NUMERICAL EXPERIMENTS ON THE INFLUENCES OF GENERAL CIRCULATION ANOMALY OVER THE TIBETAN PLATEAU AND SURFACE ALBEDO CHANGE IN NORTHWEST CHINA ON SUMMER PRECIPITATION

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ABSTRACT

An advanced three-level global atmospheric general circulation model has been used to study the summer precipitation anomaly in Northwest China, based on the synoptic fact and the statistical analysis of the precipitation, the surface albedo in Northwest China, and the synoptic systems over the Tibetan (Qinghai-Xizang) Plateau. The results show that either the anticyclone intensified over the plateau or the surface albedo enhanced in Northwest China results in summer precipitation reduction east of Northwest China. Especially, when both of them appear simultaneously, summer precipitation was obviously reduced and severe drought occurred in most areas of Northwest China. Moreover, the simulated difference of precipitation rate of Northwest China is similar to the actural precipitation distribution in Northwest China in 1995, which is the most severe drought year in Northwest China in the past fifty years. So the tendency in drought severity intensified, drought frequency accelerated, drought persistence period extended, and drought areas expanded in Northwest China in recent years is maybe a result of the influences of human activities (e. g. vegetation was reduced, and desertification worsened) on drought circulation pattens over the Tibetan Plateau.

Key words: Tibetan Plateau, Northwest China, general circulation model (GCM), surface albedo change

I. INTRODUCTION

The research on physical mechanism of the large-scale arid climate is one of the major subjects of the global climatic variability. The arid climate changes in Northwest China, as a regional climate anomaly, have not yet reached a systematic conclusion on physical factors and numerical experiments at present. The study of the arid climate changes has been concentrated on African Sahel. In most of 1970s—1980s, sub-Saharan Africa experienced a continuous drought. Many reports indicate that GCMs are very useful in determining the drought mechanism. In recent years, a lot of observations and numerical experiments have revealed the significant impacts of land-surface processes on general circulation and climate. The change of the physical factors or parameters dominating land-surface processes, such as albedo, roughness, ground temperature, soil humidity, and so forth, can result in the change of the physical exchange between ground and atmosphere, and the budget of atmospheric energy and water, thus affecting general circulation and climate. Especially, the study for the influence of surface albedo on climate is an important aspect in them. For example, Charney et al. (1977) first suggested the "biogeophysical feedback mechanism" as a partial explanation for the recurrent drought in desert border areas, and verified the hypothesis by using Giss model, i. e., high albedo causes a decrease of precipitation in semi-arid regions such as Sahel etc. Chervin (1979), Sud and Fennessy (1982) studied the effects of surface albedo change on precipitation in Thar of India, the western plain of America, and Northeast Brazil using different GCMs respectively. Luo (1985) indicated that low albedo causes more advection and precipitation than high albedo, and that high albedo causes severe drought and maintains this drought in Loess Plateau. Wang et al. (1993) did a long-range numerical forecast experiment on drought and flood in the middle and upper reaches of the Huanghe River in July by using a simple OSU two-level model. Their results indicate that the Pacific SST in June, the Arctic sea ice and general circulation anomaly etc. play an important role in forming drought and flood in the middle and upper reaches of the Huanghe River in July. Sun et al. (1993) made a series of numerical forecast experiments on the effects of heat source intensity change in the Tibetan Plateau on the runoff in the upper reaches of the Huanghe River. Their results show that the heat source intensity change in the Tibetan Plateau is one of the factors which lead to the variation of the runoff in the upper reaches of the Huanghe River. The probability of studying the regional drought and flood by using OSU model is therefore verified.

Northwest China is located in the arid and semi-arid region. In this area, the numerical experiments on interaction between surface and atmosphere are still insufficient. However, studies on this subject will have important significance for recognizing drought climate rules or mechanism, and improving its prediction level. In this paper, an advanced three-level global atmospheric general circulation model will be used to study the influences of general circulation anomaly over the Tibetan Plateau and surface albedo in Northwest China on summer precipitation. The experimental results and the observation facts will be analysed and discussed.

II. DESIGN OF NUMERICAL EXPERIMENTS

1. *Model Description*

The model used is a three-level global atmospheric general circulation model (Chen et al. 1993) including a planetary boundary layer (PBL). The physical processes in the model include the conditions at the earth's surface, turbulent fluxes in the boundary layer, friction, diabatic heating and moisture sources, cloud types and radiations. The conditions at the earth's surface involve the orography, surface type, surface albedo, ground temperature, ground hydrology, snow mass budget, snowmelt, monthly climatological sea-surface temperatures and sea ice. The turbulent fluxes are momentum, sensible heat and moisture fluxes. The diabatic heating consists of convective adjustment, large-scale condensation and evaporation cumulus convection. For the calculation of the radiation, the concentrations of absorption gases in atmosphere, such as water vapour, carbon dioxide and ozone, are all constant, while the amount of high-, medium-, and low-level clouds is variable. As for the more detailed description of this model, please see Chen et al. (1993).

2. *Design of Numerical Experiments*

The experimental schemes are as the following: (1) Control experiment (EXP. 1). Running AGCM for ten model years, then taking the last fields from January 1 to December 31 as the results of the control experiment. (2) Experiment on surface albedo change in Northwest China (EXP. 2). According to the variation of area of desert and desertification, lake surface, forest cover and glacier in Northwest China in recent years, based on the different surface albedoes in different surface types in AGCM, we enhance the surface albedo by an average of 0. 055 in Northwest China and its neibour regions so as to approach the facts of Northwest China as possible. We enhance the surface albedo in Northwest China and its neibour regions from May 1 to July 31, and take the mean value of July 1—July 31. (3) Experiment on the anomaly general circulation over the Tibetan Plateau (EXP. 3). Sun et al. (1989) once pointed out that the closed and steady high at 500 hPa over the Tibetan Plateau and its neibour regions is one of the major circulation pattens of summer drought in Gansu and even in Northwest China. The high at 500 hPa over the Tibetan Plateau is always accompanied with high temperature center (Sun et al. 1984). So we start to increase temperature at 500 hPa over the Tibetan Plateau from June 1 in the experiment. Then, the closed high appears after the model is integrated (figure omitted). We run the AGCM until July 31 and take the mean value of July 1—July 31. (4) Experiment on simultaneous variation of general circulation over the Tibetan Plateau and surface albedo in Northwest China (EXP. 4). In this experiment, we add the factors of EXP. 2 and EXP. 3 to the model simultaneously, run the AGCM from Juny 1 to July 31, and take the mean value of July 1—July 31.

III. RESULTS OF NUMERICAL EXPERIMENTS

There are a lot of experimental results obtained from the tests. Here, the attention is focused on the differences of the air flow at the upper and lower level and precipitation in Northwest China. It is noteworthy that the results of EXP. 2—EXP. 4 must deduct the results of EXP. 1 in order to remove system error.

1. *Results of EXP.* 1

In order to show the ability of the AGCM reproducing the climate mean patterns, we give some results from the control experiment. For detailed results of experiments about the global mean climatic patterns of the air flow, surface temperature, sea surface pressure and precipitation in Jan. and Jul., refer to Chen et al. (1993). Because it is an important symbol for a climate model to simulate the seasonal variation successfully, we just show the seasonal variation of the precipitation obtained from control experiment only. The latitude-time cross-section of rainfall along 110—120°E is shown in Fig. 1. From Fig. 1, we see that there are two distinct rainfall belts. One is the ITCZ in South

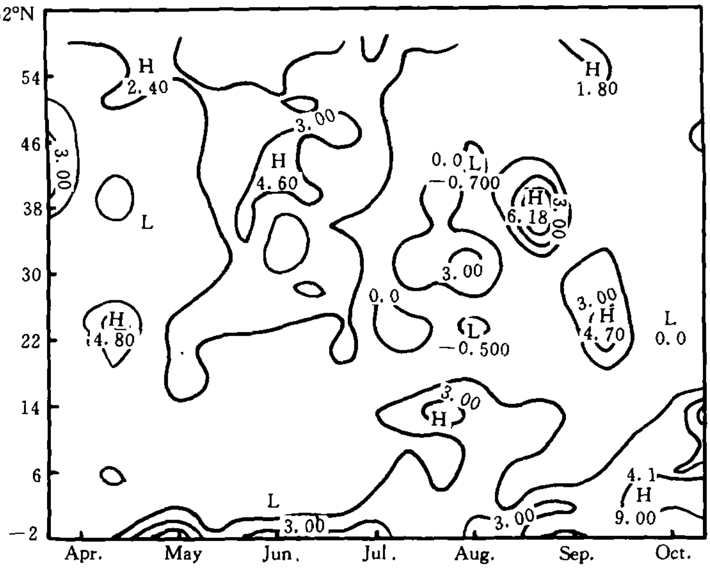

Fig. 1. The simulated latitude-time cross-section of the precipitation along 110—120°E.

China Sea and the other is in the mainland. For the former, Chen et al. (1993) have discussed it. For the latter, its formation is related to the advance and retreat of the summer monsoon in China. The simulated mainland rainfall belt is in the southern side of 28°N during April and May, and is closer to the rain belt in the former flood season, it jumps to near 30°N in June and is similar to the Changjiang River Meiyu, then it jumps to near 34°N in July and is similar to the Huanghe-Huaihe River rainfall belt, then it jumps again to 38—42°N in August and is closer to North China rainfall belt. The simulated rainfall belt withdraws rapidly to the south after August. The simulated seasonal variations above are in better agreement with the analysis of the seasonal variations of the precipitation in the eastern region of China (eastern side of 110°E, 20—45°N) during 1951 —1993 (Guo and Ye 1996). It shows that this model can successfully simulate the most features of the observations in the Asian summer monsoon region. This will also be of significance in studying regional climate of Northwest China.

2. *Results of EXP. 2*

Northwest China, an arid and semi-arid region, forms the horizontal inhomogeneties of thermal and dynamic characters in the land surface induced by man-made factors which can change the regional climate. Based on the positive feedback effect of "plant-albedo-stability", deterioration of vegetation cover would entail a higher albedo, which results in an increase of atmospheric stability, in turn causes a decrease of convective activity in atmosphere and of precipitation. Since changing surface albedo may affect the variation of general circulation, at first, we tested if the abnormal surface albedo in Northwest China and surrounding areas can affect general circulation. Figure 2 is the difference of simulated

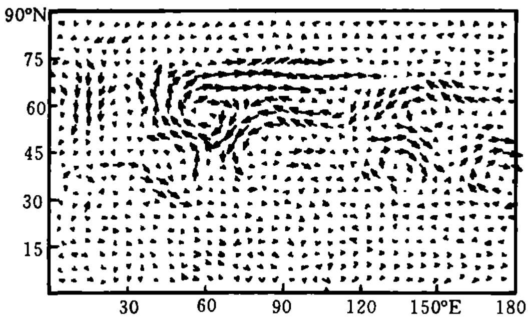

Fig. 2. The difference of simulated monthly mean wind vectors at 250 hPa level in July.

monthly mean wind vectors at 250 hPa level in July (EXP. 2 minus EXP. 1). We can see that the centre of South Asia high is located at the 250 hPa level over the northeast of Tibetan Plateau (38°N, 94°E). There is a cyclonic circulation on its northwestern side, whose centre is located near Lake Balkhash. Such is the large-scale circulation pattern in which the precipitation decreases in eastern Northwest China and increases in western in summer. According to the statistics by one of authors, when the aforementioned circulation pattern appeared in July in 1982, the precipitation anomaly reached −42% in east of Gansu (Sun et al. 1989). For the 975 hPa level (figure omitted), it is noteworthy that there is an intensified south flow near the juncture of Xinjiang and Gansu (30—40°N, 95—100°E) corresponding to the large-scale circulation pattern, which is favourable to abundance of rainfull in western of Northwest China and to reduction of rainfall in the eastern part of Northwest China.

Figure 3 is the difference of simulated monthly mean precipitation in July in Northwest China (EXP. 2 minus EXP. 1). From Fig. 3, we can see that as the surface albedo is enhanced, the feature of precipitation distribution is as follows: the precipitation increased north of Xinjiang, west of Gansu and northwest of Qinghai; the condition of the eastern side of Northwest China (including the east of Qinghai and Gansu, Ningxia and

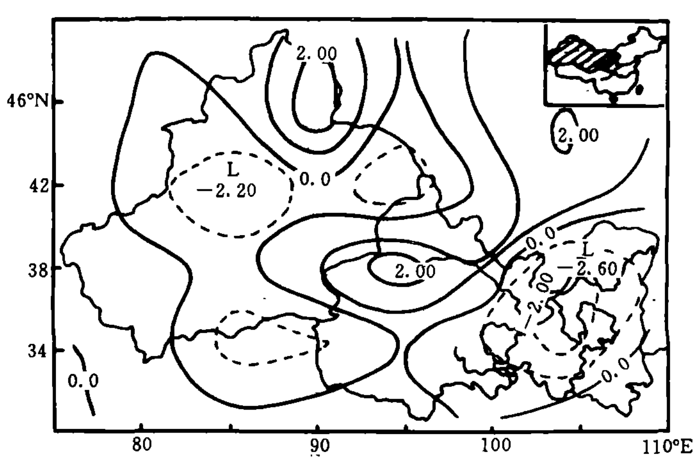

Fig. 3. The difference of simulated monthly mean precipitation in July.

Shaanxi) is opposite. The spatial distribution character of precipitation is in agreement with the simulated flow fields in the upper and lower layers, the high is entrenched over the northeast of the Tibetan Plateau, the precipitation is, of course, inclined to decrease east of Northwest China controlled by the anticyclone. The simulated results are also conformed to the inference of albedo effect and the hypothesis about desert self-induction effect advanced by Charney (1975), i. e., increasing the surface albedo would entail a lesser surface net long wave radiation and hence the heat transfers to the overlying atmosphere, which in turn would be conductive to subsidence, this results in a reduction of precipitation.

3. *Results of EXP.* 3

Observational facts (Sun et al. 1989) indicate that structures of high temperature and anticyclone usually appear at 500 hPa level over the Tibetan Plateau during July to August in midsummer due to the effect of heat and dynamic forcing, and high temperature center is accompanied with anticyclone center. Based on these facts, we attempt to increase the intensity of anticyclone over the Tibetan Plateau in this experiment by adding the temperature in troposphere to examine whether the abnormal circulation over the Tibetan Plateau and surrounding areas can influence the precipitation of Northwest China in summer. The results are satisfying. From the difference of simulated monthly mean wind vectors in July (EXP. 3 minus EXP. 1, Fig. 4), we can see that at 250 hPa level the South Asia high is a western pattern whose center is located at near 31°N, 75°E. This is another flow pattern in which the precipitation decreases in the east of Northwest China in midsummer (Sun et al. 1989). In the situation, the east of Northwest China is controlled by north flows and hence showers usually arise. At 975 hPa level (figure omitted), the SW flows are weakened obviously in the Asian summer monsoon region.

Comparing the difference of simulated monthly mean precipitation in July (EXP. 3 minus EXP. 1, Fig. 5) with Fig. 3, their spatial characteristics are basically similar, i. e., the summer precipitation increases in the west of Northwest China; the condition of the eastern side of Northwest China is opposite.

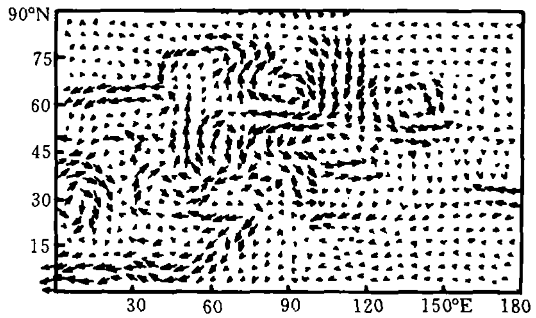

Fig. 4. The difference of simulated monthly mean wind vectors at 250 hPa level in July.

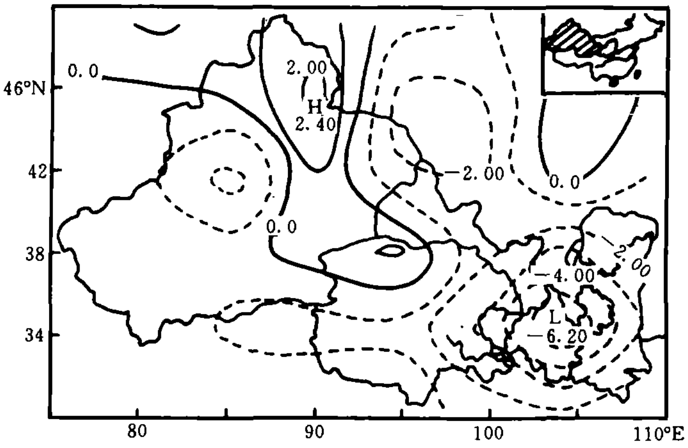

Fig. 5. The difference of simulated monthly mean precipitation in July.

4. *Results of EXP.* 4

We do EXP. 4 in order to examine whether the weather forecast experience (e. g., an existing anticyclone over the Tibetan Plateau) and the current actual conditions of surface type in Northwest China (e. g., surface albedo is enhanced) are the major factors forming drought. From Fig. 6 (EXP. 4 minus EXP. 1), we can see that under the conditions of both (the circulation over the Tibetan Plateau and the surface albedo in Northwest China) change simultaneously, a closed anticyclone appears at 250 hPa level (Fig. 6a) over the Tibetan Plateau and its surrounding areas, whose center is located in the region of the middle-north of the Tibetan Plateau (35—40°N, 85—90°E). According to Figs. 2 and 4, we find out clearly that the high center is located in the northeast of the Tibetan Plateau in Fig. 2 and northwest in Fig. 4. In 975 hPa (Fig. 6b), a closed cyclone appears over the Tibetan Plateau and its surrounding areas with obviously west flows along 30°N in the south of Tibetan Plateau. It is well known that under the control of these circulation patterns (warm anticyclone at the upper level and warm cyclone at the lower lever), the

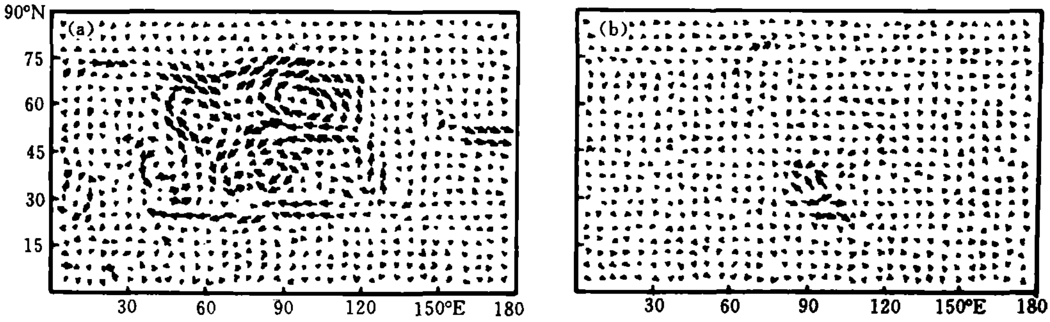

Fig. 6. The difference of simulated monthly mean wind vectors at 250 hPa (a) and 975 hPa (b) level in July.

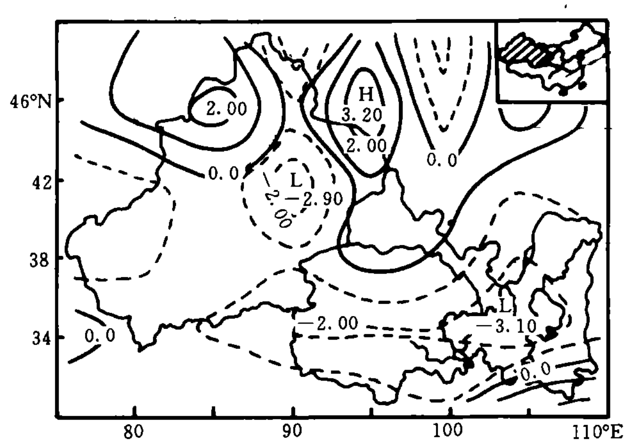

Fig. 7. The difference of simulated monthly mean precipitation in July.

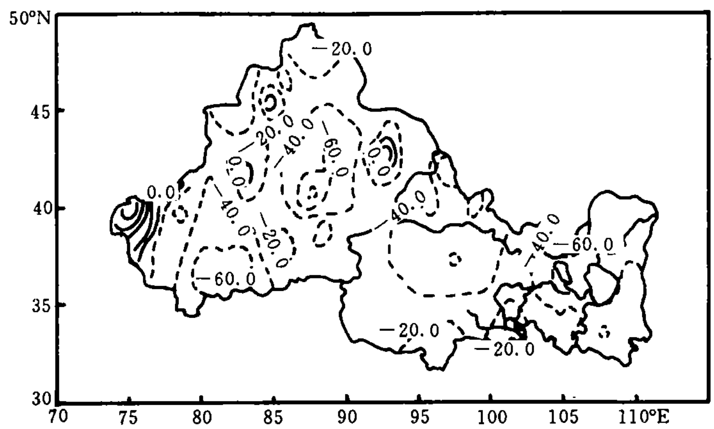

Fig. 8. Abnormal percentage of rainfall in Northwest China during January to June in 1995.

drought and lack of rainfall arise obviously in the most part of Northwest China.

The difference of simulated monthly mean precipitation in July (EXP. 4 minus EXP. 1) is shown in Fig. 7. From Fig. 7, it is seen that the precipitation decreased in the whole Northwest China, which is suited to the condition of the upper and lower layer circulation. The simulated results are also in close agreement with the actual condition of rainfall in Northwest China in severe drought years (such as 1995, which is the most severe drought year in the past fifty years in Northwest China), the actual condition of rainfall (Fig. 8) is in close agreement with Fig. 7.

IV. CONCLUSIONS

Based on the above analysis and discussion, we may come to the following preliminary conclusions:

(1) The control experiment shows that the advanced three-level AGCM can reproduce most features of the observation, especially in the Asian summer monsoon area. It can simulate not only the mean climate patterns, but also the climate seasonal variation. The

ability of the AGCM to reproduce the regional climate aspects is verified.

(2) The change in surface albedo can influence the formation and evolution of the arid climate in Northwest China. When the surface albedo is enhanced in Northwest China and its surrounding areas, the precipitation decreased on the eastern side of Northwest China (including the east of Qinghai and Gansu, Ningxia and Shaanxi) in summer; the condition of the western side of Northwest China (north of Xinjiang, west of Gansu and northwest of Qinghai) is opposite. The simulated spatial distribution of precipitation is suited to the simulated pattern of the upper and lower level circulation, and is also identical with synoptic observation.

(3) The general circulation anomaly over the Tibetan Plateau can also influence the formation and evolution of the arid climate in Northwest China. When the circulation over the Tibetan Plateau and its surrounding areas is abnormal, the influence on the local climate exhibits similarity to the results in (2), and the simulated spatial distribution of precipitation is suited to the simulated pattern of the upper and lower level circulation, and is also in close identical with synoptic observation.

(4) Simultaneous variation of general circulation over the Tibetan Plateau and surface albedo in Northwest China have a significant influence on the formation and evolution of the arid climate in Northwest China. The simulated results indicate that in the case of anticyclonic circulation at the upper layer and cyclonic circulation at the lower layer can result in reduction of precipitation in Northwest China in summer. This is in close agreement with spatial distribution of precipitation of severe drought in 1995. This implies that the tendency of drought severity intensified, drought frequency accelerated and drought persistence period extended in Northwest China in recent years may be related to vegetation reduction and desertification extension, which enhanced the surface albedo, as well as the drought circulation patterns maintaining over the Tibetan Plateau. These problems remain to be studied further.

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