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Short Communications

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Short Communication

Consistency of global warming trends strengthened since 1880s

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Global mean surface temperature (GMST) is one of the most important large-scale indicators for characterizing climate change on Earth, and Surface Temperature (ST) is also the most accurate key climate element currently understood by scientists and the public. Even so, there have been extensive discussions about the accuracy of global (regional) surface temperature (air temperature) changes [1]. From the perspective of climatic data acquisition and data reliability, the current GMST series and the evaluation of global warming rates are all based on several observation-based datasets produced by combining anomalies of Land Surface Air Temperatures (LSAT) and Sea Surface Temperatures (SST). Compared with the larger uncertainties evaluated from regional climate change observation studies [2-4], the theory and methodology of global ST change observations are more mature, and the conclusion of global warming trend since the last century is beyond doubt [5]. However, due to the diversities in the station data collection and statistical methods in processing these data, the differences between the GMST series lead to slight differences in warming trends at different time periods. In particular, discussions of short-term climate trends in recent years [6-8] have stimulated many studies about how to accurately detect past changes in climate. It is of great scientific importance for global climate change responses to accurately understand or to reduce the uncertainties in assessing GMST trends. These issues have been extensively discussed in previous IPCC assessment reports.

To evaluate the warming since the major industrialization took place (represented by the multi-year average surface temperature of 1850-1900), we have extended CMA-LSAT1.0 [9] back to 1850 and upgraded it to C-LSAT2.0 (with more stations data used), and merged C-LSAT2.0 and ERSSTv5 [10] into a new China Merged global Surface Temperature dataset (CMST) [11]. The CMST was also extended/updated to the period of 1854-2019. The overall annual uncertainty of GMST is composed of uncertainties from the land and marine components: The annual uncertainty of the land component (GLSAT series) (U_L) is based on C-LSAT2.0. Similar to Brohan et al. [12] and Li et al. [13], the 5%-95% uncertainty levels resulting from observation errors, sampling errors and bias errors were evaluated separately. The estimation of the 5%-95% annual uncertainty range for the marine component (GSST series) (U_s) (based on ERSSTv5 [14]) uses an ensemble approach of combining the reconstruction and parametric uncertainties together. We finally synthesized the total global annual uncertainty of the GLSAT series (U_G) (based on CMST) by

$$U_G^2 = (0.29U_L)^2 + (0.71U_S)^2, \quad (1)$$

where 0.29 and 0.71 are the proportion of land and ocean areas to global area, respectively.

Figs. 1a, b, are the GLSAT series from 1850 to 2019, and the GMST series from 1854 to 2019 along with their uncertainty ranges at 5%-95% level. Fig. 1c shows the five currently used GMST observation series [1]. The length of two of these series (NOAAGlobalT5 and GISS4) is

1880-2019, the length of CMST series is 1854-2019, and the length of HadCRUT4 and BEST series cover 1850-2019 (all are in 5×5 grid resolution except for BE in 1×1 resolution). During the period 1854-1879, a considerable level of differences among the three longest GMST series is shown: the CMST is the highest, the HadCRUT4 is the second, and BEST is the lowest. This is mainly due to the use of the different SST datasets in the three GMST series. In the above three datasets, only the CMST data set uses ERSSTv5, and the other two use HadSST3 as the SST datasets, while the difference in the anomaly series between ERSSTv5 and HadSST3 between 1854 and 1879 is obvious. This shows that there is still a large level of uncertainty in global SST changes before 1880 [9].

From Figs. 1b and 1c, between 1854 and 1879, the 5%-95% uncertainty range of the GMST series is approximately 0.09 ℃; those of HadCRUT4 and BEST are approximately 0.12 ℃ and 0.13 ℃, respectively; and the average difference of the GMST anomalies between CMST and other two datasets is about 0.09 ± 0.015 ℃ (CMST-HadCRUT4) and 0.20 ± 0.016 ℃ (CMST-BEST) [13]. Obviously, the difference between the CMST and BEST has exceeded the significance at 5% level. These results imply that the structural uncertainties (defined as the differences between different GST datasets) of the GMST anomaly series from each datasets during 1854-1879 have yet to be fully resolved.

Obviously, after 1880, the five global series show much greater consistency. Karl et al. [7] comprehensively studied the data uncertainty and fitting uncertainty. Now the trends for GLSAT (derived from C-LSAT2.0) and GMST (derived from CMST) are reassessed and compared with the averaging of all the 5 GMST series in different periods (Table 1). It is clear that, regardless of which time period is selected, the linear trend has passed the 5% level of significance test.

Therefore, the significant warming of GLSAT and GMST is unequivocal, and there is excellent consistency between the various series.

Table. 1. the trends for GLSAT and GMST based on the C-LSAT2.0 and CMST in different periods (℃/10 a)

	1880-2019	1900-2019	1960-2019	1980-2019
GLSAT (C-LSAT2.0)	0.103±0.016	0.115±0.020	0.252±0.035	0.293±0.055
GMST (CMST)	0.072±0.010	0.084±0.011	0.150±0.023	0.185±0.032
GMST (Ave. of 5)	0.071±0.010	0.086±0.011	0.155±0.019	0.179±0.030

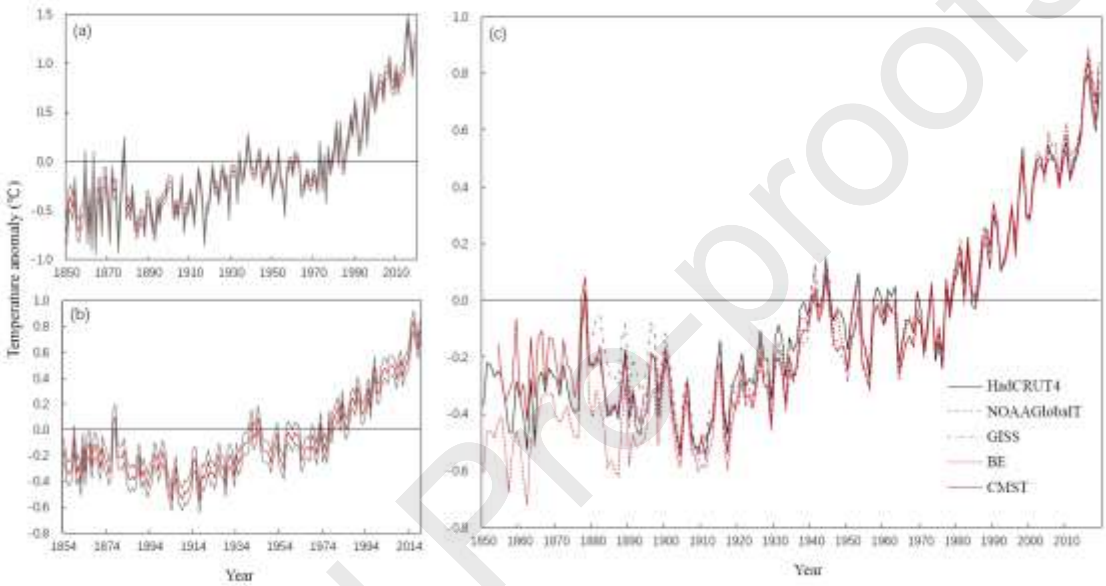

Fig. 1. The variations of global mean SAT and ST anomalies (together with their uncertainties) and the comparison with GMST anomaly derived from other datasets. (a) 1850-2019 GLSAT and 5%-95% uncertainty range based on CLSAT2.0; (b) 1854-2019 GMST based on CMST and 5%-95% uncertainty range; (c) comparison of 5 representative GMST series. All the surface temperature anomaly is refer to 1961-1990 average.

To further analyze the spatiotemporal features of GMST changes at centennial time scale, an EOF analysis was performed on the GMST change field based on the CMST dataset from 1900 to 2018. We use 1900-2018 because the grid box numbers before 1900 and in 2019 are relatively low, but the EOF result would not change much when the period is a little different. Fig. 2 shows the first 2 eigenvectors and their time coefficients. The first 2 eigenvectors account for approximately 41.5% of the variance in the GMST change during this period. Obviously, the 1st eigenvector (with a variance contribution of 33.0%) is a global uniform warming pattern (Fig. 2a, c). For the 119 years, the globe (both the ocean and land) has shown a consistent warming. However, from the perspective of the speed of warming, the warming is greater over the land than over the ocean, is greater in the Northern Hemisphere than in the Southern Hemisphere, and is greater in the high latitudes than in the low latitudes. The regions with the least warming are mainly located in the northwestern Pacific, mid-high latitudes in the Southern Hemisphere, and mid-high latitudes in the Atlantic. The 2nd mode (with a variance contribution of 8.4%) shows a consistent positive anomaly in most parts of the land areas in the Northern Hemisphere except for the regions such as Central Asia, northwestern North America, and Alaska. In contrast, the anomaly in the Southern Hemisphere continents is in opposite sign. In the Pacific, there exhibits a typical mode opposite to IPO (Inter-decadal Pacific Oscillation), with a positive anomaly in the western Pacific (Fig. 2b, d). The anomaly in the Indian Ocean is predominantly negative, while the anomaly in the Atlantic Ocean is negative in the south and positive in the north. Judging from the time coefficients corresponding to the second mode, this mode is obviously in a multi-decadal quasi-periodic change. Its correlation coefficient with the IPO index reaches -0.88, which suggests that the variation in GMST is closely related to the IPO.

From the above analyses, the consistency of the current GLSAT and GMST warming trends after 1880 is found to be further strengthened. It is generally believed that long-term GMST changes can be divided into the external “signals” and the internal “noise” [15]. Obviously, of the two most important EOF eigenvectors of GMST changes, the 1st mode is undoubtedly controlled by external forcing (mainly anthropogenic factors), while the 2nd mode is mostly contributed by the internal variability.

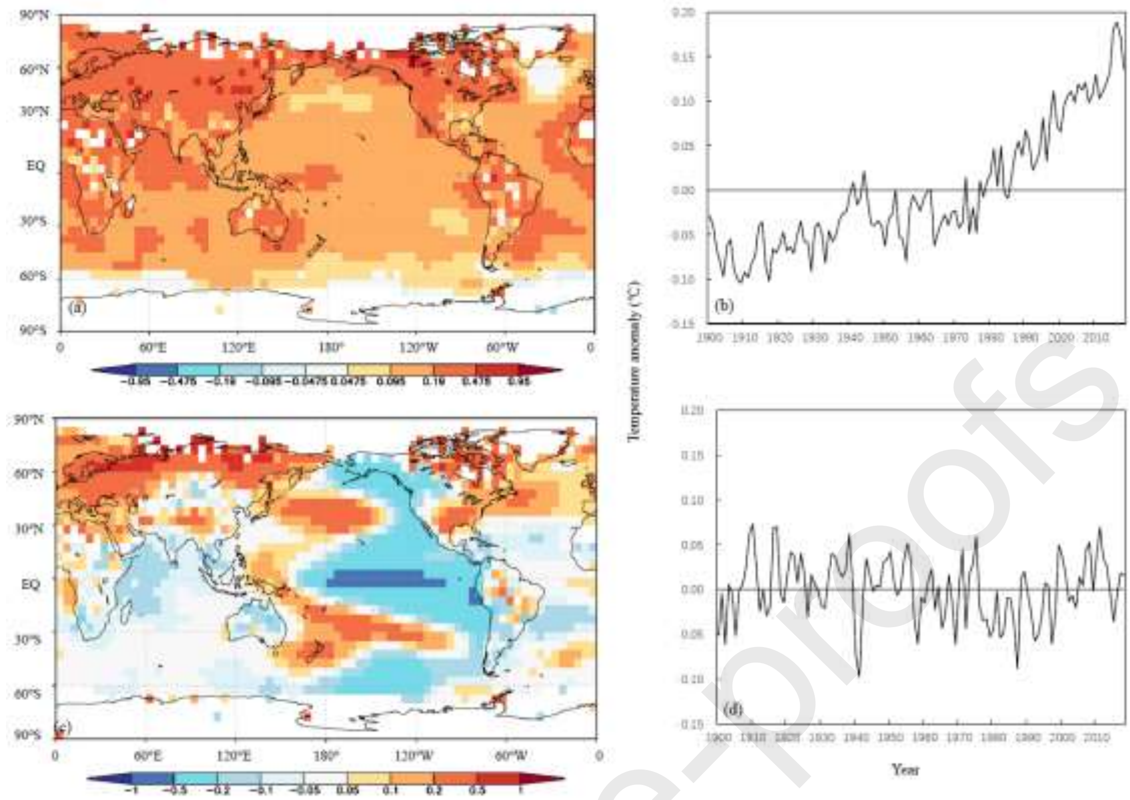

Fig. 2. The first 2 eigenvectors (a, c) and time coefficients (b, d) of EOF of GMST change during the periods of 1900 - 2018

Conflict of interest

The authors declare that they have no conflict of interest.

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Author contributions

Qingxiang Li designed the study and all of the authors contributed to the ideas, data analysis, interpretation and manuscript writing. All of the authors reviewed the manuscript.

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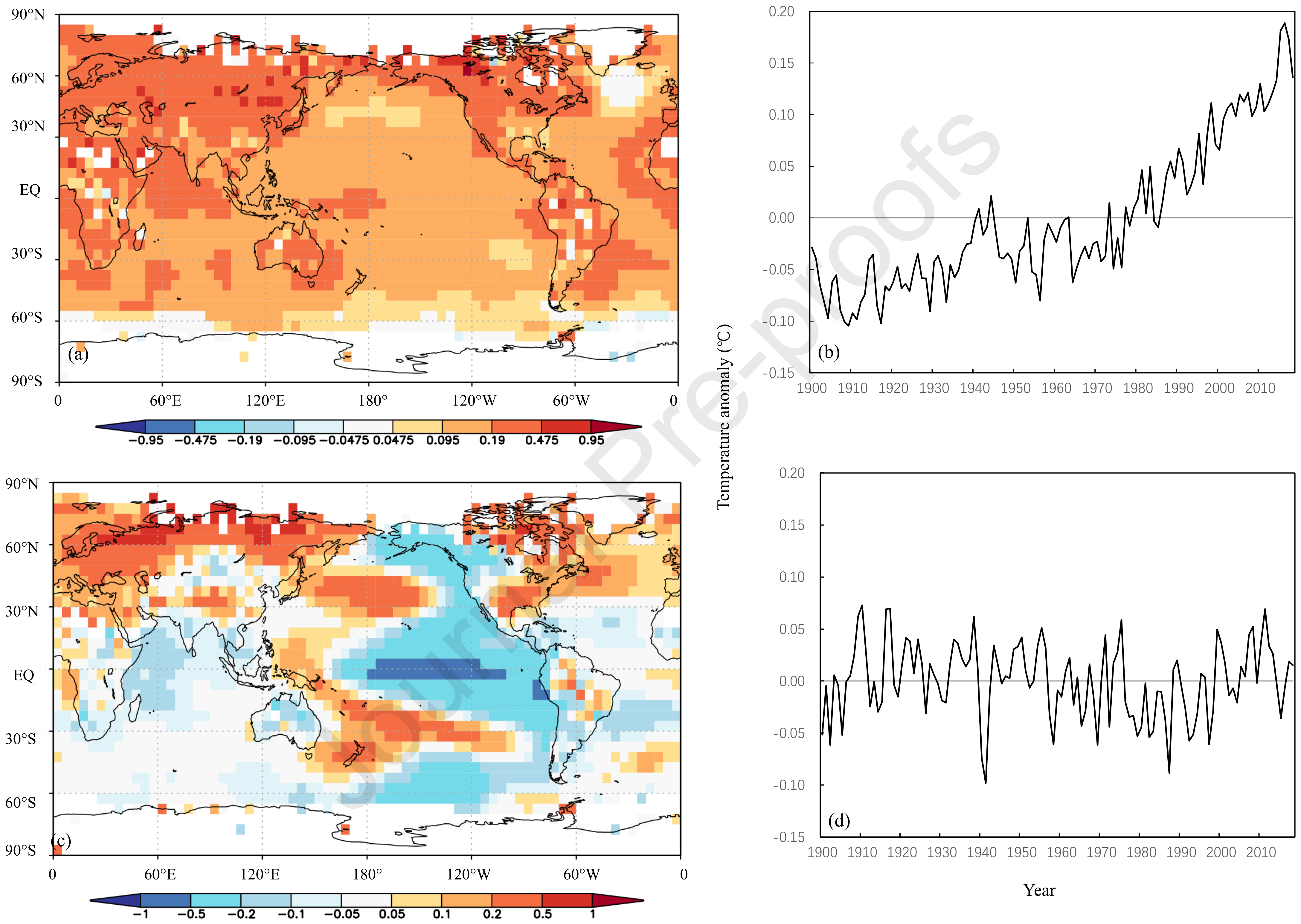
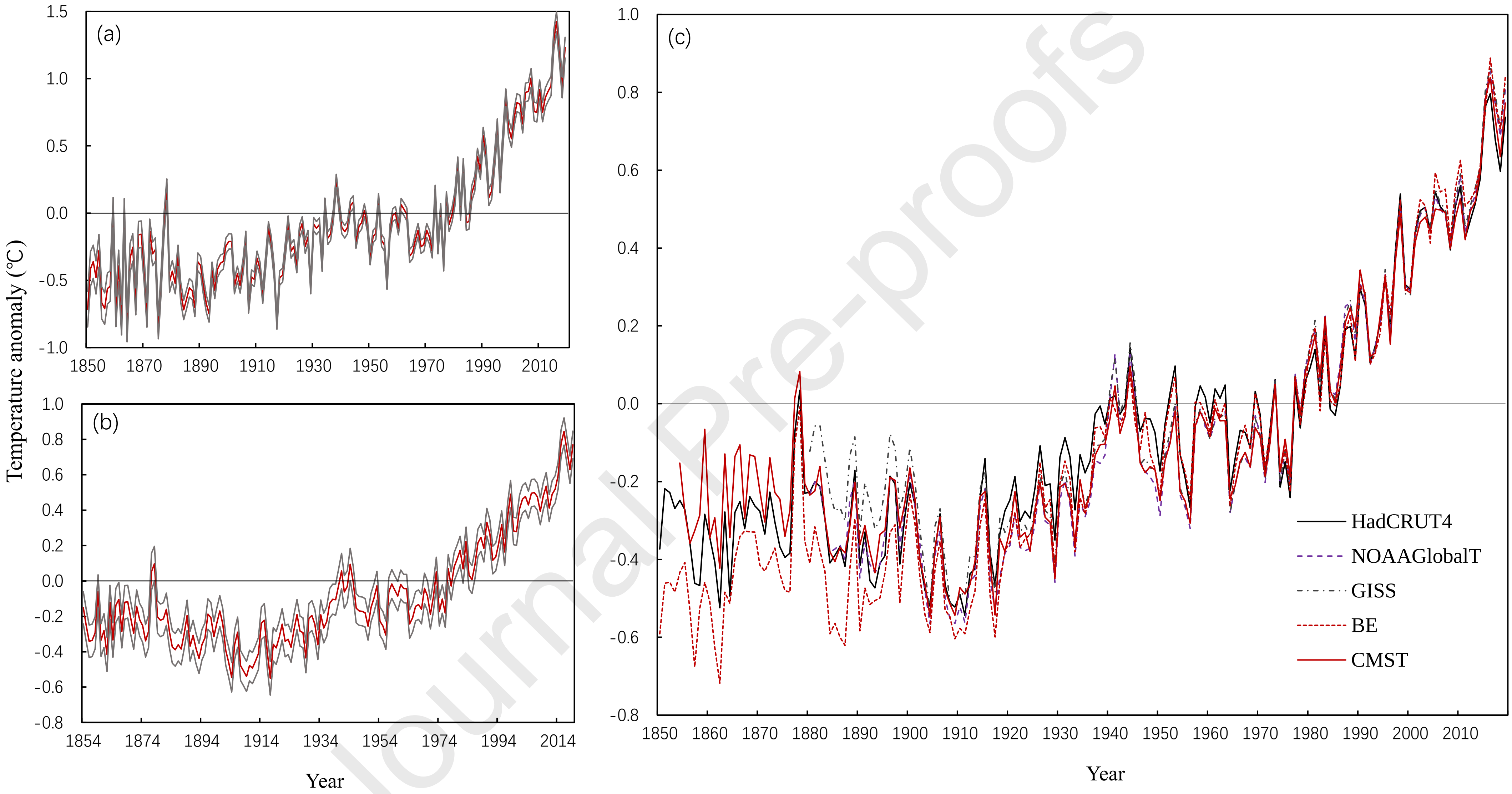


(a)
(b)
(c)
(d)
90°N
60°N
30°N
EQ
30°S
60°S
90°S
0
60°E
120°E
180°
120°W
60°W
−0.95 −0.475 −0.19 −0.095 −0.0475 0.0475 0.095 0.19 0.475 0.95
−1 −0.5 −0.2 −0.1 −0.05 0.05 0.1 0.2 0.5 1
Temperature anomaly (°C)
Year
1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010
0.20 0.15 0.10 0.05 0.00 -0.05 -0.10 -0.15



(a)
(b)
(c)
Temperature anomaly (°C)
Year
Year
HadCRUT4
NOAAGlobalT
GISS
BE
CMST