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Changes in extreme temperature events over the Hindu Kush Himalaya during 1961−2015

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Abstract

This study uses the CMA (China Meteorological Administration) global land-surface daily air temperature dataset V1.0 (GLSATD V1.0) to analyze long-term changes in extreme temperature events over the Hindu Kush Himalaya (HKH) during 1961−2015. Results show there was a significant decrease in the number of extreme cold events (cold nights, cold days, and frost days) but a significant increase in the number of extreme warm events (warm nights, warm days, and summer days) over the entire HKH during 1961−2015. For percentile-based indices, trends of extreme events related to minimum temperature (Tmin) were greater in magnitude than those related to maximum temperature (Tmax). For absolute-value based indices, maximum Tmax, minimum Tmin, and summer days all show increasing trends, while frost days and the diurnal temperature range (DTR) show significant decreasing trends. In addition, there was a decrease in extreme cold events in most parts of east HKH, particularly in Southwest China and the Tibetan Plateau, while there was a general increase in extreme warm events over the entire HKH. Finally, the change in extreme cold events in the HKH appears to be more sensitive to elevation (with cold nights and cold days decreasing with elevation), whereas the change in warm extremes (warm nights, warm days, and maximum Tmax) shows no detectable relationship with elevation. Frost days and minimum Tmin also have a good relationship with elevation, and the trend in frost days decreases with an increase in elevation while the trend in minimum Tmin increases with an increase in elevation.

Keywords: Climate change; Extreme temperature events; HKH; Land-surface air temperature; Elevation-dependent warming

1. Introduction

Previous studies have indicated that the socio-economy and natural systems are more sensitive to changes in extreme events than to changes in climate means (Katz and Brown, 1992; Karl et al., 1999; Easterling et al., 2000; Meehl et al., 2010; Stocker et al., 2013). In recent years, the impacts of extreme climate have been reported to be damaging to societal infrastructure and agricultural production; in addition, they increase energy consumption, increase the risk to human health and lives, increase the risk of species extinctions, and cause an increase in water resource management related problems (Karl and Easterling, 1999; Easterling et al., 2000).

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In recent decades, the temporal and spatial characteristics of extreme temperature changes have attracted considerable attention on both global and regional scales (Easterling et al., 2000; Zhai and Pan, 2003; Domonkos et al., 2003; Alexander et al., 2006; Vincent and Mekis, 2006). For example, Alexander et al. (2006) indicated that most global continents showed significant changes in temperature extremes during 1951–2003, especially for those indices related to daily minimum temperature. Based on an analysis using the CMIP3 and CMIP5 simulation data, Sillmann et al. (2013) also showed that over 70% of global lands experienced a significant decrease in the annual occurrence of cold nights and a significant increase in the annual occurrence of warm nights. However, results on a regional scale differ from region to region (Easterling et al., 2000). For example, the Hindu Kush Himalaya (HKH) is vulnerable to climate change and variability, and as such concerns climate scientists from countries such as China, India, Nepal, and Pakistan (Liu et al., 2006; You et al., 2008a; Singh et al., 2011; Eriksson et al., 2009; Zahid and Rasul, 2011).

Almost all extreme temperature indices on the Tibetan Plateau (TP) show statistically significant trends over the past half century, and stations in the northwestern, southwestern, and southeastern TP have larger trend magnitudes (Zhai and Pan, 2003; Liu et al., 2006; You et al., 2008a; Zhou and Ren, 2011; Yan and Liu, 2014). In Pakistan, Zahid and Rasul (2011) analyzed absolute extreme temperature events and showed that the frequency of extreme maximum (minimum) temperature events exhibited increasing (decreasing) trends throughout Pakistan, and a marked increase (decrease) occurred in northern Pakistan, southern Punjab, Sindh, and Baluchistan during 1965–2009. In northern India, Kothawale et al. (2010) found a significant decreasing trend in the frequency of cold days over the western Himalayas but a significant increasing trend in the frequency of warm nights in northwestern India during 1970–2005. In Nepal, Baidya et al. (2008) indicated that most of the temperature extreme indices experienced consistent changes but that there were relatively higher trends in mountainous regions during 1971–2006. Shrestha et al. (2016) conducted a study of the Koshi River Basin and the transboundary basin between China, Nepal, and India and found an increase in the daily maximum and minimum temperatures and number of warm nights in the basin. However, most extreme temperature indices showed a consistently different pattern in the mountains than on the Indo-Gangetic plains. Researchers from other countries such as Iran (Rahimzadeh et al., 2009), Myanmar, Vietnam, and Laos (Manton et al., 2001) have also studied the HKH. Panday et al. (2014) indicated a significant decreasing trend in frost days and a significant increasing trend in warm nights in the east HKH during 1960–2000. Their study also analyzed CMIP3 and CMIP5 simulation data and indicated that the change characteristics observed in past decades would continue in the future. In general, the warming trends in minimum temperature (Tmin) indices for the HKH are of greater magnitude than those of maximum temperature (Tmax), although the magnitude differs from region to region, which is consistent with the results of previous studies (Alexander et al., 2006).

The HKH is monitored by an observation station network that covers an elevation ranging from low-lying plains to mountains and plateaus at nearly 5000 m a.s.l (Revadekar et al., 2013). Some studies have found a possible elevation-dependent warming (EDW) in the HKH that could have a significant impact on mountain ecosystems, hydrological regimes, and biodiversity (Chen et al., 2003; Liu et al., 2009; Yan and Liu, 2014; Yan et al., 2016; Pepin et al., 2015; Shrestha et al., 1999; Shrestha, 2008). Giorgi et al. (1996) analyzed EDW in the Alps using a regional model, and results suggested that significant warming or cooling at high elevations could be used as an early detection tool for global warming, especially in northern winters and spring. Yan and Liu (2014) recently investigated the warming trends at 139 stations on the TP and determined that the TP is a region that is very sensitive to global warming. Pepin et al. (2015) investigated EDW over the TP and found that the vertical change in the annual and winter warming rates was a reflection of more rapid warming at higher altitudes. However, these previous studies mainly focused on mean temperature changes and did not aim to examine EDW phenomenon in terms of extreme temperature events. However, in India and its neighboring countries, Revadekar et al. (2013) analyzed the impact of elevation and latitude on changes in temperature extremes and determined that stations at high elevations recorded more obvious absolute trends in extreme temperature indices.

Previous analyses have been mostly limited to individual countries and an overall analysis of the HKH as a whole is lacking, both for changes in extreme temperature events and for EDW in terms of extreme temperature. Therefore, one of the objectives of this paper is to provide a comprehensive analysis of temperature extreme changes over the entire HKH. The other objective is to analyze the possible impact of elevation on long-term trends of temperature extreme indices. In this respect, a new multi-source dataset is used in this paper to analyze changes in extreme temperature events over the HKH during 1961–2015.

This paper is organized as follows. Section 2 describes the study region, data sources, extreme indices, and statistical methods. Results are presented in Section 3; the temporal and spatial characteristics of extreme temperature changes in the HKH are analyzed in Section 3.1, and the possible impact of elevation on changes in extreme temperature events is analyzed in Section 3.2. Section 4 then presents a discussion of results and conclusions are given in Section 5.

2. Study region, data sources, extreme indices, and statistical methods

The HKH (20–40°N, 60–105°E) spans six entire countries (Nepal, Pakistan, Afghanistan, Bhutan, Burma, Bangladesh), parts of nine other countries (China, India, Iran, Turkmenistan, Uzbekistan, Tajikistan, Kazakhstan, Vietnam and Laos), and has an elevation range between sea level and more than 8000 m a.s.l. (Fig. 1).