A GCM Study on the Mechanism of Seasonal Abrupt Changes①

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ABSTRACT

In this paper the observational studies and some related dynamical and numerical researches on seasonal abrupt changes were reviewed first. Then a speculation that the seasonal variation of insolation and the nonlinear dynamic interaction account for the abrupt changes was put forward and was asserted by a set of GCM sensitivity experiments. The results show that the abrupt changes would exist in case that all the earth surface was grass land and there was no topography. However, many factors may have influences on the abrupt changes. Hence this phenomenon is quite complicated and needs further investigations.

Key words: Abrupt change, GCMs, Sensitivity experiments

I. REVIEWS ON THE STUDIES OF SEASONAL ABRUPT CHANGES

1. *On the Observational Studies*

It was Yeh et al. (1959) who first revealed that there exist abrupt changes in the general atmospheric circulation in the Northern Hemisphere in June and October although some related studies had emerged before them (Zhu, 1934; Tu and Huang, 1944) based on the analysis of the surface maps and data. Yeh et al. (1959) pointed out that there are two times of abrupt migration of the westerly jet in June and October, respectively. In 1956, the jet along 120°E was at 35°N in May and then moved abruptly to 40°N in June and stayed there until October 15. Then a new jet appeared and moved to 25°N–30°N and the new jet became dominant. These two abrupt changes are corresponded to the beginning of the Meiyu season in the Yangtze River valley and the establishment of winter monsoon over the East Asian continent. They found that the abrupt change in October is not as strong as that in June. After that, the conception has been widely accepted that there are abrupt changes in the general circulation in the Northern Hemisphere. Some other methods which can more directly express the abrupt changes also have been developed. For example, Zeng et al. (1988) suggested to represent the abrupt change by the time–meridional cross–section of geopotential height averaged over a large area, and Zeng and Zhang (1992) reexamined the abruption by calculating the criteria of similarity of two patterns. However, such abrupt changes are only distinctive in certain regions and in some special years. These regional and annual differences of the seasonal variation have been noticed by some scientists. Recently, Wang et al. (1992) found that the South Asia high shifted abruptly in 1988 but gradually in 1986. Huang and Sun (1992) pointed out that the intensity of the convective activities around the Philippines has some relationship with the seasonal variation. When the convective activities are weak, the seasonal

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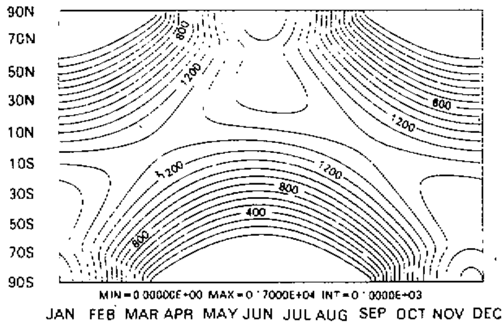

Fig. 1. The latitude–time distribution of the zonal mean insolation (W / M^2).

variation is intensive.

Although much work has been done in the field of the observational study of the seasonal abrupt changes, the detail and the mechanism remain unclear. It is interesting to note that many features of the abrupt changes can be well simulated by the IAP model (Zeng et al., 1988; Yuan, 1990).

2. *On the Mechanism Studies*

The research on the mechanism of the seasonal abrupt changes is focused on two aspects. The first is about the effect of huge mountains like the Qinghai–Xizang (Tibetan) Plateau. Hahn and Manabe (1975) tended to believe that the influence of the Qinghai–Xizang (Tibetan) Plateau on the formation of East Asian monsoon and its seasonal abrupt changes is remarkable. By using the GFDL (Geophysical Fluid Dynamics Laboratory) atmospheric circulation model they simulated the Asian monsoon very well, including the position and intensity of the Somali jet and the abrupt movement of the sub–tropical jet over the plateau, when the Qinghai–Xizang (tIBETAN) Plateau is included in the model, and vice versa. The second aspect is focused on the non–linear dynamics of the general circulation (Li et al., 1983). They considered that the non–linear mechanism is probably the main cause of the abrupt seasonal changes. However it should be noted that the real atmospheric circulation is quite complex and it is impossible to make the problem clear by using highly–simplified truncated models. Hence it is believed that the best way at present to study the effect of any factor is to do numerical experiments by means of GCMs.

II. INSOLATION AND THE NON–LINEAR MECHANISM

In Fig. 1 we present the annual cycle of zonal mean insolation. It can be found that the seasonal variability of the insolation in the middle latitudes in the Northern Hemisphere is by no means uniform in whole year. The variability is greater in spring and autumn than that in summer and winter. This means that even if the climate system were the insolation–forced linear system the seasonal variability of any variable would not be uniform in the whole year.

We should note that it is difficult to give a strict definition to the abrupt changes, and hence it is difficult to tell the difference of the abrupt changes from the non–uniform change.

Furthermore, the real climate system is non–linear. So it is possible that the non–uniform feature of the seasonal variation of the insolation in middle latitudes and the non–linear dynamics are the two causes of abrupt seasonal changes.

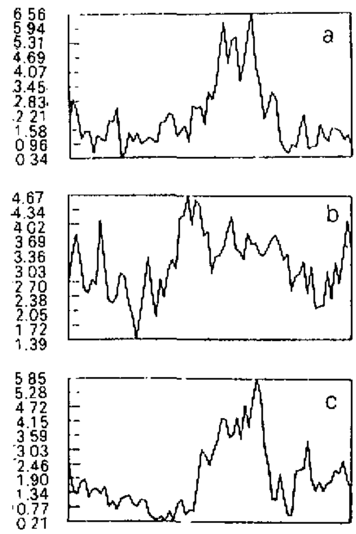

Fig. 2. The annual cycle of the simulated cloud amount over India, East China and Australia in the control experiment.

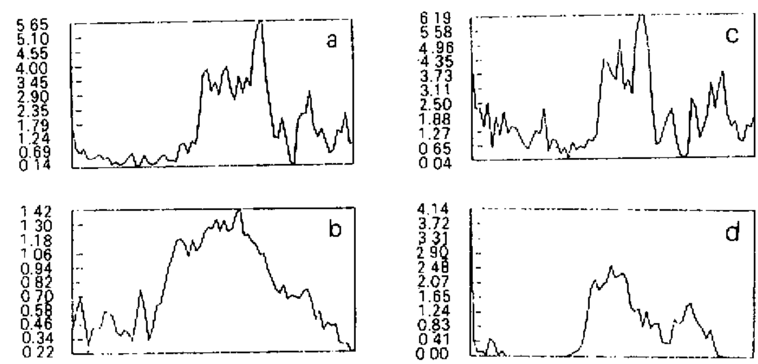

Fig. 3. The annual cycle of the simulated precipitation over India in the four tests mm d^{-1}.

III. RESULTS FROM A SET OF NUMERICAL EXPERIMENTS BY MEANS OF A GCM

The model used here is the two-level general atmospheric circulation model of the Institute of Atmospheric Physics. According to Zeng's suggestions (Zeng et al., 1988), four experiments were performed. In the control experiments (Test 0) the model is integrated for one year initiated from the end of the 25th year of the model climate. In each of the other three experiments the initial condition and the integration time are the same as the control run. In the first sensitivity experiment (Test 1), the global ocean is replaced by grassland and the land remains the same as Test 0. In the second sensitivity experiment (Test 2), the topography is removed and in the last experiment (Test 3), all the earth surface is covered by grassland without topography.

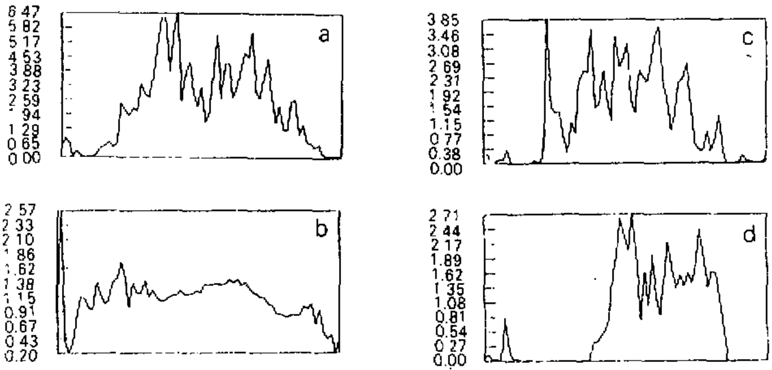

Fig. 4. Same as Fig. 3, but over East China.

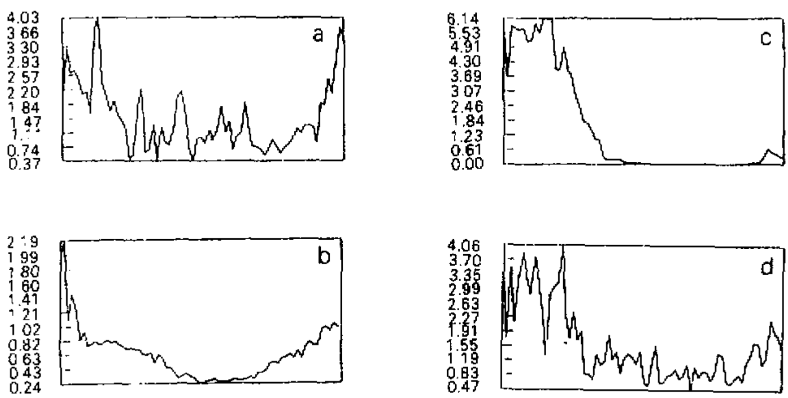

Fig. 5. Same as Fig. 4, but over Australia.

In the control run (Test 0), the seasonal abrupt change is well simulated. In Fig. 2 we present the annual cycle of the simulated mean cloud amount over East China, India and Australia. One can find that there exists an abrupt seasonal variation over these monsoon regions obviously. The model can also reasonably simulate the abrupt changes of the planetary scale circulation which was ever studied by Zeng et al. (1988). In Fig. 3 we show the annual cycle of averaged Indian precipitation in the four experiments. It is easy to find that the abrupt changes exist in Test 0 and all the other three tests. The time of the abrupt changes in Test1 is a little earlier than in Test 0, while the time of the abrupt changes in Test 2 and Test 3 is almost the same as in Test 0.

In Fig. 4 we present the annual cycle of averaged precipitation over East China in the four tests. The abrupt changes is well simulated except in Test 1. The time of the abrupt changes is earlier in Test 2 and later in Test 3 than that in Test 0. The annual cycle of the simulated mean precipitation over Australia is presented in Fig. 5. The abrupt change is clear in all tests but Test 1. The abrupt changes in the three tests occur in the late February or the early March.

Therefore, the above results suggest that topography and the continent / ocean distribution are not the necessary factors to the seasonal abrupt changes, especially over East Asia.

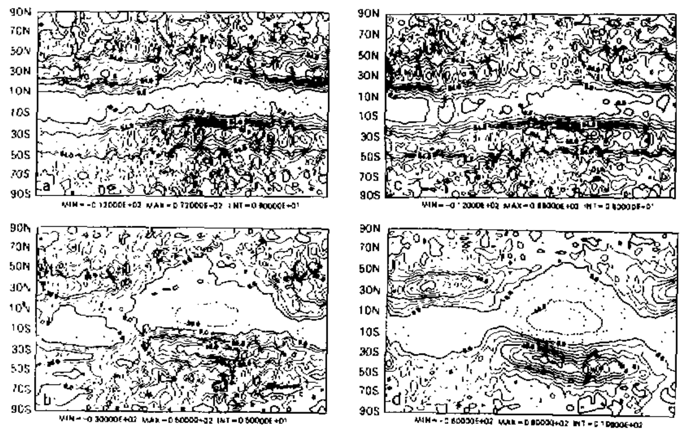

Fig. 6. The latitude-time distribution of the simulated 400 hPa zonal wind at 120°E (ms^{-1}).

Thus the conclusion in Section II and the GCM experimental results seem to support the idea that the non-uniform variation of the insolation in middle latitudes and the non-linear dynamics in the climate system are the main causes of the abrupt seasonal variation since there are no other possible factors that could be responsible for the abrupt changes in the general circulation.

Nevertheless, the problem of abrupt changes is very complicated. In Fig. 6 we present the annual cycle of the simulated 400 hPa zonal wind at 120°E in each experiment. We find in Test 0 that the jet in the tropics becomes weak suddenly in June and becomes strong again abruptly in September. Hence there are two times of abrupt changes in Test 0. Whereas in Test 2 there is little change in the position and intensity of the jet. This means that with the existence of land / sea contrast the abrupt change is clear when there is topography and vice versa. However, when there is no land / sea contrast, the effects of the topography are quite uncertain. It should be also pointed out that the abrupt change is most obvious in monsoon regions like India, China and Australia, but unclear or even does not exist in other regions. Therefore, in Fig. 6 the north-southward movement of the jet is not fast, although not all the variables behave just like the 400 hPa zonal wind.

IV. CONCLUDING REMARKS

The results in this study through numerical experiments tend to support the view that the non-uniform variation of the insolation in the middle latitudes and the non-linear dynamic interaction in climate system are the main causes of abrupt seasonal changes while the existence of topography and the land / sea contrast are not the necessary factors. However, with the existence of the land / sea contrast the effect of topography upon abrupt changes is of importance.

The problem of the abrupt change is very complicated. The abrupt change is most obvious in monsoon regions but not clear in zonal mean fields. It is also noted through observational study that the abrupt change is not clear or even does not exist in some years.

The abrupt change is directly related to the monsoon circulation and the monsoon climate and hence the climate over China. Researches on the mechanism of the abrupt change and the monsoon circulation are valuable for the monsoon study and for the agriculture in

China and for many other aspects.

Some uncertainties about the current study still remain in the uncertainties of the model. It is necessary to make model intercomparisons on studies of the abrupt changes and it should be a valuable project of the AMIP(Atmospheric Model Intercomparison Program).

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