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Future changes in precipitation and water resources for Kanto Region in Japan after application of pseudo global warming method and dynamical downscaling

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ABSTRACT

Study region: The Kanto region, Japan.
Study focus: Detailed assessment of present and future climate conditions and their effects on water resources in the Kanto region of Japan using a modified pseudo global warming dynamical downscaling method with a numerical weather prediction model.
New hydrological insights: In future climate conditions, results on the change in annual precipitation are scattered, with significant variations in mean annual precipitation and the standard deviation in very limited areas. In contrast, minimum annual precipitation is found to decrease and years with low rainfall to be more frequent. During the drier summer season, the minimum accumulated rainfall is expected to become smaller across a wide region in the future. In addition, frequency distributions of future daily precipitation show a decrease of weak precipitation and an increase of heavy precipitation. Such variations are unfavorable for water recharge and indicate that water resources management will become increasingly difficult in the future because of global warming. The lower rainfall conditions are due to the lower relative humidity, more frequent stable stratifications and sub-synoptic atmospheric conditions leading to higher-pressure anomalies around Japan.

1. Introduction

Global warming has worldwide significance for human activities. To investigate the effects of climate change due to global warming, projections using atmosphere-ocean coupled general circulation models (AOGCMs) provide important information. However, the spatial resolution of AOGCMs is too coarse to permit assessment of the impacts of future climate change on a specific region, basin, or city. Furthermore, some important regional features are often not resolved in AOGCMs. Detailed investigations into the effects of climate change demand regional climate information with higher spatial resolution. Therefore downscaling methods have been applied to AOGCMs output (Leung et al., 2003; Wang et al., 2004). Generally, there are two types of downscaling methods: statistical and dynamical downscaling methods. In statistical downscaling, statistical relationships between global and regional climatic variables are used to generate higher-resolution regional climate information. Dynamical and physical theories of meteorology are applied in dynamical downscaling using a numerical model (Dickinson et al., 1989; Giorgi, 1990). The computational load of statistical downscaling is low, but it is uncertain whether relationships that hold in the current climate would be applicable under future climatic conditions. Dynamical downscaling (DDS) requires strong computational capability and the volume of the downscaling output is considerable. However,

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universal dynamical and physical theories can be applied to both current and future climatic conditions. Therefore, in this study, DDS is used to produce higher-resolution climate information.

There are uncertainties in AOGCM climate projections, which are caused by uncertainty in future emission scenarios, imperfect initial and boundary conditions, incomplete understanding of climate systems, and model imperfections. To reduce these uncertainties, studies have proposed an analysis method based on projections from multiple AOGCMs, the so-called multi-model ensemble method (Collins, 2007; Knutti et al., 2010). Such a concept is invaluable in assessments of the effects of climate change using a DDS method. One problem to be addressed in DDS of future climate conditions is AOGCM incompleteness. The purpose behind simulating past and current climates using AOGCMs is not to create perfect reproductions but to enable the general characteristics of the climate to be established. The finer climate information generated as a DDS output is strongly influenced by AOGCM bias (Kato et al., 2001). Therefore, it is difficult to evaluate the reproducibility of current climate conditions obtained by DDS with a forcing from an AOGCM. However, climatological reanalysis data can be used for DDS forcing of past and current climates. To obtain future DDS outputs, Sato et al. (2007) generated initial and boundary conditions by coupling 6-hourly reanalysis data and climatological monthly mean anomalies of global warming extracted from an AOGCM. The resulting forcing data, which they called the pseudo global warming (PGW) condition, was used for DDS of future climate to investigate precipitation in Mongolia. DDS was applied to the present climate using both reanalysis data and the AOGCM output, and demonstrated better reproducibility of DDS precipitation when using reanalysis data than when using the AOGCM output. The two DDS results showed similar variations in future precipitation (i.e. decreasing and increasing over northern and southern Mongolia, respectively). Yoshikane et al. (2012) examined the reproducibility of downscaling results for future rainy seasons, or June climate, in Japan from DDS with PGW conditions. They found similar characteristics between results based on PGW conditions and direct outputs from an AOGCM. These studies indicate the potential of the PGW condition for generating reliable DDS results of future climate. Kawase et al. (2009) used DDS with the PGW condition to examine activities of the Baiu rainband, which forms during June and July around Japan. They found a southward shift and an increase in the precipitation from the rainband under future climate conditions.

In the above DDS studies, PGW conditions were generated from 6-hourly reanalysis data and climatological monthly mean anomalies in future climate conditions. In that method, the range of inter-annual variations and the diurnal cycle were the same as that for reanalysis data. In Xu and Yang (2012), atmospheric conditions for DDS were prepared with climatological mean conditions using reanalysis data and 6-hourly future anomalies using an AOGCM. The DDS results with the high-frequency (6-hourly) anomaly showed similar characteristics to the original AOGCM, and the root-mean-square errors were smaller. In this study, PGW conditions for DDS were prepared with future high-frequency anomalies. Then, a DDS method with high-frequency-anomaly PGW (hereafter, HF-PGW) conditions was applied to the Kanto region of Japan using output from five different AOGCMs in order to investigate future changes in precipitation. Herein, focus was given to the Tone River basin which is the second longest river in Japan and flows through the Kanto region. Furthermore, the Tone River basin is the largest in Japan and precipitation in this basin forms the primary water resources for the Tokyo metropolitan area. In 2012 and 2013, the total impounded water amount of eight dams in the basin fell to 40% of capacity, and a 10% reduction in water intake was implemented. The potential impacts of climate change on future water resources in the Kanto region, as addressed in this study, should be seen in the context.

In the next section, we describe the data and methods used for preparation of the HF-PGW conditions and DDS using a numerical weather prediction model. In Sections 3, DDS results for the current climate are evaluated. General features of future precipitation variability and its effects on water resources are discussed in Section 4. Relationships between limited precipitation and atmospheric conditions are also examined in Section 4. Finally, we present a discussion of the results and our conclusions in Section 5.

2. Data and methods

2.1. Data

2.1.1. Japanese 25-year reanalysis

Japanese 25-year reanalysis (JRA-25) data, developed by the Japan Meteorological Agency (JMA), were used for downscaling of the present climate conditions and as the base state for the HF-PGW conditions. The global spectral model used in JRA-25 has a spectral resolution of T106 and 40 vertical layers, with the height of the top layer set to 0.4 hPa. Atmospheric variables in JRA-25 are converted from spectral to latitude–longitude coordinates with a resolution of $1.25^\circ \times 1.25^\circ$. In JRA-25, surface and upper air observations, and multiple satellite data are assimilated with a three-dimensional variational method. More details of JRA-25 are provided by Onogi et al. (2007).

JRA-25 covers the period from January 1979 to December 2004. The reanalysis product from the JMA Climate Data Assimilation System (JCDAS) has been available since January 2005. JCDAS runs the same system as JRA-25. The same quality and accuracy are expected in JRA25 and JCDAS; therefore, both products are considered as homogeneous data sets. Using JRA-25 and JCDAS, we applied DDS to the 2000–2010 data to obtain detailed outputs regarding the current climate conditions.