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Impacts of Global Warming on Hydrological Cycles in the Asian Monsoon Region

Koji DAIRAKU*[1], Seita EMORI[2], and Toru NOZAWA[3]

[1]*Storm, Flood, and Landslide Research Department, National Research Institute for Earth Science and Disaster Prevention, Tsukuba, Japan*

[2]*Climate Risk Assessment Research Section, Center for Global Environmental Research, National Institute for Environmental Studies, Tsukuba, Japan*

[3]*Atmospheric Physics Section, Atmospheric Environment Division, National Institute for Environmental Studies, Tsukuba, Japan*

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ABSTRACT

The hydrologic changes and the impact of these changes constitute a fundamental global-warming-related concern. Faced with threats to human life and natural ecosystems, such as droughts, floods, and soil erosion, water resource planners must increasingly make future risk assessments. Though hydrological predictions associated with the global climate change are already being performed, mainly through the use of GCMs, coarse spatial resolutions and uncertain physical processes limit the representation of terrestrial water/energy interactions and the variability in such systems as the Asian monsoon. Despite numerous studies, the regional responses of hydrologic changes resulting from climate change remains inconclusive. In this paper, an attempt at dynamical downscaling of future hydrologic projection under global climate change in Asia is addressed. The authors conducted present and future Asian regional climate simulations which were nested in the results of Atmospheric General Circulation Model (AGCM) experiments. The regional climate model could capture the general simulated features of the AGCM. Also, some regional phenomena such as orographic precipitation, which did not appear in the outcome of the AGCM simulation, were successfully produced. Under global warming, the increase of water vapor associated with the warmed air temperature was projected. It was projected to bring more abundant water vapor to the southern portions of India and the Bay of Bengal, and to enhance precipitation especially over the mountainous regions, the western part of India and the southern edge of the Tibetan Plateau. As a result of the changes in the synoptic flow patterns and precipitation under global warming, the increases of annual mean precipitation and surface runoff were projected in many regions of Asia. However, both the positive and negative changes of seasonal surface runoff were projected in some regions which will increase the flood risk and cause a mismatch between water demand and water availability in the agricultural season.

Key words: hydrologic change, dynamical downscaling, regional climate model, Asian monsoon region

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1. Introduction

The hydrologic cycle is vital to human life and natural ecosystems. It has complex interactions within the climate system, and it also has an important role in regulating climate stability and variability. The industrial transformation and human activities may influence the hydrological cycle globally and regionally. The compelling evidence of the attribution of human activities to the hydrologic change and variability has not yet been provided systematically. Faced with threats to human life and natural ecosystems, such as

*Corresponding author: Koji DAIRAKU, dairaku@bosai.go.jp

droughts, floods, and soil erosion, water resource planners must increasingly make future risk assessments (Schnur, 2002). Historically, stable climatic conditions have been assumed for water resource management, planning, and civil engineering designs. However, global climate changes may lead to changes in rainfall events by an enhancement of atmospheric moisture content (Palmer and Rälsänen, 2002). Therefore, the hydrologic changes and the impact of these changes constitute a fundamental global-warming-related concern.

Floods and droughts caused by Asian monsoons affect agriculture, water resources, and the economies of many Asian countries where billions of people live and which are characterized by diverse geography. Dairaku and Emori (2006) suggest that the changes in the Asian summer monsoon resulting from climate change will especially affect the hydrological components such as extreme precipitation. Societies in Monsoon Asia must urgently learn how to adapt to climate changes and cope with the large variability of the Asian monsoons. Is the Asian monsoon system resilient to the anthropogenic transformation of land, water, and air? The importance of the coupled human and environment system in the Asian monsoon region is raised as a key question by the Monsoon Asia Integrated Regional Study (MAIRS; Fu et al., 2006). To control water resources in the face of drought, flood, and soil erosion, which frequently present a serious threat to human life and natural ecosystems, predictions and risk assessments are being required more frequently by policy makers.

Hydrologic predictions that account for global climate changes mainly use GCMs (Coe, 2000; Koster et al., 2000; Vörösmarty et al., 2000; Palmer and Rälsänen, 2002; Milly et al., 2002). Despite numerous studies, the regional responses of hydrologic changes (atmosphere-ocean-land interactions, precipitation, and extreme events such as droughts and floods) resulting from climate change remain unclear and have many uncertain factors (e.g., model uncertainties, large amplitude of natural variability and anthropogenic influences such as black carbon, deforestation, and irrigation).

One of the approaches dealing with these uncertain inputs and processes in climate prediction is to use ensemble projections that produce predictions in the form of the probability (Collins, 2007). However, this approach is very expensive computationally and cannot deal with the uncertainty associated with spatial resolutions. Though detailed information for regional areas is frequently required, coarse spatial resolutions (those with grid spacing of approximately 300 km) and uncertain physical processes particularly limit the representation of terrestrial water/energy interactions and the variability and extremes in such systems as the Asian monsoon. Therefore only a very restricted number of regional-scale estimates are available to planners.

To solve this problem, downscaling methods are employed to produce finer scale information from GCMs with coarse spatial resolution. Two kinds of methods are usually employed. One is statistical downscaling, which estimates local scale variables (e.g., precipitation, temperature, and wind) from GCMs usually based on statistical relationships between synoptic-scale conditions and local-scale variables. Another is dynamical downscaling, which is usually achieved by a high-resolution regional climate model (RCM).

The model is conducted in a limited region and driven by lateral boundary conditions obtained from GCMs (so-called nesting). Therefore, the RCM is strongly controlled by the imposed lateral boundaries that bring large-scale circulations down into the RCM domain. Therefore, it is strongly desired that the boundary conditions are as accurate as possible and the simulated synoptic circulations of RCM should not be greatly different from those of the GCM.

Mesoscale atmospheric systems can be categorized into two groups. The first group is surface inhomogeneities-induced mesoscale systems such as sea and land breezes, mountain valley winds, urban circulations, and forced airflow over rough terrain. The second group is synoptically-induced mesoscale systems such as fronts, squall lines, and hurricanes (Pielke et al., 2002). Because of the higher resolution, the RCM is expected to have the advantage of higher accuracy and the ability to "add value" in small-scale features not well represented by the GCM (Castro et al., 2005).

Surface boundary forcing, such as topography, is the dominant factor for generating small-scale atmospheric variability (Wang et al., 2004), therefore a higher resolution simulation by the RCM is expected to be able to improve the regional circulation pattern and produce realistic intensities and frequencies for mesoscale features, such as orographic precipitation resulting from realistic topography. These mesoscale features can be considered as a boundary value problem.

On the other hand, the synoptically induced mesoscale systems are not necessarily improved by a higher resolution simulation by the RCM. As mentioned above, it is necessary that the boundary conditions are as accurate as possible. And also, the adequate representation of physical processes may be necessary. Therefore, model physics has been an im-