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A study of extreme floods in China for the past 100 years

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Abstract The peak flow and volume characteristics of the extreme floods of China are discussed, together with their seasonal and geographic distribution. Their secular variation is reviewed and a comparison made between extreme floods of the twentieth century and the past 500 years, and with the world extreme flood records. Some characteristics of heavy and large area storms—the causes of extreme floods—are discussed. The conclusions contribute to a better understanding of characteristics of extreme floods of China.

INTRODUCTION

China is a country suffering serious and frequent flood disasters. With the growth of population and rapid economic development, flood disasters are getting more serious: for example, the 1994 flood alone caused US$21 billion of direct economic losses, the 1995 flood—US$20 billion, the 1996 flood—US$26.5 billion, and the 1997 flood—US$25 billion. Meanwhile the floods have caused great losses of life.

China is a vast country of different geographical conditions and different kinds of flood categories, such as snowmelt flood (northwest China), storm flood (east and south China), and mixture flood (the region between west and east China). The major category is that of the storm floods and therefore in this paper we focus on characteristics of storm floods.

The following aspects of the extreme floods will be discussed in this paper: the flood volume and flood peak flow, the seasonal and geographic distribution, the secular variation and the comparison between extreme floods of the twentieth century and the past 500 years, as well as the comparison of extreme floods in China and the rest of the world. Then some characteristics of heavy and large area storms—the cause of extreme floods—are discussed.

For convenience, some special terms will be introduced in the paper: (a) the annual biggest flood event, the biggest flood event in a year; which can form a time series of annual biggest flood events; (b) the extreme flood event, a flood event having a flood peak discharge greater than or equal to that of the mean annual biggest flood events of the river; and (c) the maximum flood event, the biggest flood event of the river in the twentieth century and the past 500 years.

FLOOD VOLUME AND PEAK FLOW OF MAXIMUM FLOOD EVENTS

The characteristics of the flood volume and the flood peak flow of maximum flood events will be discussed in three aspects.

Firstly, the comparison of flood volume of maximum flood events and the normal flood events is given in Table 1. The table shows that the flood volume and the peak flood discharge of maximum flood volume events greatly protrude deviate from their mean annual value, especially in the semiarid region (northwest China) showing the feature of biggest flood events becoming extreme.

Table 1 Comparison of the biggest flood events and mean annual value.

River basins	Stations	Basin area (km^2)	Observed biggest flood events					
			Volume W_m (10^8 m^3)	Peak flow Q_m (m^3 s^{-1})	Duration (day)	Time (year)	W_m/W (%)	Q_m/Q (%)
Songhuajiang	Harlbin	389 769	565	16 200	60	1932	124	358
Liao he	Tieling	120 764	30	14 200	25	1951	73	352
Haihe	Tiajing	263 631	301	9 920	30	1963	132	124
Yellow River	Huayanko	730 036	171	33 000	30	1949	30	421
Huaihe	Bonbu	121 330	397	11 600	30	1954	144	268
Yangtze River	Hankou	1 488 036	6000	76 100	120	1954	80	155
Zujiang River	Wuzhou	329 705	1070	54 500	30	1915	48	172

W: mean annual runoff volume;
Q: mean annual biggest flood peak discharge.

Secondly, the comparison of maximum flood events in China and that of the rest of the world (Fig. 1) is discussed. In the figure one can see that the maximum flood peak discharge of China for the past 100 years is nearly equal to the world records of highest flood peak discharge in any catchment area (WMO, 1986; Hansen *et al.*, 1982) showing that the flood situation in China is as serious as in some regions of the world where the highest flood events occurred.

Thirdly, the comparison of maximum flood events in the twentieth century and that of a historic period (1500–1995) is given in Fig. 2. The figure shows that the discharge

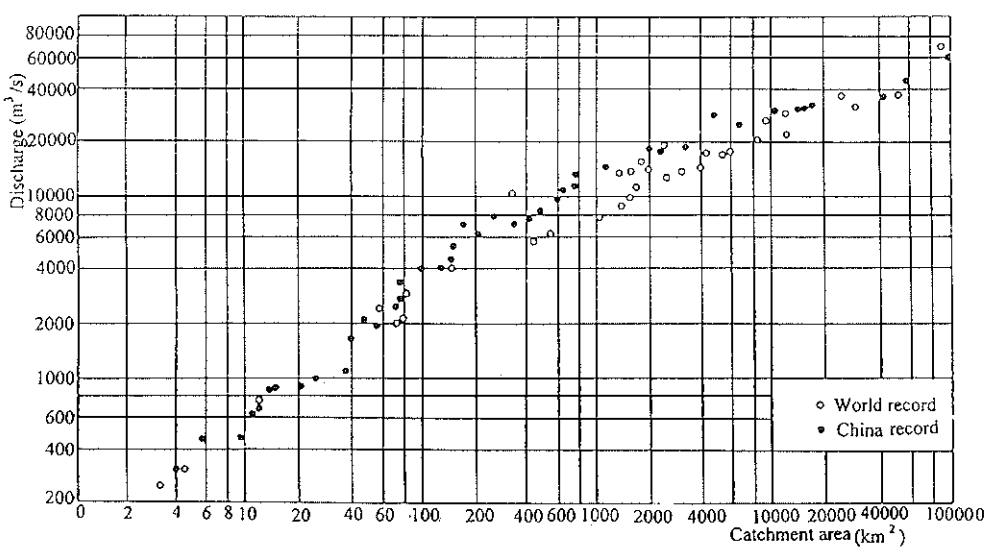

Fig. 1 Comparison of biggest flood peak discharge records in different catchments for the past 100 years of China with world records.

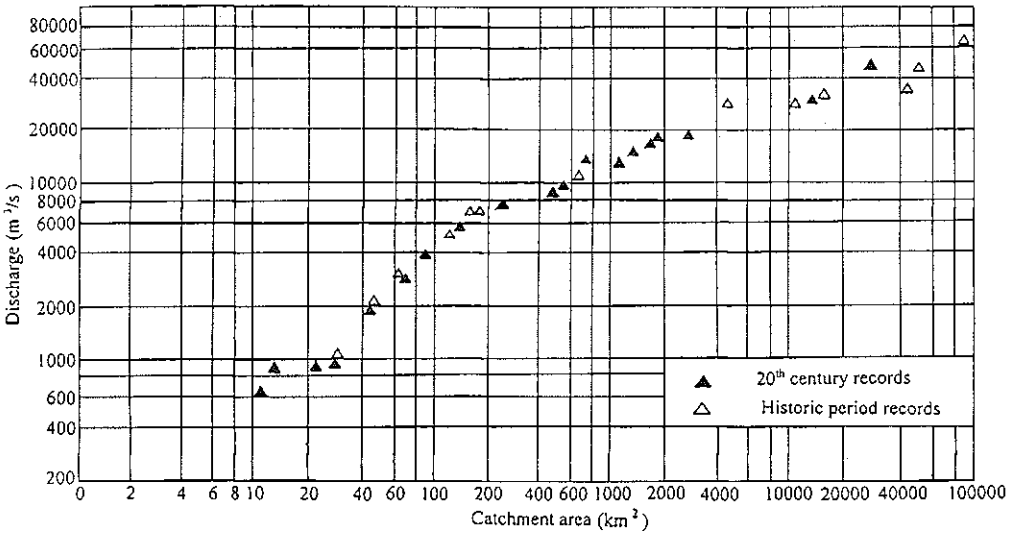

Fig. 2 Comparison of maximum flood peak discharge for the past 100 years of China and that of the historic period (1500–1900).

records of maximum flood events in the twentieth century are nearly equal to the historic records of the past 500 years, which may provide some information for the flood situation in the twenty-first century. Taking into consideration the effects of heavy human activities and climate change on floods, the extreme flood situation may become more serious in the next century.

SEASONAL DISTRIBUTION OF EXTREME FLOODS

Main flood period of rivers in China

China lies in the monsoon region of Asia and has a vast span from 20°N to 50°N of latitude. The river flow regime obviously presents monsoon features of flood period and low flow period. The main flood period first comes to South China in April or May and then advances to north and west China. Table 2 has been compiled by choosing some representative hydrological stations of Chinese rivers and calculating the frequency of extreme flood events occurring in each month in the past 100 years. The Table shows that all the extreme flood events appeared in the main flood period, especially in July and August. Some rivers might have two main flood periods, but most of the extreme flood events occurred during the first one.

GEOGRAPHICAL DISTRIBUTION OF MAXIMUM FLOOD EVENTS

Using the maximum flood peak discharge records observed at more than 2000 hydrological stations with catchment areas of 500–5000 km^2, and expressing them in terms of discharge of a standard catchment area of 1000 km^2, the geographic

Table 2 Frequency of occurrence of extreme flood events in different month.

River	Station	Times of extreme flood	Frequency (%)							
			Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.
Zujiang	Wuzhuo	48	0	2.1	4.2	33.3	33.3	25.0	2.1	0
	Hengshi	27	3.7	3.7	29.6	48.2	11.1	3.7	0	0
	Nanning	45	0	0	0	6.6	35.6	35.6	13.3	8.9
	Yuren	75	4.0	9.3	13.4	40.0	6.7	9.3	16.0	1.3
Yangtze	Yichang	64	0	0	0	1.6	60.9	28.1	9.4	0
	Beipei	77	0	0	5.2	5.2	33.8	18.2	31.1	6.5
	Ankang	104	0	1.9	6.7	8.7	31.7	13.5	26.9	10.6
	Waizhou	33	0	18.2	18.2	39.4	15.2	3.0	6.0	0
Huaihe	Xixian	20	0	0	5.0	25.0	45.0	25.0	0	0
	Zhoukou	33	0	3.0	3.0	9.1	27.3	36.4	15.1	6.1
Yellow	Shanxian	33	0	0	0	27.3	51.5	21.2	0	0
	Heshiguan	18	0	0	5.6	0	33.3	38.9	11.1	11.1
	Xianyang	23	0	0	0	0	30.4	34.8	34.8	0
Hailuanhe	Guantai	14	0	0	0	0	14.3	71.5	7.1	7.1
	Luanxian	13	0	0	0	0	38.5	61.5	0	0
Songhuajia	Harlbin	17	0	0	0	0	5.8	47.1	47.1	0
Heahe	Yinloxia	38	0	0	0	10.5	44.7	36.9	7.9	0
Yilihe	Yamadu	240	0	3.3	12.9	25.0	31.3	26.7	0.8	0

distribution of observed maximum flood discharge of a standard area have been drawn up (Fig. 3) (Luo, 1992). The Figure shows (a) the maximum flood of the monsoon region (east China) is more serious, both in flood volume and in frequency of occurrence, than that of the non-monsoon region (west China); (b) the maximum flood peak discharge in the semiarid region (northwest China) stands out from the normal values of the humid region (east and southeast China); and (c) the region suffering typhoon influence where extreme flood events occur more frequently than other regions of China.

SECULAR VARIATION OF BIGGEST FLOOD EVENTS

Deviation coefficient of biggest flood peak discharge

By using the series of annual biggest flood peak discharge of medium sized basins (5000–10 000 km^2) the distribution map of deviation coefficient Cv for east China has been made (Fig. 4). The figure shows a tendency for the distribution of coefficient Cv to increase from south China to north China. The highest value of Cv (1.0–1.5) appears in north China, showing the drastic variation of the biggest flood peak discharges in this region.

Inter-annual variability of biggest flood peak discharge

Figure 5 presents the time-series of the biggest annual flood events in the past 500 years (Zhang, 1997). The figure shows some characteristics of the inter-annual variation of the biggest flood events as follows:

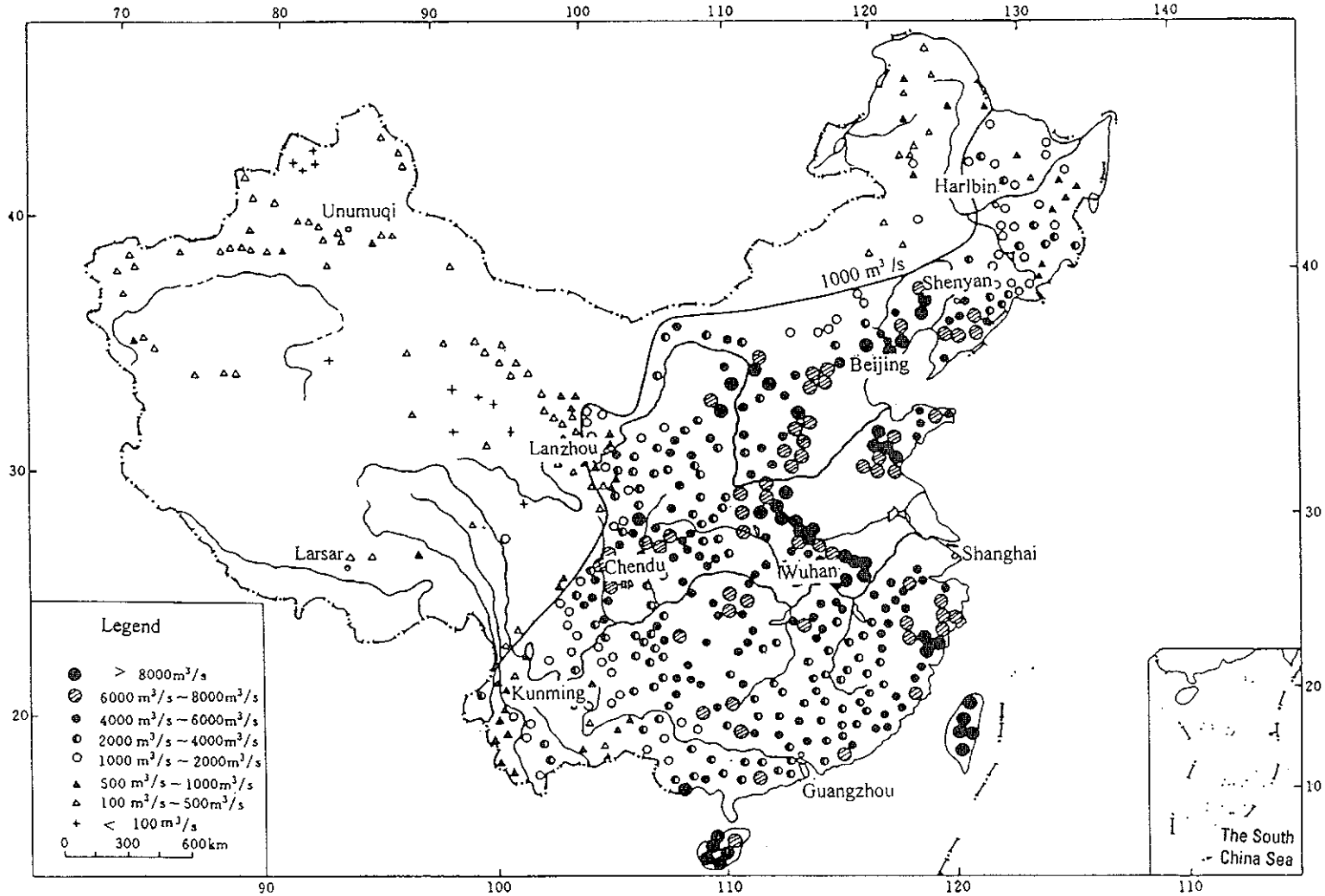

Fig. 3 Geographic distribution of observed maximum flood peak discharge (in terms of a standard catchment area of 1000 km^2).

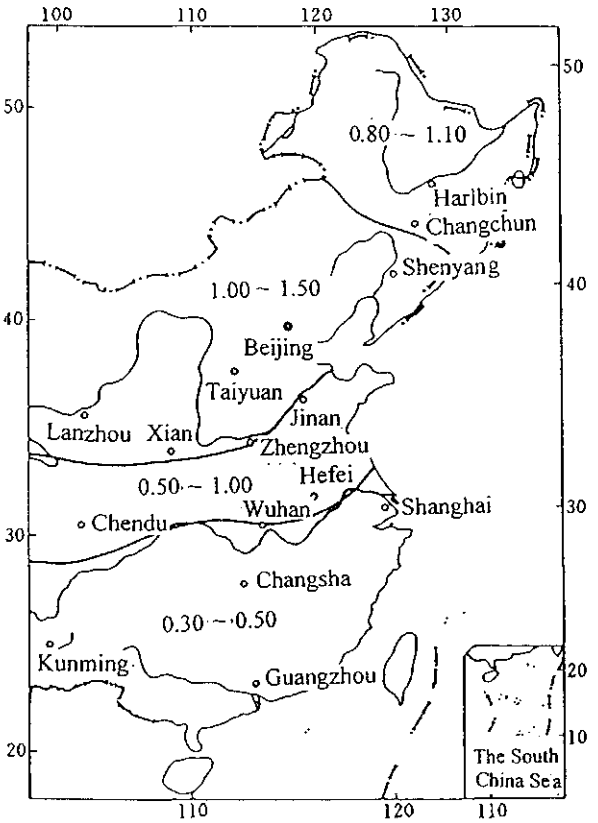

Fig. 4 Regional distribution of deviation coefficient (Cv) of annual biggest flood peak discharge for middle-sized river basins (5000–10 000 km^2) in east China.

(a) There are alternating periods in which floods occur with low frequency (e.g. the sixteenth century) and with high frequency (e.g. seventeenth century). In the eighteenth century the north of China was in a low frequency period and the south was in a high frequency period. In the nineteenth century, north China was in high frequency period and south China was in low frequency period. In the first half of the twentieth century, China was in the high frequency period of extreme flood, during which some serious extreme flood events came one by one, such as in 1931 (Huai River extreme flood), 1933 and 1958 (Yellow River extreme floods), 1935 and 1954 (Yangtze River extreme floods), 1939 and 1963 (Hai River extreme floods), 1957 (SonhuaJiang River extreme flood). Following the first half of the century there was a low frequency period, but since the end of the 1980s a new high frequency period has returned: a lot of extreme flood events occurred one after the other, such as in 1991 (Huai River extreme flood), in 1994 and 1995 (Zujiang River extreme floods), in 1996 and 1998 (Yangtze River extreme floods).

(b) There is a phenomenon that the extreme flood events came one by one forming a group of extreme flood events. For example, the Hai River flood events appeared continually in 1652, 1653, 1654 and 1822, 1823, 1824; the Yangtze River—1848, 1849 and 1931, 1932, 1933; the Zhujiang River—1848, 1849 and 1914, 1915; the

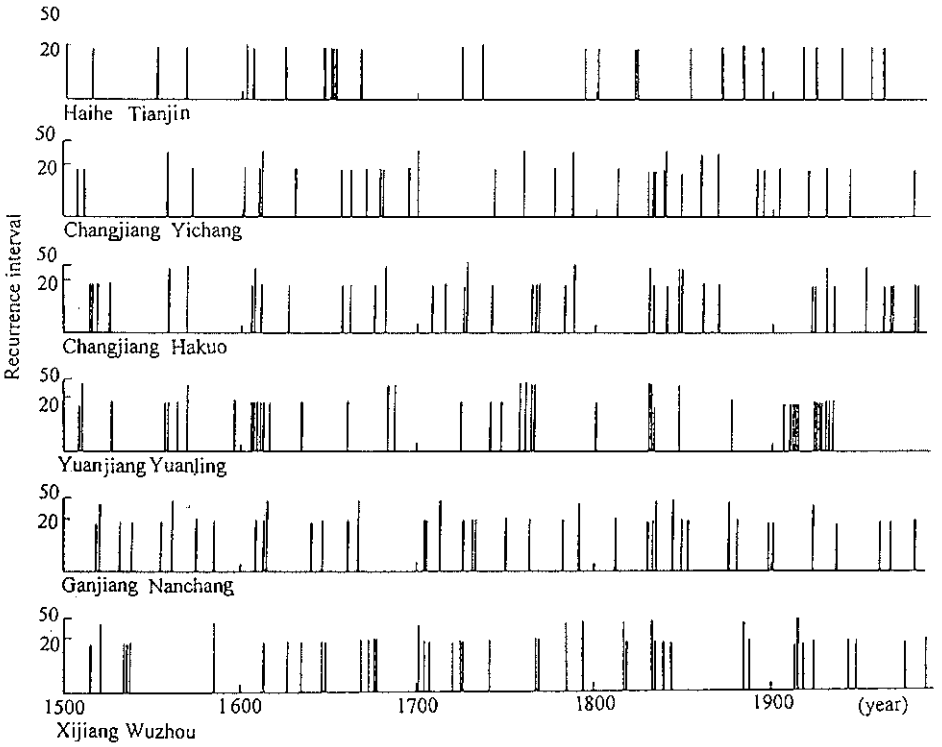

Fig. 5 Time series of extreme flood events of major rivers for the past 500 years. (Note: recurrence interval represents discharge of extreme flood events.)

Songhajiang River—1956, 1957. This kind of phenomenon was especially noticeable in some rivers, such as the Hangjing River (a branch of Yangtze River) where the extreme flood events appeared continually in the years of 1608, 1609; 1611, 1612, 1613; 1911, 1912, 1913; and 1925, 1926, 1927. Thirty percent of the extreme flood events in the Hangjing River over the past 500 years appeared in groups of continual flood events.

(c) Although the occurrences of extreme flood events of different rivers represent high and low frequency periods alternately, extreme flood events appear in different regions of China in most years because of the vast territory. So China has to face flood protection problems year in and year out.

CAUSE OF EXTREME FLOOD—HEAVY STORMS

Monsoon rainfall and its seasonal variation

China lies in the monsoon region of East Asia, the formation and movement of rain-belts in the country are closely related to the moving of the summer monsoon of east Asia. The summer monsoon begins in April or May in south China and then advances to north China. In the process of advance there are three relatively stable stages which form corresponding rain season and rain-belt shown in Fig. 6. In the Figure one can see that the first rain-belt appears along the Zujiang River in April or May which is the

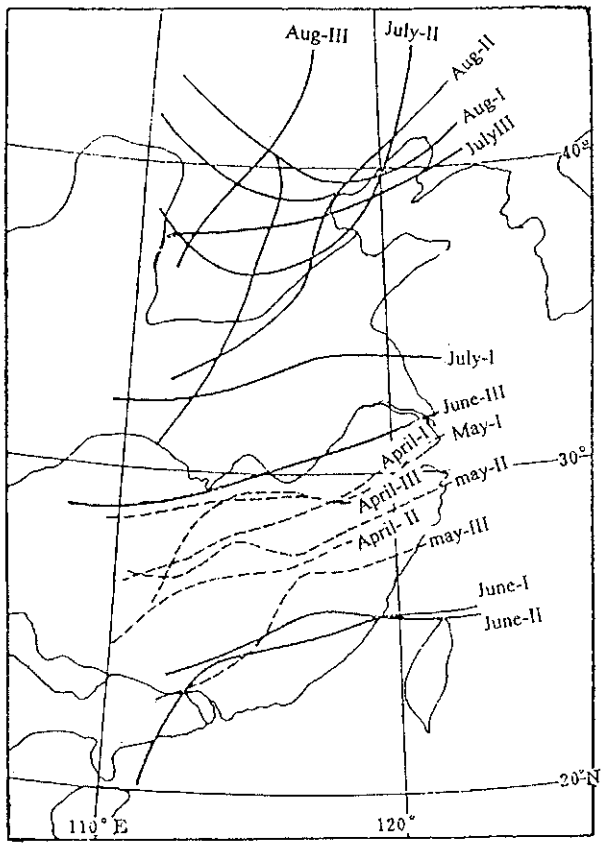

Fig. 6 Movement of monsoon rain belts in a year from south to north China (I: first 10-day period of month; II: the middle 10-day period of month; III: the last 10-day period of month).

major reason for extreme flood events of south China; the second rain-belt lies in the region between the Yangtze River and the Huai River, which is the major reason for extreme flood events of the Huai River and the middle–low reaches of the Yangtze River; the third rain-belt comes in the region of middle and lower reaches of the Yellow River and the Hai River, which is the major reason for extreme flood events of north China. After September the rain season stops and the whole country has a drought season (Liu, 1997).

Intensity and regional distribution of heavy storms

Figure 7 shows the highest point rainfall records for different durations in China. The figure shows that the observed rainfall depth in China is nearly equal to the world records in each duration (Hansen *et al.*, 1982). Figure 8 presents the regional distribution of maximum 24-h point rainfall depth showing that there are four regions where heavy storms occur frequently. The four regions are the storm region of southeast littoral of China, the Taihang mountains storm region in north China, the Dabe mountain storm region in middle and downstream of Yangtze River, and the

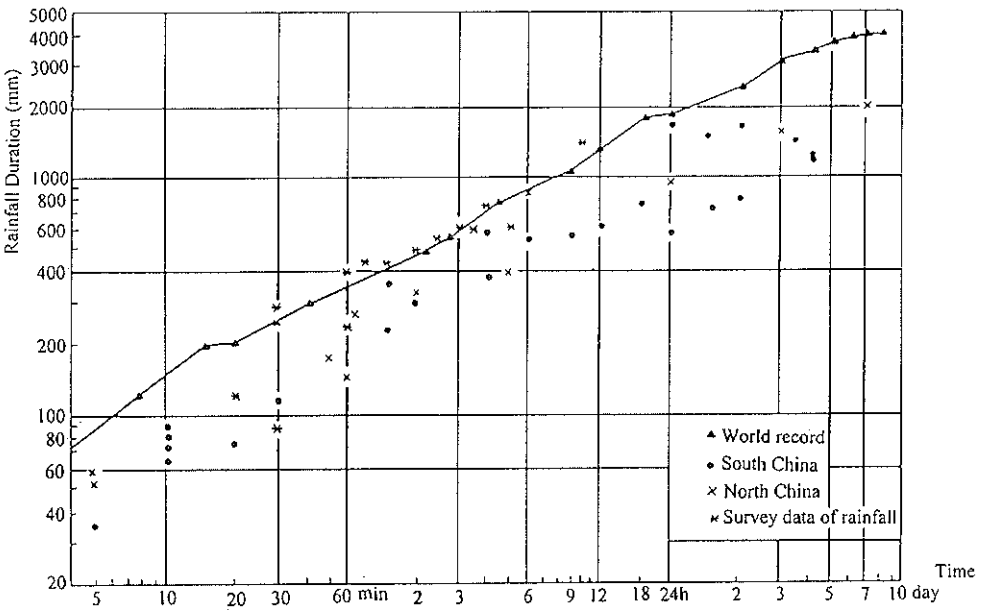

Fig. 7 Comparison of maximum point rainfall of China and that of the world's records.

Qinglin mountain storm region around the north and east of Sicuang basin. Comparing Fig. 8 with Fig. 3, one can see that the geographic distribution of extreme flood strongly reflects the regional distribution of the extreme storms.

CONCLUSIONS

The maximum flood events of China for the past 100 years are nearly equal to those of historical records of the country for the past 500 years and to those of world records, showing the flood situation in China is as serious as that in the historical period and as in some regions of the world where the world maximum flood events occurred.

There are alternate periods in which extreme flood events occur with high or low frequency. Since the end of the 1980s, China has entered a new high-frequency period of extreme flood events. Considering the effects of heavy human activities and climate change on floods, the extreme flood situation may be getting more serious in the first half of the next century.

There are intense seasonal and secular variations of extreme floods, which increase the difficulty of flood protection and flood disaster reduction. On the other hand the extreme flood events appear nearly every year in different regions of China because of the vast territory of the country; therefore China has to face the menace of extreme flood every year.

All of the extreme flood events are formed by summer monsoon rainfall, so the extreme flood situation presents obviously monsoon features either in aspect of seasonal variation or in geographical distribution. The observed rainfall depth in China is nearly equal to the world records in each duration showing that east China is one of the major heavy storm regions of the world.

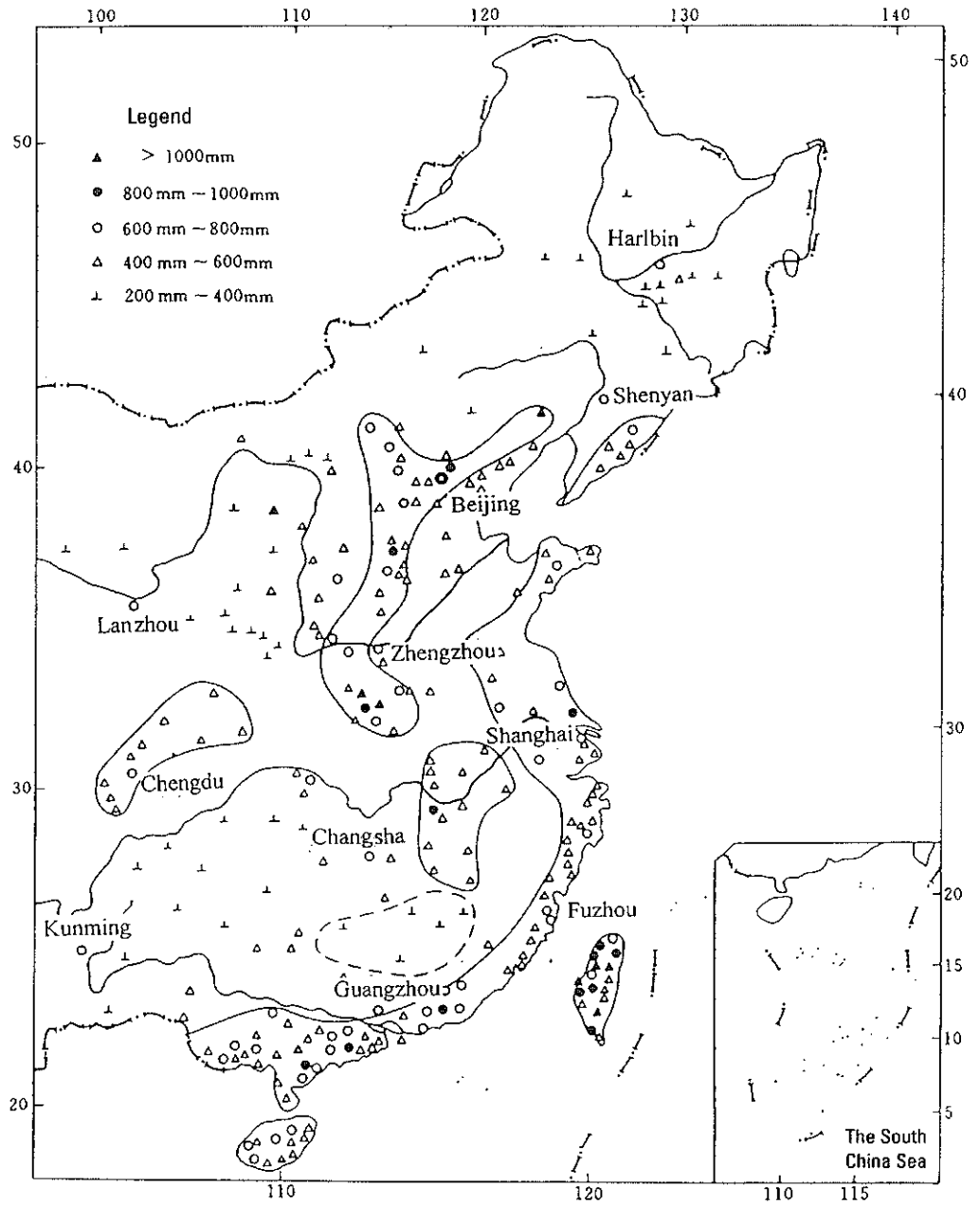

Fig. 8 Regional distribution of maximum 24-h point rainfall depth in east China.

REFERENCES

Hansen, E. M., Screiner, L. C. & Miller, J. F. (1982) Application of probable maximum precipitation estimates. United States of the 105th Meridian. *Hydrometeorological Report no. 52, NWS, NOAA, US Dept of Commerce, Washington, DC.*

Liu Guowei (1997) *Atmosphere Process in Hydrologic Cycle* (in Chinese), 1–19, 171–175. China Sciences Press.

Luo Chenzheng (1992) *Historical Extreme Floods of China* (in Chinese), 3–20. China Book Shop Press.

WMO (1986) *Manual for Estimation of Probable Maximum Precipitation* (second edn), 257–269. WMO no. 332, Geneva, Switzerland.

Zhang Hailun (1997) *Flood and Drought Disasters of China* (in Chinese), 116–139. China Waterpower Press.