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Can temperature extremes in China be calculated from reanalysis?

Qinglong You [a,b,*], Klaus Fraedrich [b], Jinzhong Min [a], Shichang Kang [c,d], Xiuhua Zhu [b], Guoyu Ren [e], Xianhong Meng [f]

[a] Key Laboratory of Meteorological Disaster, Ministry of Education, Nanjing University of Information Science and Technology, Nanjing 210044, China
[b] Max Plank Institute for Meteorology, KlimaCampus, Hamburg 20144, Germany
[c] State Key Laboratory of Cryospheric Science, Chinese Academy of Sciences (CAS), Lanzhou 730000, China
[d] Laboratory of Tibetan Environment Changes and Land Surface Processes, Institute of Tibetan Plateau Research, CAS, Beijing 100085, China
[e] Laboratory for Climate Studies, National Climate Center, China Meteorological Administration (CMA), Beijing 100081, China
[f] Key Laboratory of Land Surface Process and Climate Change in Cold and Arid Regions, CAS, Lanzhou 730000, China

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ABSTRACT

Based on daily maximum, minimum and mean surface air temperature from National Centers for Environmental Prediction/National Center for Atmospheric Research Reanalysis (NCEP/NCAR) and European Centre for Medium-Range Weather Forecasts (ECMWF) reanalyses, the distributions of twenty temperature indices are examined in China during 1958–2011. ECMWF includes ERA-40 for the period 1958–2001 and ERA-Interim during 2002–2011. The consistency and discrepancy of extreme indices between reanalyses and observations (303 stations) are assessed. In most cases, temperature indices between NCEP/NCAR and ECMWF have good agreements. For both reanalysis, cold days/nights have decreased, while warm days/nights have increased since 1980. Temperatures of the coldest days/nights and warmest days/nights significantly increase over the entire China, and the diurnal temperature range demonstrates slight variations; the amounts of growing season length, and summer/tropical days have increased, consistent with the decrease in numbers of frost/ice days. Furthermore, the persistence of heat wave duration and warm spell days has increased and consecutive frost days have reduced. Meanwhile, consecutive frost days, cold wave duration and cold spell days from NCEP/NCAR have decreased and consecutive frost days have increased, while these indices from ECMWF turn to the opposite directions. Compared with observations, temperature extremes from two reanalyses have small relative bias and the root mean squared errors, while correlation coefficients are positively high. These suggest that both reanalyses can reproduce the variability of temperature extremes obtained from observations, and can be applied to investigate climate extremes to some extent, although the biases exist due to the assimilation differences.

1. Introduction

Due to the contradiction between the lack of observations and the increasing demand from the scientific community, it becomes urgent to acquire dataset with high resolution and long record in support of climate research and modeling, especially in the data scarce region such as the Tibetan Plateau (Kang et al., 2010). Reanalysis data refer to the results of state-of-the-art model output, data assimilation of numerical models, and the integration of non-regular observations, rawinsonde, aircraft, satellite and other data sources (Kalnay et al., 1996; Kistler et al., 2001). Reanalysis data extend for several decades, cover the entire globe from the Earth's surface to the above of the stratosphere, and play an extremely important role in the field of atmospheric science and climate research. Meanwhile, reanalysis data can be applied to understand the laws of atmospheric motion, investigate global and regional climate change and variability, identify the causes of climate variations and prepare for the input datasets for climate modeling. Reanalysis data are widely used in atmospheric science, diagnostic analysis, as well as the initial field for driving the regional and global climate models (Kalnay et al., 1996; Kistler et al., 2001; Uppala et al., 2005; Dee and Uppala, 2009).

However, it is noticed that that reanalysis data should not be equated with "observations" and "reality". The changing mix of observations and biases between observations and models can produce spurious variability and trend in the reanalysis. Zhao and Fu (2006) divided the reanalysis errors into the two classifications: (1) observing system changes such as lack of observations and errors in observations may lead to discrepancies and errors in reanalysis products, which can be regarded as the systematic errors; (2) numerical prediction models and assimilation programs such as shortcoming in the assimilating model/methodology can produce inaccurate/false data for reanalysis data. In summary, the uncertainties in the reanalysis data are difficult to understand and qualify, and more recent researches are to facilitate comparisons between reanalysis and observational datasets (Bengtsson et al., 2004; Simmons et al., 2004).

The widespread used reanalysis included the National Centers for Environmental Prediction/National Center for Atmospheric Research

* Corresponding author at: Key Laboratory of Meteorological Disaster, Ministry of Education, Nanjing University of Information Science and Technology, Nanjing, 210044, China.
E-mail address: yqingl@126.com (Q. You).

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Reanalysis (NCEP/NCAR hereafter) (1948–present) (Kalnay et al., 1996) and European Centre for Medium-Range Weather Forecasts (ECMWF) 40 year reanalysis (ERA-40 hereafter) (1957–2002) (Uppala et al., 2005). ERA-Interim is the latest global atmospheric reanalysis produced by ECMWF covering the data since 1979 (Dee et al., 2011), and it is regarded as the new, more ambitious and next generation reanalysis to succeed ERA-40 (Dee and Uppala, 2009). On the global and regional scales, several studies have been retrieved different parameters and variables from reanalysis to compare the credibility with observations (Kalnay et al., 1996; Su et al., 1999; Zhang and Qian, 1999; Xu et al., 2001; Wei and Li, 2003; Simmons et al., 2004; Frauenfeld et al., 2005; Zhao and Fu, 2006; Xie et al., 2007; Zhao et al., 2007, 2008; You et al., 2009). However, the results are sensitive to the time period, regions, and selected observations.

In China, the observed surface air temperatures have been applied to evaluate the applicability of NCEP/NCAR reanalysis. The preliminary analysis shows that the monthly mean temperature from reanalysis is lower than the observed value. On a seasonal basis, surface air temperature in summer has a good credibility for reanalysis, while the winter has a poor credibility (Xu et al., 2001; Zhao and Fu, 2006; Ma et al., 2008; Zhao et al., 2008). Compared with NCEP/NCAR, ERA-40 reanalysis represents the temperature of the lower troposphere over East Asia very well, and can be used to study the inter-decadal climate change in that region (Huang, 2006). There are studies focusing on the applicability of reanalysis in the Tibetan Plateau. It is found that the surface air temperature from NCEP/NCAR does not identify significant warming and there are large geographical differences, while it shows more pronounced warming in the North China Plain region (Su et al., 1999; Xu et al., 2001; Ma et al., 2008). Over the Tibetan Plateau and its vicinity, Su et al. (1999) analyzed and tested the credibility of NCEP/NCAR reanalysis, and pointed out that the reanalysis is more reasonable because the mean distribution patterns from reanalysis are similar to observations. Wei and Li (2003) carried out the applicability of NCEP/NCAR reanalysis along the Qinghai-Tibet Railway, and found systematic temperature values obtained from reanalysis are less than the actual observed values. Frauenfeld et al. (2005) compared ERA-40 reanalysis with observations, and revealed that ERA-40 reanalysis is less susceptible to the influence of the local assimilation system after the spectral models with the real terrain are used. Xie et al. (2007) investigated two automatic weather stations' data in the southern Nyainqentanglha Mountains and Everest Northern Slope, and compared them with NCEP/NCAR reanalysis. They indicated that NCEP/NCAR reanalysis can reflect changes in the temperature at the synoptic scale, but temperature value from reanalysis is lower than the corresponding observed values. You et al. (2009) analyzed the applicability of NCEP/NCAR reanalysis in the glacier nearby Namco Lake district, and illustrated that reanalysis of the temperature is relatively good, and application of reanalysis in the critical region should take the impact of altitude into account. These results are identified for the surface air temperature in the entire Tibetan Plateau by the comparisons between observations and reanalyses including NCEP/NCAR and ERA-40 reanalysis (You et al., in press).

Overall, the applicability of reanalysis has been assessed and compared with the climate mean anomalies (such as the monthly and annual mean temperature). Fewer studies have been focused on the extreme climate and weather events such as extreme heat waves, extreme low temperatures, cold wave duration, which are more sensitive to climate change than their mean values (IPCC, 2007). Reanalysis data can be a potentially useful source of data for monitoring long-term changes in extremes in data sparse regions, but they have not been used in the field of temperature extremes (Zhang et al., 2011). The purpose of the present study is to evaluate the climate extremes calculated from reanalysis in China, the applicability of the inter-annual climate is evaluated with observations, which are needed to better understand the pattern, cause, frequency and intensity of climate extreme in China.

2. Data and methods

2.1. Reanalysis data

In this study, the daily maximum, minimum and mean temperatures from NCEP/NCAR, ERA-40 and ERA-Interim reanalysis are selected, which are in accordance with 190 grid points covering the entire China (Fig. 1). NCEP/NCAR reanalysis is provided by the National Oceanic and Atmospheric Administration (NOAA)/Earth System Research Laboratory (ESRL)/Physical Sciences Division (PSD), Boulder, Colorado, USA, from their website at http://www.cdc.noaa.gov/. The datasets cover January 1948 to the present with a spatial resolution of $2.5° \times 2.5°$ (Kalnay et al., 1996), and are initialized with a wide variety of weather observations, including ships, planes, satellite observations. The daily maximum, minimum and mean temperatures of ERA-40 and ERA-Interim reanalysis data are obtained from the ECMWF website (http://www.ecmwf.int/). For ERA-40 reanalysis, it is available from September 1957 to August 2002 with a spatial resolution of $2.5° \times 2.5°$ (Uppala et al., 2005). Compared with NCEP/NCAR, ERA-40 is produced by use of a wide range of observing systems, such as the satellite data and vertical temperature profile radiometer radiances starting in 1972 (Ma et al., 2009). Due to ERA-40 stop by 2002, ERA-Interim (1979–present) is used to extend ERA-40 to the present. It is shown that the difference of temperature between ERA-40 and ERA-Interim is slight during the overlapping period (1979–2001) (Fig. 1). Thus ERA-40 is used before 2001 ERA-Interim is applied after 2001 for this study. ERA-Interim use input observations prepared for ERA-40 until 2002 and has a spatial resolution of $1.5° \times 1.5°$ (Dee et al., 2011). Both NCEP/NCAR and ERA-40 were assimilated using a 6-hourly 3D variational analysis (3DVAR), but ERA-Interim is based on a 12-hour four-dimensional variational analysis (4DVAR). Furthermore, the surface sea temperature and sea-ice concentrations described as boundary conditions differ in each reanalysis, and the forecast models and physical parameterizations are also different (Zhang et al., 2012). To qualify the comparison, all reanalyses are interpolated into $2.5° \times 2.5°$ horizontal resolution using the linear interpolation methods.

2.2. Observations

To validate the reanalysis data, the daily maximum, minimum and mean temperatures for 303 stations are used in China (Fig. 1), provided by the National Meteorological Information Center, China Meteorological Administration (NMIC/CMA). The quality of observational data in China, meeting the World Meteorological Organization's (WMO) standards, and the climate extreme and its connection with atmospheric patterns have been discussed (You et al., 2011). For the calculation of observations, the internationally agreed indices are adopted, which are generated by the WMO Commission for Climatology (CCl), the World Climate Research Program (WCRP) project on Climate Variability and Predictability (CLIVAR) and Joint WMO-Intergovernmental Oceanographic Commission (IOC) Technical Commission for Oceanography and Marine Meteorology (JCOMM) Expert Team (ET) on Climate Change Detection and Indices (ETCCDI) (http://cccma.seos.uvic.ca/ETCCDI) (Peterson and Manton, 2008). Releasing climate indices and sharing the ETCCDI's indices are of great use to scientific community working on adaptation and climate model validation. In this study, the ETCCDI's indices from observations derived from You et al. (2011) will be applied to compare and validate the reanalyzed temperature extremes indices.

2.3. Extreme indices and calculation

Twenty temperature indices are selected in this study (Table 1). As it can be seen, some indices are commonly used to assess the intensity, frequency and duration of climate extreme events, and widely analyzed on the regional and global scales (e.g. Alexander et al., 2006; Peterson