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Missing (in-situ) snow cover data hampers climate change and runoff studies in the Greater Himalayas

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HIGHLIGHTS

- Remotely sensed snow-cover data need to be validated by in-situ measurements.
- More in-situ snow measurement programs are needed along representative valley profiles.
- Free access to snow data is a necessity in the context of changing climatic conditions.
- Extreme parameterization shall be used with precaution in climate change projections.

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ABSTRACT

The Himalayas are presently holding the largest ice masses outside the polar regions and thus (temporarily) store important freshwater resources. In contrast to the contemplation of glaciers, the role of runoff from snow cover has received comparably little attention in the past, although (i) its contribution is thought to be at least equally or even more important than that of ice melt in many Himalayan catchments and (ii) climate change is expected to have widespread and significant consequences on snowmelt runoff. Here, we show that change assessment of snowmelt runoff and its timing is not as straightforward as often postulated, mainly as larger partial pressure of H_2O, CO_2, CH_4, and other greenhouse gases might increase net long-wave input for snowmelt quite significantly in a future atmosphere. In addition, changes in the short-wave energy balance – such as the pollution of the snow cover through black carbon – or the sensible or latent heat contribution to snowmelt are likely to alter future snowmelt and runoff characteristics as well. For the assessment of snow cover extent and depletion, but also for its monitoring over the extremely large areas of the Himalayas, remote sensing has been used in the past and is likely to become even more important in the future. However, for the calibration and validation of remotely-sensed data, and even more so in light of possible changes in snow-cover energy balance, we strongly call for more in-situ measurements across the Himalayas, in particular for daily data on new snow and snow cover water equivalent, or the respective energy balance components. Moreover, data should be made accessible to the scientific community, so that the latter can more accurately estimate climate change impacts on Himalayan snow cover and possible consequences thereof on runoff.

1. Introduction

The Greater Himalayas are the source of eleven major river systems of Asia, namely the Amu Darya, Syr Daria, Indus, Ganges, Tsangpo/Brahmaputra, Irrawaddy, Salween, Mekong, Yangtze, Yellow, and Tarim (Fig. 1), and cover a surface of about 7×10^6 km^2. An estimated 1.3 billion people live in these river basins and depend on its waters (Xu et al., 2009). As a result of ongoing and projected climatic changes in the Greater Himalayas (Kumar et al., 2013), runoff and other water resources might be altered quite significantly, as might be biodiversity and local livelihoods, at least in the montane and alpine zones of the Greater Himalayas (Xu et al., 2009; Mathison et al., 2013). The expected changes in availability and timing of runoff, as well as socio-economic developments in the region will require challenging definition and prioritization of choices for adaptation measures (Moors et al., 2011).

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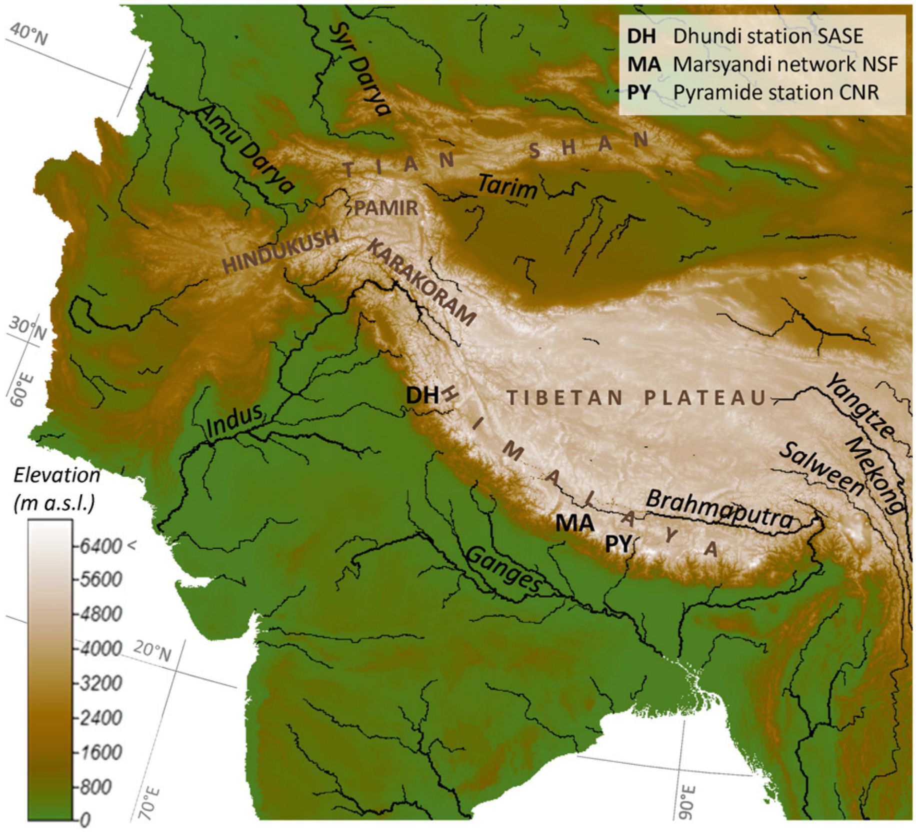

Fig. 1. Schematic view of the Greater Himalayas with its large river systems and localization of three important in-situ measurement sites for meteorological and snow-related data.

Over the past few years, public and scientific interest was focused mainly on the state and fate of the wider Hindukush–Karakoram–Himalayan glaciers and the possible consequences of glacier wasting on runoff (e.g., Akhtar et al., 2008; Kaser et al., 2010; Bolch et al., 2012; Kääb et al., 2012; Sorg et al., 2012). At the same time, however, snow cover and changes thereof were paid comparatively little attention. Although the mean annual contribution of snowmelt to downstream runoff of the larger streams – such as the Ganges at the Indo-Bangladeshi border – might have a mean annual contribution of only 1–5% (Collins et al., 2013), it might be a very crucial runoff component in the upper parts of these streams, in particular if runoff is considered on a seasonal basis (Siderius et al., 2013; Collins et al., 2013). Moreover, snow cover variability in Eurasia, or in the Greater Himalayas, may not only have local and regional, but also continental and global consequences (Barnett et al., 1989; Yasunari et al., 1991), which may become by far more important than the ongoing and expected future glacier wasting.

Because of the large size of the Himalayan region and typically difficult access to high mountain areas – in particular during winter – large scale snow cover dynamics has mainly been assessed by remote sensing. Rikiishi and Nakasato (2006), for instance, reported that snow cover in the Greater Himalayas has decreased by about one-third between 1966 and 2001 and that snow-cover duration has been reduced by 23 days during the same period and at elevations of 4000–6000 m. Although these rates might be slightly overestimated due to the binary definition of the 25×25 km pixel information and decadal climate oscillations (Zhang et al., 2004), the decrease is still substantial and expected to represent a serious threat to sustainable water supply for agricultural and other uses in the headwaters of Himalayan streams.

The objective of this contribution is to review past and current research on future runoff from glaciers and snow cover in the Greater Himalayas and to discuss further needs for a solid scientific basis, also in view of providing robust information to decision makers for the development of adaptation measures.

We discuss the adequacy of the assumed stationary character of parameter values and related uncertainties by addressing a set of research issues, namely the (i) importance of runoff modeling from snow cover in the Greater Himalayas; (ii) possibilities and limitations of remotely-sensed data in determining snow cover characteristics; (iii) possible shortcomings of commonly used parameterizations in snow cover–runoff modeling for current and future climates; (iv) crucial role of in-situ measurements for the validation and calibration of snow cover–runoff models; and the (v) monitoring of snow cover and related variables with in-situ data.

2. Contribution of snow cover to runoff from the Himalayas

Research has largely neglected the role of snow cover to runoff in the Greater Himalayas so far, despite the fact that its contribution can be much more important than that of ice melt in several of the Himalayan catchments. In one of the rare contributions focusing on runoff from snow melt, Prasch et al. (2012) state that only 2% of annual runoff stems from glacier melt in the high-altitude Lhasa river basin at Lhasa (Central Himalayas, catchment size: 26,000 km^2, elevation range 3600–7160 m asl., ca. 1.3% glacierization in 1970), whereas more than 50% originates from the melting of the seasonal snow cover (mean 1971–2000). Similarly, in the Annapurna region of Central Nepal, winter snowfall has been shown to contribute up to 35% of annual precipitation for elevations >3000 m asl. Here, snow water equivalent (SWE) can reach over 1000 mm (Lang and Barros, 2004), as evaluated by a temporary measuring network over a 5-year period in the Marsyandi valley. By contrast, satellite-derived TMPA (Huffman et al., 2007) and APHRODITE data (Yatagai et al., 2012) point to very limited winter precipitation in the Khumbu region (Eastern Nepal). At the same time, however, observational data from the Pyramid station (http://evk2.isac.cnr.it/) indicate that winter snow depth can be astonishingly high during individual years (also see Fig. 7).