomaly of the general circulation, drought, flood and low temperature in widely ranged areas so as to raise the skill in long-range weather forecasts and improve the beneficial results of the service.

(4) The research on the long-range numerical weather forecasts. Based on the experimental research, a global spectral model with seven vertical layers for the long-range weather forecasts will be developed, thus diminishing the limitation that the long-range forecasts are made only by synoptic and statistical method, and improving the forecast accuracy.

(5) To set up long-range forecasting data bank, in order to serve effectively the observational research and the diagnostic analysis of the global atmosphere, dynamical or statistical model experiments and numerical simulation.