Journal of Hydrology 400 (2011) 477–489

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

# Daily $\delta^{18}O$ and $\delta D$ of precipitations from 2007 to 2009 in Guangzhou, South China: Implications for changes of moisture sources

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ARTICLE INFO

*Article history:*
Received 6 May 2010
Received in revised form 30 November 2010
Accepted 1 February 2011
Available online 23 February 2011

This manuscript was handled by L. Charlet, Editor-in-Chief

*Keywords:*
Precipitation
Stable isotope
Moisture source
Monsoon
Paleoclimate
South China

## SUMMARY

Oxygen and hydrogen stable isotopes ($\delta^{18}O$ and $\delta D$) in precipitation collected in every event from 2007 to 2009 in Guangzhou, South China, are presented in this paper. The total correlation between $\delta^{18}O$ and $\delta D$ is obtained as $\delta D = (8.46 \pm 0.13)\,\delta^{18}O + (15.0 \pm 0.9)$. More negative $\delta^{18}O$ and $\delta D$ generally occur during summer and autumn, while less negative or even positive $\delta^{18}O$ and $\delta D$ occur during winter and spring. Significant negative correlations between precipitation $\delta^{18}O$ and temperature, and between precipitation $\delta^{18}O$ and precipitation amount are observed. Regression line changes from year to year are likely due to changes in moisture sources for the precipitation. The moisture contributed by adjacent seas or local evaporation account for the main precipitation during winter and early spring, while summer monsoon brings huge amounts of moisture from remote seas associated with higher temperature and larger precipitation amounts. Seasonal variations of the precipitation D-excess provide more details for changes in moisture sources. Higher D-excess values during winter and early spring are estimated to correspond to a lesser proportion of remote moisture, while lower D-excess values during summer and autumn correspond to larger remote moisture transported by summer monsoons. This generally agrees with the results of model analysis on single isobaric backward trajectories for air parcels during specific time periods. Results of this study imply that precipitation $\delta^{18}O$ and $\delta D$, as well as some related paleoclimate proxies such as $\delta^{18}O$ in speleothem and tree ring, and $\delta D$ in plant-derived organic compounds and tree ring, currently cannot indicate changes in temperature or precipitation amount separately, but should be comprehensive proxies for monsoon climate.

## 1. Introduction

Oxygen and hydrogen isotopes in precipitation have long been known to be closely associated with climatic and environmental variables, and are broadly utilized in hydrological, meteorological, and paleoclimatic studies (Hoefs, 2004). The International Atomic Energy Agency (IAEA), in cooperation with the World Meteorological Organization (WMO), has conducted a worldwide program called Global Network of Isotopes in Precipitation (GNIP) to survey oxygen and hydrogen isotopes in global precipitation that occurred since 1958 (IAEA/WMO, 2006). The data gathered helped in understanding the response of precipitation oxygen and hydrogen isotopes to climatic/environmental changes (Gat, 1996; IAEA/WMO, 2006). This is very important in studies of climate changes, because some essential paleoclimate proxies such as $\delta^{18}O$ and $\delta D$ in ice cores and tree rings, $\delta^{18}O$ in speleothem, and $\delta D$ in some plant-derived compounds in sediments are generally linked to $\delta^{18}O$ or $\delta D$ in precipitation in order to interpret their paleoclimate implications.

This is particularly important in South China. The precipitation of South China is controlled by the East Asian Monsoon with main precipitation amount generally associated with East Asian Summer Monsoon (EASM). Thus, precipitation change is the key to indicating the evolution of the EASM. In addition, most paleoclimate proxies adopted in paleoclimate studies in this region are associated with precipitation. Some of the essential proxies, such as speleothem $\delta^{18}O$ (Wang et al., 2001, 2008) and $\delta D$ of selected plant-derived organic compounds in sediments (Jia et al., 2008), are directly linked to $\delta^{18}O$ and $\delta D$ in precipitation. Therefore, understanding the response of precipitation $\delta^{18}O$ and $\delta D$ to climate changes in this region is important to understand the paleoclimate records derived from these proxies. The $\delta^{18}O$ and $\delta D$ in the precipitation in South China have long been an issue of concern (Gat, 1996; IAEA/WMO, 2006). There are several GNIP stations in South

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doi:10.1016/j.jhydrol.2011.02.002

China, some of which have more than 10 years of continuous precipitation $\delta^{18}$O and $\delta D$ records in monthly resolution, such as Hong Kong and Guilin (Gat, 1996; IAEA/WMO, 2006). These data, together with those gathered in previous studies in China, have basically outlined the variations of precipitation $\delta^{18}$O and $\delta D$ in South China (Araguas-Araguas et al., 1998; Hoffmann and Heimann, 1997; Wei and Lin, 1994; Zheng et al., 1983). The apparent negative correlations between precipitation $\delta^{18}$O and air temperature (the so-called *temperature effect* that is reverse of that in high latitude regions) and between precipitation $\delta^{18}$O and precipitation amount (the so-called precipitation *amount effect*) are generally presented in South China (Araguas-Araguas et al., 1998; Hoffmann and Heimann, 1997; Vuille et al., 2005; Wei and Lin, 1994; Zheng et al., 1983). Winter and summer monsoons prevail in different seasons and bring moisture from different sources over South China (Bryson, 1986). It is the seasonal changes in moisture sources that arouse the above apparent correlations (Araguas-Araguas et al., 1998; Hoffmann and Heimann, 1997; Vuille et al., 2005; Wei and Lin, 1994; Zheng et al., 1983), and such changes in moisture source can likely be traced by temperature, precipitation amount and stable isotopes in precipitation (Wright et al., 2001).

The moisture sources for precipitation in South China are very complicated. There are three summer monsoon sub-systems in East and South Asia: the EASM, the western North Pacific summer monsoon (WNPSM), and the Indian summer monsoon (ISM) (Wang and Lin, 2002). These sub-systems may bring moisture from the west Pacific, the South China Sea (SCS), and the Indian Ocean and possibly influence precipitation in South China (Fig. 1). In addition, typhoon activity in South China is very active. Typhoons bring huge amount of moisture from remote oceans and significantly contribute to precipitation in this region, further complicating moisture supplies in South China. Event such as typhoon, storm can be traced by stable isotopes in precipitation (Lawrence et al., 1982, 1998, 2002; Lawrence and Gedzelman, 1996). However, such event generally lasts for 1–2 days in a definite location. The existed GNIP data in South China are all in monthly time resolution, and they are not adequate to trace moisture sources for the precipitation, particularly for precipitation associated with events such as typhoon. With this concern, we monitor event precipitation $\delta^{18}$O and $\delta D$ in Guangzhou. Rainwater samples of each precipitation event other than the monthly average are collected. The aim is to investigate the influence of changes in moisture sources and other climatic/environment variables such as temperature and precipitation amount on $\delta^{18}$O and $\delta D$ in precipitation.

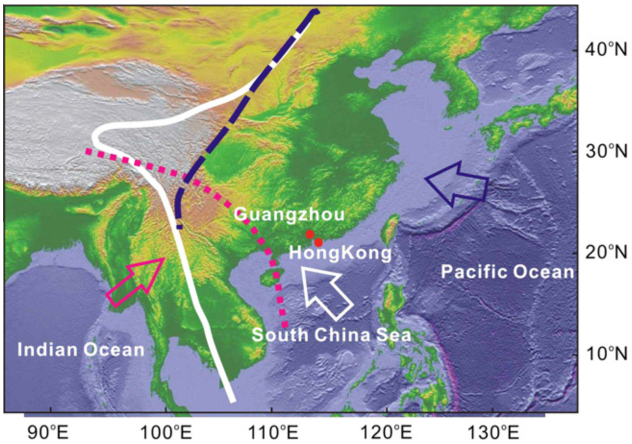

**Fig. 1.** Locations of precipitation sample and the possible moisture sources for the precipitation in South China. The arrows roughly indicate the directions for the moisture transport, and the lines indicate the maximum extent of the moisture from the western North Pacific (blue dashed line), the South China Sea (white solid line), and the Indian Ocean (pink dotted line), which are modified after Bryson (1986) and Winkler and Wang (1993). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

In this study, we report on the primary results of our monitoring activity conducted from 2007 to 2009. The correlation between $\delta^{18}$O and $\delta D$ and their relationship with temperature and precipitation amounts will be discussed. More importantly, their responses to changes in moisture sources (i.e., typhoon process) will be discussed. This may prove beneficial in understanding the response of precipitation $\delta^{18}$O and $\delta D$ to climatic/environmental variables in South China and in understanding the paleoclimatic records associated with precipitation $\delta^{18}$O and $\delta D$ in monsoon climate studies.

## 2. Study site

The location of study is Guangzhou (23°09′N, 113°21′E), located at the lower reaches of Pearl River in South China next to the northern South China Sea (SCS). Guangzhou has a sub-tropical style of climate controlled by the East Asian Monsoon. It has warm and wet summers and cold and dry winters. According to historical meteorological data from 1970 to 2000,[1] the mean annual air temperature in Guangzhou is 22.0 °C and the mean annual precipitation amount is 1736 mm. Seasonality in Guangzhou is significant. As shown in Fig. 2, the minimum monthly temperature of 13.6 °C occurs in January and the maximum monthly temperature of 28.6 °C occurs in July. Over 80% of the annual precipitation occurs during the rainy season from April to September. The precipitation that occurs during dry season from October to March accounts for about 20%.

The climate parameters (temperature, precipitation amount and relative humidity) of the past 3 years (2007–2009) are summarized in Table 1, together with those from 1970–2000 for comparison (Fig. 2). Occurrences of maximum monthly temperatures (July or August) and minimum monthly temperatures (January or February) are the same. However, the maximum monthly temperature of 30.8, 29.2, and 29.8 °C for 2007, 2008, and 2009, respectively, were significantly higher than the average temperature that occurred from 1970 to 2000, which was 28.6 °C. A very low temperature of 11.6 °C, about 2 °C lower than the average from 1970 to 2000, occurred in February 2008 at the time when a large-scale ice-snow disaster happened in South China. In contrast, a high monthly temperature of 20.9 °C occurred in February 2009, about 6.4 °C higher than the average temperature that occurred from 1970 to 2000.

Similar to the average temperature that occurred from 1970 to 2000, most of the precipitation during 2007–2009 occurred from April to September. However, the precipitation amounts in March and November 2009 were significantly larger than their corresponding averages, while the precipitation amount in July 2007 was significantly smaller than the average. An extremely large precipitation amount of 874 mm occurred in June 2008, resulting in a large annual precipitation amount of 2354 mm for that year. This was significantly larger than the average precipitation amount for 1970–2000, which was about 1736 mm. On the other hand, the annual precipitation amounts of 1370 and 1492 mm for 2007 and 2009, respectively, were smaller than the average.

## 3. Materials and methods

The precipitation samples were collected at the top of a $\sim$15 m-high experiment building in the Guangzhou Institute of Geochemistry (GIG) using a glass beaker. The sample collection is based on

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[1] The average meteorological data of Guangzhou from 1970 to 2000 is obtained from the website of China Meteorologic Data Sharing Service System (CMDSSS). The address is http://cdc.cma.gov.cn/index.jsp.

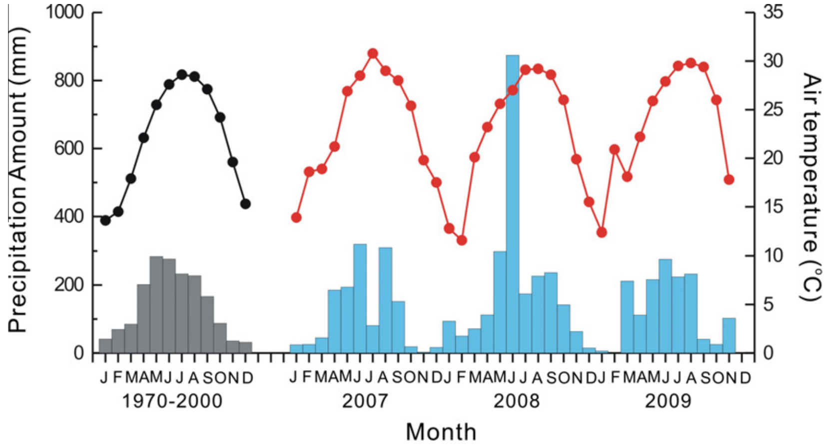

**Fig. 2.** Monthly air temperature and precipitation amount in Guangzhou from 2007 through 2009, and their backgrounds during 1970–2000. The meteorological parameters during 1970–2000 are available from China Meteorologic Data Sharing Service System (CMDSSS) at http://cdc.cma.gov.cn/index.jsp.

**Table 1**
Meteorological parameter summaries in Guangzhou.

| Year | $P^a$ (mm) | $T^a$ (°C) | RH$^a$ (%) | Max. $T^a$ (°C) | Min. $T^a$ (°C) | Max. $P^a$ (mm) |
|---|---|---|---|---|---|---|
| 1970–2000[*] | 1736 | 22.0 | 77.3 | 28.6 (Jul.) | 13.6 (Jan.) | 283.7 (May) |
| 2007[#] | 1370 | 23.2 | 71.0 | 30.8 (Jul.) | 13.9 (Jan.) | 319.8 (June) |
| 2008[#] | 2354 | 22.4 | 69.8 | 29.2 (Aug.) | 11.6 (Feb.) | 874.3 (June) |
| 2009[#] | 1492 | 22.9 | 66.9 | 29.8 (Aug.) | 12.4 (Jan.) | 275.5 (June) |

[a] *P* means annual mean precipitation amount, *T* means annual mean temperature, RH means annual mean relative humidity, Max. *T* means maximum monthly temperature, Min. *T* means minimum monthly temperature, and Max. *P* means maximum monthly precipitation amount.

an event from the beginning to the end of a precipitation. If there were more than one precipitation event within a day, each shower was collected as an individual sample. Hourly samples were collected during certain sustaining typhoon events (i.e., June 25–26, 2008). Almost every precipitation from January 11, 2007 to November 14, 2009 were collected, except for an event in November 2007 when only a very small precipitation amount (<1 mm) was rendered. The sample number totaled up to 314 (76 in 2007, 169 in 2008, and 69 in 2009). The water samples were sealed in 22 ml plastic bottles or 2.8 ml glass vials with poly-seal cone closures, depending on the precipitation amount right after the end of the precipitation event, and then kept in a refrigerator at about 4 °C. Related meteorological parameters, such as daily air temperature, precipitation amount, and relative humidity, were obtained from Guangzhou Meteorological Satellite Ground Station (GMSGS). The distance between sampling site and meteorological station is less than 2 km, with no difference in altitude. The meteorological parameters in these two sites are nearly the same in daily resolution.

Stable isotope compositions ($\delta D$ and $\delta^{18}O$) of the water samples were measured on a GV Isoprime II Isotope Ratio Mass Spectrometry (IRMS) coupled with Dual Inlet® and an on-line aqueous preparation system (Multiprep®). This was conducted in the Key Laboratory of Isotope Geochronology and Geochemistry of Chinese Academy of Sciences in GIG. Hydrogen and oxygen isotopes of the water samples were determined by gaseous equilibration method. About 0.2 ml water were put into a pre-cleaned and dried 2.8 ml glass bottle. For hydrogen isotope measurement, Pt catalyst (Hokko Beads) was put into the bottle. The bottle was first evacuated, then high purity $H_2$ or $CO_2$ gas was introduced for hydrogen and oxygen isotope measurement, respectively. The introduced gas was equilibrated with the water samples for 1.5 h or 4.5 h at 40 °C for hydrogen and oxygen isotope analysis, respectively. After equilibrium, the gas was passed through a water trap system to remove moisture. Afterward, it was introduced into the mass spectrometry by the Dual Inlet system. The hydrogen and oxygen isotopes were measured using dual inlet mode, in which the sample gas and a reference gas (high purity $H_2$ and $CO_2$ for hydrogen and oxygen isotope, respectively) were introduced into the mass spectrometry one after the other. Ten replicates were taken for each measurement. Isotopic compositions of the reference gases were calibrated using an international water standard reference (Vienna Standard Mean Ocean Water: V-SMOW). The hydrogen and oxygen isotopic results were expressed as $\delta D$ and $\delta^{18}O$ relative to the V-SMOW. Several Chinese national water isotope standard references such as GBW04401, GBW04402, and GBW04403, and a laboratory working standard were repeatedly measured with the samples. Results indicate that the analytical reproducibility is 1–2‰ for $\delta D$ and better than 0.1‰ for $\delta^{18}O$. Moreover, the measured $\delta D$ and $\delta^{18}O$ values of the standard references agree with the certified values within analytical errors. Details of the analytical method refer to Xie et al. (2009). The analyzed results, together with the observation data, are listed in Table 2.

Model analysis of single isobaric backward trajectories of air parcels can provide hints for movement of main air masses, and can be used in tracing sources for air moisture (Lawrence et al., 1982; Lee et al., 2003). An on-line Hybrid Single particle Lagrangian integrated trajectory (HYSPLIT) model is available from the NOAA Air Resources Laboratory (Draxler and Rolph, 2010) at (http://ready.arl.noaa.gov/HYSPLIT.php). We perform our model analysis at 850 mb (96 m) height, and most of the trajectories were modeled over a 4 day (96 h) period, while the trajectories of typhoon events were modeled covering the whole typhoon period.

## 4. Results

The time-series variations of the $\delta D$ and $\delta^{18}O$ of the precipitation in Guangzhou from 2007 to 2009, together with the observed daily precipitation amount and air temperature, are shown in Table 2 and Fig. 3. Seasonal variation of the $\delta D$ and $\delta^{18}O$ has, significantly more negative values generally occurring during summer and less negative values occurring during winter. In detail, the $\delta^{18}O$ vary from −16.43‰ to 5.11‰. The most negative values (−13‰ to −15‰) generally occur in May, July, August, and September. There are some positive $\delta^{18}O$ values occurring in some precipitations in February and April 2007, in February, March, April, and November 2008, and in March, April, and May 2009 (Fig. 3). The $\delta D$ vary from −118‰ to 49.9‰, and the occurrences of most negative values and positive values are nearly the same as those of the $\delta^{18}O$. Such $\delta D$

**Table 2**
The oxygen and hydrogen isotopes, deuterium-excess, and daily meteorological parameters.

| Date (mm/dd/yy) | $\delta^{18}\mathrm{O}^{a}$ (‰) | $\delta D^{a}$ (‰) | D-excess$^{b}$ (‰) | $T^{c}$ (°C) | $P^{c}$ (mm) |
|---|---|---|---|---|---|
| 01/11/2007 | 5.11 | 49.9 | 9 | 15.5 | 0.1 |
| 01/20/2007 | −4.21 | −1.8 | 32 | 12.6 | 12.2 |
| 01/20/2007 | −4.18 | −7.3 | 26 | 12.6 | 12.2 |
| 01/21/2007 | −4.42 | −28.9 | 6 | 11.0 | 11.1 |
| 02/14/2007 | −0.64 | 8.9 | 14 | 18.6 | 17.5 |
| 03/26/2007 | −6.75 | −4.8 | 49 | 24.2 | 1.0 |
| 03/27/2007 | −3.97 | 6.2 | 38 | 23.5 | 4.7 |
| 03/27/2007 | −4.92 | −7.5 | 32 | 23.5 | 4.7 |
| 03/30/2007 | −4.62 | 9.3 | 46 | 24.4 | <0.1 |
| 04/02/2007 | −5.27 | −9.6 | 33 | 21.6 | 30.2 |
| 04/03/2007 | 0.16 | −5.2 | −6 | 14.3 | 1.0 |
| 04/03/2007 | −3.45 | −7.9 | 20 | 14.3 | 1.0 |
| 04/09/2007 | −3.78 | 34.5 | 65 | 19.1 | 0.1 |
| 04/10/2007 | −3.29 | 10.8 | 37 | 17.4 | 15.5 |
| 04/17/2007 | −4.75 | −5.1 | 33 | 24.5 | 31.6 |
| 04/22/2007 | −3.97 | −7.5 | 24 | 25.5 | 4.0 |
| 04/24/2007 | −6.00 | −23.9 | 24 | 22.1 | 52.8 |
| 04/25/2007 | −5.79 | −13.8 | 33 | 20.1 | 8.8 |
| 05/04/2007 | −4.51 | −8.6 | 27 | 22.9 | 15.7 |
| 05/04/2007 | −5.86 | −24.2 | 23 | 22.9 | 15.7 |
| 05/05/2007 | −9.79 | −65.4 | 13 | 24.3 | 14.0 |
| 05/18/2007 | −5.76 | −17.9 | 28 | 27.7 | 5.6 |
| 05/19/2007 | −12.88 | −80.0 | 23 | 23.7 | 6.9 |
| 05/21/2007 | −11.77 | −69.5 | 25 | 23.0 | 40.7 |
| 05/21/2007 | −10.32 | −57.6 | 25 | 23.0 | 40.7 |
| 05/21/2007 | −9.35 | −47.1 | 28 | 23.0 | 40.7 |
| 05/26/2007 | −3.39 | −1.1 | 26 | 26.3 | 29.9 |
| 05/26/2007 | −5.04 | −12.6 | 28 | 26.3 | 29.9 |
| 05/27/2007 | −6.45 | −23.0 | 29 | 26.0 | 21.5 |
| 05/28/2007 | −3.19 | −2.5 | 23 | 27.2 | 0.1 |
| 06/02/2007 | −1.82 | −3.4 | 11 | 28.2 | 2.3 |
| 06/02/2007 | −3.84 | −11.9 | 19 | 28.2 | 2.3 |
| 06/04/2007 | −4.19 | −13.1 | 20 | 29.0 | 0.2 |
| 06/06/2007 | −5.09 | −13.4 | 27 | 27.2 | 4.8 |
| 06/06/2007 | −3.88 | −14.4 | 17 | 27.2 | 4.8 |
| 06/06/2007 | −6.96 | −29.9 | 26 | 27.2 | 4.8 |
| 06/07/2007 | −6.93 | −49.4 | 6 | 27.8 | 30.2 |
| 06/08/2007 | −9.05 | −49.2 | 23 | 26.7 | 25.3 |
| 06/09/2007 | −8.67 | −67.9 | 2 | 25.4 | 11.5 |
| 06/09/2007 | −7.88 | −36.2 | 27 | 25.4 | 11.5 |
| 06/11/2007 | −7.25 | −52.1 | 6 | 27.8 | 10.7 |
| 06/12/2007 | −7.91 | −40.2 | 23 | 26.5 | 6.1 |
| 06/13/2007 | −4.91 | −29.6 | 10 | 27.9 | 24.1 |
| 06/16/2007 | −9.92 | −50.7 | 29 | 27.5 | 31.0 |
| 06/17/2007 | −7.82 | −43.3 | 19 | 26.1 | 20.2 |
| 06/28/2007 | −8.10 | −57.5 | 7 | 28.3 | 1.1 |
| 06/28/2007 | −8.69 | −59.6 | 10 | 28.3 | 1.1 |
| 06/29/2007 | −12.46 | −92.1 | 8 | 26.9 | 34.5 |
| 06/29/2007 | −13.51 | −98.3 | 10 | 26.9 | 34.5 |
| 06/30/2007 | −12.14 | −89.9 | 7 | 26.7 | 16.7 |
| 07/01/2007 | −6.08 | −37.2 | 11 | 27.0 | 11.9 |
| 07/04/2007 | −8.77 | −62.7 | 7 | 30.2 | 5.3 |
| 07/06/2007 | −3.88 | −22.1 | 9 | 28.8 | 16.7 |
| 07/20/2007 | −2.88 | −21.1 | 2 | 30.4 | 2.3 |
| 07/21/2007 | −4.98 | −36.5 | 3 | 30.0 | 29.5 |
| 08/08/2007 | −4.35 | −34.7 | 0 | 30.9 | 0.4 |
| 08/09/2007 | −10.68 | −88.0 | −2 | 30.1 | 3.1 |
| 08/11/2007 | −14.11 | −107.5 | 5 | 26.0 | 25.0 |
| 08/11/2007 | −14.65 | −114.2 | 3 | 26.0 | 25.0 |
| 08/12/2007 | −13.81 | −107.5 | 3 | 28.5 | 3.0 |
| 08/13/2007 | −9.20 | −71.4 | 2 | 28.5 | 4.3 |
| 08/14/2007 | −13.40 | −108.2 | −1 | 27.3 | 99.6 |
| 08/16/2007 | −12.59 | −100.7 | 0 | 26.7 | 21.0 |
| 08/22/2007 | −4.52 | −34.4 | 2 | 26.5 | 7.2 |
| 08/25/2007 | −7.66 | −55.4 | 6 | 27.7 | 2.5 |
| 08/26/2007 | −7.03 | −57.6 | −1 | 27.8 | 2.0 |
| 09/02/2007 | −6.87 | −47.3 | 8 | 27.6 | 48.8 |
| 09/03/2007 | −7.95 | −58.5 | 5 | 27.4 | 1.6 |
| 09/04/2007 | −13.00 | −100.1 | 4 | 26.2 | 33.6 |
| 09/24/2007 | −8.68 | −66.6 | 3 | 25.5 | 17.2 |
| 09/25/2007 | −7.90 | −60.4 | 3 | 26.8 | 19.5 |
| 10/31/2007 | −6.19 | −43.2 | 6 | 19.1 | 18.1 |
| 12/23/2007 | −3.23 | −8.5 | 17 | 15.0 | 5.2 |
| 12/23/2007 | −3.88 | −14.3 | 17 | 15.0 | 5.2 |
| 12/23/2007 | −4.31 | −19.0 | 16 | 15.0 | 5.2 |
| 12/24/2007 | −4.54 | −19.0 | 17 | 15.6 | 11.0 |
| 01/16/2008 | −0.95 | 7.3 | 15 | 10.2 | 0.8 |
| 01/17/2008 | −4.94 | −25.2 | 14 | 8.3 | 3.6 |
| 01/25/2008 | −7.11 | −39.9 | 17 | 8.5 | 39.7 |
| 01/25/2008 | −7.58 | −48.6 | 12 | 8.5 | 39.7 |
| 01/29/2008 | −4.43 | −15.6 | 20 | 6.7 | 9.5 |
| 01/29/2008 | −5.08 | −22.6 | 18 | 6.7 | 9.5 |
| 01/30/2008 | −3.92 | −16.6 | 15 | 6.3 | 30.8 |
| 02/01/2008 | −1.89 | −1.5 | 14 | 5.7 | 0.1 |
| 02/02/2008 | −5.05 | −25.9 | 15 | 5.4 | 17.1 |
| 02/04/2008 | −2.90 | −6.1 | 17 | 7.1 | 4.0 |
| 02/04/2008 | −2.12 | 2.4 | 19 | 7.1 | 4.0 |
| 02/04/2008 | −1.96 | 6.9 | 23 | 7.1 | 4.0 |
| 02/05/2008 | −2.90 | −6.8 | 16 | 8.0 | 1.5 |
| 02/17/2008 | 4.02 | 44.8 | 13 | 11.8 | 1.1 |
| 02/17/2008 | 4.07 | 43.9 | 11 | 11.8 | 1.1 |
| 02/23/2008 | −3.15 | −15.7 | 9 | 19.6 | 0.2 |
| 02/24/2008 | −2.36 | −5.8 | 13 | 16.9 | 5.9 |
| 02/24/2008 | −5.32 | −23.8 | 19 | 16.9 | 5.9 |
| 02/25/2008 | −4.25 | −12.8 | 21 | 15.8 | 19.2 |
| 02/29/2008 | 2.29 | 27.8 | 9 | 13.3 | 0.7 |
| 03/18/2008 | −0.91 | 1.1 | 8 | 22.0 | 1.7 |
| 03/18/2008 | −1.13 | 2.4 | 11 | 22.0 | 1.8 |
| 03/22/2008 | −2.77 | −0.3 | 22 | 20.2 | 38.9 |
| 03/22/2008 | −4.15 | −16.2 | 17 | 20.2 | 38.9 |
| 03/25/2008 | 0.44 | 10.6 | 7 | 18.1 | 1.5 |
| 03/26/2008 | 0.22 | 17.6 | 16 | 18.7 | 1.0 |
| 03/27/2008 | −1.76 | −1.1 | 13 | 21.3 | 17.1 |
| 03/28/2008 | −2.45 | −2.6 | 17 | 23.7 | 0.6 |
| 03/28/2008 | −2.58 | −0.4 | 20 | 23.7 | 16.2 |
| 03/30/2008 | −1.24 | 3.5 | 13 | 21.0 | 0.7 |
| 03/31/2008 | −3.15 | −6.9 | 18 | 16.0 | 9.7 |
| 04/01/2008 | −3.06 | −5.1 | 19 | 15.9 | 5.5 |
| 04/01/2008 | −2.72 | −6.9 | 15 | 15.9 | 5.5 |
| 04/02/2008 | −3.28 | −13.8 | 12 | 15.7 | 3.0 |
| 04/03/2008 | −3.71 | −15.5 | 14 | 15.5 | 3.9 |
| 04/04/2008 | −2.93 | −11.2 | 12 | 20.2 | 0.4 |
| 04/12/2008 | −2.55 | −9.5 | 11 | 25.6 | 2.6 |
| 04/17/2008 | 1.09 | 5.7 | −3 | 26.7 | 26.7 |
| 04/19/2008 | −5.30 | −32.1 | 10 | 24.1 | 26.2 |
| 04/20/2008 | −4.55 | −25.6 | 11 | 24.7 | 6.3 |
| 04/23/2008 | −3.92 | −24.6 | 7 | 20.8 | 0.1 |
| 04/25/2008 | −2.60 | −10.7 | 10 | 20.4 | 2.7 |
| 04/27/2008 | −2.69 | −2.7 | 19 | 21.8 | 32.0 |
| 05/01/2008 | −2.22 | −6.1 | 12 | 24.8 | 0.3 |
| 05/02/2008 | −2.27 | −3.2 | 15 | 25.2 | 0.7 |
| 05/02/2008 | −2.61 | −5.1 | 16 | 25.2 | 0.8 |
| 05/02/2008 | −2.17 | −3.3 | 14 | 25.2 | 0.4 |
| 05/02/2008 | −2.36 | −6.0 | 13 | 25.2 | 6.5 |
| 05/02/2008 | −2.26 | −8.3 | 10 | 25.2 | 2.8 |
| 05/02/2008 | −2.48 | −13.7 | 6 | 25.2 | 2.6 |
| 05/04/2008 | −6.75 | −44.1 | 10 | 27.9 | 13.3 |
| 05/06/2008 | −8.80 | −63.7 | 7 | 23.5 | 34.1 |
| 05/09/2008 | −6.29 | −47.9 | 2 | 28.4 | 3.4 |
| 05/10/2008 | −6.17 | −47.8 | 2 | 23.7 | 3.8 |
| 05/18/2008 | −3.62 | −16.4 | 13 | 25.2 | 17.7 |
| 05/19/2008 | −6.10 | −37.9 | 11 | 22.2 | 3.7 |
| 05/19/2008 | −6.89 | −45.8 | 9 | 22.2 | 9.2 |
| 05/19/2008 | −5.71 | −45.0 | 1 | 22.2 | 3.8 |
| 05/19/2008 | −9.96 | – | – | 22.2 | 34.4 |
| 05/20/2008 | −6.22 | −41.5 | 8 | 21.7 | 13.2 |
| 05/21/2008 | −7.46 | −46.6 | 13 | 22.9 | 5.2 |
| 05/21/2008 | −2.80 | −10.7 | 12 | 22.9 | 1.2 |
| 05/22/2008 | −4.39 | −22.1 | 13 | 24.3 | 12.0 |
| 05/22/2008 | −1.11 | −5.2 | 4 | 24.3 | 1.7 |
| 05/22/2008 | −3.96 | −20.5 | 11 | 24.3 | 9.5 |
| 05/22/2008 | −7.39 | −49.3 | 10 | 24.3 | 1.9 |
| 05/23/2008 | −5.58 | −36.9 | 8 | 27.2 | 10.6 |
| 05/24/2008 | −3.05 | −11.5 | 13 | 28.1 | 1.0 |
| 05/24/2008 | −3.39 | −19.8 | 7 | 28.1 | 4.2 |
| 05/25/2008 | −3.32 | −18.9 | 8 | 27.4 | 13.5 |
| 05/26/2008 | −2.64 | −10.6 | 11 | 25.7 | 33.8 |
| 05/26/2008 | −5.23 | −36.1 | 6 | 25.7 | 22.0 |

**Table 2** (*continued*)

| Date (mm/dd/yy) | $\delta^{18}O^{a}$ (‰) | $\delta D^{a}$ (‰) | D-excess[b] (‰) | $T^{c}$ (°C) | $P^{c}$ (mm) |
|---|---|---|---|---|---|
| 05/26/2008 | −4.59 | −24.8 | 12 | 25.7 | 17.0 |
| 05/26/2008 | −3.21 | −15.0 | 11 | 25.7 | 33.8 |
| 05/27/2008 | −2.78 | −9.3 | 13 | 28.3 | 11.4 |
| 05/27/2008 | −2.75 | −7.6 | 14 | 28.3 | 7.9 |
| 05/28/2008 | −3.27 | −14.4 | 12 | 27.9 | 13.0 |
| 05/29/2008 | −3.92 | −20.5 | 11 | 26.4 | 22.7 |
| 05/29/2008 | −7.07 | −43.1 | 14 | 26.4 | 17.2 |
| 05/30/2008 | −4.99 | −25.8 | 14 | 24.8 | 22.7 |
| 05/31/2008 | −4.36 | −28.5 | 6 | 25.6 | 6.0 |
| 06/01/2008 | −6.48 | −45.2 | 7 | 24.8 | 29.7 |
| 06/03/2008 | −9.97 | −74.5 | 5 | 26.9 | 90.6 |
| 06/03/2008 | −7.41 | −58.9 | 0 | 24.6 | 75.9 |
| 06/04/2008 | −8.74 | −56.0 | 14 | 26.4 | 21.5 |
| 06/04/2008 | −8.10 | −58.3 | 7 | 26.4 | 8.5 |
| 06/06/2008 | −12.65 | −97.4 | 4 | 23.7 | 54.1 |
| 06/07/2008 | −13.73 | −101.2 | 9 | 25.7 | 14.0 |
| 06/07/2008 | −7.02 | −49.2 | 7 | 25.7 | 13.0 |
| 06/08/2008 | −7.51 | −52.4 | 8 | 25.9 | 14.7 |
| 06/11/2008 | −7.58 | −51.4 | 9 | 28.0 | 9.8 |
| 06/12/2008 | −9.55 | −71.9 | 4 | 28.1 | 12.7 |
| 06/13/2008 | −10.87 | −78.8 | 8 | 25.2 | 12.0 |
| 06/13/2008 | −12.67 | −92.1 | 9 | 25.2 | 43.9 |
| 06/13/2008 | −14.88 | −110.7 | 8 | 25.2 | 39.8 |
| 06/14/2008 | −13.65 | −98.9 | 10 | 25.7 | 48.0 |
| 06/14/2008 | −12.15 | −90.4 | 7 | 25.7 | 3.2 |
| 06/15/2008 | −13.77 | −100.3 | 10 | 27.3 | 40.1 |
| 06/16/2008 | −12.26 | −88.1 | 10 | 26.7 | 3.3 |
| 06/16/2008 | −10.72 | −76.1 | 10 | 26.7 | 11.7 |
| 06/17/2008 | −8.16 | −61.1 | 4 | 26.8 | 8.8 |
| 06/18/2008 | −8.18 | −58.0 | 7 | 25.4 | 33.0 |
| 06/18/2008 | −9.64 | −73.1 | 4 | 25.4 | 7.1 |
| 06/25/2008 | −9.35 | −67.2 | 8 | 27.5 | 2.9 |
| 06/25/2008 | −9.83 | −66.6 | 12 | 27.5 | 5.9 |
| 06/25/2008 | −11.06 | −76.0 | 12 | 27.5 | 17.5 |
| 06/25/2008 | −9.23 | −73.1 | 1 | 27.5 | 10.7 |
| 06/25/2008 | −9.68 | −66.6 | 11 | 27.5 | 2.5 |
| 06/25/2008 | −9.89 | −67.3 | 12 | 27.5 | 2.7 |
| 06/25/2008 | −11.91 | −83.2 | 12 | 27.5 | 4.2 |
| 06/25/2008 | −12.30 | −83.7 | 15 | 27.5 | 26.0 |
| 06/26/2008 | −10.70 | −75.3 | 10 | 25.9 | 18.8 |
| 06/26/2008 | −9.15 | −61.3 | 12 | 25.9 | 10.0 |
| 06/26/2008 | −8.05 | −53.9 | 11 | 25.9 | 4.2 |
| 06/26/2008 | −10.38 | −72.5 | 11 | 25.9 | 9.0 |
| 06/26/2008 | −9.80 | −73.8 | 5 | 25.9 | 7.5 |
| 06/26/2008 | −9.37 | −66.7 | 8 | 25.9 | 7.1 |
| 06/26/2008 | −12.36 | −93.6 | 5 | 25.9 | 65.3 |
| 06/26/2008 | −7.77 | −51.4 | 11 | 25.9 | 2.0 |
| 06/26/2008 | −8.39 | −59.1 | 8 | 25.9 | 4.4 |
| 06/26/2008 | −7.83 | −56.1 | 7 | 25.9 | 2.4 |
| 06/26/2008 | −8.00 | −59.6 | 4 | 25.9 | 3.2 |
| 06/26/2008 | −7.72 | −55.5 | 6 | 25.9 | 0.2 |
| 06/27/2008 | −9.05 | −67.6 | 5 | 26.4 | 1.2 |
| 06/28/2008 | −7.48 | −52.5 | 7 | 26.2 | 17.8 |
| 06/29/2008 | −9.15 | −65.8 | 7 | 25.0 | 60.0 |
| 06/29/2008 | −7.75 | −52.2 | 10 | 25.0 | 4.1 |
| 06/30/2008 | −6.41 | −43.1 | 8 | 25.8 | 3.1 |
| 07/01/2008 | −5.51 | −35.9 | 8 | 26.2 | 8.3 |
| 07/09/2008 | −9.10 | −66.3 | 7 | 27.0 | 12.6 |
| 07/10/2008 | −8.17 | −57.2 | 8 | 27.1 | 7.4 |
| 07/13/2008 | −7.21 | −46.6 | 11 | 26.0 | 16.6 |
| 07/14/2008 | −8.06 | −56.5 | 8 | 27.3 | 52.8 |
| 07/16/2008 | −8.16 | −56.1 | 9 | 27.9 | 0.9 |
| 07/31/2008 | −8.39 | −59.5 | 8 | 28.2 | 14.1 |
| 07/31/2008 | −7.41 | −55.5 | 4 | 28.2 | 5.3 |
| 07/31/2008 | −5.94 | −42.3 | 5 | 28.2 | 3.4 |
| 07/31/2008 | −8.26 | −59.4 | 7 | 28.2 | 22.8 |
| 08/04/2008 | −6.64 | −40.8 | 12 | 30.0 | 18.3 |
| 08/05/2008 | −10.24 | −75.8 | 6 | 27.2 | 7.2 |
| 08/06/2008 | −14.83 | −110.6 | 8 | 26.7 | 15.7 |
| 08/07/2008 | −5.36 | −45.1 | −2 | 26.6 | 0.7 |
| 08/11/2008 | −11.10 | −82.0 | 7 | 27.7 | 2.5 |
| 08/12/2008 | −11.35 | −83.1 | 8 | 27.1 | 6.8 |
| 08/12/2008 | −7.78 | −64.1 | −2 | 27.1 | 1.2 |
| 08/21/2008 | −9.87 | −72.1 | 7 | 31.7 | 4.5 |
| 08/23/2008 | −10.61 | −79.1 | 6 | 25.0 | 2.5 |
| 08/23/2008 | −11.73 | −100.0 | −6 | 25.0 | 6.8 |
| 08/24/2008 | −4.40 | −30.4 | 5 | 26.6 | 1.2 |
| 08/24/2008 | −4.31 | −27.2 | 7 | 26.6 | 4.5 |
| 09/01/2008 | −5.95 | −37.3 | 10 | 28.9 | 4.9 |
| 09/02/2008 | −7.12 | −46.4 | 11 | 27.3 | 19.0 |
| 09/03/2008 | −7.46 | −47.0 | 13 | 27.4 | 12.5 |
| 09/04/2008 | −7.22 | −47.1 | 11 | 26.1 | 27.5 |
| 09/04/2008 | −7.05 | −41.3 | 15 | 26.1 | 27.8 |
| 09/05/2008 | −8.20 | −54.1 | 12 | 26.4 | 13.6 |
| 09/05/2008 | −9.43 | −61.7 | 14 | 26.4 | 14.3 |
| 09/06/2008 | −7.67 | −47.5 | 14 | 26.8 | 4.0 |
| 09/08/2008 | −9.97 | −69.1 | 11 | 27.8 | 5.0 |
| 09/18/2008 | −8.08 | −57.8 | 7 | 27.9 | 21.9 |
| 09/18/2008 | −6.44 | −45.0 | 6 | 27.9 | 10.5 |
| 09/24/2008 | −9.37 | −65.7 | 9 | 26.4 | 38.6 |
| 10/04/2008 | −6.24 | −45.2 | 5 | 26.4 | 44.5 |
| 10/04//2008 | −6.93 | −53.0 | 2 | 26.4 | 45.6 |
| 10/05/2008 | −13.98 | −111.8 | 0 | 24.2 | 90.6 |
| 10/14/2008 | −6.71 | −48.5 | 5 | 23.3 | 11.5 |
| 10/18/2008 | −5.30 | −39.7 | 3 | 27.5 | 3.0 |
| 10/31/2008 | −0.54 | −8.4 | −4 | 27.4 | 0.1 |
| 11/02/2008 | −1.12 | −9.2 | 0 | 26.6 | 0.1 |
| 11/03/2008 | −5.20 | −31.2 | 10 | 21.8 | 18.0 |
| 11/04/2008 | −6.31 | −52.0 | −2 | 22.4 | 0.2 |
| 11/07/2008 | 0.01 | 14.3 | 14 | 25.4 | 49.8 |
| 12/04/2008 | −5.00 | −28.2 | 12 | 18.7 | 1.5 |
| 12/29/2008 | −3.78 | −13.1 | 17 | 16.0 | 7.3 |
| 01/26/2009 | −3.61 | −20.6 | 8 | 8.4 | 7.2 |
| 02/15/2009 | −3.03 | −8.1 | 16 | 23.7 | 0.1 |
| 03/05/2009 | −5.39 | −28.9 | 14 | 21.1 | 24.6 |
| 03/05/2009 | −4.63 | −20.2 | 17 | 16.7 | 15.1 |
| 03/06/2009 | −5.06 | −23.9 | 17 | 16.7 | 16.0 |
| 03/07/2009 | −4.01 | −13.5 | 19 | 12.2 | 3.5 |
| 03/13/2009 | −3.96 | −16.9 | 15 | 12.0 | 1.8 |
| 03/23/2009 | −2.90 | −9.8 | 13 | 17.0 | 1.2 |
| 03/24/2009 | −3.44 | −11.7 | 16 | 25.4 | 12.2 |
| 03/25/2009 | −0.53 | 6.5 | 11 | 21.0 | 4.8 |
| 03/26/2009 | −4.45 | −23.3 | 12 | 17.4 | 24.2 |
| 03/28/2009 | −7.89 | −52.4 | 11 | 19.1 | 80.0 |
| 03/30/2009 | −6.19 | −32.6 | 17 | 22.2 | 21.6 |
| 04/02/2009 | −2.28 | 0.7 | 19 | 17.0 | 1.6 |
| 04/04/2009 | −0.53 | 0.8 | 5 | 18.9 | 2.4 |
| 04/13/2009 | −3.82 | −18.7 | 12 | 21.2 | 14.7 |
| 04/15/2009 | −4.17 | −23.4 | 10 | 23.0 | 12.8 |
| 04/16/2009 | −6.78 | −42.5 | 12 | 22.7 | 11.2 |
| 04/18–19/2009 | −6.65 | −38.1 | 15 | 24.3 | 16.5 |
| 04/19/2009 | −3.95 | −24.1 | 8 | 26.5 | 6.5 |
| 04/19–25/2009 | 1.61 | 17.1 | 4 | 24.5 | 38.2 |
| 05/17/2009 | −7.61 | −47.1 | 14 | 27.0 | 27.1 |
| 05/18/2009 | −5.10 | −26.6 | 14 | 26.7 | 3.5 |
| 05/19/2009 | −6.15 | −32.9 | 16 | 26.8 | 12.3 |
| 05/19/2009 | −3.52 | −18.3 | 10 | 27.5 | 8.0 |
| 05/20/2009 | −5.67 | −29.0 | 16 | 25.9 | 26.5 |
| 05/21/2009 | −6.19 | −39.0 | 10 | 25.5 | 24.2 |
| 05/22–24/2009 | −5.88 | −37.2 | 10 | 24.9 | 79.0 |
| 05/25/2009 | 0.73 | 11.0 | 5 | 24.9 | 2.1 |
| 05/27/2009 | −3.61 | −16.1 | 13 | 27.1 | 11.4 |
| 05/28–29/2009 | −4.97 | −29.4 | 10 | 22.8 | 13.6 |
| 06/03/2009 | −6.62 | −40.1 | 13 | 27.6 | 16.0 |
| 06/04/2009 | −10.37 | −66.1 | 17 | 26.8 | 72.8 |
| 06/08–09/2009 | −3.45 | −16.9 | 11 | 25.4 | 8.2 |
| 06/09/2009 | −4.77 | −23.6 | 15 | 28.3 | 43.2 |
| 06/10/2009 | −4.73 | −24.4 | 13 | 28.2 | 20.6 |
| 06/12/2009 | −4.68 | −25.8 | 12 | 26.1 | 8.8 |
| 06/13–14/2009 | −3.45 | −23.5 | 4 | 27.5 | 27.6 |
| 06/15/2009 | −5.22 | −30.4 | 11 | 25.9 | 14.3 |
| 06/16–26/2009 | −4.33 | −32.1 | 3 | 28.6 | 50.5 |
| 06/26–30/2009 | −10.02 | −69.8 | 10 | 27.6 | 25.2 |
| 07/01–06/2009 | −6.28 | −41.9 | 8 | 28.7 | 30.0 |
| 07/11/2009 | −8.68 | −59.0 | 10 | 28.4 | 18.5 |
| 07/15/2009 | −8.52 | −60.0 | 8 | 28.6 | 2.0 |
| 07/19/2009 | −16.43 | −117.6 | 14 | 27.3 | 8.5 |
| 07/19/2009 | −9.25 | −59.2 | 15 | 27.0 | 7.5 |
| 07/20/2009 | −8.21 | −49.1 | 17 | 28.3 | 21.5 |
| 07/26/2009 | −6.70 | −41.7 | 12 | 29.0 | 5.0 |

(*continued on next page*)

**Table 2** (*continued*)

| Date (mm/dd/yy) | $\delta^{18}O^a$ (‰) | $\delta D^a$ (‰) | D-excess[b] (‰) | $T^c$ (°C) | $P^c$ (mm) |
|---|---|---|---|---|---|
| 07/29/2009 | −5.73 | −33.5 | 12 | 28.9 | 16.7 |
| 07/30/2009 | −8.16 | −50.5 | 15 | 28.5 | 35.4 |
| 07/31/2009 | −7.80 | −51.5 | 11 | 29.5 | 15.0 |
| 08/02–06/2009 | −9.99 | −65.5 | 14 | 29.5 | 111.1 |
| 08/09–17/2009 | −12.15 | −88.9 | 8 | 29.6 | 42.5 |
| 08/23/2009 | −6.22 | −37.0 | 13 | 30.5 | 7.3 |
| 08/25/2009 | −7.03 | −36.6 | 20 | 28.5 | 11.3 |
| 08/29/2009 | −4.84 | −31.3 | 7 | 30.4 | 15.3 |
| 08/30/2009 | −5.58 | −28.6 | 16 | 26.9 | 33.3 |
| 09/05/2009 | −4.33 | −21.7 | 13 | 31.0 | 31.3 |
| 09/14/2009 | −5.11 | −24.9 | 16 | 28.8 | 6.8 |
| 09/15/2009 | −12.13 | −83.5 | 14 | 26.5 | 17.5 |
| 09/21/2009 | −4.73 | −25.8 | 12 | 30.7 | 5.5 |
| 09/29/2009 | −6.22 | −38.5 | 11 | 25.1 | 8.0 |
| 10/13/2009 | −2.61 | −4.0 | 17 | 26.6 | 1.0 |
| 10/20/2009 | −3.89 | −10.4 | 21 | 23.5 | 20.1 |
| 11/09/2009 | −3.24 | −12.6 | 13 | 25.6 | 1.4 |
| 11/11/2009 | −3.03 | −12.0 | 12 | 26.0 | 9.5 |
| 11/12/2009 | −4.76 | −17.2 | 21 | 20.0 | 62.5 |
| 11/14/2009 | −4.35 | −8.2 | 27 | 12.1 | 7.4 |

[a] The $\delta D$ and $\delta^{18}O$ are relative to V-SMOW.

[b] D-excess is calculated by $d = \delta D - 8 \times \delta^{18}O$ (Dansgaard, 1964).

[c] $T$ means daily surface air temperature, P means precipitation amount.

and $\delta^{18}O$ seasonal variations agree with the general variation patterns in South China controlled by the monsoon climate (Araguas-Araguas et al., 1998; Wei and Lin, 1994).

## 5. Discussions

### 5.1. Correlations between $\delta^{18}O$ and $\delta D$ and climate parameters

An excellent positive correlation between $\delta D$ and $\delta^{18}O$ can be broadly observed in natural meteoric waters from rivers, lakes, and precipitations around the world. The regression line, $\delta D = 8\ \delta^{18}O + 10$, is defined as the global meteoric water line (GMWL) (Craig, 1961). The regression has gradually been modified on the $\delta D$ and $\delta^{18}O$ data of the precipitations collected from stations of the GNIP program organized by IAEA/WMO (Yurtsever and Gat, 1981; Rozanski et al., 1993). The more recent version is $\delta D = 8.07\ (\pm 0.02)\ \delta^{18}O + 9.9\ (\pm 0.1)$. This was calculated from the data of all GNIP stations from 1961 to 2000 (Gourcy et al., 2005). This regression is very close to the GMWL. Similarly, the local meteoric water line (LMWL) in a given location basically agrees with this regression, though regional differences in the LMWLs are broadly observed due to regional differences in climate conditions and moisture sources (Merlivat and Jouzel, 1979). Additionally, LMWLs may change from year to year in a given station. For example, in South China where the monsoon climate prevails, annual differences in LMWLs are significant. This may be attributed to changes in local climate conditions and moisture supplies (Wei and Lin, 1994).

The first LMWL in Guangzhou was reported as $\delta D = 9.83\ (\pm 0.55)\ \delta^{18}O + 18.7\ (\pm 0.3)$ ($r^2 = 0.95$) (Fig. 4). This was established from 18 selected precipitation water samples collected from January to October 1980 (Zheng et al., 1983). This LMWL has a significantly larger slope and intercept compared to the GMWL. Current available $\delta D$ and $\delta^{18}O$ data of the precipitation water from GNIP Guangzhou station only lasted for 3 years, from 1986 to 1989 (IAEA/WMO, 2006). These data were weighed by monthly average precipitations, and the data of most winter months from December through February and August were not provided. The LMWL they yield is $\delta D = 7.76\ (\pm 0.65)\ \delta^{18}O + 5.4\ (\pm 3.6)$ ($r^2 = 0.83$). This has a relatively smaller slope and intercept compared to those of the GMWL (Fig. 4).

Our results cover nearly all precipitation events that occurred from 2007 to 2009 in Guangzhou. These results can likely provide

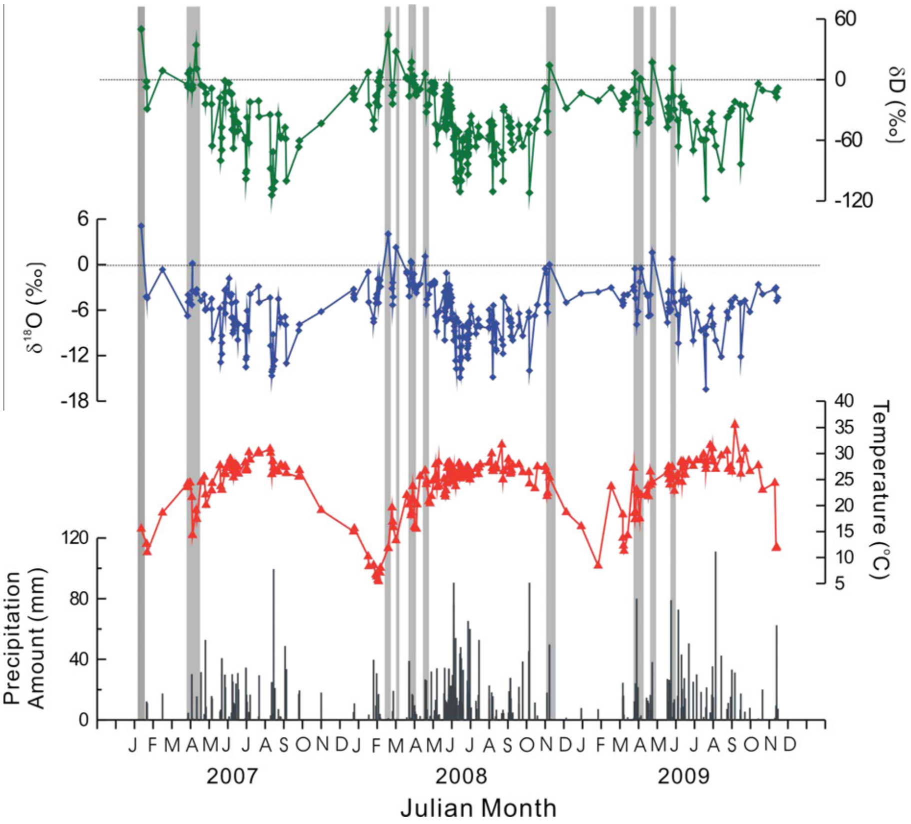

**Fig. 3.** Temporal variations of the precipitation $\delta^{18}O$, $\delta D$ precipitation amount, and air temperature during 2007–2009 in Guangzhou. The bars highlight the positive $\delta^{18}O$ and $\delta D$, which generally occur in winter and early spring.

more details about the $\delta D$ and $\delta^{18}O$ correlation of the precipitation water in this region. These are shown in Fig. 4, together with the former LMWLs mentioned above and the GMWL. The relationship between $\delta D$ and $\delta^{18}O$ in 2007, 2008, and 2009 were calculated separately. The regression for 2007 yields $\delta D = 8.96\ (\pm 0.42)\ \delta^{18}O + 23.0\ (\pm 3.2)$ ($r^2 = 0.86$, N = 76). Compared with the GMWL, it has a relative larger slope and intercept and slightly drifts away from the GMWL in Fig. 4. The regression for 2008 and 2009 are $\delta D = 8.42\ (\pm 0.10)\ \delta^{18}O + 12.3\ (\pm 0.7)$ ($r^2 = 0.98$, $N = 173$) and $\delta D = 7.96\ (\pm 0.18)\ \delta^{18}O + 12.9\ (\pm 1.1)$ ($r^2 = 0.97$, $N = 69$), respectively. Their slopes and intercepts are similar to those of the GMWL and they are located very close to the GMWL in Fig. 4. All regressions for 2007, 2008, and 2009 are some different from the former LMWLs (Fig. 4). This suggests that the relationship between $\delta D$ and $\delta^{18}O$ is changeable in different calendar years. The result of a single year may not effectively represent the $\delta D$ and $\delta^{18}O$ correlation in this region. The total relationship between $\delta D$ and $\delta^{18}O$ from 2007 to 2009, $\delta D = 8.46\ (\pm 0.13)\ \delta^{18}O + 15.0\ (\pm 0.9)$ ($r^2 = 0.93$) (Fig. 4).

Both changes in climate conditions and moisture sources can contribute to the change of $\delta D$ and $\delta^{18}O$ correlation of precipitation water (Merlivat and Jouzel, 1979). The drifts of the slopes and the intercepts of the regressions in 2007, 2008, and 2009 do not appear to be correlated to the change of air temperature and precipitation amount. The climate conditions in 2007 and 2009 are similar (Fig. 3) with the annual precipitation amounts of 1370 and 1492 mm and annual mean temperature of 23.2 and 29.9 °C, respectively. Conversely, the LMWLs for 2007 and 2009 are significantly different. On the contrary, the annual precipitation amount in 2008 is significantly larger than that in 2009, and the annual mean temperature is significantly lower. However, the LMWLs for 2008 and 2009 are similar. Thus, the change in moisture sources may play an important role in controlling the change of $\delta D$ and $\delta^{18}O$ of precipitation water in this region.

The correlation between $\delta D$ and $\delta^{18}O$ of precipitation water and temperature called "*temperature effect*" (Dansgaard, 1964) is generally positive in high latitude regions (Merlivat and Jouzel, 1979). However, in South and East Asia where the monsoon climate prevails, the correlation generally does not exist or is even inverse in monthly or even higher time resolution. This is due to significant changes in moisture sources supplied by the monsoon (Araguas-Araguas et al., 1998; Johnson and Ingram, 2004; Wei and Lin, 1994). The results show moderate to robust negative correlations ($p < 0.006$ to $p < 0.0000001$) between precipitation water $\delta^{18}O$ and daily or instant air temperatures. The regression lines are also different from year to year (Fig. 5a). The results were calculated into monthly means weighed by the amount of precipitation to compare with the GNIP results in Guangzhou and Hong Kong. As shown in Fig. 5b, both the monthly results in Guangzhou from 1986 to 1989 and from 2007 to 2009 exhibit moderate to robust negative correlation, but their regression lines are significantly different. They are also different from those of the Hong Kong station from 1961 to 2004. Therefore, the relationship between precipitation water H–O isotopes and local air temperatures are temporally and regionally changeable. This agrees with the former conclusion that local temperature is not the key to controlling the H–O isotopes of precipitation; thus, precipitation $\delta D$ and $\delta^{18}O$ are not suitable to indicate local temperatures in this region (Araguas-Araguas et al., 1998; Johnson and Ingram, 2004; Wei and Lin, 1994).

The so-called *amount effect* (Dansgaard, 1964), with precipitation $\delta^{18}O$ negatively correlating to precipitation amount, is

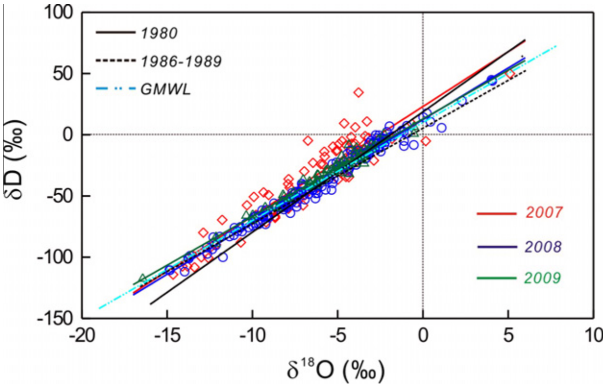

**Fig. 4.** Correlations between $\delta D$ and $\delta^{18}O$ in the precipitation. The regression lines are calculated separately for each year. The regression line for the whole data during 2007–2009, the GMWL, and some previous results in Guangzhou are shown together for comparison. The GMWL of 1980 is $\delta D = 8.46\ (\pm 0.13)\ \delta^{18}O + 15.0\ (\pm 0.9)$ ($r^2 = 0.93$); the GMWL of 1986–1989 is $\delta D = 7.76\ (\pm 0.65)\ \delta^{18}O + 5.4\ (\pm 3.6)$ ($r^2 = 0.83$); the GMWL of 2007 is $\delta D = 8.96\ (\pm 0.42)\ \delta^{18}O + 23.0\ (\pm 3.2)$ ($r^2 = 0.86$, N = 76); the GMWL of 2008 is $\delta D = 8.42\ (\pm 0.10)\ \delta^{18}O + 12.3\ (\pm 0.7)$ ($r^2 = 0.98$, N = 173); the GMWL of 2009 is $\delta D = 7.96\ (\pm 0.18)\ \delta^{18}O + 12.9\ (\pm 1.1)$ ($r^2 = 0.97$, N = 69); and the total GMWL of 2007–2009 is $\delta D = 8.46\ (\pm 0.13)\ \delta^{18}O + 15.0\ (\pm 0.9)$ ($r^2 = 0.93$).

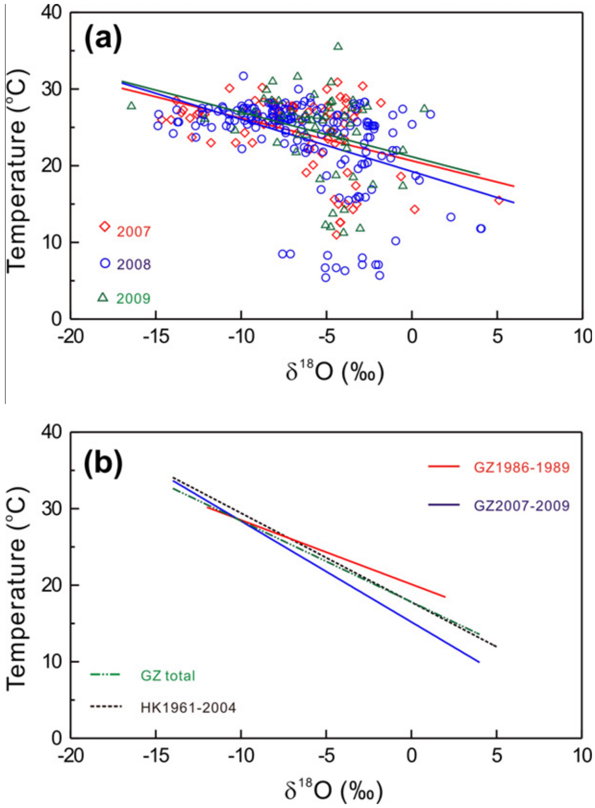

**Fig. 5.** Correlations between precipitation $\delta^{18}O$ and air temperature ($T$). (a) Regression lines for the event precipitation data in each year and their correlation significance. The correlation of 2007 is $T = -0.56\ (\pm 0.14)\ \delta^{18}O + 20.6\ (\pm 1.1)$ ($r = -0.42$, $N = 76$, $p < 0.00009$); the correlation of 2008 is $T = -0.68\ (\pm 0.11)\ \delta^{18}O + 19.2\ (\pm 0.8)$ ($r = -0.44$, $N = 174$, $p < 0.0000001$); the correlation of 2009 is $T = -0.59\ (\pm 0.20)\ \delta^{18}O + 21.4\ (\pm 1.2)$ ($r = -0.30$, $N = 69$, $p < 0.006$). (b) Regression lines for the monthly weighted average data in Guangzhou and Hong Kong, and their correlation significance. The regression of 1986–1989 monthly weighted data is GZ1986–1989: $T = -0.84\ (\pm 0.28)\ \delta^{18}O + 20.1\ (\pm 1.6)$ ($r = -0.49$, $N = 30$, $p < 0.003$); the regression of 2007–2009 monthly weighted data is GZ2007–2009: $T = -1.32\ (\pm 0.27)\ \delta^{18}O + 15.2\ (\pm 0.2)$ ($r = -0.64$, $N = 34$, $p < 0.00003$); the regression of total monthly weighted data (1986–1989 and 2007–2009) is GZ total: $T = -1.06\ (\pm 0.20)\ \delta^{18}O + 17.8\ (\pm 0.1)$ ($r = -0.64$, $N = 34$, $p < 0.000001$); and the regression of monthly weighted data of Hong Kong (1961–2004) is HK1961–2004: $T = -1.16\ (\pm 0.07)\ \delta^{18}O + 17.8\ (\pm 0.4)$ ($r = -0.67$, $N = 386$, $p < 0.0000001$). The monthly weighted isotopic data from GNIP was precipitation amount weighted averaged by the precipitations between 15 of past month and 15 of this month, and our monthly weighted isotopic data was precipitation amount weighted averaged by the precipitations between first day and the last day of this month. The monthly air temperature/amount was averaged by the daily temperature/amount between the first day and the last day of this month.

generally observed in tropical regions (Araguas-Araguas et al., 1998; Gourcy et al., 2005; Wei and Lin, 1994). This can also be seen in our results in Guangzhou from 2007 to 2009. The daily precipitation $\delta^{18}O$ shows moderate to robust negative correlation to the precipitation amounts like that between precipitation $\delta^{18}O$ and temperature (Fig. 6a). The regression lines for such correlations are variable in different years. Moreover, such correlations are also significant in monthly resolution means of the results during 2007–2009. In addition, the regression line for such correlation is significantly different from that of the GNIP results during 1986–1989 in Guangzhou and during 1961–2004 in Hong Kong (Fig. 6b). This indicates that the relationship between precipitation water H–O isotopes and precipitations are also temporally and regionally different in South China. Therefore, the change of precipitation $\delta^{18}O$ is basically associated with precipitation amount, but using precipitation $\delta^{18}O$ to indicate precipitation amount change quantitatively in South China is not feasible.

### *5.2. Deuterium-excess and moisture sources in Guangzhou*

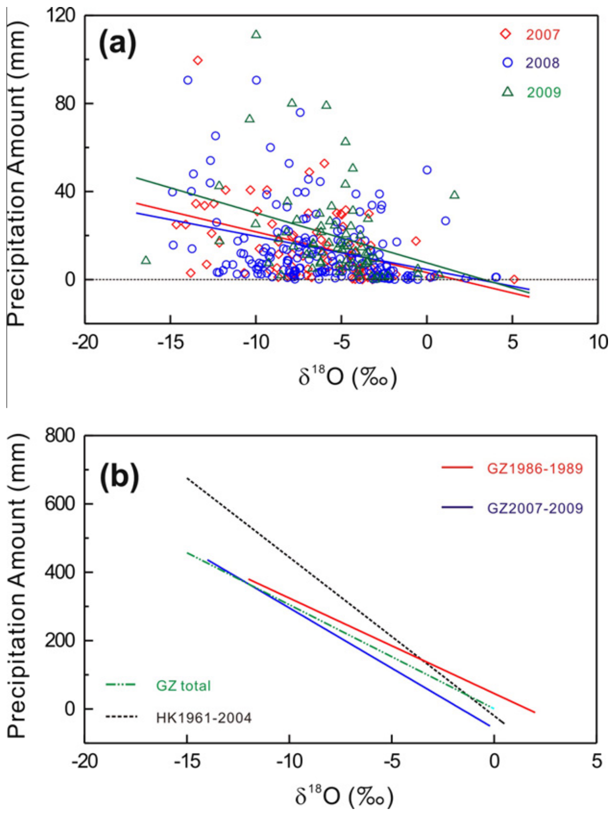

**Fig. 6.** Correlation between precipitation $\delta^{18}O$ and precipitation amounts ($P$). (a) Regression lines for the event precipitation data in each year and their correlation significance. The correlation of 2007 is $P = -1.85(\pm 0.47)\ \delta^{18}O + 3.2\ (\pm 3.6)$ ($r = -0.42$, $N = 75$, $p < 0.00009$); the correlation of 2008 is $P = -1.53\ (\pm 0.33)\ \delta^{18}O + 4.5(\pm 2.4)$ ($r = -0.33$, $N = 174$, $p < 0.000004$); the correlation of 2009 is $P = -2.27(\pm 0.84)\ \delta^{18}O + 7.6\ (\pm 5.2)$ ($r = -0.32$, $N = 69$, $p < 0.004$). (b) Regression lines for the monthly weighted average data in Guangzhou and Hong Kong, and their correlation significance. The regression of 1986–1989 monthly data is GZ1986–1989: $P = -27.9\ (\pm 10.8)\ \delta^{18}O + 45.3\ (\pm 60.5)$ ($r = -0.43$, $N = 31$, $p < 0.009$); the regression of 2007–2009 monthly data is GZ2007–2009: $P = -35.2\ (\pm 7.9)\ \delta^{18}O - 56.9\ (\pm 51.8)$ ($r = -0.64$, $N = 34$, $p < 0.00003$); the regression of total monthly data (1986–1989 and 2007–2009) is GZ total: $P = -30.4\ (\pm 6.5)\ \delta^{18}O + 0.5\ (\pm 39.5)$ ($r = -0.51$, $N = 65$, $p < 0.000007$); and the regression of monthly data of Hong Kong (1961–2004) is HK1961–2004: $P = -46.4\ (\pm 3.0)\ \delta^{18}O - 20.0\ (\pm 17.1)$ ($r = -0.61$, $N = 386$, $p < 0.0000001$).

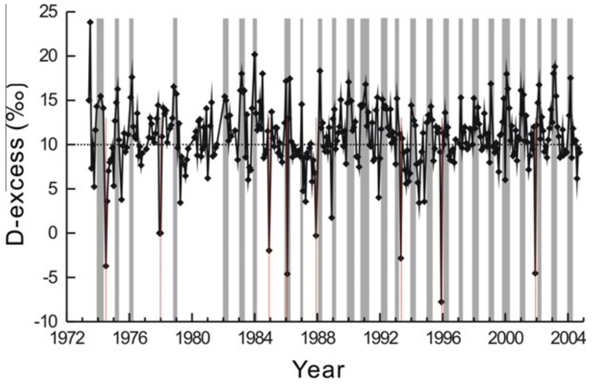

**Fig. 7.** Long-term D-excess of the monthly average precipitation in Hong Kong during 1972–2004. The shaded bars highlight the maximum D-excess within a year, which generally occurred in winter through early spring. The dash lines marked the extreme low D-excess values, randomly occurring in different seasons. The mechanism for these extreme low D-excess is not yet known.

Deuterium-excess (D-excess), defined as $d = \delta D - 8 \times \delta^{18}O$, is generally associated with the moisture sources of the precipitation (Dansgaard, 1964). It is generally negatively correlated with the relative humidity of the air masses formed above the ocean (Merlivat and Jouzel, 1979; Pfahl and Wernli, 2008; Uemura et al., 2008), and appears to be used to indicate climatic changes in the moisture source regions (Masson-Delmotte et al., 2005; Petit et al., 1991). In South China, seasonal changes in monsoon circulation provide moisture from different sources during winter and summer; thus the D-excess of precipitation water in this region shows significant seasonal variety (Araguas-Araguas et al., 1998). This is well presented in the long-term monthly resolution record in Hong Kong during the past 30 years. As shown in Fig. 7, most high D-excess within a year occur from winter through early spring (December to March) except for some high values that occurred in the summer of 1977, 1980, 1981, 1984, 1989, and 1992. The summer monsoon in the SCS generally starts in May and withdraws in late September to October (Wang and Lin, 2002). Thus, moisture for the precipitation from December to March in this region is likely from adjacent seas or local evaporation rather than transported from remote seas. Relative humidity during this period is the lowest within a year in this region, and the moisture formed during this period may have high D-excess. During summer and autumn, the summer monsoon brings huge amount of moisture from remote seas, which is generated under the condition of high relative humidity. In particular, there are some typhoons striking this region during summer and autumn which contribute to heavy precipitation. Typhoons generally form in the remote regions of the SCS or the west Pacific where temperature and humidity are higher than those in the coastal regions of South China. Moreover, $\delta^{18}O$ in precipitation associated with tropical cycle such as typhoon is even lower of about 6‰ than that in normal summer precipitation (Lawrence and Gedzelman, 1996). Thus, a typhoon brings a large amount of such moisture to South China and results in lower D-excess and lower $\delta^{18}O$ in the precipitation water during summer and autumn.

Generally, typhoon lasts for only several days; thus, monthly records do not seem adequate when they are used to look for the contribution of typhoons to moisture. In this respect, the daily or event record can provide more details. Fig. 8 shows the D-excess together with $\delta^{18}O$ of event records during 2007–2009 in Guangzhou. The typhoons that influenced Guangzhou during this period are also marked in Fig. 8 (the path information for each typhoon is available in the information bulletin of the Bureau of Water Resources of the Committee of Pearl River Water Resources and the National Meteorological Center of China posted at their websites with the address, http://59.42.107.152/zjwwebsyq, and http://map.weather.gov.cn/, respectively). The D-excess variation in

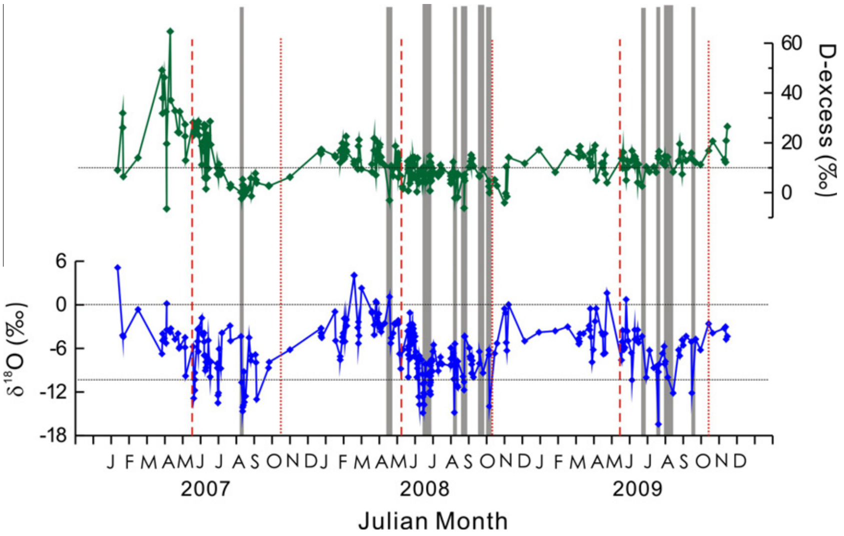

**Fig. 8.** Temporal variations of the D-excess and $\delta^{18}O$ of the precipitation events during 2007–2009 in Guangzhou. The vertical dash lines indicate the onset of the South China Sea Summer Monsoon (SCSSM). The dotted lines indicate the withdrawal of the SCSSM. The shaded bars indicate the typhoon events that influence Guangzhou.

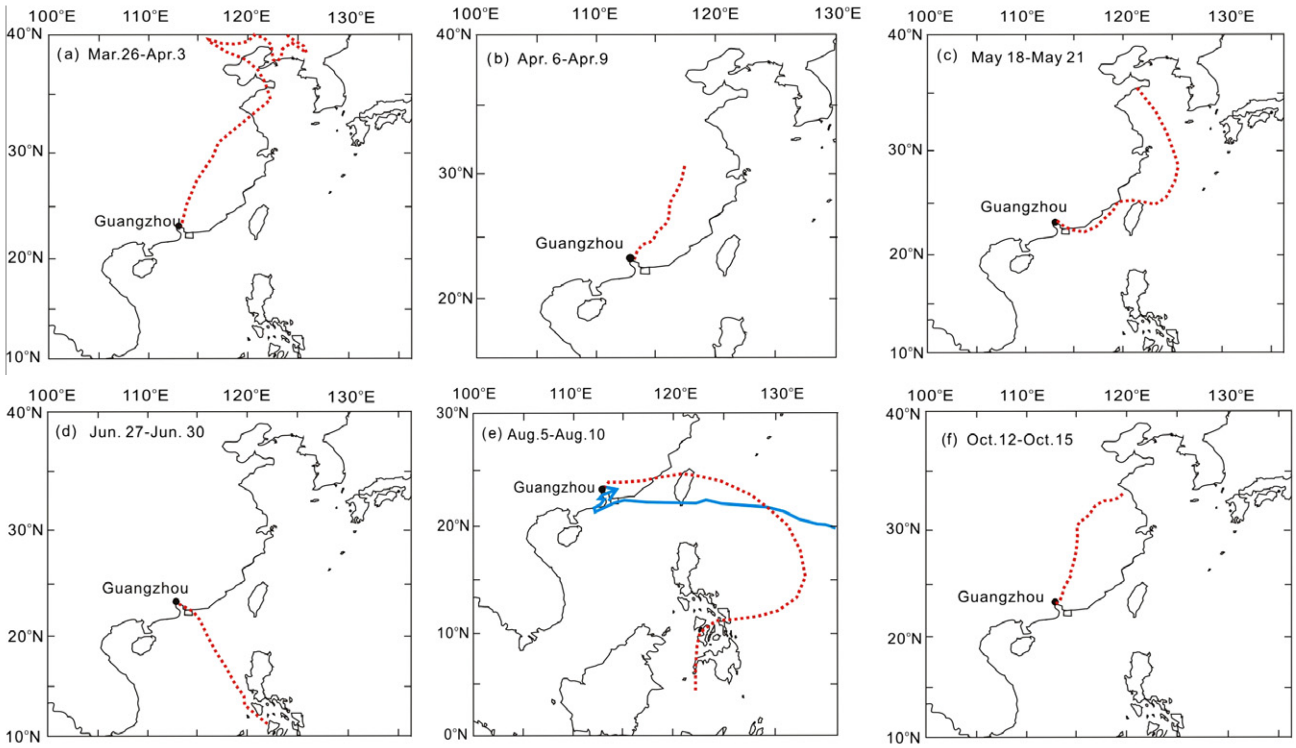

**Fig. 9.** Modeled trajectory on air-mass transport and typhoon path in selected periods and some special air trajectories in 2007. The red dash line is the air trajectory modeled using the on-line Hybrid Singleparticle Lagrangian integrated trajectory (HYSPLIT). The termination of the model analysis for the trajectory all corresponds to Guangzhou. The solid blue line with arrow is the path of typhoon (include tropical hurricane, storm, super-typhoon). (a) From March 26 to April 3; (b) From April 6 to 9; (c) From May 18 to 21, close to onset of the SCSSM; (d) From June 27 to 30; (e) From August 5 to 10, covering the whole period of typhoon *Pabuk*; (f) From October 12 to 15, close to the withdrawal of the SCSSM. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2007 agrees with the long-term variation pattern in Hong Kong, with the large D-excess values occurring at March and April and up to 65 for the maximum. The average D-excess in Guangzhou during the whole period of 2007 is 16.6 ± 13.5‰ (1$\sigma$). This value is significantly higher than that of the long-term average in Hong Kong which is 10.5 ± 4.1‰ (1$\sigma$), indicating a larger proportion of local moisture for the precipitation in 2007. This agrees with the situation that only one typhoon (*Pabuk*) passed through Guangzhou in the early August of 2007. Along with this typhoon process, both $\delta^{18}O$ and D-excess reached the minima of this year except for the rapid drop of D-excess in early April.

Such estimations on moisture sources can further be examined by the model analysis of single isobaric trajectory of air parcels. Fig. 9 shows the results of model analysis of six time intervals in 2007. The moistures of the high d precipitation from late March to early April were clearly transported from North China (Fig. 9a and b), and those for the precipitation with low $\delta^{18}O$ and high d during the onset of the summer monsoon (early March) are from seas to the north (Fig. 9c). Similarly, the precipitation with extreme negative $\delta^{18}$O and decreasing d in late June is contributed from remote SCS as indicated by the modeled trajectory (Fig. 9d). The air-mass trajectory during the typhoon (*Pabuk*) period is consistent with the path of *Pabuk* (Fig. 9e), indicating moisture source from the west Pacific. This agrees well with the most negative $\delta^{18}$O and the lowest d during this period. Not all the $\delta^{18}$O and d in precipitation, however, agree with modeled trajectory of the moisture. The low d values during the withdrawal of the summer monsoon (middle October) may attribute to a source from remote seas, while the modeled trajectory points to inland sources (Fig. 9f). Model trajectories may provide the source information of the main air masses. Other factors such as local temperature, humidity may also influence the d values of the local-evaporated moistures, and make the correlation between precipitation isotopes and modeled trajectories complicated. Coupling both results may provide more details on the moisture sources for the precipitation.

The D-excess variation patterns in 2008 and 2009, however, are different from those in 2007. In 2008, the high d values generally occur from January to March, and the low values occur in August. The average d is 9.7 ± 5.1‰ ($1\sigma$), similar to the long-term average in Hong Kong both in the value and the variation range. There were six typhoons that passed through Guangzhou in 2008. Not all the typhoon precipitations have a minimum $\delta^{18}$O. The $\delta^{18}$O of the typhoon precipitations in the middle of April is positive (~1.1‰), but they all show minimum D-excess values (Fig. 8).

Here, eight intervals in 2008 were selected for air-mass trajectory model analysis, including the six typhoon periods (Fig. 10). Similar to those in 2007, the high d value in early February show an inland moisture source (Fig. 10a), and the decreasing d during the onset of the summer monsoon in early May correspond to moistures for seas to the north (Fig. 10c). The modeled trajectory during the typhoon period of *Neoguri* in middle April is consistent with the path of *Neoguri*, indicating moisture from the SCS (Fig. 10b). As a result, the d value is low (−3‰). However, such moisture sources seem difficult to interpret the positive $\delta^{18}$O at that time. Not only the climate conditions in its source region and the distance of source, the relative size, longevity, cloud depth of typhoon may also controlled the mean isotopic value of typhoon precipitation in a definite location (Lawrence and Gedzelman, 1996; Lawrence et al., 1998, 2002). The positive $\delta^{18}$O during this period may be associated with the characteristic of *Neoguri*. Further studies, however, are needed for more details.

The air-mass trajectories during the other typhoons that influenced Guangzhou in 2008 are shown in Fig. 10d–g, together with the path of the corresponded typhoon. All these typhoons were originated from the west Pacific, while the modeled trajectories indicate varied sources for the air masses. In details, the moisture sources are tracked to the Indian Ocean during the periods of *Fengshen* from June 17 to 27 (Fig. 10d) and *Nuri* from August 17 to 23 (Fig. 10f), to the southern SCS during the period of *Kammuri* from August 3 to 8 (Fig. 10e), and to the west Pacific during the period of *Hagupit* from September 17 to 25 (Fig. 10f). The mechanism for the difference between the modeled trajectory and the typhoon path is not well-known. However, the trajectories and typhoon paths both suggest moisture sources from remote seas during these periods. Thus low d and $\delta^{18}$O values are expected for the precipitations during these periods, and this agrees with the observation shown in Fig. 8. It is worth noting that the trajectory during the period of typhoon *Higos* in late September through early October suggests moisture sources from the north inlands (Fig. 10h), while *Higos* came from the west Pacific. D-excess values are low and $\delta^{18}$O are extreme negative during this period as shown in Fig. 8, suggesting remote ocean moisture sources. It is likely that moisture carried by typhoon should be much larger than that by general air transport. As a result, the stable isotopes of the precipitations mainly show the typhoon information, which generally agree with the paths of the typhoons, resulting in low d values in the precipitation. Inland moisture source was suggested by the model trajectory, while huge moisture transported from the west Pacific and the SCS by *Higos* conceal such effect and maintain low d value for the precipitation (Fig. 10h).

The D-excess in 2009 shows no apparent decreasing or increasing trend, and the variation range is relatively small, with an average of 13.1 ± 4.1($1\sigma$)‰, which is slightly higher than that of 2008. There were four typhoons passing through Guangzhou in 2009. Most of the minimum $\delta^{18}$O are associated with typhoon, but D-excess of the typhoon precipitation does not show apparent minimum values (Fig. 8). Six periods, including the four typhoons were selected for trajectory model analysis and the results were shown in Fig. 11. Inland source is suggested in late April (Fig. 11a), and sea source is indicated during the period of summer

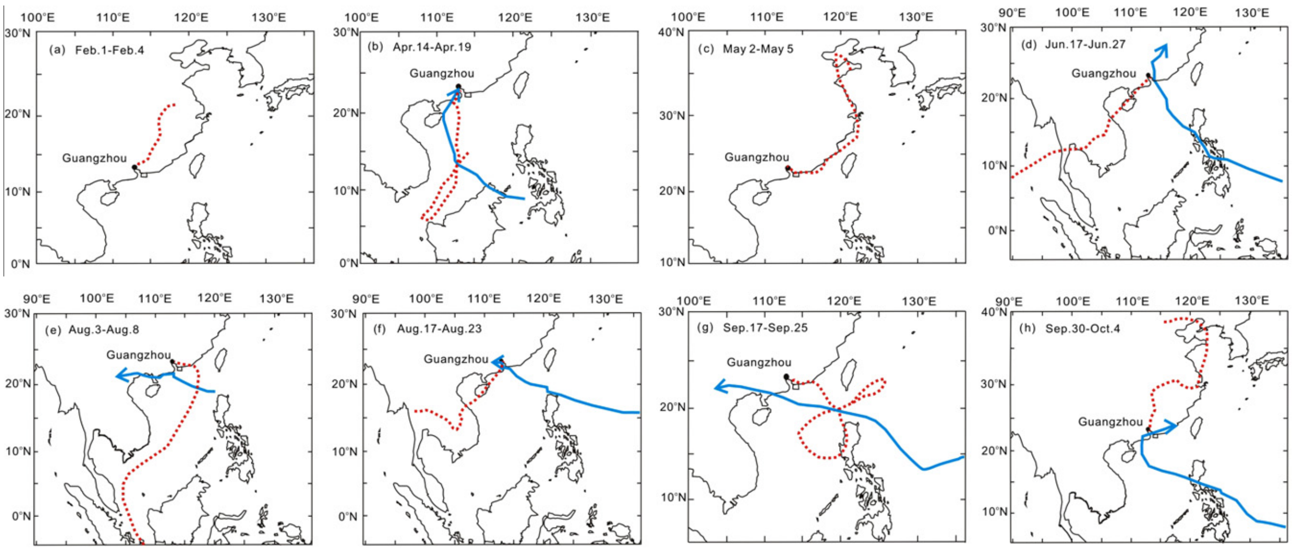

**Fig. 10.** Modeled trajectory on air-mass transport and typhoon path in selected periods of 2008. (a) From February 1 to 4; (b) From April 14 to 19, typhoon *Neoguri*; (c) From May 2 to5, close to onset of the SCSSM; (d) From June 17 to 27, typhoon *Fengshen*; (e) From August 3 to 8 typhoon *Kammuri*; (f) From August 17 to 23, typhoon *Nuri*; (g) From September 17 to 25, typhoon *Hagupit*; h) From September 30 to October 4, close to the withdrawal of the SCSSM.

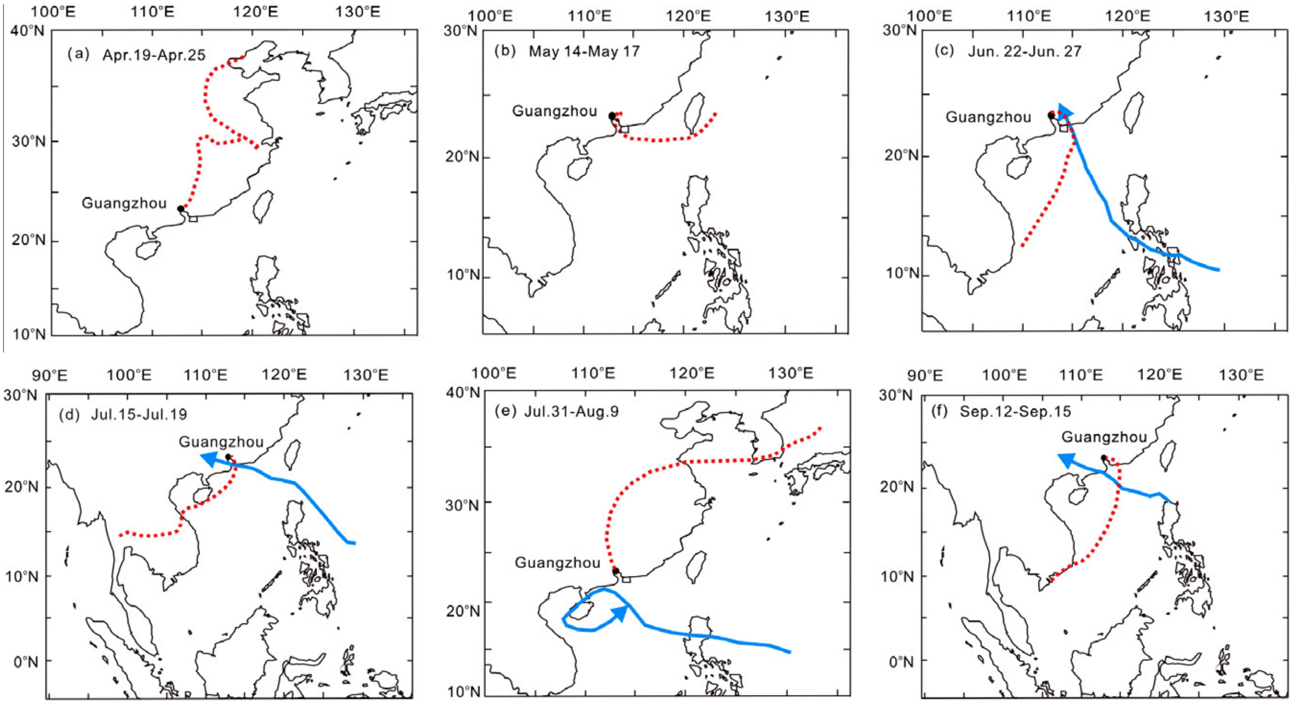

**Fig. 11.** Modeled trajectory on air-mass transport and typhoon path in selected periods and some special air trajectories in 2009. (a) From April 19 to 25; (b) From May 14 to 17, close to onset of the SCSSM; (c) From June 22 to 27, typhoon *Nangka*; (d) From July 15 to 19, typhoon *Molave*; (e) From July 31 to August 9, typhoon *Goni*; (f) From September 12 to 15, typhoon *Koppu*.

monsoon onset in middle May (Fig. 11b). The corresponding $\delta^{18}O$ agree with such difference of moisture sources, with positive $\delta^{18}O$ in late April and quite negative $\delta^{18}O$ in middle May (Fig. 8). However, d values is low (~4‰) in late April but high in middle May (~16‰), which appears not agree with their source characteristics. The modeled trajectories during the four typhoon periods are not all consistent with the paths of these typhoons (Fig. 11c–f). All the $\delta^{18}O$ during these periods show quite negative values, agreeing with the general sources from remote seas despite of the difference between modeled trajectories and typhoon paths. The d values, varying from 4‰ to 20‰ (Fig. 8), seem not agree well with the general law of source controls on precipitation stable isotopes.

On summary, both H–O isotopes and d value in precipitations in Guangzhou are closely associated with their moisture sources. Coupled $\delta^{18}O$ and *d* value may provide hints for moisture sources of precipitation as verified by the trajectory model analysis and typhoon paths. However, not all the changes in precipitation stable isotopes agree well with changes in moisture sources. Some other un-known factors may also take effects, and further investigates are needed.

### 5.3. Implications for paleoclimate records related to precipitation $\delta^{18}O$ and $\delta D$

Some paleoclimate proxies, for instance $\delta^{18}O$ of stalagmites and $\delta D$ of selected plant-derived organic compounds in sediments, tend to link to $\delta^{18}O$ or $\delta D$ of local precipitation in order to interpret their paleoclimate implications. Speleothem $\delta^{18}O$ is primarily controlled by $\delta^{18}O$ of drip-water and the temperature in caves. Even though many complicated processes such as infiltration and evaporation may influence drip-water $\delta^{18}O$, it is basically linked to $\delta^{18}O$ of precipitation water (Lachniet, 2009). The most important effort in studying $\delta D$ of selected plant-derived organic compounds in sediments and $\delta D$ and $\delta^{18}O$ in tree ring cellulose are to reconstruct $\delta D$ and $\delta^{18}O$ of ambient water/moisture during the growth of plants (Anderson et al., 2002; Huang et al., 2002; Hou et al., 2008; Jia et al., 2008; McCarroll and Loader, 2004; Sauer et al., 2001). Paleoclimate records derived from these proxies basically link to the $\delta^{18}O$ or $\delta D$ changes during atmospheric hydrological cycle, and help decipher the climatic information inside. Therefore, understanding the response of precipitation $\delta^{18}O$ and $\delta D$ to changes of climatic/environmental factors is the key to understanding the paleoclimate implications for these proxies.

Note that one of the most striking achievements for stalagmite $\delta^{18}O$ studies is the reconstruction of the evolution of the East Asian Monsoon in a varied time scale (Wang et al., 2001, 2008). Thus, understanding the response of monsoon precipitation $\delta^{18}O$ and $\delta D$ to climate processes is very important for such studies. Our results, together with a number of previous results (Araguas-Araguas et al., 1998; Johnson and Ingram, 2004; Wei and Lin, 1994), indicate that seasonal change of moisture sources is the most important factor influencing the precipitation $\delta^{18}O$ and $\delta D$ in this region. During seasons when the summer monsoon prevails, huge amount of moisture were brought from remote seas by the summer monsoon, contributing to the majority of the precipitation in this region and associating with warm climate. This results in the apparent amount effect and the significant negative correlation between precipitation $\delta^{18}O$ and $\delta D$ and local air temperature. However, the temporal and spatial differences in the correlation between precipitation $\delta^{18}O$ (and $\delta D$) and local temperature and precipitation amount of our results suggest that obtaining quantitative temperature or precipitation amount records from precipitation $\delta^{18}O$ and $\delta D$ is not feasible. Mostly controlled by changes in moisture sources, precipitation $\delta^{18}O$ and $\delta D$ cannot provide separate temperature and precipitation amount information. The same is true in speleothem and tree ring $\delta^{18}O$, and in plant-derived compound $\delta D$. Currently, these paleoclimate proxies can only qualitatively describe the monsoon climate. Generally, stronger summer monsoon associates with more negative $\delta^{18}O$ in speleothem and tree ring and more negative $\delta D$ in plant-derived compounds, which may indicate larger precipitation amount, warmer climate, or most importantly, larger proportion of the moisture being transported from remote seas.

## 6. Conclusions

Time series records of oxygen and hydrogen stable isotopes ($\delta^{18}O$ and $\delta D$) of the precipitation water collected in every event from 2007 to 2009 in Guangzhou were presented. The relationship between variations of these precipitation isotopes and climate variables were investigated to evaluate the response of precipitation $\delta^{18}O$ and $\delta D$ to climate changes. Moreover, model analysis on trajectory of air-mass, together with the typhoon paths and the isotopes, were handled to discuss on changes in the moisture sources. The following conclusions were drawn:

(1) Grand correlation between $\delta^{18}O$ and $\delta D$, similar to the GMWL, is observed in the precipitation in Guangzhou. The regression lines, however, are slightly different from year to year.

(2) Seasonal variations of the precipitation $\delta^{18}O$ and $\delta D$ are significant, and more negative $\delta^{18}O$ and $\delta D$ generally occur during summer and autumn. On the other hand, the less negative and, in some cases, even positive $\delta^{18}O$ and $\delta D$ occur during winter and spring. Significant negative correlations between precipitation $\delta^{18}O$ and temperature, and between precipitation $\delta^{18}O$ and precipitation amount are observed. The regression lines, however, change from year to year, and appear to differ from those in the adjacent Hong Kong Station. The change in moisture sources for the precipitation is likely the key for such apparent correlations. Moisture contributed from adjacent seas or local evaporation account for the main precipitation during winter and early spring, while the summer monsoon brings huge amount of moisture from remote seas, which is associated with higher temperature and larger precipitation amounts.

(3) Seasonal variations of the precipitation D-excess with the air trajectory and typhoon path appear to provide more details for changes in moisture sources. Higher D-excess values during winter and early spring correspond to a lesser proportion of remote moisture, while lower D-excess values during summers and autumn correspond to larger remote moisture transported by the summer monsoon. In particular, precipitation brought by typhoons generally has minimum D-excess. However, an exception with no apparent trend for D-excess is observed in 2009.

The results imply that precipitation $\delta^{18}O$ and $\delta D$, as well as some related paleoclimate proxies such as $\delta^{18}O$ in speleothem and tree ring, and $\delta D$ in plant-derived organic compounds, currently cannot indicate changes in temperature or precipitation amount separately. They should be comprehensive proxies for monsoon climate. More negative values of these proxies are generally associated with a stronger summer monsoon, which may indicate warmer climate, larger precipitation amount, or most importantly, larger proportion of moisture from remote seas (SCS and/or west Pacific).

## Acknowledgements

The authors thank the anonymous reviewers for their constructive comments, which helped to improve the manuscript. This work was financially supported by the National Basic Research Program of China (No. 2009CB421206), the Knowledge Innovation Project of the Chinese Academy of Sciences (KZCX2-YW-138), and the National Natural Sciences Foundation of China (No.40830852). This is contribution No. IS-1293 from GIGCAS.

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