Calibrating and evaluating reanalysis surface temperature error by topographic correction

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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-meter surface temperature, precipitation, and radiation fluxes. Among those elements, the 2-meter 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 sub-optimal 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 2004a, b; 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. In this paper, we attempted 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.

2. Data and Method

The reanalyzed monthly mean 2-meter surface temperature for the periods of 1979-2001 are obtained from the National Center for Environmental Prediction / National Center for Atmospheric Research (NCEP/NCAR; Kalnay et al. 1996; Kistler et al. 2001) reanalysis at a resolution of 192×94 Gaussian grid (approximately 1.92°× 1.875°) and the European Centre for Medium-Range Weather Forecast 45-year reanalysis (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.

To investigate the topographic effects on reanalysis surface temperature quantitatively, the China’s mainland territory is divided into 3 regions as Eastern coastal plain-hill regions, Inner Mongolia plateau-Loess Plateau-Yunnan Guizhou Plateau, and Tibetan Plateau with an average elevation of less than 500m, 500 to 3000m and over 3000m, 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 the West and Northwest China.

The 2-meter temperature with the corresponding elevation from the two reanalyzed products and the observations all were transformed to a finer 0.5° × 0.5° latitude-longitude. The reanalysis datasets were interpolated by bi-linear interpolation, and the station values were converted through the kriging interpolation technique. The interpolated surface temperature was calibrated by the topographic correction to remove the errors introduced by the elevation differences at each grid point using the following equation:

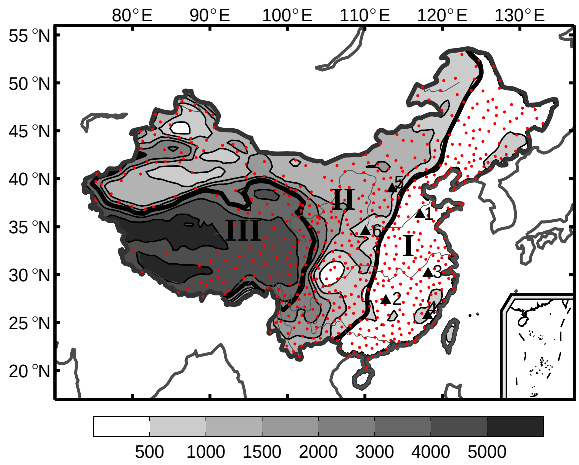

FIG. 1. Division of 3 subregions in mainland China with topography (m) and station distribution

$$T = T_{interped} + \gamma \Delta Z$$

Where T is the corrected surface temperature (℃), and the $T_{interped}$ is the interpolated one (℃), γ is the lapse rate (assumed to be -6.5 ℃ km^{-1}), and the ΔZ is the difference in elevations (m) between the interpolated and native topography taken from the 0.5° × 0.5° ISLCP-II data

3. Results and remarks

Shown in Figure 2 **a**re 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. It is meaningful that the difference of the temperature are nearly in inverse proportion 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. According to Table 1, it is obvious that the temperature bias has a strong negative correlation with the elevation difference in 3 regions. The minimum coefficient almost approaches to -0.40, and the maximum one is -0.95, which all exceed 99.9% confidence level. As far as the relationship between the differences of temperature and elevation are concerned, higher correlations are found in summer than in winter. It can be noted that the standard deviation (***Std***) of the temperature differences between the ERA-40 and the observations increase sharply with elevation difference for both seasons.

"Topographical correction" was conducted for the interpolated temperature of reanalyzed products and observations at each grid. Despite such 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. For example, the ***Std*** of the temperature differences between the ERA-40 reanalysis and the observations in summer are reduced by an average of 43.6%. In winter, the reduction is 47.1% in region III, but the ***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 has the topographic gradient, the better corrected effects are expected for the interpolated surface temperature.

Figure 3 is same as figure2, 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 region 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 the ERA-40 reanalysis 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.

TABLE 1. Correlation and standard deviation of elevation and temperature difference between interpolated reanalysis value and observations in 3 regions

		Region I		**Region II**		**Region III**	
		summer	**winter**	**summer**	**winter**	**summer**	**winter**
The standard deviation of elevation difference (m)	**ERA-40 - Obs**	163.5		276.6		633.7	
	NCEP/NCAR–Obs	165.5		283.8		668.0	
The standard deviation temperature difference (℃)	**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
The 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
The standard deviation of the temperature difference by the topographic correction (℃)	**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

Dramatic improvements have been achieved through a “topographical correction” for the interpolated surface temperature, especially in the region with higher altitude and complex terrains, which indicates that the differences of elevations between the interpolated reanalyzed grid cell and the station mainly account for the interpolated surface temperature bias. However, the effects of topographic correction also show a seasonal and regional dependency to a certain extent. Besides the overall elevation and the complexity of the terrain, the station density together with the interpolation method can introduce biases when the irregular observations are converted into gridded data. Hence, there are many uncertainties existed in the interpolated observations in the sparsely-populated high mountainous and desert areas of the West and Northwest China due to the lack of the observational coverage. In addition, the inconsistencies in the assimilated system are the other important error sources for the interpolated reanalysis. That is, the biases of interpolated surface temperature are resulted both from 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. Due to the differences of treatments for surface observations between two assimilated systems, the ERA-40 calibrated surface temperature is closer to the observations than the NCEP/NCAR counterparts in the most areas of China, especially in the West and Northwest China

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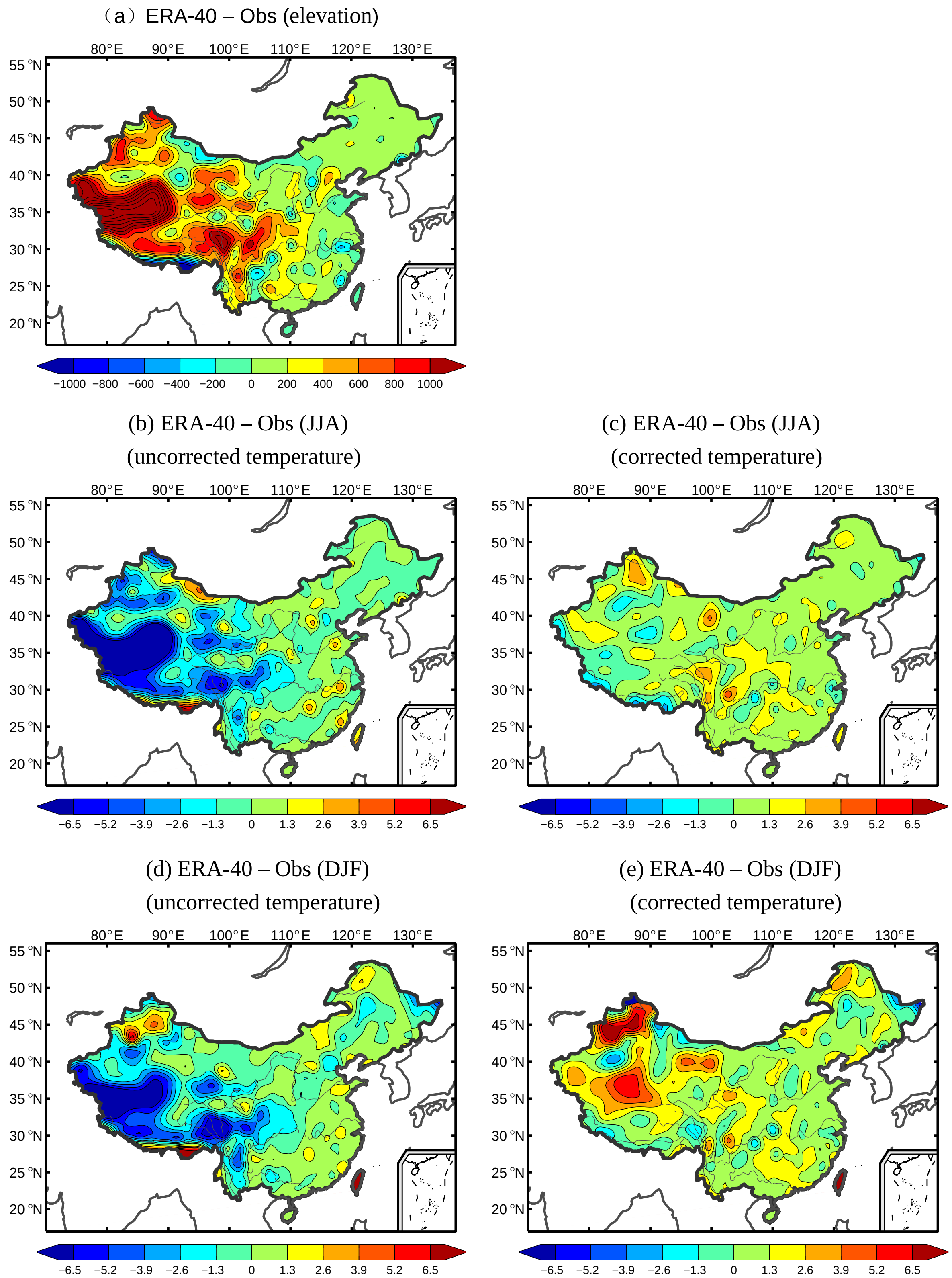

FIG. 2. The differences of elevation and temperature between the ERA-40 reanalysis and observed values interpolated from meteorological station using the Kriging interpolation over China; **(a)** is the difference of elevation (m), **(b)** and **(d)** are the differences of uncorrected temperature (℃), **(c)** and **(e)** are the differences of corrected temperature (℃)

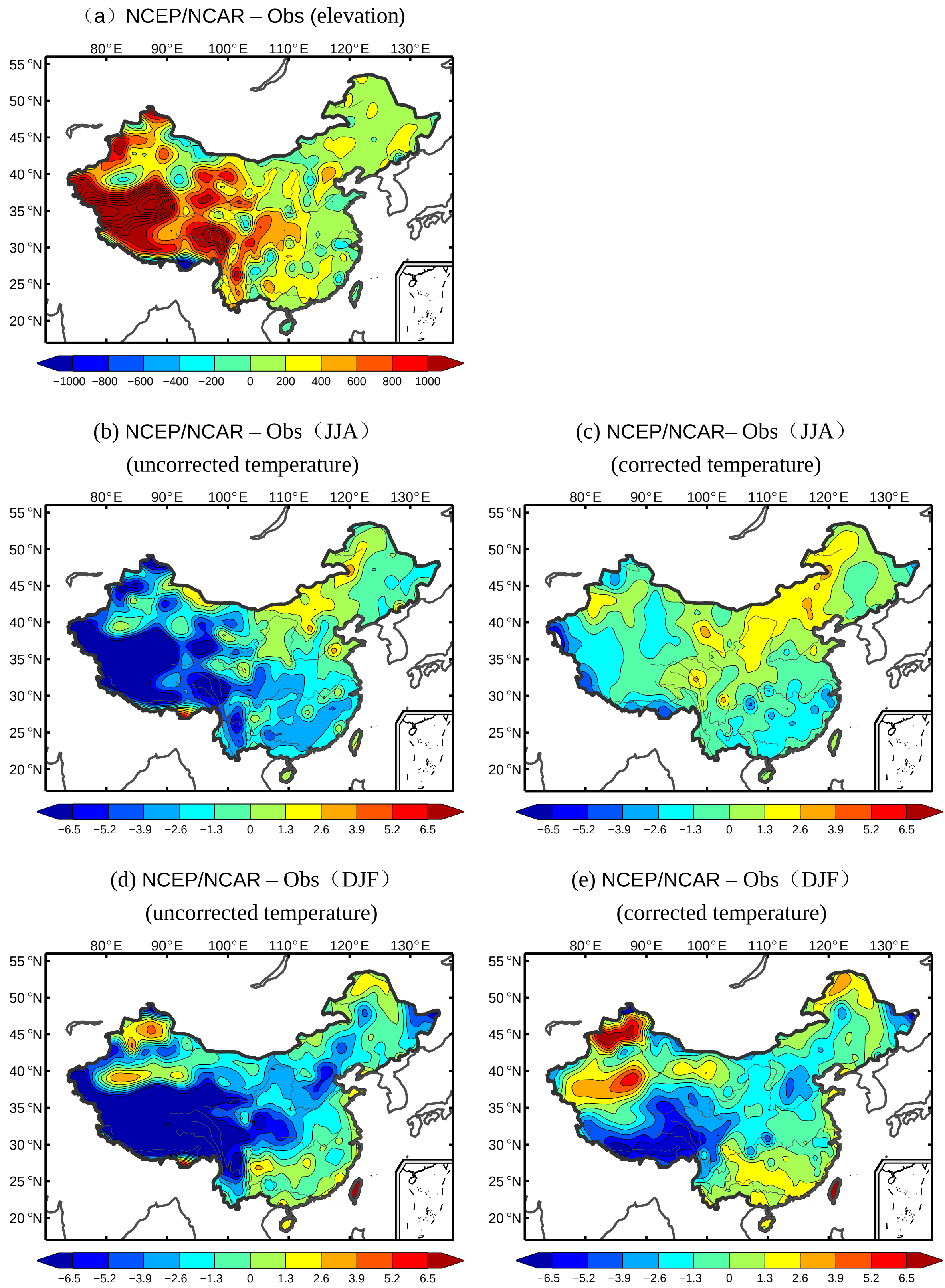

FIG.3. The differences of elevation and temperature between the NCEP/NCAR reanalysis and observed values interpolated from meteorological station using the Kriging interpolation over China; **(a)** is the difference of elevation (m), **(b)** and **(d)** are the differences of uncorrected temperature (℃), **(c)** and **(e)** are the differences of corrected temperature (℃)