# COMPARATIVE STUDY ON THE LAND-COVER CHANGE AND GLOBAL WARMING IMPACTS ON REGIONAL CLIMATE IN NORTHEAST ASIA

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## 1. INTRODUCTION

Mongolia is situated in an arid/semi-arid zone in Northeast Asia. The southern part of the territory has a desert type climate. The thermal effect of the Tibetan Plateau is the principle reason for the desert climate, remotely suppressing convective systems in the arid region (Sato and Kimura, 2005a). On the other hand, Taiga forest covers the northern part of Mongolia, extending to Siberia in Russia. More than half of the annual precipitation is observed during the summer season in Mongolia (Batima and Dagvadorj, 2000). The territory has a prominent meridional contrast in its rainfall amount as well as in its surface conditions that changes drastically from desert to grassland and to forest over a range of only several hundreds of kilometers from south to north. In general, such transition zones are very vulnerable to the climate change; as are the economic activities in this region.

Annual precipitation in Northeast Asian arid region is only several ten millimeter to few hundred millimeter per year. Most part of the annual precipitation, which has the large interannual variation, falls in the warm season. Thus, this study mainly focuses on the June-July-August period. Yatagai and Yasunari (1994) showed a significant increasing trend in wintertime air temperature from 1951 through 1990. On the other hand, the summertime temperature change does not show increase/decrease trend in the same period. Precipitation trend during 1960-1998 shows that both increasing and decreasing trends coexist in Mongolia (Endo et al., 2006). Figure 1 shows interannual variation of daily mean, daily maximum, and daily minimum temperature in July at eight stations in Mongolia. As shown by Yatagai and Yasunari (1994), longer-term trend is very small in summer before around 1990. However, after 1990, significant increase in daily minimum temperature is observed even in summer. In Mongolia, after the change of political system, the number of livestock had increased (Sugita et al., 2006), which may accelerate the land surface degradation. As examined by Eastman et al. (2001), intense grazing may have the potential to alter the local climate. In order to know how regional temperature and precipitation can be affected by the two factors, global warming and land cover change, sensitivity experiments were carried out using the regional climate model (RCM).

## 2. METHOD

### 2.1 *Model description*

The Terrestrial Environmental Research Center - Regional Atmospheric Modeling System (TERC-RAMS; Sato and Kimura, 2005b) is used. Two-level two-way nesting is adopted in the model. The coarser grid system is centered at 105$^{o}$E, 40$^{o}$N with 80 x 60 grids of 150 km grid interval. And nested fine grid system with 102 x 57 of 30 km grid interval is centered at 104$^{o}$E, 47$^{o}$N covering Mongolian territory. The cumulus parameterization and bulk type microphysics parameterization is adopted to calculate the precipitation.

### 2.2 *Numerical experiments*

This study performed four numerical experiments, in which two experiments aim at global warming simulation and other two experiments for studying the land cover impact, as listed in Table 1. Each experiment integrates for ten years of June-July-August.

The GW-CTL experiment represents a hindcast simulation for current climate during 1993 and 2003 using six-hourly NCEP/NCAR reanalysis data for the nudging method. The GW-WM experiment is basically same with the GW-CTL experiment except

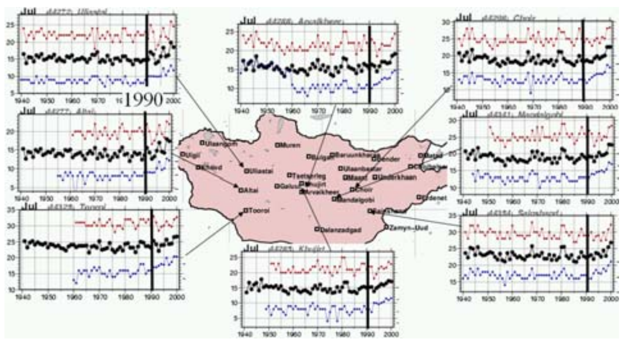


Figure 1: Interannual variation of daily mean, daily minimum, and daily maximum temperature in July over Mongolia.

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Table 1: List of numerical experiments.

| Run | forcing | vegetaion |
|---|---|---|
| GW-CTL | 6-hrly NCEP/NCAR (whole coarse domain) | USGS |
| GW-WM | 6-hrly NCEP/NCAR with monthly mean GCM difference (Sato et al., 2006) (whole coarse domain) | USGS |
| LC-CTL | 6-hrly NCEP/NCAR (boundary) | USGS |
| LC-DS | 6-hrly NCEP/NCAR (boundary) | desertification |

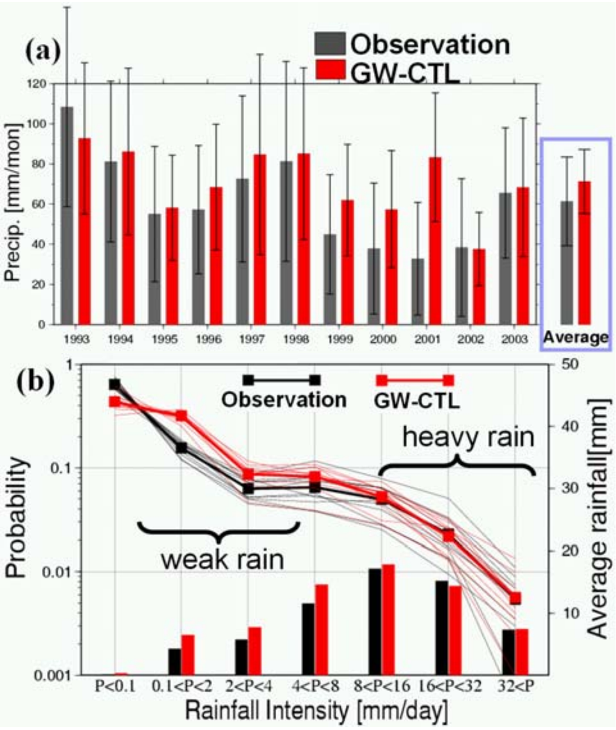


Figure 2: (a) Interannual variation of averaged precipitation in July. Error bars indicate the standard deviations precipitation between observed stations. (b) Probability density distribution of daily rainfall intensity in July.

for the forcing meteorological data. The monthly mean difference of meteorological variables before and after the global warming was computed by the output of MRICGCM2 (Yukimoto et al., 2001) simulation based on A2 scenario run. The spatial patterns of the differences in meteorological variables are added on the six-hourly NCEP/NCAR reanalysis data. The new forcing dataset as this process were used as the forcing data in GW-WM experiment. The difference between GW-CTL and GW-WM gives the impact of global-warming-induced large-scale climate change on the regional climate system. The detail description and the validity of this method appear in Sato et al. (2006).

In order to study the influence of land cover change on the regional climate system in Northeast Asia, two experiments were carried out changing the land surface vegetation in regional climate model.

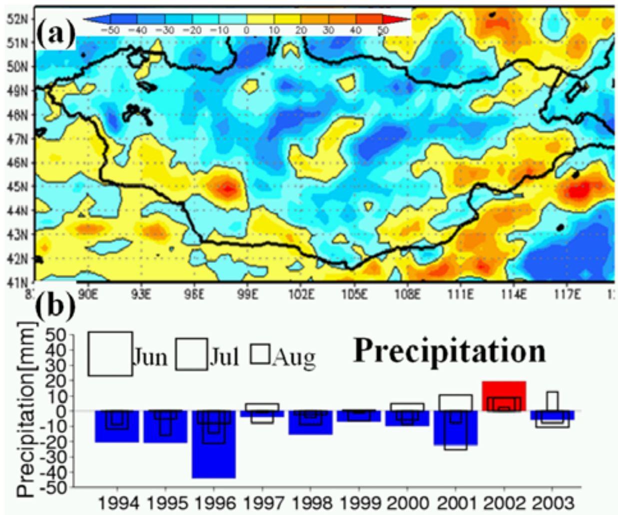


Figure 3: Change of JJA precipitation induced by the global warming (GW-WM minus GW-CTL: mm). (a) Eleven-year average distribution. (b) Year-to-year comparison.

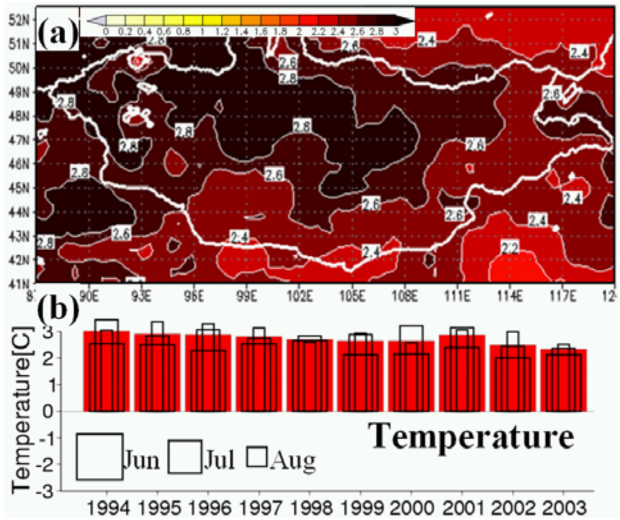


Figure 4: As in Fig. 3 except for temperature ($^oC$)

The LC-CTL experiment used USGS land cover characterization data to determine the surface vegetation in the model, while, in the LC-DS experiment, vegetation map was modified to assume the desertification condition. The grassland in Mongolia was replaced by semi-desert type, and semi-desert type was replaced by desert type classification. The NCEP/NCAR reanalysis data was also used for the nudging; but, it was given only for the lateral boundaries. The difference between LC-CTL and LC-DS conducts the impact of land cover change on the regional climate system.

## 3. RESULT

### 3.1 *Global warming*

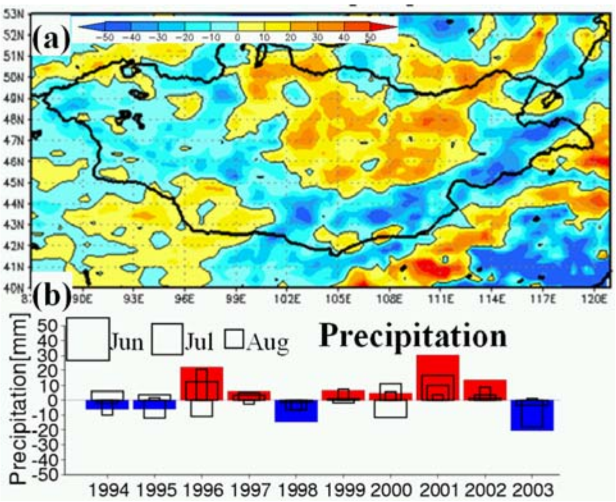


Figure 5: As in Fig. 3 except that induced by land cover change.

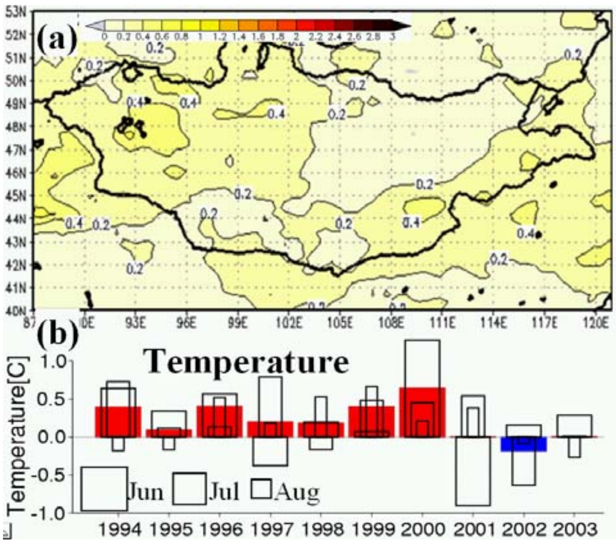


Figure 6: As in Fig. 5 except for temperature ($^{o}$C).

First of all, GW-CTL experiment will be explained in order to show the performance of the model. Figure 2a illustrates the 11-year mean precipitation for July by GW-CTL run. The regional climate model well simulates the interannual variation of the summertime precipitation in Mongolia although overestimation can be found in relatively dry years during 1999-2001. Figure 2b shows the probability density distribution of daily rainfall intensity. Frequency of heavy rainfall (16 mm < P) and middle rainfall (4 mm < P < 16 mm) is considerably good in GW-CTL. Therefore, RCM can precisely simulate the rainfall intensity as well as the total amount. However, probability of weak rainfall (P < 4 mm) by RCM is considerably higher than that observed. The fact points out the difficulty simulating and observing very light precipitation over the arid region.

Figure 3a shows the change of precipitation in June-July-August after the global warming as simulated by the regional climate model using the output from A2 scenario run of MRICGCM2 (GW-WM minus GW-CTL). Decrease of precipitation is prominent over northern and western mountainous region in Mongolia. Over northwestern Mongolia, precipitation decreases up to 30 mm during JJA. On the other hand, slight increase can be found in southern region around Gobi. Very complex horizontal structure of rainfall variation, in which increasing and decreasing features coexist in Mongolia, is simulated by the global warming experiments. Figure 3b shows interannual variation of Precipitation in JJA averaged for whole Mongolia. Most years except for 2002 experiences decrease in precipitation, which conducts the decreasing signal for 11-year average. The amplitudes of decrease are pronounced in the year when much precipitation was occurred, for example 1993 and 1994.

Figure 4a shows the change of daily mean temperature. Since the temperature in the RCM is strongly affected by the atmospheric forcing dataset, the temperature rises by 2.5 $^{o}$C in most part of Mongolia. Year-to-year comparison of the temperature change is shown in Fig. 4b. The increment of temperature is very robust exceeding 2 $^{o}$C in every year.

It is reconfirmed, from the GW-CTL and GW-WM runs, that the global warming has very large impacts on the temperature and precipitation in Northeast Asian arid/semi-arid area.

### 3.2 *Land cover change*

Figure 5a shows the JJA precipitation change after the land cover change (LC-DS minus LC-CTL). In the 11-year average, the precipitation increases over the Central Mongolia while it tends to decrease around the border with China. The result conflicts with the previous study by Xue (1996) which investigated, by GCM experiments under a typical year condition, that the precipitation decreases after the desertification. The detail comparison of precipitation in LC-CTL and LC-DS appears in Fig. 5b. Actually, it is quite difficult to obtain a proper answer for the question how precipitation may change after the land cover change in Mongolia. In some years, precipitation increases more than 20 mm during JJA; however, in other years, precipitation decreases. These results suggest the difficulty to conduct increase/decrease trend due to the land cover change because the precipitation in this area is deeply related to the activity of synoptic-scale disturbances. Thus, the land cover change in a limited area can affect the convective systems through the two aspects. The evapotranspirated moisture from the grassland may contribute to the enhancement of the convective systems. On the other hand, the desertification changes the surface Bowen ratio; as a result, larger part of radiation energy can be used for sensible heat flux, which also enhances the convection.

Figure 6a shows the temperature change after the desertification. The summertime temperature increases less than 0.5 $^{o}$C due to the land cover change. The weak increasing feature can be simulated in many years while, in 2001 and 2002, temperature does not increase. Because the precipitation change also affects the temperature change, it is still difficult to evaluate the temperature change although the temperature change is more robust than the precipitation change.

## 4. Conclusion

This study compares the impact of the global warming and land cover change on regional climate system in Northeast Asia, especially in Mongolia. Northern China and Mongolia is a transition zone of vegetation from desert and semi-desert to Mongolian grassland and Taiga forest. Recently, land degradation including desertification has been a real threat in this region. Additionally, the global warming due to increasing green house gas concentration is considered to give a large influence on the regional climate, especially in landlocked high-latitude country. In the recent ten years, summertime temperature shows drastic increase in whole Mongolian territory. Numerical integrations using regional climate model were carried out to obtain the perspective of regional climate changes induced by human activities. Two sensitivity experiments were done; the global warming experiment and the desertification experiment. The global warming experiment indicated that the precipitation decreases over Mongolia up to 20 mm, and air temperature rises by 2.5 $^{o}$C in warm season. On the other hand, in the desertification experiment, increase/decrease of precipitation had an interannual variation; precipitation decreased in only half cases due to replacing the grassland to the desert in the model. In other cases, precipitation increased after the desertification probably due to the active convection. These integrations indicate that the global warming has larger impact on temperature than the desertification. And desertification impact on precipitation is quite complicated for this region, which should be studied under many synoptic-scale atmospheric conditions, because incoming water vapor has large interannual variation.

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