Hydrological balance over northern Eurasia from gauge-based high-resolution daily precipitation data

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ABSTRACT: A gauge-based high-resolution daily precipitation data set for northern Eurasia, including Russia and former Soviet Union countries, has been developed as a part of the Asian Precipitation −− Highly Resolved Observational Data Integration Towards Evaluation of Water Resources (APHRODITE's Water Resources) project. It is important to validate climate models with high-resolution grid precipitation data, because precipitation is a key parameter used by such models to evaluate atmospheric circulation. However, a daily gridded precipitation data set for Asia and, in particular, northern Eurasia has not yet been fully developed. We developed a grid precipitation data set for 1960-1990 (31 years) by using daily gauge-based precipitation data homogenized with the technique of Groisman and Rancova (*Internat. J. Climatol*, 21, 2001). Using this new grid precipitation data set, we validated the precipitation simulated by the European Centre for Medium-Range Weather Forecasts 40 years re-analysis and water balance over northern Eurasia; this validation is important for understanding the freshwater resources of both that region and the Arctic.

Key words daily precipitation; Russia; central Asia

1 INTRODUCTION

Various studies have recently showed the global and regional precipitation changes that are likely to be associated with global warming (IPCC, 2007), thus improving our understanding of the impacts of global warming on regional water resources and on the frequency of extreme events such as heavy rainfalls and drought. To validate the capability of a climate model to simulate not only various aspects of climate change but also regional precipitation, it is necessary to compare the model's precipitation results against observed precipitation data (e.g. Yatagai et al. 2008a, b). However, no precipitation data set with sufficiently high spatial and temporal resolution is available for evaluating climate models for Asia or, especially, northern Eurasia. In order to validate high-resolution climate model, a long-term gauge-based high-resolution daily precipitation data set has been developed for northern Eurasia, including countries of the former Union of Soviet Socialist Republics (USSR), as a part of the Asian Precipitation −− Highly Resolved Observational Data Integration Towards Evaluation of Water Resources (APHRODITE's Water Resources) project. The primary objectives of the APHRODITE project are to (1) release official state-of-the-art daily gridded precipitation data sets based on rain-gauge observations, (2) assess the projections of climate models by observing precipitation in the field, including extreme events, and (3) make suggestions to regional water resources managers in Asian countries. See the APHRODITE's Water Resources website (http://www.chikyu.ac.jp/precip/) for details.

The hydrological cycle over northern Eurasia significantly affects the freshwater supply to the Arctic, thus the oceanic thermohaline circulation. Interseasonal variations of meteorological fields in relation to storm track or transient eddy can influence moisture transport from low latitudes to the polar region (e.g.

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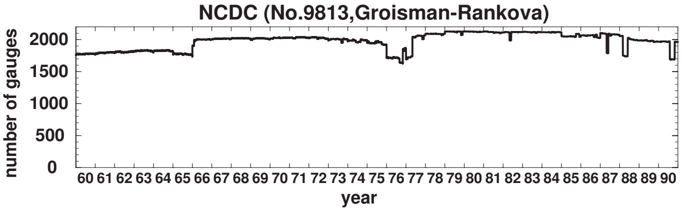

Figure 1: Number of daily gauge observations for the former USSR countries collected by NCDC (data set 9813) for 1960-1990.

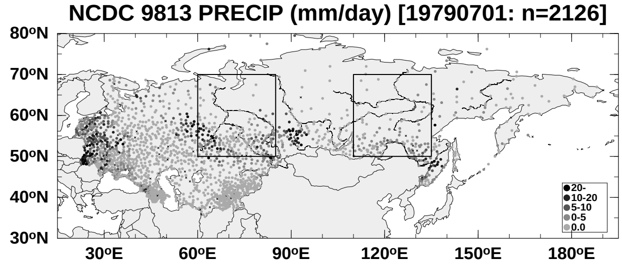

Figure 2: Precipitation [mm day^{-1}] on 1 July 1979 from rain gauge data (NCDC data set 9813). The areas enclosed by boxes are eastern Siberia (the Lena River basin) and western Siberia (the Ob River basin).

Fukutomi et al. 2007), especially during the northern summer, when the temperature gradient is largest. During the northern summer, an east-west oscillation with a period of 6-8 years in precipitation is the dominant pattern over northern Eurasia (Fukutomi et al., 2003), but the mechanisms accounting for this oscillation, especially in relation to the interseasonal variation, are still not fully understood. To evaluate interseasonal variation and the hydrological balance over northern Eurasia, high temporal and spatial resolution gridded precipitation data are needed.

In this paper, we describe in detail a new daily gridded data set developed for northern Eurasia as a part of the APHRODITE project, and we use this data set to evaluate the simulation of precipitation by the European Centre for Medium-range Weather Forecasts (ECMWF) forecast model's 40-year re-analysis as a validation result.

2 DATA AND METHODOLOGY

2.1 *Input gauge data*

Gauge-based daily precipitation data (data set 9813 Daily and Sub-daily Precipitation for the Former USSR, version 1.0) homogenized for wetting bias and rain gauge changes by the technique developed by Groisman & Rankova (2001) are available from the US National Climatic Data Center (NCDC) for 1891-2001 (NCDC, 2005). In former USSR countries, there are 2188 daily precipitation observation stations, but many fewer observations were recorded before 1960 and after 1990; therefore, we used the data for 1960-1990 (31 years). During this period observations were continuously conducted at more than 1500 stations (Fig. 1). Figure 2 shows an example of precipitation from data set 9813. The observation sites are dense over the southwestern former USSR and somewhat sparser in the north of central Eurasia.

2.2 *Objective technique*

We used an algorithm similar to that of Yatagai et al. (2008a, b) to create gridded precipitation data from the rain gauge data for northern Eurasia (hereafter, we call this product "APHRO-RU"). The algorithm of Yatagai et al. (2008a, b) is the same as that of Xie et al. (2007) except for the interpolation method used; like Yatagai et al., we apply the Shepard (1968) method to interpolate the daily climatology from the observation data for each target day. In this study, we (1) derived the 31-year daily precipitation climatology and interpolated the climatology onto a 0.05° grid, (2) computed the analysis field of the daily climatology anomalies for each target day, and finally (3) averaged daily precipitation at 0.05° grids over 0.5°. See Xie et al. (2007) and Yatagai et al. (2008a) for details. For the regions out of former USSR countries, we used a rain gauge data set obtained via the Global Telecommunication System network for the climatology.

2.3 *Meteorological data*

We used the meteorological data set of precipitation and vertical integral of divergence of moisture flux from the ECMWF 40-year re-analysis (hereafter ERA40) on a 2.5° grid, 4 times daily, for 1960-1990, corresponding to the period of the APHRO-RU data set.

3 VALIDATION RESULT

3.1 *Validation of ERA40 with APHRO-RU*

As a preliminary analysis, we first validated precipitation as simulated by ERA40 with our product. Figure 3 shows the 31-year climatologies of APHRO-RU and ERA40 precipitation for four months. The general precipitation pattern of ERA40 is very similar to that of APHRO-RU and quantitatively reasonable throughout the year, but smaller scale structures are found in APHRO-RU, particularly over mountainous regions, such as to the east of the Black Sea and north of Mongolia. In APHRO-RU, we can also see small structures over the Amur River basin during the northern summer. Precipitation maxima in ERA40 sometimes differ from those of APHRO-RU in some regions. For example, in July we can see a maximum at around 100°E, 70°N in ERA40 but not in APHRO-RU. These differences may be due in part to moisture convergence of the ERA40 model, or they might be caused by the sparse gauge distribution in some regions in APHRO-RU. In general, ERA40 tends to overestimate the precipitation climatology over northern Eurasia during the northern winter/spring, and underestimate that during summer.

3.2 *Water budget over northern Eurasia*

Figure 4 shows the annual cycle of precipitation over western (60-85°E, 50-70°N; the Ob River basin) and eastern (110-135°E, 50-70°N; the Lena River basin) Siberia for APHRO-RU and ERA40 simulation, where precipitation is largest (Fig. 3), and where Fukutomi et al. (2003) showed an east-west dipole structure of circulation and precipitation anomalies in interannual variation during the northern summer. Over both regions, precipitation maxima are found during the summer, and minima during the winter (Fig. 3).

Moisture convergence (ERA40) (Fig. 4) shows an annual cycle over the Ob River basin, with a summer maximum, and a semiannual cycle over the Lena River basin, as described in previous studies (e.g. Fukutomi et al. 2003). If the total of precipitable water is constant despite the seasonal variation, then evaporation (evapotranspiration) can be estimated by subtracting the moisture flux convergence from the precipitation. This is one of the advantages of gridding; a gridded precipitation data set is useful for estimation of evaporation. During summer over the Ob River, the moisture flux convergence is negative, indicating that evaporation is larger than precipitation. This finding is consistent with those of previous studies (e.g. Fukutomi et al. 2003), though our time period and data set are different. During summer, the precipitation climatology as simulated by ERA40 is underestimated $\sim$ 0.16-0.17 mm day^{-1} and the evaporation climatology overestimated. On the other hand, during winter, evaporation is underestimated in ERA40 simulation. This underestimation might be partly because rain gauges cannot accurately capture snow, but the precipitation over the Lena River basin in APHRO-RU shows quantitatively good agreement with the moisture convergence.

The precipitation maximum over western Siberia in July-August in APHRO-RU (Fig. 4a) lags slightly behind the maximum reported by Fukutomi et al. (2003), who observed a clear maximum in July. This difference is partly due to the different observation time periods; the precipitation maximum occurred in August during 1961-1966 in APHRO-RU (data not shown). We need to carefully investigate changes in the seasonal cycle, because such changes may occur in response to global warming or global climate change associated with human activities.

To understand the hydrological balance over northern Eurasia we also need to investigate the role of interseasonal variation of meteorological fields or transient eddy, and to clarify the possible relation to the seasonal variation. Because APHRO-RU is a high temporal and spatial resolution data set, we can use APHRO-RU high-resolution precipitation data to clarify the mechanisms determining the hydrological balance over northern Eurasia, including the seesaw pattern observed during northern summer.

4 SUMMARY

A gauge-based high-resolution daily precipitation data set (0.5° horizontal resolution) for northern Eurasia, including the countries of the former USSR, for 1960-1990 has been developed as a part of APHRODITE's Water Resources project, on the basis of data homogenized by using the algorithm of Groisman and Rancova (2001). In this analysis, we used this data set to validate the precipitation in the ECMWF 40-year re-analysis and the water balance over northern Eurasia. ERA40 reliably predicts the precipitation pattern throughout the year, but more small-scale structures are found in the APHRODITE product, particularly over mountainous regions, and ERA40 tends to underestimate the wintertime 31-year precipitation climatology.

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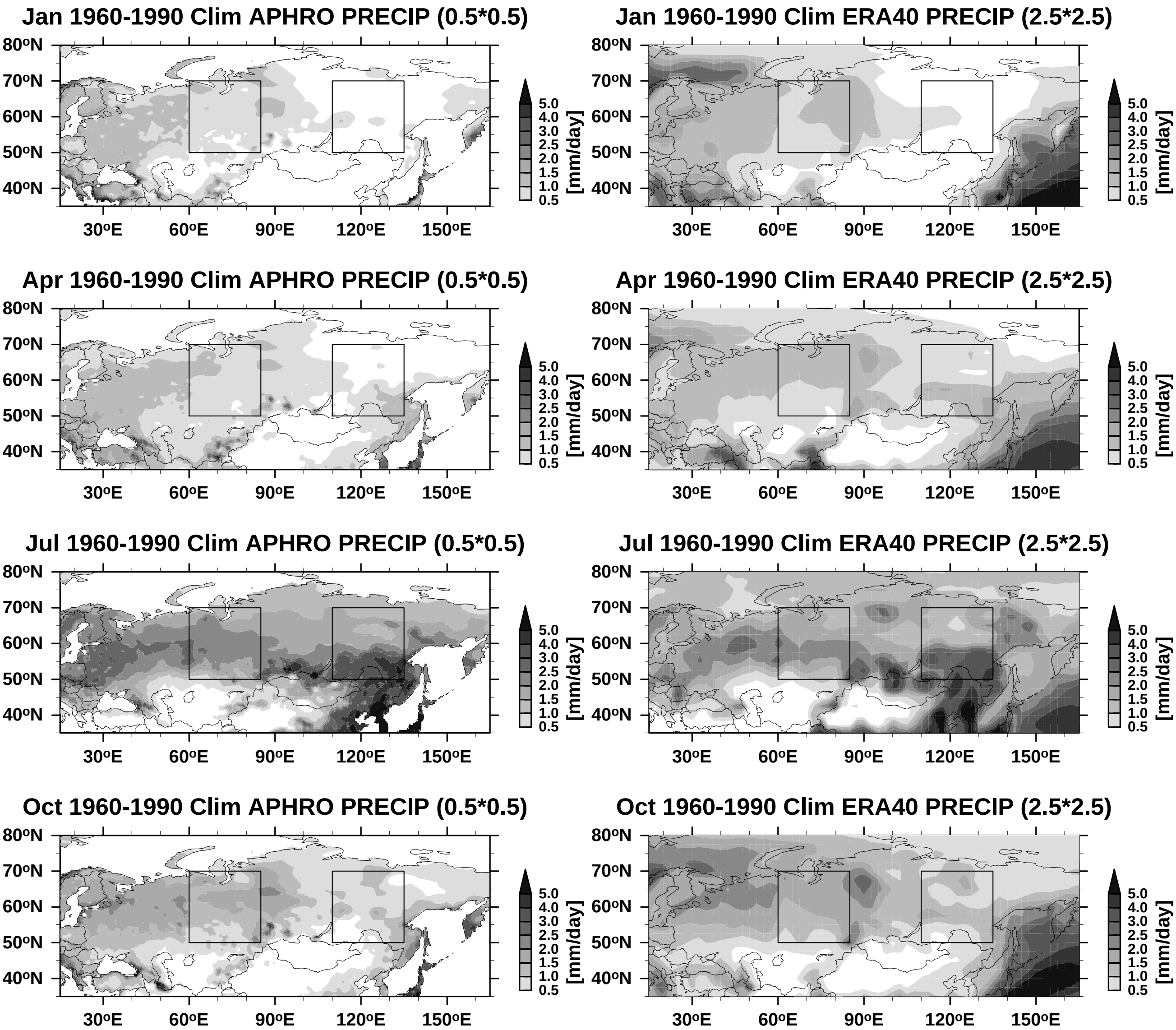

Figure 3: Precipitation climatologies for January, April, July, and October for (a) APHRO-RU on a 0.5°×0.5° grid and (b) the ECMWF 40-year re-analysis on a 2.5°×2.5° grid. The areas enclosed by boxes are eastern Siberia (the Ob River basin) and western Siberia (the Lena River basin).

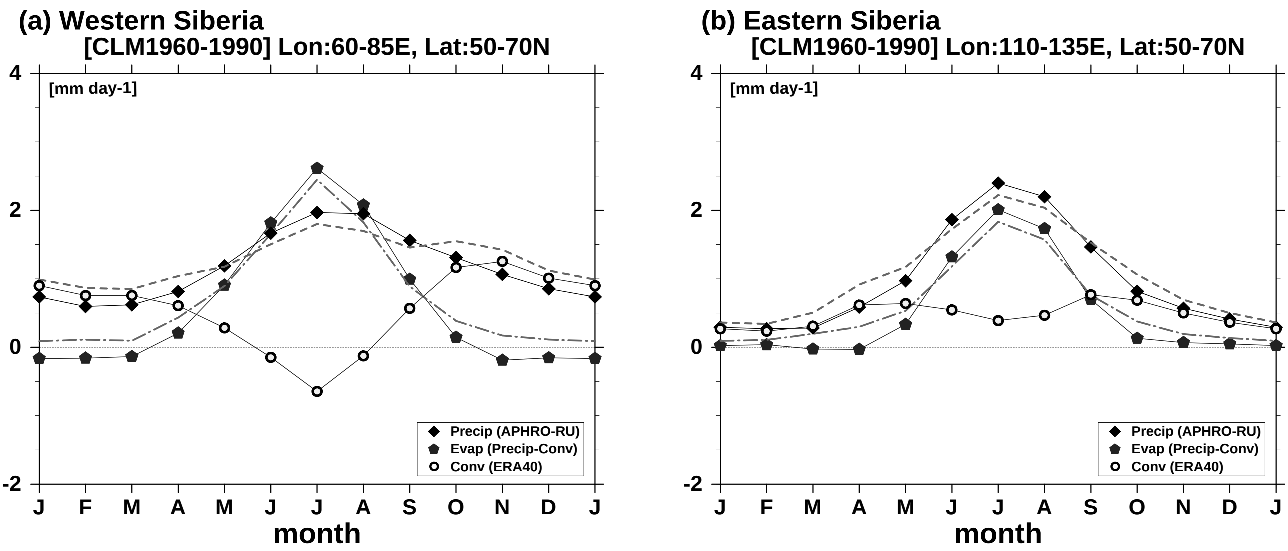

Figure 4: Annual cycle of precipitation (diamonds), moisture flux convergence (open circles), and evaporation (pentagons) over (a) western Siberia and (b) eastern Siberia (see Fig. 1 for the domains). Evaporation was estimated by subtracting convergence from precipitation. Dashed and dotted-dashed lines indicate precipitation and convergence based on total precipitation of the ECMWF 40-year re-analysis instead of on APHRO-RU precipitation.

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