An integrative estimation model of summer rainfall-band patterns in China*

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Abstract Three variation indices are defined to objectively and quantitatively represent fluctuations of three rainfall-band patterns in summers in China for the period from 1951 to 2005, and the variation features of these indices are analyzed on both of interdecadal and interannual scales. A new method is proposed to establish an integrative estimation model based on the analysis of rainfall-band indices, and the model is applied to air, ocean factors to estimate their roles on variations of three rainfall-band patterns on different time-scales. The tests of estimation effects show that the fluctuations of three rainfall-band patterns are composed of variations on both significant interdecadal and interannual scales, of which the interannual variation is mainly influenced by the Elnino/Lanina events, the East Asia monsoon and the ridge locations of subtropical high pressures in western pacific, while the interdecadal variation is mainly controlled by the Pacific decadal oscillation and interdecadal oscillations of the Arctic oscillation, ENSO, Nino3 sea surface temperature and summer monsoon. The estimated results from the integrative estimation model of rainfall-band patterns suggest that the way of estimation first according to each time scale of both the interdecadal and interannual scales, then estimating with an integration, which is proposed in this paper, has an obvious improvement on that without separation of time scales.

Keywords: **rainfall-band pattern, interannual variation, interdecadal variation, integration, estimation model.**

In China, the distribution patterns of summer rainfall bands are one of important contents in the short-term climate forecast. In general, the summer rainfall bands shift from the south of China towards the north of China, and the precipitation decreases progressively from the southeast of China towards the northwest of China in geographic distribution. Due to complicated influences of various factors, however, that the rainfall-band shifts fast or slowly, even stays for a longer period in a region, leads to a big different rainfall-band distribution pattern among particular years. The Climate Forecast Division at the National Climate Center of China summarized three main rainfall-band patterns[1] in the summer rainfall distribution in the east of China since 1951, according to south-north geographic locations of heavy precipitation in summers, i.e. pattern I represents that the main rainfall concentrates in the north of China; pattern II means that heavy precipitation mainly locates in the region between down-reaches of the Yellow River and Yangtze River; pattern III denotes that the summer rainfall mainly falls in the south of China. These three rainfall-band patterns feature well not only geographic distribution of summer rainfall in China but also comparatively make clear of causes in the background of the general atmospheric circulation[2], so that are put into use in the routine forecasts and climate researches.

Zhao[1], Cheng and Zhao[2] analyzed and summarized the features and causes of interannual variations of the patterns in China, including factors in the general atmospheric circulation, ocean, solar activities, and found some effective factors that affect on the rainfall-band locations. Though scientists studied further how to classify and forecast these rainfall-band patterns[3,4], no quantitative representation for the three rainfall-band patterns was found before, so that it is difficult to estimate digitally the interannual and interdecadal variations and the corresponding causes. This paper defines firstly objective and quantitative indices to represent the fluctuations of three summer rainfall-band patterns in China, and analyzes their variation characteristics on interdecadal and interannual scales. Then we propose a new way to establish an integrative estimation model of three rainfall-band patterns.

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1 Data

This work uses both data of precipitation and factors.

1.1 Precipitation data

The data of monthly precipitation at 160 meteorological stations for years from 1951 to 2005 were provided by the Climate Forecast Division at the National Climate Center of China, and the summer rainfall is usually accounted as the sum of monthly precipitation in June, July and August. The anomaly percentages were calculated and used in this study based on yearly summer rainfall and the average over 55 years.

1.2 Physical factors

To establish estimation model of the summer rainfall-band patterns in China, we selected 8 physical factors, which have been proved by previous researches, to be significant influencing factors on summer rainfall in China as:

x_1: Pacific decadal oscillation (PDO) index[5]. It indicates climate variability on interdecadal time scale in Pacific. When the PDO is in its warm phase, the SST in central and east tropical Pacific is abnormally warm, while the SST in the north Pacific is abnormally cold, and *vice versa* for the cold phase of PDO. The PDO has significant affects on the climate in Pacific area[6], and has conditional effects on interannual variability[7].

x_2: Arctic oscillation (AO) index. This is a circular mode of oscillations in the general atmospheric circulation over middle and high latitudes of the North Hemisphere, and it apparently influences the climate in the North Hemisphere area including China[8—10].

x_3: Multivariate ENSO Index (MEI). It is defined as a composition of 6 variables of the ENSO indices in the tropical Pacific. The 6 variables include sea level pressure (SLP), the U and V components of surface wind, sea surface temperature (SST), ground temperature and total amount of clouds. The MEI represents objectively the coupled phenomena of the El Nino and the south oscillation (SO)[11].

x_4: Nino3 SST index. This index is defined as an average of SST over center equator Pacific area between 5°N — 5°S, 150°W — 90°W, where the single of El Nino is the most significant[12].

Above 4 factors are quoted from the Climate Diagnose Center of the National Ocean and Atmosphere Administration of USA.

x_5: East-Asia Monsoon intensity index. This is defined as a difference of SLP between 110°and 160°E in average over 10°—50°N[13]. The intensity of East-Asia Monsoon and interactions with other circulation systems affect importantly the geographic distribution of summer rainfall in China[14—16].

x_6: The intensity index of the subtropical high pressure in the west Pacific. It is defined as the sum of average geopotential height code at 500 hPa 588 dagpm grids[1]. This factor acts importantly on summer floods / droughts in China[17].

x_7: The ridge index of the subtropical high pressure in the west Pacific. This is defined as the average latitudes of 9 cross points of subtropical high ridge passing 9 longitudes from 110°E to 150°E at interval 5°[1]. That the subtropical high ridge in west Pacific moving towards north and backwards to south controls directly the geographic locations of summer rainfall band in China[18].

x_8: The intensity index of geopotential height oves the Qinghai-Tibet plateau. This index is defined as the difference of average heights at 500 hPa over the area between 25—35°N and 80—100°E from the 500 dagpm accumulation[19]. The Qinghai-Tibet plateau is the most important heating source on the Earth and its variation of intensity plays an important role in climate fluctuation in China[20].

The last four factors x_5—x_8 are from the Climate Forecast Division at the National Climate Center of China.

2 Representations of the summer rainfall-band patterns and their variation features on different time scales

For convenience, we take patterns I, II, III respectively to represent the three summer rainfall-band patterns in China, which were classified in experiences by the Climate Forecast Division at the National Climate Center of China[1]. During the period from

1951 to 2005, pattern I occurred in 19 years, pattern II happened in 17 years, and pattern III appeared in 19 years (Table 1).

Table 1. Years in which each pattern of summer rainfall-band occurred for 1951—2005

Pattern	Year
Pattern I	1953 1958 1959 1960 1961 1964 1966 1967 1973 1976 1977 1978 1981 1985 1988 1992 1994 1995 2004
PatternII	1956 1957 1962 1963 1965 1971 1972 1975 1979 1982 1984 1989 1990 1991 2000 2003 2005
Pattern III	1951 1952 1954 1955 1968 1969 1970 1974 1980 1983 1986 1987 1993 1996 1997 1998 1999 2001 2002

Fig. 1 presents the composite rainfall distribution in summer (June-August) for each pattern over corresponding years as listed in Table 1[1]. The features of rainfall geographic distribution of these three rainfall-band patterns are very clearly shown in three panels in Fig. 1 respectively. Pattern I (Fig. 1(a)) characterizes that positive anomalies of rainfall occupy a large area in the Yellow River basin and north of the basin, while negative anomalies of rainfall locates in the region between the Yellow River and Yangtze River basins, and weaker positive anomalies spread also in the south of China. Pattern II (Fig. 1(b)) features positive rainfall anomalies located mainly in the region between the Yellow River and Yangtze River, and higher positive anomalies concentrate in the Huaihe basin. The rainfall in north of Yellow River and south of Yangtze River appears mostly below average. Pattern III (Fig. 1(c)) shows a trait that above average of rainfall is obviously in south of the Yangtze River and along the Yangtze River valley, while rainfall is usually below the normal in north of the Huaihe River and the coastal areas in the southeast of China.

In this work, we defined the 3 variation indices of rainfall-band patterns as correlation coefficients of the anomaly field between the composed anomaly percentage values at 160 stations for each pattern in each year, which are the same as shown in Fig. 1[1]. For the period from 1951 to 2005, we get 55-year correlation coefficients as the index-values for each pattern index time series. For instance, the vertical bar for 1951 in Fig. 2(a) is a correlation coefficient of rainfall anomaly in 160-station field between pattern I as shown in Fig. 1(a) and observed anomaly percentages in 1951, and so on. Due to the sample size is 160 for each correlation coefficient, the significant criterion at confidence 0.05 is 0.16 in the index-value, which is plotted as horizontal dashed lines in Fig. 2. When a pattern index-value in a year is greater than the threshold 0.16, we may determine the geographic distribution of summer rainfall in that year belonging to this pattern. The higher the positive value is, the more typical the pattern of summer rainfall is in that year. If the index value is lower than the threshold 0.16 or is negative, the rainfall pattern in that year should be less similar to this pattern or belong to another pattern.

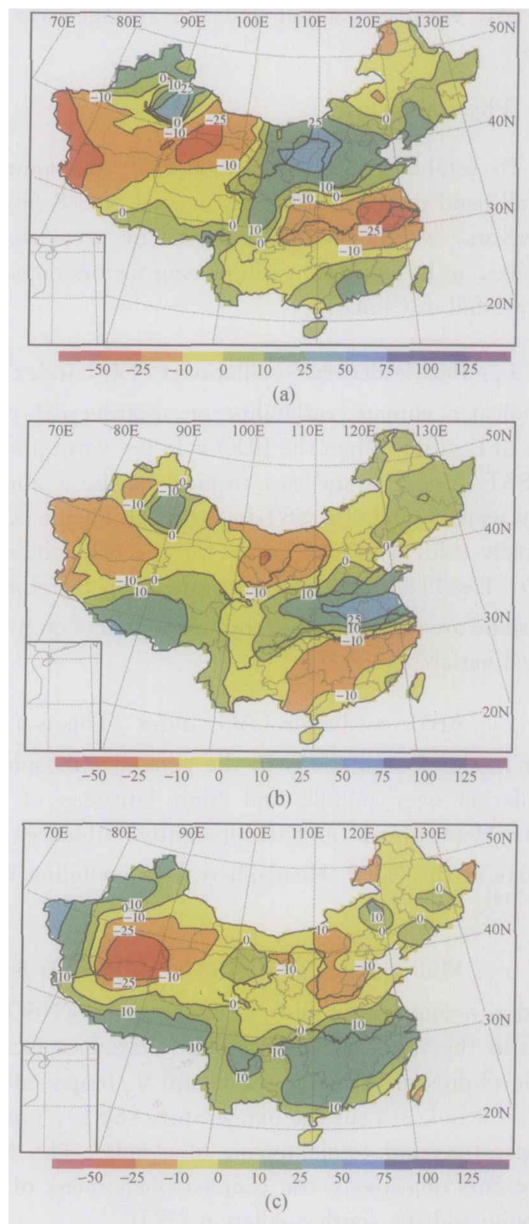

Fig. 1. Three patterns of summer rainfall-band geographic distribution. (a) Pattern I, (b) pattern II, (c) pattern III[1].

Fig. 2(a) illustrates that in 19 years of 55 years (1951—2005) pattern I index values are greater than the threshold 0.16, of that in 17 years agree with those in experienced classification by the Climate Forecast Division at the National Climate Center of China comparing to the years in pattern I in Table 1. Only two years, 1977 and 1981, are classified in pattern I by experience listed in Table 1, which are lower than the threshold 0.16 in our study as shown in Fig. 2(a). It is found, by watching the observational charts of summer rainfall in the two years, that in 1977 there were many regions in the East of China with positive rainfall anomalies, while in 1981 the rainfall was less than normal in most areas in the East of China, so that the rainfall patterns are not apparent. Moreover, two years, 1970 and 1990, are not listed in pattern I in Table 1, but the index-values are higher than the threshold in pattern I in Fig. 2(a). The observational rainfall charts demonstrate that in 1970 the rainfall pattern has features in both of pattern I and pattern III, positive rainfall anomalies spread in the upper-middle reaches of the Yellow River and the south of the northeastern China besides in the Yangtze River valley and south of the river; that in 1990 the rainfall pattern features both of pattern I and pattern II indeed (Fig. 2(a) and (b)).

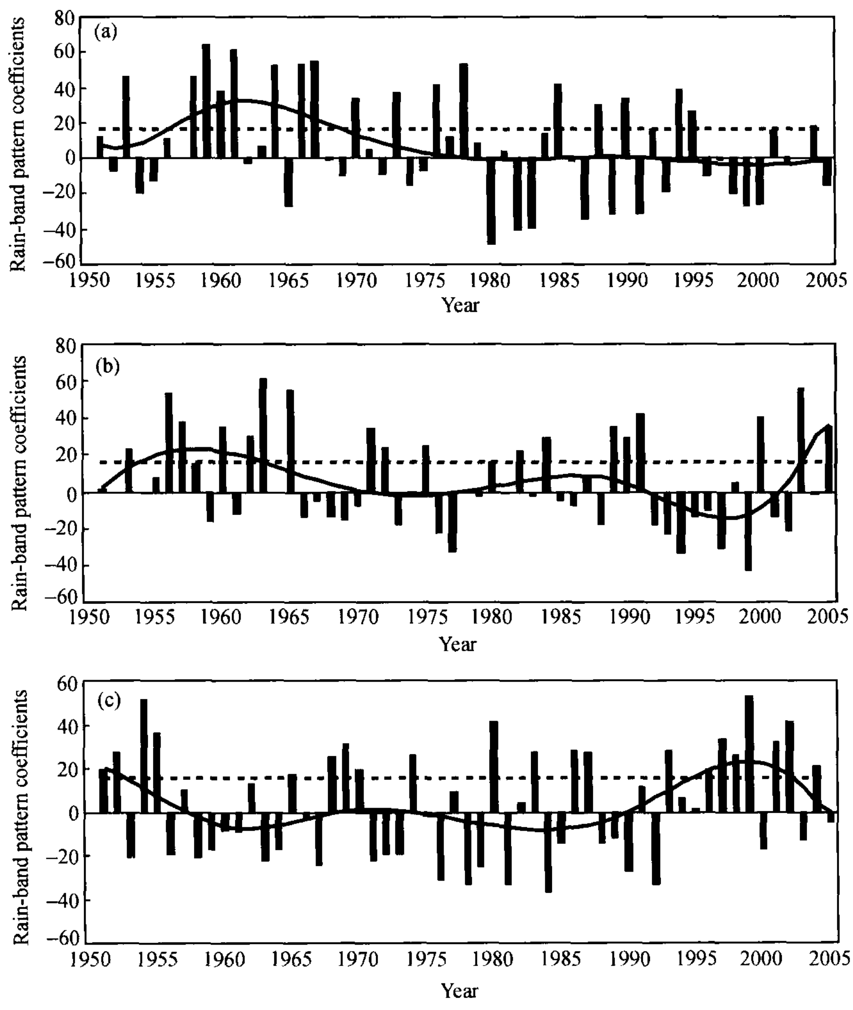

Fig. 2. The yearly index-values of three rainfall-band patterns in China. (a) For pattern I; (b) for pattern II; (c) for pattern III. Vertical bars indicate the yearly index-values, smooth solid curves denote fit in 3-order spline function, and horezonal dashed lines are the threshold at confidence 0.05.

Pattern II index series (Fig. 2(b)) shows that the values are higher than the threshold in 18 years, in which 16 years agree with those in experienced classification comparing to the years in pattern II of Table 1. Only 1979 is classified in pattern II by experience listed in Table 1, which is lower than the threshold in Fig. 2(b). In fact, in 1979 the region with positive anomalies shifts towards the west of the south of the Yellow River, meanwhile the northwest of the north of China had also rainfall more than normal obviously, thus the year should not belong to pattern II. For other two years, 1953 and 1960, are listed in pattern I in Table 1, but the index-values are higher than the threshold in both of pattern II and pattern I in Fig. 2. They feature both of pattern I and of pattern II (Fig. 2(a) and (b)).

From Fig. 2(c) we can see that the values are higher than the threshold in 21 years in pattern III index series. The 19 years listed in pattern III of Table 1 are all consistent with our results shown in Fig.2(c). In addition, in 1965 and 2004 pattern III index-values are slightly higher than the threshold, which means that the geographic distribution of summer rainfall features somewhat got closing to pattern III in these two years.

In totally 3 patterns and 55 years, there are 52 years, in which the pattern index-values are higher than the threshold at confidence 0.05, which agrees well to the classification by experience, i.e. the consistent rate reaches up to 95%. Only in 3 years—1977, 1979 and 1981—the pattern index-values did not pass the threshold at confidence 0.05, and they did not appear indeed similar to any pattern of the three patterns. In practice, the 3 indices of rainfall-band patterns, which were proposed in this paper, represent not only quite well the experienced classifications by the Climate Forecast Division of the National Climate Center of China, but also may denote those years in which the summer rainfall featuring double patterns. Therefore, these 3 pattern-indices may be used as objective and quantitative representations for summer rainfall-band patterns in China.

The smooth solid curves in Fig. 2 are in the 3-order spline approximations of the rainfall pattern-indices. They reveal trends of interdecadal oscillations in the rainfall patterns. It can be seen easily that pattern I (Fig. 2(a)) dominated at the end of the 1950s and at the end of the 1960s, whereas became weaker since the middle of the 1970s. Pattern II (Fig. 2(b)) was in preponderance in the early 1950s and in the middle of the 1960s, and in little superiority in the 1980s comparing to that in the 1970s and the 1990s, in which pattern II was much weaker, but it became stronger since 2000. Pattern III (Fig. 2(c)) differs from other two patterns apparently. It dominated obviously in the 1990s and secondly in the early 1950s, then the pattern became weaker in a long period from the middle of the 1950s to 1980s.

Comprehensively, the summer rainfall-band patterns in China feature both of interannual and of interdecadal fluctuations. In the interdecadal variations, pattern III (the southern pattern) and pattern II (middle pattern) dominated in the early 1950s; pattern I (the northern pattern) and pattern II occupied mainly during the period from the middle 1950s to the middle 1970s; only pattern III was in preponderance in the whole 1990s; pattern II appeared stronger in the early 2000s.

The interannual variations are also obvious in the summer rainfall-band patterns in China. Fig. 3 demonstrates results from the maximum entropy spectrum analyses of three rainfall-band pattern indices. It is shown that pattern I varies in significant periods of 7.71 and 3.0 years, pattern II fluctuates in significant 7.71- and 3.6-year periods, pattern III oscillates in the significant period of 3.0 years only. Thus, the fluctuations of rainfall-band patterns in China are superposed by the interannual and interdecadal variations.

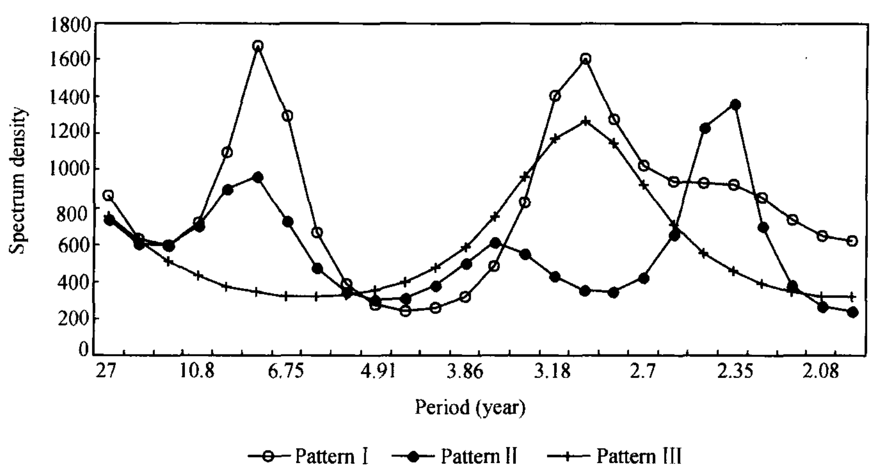

Fig. 3. The maximum entropy spectrum analyses of 3 rainfall-band patterns in China.

3 The integrative estimation model of summer rainfall-band patterns in China

In this section, we propose an integrative estimation model to describe the variations of the summer rainfall-band patterns in China. Its basic principle is to separately estimate variations on different time scales, based on the facts that the summer rainfall-band patterns vary significantly on both of interannual and interdecadal scales, and these two time scales are influenced by different physical factors, such as the interannual fluctuations are affected more by air-sea interactions whereas the interdecadal oscillations are controlled mainly by external forcing. We establish estimation models separately for each of the interannual and interdecadal scales to get better estimations. The model for each of the 3 pattern indices and its statistical relationship with physical factors may be presented as follows:

$$P_k = P_{ak}(x_{di}) + P_{dk}(x_{di}) + e, \qquad (1)$$

where P_k denotes a pattern index to be estimated, $k = 1, 2, 3$; P_{ak} indicates the component of interannual fluctuations; x_{ai} the physical factors which influence the interannual variations of the rainfall pattern, $i = 1, 2, \cdots, 8$; P_{dk} the component of interdecadal oscillations; x_{di} the physical factors which control the interdecadal variations of the rainfall pattern, $i = 1, 2, \cdots, 8$; and e is the white noise.

Firstly, we separate each series of the pattern indices and physical factors into a component series for the interannual scale and another component series for the interdecadal scale, which are fitted by using the 3-order spline function particularly, then establish estimation models for the component on the interannual scale and component on the interdecadal scale respectively:

$$P_{ak} = \beta_0 + \beta_1 x_{a1} + \beta_2 x_{a2} + \cdots \beta_8 x_{a8}, \qquad (2)$$

$$P_{dk} = \beta_0 + \beta_1 x_{d1} + \beta_2 x_{d2} + \cdots \beta_8 x_{d8}, \qquad (3)$$

where $\beta_0, \beta_1, \cdots, \beta_8$ are regressive coefficients to be estimated. It may be proved with the method of eigene-root condition number[3] that there exists no complex common linearity, i.e. no any linear correlation among the 8 physical factors, such as PDO, AO, ENSO and others. Thus we may utilize the method of stepwise selection to evaluate regressive coefficients in (2) and (3). Taking results from (2) and (3) into (1), we obtain all estimation values of each pattern index year by year.

Drawing supports from correlationship between the stepwise selected factors and the pattern indices of rainfall-band, we may evaluate not only the interannual and interdecadal variations of the rainfall patterns, but also can explain the influence-extent of each factor on the transformation or abnormality of the rainfall patterns.

Table 2 lists regressive coefficients that were stepwise-selected into the estimation models of 3 rainfall patterns for interannual fluctuations. We can see that the selected factors in the estimation model of the pattern I for interannual variation are the ENSO index, x_{a3}, the Nino3 SST, x_{a4}, and the ridge index of the subtropical high pressure in west Pacific, x_{a7}, of which the signs of regressive coefficients for x_{a3} and x_{a7} are positive, whereas negative for x_{a4}. This means significant influences of these three factors on the interannual variation of pattern I. When the south oscillation (SO) is stronger than normal, the Nino3 SST is in the cold phase, i.e. the Lanina event occurs, and the ridge of the subtropical high pressure in west Pacific locates at further northern than normal, the heavy rainfall-band appears in the Yellow River basin and north of the river, whereas deficient rainfall happens in the Yangtze River and Huaihe valleys. The factors in the model of pattern II for interannual fluctuations are the ENSO index, x_{a3}, the Nino3 SST, x_{a4}, and the East-Asia Monsoon intensity index, x_{a5}, where the signs of regressive coefficients for x_{a3} and x_{a7} are opposite to those for pattern I. It suggests that when the SO is weaker than normal, the Nino3 SST is in the warm phase, i.e. the typical El Nino event happens, and the East-Asia Monsoon is more intensive than normal, the heavy rainfall-band falls in the region between the Yellow River basin and the Yangtze River valley, whereas the summer rainfall is less than normal in north of the Yellow River and south of the Yangtze River. It is worthy to note, that the ENSO and the Nino3 SST play roles onto pattern II opposite to those onto pattern I. The model of pattern III contains two significant factors, the East-Asia Monsoon intensity index, x_{a5}, and the ridge index of the subtropical high pressure in west Pacific, x_{a7}. It is interesting that the East-Asia Monsoon plays action on pattern III in contrast with that onto pattern II, whereas the subtropical high pressure in west Pacific acts on pattern II in antithetic to that onto pattern I, i.e. when the East-Asia Monsoon is weaker than normal and the subtropical high pressure in west Pacific locates more southern than normal, the high rainfall-band occupies in Yangtze River basin and south of the river, whereas the rainfall is deficient in north of the Huaihe valley.

Table 2. Regressive coefficients in the estimation models of 3 rainfall patterns for interannual fluctuations

Pattern	x_{a1}	x_{a2}	x_{a3}	x_{a4}	x_{a5}	x_{a6}	x_{a7}	x_{a8}
I			28.2927	−40.7956			6.1003	
II			−18.3817	30.9733	51.7418			
III					−38.6058		−4.2042	

Generally, the estimation models suggest that the important factors affecting the abnormities and variations of the 3 patterns of the summer rainfall-band in China are the El Nino / Lanina events, the East-Asia Monsoon and the location of the subtropical high pressure in west Pacific.

The regressive coefficients in the estimation models of 3 rainfall patterns for interdecadal oscillations are shown in Table 3. The first 5 of 8 factors contribute significantly to the interdecadal oscillations in the 3 rainfall patterns. According to the sign of individual regressive coefficient, when the Nino3 SST x_{d4} and the PDO x_{d1} are in cold phases, the AO x_{d2} is weaker than normal, while the ENSO x_{d3} and the East Asia monsoon x_{d5} is stronger than normal, pattern I occurs, i.e. the heavy summer rainfall-band tends to fall in northern China. The effects of the factors on pattern II are much different from those on pattern I, 4 of the 5 factors affect oppositely except for the factor AO, i.e. when the Nino3 SST and the PDO are in warm phases, while the AO, ENSO and the East Asia Monsoon are weaker than normal, the high rainfall-band tends to fall in the region between Yellow River and Yangtze River, i.e. pattern II comes. A contrary consequence emerges between pattern III and pattern I, but the East Asia Monsoon acts stronger while the ENSO and PDO influence comparatively weaker pattern I. When the Nino3 SST and PDO are in warm phases, the AO is stronger than normal, while the ENSO and summer monsoon are weaker than normal, the summer rainfall-band is likely to shift towards the southern China.

Table 3. Regressive coefficients in the estimation models of 3 rainfall patterns for interdecadal oscillations

Pattern	x_{d1}	x_{d2}	x_{d3}	x_{d4}	x_{d5}	x_{d6}	x_{d7}	x_{d8}
I	−42.8077	−41.1005	29.6830	−50.1969	34.1808			
II	23.8399	−85.2634	−47.9696	50.2044	−16.5450			
III	13.9272	45.7151	−15.2315	57.0377	−51.2450			

By integrating results of the estimation models of 3 rainfall-band patterns for both of the interannual and interdecadal variations, we may produce estimations of summer rainfall-band patterns for each year during the period from 1951 to 2005. In order to compare effects of this new way of estimation model to those without separations of interannual and interdecadal scales, we established and computed correspondingly statistical models including the factors selected in stepwise and the signs of regressive coefficients but without separations of time scales, and found that the results are very close to those listed in Table 2 except for some differences in magnitude of the regressive coefficient only. Table 4 lists accurate percentages for each of the 3 rainfall patterns and corresponding models without separations of interannual and interdecadal scales. These suggest that the models without separations of time scales account for correlationships of the rainfall-band patterns with selected factors on the interannual time scale only, but fail to reveal oscillations on the interdecadal scale, so that the estimated accuracies are quite low, whereas the percentages of hits are obviously improved by the new method with separations of the interannual and the interdecadal scales (Table 4). In addition, the estimations for pattern III, i.e. for the southern pattern, are apparently lower than patterns I and II in both of the models with and without separations of time scales, suggesting that the abnormality and variations of summer rainfall in the southern China are complicatedly controlled by some physical factors.

Table 4. Comparisons of accuracies (%) of two kinds of estimation models of 3 rainfall patterns

	I	II	III
The models with separations	84	71	63
The models without separations	37	42	16

4 Conclusions and discussion

(1) Three rainfall-band pattern indices, which are defined in this paper, may objectively and quantitatively represent features of summer rainfall-band patterns in China. Analyses show that the variation of the three patterns is superposed of significant interdecadal and interannual fluctuations. The northern pattern (pattern I) and the middle pattern (pattern II) dominated during the period from the middle 1950s to the middle 1970s. Pattern I declined after the middle 1970s. The southern pattern (pattern III) was significantly rife in the whole 1990s. Pattern II (middle pattern) tended to increase in the early 2000s. The interannual fluctuations are similar between pattern I and pattern II, both vary in significant periods of 7—8 years and of 3—4 years, whereas pattern III oscillates significantly in a 3-year period.

(2) The El Nino/Lanina events, the East Asia Monsoon and the ridge locations of subtropical high pressures in western Pacific influence significantly the interannual variations of three rainfall-band patterns. When the Lanina event occurs and the ridge location of subtropical high pressures in western Pacific is prone to northern than normal, pattern I occurs in higher possibility. When the El Nino event happens and the East Asia Monsoon is stronger than normal, the pattern II comes out in higher possibility. When the East Asia Monsoon is weaker than normal and the ridge location of subtropical high pressures in western Pacific is prone to southern than normal, pattern III happens in higher possibility.

(3) The PDO and interdecadal oscillations of the AO, ENSO, Nino3 SST and the summer monsoon control mainly the interdecadal oscillation of summer rainfall-band. These 5 factors affect pattern I oppositely with that on pattern III, whereas they affect pattern II similarly to those on pattern III except for the factor AO similarly to that on pattern I in the interdecadal oscillations.

(4) We proposed a new way to establish an integrative estimation model based on apparent difference of physical factors affecting variations of the rainfall-band patterns on interdecadal scale from those on interannual scale. The results of estimations show that the new way by integrating results of estimations with separations of time scales obtains much improvements comparing to that without separations of time scales. It suggests that this new method might be applied to the short-term climatic forecasts. Of course, this is based on searching previous predictors that influence the variations of rainfall-band on interannual and interdecadal scales. One were believable to have a help to obtain more objective and quantitative forecasts if a certain estimation of the probably coming rainfall-band pattern had been firstly gotten when preparing the rainy season floods/droughts forecasts.

References

1 Zhao Z. The Summer Droughts/Floods in China and Environmental Fields (in Chinese). Beijing: Meteorological Press, 1999, 1—9.

2 Cheng X. and Zhao Z. A Study of Precipitation Forecasts for Rainy Season in China and Applications (in Chinese). Beijing: Meteorological Press, 2000, 1—20.

3 Sun L., Zhao Z., Xu L. et al. Classification of summer rainfall patterns for rainy season in the Eastern China and analysis of the circulation causes. Journal of Applied Meteorological Science (in Chinese), 2005, 16 (supl): 56—62.

4 Xu L., Zhao Z., Sun L. et al. Classification of large scale pluvial (deficient) patterns in China and analysis of the environmental field features. Journal of Applied Meteorological Science (in Chinese), 2005, 16 (sup): 77—84.

5 Mantua N. J., Hare S. R., Zhang Y. et al. A Pacific interdecadal climate oscillation with impacts on salmon production. Bull Amer Meteor Soc, 1997, 78: 1069—1079.

6 Bond N. A. and Harrison D. E. The Pacific decadal oscillation, air sea interaction and central north Pacific winter atmospheric regimes. Geophys Res Lett, 2000, 27(5): 731—734.

7 Minobe S. and Mantua N. J. Interdecadal modulation of interannual atmospheric and oceanic variability over the North Pacific. Progress in Oceanography, 1999, 43: 163—192.

8 Thompson D. W. J. and Wallace J. M. The Arctic oscillation signature in the wintertime geopotential height and temperature fields. Geophys Res Lett, 1998, 25: 1297—1300.

9 Gong D., Zhu J. and Wang S. Significant correlation between summer rainfall in Changjiang basin and previous Arctic oscillation, Chinese Science Bulletin (in Chinese), 2000, 47(7): 546—549.

10 Wei F., Song Q. and Han X. Distribution structure of sea surface pressure in the North Hemisphere for the last 100 years and its influences on plum abnormality in the middle-lower reaches of Changjiang. Progress of Natural Sciences (in Chinese), 2006, 16 (2): 215—222.

11 Wolter D. W. J. and Timlin M. S. Measuring the strength of ENSO—how does 1997/98 rank? Weather, 1998, 53: 315—324.

12 Cane M. A., Zebiak S. E. and Dolan S. C. Experimental forecasts of El Nino. Nature, 1986, 321: 827—832.

13 Zhao H. and Zhang X. Relationships between the East Asia monsoon and summer rainfall band in China. Meteorological Monthly (in Chinese), 1998, 19(9): 3—8.

14 Wang Q., Ding Y. and Jiang Y. Relationships between the activities of Asia monsoon and precipitation in mainland China. Journal of Applied Meteorological Science (in Chinese), 1998, 9 (suppl): 84—89.

15 Cheng L., Zhu Q. and Lu H. The East Asia Monsoon (in Chinese). Beijing: Meteorological Press, 1991, 1—360.

16 Xue F. Interannual to interdecadal variation of East Asian summer monsoon and association with the global atmospheric circulation and sea surface temperature. Advances in Atmospheric Sciences, 2001, 18(4): 567—575.

17 Huang J., Liu K. and Zhao X. Influence of factors of the subtropical high pressure and Arctic eddy on summer rainfall in China. Chinese Atmospheric Science (in Chinese), 2004, 28(4): 517—526.

18 Zhang Q. and Tao S. A study of jumping towards north and abnormality of summer subtropical high pressure in western Pacific. Acta Meteorologica Sinica (in Chinese), 1999, 57(5): 539—548.

19 Zhao Z. The Long-term ocillations of summer potential height field in Tibet and climte change. Acta Meteorologica Sinica (in Chinese), 1995, 53(1): 108—114.

20 Sun Y. and Ding Y. The influence of abnormally heating source in Tibet on abnormally activities of the East Asia summer monsoon in 1999. Chinese Atmospheric Science (in Chinese), 2002, 26(6): 817—828.