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Variation in surface air temperature of China during the 20th century

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Abstract

The 20th century surface air temperature (SAT) records of China from various sources are analyzed using data which include the recently released Twentieth Century Reanalysis Project dataset. Two key features of the Chinese records are confirmed: (1) significant 1920s and 1940s warming in the temperature records, and (2) evidence for a persistent multidecadal modulation of the Chinese surface temperature records in co-variations with both incoming solar radiation at the top of the atmosphere as well as the modulated solar radiation reaching ground surface. New evidence is presented for this Sun–climate link for the instrumental record from 1880 to 2002. Additionally, two non-local physical aspects of solar radiation-induced modulation of the Chinese SAT record are documented and discussed.

Teleconnections that provide a persistent and systematic modulation of the temperature response of the Tibetan Plateau and/or the tropospheric air column above the Eurasian continent (*e.g.*, 30°N–70°N; 0°–120°E) are described. These teleconnections may originate from the solar irradiance-Arctic–North Atlantic overturning circulation mechanism proposed by Soon (2009). Also considered is the modulation of large-scale land–sea thermal contrasts both in terms of meridional and zonal gradients between the subtropical western Pacific and mid-latitude North Pacific and the continental landmass of China. The Circum-global teleconnection (CGT) pattern of summer circulation of Ding and Wang (2005) provides a physical framework for study of the Sun–climate connection over East Asia. Our results highlight the importance of solar radiation reaching the ground and the concomitant importance of changes in atmospheric transparency or cloudiness or both in motivating a true physical explanation of any Sun–climate connection. We conclude that ground surface solar radiation is an important modulating factor for Chinese SAT changes on multidecadal to centennial timescales. Therefore, a comprehensive view of local and remote factors of climate change in China must take account of this as well as other natural and anthropogenic forcings.

Highlights

► Evidence for a persistent multi-decadal effect on Chinese air temperature is found. ► Evidence for a Sun-climate link, including a unique solar fingerprint, is uncovered. ► Demonstrable solar forcing of Chinese temperature changes at multidecadal timescales.

Introduction

Instrumental temperature records in China for the 20th century have long been suggested to represent variations and changes of climate for an area far broader than China alone (Zhu, 1973, Bradley et al., 1987, Wang and Gong, 2000, Tang et al., 2009). As early as 1962, Chinese surface air temperature (SAT) records constructed by Wang et al., 2001, Wang et al., 2004 were shown to contain significant warming peaks and trends in the first half of the 20th century. The final compilation (summarized in Wang et al., 2001, Wang et al., 2004 with the most recent update and intercomparison reported by Tang et al. (2009)) aggregated from ten regional SAT series from 1880 to 2002 shows three significant decade-long warming intervals during the 1920s, 1940s, and 1990s (see highlights in Fig. 1a) as well as the extended relative cooling phase between the 1950s and early 1980s. The early 20th century warming in China offered the opportunity for a full examination of the concomitant natural warming across the globe with evidence extending across the Arctic–North Atlantic–North American–North Pacific regions (Diaz and Quayle, 1980; Rogers, 1985; Fu et al., 1999; Drinkwater, 2006; Holland et al., 2008; Kauker et al., 2008; Box et al., 2009; Bronninmann, 2009; Helama et al., 2010; Wood and Overland, 2010; Wood et al., 2010; Frauenfeld et al., 2011; see also Soon (2009) for additional evidence and synthesis) to the Indian ocean and tropical Pacific (Fu et al., 1999, Giese et al., 2010). It is important to note that the warming of the 1920s can be shown to relate to warming in the subsurface water in the Greenland and North Atlantic regions (Drinkwater, 2006, Holland et al., 2008). Further, such a double-peak warm interval[1] (*i.e.*, the 1920s and 1940s) also appears in the composite index from eight ice cores in West Antarctica (*i.e.*, measurements of water stable isotopes, either $\delta^{18}O$ or δD, as proxies of West Antarctic surface temperature) compiled by Schneider and Steig (2008, see their Figure 1a).

Significantly, Bronninmann (2009) called for a more thorough investigation of these early 20th century warming tendencies using regional temperatures because globally or hemispherically averaged data can hide physical insights. In heeding Bronninmann's (2009) call, this paper focuses on the 1920s and 1940s warming in the SAT record for the whole of China. Moreover, this warming is most likely naturally induced as Wood and Overland (2010) correctly remark that “greenhouse gas forcing is not now considered to have played a major role” for the observed warming in 1920s and 1940s in the Arctic and elsewhere. By contrast, the rapid warming of 0.5 °C/decade in the China-wide SAT data since the mid-1980s (Wang and Gong, 2000) has raised the possibility of early detection of the imprints of anthropogenic CO_2 global warming in the Chinese record over large geographical areas with middle to high elevations (>2000 m; namely the Qinghai–Tibetan [or Xi-Zang in Chinese] Plateau; see Wu et al. (2007) for a detailed physical discussion of the mechanical and thermal forcing by the Qinghai–Tibetan Plateau).

Regarding the potential warming from increasing atmospheric CO_2, several authors including Wang and Gong (2000) have noted that, the overall warming temperature history of China and the globe during the 20th century can be interpreted as a natural and persistent recovery from the Little Ice Age of AD 1300–1900 (*e.g.*, Zhu, 1973, Wang and Zhang, 2011, Hameed and Gong, 1994, Hsu, 1996, Wang et al., 2001, Yang et al., 2002, Soon et al., 2003, Wang et al., 2006, Akasofu, 2010, Ge et al., 2010, Lee and Zhang, 2010) for it is hardly conceivable for all the natural warming and cooling processes to cease suddenly in the late 20th century. Wang and Gong (2000) highlighted that “the warming time series in China indicates a sinusoidal variation over the past hundred years and is different than for global average.”

Zhou and Yu's (2006) attempt to simulate the Chinese SAT using theoretical insight and climate modeling results have been met with both successes and failures. Figure 1 of Zhou and Yu (2006) shows the similarities and differences between the China-wide and Northern Hemisphere or globally averaged time series, including the very distinctive characteristic of the 1920s and 1940s warming in China. The key lesson of Zhou and Yu (2006) was the failure of any climate model, even by those forced with sea surface temperatures (SST), to capture the early warming of the 1920s as well as the insufficiency of atmospheric CO_2 forcing to explain the warming trend in the last half of the 20th century in China. Remarkably, Zhou and Yu (2006) encouraged international modeling groups to make model runs without forcing by well-mixed greenhouse gases, including anthropogenic CO_2 forcing.

This exemplifies critical insights that are required to understand all factors that affect climatic change. Such a call is scientifically significant in that it argues for the importance of understanding key natural processes that led to decadal and multidecadal variations found in the instrumental temperature records. In this paper, we use such an approach to investigate the role of the local and non-local forcing-feedback responses that are created by persistent variations in the incoming solar radiation at the top of the atmosphere and/or the modulated solar radiation reaching ground

surface as represented specifically both by Total Solar Irradiance (TSI) and sunshine duration (SSD) indices, respectively (see more explanation of this in Section 2).

Recent progress reports from Chinese meteorologists and climatologists (*e.g.*, Zhao et al., 2005, Wang et al., 2006, Ding et al., 2007, Zhou et al., 2009a, Qian et al., 2010) placed similar emphasis on understanding natural factors of climate change as well as those resulting from anthropogenic forcing. In addition to anthropogenic emissions of gases and aerosols (Qian et al., 2007, Chung et al., 2010), it is clear that anthropogenic factors can result in local and regional climatic changes that were forced by significant land-use changes in China over the last 50 years. These effects include the damming of rivers, urbanization, irrigation, changing agricultural practices as well as the changing areas of forested and desert land surfaces (Zhou et al., 2004, Zhang et al., 2005, Ren et al., 2008, Yang et al., 2011). Although anthropogenic effects are not limited to just CO_2 emissions, it is expected that local and even regional temperature trends, such as the China-wide time series adopted in this study, will contain useful information for examining the physical processes involved. It is expected that several of the non-local and solar radiation-induced forcing-feedback mechanisms (for criticisms of studies of climate change that consider only a single causal factor, for example, the increase of atmospheric CO_2, see Soon, 2007, Pielke et al., 2009, Soon and Legates, 2010) will arise from these physical processes.

China is large geographically, has a long geological history, and exhibits strong seasonality in temperature variations such that processes that affect China must be critically examined. For example, the modeling study by Li et al. (2007) attributed the summer cooling trend over Eastern China since the 1950s to dynamical and thermal responses induced by regional anthropogenic sulfate aerosol forcing. But the quantitative effects of aerosol radiative forcing are highly uncertain in both sign and amplitude (Anderson et al., 2003, Kiehl, 2007, Knutti, 2008, Myhre, 2009, especially his Figure 1). Zhao et al. (2005) have outlined also the relevant meteorological and climatic processes that affect both the summer and winter monsoonal climate in China. These range from the El Niño/Southern Oscillation phenomenon (ENSO), snow cover and depth over the Tibetan Plateau, locations of the Siberian High, sea surface temperatures of the Indian Ocean, and the North Pacific Ocean, as well as atmospheric circulation indices such as the North Atlantic Oscillation, Arctic Oscillation, Western Pacific subtropical high, and even the Antarctic Oscillation (Zhao et al., 2005). Qian et al. (2010) raised an even more fundamental issue of the need for a proper reference frame, arguing for the use of a modulated annual cycle as opposed to the traditional anomaly of changes in the mean climatology over time. This provides for a more correct physics-based study of the multi-timescale variability of the surface air temperature variations in China. However, we concede at the outset that a full quantitative accounting of the SAT variations for all spatial domains and temporal scales in China is not yet possible.

We also refer to the cited references for discussions on interannual variations that are linked and correlated to the more dynamic, both local and non-local, indices and variables such as ENSO, winter and summer monsoonal circulation indices, Indian Ocean SST, and the western Pacific subtropical high. We await future studies using more sophisticated statistical analyses and tools (*e.g.*, Qian et al., 2010) to unravel the complex spatial–temporal patterns of the variability of the ten regional Chinese climate records that must necessarily involve the precipitation records (Wang et al., 2004) as well as various other natural and anthropogenic factors discussed above. An important discussion has been initiated by B. Wang et al. (2008) where the warming of the Tibetan Plateau over the past 50 years has been shown to enhance subtropical frontal summer rainfall in East Asia.

Finally, we wish to emphasize, as in Soon (2009; see clarification on pp. 148–149), that the focus here is on multidecadal variations/signals in the Chinese SAT records. We have largely avoided discussion on changes and variations on interannual and even decadal timescales that are required to account for variations in the solar UV radiation as well as the complex dynamic coupling involving the stratosphere and troposphere. To support our focus on multidecadal variations using only the instrumental thermometer records studied here, we supplement our discussion with available paleoclimatic evidence (Section 3 below). For the convenience of the reader, we list all acronyms in this paper in Appendix A.

Section snippets

China-wide surface air temperatures

We adopt a primary surface air temperature record (SAT) for China (from 1880 to 2002) based upon the 10-region-averaged reconstruction by Wang and Gong (2000) and Wang et al., 2001, Wang et al., 2004. This homogenized SAT time series attempts to resolve issues associated with the urban heat island and other non-climatic discontinuities resulting from historical land use changes, though the impact of such issues still range between quantitatively significant (Portman, 1993, Zhou et al., 2004, …

Results and discussion

Annual-mean SAT time-series for China are presented from 1870 to 2008 by (1) Peking University (Wang et al., 2001, Wang et al., 2004), (2) Chinese Academy of Meteorological Science (Lin et al., 1995), (3) CRU (Mitchell et al., 2002), and (4) for 1871–2008 from 20CRv2 dataset (Compo et al., 2011). Although good agreement exists among these four sources, especially post-1979, large qualitative and quantitative differences exist prior to 1979 (Fig. 1b).

The 20CRv2 reanalysis product is based upon…

Conclusion

We have presented evidence that China's surface air temperatures during the 20th century were influenced by variations in both the incoming solar irradiance and ground surface solar radiation. This argues for a significant role for Sun–Earth relationships as a natural cause for observed multidecadal climate oscillations. Such an argument is distinct from, and also an alternative to, the allocation of a dominant anthropogenic cause for the variation in Chinese SATs since 1980. Both empirical…

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We thank Dr. TianJun Zhou for sharing with us the 10-region averaged Chinese temperature record of Professor Shao Wu Wang of Peking University and Drs. Gerald Stanhill and Shabtai Cohen for sharing their compilation of the Japanese sunshine duration data. We also thank Drs. Gene Avrett, Bob Carter, and two anonymous referees for a careful reading of the manuscript and suggesting important improvements.…

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