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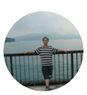

Zhi-jun Dai
East China Normal University

Jinzhou Du
East China Normal University

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Runoff characteristics of the Changjiang River during 2006: Effect of extreme drought and the impounding of the Three Gorges Dam

Zhijun Dai,[1] Jinzhou Du,[1] Jiufa Li,[1] Weihua Li,[1] and Jiyu Chen[1]

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[1] In 2006, the Changjiang basin runoff reached its lowest level in the last 50 years, and the water level in the Three Gorges Dam (TGD) was raised from 135 m to 156 m. Based on routine water level and runoff measurements at 10 field stations, the water level in flood season during the last 50 years was lowest in 2006, a situation here we describe as "no flood in the flood season" (NFFS). In contrast, there was no obvious change in runoff of the mid-lower reaches of the Changjiang river (MLRCR) in the drought season in 2006, which we correspondingly describe as "no drought in the drought season (NDDS)". The extreme drought of Changjiang and impounding of TGD contributed to NFFS. However, the adjustment of TGD and the replenishment from tributaries and lakes resulted in NDDS. Meanwhile, 54% of the water flux was lost at Datong during September 20 to October 27, 2006, in comparison with the same period in 2005. It can be estimated that the impounding of TGD and the extreme drought in 2006 contributed 9% and 45% of this loss, respectively. **Citation:** Dai, Z., J. Du, J. Li, W. Li, and J. Chen (2008), Runoff characteristics of the Changjiang River during 2006: Effect of extreme drought and the impounding of the Three Gorges Dam, *Geophys. Res. Lett.*, *35*, L07406, doi:10.1029/2008GL033456.

1. Introduction

[2] The study of changes in water flow of a river basin especially in drought years is of great importance for water resource management, water pumping, hydropower installations and intrusion of salt water [*Chen and Chen*, 2000; *Zhang and Chen*, 2003; *Chen et al.*, 2004; *Laaha and Blöschl*, 2005]. In recent years, there is an increasing trend in the frequency of extreme events, i.e. low runoff in drought years, floods during intense rainfall, and the warmed climate due to global warming effects [*Intergovernmental Panel on Climate Change*, 2001; *Jiang and Shi*, 2003; *Romanovicz*, 2007]. However, most researchers have focused on the flooding processes, occurrence mechanics and flood frequency in the river basin, along with regulation by dams and irrigation [*McClelland et al.*, 2004; *Berezovskaya et al.*, 2004; *Onuchin et al.*, 2006]. Only a few studies have been conducted so far on the subject of riverine responses to the extreme drought events in drought years [*Chen et al.*, 2001], especially to combined extreme drought event and underway impounding of the Three Gorges Dam (TGD).

[3] The Changjiang River is the longest river in China and receives a large volume of runoff. However, the Changjiang River is still one of the world's top ten rivers in terms of water shortage, resulting from intensive human activities in the river basin (C. M. Wong et al., World's top 10 rivers at risk, 2007, World Wildlife Fund International, Gland, Switzerland, available at http://assets.panda.org/downloads/worldstop10riversatriskfinalmarch13.pdf). In 2006, natural and human events, which include extreme high temperatures, low annual rainfall, the worst drought of the Changjiang River in the last 50 years, and the impounding of TGD from 135 m to 156 m, all occurred simultaneously. Therefore, by comparison with normal years, problems associated with the water resource shortage and advanced intrusion of the estuarine salt water became more obvious in 2006 [*Jia*, 2006]. If water shortage in the Changjiang reaches a crisis point, it could seriously influence development of the economics and industry of the Changjiang basin, especially the MLRCR basin since the Changjiang basin is the axis of the economic development in China. Thus, the purpose of this study was focused on the changes in the runoff of MLRCR during 2006 and discussion of the reasons for changes in discharge. The study of the extreme drought event in the river basin will be helpful in improving the management of the Changjiang water resource and the allotment policy of the water resource among the Changjiang and the other tributaries and lakes.

2. Sampling Stations and Methods

[4] Water level data were collected from the gauging stations, as shown in Figure 1. The discharge of Yichang and Datong can represent the total discharge of the upper and lower reaches of the Changjiang River, respectively. The discharges of Chenglingji and Hukou represent the runoff from Dongting and Poyang lakes into the Changjiang River. Statistical analysis of the different water levels and discharges in flood (May–Oct.) and dry seasons in 2006 relative to normal years was applied to the study of the characteristics of runoff in MLRCR and its relation with tributaries, lakes and the impounding of TGD. In addition, the discharge hydrological parameters of standard deviation (σ) and coefficient of variation (C_V) were calculated by the Moment method [*Greenwood et al.*, 1979]. The routine runoff and water levels of field gauge stations were obtained from reports of the Hydrological Committee of the Changjiang (Figure 1).

3. Results

3.1. The Characteristics of the Water Level

[5] In 2006, the worst drought in the last 50 years coincided with an increase of the TGD water level from

[1]State Key Lab of Estuarine and Coastal Research, East China Normal University, Shanghai, China.

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Figure 1. Hydrological stations.

135 to 156 m. Plots of the water level (m) of field gauge stations versus calendar years during 2000∼2006 are shown in Figure 2.

[6] It is seen in Figure 2 that changes in the water levels during 2000∼2005 were strongly seasonal. However, in comparison with other years, variations in the water levels were weaker in 2006 so that the difference between the maximum and minimum was smaller than that of normal years. Moreover, the lowest water level of the flood season in history was observed in this year at each hydrological station along MLRCR (Table 1).

3.2. The Characteristics of the Runoff

[7] Monthly runoff and mean water level at each hydrological station along MLRCR were calculated by averaging the daily flow and water levels of each month during the years 2000 to 2005 (Figure 2). It can be seen in Figure 2 that the flow of MLRCR was controlled by season, and followed a similar pattern of the changes in the water level. In addition, the flow peaked in July or August and reached a minimum in February, consistent with previous studies [*Chen et al.*, 2001; *Yang et al.*, 2005].

[8] However, runoff during 2006 at the Datong hydrological station shows a smoothness of seasonality compared to normal years (Figure 2). It can be seen in Table 2 that the discharge ratio of the flood season to the dry season R_a and that of the maximum to the minimum R_b during 1950∼2005, as well as the runoff at Yichang, Hankou and Datong stations are all much more than those in 2006. Moreover, both values of standard deviation (σ) and variation coefficient (C_V) obtained by the Moment method [*Greenwood et al.*, 1979] show that the degree of deviation from the mean discharge is rather small in 2006 compared to those during 1950∼2005, further indicating the discharge smoothness of seasonality compared to normal. So, the obvious characteristics of MLRCR in 2006 is entitled here “no flood in the flood season, no drought in the dry season” (NFFS-NDDS).

[9] In addition to 2006, the Changjiang River also experienced extreme drought in 1978. The great reduction in discharge brought about a prolonged saltwater intrusion into the estuary, surrounding the Chongming Island for 5 months. All Shanghai’s waterworks along the Huangpu River were strongly influenced by the saltwater [*Chen*, 1998; *Chen et al.*, 2001]. However, the monthly flow data in seasonal variation and the statistic parameters for 1978 (Table 2) show a similar trend as those in years with normal flow (Figure 2), indicating that there was no NFFS-NDDS in 1978. Therefore, runoff of MLRCR in 2006 showed a notable difference from both normal years and the extreme drought year.

3.2.1. Runoff During the Flood Season

[10] If the monthly discharge from May to October can be considered to represent runoff in the flood season, it can be concluded from Figure 2 that the discharge curve for the 2006 flood season along MLRCR from Yichang, Luoshan and Hankou to Datong was modulated in comparison with those in normal years. The peaks of discharge from May to October were also much lower than those in the normal years (Figure 2). The discharge in the 2006 flood season at Yichang hydrological station was only 50–60% of that of the historical average for that period, and that at Datong was below 80% (Table 3). For MLRCR, the 2006 flood season discharge was almost equal to that in the dry season in normal years (Figure 2).

3.2.2. Runoff During the Dry Season

[11] As expected, curves showing change in MLRCR discharge between the flood and dry seasons are steeply sloping in all studied years except for 2006 (Figure 2). In most cases, the decreased value of the discharge in 2006 in the Yichang, Hankou and Datong fell below 2000 $m^3 \cdot s^{-1}$ (15%) compared with that in normal years (Table 3).

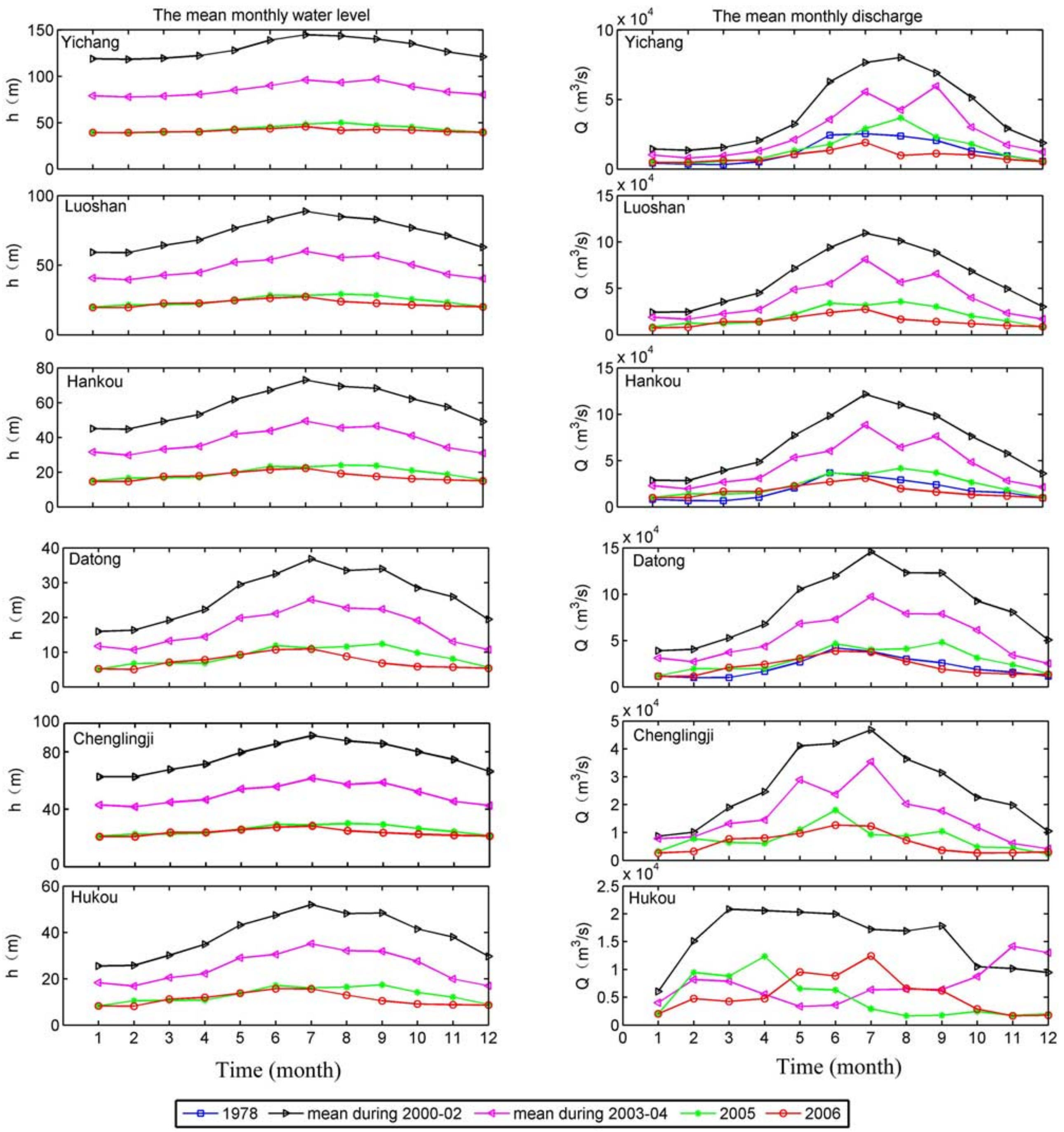

Figure 2. Variations in water level and flow of the each hydrological station of the mid-lower reaches along the Changjiang River.

Moreover, although extreme drought occurred in 2006, the discharge in November and/or December is slightly higher than that in same months of normal years. Although the drought in 2006 was more intense than that in 1978, it is noted that the runoff of the dry season in 2006 is higher than that in 1978 (Table 3). Thus, ‘‘no drought – dry season’’

Table 1. Observed Minimum Water Levels (H_{min}) of the 2006 Flood Season and Their Ranks in the Minimum Values Series of the Same Seasons in the Years 1950 to 2006

Station	Yichang	Zhicheng	Shashi	Jianli	Luoshan	Hankou	Datong
H_{min}, m	40.46	38.64	33.03	26.79	22.01	17.07	6.58
Date of the observed H_{min}	Agu.21	Agu.22	Agu.22	Agu.23	Agu.23	Agu.25	Agu. 30
Order series last 1950∼2006	1st	1st	1st	1st	1st	2nd	1st

Table 2. Statistical Parameters of the Monthly Discharges of 1950-2005, 1978 and 2006[a]

	Yichang				Hankou				Datong			
	R_a	R_b	σ	C_V	R_a	R_b	σ	C_V	R_a	R_b	σ	C_V
1978	8.2	3.8	8428	0.7	5.7	2.9	10252	0.6	4.3	2.4	10610	0.5
1950–2005	7.7	3.7	9604	0.7	5.1	2.6	12015	0.5	4.5	2.4	13571	0.5
2006	4.1	2.2	4095	0.5	3.0	1.7	6646	0.4	3.4	1.7	9300	0.4

[a]R_a, the discharge ratio of the flood season to the dry season; R_b, the discharge ratio of the maximum to the minimum; σ, the discharge hydrological parameters of standard deviation; C_V, coefficient of variation.

(NDDS) is one of the notable properties of the 2006 MLRCR runoff pattern.

4. Discussion

[12] As mentioned above, the properties of MLRCR in 2006 are NFFS-NDDS. Next, we discuss the dominant factors for the extreme hydrological regime of NFFS-NDDS in the Changjiang River.

4.1. Factors Impacting on NFFS

[13] Table 4 shows that in flood seasons of normal years, the annual runoff at Yichang station can contribute about 50% of that at the Datong station. This means that the other half of the runoff in the lower reaches originated from the upper reaches of the Changjiang River. Thus, the runoff of Datong can be partially controlled by the changes of the runoff of Yichang, which represents the runoff of the upper reaches of the Changjiang River. However, because most of the areas in the upper reaches of the Changjiang River had suffered drought in the summer of 2006, the water level of Yichang was the lowest record in flood seasons in history (Table 1). The mean runoff in the flood season in 2006 was around 65% of the mean runoff in flood seasons from 2000 to 2005. Therefore, the sharp decrease of the runoff from the upper reaches (Yichang) of the Changjiang River is one of the direct factors contributing to NFFS during 2006 in MLRCR. The second factor was the decrease of rainfall of the flood season in 2006 along MLRCR to around 30% below average of normal [*Changjiang Water Resource Commission*, 2007]. Finally, considering that there was only a slight period (September 20 to October 27 of 2006) of impounding of TGD in flood season and withdraw water of MLRCR occurred at downward of Datong [*Zhang and Chen*, 2003], the impounding of TGD from September 20 to October 27 of 2006 was the third factor leading to NFFS since the discharge of 1.05×10^{10} m^3 was retained in TGD. Therefore, the NFFS is mainly controlled by decrease of rainfall of both upper reaches and MLRCR.

4.2. Factors Impacting on NDDS

[14] The replenishment of runoff from the lakes and tributaries is an important part of the MLRCR water budget. For example, in the 2006 dry season, the Dongting lake, Hanjiang river and Poyang lake contributed around 28%, 6.0% and 29% respectively to the runoff of the Changjiang River. In addition, the discharge into the Dongting lake via three distributaries of the Changjiang River in 2006 accounted for only 9% of the discharge of the Chenglingji station. Obviously, these values are slightly higher than those in normal years (Table 4), indicating that replenishment from lakes and tributaries in 2006 was higher than normal.

[15] In normal years, the minimum discharge at Datong is usually smaller than 1.0×10^4 m^3·s^{-1}, which is considered to be a controlling water flux into the ocean. However, this value in 2006 was greater than 1.1×10^4 m^3·s^{-1}. This relatively high discharge in the 2006 dry season may reflect the adjustment of TGD or other factors such as replenishment from underground water along the banks and lakes of MLRCR.

4.3. Estimating the Contributions of TGD and Drought

[16] River water fluxes are influenced by both climatic change and anthropogenic actions [*Milliman*, 1997; *Ye et al.*, 2003; *Onuchin et al.*, 2006; *Xu et al.*, 2008]. Because of the operation of TGD, sediment input into MLRCR has been greatly decreased, which has had significant effects on the environment [*Yang et al.*, 2006, 2007]. Moreover, the impounding of TGD can influence the water discharge distribution of MLRCR. In the impounding of TGD from September 22 to October 27 in 2006, the total impounded water in the Three Gorges Reservoir was around 1.05×10^{10} m^3 while the total river discharge at Datong was 5.21×10^{10} m^3. In the same period of 2005 (September 20–October 27),

Table 3. Percentages of Discharge in 2006 in Comparison With Those in Normal Years

Normal Year	Flood Season, %			Dry season, %			Annual, %		
	Yichang	Hankou	Datong	Yichang	Hankou	Datong	Yichang	Hankou	Datong
1978	63	80	92	110	132	27	73	94	103
2000	53	65	73	88	90	80	61	72	75
2001	61	76	81	91	95	89	68	82	84
2002	65	61	62	95	96	91	72	70	70
2003	59	64	70	105	93	84	69	72	74
2004	62	69	78	91	108	114	69	79	88
2005	54	65	71	92	90	89	62	72	76

Table 4. Percentages of Runoff in Each Station in Comparison With Those Assumed to Reach the Sea as Estimated at Datong Station

	Runoff in the Flood Season, %				Runoff in the Dry Season, %				Annual Runoff, %			
Year	Yichang	Chenglingji	Shayang[a]	Hukou	Yichang	Chenglingji	Shayang[a]	Hukou	Yichang	Chenglingji	Shayang[a]	Hukou
1978	58				41				70			
2000	60	29	6	5	32	27	4	37	51	28	5	16
2001	58	29	3	16	35	28	6	29	50	28	4	20
2002	42	35	3	18	34	29	4	19	40	33	3	18
2003	52	29	7	12	28	29	4	25	44	29	6	16
2004	55	31	4	8	44	24	8	32	52	29	5	14
2005	58	26	8	7	34	28	7	40	51	27	8	17
2006	44	29	5	23	35	28	6	29	41	29	5	25

[a]The runoff at Shayang station is supposed to be from the Hanjiang River into the Changjiang River.

the total river discharge at Datong was 1.12×10^{11} m^3. So, the river discharge at Datong in 2006 is only 46% of that in 2005, indicative of a decrease (or loss) of 54%. This loss should result from the impounding of TGD and the extreme drought in 2006, which contribute 9% and 45%, respectively. Because TGD impounded water is only about 2–10% of annual water discharge of the Changjiang River [*Xu et al.*, 2008], TGD (9% impounding) played a much smaller role than drought (45%) in NFFD. These calculations are the first quantitative estimates of the effects of the impounding of TGD and the drought during September 20–October 27 and allow to separate climate effects (drought) from anthropogenic action (TGD) on the river discharge into the sea.

5. Conclusions

[17] The Changjiang river basin experienced extreme drought in 2006. Based on the water level and discharge during a historical drought year and a normal year, we conclude that the water discharge in 2006 has following characteristics:

[18] (1) Variations in the runoff in the mid-lower reaches of the Changjiang River in 2006 can be described as "no flood in the flood season, no low flow in the dry season". The river discharge in the flood season is 20∼30% less than that in a normal year, but in the dry season the discharge remains the same.

[19] (2) The characteristic "no flood in the flood season" in the mid-lower reaches of the Changjiang River is a result of the decreased river discharge at Yichang station, and impounding of TGD. However, the characteristic "no low runoff in the dry season" is a result of the water supply from TGD, lake and tributaries in the mid-lower reaches of the Changjiang River.

[20] (3) In 2006 the river discharge at Datong from September 20–October 27 was 54% lower than that at the same period in 2005. It is reasoned that this loss is contributed by the impounding of TGD (9%) and the extreme drought (45%) in 2006. These numbers are the first quantitative estimates of the effects of the impounding of TGD and the drought during September 20–October 27.

[21] (4) In 2006 there was an extensive decrease in the water level along the mid-lower reaches of the Changjiang River, and reached the lowest record in the history.

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J. Chen, Z. Dai, J. Du, J. Li, and W. Li, State Key Lab of Estuarine and Coastal Research, East China Normal University, Shanghai, 200062, China. (jzdu@sklec.ecnu.edu.cn)