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Projection of global warming onto regional precipitation over Mongolia using a regional climate model

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Summary Climate change due to global warming is of concern to the public and may cause significant changes in the hydrological regimes in arid/semi-arid areas including Mongolia, which locates at a boundary between arid and humid regions. However, general circulation models (GCMs) are not sufficient to evaluate climate change on a regional-scale. In this study, two kinds of dynamical downscaling (DDS), referred to as method-G and method-R, using a regional climate model (RCM) are applied to investigate the rainfall change over Mongolia in July due to the global warming. Method-G is a traditional DDS method in which an RCM is directly nested within a GCM, while method-R is newly suggested in this study and aims to improve the reproductivity of a regional climate. For current climate simulation, method-R uses reanalysis data as a boundary forcing of the RCM while a specially created boundary condition, in which projected changes of meteorological variables in a GCM simulation are added on reanalysis data, is used for global warming simulation. Compared with in situ observations, the rainfall amount for July is very well reproduced by the RCM, even in a smaller area of four subregions in Mongolia. Rainfall intensity by method-R is very close to actual observations; on the other hand, method-G fails to simulate heavy rainfall events stronger than 16 mm day^{-1}. The two DDS methods show similar results with respect to the changes of precipitation in July due to the global warming, which are that precipitation decreases over northern and increases over southern Mongolia. In method-R, a decrease of precipitation of middle to heavy rainfall intensity, stronger than 4 mm day^{-1}, contributes largely to the decreased July precipitation in northern Mongolia. Soil moisture over Mongolia also tends to decrease in July because of

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the combined effect caused by the decrease of precipitation and the increase of potential evaporation due to rising air temperature. This situation indicates that severe droughts may occur more frequently from the effects of global warming.

Introduction

Climate change due to global warming is a worldwide public concern. In the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report (Houghton et al., 2001), a warming trend of annual mean temperature was predicted for most parts of Northeast Asia by General Circulation Models (GCMs). However, the estimates of precipitation after global warming were quite different among GCMs, indicating the difficulties in predicting precipitation in this region.

Mongolia is situated in an arid and 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). Synoptic scale disturbances, e.g., cyclones, troughs, and cut-off lows, are likely to interact with the complicated topography in Mongolia, and generate convective precipitation systems. The territory has a prominent meridional contrast in its rainfall amount as well as in its surface conditions that changes 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 sensitive to climate change; as are the economic activities in this region (Sugita et al., this issue).

Estimations of the effects of global warming on water resources in a region or in a river basin are required by decision makers to prevent such effects from spreading to a region's economy. Currently, GCMs are the only tool to simulate global change due to greenhouse gas emission that causes the changes of precipitation on global and continental scales under the effects of global warming. However, it has been difficult to simulate the climate in smaller areas, ones on a national or even a river basin scale, due to the limitations in horizontal resolution as well as in physical parameterizations of GCMs. The dynamical downscaling (DDS) technique, which estimates higher-resolution climatic conditions in a physical model by taking account of detailed geographic information such as topography, allows us to obtain smaller scale prediction. A regional climate model (RCM) nested within GCM simulations (hereafter Method-G) has been a traditional tool to carry out DDS, although RCMs also contain some limitations in physical parameterizations. Reproduction of a regional climate system by method-G still has some difficulties since simulated climates in an RCM are strongly influenced by larger scale forcing given by a GCM, which may have strong model bias (Kato et al., 2001). On the other hand, an RCM allows reanalysis data, which is computed using observed data, to be employed as a model forcing (hereafter Method-R). Method-R is known to more plausibly reproduce a regional climate system for current years (Wang et al., 2004).

This study aims to predict rainfall after global warming utilizing two DDS methods using an RCM, by means of method-G and method-R. A comparison between the two methods is carried out to show the regional climate prediction ability of method-R, especially in and around the boundary between the humid and the arid areas in Northeast Asia. Finally, changes in the rainfall characteristics in subregions of Mongolia are discussed based on the results of method-R, as well as method-G.

Method

Data

Summertime (June, July and August) precipitation contributes more than 60% of the annual precipitation over Mongolia. We focus our analysis on the precipitation in July when approximately 20% of the annual precipitation falls. Horizontal resolutions of the compiled global precipitation datasets (e.g., Adler et al., 2003), are not sufficient to investigate rainfall in the study area due to their coarse horizontal resolution. Therefore, the daily precipitation data observed at 65 meteorological stations as shown in Fig. 1, provided by the Institute of Meteorology and Hydrology, Mongolia, are used to validate the simulated precipitation in recent years. In order to compare the model estimates

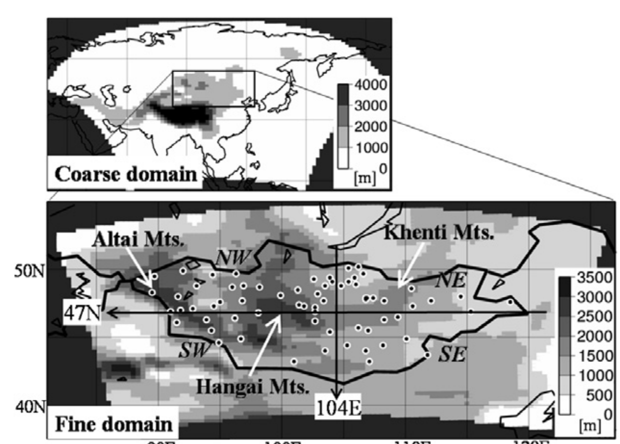

Figure 1 Calculation domain of regional climate model. Circles indicate the locations of meteorological stations. Colors indicate altitude ranges. Four subregions, NW, NE, SW, and SE, are indicated.