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Review

Climate change in the Hindu Kush Himalaya

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The Hindu Kush Himalaya is the highest mountainous and plateau system in the world, sitting on most of the world's highest peaks over 8000 m in height (Fig. 1). This region encompasses an area of more than 4.3 million km^2 and is characterized by a diversity of physiographic landscapes, climate types and bio-systems, the largest cryosphere in the world beyond the two poles, and being the source of a number of highly important large rivers including the Brahmaputra, Ganges, Indus, Mekong, Yangtze, and Yellow Rivers. The HKH is populated by about 210 million people and an additional 1.3 billion people live in downstream basins of the ten large rivers originating from this region.

Obvious climate changes have occurred in the HKH and may have exerted a large impact on its natural and human systems, as reported by many research groups and the IPCC (Singh et al., 2011; IPCC, 2013; You et al., 2017). Our understanding of climate change and its impact is better in a few areas, including the eastern Tibetan Plateau (TP), the Yunnan-Guizhou Plateau, and the low-lying plains of northern India. In most of the other areas, however, research has been relatively scant due to the big data gap. There are few high-quality historical observational data for these areas and a lack of human capacity for dealing with and analyzing observational and modeling data. In particular, as yet, there has been no analysis of past climate changes in the HKH as a whole and this prevents an in-depth understanding of climate change and its mechanism and the validation of climate models and their application in projecting future climate scenarios in this highly vulnerable region.

A comprehensive assessment of the HKH is underway as part of the larger Hindu Kush Himalaya Monitoring and Assessment Program (HIMAP). This assessment will consider many critical questions, including chapters on observed and projected HKH climate change and how climate change will impact the mountainous glaciers, water resources, and ecosystems of the region. The climate change chapter will present a broad overview of the weather and climate elements pertaining to the HKH, focusing more specifically on the linkages of large-scale drivers of climate change and variability in the region, past and present regional climate variations including extreme weather and climate change, and the projections of future climate using global and high-resolution regional climate models. Because no publication of observations of the overall HKH are available, a series of analyses have been conducted using recently developed global land climate datasets by the China Meteorological Administration (CMA) in combination with an assessment of previous publications on different areas of the HKH. A reanalysis of modeled outputs from global and regional models has also been conducted to determine likely future climate scenarios in the region. Since these results are new and very pertinent, it is therefore necessary to publish them as peer-reviewed papers.

This special issue includes seven papers. One is an overview of recent research in the HKH (You et al., 2017), three discuss observed climate changes over the past century or more (Ren et al., 2017; Sun et al., 2017b; Zhan et al., 2017), and three address projected future trends of climate under various representative concentration pathways (RCPs) (Wu et al., 2017; Sanjay et al., 2017; Rajbhandari et al., 2017). We summarize the main findings of these papers as follows (also see Table 1).

You et al. (2017) gave an overview of climate change observations in the HKH. They reported some consensus regarding recent climate change in the HKH for the TP in particular, as reported over the past decade, and also note the current scientific challenges and make research recommendations. This overview confirms the significant annual and

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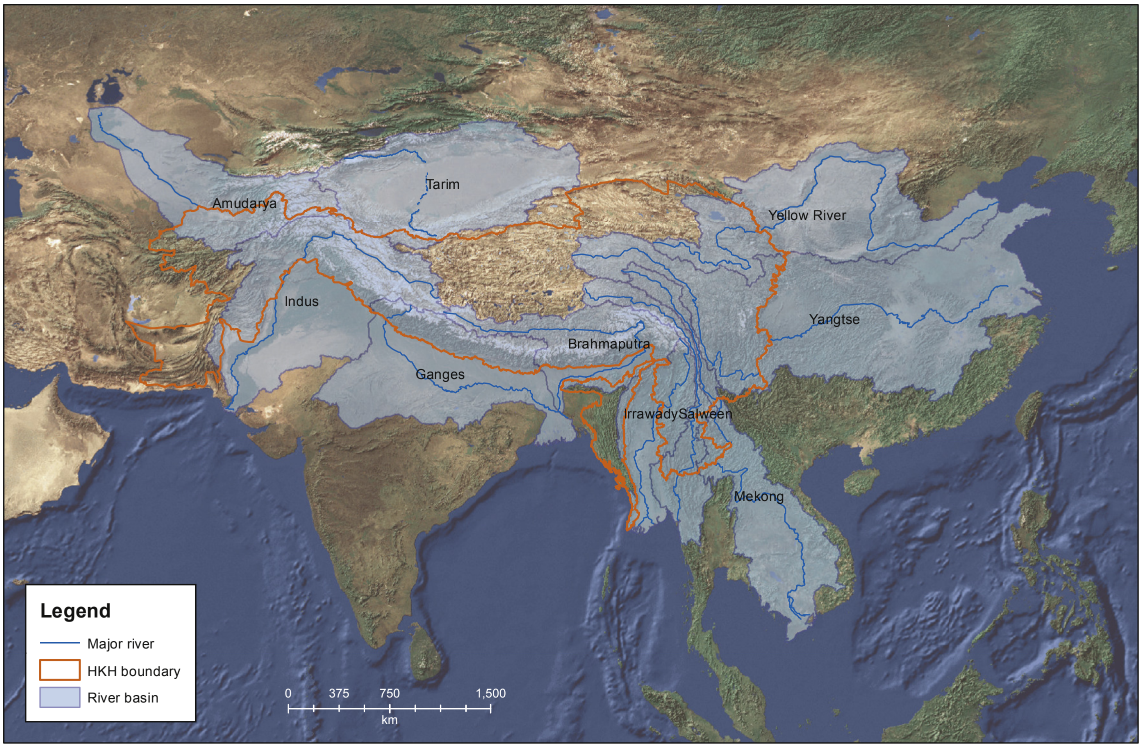

Fig. 1. Hindu Kush Himalaya and the major rivers originating from it.

Table 1
Observed changes in mean and extreme climates over the HKH during 1901–2014 and 1961–2015 (summarized from Ren et al. (2017); Sun et al. (2017b); Zhan et al. (2017)).

Indicator	Index	ID	Period	Trend direction	Trend value	Unit	Uncertainty level
Mean temperature and total precipitation	Mean temperature	T_{mean}	1901–2014	⬆	0.104	°C per decade	M
			1951–2014	⬆	0.195	°C per decade	L
	Total precipitation	P_{total}	1901–2014	⇩	−0.360	% per decade	H
	Total precipitation		1961–2013	⬆	3.529	% per decade	M
Extreme temperature event	Cold nights	TN10p	1961–2015	⬇	−0.977	d per decade	M
	Cold days	TX10p	1961–2015	⬇	−0.511	d per decade	M
	Warm nights	TN90p	1961–2015	⬆	1.695	d per decade	M
	Warm days	TX90p	1961–2015	⬆	1.239	d per decade	M
	Frost days	FD	1961–2015	⬇	−3.636	d per decade	M
	Summer days	SU	1961–2015	⬆	6.741	d per decade	M
Extreme precipitation event	Intense precipitation	IPA	1961–2012	⬆	6.16	% per decade	H
	1-d maximum precipitation	RX1DAY	1961–2013	⬆	2.14	% per decade	H
	3-d maximum precipitation	RX3DAY	1961–2013	⬆	2.26	% per decade	H
	5-d maximum precipitation	RX5DAY	1961–2013	⬆	2.34	% per decade	H

Note: Arrows indicate upward and downward trends, with the solid arrow indicating a significant trend ($p < 0.05$). Uncertainty levels of H (high), M (medium), and L (low) denote that the uncertainties of the estimates mainly due to data coverage and quality are large, moderate, and small, respectively.

winter warming in the TP region and also shows that amplified climate warming or so-called elevation-dependent warming (EDW) has seemed to occur over the TP. However, this phenomenon also seems to be regional and time dependent, with the TP and its surrounding areas having witnessed the clearest EDW over the last two decades. During the past two decades, which has been referred to as the global warming slowdown or hiatus, the annual and cold-season mean surface air temperatures over the TP have continued to increase, whereas the surface air temperature of northern and eastern China has experienced a remarkable leveling off or even decline in a few areas (Li et al., 2015; Sun et al., 2017a).

Ren et al. (2017) showed that during 1901–2014, the annual mean surface air temperature significantly increased in the HKH as a whole. The warming rates, in terms of annual mean surface air temperature, annual mean maximum temperature, and annual mean minimum temperature, reached 0.104 °C per decade, 0.077 °C per decade, and 0.176 °C per decade,