The Sensitivity of Numerical Simulation of the East Asian Monsoon to Different Cumulus Parameterization Schemes①

Cheng Anning (成安宁) *Chen Wen* (陈 文) and *Huang Ronghui* (黄荣辉)
Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100080
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ABSTRACT

In this paper, a 5-level spectral AGCM is used to examine the sensitivity of simulated East Asian summer monsoon circulation and rainfall to cumulus parameterization schemes. From the simulated results of East Asian monsoon circulations and rainfalls during the summers of 1987 and 1995, it is shown that the Kuo's convective parameterization scheme is more suitable for the numerical simulation of East Asian summer monsoon rainfall and circulation. This may be due to that the cumulus in the rainfall system is not strong in the East Asian monsoon region.

key words: Convective parameterization scheme, East Asian monsoon, numerical simulation

I. INTRODUCTION

As a major source of energy for atmosphere motion, cumulus convection is important to the general circulation. The effects of cumulus convection on the atmospheric circulation display mainly as follows: 1. latent heat release; 2. the sensible heat, water vapour and momentum transports; 3. The formation of cloud, which can influence the radiation. Thus, cumulus convection plays key roles in determining the structure of the temperature and moisture fields in the atmosphere, and also influences the general circulation indirectly by inducing changes in the mean meridional circulation. On the contrary, the large-scale general circulation can make the feedback restrict and affect convective activities. Since cumulus convections have scales considerably less than those of the large-scale flow, its effect must be parameterized in terms of the large-scale flow in the general circulation model (GCM). With the development of numerical weather prediction, the cumulus convective parameterization technique has been widely used in the numerical forecasting models and the numerical modelling of atmospheric general circulation, and the following three different cumulus convective parameterization schemes have been developed: the moist convective adjustment scheme proposed by Manabe(1964), the convective parameterization scheme considering the convergence and divergence of moisture and the atmospheric instability put forward by Kuo (1965), and the convective parameterization scheme of mass-flux considering the interaction between the cumulus group and its surrounding environment proposed by Arakawa-Schubert (1974). Recently, these convective parameterization schemes have been improved further, such as the moist convective adjustment scheme developed by Betts (1986) and Betts and Miller (1993), and the mass-flux scheme improved by Tiedtke (1989) and Hack (1994).

Many investigations have shown that the different result of simulation and forecast of synoptic system can be obtained by using different convective parameterization schemes. Recently, there are some studies which examine the sensitivity of simulated climate to cumulus

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paramterization scheme, such as Albrecht et al. (1986), Numaguchi and Matsuno (1992), Hack (1994), Baik and Takahashi (1995). Their results showed that the simulated climate is very sensitive to the convective parameterization scheme, especially the rainfall in the tropics. However, the investigations on the comparison between the simulated results of East Asian monsoon using these convective parameterization schemes are very little in the previous studies.

Because the East Asian monsoon is a subtropical monsoon, the cumulus convective activities in the East Asian monsoon rainfall system are not so strong as the tropical convections, and even the rainfall system used to be a mixing of cumulus and stratus. Moreover, many observational facts show that there are the planetary–scale, the synoptic–scale and the meso–α and meso–β scale rainfall systems in the East Asian rain belt. The interaction between them and the convective activities of cumulus play very important role in the formation, dissipation and maintenance of rain belt in the East Asian monsoon region. Thus, it is very important how to describe the effect of cumulus convection in the numerical simulation of monsoon variabilities, and it is necessary to investigate the influence of different cumulus convective parameterization scheme on the numerical simulation of East Asian monsoon circulation and precipitation. This is very significant for the studies on the predictability of monsoon variabilities. Therefore, in this paper, we extend the previous investigations to examine the sensitivity of simulated East Asian monsoon to cumulus parameterization schemes. For this purpose, the Manabe scheme, the Kuo scheme and the Arakawa–Schubert scheme and a 5–level spectral AGCM are used in the investigation.

II. BRIEF DESCRIPTION OF THE MODEL AND THE CONVECTIVE PARAMETERIZATION SCHEMES

The ImPKU–GCM spectral atmospheric general model has been developed from PKU–5L GCM at the Research Center for short–term Climate Prediction of the Institute of Atmospheric Physics, Chinese Academy of Sciences. Many important improvements have been made before this investigation. In the vertical, the atmosphere is divided into five levels in the model, and the horizontal resolution is $5.625° \times 5.625°$. A reference atmosphere is introduced in the dynamical frame of the model. Moreover, the total energy conservation is satisfied in the model, and this can make the long–term integration of the model be stable.

The convective parameterization schemes used in the model are the Manabe scheme, the Kuo scheme and the Arakawa–Schubert scheme (i.e., the A–S scheme), respectively.

The above–mentioned three kinds of convective parameterization scheme are used to simulate the East Asian monsoon rainfall and the circulation during the summers of 1987 and 1995, respectively. The geopotential and wind fields in June 1 of 1987 and May 1 of 1995 are taken as the initial fields of the model, and the distributions of SST are taken those in 1987 and 1995, respetively. The model is integrated to September 1 in each year. The monthly mean is made for the monsoon precipitations and circulations simulated by using the different convective parameterization schemes, and it is compared with the observed data.

III. INFLUENCE OF THE CONVECTIVE PARAMETERIZATION SCHEMES ON THE NUMERICAL SIMULATION OF SUMMER MONSOON RAINFALL IN EAST ASIA

The interannual variability of Asian monsoon is complex. In order to study well the sensitivity of Asian monsoon simulation to cumulus parameterization schemes, it is necessary to divide the summers into the weak monsoon summers and the strong monsoon summers. By calculating the broad–scale monsoon index defined by Webster and Yang (1992) from the

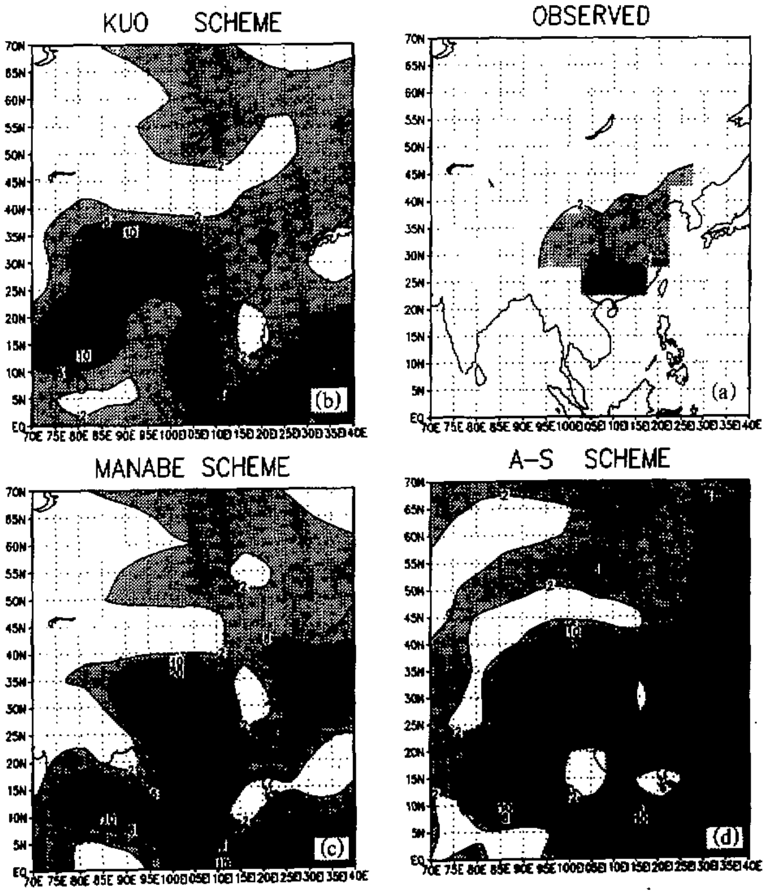

Fig. 1. The observed and simulated distributions of mean daily monsoon rainfall in East Asia during June of 1987 (mm / day). (a) observed (b) Kuo scheme (c) Manabe scheme (d) A-S scheme.

observed data, the summer monsoon is categorized into the weak and strong monsoon year. Because of the computation capability, we only select the summer of 1987 and the summer of 1995 as the representative of weak and strong Asian monsoon summer, respectively.

1. *In the Summer of 1987*

According to the monsoon index defined by Webster and Yang (1992), the summer of 1987 was one of the weak Asian monsoon summers. However, the East Asian monsoon is influenced not only by the Indian monsoon, but also the western Pacific subtropical high. The interannual variation of East Asian monsoon rainfall is contrary to that of the Indian monsoon rainfall (See Tao and Chen, 1985). During the summer of 1987, the monsoon rainfall in East Asia was strong, and severe flood was caused in the Yangtze River basin.

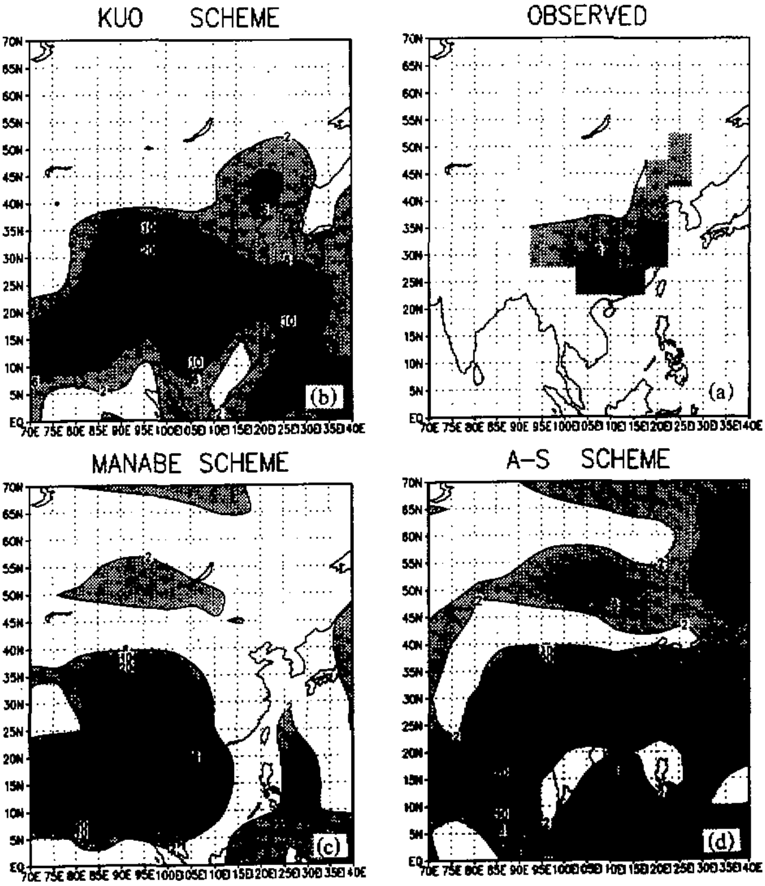

Fig. 2. The observed and simulated distributions of mean daily monsoon rainfall in East Asia during July of 1987 (mm / day). (a) observed (b) Kuo scheme (c) Manabe scheme (d) A-S scheme.

Figs. 1-3 show the observed and simulated distributions of mean daily monsoon rainfall in East Asia during June, July and August of 1987, simulated by using the Manabe's, the Kuo's and the A-S's convective parameterization schemes, respectively. In June, all three simulations predict heavy rainfall in the Tibetan Plateau with the smallest one in the experiment with the Kuo scheme. The main difference among those experiments is that there are no rain belt around the Yangtze-Huaihe River basin in the experiments with the Manabe and the A-S schemes. Therefore, the distribution of rain belt simulated with the Kuo scheme is in better agreement with the observation than those with other two convective parameterization schemes. From the observed rainfall in July, the rain belt shifted northward. The rainfall in the Yangtze-Huaihe River basin increased and the Meiyu season started. The simulations with the Kuo and the A-S schemes also show these features. However, in the experiment with the Manabe scheme the Meiyu does not appear there. In August the rain belt moves to North

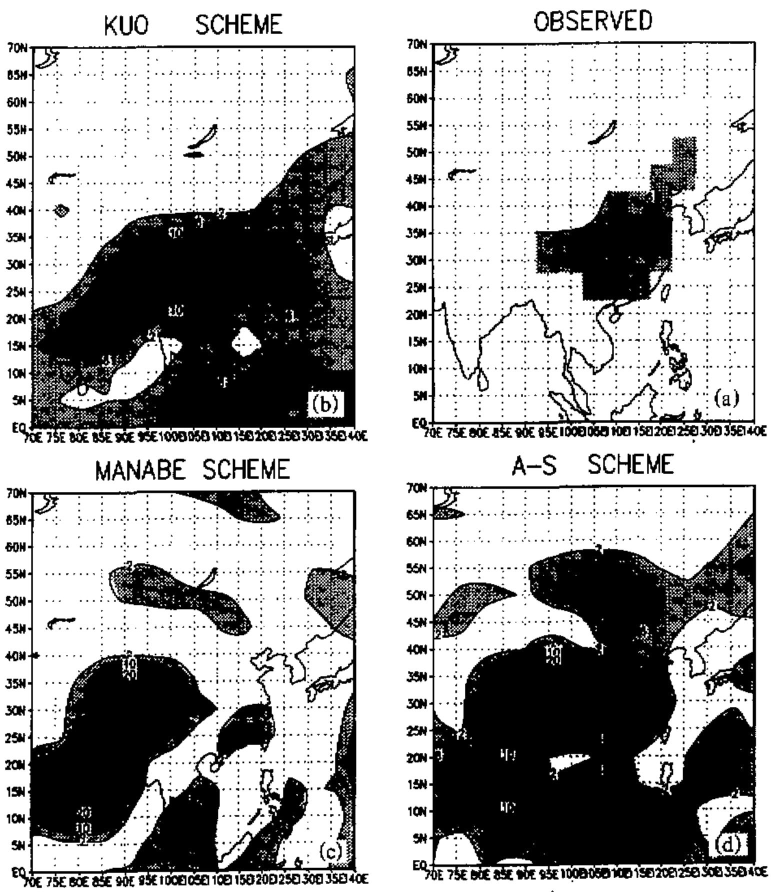

Fig. 3. The observed and simulated distributions of mean daily monsoon rainfall in East Asia during August of 1987 (mm / day). (a) observed (b) Kuo scheme (c) Manabe scheme (d) A-S scheme.

China. The results also present that the simulations with the Kuo and the A-S schemes are in better agreements with the observation than that with the Manabe scheme. But in the experiment with the A-S scheme there is too strong rainfall in the Tibetan Plateau. Comparing with the observation, it can be found that in the summer the distribution of East Asian monsoon rain belt simulated by using the Kuo's convective parameterization scheme is better, while with the Manabe scheme the East Asian summer monsoon rainfall can hardly be simulated. During the summer of 1987, the Meiyu in the Yangtze River and the Huaihe River basin was stronger, but in the result simulated with the Manabe scheme the Meiyu did not appear there. Moreover, the distributions of monsoon rain belt during July and August simulated by using the A-S scheme are not so good as the results by the Kuo scheme. These differences may be mainly due to that the description of different convective parameterization scheme for the rainfall mechanism and the heating, the moistening around cumulus group is different. The

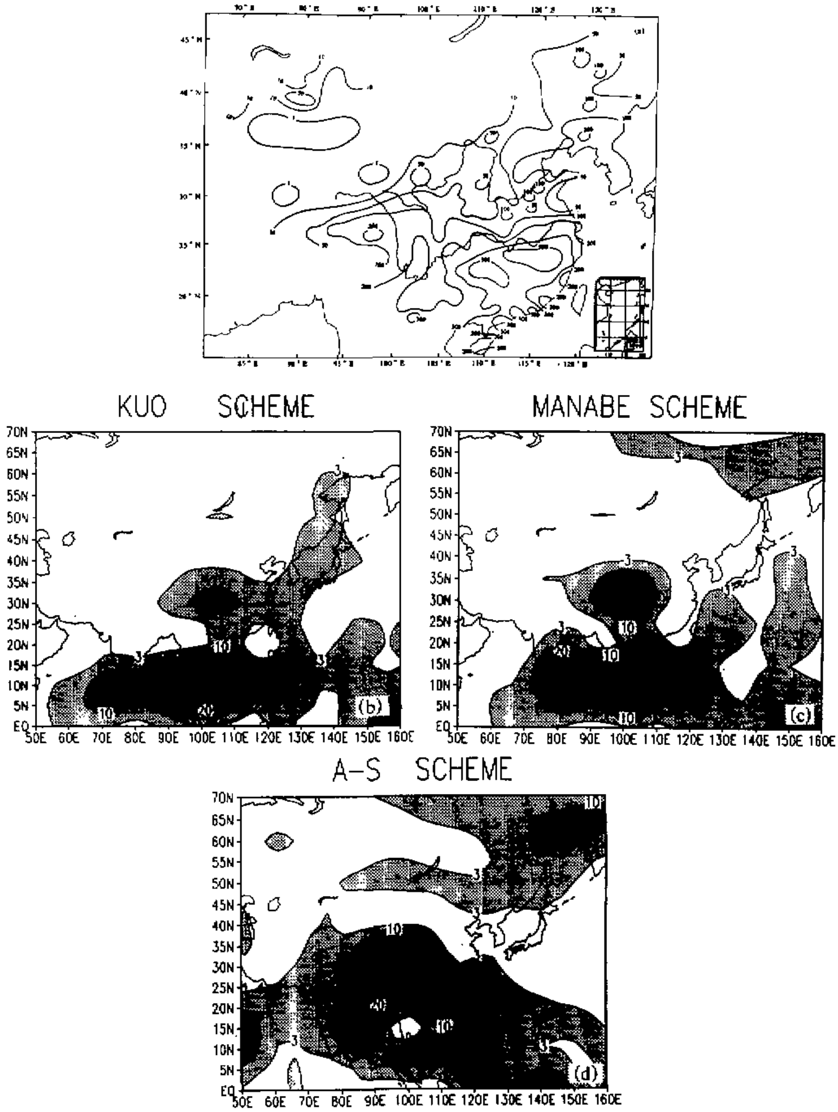

Fig. 4. The observed and simulated distributions of mean daily monsoon rainfall in East Asia during June of 1995 (mm / day). (a) observed (mm / month) (b) Kuo scheme (c) Manabe scheme (d) A-S scheme.

Kuo scheme may be able to reflect the rainfall cloud system well in the East Asian monsoon region, where the convective activities are not so strong as the tropical convective activities. Therefore, the better simulation of the summer monsoon rain belt in East Asia can be

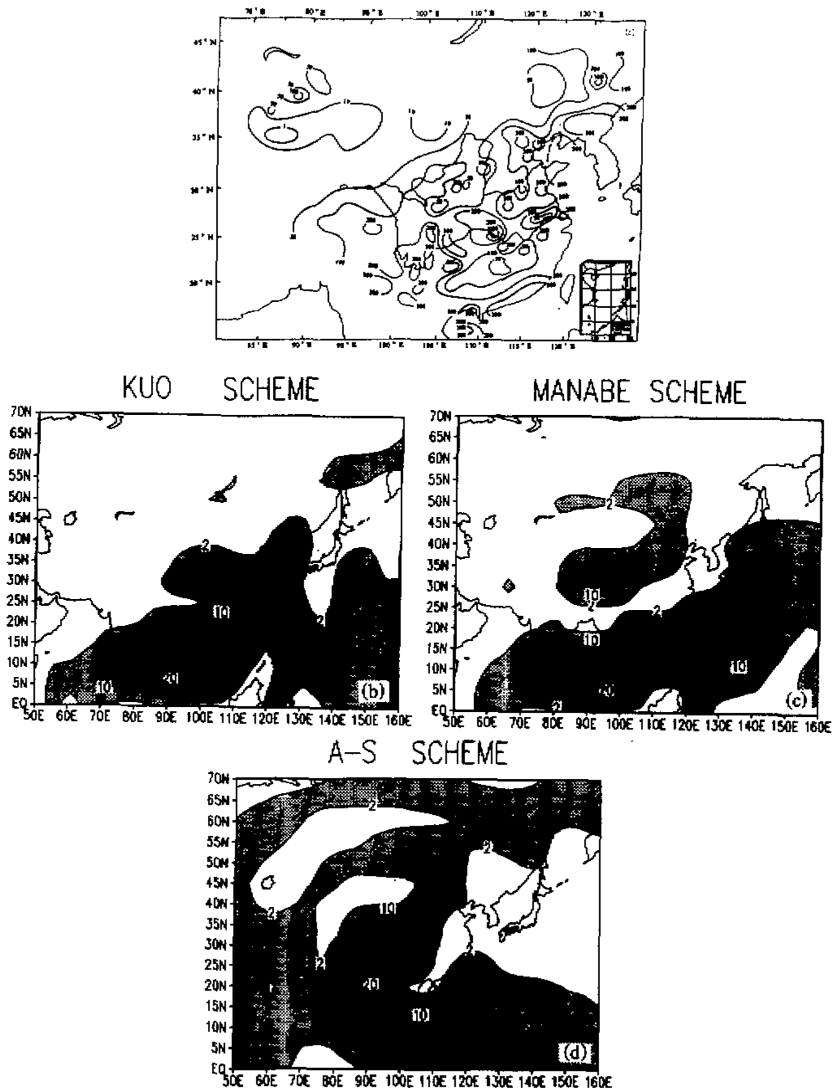

Fig. 5. The observed and simulated distributions of mean daily monsoon rainfall in East Asia during July of 1995 (mm / day). (a) observed (mm / month) (b) Kuo scheme (c) Manabe scheme (d) A-S scheme.

obtained by using the Kuo's convective parameterization scheme.

2. *In the Summer of 1995*

As mentioned above, the summer of 1995 was one of the strong Asian monsoons.

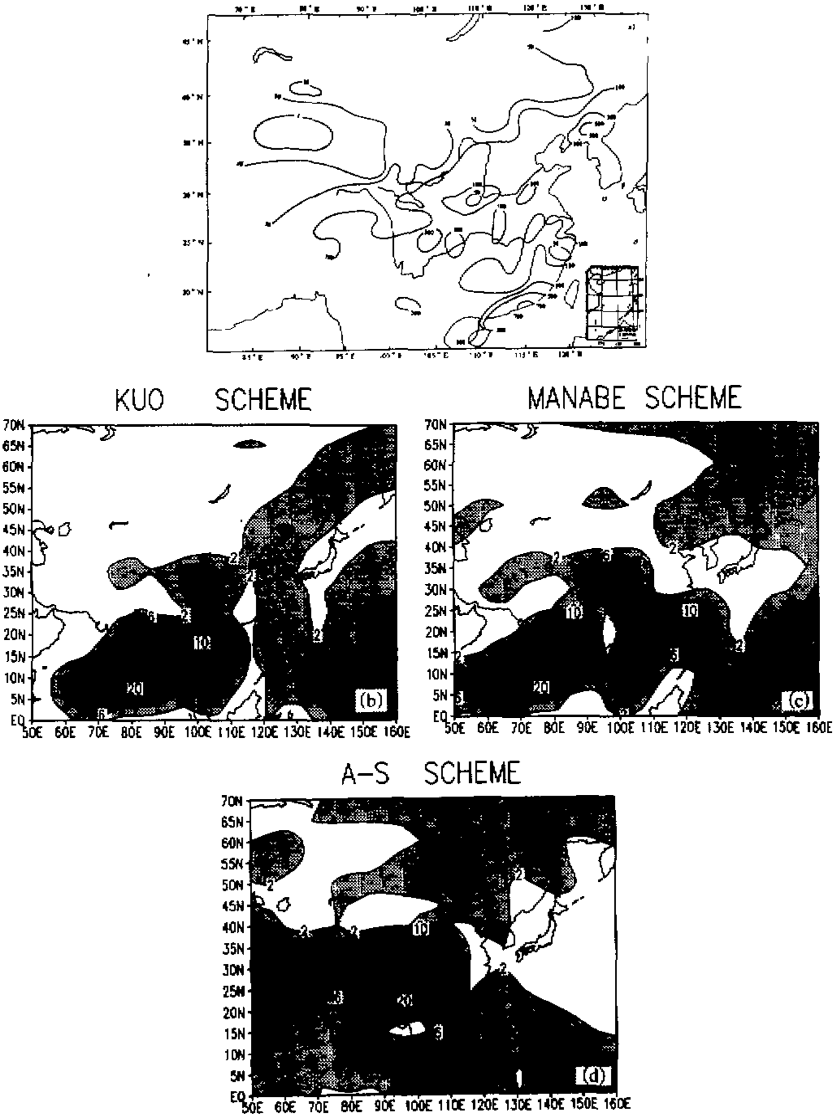

Fig. 6. The observed and simulated distributions of mean daily monsoon rainfall in East Asia during august of 1995 (mm / day). (a) observed (mm / month) (b) Kuo scheme (c) Manabe scheme (d) A-S scheme.

However, the summer rainfall in East Asia is contrary to that in India. During the summer of 1995, the monsoon rainfall in East Asia was weak, particular drought occurred in the Yangtze River and the Huaihe River basin. The rain belt was in South China during June and in the northern part of North China and the southern part of Northeast China during July–August as shown in Figs. 4(a)–6(a).

From the numerical simulations of East Asian monsoon rainfall during June–August of 1995 (Figs. 4–6), it may be found that there are large differences between the results simulated by using these cumulus parameterization schemes. Compared with the simulation in 1987, the rainfall decreases in the Tibetan Plateau and increases in Indian Peninsula. In June, the experiments with the A–S scheme and the Manabe scheme give unreasonable rain belt in the north of 55°N, while the result, with the Kuo scheme predicting relatively heavy rainfall in Japan and Korean peninsula, is in agreement with the observation. In the Yangtze–Huaihe River basin, the simulated precipitation with the Kuo and the A–S schemes is better than that with the Manabe scheme comparing with the observation. During July and August, it shows that the experiment with the A–S scheme gives too heavy rainfall in the Tibetan Plateau and unreasonable rainfall in high latitudes, and the experiment with the Manabe scheme also gives unreasonable rainfall in the Yangtze–Huaihe River basin, Korean Peninsula and Japan; Besides, the results also show that the northward movement of monsoon rainfall cannot be simulated well with the Manabe scheme. The result with the Kuo scheme is comparatively better than those with other two schemes in the distribution of rainfall in East Asia and the northward movement of rain belt is well simulated by using the Kuo's cumulus parameterization scheme. Although the northward movement of rain belt can be well simulated by using the A–S's, the rain belt simulated by this scheme is located over Baikal Lake.

From the above-mentioned simulations, it may be seen that the East Asian summer monsoon rainfalls simulated by the Kuo's scheme are in good agreement with the observations in both the strong Asian monsoon summer and the weak Asian monsoon summer.

IV. INFLUENCE OF THE CONVECTIVE PARAMETERIZATION SCHEME ON THE NUMERICAL SIMULATION OF SUMMER MONSOON CIRCULATION OVER EAST ASIA

As similar to the simulations of East Asian monsoon rainfall described in the previous section, the Kuo's, the A–S's and the Manabe's convective parameterization schemes are used to simulate the East Asian summer monsoon circulations during the weak Asian monsoon summer, i.e. the summer of 1987, and during the strong Asian monsoon summer, i.e., the summer of 1995, respectively. The following two cases are summarized, respectively.

1. *In the Summer of 1987*

As the above-mentioned observation, the summer of 1987 was one of the weak Asian monsoons. During that summer, the southwest monsoon was weak, and the northward movement of the western Pacific subtropical high was not obvious. It can be seen from the observation (figure omitted) that the ridge line of the western Pacific subtropical high remained at about 20°N from early June to mid-July and it moved to 30°N in late July. This made the monsoon rain belt stay in the Yangtze River and the Huaihe River basin.

The sensitivity of simulated East Asian summer monsoon circulation during June–August of 1987 to cumulus convective parameterization schemes is also made by using the Kuo's, the A–s's and the Manabe's schemes. From the numerical simulations of monsoon circulations over East Asia in June, July and August of 1987, it may be found that there are large differences between the results simulated by using these three convective parameterization schemes. Figs. 7–9 are the monthly mean monsoon circulations at 850 hPa over East Asia in June, July and August, 1987, simulated by using the Kuo's, the A–S's and the Manabe's convective parameterization schemes, respectively. Compared with the observation, we can find that all three schemes give similar simulations of the Somali jet over East

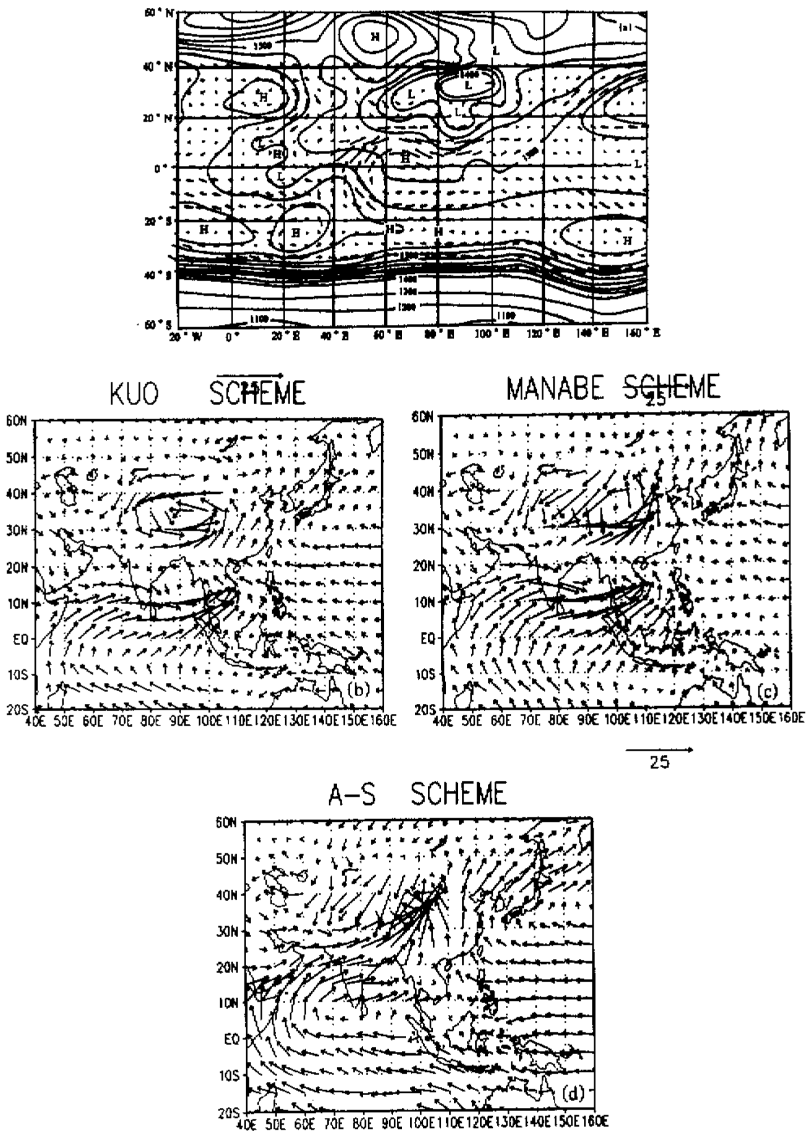

Fig. 7. The observed and simulated monthly mean monsoon circulation at 850 hPa over East Asia in June, 1987. (a) observed (b) Kuo scheme (c) Manabe scheme (d) A–S scheme.

Africa and the southwest monsoon over India. The main differences present in the simulations of the monsoon depression centered at about (100°E, 35°N) and the western Pacific subtropical high. The location and intensity of the monsoon depression simulated with the Kuo scheme are in better agreement with the observation. However, the results with the A–S

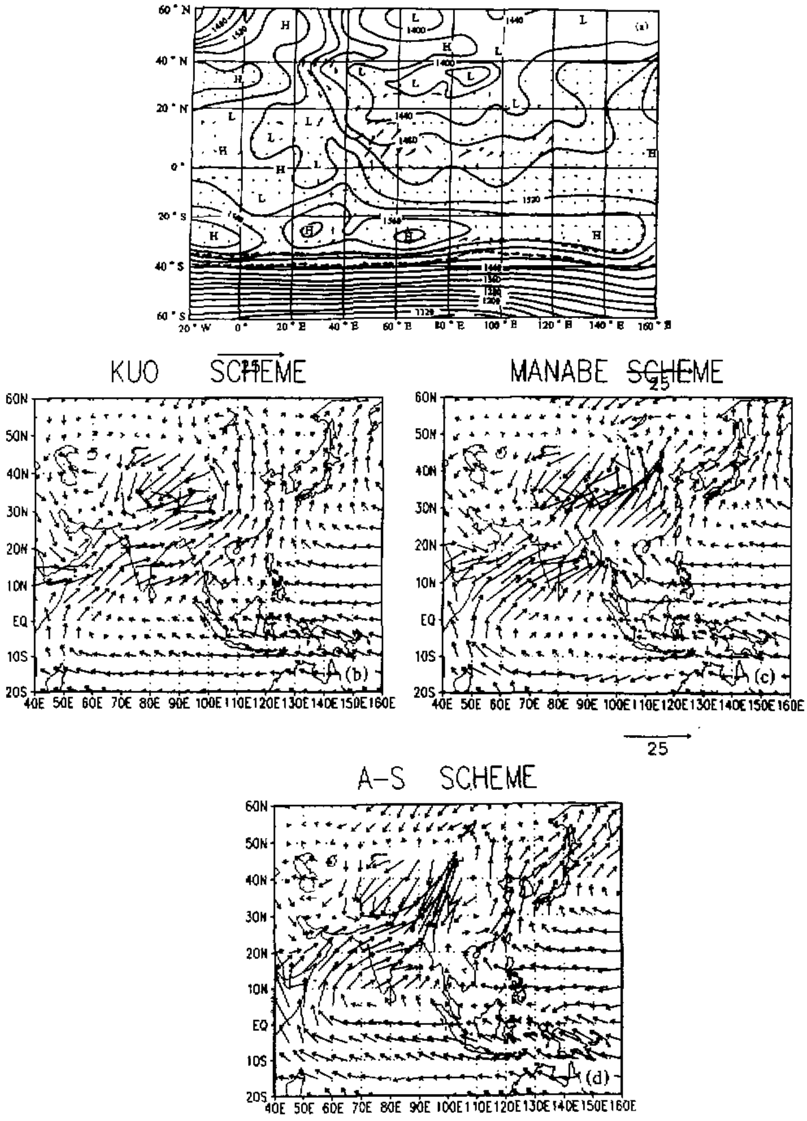

Fig. 8. The observed and simulated monthly mean monsoon circulation at 850 hPa over East Asia in July, 1987. (a) observed (b) Kuo scheme (c) Manabe scheme (d) A–S scheme.

scheme and the Manabe scheme give stronger monsoon low. Regarding to the western Pacific subtropical high, the simulations with the Kuo and the A–S scheme give analogous results with the obersvation; while the simulation with the Manabe scheme is not good, for example, in August it presents an unreasonable low in 20°N of the western Pacific.

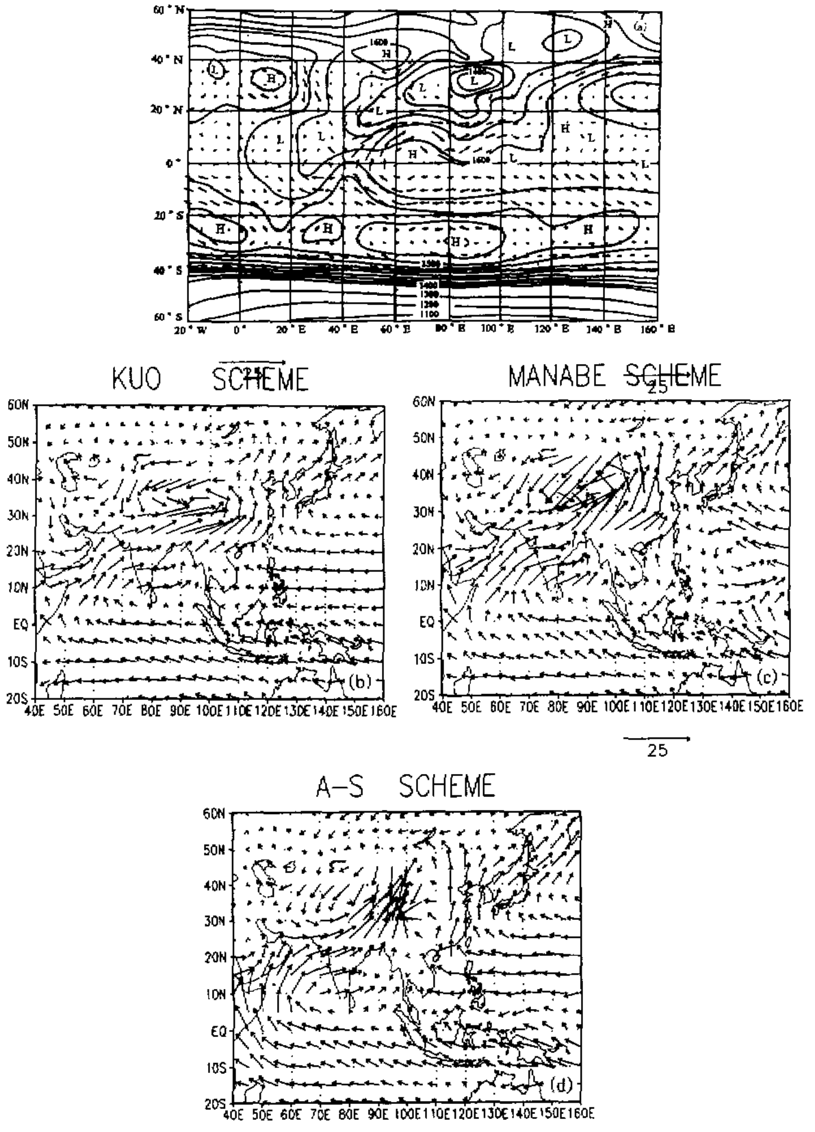

Fig. 9. The observed and simulated monthly mean monsoon circulation at 850 hPa over East Asia in August, 1987. (a) observed (b) Kuo scheme (c) Manabe scheme (d) A–S scheme.

2. *In the Summer of 1995*

As the above-mentioned observation, the summer of 1995 was one of the strong Asian monsoons. During that summer, the southwest monsoon was strong, and the northward movement of the western Pacific subtropical high was obvious.

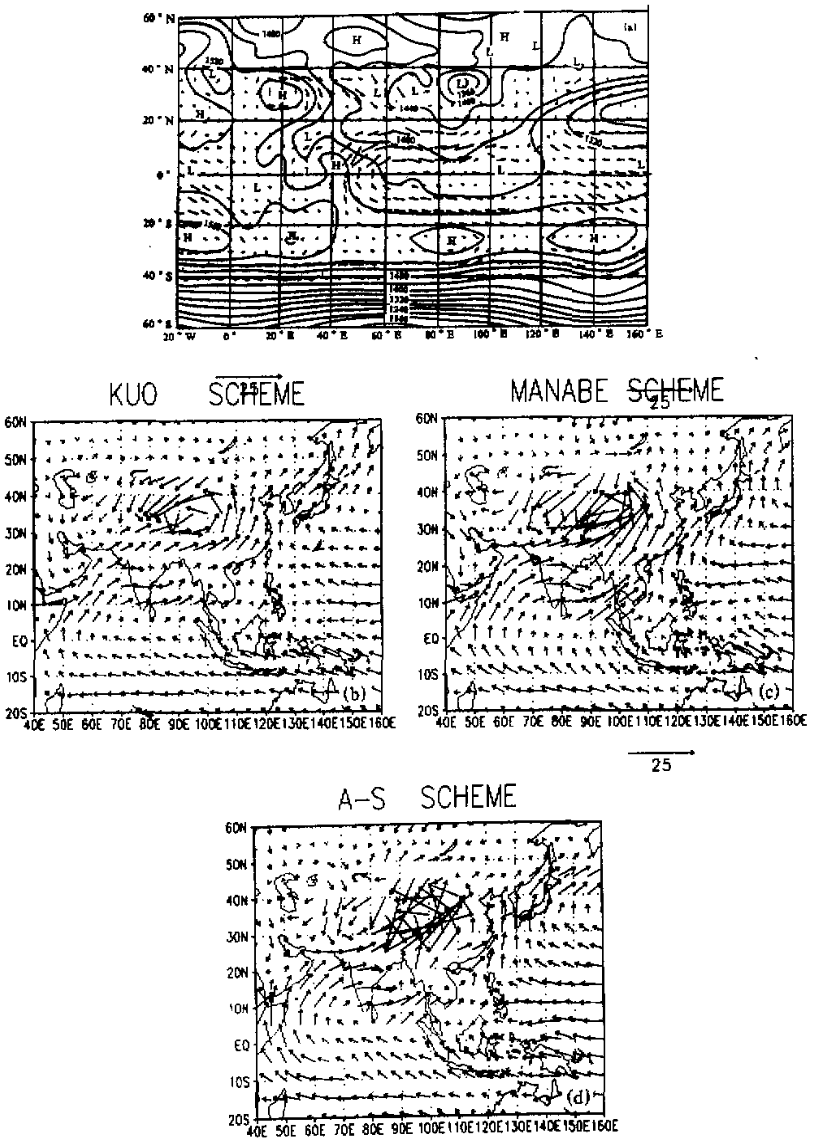

Fig. 10. The observed and simulated monthly mean monsoon circulation at 850 hPa over East Asia in June, 1995. (a) observed (b) Kuo scheme (c) Manabe scheme (d) A–S scheme.

It can be seen from the observation (figure omitted) that the ridge line of the western Pacific subtropical high shifted abruptly from 20°N to 30°N in mid–June, and it again shifted abruptly northward to 35°N in mid–July. This made the monsoon rain belt move to the Yellow River basin and North China from mid–July.

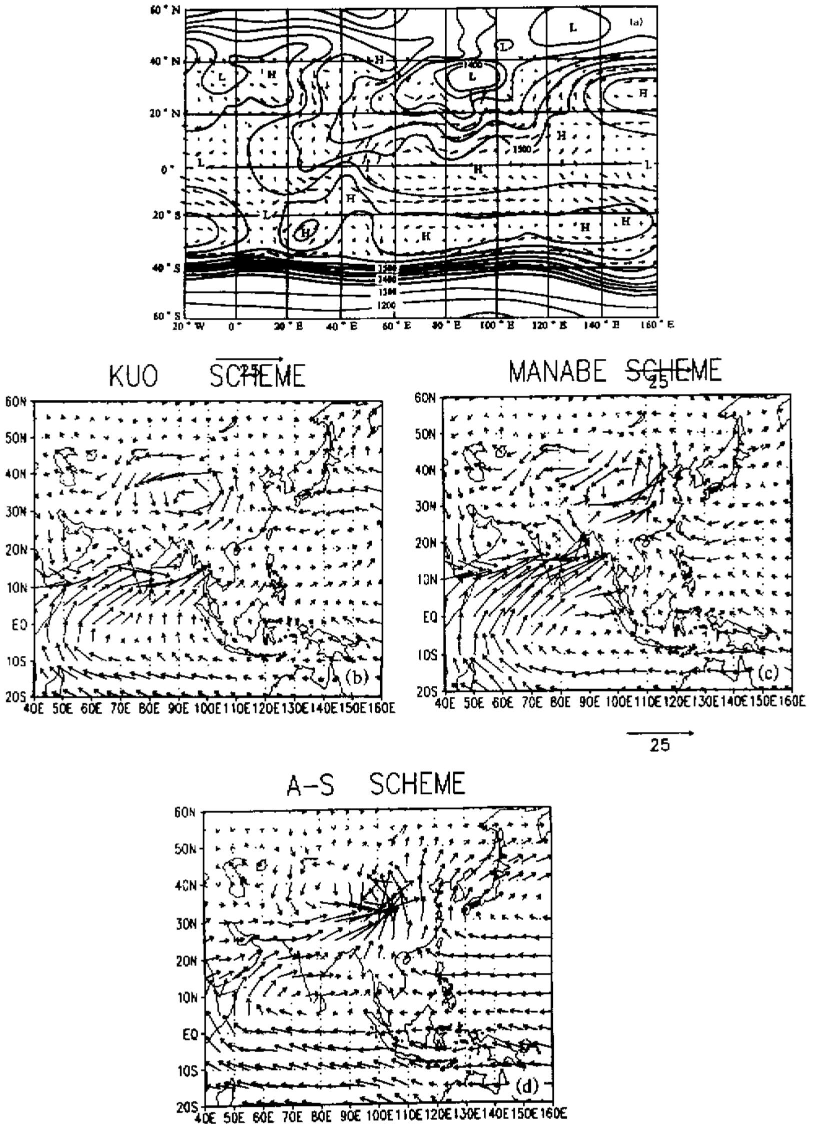

Fig. 11. The observed and simulated monthly mean monsoon circulation at 850 hPa over East Asia in July 1995. (a) observed (b) Kuo scheme (c) Manabe scheme (d) A–S scheme.

The sensitivity of simulated East Asian summer monsoon circulation during June–August of 1995 to cumulus convective parameterization schemes is also made by using the Kuo's, the A–S's and the Manabe's schemes. From the numerical simulations of monsoon circulations over East Asia in June, July and August, 1995, it may be seen that there are large

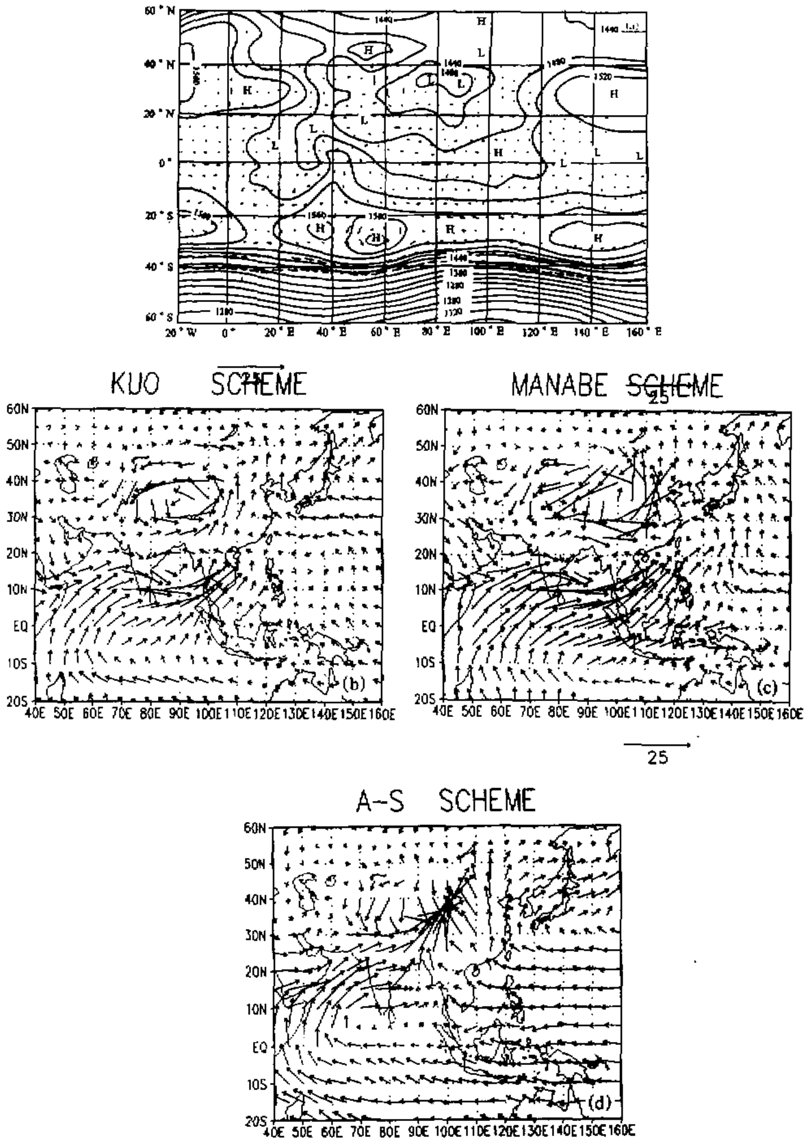

Fig. 12. The observed and simulated monthly mean monsoon circulation at 850 hPa over East Asia in August, 1995. (a) observed (b) Kuo scheme (c) Manabe scheme (d) A-S scheme.

differences between the results simulated by using these three convective parameterization schemes. Figs. 10–12 are the monthly mean monsoon circulations at 850 hPa over East Asia in June, July and August, 1995, simulated by using the Kuo's, the A–S's and the Manabe's convective parameterization schemes, respectively. Compared with the weak monsoon year 1987, the simulated southwest monsoons over India and the Somali jet are enhanced and the monsoon depression over East Asia is weak. Both the intensity and location of the monsoon depression simulated with the Kuo scheme are also in better agreement with the observation. Although the intensity of the monsoon depression simulated with the Manabe scheme is similar with the observation, its location is to the east. Comparing the simulated monsoon circulation in June with that in July of 1995, it may be seen that the northward movement of the subtropical high is obvious in the simulation with the Kuo scheme and not obvious in the simulation with other two schemes. Besides, Figs. 10–12 also show that there is a large difference between the results with these schemes within the area between 90°E and 110°E at about 10°N. In this region, the circulations simulated with the Kuo and the Manbe schemes are stronger and in better agreement with the observation than that with the A–S scheme.

V. CONCLUSIONS AND DISCUSSIONS

In this investigation, a 5–level spectral AGCM (Im PKU–5L AGCM) is used to examine the sensitivity of simulated East Asian summer monsoon circulation and rainfall to cumulus convective parameterization schemes. From the results of the East Asian monsoon circulations and rainfalls during the summers of 1987 and 1995, simulated by using the Kuo's, the Arakawa–Schubert's and the Manabe's convective parameterization schemes, it is shown that the Kuo's convective parameterization scheme is more suitable for the simulation of East Asian summer monsoon rainfall and circulation than the A–S's scheme, although the result simulated by using the A–S's cumulus paramereization scheme is better in the tropics. Moreover, it is also shown that the Manabe's scheme may be not suitable for the simulation of summer monsoon rainfall and circulation in East Asia. This may be due to that the cumulus in the rainfall system in the East Asian monsoon region is not so strong as the tropical convective activities.

However, only two cases are investigated in this paper, so the above–mentioned conclusions are preliminary. Moreover, what cause is the Kuo's cumulus paramererization scheme suitable to the simulation of the summer monsoon circulation and rainfall in East Asia, and what convective parameterization scheme should be used in the simulation of summer monsoon circulation and rainfall in East Asia? These should be studied further.

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