Application and Study of Precipitation Schemes in Weather Simulation in Summer and Winter over China*

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ABSTRACT

Through simulation of summer and winter precipitation cases in China, the cloud precipitation schemes of model were examined. Results indicate that it is discrepant between convective precipitation simulated by the Kain-Fritsch (KF) scheme and Betts-Miller (BM) scheme in summer, the former scheme is better than the latter in this case. The ambient atmosphere may be varied by different convective schemes. The air is wetter and the updraft is stronger in the KF scheme than in the BM scheme, which can induce the more grid scale precipitation in the KF scheme, i.e., the different cumulus schemes may have the different and important effect on the grid scale precipitation. However, there is almost no convective rain in winter in northern China, so the effect of cumulus precipitation on the grid scale precipitation can be disregarded. Therefore, the gird scale precipitation is primary in the winter of northern China.

Key words: simulation, precipitation scheme, convective precipitation, grid scale precipitation

1. Introduction

Moist physical process in the numerical model has a great influence on the accuracy of numerical prediction. The process of cloud precipitation is one of the most important diabatic heating physical processes in the numerical model, which makes an impact on the large-scale circulation by the feedback of sensible heat, latent heat, and momentum transport, and plays a crucial role in determining the vertical structure of atmospheric temperature and humidity fields. It is also the key factor given most concern for the precipitation prediction.

There are mainly two kinds of cloud precipitation schemes, namely, subgrid cumulus convective parameterization and grid scale explicit precipitation schemes. The former dates back to the middle of 1950s, and now many kinds of schemes are proposed, mainly including shallow convection parameterization and deep convection parameterization schemes. The shallow convection process is also called non-precipitable convection process and the deep convection is called precipitable convection process which can cause not only the change of vertical structure of moisture-heat field but also the net-release of latent heat as well as convective rainfall. The deep convective parameterization scheme mainly includes pumping scheme (Charney and Eliassen, 1964), moist convection adjustment scheme (Manabe et al., 1965; Betts, 1986; Betts and Miller, 1986), large-scale water vapor convergence scheme (Kuo, 1965, 1974), convection mass flux scheme (Arakawa and Schubert, 1974; Grell, 1993), and release of convective available potential energy (CAPE) scheme (Kreitzberg and Perkey, 1976; Fritsch and Chappell, 1980; Kain and Fritsch, 1990), etc. Actually, there are similarities between these schemes in some ways, not absolutely different. Generally, the explicit precipitation scheme can be divided into two kinds, i.e., warm cloud scheme and mixed phase cloud scheme according to whether it contains ice phase process. The scheme has a clear physical basis, however, as mesoscale model grid spacing still has a far way to be able to show the whole process of explicitly calculating cloud, cumulus convective parameterization

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scheme has been attempted to be used in calculating subgrid scale precipitation and the explicit precipitation scheme used in grid scale precipitation. The combination of the two schemes is called whole physical process scheme or mixed scheme. A very important problem of the two schemes in practical application is what relations exist between them in different time and weather processes and which one is dominant, so as to offer further and more careful reference for the practical prediction. In the moist physical process, it is a very important scientific subject for the development, selection, and application of cloud precipitation scheme, and it is also a focus studied in the current numerical prediction.

This paper firstly made a brief description of the basic principles of two cumulus convective parameterization schemes commonly used and a mixed phase cloud precipitation scheme, using the latest mesoscale numerical prediction model WRF (weather research and forecasting) developed in USA. Through the simulation of winter precipitation in northern China and summer precipitation in the Yangtze and Huaihe River Basin, we examined the selection of cloud precipitation scheme in different seasons and areas, made a thorough discussion on the characters of the cloud precipitation scheme applied, and studied preliminarily the effect of different cumulus convection schemes on grid scale precipitation prediction.

2. A brief description of model cloud precipitation scheme and experiment design

2.1 *Description of cloud precipitation scheme*

2.1.1 *Betts and Miller convective parameterization scheme (BM scheme for short)*

The selection of reference profile of convection adjustment moisture-heat field is an important part in convection adjustment scheme. Manabe et al. (1965) took "mean moist static energy line" as the reference profile, while Betts and Miller (1986) took "observational quasi-equilibrium state line" or "modified moist adiabat" as the reference profile of deep convection adjustment, and "mixed line" as the reference profile of shallow convection adjustment.

The problem needed to be solved in new convection adjustment scheme is to confirm whether the convection adjustment characteristic time τ makes convection adjustment as well as convection adjustment moisture-heat field's reference profile T_α, q_α.

(1) Process of deep convection adjustment

The control condition for deep convection adjustment is the conservation of the air column's moist static energy before and after adjustment, i.e.,

$$\int_{p_{\mathrm{T}}}^{p_{\mathrm{B}}} (h-\bar{h})\mathrm{d}p = 0,$$

where $h = gz + c_pT + Lq$ is moist static energy.

After the first guess of convection adjustment is determined, it will be revised according to the control condition of moist static energy conservation. The rainfall amount is estimated when moisture-heat field's reference profile of convection adjustment is determined.

(2) Process of shallow convective adjustment

The control condition for shallow convection adjustment is that there is no convective precipitation occurring in the entire column, i.e.,

$$\int_{p_{\mathrm{T}}}^{p_{\mathrm{B}}} \frac{q_\alpha - \overline{q}}{\tau}\frac{\mathrm{d}p}{g} = \frac{c_p}{L}\int_{p_{\mathrm{T}}}^{p_{\mathrm{B}}} \frac{T_\alpha - \overline{T}}{\tau}\frac{\mathrm{d}p}{g} = 0.$$

In the process of shallow convection adjustment, saturated pressure deficit is assumed to be invariable from cloud base to cloud top, and the reference thermal profile is paralleled to mixed line.

Although BM convective parameterization scheme cannot give a detailed description of the interaction between cumulus convective parameterization and ambient force field, this scheme has two characteristics: firstly, the influential effects of both deep convection adjustment and shallow convection adjustment processes are simultaneously taken into consideration; secondly, virtual moist adiabatic (modified moist adiabat) is taken as convection adjustment reference profile.

2.1.2 *Kain-Fritsch convective parameterization scheme (KF scheme for short)*

KF scheme (Kain and Fritsch, 1990) is developed on the basis of Fritsch-Chappell scheme (Fritsch and Chappell, 1980). Fritsch-Chappell scheme holds that

CAPE in the air can directly be utilized in controlling and adjusting the cumulus convective process and describing the feedback of cumulus process on ambient field. In KF scheme, entrainment, detrainment, updraft, downdraft, etc. are taken into consideration; one-dimensional entrainment/detrainment plume current model is introduced; the drag effect of condensate in vertical motion is taken into account, and the criteria for parcel's upward and downward drift in the lifting condensation level are revised. Precipitation efficiency is determined by both cloud base height and wind vertical shear, and convection adjustment characteristic time τ is calculated by the mean wind between cloud base and 500 hPa, namely the middle troposphere. This scheme avoids following single small cloud's route, with an assumption of mass distribution of accumulated mixed air parcel and integration produces net-entrainment/detrainment rate. The new model improved sensitivity of convective parameterization scheme to cloud scale ambient, which mainly due to introducing into the physical actual estimate of cloud lateral detrainment rate, and allowing upward current mass flux to vary with the environment condition in the cloud layer.

2.1.3 *NCEP simple ice phase cloud scheme*

This scheme is proposed by Hong et al. (1998). They made some modification and increased the effect of ice deposition process. It is a cloud scheme that contains the ice phase process and concretely includes three water substances, namely vapor, cloud water/ice, and rain/snow. Cloud water/ice is a kind of water substance, which is differentiated by temperature, and when the temperature is below or equal to freezing temperature, i.e., below 0°C, it is considered to be cloud ice, and otherwise it is considered to be cloud water. Similarly, rain/snow is taken as water substance differentiated to be rain or snow based on whether the temperature is above or below 0°C.

2.2 *Design of numerical experiment scheme*

The model used in this paper is the latest mesoscale numerical prediction WRF model developed in USA, which adopted the Arakawa-C leap-frog scheme and fully compressed non-hydrostatic dynamic frame, whose coordinate can select the mass terrain-following coordinate or altitude terrain-following coordinate. Physical processes include cloud microphysical explicit precipitation, sub-grid cumulus convective parameterization, long-wave radiation, short-wave radiation, land process, boundary layer process, sub-grid diffusion, etc.

Primarily studying selection and application of cloud precipitation scheme in China, we take 20 km as model grid spacing and use the mass terrain-following coordinate and other physical process consistently, so as to study the effects of different cloud precipitation schemes on precipitation prediction.

This paper designed two numerical experiment schemes. Through the simulation analysis of winter precipitation in northern China and summer precipitation in mid-lower reaches of the Yangtze River Basin in 2002, respectively, we studied the application features of different cloud precipitation schemes in different areas and seasons in China, and made a thorough discussion. AVN analysis data are adopted in the model.

Experiment 1: BM subgrid cumulus parameterization scheme and grid scale explicit precipitation scheme (NCEPCLOUD3 Scheme) are selected and the schemes are abbreviated to BM-S in summer, BM-W in winter.

Experiment 2: KF subgrid cumulus parameterization scheme and grid scale explicit precipitation scheme (NCEPCLOUD3 Scheme) are selected and they are abbreviated to KF-S in summer, KF-W in winter.

3. Application and analysis of summer precipitation scheme over China

3.1 *Weather situation*

Persistent rainfall occurred from 19 to 25 June 2002 in central and eastern China. Figure 1 illustrates the daily precipitation distribution from 08 BT 22 June to 08 BT 25 June (Beijing Time, the same hereafter). As is shown, from 08 BT 22 June to 08 BT 23 June (Fig.1a), there are large rainfall areas including the Yangtze-Huaihe River Basin, central and eastern parts of North China, and southern Northeast China, and strong rainfall areas were of zonal

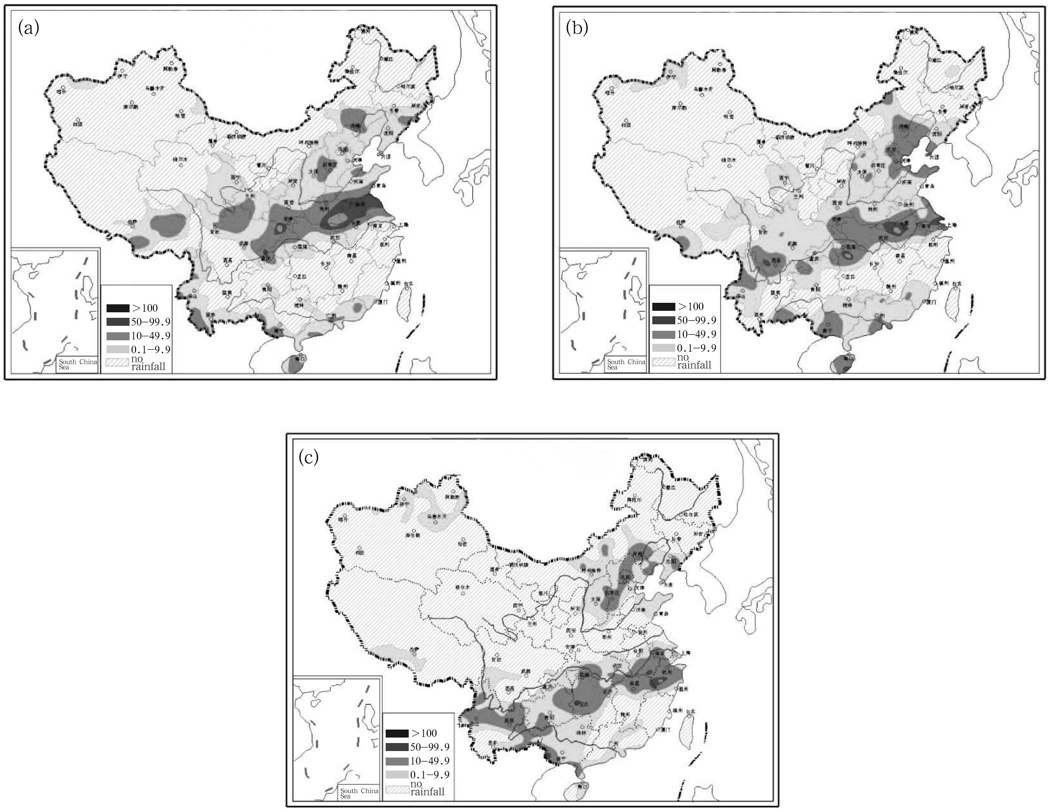

Fig.1. Observational daily precipitation from 00Z, 22 to 00Z, 25 June 2002 in China. (a) 00Z, 22–00Z, 23; (b) 00Z, 23–00Z, 24; and (c) 00Z, 24–00Z, 25.

distribution. The strongest rainfall occurred in north of the Yangtze River and south of the Huaihe River. In southern Henan, northern Hubei, northern Anhui, and northern Jiangsu Provinces, their rainfall amounts all exceeded 50 mm in 24 h, reaching the level of heavy rainfall, even in some areas of southern Henan Province and western Anhui Province, their amount was over 100 mm in 24 h, reaching the level of great heavy rainfall. From 08 BT 23 to 08 BT 24 June (Fig.1b), the rainfall areas diminished and the strong rainfall belt went downward south slowly between the Yangtze and Huaihe Rivers, and there was still rainstorm in areas of Hefei, Nanjing, and Shanghai, and strong rainstorm in west of Hefei. From 08 BT 24 to 08 BT 25 June (Fig.1c), with the cold air from the north invading, the rainfall area was further shrunk, dividing into northern and southern parts; the rainfall weakened or even disappeared in areas of north of the Yangtze River; stronger rainfall belt weakened and moved to the south of the Yangtze River, and rainstorm only occurred in the central of Zhejiang Province, but almost no strong rainfall in other areas.

3.2 *Influential analysis of different cumulus convection scheme on subgrid cumulus convective precipitation prediction*

Figure 2 depicts the convective precipitation from 08 BT 22 to 08 BT 25 June simulated with BM-S scheme. Figure 3 depicts the counterpart but with KF-S scheme. Comparison of Fig.2a with Fig.3a indicates that in the precipitation 24h prediction from 08 BT 22 to 08 BT 25 June, the range of rainfall predicted in KF scheme is basically consistent with that in BM scheme, i.e., there are obvious rainfalls both in the Huaihe River Basin and of zonal distribution; and there is almost no rainfall in south of the Yangtze River and north of 36°N. The main difference between the two figures is that the intensity of convective precipitation in KF scheme is stronger than in BM scheme. Also, there is discrepancy in the position of strong

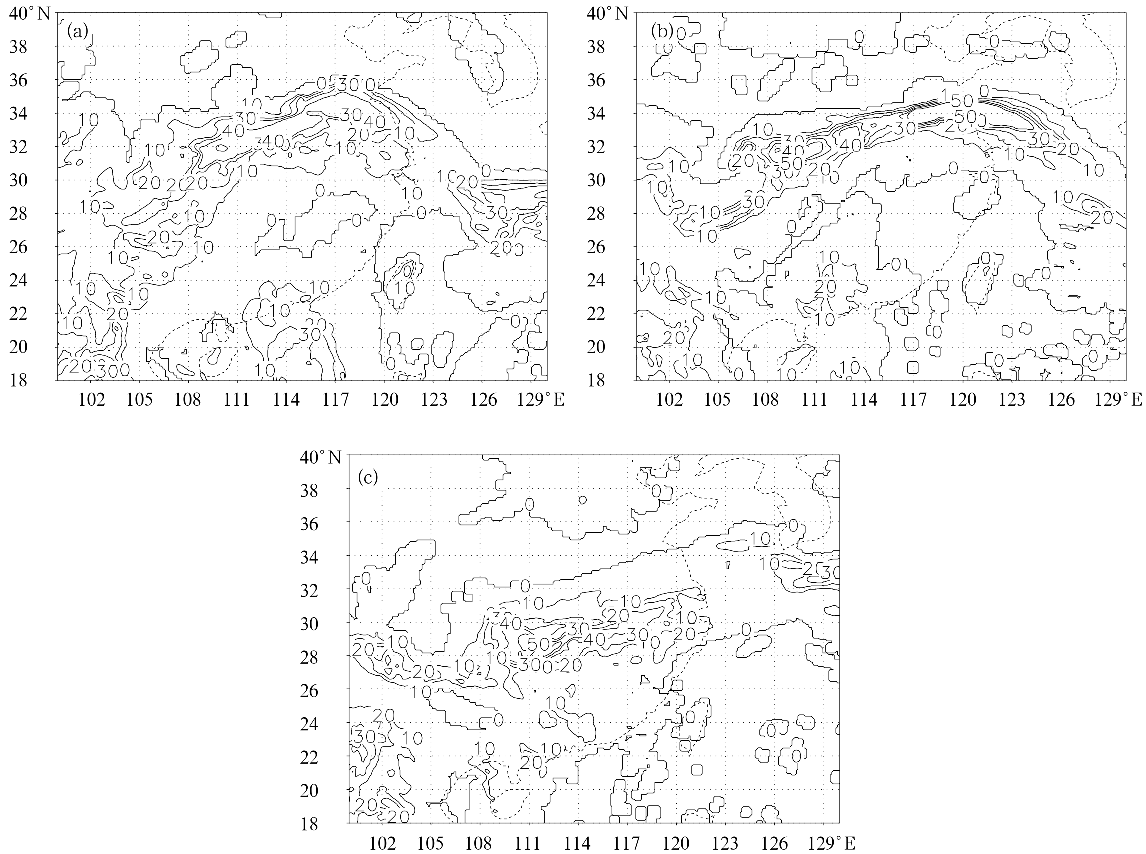

Fig.2. Daily convective precipitation predicted with BM-S from 00Z, 22 to 00Z,25 June 2002. (a) 00Z, 22−00Z, 23; (b) 00Z, 23−00Z, 24; and (c) 00Z, 24−00Z, 25.

rainfall area, i.e., the area predicted in KF scheme is slightly to the further south than that in BM scheme.

Comparison of Figs.2b and 3b indicates that in the 24-48 h precipitation prediction from 08 BT 23 to 08 BT 24 June, the range of convective precipitation predicted in KF scheme is basically consistent with that in BM scheme; there are obvious rainfalls both in the Yangtze-Huaihe River Basin and of zonal distribution; it moves towards south slowly compared with the precedent 24 h precipitation prediction. The main difference between the two figures is that there is still discrepancy in the position of strong rainfall area, i.e., the area predicted in KF Scheme is slightly to the further south than in BM scheme, which is uniform with the precedent 24 h prediction. However, the intensity of convective precipitation in KF scheme is weaker than that in BM scheme, which is contrary to the precedent 24 h prediction. Similarly comparison of Fig.2c with Fig.3c indicates that in the 48-72 h precipitation prediction from 08 BT 24 to 08 BT 25 June, the strong rainfall belt originally located in the Yangtze-Huaihe River Basin obviously moves south to the Yangtze River Basin; the range of rainfall areas predicted is much the same. However, with respect to the position of strong rainfall area, the area predicted in KF scheme is slightly to the further south than in BM scheme, and the rainfall belt predicted in KF scheme is a bit narrower than in BM scheme; the intensity of precipitation predicted is basically similar in the two schemes.

Comparison of simulations (Figs.2 and 3) with weather situation indicates that the convective precipitations predicted in the two schemes are of zonal structure, which is consistent with the actual situation. But the strong rainfall areas predicted in the two schemes are in the further north and the rainfall intensity is weaker than that of the actual situation. The position of strong rainfall predicted in KF scheme

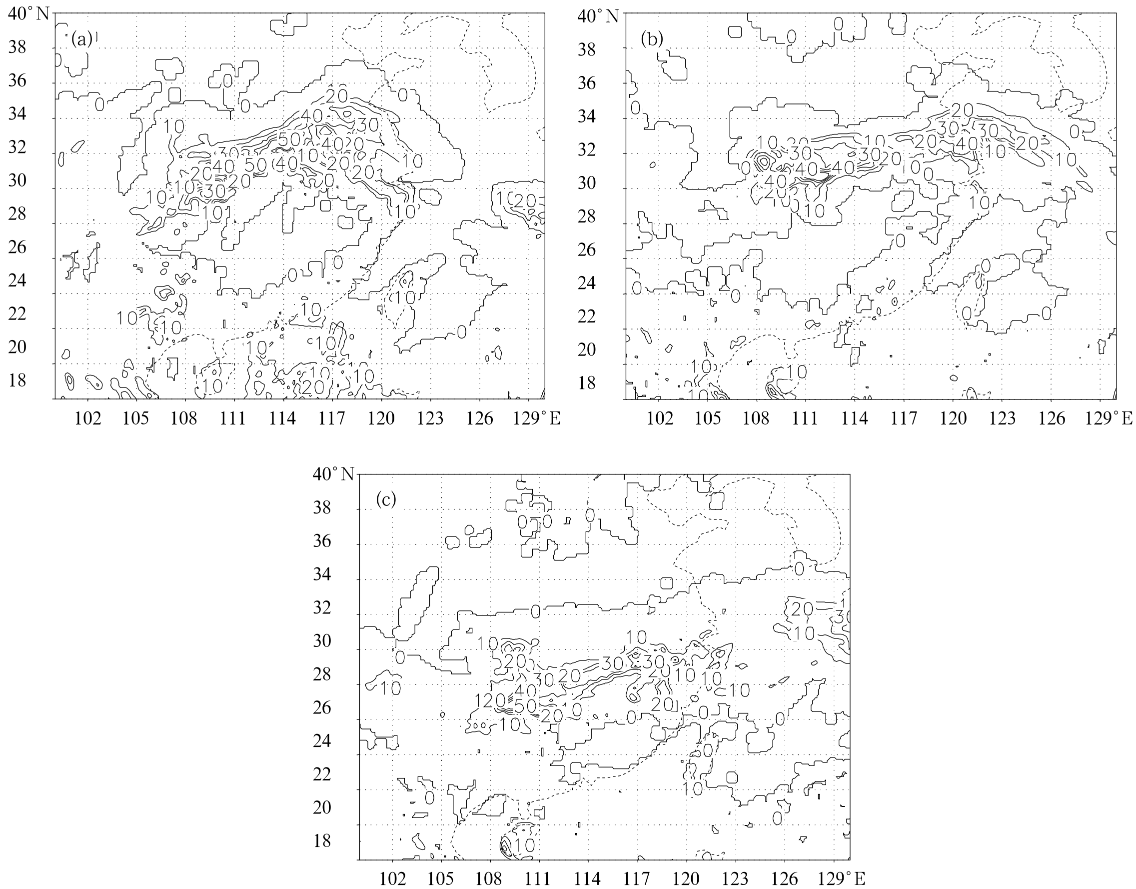

Fig.3. Daily convective precipitation predicted with KF-S from 00Z, 22 to 00Z, 25 June 2002. (a) 00Z, 22−00Z, 23; (b) 00Z, 23−00Z, 24; and (c) 00Z, 24−00Z, 25.

is more conform to the actual situation. On the whole, the precipitation case this time predicted by KF scheme is better than that predicted by BM scheme.

3.3 *Influential analysis of different cumulus convection scheme on grid scale precipitation prediction*

The interaction between the large-scale circulation and ambient air is a very complicated nonlinear process, which is still one of the most challenging problems that the meteorologists are facing today. The vertical distribution of atmosphere heating and drying effect after convection triggers and starts still needs to be studied deeply. Moreover, the large-scale system and the feedback effect of ambient atmosphere need to be learned more. This paper puts stress on studying different cumulus convective scheme's influence on grid scale precipitation prediction. The cumulus convection has influenced the distribution of ambient atmospheric field, i.e., the distribution of atmospheric temperature and humidity changes, which certainly induces the change of grid scale cloud physical process. Firstly, the influential result of grid scale precipitation is given. Figure 4 represents precipitation prediction field of 0-24 h and 24-48 h grid scales in BM-S and KF-S schems, respectively. As the figures shown, in the 0-24 h grid scale precipitation prediction, the range of grid scale precipitation in BM-S scheme (Fig.4a) is quite similar to that in KF-S scheme (Fig.4b), but the precipitation intensity in KF-S scheme is stronger than in BM-S scheme. In Fig.4b, the rainfall centers are in the middle of Henan Province, south of Shandong Province, and north of Hubei Province, besides, there is a rainfall center in west of Hetao, reaching 50 mm; In BM-S, there is only one rainfall center, only 20 mm. In Figs.4c and 4d, the differences and similarities

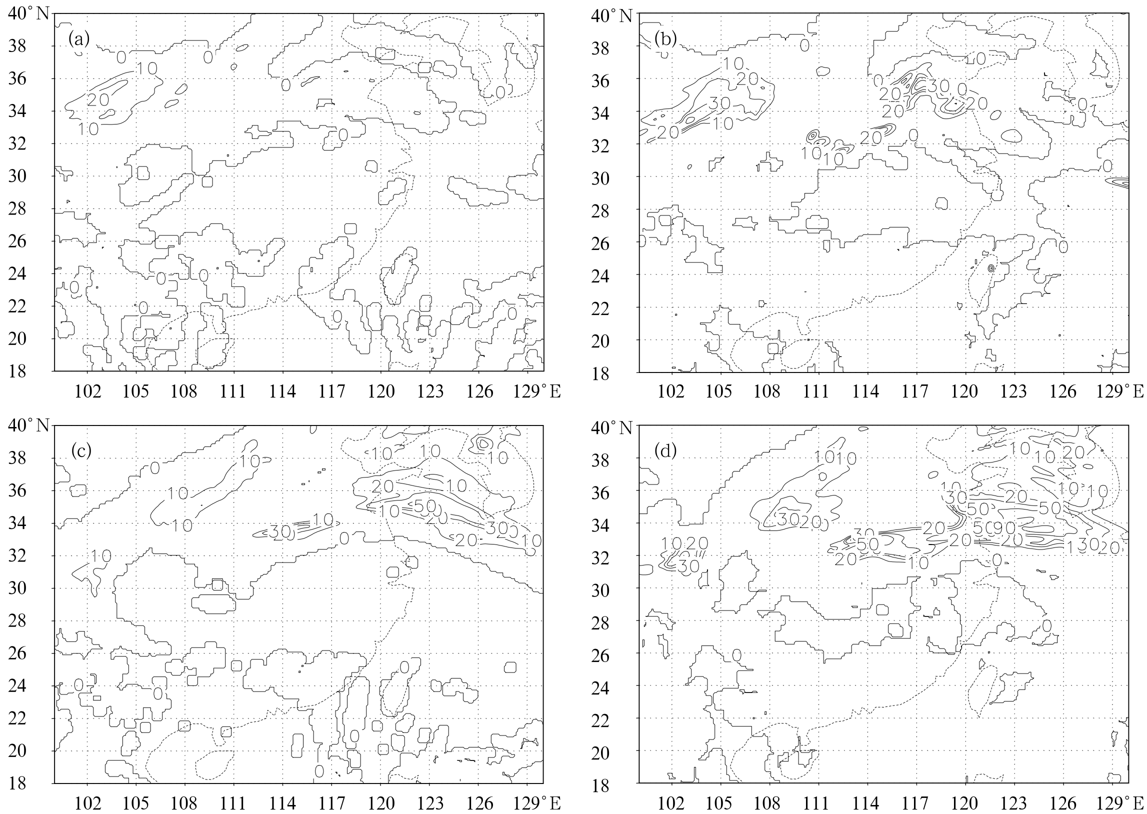

Fig.4. Daily grid-scale precipitation forecast with BM-S scheme (a, c) and KF-S scheme (b, d). (a) and (b) are for 0-24 h forecast, (c) and (d) are for 24-48 h forecast.

are analogous with those between Figs.4a and 4b, i.e., the range of rainfall areas is much the same, and grid scale explicit precipitation occurred in most areas north of the Yangtze River; there are 4 rainfall centers in this rainfall range; however, the rainfall center areas in KF-S are larger than those in BM-S, and its intensity in KF-S is stronger than in BM-S.

From the above analysis we can see that as cumulus convective parameterization schemes are different, the ambient atmosphere changes, which leads to the difference of grid scale precipitation. To examine the cause of the difference thoroughly, this paper studied the changes of vertical velocity, humidity, and temperature fields, as well as the possible causes in different cumulus convective schemes on the basis of meteorological elements field which has an important impact on precipitation.

As the range of precipitation this time is very large, the change of meteorological elements in a certain area may be not representative, here we mainly study the causes for changes in grid scale precipitation. We select the obvious grid scale precipitation regions in the two schemes, and do area average on the regional elements to study the cause for precipitation change with the average change of elements. Analyzing Fig.4, we take 33°-35°N, 112°-120°E; 32°-34°N, 112°-120°E respectively BM-S, KF-S, respectively then do regional average on the vertical velocity, potential temperature, and humidity fields in the two regions, and subsequently conduct the corresponding subtraction of both averages (KF-S minus BM-S), thus Fig.5 is yielded.

In the vertical velocity difference figure (Fig.5), it is basically zero area in the lower troposphere (below 600 hPa), but it is positive area above 600 hPa, and only by the period of 06 BT 23 June, there exists a weak and narrow negative area. This shows that in the area of obvious rainfall produced by model 48 h integration, the updraft in KF-S is stronger than in BM-S in most of time, i.e., the updraft height in KF-S

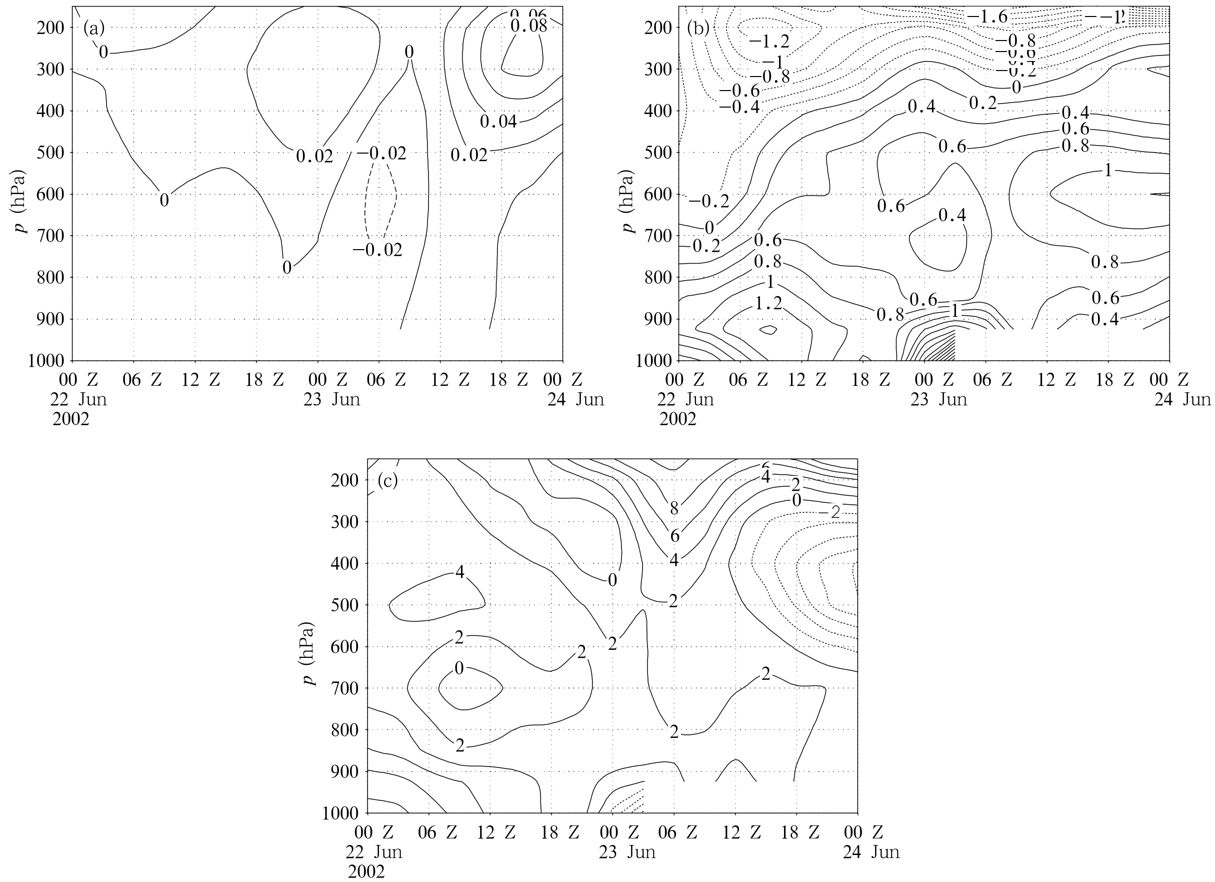

Fig.5. Temporal-height cross-section of regional average differences of vertical wind (a), potential temperature (b), and humidity (c) by KF-S minus BM-S scheme.

is higher than in BM-S. Particularly, during 13 BT 23 to 00 BT 24, the updraft in KF-S above 500 hPa is higher than in BM-S by 0.02-0.08 m s^{-1}, which shows that the updraft in KF-S is of more obvious strong features than that in BM-S. To make further understanding the cause of this phenomenon, it is proper to study the change of vertical movement which contains convective weather process from the change of atmospheric stability. From the potential temperature difference figure (Fig.5b) we can see that, all areas in the middle and lower troposphere (below 600 hPa) are positive, while those in the middle and high troposphere are basically negative, especially after 12 h integration, below 400 hPa is obvious positive area, and above 300 hPa is obviously negative . This shows that the potential temperature in the middle and low troposphere in KF-S is higher than in BM-S, and the potential temperature in the middle and high troposphere in KF-S is lower than in BM-S. The temperature difference figure (omitted) is similar to the potential temperature difference figure. This reveals that there is higher energy in the middle and lower troposphere, and lower energy in the middle and high troposphere in KF-S than in BM-S experiment, i.e., make KF-S more unstable than BM-S, so as to produce stronger updraft in KF-S. The interaction between cumulus convection and ambient air has been taken into consideration carefully by KF scheme and the stronger instability may cause ambient air to produce stronger upward movement, which will be studied thoroughly from the aspect of difference of physical process by the two schemes themselves.

In the relative humidity difference figure (Fig. 5c), from 00 BT 22 to 12 BT 23 June, most of the relative humidity in the whole atmosphere in KF-S is greater than that in BM-S by 0−8%, and only during 14 BT 23 to 00 BT 24 June, at 650-280 hPa, the relative humidity is greater than in BM-S. From the analysis of Fig.5, we can obtain that in the rainstorm this time, the atmospheric stratification in KF-S is more unstable most of time than in BM-S; the updraft and humidity are stronger or greater than that in BM-S, i.e., the ambient field in KF-S is more favorable to produce precipitation compared with BM-S. This proves that KF and BM cumulus parameterization schemes can cause the ambient air different, and KF scheme can make ambient air wetter and updraft stronger, which can induce more precipitation. This also reveals that different cumulus convective schemes have different and important effects on grid scale precipitation.

4. Application and analysis of winter precipitation in North China

4.1 *Weather situation*

During 18-23 December 2002, a 6 d persistent snowfall occurred in Beijing. This snow process lasted for a long time, which was mainly due to the combined action of the easterly airflow in the lower atmosphere and warm-wet air from the sea; besides, there was no cold air action during this period, so snowfall system maintained stably. The amount of accumulated snowfall reached over 10 mm generally, and especially it was the most in Shijingshan District of Beijing, reaching 14.1 mm. The snowfall amount in 6 days went beyond that in a normal year, which broke the persistent snowfall record of the corresponding period during the period of 128 yr in Beijing, rather rarely in history.

4.2 *Influence and analysis of different cumulus convection scheme on subgrid cumulus convective precipitation prediction*

According to the same numerical experiment scheme, the persistent snowfall during 18-23 December is given by model integration. In order to make the simulation more close to the actual situation, every initial field integrates only 48 h, and in this way the 6 d persistent snowfall process was achieved by 3 times, i.e., the initial times were at 00 BT 18, 00 BT 20, and 00 BT 22 December, respectively. There was no subgrid cumulus convective precipitation (figure omitted) for 6 days in Beijing in both BM-S and KF-S. In the two experiments, there was very weak convective precipitation in south of 35°N and their distribution are quite similar. Based on the analysis, we can obtain that there is little cumulus convective precipitation occurring during the winter snowfall process in northern China, i.e., different cumulus convection scheme has little influence on subgrid cumulus convective precipitation prediction. In other words, it is consistent with the actual situation that cumulus precipitation can be disregarded for winter precipitation in northern China.

4.3 *Influence and analysis of different cumulus convection scheme to grid scale precipitation prediction*

Comparing the grid scale precipitation prediction in the two experiments, we can see that the range and intensity of the rainfall are quite similar. Figure 6 illustrate the most obvious rainfall actual situation from 00 BT 22 to 00 BT 23 December and the grid scale precipitation prediction fields in BM-W and KF-W experiments. As shown in Fig.6a, there are widespread rainfall areas from North China to the Yangtze River Basin, the snowfall amount around Beijing is generally about 10 mm, and the rainfall amount around Taiyuan and Shijiazhuang exceeds 10 mm. On the whole, the rainfall intensity is uniform, which is consistent with the feature of stratiform cloud precipitation, i.e., persistent and uniform. In Figs.6b and 6c of grid scale precipitation prediction in BM-W and KF-W schemes, the range and intensity of rainfall in mainland of China in the two experiment are almost the same, as well as the fine structure in the rainfall areas; the main difference existing in the ocean south of Korea Peninsula is that the intensity of grid scale precipitation in BM-W is weaker than in KF-W scheme. However, the range and the position of rainfall are basically the same. The features of the convective precipitation distribution at this day predicted by BM-W and KF-W schemes (figure omitted) are that there is almost no convective precipitation in the mainland north of the Yangtze River, and it only occurs in the ocean south of Korea Peninsula; the range of rainfall is much the same, but the intensity of convective precipitation in BM-W is stronger than in KF-W. According to the above

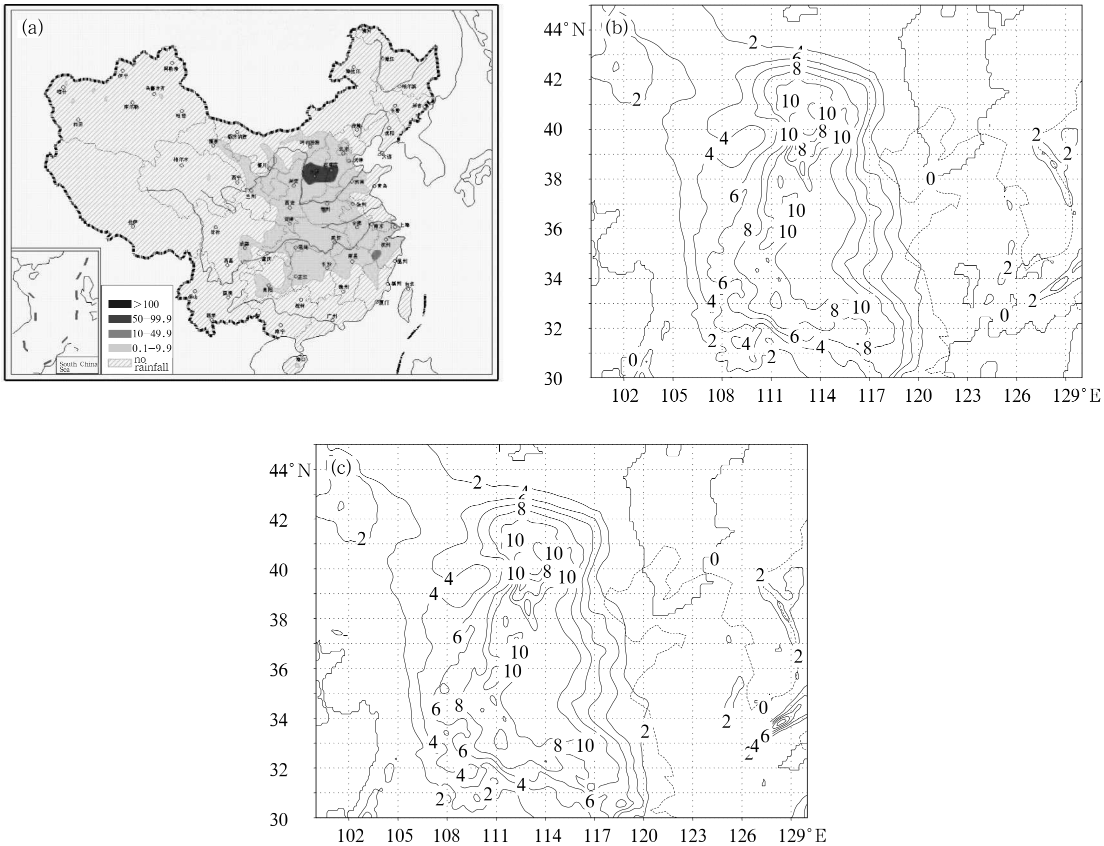

Fig.6. Precipitation distribution from 00Z 22 to 00Z 23 December 2002. (a) Observation, (b) grid-scale forecast of BM-W, and (c) grid-scale forecast of KF-W.

analysis, it proves that there is almost no convective precipitation in winter in North China, thus the effect of different cumulus convective schemes on the grid scale precipitation can be disregarded. Meantime, we can infer that the gird scale precipitation is primary in the winter precipitation of North China.

5. Conclusions

Through simulation and analysis of summer and winter precipitation cases in China, the following conclusions can be drawn.

(1) The simulation of summer precipitation in middle-lower reaches of the Yangtze River Basin indicates that the strong rainfall areas predicted by KF and BM schemes are both in further north and the intensities are weaker compared with the actual situation. The position of strong rainfall areas predicted by KF is more close to actual situation. On the whole, the persistent precipitation process in this case predicted by KF scheme is better than that predicted by BM scheme.

(2) In summer, KF and BM cumulus schemes can cause different changes of ambient air; KF scheme makes the ambient air wetter and the updraft airflow stronger, which can induce more precipitation and leads to the difference of grid scale precipitation. This reveals that the different cumulus schemes may have different and important effect on the grid scale precipitation.

(3) There is almost no convective precipitation in winter in North China , thus the effect of cumulus precipitation on the grid scale can be disregarded. Meantime, the conclusion can be drawn that the gird scale precipitation is primary in the winter precipitation of North China.

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