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Role of the warming trend in global land surface air temperature variations

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Abstract Global warming and its climatic and environmental effects have mainly been investigated in terms of the absolute warming rate. Little attention has been paid to the contribution of absolute warming rate to variability on various time scales of surface air temperature (SAT), which may be a more direct index for measuring the ecoclimatic effect of warming trend. The present study analyzed the role of secular warming trend in the variations of global land SAT for 1901–2016. Less than one-third of annual SAT variations were contributed by the warming trend over large parts of the globe generally. The ratios were up to two-thirds over eastern South America, parts of South Africa and the regions around the southwestern Mediterranean and Sunda islands where the absolute warming rate was moderate but the endemic species were undergoing exceptional loss of habitat. The ratios also exhibited smallest seasonal difference over these regions. Therefore, the ratio of the warming trend to the SAT variations may be a better measure compared to the absolute warming rate for the local ecoclimate. We should also pay more attention to the regions with high ratio, not only the regions with the high absolute warming rate.

Keywords Surface air temperature, Warming trend, Variations, Ratio

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1. Introduction

The warming trends of global SAT over the past 160 years have become the focus of many studies in the recent decades (Hansen et al., 2010; Wu et al., 2011; IPCC, 2013; Ji et al., 2014; Zuo et al., 2018). However, these studies focused on the warming trend isolation, without qualifying its role in relation to the total SAT variations at multiple time scales. Many studies have reported the important effects of the global warming trend on the ecological environment (Vitousek, 1994; Peñuelas and Filella, 2001; Walther et al., 2002; Root et al., 2003; Jones et al., 2012). However, even the absolute warming rates were the same, their influence on the local ecological environment varied considerably in different regions. For example, if a 1.5 K warming was only half or less than half of the variance of interannual or decadal variations, its direct influence on the local ecosystem was limited. However, if the 1.5 K warming was more than twice the variance of interannual to decadal variations, its impact on the local ecological environment may be vital because it dominated the SAT variations. The simple warming rate cannot effectively reveal the details ecoclimatic effect of the warming trend. Hence, we need to explore the contribution of the warming trend to the total variations of SAT. This study tried to answer the following question: What is the role of the warming trend in the variations of land SAT? The

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significance of comparing the warming trend and variability is to diagnose the regions where the signal of temperature trend can be distinguished from background temperature variability. These analyses may have direct applicability to the evaluating the effect of the warming trend on the local ecosystem.

2. Materials and methods

The data used in this study was the monthly land surface air temperature from the Climatic Research Unit, University of East Anglia, for the period January 1901 to December 2016, with a horizontal resolution of 0.5°×0.5° in longitude and latitude (Jones et al., 2012). We adopt the method named ensemble empirical mode decomposition (EEMD) to extract signals of surface air temperature variations at various times scales for 1901–2016 at each grid (Wu et al., 2011; Ji et al., 2014). The SAT time series (1901–2016) at each grid point was decomposed into six intrinsic mode functions (IMFs) and a residual secular trend (ST) where IMF1 is the SAT quasi-biennial variations (2–3 year cycle), IMF2–4 was the SAT variations at interannual-decadal time scales (4–19 year cycle) and IMF5–6 was the SAT variations at multi-decadal time scales (20–80 year cycle).

3. Results

The variance of annual SAT on quasi-biennial, on interannual to decadal, multi-decadal time scales and the ST, as well as the their ratios with respect to the total variance are shown in Figure 1. Generally, the variations at all time scales increase zonally from the equator to mid-high latitudes. Over most parts of the global land area, the ST variance is approximately equal to the quasi-biennial variability, which is larger than the variance at interannual to decadal and multi-decadal time scales. Thus, the contributions of quasi-biennial variability and the ST to the total variations are much larger than those of the interannual to decadal and multi-decadal variations (Figure 1e–1h). However, except for the quasi-biennial variability, the ratios do not exhibit a zonal increase from the equator to mid-high latitudes, quite unlike the characteristics of the variance itself. The largest ratio, more than 50% and up to 80%, of the ST to total variations occurred over eastern South America, southern Africa and the regions around the Mediterranean Sea, Sunda Islands and northern China where the ratios of the quasi-biennial variability and the multi-decadal variations were generally smallest. Thus, although the absolute warming rate over these regions was not the most intense, its contribution to the total variations was the largest. The warming trend played a dominant role in the variations of SAT over these agricultural/pasture/forest regions. Most of these highest-ratio regions are the land biodiversity hotspots where endemic species are undergoing exceptional loss of habitat because of their unique vulnerabilities to climate change (Myers et al., 2000). Additionally, the role of the ST in the total variations over the regions neighboring these highest-ratios regions, such as western South America, Sahel and central China, was generally the weakest where the role of multi-decadal variations was the largest. The distinctive role of the warming trend in the neighboring SAT may lead to the intense regional climate change and variability.

Taking one month for each season, the STs in January and April were generally more robust than those in July and October (Figure 2a–2d). The ST variances were generally larger in the high latitude zone than those in lower latitudes in January and April. In particular, the ST variances around Alaska, Greenland and eastern Russia were 20 times those around China, most parts of Africa and South America in January and April. However, the ST variances in July and October did not exhibit the zonal increase from the equator to the mid-high latitudes. Among the four seasonal months, the ST variances over southern China, western South America and coastal southwestern Africa were generally the smallest, similar to those in the annual mean. The ratios of ST to the sum of ST and multi-decadal variations over most of Eurasia were larger than 60% in April but less than 40% in the other three seasonal months (Figure 2e–2h). The warming trend dominated the SAT long-term variations over most parts of South America in April and over Africa and Australia in July, contributing more than 80%. The effects of the warming trend over North America were relatively weak, with less than 40% of the variances of the long-term variations explained by the warming trend in all four seasonal months, with values particularly low in October.

The time evolution of annual SAT, and the ST and multi-decadal variations over some regions where the warming trends or the contributions of the warming trend to the variations were the largest or smallest for 1901–2016 are further investigated (Figure 3). Firstly, in comparison with the mid- and high- latitude areas (North America (20°N–60°N, 180°–50°W), Siberia (45°N–65°N, 30°E–140°E) and Greenland (60°N–90°N, 50°W–0°)), the variations of annual SAT over the low latitude regions)eastern South America (30°S–0°, 50°W–30°W), Sahara (0°–20°N, 5°E–45°E), and eastern China (20°N–40°N, 100°E–130°E)) were quite moderate. The secular annual-average warming rates over both North America and eastern South America were about 1.5 K for 1901–2016, but variations on other time scales in eastern South America were much weaker than those in North America. The monthly STs were quite different over the two regions. The warming was more than 2.0 K in January and less than 1.0 K in other three seasonal months over North America whereas the warming was consistently about 1.5 K

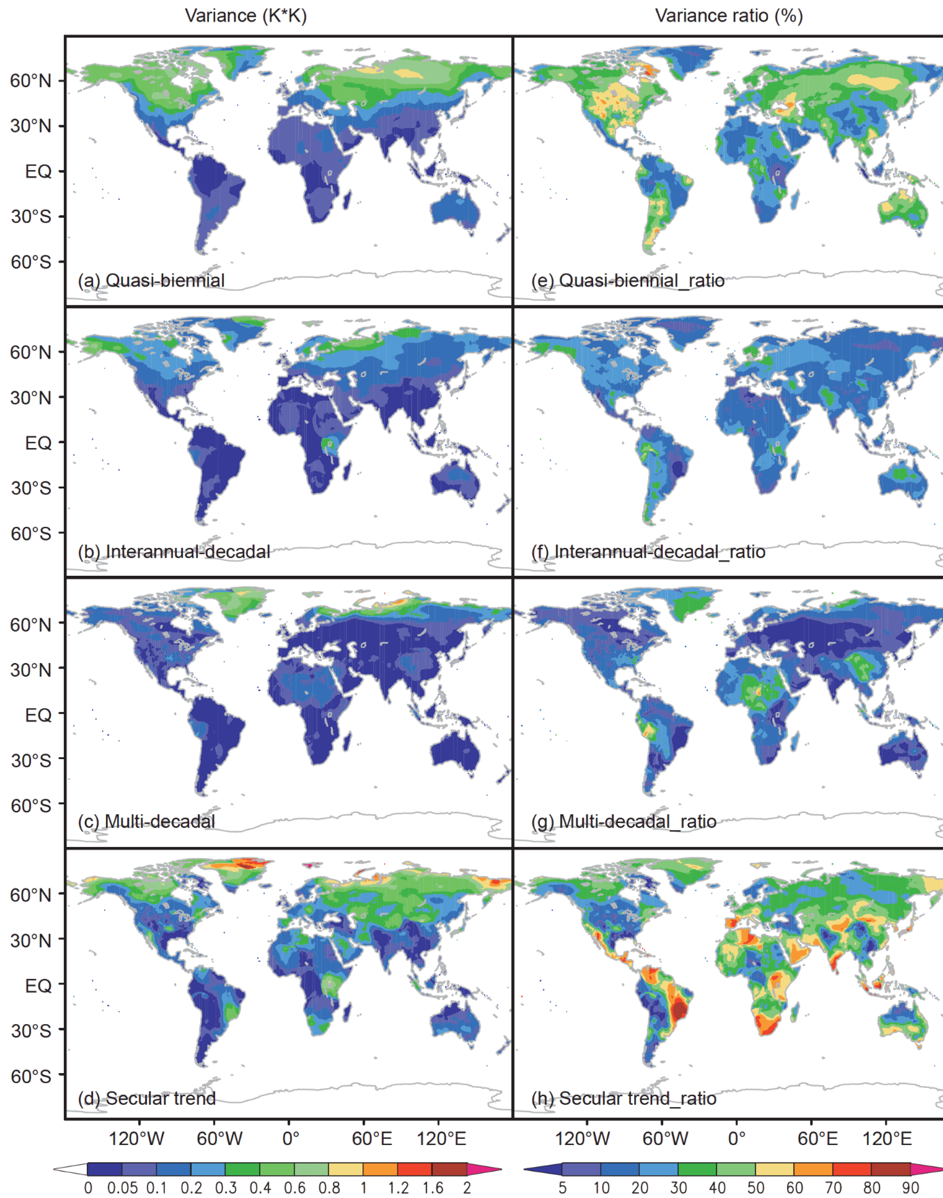

Figure 1 Spatial distributions of variances of land SAT at multiple time scales. (a) Quasi-biennial; (b) interannual-decadal; (c) multi-decadal time scales; (d) secular trend (ST) respectively (K^2). (e)–(h) as for (a)–(d), but for the ratio of the variance at the particular time scale to the total variances (%).

in all four seasonal months over eastern South America. The smallest secular warming rate occurred over eastern China and the Sahara (generally less than 1.0 K but approximately 1.5 K in April), but their multi-decadal variations were as large as those in North America (Figure 3, right panel). The secular annual warming rate over Siberia and Greenland were robust, about 2.0 and 3.0 K respectively. Nevertheless, the SAT variations were also intensive. The strong annual warming rates were the consequence of the robust warming in April over Siberia (about 3.0 K) and the dramatic warming in January over Greenland (about 6.0 K). The warming in the other three seasonal months was more modest, less than 1.5 K over Siberia and approximately 2.0 K over Greenland. The time evolution of multi-decadal variations exhibited an obvious cold phase for the 1960s–1980s and warming phases for the 1920s–1940s and after 1980s (Figure 3, right panel). As a consequence of multi-decadal variations, the annual SAT was generally colder for the 1960s–1980s than for the 1920s–1940s except in eastern South America and Siberia. There was little multi-decadal variation over eastern South America. The annual multi-decadal variations were weak over Siberia due to the different time evolution in different seasons. Consequently, the annual SAT over Siberia and eastern South America exhibited continuous warming.

Overall, considering the quite weak SAT variations over eastern South America, the moderate ST with little seasonal difference generally dominated the SAT variations over this region. In comparison, the role of STs over eastern China and

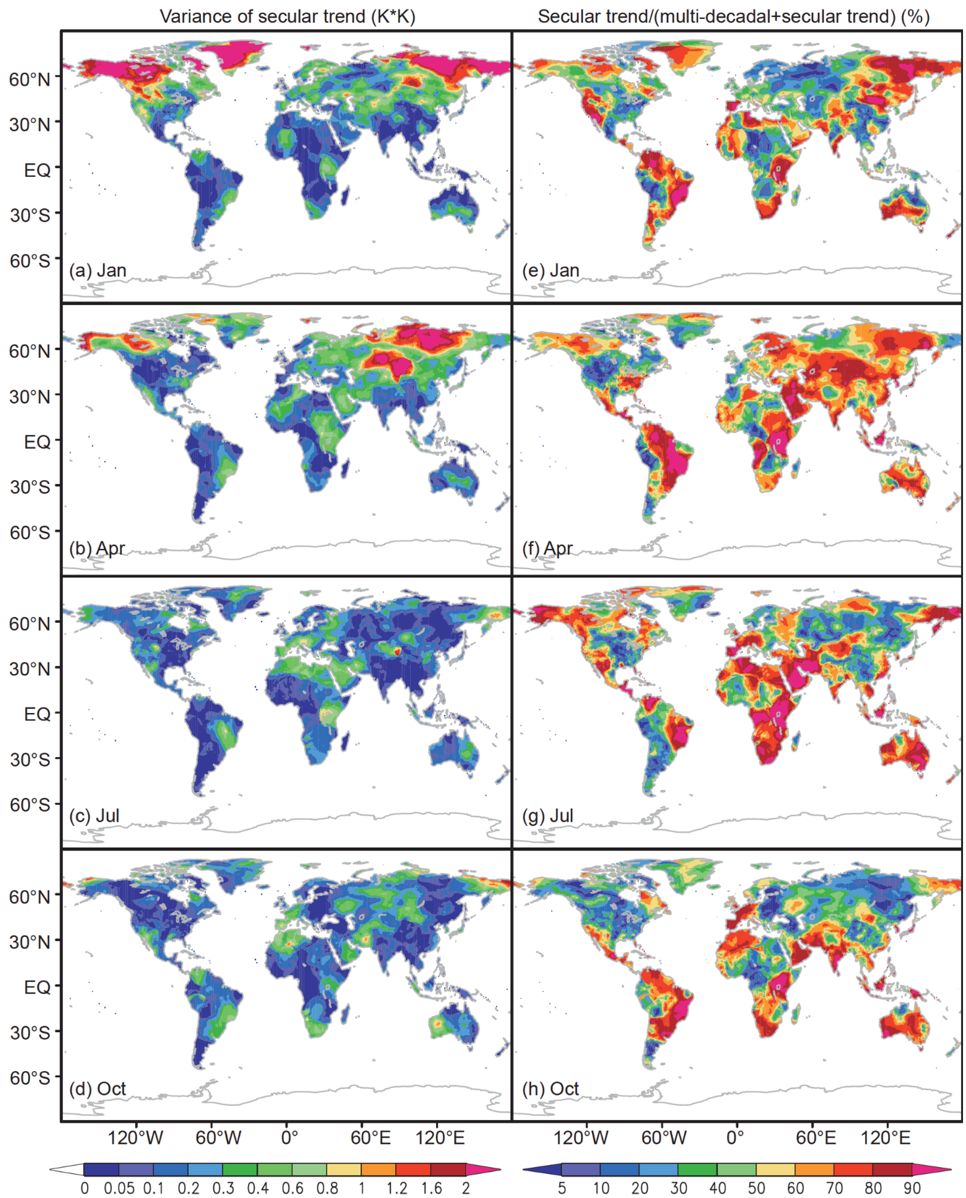

Figure 2 Spatial distributions of the secular trend variances in (a) January, (b) April, (c) July and (d) October. (e)–(h) as for (a)–(d), but for the ratio of the secular trend to the sum of the secular trend and multi-decadal variations.

Sahara was delicate and shows considerable seasonal difference because of their weak ST but medium SAT variations. The role of ST over Greenland and Siberia was considerable but not dominant because both the ST and the SAT variations over the two regions were intensive. The ST over Greenland was the largest and shows the largest seasonal difference.

4. Discussion and conclusion

Here we have shown that the contribution of the warming trend to the variations of land SAT is approximately equivalent to that of the quasi-biennial variability at a global scale. Thus, the warming may be not an immediate problem for the local environment although its effects were substantial. For some regions such as eastern South America, Sunda Islands, parts of southern Africa and eastern India, the role of the warming is dominant because its contribution was more than two-thirds, much larger than those at other time scales. Meanwhile, because the SAT variability over these regions was generally gentle, it may have formed a relatively vulnerable ecosystem (Paaijmans et al., 2013). Consequently, the disastrous damage of the warming trend to the local ecosystem may be exaggerated if the land SAT maintains the present warming trend in the future. Many studies have suggested that the warming trend was mainly caused by anthropogenic greenhouse gas especially after the 1950s

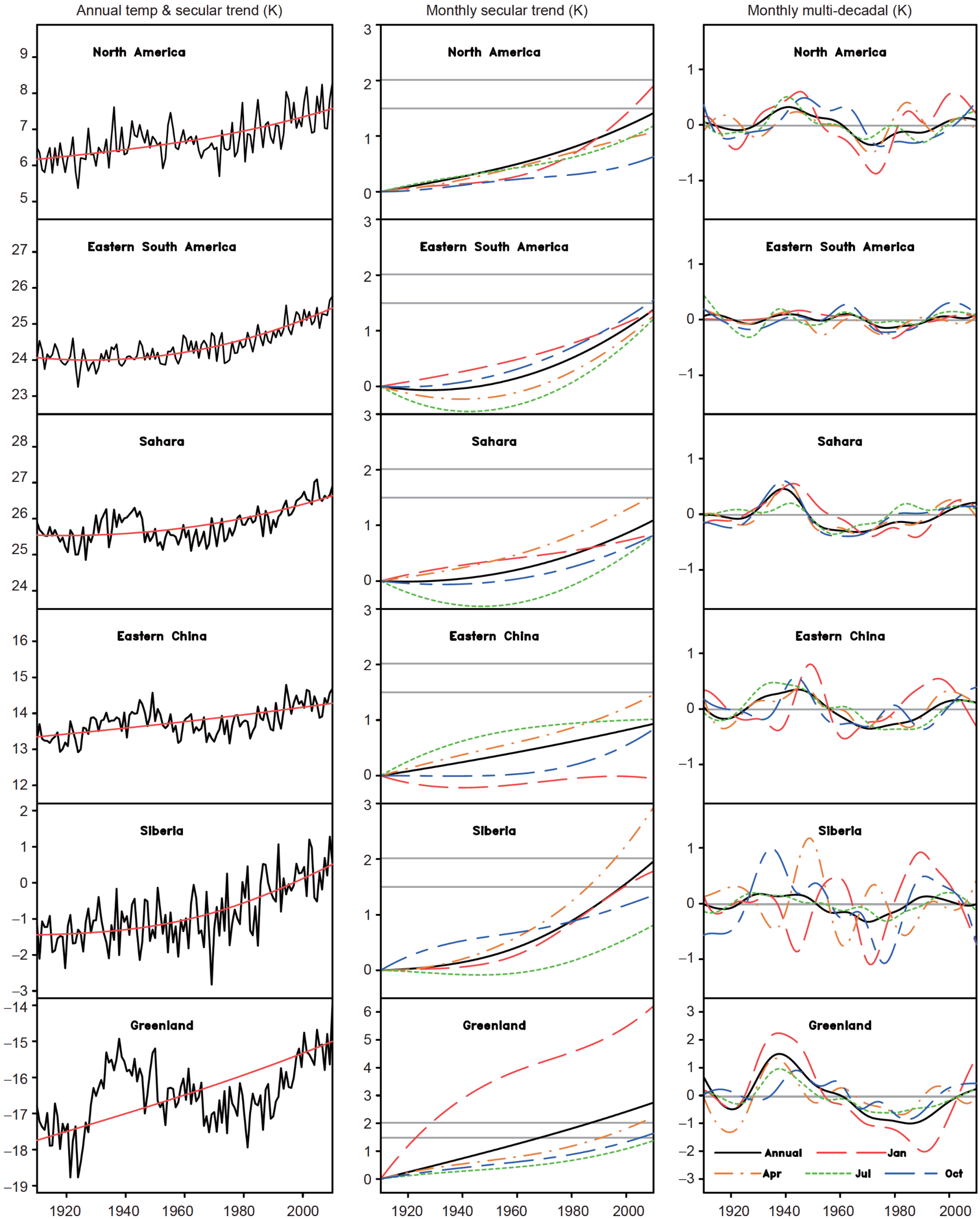

Figure 3 Time series of annual SAT (thin black curve, left panel) and its secular trend (thick red lines, left panel), monthly secular trend (middle panel) and multi-decadal variations (right panel) over various regions (From top: North America (20°N–60°N, 180°–50°W), East South America (30°S–0°, 50°W–30°W), Sahara (0°–20°N, 5°E–45°E), eastern China (20°N–40°N, 100°E–130°E), Siberia (45°N–65°N, 30°E–140°E) and Greenland (60°N–90°N, 50°W–0°)). In the middle and right panels, black solid lines denote annual mean, red long-dashed lines denote January, orange long dashed dotted lines denote April, green short-dashed lines denote July and blue long-short-dashed lines denote October.

(IPCC, 2013). We also find the warming trend after the 1950s has accelerated (Figure 3). Thus, the warming trend over eastern South America may be sustained in the future with the increase of anthropogenic greenhouse gases. We should pay more attention to the possible ecoclimatic damage of the warming trend and its aftereffects. On the other hand, it seems that the role of the warming trend was relatively moderate and the role of multi-decadal variations was relatively robust over some regions, such as eastern China and the Sahara. Nevertheless, we cannot conclude that there is no cause for concern since anthropogenic activity could lead to decadal to multi-decadal variations via other factors such as aerosols (Mitchell et al., 1995; Booth et al., 2012; Zhang et al., 2013) and lead to a significant influence on the ecological environment over these regions. In addition, the sensitivity of the ecosystem to warming is diverse in different regions (Piao et al., 2014; Zhu et al., 2016). For example, when the warming trend is equivalent to or larger than the SAT internal variability, its effect on the local ecosystem may be vital in the regions where the ecosystem is quite sensitive to the SAT variations (e.g. mid-high latitudes). However, for the regions where SAT change is not the first leading factor to the local ecosystem (e.g. some tropics), the effect may be much more moderate. How the warming trend impacts the local ecosystem needs to be further investigated.

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