Simulation of Effects of Grassland Degradation on Regional Climate over Sanjiangyuan Region in Qinghai-Tibet Plateau*

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ABSTRACT

Regional climate model (RegCM3) was applied to explore the possible effects of land use changes (e.g., grassland degradation in this study) on local and regional climate over the Sanjiangyuan region in the Qinghai-Tibet Plateau. Two multiyear (1991–1999) numerical simulation experiments were conducted: one was a control experiment with current land use and the other was a desertification experiment with potential grassland degradation. Preliminary analysis indicated that RegCM3 is appropriate for simulating land-climate interactions, as the patterns of the simulated surface air temperature, the summer precipitation, and the geopotential height fields are consistent with the observed values. The desertification over the Sanjiangyuan region will cause different climate effects in different regions depending on the surrounding environment and climate characteristics. The area with obvious change in surface air temperature inducing by grassland degradation over the Sanjiangyuan region is located in the Qinghai-Tibet Plateau. A winter surface air temperature drop and the other seasons' surface air temperature increase will be observed over the Qinghai-Tibet Plateau based on two numerical simulation experiments. Surface air temperature changes in spring are the largest (0.46°C), and in winter are the smallest (smaller than 0.03°C), indicating an increasing mean annual surface air temperature over the Qinghai-Tibet Plateau. Surface air temperature changes will be smaller and more complex over the surrounding region, with minor winter changes for the regions just outside the plateau and notable summer changes over the north of the Yangtze River. The reinforced summer heat source in the plateau will lead to an intensification of heat low, causing the West Pacific subtropical high to retreat eastward. This will be followed by a decrease of precipitation in summer. The plateau's climate tends to become warm and dry due to the grassland degradation over the Sanjiangyuan region.

Key words: Sanjiangyuan region, grassland degradation, regional climate model (RegCM3), climate change, numerical simulation

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1. Introduction

Land use/land cover change (LUCC) and its impacts on climate changes have been recognized by the International Geosphere-Biosphere Programme (IGBP) as a key research item for better understanding of the climate variability. Over the last two and half decades, the scientific community has made notable efforts in understanding land use/land cover change as a part of the climate system (Mahmmod et al., 2006). Land use change influences the climate variability through changing surface albedo, land roughness, and soil hydrological and thermal features. Human-induced land use changes and the resulting alterations in the ground surface features are the major but poorly recognized drivers of the long-term global climate patterns (Pielke, 2005). Therefore, further research will be necessary for understanding of the effects of LUCC on climate changes.

Quantitative evaluation of the climate changes caused by the land use change is very difficult because long-term meteorological and land surface

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observational data are usually not available, and furthermore, the land-atmosphere interactions are highly nonlinear (Cui et al., 2006). A possible solution is to use the regional climate model (RCM) and global circulation model (GCM) in exploring the interactions between the land use change and the climate change (Suh and Lee, 2004).

Most of the previous investigations have primarily focused on the influences of LUCC of tropical deforestation on climate (e.g., Shukla et al., 1990; Nobre et al., 1991; Henderson-Sellers et al., 1993) and impacts of Saharan desertification on climate changes (e.g., Xue, 1997; Clark et al., 2001; Snyder and Foley, 2004; Cui et al., 2006). Fan et al. (1998) studied the effects of afforestation in Northeast China on the climate of East and South Asia with the help of GCM-SSiB model. Lu and Chen (1999) studied the influences of the vegetation cover changes on the regional climate in Northeast China with NCAR RegCM2. Zheng et al. (2002) and Gao et al. (2003) investigated the climate effects of land use change in China by a regional climate model (RegCM2). Chen et al. (2004) analyzed the relationship between the dynamic changes of the vegetation cover and climate factors in the farming-pastoral zone in North China. All these researches are helpful for good understanding of impacts of LUCC on regional climate changes. However, regional responses of climate to LUCC are highly variable from one location to another, and even the same land use change may cause different climate effects in different regions depending on the surrounding environment and climate characteristics (Gao et al., 2003). As for previous researches, it is difficult to reflect the interannual change and secular effects of climate induced by land use change for the short duration of the simulations with usually several months. The land-atmosphere system could not reach a new equilibrium state with short time integral under forced perturbation resulting from land use change. Therefore, detailed regional studies and simulation experiment with the longer integral time will be needed to assess specific responses of regional climate to the land use change in different parts of the world.

The Sanjiangyuan region (31°39′–36°12′N, 89°45′–102°23′E) is located in the Qinghai-Tibet Plateau, south of Qinghai Province. As the source of the Yangtze River, the Yellow River, and the Lancang River, the Sanjiangyuan region is the largest nature reserve in China, covering 31.8×10^4 km^2. The eco-environment in the Sanjiangyuan region is highly sensitive and vulnerable. In recent years, deterioration of the eco-environment, grassland degradation, and desertification in the Sanjiangyuan region are greatly serious because of irrational exploitation of the natural resources and rapid growth of the population. Pan and Liu (2005) indicated that the significant changes of land use had taken place in the past 15 years (Table 1) according to the remote sensing of land use in the source regions of the Yangtze River and the Yellow River from 1986 TM (Thematic Mapper) and 2000 ETM (Enhanced Thematic Mapper) data. The decreasing area occurred to the grassland, forest land, wetland, and water land, whereas increasing area included the unused land, cultivated land, and construction land.

This paper aims to investigate the impacts of grassland degradation on regional climate change in the Sanjiangyuan region. In this study, two multiyear numerical simulation experiments are set up by using a regional climate model (RegCM3) for two scenarios

Table 1. Changes of the individual land use categories in the source regions of the Yangtze River and the Yellow River during 1986–2000 (unit: km^2; Pan and Liu, 2005)

	The source region of the Yangtze River			The source region of the Yellow River		
	1986	2000	Changes	1986	2000	Changes
Construction land	2.2	4.84	2.64	26.14	28.37	2.23
Cultivated land	3.24	4.66	1.42	177.24	187.71	10.46
Grassland	78469.64	75818.14	−2651.5	43732.76	43465.73	−267.03
Forest land	23.67	10.84	−12.83	689.25	683.16	−6.09
Wetland	7220.36	4137.96	−3082.4	2473.28	2141.70	−331.58
Water land	6934.16	6606.01	−328.15	3452.85	3198.97	−253.88
Unused land	28766.64	34837.46	6070.82	14084.93	14988.36	2.84

with the current land use and the potential pattern, respectively.

Section 2 presents the model and simulation experiment design. In Section 3, we analyze the simulated results based on the control experiment to evaluate the performance of the RegCM3, and then use the RegCM3 to reproduce the regional climate in the study region. The effects of grassland degradation on regional climate in the Sanjiangyuan area are discussed in Section 4. Conclusions are summarized in Section 5.

2. Model description and experiment design

2.1 The regional climate model (RegCM3)

Regional climate model (RegCM), which was developed by NCAR/ICTP (the Nation Center for Atmospheric Research/the Abdus Salam International Centre for Theoretical Physics), has been developed rapidly since the 1980s. It is a primitive equation of σ vertical coordinate and grid-point-limited area model. The first generation of NCAR RegCMs was developed upon NCAR-PSU (Pennsylvania State University) Mesoscale Model version 4 (MM4) in the late 1980s (Dickinson et al., 1989; Giorgi, 1989). The first major upgrade of the physical and numerical schemes of the model was introduced by Giorgi et al. (1993a, b), and then the second generation of RegCMs was developed, which was referred to as RegCM2 hereafter. RegCM3 used in this study is the latest version of RegCMs developed by ICTP (Elguindi et al., 2006). The major improvements of RegCM3 are some physical schemes that have been modified, for example, radiative transfer package (the CCM2 has been replaced by that of the CCM3), cloud and precipitation processes, new parameterizations for ocean surface fluxes (Zeng et al., 1998), a cumulus convective scheme (Emanuel, 1991; Emanuel and Zivkovic-Rothman, 1999), and a mosaic-type parameterization of subgrid-scale heterogeneity in topography and land use (Giorgi et al., 2003; Elguindi et al., 2006). Because of its higher horizontal resolution and comprehensive physical parameterizations, RegCM was able to represent regional climate features exactly and thus had been applied to research of regional climate changes. Climate change experiments with RegCMs nested in

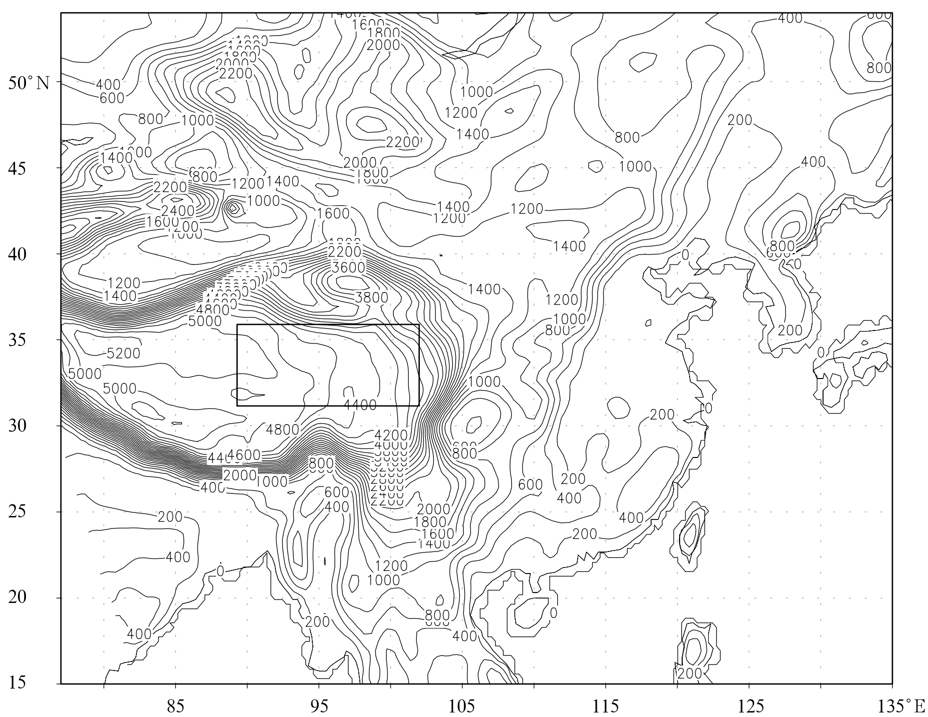

Fig. 1. The topography of simulated area and the location of Sanjiangyuan region (unit: m). Black real line is terrain contour, and the black rectangle represents the location of Sanjiangyuan region.

the coarser resolution general circulation models (GCMs) have become common particularly over the past half decade (Giorigi et al., 1998), and are now being used to form climate scenarios for models (Mearns et al., 1997, 2001, 2003; Brown et al., 2000; Easterling et al., 2003).

2.2 Experimental design and database

In order to research the impacts of grassland degradation on regional climate over the Sanjiangyuan region in the Qinghai-Tibet Plateau. Two numerical simulation experiments were performed with same horizontal resolution and parameters in the same domain covering the period from 1991 to 1999. One is the control experiment (marked as Exp. A) with current land cover, another is desertification experiment (marked as Exp. B) with potential grassland degradation.

The simulated domain, shown in Fig. 1, is centered at 35°N, 105°E with a horizontal grid-point spacing of 60 km, including 82 grid points in north-south direction, 92 in east-west direction, and 18 layers in the vertical section. The high spatial resolution of the model shows a clear representation of the topography which is not possible in GCM.

Lateral boundary treatment used is exponential relaxation with 6-h updates. Planetary boundary layer scheme has been developed by Holtslag and Boville (1993) and convective precipitation is computed by using Grell scheme (1993). Land surface processes are computed using the Biosphere-Atmosphere Transfer Scheme version 1e (BATS1e) which was described in detail by Dickinson et al. (1993). BATS is a surface package designed to describe the role of vegetation and interactive soil moisture in modifying the surface-atmosphere exchanges of momentum, energy, and water vapor. The model has the capability to deal with 20 vegetation types, 12 classes of soil textures from coarse (sand) to fine (clay), and 8 kinds of different soil colors from light to dark for the soil albedo assessment.

The land use/vegetation cover data used in the current research are obtained from the Global Land Cover Characterization (GLCC) derived from 1-km Advanced Very High Resolution Radiometer (AVHRR) data. The elevation data used here are collected from the United States Geological Survey (USGS). Both the land use and elevation data files are available at 10-min interval. Sea surface temperature data used in simulation are the Optimum Interpolation Sea Surface Temperature (OISST) 10 availables from the National Ocean and Atmosphere Administration (NOAA) on weekly time scale. The National Centers for Environmental Protection (NCEP) reanalysis dataset with a 2.5° horizontal resolution was accepted as the initial and boundary condition.

The two simulation experiments are from 17 February 1991 to 28 February 1999. To eliminate the spin-up effects of the model, the simulation results are analyzed during 1 March 1991 and 28 February 1999.

All parameters in Exp. B are the same as those in Exp. A except that the short grass of land cover/vegetation classes over the Sanjiangyuan region is replaced by semi-desert (Fig. 2).

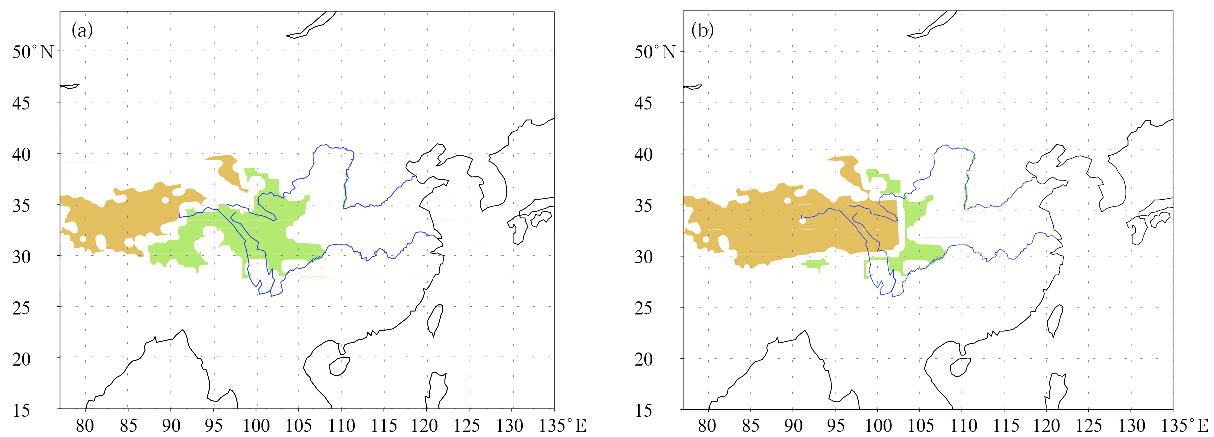

Fig. 2. Distribution of short grass and semi-desert over the Sanjiangyuan region in Experiment A (a) and Experiment B (b). Green shadow area is short grass; yellow shadow area is semi-desert.

3. Analysis of the control experiment

The performance of RegCM3 in modeling the regional climate is highly variable from place to place, and thus it is necessary to investigate whether the RegCM3 performs well in modeling present-day regional climate over China before exploring the impacts of the land use change on regional climate in the Sanjiangyuan region with the help of RegCM3.

Comparison was conducted between the observed data and the simulated results to evaluate the RegCM3 performances in climate modeling in China. We applied the monthly mean surface temperature and precipitation data produced by the Climate

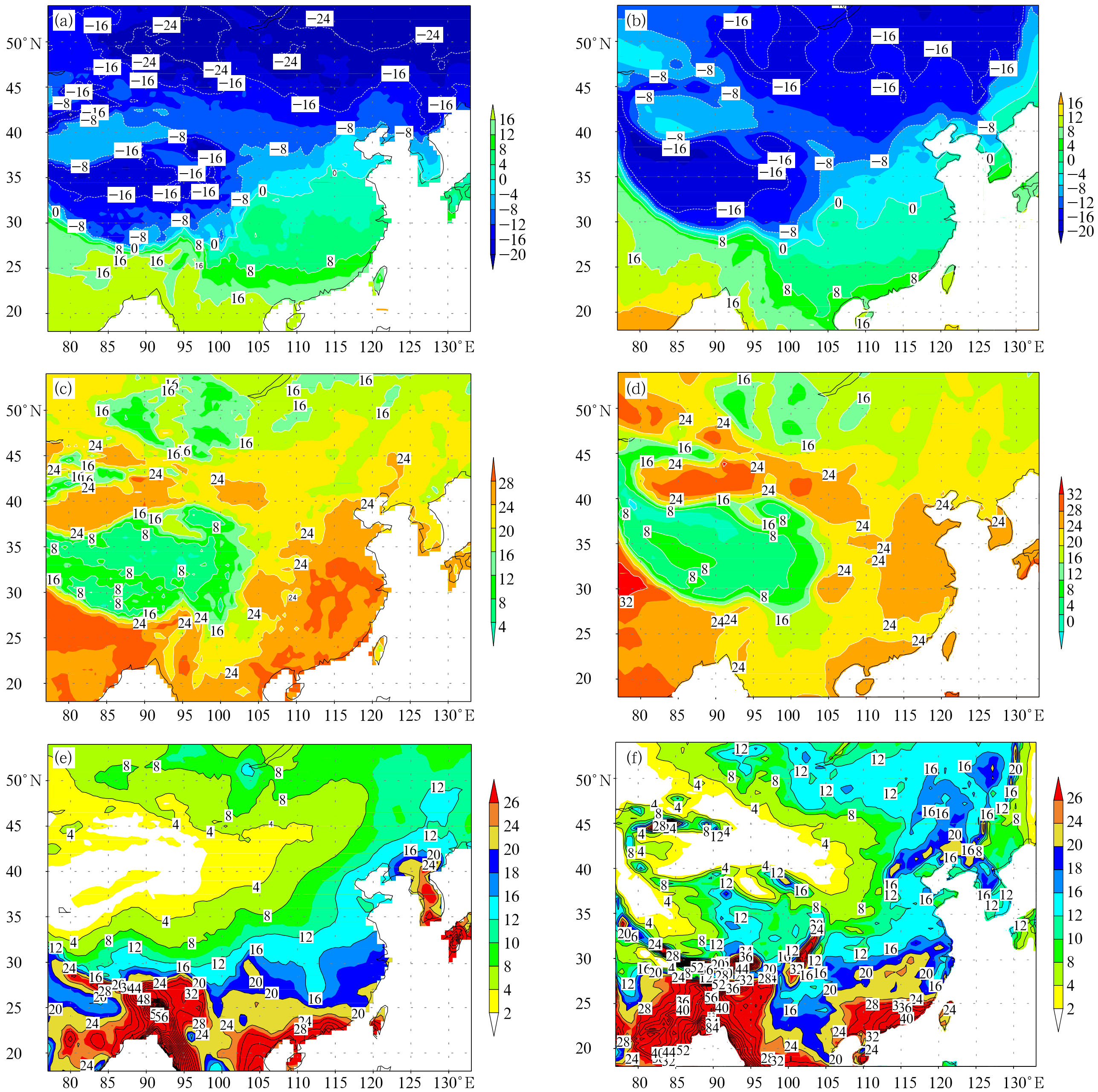

Fig. 3. Observations compared to results from the control experiments. (a) and (b) are observation of monthly mean temperature and simulated value of Exp. A in January, respectively; (c) and (d) are observation of monthly mean temperature and simulated value of Exp. A in July, respectively; (e) and (f) are observation of daily mean precipitation and simulated value of Exp. A in summer (JJA), respectively.

Research Unit (CRU) of the University of East Anglia to validate the model for temperature and precipitation modeling. CRU provides a climate dataset of global land surface monthly mean values (temperature, precipitation, etc.) available at 0.5° resolution for the period of 1901–2001, and is often used in the regional climate study as observations because of its high resolution (Gong and Wang, 2002; Chen and Shi, 2002; Cholaw, 2003; Fu et al., 2004; Wang and Xiong, 2004).

The observed monthly mean temperature (unit:°C) and summer precipitation (unit: mm day^{-1}) from CRU are compared with simulated data in Exp. A during 1991–1999 in Fig. 3. Figure 3 shows that the patterns of the simulated surface air temperature are consistent with those of the observed surface air temperature. The centers of high and low temperature and seasonal variation of temperature are well reproduced in the modeling results. The Qinghai-Tibet Plateau is clearly identified by the lower temperature compared to that of the surrounding regions of the same latitudes in summer and winter. The distributions of the surface air temperature vary with the season in East China due to the influence of the latitude and land-sea surface, and the surface air temperature gradient in winter is obvious in East China. In summer, the north-south difference of the surface air temperature is smaller and the isothermal is approximately parallel with coastline since the influence of the distance from ocean. Figure 3 also shows a little bias between the observation and the simulated temperature. The simulated temperature is higher than observed values in the regions both north and south of Tianshan Mountains, while lower than that in East China.

As shown in Figs. 3e and 3f, the rain belts in summer are fitted with the observed field except that simulated precipitation is higher than the observed value, especially in Northeast China. Some unreal great precipitation areas appear in Tianshan area and the eastern edge of Qinghai-Tibet Plateau. This deficiency may be mainly contributed to the complex topography.

For the convenience of data analysis, the observational data was interpolated to model grid of control experiment. The correlation coefficients between simulated and observational 8-yr monthly mean surface air temperature and precipitation during 1991–1999 were calculated to quantitatively evaluate RegCM3 performance for the spatial pattern of meteorological elements. Root-mean-square error and normal-mean-square error were calculated for investigating the bias between the model output and observational data. The results indicate that the simulated and the observed 8-yr mean monthly surface temperature are highly spatially correlated with correlation coefficient of >0.9, except July and August with 0.82 and 0.79, respectively. The normal-mean-square error ranges from 0.06 (in January) to 2.5 (in March). The correlation coefficient varies from 0.77 (in June) to 0.03 (in November) for multi-year monthly precipitation, and above 0.8 for multi-year summer mean daily precipitation which exceeded 99% confidence level. The normal-mean-square error ranges from 0.6 (in June) to 8.8 (in September) for multi-year monthly total precipitation, and 1.3 for multi-year summer precipitation. The above-mentioned analysis shows that the RegCM3 performs well in simulating monthly mean temperature all the year round and multi-year seasonal precipitation in summer. However, the RegCM3 model does not work well in simulating precipitation in winter and autumn.

4. Analysis of the effects of the grassland degradation on regional climate in China

4.1 Effects on temperature

Land use change influences the climate by altering surface albedo, land roughness, soil hydrological, and thermal features, which results in further changes of the surface solar, longwave radiation fluxes, fluxes of momentum, sensible heat, and latent heat. Basing on the model outputs of control experiment (Exp. A) and desertification experiment (Exp. B), we calculated the differences of monthly mean surface air temperature and ground temperature between Exp. B and Exp. A (Fig. 4).

Figure 4 reveals that the grassland degradation

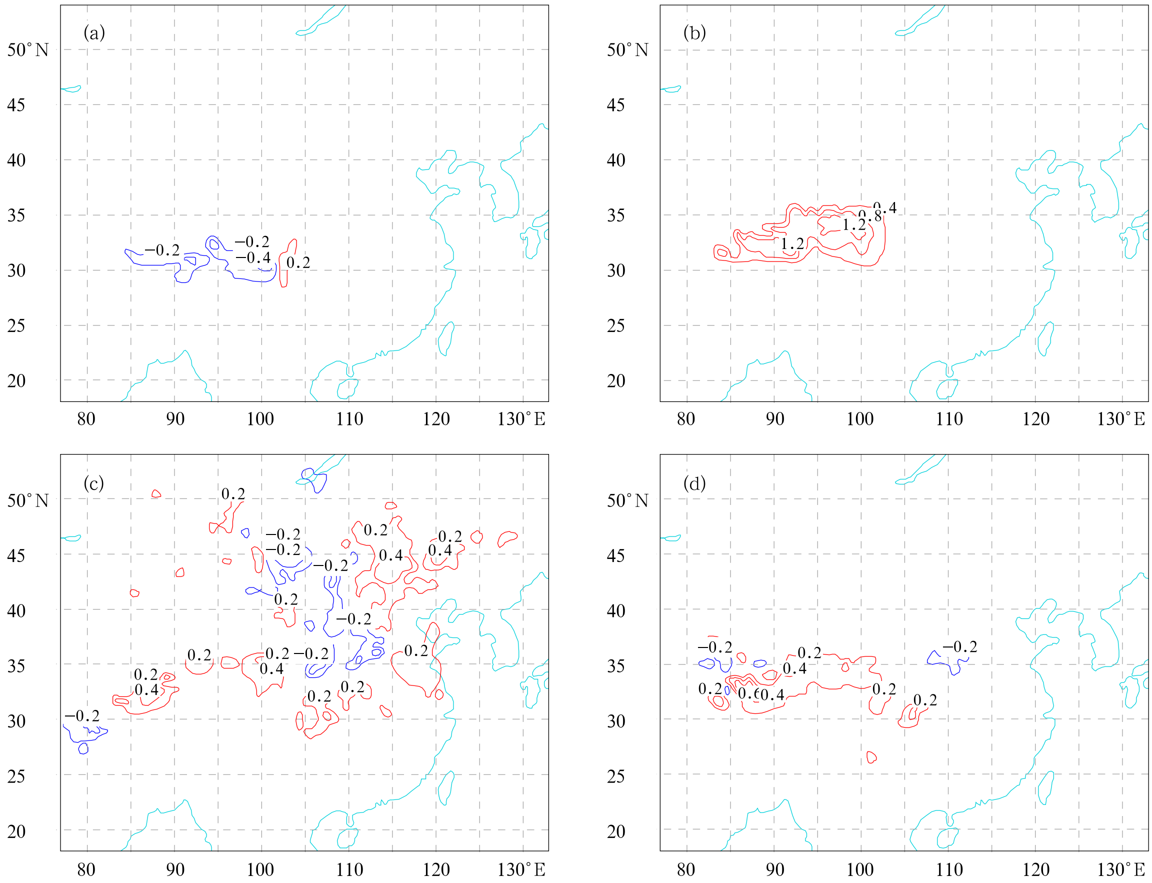

Fig. 4. Distribution of monthly mean surface air temperature difference between Exp. B and Exp. A for 8 yr (1991–1999; unit: °C). (a) January, (b) April, (c) July, and (d) October.

over the Sanjiangyuan region causes different climate effects in different areas and seasons. In winter, the grassland degradation in the Sanjiangyuan region will result in a decrease of surface air temperature (0.2–0.4°C) over the Tibetan Plateau (Fig. 4a), while no significant changes were found in East China. In summer, the spatial patterns of difference of the monthly mean surface air temperature between Exp. B and Exp. A are more complicated and extended in winter (Fig. 4c). The spatial modes of "positive-negative-positive" of the surface air temperature can be easily identified, which indicates that the temperature increases 0.2–0.4°C in the Qinghai-Tibet area, decreases between 0.2 and 0.4°C in central region, and increases from 0.2 to 0.4°C in eastern regions, especially in the east and central parts of Inner Mongolia Autonomous Region. Multi-year summer surface air temperature will decrease about 0.2°C in the downstream of Indus and Ganges Rivers of southwest of Tibetan Plateau. In spring and autumn, the increase of surface air temperature is found over the southern Qinghai-Tibet area (Figs. 4b, 4d). The change of surface air temperature in spring is the most distinct with values 0.6–1.2°C. The range of values and region of the temperature change in autumn is smaller than that in spring.

Figure 5 shows the annual cycle of area average (30°–36°N, 80°–102°E) of multi-year mean temperature difference between Exp. B and Exp. A, and demonstrates that for the Qinghai-Tibet Plateau region, the impacts of the grassland degradation on multi-year average temperature over the Sanjiangyuan region are characterized by decreasing temperature in winter (December, January, and February) and increasing temperature in spring (March, April, and May), summer (June, July, and August), and autumn (September, October, and November). Maximum

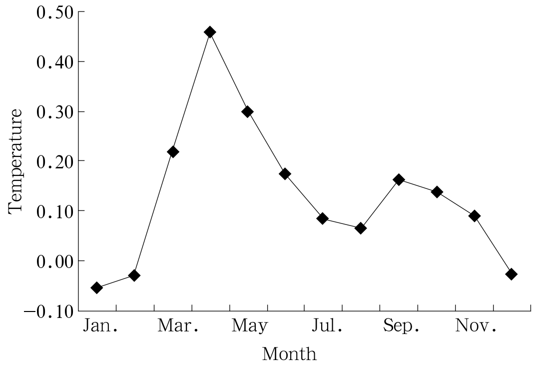

Fig. 5. The annual cycle of area average of multi-year mean temperature difference between Exp. B and Exp. A (unit:°C).

temperature change 0.45°C appears in spring, while minimum change 0.03°C is recorded in winter, which indicates the increase in annual mean temperature.

As for the ground temperature, the changes due to grassland degradation are more obvious than those of the surface air temperature. Furthermore, the variability features of the multi-year mean monthly ground temperature are consistent with those of the surface air temperature: namely, decreases in winter (December, January, and February) and increases in other three seasons over the most parts of the study region. The decrease in ground temperature is found over the Qinghai-Tibet Plateau in winter with the values around 0.6°C. The spatial modes of "positive-negative-positive" of the ground temperature can also be easily identified in summer, which indicates that the temperature increases 0.2–1.6°C in the Qinghai-Tibet area, decreases between 0.2°C and 0.4°C in the central region, and increases from 0.2°C to 0.8°C in the east and central parts of Inner Mongolia Autonomous Region. It is concluded that the ground temperature change is the direct cause of the surface air temperature change.

To summarize the results above, the influences of grassland degradation over Sanjiangyuan region on temperature are a decrease of winter temperature and an increase of summer temperature in the Qinghai-Tibet Plateau, which indicates the increase of the annual range of temperature and the annual mean temperature. The temperature change is also found over the north of the Yangtze River. The results above reveal further evidence which climate elements change resulting from land use change have a spatial incongruity tendency for different geographical environment (Gao et al., 2003).

4.2 Effects on precipitation

Land use change can influence the precipitation by modifying both energy balance and water balance. The impacts of grassland degradation on precipitation are very complex because of complicated interactions between land surface and atmosphere, such as interactions between land surface albedo and soil moisture, soil moisture and temperature, land surface albedo and temperature, and so on. Generally, grassland degradation will increase surface albedo, reduce roughness, and weaken regulation function of vegetation cover for water cycle, which further increases sensitive heat flux, and reduces evaporation and precipitation. Previous researches showed that there are two processes in the opposite direction (Li et al., 2000): on the one hand, the increase of land surface albedo caused by grassland degradation can induce a downward current of the air; on the other hand, the decrease of soil moisture caused by grassland degradation can result in an upward current of air, which of both the processes plays a major role depending on the study region.

As for the impacts of grassland degradation on precipitation, only summer precipitation is conducted in the current research, because precipitation occurs mainly in summer and hydrological processes need several months to reach a new balance after land use change.

Figure 6 shows the differences of daily mean precipitation between Exp. B and Exp. A in summer (June, July, and August) from 1991 to 1998 and demonstrates that summer precipitation decreases in most parts of the study region. The summer precipitation changes occur mainly in the Qinghai-Tibet Plateau and south of it, as well as westerly downstream region over the eastern plateau. The most obvious change in summer precipitation can be found in northeastern China with value 2.5 mm day^{-1}. In addition, it is noted that an increase of summer precipitation occurs in the midstream of the Ganges River Basin

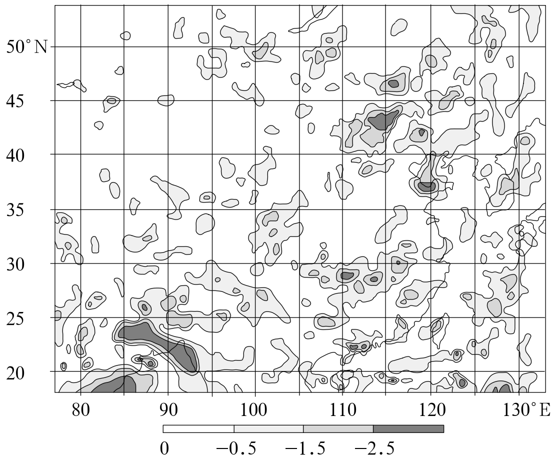

Fig. 6. Differences of daily mean precipitation between Exp. B and Exp. A in summer (JJA) from 1991 to 1998 (unit: mm day^{-1}).

in the southwestern edge of the Qinghai-Tibet Plateau.

The results mentioned above designate that regional climate in China will become towards warming and drying due to the grassland degradation in the Sanjiangyuan region, which is consistent with results induced by Zhao and Zeng (2002). This research denotes that vegetation degradation can result in increase in the surface albedo and decrease in surface roughness, which will further lead to decreasing precipitation and increasing temperature.

4.3 Effects on circulation

Grassland degradation in the Sanjiangyuan region influences not only on the surface air temperature and precipitation in the Qinghai-Tibet Plateau, but also on water vapor and energy carried by the air circulation in the surroundings, particularly in the westerly downstream regions. In order to estimate the influences of grassland degradation on the atmospheric circulation, 500- and 850-hPa geopotential height fields were simulated and compared with the differences between the desertification experiment and the control experiment.

Figure 7 presents the comparison of the simulated 850- and 500-hPa geopotential heights from the desertification experiment and the control experiment, and the results demonstrate that the influences of grassland degradation on geopotential height field appear evident seasonal variability in the study domain. There is no distinct change in geopotential height fields in winter (January), whereas the most remarkable changes of geopotential height field identified in summer. It may evince that the warm and wet air is easily influenced by the vegetation cover (Zheng et al., 2002).

In respect of the differences of 850-hPa geopotential height field between the desertification experiment and the control experiment, the range of influence caused by the grassland degradation is smaller in spring and autumn than that in summer (Figs. 7a and 7c). The changes of geopotential height take place mainly in the Qinghai-Tibet-Sichuan region, and are characterized by weakening in spring and intensification in autumn. At the same time, 850-hPa geopotential height field has no significant change in other region. The season with significant change is in summer. Figure 7b shows that the negative difference of geopotential height between Exp. B and Exp. A mainly occurs in the Sanjiangyuan region and its downstream regions in summer, whereas a reinforced geopotential height field is displayed in the south of the experiment region. According to the two experiments above, we see that the range of surface thermal depression in the Qinghai-Tibet Plateau expands northeastwards, while the ridge of Pacific subtropical high shrinks eastwards in summer. Circulation change corresponding to geopotential height fields mainly displays at the 850-hPa level, showing the easterly component of summer monsoon with a little weakening.

Figure 7d shows the distribution of difference between Exp. B and Exp. A in August for 500-hPa monthly mean geopotential height during the corresponding period, and indicates that the change of the 500-hPa geopotential height field is consistent with that of 850 hPa, namely, geopotential height between South Asian high and western Pacific subtropical high decreases due to the grassland degradation in the Sanjiangyuan region. According to the former analysis, it is deduced that eastern edge of South Asian high shrinks westwards and the ridge of western Pacific subtropical high moves back eastwards. It is notable that reasons of positive difference of geopotential height between Exp. B and Exp. A in southwest of Qinghai-Tibet Plateau still lack of a convincing explanation.

The grassland degradation in the Sanjiangyuan

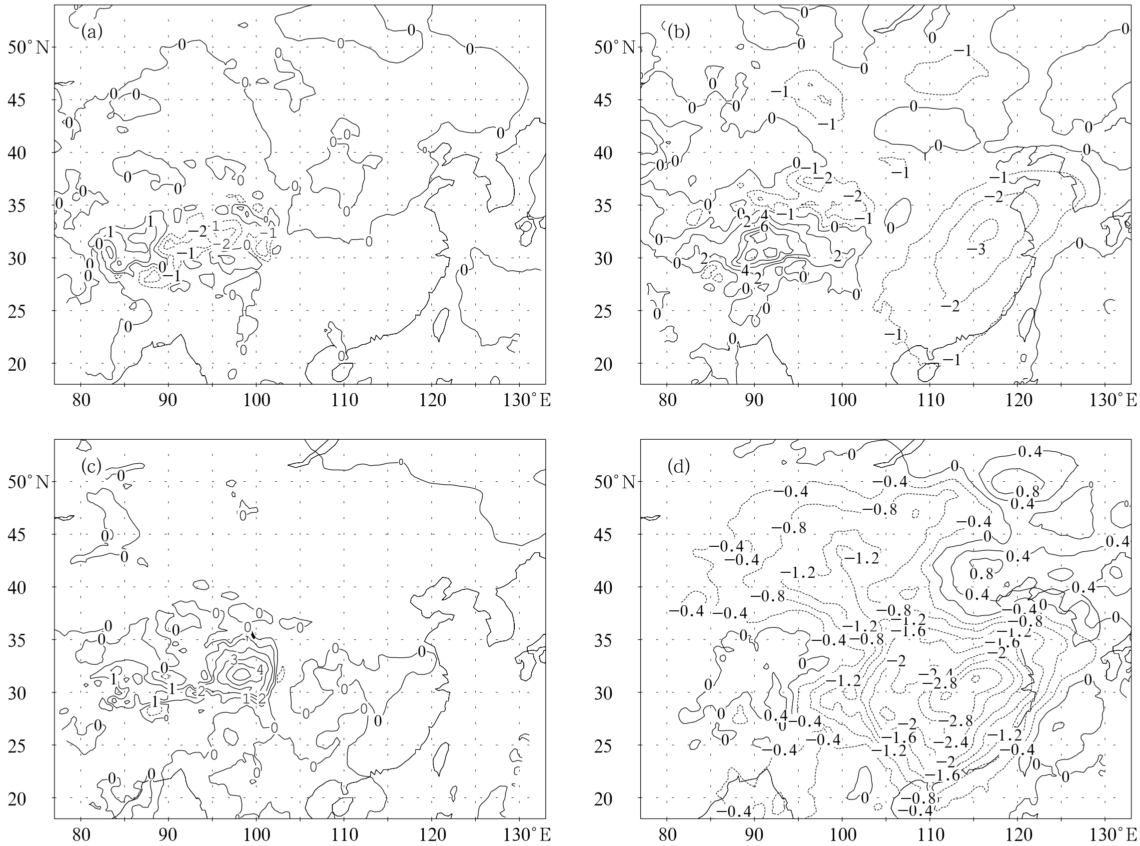

Fig. 7. Changes of 850- and 500-hPa geopotential height fields (unit: gpm). Difference between Exp. B and Exp. A in April (a), August (b), and October (c) for 850-hPa and in August (d) for 500-hPa monthly mean geopotential height from 1991 to 1998, respectively.

region plays an important role in regional climate change in the Qinghai-Tibet Plateau and in the surroundings. Especially in summer, this influence is more extensive and complicated. It is clear that the grassland degradation will impact on the air temperature and summer precipitation as well as local circulation. The temperature in the Qinghai-Tibet Plateau will decrease in winter and increase in summer due to the grassland degradation in the Sanjiangyuan region. This reinforcement of the heat source in summer over the Qinghai-Tibet Plateau will produce that the thermal depression in Qinghai-Tibet Plateau strengthens and the western Pacific subtropical high shrinks eastwards at the same time, implying a decline of precipitation in summer, especially in the northeast China.

5. Conclusions

The ICTP RegCM3 was used to investigate the impacts of the grassland degradation on the regional climate in the Sanjiangyuan region in the Qinghai-Tibet Plateau. Some interesting conclusions can be summarized as follows:

(1) RegCM3 works well in simulating the basic features of the climate in the study region. The simulated surface air temperature, summer precipitation, and 500-hPa geopotential height from the control experiment are consistent with the observations in the spatial pattern and annual cycle.

(2) The biased results can be found in the simulation experiment. In the Qinghai-Tibet region, negative biases of the surface air temperature can be seen in winter, whereas positive biases can be found in summer. There are positive biases of the surface air temperature in other study regions. The errors of simulating the precipitation in winter, spring, and autumn, and overestimating the precipitation in summer are

obvious in the study region. The simulated 500-hPa geopotential height field is weaker than the observed values of 500 hPa.

(3) The grassland degradation in the Sanjiangyuan region can significantly affect the surface air temperature and summer precipitation in China. The notable climate changes take place in the Qinghai-Tibet Plateau and its downstream regions. In the Qinghai-Tibet Plateau, the warming (range from $-0.03°C$ to $0.45°C$ for multi-year monthly mean, $0.134°C$ for multi-year annual mean) and drying induced by the grassland degradation over the Sanjiangyuan region can be identified. This trend towards warming has been observed (Li et al., 2006; Zhang et al., 2004), corresponding to a concurrent human-induce land use change towards urban and desert areas (Cui et al., 2006). Therefore, we can tentatively conclude that at least some of the observed temperature increases and precipitation decreases are due to the land use changes (Cui et al., 2006).

(4) The grassland degradation in the Sanjiangyuan region results in the weakening of the East Asian summer monsoon in China, which will be responsible for the decreasing of the summer precipitation.

The influences of the grassland degradation on regional climate changes are very complex because of the diversiform interactions between the land surface and the atmosphere, which are different from place to place and are due to different scales of study region, and different seasons as well. Although some valuable conclusions have been drawn in the current research, which will be greatly important for further understanding of and better insight into the possible role of the land use changes in the current global warming, detail and further researches in the near future are still necessary because different scales of the land use change will have different effects on regional climate changes. Furthermore, the results may be sensitive to the parameterization schemes of various physical processes, and the proper validation and modification of parameterization schemes based on observed records in the study domain are also needed.

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