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Verification of the applicability of PRECIS-simulated temperature on the Loess Plateau of China

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ABSTRACT

Temperature is a critical variable in plant growth and water cycle. Under the background of global warming, projection of potential changes in temperature can provide important information for related issues. Although Regional Climate Models (RCMs) are popular for climate projection due to higher resolution compared with General Circulation Models (GCMs), their simulation accuracy should still be assessed in details. By using ERA40 reanalysis data as the boundary conditions to run PRECIS, this study assessed the ability of PRECIS to simulate temperature on the Loess Plateau of China. The spatial distribution and temporal changes of mean, maximum and minimum temperature as well as extreme temperature events from PRECIS were compared with those observed. Results show that the spatial distributions of the observed mean and minimum temperature are simulated with an absolute error of <2 °C in most regions; however, the spatial patterns of maximum temperature are not reproduced well since the absolute error is >2 °C. The temporal trends of three temperature variables are presented similarly as the observed, among which the mean temperature is best simulated; however, the performance differs at different time scales. Although the deviations of monthly temperature are different for each season, the change rates of annual mean temperature are better simulated with deviation of 0.011 °C a^{-1}. For extreme temperature events, most of the simulated indices have similar spatial distribution and temporal trend as the observed, but the deviations of change rates are overvalued . Therefore, the PRECIS-simulated temperature cannot be directly used and further correction should be carried out on the Loess Plateau.

1. Introduction

The Fifth Assessment Report of the Intergovernmental Panel on Climate Change concluded that the global average surface temperature has increased by 0.85 °C from 1880 to 2012 and has greatly altered natural resources and human society [1]. Furthermore, the changes in temperature and their impacts would continue in future; therefore, it is necessary to project potential changes in temperature to provide useful information for development of climate change adaptation strategies.

Projection of climate change mainly depends on GCMs (General Circulation Models), but GCMs cannot provide enough regional climate information due to low horizontal resolution (hundreds of km). Thus precipitation and temperature were poorly simulated at regional scale [2]; Therefore, downscaling is essentially used to improve the performance of GCMs and provide detailed climate change information. Among the downscaling methods, dynamical methods by Regional Climate Models (RCMs) can better simulate the regional characteristics of climate since they can describe detailed topography, sea-land distribution, vegetation and other underlying surface characteristics [3,4]. Therefore, RCMs are useful tools to downscale GCMs.

Some RCMs have been developed to downscale GCMs, such as PRECIS (Providing Regional Climates for Impacts Studies), RegCM4 (Regional Climate Model Version 4) [5–8],CCLM (COSMO model in Climate Mode) [9], MM5V3 (Fifth-generation Penn. State/NCAR Meso-scale Model Version 3) [10] and RIEMS (Regional Integrated Environment Model System) [11]. Among the RCMs, PRECIS has been widely used in India [12], Pakistan [13], South America [14], Mediterranean [15] and other regions for climate projections and impact assessments on crop yield [16], water [17,18] and energy [17,19]. To guarantee the accuracy of climate prediction and impact assessment, the applicability of PRECIS has been evaluated for some regions. Overall, PRECIS can simulate the change trend of climatic variables, but greater errors were detected for the regions with complex topography [5,20]. Therefore, it is still necessary to carry out detailed assessment for a specific region before application.

The Loess Plateau of China (CLP) is famous for its soil erosion in the world due to intensive rainstorms, steep slopes, low vegetation cover and erodible loessial soil [21]. On the other hand, the sustainable development of CLP is restricted by water scarcity since it is located in a semi-humid to arid transition zone. Water resource management is

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thus of utmost importance for this region. However, CLP is sensitive to global warming and tends to be warmer and drier during the past 50 years, which further aggravated water scarcity [22]. Therefore, its future climate should be projected to provide information for soil loss reduction and water resource management. However, the spatial distribution of climate is significantly influenced by the altitude and terrain [23]. The accuracy of RCM should thus be assessed in details for CLP.

The objective of this study is to assess the ability of PRECIS to simulate temperature on CLP by comparing PRECIS-simulated and the observed temperature from 50 weather stations. The evaluation is carried out for the mean, maximum and minimum temperature as well as extreme temperature events about their spatial distribution and temporal changes. The results can present a guideline for model application and calibration.

2. Data and methodology

2.1. PRECIS and dataset

PRECIS is a regional climate modeling system developed by the UK Met Office Hadley Center [24] with relatively high horizontal resolution of 0.44° and 19 vertical levels in atmosphere. The convection scheme is the one proposed by Gregory and Rowntree [25]. The lateral boundary conditions for HadRM3P are available from a range of model(s) and observationally based sources. In the HadRM3P, the surface physics calculations are performed using the four-layer soil model MOSES (Met Office Surface Exchange Scheme) [26].

Two parts of data are needed for model evaluation, i.e. the simulated and observed temperature on CLP. Using ERA40 reanalysis data from ECMWF (European Centre for Medium-Range Weather Forecasts) as boundary conditions, the temperature was simulated with a resolution of 50 km × 50 km for the period of 1960–2000. The observed temperature was collected from 50 weather stations of China Meteorological Administration with the same period. To assess the model performance, the simulated data was extracted for the grids where included the weather stations (Fig. 1).

2.2. Evaluation methods

For climate models, their ability to reproduce the spatial distribution and temporal trend in climatic variables is very important. This study, therefore, compared the two aspects of each variable between the

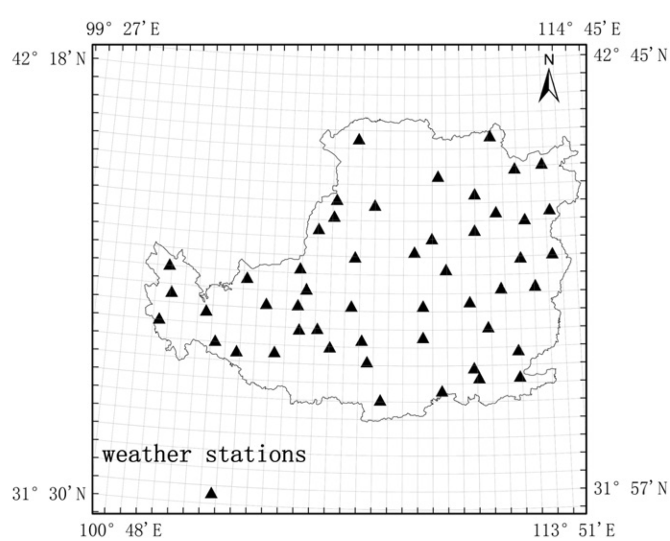

Fig. 1. Location of weather stations and distribution of PRECIS grids.

observed and simulated on different time scales (day, month and year). The variables included three observed indices, i.e. mean temperature (T_{mean}), maximum temperature (T_{max}) and minimum temperature (T_{min}), and five derived indices for extreme temperature events [27] (Table 1). The spatial distribution of each variable was obtained by ordinary Kriging interpolation method, and the differences were computed between the two maps. For temporal trend, the linear trends were computed for each variable and compared between the observed and the simulated. *t*-test, F test and KS (Kolmogorov-Smirnov) test ($p = 0.05$) were used to verify data from two groups whether they have similar mean values, variations and probability distribution.

3. Results

3.1. Spatial distribution of temperature

During 1960–2000, PRECIS can simulate the spatial variations in temperature (T_{mean}, T_{max} and T_{min}), i.e. decrease from southeast to northwest (Fig.2a&b, d&e, g&h). However, some differences are detected (Fig.2c, f&i), and the simulated values are higher than the observed in most areas. For T_{mean} and T_{min}, the differences between the observed and simulated are both <2 °C in most areas (Fig.2c&i); however, those for T_{max} are >2 °C in most areas and are even >4 °C in a north-south zone (Fig.2f).

The spatial variations can be also interpreted by the standard deviation of temperature. The standard deviations of T_{mean} and T_{min} for the observed and simulated are all close to 3.3 °C, and the results of F test show that 30 and 31 stations cannot reject the hypothesis that they have the same variance for T_{mean} and T_{min}, respectively. The above results suggest that the simulated spatial variations in T_{mean} and T_{min} are almost consistent with the observation. However, for T_{max}, the standard deviations of the simulated values are overestimated by 0.8 °C, and only 11 stations pass F test, which implies that PRECIS overestimated the spatial variations in T_{max}.

3.2. Temporal trend in temperature

For daily temperature, PRECIS can satisfactorily simulate the frequency distribution of the observation (Fig.3). T_{mean} is best simulated since the frequency distribution is almost the same as the observation; however, the distribution curve of the simulated T_{max}/T_{min} is slightly moved to the right/left of the observed.

Monthly T_{mean} is slightly overestimated by 0.3 °C for both the mean values and standard deviation averaged across all months (Table 2), and it is overestimated in spring and summer while underestimated in autumn and winter (Fig.4). However, the errors for monthly mean T_{max} and T_{min} are much greater than those of T_{mean}. Monthly T_{max} is overestimated by 3.8 °C while monthly T_{min} underestimated by 1.7 °C (Table 2). The errors of T_{max} are the greatest for March through May with a bias of >5 °C, and those of T_{min} are the greatest from October to March with a bias of >2 °C.

On annual scale, the errors are similar as those for monthly temperature. The deviations of annual T_{mean} are the smallest (0.2 °C), while those

Table 1
Definition of extreme temperature indices.

Name	Define	Unit
ETR	Intra-annual extreme temperature range	°C
FD	Days with absolute minimum temperature < 0 °C	day
GSL	Period between when T_{mean} > 5 °C for >5 d and T_{mean} < 5 °C for >5 d	day
HWDI	Maximum period >5 consecutive days with T_{max} > 5 °C above the 1961–1990 daily T_{max} normal	day
TN90	Percent of time T_{min} > the 90th percentile value of daily minimum temperature	%