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Can monsoon moisture arrive in the Qilian Mountains in summer?

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ABSTRACT

The isotopic composition of precipitation has been measured in samples simultaneously collected during individual precipitation events at a high-altitude station (Hulugou at 3260 m a.s.l.) in the middle Qilian Mountains, northwestern China. The observed changes of $\delta^{18}O$ (δD) and deuterium excess with surface air temperature, precipitation and season have been evaluated to derive information on water vapor sources and the effects from monsoon moisture. The results indicated monsoonal moisture can arrive in the Qilian Mountains in summer, as indicated by: (1) under temperatures between 8 °C and 15 °C, the precipitation events are characterized by the decrease of $\delta^{18}O$ and d excess owing to the influence from monsoonal moisture; (2) $\delta^{18}O$ and δD showed statistically negative correlation with precipitation, which reflected the amount effect in at precipitation events scale; (3) not only the water vapor transporting vector but also composite circulation maps verified the arrival of monsoonal moisture in summer along the eastern margin of the Tibetan Plateau, which made a great contribution to regional precipitation under climate warming.

1. Introduction

The isotopic ratios of oxygen and hydrogen ($^{18}O/^{16}O$ and $^{2}H/^{1}H$, respectively) are powerful tools in studying climatic processes because of their wide variations in time and space (Dansgaard, 1964; Vodila et al., 2011; Aggarwal et al., 2012; Hughes and Crawford, 2013). Their variability in natural archives of precipitation is also valuable in hydrological studies (Yang et al., 2011; Kong and Pang, 2012). Such studies require a good understanding of isotopic fractionation in controlling the isotopic composition of precipitation, the primary input to hydrological systems such as surface water bodies, groundwater, and glacier ice in polar and high mountain regions (Pang et al., 2011; Jeelani et al., 2013). In general, $\delta^{18}O$ values of meteoric precipitation are related to fractionation processes associated with the evaporation and condensation history of the precipitating water vapor. The isotopic composition of the water vapor sources, the temperature at which condensation occurs, the degree to which the water vapor has traveled over land, and the amount of precipitation have a significant influence (Dansgaard, 1964). $\delta^{18}O$ and δD of precipitation at middle and high latitudes are linearly related to the annual mean temperature (Dansgaard, 1964) and themselves are strongly related, following the Global Meteoric Water Line (GMWL): $\delta D = 8\delta^{18}O + 10$ (Craig, 1961). Observed changes of precipitation $\delta^{18}O$, δD and deuterium excess ($d = \delta D - 8\delta^{18}O$) with surface air temperature, altitude and season have been evaluated to derive information about the effects of sub-cloud evaporation and moisture recycling on the formation and isotopic composition of precipitation under arid climatic conditions (Pang et al., 2011; Ma et al., 2012). Recent studies have shown that scope remains for improving understanding of isotopic processes, particularly those leading to the deuterium excess in polar and high mountain regions (Kreutz et al., 2003; Pang et al., 2011).

In addition to the influence of temperature during condensation of raindrops in a cloud, and evaporation processes thereafter, the isotopic composition of precipitation at a site is affected by the origin and trajectory of moisture-bringing air masses (Aravena et al., 1999; Vander et al., 2010; Theakstone, 2011; Xie et al., 2011), and changes of $\delta^{18}O$ between moisture source areas and

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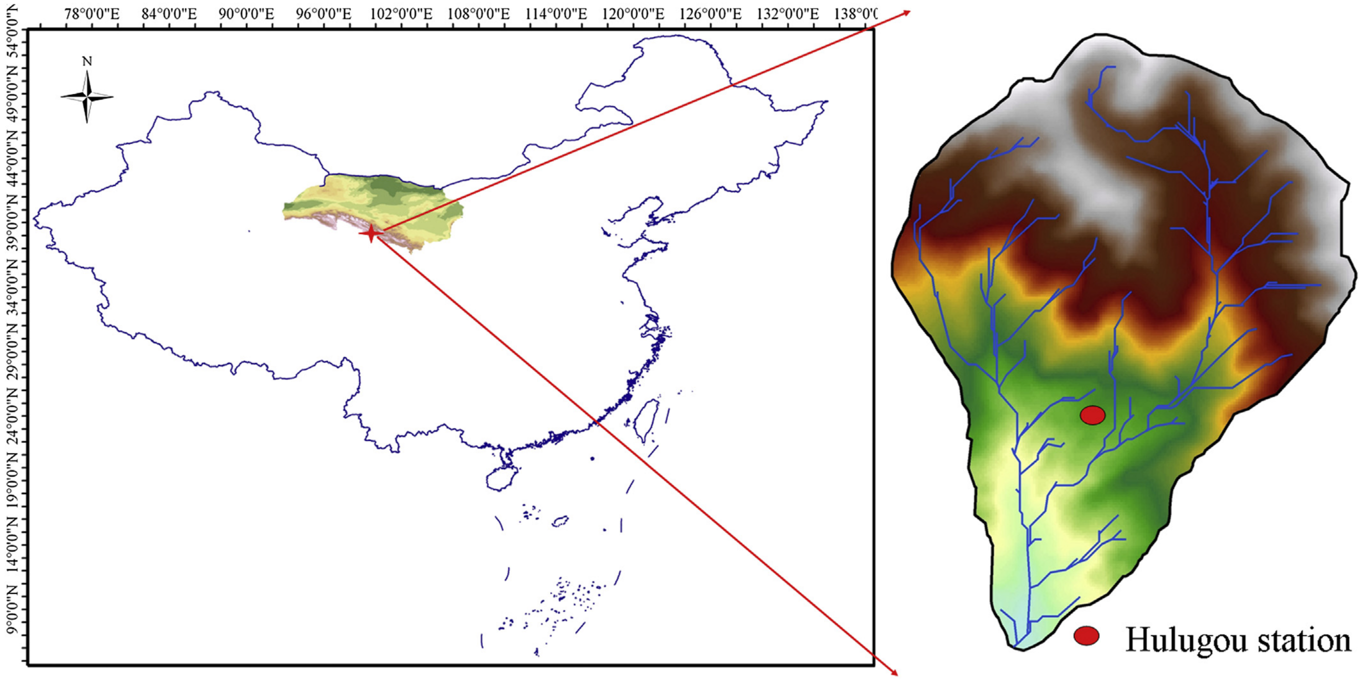

Fig. 1. Location of Hulugou station.

sites of precipitation are strongly influenced by atmospheric circulation. The prevailing synoptic circulation may determine the $\delta^{18}O$ value in a particular precipitation event (Barlow et al., 1997). Burnett et al. (2004) provided a first step toward an understanding of how different winter circulation types influence precipitation $\delta^{18}O$, and their work underscored the importance of circulation in interpretation of $\delta^{18}O$ archives in middle New York State. Tian et al. (2007) found that stable isotope variations of precipitation in western China are influenced by the moisture sources. Barras and Simmonds (2008a,b) demonstrated that isotope ratios in southern Tasmanian precipitation are modified by the local and large scale circulation system, which is important in understanding such natural climate archiving as speleothems. Thus, understanding the relationships between atmospheric circulation and $\delta^{18}O$ in individual precipitation events is a prerequisite for interpreting isotopic archiving in Qilian Mountains, where the different moisture sources should play an important role in determining variations of the isotopic composition in precipitation.

In recent decades, great efforts have been devoted to exploring the climatological and hydrological signals of precipitation in the Qilian Mountains and adjacent regions through stable isotope studies (Tian et al., 2001, 2007; Wu et al., 2010; Zhao et al., 2011; Ma et al., 2012). These studies have increased knowledge and understanding of the temperature effect, the precipitation amount effect, the Local Meteoric Water Line (LMWL) equation, and the variability of stable isotopes and d excess at temporal and spatial scales. However, because of the variable atmospheric circulation, the complex topography, and the secondary evaporation of water vapor from inland surface water, there still is no clear understanding of the monsoon signal, or identification of vapor sources, in the region. Furthermore, the relatively short-term availability of precipitation $\delta^{18}O$ and δD records limits in-depth knowledge. Accordingly, this study examines the relationship between atmospheric circulation and precipitation $\delta^{18}O$ values in Hulugou basin, middle Qilian Mountains, during 2012–2013. Circulation back trajectories, weather maps, and $\delta^{18}O$ values for 59 precipitation events are also been examined in order to determine the air mass circulation during the sampling period.

2. Study area, precipitation sampling, and data analysis

2.1. Study area

The Hulugou basin in the middle Qilian Mountains, Qinghai Province, China, at 38°12′14″–38°16′23″N and 99°5′37″–99°53′54″E (Fig. 1) has a catchment area of 23.1 km^2. It is the representative of the Qilian Mountains, and is well suited for cold alpine catchment research. The altitude ranges is from 2960 m to 4820 m. The basin is very cold (annual mean temperature 3.1–3.6 °C) and has little evaporation (Yang et al., 2013). The annual mean precipitation ranges from 400 to 600 mm. The basin is the water source of the Heihe river. The terrain is complex with a clear

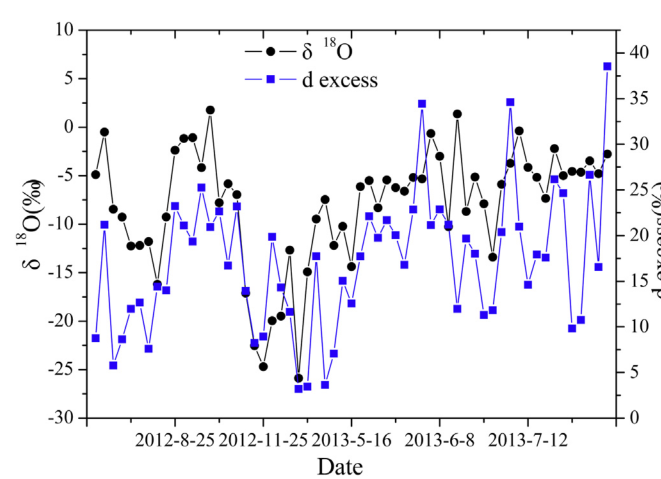

Fig. 2. Seasonal variations of $\delta^{18}O$ and d-excess in precipitation at Hulugou station.