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Abrupt change of the mid-summer climate in central east China by the influence of atmospheric pollution

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Abstract

Following the great flooding of summer 1998, the mid-lower Yangtze Basin further suffered from another large flooding in summer 1999. Successive droughts through 3 recent summers (1997–1999) appeared in north China in addition, leading to an abnormal summer climate pattern of "north drought with south flooding". Such southward move of the summer monsoon rainy belt in east China started in the late 1970s–early 1980s. Its main cause may not be a purely natural climate change, but the acceleration of industrialization in east China could play a major role by emitting large volumes of SO_2, especially from the rapidly growing rural factories of east China. The annual release of SO_2 in China exceeded 20 Tg during 1992–1998, so dense sulfate aerosols covered the central east China which significantly reduced the sunlight. Although present estimates for the changes of clear sky global solar radiation may include some error, they show that the negative radiative forcing of sulfate aerosols in central east China by far exceeds the effect of greenhouse warming in summer. Hence the mid-summer monsoon rainy belt of east China has a trend moving southward in 21 recent years (1979–1999), showing the very sensitive characteristic of the summer monsoon system to the change in heat equilibrium of the land surface. The occurrence rate of summer climate pattern of "north drought with south flooding" in east China during 21 recent years is the largest since AD 950; such anomalous climate has brought large losses to China. The only possible way to reverse this southward trend of summer monsoon rainy belt is to significantly reduce air pollution by using more clean energy. Recently, the PRC has paid serious attention to this problem by adopting a series of countermeasures.

Keywords: Summer monsoon rainy belt; Southward retreat; Increasing amount of sulfate aerosol; Enterprises outside cities; Negative radiative forcing

1. Introduction

Abrupt change of summer climate has been occurring in east China since the early 1980s with a southward retreat of summer monsoon rainy belt (SMRB). This phenomenon was more significant during the 1990s; most of the summers were droughty in north China, while the mid-lower Yangtze Basin has suffered from more summer flooding, resulting in a series of abnormal summer climate patterns of "north drought with south flooding". This trend has developed to a climax during 1997–1999: north China encountered 3 yr of persistent droughts with the successive flooding of 1998 and 1999 in the mid-lower Yangtze Basin. These brought large losses to the lives of people lives and the economic development of China.

The climate of China has worsened during 40 recent years, the disaster crop area has expanded from 16.7% in the 1950s to 33.0% in the 1990s, which means $\frac{1}{3}$ of crop area in China was struck in recent years (Hu, 1998). The present author has researched the causes of the summer abnormal climate of China for many years. He believes that the main cause of the worsening of the summer climate in China might not be a purely natural climate change, but the acceleration of industrialization in east China could play a crucial role by emitting large

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volumes of SO_2. The annual release of SO_2 in China had surpassed 20 Tg in the period 1992–1998, hence dense sulfate aerosols covered the central east China thereby significantly reducing the sunlight. Accordingly, the mid-summer west Pacific high and its northern SMRB of east China have a trend of moving southward during 21 recent years, and a series of abnormal summer climate was formed. Analyzing the summer climate change, atmospheric pollution and clear sky solar radiation data of China, the present paper may have found the main cause for the abnormally frequent occurrences of the summer climate pattern characterized as "North drought with South flooding" in east China. It shows that increasing levels of sulfate aerosols may have played a dominant role in summer climate of east China, especially during mid-summer.

2. Atmospheric pollution in China and its effect on summer climate

China is a country mainly using coal, 80% of its energy comes from coal combustion. China has achieved great progress in economic development during the recent 20 years, but one of the costs—the atmospheric pollution by coal burning—is severe. The amounts of both Chinese coal production and sulfur emission have shown the largest increase in the world over the past 20 years (Lefohn, 1999); according to Fig. 6 of Sun et al. (1997), the coal production of China in 1990 was about 5 times larger than that of 1960. Acid rain first appeared in China in the late 1970s; now more than 30% of the territory has suffered from its damaging effect, even some cities of north China located in the region of alkaline soil are also affected (Zhang, 1999). Coal burning not only releases greenhouse gases, but also emits large volumes of smoke containing SO_2. After transformation into sulfate aerosol in air, it will significantly backscatter and scatter incoming radiation, hence the amount of heating in summer will be significantly reduced. More than 10 years ago, Xu (1987, 1989a) had pointed out that the summer west Pacific high with its northern SMRB in east China and the ITCZ of west Africa both have a southward retreating trend, and they may all be caused by the decrease of clear sky direct solar radiation of the Northern Hemisphere. Xu (1989b) further indicated a lowering trend of mid-summer temperatures in the Yangtze-Huaihe Basins, which is also the location of a positive correlation between mid-summer temperature and the clear sky direct solar radiation of east China; hence it manifests the possible cause of climate change: the mid-summer west Pacific high with its northern SMRB has a trend moving southward. This is probably due to the decrease of clear sky direct solar radiation. As a consequence, the mid-summer temperature of the Yangtze-Huaihe Basins then tends to decrease owing to more rain in the mid-lower Yangtze Basin (the SMRB retreated here) and more overcast days in Huaihe Basin. In addition, Xu (1988) found that the summer temperature of central China is very sensitive to the concentration of aerosols.

It is evident from Fig. 1 that the clear sky direct solar radiation (*S*) and clear sky global solar radiation (*Q*) of all 9 stations in China have a significant lowering trend. The mid-summer (July–August (JA)) pentad number (*Kn*) of the northward west Pacific high at 500 hPa (with its ridge line's latitude in section of 110–130°E > 26°N) also shows a downward trend since 1979. Similarly the SMRB located on the north side of west Pacific high also retreated southward in the year of lesser *Kn*. As a consequence, north China suffered from less rain during these summers (Fig. 1).

The average *Kn* was 8.2 pentads during the period of 1958–1978, but it reduced to 5.3 pentads in the next 21 years (1979–1999). This also means that the residing time of SMRB (located on the north side of *Kn*) in north China has been shortened by 35.4%. Especially, in the year 1980, 1987 and 1993, the *Kn* decreased to 2 pentads, it even reduced to 1 pentad in 1999. Such phenomena have never been observed before the 1980s. In such mid-summers with abnormally low *Kn*, the west Pacific high and its northern SMRB had less time to move north during this main rainy season of north China. As a consequence, large-scale droughts occurred in north China (including the mid-lower Yellow River Basin) with summer flooding frequently appearing in the mid-lower Yangtze Basin.

The mid-summer trend distribution (Fig. 2) of rainfall and temperature for 40 recent years (1960–1999) clearly shows the above characteristic. When the mid-summer *Kn* significantly reduced from the 1960s to the 1990s (Fig. 1), the SMRB in mid-summer moved southward as shown in Fig. 2a: the central line of increasing rainfall was situated in the mid-lower Yangtze Basin (28–31.5°N, east of 113°E). Large areas of central east China (32.5–41°N, east of 110°E) including north China and the Huaihe Basin have a droughty trend, the central region of lesser rain is located in the lower Yellow River Basin, especially in the Shandong Peninsula. The mid-summer temperature trend distribution (Fig. 2b) corresponds well with the rainfall trend (Fig. 2a), the cooling region (−0.3°C to −0.4°C/10 yr) is mainly situated in the region with increasing rainfall. The region with rising temperature occurred mainly in the droughty area, north of 34°N.

The above-mentioned mid-summer trend developed to a climax in 1999: following the great flooding of 1998 in the mid-lower Yangtze Basin this region further encountered severe summer flooding in 1999, and large-scale drought prevailed over most areas north of 32°N. The average temperature of the mid-lower Yangtze

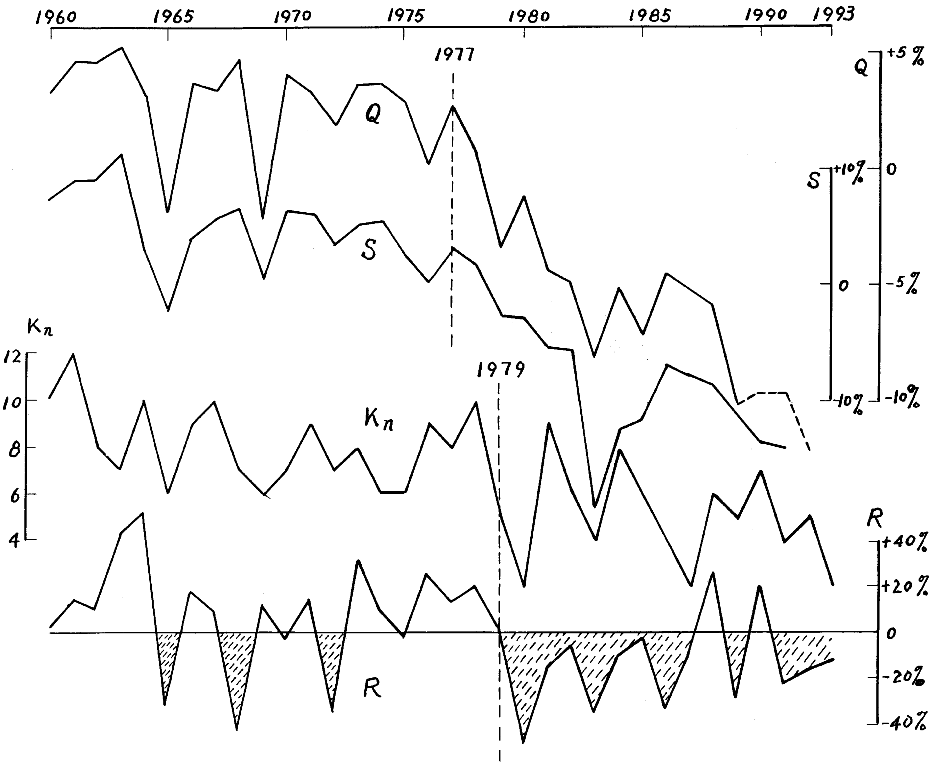

Fig. 1. Time series of radiative properties: Clear sky global solar radiation (Q) and clear sky direct solar radiation (S) of 9 stations in China for 33 recent winters, respectively; Pentad number (Kn) of the northward west Pacific high at 500 hPa level with its ridge line's latitude in section of 110–130°E⩾26°N in JA; R: the average rainfall (R) anomaly percent of north China (36–41°N, east of 110°E) during JA.

Basin during JA was lower than normal by about 2°C; actually, this was a year without mid-summer in this region.

To eliminate the effect of such extreme abnormality, a comparison was made between the average rainfall and average temperature in the following 2 periods: (1) the 20 recent years (1979–1998) with acceleration of industrialization and (2) 28 former years (1951–1978).

The large analogue between Figs. 3a and 2a suggests that the mid-summer SMRB of east China has moved southward to the mid-lower Yangtze Basin during the period of accelerating industrialization since 1979. Normally, the monsoon rainy belt resides in north China (north of 36°N) during mid-summer (JA), this is the main rainy season of the above region with the SMRB reaching its northernmost position of a year. The region of lower temperature in Fig. 3b is basically approaching the one of Fig. 2b, but the significantly negative center on the south side of the mid-lower Yangtze River has been weakened in Fig. 3b. This may be relevant to the fact that the extremely abnormal mid-summer of 1999 had not been included in the data of Fig. 3b. However, the significant southward trend of SMRB and its lower temperature region of east China during the period of accelerated industrialization of the 20 recent years (1979–1998) is still clearly shown in Figs. 3a and b (relative to the 28 former years).

3. Significant effect of SO_2 release in enterprises outside cities

The 5 year running average latitude (curves 2 and 3 in Fig. 4) of the central axis of SMRB in east China (east of 110°E) clearly shows a trend of moving southward since the late 1970s. This was more significant in mid-summer (JA), see curve 3 of Fig. 4. This corresponds well with the downward trend of the winter clear sky global solar radiation of 9 stations in China (curve 1 in Fig. 4) due to the sharp increase in the use of coal (Xu, 1997).

The annual emission data of SO_2 in China were taken from "The Bulletin of the Environmental State in China" since 1989 (National Environment Protection Bureau, 1989–1999), earlier data were taken from Zhu (1987) and Qu (1989), respectively. The above data are the amounts of annually emitted SO_2 from larger cities (at or above county level). The atmospheric pollution from the enterprises outside cities (in villages and towns)

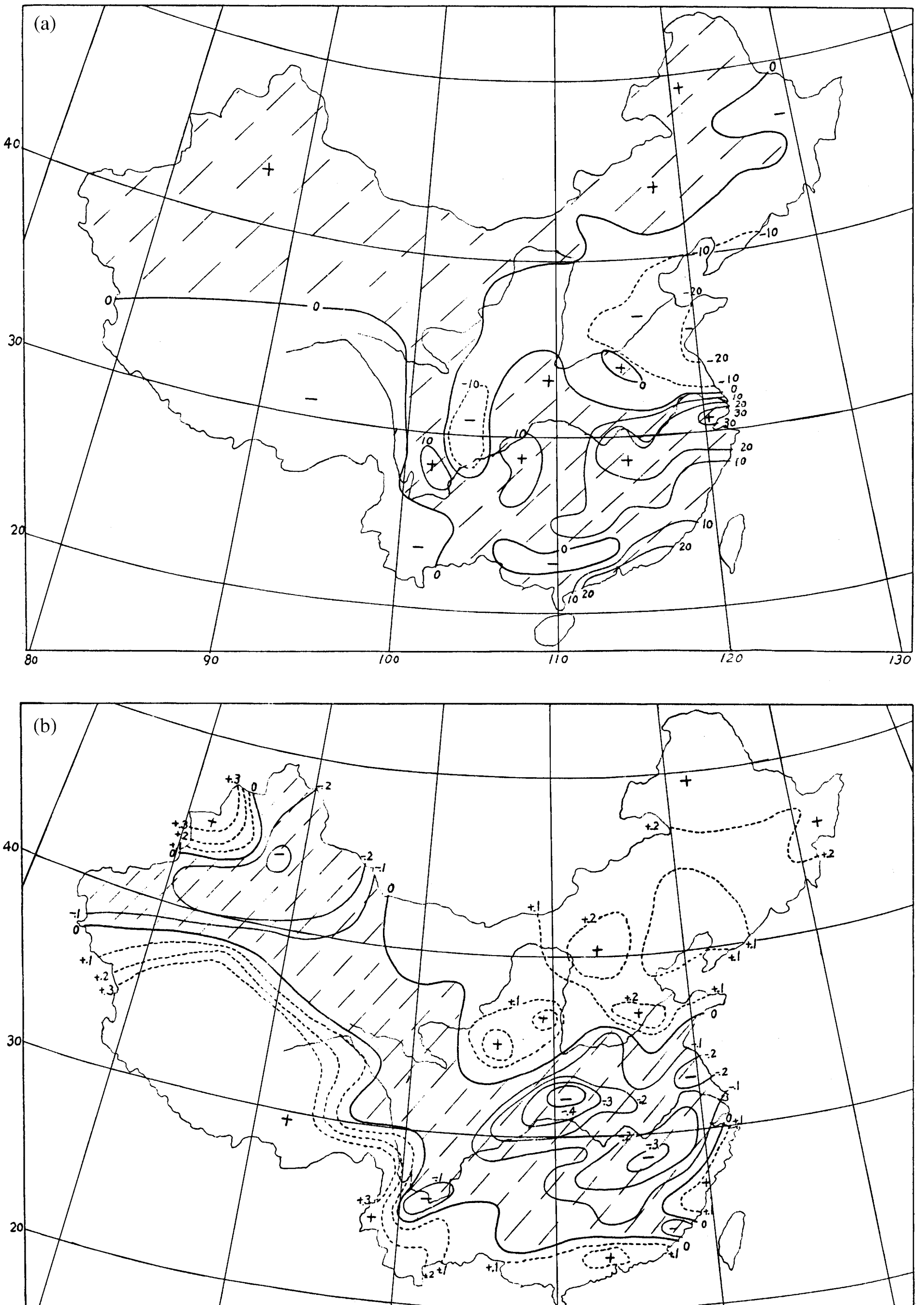

Fig. 2. (a) The mid-summer (JA) rainfall trend distribution (unit: mm/10 yr) of China for the years 1960–1999. (b) Same as Fig. 2a, but for temperature (unit: °C/10 yr).

has shown a significantly increasing trend since the mid 1980s. In 1985 the annual emission of SO_2 was only 1.34 Tg (Wang, 1993), but it rose to 2.22 Tg in 1990 and 5.49 Tg in 1995. These data were taken from the associative investigations of the following 3 administrations of China: National Environment Protection Bureau, Agriculture Ministry, and National Statistical Bureau (1992); however, a decrease to 4.89 Tg started in

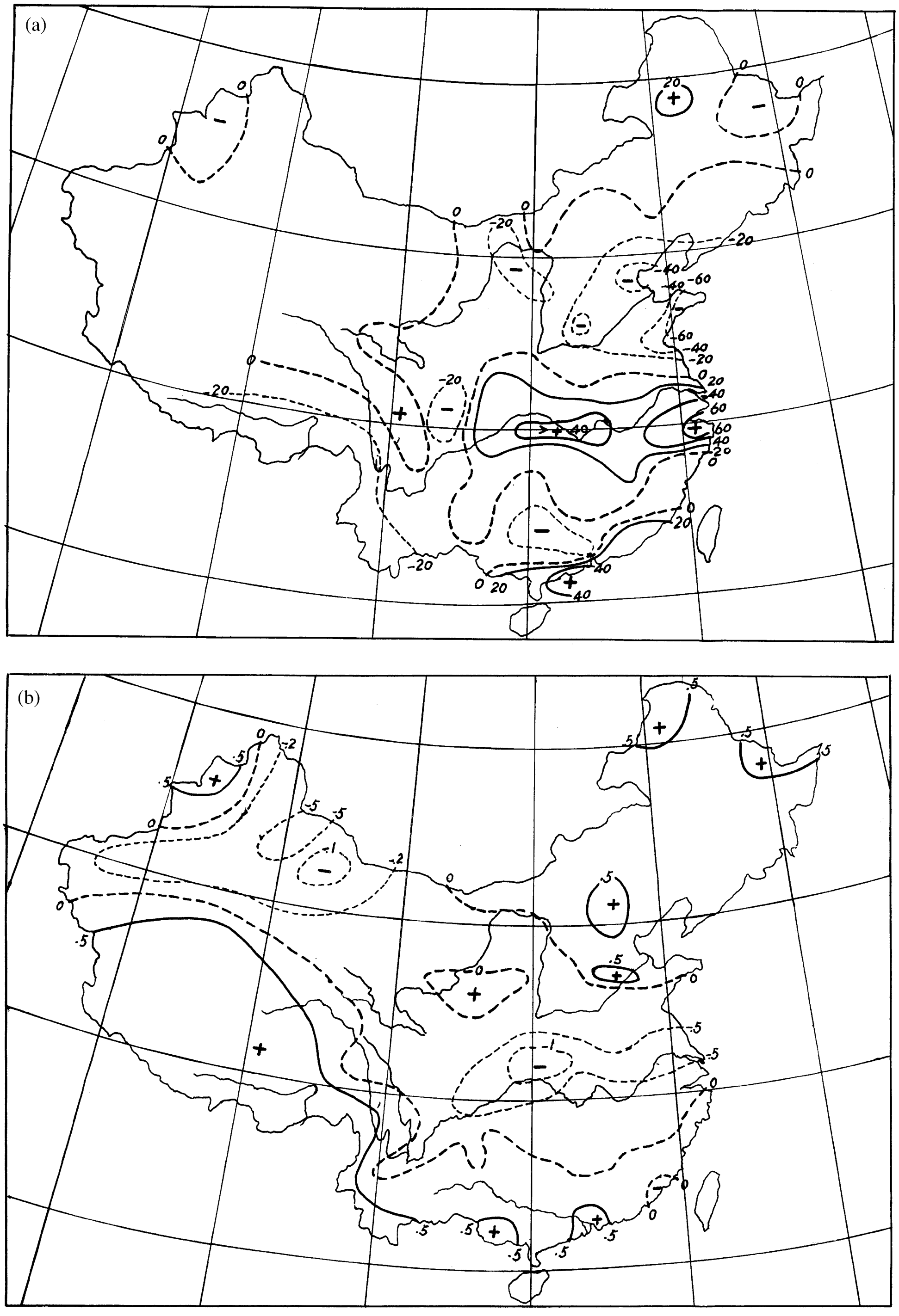

Fig. 3. (a) Distribution of the average anomalies of mid-summer (JA) rainfall in China for 20 recent years (1979–1998) relative to the mean value of 28 former years (1951–1978) (unit: mm). (b) The same as Fig. 3a, but for temperature (unit: °C).

1997 (Bulletin of the Environment State in China, 1998). Using the above data for linear interpolation since 1986 and adding the annual SO_2 data in cities, the total annual emissions in the whole of China were obtained. It shows that following the sharp increase of released SO_2 since the mid-1980s (curves 4 and 5 in Fig. 4), the clear

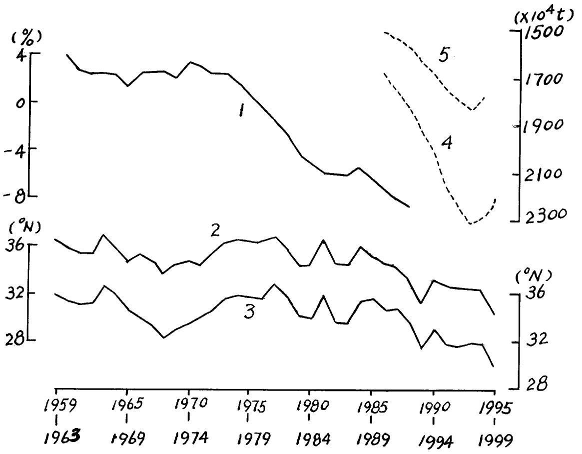

Fig. 4. Five-year running averages. (1) Winter clear sky global solar radiation of 9 stations in China. (2) and (3) Average latitudes of the central axis of monsoon rain belt in summer (JJA) and mid-summer (JA), respectively. (4) Annual SO_2 emissions in the whole of China. (5) Annual SO_2 emissions in cities of China.

sky global solar radiation of China decreased significantly accompanied with a southward moving trend of SMRB of east China (especially in mid-summer). It is notable that since the 1980s, especially during the 1990s, the atmospheric pollution of China has sharply increased due to the extensive development of enterprises outside cities. "The Bulletin of Environmental State in China in 1997" reported: "The enterprises outside cities developed persistently since early 1990s, their proportion in the whole industrial output value of China rose from 23.8% in 1989 to 42.5% in 1995. Thus the emissions of industrial pollution also showed a sharp increase, the annual amounts of rural SO_2, smoke, and dust reached 5.49, 9.93, and 13.58 Tg in 1995, contributing 28.2%, 54.2%, and 68.3% of the total annual industrial emissions in China, respectively. Curve 4 (Fig. 4) shows that the annual release of SO_2 in the whole of China (including rural) increases more than the emission in cities (curve 5). Although the SO_2 emissions in cities have decreased to some extent in the late 1990s (curve 5), the annual released amount of SO_2 in the whole of China exceeded 20 Tg during the most years (1992–1998) of the 1990s due to the slowness of decreasing release of SO_2 outside cities. The maximum of annual releasing amount of SO_2 in the whole of China reached 23.7 Tg in 1995, then a weak decreasing trend is observed in curve 4 owing to a series of countermeasures for reducing atmospheric pollution.

In brief, the phenomena of "increasing atmospheric pollution-decreasing clear sky solar radiation-southward move of the SMRB in east China" could result from the acceleration of industrialization since the late 1970s which had an enhanced trend during the 1990s.

Table 1 clearly shows the latitudinal variation of the central axis of SMRB in east China since the late 1970s. The difference of the average latitude of the central axis of mid-summer (JA) SMRB in east China between 3 preceding years (1976–1978) and 3 recent years (1997–1999) reached 10.4°. Its southward moving trend during 22 recent years (1978–1999) reached 3.14°N/10 yr, which was further enhanced at 5.39°N/10 yr in 15 recent years (1985–1999)! Hence, the north China had suffered from frequent droughts in most summers (13 out of 20) of the 20 recent years (1980–1999), while the mid-lower Yangtze Basin encountered more summer flooding ($\frac{12}{20}$). Half of 20 recent summers suffered from both droughts prevailing in north China and flooding occurring in the mid-lower Yangtze Basin. They are years of 1980, 1982, 1983, 1984, 1987, 1989, 1991, 1993, 1998, and 1999. In comparison with historical data of drought/flooding patterns in east China (Wang and Zhao, 1987), the occurrence of the climate pattern "north drought with south flooding" in east China during the 20 recent years is the highest since AD 950. This could mean that the mid-summer abnormal climate of east China is effected by the accelerated industrialization and by far exceeds the natural climate oscillation of the 1000 recent years, leading to frequent occurrences of summer climate disasters in east China.

4. Test for significant correlation

The relations among time series in Figs. 1 and 4 should be further verified by calculating correlations. In the calculation, we have considered the auto-corelations (AC) of each time series. This means that when the AC of a certain time series is strong, then the significance of its correlation with other time series will be seriously affected by the number of freedom, which may be unequal to the original sample volume (n) of time series. The test of significance for any correlation must consider

Table 1
The latitudinal variation of the central axis of SMRB in east China

Average latitude (°N)	JJA	JA
1976–1978	37.7	38.7
1997–1999	29.2	28.3
Difference (°N)	8.5	10.4
Trend (°N/yr)		
1978–1999	−0.311	−0.314
1981–1999	−0.399	−0.417
1985–1999	−0.513	−0.539

the inherent persistence in time series, so we estimated the number of independent samples of time series—the effective sample number (N) in each set when calculating correlation for significance by utilizing the method of Chen (1982). The calculated results for each correlation with longer time series (>30 yr) are listed in Table 2. It shows that the Kn positively responded to the change of S or Q at a significance level of 95%; such significant correlations even existed when Kn lagged 4.5–5.5 yr. The mid-summer rainfall anomaly percent of north China (R) also positively responded to the change of S or Q at a significance level of 95%, but with a time lag of 1.5 yr. The latitude of central axis of SMRB of east China in July–August (LrJA) has significant correlations to preceding S and Q only at longer lags of 7.5–8.5 yr; however, it is highly connected to Kn (data: 1951–2000) without time lag (Table 2). In short, the decrease of solar radiation in China by the increasing release of SO_2 has considerable influences on the mid-summer rainfall distribution of central east China—a southward retreat of SMRB in 21 recent years. Such influences may be either in direct form through a significant correlation link among Q–Kn–LrJA, or indirectly modulated by a more complex form such as certain interactions between the change of solar radiation and heat content of ocean. This can be deduced form the time lag of 1.5–8.5 yr for correlations of Kn, R and LrJA to preceding S and Q.

Table 2
A Series of correlations showing significant relations between the changing solar radiation of China (S, Q) and mid-summer pacific high (kn)—rainfall distribution in central east China[a]

Correlation	Lagging years	n	N	r	Level of significance
$S-Kn$	0.5	32	15	0.52	0.95
	4.5	32	21	0.44	0.95
	5.5	32	15	0.52	0.95
$S-R$	1.5	32	28	0.37	0.95
	4.5	32	32	0.35	0.95
S–LrJA	7.5	32	32	0.31	0.95
	8.5	32	32	0.39	0.95
$Q-Kn$	0.5	33	14	0.54	0.95
	1.5	33	15	0.56	0.95
	4.5	33	24	0.40	0.95
$Q-R$	1.5	33	30	0.36	0.95
Q–LrJA	0.5	33	33	0.30	0.95
	1.5	33	33	0.31	0.95
	6.5	33	33	0.32	0.95
	7.5	33	33	0.40	0.95
Kn–LrJA	0	50	38	0.55	0.999

[a] The correlations have been calculated between winter solar radiation (S, Q) and following mid-summer climate indices with different time lags; n and N are the original sample volume and effective sample number of each time series separately; r: correlation coefficient.

5. Direct radiative forcing by increasing sulfate aerosols in east China

The data of clear sky solar radiation used in Fig. 1 are of 9 stations, their sites are shown in Fig. 5. Most of these data began at winter 1959–1960, except data of Heihe and Harbin, which started at winter 1961–1962 and winter 1960–1961, respectively.

For minimizing the effect of clouds, clear sky solar radiation data were obtained as follows: The maximum (Sm) of all daily clear sky (daily average cloud amount $\leqslant 1$) direct solar radiation is determined. The average value Sm from 10 days of winter season (DJF) is taken as winter clear sky solar radiation (Sw) for each station (Xu, 1990). The winter clear sky global solar radiation (Qw) was calculated in the same way, but using all daily global solar radiation data of the above selected days with Sm. This strict limit for clear sky days is suitable in winter only, since clear sky is rare in east China during summer due to monsoon activity. However, we should also estimate the actual change of summer radiative forcing by anthropogenic aerosols for 30 recent years. So we take a new criterion (daily average cloud amount $\leqslant 3$) for defining summer clear sky days. We tentatively calculated the summer clear sky global solar radiation for 5 stations of east China for 2 periods without significant effect of volcanic aerosols: Period 1 consists of the summers 1959–1961, except Heihe and Harbin, their periods are 1961–1963 and 1960–1962, respectively; Period 2 consists of the summers 1989–1991. The influence of Pinatubo clouds was significant in China starting from summer 1992 only (Xu, 1995). Table 3 shows the changes (CQs) of summer clear sky global solar radiation of 5 stations in east China from period 1 to period 2 with corresponding changes for winter (CQw) of all 9 stations, respectively.

From Table 3, it is notable that the negative changes of clear sky global solar radiation from period 1 to period 2 both of winter and summer are very significant, corresponding well with the increasing release of sulfate aerosols in China for 20 recent years. Although the average per cent change of CQw is larger than that of CQs due to more coal combustion for heating in winter, the absolute value of average CQs ($-42.5\,W/m^2$) is significantly greater than that of CQw ($-26.5\,W/m^2$). This is reasonable, since the summer solar radiation is several times larger than that of winter; at higher solar zenith angles, the summer incident flux will be reduced substantially by Rayleigh scattering compared to winter.

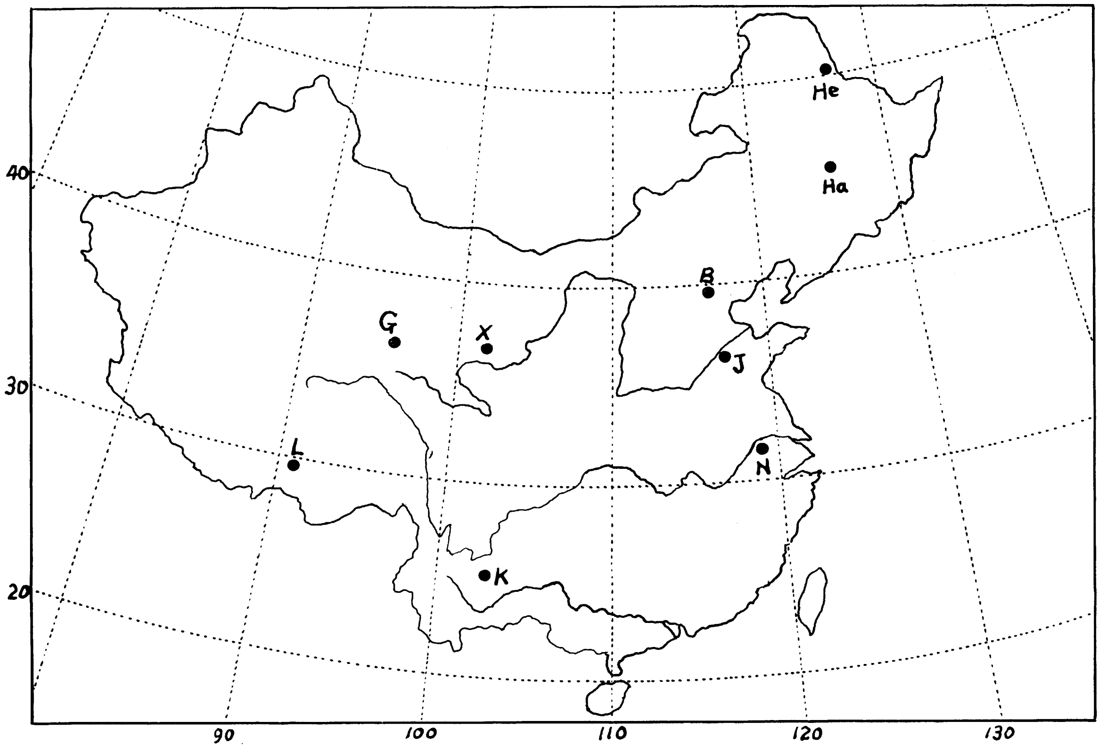

Fig. 5. The sites of 9 stations with clear sky solar radiation data in China. He (Heihe), Ha (Harbin), B (Beijing), J (Jinan), N (Nanjing), X (Xining), G (Germu), K (Kunming), L (Lasa).

Table 3
The changes of averaged clear sky global solar radiation from period 1 (1959–1961) to period 2 (1989–1991) in winter (CQw) and summer (CQs), except the data of Heihe and Harbin in period 1, see text

Station	CQw (W/m^2)	(%)	CQs (W/m^2)	(%)
(1) Heihe	−12.1	−9.4	−51.1	−10.9
(2) Harbin	−18.1	−11.7	−10.4	−2.4
(3) Beijing	−37.9	−17.1	−60.7	−13.1
(4) Jinan	−34.6	−15.6	−55.0	−11.8
(5) Nanjing	−30.0	−12.4	−35.2	−7.9
(6) Kunming	−41.8	−12.6		
(7) Xining	−26.6	−10.8		
(8) Germu	−4.1	−1.6		
(9) Lasa	−97.7	−29.6		
Average of (1)–(5)	−26.5	−13.2	−42.5	−9.2
Average of (1)–(9)	−34.1	−13.4		

In July 1996, the aerosol induced change in downward solar flux of about 100 W/m^2 per unit optical depth had been measured in the US eastern seaboard (Russel et al., 1996). Moreover, the local shortwave planetary albedo increase in 40–60°N caused by anthropogenic aerosol particles combining the effects of particle in cloudless parts of the atmosphere and of changed cloud optical properties in summer is significantly larger than that of winter (Grassl, 1988).

Wang et al. (1998) had calculated the spatial distribution and seasonal variation of sulfur oxidation and sulfate in East Asia and China by using the 3-D Euler model for sulfur transport; they found that the largest concentration of sulfate aerosol in East Asia was

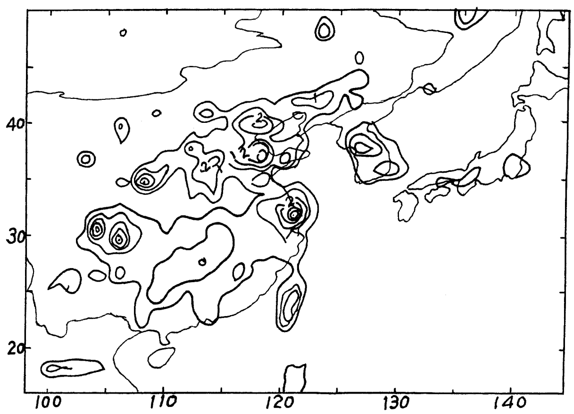

Fig. 6. Summer distribution of sulfate aerosol (μg/m^3) in East Asia at 70 m height (Wang et al., 1998).

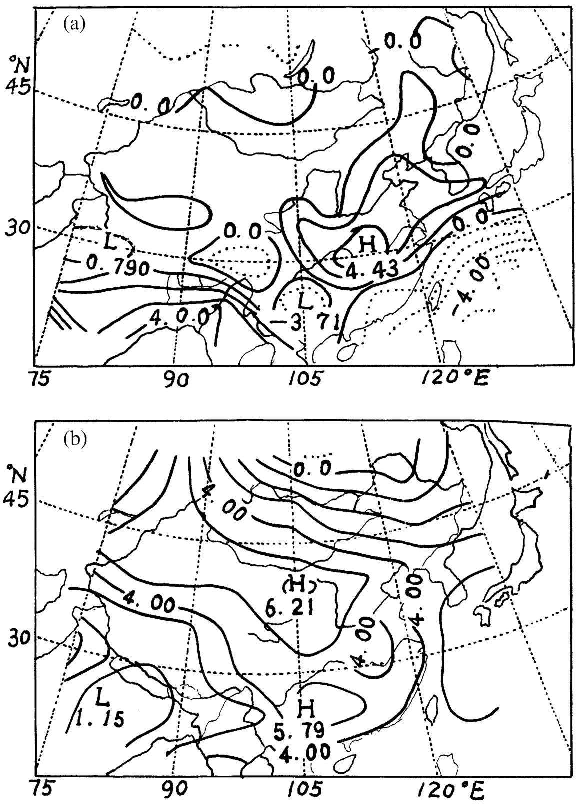

Fig. 7. Distributions of predicted summer anomaly of precipitation (a) and temperature (b) in 2050 due to the effect of increasing greenhouse gases only, taken from Geng et al. (1997).

located in central east China during every season, this feature was also shown in Fig. 5 of Xu and Carmichael (1999), but even with larger concentration. Three stations in Table 2 (Beijing, Jinan, and Nanjing) are just located in the region of dense sulfate aerosol (Fig. 6). The average change of summer clear sky global solar radiation (CQs) of above 3 stations reaches $-50.3\,W/m^2$ from period 1959–1961 to 1989–1991, which manifests the significantly negative radiative forcing of increasing sulfate through 30 recent years. Such large regional negative forcing is not impossible. Evaluating the surface radiation budget in climate models, Garratt et al. (1998) have suggested that the inclusion of aerosols in models would reduce the annual solar downward flux by 15–20 W/m^2 over land, which should be further enhanced in polluted regions. Qiu and Yang (2000) have calculated the variation of the characteristics of atmospheric aerosol optical depths and visibility for 5 stations of north China during 1980–1994; according to Figs. 4b and 6b of their paper, the average optical depths of Harbin, Beijing, and Zhengzhou (34.8°N, 113.7°E) in years 1990, 1991, and 1994 are about 0.44 in winter and 0.47 in summer, except for higher values in 1992–1993 influenced by Pinatubo's clouds. According to Fig. 3 of Nemesure et al. (1997), the above values of aerosol optical depth will produce a global average forcing of about -16 to -20 W/m^2.

The change of clear sky global solar radiation in central east China between periods 1 and 2 without significant effect of volcanic clouds manifests a significant decrease of global solar radiation in 30 recent years. This is most likely caused by increasing sulfate aerosol due to the acceleration of China's industrialization. According to Fig. 7 of Lefohn et al. (1999), the amounts of sulfur emissions in China in 1990 were about 2.8 times that in 1960 or in 1970. Although the values of CQw and CQs may include some error in representing the actual changes of clear sky global solar radiation, their trend and numerical order can be confirmed. Both the average destrease of CQw and CQs are significantly greater than the estimate of the radiative heating (2.45 W/m^2) due to the increase of greenhouse gas concentration since pre-industrial time (IPCC, 1994). The above negative radiative forcing may be overwhelmed by the influence of global greenhouse warming in winter. The regional climate in the temperate zone of East Asia is dominated by large-scale circulation in winter, which is influenced by global warming. However, the land–sea contrast of radiative forcing in summer is a more important factor influencing monsoon system. As indicated above, the most significant decrease of solar heating by sulfate aerosols occurred in central east China during summer. This inevitably leads to a sharp weakening of the strength of summer monsoon system in east China with reducing number of *Kn* accompanied by a southward retreat of SMRB during the past 20 years, which is also suggested by the statistics in Table 2.

The result of the present work has been supported by a series of climate experiments (Coakley and Cess, 1985; Pittock et al., 1988), which may be summarized as follows: After emission of either volcanic aerosols in the stratosphere or anthropogenic aerosols in the troposphere, the solar heating on the land surface tends to decrease. The thermal states of land surface in summer sensitively respond to the atmospheric aerosols above a certain optical depth: convection is suppressed in the cooling latitudes with a notably southward retreat of atmospheric front and SMRB. The German climate computing center recently conducted a model experiment with separate runs to simulate the climate response to increases in CO_2 alone and to increases in CO_2 together with direct sulfate aerosol forcing during the period 2030–2049 (Raisanen, 1998). Increasing CO_2, when acting alone, was found to lead to a poleward shift and an intensification of the midlatitude surface westerlies in both hemispheres. On the other hand, the northward shift in the midlatitude westerlies is canceled by the direct radiative forcing of anthropogenic sulfate aerosols in the Northern Hemisphere during winter and replaced by a southward shift in summer.

Geng et al. (1997) had predicted the climate of China in 2050 by using the Hadley Center CGCM. It was shown that there exist great differences between the predicted future climate changes over China considering only caused effect of greenhouse gases or the effects of both greenhouse gases and aerosols.

When considering the effect of increasing greenhouse gases only, summer monsoon rain will significantly increase in large parts of China, especially from the Yangtze Basin to most parts of north China (Fig. 7a) together with a large rise of summer temperature over the whole of China (Fig. 7b). This summer climate trend will be greatly changed, when considering both the effect of greenhouse gases and that of aerosols. Most of north China will suffer from lesser rain, positive rain anomaly will be restricted in the Yangtze Basin and regions south of it (Fig. 8a), a negative summer temperature anomaly will appear in the Yangtze-Huaihe Basins, with positive anomaly restricted in north China and west provinces (Fig. 8b). The general trend of central east China (east of 105°E) in Fig. 8 is similar to those of Figs. 2 and 3. Moreover, the calculated results of climate experiments by the Hadley Centre (included in the contents of the Web site of the Data Distribution Center of IPCC (IPCC DDC, 2000)) show the same distribution of summer rainy trend in east China for 2070–2099 by considering the effects of both greenhouse gases and sulfate aerosols (GS1at3-Cont3): less rain will appear in north China with more rain occurring in the south of mid-lower Yangtze River.

The similarity of the summer climate trend distribution in central east China in the 20 recent years, to the predicted year 2050, and years 2070–2099 is evident. This could be considered as a proof of the fact that present summer climate change of central east increasing sulfate aerosols has significantly influenced China. But this also raises the following question: Does this means that recent mid-summer climate anomaly of central east China, most likely caused by increasing release of SO_2, has developed to such an extent, that already the climate expected in 50 yr takes place now?

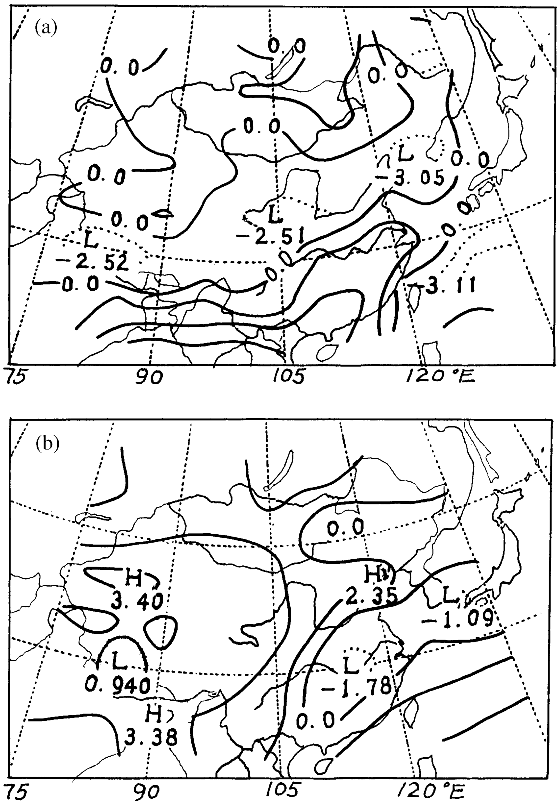

Fig. 8. Distributions of predicted summer anomaly of precipitation (a) and temperature (b) in 2050 due to the effects of both greenhouse gases and aerosols, taken from Geng et al. (1997).

6. Conclusion and discussion

The mid-summer climate of central east China has undergone an abrupt change over the past 20 years: north China tends to have lesser rain with more droughts occurring, while more rain with frequent flooding appeared in the mid-lower Yangtze Basin with a cooling trend in this region. The occurrence rate of abnormal summer climate pattern of "north drought with south flooding" in east China during 20 recent years is the highest since AD 950. The scope of summer drought of north China has expanded southward to Huaihe Basin. The central axis of mid-summer SMRB has a trend moving southward at an average rate of 0.3 latitudes per year; its average location of 3 recent years

(1997–1999) even situated on the south side of the Yangtze River. The above trend proceeds wholly inversely with the global warming in the 20 recent years. Its main cause could be the accelerating industrialization through mainly using coal in east China. This has played a key role by emitting large volumes of SO_2, especially from the rapidly growing rural factories of east China, which has become the first contributor of increasing release of SO_2 in China during the 1990s. The annual amounts of released SO_2 are wholly governed by the amounts of coal consumption. According to Deng (2000), the above 2 factors had a very high correlation reaching 0.96 during 1983–1995. The annual emitted amount of SO_2 in China had steadily surpassed 20 Tg during 1992–1998, so dense sulfate aerosols covered the central east China significantly reducing the solar radiation. The clear sky global solar radiation (Q) had decreased by 13.2% in winter and 9.2% in summer from year 1959–1961 to 1989–1991; however, the above change of Q (%) produced sharp decrease of radiative forcing at $-42.5\,W/m^2$ in summer with $-26.5\,W/m^2$ in winter. Although some error may exist in these values, they are significantly greater than the estimate of radiative forcing ($2.45\,W/m^2$) due to the increasing greenhouse gas concentration since pre-industrial times. The key problem is that the greater losses of radiative heating by sulfate aerosols over central east China just occur in summer- the most sensitive season of summer monsoon system to the heating contrast between land and ocean. Hence it is reasonable: the mid-summer monsoon of central east China responded so significantly to the considerably negative radiative forcing of increasing sulfate aerosols, which is also indicated by the statistical investigation in Table 2.

The similarity of the summer climate anomaly distribution of central east China among 20 recent years, with the predicted year 2050, and predicted trend of 2070–2099 by climate experiments should make us vigilant. Has the mid-summer climate of central east China developed more rapidly under the severe effect of increasing sulfate aerosols?

The expanding desert in northern China is another source of increasing atmospheric aerosols in East Asia. According to the estimation of Jie (1999), it emits 43 Tg dust particles per year; although such dust emissions are lesser in summer (2.5 Tg), there still is the effect of reduced solar heating of central east China.

It should also be pointed out that recently the Chinese government adopted a series of measures to reduce the atmospheric pollution for a sustainable development of China (Zhang, 1999). So the releasing amount of SO_2 has been decreased since the late 1990s (see curve 4 of Fig. 4). However, great efforts will be needed for achieving an equilibrium between economic development and environment protection. Further monitoring of the atmospheric environment and summer monsoon characteristic of China with more complete solar radiation data is vital, not only for East Asia, but is also of global change importance.

Finally, we should also pay attention to the fact that the influence of increasing sulfate aerosols is not only important for the mid-summer of east China, but may also prevail in the whole Eurasian continent. Kiehl and Rodhe (1995) had indicated that the maximum sulfate aerosol forcing is in central Europe, is it also responsible for the southward retreat of both the summer north Africa high at 500 hPa level and the ITCZ in Sahel (Xu, 1987, 1989a).

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