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ANALYSES OF INTRASEASONAL OSCILLATION CHARACTERISTICS OF FLOOD-CAUSING RAINSTORMS IN XIJIANG RIVER VALLEY DURING THE ANNUALLY FIRST RAINING SEASON IN THE PAST YEARS

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Abstract: Based on the daily precipitation data of nine stations representing the Xijiang River valley and the National Center for Environmental Prediction/National Center for Atmospheric Research (USA) reanalysis data, this study uses the wavelet analysis and band-pass filter methods to investigate the atmospheric intraseasonal oscillation characteristics of flood-causing rainstorms in the valley during the annually first raining seasons in 1968, 1994, 1998, 2002 and 2005. Results show that the daily precipitation in the valley exhibits significant quasi-biweekly (10 to 20 days) oscillations. The flood-causing rainstorms in the valley were mainly associated with the confluence of low-frequency warm and humid airflow in the lower latitudes and cold and dry airflow in the higher latitudes. The low-frequency vortexes were propagating or in control when this type of rainstorms took place over the valley, being favorable for the convergence of moisture at lower levels and thus vital to the formation of the rainstorms.

Key words: rainstorms; intraseasonal oscillation; filter; Xijiang River valley; annually first raining season

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1 INTRODUCTION

Xijiang River is a main branch of the Pearl River. While several of its main branches inside Guangxi Zhuang Autonomous Region flow from northwest to southeast, its lower reach—starting from Wuzhou of Guangxi and through Guangdong Province, flows generally from west to east. As shown in the data of the past 40 years, flood-causing rainstorms took place in the valley in the Junes of 1968, 1994, 1998, 2002, and 2005. Unusually, severe floods occur in the Guangdong section of the Xijiang River when flood water coming from its upper and middle reaches mixes with heavy rainfall of the province. In the few days before and after 24 June 2005, huge floods were observed over the valley as a main astronomical tide coincided with heavy rainfall.

As shown in studies, atmospheric low-frequency oscillations are closely related with medium- and short-term climate and short-term weather changes. Quasi-biweekly oscillations—an important component of these oscillations, play significant roles in the monsoon regions of South Asia and East Asia[1]. Substantial intraseasonal oscillations (ISO) exist in the activity of monsoons. A recent study by Li et al.[2] clearly indicates that the activity of ISO in the tropical atmosphere is important to the establishment and anomaly of Asian monsoons. Atmospheric ISO in the tropics is closely related with the evolution of monsoon systems (their onset, active, break, and retreat phases) and regional droughts and floods[3-9]; accurate forecasts of the evolution may help improve short-term forecasts of monsoons. In the Asian-Australian Monsoon Research Prospectus (AAMRP), ISO was listed as one of the frontiers and key issues in international research in the few years to come. At present, significant achievements have been obtained and much progress has been made in the observation of the general characteristics of global ISO and tropical atmospheric ISO and the mechanisms behind them. A new point of view holds that taking into account the air-sea interactions should become the main direction in the research of

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atmospheric ISO in the tropics; air-sea coupling models may be the best possible means of research[10]. The anomalous variation in the monsoon system of East Asia is the principle governing factor of the anomalies of weather and climate (especially precipitation) that cause disasters in China. As shown in studies, the flood disasters in the eastern China are very much related to the ISO in tropical atmosphere; especially, the precipitation in the middle and lower reaches of the Yangtze River and southern China is closely related to the propagation of low-frequency oscillations (LFO). The occurrences of flood disasters in the valley of the Yangtze River in 1998 are connected with the convergence of the low-frequency cyclones from the low latitudes and mid- and high-latitudes (Chen et al.[11]). In a study on the ISO during the precipitation of a flooded area over the valleys of the Yangtze and Huaihe Rivers during the Meiyu season of 1991 (Mao et al.[12]), the LFO was shown to have important contribution to the formation of these floods; the LFO of the precipitation in the valleys of the Yangtze and Huaihe Rivers is closely related with the low-frequency variation and propagation of a 500-hPa subtropical high in North Pacific. According to Lin et al.[13], who presented an analysis of the background of monsoon circulation for sustained rainstorms in southern China in June 2005, the process—lasting from June 18th–23rd, can be attributed to the northward propagation of the ISO of tropical monsoon to the southern part of China. So far, most of the previous work focuses on the relationship between the precipitation or hard rain in the east of China and the atmospheric LFO, especially with regard to the connection between the LFO and droughts and floods in the valleys. For the flood-causing rainstorms in the Xijiang River valley, although the mechanisms of generation and methods of forecasting have been studied using the composite analysis[14] and analogue forecast[15], in addition to some other relevant work, study remains relatively little on the relationship between the rainstorms during the annually first rainy season in the valley and the atmospheric LFO. In this study, the wavelet analysis and Butterworth band-pass filter were used to conduct a preliminary investigation into the LFO characteristics of this type of heavy rain in the valley in the Junes of 1968, 1994, 1998, 2002, and 2005, in the hope of providing some basis of reference and useful clues in the medium-term forecast of the rains that cause floods.

2 DATA AND METHODS

Nine representative stations (Du'an, Fengshan, Liuzhou, Nanning, Hexian, Guiping, Guilin, Wuzhou, and Gaoyao) over the Xijiang River valley (roughly bounded by 22.5–27° N, 107.5–115°E) April through September in 1968, 1994, 1998, 2002, and 2005 were selected for their daily rainfall. The data during these months were used for comparison and to highlight the characteristics of the annually first rainy season. Having been processed for anomaly to remove the effect of seasonal change tendencies, the NCEP/NCAR daily reanalysis data—at a resolution of 2.5° ×2.5° for the corresponding time period, were used. The averages of daily rainfall for these nine stations were used to represent the series of daily precipitation amount of the valley, and the Mexican hat wavelet analysis[16] and the Butterworth band-pass filter[17] were the methodology in analyzing the LFO characteristics of the rains in question. For the five years to be studied the flood-causing torrential rains occurred on 19–29 June 1968, 8–18 June 1994, 18–25 June 1998, 9–16 June 2002, and 15–23 June 2005, respectively.

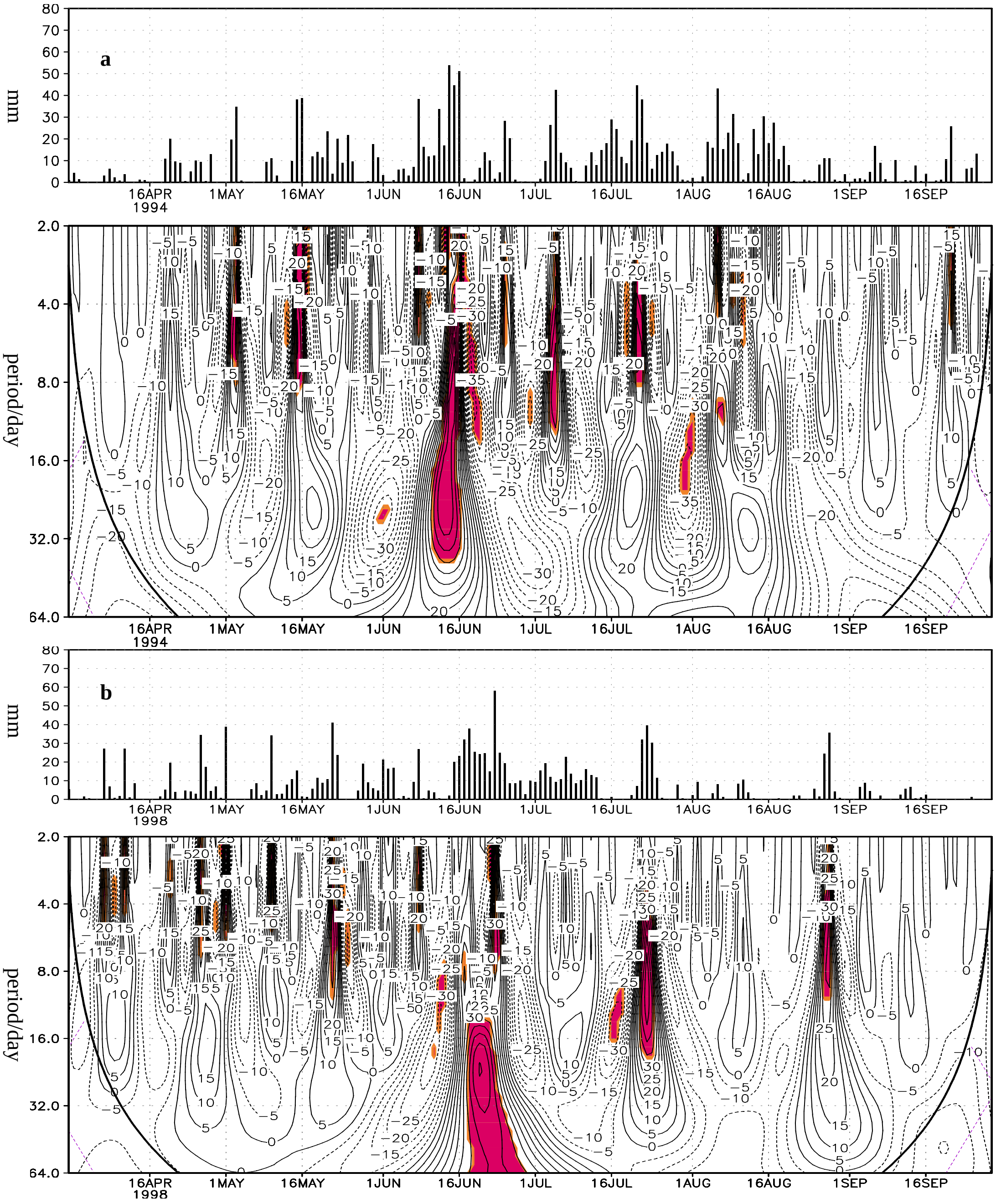
3 LFO CHARACTERISTICS OF FLOOD-CAUSING TORRENTIAL RAINS IN THE RAINY SEASON

Wavelet analysis was performed for the precipitation series of the valley for a total of 183 days in April through September of the five years; the years of 1994, 1998 and 2005 (Fig. 1) were studied. Results are as follows. Significant quasi-weekly oscillations of 5 to 8 days and quasi-biweekly oscillations of 10 to 22.5 days were observed from April to September of 1968 (figure omitted); the former oscillations mainly occurred in April to mid-May, mid-July and September, and the latter oscillations mainly in late May to mid-July and August. Significant quasi-biweekly oscillations of 5 to 8 days and 10 to 28 days were observed from April to September of 1994 (Fig. 1a); the former oscillations mainly occurred in early April and from late August to September, and the latter oscillations mainly from mid-April to mid-August. In 1998, quasi-weekly oscillations of 5 to 7 days and quasi-biweekly oscillations of 10 to 20 days were observed from April to May, significant quasi-biweekly oscillations of 10 to 22.5 days from June to July, and significant quasi-weekly oscillations of 5 to 7 days from August to September. In 2002 (figure omitted), periodic oscillations of 20 to 30 days were observed in May, quasi-biweekly oscillations of 10 to 20 days from June to August, and significant oscillations of 10 to 30 days in September. In addition to these, significant periodic oscillations of 5 to 8 days existed from April to August. In 2005 (Fig. 1c), quasi-biweekly oscillations of 8 to 15 days were observed from mid-April to July, quasi-weekly oscillations of 5 to 8 days and 30 to 60 days in August and September.

For these five years, the wavelet coefficients are positive during the flood-causing torrential rains in the river valley, suggesting relatively large amount of rainfall. These rains correspond well to the positive phase of the quasi-biweekly oscillations.

4 CONTRIBUTION OF VARIANCE OF LOW-FREQUENCY WIND FIELD

Figure 2 gives the spatial distributions of variance contribution by a 10-20 day filter of the 850 hPa wind field for Aprils, Mays and Junes of 1968, 1998, 2002, and 2005, respectively, and a 10-30 day filter of the 850 hPa wind field for April, May and June of 1994, respectively; they show the characteristics of the low-frequency wind field among different areas. In the annually first rainy seasons of the five years, the overall variance contribution by the low-frequency wind field is between 10% and 70% and the central variance contribution is between 30% and 70%, with the area of the maximum variance contribution located in the Indo-china Peninsula and South China Sea. This shows the presence of active low-frequency wind fields in these regions, which is related with the significant low-frequency characteristics of the Southwest Monsoon.



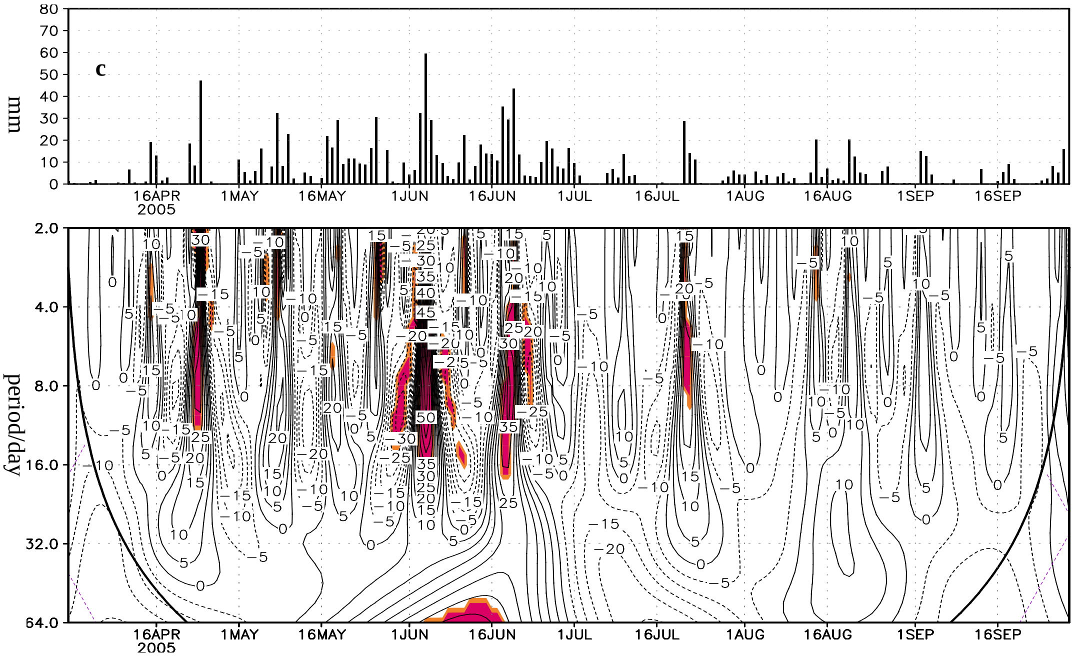
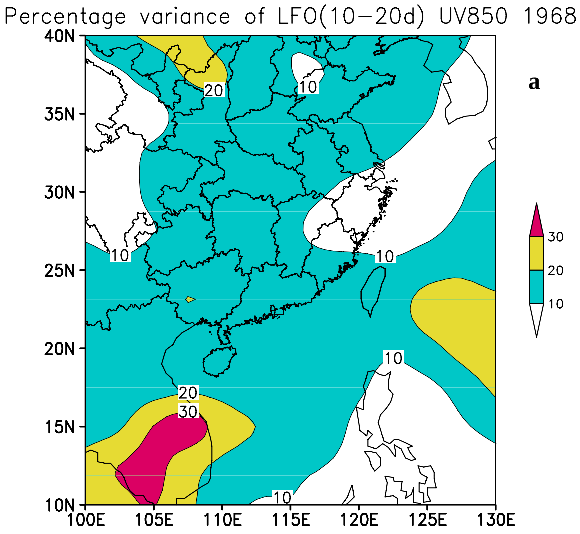
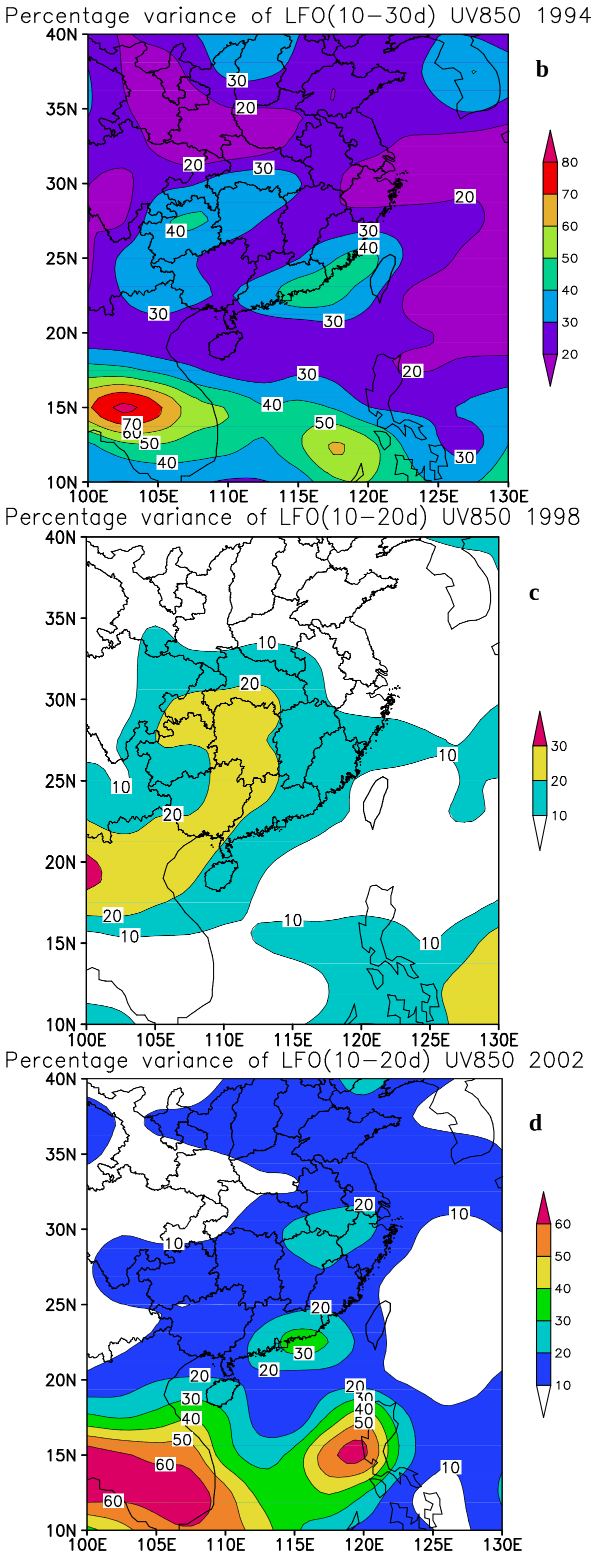


Fig. 1. Mexican-hat wavelet analysis of precipitation amount over the Xijiang River valley from April to September in 1994 (a), 1998 (b) and 2005 (c). The shades indicate the areas surpassing the 0.05 significance level and the overlapped areas on two sides stand for the domains of boundary-layer effects

5 VARIATION OF LOW-FREQUENCY WIND WITH TIME

A 10-20 day filter and a 10-30 day filter were performed on the 850 hPa anomalous wind field of 1968, 1998, 2002, and 2005 and that of 1994, respectively before undertaking analysis of the filtered wind fields for June 1st–30th. Results indicated that during the flood-causing heavy rain of June 1968, a northeasterly flow, formerly located northwest of the a low-frequency anticyclone near the island of Taiwan from June 17th–21st, began to move northward on June 22nd–23rd, which were followed by the northward shift of the northeasterly dominant over the Xijiang River basin. At the same time, a southwesterly airflow, located at the northwestern side of the low-frequency anticyclone, met with a southwesterly airflow in front of the low-frequency trough over the Bay of Bengal, forming a cold shear over the valley (Fig. 3a). On June 24th–25th, the center of the low-frequency anticyclone in northern South China Sea headed north and a southwesterly airflow to its northwest then controlled the Xijiang River valley. On June 26th–29th, the anticyclone kept moving northward to areas near the East China Sea, with the southeast-east wind to the south taking control of the valley, ending the precipitation gradually. In the case of June 1994, a south-to-southwest jet stream, located to the northwest of a low-frequency anticyclone with its center in northeastern South China Sea, affected the valley on June 8th–14th and encountered on June 15th the northeasterly flow of a low-frequency cyclone centering on the East China Sea to form a warm shear over the valley area (Fig. 3b); on June 16th–18th, north-to-northeast winds north of the shear moved south, resulting in the disappearance of the shear and dominance of the northeasterly airflow over the valley, and subsequent weakening and ending of the precipitation. In the case of June 1998, the part of the Chinese continent south of 30° N was dominated by a southwesterly wind west of a low-frequency anticyclone from the northern South China Sea to West Pacific on June 11th–16th, which supplied moisture and energy needed for the onset of a flood-causing torrential rain in the valley on June 18th–25th. North of the valley, a north-to-northeast wind prevailed east of a low-frequency anticyclone over central China and south of the valley, a west-to-southwest wind dominated in front of a low-frequency trough over eastern China on June 17th–20th. Located in a weak convergence zone, the valley witnessed the formation of a low-frequency cyclonic circulation on June 21st as the above two winds merged; the valley was generally under the control of a low-frequency cyclone on June 23rd (Fig. 3c). In fact, the valley had been within an enhancing low-frequency cyclonic circulation field until June 24th, suggesting that the presence of a converging low-level flow field over the valley is conducive to heavy rains that cause floods. On June 25th, the low-frequency cyclonic circulation began to move south and the valley was gradually in the control of a low-frequency anticyclone, which led to the ending of the precipitation. In the case of June 2002, a west-to-southwest airflow, originating from the South China Sea, prevailed south of the valley while a northerly dry and cold airflow, initiating from behind the East Asian trough, was active north of the valley on June 9th–10th, exposing the valley to a weak convergence. On 11th–14th, airflows converged significantly (Fig. 3d), winds increased substantially, and a shear, formed from the cold and warm low-frequency airflows, controlled the low level above the valley to increase the precipitation there. On 15th–16th, the shear weakened a little and gradually moved south toward the coast of southern China as severe rainfall persisted. Starting from June 17th, westerly winds prevailed over the valley and precipitation weakened. In the case of June 2005, a warm and humid west-to-southwest airflow northwest of a low-frequency anti-cyclone in the South China Sea controlled the southern part of the valley on June 15th–19th, making the wind speed convergent. On June 20th, a northwesterly flow west of the low-frequency cyclone in the north began to join a west-to-southwest flow in the south (Fig. 3e), and the valley happened to be in an area where they met. On June 22nd, a band in which the west-to-southwest wind converged with the northwest wind moved south while weakening slightly. On June 23rd, precipitation ended as the northwesterly wind took control in the valley. From the above description of how the 850-hPa wind field varied during the heavy rains that caused floods in the five years, one knows that this type of rain is the result of a low-frequency system or shear formed from the convergence of a cold and a warm regime coming respectively from north and south, while the wind direction of the valley was always invariable or affected by a diverging flow field when it is not the raining season.





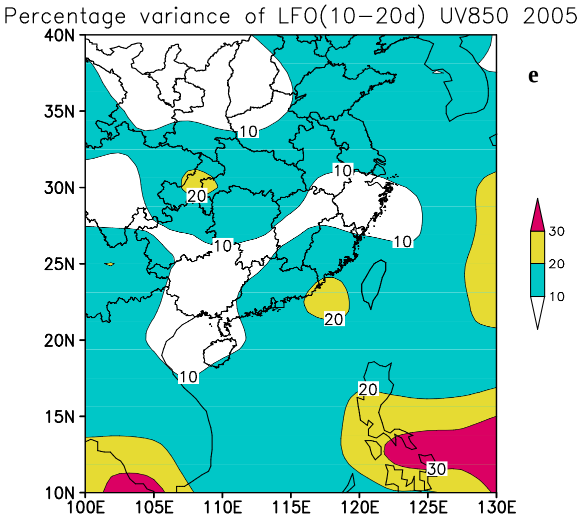
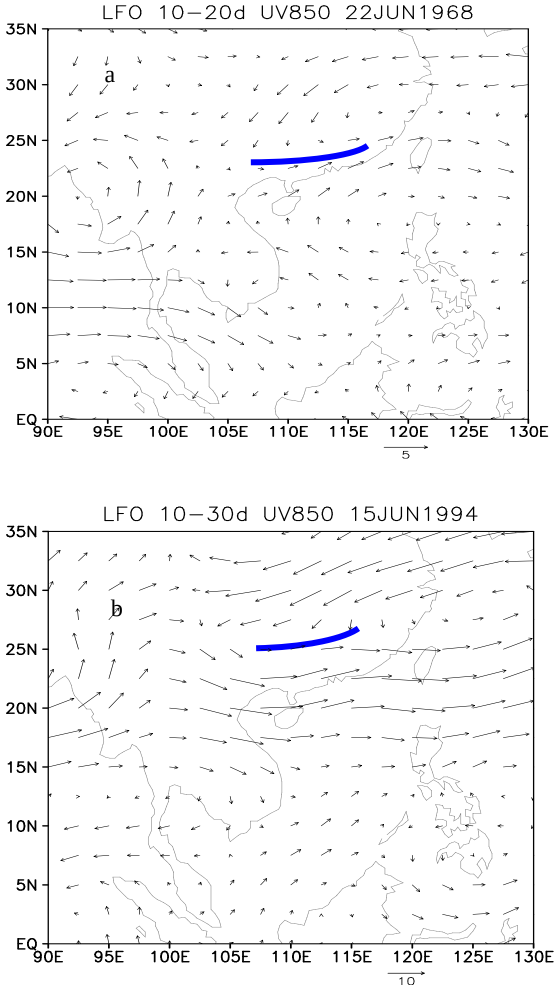


Fig. 2. Contribution of variance by the 850-hPa low-frequency wind field in April to June of 1968, 1994, 1998, 2002, and 2005 (Unit: m/s)



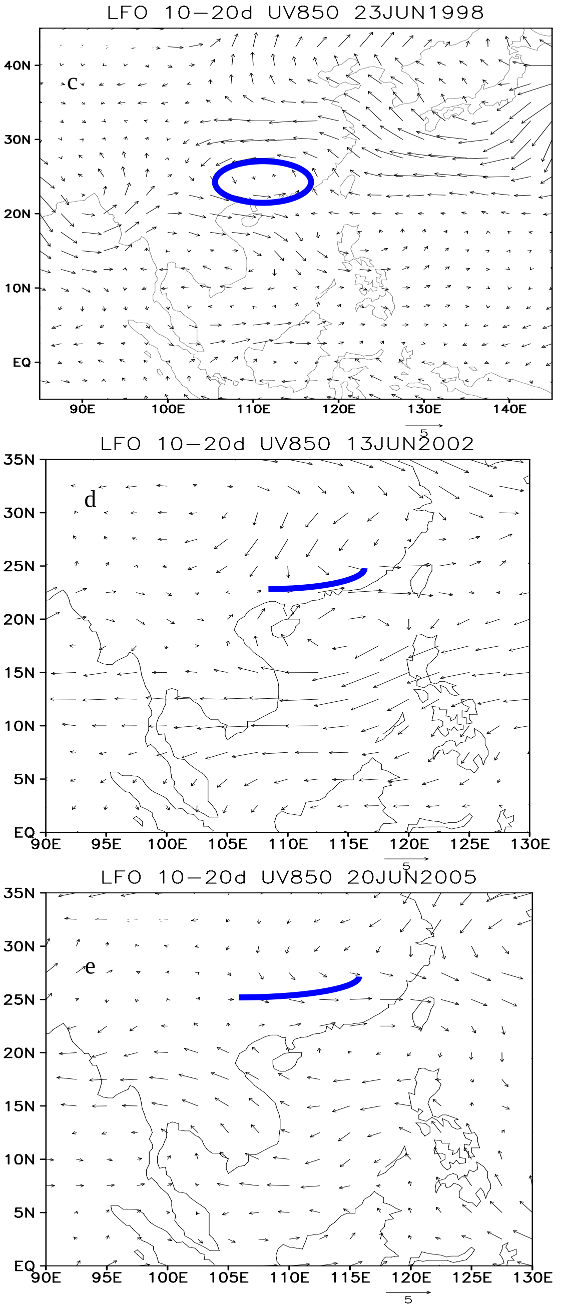
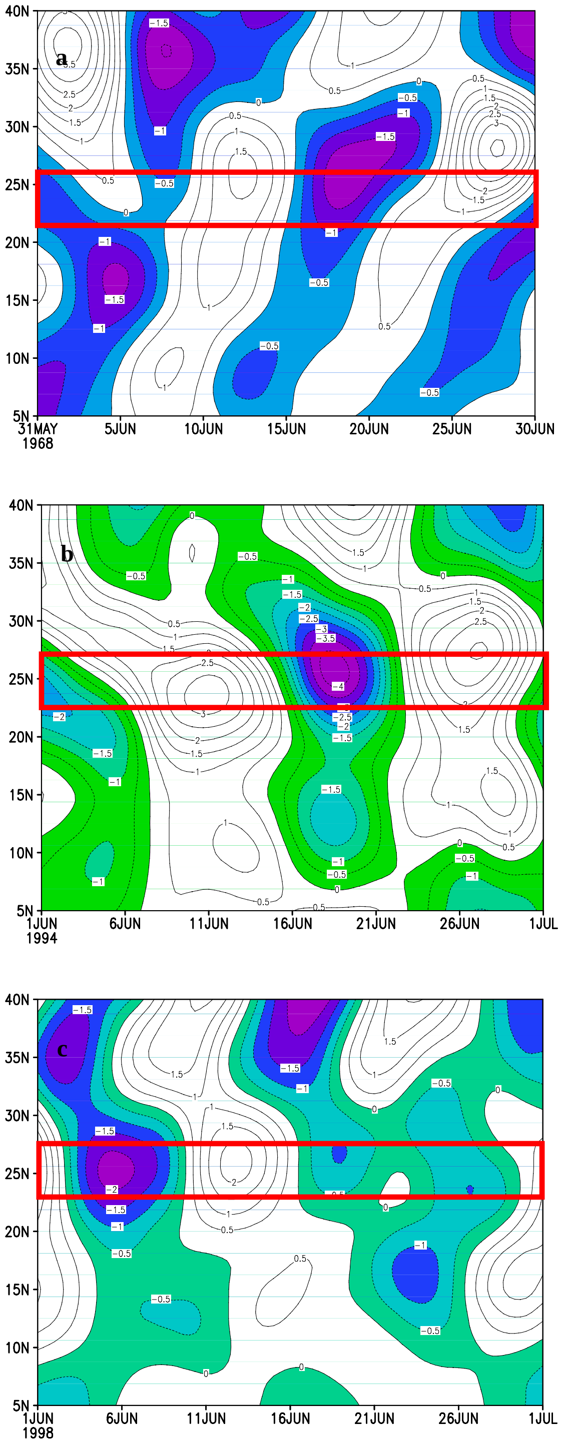


Fig. 3. 850-hPa wind field during the heavy rains of June 22, 1968 (a), June 15, 1994 (b), June 20, 1998 (c), June 13, 2002 (d), and June 20, 2005 (e)

6 MEETING OF LOW-FREQUENCY NORTHERLY AND SOUTHERLY WIND FIELDS OVER THE VALLEY

A 10-to-20 day filter is applied to the 850-hPa meridional anomalous wind field for 1968, 1998, 2002 and 2005 while a 10-to-30 day filter is applied to that of 1994. Then, the filtered meridional wind fields of June was used to determine latitude-time cross sections averaged over 107.5–115° E (Fig. 4). The positive value denotes the southerly wind while the negative one stands for the northerly wind. For the heavy rains of the five years, one thing is common:

low-frequency southerly systems encountered low-frequency northerly ones over the valley on 19–23 June 1968, 15–16 June 1994, 18 June 1998, 9–17 June 2002, and 18–22 June 2005, respectively.



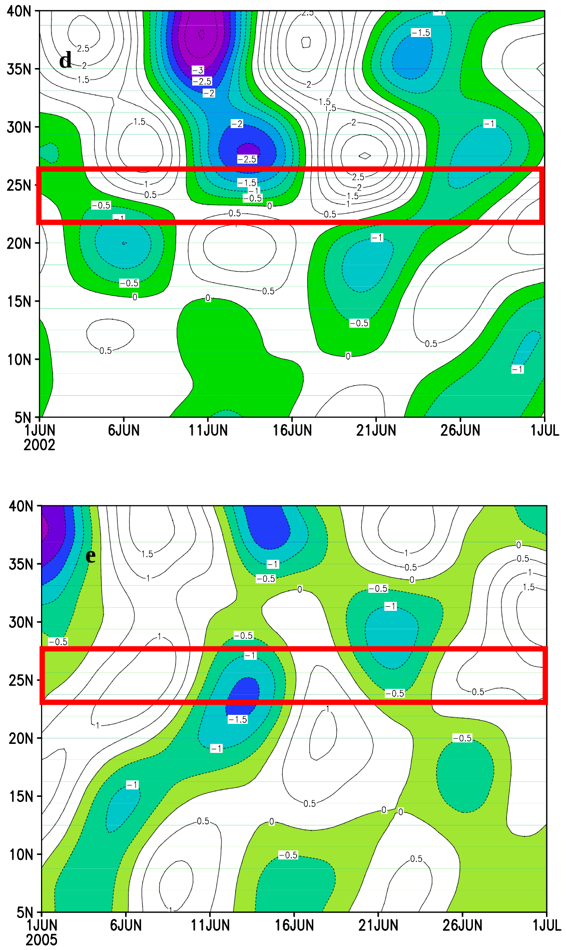


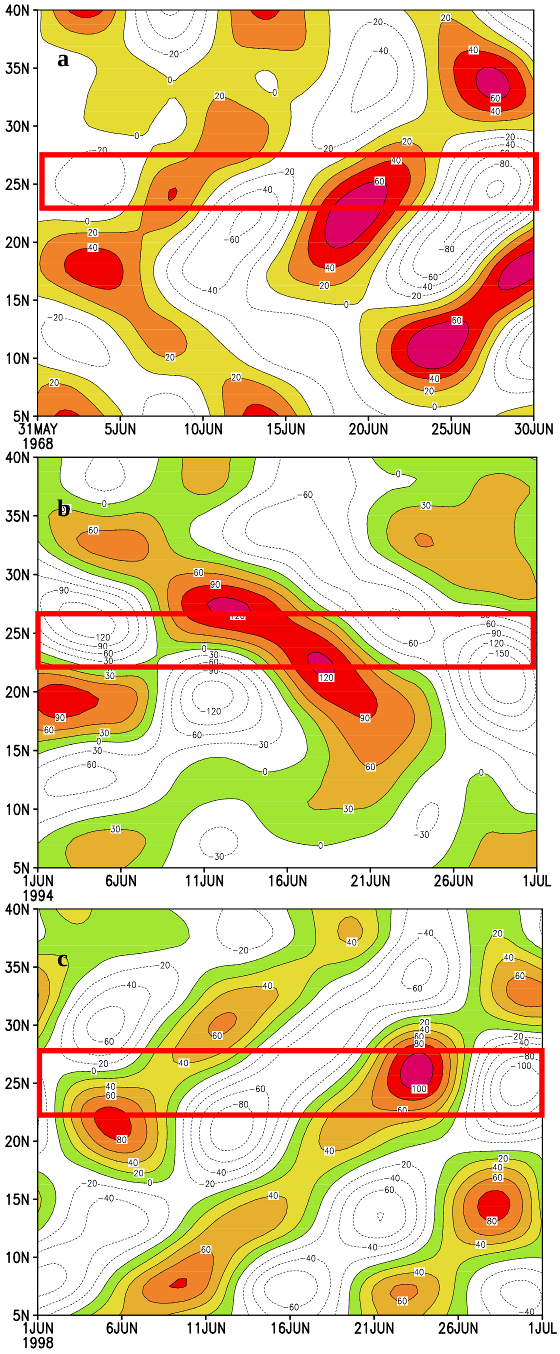
Fig. 4. Longitude-time cross sections of low-frequency 850-hPa winds in Junes of 1968, 1994, 1998, 2002, and 2005. The shades indicate where the northerly wind is. Unit: m/s

Through a similarity study[15], He et al. found that weather situation is very similar for large-scale, sustained heavy rains in the valley, with main weather types of either frontal troughs, forming from cold air merging with warm air, or tropical cyclones meeting with the Intertropical Convergence Zone (ITCZ), resulting from a situation in which landfalling tropical cyclones headed north to move to the upper reaches of the Xijiang River, together with northward advancement of the ITCZ as well. On the level of 850 hPa, an inverse trough or an enclosed low pressure, and a shear are usually observed in the area of the valley, together with a southwest or south low-level jet stream south of it or over southern China. Through composite analysis, Huang[14] held that this type of rain occurs in association with well-defined low-level jet streams at mid- to lower-levels from the Bay of Bengal to southern China, exposing Guangxi to its left-side convergence zone where the transported moisture and energy is conducive to their convergence and lifting for energy release. These results are similar to those obtained through low-frequency filter analysis, suggesting the presence of significant low-frequency oscillations in the governing systems of these flood-causing heavy rains in the valley and providing basis for medium-term forecasting.

7 DISTRIBUTION AND PROPAGATION OF LOW-FREQUENCY VORTEX SYSTEMS

7.1 *Meridional propagation of low-frequency vortex systems*

A 10-to-20 day filter is applied to the 850-hPa meridional anomalous wind field for 1968, 1998, 2002 and 2005 while a 10-to-30 day filter is applied to that of 1994. Then, the filtered meridional wind fields of June were used to determine latitude-time cross sections averaged over 107.5–115° E (Fig. 5).



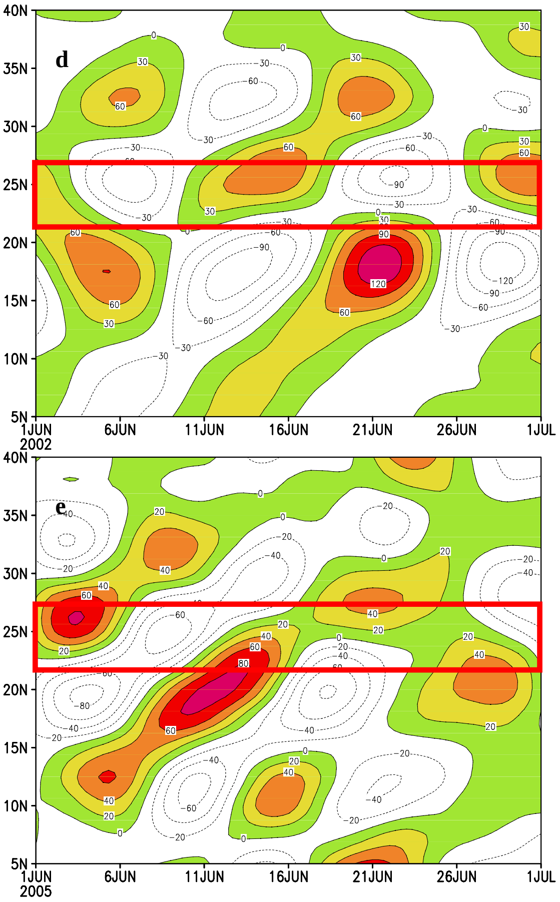


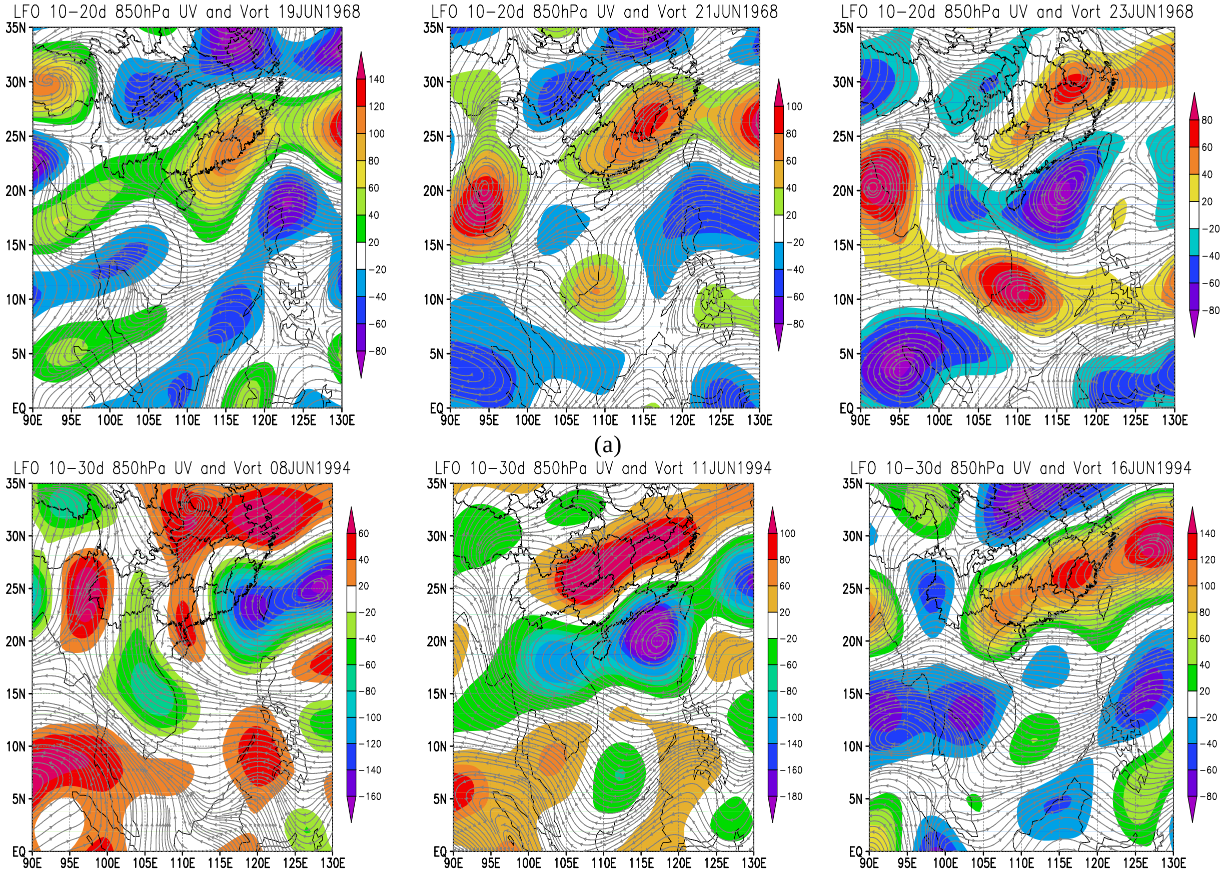
Fig. 5. Longitude-time cross sections of low-frequency vorticity in Junes of 1968, 1994, 1998, 2002, and 2005. The shades indicate where the positive vorticity is. Unit: 10^{-5} s^{-1}

Figure 5 shows that on 17–23 June 1968 a low-frequency vortex system, with the center value of 60×10^{-5} s^{-1} over the valley, was observed to move north with intensity unchanged. Fig. 5b shows that on 18–25 June 1994 the heavy rain was associated with a low-frequency vortex system propagating southward to the valley from mid-latitudes (around 35° N) in early June, during which the vortex gradually intensified, with the center value increasing from 60×10^{-5} s^{-1} to 120×10^{-5} s^{-1}. Fig. 5c shows that on 18–25 June 1998 the heavy rain was corresponding to a low-frequency vortex system moving north in early June from low-latitudes to reach the valley, with the intensity gradually increasing (from 60×10^{-5} s^{-1} to 100×10^{-5} s^{-1} at the center). Fig. 5d shows that on 9–16 June 2002, a low-frequency vortex system, moving north with intensity unchanged, was observed over the latitudes of the valley with the center value at 60×10^{-5} s^{-1}, corresponding to the time of heavy rain. Fig. 5e shows that a low-frequency vortex system started to move north from 10° N in the early days of June 2005 while intensifying significantly (with the center value growing from 60×10^{-5} s^{-1} to 80×10^{-5} s^{-1}). It reached to 20–25° N some time around mid-June before continuously heading further north to 23–28°

N around June 23rd, as the centre value weakened to 40×10^{-5} s^{-1}. The development generally agrees with the time of the heavy rain in the valley (June 15th–23rd). Summing up, low-frequency vortexes propagated into the valley of Xijiang River and intensified during the flood-causing rains in Junes of 1994, 1998 and 2005 while they dominated in the cases of 1968 and 2002, being favorable for the convergence of low-level moisture above the valley and contributing to the occurrence of these rain processes.

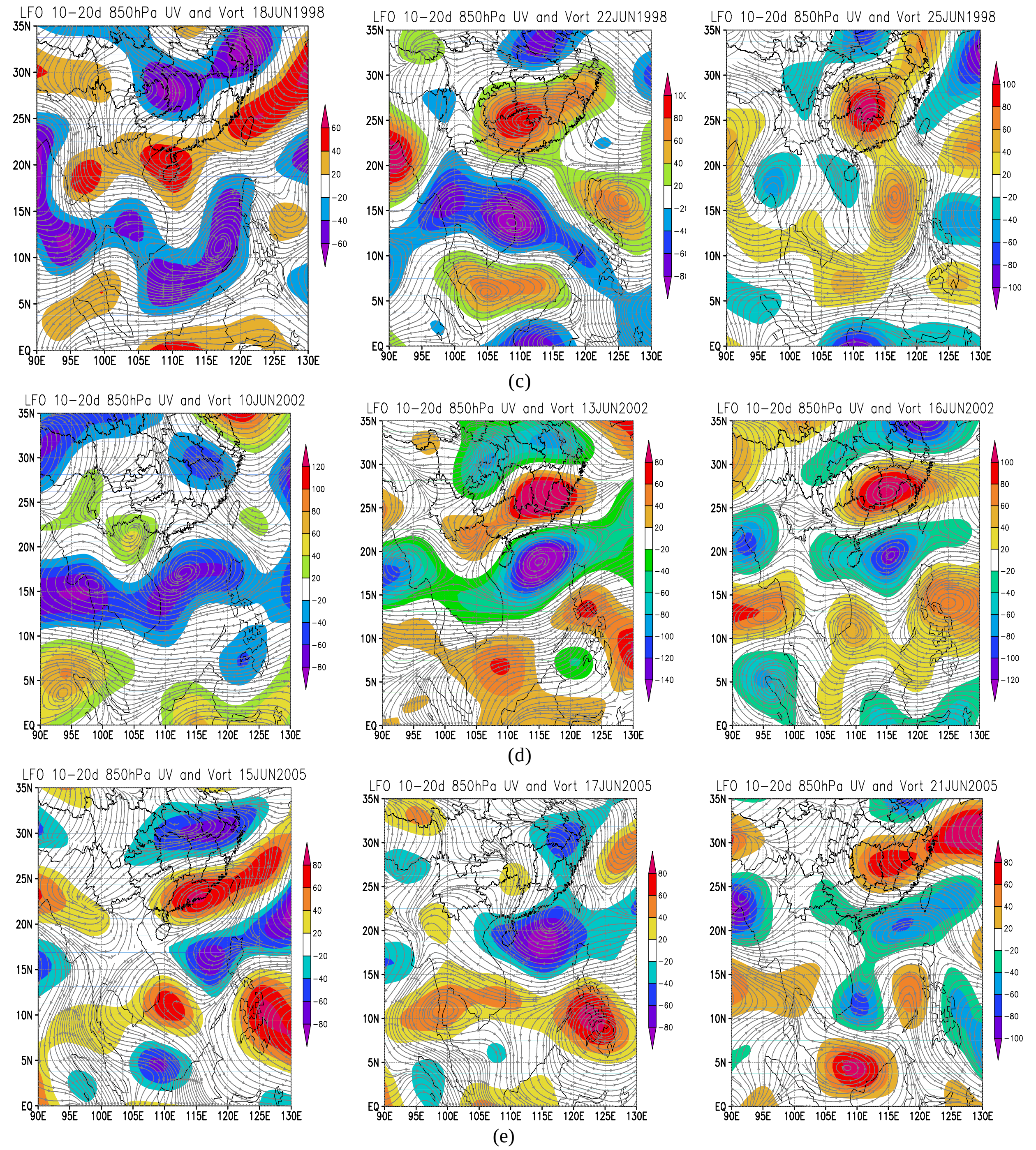
7.2 *Two-dimensional distribution of temporal variation of flow fields of the low-frequency vortexes*

A 10-to-20 day filter is applied to the 850-hPa meridional anomalous wind field for 1968, 1998, 2002 and 2005 while a 10-to-30 day filter is applied to that of 1994. Then, temporal variations of two-dimensional plane for the vorticity and flow fields of June 1st–30th in the five years were made. The study has the following findings. On 17–23 June, 1968, the eastern valley began to be affected by the center of low-frequency vorticity, which then moved toward the northeast; on June 21st, the positive vorticity was the maximum over the valley and so was the cyclonic curvature, as reflected by the flow field (Fig. 6a). On June 24th–29th, the center of negative vorticity in the northern South China Sea started to move to Jiangxi province, which was located to the east of the valley, while the anticyclonic curvature of the flow field was also large over the valley (figure omitted). On 8–18 June, 1994, the center of positive vorticity in the northern part of the valley began to pass through the valley in a northwest-southeast direction; the positive vorticity and cyclonic curvature became the largest on June 15th (Fig. 6b). On 18–25 June 1998, the center of positive vorticity near the Hainan Island went through the valley from south to north; it was just over the valley on June 22nd with cyclonic curvature being the largest (Fig. 6c). On 9–16 June 2002, a positive-vorticity center near Vietnam headed northeast over the valley; positive vorticity became the largest on June 13th when the cyclonic curvature was also quite large (Fig. 6d). On 11–17 June 2005, a positive-vorticity center in the northeastern SCS moved northwest to the valley and weakened substantially there; On June 18th–23rd, the center gradually intensified while moving east out of the valley; positive vorticity was relatively large in the valley on June 15th and so was the cyclonic curvature of the flow field (Fig. 6e). In summary, low-frequency vorticity systems exerted all of the heavy rain that caused floods in the five years.



(a)

(b)



(c)

(d)

(e)

Fig. 6. Low-frequency vorticity fields (unit: 10^{-5} s^{-1}) and low-frequency flow fields (unit: m/s) for the flood-causing heavy rains in the Xijiang River valley in 1968 (a), 1994(b), 1998 (c), 2002 (d), and 2005 (e).

8 SUMMARY

(1) Significant low-frequency oscillations of 10 to 20 days existed in the flood-causing heavy rains in Junes of 1968, 1998, 2002, and 2005 and significant low-frequency oscillations of 10 to 30 days existed in the flood-causing heavy rains in June of 1994; the time of severe rainfall coincided with the positive phase of low frequencies.

(2) One of the most important reasons for the flood-causing heavy rains of the five years is that low-frequency warm and wet air flows from low-latitude oceans meet with low-frequency dry and cold airflow from high latitudes over the valley of the Xijiang River.

(3) The presence and propagation of low-frequency positive-vorticity systems are playing an important role in the formation of flood-causing heavy rain by converging and lifting the low-level moisture above the valley.

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