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Precipitation variability in High Mountain Asia from multiple datasets and implication for water balance analysis in large lake basins

Chunqiao Song [a,b,*], Bo Huang [b,c,*], Linghong Ke [d], Qinghua Ye [e]

[a] Department of Geography, University of California, Los Angeles, Portola Plaza, Los Angeles, CA 90095, United States
[b] Department of Geography and Resource Management, The Chinese University of Hong Kong, 999077, Hong Kong
[c] Shenzhen Research Institute, The Chinese University of Hong Kong, Nanshan District, Shenzhen 518172, China
[d] Department of Land Surveying and Geo-Informatics, The Hong Kong Polytechnic University, 999077, Hong Kong
[e] Institute of Tibetan Plateau Research (ITP), Chinese Academy of Sciences (CAS), Building 3, Yard 16 Lincui Rd., Chaoyang District, Beijing 100101, China

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ABSTRACT

For the period 1979–2011, eight gridded monthly precipitation datasets, including GPCP, CMAP-1/2, TRMM, PREC/L, APHRODITE, NCEP-2 and ERA-Interim, are inter-compared with each other and station observations over High Mountain Asia (HMA). The precipitation variability from the first six gauge-based or merged analysis datasets agree better with each other than with the two reanalysis data. The long-term trend analysis of GPCP, CMAP-1, PREC/L and APHRODITE precipitation datasets consistently reveals moderate increases in the inner and northeastern Tibetan Plateau (TP) and northwest Xinjiang, and obvious decreases in the southeast TP. However, in the Himalayas and Karakorum, there are large discrepancies among different datasets, where GPCP and APHRODITE precipitation datasets show significant decreases along the Himalayas while other datasets show strong spatial heterogeneity or slight variations. The larger uncertainties in the rugged area may be largely attributed to scarce station observations, as well as the stronger snow-induced scattering by microwave measurement. To assess which precipitation datasets tend to be more suitable for hydrologic analysis in HMA, we further investigate the accuracy of precipitation estimates at basin scale by comparing with gauge-based observations, and examine the coherences of annual lake water budgets and precipitation variability over four large closed lake catchments. The results indicate that two reanalysis precipitation datasets show evidently weaker correlations with station observations; the other six datasets perform better in indicating inter-annual variations of lake water budgets. It suggests that these merged analysis precipitation datasets, especially for GPCP, CMAP-1/2 and PREC/L, have the potential in examining regional water balances of the inner basins in HMA.

1. Introduction

High Mountain Asia (HMA, hereinafter), located in the hinterland of Eurasia, consists of a large number of Earth's highest mountains and extensive basins, north from the Altai Mountain and Tianshan Mountain ranges, south to the Himalayas, west from the Pamir, and east to the Qilian and Hengduan Mountains. It is characterized by rather complex terrains. HMA is of considerable importance to Asian monsoon and even global general circulations via mechanical and thermal forcing (Duan and Wu, 2008; Hsu and Liu, 2003; Yanai et al., 1992) because of its high altitude, topographical effects, and the broad span of tropical to extratropical circulations. This area accommodates many lakes and glaciers (Song et al., 2013, 2015b; Yao et al., 2012), where more than ten large Asian rivers originate (Immerzeel and Bierkens, 2012). Thus, an investigation of spatiotemporal precipitation variability over HMA is crucial for understanding associations between climate change and regional water balances (Yang et al., 2014).

The recent studies on climate change in HMA revealed that the air temperature increased rapidly after the 1980s (Gautam et al., 2013; Liu and Chen, 2000; Unger-Shayesteh et al., 2013; Xu et al., 2008; You et al., 2010), whereas changes in precipitation showed strong spatio-temporal heterogeneity (Xu et al., 2008; Yang et al., 2011). The spatio-temporally inconsistent trends of precipitation may be associated with various dominations from large-scale atmospheric circulations (Yang et al., 2011; Yao et al., 2012). At present, it is difficult to generate high-quality gridded precipitation data over the whole HMA only via spatial interpolations of scarce station observations due to complex topography and spatially uneven distribution of weather stations. Therefore, high-quality precipitation estimates with good spatiotemporal coverage are necessary and helpful to better understand precipitation variability in HMA and its hydrological impacts.

* Corresponding authors at: Department of Geography and Resource Management, The Chinese University of Hong Kong, 999077, Hong Kong.
E-mail addresses: chunqiao@ucla.edu (C. Song), bohuang@cuhk.edu.hk (B. Huang).

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With the increasing availability of regional or global precipitation datasets, including reanalysis, satellite measurements and merged analysis, there have been a large number of literatures on comparing and evaluating the accuracy of these precipitation data in this area (Andermann et al., 2011; Ma et al., 2009; Tong et al., 2014; Wang and Zeng, 2012; You et al., 2012, 2015). A common conclusion could be drawn that various precipitation data have large biases relative to station observations due to complex topographic effects and the lack of sufficient constraints from gauge data in HMA. Although most studies focus on evaluating the data performance based on existing weather stations (mostly at lower altitudes), it is difficult to quantify whether the station observations are representative for the gridded precipitation data, especially in most mountainous areas without observations. Moreover, these comparative studies were conducted under different rules, including the selection of assessed precipitation datasets, data period, temporal and spatial sampling resolution, and geographic extent of target area. Thus it is hard to synthesize conclusions from different literatures.

In this study, we select eight commonly used gridded precipitation datasets spanning 1979–2011, including the version-2 National Centers for Environmental Prediction reanalysis (NCEP-2) (Kanamitsu et al., 2002), European Center for Medium-range Weather Forecasts (ECMWF) reanalysis ERA-Interim (Dee et al., 2011), Global Precipitation Climatology Project (GPCP) (Adler et al., 2003), Climate Prediction Center (CPC) version-1/2 Merged Analyses of Precipitation (CMAP-1 and CMAP-2) (Xie and Arkin, 1996; Xie and Arkin, 1997), the version-7 Tropical Rainfall Measuring Mission (TRMM) Multi-Satellite Precipitation Analysis (Huffman et al., 2007), Asian Precipitation-Highly Resolved Observational Data Integration toward the Evaluation of Water Resource (APHRODITE) (Yatagai et al., 2009, 2012), and Precipitation Reconstruction over Land (PREC/L) (Chen et al., 2002). These datasets are generated using inconsistent input sources, data processing and quality-control techniques, and different algorithms. In this study we investigate the spatial and temporal variations of precipitation over HMA through the inter-comparison of each two datasets with a focus on inter-annual and decadal timescales. The general pattern of annual precipitation trends from gridded datasets is also compared with the isoline map of precipitation trend derived from station observations. Following the examination of precipitation variability, its potential influences on regional water balance in HMA are investigated based on the correlation analysis of observed lake water budgets and annual precipitation from different precipitation products over four large closed lake catchments.

2. Study area

The study area comprises the Tibetan Plateau (TP, hereinafter) and surrounding mountainous regions, mostly located in China (shown in Fig. 1). The geographical extent ranges from approximately 25°N to 52.5°N, and 70°E to 105°E. Due to the high altitudes and strong topographical effects, HMA plays an important role in determining the formation and dynamics of regional climate in East and South Asia, as well as atmospheric circulations of the Northern Hemisphere (Liu et al., 2008; Yanai et al., 1992). Various atmospheric circulation systems, combined with the huge topographic and horizontal gradient effects exert complex controls on the spatio-temporal pattern and variability of precipitation. For instance, the precipitation in the southern HMA is mainly influenced by the warm-moist Indian monsoon in summer while by the westerlies in winter (Yao et al., 2012). The East Asian monsoon also influences the eastern parts.

As most lake basins in HMA have no outlets (endorheic basins) and minimally disturbed by human activities (e.g. agricultural irrigation), annual lake water budgets are mainly affected by local climate conditions including precipitation and evaporation, and the amount of glacial meltwater within the catchments. In this study, four lakes (Issyk Kul Lake, Lake Qinghai, Silingco, and Yamzhog Yumco) are selected to investigate which precipitation datasets are eligible for hydro-climatological analysis in the high-altitude catchments. As shown in Fig. 1 and Table 1, these lakes are distributed in different geographical sub-zones, and thus precipitation variability display strong spatio-temporal heterogeneity

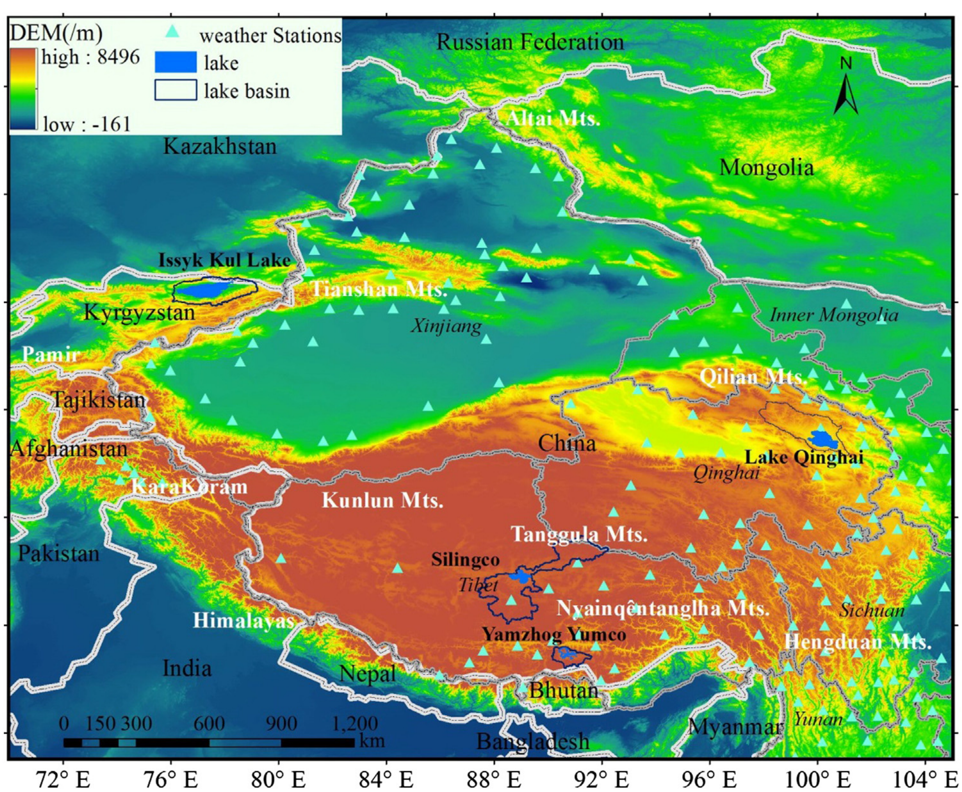

Fig. 1. Geographical location and topographical characteristics of High Mountain Asia. The four examined lakes: Issyk Kul Lake, Lake Qinghai, Silingco and Yamzhog Yumco, are respectively located in the northwestern Tianshan Mountains, northeastern HMA, inner Tibetan Plateau and southern HMA.