Precipitation Stable Isotope Variations and Their Relationship with Moisture Sources in the Bagrot Valley, Upper Indus River: Postprint

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Date: 2019-03-07T00:00:00+00:00

Abstract

Based on observations of precipitation stable isotopes ($ $18O and δD) in Bagrot Valley of the upper Indus River basin from August 2015 to July 2016, together with local meteorological data, this study analyzed the variation characteristics of precipitation stable isotopes, the meteoric water line, and moisture sources in the research area using isotopic tracing and statistical analysis methods combined with the HYSPLIT model. The results indicate that seasonal variations of precipitation stable isotopes in Bagrot Valley were pronounced during the observation period, with $ $18O and δD values being lower in autumn and winter and higher in spring and summer, consistent with temperature variations and exhibiting a significant temperature effect, while the precipitation amount effect was not evident. Moreover, it was found that both the intercept and slope of the local meteoric water line in the study area were lower than those of the global meteoric water line, reflecting relatively strong sub-cloud secondary evaporation during precipitation processes. In particular, different precipitation forms resulted in different slopes and intercepts of the local meteoric water line in this region. When liquid precipitation (rainfall) occurred, raindrops experienced relatively strong secondary evaporation during their descent in the relatively arid climate environment, resulting in lower slopes and intercepts of the local meteoric water line; when solid precipitation (snowfall) occurred, lower temperatures led to reduced influence from recycled water vapor and secondary evaporation, causing both the slope and intercept of the local meteoric water line to be higher. In Bagrot Valley and its surrounding areas, the slope of the local meteoric water line showed little difference from south to north, while its intercept generally decreased with increasing latitude, possibly related to the gradually intensifying non-equilibrium fractionation of stable isotopes caused by sub-cloud secondary evaporation. Through precipitation stable isotope observations at the Bagrot Valley station combined with backward trajectory tracking using the HYSPLIT

model, the study also found that the research area was primarily influenced by westerly circulation and local circulation throughout the year. However, compared with nearby stations to the north of the study area (Muztagh Ata, Hotan, etc.), Bagrot Valley, being located further south, still occasionally experienced influence from southern maritime moisture. These research findings may have certain implications for the interpretation of tree-ring stable isotope records in this region.

Full Text

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DOI: 10.12118/j.issn.1000-6060.2019.02.04
Journal: Arid Land Geography

Introduction

Stable isotopes in precipitation (δ^{18}O and δD) serve as integrated tracers of atmospheric processes worldwide. These isotopic compositions are influenced by numerous factors, including condensation temperature, atmospheric humidity, air pressure, precipitation amount, moisture sources, and orographic terrain. Over recent decades, substantial research efforts have been dedicated to studying precipitation isotopic composition across various regions of the Tibetan Plateau, China, which lies at the convergence zone between westerlies and the Indian monsoon. However, few studies have been conducted in the Upper Indus Basin (UIB), located in the western Tibetan Plateau.

Data and Methods

This study investigates stable isotope characteristics in precipitation, relationships between isotopic variations and meteorological factors, the Local Meteoric Water Line (LMWL), and moisture sources in a typical watershed of Bagrot Valley, Upper Indus Basin. The analysis is based on observations of precipitation stable isotopes (δ^{18}O and δD) and local meteorological factors from August 2015 to July 2016, combined with the HYSPLIT model.

The d-excess parameter, first defined by Dansgaard in 1964, is calculated as:

$$d = \delta D - 8\delta^{18}O$$

This parameter provides important information about moisture source conditions and evaporation processes. The weighted average isotopic composition is calculated using:

$$\delta^{18}O_w = \frac{\sum P_i \delta^{18}O_i}{\sum P_i}$$

where $\delta^{18}O_i$ and P_i represent the isotopic composition and precipitation amount for each event, respectively, and $\delta^{18}O_w$ is the precipitation-weighted average.

Seasonal Variations in Stable Isotopes

Precipitation δ^{18}O and δD values in Bagrot Valley exhibited pronounced seasonal cycles from August 2015 to July 2016. The isotopic compositions were more depleted during autumn and winter, and relatively enriched in spring and summer, indicating a dominant temperature effect rather than a precipitation amount effect. The δ^{18}O and δD values ranged from -22.54‰ to 9.70‰ and -165.69‰ to 81.90‰, respectively, with weighted averages of -5.92‰ and -40.87‰. The d-excess values varied from -14.19‰ to 21.52‰, with a weighted average of 6.52‰, which is close to the global average of 10‰.

[Figure 2: see original paper]

Relationships with Meteorological Factors

Correlation analysis reveals significant relationships between stable isotopes and local meteorological conditions (Table 2). Temperature shows positive correlations with δ^{18}O and δD, while precipitation amount exhibits negative correlations. The correlation coefficients vary by season, with stronger relationships during the autumn-winter period.

Local Meteoric Water Line (LMWL)

The LMWL for Bagrot Valley was derived from the isotopic data. The overall relationship is:

$$\delta D = 7.82\delta^{18}O + 3.99 \quad (R^2 = 0.98, n = 71, P < 0.01)$$

When separated by precipitation phase, rainfall events show:

$$\delta D = 7.77\delta^{18}O + 4.28 \quad (R^2 = 0.99, n = 83, P < 0.01)$$

While small precipitation events ($ $5 mm) exhibit:

$$\delta D = 9.00\delta^{18}O + 26.27 \quad (R^2 = 0.99, n = 12, P < 0.01)$$

The lower intercept and slope of the LMWL compared to the Global Meteoric Water Line (GMWL: $\delta D = 8\delta^{18}O + 10$) indicate strong sub-cloud evaporation due to the relatively arid climate. Snowfall events show higher slope and intercept, resulting from minimal impacts of recycled moisture and sub-cloud evaporation at low temperatures.

Moisture Source Analysis

HYSPLIT model trajectories and isotopic results demonstrate that Bagrot Valley is consistently dominated by westerlies and local moisture recycling throughout the year. However, compared to more interior locations like Muztagata and Hotan where marine moisture cannot reach, Bagrot Valley occasionally receives marine moisture from the ocean due to its more southerly location.

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Abstract

Precipitation stable isotopes are integrated tracers of atmospheric processes worldwide. The precipitation stable isotopes (δ^{18}O and δD) are influenced by numerous factors, including condensation temperature, atmospheric humidity, air pressure, precipitation amounts, moisture sources, and orographic terrain. In recent decades, many efforts have been dedicated to studying precipitation isotopic composition in various regions in the Tibetan Plateau, China, located at the convergence between the westerlies and Indian monsoon. However, few studies are conducted in the Upper Indus Basin (UIB), which is located in the western Tibetan Plateau. Based on the observation of precipitation stable isotopes (δ^{18}O and δD) and local meteorological factors from August 2015 to July 2016, combined with the HYSPLIT model, this study investigated the characteristics of stable isotopes in precipitation, the relationship between isotopic variations and meteorological factors, Local Meteoric Water Line (LMWL), and the moisture sources of a typical watershed in Bagrot Valley, Upper Indus Basin. The results show that precipitation δ^{18}O and δD in Bagrot Valley displayed an obvious seasonal change. The δ^{18}O and δD values are more depleted in autumn and winter but relatively enriched in spring and summer, indicating a significant temperature effect rather than precipitation amount effect. Moreover, the lower intercept and slope of Local Meteoric Water Line (LMWL) relative to GMWL indicated a strong sub-cloud evaporation owing to the relatively arid climate in the study area. Interestingly, different precipitation phases led to a difference in intercept and slope of meteoric water line. The lower intercept and slope of rainfall events result from strong sub-cloud evaporation. While meteoric water line of snowfall events has higher slope and intercept. It resulted from little impacts of recycled moisture and sub-cloud evaporation, due to the low temperature. Besides, compared with adjacent regions, the slopes of the LMWLs are nearly the same, however, the intercepts were increased with the latitude (except Shiquanhe), this may be caused by the strengthening sub-cloud evaporation and weakening effect of the marine moisture. In addition, the outputs of HYSPLIT model and results of precipitation stable isotopes demonstrated that Bagrot Valley is consistently dominated by the westerlies and local moisture recycling throughout the year and moisture source changes affect stable isotopes in precipitation. However, compared with Muztagata and Hotan, where marine moisture cannot reach, the study area of Bagrot Valley is affected by the marine moisture from the ocean occasionally as it lies southern to Muztagata and Hotan.

Keywords: Upper Indus Basin; precipitation stable isotopes; meteoric water line; moisture sources

Note: Figure translations are in progress. See original paper for figures.