Numerical experiment on precipitation change over Mongolia under global warming

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1. Introduction

Many researches in relation to climate change caused by global warming have been carried out. General Circulation Models (GCMs) contributes largely on the improvement of prediction as well as understanding the complex earth systems. GCMs' predictions can be utilized for making national policies on economy, agriculture and so on. However, spatial resolution of the GCMs are still coarse to evaluate the regional or national scale variations although very high resolution GCM have been developed in very recent years.

Regional climate models (RCMs) give us advantages to study climate changes with high resolution in aid of GCMs or reanalysis data as a model boundary. Additionally, computational cost will be smaller than high resolution GCM since RCM can simulate the climate over the region of interest.

In current study, we aim to study two methods of downscaling using RCM. In first method, as generally attempted, RCM is nested from GCM using six-hourly GCM prediction as boundary conditions. In second method, the boundary variables are given by pseudo global warming condition in which monthly deviations from current climate are superimposed on six-hourly reanalysis data.

2. Method

2.1 Model description

The Terrestrial Environmental Research Center - Regional Atmospheric Modeling System (TERC-RAMS; Sato and Kimura, 2005) is developed by replacing the physical parameterizations from the original RAMS (Pielke et al., 1992). The outer six grids are assumed as a lateral boundary where external meteorological datasets are nudged by a linear coefficient. Two-level, two-way nesting is adopted in the model. The coarser grid system is centered at 105E, 40N 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 104E, 47N covering Mongolian territory. The cumulus parameterization and bulk type Microphysics parameterization presented is adopted to calculate the precipitation. Vegetation distribution in the model is obtained by USGS (U. S. Geological Survey) global land surface characterization dataset.

Since precipitation will be the most important element considering climate change in arid area, July is focus of this study when contribution to the annual precipitation is large. Initial soil moisture distribution, which is used for all simulations, is estimated after one month spin up for July of 2003.

2.2 Numerical experiments

We performed four numerical experiments as listed in Table 1. Each experiment integrates for ten years of July. The RCM.hindCTL experiment represents a hindcast simulation for current climate during 1993 and 2003 using six-hourly NCEP/NCAR reanalysis data. The RCM.gcmCTL and RCM.gcmA2 experiments indicate the dynamic downscaling simulations using six-hourly data from MRI (Meteorological Research Institute) GCM for present climate and future climate based on SRES (Special Report on Emissions Scenarios) A2 (heterogeneous world) scenario (IPCC, 2000), respectively. The RCM.hindWM experiment is basically same with RCM.hindCTL experiment except for the boundary meteorological data in which monthly mean difference of meteorological variables caused by global warming estimated by MRIGCM is added on the six-hourly NCEP/NCAR reanalysis ata.

Quantitive evaluation of each experiment is carried out by taking average for whole Mongolia, and for four regions of NW, NE, SW, and SE in Mongolia divided by 104E and 47N. The simulated precipitation is tested by rain gauge data provided by Institute of Meteorology and Hydrology, Mongolia. Comparisons are conducted for grid points which are corresponding to the rain gauges, while other grid points are out of use.

Table 1: List of experiments

Run name	Boundary	Period
RCM.hindCTL	6-hrly NCEP/NCAR	1993-2003
RCM.gcmCTL	6-hrly GCM-control	1991-2000
RCM.gcmA	2 6-hrly GCM-A2	2071-2080
RCM.hindWM	6-hrly NCEP/NCAR with monthly mean GCM difference	1993-2003

3. Result

3-1. RCM.hindCTL

First of all, hindcast experiment will be explained in order to show the performance of RCM. Figure 1a illustrates the 11 years mean precipitation for four regions and whole Mongolia by RCM.hindCTL run. In RCM.hindCTL, northern two regions are higher than southern two regions, which indicate that characteristic rainfall distribution is clearly produced in the model. The RCM produces arid summer in southern two regions of Mongolia which is consistent with observation, although it slightly overestimates the precipitation in NW, SW, and SE regions. Figure 1b summaries the probability of daily rainfall categorized by its intensity. Frequency of heavy rainfall (16<P) and middle rainfall (4<P<16) is considerably good in RCM.hindCTL. Therefore, RCM can precisely simulate the rainfall intensity as well as the total amount. However, probability of weak rainfall (P<4) by RCM is considerably higher than that observed. The fact points out the difficulty simulating and observing very light precipitation over the arid region.

Interannual variation of precipitation in July for whole Mongolia is captured very well in RCM (Fig.2). Overestimation by the model is prominent for some dry years of 1999, 2000, and 2001. This discrepancy would come from the assumption of initial soil moisture mentioned in section 2.1.

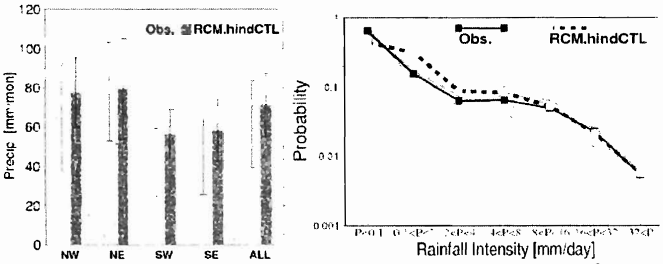

Figure 2: Interannual variation of precipitation for whole Mongolia in July by observation and RCM.hindCTL. Error bars in each year and average indicate standard deviation for stations and years, respectively.

3-2. RCM.gcmCTL and RCM.gcmA2

Rainfall distribution by RCM.gcmCTL run is tested with observation (no figures). In RCM.gmtCTL, Precipitation over northeast Mongolia is too less caused by the northeastward extension of the arid region, while precipitation over southwest Mongolia is too much due to too much rainfall in mountainous region. These results show that the predictability of the downscaled precipitation in present climate is worse than that in RCM.hindCTL even though the MRIGCM gives plausible results in large scale distributions.

Ten-years mean of July precipitation is compared between RCM.gcmCTL and RCM.gcmA2 runs, which provides the direction of change in precipitation after the global warming. Increase of rainfall amount in July is found in SE Mongolia, while the other three regions experiences decrease, which leads to the decrease for whole Mongolia. However, as addressed above, one should be note that the RCM.gcmCTL is somewhat apart from observation and RCM.hindCTL in rainfall distribution. Thus, amplitudes of the difference between RCM.gcmCTL and RCM.gcmA2, that is the change caused by global warming, is very small compared to the difference between RCM.gcmCTL and observation. Therefore, these results suggest the difficulty to evaluate the rainfall variation in a regional scale if large scale climate can be simulated correctly.

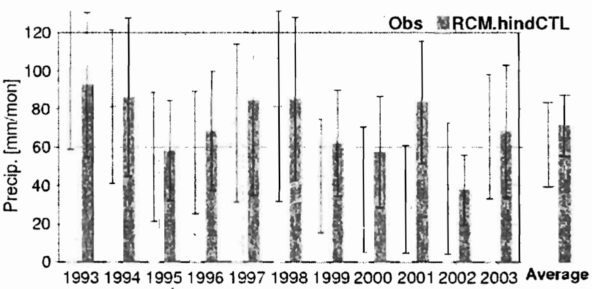

Figure 1: (a) 11-years average of precipitation in July averaged for four regions and whole Mongolia. Left (observation), right (RCM). (b) Probability distribution of daily rainfall intensity for all Mongolia.

3-3. RCM.hindWM

As described in section 3-1, RCM.hindCTL successfully captures the interannual variation and horizontal distribution of the precipitation in July. Thus, comparison between RCM.hindCTL and RCM.hindWM is carried out in order to discuss detail feature of the rainfall variation induced by global warming. Figure 3 shows the amplitude of change in precipitation. Decrease is evident over northern and western mountainous region in Mongolia. Over northwestern Mongolia, monthly

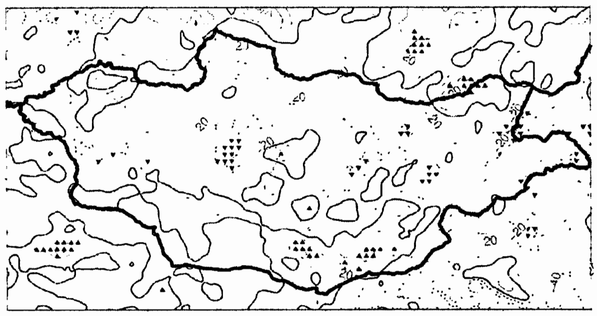

Figure 3: Difference of precipitation in July between RCM.hindCTL and RCM.hindWM [mm/month]. Positive value indicates that the precipitation increases by global warming. Triangles and opposite triangles corresponds to the grids where statistically significant increase and decrease are detected.

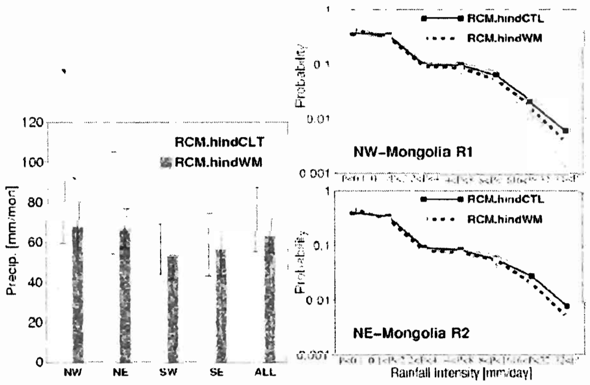

Figure 4: Same with Fig.3 but for RCM.hindWM (right) and RCM.hindCTL (left).

precipitation decreases up to 30 mm month-1. On the other hand, slight increase can be found in southern region around Gobi. Very complex horizontal structure of rainfall variation, where increasing and decreasing features coexist in Mongolia, is simulated by pseudo global warming test.

Figure 4 shows interannual variation of Precipitation in July averaged for whole Mongolia. Most years except for 2002 experiences decrease in Precipitation, which leads to decrease for 11 years average. The amplitudes of decrease are significant in the year when much precipitation was occurred, for example 1993 and 1994. Apparent change is not found in 1995 and 2003.

Quantitive comparison of regional averaged precipitation is shown in Fig. 5. In northwest and northeast Mongolia, rainfall decrease around 10 mm month-1, while tiny decrease is found in southern two regions. Thus, decrease over northern Mongolia mainly contributes to the decrease of precipitation in whole Mongolia. In RCM.hindWM, heavy rainfall as well as weak rainfall decrease in respect to the rainfall intensity. Over southern regions, Change of rainfall intensity is complex, and it needs to be investigated more.

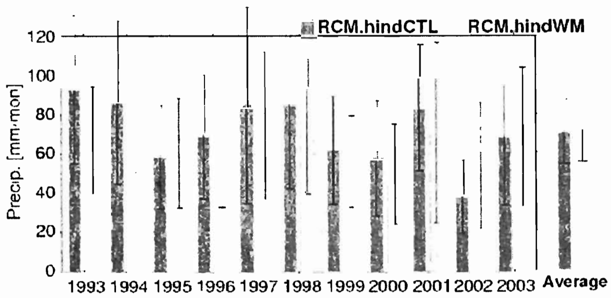

Figure 5: 11-years mean precipitation in July (left). Error bars indicates standard deviation for 11-years. change of rainfall intensity for NW and NE Mongolia (right).

The RCM.hindWM is based only on one GCM (MRIGCM) and on one SERES scenario (A2). The direction of change may differ when other GCMs or other scenarios are chosen. Neverthless, the sensitivity experiment like RCM.hindWM makes it very easy to apply GCM ensemble and other SRES scenarios.

4. Conclusion

Rainfall change under the global warming environment is investigated by two methods using 6-hourly GCM output and modified reanalysis data. The both results indicate that rainfall in July decreases over northern mountainous region while it slightly decreases around the Gobi, which leads to net decrease of averaged precipitation over whole Mongolia. Thus, this study suggests the validity of pseudo global warming experiment like RCM.hindWM for dynamic downscaling.

Hindcast experiment with GCM anomaly (RCM.hindWM) reveals the detail features of rainfall change as follows. Decrease of rainfall is significant for years when much rainfall occurs in Mongolia, while slight decrease can be found in relatively dry summers in Mongolia. In northern Mongolia, not only heavy precipitation but also middle and light precipitation occurs less frequent compared with current climate (RCM.hindCTL), which denotes the mountain induced rainfall may decrease after the global warming. Horizontal pattern of the rainfall change is consistent with the difference between RCM.gcmCTL and RCM.gcmA2. Seasonal variability of the rainfall change and application for other GCMs will be future work.

References

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