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Changes in extreme precipitation events over the Hindu Kush Himalayan region during 1961−2012

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Abstract

Based on a new multi-source dataset (GLDP-V1.0) recently developed in China Meteorological Administration, we employed precipitation indices including percentile-based indices of light (below the 50th percentile), moderate (between the 50th and 90th percentile), and intense (above the 90th percentile) precipitation, maximum 1-day, 3-day, and 5-day precipitation amounts (RX1DAY, RX3DAY, and RX5DAY, respectively), and consecutive wet and dry days (CWDs and CDDs) to analyze variations in extreme precipitation events in the Hindu Kush Himalayan (HKH) during 1961−2012. The main results are presented as follows. Firstly, there was a significant increase in the amount of light and moderate precipitation and number of associated days over various parts of India and northern Tibetan Plateau during 1961−2012; but the intensity of light precipitation decreased significantly in the Hindu Kush and central India, and the regional average intensity also decreased. Secondly, the amount and frequency of intense precipitation mostly increased significantly on the Tibetan Plateau, but there was a heterogeneous change over the remainder of the HKH, and regional average annual intense precipitation amount and frequency significantly increased over the HKH during 1961−2012. Thirdly, regional average RX1DAY, RX3DAY, and RX5DAY all showed significant upward trends during 1961−2012, and there was a significant increased tendency of consecutive wet-days in most parts of the study region; however, trends of consecutive dry-days were mostly opposite to those of consecutive wet-days, with regional averaged consecutive dry-days showing no noticeable trend.

Keywords: Climate change; Trend; Extreme precipitation events; HKH region; Tibetan Plateau

1. Introduction

The Hindu Kush Himalaya (HKH) region, as defined by Sharma et al. (2016), comprises many of the world's most extensive river basins and highest mountains (and one of the greatest mountain systems). With the exception of the North and South Poles, the HKH region contains the largest area of

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permanent ice cover worldwide, and as such is often referred to as the Third Pole of the Earth, and it provides ecosystem services sustaining the livelihoods of an enormous population. The HKH is characterized by extreme topographic and climate heterogeneity, where the steep mountains force vapor uplift and block moisture transport, thus producing strong horizontal and vertical gradients in precipitation (Sharma et al., 2016; Yanai and Li, 1994; Qiu, 2008; Yao et al., 2012); as a result, the distribution of water resources is extremely uneven, and both floods and droughts are common. This effect makes the HKH susceptible to changes in climatic conditions, particularly to changes in extreme precipitation. Understanding decadal changes in extreme precipitation is therefore significant for local and regional hydrology, agriculture, ecology, industry, and hydroelectric power generation, all of which rely on the timely and sufficient delivery of water in major river systems.

Previous studies have indicated that there has been a slight increase in precipitation on the Tibetan Plateau (TP) (You et al., 2015) since the 1960s, although the increase has not been as pronounced as that of temperature. This result is part of a broader climatic moistening trend that has been observed in western China, including the TP and Northwest China (Ren et al., 2000, 2005, 2015; Qin et al., 2005; You et al., 2015). Increasing trends in winter precipitation have also been reported over a few stations in the Indus basin since the post-1960s (Fowler et al., 2005), although no spatially coherent pattern of long-term change in precipitation has yet been detected over the region (Fricke and Höffken, 1999). For example, Shrestha et al. (2016) found that changes of extreme precipitation indices are different in the mountains than on the Indo-Gangetic plains, although their results were not statistically significant. Palazzi et al. (2013) summarized trends in precipitation in the HKH region and reported a generally decreasing trend in the Himalayas during summer over previous decades, but found no statistically significant trends during wintertime.

However, other studies have determined a significant change in recent extreme precipitation events in some areas of the HKH. For example, a number of studies have reported that western China (including the TP) has experienced a significant change in extreme precipitation events over the past decades (Du and Ma, 2004; Ren et al., 2012; You et al., 2015); such results are consistent with an increase in annual precipitation total and precipitation intensity but a decrease in wet days during the same period (Ren et al., 2015). Some stations over the Karakoram regions have also recorded an obvious increase in the number of wet days and extreme precipitation events during the past few decades (Klein Tank et al., 2006; Choi et al., 2009. In addition, a growing trend in extreme precipitation in contiguous areas (from the northwestern Himalayas in Kashmir to the Deccan Plateau in India) was determined during 1910–2000 (Sen Roy and Balling, 2004) and over central India during the monsoon seasons from 1951 to 2000 (Goswami et al., 2006).

However, studies of extremes in the HKH have certain limitations. For example, previous research based on station observation data has usually focused on changes in extreme precipitation in one country or in one region of the HKH. Therefore, a systematic analysis of spatial and temporal characteristics of long-term variations in extreme precipitation for the entire HKH region is lacking. The gridded precipitation products based on remote sensing data, which are frequently used in global or Northern Hemisphere studies, are often not capable of capturing large and abrupt precipitation variations over short distances, due to the coarse resolution and orographic effects in high-altitude areas (Dahri et al., 2016).

In this paper, the HKH is defined as a rectangular region with a boundary of 60–105°E and 20–40°N that includes the HKH high mountains and adjacent plain areas. Extreme precipitation is analyzed using a new multi-source dataset based on station data obtained in the HKH from 1961 to 2012, with a focus on long-term variations in extreme precipitation within the region.

2. Data and methods

The China Meteorological Administration (CMA) Global Land Daily Precipitation dataset V1.0 (CMA GLDP-V1.0) is the source of daily precipitation measurements used in this current analysis. Data have been subjected to quality control and records span a period of 65 years (1951–2015). However, many stations lack data both prior to 1960 and after 2013 in the HKH region; therefore, the period 1961–2012 is used in this analysis. In addition, as the spatial coverage of records was improved after the 1960s, the period 1961–1990 is selected as the reference period (Fig. 1a). Given that precipitation amounts below 1 mm can introduce uncertainties in estimating the annual number of wet-day biases (Zhang et al., 2011), in this study wet-days are considered to be days on which there was no less than 1 mm of rainfall, and PRCPTOT (total precipitation) is the total of all the daily precipitation on wet days. The SDII (simple daily intensity index), or precipitation intensity, is defined as PRCPTOT divided by the number of wet-days. Consecutive wet-days (CWDs) and consecutive dry-days (CDDs) are frequently used to detect flooding and drought events, and are defined as the maximum number of consecutive days when precipitation ≥ 1 mm or < 1 mm. The maximum 1-day, 3-day, and 5-day precipitation amounts (RX1DAY, RX3DAY, and RX5DAY, respectively) are the maximum 1-day or maximum consecutive 3-day or 5-day precipitation in a year.

If any station in the HKH has a year in which there are less than half-valid daily precipitation data for one or more months, this year is flagged as missing, and the data in the year are not used in the subsequent calculation process. To enable use of the optimum spatial density of stations in the major study region, a certain standard is employed in station selection, as follows: stations selected should have at least 5-year precipitation records during the base period 1961–1990, and at least 10 years in the total period 1961–2012. To reduce uncertainties in extreme precipitation analysis, stations with less than 50 wet-days during the base period are totally eliminated from analysis. A final total of 1122 stations and