Simulation of Climate Change Induced by CO_2 Increasing for East Asia with IAP/ LASG GOALS Model①

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ABSTRACT

Two simulations, one for the control run and another for the perturbation run, with a global coupled ocean–atmosphere–land system model (IAP / LASG GOALS version 4) have been carried out to study the global warming, with much detailed emphasis on East Asia. Results indicate that there is no climate drift in the control run and at the time of CO_2 doubling the global temperature increases about 1.65°C. The GOALS model is able to simulate the observed spatial distribution and annual cycles of temperature and precipitation for East Asia quite well. But, in general, the model underestimates temperature and overestimates rainfall amount for regional annual average. For the climate change in East Asia, the temperature and precipitation in East Asia increase 2.1°C and 5% respectively, and the maximum warming occurs at middle–latitude continent and the maximum precipitation increase occurs around 25°N with reduced precipitation in the tropical western Pacific.

Key words: Climate change simulation, Coupled climate model, East Asia

1. Introduction

East Asia is a significant monsoon region where it has large climate variability and the drought and flood in summer occur almost every year. The economic development in East Asia is strongly affected by climate anomalies and climate change. The future climate change due to global warming for East Asia will be a problem that many countries in East Asia are seriously concerned about, and also the major subject that climatologists are dealing with. The differences of region–average values between the transient run and the control run at the time of CO_2 doubling for surface air temperature and precipitation in East Asia from nine coupled model simulations have been given in IPCC (1996). Chen et al. (1996) once discussed the climate change in East Asia induced by the greenhouse effect with a coupled ocean–atmosphere model (IAP CGCM M2+20) in detail. It is noted that the control run with M2+20 has obvious climate drift with 3.2°C decrease in temperature during 130–year integration (Chen, 1994), which may bring some uncertainty for assessment of global warming. Besides, M2+20 used a slab mixed layer ocean model in the Arctic Ocean, which led to a very strong warming in winter in the Arctic region (Yu et al., 1996). These shortcomings should be

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corrected. In recent years a global ocean–atmosphere–land system model (GOALS) has been developed in State Key Laboratory of Atmospheric Sciences and Geophysical Fluid Dynamics (LASG), Institute of Atmospheric Physics (IAP) (Wu et al., 1997). In this paper the climate changes induced by atmospheric CO_2 concentration increasing in East Asia simulated by IAP / LASG GOALS model are presented and compared with that simulated by IAP CGCM M2+20.

2. Model and experiment design

The IAP / LASG GOALS is a global coupled ocean–atmosphere–sea ice–land system model. The model details can be found in Wu et al. (1997) and Zhang et al. (2000). Briefly, the atmospheric component of IAP / LASG GOALS model is a nine–layer spectral R15 atmospheric general circulation model (AGCM, an equivalent grid spacing of roughly $7.5° \times 4.5°$) (Wu et al., 1996). The ocean component of GOALS is a global ocean general circulation model (OGCM) with $5° \times 4°$ grid spacing and 20 levels in the vertical, extending to 88°N with an explicit diffusion scheme (Zhang et al., 1996; Yu, 1997). A simple thermodynamic sea–ice model based on Semtner (1976) and Parkinson and Washington (1979) is incorporated into the ocean model. The land surface is a simplified version of the simple biosphere model (Xue et al., 1991). A modified monthly flux anomaly (MFA) coupling scheme (Yu and Zhang, 1998) is employed to perform the air–sea–ice coupling.

The model used here is its fourth version. In this version a daily flux anomaly exchange (DFA) including fresh water is applied (Yu and Zhang, 1998). The time step for coupling is one day. The model was coupled for 10 years from the equilibrium states of atmosphere and ocean component firstly. The last states of atmosphere and ocean in the 10–year integration served as the initial condition for later experiments.

The experiments include two integration runs, one for the control run and another for the perturbation run. Both the two cases are integrated for 80 years with initial equivalent CO_2 concentration of 345 ppm. For the control run, the equivalent concentration of CO_2 remains constant, but for the perturbation one it undergoes transient increase with a rate of 1% per year. As usual, the climate changes are defined as differences between the perturbation run and the control run during the same period.

3. The background of global warming

The global mean surface air temperatures of the control and transient simulations from the GOALS model are shown in Fig. 1a. There is no climate drift in the 80–year control run integration. Around the time of CO_2 doubling (61th–80th model years average), the global temperature increases about 1.65°C. The global warming at the time of CO_2 doubling simulated by IAP CGCM M2+20 is about 2.5°C, which is higher than that from the GOALS model. By comparing the geographic distribution of global warming simulated by the GOALS model (figures not shown) with that by M2+20, the largest differences occur at high northern latitudes. In M2+20 simulation the maximum warming is more than 12°C and is located at high northern latitudes (See Fig. 3c, Yu et al., 1996), but for GOALS model the high northern latitudes warm less than the middle northern latitude continents. This difference may be related to the differences of sea ice variation around the Arctic Ocean between these two model simulations. In the M2+20 simulation the area of sea ice in the Arctic reduces obviously, as the surface air temperature increases (See Figs. 8 and 9, Yu et al., 1996).

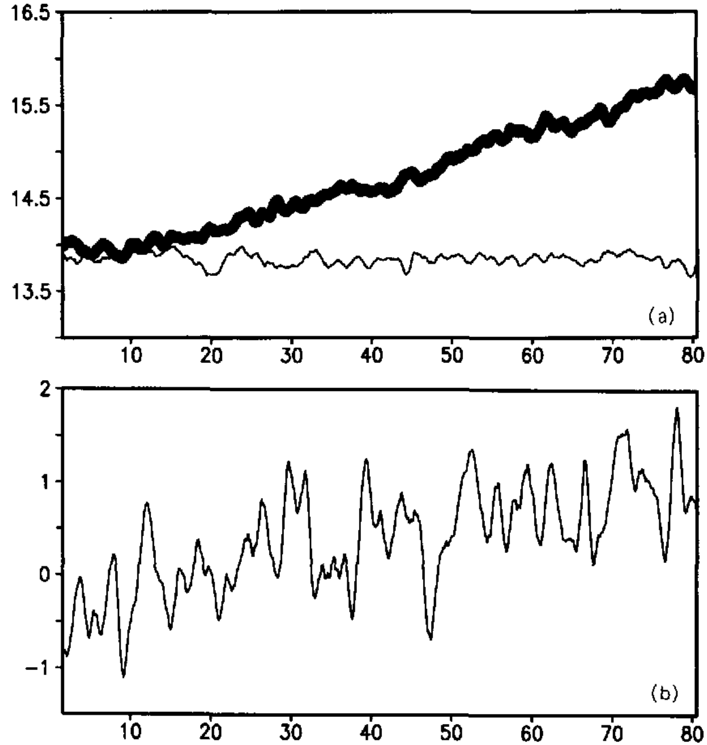

Fig. 1. (a) Time evolution of the globally averaged surface air temperature (°C) for the control run (thin line) and the perturbation run (thick line); (b) variation of the globally averaged precipitation rate (%).

Obviously, the positive feedback between the ice albedo and the surface air temperature in M2+20 amplifies projected climate warming at high latitudes, especially in winter season. In the M2+20 January simulation the maximum warming is more than 22°C in the Arctic Ocean, which seems to be unreasonably high. Obviously, the too strong warming at high northern latitudes in the M2+20 simulation is directly related to a slab mixed layer ocean model in the Arctic Ocean used in M2+20. It is interesting to note that there is no decrease trend for the sea ice variation in the GOALS model simulation, where a global ocean general circulation model extend to 88°N. In the GOALS model simulation the variations of sea ice exhibit decade–scale variability, even if the global temperatures increase almost linearly. It means that in the background of global warming, the variations of others climate variables except for temperature may be more complicated. The variations of sea ice in the GOALS simulation may be attributed to some positive and negative feedback processes and also may be related to the coupling schemes between ice–air and ice –water used in GOALS. Because the variations of sea ice have decade–scale variability, the variations of temperature at northern high

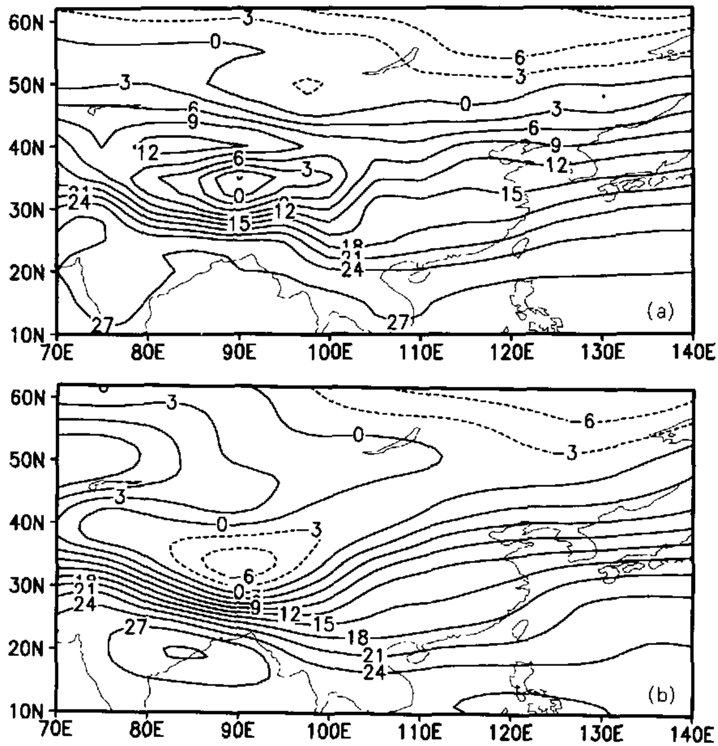

Fig. 2. Annual mean temperature (°C) over East Asia from observation (a) and the control run (b).

latitudes are more complicated in GOALS than in M2+20. It also shows that the simulation of sea ice will have a very important effect on global warming, especially in the high latitude regions.

Figure 1b shows the variation of globally averaged precipitation rate. It exhibits a weak increase trend with a stronger interannual variability. Around the time of CO_2 doubling, the globally averaged precipitation rate only increases about 0.09%.

4. Simulated regional climate for East Asia

Before discussing regional climate changes for East Asia in the perturbation run, it is necessary to estimate the ability of the GOALS model of simulating observed regional climate of East Asia in the control run.

The GOALS model is able to simulate the observed spatial distributions of temperature and precipitation in East Asia (70–140°E, 10–62°N) rather well (Figs. 2 and 3), except that the simulated temperature is lower than the observed over the Tibetan Plateau and precipitation is much more from southern East Asia to South China. The GOALS model can also reproduce the observed annual cycles of temperature and precipitation rather well (figure

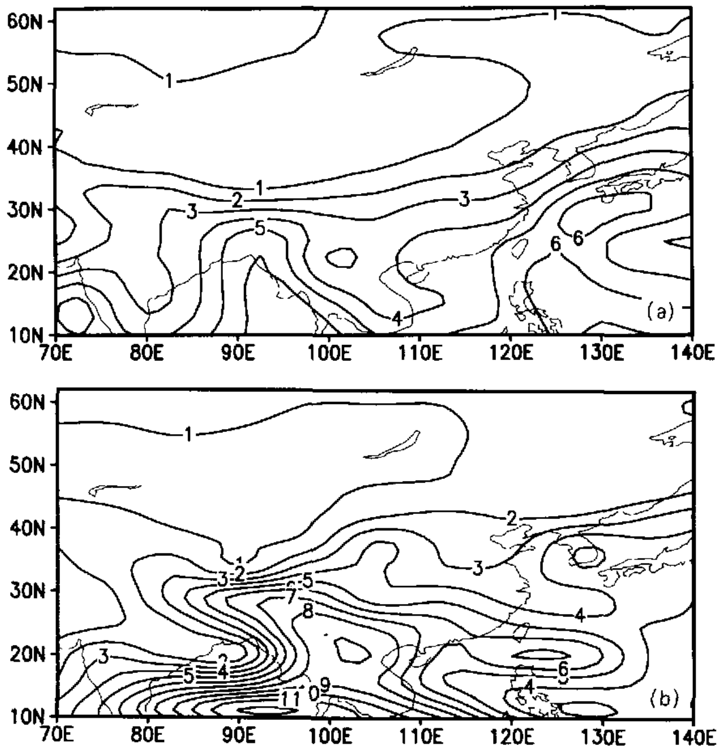

Fig. 3. As in Fig. 2, but for precipitation (mm / day).

omitted). The observation data of climatology come from Shea (1986). For the geographical distributions, generally, the simulation of temperature is better than that of precipitation.

Table 1. Observed and simulated annual mean temperature and precipitation averaged over East Asia

		Observation	GOALS		IPCC(1995) Bias * *
		Average	Average *	Bias	
Temperature (°C)	Year	13.9	12.0	−1.9	
	Winter	2.9	1.0	−1.9	−9 to +3
	Summer	23.1	23.3	0.02	−5 to +5
Precipitation	Year (mm / day)	2.98	3.45	0.47	
	Winter (mm / day)	1.26	2.37	1.11	
	(%)			88%	+20% to +200%
	Summer (mm / day)	5.34	4.35	−0.99	
	(%)			−19%	−30% to +60%

* Average is made from 65–74 years in the control run.

* * This column shows the difference ranges between observed averages and control run averages simulated by nine models for East Asia (IPCC, 1996).

For the regional annual average, the model underestimates temperature and overestimates rainfall amount in general (Table 1). Table 1 also shows the difference ranges between observed averages and control run averages simulated by nine coupled models for East Asia (IPCC, 1996).

Compared with the simulations of nine coupled models from IPCC (1996), the simulated biases of regional average from the GOALS model are almost the smallest except for the winter precipitation simulation. Compared with M2+20 simulation (Chen, 1996), the GOALS model has smaller biases except for the winter precipitation simulation. One thing should be pointed out that many CGCMs much overestimate the precipitation in China, especially there is a simulated false precipitation center over the middle–west part of China (Fig. 2.8, Gao, 2000). The geographic distribution of precipitation simulated by GOALS for East Asia is rather reasonable. The above description may increase a little confidence about the climate change simulation for East Asia with the GOALS model.

5. Climate change in East Asia

5. 1 *Climate changes averaged over East Asia*

Figures 4a and 4b show the temporal climate changes in East Asia. There are

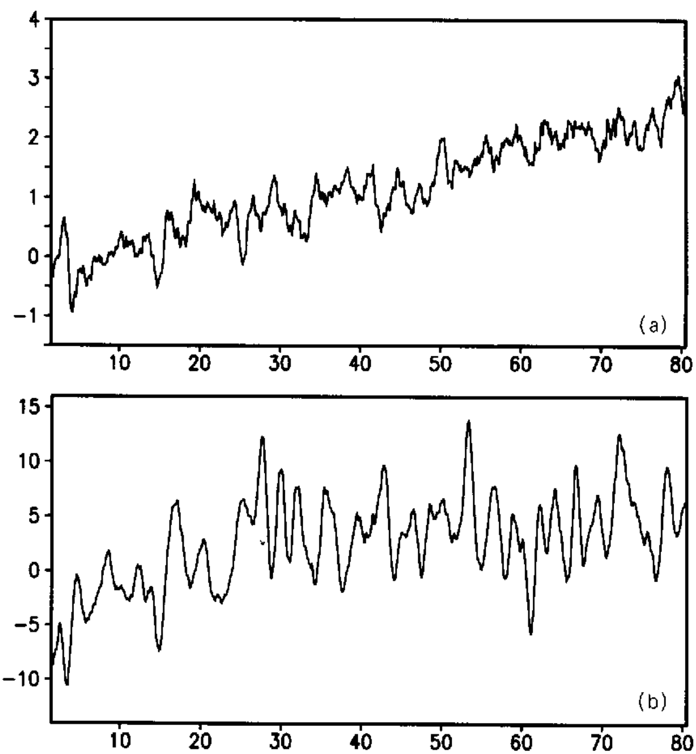

Fig. 4. Time evolution of regionally averaged change of surface air temperature (°C) (a) and precipitation rate (%) (b) in East Asia.

also increase trends for the regionally averaged surface air temperature and precipitation. The increase rates of surface air temperature and precipitation in East Asia are lager than that for the global average. And it has a more significant annual variability for temperature, compared to that of global average.

The annual and seasonal mean climate changes averaged over East Asia around the time of CO_2 doubling (65th–74th years) have been summarized in Table 2. Compared to the simulation of IAP CGCM M2+20 (Chen et al., 1996), M2+20 has a much stronger response to CO_2 increase. Around the time of CO_2 doubling, the temperature and precipitation increase 3.6°C and 9.8% respectively in the regional average for East Asia in M2+20 simulations, which are higher than 2.1°C and 5% simulated by GOALS model. In both models the maximum warming occurs in winter and the minimum warming occurs in summer. There are some obvious differences in the details of precipitation changes between the two models. In the M2+20 simulation, the reduced precipitation occurs in winter, while the maximum precipitation increase occurs in summer. In the GOALS model simulation, there are contrary precipitation changes: the maximum precipitation increase in winter and the reduced precipitation in summer. Examining the zonal mean variations of temperature and precipitation in East Asia (figure omitted), in the GOALS simulation, the maximum warming occurs at middle latitudes (30–45°N) and the maximum precipitation increase occurs around 25°N with the reduced precipitation at low latitudes. While in the M2+20 simulation, the warming increases obviously from low to high latitudes and precipitation has maximum increases around 10°N and 50°N and a reduction in 25–35°N (See Fig. 1, Chen et al., 1996). The above descriptions indicate that there is large uncertainty for the details of regional climate changes, even though the general trend of climate changes is the same. In this situation it is better to utilize results from a range of coupled models to assess the regional climate changes.

Table 2. Annual and seasonal mean climate changes averaged over East Asia

		Temperature (°C)	Precipitation (%)
GOALS	Year	2.1	5.0
	DJF	2.4	22.0
	MAM	2.3	3.3
	JJA	1.7	−2.1
	SON	1.9	5.5
IPCC1995 *	DJF	1.4 to 4.8	0 to 18
	JJA	0.6 to 3.5	0 to 16

* This line shows the difference ranges between averages at the time of CO_2 doubling of transient and control run simulated by nine models for East Asia (IPCC, 1996)

5. 2 *Geographic distribution of climate changes*

As for the geographic distribution of climate changes, people usually use the annual mean distributions of climatic variables around the time of CO_2 doubling. It may describe the basic features of geographic distributions for the temperature changes, since the global temperature change has a dominant warming trend. But for the precipitation changes it is more complicated. There may be different precipitation patterns for different periods. In this paper we use the empirical orthogonal function (EOF) to analyze 80–year climatic change.

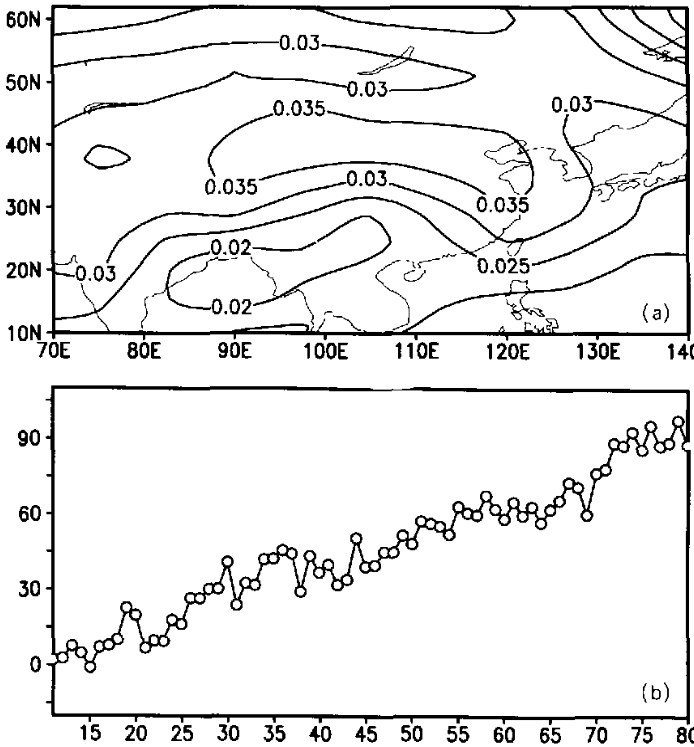

Fig. 5. (a) the first EOF mode of surface air temperature; (b) the time series for the first EOF mode of surface air temperature.

Figures 5, 6, 7 and 8 show the first and second EOF components with their time series for temperature and precipitation, respectively. The first EOF mode of temperature (Fig. 5) shows the maximum warming in 30–45°N and the minimum warming from the Bay of Bengal to Southwest China. The time series of the first EOF mode of temperature shows an intense increase during 80 years. The first mode can explain 72% of the total variance of temperature. It illustrates the basic feature of warming in East Asia: the temperature in the whole East Asia will increase gradually and the most obvious warming areas are located at North and Northwest China. The first EOF pattern of temperature is very similar to the geographic distribution of annual mean temperature of 65th–74th model years (figure omitted). The second EOF mode of temperature, which seems to show a quasi–40 year oscillation (Fig. 6b), only explains 3.4% of the total variance of temperature. It means that in some years the intense warming may occur in Northeast China, but in some years, e.g. the 25th and 73th model years, the cooling may occur in Northeast China in the background of global warming. The third and fourth EOF modes (figure omitted) exhibit the patterns with positive and negative centers, which leads warming details in East Asia to be more complicated.

For precipitation, the first EOF mode of precipitation can explain 13.5% of the total variance of precipitation, which shows an increase of precipitation in most of East Asia, with the

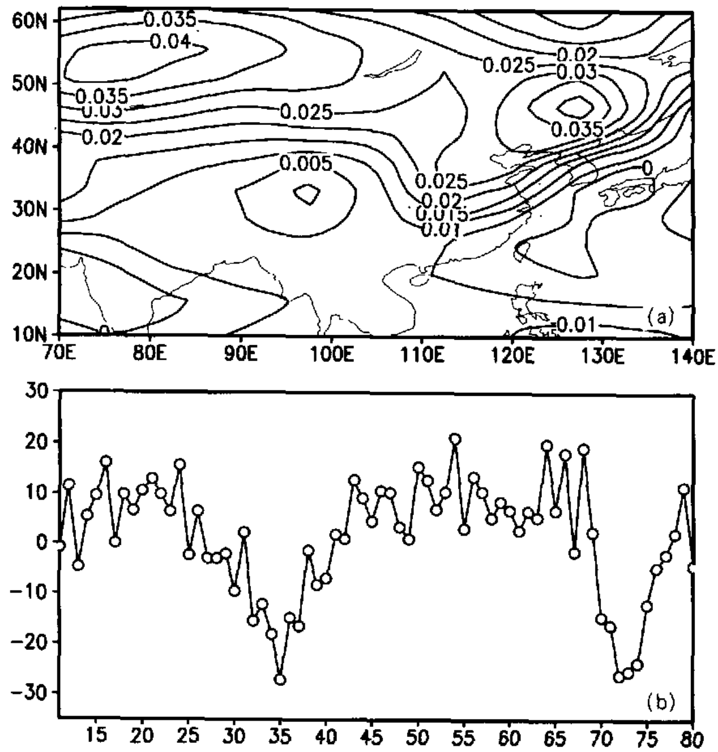

Fig. 6. (a) the second EOF mode of surface air temperature; (b) the time series for the second EOF mode of surface air temperature.

maximums at the Bay of Bengal, North India and Southwest China (Fig. 7a). There is a reduced precipitation in the South China Sea, the tropical West Pacific and the west of Baikal. The time series of the first mode (Fig. 7b) exhibits a weak increase trend with strong interannual variability and has positive values for almost every model year. It means that the basic feature of precipitation change is that precipitation increases gradually in most middle and high latitudes in East Asia, and exhibits strong interannual variations. The second EOF mode of precipitation can explain 4.7% of the total variance of precipitation. The intense precipitation increases occur in the tropical West Pacific and the west part of Southwest China with precipitation decreases in most of North and Northeast China (Fig. 8a). There is no trend variation in the time series of the second mode (Fig. 8b), but which shows a nearly 20–year period variation. The first ten EOF modes of precipitation rate can account for 42.3% of its whole variance, which indicates that the evolution of precipitation pattern is much more complicated than that of the surface air temperature. Figure 9 shows the precipitation change for annual mean and summer season mean at the time of CO_2 doubling (65th–74th model years). It can be seen that precipitation increases in the monsoon regions and reduces in ITCZ in both annual mean and summer. In the rainfall season of China, the maximum rainfall increase occurs in the Yangtze River and Huaihe River basins and

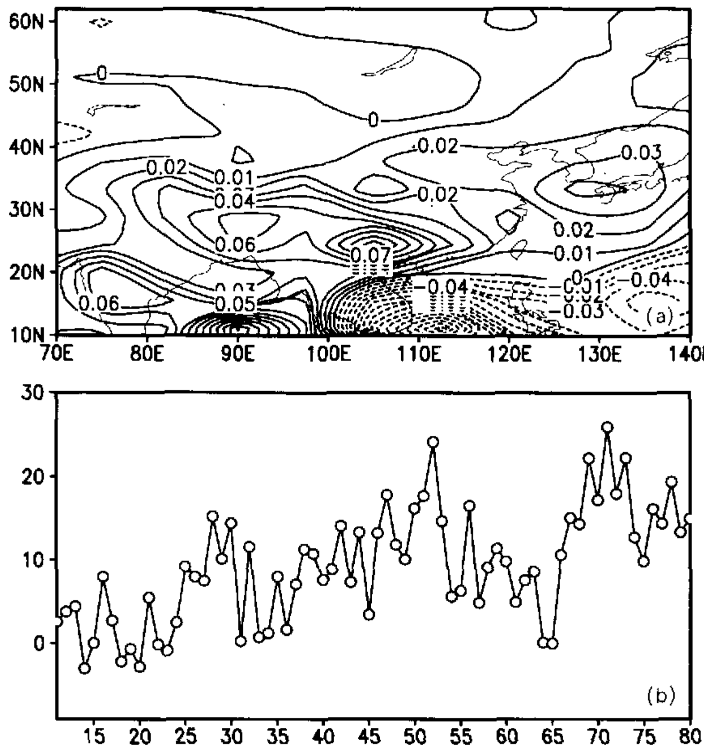

Fig. 7. (a) the first EOF mode of precipitation rate; (b) the time series for the first EOF mode of precipitation rate.

Northeast China, and reduced rainfall occurs in North China, which bear a resemblance to the precipitation changes happened during recent decades in China (Fig. 4.6, Ma, 1999). The above description suggests that the drought and high temperature occurred in North China may be partly attributed to the effect of global warming induced by CO_2 increase.

6. Summary

Two simulations, one for the control run and another for the perturbation run, with a global coupled ocean–atmosphere–land system model (IAP / LASG GOALS version 4) have been carried out to study the global warming effect with much detailed emphasis on East Asia. The results from GOALS model are compared with that from IAP CGCM M2+20. The results are described as follows.

1) There is no climate drift in the control run from GOALS model and around the time of CO_2 doubling (average over the 61th–80th model years), the global temperature increases about 1.65°C.

2) GOALS model is able to simulate the observed spatial distribution and annual cycles of temperature and precipitation in East Asia (70–140°E, 10–62°N) rather well. But in

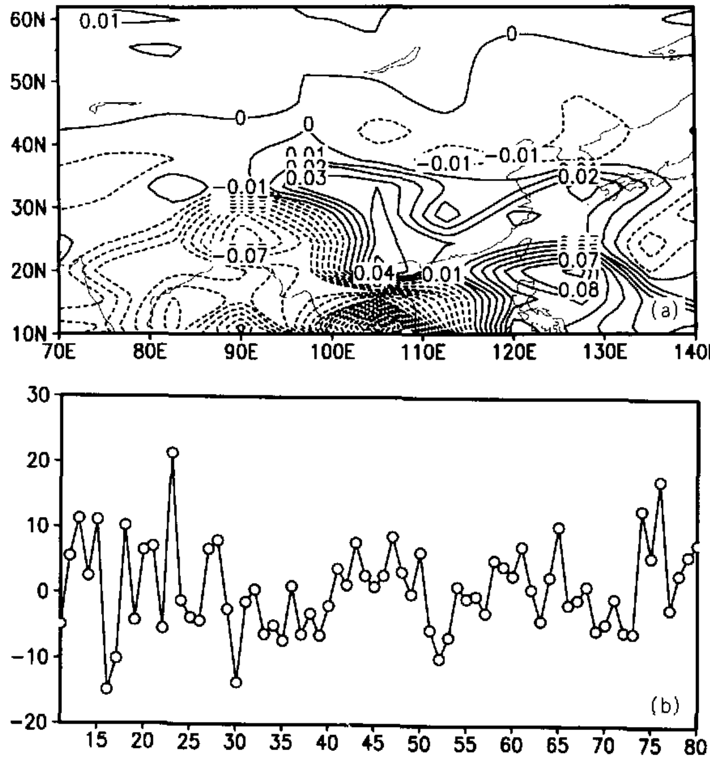

Fig. 8. (a) the second EOF mode of precipitation rate; (b) the time series for the second EOF mode of precipitation rate.

general, the model underestimates temperature and overestimates rainfall amount for the regional annual average.

3) Both GOALS and M2+20 projections show that both temperature and precipitation will increase in East Asia under the background of global warming. The two model projections also show the maximum warming in winter and the minimum warming in summer, however, the details of climate variations between the two models are different. At the time of CO_2 doubling (average over the 65th–74th model years), the temperature and precipitation in East Asia increase 2.1°C and 5% respectively in GOALS model, which is weaker than the response in M2+20. One reason of stronger response in the M2+20 simulation is owing to using a slab mixed layer ocean model in the Arctic Ocean in M2+20. These differences also suggest that there is large uncertainty for the details of regional climate changes by use of CGCM. In this situation it is better to utilize results from a range of coupled models to assess the regional climate changes.

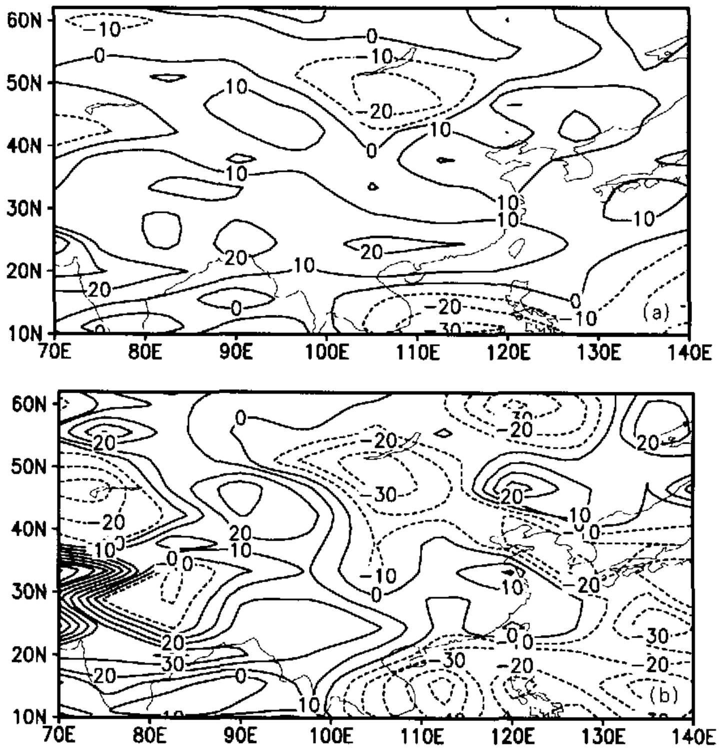

Fig. 9. The spatial distribution of precipitation change (%) for annual mean (a) and summer (b) at the time of CO_2 doubling.

4) The basic features of geographic distributions of climate change during 80 years are that the maximum warming is located in the middle–latitude continent with the minimum warming in the Bay of Bengal to Southwest China and the maximum precipitation increase occurs around 25°N with reduced precipitation in the tropical western Pacific. The evolution of precipitation pattern is much more complicated than that of the surface air temperature. Although it is very difficult to detect the anthropogenic climate change from the natural climate change, some analyses suggest that the drought and high temperature occurred in North China may be partly attributed to the effect of global warming induced by CO_2 increase.

In this paper the climate changes induced by an idealized increase of CO_2 in East Asia are simulated. Because of the model's shortcomings and the other uncertainties that may exist in the simulated regional changes caused by CO_2 increase, more efforts, including improvements of model system, more practical scenario of greenhouse and other methods of reducing uncertainties, need to be paid to upgrading the research standard.

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用 IAP/ LASG GOALS 模式模拟 CO_2 增加引起的东亚地区气候变化

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摘　要

用一个全球耦合的海洋—大气—陆地系统模式(IAP/LASG GOALS)研究因 CO_2 增加引起的全球增暖，重点是讨论东亚地区气候变化。完成了两个试验，一个是 CO_2 含量保持不变的对照试验，一个是 CO_2 浓度按每年 10%增加的扰动试验。结果表明，在对照试验中没有出现气候漂移，在 CO_2 含量加倍时全球平均地面气温将增加 1.65°C。GOALS 模式能较好模拟观测的东亚温度和降水的空间分体和年循环，但模拟的年平均温度略偏低、年降水稍偏大。在 CO_2 含量加倍时，东亚地区温度和降水将分别增加 2.1°C 和 5%，最大增温出现在中纬度大陆上，最大的降水增加出现在 25°N 附近。

关键词： 气候变化模拟，耦合气候模式，东亚