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Editorial: Climatic and associated cryospheric and hydrospheric changes on the Third Pole - Volume II

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Editorial on the Research Topic
Climatic and associated cryospheric and hydrospheric changes on the Third Pole - Volume II

The Third Pole (TP) region refers to the high lands in Asia, including the Tibetan Plateau, Himalayas and their surrounding mountains, as well as the Pamir Plateau, the Tianshan Mountains and the Altai Mountains (Yao et al., 2022). It is home to more than 100,000 km^2 of glaciers, containing the largest volume of ice outside the Arctic and Antarctic (Yao et al., 2012).

The warming rate of the TP is twice the global average in the past half century (Chen et al., 2015; Pepin et al., 2015). Climate warming has altered the water vapor supply and regional climate characteristics of the TP (Yang et al., 2014). The changes in cryosphere such as glacier retreat, permafrost degradation, and snow-to-rain in precipitation (Kang et al., 2010) have also greatly changed the hydrological cycle (Yang et al., 2011) and land surface conditions (such as vegetation, soil, lake, and geomorphology), leading to prominent differences among major TP river basins in various components of changes, including actual evapotranspiration, terrestrial water storage, and river runoff (Bibi et al., 2018; Yao et al., 2019). Due to the complex land surface environment and the influence of atmospheric circulation in the TP, river runoff components (rainfall-runoff, ice and snow melting, soil freezing/thawing) could be also largely different. These changes have a profound impact on the regional water cycle, changing the spatiotemporal patterns of available freshwater supply (Immerzeel et al., 2010; Lutz et al., 2014). However, up to now, the quantification of the atmosphere, cryosphere, biosphere and hydrosphere over the TP still has large uncertainties, due to a lack of necessary ground-based observations (across a range of different hydrometeorology and cryosphere variables) and advanced satellite technology (e.g., new sensors for permafrost ice monitoring, and atmospheric ice monitoring).

This Research Topic aims to cover recent climate changes over the TP (or comparable cold regions) and its associated impacts on the cryosphere and hydrosphere. Different from "Climatic and Associated Cryospheric and Hydrospheric Changes on the Third Pole-Volume I," this Research Topic ("*Climatic and Associated Cryospheric and Hydrospheric Changes on the Third Pole-Volume II*") tends to quantify the atmosphere, cryosphere, biosphere and hydrosphere of the TP in different aspects with acceptable accuracies, based on *in situ* observations, satellite remote sensing, and numerical modeling. These studies address changes in atmospheric ice, seasonal snow cover, mountain glaciers, permafrost, lakes, vegetation, evapotranspiration, terrestrial water storage as well as water-related disasters, and examine how these changes are linked to climate change across different spatial scales (from a catchment to the whole TP). Results from these studies will improve our understanding of cryosphere–hydrosphere–atmosphere interactions over the TP.

This Research Topic includes nine original research articles and one brief research report. This is a multidisciplinary Research Topic bridging the gaps in cryosphere, climatology, hydrology, geomorphology, biogeochemistry, and remote sensing sciences.

Liu et al. present a low-cost approach by integrating remote sensing data and limited underwater surveys for lake volume estimation on the TP, by coupling the lake hypsometric curve and bottom elevation. Their studies on nine TP lakes with different sizes and geometric characteristics show an overall bias in volume estimate of about 15%. The method proposed by their paper is expected to provide a simplified but efficient solution for estimating the lake water volume on the TP and other ungauged areas.

Liu et al. examine the hydrological budgets and their driving forces of closed Chinese inland basins. In their study, trends and magnitudes of precipitation, terrestrial water storage, and actual evapotranspiration were detected by the rank-based non-parametric Mann–Kendall test method. Their results showed that both precipitation and actual evapotranspiration significantly increased in the Chinese inland basins. Moreover, the annual terrestrial water storage in the Chinese inland basins significantly decreased mainly due to the increased actual evapotranspiration, in which approximately 60% was attributed to increased irrigation diversions.

Yang et al. evaluate the total mass, spatial distributions, and long-term trends of atmospheric ice over the TP. Based on the estimations using multiple satellite datasets (Aqua, Terra, the Suomi National Polar-orbiting Partnership, and NOAA-20), they concluded that the total mass of atmospheric ice could be up to 0.26 ± 0.03 Gt over the TP from 2013 to 2020. In general, the southwest and northeast TP were the low-concentration areas (0. 05 kg/m^2 on average), while the southeast TP was the high-concentration area (0.09 kg/m^2 on average). The plentiful water vapor transported by the Southwest Summer Monsoon and steep topography could be the major contributors to the rapid growth and the higher ice concentration of atmospheric ice in southeast TP.

Half of the annual water discharge in the upper Indus Basin is contributed from the glacier and snow-fed basins in the Hindu Kush, Karakoram, and Himalayan regions, which are sensitive to climate change. Moazzam et al. indicates that the snow cover area in Astore (Western Himalayas) and Shigar (Karakoram region) has an increasing trend with a rate of 11.16 km^2/year and 4.27 km^2/year, respectively. The increasing annual precipitation and decreasing annual mean temperature also support the phenomenon of expanding snow cover area in these areas. Their further analyses on snow cover changes with elevation reveal that snow cover area was decreasing on foothills while increasing at the valley top.

Liu et al. explore the spatial-temporal changes in the lake area on the northeastern TP from 1988 to 2019 and their driving factors based on Landsat images, meteorological data, and glacier and permafrost data. It suggests that the lake areas increased at rates of 0.01–16.03 km^2/year from 1988 to 2019. In more detail, the change was featured by a decrease during 1988–2000, a moderate increase during 2000–2012, and an accelerated increase during 2012–2019. The precipitation (other than glacial meltwater) was the primary driving factor for this dramatic change in the lake area of this region, while the permafrost degradation further intensified the lake expansion.

Park et al. implement a water age calculation scheme into a coupled hydrological and biogeochemical model to assess the mechanisms through which climate warming affects the soil water storage–evapotranspiration–water age feedback cycle in a boreal forest. Their results suggest that permafrost warming (characterized by earlier soil thawing and later freezing) induced higher evapotranspiration, thereby shortening the residence time of precipitation-sourced water in the active layer and further rejuvenating water in soil layers and in evapotranspiration. Under future climate warming conditions, this effect is expected to intensify and the water cycle will be accelerated.

Deng et al. explore the relationship between changes in terrestrial water storage and vegetation on the TP to understand further the role of vegetation in the changes of water systems in alpine mountains. They combine terrestrial water storage anomalies data and vegetation indices to determine how they interact. Their results indicate a significant warming rate of 0.44°C/decade over the TP from 1980 to 2020, while evapotranspiration and precipitation trended upward significantly (12.9 and 15 mm/decade, respectively). Under the current climate change state (the increased rate of precipitation is faster than actual evapotranspiration), vegetation change has an insignificant impact on the changes in terrestrial water storage; in contrast, changes in terrestrial water storage (surplus/deficit) significantly affect vegetation changes (greening/browning) in parts of the TP.

Mountains glacier, as one of the most important components of terrestrial water storage, effectively regulates and stabilizes surface water resources. However, how much the mountain glacier mass balance contributes to terrestrial water storage changes around mountain regions is unknown. Li et al. combine multi-source datasets to quantify the contribution rate over high-elevation mountain regions. They find that the glacial melting mass loss is equivalent to about 49% of the total terrestrial water storage decline during 2006–2015 at a global scale. There are larger contributions in the regions with more glaciers. Glacier mass together with other storage components play diverse roles in changing terrestrial water storages across different mountain regions and watersheds, but factors with great influence are glaciers, groundwater, soil water, reservoirs, and lakes.

Gao et al. develop a multi-source data fusion snow cover dataset for the TP, and conduct snow zonation and comparative snow variability analysis. They find that from 2000 to 2021, 23.0% of TP has experienced a significant decrease in snow cover days (mainly in the southeast) and 4.9% has experienced a significant increase (mainly in the northwest). The contrasting change in the snowpack on the TP, with a large decrease at lower elevations and an increase at higher elevations, will bring new challenges to water resources management in the region.

Finally, a study of the water-related extreme disaster on the TP is reported by Wang et al. Global warming is inducing dramatic changes in fluvial geomorphology and reshaping the hydrological connections between rivers and lakes. The water level and area of the Salt Lake have increased rapidly since the Zonag Lake outburst in the Hoh Xil region of the TP in 2011, threatening the downstream infrastructure. Wang et al. extract the long time series of the Salt Lake areas and analyze its spatiotemporal variation from 1973 to 2021, and finally assess the overflow risk of Salt Lake that is a downstream closed lake. They found that, the area change of the Salt Lake was consistent with the variation in precipitation before the outburst event. After that, it showed a remarkable area expansion (circa 350%), especially in the southeast direction. Without the construction of the emergency drainage channel, their simulation results indicated that the earliest and latest times of the Salt Lake overflow event are predicted to occur in 2020 and 2031, respectively.

Author contributions

LW: Conceptualization, Funding acquisition, Investigation, Writing–original draft, Writing–review and editing. CS: Funding acquisition, Writing–review and editing. XL: Conceptualization, Writing–review and editing. TC: Writing–review and editing. MR: Writing–review and editing.

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Conflict of interest

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