Extended-Range Forecasts of the Principal 20–30-Day Oscillation of the Circulation over East Asia During the Summer of 2002

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ABSTRACT

Daily 850-hPa meridional wind fields in East Asia from March to September 2002 were used to establish a model of the principal oscillation pattern (POP). This model was then used to conduct independent extended-range forecasts of the principal temporal and spatial variations in the low-frequency meridional wind field on a time scale of 20–30 days. These variations affect the occurrence of heavy precipitation events in the lower reaches of the Yangtze River valley (LYRV). The results of 135 forecast experiments during the summer half year show that the predicted and observed anomalies are strongly correlated at a lead time of 20 days (mean correlation greater than 0.50). This strong correlation indicates that the model is capable of accurately forecasting the low-frequency variations in meridional wind that corresponded to the 3 heavy precipitation events in the LYRV during the summer of 2002. Further forecast experiments based on data from multiple years with significant 20–30-day oscillations show that these prediction modes are effective tools for forecasting the space-time evolution of the low-frequency circulation. These findings offer potential for improving the accuracy of forecasts of heavy precipitation over the LYRV at lead times of 3–4 weeks.

Key words: 20–30-day oscillation, East Asia, heavy precipitation, lower reaches of the Yangtze River valley, extended-range forecast

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1. Introduction

The 10–30-day extended-range forecasts fall in between weather forecasts and climate projections, which makes the practice of such extended-range forecasting complicated in terms of both scientific research and meteorological services. Long-life-cycle atmospheric phenomena, such as the planetary-scale upper troposphere circumglobal teleconnection (CGT) in the Northern Hemisphere (Ding and Wang, 2005), the southern circumglobal teleconnection wave train (SCGT) in the midlatitude Southern Hemisphere (Yang, 2009), the Madden-Julian Oscillation (MJO), and the Arctic Oscillation (AO), have significant effects on synoptic-scale systems. Previous studies have shown that these specific flow patterns, when persistent, enhanced the predictability of weather processes at 10–30-day extended-range lead times. Moreover, the late stages of these flow patterns are often accompanied by extreme weather and abnormal climatic events (e.g., heavy precipitation, strong heating or cooling, etc.). With timescales of about 10–70 days, these tropical and extratropical intraseasonal oscillations (ISOs) can be used to improve 10–30-day extended-range forecasts in affected areas (Waliser et al., 2003; Jones et al., 2004; Wheeler and Hendon, 2004; Maharaj and Wheeler, 2005; Cassou, 2008; Love et al., 2008; Agudelo et al., 2009; Jones, 2009; Wheeler et al., 2009; Yang et al., 2010; Ajayamohan et al., 2011; Carvalho et al., 2011; Krishnamurthy and Misra, 2011;

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Liebmann et al., 2011; Roff et al., 2011).

The 20–30-day oscillations (e.g., the SCGT, the tropical western Pacific pattern (TWP), etc.) play a fundamental role in the occurrence of heavy precipitation events during summer in the lower reaches of the Yangtze River valley (LYRV; 30.5°–32.0°N, 118.0°–122.5°E). These oscillations modulate medium-term variations in the Meiyu season in the LYRV, indicating that the ISO in the Southern Hemisphere midlatitudes and that over the western Pacific both influence the summer East Asian subtropical monsoon (Yang, 2009). The MJO (a 30–60-day oscillation in the tropical atmosphere) and short-term (10–20-day) oscillations appear to play a more limited role in these processes. Therefore, 20–30-day oscillations in the circulation over East Asia could be used to construct a bridge between daily numerical weather forecasts and seasonal forecasts of heavy precipitation during summer in the LYRV, filling the time gap between medium-term weather forecasts and short-term climate predictions.

Chinese scientists have analyzed relationships between ISO and precipitation variations in East China over the past two decades, with numerous important results (Yang, 1993; Han et al., 2006; Ding and Liu, 2008; Zhang et al., 2009; Mao et al., 2010; He et al., 2011; Bai et al., 2011). Furthermore, the studies and experiments aimed at implementing and improving extended-range forecasts have been based in part on ISO (Yang, 1998, 2008, 2011; Ding and Liang, 2010; Chen et al., 2010; Ju et al., 2010; Zhu et al., 2010; Sun et al., 2011). Yang (1998) used a principal oscillation pattern (POP) analysis (Hasselmann, 1988; von Storch and Xu, 1990), which is able to objectively separate different low-frequency oscillation modes, to establish prediction models and to perform a forecast of the evolution of the MJO in the western Pacific region during the summer half year of 1994. The results of this study showed good predictive power for 10–30-day variations in the western Pacific subtropical high and the East Asian rainband. Yang (1998) further showed that the method was able to improve operational medium-term forecasts of continuous precipitation in the LYRV during the period 1995–2005. The ability of extended-range forecasts to predict the spatial and temporal evolution of ISO in East Asia on time scales of 20–30 days has yet to be systematically studied either in China or abroad. These 20–30-day ISOs are closely linked to the occurrence of heavy precipitation events in the LYRV during summer. Most previous studies have focused on the relationships between the 30–60-day oscillation, continuous precipitation, and the occurrences of droughts and floods. Moreover, the differences in the predictive power of different ISO timescales (20–30, 30–40, 40–50, 50–60, 60–70 days, etc.) for forecasting high-impact weather events in different areas are still unclear.

Previous studies have shown that ISOs at different timescales have different effects on the occurrence of heavy precipitation events in the LYRV: the 20–30- and 15–20-day oscillations are most closely related to heavy precipitation events, with 20–30-day oscillations the more dominant of these two (Yang, 2009). The link between the 30–60-day oscillation and the occurrence of heavy/strong precipitation was insignificant in this region, even though it appeared to be linked to relatively weak and continuous precipitation processes. If the ISO period was longer ($>$ 30 days) or became shorter ($<$ 15 days), the frequency of strong precipitation in the LYRV would be reduced significantly. We therefore undertake to establish a dynamic statistical model based on the 20–30-day oscillation modes in East Asia and the western Pacific, which are closely connected to the occurrence of heavy precipitation events in the LYRV. This model will predict the patterns and evolution of the principal 20–30-day ISOs, which will in turn provide a strong indication of the probability of heavy precipitation.

In this paper, independent 30-day forecasts of changes in 850-hPa low frequency meridional wind are performed based on POP analysis of the active 20–30-day oscillations in the year of 2002 (Yang, 2009). Furthermore, the results of forecasts using data from multiple years with significant 20–30-day oscillations are analyzed, and the possible reasons for interannual variations in the intensity of the 20–30-day oscillations are discussed. The results will provide some new insights into the viability of extended-range forecasts of heavy precipitation over the LYRV in summer.

2. Prediction models

2.1 Data

Daily 850-hPa wind fields for the region 0°–45°N, 90°–180°E were taken from the NCEP/NCAR reanalysis (Kalnay et al., 1996) during the period 1979–2005. The NCEP/NCAR reanalysis was provided on 2.5°×2.5° grids. The 850-hPa low-frequency meridional wind field over East Asia was obtained via 20–30-day band-pass filtering (Butterworth filtering), and the basic data matrix was constructed following normalization. Daily precipitation observations at 25 stations in the region 30.5°–32.0°N, 118.0°–122.5°E from 1 May to 31 August 2002 were averaged to estimate daily precipitation in the LYRV. Forecasts of the 850-hPa meridional wind fields were conducted from 1 March to 30 September 2002. Springtime sea surface temperature anomalies (SSTA) were averaged over the Pacific area (40°S–45°N, 120°E–90°W) from March to May using the Hadley Centre Global Sea Ice and Sea Surface Temperature (HadISST) dataset (Rayner et al., 2006).

2.2 POP analysis

Figure 1a shows the temporal evolution of daily precipitation over the LYRV during the period of May to August 2002. Precipitation before 1 June was concentrated in a series of process intervals, with each process interval lasting approximately 7 days. Three significant heavy precipitation events took place between 1 June and 31 August, i.e., on 20 June, 17 July, and 14 August, respectively. The greatest daily mean precipitation in this region during these events exceeded 25 mm. Active precipitation periods alternated with interruptions throughout the May–August period, with significant intraseasonal oscillations. To better understand the low-frequency oscillatory variations of rainfall over the LYRV, Fig. 1b shows the statistical parameter F from the non-integral power spectrum analysis (Schickedanz and Bowen, 1977). Significant non-integral periods in this time series include high-frequency variations of 4.0, 7.0, and 9.0 days and an extremely significant period on the timescale of 27 days (99% confidence level). The high-frequency oscillations with periods shorter than 10 days were not significantly related to heavy precipitation events, while the ISOs with a period of approximately 27 days were closely related to heavy precipitation events. The intensity of this ISO was significantly and positively correlated with the frequency of heavy precipitation in the LYRV (Yang, 2009). The principal period of the low-frequency oscillation of precipitation over the LYRV during the period of May–August 2002 was thus 20–30 days. This oscillation was strongly associated with the frequency of heavy precipitation in this region, which led to flooding during summer 2002.

POP analysis was applied to the daily low-frequency meridional wind field at 850 hPa in East

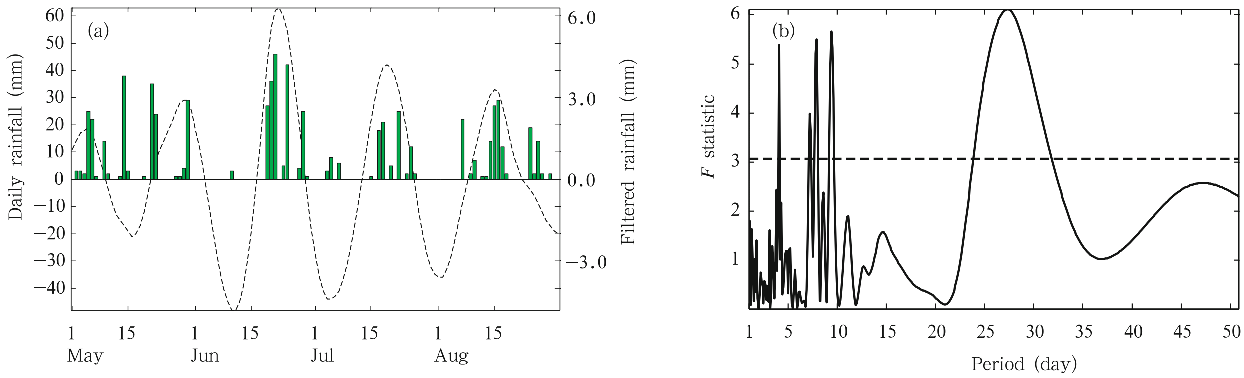

Fig. 1. (a) Time series of daily precipitation (mm) over the LYRV from May to August 2002. The 20–30-day band-pass filtered data are shown as a dashed line. (b) Statistical parameter F from the non-integral power spectrum analysis. Horizontal dashed line indicates the 95% significance level.

Asia to find the temporal and spatial variations of the principal 20–30-day oscillation pattern. The real part and imaginary part (Figs. 2a and 2b) and the corresponding time coefficients of the real part and imaginary part (Fig. 2c) were calculated for the spatial distribution of the first principal oscillation pattern (POP1) of the 20–30-day low-frequency oscillation. The POP1 explains 36.5% of the variance and has a rotation period of approximately 27.4 days. The POP cycle of POP1 consists of $\cdots \longrightarrow p_{\rm i} \longrightarrow p_{\rm r} \longrightarrow -p_{\rm i} \longrightarrow -p_{\rm r} \longrightarrow p_{\rm i} \longrightarrow \cdots$. The real part ($p_{\rm r}$, Fig. 2a) and imaginary part ($p_{\rm i}$, Fig. 2b) of POP1 correspond to a pronounced wave train in the subtropical and mid-latitude regions of East Asia with alternating signs. The imaginary part occurs one quarter of the rotation period before the real part (i.e., approximately 7 days).

As shown above, a wave train associated with an eastward propagating ISO with a timescale of 20–30 days is evident from the POP analysis. This wave train is part of a teleconnection wave train across the northern Pacific from East Asia to North America. This teleconnection wave train resembles the summer Tokyo–Chicago Express (from Japan and Northeast China to the east, passing over the North Pacific to western Canada, the northern Great Plains, and the central–western U.S.) or the Shanghai–Kansas Express (from the central and low reaches of the Yangtze River in China to the northern U. S. via North Pacific) (Lau and Weng, 2002; Ding and Liu, 2008). The corresponding time coefficients indicate that the intense periods of heavy precipitation over the LYRV (beginning of late May, end of mid June, middle of mid July, and middle of mid August; Figs. 3a–3d) all occurred when the time coefficient of the imaginary part was in the positive phase (Fig. 2c). This relationship is par-

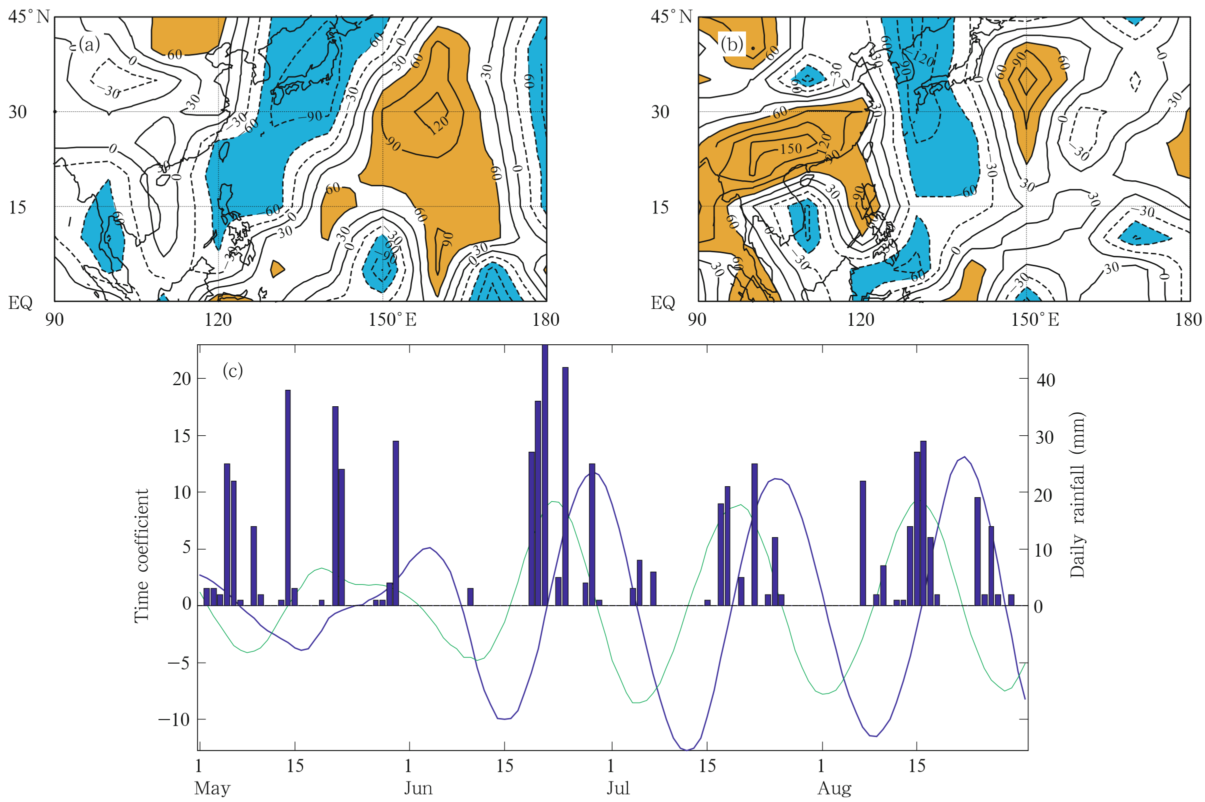

Fig. 2. The spatial distribution of the first principal 20–30-day oscillation pattern (POP1) of 850-hPa low-frequency meridional wind anomalies over East Asia for May–August 2002, decomposed into (a) the real part $p_{\rm r}$, (b) the imaginary part $p_{\rm i}$, and (c) the time coefficients and daily precipitation over the LYRV. Values in (a) and (b) are multiplied by 1000; shaded areas represent regions with values $\geqslant$ 60 or $\leqslant$ –60. Blue (green) line in (c) represents the time coefficients of the real (imaginary) parts; bars represent the time series of daily precipitation over the LYRV.

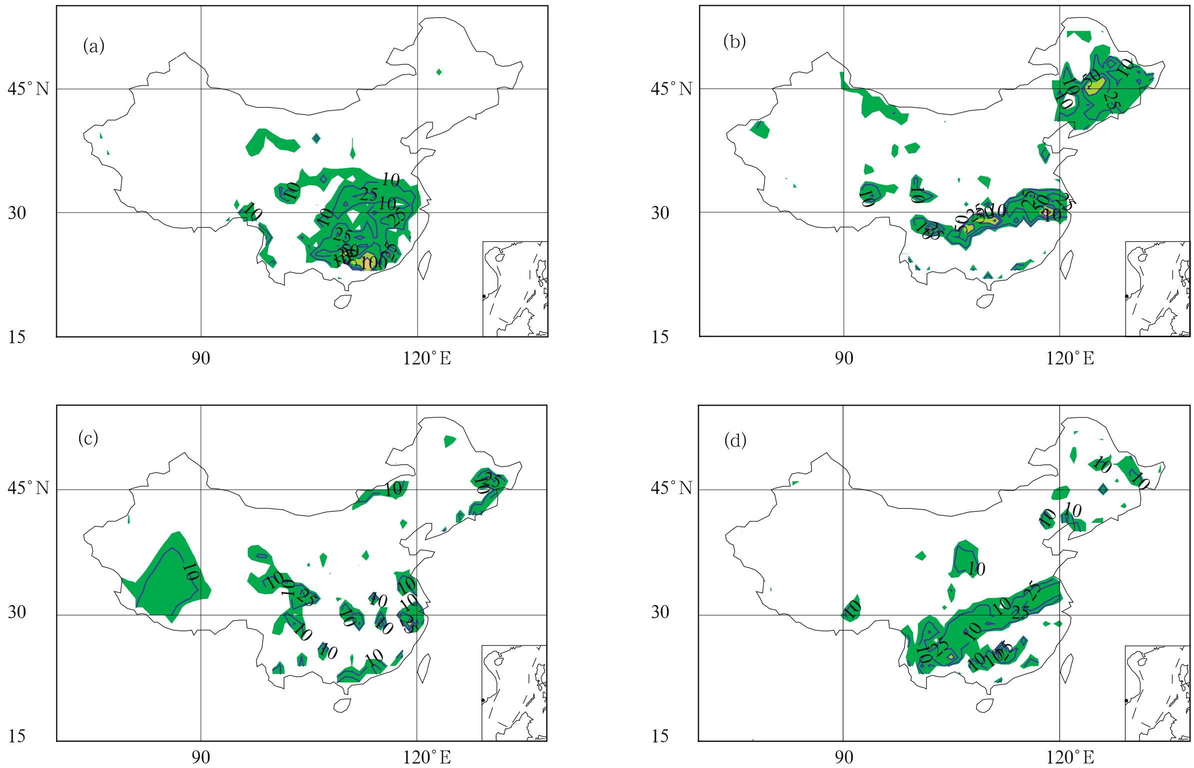

Fig. 3. Spatial distributions of daily precipitation (mm day^{-1}) in China for (a) 21 May, (b) 20 June, (c) 17 July, and (d) 14 August 2002.

ticularly apparent for the three intense heavy precipitation events that occurred in the LYRV between mid June and mid August; corresponding precipitation observations are shown for June 20 (Fig. 3b), July 17 (Fig. 3c), and August 14 (Fig. 3d). Southerly wind anomalies were significantly enhanced during these positive phases in the areas east of 105°E and south of the Yangtze River region (Fig. 2b), together with substantially enhanced water vapor transport from the South China Sea.

Figure 4 shows the distribution of the correlation between 20–30-day low-frequency precipitation over the LYRV (Fig. 1a) and 850-hPa meridional wind anomalies during the period 1 May–31 August 2002. This correlation distribution clearly illustrates the structure of the meridional wave train, in which positive correlations are concentrated in the areas to the south of the Yangtze River, while negative correlations are concentrated in the subtropical northwestern Pacific. Correlations in both of these regions are statistically significant at the 95% confidence level (the average number of independent samples in related significant grids is approximately 14 days; accordingly, the significance of a correlation coefficient greater than 0.50 is 0.05). The low-frequency variations in the 850-hPa meridional wind indicate that the areas to the south of the Yangtze River region and the subtropical

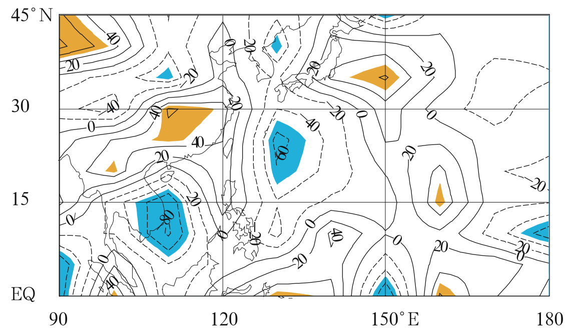

Fig. 4. Correlation between precipitation over the LYRV and 850-hPa meridional wind anomalies on the 20–30-day timescale for 1 May–31 August 2002. Values are multiplied by 100; correlations at the 95% significance level are indicated by shadings.

northwestern Pacific were the two key areas affecting low-frequency variations in precipitation and heavy precipitation processes over the LYRV (concordant with Fig. 2b). It is therefore important to take 10–30-day extended-range forecasts of low-frequency variations in meridional wind in these two key areas into consideration when forecasting the occurrence of heavy precipitation events in the LYRV. Low-frequency signals in the low-level wind field in the East Asian subtropics and the evolution of associated POP modes may provide important information for 10–30-day extended-range forecasts of heavy precipitation over the LYRV in summer. Forecasts of the evolution of these low frequency signals may accurately predict periods of heavy precipitation during the future 30 days in the LYRV.

3. Forecasting method and results

POP analysis combines some aspects of dynamical models and those of statistical analysis. This method can effectively separate a variety of spatial and temporal scales and reveal cyclical changes in the oscillation modes of complex climate systems. In addition to its use as an analysis tool, POP analysis can also be used for forecasting low-frequency spatial wave propagation (i.e., forecasting the POP cycle chain: $\cdots \longrightarrow p_{\rm i} \longrightarrow p_{\rm r} \longrightarrow -p_{\rm i} \longrightarrow -p_{\rm r} \longrightarrow p_{\rm i} \longrightarrow \cdots$). In practical forecasts, the accuracy of independent samples must be considered when assessing a forecast

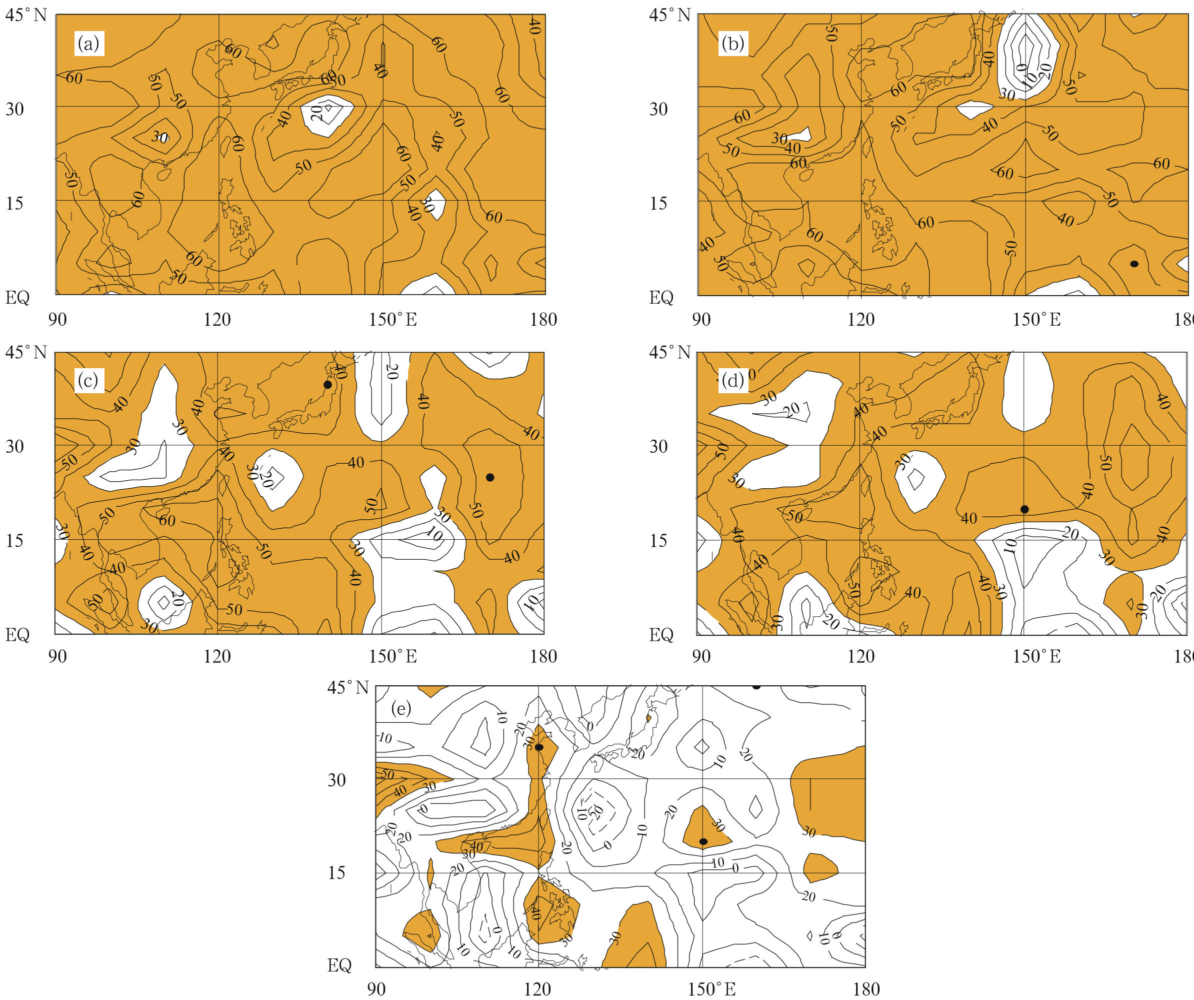

Fig. 5. Correlations between predicted and observed filtered 850-hPa meridional winds for forecast lead times of (a) 5 days, (b) 10 days, (c) 15 days, (d) 20 days, and (e) 25 days during the boreal summer of 2002. Values are multiplied by 100; correlations at the 95% significance level are indicated by shadings.

method's actual predictive capability (Yang, 1998). The changes of POP (spatial distribution; i.e., complex eigenvector $\boldsymbol{p} = p_{\mathrm{r}} \pm ip_{\mathrm{i}}$) are related to the sample sequence length; accordingly, the finite memory method is used for the predictions in this paper. The subsequence length N_0 is maintained, and the slide forecast experiments using independent samples are performed. In this study, 135 forecasts of the propagation of the wave train were performed during early and middle summer (19 April–31 August 2002). Each forecast was run for $\tau = 30$ days, with a subsequence length $N_0 = 50$ days.

The complex eigenvector changes according to the sample, so the model reflects the dynamic evolution of low-frequency system characteristics (i.e., the variation of the POP coefficients $z_{\mathrm{r}}(t)$ and $z_{\mathrm{i}}(t)$ in the two-dimensional z plane is related to the dynamic orthogonal bases p_{r} and p_{i}). This dynamic evolution allows the method to adapt to temporal changes in the spatial structure of the principal 20–30-day oscillation system, and to partially reflect the nonlinear characteristics of the 20–30-day oscillation. Figures 5a–5e show the distributions of the correlation between predicted and observed low-frequency meridional wind fields at forecast lead times of 5, 10, 15, 20, and 25 days. The correlations are calculated for 135 independent forecasts. The results of the 5–20-day forecasts are reasonable in the subtropical East Asia (Figs. 5a–5d) at the 95% significance level and above. These forecasts of 20–30-day anomalies in meridional wind in the two key areas (east of 100°E and south of the Yangtze River in China and the subtropical northwestern Pacific region) provide valuable information for forecasts of heavy precipitation events in the LYRV. The area of significant correlation is substantially reduced in the 25-day forecast (Fig. 5e), with the only areas of high correlation located in the South China Sea and tropical West Pacific. The POP model forecasts of heavy precipitation over the LYRV therefore exhibit skill at lead times of 1–20 days, and are capable of effectively predicting the spatial distributions of low-frequency meridional wind anomalies in East Asia for up to 20 days.

Figure 6 shows the 10-day forecast (5 June 2002; Fig. 6b) of the 20–30-day low-frequency 850-hPa meridional wind field initialized on 26 May 2002, along with the observation on 5 June 2002 (Fig. 6a). The eastward propagation of the meridional wind wave train through the subtropical region in East Asia is accurately predicted (Fig. 6b), and the positive-negative-positive spatial distribution is very consistent with the observations (i.e., the spatial distributions of low-frequency southerly and northerly winds are similar to those observed) (Fig. 6a). Figure 7 shows the 24-day forecast (19 June 2002; Fig. 7b) of the 20–30-day low-frequency 850-hPa meridional wind field initialized on 26 May 2002, along with the observation on 19 June 2002 (Fig. 7a). The 24-day forecast is able to predict the formation and strength of a southerly (positive) wind anomaly in the area to the south of the Yangtze River and in the subtropical northwestern Pacific. This southerly anomaly leads to the heavy precipitation event that occurred over the LYRV on 20 June 2002 (Fig. 3b). The changes in the low-frequency signal of the meridional wind anomaly in these key re-

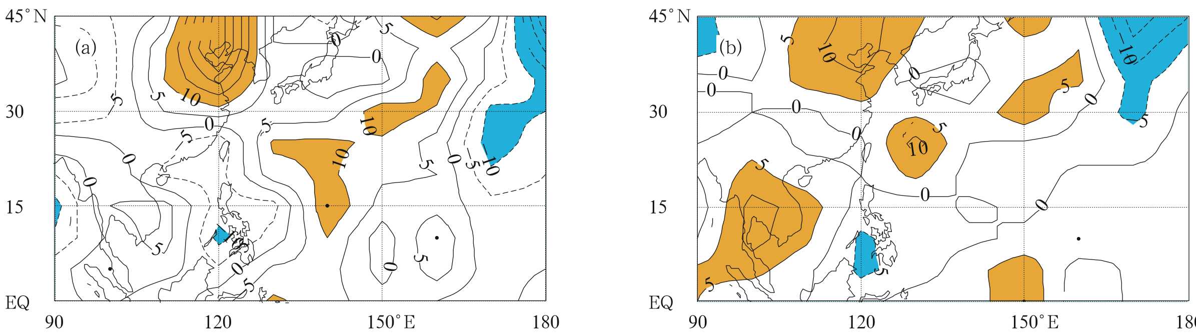

Fig. 6. Meridional wind anomalies at 850 hPa over East Asia on 5 June 2002 according to (a) the observation and (b) a 10-day forecast using the POP model (initialized on 26 May 2002). The contour interval is 0.5 m s^{-1}, and the values are multiplied by 10.

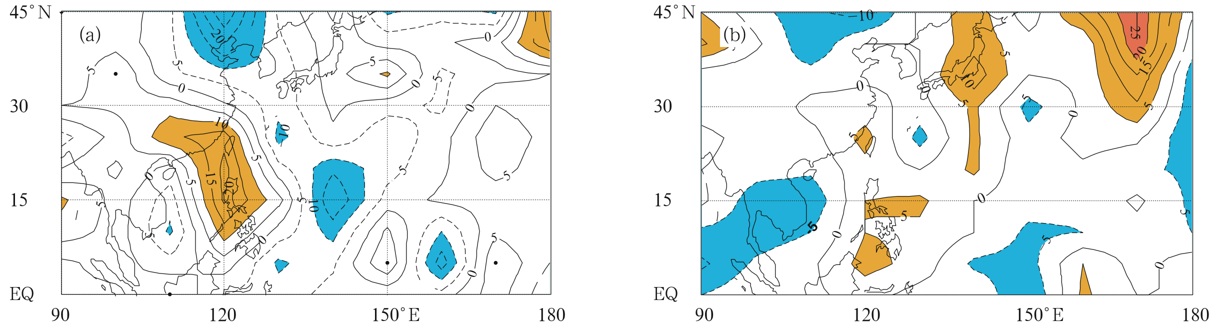

Fig. 7. As in Fig. 6, but on 19 June 2002. Panel (b) shows a 24-day forecast using the POP model (initialized on 26 May 2002).

gions were good indicators of the heavy precipitation over the LYRV; however, the predicted magnitudes of these anomalies are weaker than observed. This discrepancy indicates that the POP forecast model was not able to accurately describe and forecast the nonlinear strengthening of the 20–30-day ISO patterns, and this highlights the need for further improvement.

The above forecast experiments show that the POP model has useful skill at forecast lead times of about 20 days. These forecasts can therefore be used to provide important information for 20-day extended-range forecasts of heavy precipitation over the LYRV. The current ECMWF numerical weather prediction model possesses useful skill at lead times of approximately 10 days for forecasts of global circulation (Miller et al., 2010). On the basis of this 10-day forecast, the forecast of the ISO pattern may be obtained for the future 30 days with the 20-day ISO forecasts based on the POP model. Accordingly, 20-day ISO forecasts based on the POP model will improve the accuracy of 10–30-day extended-range forecasts of heavy precipitation.

Forecast skill varies from one summer to another. In particular, forecasts are more skillful for periods with stronger ISO. Additional forecast experiments during years of strong 20–30-day oscillation (Yang, 2009) led to similar results, and demonstrated that the POP method has good predictive skill at lead times of 5–20 days. Figure 8 shows the distributions of correlation coefficients between observations and forecasts of low-frequency meridional wind at lead times of 20 days for the years 1979, 1984, 1987, 1991, 1997, 1998, 1999, and 2005. All of these years exhibited strong 20–30-day ISOs. The correlations in the key areas to the south of the Yangtze River and over the northern Pacific and southern Japan vary interannually. The largest correlations were found in 1984, while those in 1999 were the smallest. The dynamic POP model established in this paper could effectively adapt to variations in the wave train structure during years with significant 20–30-day ISOs; similarly, the POP method is able to forecast the 20–30-day ISOs at 20-day lead times with high accuracy. For example, in mid July 2011, a slow eastward-propagating wave train was closely related to an extreme heavy precipitation event in the LYRV on 18 July 2011. The POP forecast model was able to successfully predict the low-frequency variation of the southerly wind anomaly in the key area at a lead time of 17 days (Yang, 2011).

On the other hand, the non-integral power spectrum indicates that the frequency of heavy precipitation over the LYRV oscillates on a quasi-biennial timescale (Yang, 2009). The 20–30-day ISO intensity also oscillates quasi-biennially, due in part to air-sea interactions in the Pacific region. Figure 9 shows the distribution of springtime SSTA in the Pacific Ocean for the years 1987, 1991, 1999, and 2002, all of which had a strong 20–30-day ISO during summer. The springtime SSTA in the regions of the northwestern Pacific and tropical South Pacific was significant and positive during all of these years, suggesting that the springtime warming in the northwestern Pacific promotes a strong 20–30-day ISO in East Asia during the following summer. Accordingly, the predictability of the 20–30-day ISO of the East Asian circulation is high during years when the springtime SSTA in the northwestern Pacific is large and positive. Changes of SSTA in the Pacific in the preceding spring therefore provide another important signal of the viability of extended-range forecasting of the 20–30-day ISO and the occurrence of heavy precipitation events over the LYRV during summer.

Heavy precipitation events were rare during years with weak 20–30-day oscillations, and the predictability of the 20–30-day ISO pattern was low. Under these conditions, the possible effects of 10–20-day and 30–60-day (MJO) oscillations were found to provide some useful information to extended-range forecasts

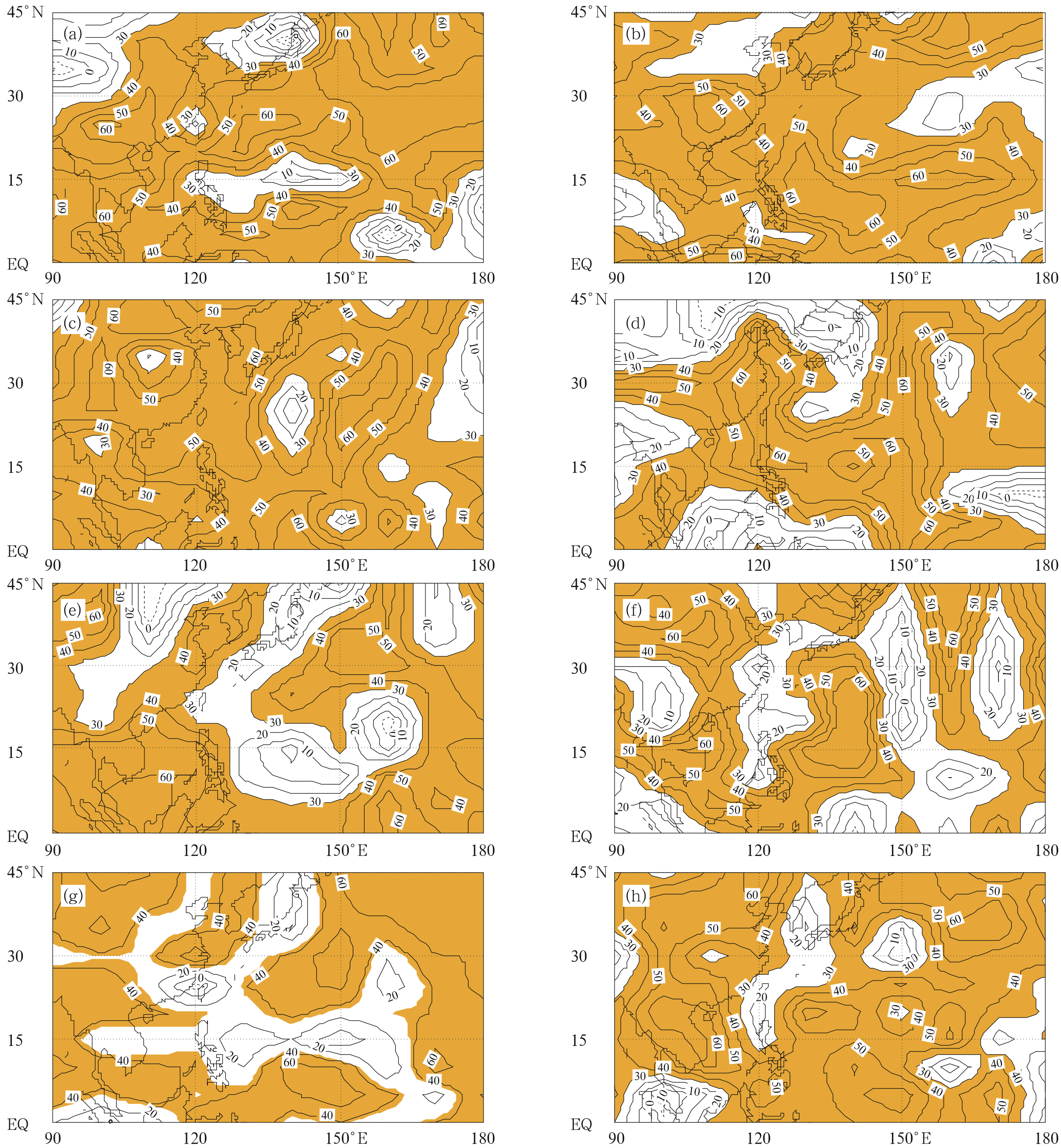

Fig. 8. As in Fig. 5, but for 20-day forecasts during the years (a) 1979, (b) 1984, (c) 1987, (d) 1991, (e) 1997, (f) 1998, (g) 1999, and (h) 2005. All of these years exhibit relatively strong 20–30-day ISOs in rainfall over the LYRV during boreal summer.

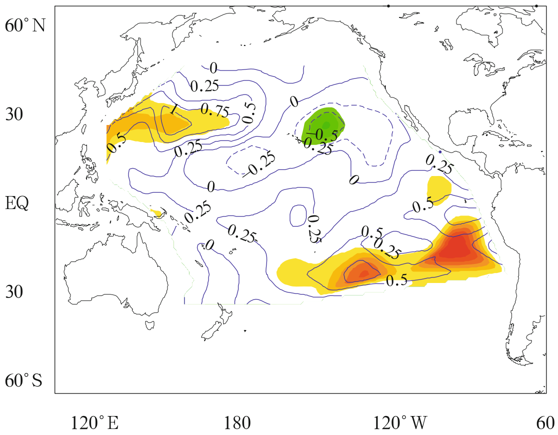

Fig. 9. Composite of SSTA in the Pacific Ocean during the preceding spring for years 1987, 1991, 1999, and 2002. All of these years exhibit relatively strong 20–30-day ISOs in rainfall over the LYRV during boreal summer. The contour interval is 0.25°C. Dashed lines indicate negative values, and areas with SSTA values significant at the 95% confidence level are shaded.

of stronger precipitation events, via the use of a low-frequency 30-day forecast based on the POP modes. The Meiyu situation in Eurasia and the subtropical western Pacific was atypical during period May–July 2002. More specifically, the circulation over the LYRV was characteristic of a poor Meiyu year; however, the precipitation intensity and the number of rainy days were more characteristic of a rich Meiyu year. A strong 20–30-day oscillation leads to an increase in the amplitude of the oscillation in the subtropical high, hence the ridge of the subtropical high is not stably located in the region of 20°–26°N, 110°–130°E. These conditions do not fit the classic Meiyu situation; however, heavy precipitation occurred frequently in association with the strong 20–30-day oscillation and led to flooding in the LYRV. This result suggests that floods (extreme heavy precipitation events) are directly related to the 20–30-day oscillation in the subtropical circulation in East Asia, rather than the evolutions of the large-scale circulation over Eurasia and the classic Meiyu. Analysis of other factors that affect the mechanism and intensity of the 20–30-day oscillations must also be researched in detail. Further study of the causes of interannual variability in the 20–30-day oscillation and the predictability of this interannual variation will be important steps toward more accurate extended-range forecasts of droughts, floods, and variations in the frequency of heavy precipitation events over the LYRV. These advances will in turn provide a deeper understanding of the mechanisms of interaction between heavy precipitation processes and the climate variations such as droughts and floods.

4. Summary and discussion

The 850-hPa meridional wind fields over East Asia were used to establish a POP model for forecasting the 20–30-day oscillation. This model was then used to perform 10–30-day extended-range forecasts of the variation in meridional winds. The results are as follows.

(1) The POP model is shown to be effective for boreal summer forecasts of the eastward propagation of the meridional wave train in the lower troposphere over the subtropical regions of East Asia and the northwestern Pacific, which has a characteristic timescale of approximately 27 days. Detailed forecast experiments were performed during the period March–September 2002. The POP model is found to be quite accurate for a forecast period of up to 20 days. This method can effectively forecast the evolution of 850-hPa low-frequency southerly wind anomalies that strongly influence the occurrence of heavy precipitation over the LYRV. The method may also provide valuable information for extended-range forecasts of heavy precipitation.

(2) Forecasts of the spatiotemporal evolution of the 20–30-day oscillations in the atmospheric circulation over East Asia provide an important basis for extended-range (10–30 days) forecasts of the intensity and time of occurrence of heavy precipitation events over the LYRV. The 20–30-day ISO signal varies significantly on interannual timescales due to air-sea interactions over the Pacific; accordingly, the forecast skill varies from one summer to another. In years with strong 20–30-day ISOs (which are marked by high SSTA in the North Pacific during the preceding spring), the POP method possesses high accuracy and provides important information for 3–4-week forecasts of heavy precipitation over the LYRV during summer.

The impact of other ISO modes, such as 10–20- and 30–60-day oscillations, must be taken into further consideration for years with weak 20–30-day ISOs. This method is capable of effectively capturing the phase of the ISO, but the predicted magnitudes of the anomalies are often weaker than observed.

The results of forecasts for multiple years show that the POP dynamic statistical model based on 20–30-day oscillation can accurately describe the propagation of the low-frequency wave train. The selection of a proper subsequence length for an independent slide prediction in dynamic modeling was shown to be quite important. This process provides feedback from changes in cycle length and the spatial structure of complex systems to the forecast model, which may then be used to improve forecast accuracy. This method therefore has important application and reference value for real-time extended-range forecasts; in fact, it is one of the most efficient methods by which to build operational extended-range forecasts. On this basis, the statistical model may be extended to forecast the occurrence probability of extreme events such as continuous precipitation events, heavy precipitation events, extremely heavy precipitation events, etc. in the LYRV at 10–30-day lead times.

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