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An Improvement of the Mass Flux Convection Parameterization Scheme and its Sensitivity Tests for Seasonal Prediction over China

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ABSTRACT

A modified cumulus parameterization scheme, suitable for use in a seasonal forecast model, is presented. This parameterization scheme is an improvement of the mass flux convection scheme developed by Gregory and Rowntree (1989; 1990). This convection scheme uses a "bulk" cloud model to present an ensemble of convective clouds, and aims to represent shallow, deep, and mid-level convection. At present, this convection scheme is employed in the NCC T63L20 model (National Climate Center, China Meteorological Administration). Simulation results with this scheme have revealed some deficiencies in the scheme, although to some extent, it improves the accuracy of the simulation. In order to alleviate the deficiencies and reflect the effect of cumulus convection in the actual atmosphere, the scheme is modified and improved. The improvements include (i) the full estimation of the effects of the large-scale convergence in the lower layer upon cumulus convection, (ii) the revision of the initial convective mass flux, and (iii) the regulation of convective-scale downdrafts. A comparison of the results obtained by using the original model and the modified one shows that the improvement and modification of the original convection scheme is successful in simulating the precipitation and general circulation field, because the modified scheme provides a good simulation of the main features of seasonal precipitation in China, and an analysis of the anomaly correlation coefficient between the simulation and the observations confirms the improved results.

Key words: cumulus convection, parameterization scheme, convection heating and moistening, numerical simulation, sensitivity test

1. Introduction

Cumulus convection plays an important role in the maintenance of the budget of energy and moisture, which has a great effect on atmospheric circulation and climate anomaly in a region or over the entire globe (Manabe et al., 1965). In the low-latitude regions, about three quarters of the precipitation is convective, and even in the mid-latitude regions, the cumulus is mainly a system generating rainfall. Cumulus convection is an effective transferrer of energy; for example, a few huge cumulus towers in the tropical zone supply energy for the Hadley circulation (Ooyama, 1964). These cumulus towers are major sources of moisture in the stratosphere; therefore, they become an important radiation valve that can regulate the energy budget of the globe. The number of cumulus towers and their space distribution are correlated with the strength of trade winds and the variation of monsoon; thus, these towers can affect the amount of moisture in the stratosphere and hence affect the climate.

At present, the development and description of cumulus, as well as the heat flux related to the radiation character of clouds, are items that are difficult to define in the calculation of the heat budget and in numerical simulations. In addition, they also directly determine the heat balance on the sea surface, which is necessary to determine in order to develop a stationary or time-varying climate model. Hence, the heat interaction between cumulus convection and its large-scale environment has become the focus of numerical forecasts by the general circulation or climate models. Moreover, the dynamic interaction between cumulus convection and a mid- or large-scale weather system is a crucial and once-neglected mechanism that is very difficult to research.

Recently, researchers have been increasingly attempting to learn more about the cumulus and to

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construct different parameterization schemes and their performance tests. As well, developing new parameterization schemes was also one of the main goals of the GATE experiments (Mintz and Arakawa, 1965). Since the late 1970s, and particularly since the 1980s, great progress has been made in research involving cumulus convection parameterization schemes, and new comprehensive mass flux schemes have been developed such as those of Albrecht (1986), Bougeault (1985), and Tiedtke (1989), based on the basic mass flux scheme (Arakawa and Schubert, 1974). The constructions of the scheme mechanism not only sum up new observations of cumulus but also try to account for their physical nature. Moreover, these schemes take into account not only the complex interaction between cumulus ensembles and the large-scale environment including cumulus ascent, submerging, entrainment, detrainment, and evaporation, but also the microphysics of clouds including unstable growth and the formation of ice crystal cores. Furthermore, the new comprehensive mass flux schemes are more objective and accurate for determining parameters. These schemes employ the diagnostic analysis method to specify the value of parameters, and the forecast or semi-forecast method to test their performance and make sensitivity tests. Consequently, the parameters of the new schemes can synthesize new cumulus data and ensure accurate calculations, and the schemes do particularly well in performance tests using the semi-forecast method.

In this paper, convection scheme (Gregory and Rowntree, 1990; Gregory and Miller, 1989), which is used at the UK Meteorological Office in large-scale numerical simulations, is modified. Gregory and Rowntree's scheme uses a "bulk" cloud to represent the interaction between an ensemble of convective clouds and the large-scale environment, and has a clear physical image. The modified Gregory scheme stresses the effects of low-level synoptic convergence on penetrative convection and restrains an excessively strong convection process.

Our modified version of the NCC T63l20 model accurately simulates the tendency of the general circulation and precipitation field of recent years. This paper consists of 5 parts: (i) introduction, (ii) the principle of Gregory and Rowntree's scheme and the design of the improved version, (iii) the specification values of the parameters and sensitivity analysis, (iv) the test of the performance of the modified scheme, and (v) conclusion and discussion.

2. The principle of Gregory and Rowntree's scheme and the design of the improved version

This is a penetrative convection scheme, applicable to moist convection of all types (shallow, deep, mid-level) and also to dry convection (Lean, 1992). In the Gregory scheme, a single cloud model is used to represent an ensemble of convective clouds, which differ from each other in characteristics and terminate at different levels. Thus the characteristics of the parcel calculated by the cloud model represent the averages over the entire ensemble.

For a column of atmosphere, working from the bottom upward, each layer of the model is tested until one is found which, with a slight excess buoyant s (0.2K), is still buoyant by more than a lower limit b (0.2K) at the next layer after ascent, while taking the entrainment of environmental air into consideration. The convective process is then initiated. The parcel continues to rise until it is no longer buoyant after being lifted from layer k to the next model layer $(k-1)$. The parcel ascent continues until the zero buoyancy level of an undiluted parcel from the starting layer of convection is reached or until the convective mass flux falls below a minimum value.

Unlike many other convection schemes that assume a quasi-equilibrium state between convection and large-scale forcing to determine the amount of convective rainfall, this scheme calculates the magnitude of convective activity by considering the stability of the lowest convection layers only. Gregory and Rowntree's scheme (1990) has been successful in imitating the bulk cloud model by summation over an ensemble of convective clouds with different characteristics, and in employing a simple closure condition in which the initial convective mass flux is related to the stability of the initial convective layer.

The Gregory scheme has been used in the NCC T63L20 model (National Climate Center, China Meteorological Administration). The seasonal climate of China is reasonably well simulated by this model. Nevertheless, the simulation has deficiencies. One of the more pronounced of these is the systematical discrepancy in the simulation of seasonal precipitation, particularly in the south of China, where precipitous clouds are mainly merging clouds consisting of stratus and cumulus. Another deficiency is that the precipitation in the center of the convection is systematically stronger than the actual observed data. Perhaps several other factors may contribute to these deficiencies, but the use of the Gregory scheme in the model is at least partly responsible.

The purpose of this paper is to modify the Gregory scheme of cumulus convection so as to alleviate the above deficiencies in seasonal climate simulation and prediction over China. The modification of the Gregory scheme utilizes the basic hypothesis set forth by Kuo (1965, 1974) and Lindzen (1981). The hypothesis is that when there is a deep layer of conditional instability and large-scale moisture convergence, cumulus exists, and the air entrained from the environment through the base and sides of the cumulus is directly proportional to the supply of moisture and detrained cloud air at high levels. We postulate that above the clouds there is organized entrainment, which is directly proportional to the large-scale moisture convergence. Organized entrainment is considered only in the lower part of the cloud layer where large-scale convergence is encountered, that is, below the level of the strongest vertical ascent. The idea of linking the cloud mass flux directly to the large-scale moisture convergence was first advocated by Lindzen (1981), who indicated that doing so may provide vertical profiles of mass flux and convective heating in agreement with observations.

The assumption ensures that the vertical distribution of the convective mass flux follows that of the large-scale ascent. The assumption is partly supported by diagnostic studies of tropical convection and is crucial for the performance of the parameterization of penetrative convection.

In order to inhibit convection over-growth in the deepest cloud, organized outflow is introduced. Organized outflow is assumed to occur only in the model layer where the buoyancy of the plume is zero in the deep convection clouds. Our assumption about the distribution of detrainment clouds is that a high detrainment rate occurs in the deepest clouds and that a low detrainment rate occurs in shallow clouds and medium deep clouds.

In addition, we have modified the closure condition of the Gregory scheme so that the mass flux of the plume in the initial convective layer ($M_{\rm I}$) is not only related to the stability of the lowest convection layers, but also exceeds a specified threshold value ($M_0 = 0.2778$ Pa s^{-1}=10 hPa h^{-1}). Our modification shows that not only an unstable condition but also an initial disturbance is necessary to invoke cumulus convection in the lower level.

The mathematical formulation of the modified Gregory scheme is described accurately in the following formulas:

$$\frac{\partial M_{\rm P}}{\partial \delta} = E_{\rm H} + E_{\rm O} - N - (D_{\rm H} + D_{\rm O}) \,, \tag{1.1}$$

$$\frac{\partial \theta_{\rm p} M_{\rm P}}{\partial \delta} = [(E_{\rm H} + E_{\rm O})\theta_{\rm E} - N\theta_{\rm N} - (D_{\rm H} + D_{\rm O})\theta_{\rm R}] + \frac{LQ}{c_p} \,, \tag{1.2}$$

$$\frac{\partial q_{\rm p} M_{\rm P}}{\partial \delta} = [(E_{\rm H} + E_{\rm O})q_{\rm E} - N\theta_{\rm R} - (D_{\rm H} + D_{\rm O})q_{\rm R}] - Q \,, \tag{1.3}$$

$$\frac{\partial l_{\rm p} M_{\rm P}}{\partial \delta} = -[Nl_{\rm N} + (D_{\rm H} + D_{\rm O})l_{\rm R}] + Q - P_{\rm rain} \,, \tag{1.4}$$

where $M_{\rm p}$ is cloud mass flux; $\phi_{\rm p} = \phi$ in cloudy air; $\phi_{\rm E} = \phi$ in environmental air; $\phi_{\rm N} = \phi$ on mixing detrainment; $\phi_{\rm R} = \phi$ on forced detrainment; $E_{\rm H}$ is mixing entrainment rate; $E_{\rm O}$ is organized entrainment rate; $D_{\rm F}$ is forced detrainment rate; $D_{\rm O}$ is organized detrainment rate; N is mixing detrainment rate; Q is conversion of water vapor to liquid water and ice; $P_{\rm rain}$ is liquid water and ice precipitated; l is the latent heat of condensation; c_p is specific heat;

$$E_{\rm O} = -\frac{1}{q}\left[\nabla \cdot (q\vec{v}) + \frac{\partial (wq)}{\partial p}\right] \,,$$

(organized entrainment is only considered in the lower part of the cloud layer where large-scale convergence is encountered); and $D_{\rm O} = (M_{\rm P})_{k=1/2}/ \triangle p$, (organized detrainment occurs only in the model layer which contains the zero-buoyancy level of the deepest clouds).

3. The determination and sensitivity analysis of the internal parameters

The internal parameters of the Gregory scheme are determined by objective analysis of real data and comparison of the convective heating and moisture profiles. Thus, this analysis can ensure that the values of the internal parameters are determined reasonably and the profiles are consistent with the actual data.

Because the Gregory scheme is a one-dimensional cloud model, the determination of the internal parameters depends on the specific research region to some extent. China's monsoon climate has distinctive features. In the south of China, torrential rain is driven by deep sheet clouds embedded with convective clouds. In addition, the density and distribution of aerosol is also taken into account in the parameterization scheme. Considering the high dust aerosol density in the north (Wang and Yang, 2001; Fu, 1998; Qian and Fu, 1999) and the high sulphate aerosol density in the south of China (Wang and Shi, 2001; Wu, 2003: Luo and Lu, 1998), we regulate the precipitous critical height. In fact, the aerosol impact upon cumulus precipitation is so complicated that it has been predigested and only the effect of the coagulate core is modeled (Huang and Xu, 1998; Wang, 1997). In order to determine the appropriate value of the internal parameters to reflect the features of a regional climate, objective analysis and sensitivity experiments must be performed.

Several experiments involving different parameters are carried out to test the sensitivity of the scheme. These internal parameters are the entrainment coefficient ε, the downdraft coefficient γ, the forced detrainment coefficient δ, the precipitous critical height $D_{\rm c}$, and the precipitation evaporation coefficient β. The summer precipitation over China in 1998 is used for simulation purposes. Each simulation experiment is carried out only under the condition of changing one parameter value and is compared mainly with the control experiment.

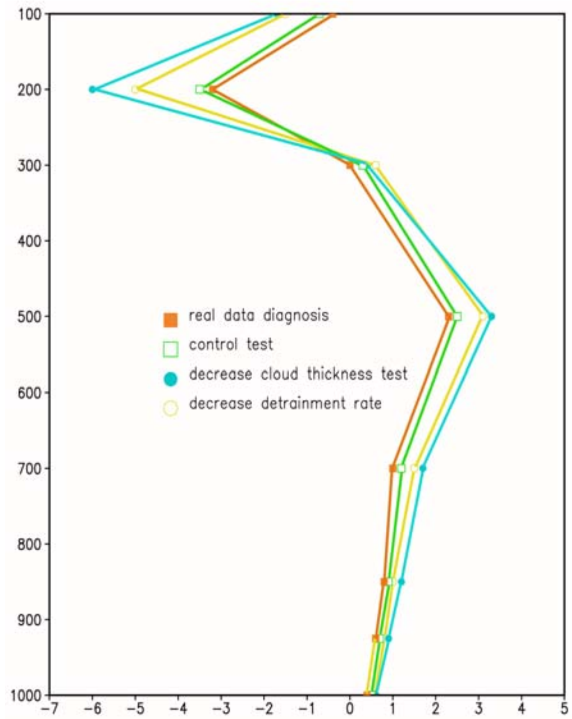

Fig. 1. July 1998 apparent heat source Q1 profiles of diagnostic data, control test, and sensitivity test for different parameter values.

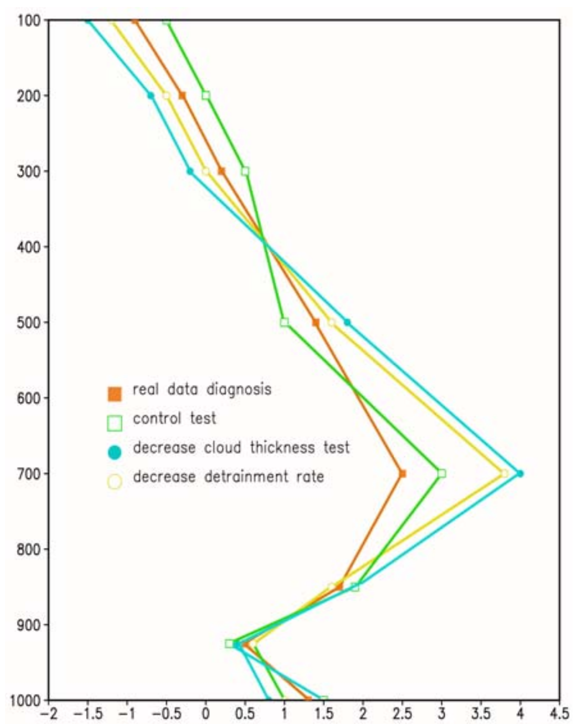

Fig. 2. July 1998 apparent heat source Q2 profiles of diagnostic data, control test, and sensitivity test for different parameter values.

In the control experiment, a few internal parameters are adjusted (see Table 1). The following factors are accounted for. (i) The air current of the downdraft simulated by the Gregory model is excessively stronger than that of the diagnostic results. Thus, this simulation causes the over-growth of cumulus convection in the precipitation center. For this reason, the downdraft coefficient γ is adjusted from 3.6×10^{-6} hPa^{-1} to 1.8×10^{-6} hPa^{-1}. (ii) The aerosol density in China is higher than in other regions, so the precipitus critical convection height (D_c) is adjusted from 6.0×10^3 m to 4.0×10^3 m on account of the effects of the condensation nucleus. The result of the adjustment of the internal parameters is analyzed and contrasted in the following discussion of our sensitivity and control experiments.

The following experiments show that a change in the value of the parameters may cause a change in cumulus convection heating and moistening. A comparison of the profile of convection heating and moistening shows that the whole character of cumulus convection depends partly on the appropriate value of the internal parameters in the convection scheme.

In order to choose appropriate values for the parameters, the actual observed data is used to diagnose the profile of the convection heating (Q1) and moistening (Q2). By a comparison and analysis of the different heating and moistening profiles (see Fig. 1 and Fig. 2), it can be confirmed that the profiles of the control test are similar to those of the actual data, although the level of heating and moistening is not changed in these sensitivity experiments. Moreover, the conclusion can be drawn that our adjustment of the values of the downdraft coefficient γ and precipitous critical height D_c is correct.

4. Performance examination of the modified convection scheme

4.1 *The comparison between the simulated Results and the observation*

In this paper, the NCC T63L20 model is used to simulate the general current tendency of the atmosphere and the precipitation field in the summer of 1998. The prediction experiments are divided into two groups. The first one (the Z1 group) makes predictions by using the modified convection scheme, and the second one (the Z2 group) uses the original Gregory convection scheme. The daily reanalysis data of NCEP/NCAR for 31 May 1998 and 31 May 1997 are chosen as the initial data field of the model. The observed data of the sea surface field from June to August in 1997 and 1998 are also chosen for the model. The methods of quantity analysis including analysis of the root of the mean standard deviation (RMSD) and anomaly correlation coefficient (ACC) are introduced to test the prediction results.

Table 1. The choice of internal parameters in the control and sensitivity experiments

Parameters (units)	Control experiment	1	2	3	4	5
δ (hPa^{-1})	3.0×10^{-5}	1.5×10^{-5}				
β (s^{-1})	1.0×10^{-3}		2.0×10^{-3}			
$D_{\rm c}$ (m)	4.0×10^{3}			6.0×10^{3}		
ε (hPa^{-1})	1.5×10^{-5}				3.0×10^{-5}	
γ (hPa^{-1})	1.8×10^{-6}					3.6×10^{-6}

Table 2. The root of mean standard deviation in the Z1 and Z2 group experiments (500-hPa Height field)

Test	Root of Mean Standard Deviation (units: 10 m)							
	Globe	Northern Hemisphere	Southern Hemisphere	East part of the Northern Hemisphere (0°–180°E)	West part of the Northern Hemisphere (0°–180°W)	30°–90°N	30°N–30°S	30°–90°S
Z1	0.95	0.83	1.11	0.78	0.92	0.89	0.57	1.32
Z2	1.23	1.27	1.24	1.42	1.13	1.31	1.11	1.25

4.2 *Prediction of the height field*

This research focuses mainly on the prediction of the atmospheric general circulation field and quantity analysis of the simulation results. In order to accurately illuminate the simulated effect, the 500-hPa geopotential height field in the summer of 1998 is chosen as a canonical example. The 500-hPa season mean height fields including the NCEP data and simulation field are described in Fig. 3. It can be seen that the general circulation in Eurasia is obviously in a longitudinal pattern. In the mid- or high-latitude areas, there are two ridges and one trough, among which the Ural High develops into a deep system, and a "Ω" pattern blocking high appears in the area near okhotsk sea. In addition, the East Asian trough is in the area of approximately 100°–120°E. In the lower latitudes, the position of the West Pacific subtropical high is inclined to the south, and its ridge is near 15°N along with the 588 isohypse extending to the coastal areas of the south of China. Above the distribution of the ridge and trough is the characteristic general circulation, which can cause heavy rain frequently in the summer.

In the Z1 group experiments, not only is the air circulation pattern of the two blocking highs including the Ural and Okhotsk highs well simulated, but also the position and intensity of the West Pacific Subtropical High; but in the Z2 group experiments, the above main features were not well simulated.

The root of the mean standard deviation $\sigma_{\rm rmsd}$ between the actual anomaly field and the simulated anomaly field is computed to evaluate the effects of the modified scheme on quantity:

$$\sigma_{\rm rmsd} = \sqrt{\frac{\sum_{n=1}^{N}[(t_{\rm f} - \bar{t}_{\rm f}) - (t_{\rm o} - \bar{t}_{\rm o})]^2}{N}} \qquad (4.1)$$

where $t_{\rm f}$ is the value of the prediction on the 500-hPa height field, $\bar{t}_{\rm f}$ is the mean of the prediction value for 30 years, $t_{\rm o}$ is the value of actual observation on the 500-hPa height field, and $\bar{t}_{\rm o}$ is the mean of the actual observation value for 30 years. N is the number of specimens.

Table 2 shows an obvious improvement in the simulation of the general current field when the model employs the modified convection scheme, especially in the area of low latitude, for which the value of RMSD is only 0.57 (units: 10 m). As well, the result of the simulation for the Northern Hemisphere is better than that for the Southern Hemisphere.

The anomaly correlation coefficient (ACCC, denoted by $C_{\rm ac}$) between the 500-hPa height forecast field and the actual observation field is computed in this section:

$$C_{\rm ac} = \frac{\sum_{i=1}^{n}[(t_{\rm f} - \bar{t}_{\rm f}) - (t_{\rm o} - \bar{t}_{\rm o})]}{\sqrt{\left(\sum_{i=1}^{n}(t_{\rm f} - \bar{t}_{\rm f})^2\right)\left(\sum_{i=1}^{n}(t_{\rm o} - \bar{t}_{\rm o})^2\right)}} \qquad (4.2)$$

Each item of the above formula has the same meaning as in formula (4.1). The Z1 group experiments show that the value of ACC in the Northern Hemisphere and the Southern Hemisphere is 0.48 and 0.37, respectively (see Table 3). In addition, these experiments also show that the value of ACC in the area of low latitude is better than in the Southern Hemisphere. On the whole, the ACC value of the Z1 group experiments is obviously better than that of the Z2 group experiments. These results prove that using the modified convection scheme can improve the forecast for a general current field.

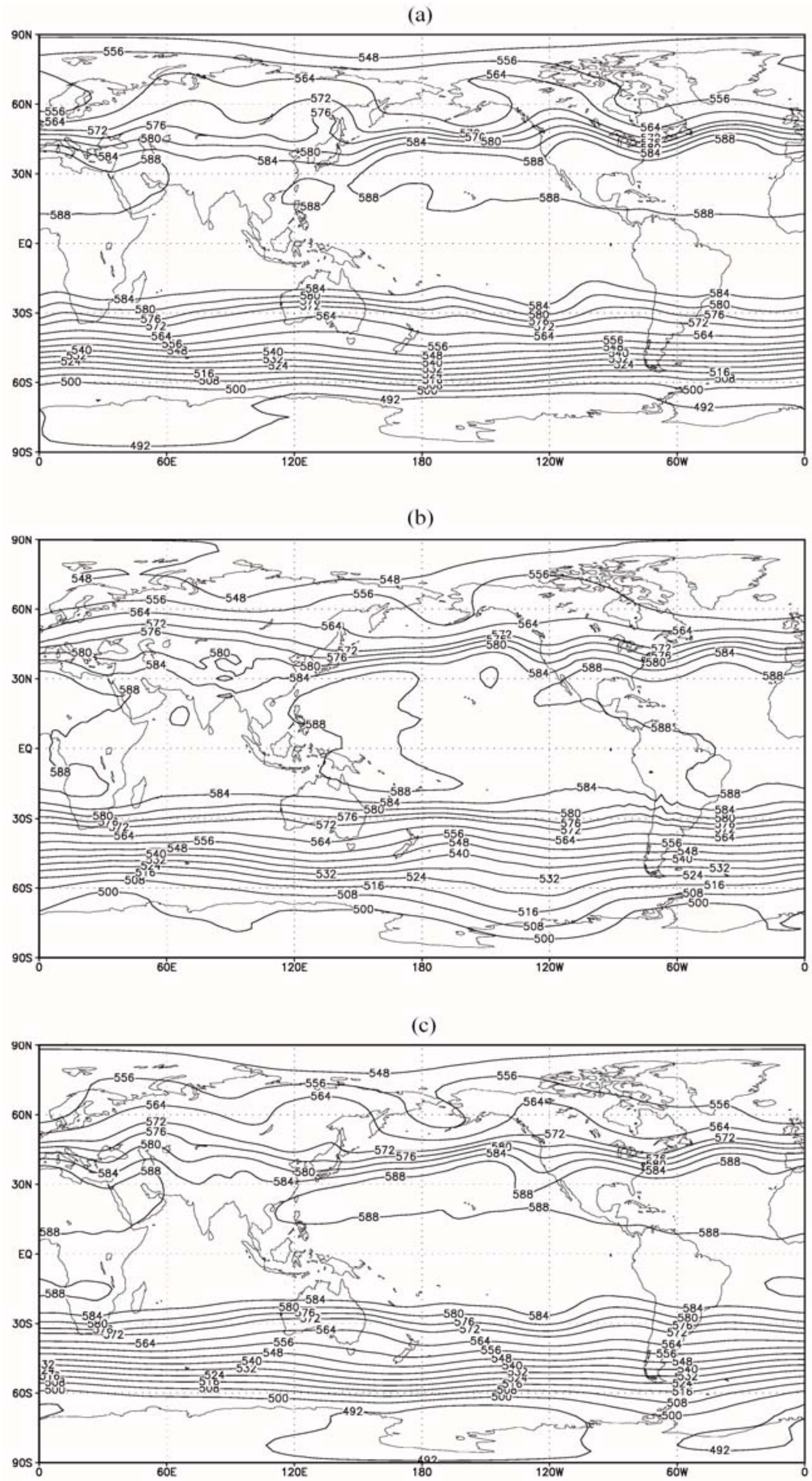

Fig. 3. July 1998 500-mb monthly mean height field. (a) The observed data (b) the simulation field by the original scheme, (c) the simulation field by the modified Gregory scheme.

4.3 *The prediction of the precipitation field*

To some extent, the effect of the improvement on the cumulus parameterized scheme depends on the simulation of precipitation. We chose the summer precipitation in China during canonical years as simulated examples. The 1998 flood of the Yangtze River valley and the 1997 drought in the north of China are chosen to be simulated by the original and modified cumulus parameterized schemes respectively.

4.3.1 *The simulation of the 1998 flood in the Yangtze River valley*

Figure 4 is the actual observed precipitation field given by 160 stations in China. It can be seen that there are three precipitation centers, located in the Yangtze River valley, the Nenjiang River valley, and the south of China.

The Z1 group simulation experiments also show that there are precipitation centers and their positions are near to the real data (see Fig. 6). In the Z2 group experiments (see Fig. 5), some differences exist and the precipitation in the Yangtze River valley is not simulated well. In addition, the precipitation anomaly fields of the real observation and simulation with the original and the modified scheme are computed, and some results can be seen in Table 4.

Table 4 shows that the anomaly correlation coefficient of the Z1 group experiments in the Yangtze River valley and the northeast of China is 0.49 and 0.31 respectively. In the north of China, the correlation coefficient is lower than the above areas and its value is 0.16. In the Z2 group experiments, however, the anomaly correlation coefficient in the Yangtze River valley is negative; this result shows that the 1998 flood of the Yangtze River valley is not simulated well.

In the Z1 and Z2 group experiments, the simulation precipitation field is interpolated onto the 160 stations throughout China, and a statistical analysis is carried out. In the statistical analysis, six threshold values are chosen as the criteria for determining the precipitation grade. The test score ($T_{\rm s}$) method and forecast efficiency (F) method are introduced to evaluate the simulation results. The formulas of the $T_{\rm s}$ and F methods are given as follows:

$$T_{\rm s}=\frac{N_{\rm c}}{N_{\rm c}+N_{\rm l}+N_{\rm e}}\ ,\quad F=\frac{N_{\rm c}+N_{\rm t}}{N_{\rm c}+N_{\rm l}+N_{\rm e}+N_{\rm t}}\ ,\quad (4.3)$$

where $N_{\rm c}$ is the number of stations where there is rainfall, and it is forecasted correctly by the model; $N_{\rm l}$ is the number of stations where there is rainfall, and it is not forecasted by the model; $N_{\rm e}$ is the number of stations where there is no rainfall, but rainfall is forecasted by the model; $N_{\rm t}$ is the number of stations where there is no rainfall, and it is not forecasted by the model.

The higher the values of $T_{\rm s}$ and F are, the better the effect of the forecast is in general. Table 5 shows that in the Z1 group experiments, the value of $T_{\rm s}$ is 0.49 for the precipitation whose amount is less than 10 mm daily, but is 0.50 in the Z2 group experiments. Table 5 also shows that for the precipitation whose amount is less than 10 mm daily, there is not an obvious difference between the Z1 and Z2 group experiments. For the precipitation whose amount is greater than 10 mm daily, the value of $T_{\rm s}$ is 0.24 in the Z1 group experiments, but 0.17 in the Z2 group experiments. These results show that for this type of precipitation, the value of $T_{\rm s}$ in the Z1 group experiments is improved by 41%. For the precipitation whose amount is greater than 25 mm daily, the value of $T_{\rm s}$ in the Z1 group experiments is much greater than that in the Z2 group experiments. Hence, modifying the convection parameterization scheme can obviously improve the forecast of strong precipitation.

In the data presented in Table 6, the above conclusion is verified further. For the precipitation whose amount is less than 10 mm, there is not an obvious difference between the F values in the Z1 and Z2 group experiments. However, for the precipitation whose amount is greater than 10 mm, especially greater than 25 mm, the F value of the Z1 group experiments is much higher than that of the Z2 group experiments. Thus, the modified convection scheme is able to simulate the magnitude and distribution of the main precipitation belt, although its simulation result still exhibits systematic discrepancy.

4.3.2 *The simulation of the 1997 drought in the north of China*

It can be shown from the above simulation that the modified scheme can reflect the feature of summer waterlogging in China. Moreover, we can utilize this modified scheme to simulate the summer precipitation in 1997 so as to further test its effects. Figure 7 is the actual observed precipitation field from 160 stations in China. It can be seen that the drought in North China exists and the feature of the summer precipitation is a gradient distribution in a solely south-north direction.

The Z1 group simulation experiments also show that the drought in North China exists and the summer precipitation is a south-north gradient distribution (see Fig. 9). In the Z2 group experiments (see Fig. 8), the amount of precipitation in North China exceeds 400 mm and the drought is not simulated well. The summer precipitation tendency is not simulated well in the Z2 group experiments. In addition, we compute the precipitation anomaly fields of the real observations and simulation with the original and the modified schemes, and we gain some comparative results (see Table 7).

5. Discussion and conclusion

In this paper, a modified Gregory convection

Table 3. The ACC in the Z1 and Z2 group experiments (500-hPa Height field)

Test	Anomaly Correlation Coefficient (units: 10 m)							
	Globe	Northern Hemisphere	Southern Hemisphere	East part of the Northern Northern (0°–180°E)	West part of the Hemisphere Hemisphere (0°–180°w)	30°–90°N	30°N–30°S	30°–90°S
Z1	0.65	0.72	0.67	0.75	0.68	0.54	0.71	0.58
Z2	0.34	0.27	0.53	0.41	0.48	0.24	0.41	0.35

Table 4. The ACC of 160 stations in the Z1 and Z2 group experiments (precipitation field)

Test	Anomaly Correlation Coefficient					
	The whole country	The west part (west of 110°E, north of 26°N)	The south Part (South of 26°N)	The Yangtze River valley (east of 110°E, 26°N–31°N)	Northeast China	North China
Z1	0.34	0.31	0.63	0.59	0.31	0.56
Z2	0.12	0.38	0.35	0.06	0.09	0.25

Table 5. The T_s value of 160 stations in China in the Z1 and Z2 group experiments during summer 1998

P_{rain}	Mean daily precipitation of June		Mean daily precipitation of July		Mean daily precipitation of August		Mean daily precipitation of summer	
	Z1 group	Z2 group	Z1 group	Z2 group	Z1 group	Z2 group	Z1 group	Z2 group
1 mm	0.56	0.61	0.47	0.38	0.44	0.41	0.49	0.50
10 mm	0.23	0.19	0.32	0.15	0.18	0.19	0.24	0.17
25 mm	0.59	0.08	0.27	0.12	0.21	0.14	0.21	0.11
50 mm	0.73	0.13	0.34	0.15	0.29	0.18	0.33	0.15

Table 6. The F value of 160 stations in China in the Z1 and Z2 group experiments during summer 1998

P_{rain}	Mean daily precipitation of June		Mean daily precipitation of July		Mean daily precipitation of August		Mean daily precipitation of summer	
	Z1 group	Z2 group	Z1 group	Z2 group	Z1 group	Z2 group	Z1 group	Z2 group
1 mm	0.67	0.62	0.59	0.57	0.53	0.61	0.59	0.60
10 mm	0.74	0.65	0.81	0.58	0.68	0.53	0.75	0.64
25 mm	0.15	0.48	0.70	0.55	0.69	0.39	0.66	0.47
50 mm	0.38	0.49	0.58	0.41	0.81	0.67	0.71	0.52

Table 7. The 1997 summer precipitation field ACC of 160 stations in Z1 and Z2 group experiments (precipitation field)

Test	Anomaly Correlation Coefficient				
	The whole China area	The western China (west of 110°E, north of 26°N)	North China (north of 26°N)	Northeast China	The southern China
Z1	0.54	0.61	0.73	0.51	0.46
Z2	0.32	0.38	0.45	0.29	0.25

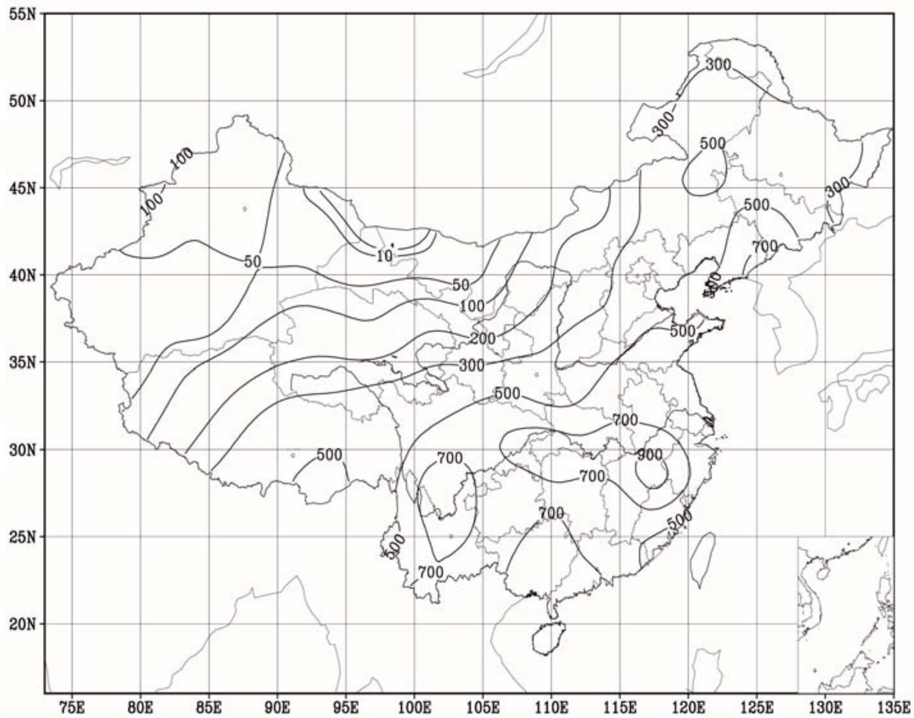

Fig. 4. The observed precipitation field of 160 stations in China in the summer of 1998.

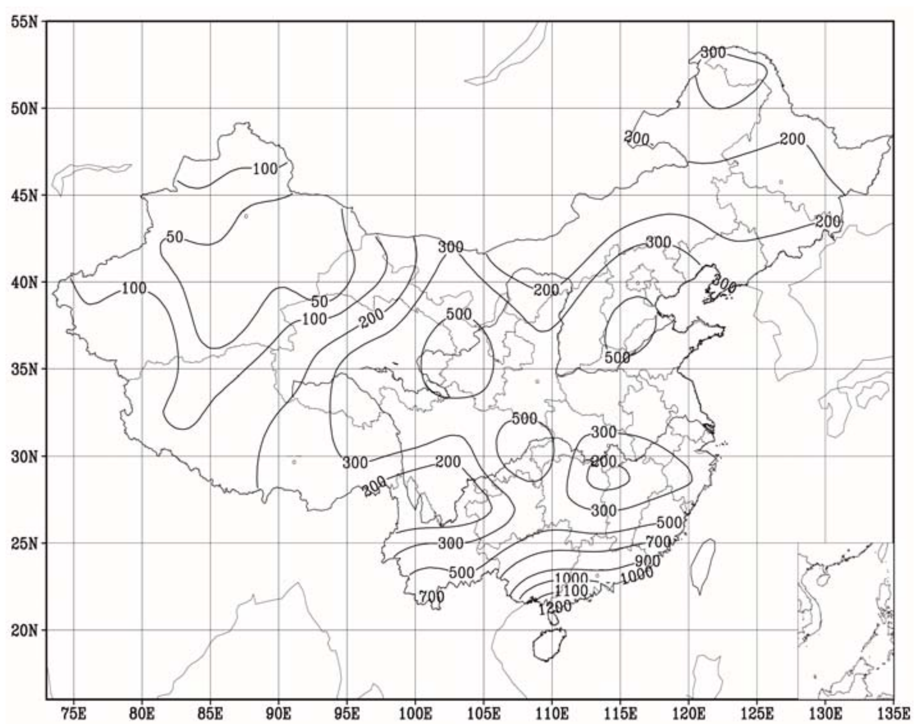

Fig. 5. The simulated precipitation field of 160 stations in China in the summer of 1998 by the original Gregory scheme.

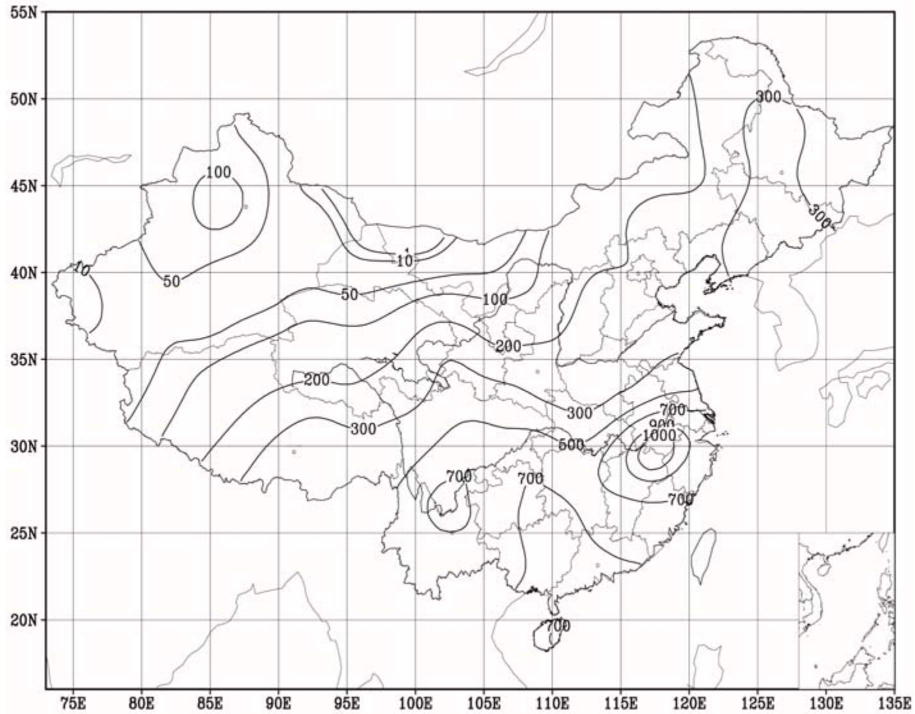

Fig. 6. The simulated precipitation field of 160 stations in China in the summer of 1998 by the modified Gregory scheme.

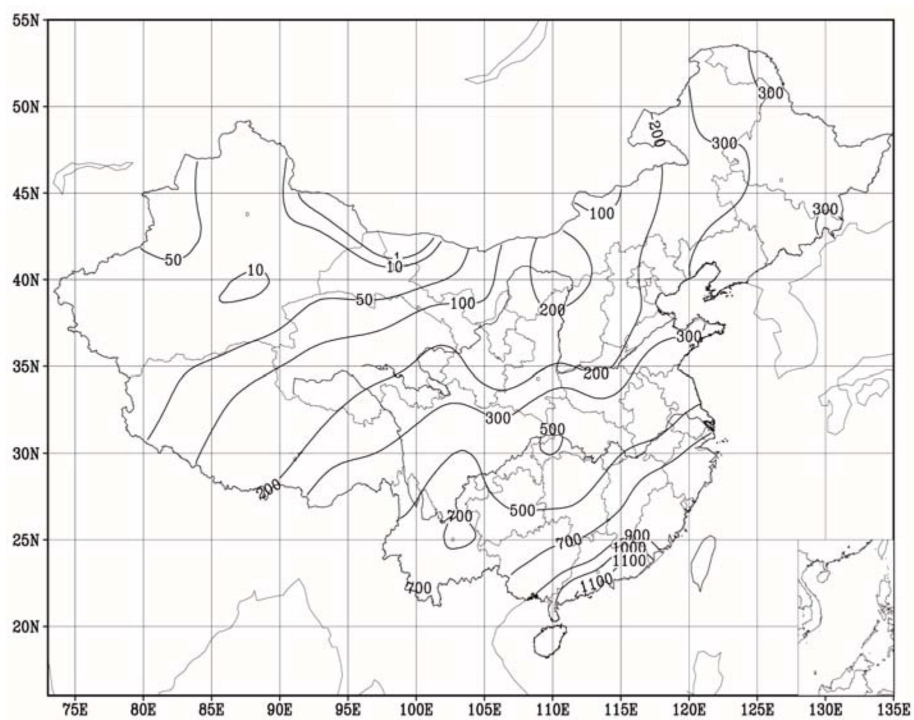

Fig. 7. The observed precipitation field of 160 stations in China in the summer of 1997.

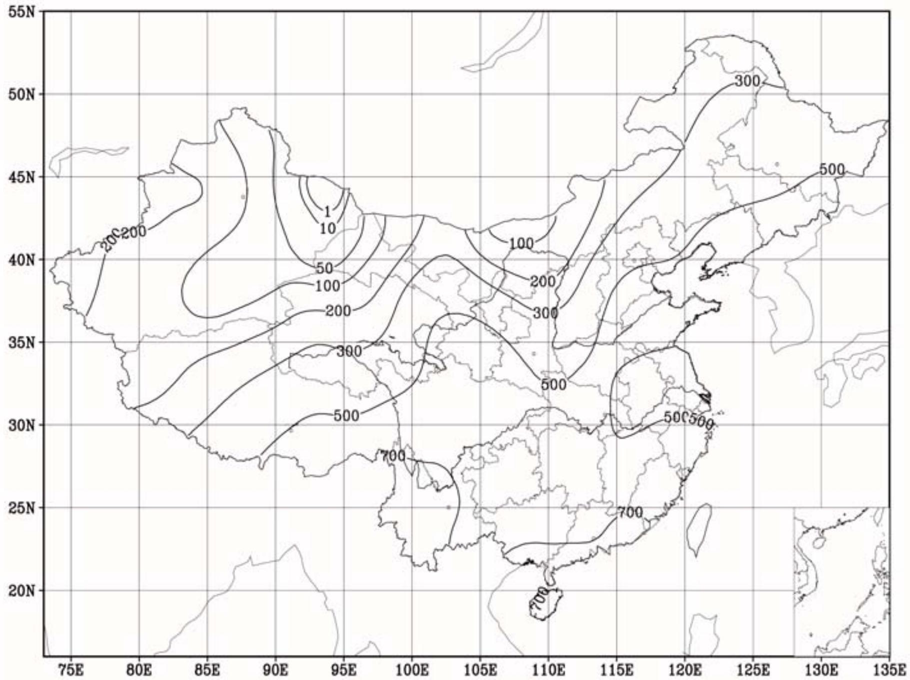

Fig. 8. The simulated precipitation field of 160 stations in China in the summer of 1997 by the original Gregory scheme.

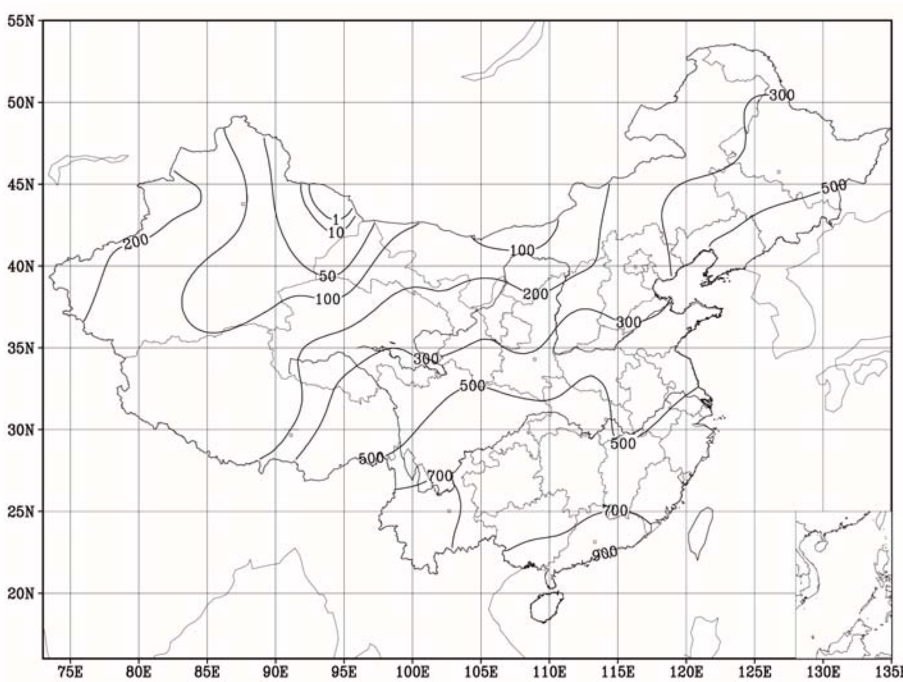

Fig. 9. The simulated precipitation field of 160 stations in China in the summer of 1997 by the modified Gregory scheme.

scheme used in the NCC T63L20 climate model is described. In the prediction of seasonal climate, the modified scheme can reflect the main features of Chinese regional climate.

The modification of the convection scheme occurs in two stages. In order to take into account the main features of precipitation clouds, the physical mechanism of the Gregory scheme is modified and developed during the first stage. The modification of the physical mechanism includes the following considerations. (i) In order to alleviate the deficiencies when the effects of synoptic scale convergence upon convection are not fully taken into account, organized entrainment is introduced in the lower level, and simultaneously, organized outflow is initiated to inhibit convection over-growing in the top level of the clouds, because in China, particularly in the south of China, a storm or a heavy storm is caused mainly by deep pallio-nimbus embedded convection clouds. (ii) In the Gregory scheme, deep convection develops more intensely than it does in the observed data from a precipitation cell, so we modify the scheme to inhibit convection over-growth. (iii) In our simulation tests, it is found that the initial mass flux is related not only to the stability of the lowest convection layers, but also to the intensity of the initial disturbance. Hence, we modify the initial mass flux to prevent virtual convection. In the second stage, the values of the internal parameters are determined, and then sensitivity tests are made.

The inexactness of the internal parameters must be taken into account in the parameterization scheme. In addition, the Gregory scheme is a one-dimensional cloud model, and its parameters depend to some extent on the features of the research area. In order to choose the appropriate parameter values, the cumulus convection heating and moistening profiles are analyzed and diagnosed. The parameter values in the control test are more reasonable than those obtained in the other tests. Hence, the values of the parameters, including the precipitous critical height and the downdraft coefficient, are modified according to the simulation and analysis results. The sensitivity tests show that the modified parameters better reflect the effects of convection heating and moistening than the former parameters.

The features of general circulation and precipitation in summer 1998 are chosen as a simulation example to test the performance of the modified convection scheme. The simulation results show that the modified scheme can accurately simulate not only the main features of air circulation, but also of the flood of the Yangtze River valley. Our tests and statistical analysis prove that the modified scheme succeeds in simulating the regional climate features over China and provides a good seasonal forecast.

However, some deficiencies still exist in the simulations made with our modified scheme, which requires some further modifications; nevertheless, it has greatly improved the quality of seasonal forecasts.

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