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Short Communication

Global land-surface air temperature change based on the new CMA GLSAT data set

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The China Meteorological Administration (CMA) has recently developed a new global monthly homogenized land-surface air temperature data set. Based on this data set, we reanalyzed the change in global annual mean land-surface air temperature (LSAT) during three time periods (1901–2014, 1979–2014 and 1998–2014). The results show that the linear trends of global annual mean LSAT were 0.104 °C/decade, 0.247 °C/decade and 0.098 °C/decade for the three periods, respectively. The trends were statistically significant except for the period 1998–2014, the period that is also known as the "warming hiatus". Our analysis generally confirms the spatial differences of global land warming over the two longer periods (since 1901 and 1979), as reported in previous Intergovernmental Panel on Climate Change (IPCC) assessment reports, but shows that the recent "warming hiatus" period was characterized by a slower warming or even a cooling trend in the low to mid-latitude zones of the two hemispheres.

Global land-surface air temperature change is an important indicator to characterize recent climate change [1]. In recent decades, several global LSAT data sets have been developed and continuously improved [1]. These include the Climatic Research Unit Temperature database/Climatic Research Unit (CRUTEM/CRU) [2], the Global Historical Climatology Network/National Centers for Environmental Information (GHCN/NCEI) [3] and the Goddard Institute for Space Studies Surface Temperature Analysis/Goddard Institute for Space Studies (GISTEMP/GISS) [4]. The Berkeley Earth/Berkeley Earth Surface Temperature (Berkeley Earth/BEST) [5] and the Japan Meteorological Agency [6] also developed their own data sets in recent years.

Monitoring and studies of global annual mean LSAT changes have been made based on these data sets, and the analysis products from these works have been widely used in the climatological community. On the basis of these products, the IPCC Assessment Report 5 (IPCC AR5) concluded that global LSAT has significantly increased since 1860 or 1900 and that this warming has been particularly marked since the late 1970s [1]. However, studies have also found that there are uncertainties in the analysis results using these data sets [7]. Because of the varied data sources, homogenization methods and region-averaging methods, the global LSAT time series produced slightly different linear trend results, especially for the last century and since 1979 [1,8]. One major problem is related to the relatively poor coverage of stations across Antarctica, Africa, South America, and Asia in the early years, which has continued in the recent period [9,10]. The IPCC AR5 concluded that the warming trends in these regions are associated with a lower confidence level [1]. Another issue is the absence of early period stations, especially before 1940. It has been found that global land-surface temperature trends can be estimated using only 172 "independent stations" [11], but this conclusion was drawn based on only a basic understanding of global climate change characteristics. Based on statistical analyses, Thorne et al. [12] indicated that better station spatial coverage can help to reduce the "structural uncertainty" of the time series. This may explain why the BEST data set produced much smaller error ranges of temperature anomalies than the other global LSAT data sets [1].

The CMA has recently developed a new global LSAT data set, referred to hereafter as CMA GLSAT-v1.0 [10]. Its sources consist of three original global data sets (CRUTEM4, GHCN-V3 and BEST), eight national data sets (Canada national climate and weather data archive, Australia high-quality climate change data set, United States Historical Climatology Network (USHCN) data set, Korean exchange data set, Vietnam exchange data set, and the data sets of the CMA, Russian Meteorological Agency and Japan Meteorological Agency), and four regional data sets (South American regional data set, Africa regional data set, European regional data set, and Antarctic climate data) [10]. The non-homogenized original

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records of GHCN-V3 served as the basic data with which to begin building the new data set. The GHCN-V3 introduced a number of improvements that included consolidating ''duplicate'' station series and updating records from recent decades [3]. When a station was included in both the GHCN-V3 and other data sets, the station was identified using an objective method, and the best data series was selected for use [10,13]. The CMA GLSAT-v1.0 contains a total of 10,271 observational stations from continents all over the world with a length of no less than 20 years for monthly mean temperature, which included a quality control and homogenization procedure.

In this paper, we briefly report the first analysis results of the global annual mean LSAT changes during different periods since 1901 based on the CMA GLSAT-v1.0 data set. The results include the recent ''warming hiatus'' period, which will be of interest to climate change researchers.

Anomalies were calculated relative to reference period 1961–1990. Only those stations with at least 15 years of records during 1961–1990 were applied. We calculated the monthly mean temperature anomaly series of every 5° by 5° latitude and longitude grid box [2]. The influence of missing data has been considered by discarding the years with monthly records of less than 6 months. A total of 7,081 stations were therefore included, with 6,159 in the Northern Hemisphere (NH) and 922 in the Southern Hemisphere (SH).

The hemispheric mean LSAT anomaly time series were constructed by area-weight averaging all the grid boxes with data using the cosines of the central latitudes of the grid boxes as weight coefficients, based on the CRU method [2,11]. It has been recognized that the differences resulting from different regional average methods have a limited effect on the results of the long-term trend analyses on the global scale, but can have a slightly larger effect on a short trend analysis [8]. Global annual mean LSAT anomaly time series were obtained by combining the time series of SH and NH. The linear trends of the mean LSAT anomaly series were obtained using the least squares method to calculate the linear regression coefficients between temperature and ordinal numbers of time (e.g., i = 1, 2, 3…114 for 1901–2014). The significance

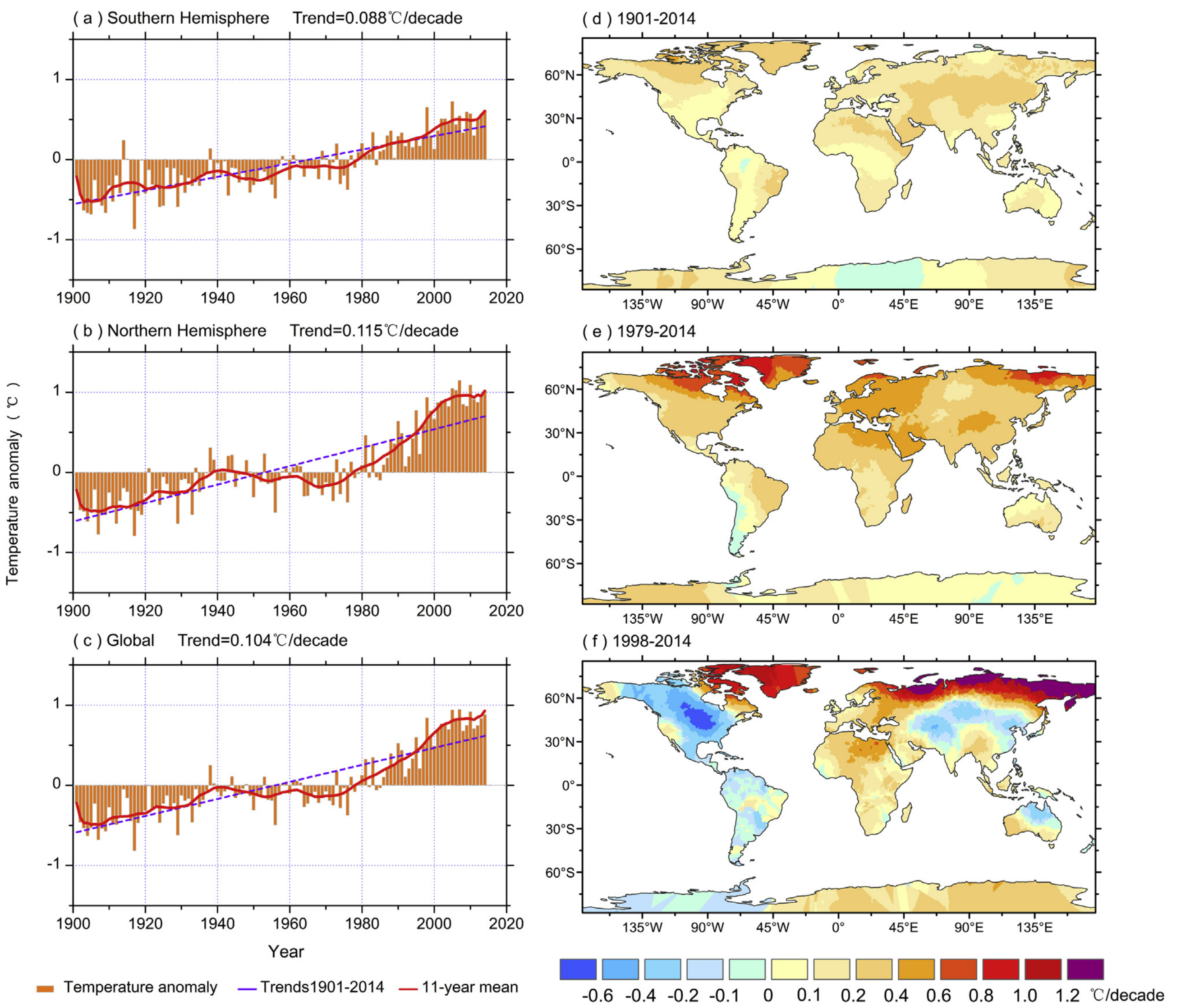

Fig. 1. Temporal (a–c) and spatial (d–f) characteristics of global land-surface air temperature. Annual mean land-surface air temperature anomalies series (bars) during 1901–2014 for Southern Hemisphere, Northern Hemisphere and Global are shown in a, b and c respectively, the red lines indicate 11-year moving averages and the purple dotted lines indicate linear trends. Trends in annual mean land-surface air temperature over three different periods: 1901–2014, 1979–2014, and 1998–2014 are shown in d, e and f, respectively.

Table 1
Linear trends of annual mean LSAT for the Southern Hemisphere, Northern Hemisphere and Global during three different periods. Unit: °C/decade.

Period	SH	NH	Global
1901–2014	0.088*	0.115*	0.104*
1979–2014	0.138*	0.317*	0.247*
1998–2014	0.087	0.105	0.098

* The trends are significant at the 5% level.

of the linear trends of the temperature series was judged using the *t*-test method. In this study, all the tests were conducted at the 5% significance level.

The annual mean LSAT anomaly time series for both hemispheres and the globe over the period 1901–2014 are shown in Fig. 1(a–c). The temperature anomaly curves bear a high similarity to those reported in previous studies [1]. The linear trends of annual mean LSAT for SH, NH and the globe were 0.088 °C/decade, 0.115 °C/decade and 0.104 °C/decade, respectively, all statistically significant at the 5% confidence level (Table 1). Much of the hemispheric and global warming occurred in two distinct periods, from the 1910s to the late 1930s and from the early 1980s to the mid-2000s. The relatively cool periods or stable periods appeared in the 1900s, 1940s–1970s and between 2005 and 2014. These results are very close to those found in previous studies [1,2,4].

Overall, the annual warming was larger in the NH (0.115 °C/decade) than in the SH (0.088 °C/decade). From the early 1950s to early 1970s, however, the series of the SH exhibited an insignificant warming, whereas the NH exhibited a slight cooling. The land warming from the early 1980s was much more remarkable in the NH than in the SH. It is also clear that the global mean LSAT change was largely determined by the NH because there were a much greater number of grid boxes containing data in the NH than in the SH.

Although the "warming hiatus" began in the late 1990s, global annual mean LSAT anomalies remained at a high level until 2014. Of the warmest 20 individual years of the global terrestrial environment, 15 occurred in the 21st century, and 2014 was the fourth warmest year since 1901.

From 1979 to 2014, the mean LSAT anomalies in the SH, the NH and the globe showed annual unprecedented and highly significant warming trends, reaching 0.138 °C/decade, 0.317 °C/decade and 0.247 °C/decade, respectively (Table 1). From 1998 to 2014, however, the two hemispheres and the globe experienced the "warming hiatus", with the SH, NH and global lands registering insignificant warming trends of 0.087 °C/decade, 0.105 °C/decade and 0.098 °C/decade, respectively.

The spatial distributions of annual mean LSAT trends for the periods 1901–2014, 1979–2014 and 1998–2014 are shown in Fig. 1(d–f). There was spatially coherent warming over the globe during 1901–2014, though the warming rates in most regions were below 0.6 °C/decade (Fig. 1d). During 1979–2014, however, the global land surface warming trends were considerably higher than those of the entire time period, with particularly large trends occurring in the high latitudes of the NH (Fig. 1e). During the recent "warming hiatus" (1998–2014), a high incoherence in global LSAT changes can be seen, with the abnormal warming in Arctic areas neighboring the Eurasian Continent and North Atlantic Ocean and remarkable cooling in North America, East and Central Asia, northern Australia and southern Africa (Fig. 1f). The slowdown of climate warming, therefore, seems to mainly occur at the low and middle latitudes of the hemispheres, and especially in the boreal cold season.

Table 1 also shows that the global annual mean LSAT increased by 0.104 °C/decade, 0.247 °C/decade and 0.098 °C/decade for the time periods 1901–2014, 1979–2014 and 1998–2014, respectively. The annual warming trends were statistically significant at the 5% confidence level for all periods except 1998–2014. These trends are generally consistent with the spatio-temporal patterns of global land warming over the longer periods of time reported in previous works [2–4]. It is also clear from our analysis that the recent "warming hiatus" was characterized by the more slowly warming or even cooling trends in the low to mid-latitude zones of the two hemispheres, with the noticeable cooling occurring in North America, East and Central Asia, northern Australia and southern Africa.

Major uncertainties in the above-mentioned results are related to the incomplete data coverage of the period before 1940s, remaining data inhomogeneities of certain stations, and urbanization effects in the regional average time series. Among these, the sparse and unevenly distributed data stations in the early years and the urbanization effects on the LSAT trends in varied periods and regions may have posed the greatest problems. Such uncertainties, especially those related to the urbanization effects, need to be addressed in future works.

Conflict of interest

The authors declare that they have no conflict of interest.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.scib.2017.01.017.

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