



Short Communication

Changes in climate regimes over China based on a high-resolution dataset

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During the 20th century the global climate has been shifted towards warmer and drier regimes, mainly due to anthropogenic warming [1,2]. Climate changes can notably disrupt the environment and ecosystems. To evaluate the impacts of climate change on ecoregions, the Köppen-Trewartha (K-T) climate classification [3] is widely used because it was constructed on the basis of surface vegetation. The K-T classification system combines temperature, precipitation, and their seasonality into a single metric. Six major climate types and several sub-climate types are defined (A: tropical, B: dry, C: subtropical, D: temperate, E: subpolar, F: polar). Each K-T climate type is consistent with certain prevalent plant species. Definitions and criteria of K-T climate types were outlined by Feng et al. [4].

Shifts in climate regimes have been investigated on both global and regional scales based on the K-T classification [5,6]. However, previous studies typically based on climate models or observations with coarse spatial resolution [6]. Therefore, they may fail to reveal regime climate change on a local scale. This is especially true for China due to its complex topography and strong climatic gradients. To address this limitation, we used a newly developed high quality monthly temperature and precipitation dataset with 0.025° resolution (~2.5 km) across China during 1951–2011 (LZU0025, [7]) to investigate the impact of climate changes on ecosystems. This dataset has been constructed based on monthly temperature data from 1,153 weather stations and precipitation data from 1,202 weather stations in China and neighboring countries via a thin plate smoothing method embedded in the ANUSPLIN software (<https://fennerschool.anu.edu.au/research/products/anusplin>). Compared to previously published climate dataset, this dataset can accurately describe the spatial and temporal characteristics of temperature and precipitation in areas with complex topography. This study focuses on climate classification during 1960–

2011 due to sparse and unevenly distributed observations before 1960 [8].

The climate types are determined by both temperature and precipitation. The variations of the average temperature in China show a notable interdecadal transition in 1984. The national mean temperature has been increased slowly before 1984 (0.10 °C/10 a.), followed by rapid warming (0.48 °C/10 a.) during 1985–2011 (Fig. 1a). The recent warming is consistent with the significant global warming since the 1980s [9]. However, the changes in average total precipitation across China are weak and no notable decadal changes can be detected [10,11]. Therefore, in order to quantify the changes in climate types, the K-T climate types before and after 1984 were analyzed.

The spatial distributions of major climate types before and after 1984 are shown in Fig. 1b and c, respectively. While the classification captures the broad scale climate patterns previously described by Huang et al. [6], it provides substantially more local details than previous studies, especially for the mountainous regions. During 1960–1984, the tropical climate (type A) appeared only in the southern edge of Hainan Province. The dry climate (type B) covered the arid and semi-arid regions across the northwest China and the western Tibetan Plateau. The subtropical climate (type C) can be found in the South China while the temperate climate (type D) appeared in the north and northeast China. The subpolar climate (type E) covered a small area, i.e., the Greater Khingan range of northeast China, and sporadically in the Tibetan Plateau, the Tianshan and Altai Mountains. The polar climate (type F) has been mainly located in the eastern Tibetan Plateau, and sporadically distributed in the Tianshan Mountains and the western Himalayan Mountains.

Although temperatures increased rapidly after 1984, the general features of the climate types in China were similar to that before 1984. The area previous covered by tropical climate (type A) expands to cover most of the Hainan Province. The subtropical climate (type C) over the Yangtze Plain advanced northwards by

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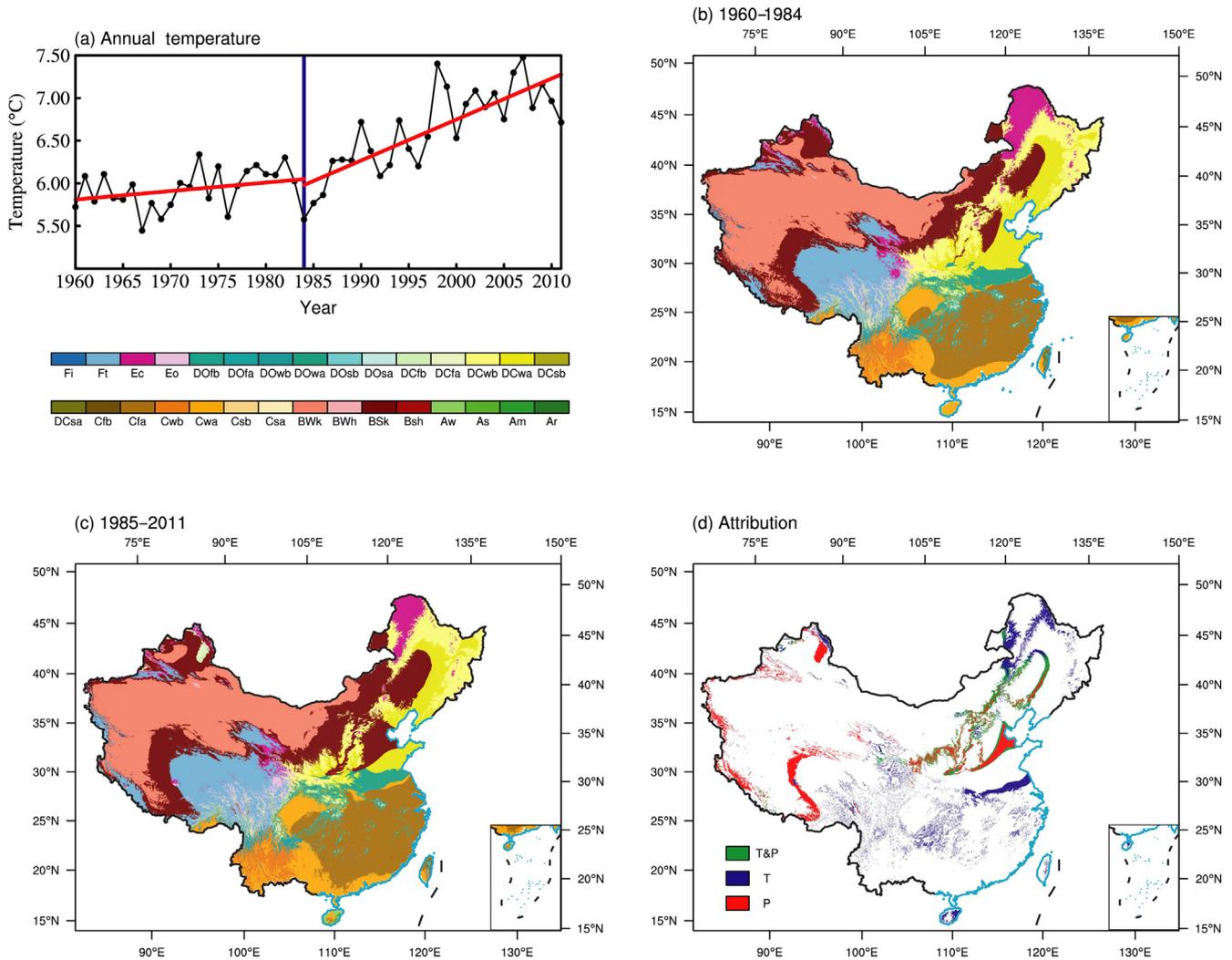


Fig. 1. Spatial distribution of the major climate types and their influence factor. (a) Temporal variations of the averaged annual mean surface air temperature in China during 1960–2011. The red lines indicate linear trends before and after 1984, while the blue line marks the interdecadal transition in 1984; (b) and (c) showed the spatial distribution of K-T climate types during 1960–1984 and 1985–2011, respectively. The colors indicate the sub-types of the K-T classification, and first capital letter in the name of sub-types specifies the belonging of its major type. (d) Changes in major climate types after 1984 compared to that before 1984. The red indicates the precipitation caused the climate type changes, the blue indicates the temperature caused the climate type changes and the green indicate the precipitation and temperature both caused the climate type changes.

about 1°. Over the margin of the East Asian Summer Monsoon (EASM) and the Yellow River estuary, the temperate climate (type D) before 1984 is shrunk and replaced by dry climate regime (type B). In the Greater Khingan range, the temperate climate (type D) advances and partly replaces the subpolar climate (type E); additionally, the areas covered by polar climate (type F) expanded westwards, replaced the dry climate (type B) in the western Tibetan Plateau.

The changes in major climate types are not spatially uniform. As shown in Fig. 1d, the most noticeable shifts are mainly occurred in the northern part of Hainan Province, the Huaihe region, the EASM margin, the Yellow River estuary, the Greater Khingan, the eastern Tibetan Plateau, and the east part of the northern Tianshan Mountains. To evaluate the relative roles of temperature and precipitation in causing the changes in climate regimes, the methods outlined by Feng et al. [4] were used. The main factor that caused the changes in climate types differed in different regions (Fig. 1d). In general, the climate regimes changes are mainly caused by precipitation variations in areas with limited precipitation (i.e., the western China). By contrast, the changes in areas where the evap-

otranspiration is limited by energy were mainly affected by temperature; examples are the Mid-Lower Yangtze and Huaihe basins. Changes in precipitation and temperature are about equally important in causing the regime shifts over the EASM margin, which is also the transition zone between the monsoon and the regions dominated by westerlies [11,12]. Specifically, due to the significant increase of precipitation, in the eastern part of the northern slopes of the Tianshan mountains, the dry climate (type B) is replaced by temperate climate (type D), and over the Tibetan Plateau, the dry climate (type B) retreated westwards, being replaced by the polar climate (type F). Decreasing precipitation in the Yellow River estuary led the dry climate to expand to this region to replace the temperate climate (type D). The Subpolar climate (type E) over the Greater Khingan was replaced by a warmer climate type due to increasing temperature. As a climatically sensitive zone, the EASM margin changed from a temperate climate (type D) to a dry climate (type B), due to changes in both temperature and precipitation. The expanding dryland in this region has exacerbated the ongoing ecological stress (e.g., steppe degradation, soil erosion, and desertification). On the other hand, the degrada-

tion of the vegetation cover could result in soil destabilization and increased dust emission [13], thereby lead to more frequent dust storms. The rising population pressure could also pose increasing threats to environmental security in the region, and adversely impact the socioeconomic development.

The high-resolution data used in the present study provide substantially increased local details about the distribution and changes in climate regimes. Our results suggest that, compared to the climate classification before 1984, the major climate types have been noticeably changed during 1985–2011. As a consequence, the majority of the plant species within these ecoregions will be forced to adapt to these changes, migrate to new locations, or become locally extinct. We expect that by providing more accurate estimates of potential ecological impacts caused by climate change, the results of this study will provide new insights into the future distributions and persistence of plant species in China. The results may also serve as a basis for planning future conservation efforts and hence migrate the potential impacts of climate change on ecoregions.

Conflict of interest

The authors declare that they have no conflict of interest.

Acknowledgments

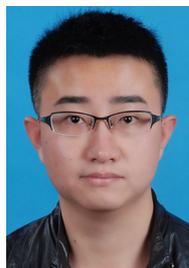
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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.scib.2019.03.001>.

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