# The isotopic composition of water vapor and the concurrent meteorological conditions around the northeast part of the Tibetan Plateau

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## Abstract

The stable isotopic ratio of water vapor ( δ $^{18}$O and δ D) was measured near a glacier in the northeast part of the Tibetan Plateau in the summer of 2003. A clear difference of the isotopic composition was found with the passing of a deep trough, which showed lighter δ D (and δ $^{18}$O ) and higher d-excess compared with those of the previous period. The dry air from the northwest, which came after the passing of the trough, seems to come from the upper troposphere/lower stratosphere. We also found a diurnal change in the isotopic composition. As the air from the northern desert has relatively small δ $^{18}$O, relatively small δD values and relatively high d-excess values, the valley wind that prevails in afternoon through evening must be bringing air from the northern desert to our site. We believe that analysis of the isotopic ratio of water vapor should be useful to understand the continental and local hydrological circulation of complicated terrains, and to interpret the ice core records in paleo-climatological studies.

*Keyword: water vapor, atmospheric branch of the hydrological cycle, isotope, arid/semi-arid region, paleo-climate.*

## 1. Introduction

Several methods have been used to investigate the relation between water vapor transport and precipitation to the arid regions of the Eurasian Continent. Recently atmospheric general circulation models (GCMs) were used to investigate the moisture source for precipitating water on the Eurasian continent, in addition to diagnostic analysis (e.g. moisture budget analysis) using meteorological reanalysis dataset.

However, these methods are not sufficient to understand the hydrological circulation in the central part of the Eurasian continent, because of the following reasons.

1. Since arid regions and mountainous regions are generally unpopulated, the quality of the objective analysis data is relatively low because of the sparse data network.
2. Modeling the atmospheric hydrological circulations over complicated topography, especially for steep mountains, is very difficult. The Taklimakan desert, one of the driest regions in the continent, is surrounded by steep mountains (e.g. northern periphery of the Tibetan Plateau and Tianshan mountains, etc).
3. The region where moisture from the northwest, south of the Tibetan Plateau, and monsoonal flow from Chinese plain area converge locates the Northwest and North China. Therefore, the atmospheric circulation field during precipitation is very different from that during the mean state and on dry days. (Yatagai and Yasunari, 1998).

An alternative tool to understand the hydrological circulation should be stable isotope. Actually, stable isotope techniques of precipitating water as well as terrain water (river flow, soil moisture, ground water, etc) are often used to better understand hydrological circulation. However, it is thought that understanding atmospheric hydrological circulation over complicated terrain like Northwest China requires analysis of the isotope ratio of the water vapor because;

1. There is too little precipitation to sample because of its arid environment.
2. As written in the previous point 3, moisture source is not single for this region.
3. Investigating isotope information on water vapor over the high mountains of this region is useful because ice core samples of glaciers are sometimes used to determine the paleo-environment.

To determine the past atmospheric condition and climate changes in this area, it is very important to clarify the relationship between the moisture source, transport, and atmospheric circulation over the glaciers in this region.

Therefore, our field experiment to collect atmospheric moisture for isotope analysis was performed on July 1st (Qiyi) Glacier in the Qilianshan Mountains in the northeast part of the Tibetan Plateau in Northwest China. After collected and analyzed water vapor near this glacier, results are compared with the concurrent meteorological fields.

## 2. Field observation and analysis

### 2.1. Location

From 11 August 2003 to 17 August 2003, we collected atmospheric samples in the Qilianshan Mountains. Location from a large-scale point of view will be shown in Fig. 3. Two stations were chosen: 1) near the terminal of Qiyi glacier at an automatic weather station (AWS), hereafter Qiyi (39.15.22N, 97.45.14E, 4250 m), and 2) at base camp, hereafter BC (39.16.35N, 97.42.50E, 3672 m). These two sites are separated by about 4 km.

### 2.2 Meteorological events and focuses

At the terminal of the Qiyi glacier (4250-m a.s.l.), an automatic weather station (AWS) has been in operation since August 2002. Figure 1 shows the time series of a) temperature at 2 m, b) relative humidity at 2 m (Rh), c) wind speed at 10m (WS), and d) wind direction at 10m (WD), and e) short wave radiation (QSD) from 11 August 2002 to 17 August 2003. During the period, snowfall occurred from 13:00 LT to 13:30 LT on 14 August at Qiyi, although the amount was very small and was not recorded at the AWS. During the show event, we had relatively high Rh and less QSD as shown in Fig.1. A sample of snow water was collected in addition to air samples. After the snow event, a strong northerly wind was observed from 16 LT to 18 LT at both Qiyi and BC (Fig.1).

We observed hail at BC for 10 minutes at about 16:30 LT, but we could not collect a sample because the amount of hail was very small and potential hail samples evaporated fast. In the late evening of 14 August and the next day, we had a very dry atmosphere and cloudless sky (Fig.1).

Mountain-valley winds commonly occur on mountain slopes. Valley of both Qiyi and BC aligns in north-south direction. Therefore, prevailed wind is, roughly speaking, either north (0 or 360 degree) or south (180 degree) as shown in Fig.1. The south of the stations is Tibetan Plateau, while that of north is Gobi desert. A relatively strong north wind from the valley occurred from near noon to near midnight, and then a relatively weak south wind from the mountain occurred until just before noon of the next day.

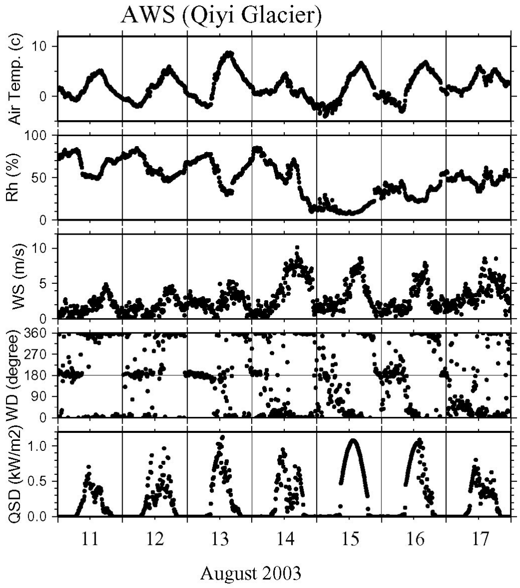

**Fig 1**: Time series of temperature, relative humidity, wind speed and direction, and short wave radiation from 11 to 17 August, 2003 at Qiyi (the terminal of the July-1st Glacier). Dots represent 30 minutes average. Numbers on the abscissa show day in August 2003, and the time at the center of the day is 12 (noon) local time.

### 2.3 Observational method

Figure 2 shows the apparatus for collecting atmospheric samples at Qiyi. The sampling altitude is approximately 1-m and 2-m above the ground at BC and Qiyi, respectively. Air samples were pumped into the Tedlar Bags for 30minutes to obtain mean values for the period. At the same time, the air temperature, relative humidity, and atmospheric pressure were measured, and then we used the measured values to estimate the specific humidity. This estimate was then used to determine the bottle size to bring the air back to Japan for the isotope measurements. We need between 4 and 8 $\mu$L of water in a sample to analyze the $\delta^{18}$O and $\delta$D content. Evacuated glass bottles of sizes 0.6, 1, 1.2, and 1.5L were brought to the field. A sample includes either one or more than two bottles, depending on the specific humidity and the need to have a certain amount of water.

**Fig. 2**: Apparatus for collecting air at Qiyi station. The view is to the north. Only this time, noontime of 15th August, we used two bags/tubes.

### 2.4 Isotope analysis of atmospheric water vapor

Samples were brought to Center for Ecologucal Research, Kyoto University, and then water vapor was extracted with liquid nitrogen in vacuum. Extracted water was equilibrated in a 6mm glass tube with CO2, which was measured for oxygen isotope ratio. Water was then reduced with pre-treated Zn shot. Produced H2 was measured for hydrogen isotope ratio. Isotope analysis was made with MAT252 (Thermoquest, USA, manufactured in Germany). Details on sampling and analysis will be described in elsewhere (Sugimoto et al., in prep).

## 3. Results

Figure 3 shows $\delta^{18}$O, $\delta$D, and d-excess from 11 August to 17 August. Measurements at BC and Qiyi are marked with circles and triangles, respectively. As mentioned in section 2.1, the distance between the two stations is only 4 km even thought the altitude difference is 578 m. Some samples were rejected either because of an accident or because the sample had less than 4 $\mu$L of water. For the latter samples, we plot only the $\delta$D values.

During the observation period, I tried to collect atmospheric water vapor samples in the morning and evening at BC every day. In addition, to understand the diurnal change of the isotopic composition, I made observations every three hours from 13 to 14 August. A trial of collecting mountain wind was made at about noontime on 15 August. Two aluminum bags, were attached to the fence of the AWS (Fig. 2),then one bag collected the atmosphere when a southerly (mountain) wind was observed and another collected when a northerly (valley) wind was observed.

### 3.1 Snow and dry air event

As written in section 2.2, snowfall occurred in the afternoon of 14 August. The $\delta^{18}$O and $\delta$D values of the snow were –4.97‰ and –29.4‰, respectively. They are not shown in Fig. 3 because they are much higher than those of the water vapor. The d-excess (10.4‰) of the snow is marked as a cross in the bottom panel of Fig. 3. Comparison of the d-excesses of the vapor and snow from the same time indicates that the snow is from the same source as the water vapor.

The dotted vertical line in the afternoon of 14 August of Fig. 3 shows the time when a strong northerly wind started blowing. This wind may explain why the evening of the 14th has a lower $\delta$D and higher d-excess compared with those of the previous period. A sample was taken from 19:00 to 19:30 of 14 August, but the water amount was not enough to obtain a reliable $\delta^{18}$O value. For this reason, we do not show the $\delta^{18}$O value in the figure; however, the estimated $\delta^{18}$O value was low (–27.1‰) and d-excess was high (67.8‰). This is consistent with a more reliable sample obtained on 15 August.

As the time series of the meteorological parameters derived from the AWS shown in Fig. 1, after the snowfall in the late evening of 14th, abnormally dry periods occurred when there was a strong northerly wind. Since the snowfall and strong wind seem to pass of a cold front, we will see large-scale atmospheric fields in the next sub-session.

### 3.2 Large-scale atmospheric fields

Figure 4 shows the atmospheric circulation field at 500 hPa from operational objective analysis data of European Centre for Medium-range Weather Forecasts (ECMWF). At 12 UTC (20 LT) of the 14th, there is a deep trough to the north of BC, and very dry air to the west of the trough is heading toward the stations. There is a clear difference in Rh (shown by color in Fig.4) between the two air masses, and we can identify that the trough accompanied a cold front. Figure 5 shows a VIS image at 2 UTC (10 LT) of 15 August. Our site was covered with a very dry air at this time, and we can see cloud system that brought snow event on 14th to the east of the cold front.

Before the trough's arrival, the stations receive moisture from the south. The snow event was dynamically induced by westerly trough, and moisture source is considered to be air mass, which evaporated from the Tibetan Plateau.

A trajectory analysis using the ECMWF data revealed that the dry air came from lowermost stratosphere over the west Siberia (not shown). Since $\delta$D is around –170‰, the air mass with a very low $\delta$D and high d-excess is considered to be mixed with the air of the mid-troposphere before we observed.

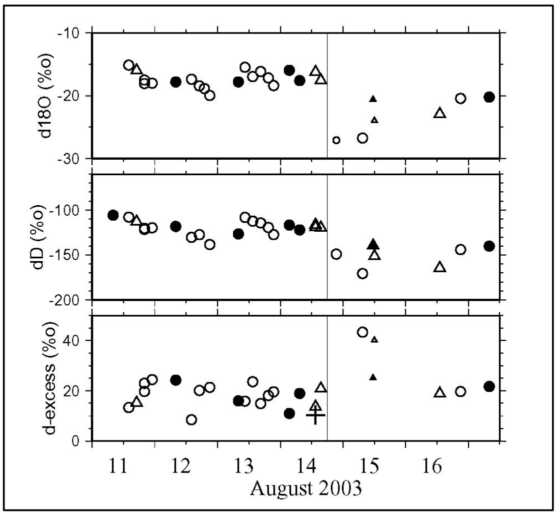

**Fig 3**: Isotopic ratios of the collected water vapor. Upper panel: ratio of the oxygen isotope ($\delta^{18}$O (‰)). Middle panel: ratio of deuterium $\delta$D (‰). Lower panel: d-excess (‰). Open circles mark samples collected at BC during valley winds, closed circles mark samples collected at BC during mountain winds, open triangles mark samples collected at Qiyi during valley winds, and closed triangles mark samples collected at Qiyi during mountain winds. The cross in the lower panel on 14 August marks the d-excess of the observed snow at Qiyi. Long tick marks on the horizontal axis mean 0 LT, whereas short tick marks are 12 LT.

### 3.3 Diurnal variation

We now discuss the diurnal changes of isotopes from noon on the 11th to noon on the 14th, all in August (Fig. 3). Based on the wind measurements (Fig.1), samples obtained when there was primarily mountain wind (valley) are shown as closed (open) circles and triangles. The data shows a diurnal change of isotopic composition, with lower

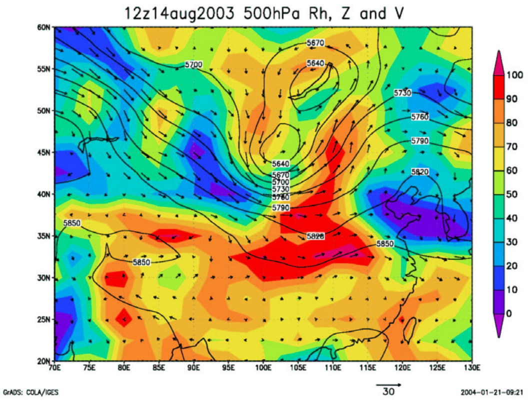

**Fig 4:** Relative humidity Rh, horizontal wind V, and geopotential height Z at 500 hPa at 12 UTC (20 LT) of 14 August.

and lower $\delta^{18}$O and $\delta$D values and higher and higher d-excess values as noon progresses to the late evening. This time period corresponds to the time that a northerly valley wind was observed. Roughly speaking, valleys of both Qiyi and BC align north-south, so that the mountain wind is weakly southerly and valley wind is strong northerly (Fig. 1). Moisture from the southern mountains in the Tibetan Plateau is from southerly winds and that from the desert is from northerly winds.

In general, the isotopic ratio of precipitation has a lower value (lighter water) in the interior of a continent or in higher mountains. However, the relation may be different if there is a large body of water nearby that has much re-evaporation. In our case, since the surface of the eastern Tibetan Plateau is wet and strong re-evaporation can occur, atmospheric moisture over the Tibetan Plateau is thought to be heavier comparing to that over the arid regions in the interior of the Eurasian continent.

Therefore, we speculate that this change was observed because BC is located in a marginal or transition area of the atmosphere, a region where the Tibetan Plateau air mass mixes with air from the arid region to the north. The Tibetan Plateau has heavier $\delta^{18}$O and $\delta$D and lower d-excess whereas the arid region has lighter $\delta^{18}$O and $\delta$D and higher d-excess. The lighter atmosphere from the northern desert comes to BC and gradually mixes with the plateau's atmosphere when the valley wind prevails.

## 3. Conclusion and remarks

- ✧ The stable isotopic ratio of water vapor was measured near July-1st Glacier from 11 to 17 August, 2003. The difference of the isotopic ratio between the two stations (BC and Qiyi, 4km in distance) are small comparing to those variation caused from diurnal cycle and change of the air mass.
- ✧ The largest change of isotopic ratio was found from August 14th to August 15th with passing a cold front, which showed lower $\delta^{18}$O (and $\delta$D) and higher d-excess compared with those of the previous period.
- ✧ The snow event on August 14th was dynamically induced by westerly trough, and moisture source is considered to be air mass, which evaporated from the Tibetan Plateau.
- ✧ A trajectory analysis using ECMWF data suggests that the air mass observed after passing of a cold front came from the lowermost stratosphere or upper troposphere.
- ✧ During August 11th to 13th, we found a diurnal change in the isotopic composition. As the day progressed from noon to late evening, the values of $\delta^{18}$O and $\delta$D became lighter and the values of d-excess became higher. As the air from the northern desert has relatively low $\delta^{18}$O and $\delta$D values and relatively high d-excess values, the valley wind that prevails in afternoon through evening must be bringing air from the northern desert to our site.
- ✧ This case study strongly suggests that analysis of the isotopic ratio of water vapor should be useful to understand the following issues;
  - Continental scale moisture transport,
  - Local circulation,
  - Ice core interpretation,
  - Stratosphere-Troposphere Exchange (STE) with monsoon circulation around the Tibetan Plateau.

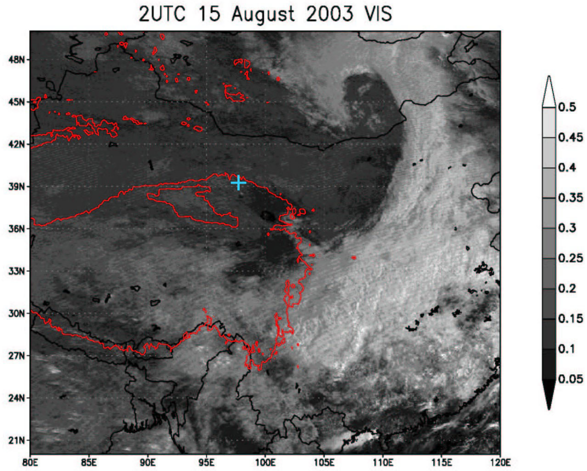

**Fig 5**: A visual image from GOES-9 at 2 UTC of 15 August, 2003. Shade represented in the bar shows albedo. A blue cross indicates of the place of our base camp (BC), which is 4km from the terminal of the July-1st Glacier.

## References

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