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Interannual trends in stable oxygen isotope composition in precipitation of China during 1979–2007: Spatial incoherence

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A B S T R A C T

According to the simulations of isotope-equipped general circulation models (GCMs) compiled by the Stable Water Isotope Intercomparison Group Phase2 (SWING2), the interannual variability and trend of precipitation isotopic composition in China during 1979–2007 are studied. Six simulations of isotope-enabled GCMs are involved, and monthly series of stable oxygen isotopes in precipitation for each grid are applied to calculate the linear trends from 1979 to 2007. Most isotope-equipped GCM simulations show an increasing trend in $\delta^{18}O$, while the GISS-E (NCEP) result shows a decreasing trend. In most areas of north China and northwest China, the GCM-simulations positively correlate with surface temperature. The correlation coefficients between oxygen isotope composition and surface air temperature generally increase from coast to inland. The correlation between observed and simulated $\delta^{18}O$ in precipitation of northwest China simulated by LMDZ (free) is best ($r = 0.73$) among different subregions and isotope-equipped GCMs. The comparison of GCMs simulations and BW model all show the low value region of $\delta^{18}O$ is in the Tibetan Plateau and the high value in south China. China's meteoric water line simulated using isotope-enabled GCMs (slopes range from 7.63 to 8.26, and intercepts range from 9.25 to 11.92) is similar to the global meteoric water line, and all the correlation coefficients are statistically significant at the 0.01 level.

1. Introduction

The stable isotopes of oxygen (^{18}O) in water have been widely considered as a good tracer in the Earth's water cycle (Dansgaard, 1953; Craig, 1961). If the climate and environment information can be well kept in ice core, loess, speleothem, and other proxies, the abundance of oxygen isotopes in these proxies can be applied in paleoclimate studies including Quaternary research (e.g., Baker et al., 2013; Roe. 2009; Vaks et al., 2003). For example, based on the good linear correlation between surface air temperature and isotopic ratio in modern precipitation, the isotopes in many ice cores have been used to reconstruct the surface air temperature in the past (e.g., Yao et al., 1997; Divine et al., 2011). However, the stable isotopes in precipitation as well as the post-deposited proxies are controlled by complex climate factors depending on locations (Liu et al., 2014; Zhang and Wang, 2016). To understand the interannual variation in stable isotopes measured in paleoclimate proxies, it is a prerequisite to have a clear knowledge about spatial pattern and environmental controls in precipitation in paleoclimate researches.

More monitoring of the stable isotopes in precipitation is useful, but the long-term observation with high spatial resolution is incomplete for most areas across the world. In China, regarding the existing nationwide stable isotope database, GNIP (Global Network of Isotopes in Precipitation; IAEA/WMO, 2015) and CHNIP (Chinese Network of Isotopes in Precipitation) (Liu et al., 2014); are often mentioned. However, in the two networks, there are only approximately 30 sampling stations, respectively, and the sampling periods are less than 10 years for most stations (Zhang and Wang, 2016). Logically, these measurements are too limited to describe all the details of stable isotopes in precipitation. Although some methods with aid of GIS (Geographic Information System) was applied to investigate the spatial pattern of isotope composition (e.g., Zhao et al., 2012; Liu et al., 2008a,b; Bowen and Wilkinson, 2002), the internal physical regime as well as interannual

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variability cannot be well considered in these models.

The isotope-enabled general circulation model (GCM) provides a practical approach to simulate the stable isotopes in precipitation and vapor in different periods and locations, and a series of physical process of fractionation is incorporated in the model (e.g., Joussaume et al., 1984; Mathieu et al., 2002; Dee et al., 2014). In past decade, several isotope-enabled GCM simulations was compiled and released by Stable Water Isotope Intercomparison Group (SWING) and its second phase (SWING2), which is a good platform to investigate the interannual trend in isotope composition in the past (Sturm et al., 2010; Risi et al., 2012). As for the domain of China, although the regional or nationwide assessment was operated by Zhang et al. (2012), Wang et al. (2015) and Che et al. (2017) using SWING and SWING2, the long-term changes of stable isotopes were not involved.

In this study, to enhance the understanding of isotopic process in precipitation in China, we focus on the interannual variation and spatial incoherence of $\delta^{18}O$ in precipitation using isotope-equipped GCMs compiled by SWING2. In addition, the temperature effect of stable isotopes in precipitation on a long term scale is also analyzed, which is useful in temperature reconstruction using climate proxies (especially ice core) in China.

2. Data and methods

2.1. Data source

In this study, six simulations of isotope-enabled GCMs are provided by the SWING2 (Sturm et al., 2010; available at http://www.giss.nasa.gov/projects/swing2), and a brief inventory is presented in Table 1. Four outputs in six are nudged with reanalysis data including MERRA, NCEP and ECMWF. More details for these GCMs were introduced in Sturm et al. (2010). These global simulations at a monthly basis from 1979 to 2007 were clipped to the terrestrial domain of China, respectively. For each gird box, a monthly series of $H_2^{18}O$, HDO and H_2O in precipitation from 1979 to 2007 were acquired. The map showing the grid boxes for each simulation is also presented in Fig. S1 in supplementary material.

To verify the accuracy of isotope-enabled GCMs, observed isotopic composition in precipitation was also applied. The main data sources were monthly measurements at GNIP stations in China which is operated by the International Atomic Energy Agency (IAEA) and World Meteorological Organization (WMO). It should be mentioned that in China most GNIP stations are located at the eastern and central parts, and the remote western China are not well observed. To improve the spatial coverage, more monthly or event-based measurements of $\delta^{18}O$ in China were selected from previous publications (Yao et al., 2013; Wen et al., 2010; Xie et al., 2011; Wang and Peng, 2001; Peng et al., 2010; Pang et al., 2011). The quality controls of isotopic data included: 1). No less than 8 months from 1979 to 2007 was applied, and event-based values were weighted to a monthly series based on precipitation amount for each event, and 2) the precision should be better than 0.15‰ for $\delta^{18}O$ and 1.5‰ for δD, respectively. In total, 1300 monthly data at 77 sampling stations were collected in this study (Fig. 1 and Table S1 in supplementary material).

In addition, a geographical parameters (latitude and elevation) based isoscape (Bowen and Wilkinson, 2002) was also used. The method (also called BW model) used a two-step regression to describe the spatial variation of heavy isotopes in precipitation. An output of $\delta^{18}O$ in precipitation with spatial resolution of $0.5° \times 0.5°$ (longitude by latitude) was applied in this study (available at http://wateriso.utah.edu/waterisotopes/pages/data_access/ArcGrids.html).

2.2. Method

The ratio of $^{18}O/^{16}O$ in precipitation is expressed as $\delta^{18}O$ relative to the Vienna Standard Mean Ocean Water (V-SMOW):

$$\delta^{18}O = \left[\frac{R_{sample}}{R_{standard}} - 1\right] \times 1000‰ \quad (1)$$

where R_{sample} is the ratio of the molecules with heavy isotopes relative to the standard molecules. To acquire the meteoric line showing the correlation between hydrogen and oxygen isotopes, similar approach is applied to δD where R_{sample} is $^2H/^1H$ (also usually expressed D/H). The deuterium excess (defined as $d = \delta D - 8\delta^{18}O$; Dansgaard, 1964). The R_{sample} for $^{18}O/^{16}O$ and $^2H/^1H$ were calculated based on $H_2^{18}O$, HDO and H_2O at each grid box in isotope-enabled GCM. The significantly anomalous grid boxes (less than −999‰ for $\delta^{18}O$ and for δD) were removed.

The long-term trend magnitude of isotope values on a winter (December, January and February), summer (June, July and August) and annual basis were calculated using a non-parametric Sen's slope and Mann-Kendall test using MAKESENS software (Sen, 1968). Pearson's correlation coefficient (r) and two-tailed t-test were also applied to assess the correlations between the simulations and observations. The spatial analyzing was processed in ArcGIS 9.3.

3. Results and discussion

3.1. Seasonal variation for each subregion

Because of the complex moisture sources and topography (ranging from 8844 m to −154 m in altitude) in China, the seasonal variation of heavy isotopes in precipitation presents a great spatial diversity. In this study, four main physical geographical zones were calculated, respectively (Fig. 2). For each subregion, the error bars indicate a good spatial coherence, and the seasonality is generally similar for different simulations. The finding was generally coincided with previous publication based on in-situ measurement (Zhang and Yao, 2004; Liu et al., 2014).

For most subregions except South China, the values of $\delta^{18}O$ are lower in winter months and higher in summer, although some slightly decline from spring to summer can be seen in many simulations. In South China, ^{18}O are depleted in summer months and

Table 1
Basic information of stable isotope-equipped GCMs used in the study.

Isotope-enabled GCM	Research institute	Grid resolution (longitude × latitude)	Nudged or free	Period	References
GISS-E (MERRA)	GISS-New York	2.5° × 2.0224°	Nudged with MERRA	1979–2007	Schmidt et al. (2007)
GISS-E (NCEP)	GISS-New York	2.5° × 2°	Nudged with NCEP	1979–2007	Schmidt et al. (2007)
isoGSM (NCEP)	Scripps-San Diego	1.875° × 1.904°	Nudged with NCEP	1979–2007	Youshimura et al. (2008)
LMDZ (free)	LMDZ-Paris	3.75° × 2.5352°	Free	1979–2007	Risi et al. (2010)
LMDZ (ECMWF)	LMDZ-Paris	3.75° × 2.5352°	Nudged with ECMWF	1979–2007	Risi et al. (2010)
MIROC (free)	JAMSTEC-Yokosuka	2.8125° × 2.7905°	Free	1979–2007	Kurita et al. (2011)