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Sensitivity Study of the South China Sea Summer Monsoon in 1998 to Different Cumulus Parameterization Schemes

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ABSTRACT

In this study, the improved high-resolution regional climate model of the China National Climate Center (RegCM_NCC) is used to examine the sensitivity of the simulated circulation and rainfall during the South China Sea summer monsoon (SCSSM) period during 1998 in an effort to compare to other cumulus parameterization schemes. The investigation has indicated that the model is capable of simulating the seasonal march of the SCSSM and that the results were very sensitive to the choice of cumulus parameterization schemes. It seems that the Kuo cumulus parameterization scheme simulates the process of the SCSSM onset reasonably well, which can reproduce the onset timing and dramatic changes before and after the onset, especially the upper- and lower-level wind-fields. However, there are still some discrepancies between the simulations and observations. For example, the model can not completely simulate the intensity of the rainfall or the location of the western Pacific subtropical high as well as the feature of the rapid northward propagation of seasonal rain belt.

Key words: South China Sea, summer monsoon, cumulus parameterization scheme, numerical simulation

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1. Introduction

The South China Sea summer monsoon (SCSSM) onset marks the arrival of the East and Southeast Asian summer monsoon and the beginning of the major rainy season in these regions (Ding, 1994), which greatly influences the social and economic development over these regions. Therefore, the question of how to correctly simulate the SCSSM has significant implications.

Generally speaking, general circulation models (GCMs) have limitations in reproducing regional details because of the relatively low spatial resolution and the simple representation of the physical processes. In order to obtain regional or local features, there have been a number of studies on regional climate modeling and climate change using limited area models since the late 1980s. Gradually, the regional climate model has been proven to be a useful tool in its ability to capture regional climate changes. Based on RegCM2/NCAR (National Center for Atmospheric Research) (Giorgi et al., 1993a,b), the National Climate Center of China (NCC) developed a regional climate model (RegCM_NCC) by modifying and assembling various physical parameterization schemes during the ninth five-year plan period in China. A good regional climate model should not only simulate the climate mean field, but also provide a good simulation of serious climate phenomenon. Due to its excellent capability, the RegCM_NCC model has been widely used in extreme weather and climate simulations as well as short-term climate predictions in China. However, most of these works were mainly focused on central and northern China or the area north of 10°–15° latitudes, where the precipitation processes are very different from those occurring further to the south (Shi et al., 2001; Liu and Ding, 2003; Ding et al., 2006a,b). For the SCS region, relatively detailed or complete investigations have been scarce. Due to the importance of the SCSSM to the whole Asian monsoon system and global weather and climate, it is very necessary to develop a regional climate model which is appropriate for the SCSSM research. Chan et al. (2004) successfully improved the simulations of regional rainfalls over the SCS on the basis of some modifications to the original RegCM_NCC. With this improved model, the simula-

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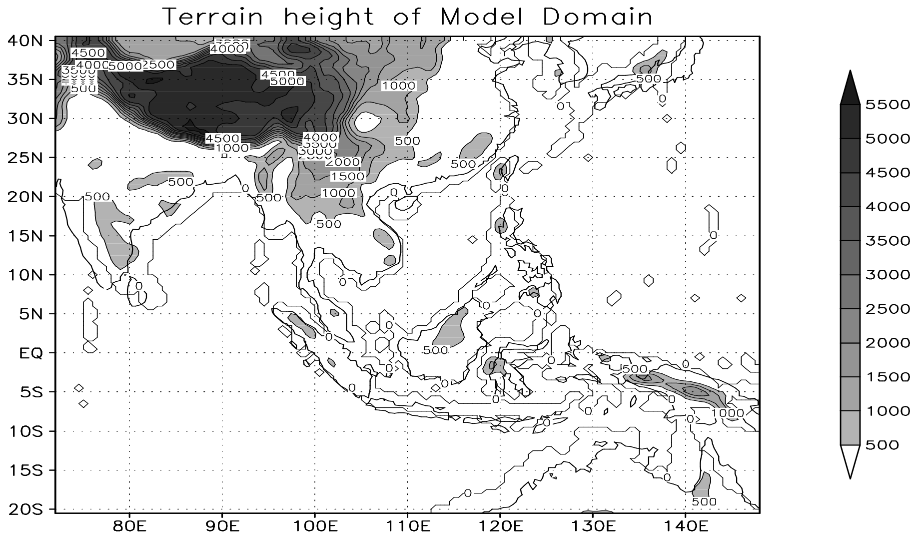

Fig. 1. Model domain and topography (units: m).

tions of the monthly mean precipitation over the SCS and South China during the SCSSM period for the five years (1994, 1996, 1997, 1998, and 1999) were found to be much closer to the observation. However, no more work has been done to further test the improved RegCM_NCC model's performance in simulating the other meteorological elements and the onset processes of the SCSSM.

As an important energy source for atmospheric motion, cumulus convection plays a key role in determining the structure of the temperature and the moisture of the atmosphere. With the development of a numerical model, different cumulus parameterization schemes have been designed and applied in these numerical weather forecasting models and the subsequent numerical simulations of atmospheric general circulation. Recently, many studies have shown that the choice of different cumulus parameterization schemes may have significant influence on the simulations of both the climate and synoptic systems. It has been pointed out that the simulated climate is quite sensitive to the cumulus parameterization scheme (Albrecht et al., 1986; Numaguchi and Matsuno, 1992; Hack, 1994; Bail and Takahashi, 1995; Chen et al., 1998; Huang et al., 2001; Pan et al., 2002). Due to the possible differences in the physical characteristics and the convective environment of the rainfall cloud among the different regions, it is very important to choose a reasonable cumulus parameterization scheme.

Recently, the comparative study of the different cumulus parameterization schemes has been an important focus in regional climate research. In this paper, the sensitivity of the simulated SCSSM circulation and rainfall to cumulus parameterization schemes is examined by using the improved RegCM_NCC with four different cumulus parameterization schemes. The detailed descriptions of the model and cumulus parameterization schemes are given in the second section of this paper. In section 3, the sensitivity results are analyzed. Finally, the summary and conclusions are given in section 4.

2. Description of model, data and cumulus parameterization schemes

In this paper, the improved RegCM_NCC is employed (Chan et al., 2004). The physical processes in this design included the Pal scheme for large-scale precipitation, the Hotslag scheme for the planetary boundary layer, the CCM3 radiation transfer scheme and the BATS scheme for land surface processes. The effective cloud droplet radius is fixed at different values over land and ocean. The neutral drag coefficient is prescribed as a function of surface wind speed and the heat and moisture exchange coefficients were set at values larger than that of momentum. The cumulus parameterization schemes used in this study include Kuo scheme (Kuo, 1965), Grell scheme (Grell, 1993), modified Mass flux scheme (Liu and Ding, 2002a,b) and Betts-Miller scheme (Betts, 1986; Betts and Miller, 1993). These four cumulus parameterization schemes are used to examine the sensitivity of numerical simulations of the rainfall and circulation during the SCSSM period to different cumulus parameterization. The model domain is shown in Fig. 1, which covers a large area including the Tibetan Plateau, the SCS and its adjoining region. It consists of 125 and 155 grid points in the longitudinal and latitudinal directions, respectively, with a 60 km resolution and a division of 16 vertical layers. The model top is at 10 hPa. For the detailed description of model's physical processes, please refer to Chan et al. (2004).

The initial atmospheric conditions and lateral boundary data used in this study were derived from the National Centers for Environmental Prediction/NCAR (NCEP/NCAR) re-analysis and lateral boundary conditions are provided every 6 hours via a relaxation method with a 15-grid buffer zone. The sea surface temperature (SST) data were taken from the NOAA (National Oceanic & Atmospheric Administration) Optimum Interpolation SST V2 weekly mean data with a $1^\circ \times 1^\circ$ spatial resolution. The model was continuously integrated from 1st April through the end of August, 1998 with four different parameterization schemes. For our research, the simulations of May and June will be discussed with the first month (April) being considered as the spin-up time. The Global Precipitation Climatology Project (GPCP) data and the NCEP/NCAR re-analysis are used for validating the large-scale features of the circulation and rainfall in the simulations.

3. Sensitivity experiments

3.1 *Monthly mean characteristics*

In 1998, the SCSSM onset consisted of two stages, namely the first onset over the northern SCS in the fourth pentad and then the remaining onset over the whole SCS in the fifth pentad of May (Ding and Liu, 2001). The observed and simulated monthly mean 850 hPa and 200 hPa flow patterns in May during the SCSSM period are given in Fig. 2 and Fig. 3, respectively. As seen in Fig. 2a, the ridge of the western Pacific subtropical high (WPSH) extends westward to the region south of the Indo-China Peninsula and the SCS is dominated by the WPSH during this time. The southeasterly flow controls the region to the south of the southern SCS, while the southwesterly flow from the WPSH prevails over the northern and middle parts of the SCS. Figs. 2b–e present the simulated results using the four cumulus parameterization schemes as mentioned above, respectively. Compared with the observations, it seems that the Kuo cumulus parameterization scheme can reproduce the characteristics of the low-level flow pattern in May, which successfully captures the distribution of the WPSH and the wind patterns over the SCS. However, the southwesterlies over the northern part of the SCS and South China are obviously a bit overestimated with the wind speeds exceeding 5 mm s^{-1} (Fig. 2b). For the other three schemes, the location and intensity of the simulated WPSH varied a bit from the observations. For example, the Grell and MFS cumulus parameterization schemes simulated the location of the WPSH farther west and north than it was observed. Similarly, the simulated southwesterlies over the northern part of the SCS and South China were also stronger than the observations (Figs. 2c and 2d). While the Betts-Miller cumulus parameterization scheme simulated the WPSH farther to the east and north (Fig. 2e).The common shortcoming of the Grell, MFS and Betts-Miller schemes was that they simulated the southeasterlies over the region to the south of the southern SCS to be too strong.

For the upper level flow at 200 hPa (Fig. 3), both the Kuo and Betts-Miller schemes simulated the distribution at the upper-level flow. Compared with the observations, the simulated center position of the South Asian high was located to the eastern flank of the Bay of the Bengal and the western part of the Ino-China Peninsula. The westerly and northwesterly divergence-wind dominated over the northern part of the SCS (Figs. 3a, 3b, and 3e). For the Grell and MFS schemes, the South Asian high was obviously simulated to far to the west (Figs. 3c and 3d).

Based on the above analysis, it can be seen that the RegCM_NCC could basically simulate the large-scale monthly mean circulation and the features of some important weather systems.

We also compared the simulated results and the observations during June (not shown). As in May, the four cumulus parameterization schemes simulated the upper-level flow patterns better than the low-level. For the low-evel patterns, it was still the Kuo scheme that successfully simulated the features of the WPSH retreating from the SCS as well as the retreat of the southwesterly from the equatorial eastern Indian Ocean through the Bay of the Bengal, Indo-China Peninsula and the northern part of the SCS that was advancing towards the Yangtze River Basin. In contrast to the results from May, the Grell scheme simulated the upper-level flow pattern and the location of the South Asian high quite reasonably.

Rainfall is an important factor for the validation of the model simulations. The cumulus convection greatly influences the rainfall during the monsoon period. Therefore, the sensitivity study of the different cumulus schemes on the simulation of the rainfall during the SCSSM period has an important significance for model's application and future improvement. Figures 4 and 5 show the simulated and observed monthly mean rainfall during the SCSSM period, respectively. It was found that in May, the southwest-northeast oriented rain belt along South China, Taiwan Island and Japan was reproduced by Kuo scheme quite well. The

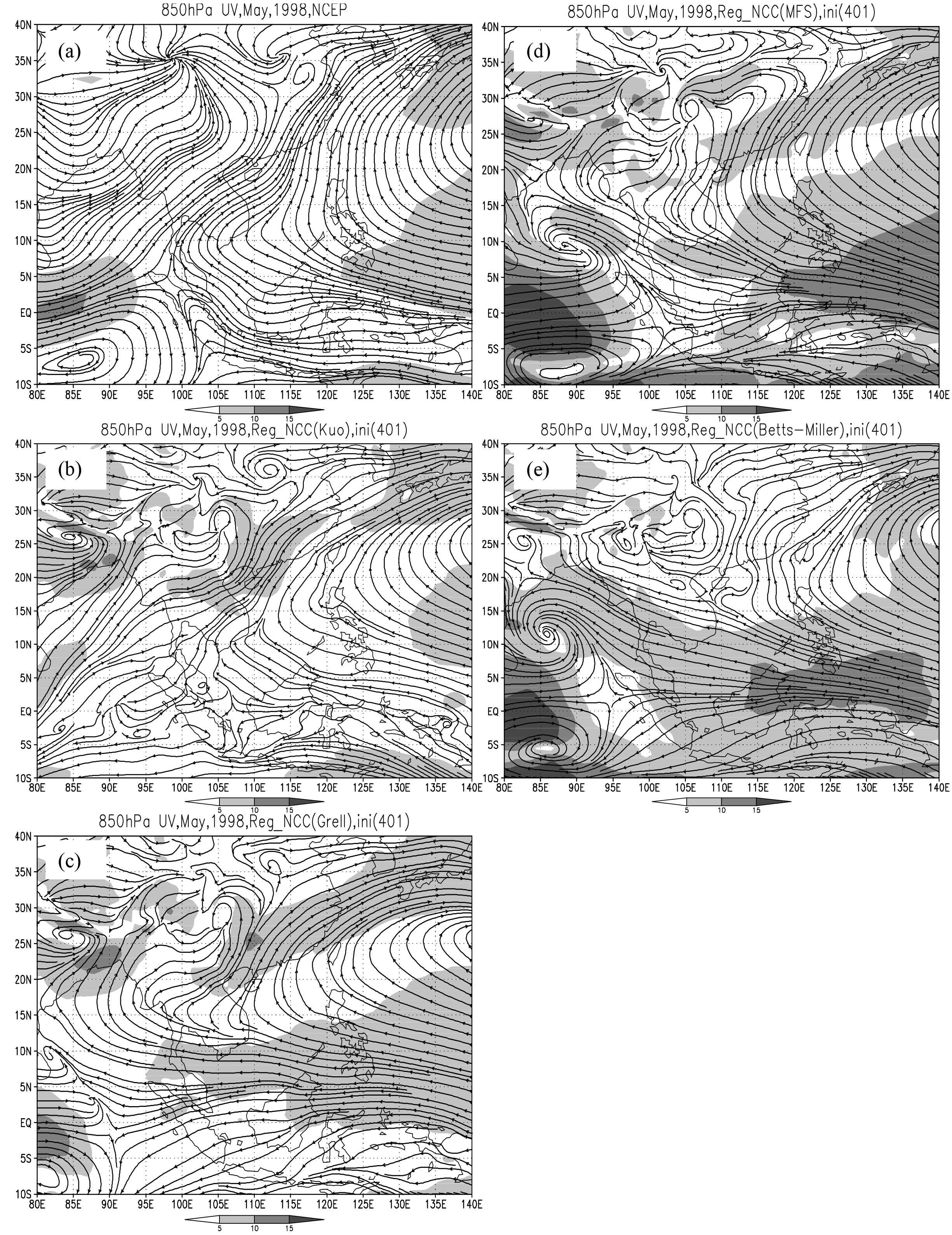

Fig. 2. 850 hPa monthly mean flow patterns in May (units: m s^{-1}; shaded areas for the wind speed exceeding 5 mm s^{-1}): (a) Observed, (b) Kuo scheme, (c) Grell scheme, (d) MFS scheme, (e) Betts-Miller scheme.

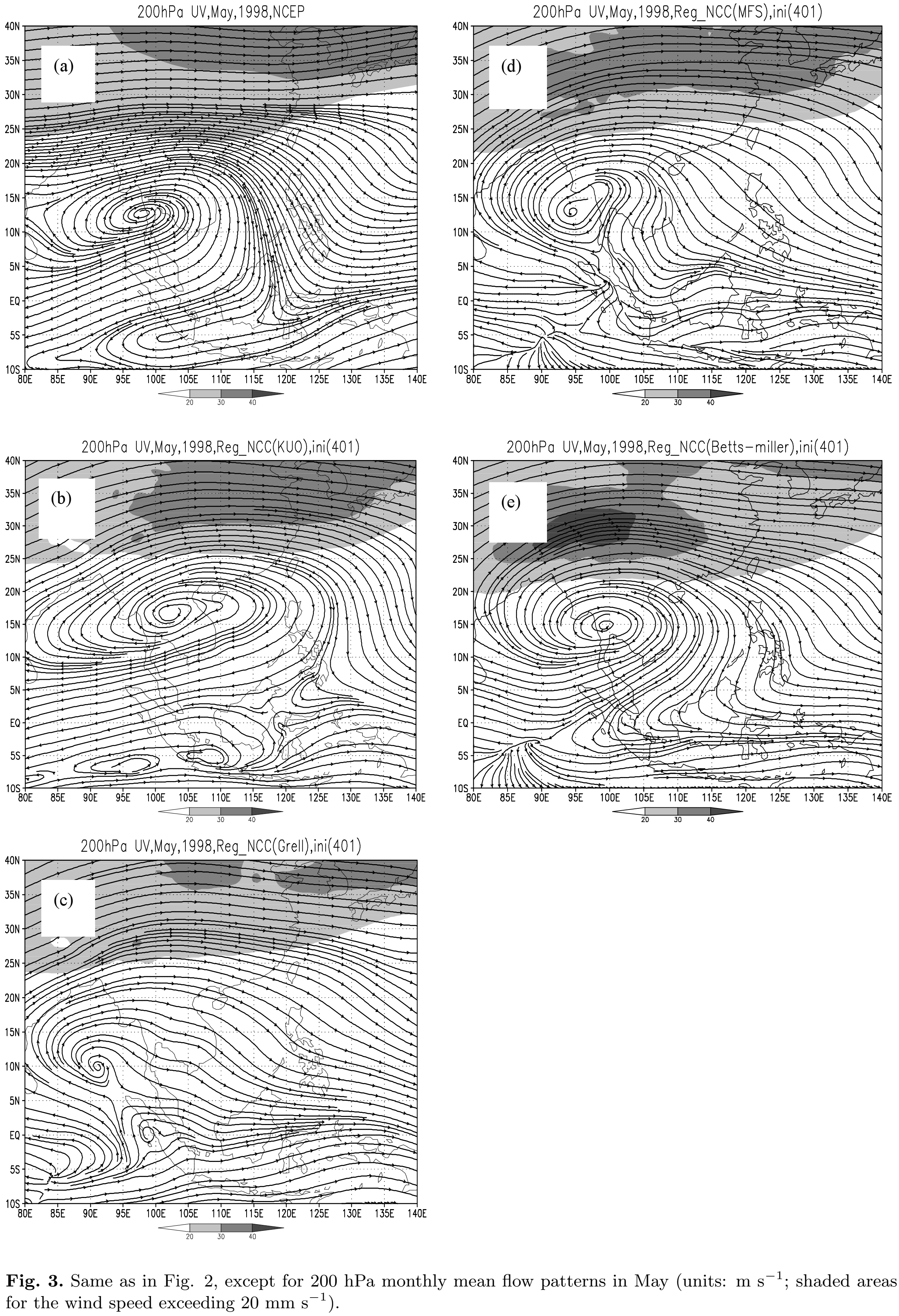

Fig. 3. Same as in Fig. 2, except for 200 hPa monthly mean flow patterns in May (units: m s^{-1}; shaded areas for the wind speed exceeding 20 mm s^{-1}).

distribution and intensity of the rainfall over the SCS was also in relatively consistent with the observations (Fig. 4b). However, the intensity of the rainfall over the region to the north of the Bay of Bengal (Tibetan Plateau) was markedly overestimated, which resulted in an spurious large rainfall center in that region. Also, the simulated rainfall amount by the Kuo scheme over eastern China was obviously stronger than in the observations. For the Grell scheme, the obvious feature was that the simulated major rain belt was located farther north and the rainfall over the SCS was too little (Fig. 4c). The MFS scheme greatly overestimated the intensity and the range of the rainfall of the major rain belt, however, the precipitation range and intensity over the SCS was closer to the observation (Fig. 4d). For the Betts-Miller scheme, it seems that the rainfall range was too concentrated and the rain belt was mainly located at the middle part of the SCS and the region to the east of it (Fig. 4e). It was found that no evident precipitation (exceeding 5 mm d^{-1}) occurred over the other areas (including eastern China). Similar to the Grell and MFS schemes, the Betts-Miller scheme also overestimated the intensity and the range of the precipitation over the region to the south of the Bay of the Bengal, which was possibly related to the adjustment of the momentum, moisture and heat exchange coefficient. In June, the above mentioned southwest-northeast rain belt strongly expanded and shifted northward, which covered a large region from southern China to southern Japan (not shown). Correspondingly, several large precipitation centers appeared, which are mainly located at the eastern part of the Bay of Bengal, South China, the region to the south of the lower reaches of the Yangtze River and the extended region to the south of Japan. In the meantime, the rainfall over the SCS was relatively scarce (Fig. 5a). By comparison, it is easily found that the simulated results are much like those in May. It is still the Kuo scheme that captured the distribution of the precipitation, although there was a clear difference between the simulated rainfall amount with those values that were observed. For example, it obviously overestimated the precipitation over eastern China. For the Grell and MFS schemes, they both grasped the features of the light rainfall over the SCS. The discrepancies between the simulated results and the observations were similar to those found in May.

For any cumulus parameterization scheme, the simulated total rainfall consists of a convective and large-scale rainfall. These two kinds of rainfall interact with one another. Tables 1 and 2 show the comparisons of the rainfall over the SCS in May and June, respectively. From Table 1, it can be seen that the simulated total rainfall by the Grell and Betts-Miller schemes were about 2–3 mm d^{-1} less than the observation, while the results obtained by the Kuo scheme was only 1.36 mm d^{-1} less. It seems that the result from the MFS scheme was closest to the observation, with only 1 mm d^{-1} positive bias in this sense. For the ensemble of the four cumulus parameterization schemes, the average rainfall was only 1.41 mm d^{-1} less than the observation with about 24% negative bias. It is completely in accordance with the bias standard (30% bias) of simulated rainfall by the present regional climate models that were indicated by the IPCC (Inertgovernmental Panel on Climate Change) report (Hewitson et al., 2004). In June, the simulated ensemble rainfall had a 32% negative bias to the observations, a bit larger than the standard bias, but still within the standard bias range (20%–80%). For the convective rainfall by the Kuo, MFS, or Betts-Miller schemes, it covered about 60% of the total rainfall, which reflects the characteristics of the rainfall in the transitional season. However, the MFS scheme obviously exaggerated the convective rainfall and neglected the large-scale rainfall, which does not coincide with the observed situation. From the above analysis, it can be seen that not only convective precipitation, but also non-convective precipitation by different cumulus schemes was different. Due to the fact that the physical process of the non-convective precipitation in the sensitivity experiments was the same, the difference in non-convective precipitation was induced by the choice of the different cumulus schemes. That is, due to the differences in the convective precipitation by the different cumulus schemes, the heat and moisture transport by convection will produce different effects on the recognizable scale motion and possibly will influence the large scale precipitation that occurs by moisture convergence.

From the above simulated results by these four cumulus parameterization schemes, there is no doubt that the distributions of the simulated monthly mean circulation and the rainfall during the SCSSM period were greatly dependent on the cumulus parameterization scheme. In general, it seems that the Kuo scheme was more suitable for the simulation of the monthly mean circulation and the rainfall during the SCSSM period although the precipitation by the MFS scheme was closer to the observations. This might be associated with the characteristics of the rainfall over the SCS during the transitional season, where the rainfall system included the the mixing of the cumulus and the stratus (Chen et al., 1998; Huang et al., 2001). Therefore, it is necessary to choose the appropriate cumulus parameterization scheme for the various rainfall cloud systems. As such, the influence of the cumulus convection on the simulation was large, which is mainly

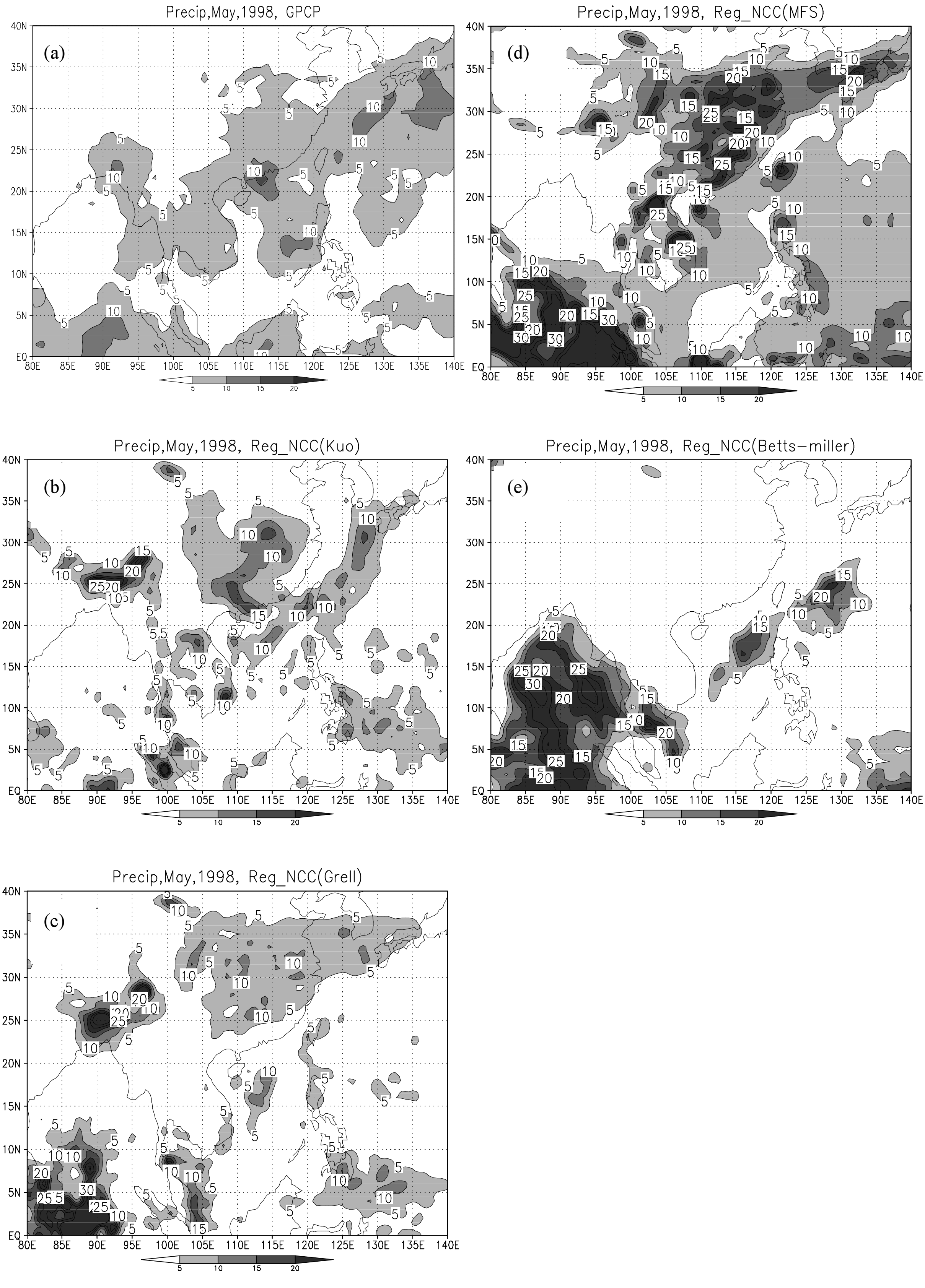

Fig. 4. Monthly mean precipitation in May (units: mm d^{-1}; shaded areas for the precipitation exceeding 5 mm d^{-1}): (a) Observed, (b) Kuo scheme, (c) Grell scheme, (d) MFS scheme, (e) Betts-Miller scheme.

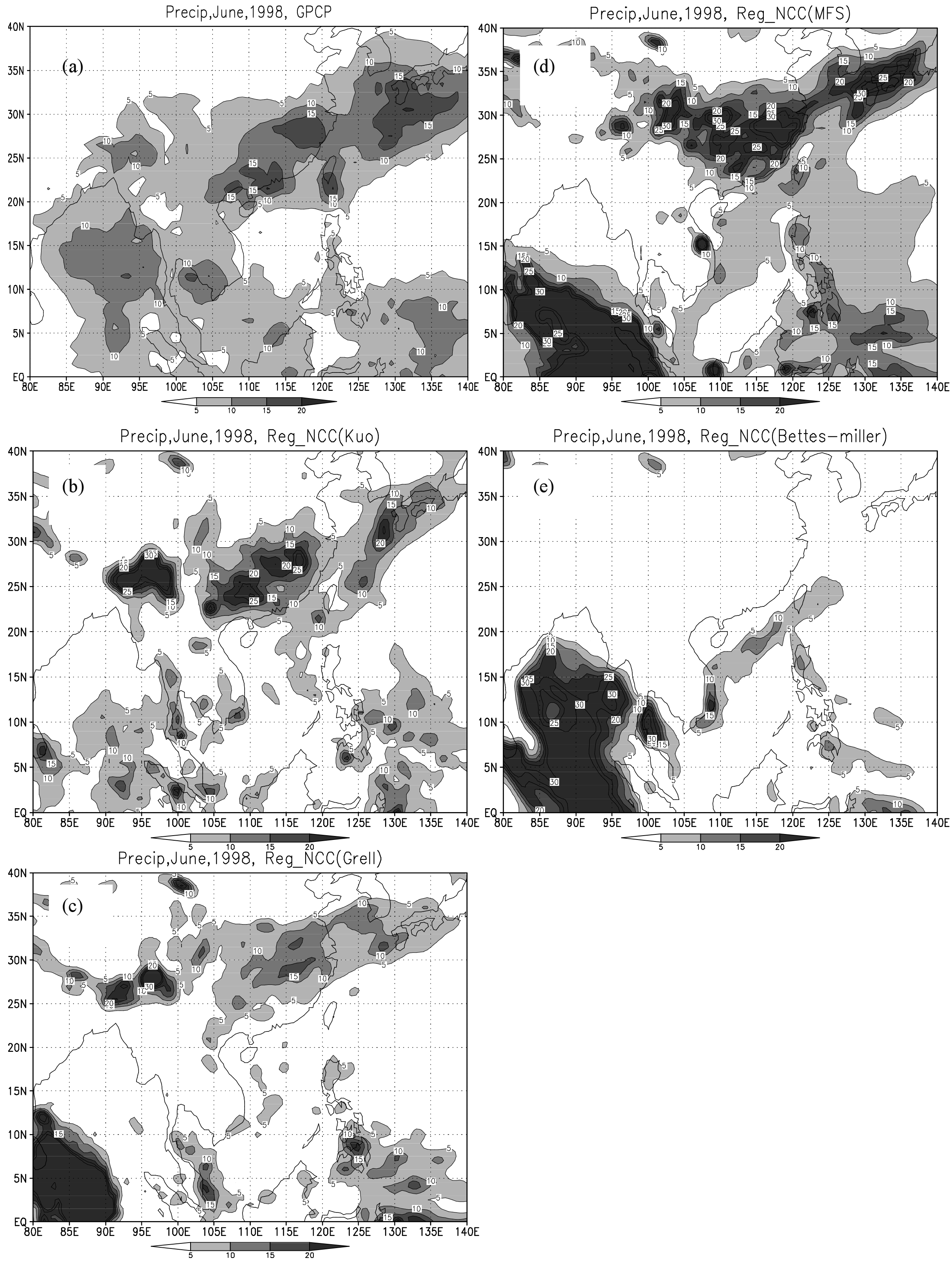

Fig. 5. Same as in Fig. 4, except for monthly mean precipitation in June.

Table 1. Comparison of precipitation over the SCS (5°–22.5°N, 110°–120°E) in May.

	Total (mm d^{-1})	Convective (mm d^{-1})	Non-convective (mm d^{-1})	Bias (mm d^{-1})
Observed	5.86	–	–	–
Kuo scheme	4.50	2.76	1.74	−1.36
Grell scheme	3.10	1.39	1.71	−2.76
MFS scheme	6.80	5.91	0.89	0.94
Betts-Miller scheme	3.41	3.34	0.07	−2.45
Ensemble	4.45	3.35	1.10	−1.41

Table 2. Comparison of precipitation over the SCS (5°–22.5°N, 110°–120°E) in June.

	Total (mm d^{-1})	Convective (mm d^{-1})	Non-convective (mm d^{-1})	Bias (mm d^{-1})
Observed	5.81	–	–	–
Kuo scheme	3.76	2.24	1.52	−2.05
Grell scheme	2.73	1.28	1.45	−3.08
MFS scheme	5.60	5.36	0.24	−0.21
Betts-Miller scheme	3.30	3.17	0.13	−2.51
Ensemble	3.85	3.01	0.84	−1.96

due to the fact that it directly influences the transport and accumulation of heat, moisture and energy, where it will result in the enhancement of the southwesterly upstream of the rainfall region and the formation of the cyclonic shear over the low-level as well as the anticyclonic shear over the upper-level. The stratification over the middle- and low-levels is therefore induced, which provides favorable conditions for the formation and enhancement of the rain belt (Chen et al., 1998; Huang et al., 2001).

3.2 *Evolution of the SCSSM*

Figures 6 and 7 show the latitude-time cross-section of the 850 hPa and 200 hPa zonal winds averaged over the region at 110°–120°E, respectively. It seems that three cumulus schemes (with the exception of the Betts-Miller scheme) all reproduced the characteristics of the southwesterly from the mid-latitudes, with it intruding southward before the SCSSM onset and with the westerly advancing northward following the SCSSM onset. However, the simulated wind patterns are obviously to far to the north (Fig. 6). For the upper-level pattern at 200 hPa, the four cumulus schemes all fairly reproduced the remarkable features of the westerly weakening and enhancing of the easterly after the onset of the SCSSM, also, the features of the several westerlies intruding southward was also well simulated (Fig. 7).

Together with the above analysis, it seems that the models simulated the upper-level flow better than the low-level. Corresponding to the upper- and low-level wind patterns, the Kuo and Betts-Miller schemes successfully simulated the process of the atmosphere's moistening over the SCS and the region to the south of the Yangtze River Basin. For the MFS and Betts-Miller schemes, the moistening belts were simulated to far north, which is closely related with the simulated position of the WPSH (not shown).

3.3 *Process of the SCSSM Onset*

The SCSSM onset is the first abrupt change occurring in the early summer and signals the beginning of the northward march of the EASM. It is important for a regional climate model to be able to simulate both the timing and the dramatic characteristics of this onset. From the above analysis, it has been demonstrated that the results of the monthly mean circulation and the rainfall were very sensitive to the choice of cumulus convective parameterization scheme. In the following we will present the simulations of the SCSSM onset by the Kuo cumulus parameterization scheme and the ensemble of the four cumulus parameterization schemes. Here, we regard the mean of the 4th and 5th pentad of May as the SCSSM onset pentad (0 pentad) (Ding and Liu, 2001), the five-day periods immediately before and after pentad 0 are referred to as pentad −1 and pentad 1, respectively. Figures 8 and 9 present the observed and simulated evolution of the circulation and precipitation. For the −1 pentad, the results by the Kuo scheme and the ensemble simulated the location of the subtropical high, the southwesterly over the northern and the southeasterly over the southern part of the SCS quite well (Figs. 8b1 and c1). However, the easterlies over the southern part of the subtropical high were simulated to be too weak by the Kuo scheme, while for the ensemble, the easterly was simulated to be relatively strong and it extended into the Bay of Bengal. Although there exists

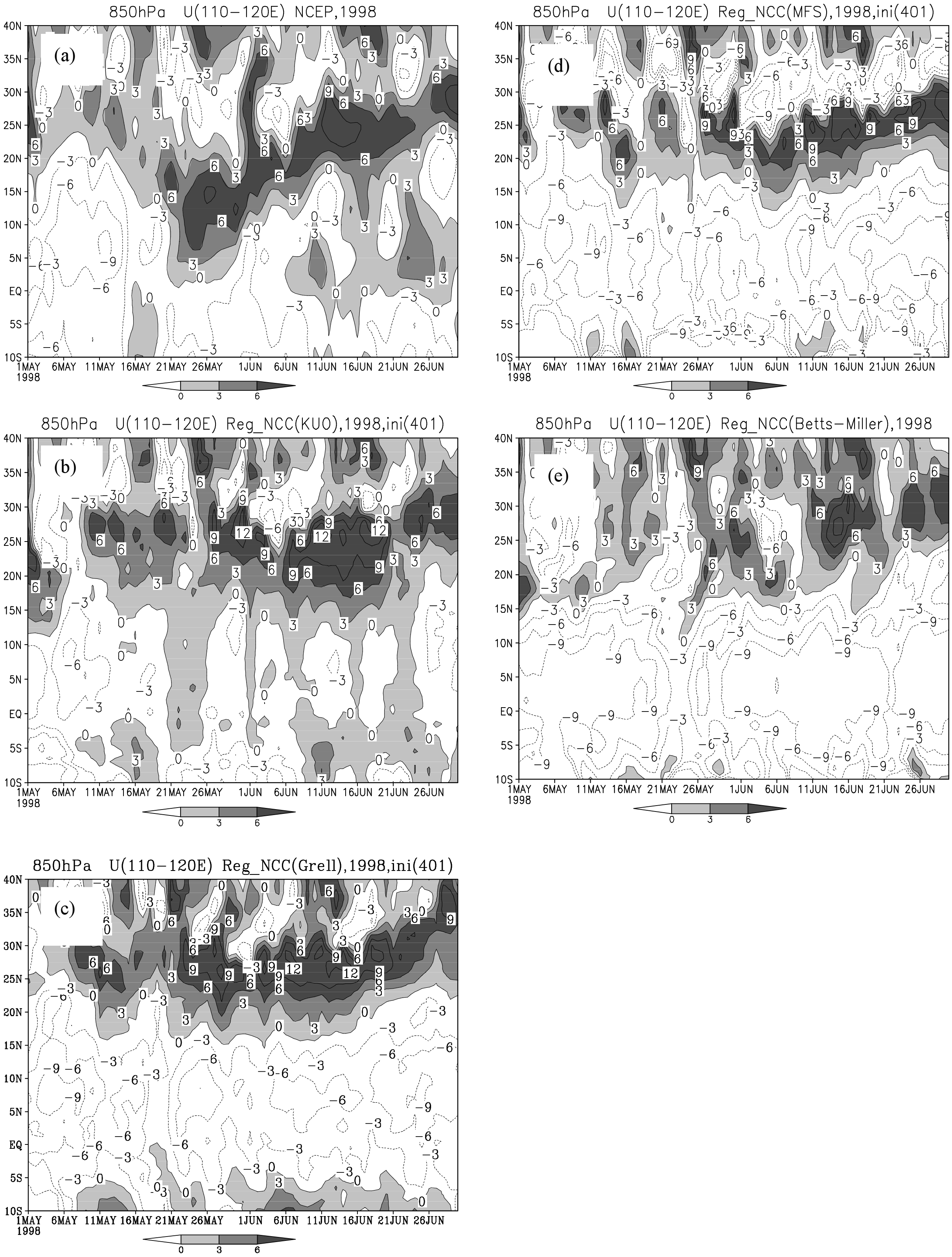

Fig. 6. Latitude-time cross section of the 850 hPa zonal wind averaged over 110°–120°E (Units: m s^{-1}; shaded areas for the wind speed exceeding 0): (a) Observed, (b) Kuo scheme, (c) Grell scheme, (d) MFS scheme, (e) Betts-Miller scheme.

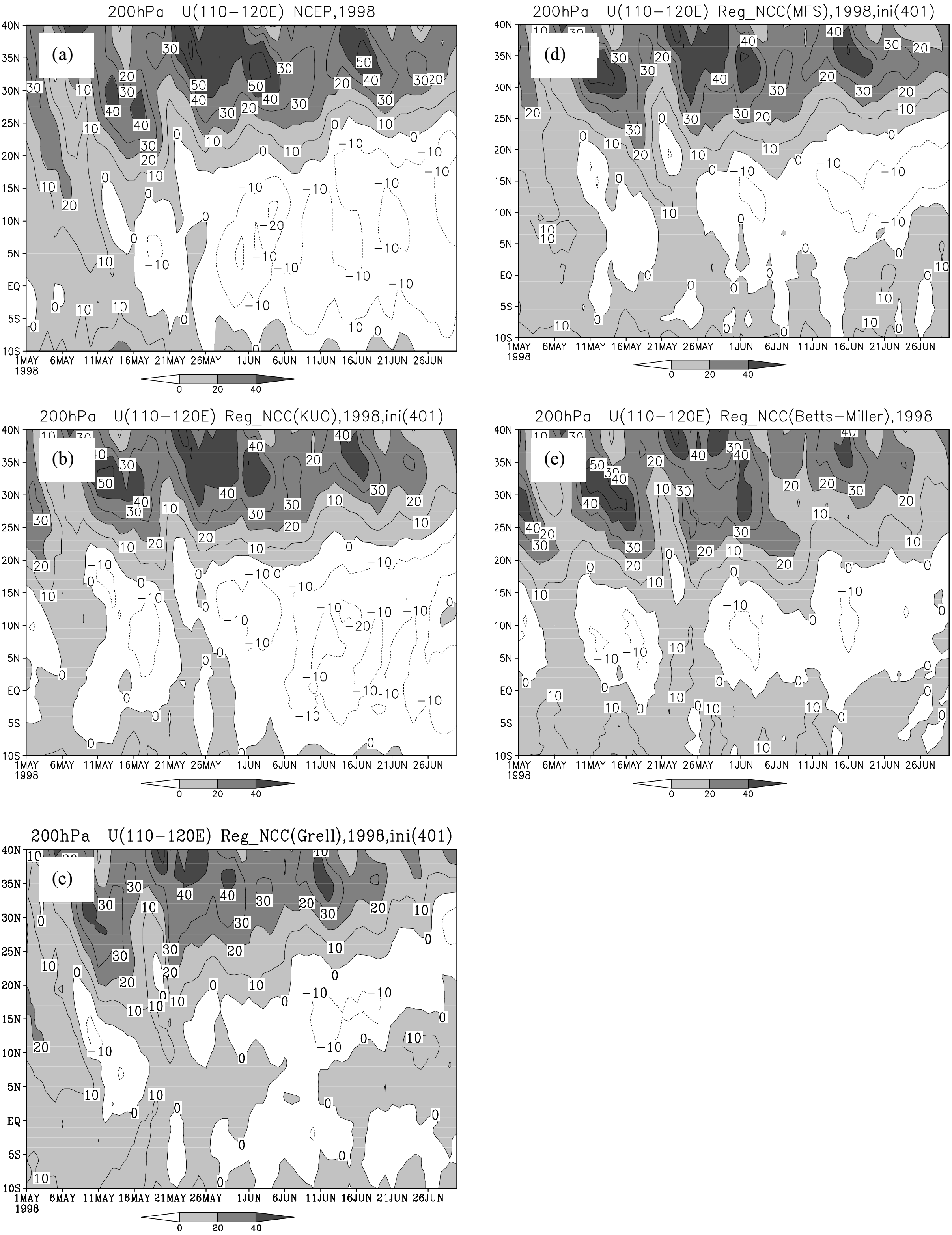

Fig. 7. Same as in Fig. 6, except displayed for the 200 hPa zonal wind (Units: m s^{-1}; shaded areas for the wind speed exceeding 0).

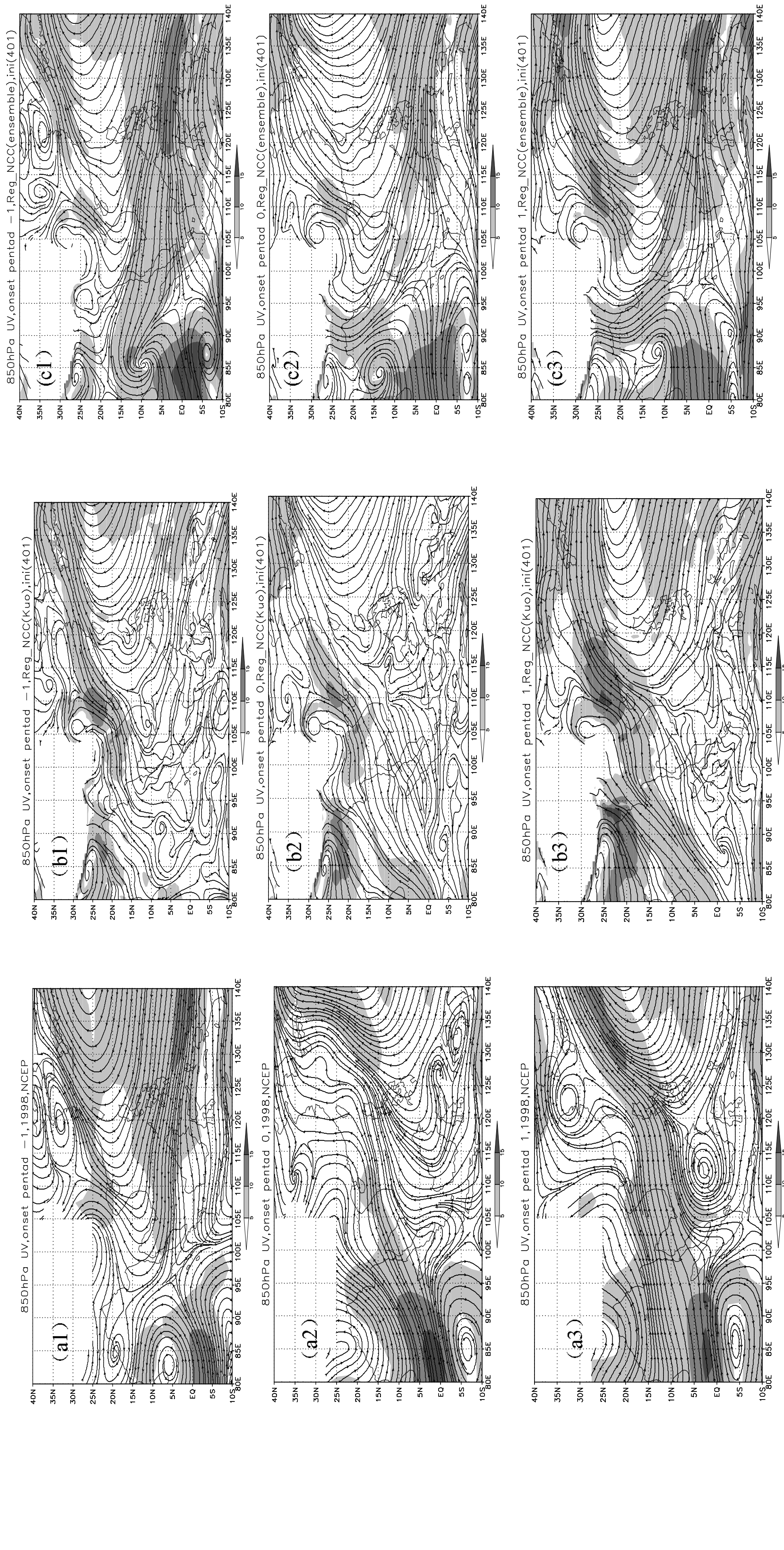

Fig. 8. The observed and simulated 850 hPa flow patterns during the process of the South China Sea summer monsoon onset (the left panel: observation; the middle panel: Kuo scheme; the right panel: the four cumulus schemes ensemble; a1, b1, and c1 represent one pentad before the SCSSM onset; a2, b2, and c2 represent the pentad of the SCSSM onset; a3, b3, and c3 represent one pentad after the SCSSM onset The unit is m s^{-1} and with the shaded areas for the wind speed exceeding 5 m s^{-1}).

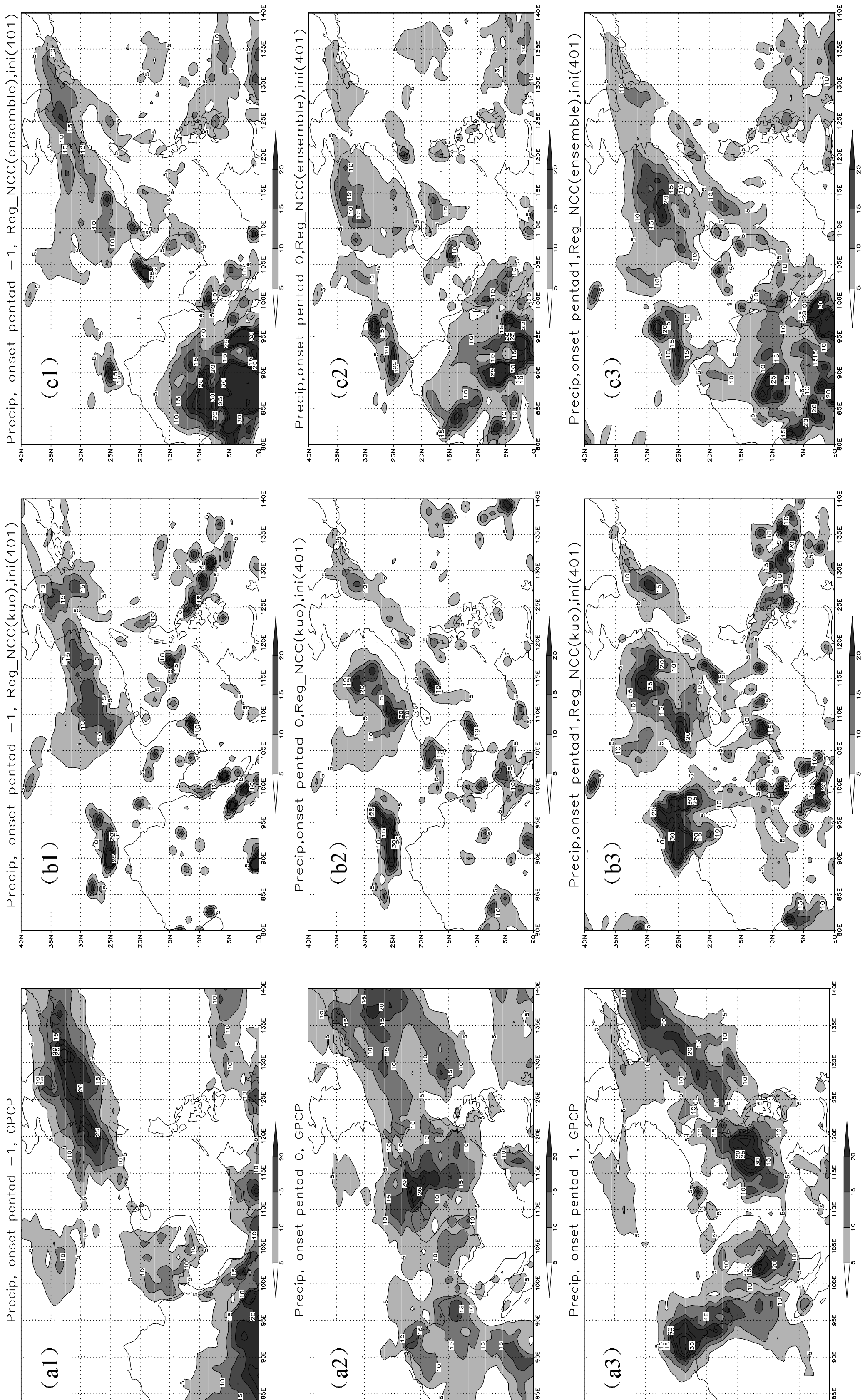

Fig. 9. The same as in Fig. 8, except for the precipitation patterns (units: mm d^{-1}; shaded areas for the precipitation exceeding 5 mm d^{-1}).

an obvious difference between the ensemble and the observation, the simulation over the SCS was quite successful. Also, the ensemble reproduced the double-cyclone phenomenon over the equatorial eastern Indian Ocean (Ding and Liu, 2001). Corresponding to the circulation, the main rainfall belts were concentrated over the coastal areas of South China and the region to the south of Japan. At this time, the SCS was clear (Fig. 9a1). Similar to the observation, both of these two sets of simulations captured the distribution of the rainfall in the pentad prior to the SCSSM onset (Figs. 9b1 and 9c1). However, the Kuo scheme cannot simulate the large rainfall areas over the equatorial eastern Indian Ocean and the ensemble exaggerated the rainfall amounts over this region as well. In the pentad of the SCSSM onset, the SCS was basically controlled by the southwesterly and the subtropical high retreated from this region (Fig. 8a2). Although the Kuo scheme simulated the characteristics of the subtropical high quite well, the location was a bit farther east and north than it was in the observations (Fig. 8b2). For the ensemble, it cannot simulate the retreating feature of the subtropical high, which makes the southwesterly from the Bay of Bengal not extend into the SCS (Fig. 8c2). In contrast to the pentad before the SCSSM onset, the migration of the subtropical high was weak and still a bit farther west. It was just because of the unsuccessful simulation of the subtropical high that makes the easterly or southeasterly wind still prevail over the SCS and the main rainfall belt remain concentrated over eastern China and the Yangtze River Basin. In pentad 1, still due to the failure of the simulated subtropical high, the pattern was obviously different from the observations and cannot reproduce the southwardly moving feature of the rainfall belt (Figs. 8b3, 8c3, 9b3 and 9c3). For the upper-level (not shown), the simulations more closely reproduced the observations, and the location and intensity of the South Asian high were consistent with the observations. It was concluded that for any cumulus parameterization schemes that the improved RegCM_NCC can successfully simulate the upper-level flow pattern. For the low-level flow pattern, the subtropical high was not well simulated, which may be due to the systematic bias of the model.

Figure 10 presents the pentad evolution of the 850 hPa, 200 hPa zonal winds and the rainfall averaged over the SCS with different cumulus parameterization schemes. From Fig. 10a it can be seen that all four cumulus parameterization schemes can simulate the abrupt increase in the zonal wind after the onset of the SCSSM. However, the intensity of the simulated westerly was obviously weaker than observed. Also, it can be seen that the results by the ensemble was much better than any single cumulus parameterization scheme, with the exception of the Kuo scheme. It should be noted that although the bias between the simulated result by the Betts-Miller scheme and the observation was the largest, they have almost the same evolutional trend. For the upper-level flow pattern (Fig. 10b), the simulated results were very close to the observations and the bias between them was clearly smaller than it was for the low-level flow pattern for any single cumulus parameterization scheme. The evolution of the rainfall over the SCS was in good correspondence with those of the zonal winds. Due to the local feature of the rainfall, Fig. 10c presents the evolution of the rainfall over the northern part of the SCS. During the fourth to fifth pentad in May, when the SCSSM begins, the rainfall over this region obviously increases. It was found that the characteristics of the increase in the rainfall was simulated quite well in comparison to the observations by any cumulus parameterization scheme, which demonstrates that the model can successfully grasp the characteristics of the variations in the rainfall. Of course, there still exists the bias between the observations and simulated results, which mainly include the increased amount and time of the maximum rainfall. To the break period of the SCSSM in June, the major rainfall belt started to advance to the mainland of China and the SCS was relatively a dry season with little rainfall. Four cumulus parameterization schemes all captured these features. Also, the simulated rainfall by the four cumulus parameterization schemes was obviously larger than the observations before the onset, while after the onset, the simulated rainfall was smaller. Corresponding to the low-level flow pattern, the evolution of the simulated rainfall by the Betts-Miller scheme also had a trend similar to the observations, which indicates that this kind of scheme was superior to other three schemes in this respect.

In general, in the simulation of the regional climate, the appropriate cumulus parameterization scheme may be more critical than initially believed. It seems that the Kuo scheme was more favorable for simulating this process than the three other cumulous parameterization schemes. However, the simulated location of the subtropical high was needed to be improved. For the rainfall, the results by this ensemble seemed more reliable and reasonable, however, the rainfall amount of the major rain belt was underestimated, especially for the SCS region. Therefore, in the simulation of the regional climate and its change, the ensemble approach may be a more feasible way to improve the simulations while avoiding the significant bias.

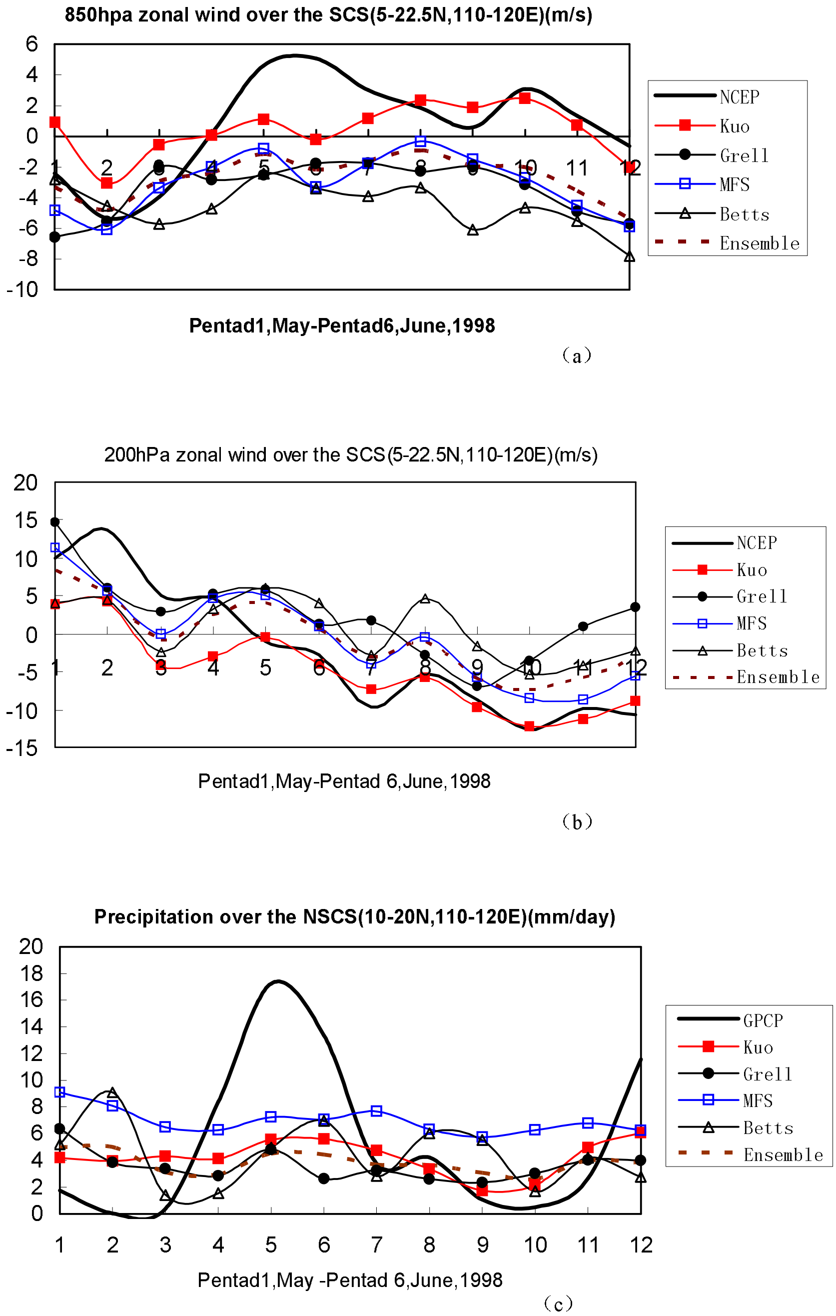

Fig. 10. The pentad evolution of the 850 hPa (a, units: m s^{-1}), 200 hPa zonal wind (b, units: m s^{-1}) and the rainfall (c, units: mm d^{-1}) averaged over the SCS.

4. Conclusions

With the high-resolution regional climate model of National Climate Center of China (RegCM_NCC), a series of sensitivity experiments, including four cumulus parameterization schemes, have been undertaken to evaluate the model's performance to reproduce the SCSSM in 1998. The results have indicated that the model is capable of simulating the overall characteristics and the results were very sensitive to the choice of the convective parameterization schemes. The preliminary conclusions can be drawn as follows:

(1) For the monthly mean conditions during the SCSSM period during 1998, the patterns of the wind, geopotential height and rainfall as simulated by the Kuo cumulus parameterization scheme were more consistent with the observations than any other cumulus scheme attempted. For the process of the SCSSM on-

set, it is still the Kuo scheme that can successfully simulate this process the best and the simulated results were better than any of the other three schemes. Furthermore, this scheme can reproduce the onset timing and the dramatic changes both before and after the SCSSM onset, especially the upper-level flow pattern. Also, the results derived from the ensembling method were obviously superior to any single cumulus parameterization scheme and were closer to the observations.

(2) However, there are still some discrepancies between the simulations and the observations. For example, the model can not fairly simulate the intensity of the rainfall or the location of the WPSH or the features of the rapid northward propagation of the seasonal rain belt. Therefore, further investigation should be done to improve the model's capability.

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