Calibrating and Evaluating Reanalysis Surface Temperature Error by Topographic Correction

TIANBAO ZHAO, WEIDONG GUO, AND CONGBIN FU

Key Laboratory of Regional Climate, Environment Research for Temperate East Asia, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China

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ABSTRACT

Based on the observed daily surface air temperature data from 597 stations over continental China and two sets of reanalysis data [NCEP–NCAR and 40-yr ECMWF Re-Analysis (ERA-40)] during 1979–2001, the altitude effects in calibrating and evaluating reanalyzed surface temperature errors are studied. The results indicate that the accuracy of interpolated surface temperature from the reanalyzed gridpoint value or the station observations depends much on the altitudes of original data. Bias of interpolated temperature is usually in proportion to the increase of local elevation and topographical complexity. Notable improvements of interpolated surface temperature have been achieved through "topographic correction," especially for ERA-40, which highlights the necessity of removal of "elevation-induced bias" when using and evaluating reanalyzed surface temperature.

1. Introduction

During the last decades, tremendous progress has been made in developing consistent long-term grid datasets for our understanding of climate variability and climate change when reanalyses of past meteorological observations using modern data assimilation systems developed for numerical weather prediction (NWP) have been used across a wide range of applications, and have become a mainstay of many types of atmospheric research (Schubert et al. 1993; Kalnay et al. 1996; Kistler et al. 2001; Kanamitsu et al. 2002; Gibson et al. 1997; Simmons and Gibson 2000; Uppala et al. 2005). These products provide basic meteorological variables, such as tropospheric pressure heights, humidity and winds, as well as 2-m surface temperature, precipitation, and radiation fluxes. Among those elements, the 2-m surface temperature plays the most important role in investigating the global or regional climate change and variability (Simmons et al. 2004; Schär et al. 2004; Frauenfeld et al. 2005). The reanalysis, however, had problems that made them suboptimal or even unusable for some applications. Perhaps the most serious problem for climate applications was that, while the assimilation system remained unchanged, changes in the observing systems did produce spurious changes in the perceived climate (Bengtsson et al. 2004a,b; Fiorino 1999; WCRP 2000; Trenberth et al. 2001). Therefore, the evaluation and validation of the reanalyzed products, whenever possible, using independent observations, are critical for the latter's proper application (Smith et al. 2001).

China is a big country with a significant portion of land territory of the world characterized by remarkable topographical gradients and complexity. Recently, China's daily surface air temperature data with a dense observation network and consistent observation practices have become available to the scientific community. In this paper, we attempt to study the effects of station elevation in calibrating and evaluating reanalyzed surface temperature in mainland China, which are important for evaluating the reliability of reanalyzed products and the performance of numerical model simulation over this region.

Corresponding author address: Tianbao Zhao, Key Laboratory of Regional Climate, Environment Research for Temperate East Asia, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China.
E-mail: zhaotb@tea.ac.cn

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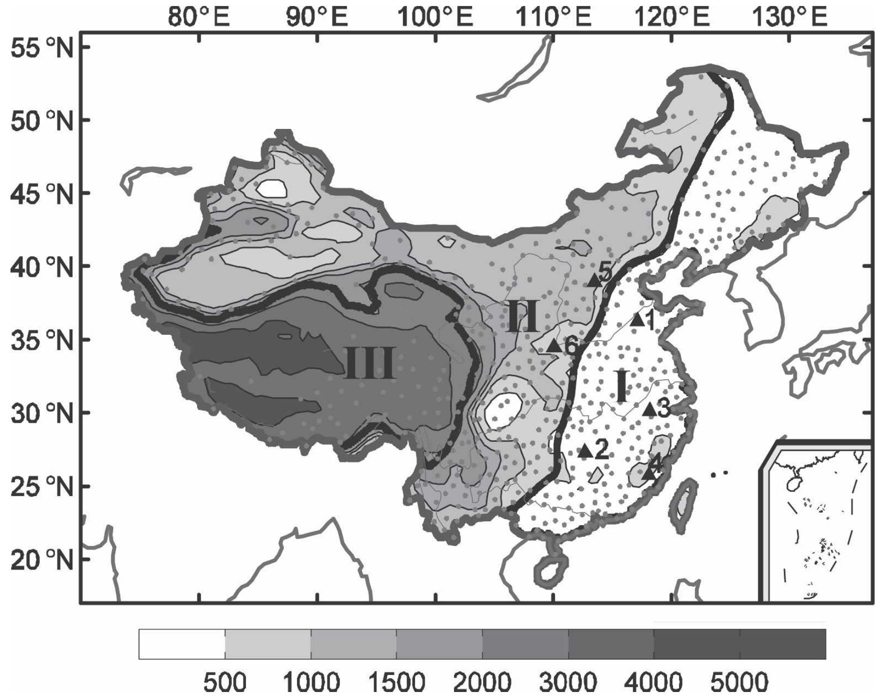

FIG. 1. Division of the three subregions in mainland China with topography (m) and station distribution.

2. Data and method

The reanalyzed monthly mean 2-m surface temperature for the period 1979–2001 is obtained from the National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP–NCAR; Kalnay et al. 1996; Kistler et al. 2001) reanalysis at a resolution of approximately 1.875° × 1.875° (192 × 94 Gaussian grid points) and the 40-yr European Centre for Medium-Range Weather Forecasts (ECMWF) Re-Analysis (ERA-40; Simmons and Gibson 2000; Uppala et al. 2005) on a 2.5° × 2.5° latitude–longitude grid. A daily temperature dataset of 597 stations in mainland China over the same period is utilized for comparison and calibration. A quality control procedure by the National Meteorological Center of the China Meteorological Administration (CMA) was applied to Chinese daily datasets to guarantee the reliability and consistency of the observations (Zhai et al. 1999).

To investigate the topographic effects on reanalysis surface temperature quantitatively, China's mainland territory is divided into three regions: eastern coastal plain–hill regions, Inner Mongolia Plateau–Loess Plateau–Yunnan Guizhou Plateau, and Tibetan Plateau with an average elevation of less than 500 m, 500–3000 m, and over 3000 m, respectively. Figure 1 is the division of the three regions and the location of the meteorological stations. The density of the stations is lower in the sparsely populated high mountainous and desert areas of west and northwest China.

Since the resolutions of the two reanalyzed grid boxes do not match each other, the 2-m surface temperature from the reanalyzed grid was transformed to a finer 0.5° × 0.5° latitude–longitude grid using bilinear interpolation at first. The elevation of the reanalyzed grid was processed in the same way. To evaluate the reanalysis temperature based on consistent spatial resolution, the station values of the observed temperature and elevation were also converted onto the same regular grid adopting the kriging interpolation technique (Phillips et al. 1992; Goovaerts 1997; Hunter and Meentemeyer 2005).

The interpolated surface temperature was calibrated using the topographic correction to remove the errors introduced by the elevation differences in a similar way to that used in the North American Land Data Assimilation System (NLDAS; Cosgrove et al. 2003). The interpolated surface temperature was adjusted at each grid point using the following equation:

$$T = T_{\text{interped}} + \gamma \Delta Z, \qquad (1)$$

where T is the corrected surface temperature (°C) and T_{interped} is the interpolated one (°C); γ is the lapse rate (assumed to be $-6.5°\text{C km}^{-1}$), and ΔZ is the difference

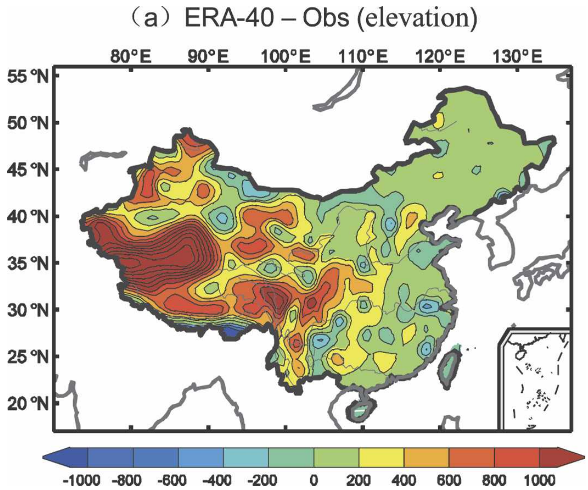

FIG. 2. The differences in elevation and in temperature between ERA-40 and observed values (ERA-40 − Obs) interpolated from the meteorological station using kriging interpolation over China: (a) The difference for elevation (m) and the differences for (b),(d) uncorrected and (c),(e) corrected temperature (°C).

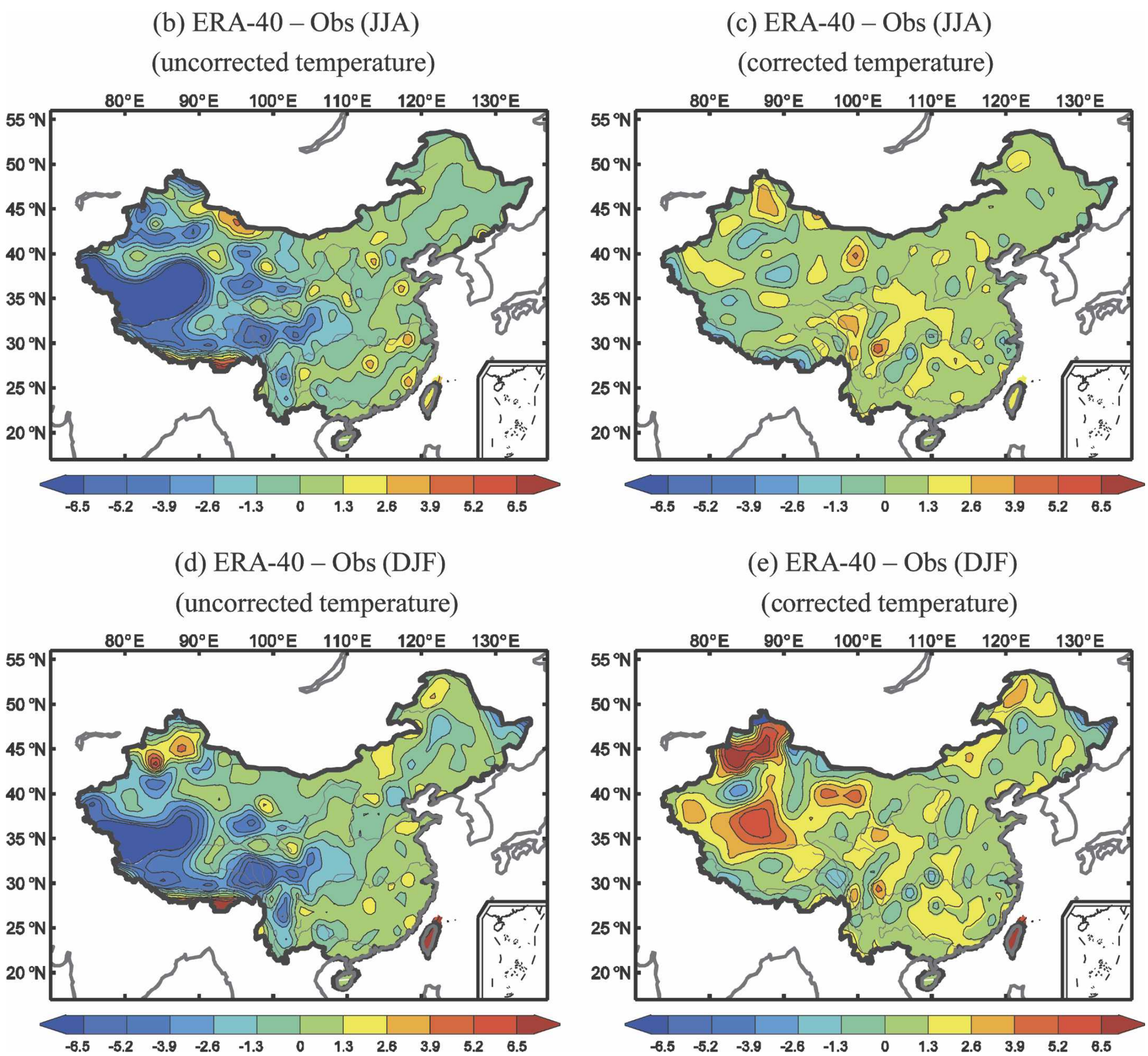

TABLE 1. Correlation and Std of elevation and temperature difference between interpolated reanalysis value and observations in three regions.

		Region I		Region II		Region III	
		Summer	Winter	Summer	Winter	Summer	Winter
Std of elevation difference (m)	ERA-40 − Obs	163.5		276.6		633.7	
	NCEP/NCAR − Obs	165.5		283.8		668.0	
Std of temperature difference (°C)	ERA-40 − Obs	0.95	1.02	1.69	1.57	4.22	3.65
	NCEP/NCAR − Obs	1.36	1.72	2.39	2.39	4.85	4.81
Correlation between the temperature and elevation	ERA-40 − Obs	−0.72	−0.42	−0.85	−0.39	−0.95	−0.88
	NCEP/NCAR − Obs	−0.55	−0.39	−0.78	−0.36	−0.93	−0.75
Std of temperature difference by the topographic correction (°C)	ERA-40 − Obs	0.76	1.12	0.97	1.88	1.34	1.93
	NCEP/NCAR − Obs	1.18	1.63	1.49	2.44	1.74	3.26

in elevations (m) between the interpolated and native topography taken from the 0.5° × 0.5° International Satellite Land Surface Climatology Project (ISLSCP-II) data (http://islscp2.sesda.com/ISLSCP2_1/data/hydrology_soils/hydro1k_elevation_xdeg/).

3. Results

Shown in Fig. 2 are the differences of elevation and surface temperature between the ERA-40 reanalysis and the observations (reanalysis minus observations) before and after topographic correction in mainland China. It is evident that the differences of, not only the elevation, but also the temperature are generally larger in the region with a higher altitude, and vice versa. To investigate the origin of the temperature errors, the differences of elevation between the reanalysis and the observations are presented in Fig. 2a, and the differences of the temperature in summer [June–August (JJA)] and winter [December–February (DJF)] between ERA-40 and the observations are shown in Figs. 2b,c. It is meaningful that the differences of the temperature are nearly inversely proportional to that of the elevation, especially in summer, which means that the interpolated temperature/elevation from native reanalysis or station values is highly dependent on the altitudes of each grid point and topographic complexity. This result may be more obvious in region III where the largest topographic gradient exists.

The correlation coefficients (R) between differences of temperature and elevation for each region are calculated as follows:

$$R = \frac{\sum_{i=1}^{n} (dh_i - \overline{dh})(dt_i - \overline{dt})}{\sqrt{\sum_{i}^{n} (dh_i - \overline{dh})^2}\sqrt{\sum_{i}^{n} (dt_i - \overline{dt})^2}}, \qquad (2)$$

where dh and dt are the difference of elevation and temperature between the interpolated reanalysis and observations, respectively, and $\overline{dh}$ and $\overline{dt}$ are their mean in each individual region. According to Table 1, it is obvious that the temperature bias has a strong negative correlation with the elevation difference in three regions. The minimum coefficient almost approaches −0.40, and the maximum is −0.95: both exceed the 99.9% confidence level. As far as the relationship between the differences of temperature and elevation is concerned, higher correlations are found in summer than in winter.

The standard deviation (Std) of differences of the temperature and elevation is also given as follows:

$$\mathrm{Std} = \sqrt{\frac{1}{n-1}(d_i - \overline{d})^2}, \qquad (3)$$

where d_i is the dh or dt, mentioned above, at each station and $\overline{d}$ is the mean value of d_i in each region. It can be noted that Std of the temperature differences between ERA-40 and the observations increases sharply with elevation difference for both seasons.

As a tentative step, "topographical correction" was conducted for the interpolated temperature of reanalyzed products and observations at each grid. Though such a correction may be very simple, the errors introduced by elevation bias can be greatly removed and a dramatic improvement has been achieved for the interpolated temperature (Figs. 2c,e). For example, the Std of the temperature differences between ERA-40 and the observations in summer is reduced by an average of 43.6%. In winter, the reduction is 47.1% in region III, but Std is actually increased in regions I and II (Table 1). Such results indicate that the effects of the topographic correction have obvious regional dependency (i.e., the larger the region's topographic gradient, the better the corrected effects are expected to be for the interpolated surface temperature).

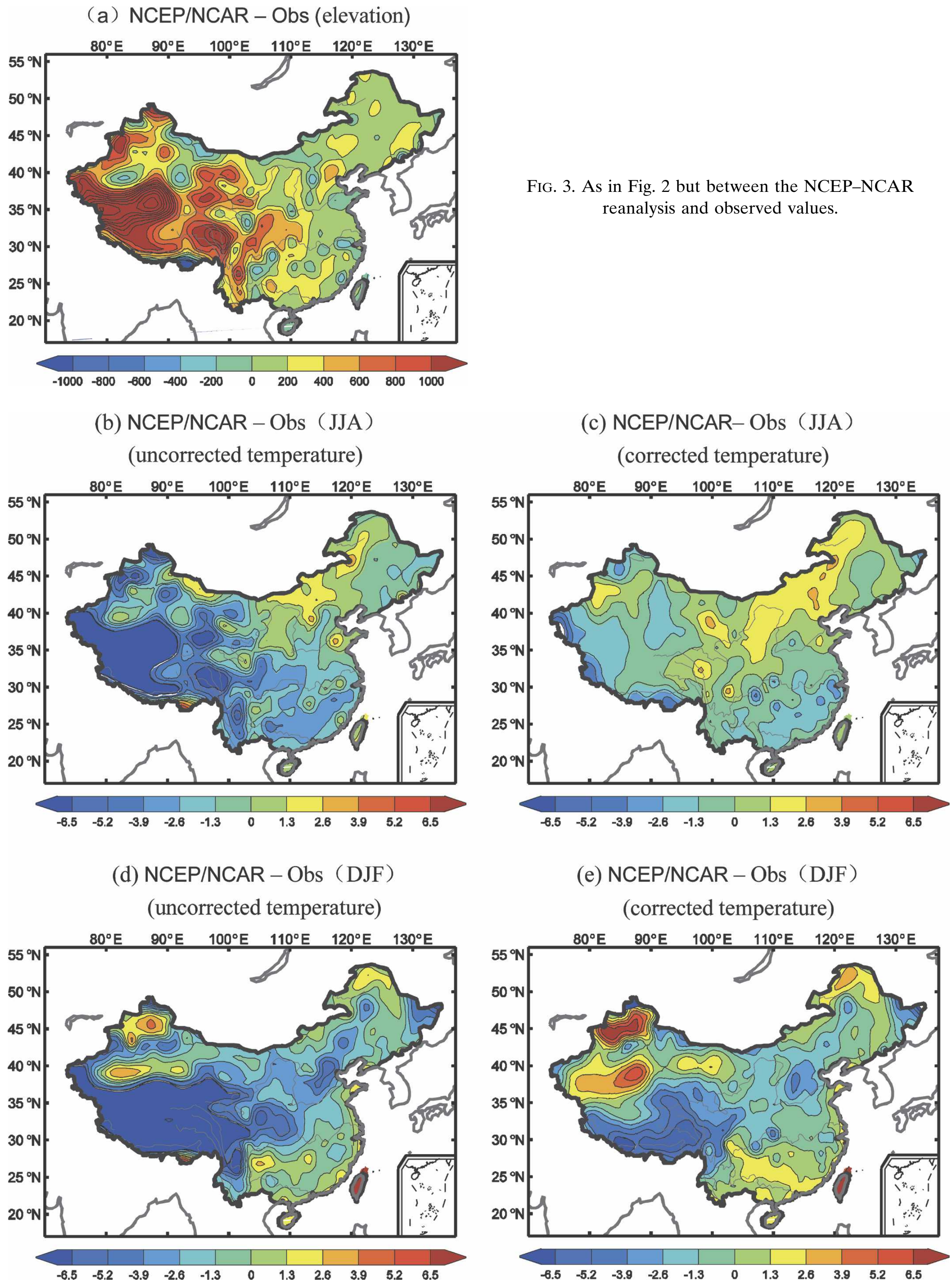

FIG. 3. As in Fig. 2 but between the NCEP–NCAR reanalysis and observed values.

Figure 3 is the same as Fig. 2 except for the differences between the NCEP–NCAR reanalysis and the observations. The correlation of the elevation differences to the surface temperature is somewhat decreased in some areas like regions I and II, which is obvious especially in winter. However, some interesting results can also be obtained similar to the results mentioned above. The correlation coefficients of the temperature bias with the elevation differences are negative and are over the 99.9% confidence level for all regions and both seasons. Table 1 suggests that the accuracy of the surface temperature in ERA-40 is more dependent on model topography than is the case for the NCEP–NCAR reanalysis. The Std of surface temperature differences is reduced by an average of 38.3% for the three regions in summer, but the reduction is only 11.7% in winter.

Dramatic improvements have been achieved through a topographical correction for the interpolated surface temperature, especially in the region with higher altitude and complex terrain, which indicates that the difference of elevation between the interpolated reanalyzed grid cell and the station mainly accounts for the interpolated surface temperature bias. However, the effects of topographic correction also show a seasonal and regional dependency to a certain extent. For example, in northwest Xinjiang (a province of China) and southwest of the Tibetan Plateau, the differences of interpolated surface temperature increase after topographic correction rather than decrease in DJF, and the effects of topographic correction become worse inversely. Besides the overall elevation and the complexity of the terrain, the station density together with the interpolation method can introduce biases when irregular observations are converted into gridded data. Hence, there are many uncertainties in the interpolated observations in the sparsely populated high mountainous and desert areas of west and northwest China due to the lack of the observational coverage. In addition, inconsistencies in both the ERA-40 and NCEP–NCAR assimilated system are the other important error sources for the interpolated reanalysis. That is, the biases of interpolated surface temperature are results of both the observations and the reanalysis. Therefore, to evaluate the reanalysis dataset in west and northwest China in terms of the biases mentioned above is not convincing enough.

According to the above analysis, the ERA-40 calibrated surface temperature is closer to the observations than the NCEP–NCAR counterparts in most areas of China, especially in west and northwest China. While the NCEP–NCAR reanalysis does not assimilate surface observations such as temperature, moisture, and wind (Kalnay and Cai 2003), ERA-40 does incorporate these variables when available. These differences of treatment for surface observations between two assimilated systems could produce many inconsistencies in their products certainly. Therefore, how to improve evaluation for the different reanalysis datasets is very crucial for their proper application to weather and climate studies. The topographical correction may be one of the important ways to evaluate the uncertainties of reanalysis surface temperature.

4. Conclusions

Based on China's daily temperature and two reanalyzed datasets from 1979 to 2001, the topographical effects on interpolated surface temperature errors and their correction are discussed in this paper. The major conclusions are summarized as follows:

1) Obvious biases of interpolated temperature, either from reanalyzed products or from the station observations, are found in mainland China, and ERA-40 is closer to the observations than the NCEP–NCAR reanalysis due to the different treatment of surface observations.
2) The interpolated temperature errors could be mainly (but not solely) attributed to the biases of interpolated elevation because the former varies very well with local elevation and topographical complexity, which indicates the necessity of calibrating reanalysis surface temperature before evaluating their accuracy and utilizing them in climate change studies.
3) Outstanding improvements of interpolated surface temperature have been achieved through a "topographical correction," especially in the boundary areas with a larger altitude difference. The effects of topographic correction for the interpolated surface temperature have a seasonal dependence. The effects of the topographic correction are better in summer than in winter, especially in the sparsely populated high mountainous and desert areas of west and northwest China.

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