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A study of longitudinal and altitudinal variations in surface water stable isotopes in West Pamir, Tajikistan

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ABSTRACT

In an effort to establish a clear relation between stable isotopes and altitude in the Pamir region, as well as to improve the understanding of stable isotope spatial variations found along the routes taken by the westerlies, surface river water samples were collected along a roughly west–east profile in Tajikistan. Here we present the spatial changes in modern surface water $\delta^{18}O$ and deuterium excess (*d*-excess), and their links with snow melt, glacier melt and seasonal precipitation patterns in Tajikistan. The results show a close relation between river water $\delta^{18}O$ and δD above the GMWL (Global Meteoric Water Line), implying that surface evaporation exerts a weaker influence. Spatially, river water $\delta^{18}O$ is gradually depleted from west to east due mainly to the effect of altitude, yielding a river water $\delta^{18}O$ vertical lapse rate of 0.09‰/100 m. River water *d*-excess shows a decreasing trend from west to east in Tajikistan. This spatial *d*-excess pattern in surface water is explained by the different moistures influenced by the Mediterranean and other in-land seas with higher *d*-excess in west, and no-Mediterranean moisture in east. Another possible reason is the differences in precipitation seasonality between the west and east of Tajikistan.

1. Introduction

Many efforts have been made to understand the relation between stable isotope variations and the hydrological cycle and atmospheric circulation on the Tibetan Plateau (TP) and its surrounding area (Li et al., 2007; Warburton and DeFelice, 1986; Xiao et al., 2014; He and Keith, 2015). Previous work has mainly focused on differences in moisture transport in the monsoonal and westerly regions, and its significance in paleoclimate research (Araguas-Araguas et al., 1998; Davis et al., 2005; Tian et al., 2007; Vuille et al., 2005; Yao et al., 1996; Bershaw et al., 2012). Large spatial changes along the Indian monsoon trajectory have been identified using latitudinal precipitation and land surface water isotopes. Altitudinal changes in water isotopes are also used to constrain the uplift of the plateau in that region (Quade et al., 2007; Rowley and Currie, 2006; Rowley et al., 2001; Holdswoith et al., 1991). A clearer understanding of how isotopes vary with elevation is now required; such a variation has been well-defined on the Indian monsoon-influenced southern slopes of the Himalaya or the southern TP by sampling river water along the vapor trajectories (Garzione et al., 2000; Kent-Corson et al., 2009; Rowley et al., 2001), but there remains a lack of information in the westerly region. Stable isotopes have also been used to rebuild paleoclimate changes from ice core records at different alpine glacier sites (Henderson et al., 2006; Thompson et al., 1989, 1997; Hren et al., 2009). Although long-term ice core

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isotope records are believed to reflect temperature change (Thompson et al., 2000), spatial changes in different ice core isotope records are also apparent, as derived from different atmospheric circulation controls (Yao et al., 2006). This hints at the investigative isotope work necessary for regions with different atmospheric circulations. Spatial river water *d*-excess can also be used to identity different types of moisture transport as it can bear different isotope signals (Tian et al., 2001; Salamalikis et al., 2015).

Tajikistan is located in Central Asia, and has a typical arid and semi-arid temperate continental climate. The country's topography is typified by a sizeable contrast in altitude between the low-lying plains in the southwest and the high Pamir Mountains in the east (Peak Somoni, the highest peak, with an altitude of 7495 m asl, is in the central Pamir). This large altitude contrast makes it an ideal region for isotope vertical gradient rate estimation. A huge number of glaciers surround the high mountains of Pamir (Aizen et al., 1996). The Fedchenko Glacier, the longest alpine glacier in the world outside of the polar regions, has the potential to yield long-term paleoclimate change signals from its ice core isotope records. The meltwater from these glaciers is Tajikistan's main available water resource. In fact, Tajikistan accounts for more than half of the total available water resource in the entire Central Asia region. Two large-scale water suppliers to the Aral Sea, the Syr Darya and Amu Darya rivers, originate in the glaciers of the western Tianshan and Pamir Mountain ranges. It is thus important to understand the isotopic hydrological cycle of this region.

Here we present river water isotope ($\delta^{18}O$ and δD) data along a west–east transect in Tajikistan. The factors influencing river water isotopes, including precipitation isotopes and their seasonal changes, vapor sources and land surface evaporation, are very complex. A thorough understanding of these factors and how they determine water isotopes is thus problematic, owing especially to a lack of continuous precipitation isotope data. However, such isotope data as there are can demonstrate links with local water cycles. Nonetheless, the distinctive vertical changes and spatial changes in river water isotopes in Tajikistan can provide vital information about water resources.

2. Methods

2.1. Research area

About 93% of Tajikistan's land surface is composed of mountains or plateaus, and more than half of its terrain is over 3000 m. Based on the elevation of the terrain, Tajikistan can be roughly divided into four geographical regions: the northern mountains and basins, mainly belonging to the Tianshan Mountains; the southwest with its lower-altitude valleys; the central mountainous region; and the Pamir plateau in the east. About 6% of Tajikistan is covered by glaciers, with an ice volume reaching 500 km^3 (Makhmadaliev, 2002). These glaciers are mainly in the central and eastern Pamir, with some located in northwestern Tajikistan. The large number of glaciers in the high mountains and plentiful snowfall in winter and spring provide sufficient water resources for the whole country. In the winter, there is heavy precipitation in the form of snow, especially in central Tajikistan. However, the summer is dry and hot in the middle and west. This seasonality affects annual river runoff. As the climate warms from March to May, glaciers and snow begin melting and river runoff increases, reaching a maximum in the period from June to August.

The main moisture supply to the region comes from westerlies, southwestern cyclones and sometimes Caspian Sea and Aral Sea evaporation. The eastern Murghab River and East Pamir Plateau rainfall are concentrated in the period from May to August. Unlike in the east, precipitation in the west of Tajikistan is highest during winter and spring (Fig. 1a), owing to the relief impact of the Siberian/Tibetan high-pressure systems during winter. Summer and autumn are the dry seasons over southwest central Asia. The seasonal precipitation patterns at meteorological stations in western Tajikistan such as at Dushanbe (Fig. 1b), imply a typical Mediterranean climate with concentrated winter and spring precipitation. Eastwards, the seasonal precipitation pattern gradually changes to a summer maximum precipitation pattern as at Carlakul in the Murghab region, an area typically controlled by westerlies (Aizen et al., 2009). From west to east, precipitation amounts decline significantly, especially during winter and spring, and there is an apparent shift from winter and spring precipitation patterns to summer precipitation patterns. The changes in precipitation recorded at six meteorological stations are also reflected in the climate record as listed in Table 1 (precipitation) and Table 2 (air temperature).

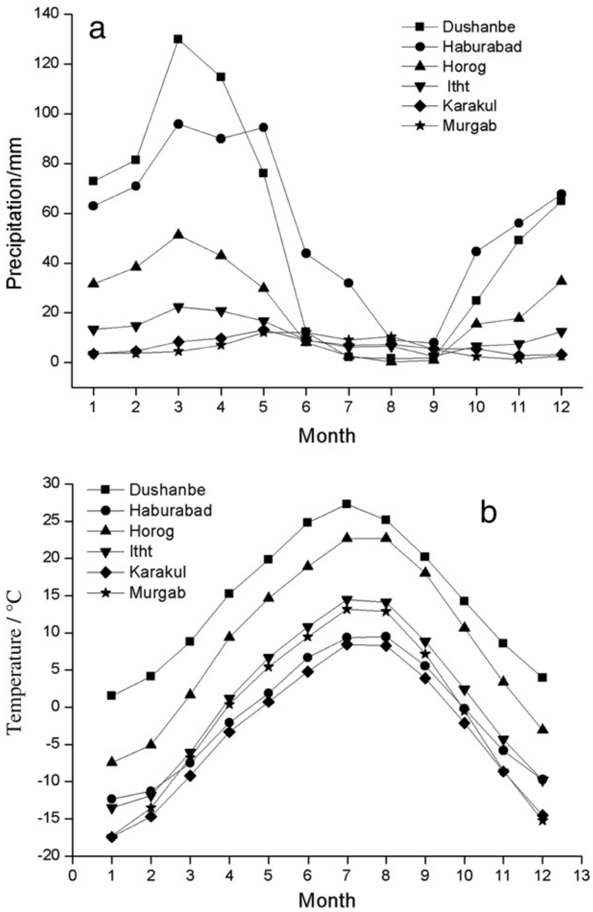

Fig. 1. Average monthly precipitation (a) and monthly air temperature (b) at Tajikistan meteorological stations.