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Article

Spatiotemporal variations of aridity in China during 1961–2015: decomposition and attribution

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ABSTRACT

Changes in global climate intensify the hydrological cycle, directly influence precipitation, evaporation, runoff, and cause the re-distribution of water resources in time and space. The aridity index (*AI*), defined as the ratio of annual precipitation to annual potential evapotranspiration, is a widely used numerical indicator to quantify the degree of dryness at a given location. This study examined the effects of climate change on *AI* in China during 1961–2015. The results showed that the nationally averaged *AI* experienced a notable interdecadal transition in 1993, characterized by increasing *AI* (wetter) between 1961 and 1993, and decreasing *AI* (drier) after 1993. Overall, the decreased solar radiation (solar dimming) was the main factor affected the nationally averaged *AI* during 1961–1993, while the relative humidity dominated the variations of nationally averaged *AI* during 1993–2015. However, the roles of individual factors on the changes in *AI* vary in different subregions. Precipitation is one of the important contributing factors for the changes of *AI* in almost all subregions, except the Mid-Lower Yangtze and Huaihe basins. Solar radiation has been significantly decreased during 1961–1993 in South China, Southwest China, Mid-Lower Yangtze and Huaihe basins, and the Tibetan Plateau. Therefore, it dominated the trends of *AI* in these subregions. The relative humidity mainly affected the Mid-Lower Yangtze and Huaihe basins, Southwest China, and the Tibetan Plateau during 1993–2015, hence dominated the trends of *AI* in these subregions. The changes of temperature and wind speed, however, played a relatively weak role in the variations of *AI*.

1. Introduction

Water is one of the most important factors affected by climate change. Changes in global climate intensify the hydrological cycle and lead to an intensification of extreme precipitations [1,2], directly influencing precipitation, evaporation, runoff, and humidity, and causing the re-distribution of water resources in time and space [3]. The dry regions may get drier while wet regions may get wetter in the context of global warming [4–9]. Additionally, the areal extent of the arid and semi-arid climate is projected to increase 11%–23% in the future [8,10], which will increase the likelihood of aridification [11] and add more hardship to the fragile ecosystems in the drylands [12]. The frequency and severity of drought are also increasing [13] and will continue to increase in a future warmer climate in many regions [14,15]. All of these changes could lead to serious threats to regional and global sustainable development [16]. China locates in the mid-latitude of the northern hemisphere with complex topography. The monsoon and westerly circulations jointly influence the climate, thereby leading to notable regional differences in climate changes on various time scales. For example, the precipitation variations between mid-latitude monsoon-dominated Asia and arid central Asia are out of phase [12,17–20]. Therefore, evaluating the changes in dryness in China can lead to a better understanding of the impacts of climate changes, which could provide guidance to the reasonable exploitation of water resources and sustainable development of economy and society.

Aridity index (*AI*) is usually defined as the ratio of annual precipitation (*P*) to annual potential evapotranspiration (*PET*) in climate change studies [21]. The *PET* is the maximum amount of evaporation from a well-watered soil vegetation surface [22]. AI quantitates the degree of water deficiency at a given location [21] and is widely used in many previous studies on current [23] and future changes of global dryness [8,9]. *AI* is also used to quantify the effects of vegetation feedback [24], green-house gases [25] and aerosol [26,27] on the dryness of global land. On regional scales, *AI* has been used to investigate the dryness in China. For example, Li et al. [28] found that the areal extent of arid climate increased in northern China during 1948–2008.

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Gao et al. [29] examined the spatiotemporal variations of *AI* in the Tibetan Plateau (TP) from 1979 to 2011. They found that the arid and semiarid northwestern TP is becoming wetter, while the semi humid regions in the eastern TP is becoming drier. However, previous studies mainly focused on the long-term trend of *AI*, and the causes and attribution analysis of *AI* variations are rare.

AI accounts for the impact of temperature, wind speed, precipitation, solar radiation, and relative humidity (*RH*). Precipitation is the major source of water for land surface. It has varied considerably in different regions and periods since the 1950s, although the changes in total precipitation average over China are weak [12,30,31]. The annual mean temperature has increased in China during the past 50–60 years, except in the Sichuan Basin [32]. The warming has been accelerated since the mid-1980s. The temporal variations of solar radiation in China are similar to many other regions of the world. The surface solar radiation has been decreasing between 1960 and 1990, which coincides with the "solar dimming", followed by gradually increasing trend since 1990, known as "solar brightening" [33]. *RH* quantifies how close the air is to saturation. Therefore, it directly affects the speed at which water will evaporate. Over the past 50 years, the surface *RH* in most of China shows a reducing trend, mainly because the increasing rate of water vapor is smaller than that of the saturated water vapor [34]. Wind speed in China remained nearly unchanged before the late 1960s. However, the wind has been continuously slowing down since the 1970s [35,36], and then leveled off after the 1990s [37]. The above results suggested that the climate factors affecting *AI* all experienced notable decadal and long-term changes in the last 50–60 years. These changes also differed in different regions, which could collectively influence the variations of *AI*. Therefore, it is important to quantify the impacts of individual drivers of *AI* in China. This study examines the relative roles of individual climate factors on the variations of *AI* in China and their regional differences, which are important in understanding the impacts of climate changes on water resources and environmental management in a future warmer climate.

2. Data and method

2.1. Data

Monthly total precipitation and daily mean minimum temperature, maximum temperature, relative humidity, wind speed, and sunshine hours during 1951–2015 from 756 stations in China were obtained from the National Meteorological Information Center (http://data.cma.cn/) at Chinese Meteorological Administration (CMA). The data had been subjected to a series of quality control to assure their reliability [38,39]. This study only analyzed the data during 1961–2015 because the observations before 1960 are scarce [38]. There are missing values in some stations, so it is necessary to screen out stations with a large amount of missing values. For a given station, if a year has missing values for one or more months, then that year is considered as having inadequate observations and was removed. Stations that have more than 5 missing years during 1961–2015 were excluded. This process retained 578 stations. As shown in Fig. 1, the stations are fairly evenly distributed across China, except in the Tibetan Plateau.

The changes in climate factors affecting the *AI* in China differed considerably in different regions due to the influences of topography, monsoon, atmospheric circulation, and land covers. To quantify the impact of individual factors on *AI*, it is necessary to examine the relative roles of each climate driver on *AI* trend in different regions [40]. Following Shi and Xu [41], we divided China into eight subregions (Fig. 1), including the Northeast (east of 110°E, north of 42.5°N), North (east of 110°E, 35°–42.5°N), Mid-Lower Yangtze and Huaihe basins (east of 107.5°E, 27.5°–35°N), South (east of 107.5°E, south of 27.5°N), Southwest (97.5°–107.5°E, south of 35°N), the Tibetan Plateau (west of 97.5°E, south of 35°N), Western part of Northwest (west of 97.5°E, north of 35°N), and Eastern part of Northwest (97.5°–110°E, north of 35°N), respectively. Among these subregions, the Northwest and the Tibetan Plateau located in the arid/semiarid and frigid high alpine zones, respectively. The other regions located in the monsoon climate zones.

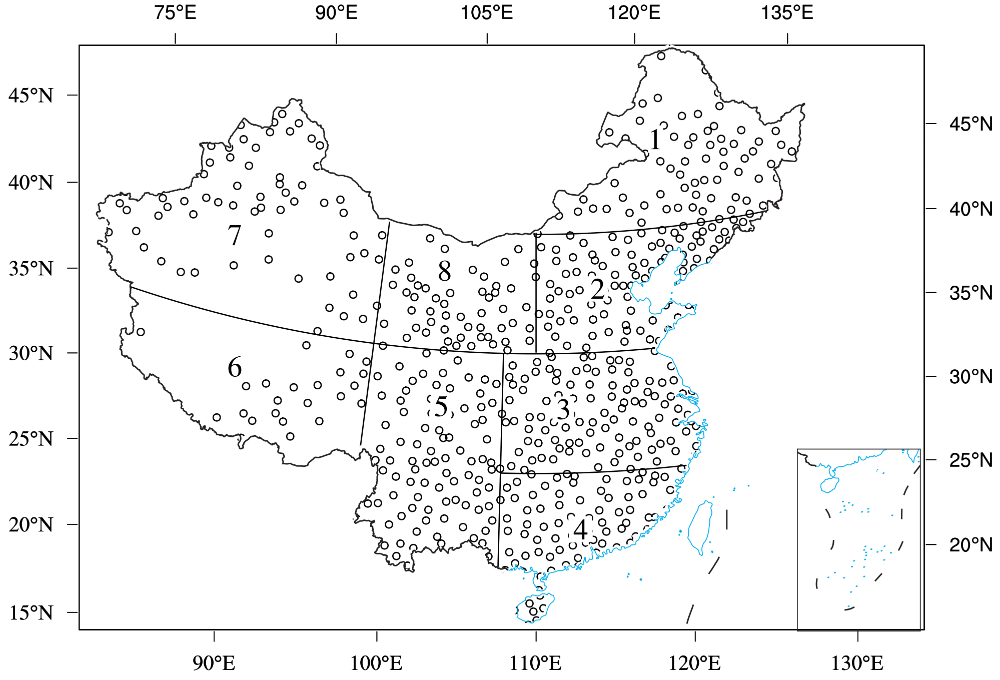

Fig. 1. Geographical distribution of the 578 meteorological stations in China and the subregions division (1. Northeast China, 2. North China, 3. Mid-Lower Yangtze and Huaihe basins, 4. South China, 5. Southwest China, 6. Tibetan plateau, 7. Western part of Northwest China, 8. Eastern part of Northwest China).

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