Water Science and Engineering, Jun. 2008, Vol. 1, No. 2, 33–46
ISSN 1674–2370, *http://kkb.hhu.edu.cn*, e-mail: *wse@hhu.edu.cn*

Recent strong inter-decadal change of Meiyu in 121-year variations

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Abstract: The strongest change in Meiyu periods in the mid-lower Yangtze Basin (MLY) since 1885 occurred in the late 1970s: a stage of weak Meiyu from 1958 to 1978 abruptly transformed into a stage of plentiful Meiyu from 1979 to 1999. The average Meiyu amount of the latter 21 years increased by 66% compared with that of the former 21 years, accompanied by a significant increase in the occurrence of summer floods in the MLY. This change was closely related with the frequent phenomenon of postponed Meiyu ending dates (MED) and later onset dates of high summer (ODHS) in the MLY. To a considerable degree, this reflects an abrupt change of the summer climate in East China. Further analysis showed that the preceding factors contributing to inter-annual changes in Meiyu in the two 21-year stages delimited above were also very different from each other. The causes of change were associated with the following: China's industrialization has greatly accelerated since the 1970s, accompanied by an increase in atmospheric pollution and a reduction of the solar radiation reaching the ground. The sand area of North China has also expanded due to overgrazing. The enhanced greenhouse effect is manifested in warm winters (especially in February). Meanwhile, the January precipitation of the MLY has for the most part increased, and El Niño events have occurred more frequently since the late 1970s. A correlative scatter diagram consisting of these five factors mentioned above clearly shows that the two stages with opposite Meiyu characteristics are grouped in two contrasting locations with very different environmental (land-atmosphere) conditions. It is quite possible that we are now entering a new stage of lesser Meiyu, beginning in 2000.

Key words: *Meiyu variations*; *strong inter-decadal change*; *effect of anthropogenic activity*

DOI: 10.3882/j. issn. 1674-2370. 2008.02.004

1 Introduction

In early summer, the warm and moist southern air (summer monsoon) usually blows northward over the shallow cold air mass of Central East China, which comes from the north, forming a quasi-stationary front with successive rain in the MLY. This normally lasts about 20 days and is the main rainy period of the MLY. As it occurs during the time of plum ripening, it is habitually called "plum rain" (Meiyu). The amounts of rain in the MLY during the Meiyu period and anomalies either in the onset date or ending date each year have wide variability and considerable influence on the economic activities and lives of people living in Central East China. The Meiyu period is also an important index characterizing the summer monsoon climate of East China. Without exception, severe flooding occurs in the MLY during each strong Meiyu year. Hence, researching long-term change in Meiyu periods and its causes is very significant. Based on Meiyu periods in the MLY from 1885 to 1964 delimited by previous research (Xu 1965), the author further delimited Meiyu periods in the northern and

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This work was supported by the National Natural Science Foundation of China (Grant No.40233037).
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Received May 2, 2008; accepted May 30, 2008

southern regions of the lower Yangtze-Huaihe Basin since 1951 (Xu 1998). Four concepts, i.e., regional rain day (RRD), concentrated rainy period (CRP), precipitation intensity of the CRP and the characteristic of the natural synoptic season of the CRP, were rationally combined as the objective criteria for delimiting Meiyu periods with daily precipitation data from five stations in the MLY (Shanghai, Nanjing, Wuhu, Jiujiang and Wuhan stations) over 116 recent years from 1885 to 2000 (Xu et al. 2001). There are now 121 years of Meiyu data from 1885 to 2005. It is evident through analysis that significant inter-decadal change has occurred in the Meiyu periods since the late 1970s, with a significant increase in Meiyu rainfall amounts (MRA) and a delay in MED (Xu et al. 2001). In this study, the abrupt changes and their causes were analyzed.

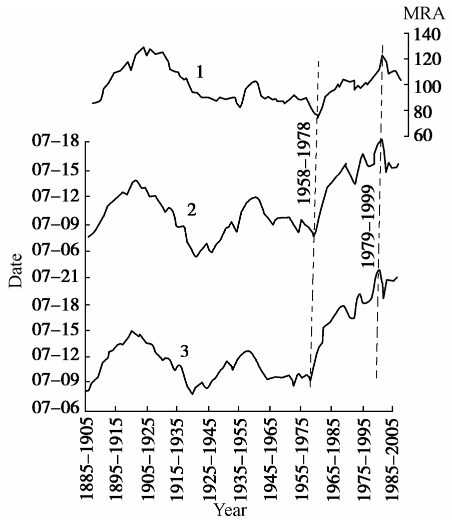


Figure 1 21-year moving average curves of MRA (curve 1), MED (curve 2) and ODHS (curve 3) in MLY

2 Low-frequency oscillations and recent inter-decadal change in Meiyu periods in MLY

Analysis of Meiyu periods since 1885 (Xu et al. 2001) shows that significant inter-decadal change began to occur in the late 1970s. The MRA was significantly less than normal in the 21 years from 1958 to 1978, and MED came earlier. During the 21 years from 1979 to 1999, on the other hand, the MED arrived later and the MRA was significantly greater than normal. These differences were significant. The non-integer wave method was used to calculate the amplitudes of long-term periods (⩾30 years) for each Meiyu index with F-tests (Table 1).

It is evident from Table 1 that low-frequency oscillation with a period of around 40 years has generally existed in all Meiyu indices during the last 121 years, as manifested in the 39.6-year period of the MED, the 39.2-year period of the MRA and the 41.5-year period of the ODHS in the MLY (Xu 1965, 1998). Most years, the ODHS corresponded with the MED, but in a few years it lagged more than five days behind (Xu et al. 2001). However, while the amplitude of the 39.6-year period reached a 2% confidence level, the amplitude of the other two periods did not reach a 5% confidence level through F-tests. This shows that a period of around 40 years exists but not very significant. More significant is the long-term delayed trend of the MOD (onset date of Meiyu) with its period length longer than 100-year (Table 1). Over the last 121 years of Meiyu variations, the contrast between the two 21-year stages delimited above in the MRA is very anomalous. The 21-year moving average curves (Figure 1) of the MRA, the MED and the ODHS in the MLY clearly show the following characteristics:

Table 1 Low-frequency oscillation condition of Meiyu in MLY

Index	Period length (year)	F value
MRA	39.2	2.20
	77.0	1.93
MOD	121.0	5.12[1)]
MED	39.6	3.98[2)]
	74.0	2.49
MPL	35.0	3.80[3)]
	70.0	2.63
ODHS	41.5	2.78
	74.0	4.01[2)]

Note: [1), 2) and 3)]The F value confidence of period's amplitude reaching 1%, 2%, and 5%, respectively; MPL is the length of Meiyu period

(1) The MRA reached a century low from 1958 to 1978: the mean value over these 21 years was less than the mean value over the last 120 years (1885–2004) by 26%, while the mean MRA of the latter 21 years (1979–1999) reached its second peak since 1885, more than the mean value of the last 120 years by 23%.

(2) The mean MED of the fomer 21 years (1958 to 1978) reached the earliest point since 1949, while the mean MED of the latter 21 years (1979–1999) reached the latest date (the end of the second 10 days in July) in the last 121 years. The mean ODHS in the MLY during the latter 21 years was especially delayed to July 22, even later than it had been in the former late stage (1900–1920) by 7.3 d. Thus, the differences between these two 21-year Meiyu stages are significant, and, in particular, the delayed MED and the ODHS of the MLY in the latter stage can be considered very anomalous.

3 Two contrasting stages of 42 recent years

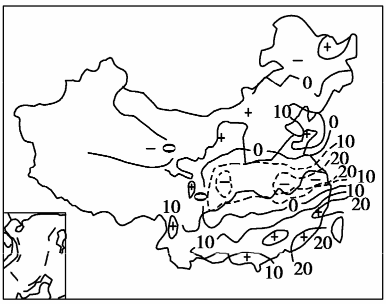
The Meiyu characteristics of two successive stages in 42 recent years (1958–1999) contrast with each other even further (Table 2), as manifested not only in lesser MRA from 1958 to 1978 followed by greater MRA from 1979–1999, but also through the different MED of the two stages. In the latter stage, the mean MED and ODHS were later than those of the former stage by 11 days and 12.8 days, respectively: the MED and ODHS of about 7 to 8 years in the latter stage arrived on July 23 or later, even no high summer occurred in 1980, 1993 or 1999, which meant that the summer monsoon rain belt could not even move steadily on the north side of the MLY during these three summers. Such severe anomalies had not occurred in the 95 years preceding 1980, according to the data. Years of significantly late MED and ODHS in the latter stage were 7 to 8 times of those of the former stage. Such changes in MRA between the two stages were also clearly reflected in summer rainfall distribution during these two stages.

Table 2 Comparison of all indices of Meiyu periods during two stages

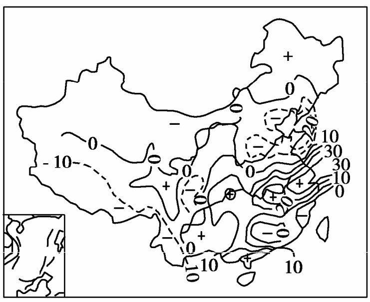
Index	1958–1978		1979–1999	
	Value	Anomaly[1)]	Value	Anomaly
MRA[2)]	74	−26	123	+23
MPL(d)	15.8	−5	24.6	+3.8
MOD in June	20.9[4)]	3.9d later	19.7	2.7d later
MED in July	8.8[4)]	2.2d earlier	18.6	7.6d later
ODHS in July	9.5[4)]	3.3d earlier	22.3	11.5d later
Wet Meiyu (MRA≥130)	(2 years): 1962,1969	−66.5	(9 years): 1979,1980,1983, 1984, 1991, 1993, 1996, 1998, 1999	+51
Dry Meiyu (MRA<70)	(9 years): 1958, 1959, 1960, 1963, 1965, 1967, 1968, 1971, 1978	+41.9	(5 years):1985, 1988, 1990, 1992. 1994	−21.2
Very late MED[3)]	(1 year): 1974	−69.3%	(7 years): 1979, 1980, 1982, 1986, 1987, 1993, 1998	+115%
Very late ODHS[3)]	(1 year): 1974	−70.9%	(8 years): 1979, 1980, 1982, 1986, 1987, 1993, 1998, 1999	+133%

Note: [1)]All anomalies in the table are based on the data of 116 recent years (1885−2000); [2)]the mean MRA of the 116 years: 100 (Xu et al. 2001); [3)]MED (or ODHS) appears on July 23 or later; [4)]the date of MOD, MED, and ODHS

Figure 2(a) shows that, in the former stage, most of Central East China (east of 104ºE) was deficient in summer rainfall, with a negative anomaly (−20% to −30%) centered in the MLY, while more summer rainfall appeared in North and South China. The distribution of summer rainfall in the latter stage (Figure 2(b)) contrasted with that of the former (Figure 2(a)). Positive anomalies prevailed in the MLY, while North and South China suffered from less summer rainfall. The contrasting distribution of summer rainfall anomalies between Figure 2(a) and Figure 2(b) shows that in the latter stage of increasing Meiyu, the summer monsoon rainy belt of China was retreating south-eastwardly.



(a) 1958−1978



(b) 1979−1999

Figure 2 Distribution of average summer rainfall anomalies (relative to the mean of 1951–2002) in China during two stages

The annual variation curve of *Kn* (pentad number of the northwardly marching West Pacific high during July and August, whose average ridge line latitude is greater than or equal to 26ºN in the range of 110ºE–130ºE) clearly shows that the average *Kn* in the latter stage is less than that of the former by 2.8 pentads (14 days), coinciding well with the fact that the average MED and ODHS of the latter stage lag behind those of the former by 11 days and 12.8 days, respectively. Over the entire 42-year period (1958–1999), the *Kn* was highly correlated with MED, ODHS, MRA, and the summer (JJA) and high summer (JA) latitudes of the rainy belts in East China, at –0.62, –0.75, –0.51, 0.55, and 0.59, respectively, all at a 0.1% confidence level. This demonstrates that the transformation of the former stage with less MRA and earlier MED/ODHS to the latter stage with greater MRA and delayed MED/ODHS was significantly influenced by the change of *Kn*, which abruptly diminished from 8.1 to 5.3 pentads at the transition between the two 21-year stages, accompanied by a significant southward movement of the summer and high summer rainy belts of East China (Xu et al. 2001). Figure 3 also shows an important difference in the Meiyu variations between the two stages.

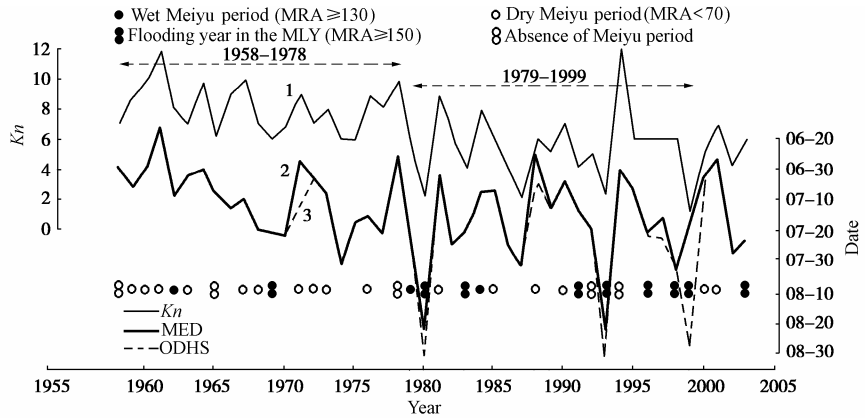


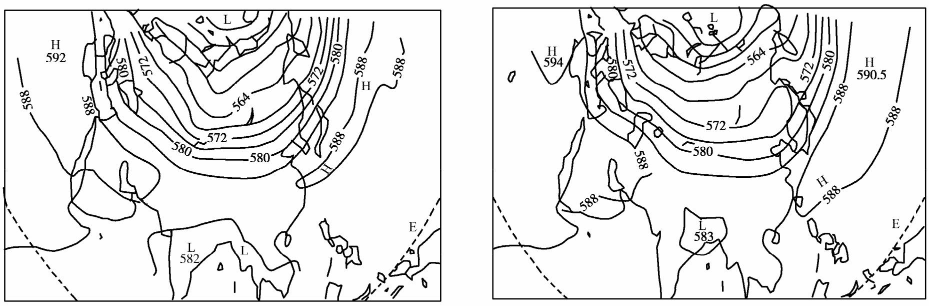
Figure 3 Close relationship between Meiyu in MLY and northward pentads (*Kn*) of West Pacific high in July and August during two stages

The average amplitudes of the inter-annual variability of all Meiyu indices in the latter stage were larger than those of the former. The standard deviations (SD) of inter-annual variability of the MED and ODHS in the latter stage were 1.42 and 1.77 times of those of the former, respectively (Table 3). Evidently, this was influenced by the anomalously great inter-annual changes in *Kn* in the latter stage.

Hence, the contrast of the Meiyu periods of the two stages is not only manifested in more plentiful Meiyu in the latter stage, but also in anomalously large inter-annual oscillations in the summer climate of the MLY. Years with a reduced level of disturbance of inter-annual oscillations and representative of the main characteristics of atmospheric circulation in July and August during the two stages were selected: 11 years in the former stage (1958, 1959, 1960, 1961, 1963, 1964, 1965, 1967, 1971, 1972 and 1978) with less MRA and earlier MED; and another 11 years in the latter stage (1979, 1980, 1982, 1983, 1986, 1987, 1991, 1993, 1996, 1998 and 1999) with greater MRA and later MED. The average 500 hPa atmospheric circulation type in July and August was then compared with different Meiyu trends from Figure 4.

Table 3 Contrasts of the SD for some indices of Meiyu periods between two stages

Stage	*Kn*（pentad）	MRA	MED（d）	ODHS（d）
(1) 1958–1978	1.6	50.8	10.9	10.6
(2) 1979–1999	5.8	75.2	15.5	18.8
(2)/(1)	3.63	1.48	1.42	1.77



(a) 11 years of the former stage

(b) 11 years of the latter stage

Figure 4 11-year average atmospheric circulation of the 500 hPa level in July and August with the prevailing Meiyu trends during two separate stages

(1) In the former stage, with less MRA and earlier MED, the corresponding average ridge line of the West Pacific high in July and August was located northward at 28ºN–29ºN (Figure 4(a)), which also affected the distribution of summer rainfall as follows: more rainfall appeared in North and South China, with less rainfall in the Huaihe and Yangtze basins (Figure 2(a)). In contrast, Figure 4(b) shows that in the latter stage, the average ridge line of the West Pacific was located southward at 24ºN–25ºN, which caused greater MRA and later MED and coincided well with the distribution of the summer rainfall anomaly in Figure 2(b): more summer rainfall occurred in the MLY with less rainfall in North and South China.

(2) A blocking situation appeared at 90ºE–140ºE and 50ºN–55ºN (Figure 4(b)), corresponding to the southward movement of the West Pacific high's ridge in July/August. Very high correlations of the 500 hPa height fields of July and August in the Northern Hemisphere with the MRA, MED, ODHS and *Kn* over the 42 years were found (significant at the 0.1% level), densely distributed at 80ºE–135ºE and 50ºN–55ºN. Except for the MRA, high correlations of the other 3 Meiyu indices with inverse signs to their north side also appeared at 115ºE–140ºE and 35°N–40ºN, which shows when blocking is (not) significantly appearing at 80ºE–135ºE and 50ºN–55ºN, there is a greater (less) MRA, later (earlier) MED/ODHS and a

southward (northward) location of the West Pacific high.

(3) In the latter stage, the West Pacific high in July and August was situated significantly farther south than normal, while the 500 hPa circulation of low latitudes showed a sharp weakening of the Indian monsoon low along with a reduced scope (Figure 4(a) and Figure 4(b)). The West Pacific typhoon numbers from July to September and the whole year in the latter stage decreased by 13% and 15%, respectively.

4 Analysis of the preceding causes of inter-annual changes of Meiyu in two stages

Many papers have indicated that the main factor contributing to inter-annual Meiyu changes is the occurrence or absence of the blocking pattern in the East Asian westerlies. This study also notes that the greater MRA with the postponed MED/ODHS in the latter stage is related to the blocking situation. However, the calculation shows that the East Asian blocking patterns, which have a high correlation with the MRA, exist only in July and never appear in any preceding month. This fully demonstrates that the relationship between Asian blocking patterns and the Meiyu is reflected within the short-medium scope, and is not related to climate processes with a time scale longer than one month.

Owing to the large difference between the two stages in the MRA, it is significant to analyze and compare the causes of inter-annual Meiyu changes. The difference in the MOD between the two stages is small, so we need only to analyze the primary causes of the inter-annual changes of MRA and MED. Using the method of selecting factors in seasonal prediction (Xu et al. 1997) through correlation fields of the Meiyu indices with each preceding monthly (January–March) 500 hPa height field of the Northern Hemisphere, the monthly SST fields of the North Pacific, the monthly air surface temperature and the monthly precipitation at 160 stations in China, we can find many high correlations. Then, based on them, we can establish the best linear regressions for simulating inter-annual changes in the MRA and MED in the two stages. It is clear from Table 4 that the contribution of 3–4 factors can simulate 0.89–0.91 of the total variance (S) of the inter-annual changes in the MRA and MED over the latter 21 years, while the contribution of 4–5 factors can allow the simulation of 0.77–0.78 of the total variance (S) of the MRA and MED over the former 21 years. Most (71%) of the factors in the latter stage were selected from the three monthly (Jan., Feb. and Mar.) 500 hPa height fields of the Northern Hemisphere. The regional height anomalies in monthly atmospheric circulation in advance of one season have a significantly larger teleconnection effect on the MRA and MED in the latter stage than the former, while the OPF (occupied percent of the factor) of regional SST anomalies of the North Pacific dropped from 33% in the former stage to 14% in the latter stage. Xu and Yang (2003) indicated that the factors of the high summer climate in the MLY had changed significantly from the 40-year period (1961–2000) to the 20-year period (1981–2000) as follows: the OPF selected from monthly

500 hPa atmospheric circulation increased from 29.4 to 75.0, while the OPF in the regional SST anomalies of the North Pacific decreased from 23.5 to 0. The above statistics coincide well with the present results, showing that, accompanied by the anthropogenic effects that have been increasing since 1979, the influence of land-atmosphere interaction is now going to be an important cause of inter-annual Meiyu change.

Table 4 General condition of preceding factors of Meiyu periods in two stages

Stage	Origin of factor	MRA			MED			Factor's total number and its percentage
		Factor's number	Month	Parameters[4)]	Factor's number	Month	Parameters[4)]	
1958–1978	500hPa[1)]	2	Jan., Mar.	*R*: 0.88	2	Jan., Mar.	*R*: 0.87	4 (44%)
	SST[2)]	2	Jan., Mar.	*F*: 10.4	1	Feb.	*F*: 13.0	3 (33%)
	R,T[3)]	1	Jan.	*S*: 0.78	1	Mar.	*S*: 0.77	2 (22%)
1979–1999	500hPa[1)]	3	Jan., Feb, Mar.	*R*: 0.95	2	Feb.	*R*: 0.94	5 (71%)
	SST[2)]	1	Jan.	*F*: 40.2	0		*F*: 44.3	1 (14%)
	R,T[3)]	0		*S*: 0.91	1	Feb.	*S*: 0.89	1 (14%)

Note: [1)]Monthly 500 hPa height fields of Northern Hemisphere;[2)] monthly SST fields of North Pacific;[3)] monthly precipitation and monthly temperature at 160 stations in China;[4)] parameters of regression equations, including complex correlation coefficient (*R*), efficiency of regression equation by *F*-test (*F*) and the simulative contribution of factors to the total variance (*S*).

5 Causal analysis of inter-decadal changes of Meiyu periods in two stages

In order to more comprehensively analyze the main preceding factors of the Meiyu periods over 42 recent years, the author identified 2 regression equations with 5 preceding factors (Table 5), whose complex correlations reached 0.75–0.78 and whose simulated contribution to the total variance of MRA over 42 recent years reached 0.56–0.60. The complex correlations of the regression equations for MED and ODHS over 42 recent years only reached 0.60–0.66. Five factors from these regression equations with the highest complex correlations needed are listed in Table 5. The climatic trend of each factor (in Table 5) over 42 recent years was calculated.

It is found that factors (3) and (4) of MRA have no significant climatic trend, which means that 40% of factors of MRA in 42 recent years cannot reflect the inter-decadal changes between the two stages, while each of the five factors influencing the variations of MED and ODHS over the 42 years does manifest its significant climatic trend. Their meanings are described below.

(1) China's industrialization has developed quickly since the late 1970s, causing an abrupt increase in coal burning and smoke. As solar radiation interacts with water vapor, the

increased SO_2 gas in the lower atmosphere tends to gradually transform into an amount of sulphate aerosol equivalent to an annual input of the total SO_2 gas released from an erupted volcano as Mt. Pinatubo (1991), causing a backscattering that reduces the total solar radiation received on the ground (Xu 1990). The G_s (factor (1)) curve shows a clear downward trend over the 42-year period (Figure 5).

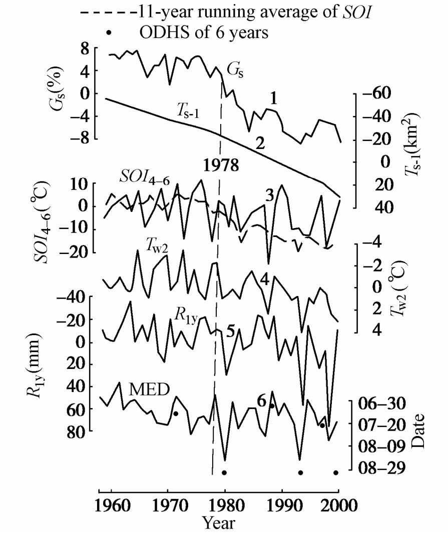


Figure 5 Curves for each of five factors significantly influencing MED and ODHS over 42-year period

(2) Owing to the increasing greenhouse effect, the winter temperature of China has risen by a large degree, so factors (2) and (8) also show a rising trend (Table 5).

Table 5 Primary factors best simulating inter-annual change of Meiyu periods over 42 recent years

	Factor	Effected indices	Climatic trend
(1)	Winter global solar radiations of clear skies at 9 stations in China (G_s)	MRA, MED, ODHS	−
(2)	February and March surface air temperature at 8 stations in southwest China ($T_{w2\text{-}3}$)	MRA	+
(3)	January SST of 4 grid points at 45°N, 160°E-175°E (SST_1)	MRA	unclear
(4)	March 500 hPa height of 5 grid points at 80°N, 20°E-60°E	MRA	unclear
(5)	January precipitation at 10 stations in MLY and the nearby southern region (R_{yj})	MRA	+
(6)	January precipitation at 4 stations in MLY (R_{1y})	MED, ODHS	+
(7)	Average *SOI* during April-June ($SOI_{4\text{-}6}$)	MED, ODHS	−
(8)	February temperature at 6 stations in West China (T_{w2})	MED, ODHS	+
(9)	Sand area of China last year ($T_{s\text{-}1}$)	MED, ODHS	+

(3) The warm and moist winter air stream has tended to strengthen in South China, with factors (5) and (6) showing these trends as well, meaning that January precipitation in the

MLY and the nearby southern region of China shows an increasing trend.

(4) Due to the effects of overgrazing and many years of drought, the sand area of North China has increased year by year. This trend was especially significant in the 1990s (curve 2, Figure 5).

(5) The *SOI* during April–June (factor (7)) significantly influences the summer precipitation in China, but this index has shown a downward trend since the late 1970s (curve 3, Figure 5).

Every factor of MED and ODHS over the 42-year period shows the same long-term trend, leading to significant differences in MED and ODHS between the two 21-year stages. As expounded in section 2, in a few years the ODHS lagged significantly behind the MED, and such kind of ODHS as the 6 dots described in Figure 5, was especially concentrated in the latter stage. In order to determine the combined effects of these factors with climatic trends, the variations of the five factors over the entire 42 years (Figure 5) are displayed in a correlative scatter diagram (Figure 6). All 21 years of the former stage are located in set (Ⅰ), while 21 years of the latter stage are in set (Ⅱ). Abscissa X_2 sums the effects of two factors (G_s, $SOI_{4\text{-}6}$), and ordinate X_3 reflects the combined effects of three other factors ($T_{w2,}$, R_{1y}, $T_{s\text{-}1}$).

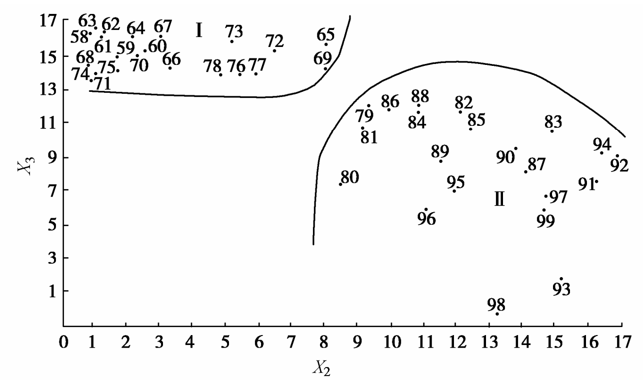


Figure 6 Locations of each of 42 recent years with respect to the combined effects of five factors

The combined effects of the five factors for each of 42 years are displayed in Figure 6. The years clearly fall into two different sets: each year in the former stage (1958–1978) is located in the left upper set (Ⅰ), while each of the latter stage (1979–1999) is located in the right lower set (Ⅱ). This shows that the five factors influencing Meiyu periods have changed significantly, causing an abrupt change of the MED and ODHS between the two stages and the factors influencing the Meiyu period have changed significantly from the former stage to the latter, thus causing an abrupt change of the MED and ODHS between the two stages and so showing an abrupt decadal change of Meiyu periods over 42 years, which means that the atmospheric constitutions over China, the thermal/hydrological conditions of the Chinese underground and the Pacific tropical air-sea circulations changed considerably around the late 1970s. All of them jointly caused an abrupt decadal change in the summer climate between the two 21-year stages in the MLY and throughout East China.

The abrupt climatic change around the late 1970s is an important problem worthy of research. Here the author analyzes the causes of changes occurring in the Meiyu periods (especially the MED) and the locations of summer rainy belts only. The abrupt changes of each factor around the late 1970s can be seen in curves 1, 2, 3 and 4 of Figure 5, and are described in Table 6.

Table 6 Factors triggering the abrupt inter-decadal climatic changes of Meiyu periods in the late 1970s

Factor	Starting time	Conditions of abrupt change
G_s	1978−1979	Without any relation to volcanic clouds, total solar radiation (G_s) of clear skies in China began to drop significantly in the winter of 1978−1979, demonstrating an abrupt rise in atmospheric pollution due to the rapid increase of Chinese industrialization.
$SOI_{4\text{-}6}$	1977	A strong El Niño occurred from April to June in 1977 (curve 3 of Figure 5). The 11-year running average value of this index also shows a downward trend starting in 1977.
T_{w2}	1979	The February temperature of West China rose higher than normal from 1979 to 1982 (curve 4 of Figure 5) due to the greenhouse effect.
$T_{s\text{-}1}$	Mid-1970s	Beginning in the mid-1970s, the expanding rate of sand areas in North China accelerated to 2 100 km^2 per year (Xu 2004).

It can be concluded that the abrupt climatic change occurring in the late 1970s was caused by the combined effects of the above factors (Table 6).

6 Notable newly changing trend of Meiyu

It is evident from curve 1 of Figure 1 that the recent MRA has decreased. The average MRA over 6 recent years (2000–2005) was less than the average MRA over 116 recent years (Xu et al. 2001) by 25.2%; it was even less, by 48.2%, than the average MRA of the preceding 21 years (1979–1999). Three years (2000, 2001 and 2005) either had no Meiyu periods or had significantly smaller MRA. The average MOD of 6 recent years was later than that of the preceding 21 years by 2.3 days, while the mean MED and ODHS of these 6 years were earlier by 4.6 days and 7 days, respectively. Through a *t*-test, it was found that the difference in MRA between 6 recent years and the preceding 21 years was significant (at a 2% confidence level). In addition, the mean anomaly of MRA of the first 6 years in each of the two 21-year stages is an indication of the whole stage, thus the lower MRA of 6 recent years means that a new, lower-MRA stage is coming to the MLY. The average summer rainfall distribution of 6 recent years shows the central axis of a plentiful rainfall region located at 33°N (The Huaihe Basin, Figure 7). Data show that summer waterlogging occurred in the Huaihe Basin in 3 recent years (2000, 2003 and 2005), while the MRA and the total summer rainfall of the MLY were less than normal in each of 6 recent years. Further research on the causes of this new inter-decadal climatic change will be conducted.

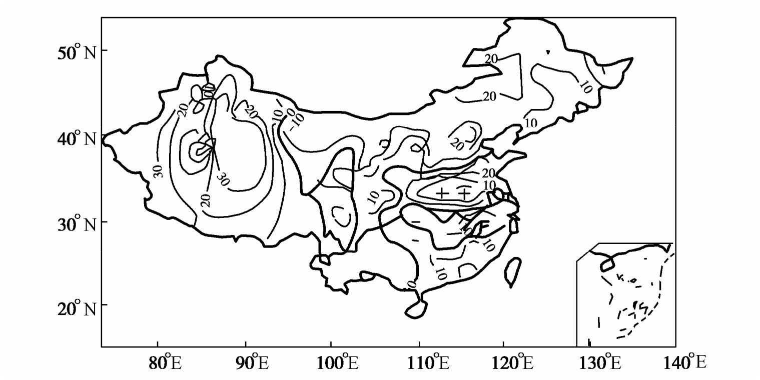


Figure 7 Distribution of average summer rainfall anomaly of China in 6 recent years (2000–2005)

7 Conclusions and discussion

(1) During the Meiyu periods in the MLY, there exists a low frequency quasi period of around 40 years with its most significant inter-decadal oscillations occurring during the 42 most recent years (1958–1999). In the first 21 years of the period (1958–1978), the MRA declined to a century low with an average value less than normal by 26% and a mean MOD that appeared earlier. On the other hand, the MRA of the latter 21 years rose to the second peak since 1885 with a mean value 23% greater than normal, and a mean MED that reached its latest date (July 18–19) since 1885, later than the normal date by 7.6 days. In the latter stage, there was a 66% greater MRA, a later MED than in the former stage by 11 days, and a later ODHS by 12.8 days. In addition, there was an absence of high summer in the MLY for three years during the latter stage, which had never occurred, according to data during the preceding 95 years (1885–1979).

(2) The significant difference in the Meiyu periods between the two stages is only one aspect of the abrupt inter-decadal change in the summer climate in East China. In the former stage, a large-scale area in Central East China from the southern Yangtze Reaches to the Huaihe Basin had less summer rainfall, with the negative anomaly centered in the MLY, and there were areas of plentiful summer rainfall both north and south of the region. The distribution of summer rainfall in the latter stage was generally in contrast to that of the former: plentiful summer rainfall appeared in the MLY and the nearby southern region, while a rainfall-deficient region including a widespread area of North China appeared, with the negative anomaly centered in Shandong peninsula. Such anomaly shows a trend stretching southwesterly to the western part of Sichuan, which corresponds to the plentiful Meiyu with delayed MED/ODHS in the MLY during the latter stage, indicating the southeasterly retreating trend of the summer monsoon rainy belt in China.

(3) Another significant difference between the two stages is the obvious enlargement of the amplitudes of inter-annual change in MRA, MED/ODHS and the summer climate in East

China during the latter stage.

(4) The most significant contrasts in the general circulation of July and August 500 hPa height fields between the latter stage and the former are as follows: more occurrences of blocking high in the East Asian region (100°E–140°E, 50°N–55°N), a more southward site of the West Pacific subtropical high, a significant weakening of the Indian monsoon low and, also, a significant decrease trend in the occurrence of the West Pacific tropical low/typhoon.

(5) Although the occurrences of the blocking high in the westerlies of East Asia were closely related to the MRA and MED, statistical analysis of the 42-year period shows that the relationships are quasi-synchronous, which means the blocking high in East Asia is not a climatic factor in the Meiyu period a month or more in advance.

(6) Large differences also exist in the preceding factors contributing to inter-annual changes in the MRA and MED of the two stages.

(7) Connecting each Meiyu factor in the two 21-year stages to form a 42-year time series through statistical analysis shows that most preceding factors (7 of the 9 factors) of the MRA and MED were both the factors of inter-annual changes in 42 recent years and the factors of inter-decadal changes between the two stages, especially each of the five preceding factors of MED and ODHS (in Figure 5) that have influences on both time scales. They are the winter global solar radiation of clear skies at 9 stations in China, reflecting the time variations of atmospheric pollution, the February surface temperature of West China, the January precipitation in the MLY, the *SOI* during April−June, and the total sand area of North China in the last year. The MRA of each year of the two stages was situated in two independent sets in the correlative scatter diagram for the combined effects of five factors over the 42-year period, clearly showing that the two stages had very different environmental (atmosphere-land) phases, which caused an abrupt inter-decadal change for MRA and especially for MED and ODHS.

(8) The present analysis shows that the causes directly triggering an abrupt change in MRA around 1978–1979 might be ascribed to the combined effects of the following: the large development of China’s economy with the consequently aggravated atmospheric pollution and decreased solar radiation received at the ground, the accelerated expansion of the total sand area in North China, the significant drop of *SOI* during April−June and the anomalous warming of West China in February.

(9) Karl and Trenberth (2003) have pointed out, “modern climatic change is dominated by human influence, which has been (around 1980 since) large enough to exceed the bounds of natural variability. The main source of global climatic change is the change of the atmospheric composition induced by anthropogenic activities, which primarily result from emissions associated with energy use, but on local and regional scales, urbanization and land use changes are also important”. Connecting this to the present analysis, it is reasonable to believe that the abrupt change of the Meiyu period in the MLY since 1979–1980 is not only an inter-decadal change, but an important sign of the beginning of human activities dominating

the global climate. Xu and Yang (2003) as well as the present study show that the components of preceding factors of Meiyu periods since 1979 have changed as follows: the factors originating from SST fields of the North Pacific have decreased significantly, while the factors of 500 hPa monthly circulation have increased rapidly, most of them situated over the northern temperate land area at an α meso-scale (250–2 500 km). In the present era of increasing human activities, the α meso-scale land-atmosphere interactions over Eurasia may play an important role in inter-seasonal teleconnection in the summer climate of Central East China. Now, a new abrupt change of the environmental (land-atmosphere) phase may occur again, at the beginning of the present century. Under the growing influence of the greenhouse effect, the total area of polar ice cover enclosed by the outer edge has been sharply reduced twice, by 52×10^4 km^2 in autumn 2001 and by 60×10^4 km^2 in late 2003, and has a downward trend line of –2 836 km^2 per year since 1978 (NERSC 2005). Owing to the effect of Chinese sand-control, the expanding trend of the total sand area in North China over the last 25 years of the last century has reversed in 2000; from then until the end of 2004, the total sand area decreased annually by 1 283 km^2 (Zhao 2006). The above causes may be related to the following new changes that have occurred since 2000: with the decrease of Meiyu of the MLY, the plentiful summer rain belt of East China moves northward, staying in the Huaihe Basin. We should pay attention to this new trend and to whether this is a further demonstration of the quasi 40-year cycle of the Meiyu period. Additional monitoring and research of the potential new trend in summer water resource distribution in East China is needed in order to adopt scientific countermeasures early.

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