Replies to Referee #2
(Referee's statements in black, our response in blue**)**

Re, -Replies.
lines 67-68, -the lines 67-68 in the previous manuscript.
L25-26, -the lines 25-26 in the revision.

Interactive comment on "Simultaneous monitoring of stable oxygen isotope composition in water vapour and precipitation over the central Tibetan Plateau" by W. Yu et al.

Anonymous Referee #2
Received and published: 17 June 2015

The paper presents an interesting dataset of rain water and vapour isotopic composition over two summer raining seasons, with associated statistical analyses. The statistical analysis on the relationship between isotopic compositions and weather conditions (relative humidity, surface pressure, and temperature) may provide useful information to understand the mechanisms controlling moisture isotopes in central Tibetan Plateau. However, the authors seem to slightly mix statistical relationship and the actual physical connection that the relationship may indicate. This weakens the paper. Detailed comments are given in the following.
Re: We thank the Referee very much for constructive comments on our manuscript. Following the Referee's suggestion, we have carefully revised the paper, and have tried to address all the concerns raised by the Referee as follows.

Major comments:
(1) For two time series with autocorrelation, the lag correlation does not necessarily tell the physical connection between the variables at that lag. It can be an artefact from the autocorrelation of the two variables themselves. The dVapor and dPrecip very likely have some autocorrelation. Thus this issue should be considered. Thus the conclusion based on the lag correlation results, such as "the d18O of water vapour affect those of precipitation on only on the same day, but also for the following several days" is problematic.
Re: We thank the Referee for pointing out one significant issue about the "autocorrelation". We have checked the $dVapor_i$ and lagged $dPrecip_{i+1}$ correlation by using partial correlation method (to control the variable of $dVapor_{i+1}$), and found there is no significant correlation between $dVapor_i$ and $dPrecip_{i+1}$. Please see Table R1 as follows. The $dVapor_i$ and lagged $dPrecip_{i+1}$ likely have some autocorrelation.
Following the Referee's comments, we have changed "*The $\delta^{18}O$ of water vapour affect those of precipitation on only on the same day, but also for the following several days*" to "*The $\delta^{18}O$ values of water vapour affect those of precipitation*" throughout the text.
We have softened the claim that the lag effect of $dVapor_i$ on $dPrecip_{i+1}$. That is to say, we have changed the "affect" to "relate" while claiming the lag effect, i.e. changed "*The isotopic composition of water vapour not only affects that of precipitation on the same day, but also affects that of precipitation for several days thereafter*" to "*The isotopic composition of water vapour not*

only relates to that of precipitation on the same day, but also to that of precipitation for several days thereafter". Please see L25-26, L164, L204-205, and L436-437 in the revised text.

However, we think the "autocorrelation" is still likely to have some significance. It may indicate that "*the source vapour for precipitation is predominantly external to the study area in summer monsoon season*" (from the Referee's comments as follows). "*Moreover, not only is water vapor on Day$_{n+4}$ the mass source for precipitation on the same day (Day$_{n+4}$), but water vapor on the previous days (Day$_{n+3}$, ..., and Day$_{n}$) is also the mass source for precipitation on Day$_{n+4}$. Certainly, the influences of water vapor on the previous days upon water vapor on Day$_{n+4}$ will gradually decrease*". We have added the above statements. Please see L171-173, L178-183 in the revised text.

Correlations

Control Variables			dV1	dP2
dV2	dV1	Correlation	1.000	-.110
		Sig. (2-tailed)	.	.325
		df	0	80
	dP2	Correlation	-.110	1.000
		Sig. (2-tailed)	.325	.
		df	80	0

Table R1. The dVapor$_{i}$ and lagged dPrecip$_{i+1}$ correlation by using partial correlation method (to control the variable of dVapor$_{i+1}$).

(2) I suggest perform the lag correlation based on existing understanding of physical processes. It is understood that part of surface water vapour isotopes come from local evapotranspiration, with moisture sources from previous precipitation events. It makes sense to look at the lag correlation between dPrecip and lagged dVapor. The decreasing lag correlation with time indicates the contribution of the event precipitation to evaporation becomes smaller.

Re: We agree with the Referee about the lag correlation between dPrecip and lagged dVapor. Similarly, we have checked the dPrecip$_{i}$ and lagged dVapor$_{i+1}$ correlation by using partial correlation method (to control the variable of dPrecip$_{i+1}$), and found there still is a significant correlation between dPrecip$_{i}$ and lagged dVapor$_{i+1}$. Please see Table R2 as follows. It indicates that "*the isotopic composition of precipitation affects that of water vapour, not only on the same day, but also for the next several days*".

Following the Referee's suggestion, we have added some lines such as "*In addition, part of surface water vapour isotopes comes from local evapotranspiration that was affected by the previous precipitation. The decreasing correlations between the $\delta^{18}O_p$ and lagged $\delta^{18}O_v$ with time indicate that the contribution of the event precipitation to evaporation becomes smaller.*" to further discuss the lag correlation between dPrecip and lagged dVapor. Please see L200-204 in the revised text.

Correlations

Control Variables			dP1	dV2
dP2	dP1	Correlation	1.000	.405
		Sig. (2-tailed)	.	.002
		df	0	52
	dV2	Correlation	.405	1.000
		Sig. (2-tailed)	.002	.
		df	52	0

Table R2. The $dPrecip_{i+1}$ and lagged $dVapor_i$ correlation by using partial correlation method (to control the variable of $dPrecip_{i+1}$).

(3) For the dVapor and lagged dPrecip correlation, it would be good to provide an assumption what physical mechanism may be there. My understanding that the source vapour for precipitation is predominantly external to the study area in summer monsoon season.

Re: We agree with the Referee about the dVapor and lagged dPrecip correlation. Following the Referee's suggestion, we have added "*Our findings indicate that the source vapour for precipitation is predominantly external to the study area in summer monsoon season*" to our paper. In addition, we think "*not only is water vapor on Day_{n+4} the mass source for precipitation on the same day (Day_{n+4}), but water vapor on the previous days (Day_{n+3}, ..., and Day_n) is also the mass source for precipitation on Day_{n+4}. Certainly, the influences of water vapor on the previous days upon water vapor on Day_{n+4} will gradually decrease*". Please see L171-173, L178-183 in the revised text.

(4) Regarding the correlation between vapour (or precip) isotopic composition and micromet variables (e.g., pressure, relative humidity), it would be better to provide more information regarding large scale weather systems. For example, high pressure and low pressure are very likely associated with different weather system and thus different moisture sources. I think this is the most interesting part of this study. This in-depth analysis and discussion would strengthen the manuscript.

Re: We thank the Referee for pointing out another significant issue about the "high/low pressure of large scale weather systems and different moisture sources". The low pressure system over the study region may be related to the Indian monsoon activities, which transported the marine moisture from the Indian Ocean. As a result, the $\delta^{18}O$ values of water vapour and precipitation are low. The corresponding precipitation amount is high. In contrast, the high pressure system may be related to the westerlies and continental circulation. Hence, the $\delta^{18}O$ values of water vapour and of precipitation are high. The corresponding precipitation amount is low. Following the Referee's suggestion, we have added a figure and some lines to demonstrate them. Please see the new Figure 4 and L269-283 in the revised text.

(5) In the results and discussion section, the generally known relationships and the specific ones resulted from this study are mixed. It is difficult to read. I suggest separate them. First present your results, and tell clearly what these results tell us, and then compare to other studies.

Re: Following the Referee's suggestion, we have divided the Section 3 -- "Results and discussion" into two sections: one is "Results", and another is "Discussion". We have moved some lines about our results, such as the correlation between $\delta^{18}O_v$ and $\delta^{18}O_p$, and the enrichment of $\delta^{18}O_p$ relative to $\delta^{18}O_v$ into the Section 3. Please see L143-156 in the revised text.

Minor comments:

The two zero-lag correlations in Table 1 and Table 2 are different. Why?

Re: Yes, they are different, because the precipitation events may not occur each day. That is to say, there are some days have no dPrecip values. As a result, the sample numbers (n) for calculating the correlations may be different. Please see the "*n*" in the Table 1 and Table 2.

To further make clear this issue, we have listed two tables (as follows, just two examples) to show the sample numbers for the lag correlations of dVapor and lagged dPrecip (Table R3), and of dPrecip and lagged dVapor (Table R4). It is easy to find that the sample numbers on Day_{i+2} are different.

Day_i	$dVapor_i$	$dPrecip_i$	Day_{i+1}	$dPrecip_{i+1}$	Day_{i+2}	$dPrecip_{i+2}$
2004-8-23	-30.5527	-20.0518	2004-8-24	-16.3748	2004-8-25	
2004-8-24	-27.4408	-16.3748	2004-8-25		2004-8-26	-15.8188
2004-8-25	-26.7013		2004-8-26	-15.8188	2004-8-27	
2004-8-26	-28.8325	-15.8188	2004-8-27		2004-8-28	
2004-8-27	-25.6197		2004-8-28		2004-8-29	-13.2175
2004-8-28	-25.4213		2004-8-29	-13.2175	2004-8-30	-13.2494
2004-8-29	-22.9129	-13.2175	2004-8-30	-13.2494	2004-8-31	
2004-8-30	-23.8581	-13.2494	2004-8-31		2004-9-1	-12.8683
2004-8-31	-25.0799		2004-9-1	-12.8683		
2004-9-1	-26.6846	-12.8683				
n		6		5		4

Table R3. The sample numbers for the lag correlations of dVapor and lagged dPrecip.

Day_i	$dPrecip_i$	$dVapor_i$	Day_{i+1}	$dVapor_{i+1}$	Day_{i+2}	$dVapor_{i+2}$
2004-8-23	-20.0518	-30.5527	2004-8-24	-27.4408	2004-8-25	-26.7013
2004-8-24	-16.3748	-27.4408	2004-8-25	-26.7013	2004-8-26	-28.8325
2004-8-25		-26.7013	2004-8-26	-28.8325	2004-8-27	-25.6197
2004-8-26	-15.8188	-28.8325	2004-8-27	-25.6197	2004-8-28	-25.4213
2004-8-27		-25.6197	2004-8-28	-25.4213	2004-8-29	-22.9129
2004-8-28		-25.4213	2004-8-29	-22.9129	2004-8-30	-23.8581
2004-8-29	-13.2175	-22.9129	2004-8-30	-23.8581	2004-8-31	-25.0799
2004-8-30	-13.2494	-23.8581	2004-8-31	-25.0799	2004-9-1	-26.6846
2004-8-31		-25.0799	2004-9-1	-26.6846		
2004-9-1	-12.8683	-26.6846				
n		6		5		5

Table R4. The sample numbers for the lag correlations of dPrecip and lagged dVapor.

Some paragraphs (1st paragraph in section 3.2) are too long. It is difficult to compare regression results when they are buried in the text. I suggest to summarize them all in a table.
Re: Following the Referee's suggestion, we have added a new table to summarize some regression results. Please see Table 3 in L727 in the revised text. In addition, we have divided 1st paragraph in the original section 3.2 into some more small paragraphs. Please see L237-238, L267-268, and L283-284 in the revised text.

English needs to be substantially improved.
Re: We thank the Referee for pointing out the issue. We have asked a native English speaker to clear up the problems throughout the text once more.

Some examples are given here
14447-5: fractionation processes that : : : by different moisture sources
Re: We have changed "*Variations of δ^{18}O result from fractionation processes that may be influenced by temperature, rainout, amount effects, and different moisture sources (Dansgaard, 1964; Jouzel and Merlivat, 1984; Rozanski et al., 1992)*" to
"*Variations of δ^{18}O result from different isotope fractionation processes that may be influenced by temperature, humidity, and vapor pressure (Dansgaard, 1964; Jouzel and Merlivat, 1984; Rozanski et al., 1992), and from different moisture sources (Breitenbach et al, 2010; Pang et al., 2014)*"
Please see L48-52 in the revised text.

14447-23: the interaction of : : :. Values
Re: Following the Referee's suggestion, we have changed it to "the interaction of δ^{18}O from water vapour and precipitation". Please see L68 in the revised text.

14448-4: understanding different moisture sources (for what?)
Re: To be helpful for describing moisture circulation and evaluating water resources. We have added this statement in the revised text in L79-80.

14448-9: interaction between : : : values
Re: By following the Referee's comments, we have changed the statement to "the interaction between δ^{18}O from water vapour and from precipitation". Please see L85-86 in the revised text.

-19: included, perhaps rephrased as 'accounted for'.
Re: We have changed "included" by "accounted for". Please see L95-96 in the revised text.

14449-2: rephrase 'faithfully'
Re: Following the Referee's suggestion, we have changed "faithfully" by "precisely". Please see L105 in the revised text.

-6: It is not clear what "duplicate analyses" are about. If they are about measuring water isotopic composition on duplicate samples, how does this confirm minimize the fractionation during the trapping process.

Re: We have no duplicate samples, for only one sample can be collected by our cryogenic coolers each day. There are some repeated statements in this section. We have deleted the statement about “duplicate analyses”. Please see L109 in the revised test.

-15: sealing should be sealed.

Re: Following the Referee’s suggestion, we have changed it to “sealed”. Please see L117 in the revised text.

14452-9: should ‘lower’ be ‘higher’?

Re: Thanks for pointing this out. Yes, “lower” should be “higher”. We have corrected it. Please see L211 in the revised text.

Simultaneous monitoring of stable oxygen isotope composition in water vapour and precipitation over the central Tibetan Plateau

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Abstract. This study investigated daily $\delta^{18}O$ variations of water vapour ($\delta^{18}O_v$) and precipitation ($\delta^{18}O_p$) simultaneously at Nagqu on the central Tibetan Plateau for the first time. Data show that the $\delta^{18}O$ tendencies of water vapour coincide strongly with those of associated precipitation. The $\delta^{18}O$ values of water vapour affect those of precipitation. In turn, the $\delta^{18}O$ values of precipitation also affect those of water vapour. Hence, an interaction exists between $\delta^{18}O_v$ and $\delta^{18}O_p$. During the entire sampling period, the variations of $\delta^{18}O_v$ and $\delta^{18}O_p$ at Nagqu did not appear dependent on temperature, but did seem significantly dependent on the joint contributions of relative humidity, pressure, and precipitation amount. In addition, the $\delta^{18}O$ changes in water vapour and precipitation can be used to diagnose different atmospheric trajectories, especially the influences of the Indian monsoon and convection. Moreover, intense activities of the Indian monsoon and convection may cause the enrichment of $\delta^{18}O_p$ relative to $\delta^{18}O_v$ at Nagqu (on the central Tibetan Plateau) to differ from that at other stations on the northern Tibetan Plateau. These results indicate that the effects of different moisture sources, including the Indian monsoon and convection currents, need be considered when attempting to interpret paleoclimatic records on the central Tibetan Plateau.

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1 Introduction

The Tibetan Plateau is a natural laboratory for studying the influences of different moisture sources, which include polar air masses from the Arctic, continental air masses from central Asia, and maritime air masses from the Indian and Pacific Oceans

(Bryson, 1986), and for reconstructing paleoclimate variations (An et al., 2001). The stable oxygen isotope (δ^{18}O) provides an important tracer for understanding atmospheric moisture cycling, especially by using the δ^{18}O records in all three phases of water (Dansgaard, 1964; Lee et al., 2005). Oxygen isotopes also act as important indicators for reconstructing paleoclimates by using their records preserved in ice cores (Thompson et al., 2000), speleothems (Cai et al., 2010), tree rings (Treydte et al., 2006; Liu et al., 2014), and lake sediments (Zech et al., 2014). Variations of δ^{18}O result from different isotope fractionation processes that may be influenced by temperature, humidity, and vapor pressure (Dansgaard, 1964; Jouzel and Merlivat, 1984; Rozanski et al., 1992), and from different moisture sources (Breitenbach et al, 2010; Pang et al., 2014).

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To better understand atmospheric moisture transport to the Tibetan Plateau and surrounding regions, the Chinese Academy of Sciences (CAS) established an observation network in 1991 to continually survey δ^{18}O variations in precipitation on the plateau (the Tibetan Plateau Network of Isotopes in Precipitation, TNIP) (Tian et al., 2001; Yu et al., 2008; Yao et al., 2013). Previous studies have shown that δ^{18}O variations in precipitation on the southern Tibetan Plateau differ distinctly from those on the northern Tibetan Plateau (Tian et al., 2003; Yu et al., 2008; Yao et al., 2013). In addition, many scientists have investigated the roles of various climatic factors, especially the Asian monsoon's influence on δ^{18}O in precipitation (Aizen et al., 1996; Araguás-Araguás et al., 1998; Posmentier et al., 2004; Vuille et al., 2005; Liu et al., 2014; Yu et al., 2014a). Recent studies have also investigated δ^{18}O in river water

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(Bershaw et al., 2012), lake water (Yuan et al., 2011), and plant water (Zhao et al., 2011; Yu et al., 2014b). In comparison, only a few studies have focused on $\delta^{18}O$ from water vapour over the Tibetan Plateau (Yatagai et al., 2004; Yu et al., 2005; Kurita et al., 2008; Yin et al., 2008). Moreover, a gap exists in the studies regarding the interaction of $\delta^{18}O$ from water vapour and from precipitation, and on the $\delta^{18}O$ enrichment between water vapour and precipitation over the Tibetan Plateau (In this study, the "enrichment" was defined as the difference of the $\delta^{18}O$ values of precipitation ($\delta^{18}O_p$) and vapour ($\delta^{18}O_v$), $\Delta\delta^{18}O = \delta^{18}O_p - \delta^{18}O_v$). An improved understanding of $\delta^{18}O$ as tracers of water movement in the atmosphere and as indicators of climate change requires detailed knowledge of the isotopic compositions in all three phases of water (Lee et al., 2005). In contrast to liquid or solid precipitation, measurements of $\delta^{18}O$ in water vapour can be taken across different seasons and synoptic situations, and are not limited to rainy days (Angert et al., 2008). Hence, $\delta^{18}O$ in water vapour has become an important topic in the fields of paleoclimatology, hydrology (Iannone et al., 2010), and ecology (Lai et al., 2006), especially for understanding different moisture sources in order to describe different patterns of circulation and to evaluate water resources.

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With this background, we launched a project in the summers of 2004 and 2005 to collect simultaneous water vapour and precipitation samples at Nagqu (31° 29' N, 92° 04' E, 4508 m a.s.l.) on the central Tibetan Plateau (the first such study), despite the difficultly of collecting water vapour samples at this high elevation. Based on the $\delta^{18}O$ data sets from these samples, this paper discusses the interaction between $\delta^{18}O$ from

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water vapour and from precipitation, considers the effects of various meteorological parameters on the $\delta^{18}O$ of water vapour and precipitation, and attempts to explain the relationships between the isotopic compositions of samples and atmospheric trajectories.

2 Sampling sites, materials, and methods

The Nagqu station lies in the middle of a short grass prairie, in a sub-frigid, semi-humid climate zone between the Tanggula and Nyainqentanglha Mountains (Fig. 1). The annual average temperature at this station was recorded as -2 ºC, with an annual mean relative humidity of 50%, and average annual precipitation of 420 mm. Most of the rainfall at this site occurred during May through August and accounted for about 77% of the annual precipitation.

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This study collected water vapour samples at Nagqu during the periods of August–October, 2004 and July–September, 2005. Based on an earlier study, if the condensation temperature falls below -70 ^{o}C, the sampling method diminishes the correction factor (-0.07‰) to below the typical error value quoted for ^{18}O analyses by modern mass spectrometers (Schoch-Fischer et al., 1984). Our study extracted water vapour cryogenically from the air, by pumping it slowly through a glass trap immersed in ethanol, which was continuously maintained at a temperature as low as -70 °C with a set of electric cryogenic coolers driven by a compressor (Yu et al., 2005). Thus the captured water vapour should precisely reflect the water vapour in the atmosphere and minimize fractionation during the sampling. Moreover, the cold trap

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was made in a linked-ball shape to increase the surface area for condensation (Hübner et al., 1979), and to ensure complete removal of all the water vapour, in order to avoid isotope fractionation during sampling (Gat et al., 2003). In addition, the validity of the cold trap operation was rechecked by connecting an extra glass trap to the outlet of the original trap. No visible condensed vapour was found within, reconfirming the validity of the water vapour sampling method. A flow meter controlled the air flow rate. For about 24 h, air was drawn at a rate of about 5 L min^{-1} (Gat et al., 2003) through a plastic tube attached to the rooftop of the Nagqu station (the height of the roof is about 6 m). At the end of each sampling, the two ends of the cold trap were sealed, and the samples melted at room temperature. Water was mixed across the trap before decanting it into a small vial and sealed. One sample of about 10 ml was collected each day. In addition, rainfall from each precipitation event at the Nagqu Meteorological Station (close to the vapour sampling site) was collected immediately and sealed in clean and dry plastic bottles. A total of 153 water vapour samples and 90 precipitation samples were collected. All the samples were stored below -15 ^{o}C until analysed. During the sampling period, some meteorological parameters, such as temperature at 1.5 m, temperature near ground, relative humidity, surface pressure, and precipitation amount were recorded.

The Key Laboratory of Tibetan Environment Changes and Land Surface Processes, Institute of Tibetan Plateau Research (Chinese Academy of Sciences, Beijing) performed the measurements of the oxygen isotopic compositions of all samples, using a MAT-253 mass spectrometer, with a precision of 0.2 parts per mil (‰) for the

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oxygen isotope ratios ($\delta^{18}O$). The H_2O-CO_2 isotopic exchange equilibration method was adopted for the oxygen isotope ratios ($\delta^{18}O$) measurements. This study expresses the measured oxygen isotope ratios ($\delta^{18}O$) as parts per mil (‰) of their deviations, relative to the Vienna Standard Mean Ocean Water (VSMOW). Unfortunately, deuterium data at Nagqu were not available for this project.

To identify the moisture transport paths and interpret $\delta^{18}O$ variability further in the time series, our study determined 120 h back trajectories for air parcels during the entire sampling period, using the NOAA HYSPLIT model (Draxler and Rolph, 1998) and NCEP reanalysis data sets (available at: ftp://arlftp.arlhq.noaa.gov/pub/archives/reanalysis). The origin of air masses as diagnosed from the back trajectory analysis appears to approximate the moisture source direction for the water vapour and for the precipitation at the study site (Guan et al., 2013). The trajectories originated at 1000, 2000, and 3000 m above ground level (a.g.l.), respectively.

3 Results

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Figure 2 displays the temporal changes of $\delta^{18}O$ in water vapour ($\delta^{18}O_v$) and in precipitation ($\delta^{18}O_p$) at Nagqu. Clearly, the trends of $\delta^{18}O_v$ closely approximate those of $\delta^{18}O_p$ (Fig. 2a and b). A strong positive relationship existed between $\delta^{18}O_v$ and $\delta^{18}O_p$ during the entire sampling period of 2004–2005 ($\delta^{18}O_v = 0.72\delta^{18}O_p - 14.43$, $r = 0.81$, $n = 86$, $p < 0.01$) (Fig. 2c). Moreover, the positive correlations between $\delta^{18}O_v$ and $\delta^{18}O_p$, whether in 2004 ($\delta^{18}O_v = 0.73\delta^{18}O_p - 14.39$, $r = 0.81$, $n = 42$, $p < 0.01$), or in 2005 ($\delta^{18}O_v = 0.71\delta^{18}O_p - 14.85$, $r = 0.78$, $n = 44$, $p < 0.01$), show similarities (Fig.

2c).

Compared with the $\delta^{18}O_v$ values, the $\delta^{18}O_p$ values experienced significant enrichment at Nagqu in 2004 and 2005. Furthermore, the enrichment of $\delta^{18}O_p$ relative to $\delta^{18}O_v$ ($\Delta\delta^{18}O = \delta^{18}O_p - \delta^{18}O_v$) in 2004 (8.2‰) was similar to that in 2005 (8.2‰), even though the sampling period in 2004 differed from that in 2005. The average enrichment at Nagqu in 2004–2005 was 8.2‰.

4 Discussion

4.1 Interaction and enrichment between $\delta^{18}O$ of water vapour and precipitation

The condensation of water vapour results in the observed precipitation. Hence, water vapour plays a key role in all precipitation events. As a result, the isotopic composition of water vapour has a direct effect on that of precipitation. Similar close relationships between $\delta^{18}O_v$ and $\delta^{18}O_p$ also exist at Heidelberg (Jacob and Sonntag, 1991) and at Ankara (Dirican et al., 2005). The isotopic composition of water vapour not only relates to that of precipitation on the same day, but also to that of precipitation for several days thereafter. As shown in Table 1, the isotopic composition of water vapour correlated positively with that of precipitation over the following three days, with correlation coefficients of 0.48, 0.45, and 0.33 (within a 0.01 confidence limit), respectively. Nevertheless, the correlation coefficients decreased gradually with time. In particular, the correlation coefficient for the fourth day decreased to as low as 0.28, and only within a 0.05 confidence limit (Table 1). In addition, the slope decreased gradually from 0.90 to 0.31 over five days (Table 1). We

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acknowledge that the $\delta^{18}O_v$ and lagged $\delta^{18}O_p$ likely have some autocorrelations. However, the "autocorrelation" is still likely to have some significance. Because water vapour provided the primary moisture source for the precipitation, these isotopic exchanges had an effect on the vapour with which the raindrop equilibrates (Angert et al., 2008). During the rain event, water vapour rapidly interacts with raindrops and tends to move toward isotopic equilibrium (Deshpande et al., 2010). Our findings indicate that the source vapour for precipitation is predominantly external to the study area in summer monsoon season. Moreover, not only is water vapor on Day_{n+4} the mass source for precipitation on the same day (Day_{n+4}), but water vapor on the previous days (Day_{n+3}, ..., and Day_n) is also the mass source for precipitation on Day_{n+4}. Certainly, the influences of water vapor on the previous days upon water vapor on Day_{n+4} will gradually decrease. Thus, these exchanges were particularly significant at the same day, but gradually weakened over the four days after the initial rainfall event. On the other hand, precipitation influences water vapour at the local scale. As the raindrop falls, the content of the raindrop contributes to the ambient water vapour, due to the re-evaporation effect. As a result, the isotopic composition of raindrops also contributes to that of the ambient water vapour. Even as the raindrops fall, the isotopic composition of the residual water vapour changes because of a "rainout effect". Consequently, the isotopic composition of precipitation has a feedback effect on the isotopic composition of water vapour. We show that the isotopic composition of precipitation affects that of water vapour, not only on the same day, but also for the next four days, resulting in correlation coefficients of 0.69,

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0.64, 0.59, and 0.41 (within a 0.01 confidence limit), respectively (Table 2). Clearly, the correlation coefficients and the slopes also decrease gradually over time, with the correlation coefficient for the fifth day decreasing even further (as low as 0.35) and correlated only within a 0.05 confidence limit (Table 2). Correspondingly, the slopes decreased gradually from 0.72 to 0.34. This may partly be the result of surface water evaporation from recent precipitation contributing to the isotopic composition of the local water vapour in the days following the rainfall event. In addition, part of surface water vapour isotopes comes from local evapotranspiration that was affected by the previous precipitation. The decreasing correlations between the $\delta^{18}O_p$ and lagged $\delta^{18}O_v$ with time indicate that the contribution of the event precipitation to evaporation becomes smaller. Apparently, an interaction exists between $\delta^{18}O$ from water vapour and precipitation. Pfahl et al. (2012) also found that microphysical interactions between rain drops and water vapour beneath the cloud base exist by using $COSMO_{iso}$ model.

As reported above, the average enrichment of $\delta^{18}O_p$ relative to $\delta^{18}O_v$ in our study was 8.2‰. In comparison, the average enrichment of $\delta^{18}O_p$ relative to $\delta^{18}O_v$ at the Delingha station (37°22' N, 97°22' E, 2981 m; see Fig. 1) on the northern Tibetan Plateau ($\Delta\delta^{18}O$ = 10.7‰) (Yin et al., 2008) was higher. This is because Indian monsoon and convection activities at Nagqu are more intense when compared with those at Delingha. Due to the combined impact of these activities, the summer $\delta^{18}O_p$ values at Nagqu were more depleted than those at Delingha (Yu et al., 2008). As a consequence, the $\Delta\delta^{18}O$ value at Nagqu fell below that at Delingha. Further south, the

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enrichment of $\delta^{18}O_p$ relative to $\delta^{18}O_v$ at the Bay of Bengal (Fig. 1) was 8.6‰ (Midhun et al., 2013), similar to that at Nagqu. While the Indian monsoon at the Bay of Bengal exceeds the intensity of that at Nagqu, the oceanic moisture does not rise to the same degree as at Nagqu. We note that the enrichment of $\delta^{18}O_p$ relative to $\delta^{18}O_v$ at the Nagqu station differs from that at the northern station (Delingha), but resembles that of the southern station (Bay of Bengal), apparently because of its unique location, which is affected by both the Indian monsoon and convection. The next section discusses the influences of those activities on water vapour/precipitation $\delta^{18}O$ changes in detail.

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4.2 The effects of meteorological and environmental factors on $\delta^{18}O$ of water vapour and precipitation

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A number of meteorological parameters affect the $\delta^{18}O$ variations of water vapour and precipitation. In particular, different processes dominate the relative humidity variations in different regions, resulting in different isotope ratios in the water vapour (Noone, 2012). The data from Palisades (USA) show that stable isotopic compositions of water vapour correlate positively with relative humidity (White et al., 1984). Wen at al. (2010) also found a positive correlation between water vapour $\delta^{18}O$ and relative humidity at Beijing (China). At a North Greenland site, both diurnal and intra-seasonal variations show strong correlations between changes in local surface humidity and water vapour isotopic composition (Steen-Larsen et al., 2013). In addition, water vapour $\delta^{18}O$ trends from the Bermuda Islands (North Atlantic) also resemble those of relative humidity (Steen-Larsen et al., 2014).

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Interestingly, the tendencies of $\delta^{18}O_v$ and $\delta^{18}O_p$ in our study oppose those of relative humidity (Fig. 3). Hence, at Nagqu the $\delta^{18}O$ values of water vapour and precipitation correlate negatively with relative humidity (RH) (Table 3). Moreover, the tendencies of $\delta^{18}O_v$ and $\delta^{18}O_p$ in our study clearly differed from those of surface temperature at 1.5 m or ground temperature at 0 m during the entire sampling period (Fig. 3). No positive correlation was found between the $\delta^{18}O$ values and temperature. Thus, the changes in the $\delta^{18}O$ values of water vapour and precipitation did not depend on changes in temperature, and did not experience a “temperature effect”. However, on the northern Tibetan Plateau, the $\delta^{18}O$ composition of water vapour and precipitation correlated positively with temperature (Yin et al., 2008). A positive correlation between the isotope record of water vapour and temperature (T) was also found at Heidelberg (Germany), western Siberia, southern Greenland, and Minnesota (USA) (respectively, Schoch-Fischer et al., 1984; Bastrikov et al., 2014; Bonne et al., 2014; Welp et al., 2008). Clearly, the relationships between $\delta^{18}O$ – T and $\delta^{18}O$ – RH at our station differ from those at other stations. This and the $\delta^{18}O$ depletion during the summer monsoon period (Fig. 3a and f) may reflect the influences of the Indian monsoon (Yu et al., 2008) and increasing convection (Tremoy et al., 2012). Due to an uplift effect of the massive mountains (such as the Himalayas), warm oceanic moisture transported by the Indian monsoon from the Indian Ocean onto the Tibetan Plateau rises to very high elevations, where very low temperatures prevail (Tian et al., 2003; Yu et al., 2008). This rise results in more depleted $\delta^{18}O$ values recorded in summertime water vapour and precipitation at Nagqu. Moreover, the intense

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convection raises the oceanic moisture to higher elevations. Hence, the convection effect for the oceanic moisture increases the more depleted $\delta^{18}O$ in water vapour and precipitation in our study region (Yu et al., 2008). However, during the monsoon period, the corresponding surface air temperature and the summer rainfall greatly exceed those during the pre-monsoon and post-monsoon periods (Fig. 3). Accordingly, an inverse correlation exists between $\delta^{18}O$ in water vapour/precipitation and surface air temperatures and rainfall, respectively, indicating the lack of a "temperature effect" on $\delta^{18}O$ in water vapour/precipitation in this study region (Table 3).

Furthermore, the $\delta^{18}O$ trends coincide with surface pressure (Psfc) during the entire sampling period (Table 3). In particular, different pressures at a large spatial scale are associated with different weather systems and thus different moisture sources. For example, the low geopotential height at 500 hPa on 6 August 2005 over the Nagqu station indicated that a low pressure system prevailed in the study region. However, a high pressure system was posed over the Bay of Bengal and the Arabian Sea (Fig. 4a). The marine moisture was transported to the Tibetan Plateau by the Indian monsoon. As a result, the $\delta^{18}O$ values of water vapour and precipitation are as low as -32.1‰ and -21.7‰, respectively (Fig. 2b). The corresponding precipitation amount was as high as 25.9 mm (Fig. 2b). In contrast, a high geopotential height at 500 hPa was observed on 5 September 2005 over Nagqu. This indicates that the study region was controlled by the high pressure system and the coastal regions were dominated by a low pressure system, which relates to the westerlies and continental circulation (Fig. 4b). Hence, the $\delta^{18}O$ values of water vapour and precipitation are as high as -17.5‰

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and -10.4‰, respectively (Fig. 2b). The corresponding precipitation amount is only 0.4 mm (Fig. 2b).

High precipitation amounts correspond to depleted isotope compositions of water vapour and precipitation, and low precipitation amounts correspond to enriched isotope compositions (Fig. 3). Specifically, the isotope compositions of precipitation exhibit greater enrichment when there has been no rainfall (P [precipitation amount] = 0) (Fig. 3a, f, e and j). This demonstrates that precipitation amount also affects the $\delta^{18}O$ variations of water vapour and precipitation at Nagqu. During precipitation events, the water vapour generally maintains a state of equilibrium with falling raindrops (Lee et al., 2006). During heavy precipitation events, the isotope ratios of water vapour and condensate decrease as saturated air rises, because of continued fractionation during condensation (Gedzelman and Lawrence, 1982), and the $\delta^{18}O$ values of precipitation tend to become more depleted (Fig. 3a and f). Correspondingly, heavily depleted $\delta^{18}O$ values of residual water vapour occur, due to the rainout effect. During periods without precipitation, water vapour deviates far from saturation, i.e., it may exhibit low relative humidity. In these circumstances, the $\delta^{18}O$ values of water vapour become highly enriched (Fig. 3a and f). Okazaki et al. (2015) also found that the main driver of the more depleted $\delta^{18}O_v$ from Niamey was a larger amount of precipitation at the Guinea coast.

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To further reveal the relationships between the $\delta^{18}O$ values and various meteorological parameters, our study modeled $\delta^{18}O$ as a function of temperature, relative humidity, surface pressure, and precipitation amount, using a simple multiple regression model. Using a *stepwise* method and based on the output of this model, the variable of temperature was excluded. The function can be expressed as:

$\delta^{18}O_v = -502.80 - 0.11\ RH + 0.82\ Psfc - 0.28\ P$ (p for RH, Psfc, and P is 0.001, 0.000, 0.000, respectively; $F = 28.276$, $F_\alpha = 5.709$, $F > F_\alpha$, $\alpha = 0.001$) (1)

$\delta^{18}O_p = -580.66 - 0.18\ RH + 0.98\ Psfc - 0.26\ P$ (p for RH, Psfc, and P is 0.022, 0.001, 0.002, respectively; $F = 15.249$, $F_\alpha = 5.932$, $F > F_\alpha$, $\alpha = 0.001$) (2)

The multiple correlation coefficients (R) between all of the independent variables (relative humidity, surface pressure, and precipitation amount) and the dependent variables ($\delta^{18}O_v$ and $\delta^{18}O_p$) are 0.60 and 0.56; and the F-statistics are significant at the 0.001 and 0.001 levels, respectively. In brief, the $\delta^{18}O$ changes in water vapour and precipitation at Nagqu relate closely to the joint contributions of relative humidity, pressure, and precipitation amount.

In addition, land surface characteristics and processes such as evaporation and transpiration may also have affected the isotopic ratios of water vapour. During dry periods, the land surface dries due to evapotranspiration, and the moisture in soil and grass (characterized by relatively enriched isotopic values) evaporates into the atmosphere. Therefore, the isotopic ratio of water vapour becomes relatively enriched (Fig. 3a and f). That is why the isotope compositions of water vapour become more enriched during days with no rainfall, compared to during days with rainfall. During heavy rain events, however, local evapotranspiration is extremely weak (Huang and Wen, 2014), because clouds and precipitation cool the surface and moisten the boundary layer, leading to high relative humidities (Fig. 3c and h) (Aemisegger et al.,

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2014). Therefore, effects of local evapotranspiration on the changes in water vapour $\delta^{18}O$ can be ignored during such rainy periods, and the corresponding $\delta^{18}O$ values in water vapour become more depleted (Fig. 3a and f). On cessation of the rain, clouds clear, the ground heats up again, and relative humidity decreases, partly due to warming, partly due to reduced humidity (Aemisegger et al., 2014). In this case, local evapotranspiration will contribute to changes in water vapour $\delta^{18}O$, which will quickly return to relatively enriched values (Fig. 3a and f) (Deshpande et al., 2010). Another short-term study by Kurita et al. (2008), undertaken not far from this study area, also demonstrated that water vapour increased gradually, accompanied by an increased contribution of evapo-transpired water that had relatively enriched isotopic values.

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4.3 $\delta^{18}O$ changes in water vapour and precipitation related to different atmospheric trajectories

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Synoptic weather circulation (especially atmospheric trajectories) strongly affects the variations of stable isotopic compositions of water vapour and precipitation (Strong et al., 2007; Pfahl and Wernli, 2008; Deshpande et al., 2010; Guan et al., 2013). This study used the NOAA HYSPLIT model to calculate 120 h back trajectories of air parcels for each day of the entire sampling period. Figure 5 shows a subset of the results of the atmospheric trajectories. The results of 12 July, 6 August, 26 August, and 5 September 2005, represent the weak monsoon, the active monsoon, the late monsoon, and the post-monsoon period conditions, respectively. During the weak monsoon period, moisture over Nagqu at 1000 m a.g.l. appears to derive

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predominantly from the coastal regions of Bengal in the south, which might have been transported earlier by the Indian monsoon and lingered there. In this way, the coastal regions of Bengal act as a moisture reservoir during the weak monsoon period. Clearly, moisture from 2000 m and 3000 m a.g.l. recycles from the westerlies (which are associated with enriched surface waters that re-evaporate and with evaporated surface water under lower humidity conditions), and this contributes to the moisture over Nagqu during the weak monsoon period (Fig. 5a). Therefore, $\delta^{18}O_v$ and $\delta^{18}O_p$ values show relative enrichment (such as -17.8‰ and -14.7‰ observed on 12 July 2005) (Fig. 2b).

Compared to the weak monsoon period (Fig. 5a), the contribution of moisture from the westerlies and regional circulation decreased during the active monsoon period (Fig. 5b) (the specific humidity fells to 2 g/kg over Nagqu). Due to the dominant Indian monsoon circulation during this period, most moisture at the 1000 m a.g.l. of the trajectories came from this direction. As a result, specific humidity over Nagqu from this pathway increased to 7 g/kg (Fig. 5b). In addition, the trajectories of the 2000 m a.g.l. airflow came from the southern slope of the Himalayas (Fig. 5b). The moisture from both of those two paths was uplifted by the high mountains. Moreover, convection over the Tibetan Plateau often occurs in the region between the two major east-west mountain ranges, the Nyainqentanglha Mountains and the northern Himalayas (Fujinami et al., 2005). As mentioned above, intense convection over the Tibetan Plateau, combined with uplift caused by the high mountains, causes oceanic moisture to rise to very high elevations. Obviously, convection of marine and

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continental air masses not only causes isotopic variations of water vapour (Farlin et al., 2013), but also significantly affects the isotopic composition of the precipitation (Risi et al., 2008). In particular, the time period when convection significantly affects the isotopic composition of precipitation relates to the residence time of water within atmospheric reservoirs (Risi et al., 2008). Hence, an interaction exists between the isotopic composition of water vapour and precipitation. This results in more depleted $\delta^{18}O$ values of water vapour and precipitation at Nagqu, such as -32.1‰ and -21.7‰ on 6 August 2005 (Fig. 2b). The corresponding maximum precipitation amount of 25.9 mm over Nagqu was observed during this sampling period in 2005 (Fig. 3j). Purushothaman et al. (2014) also reported the highly depleted nature of water vapour at Roorkee (northern India) during rainy periods, due to the intense Indian monsoon.

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Although moisture over Nagqu that derived from the Bay of Bengal decreased during the late monsoon period, some of the trajectories continued to originate in the coastal regions. Figure 5c details one selected event on 26 August 2005, during which the trajectories came from the coastal regions of western India (near the Arabian Sea). The specific humidity over Nagqu from those pathways decreased to 2-6 g/kg, compared with those during the active monsoon period. Moisture from those paths was uplifted by the high mountains, via the Indian continent, and also contributed to the relatively depleted $\delta^{18}O$ values of water vapour and precipitation (-32.6‰, -25.0‰) (Fig. 2b).

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Trajectories after the rainy season (such as 5 September 2005, accompanying the Indian monsoon retreat) show that all the moisture had been recycled from the

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continent (Purushothaman et al., 2014): (1) moisture from the regional circulation dominated the moisture sources in the study area, and (2) moisture from the westerlies also affected the Nagqu region (Fig. 5d). During this period, no contributions from the Bay of Bengal or the coastal regions of Bengal/western India appeared to have significantly enriched $\delta^{18}O$ values of water vapour (such as -17.5‰ on 5 September 2005) (Fig. 2b). During the dry season, specific humidity over Nagqu from those pathways decreased below 3 g/kg, and isotopic re-equilibration of rain droplets with surrounding water vapour appear to have affected the $\delta^{18}O$ variations of precipitation (Sturm et al., 2007). Consequently, the $\delta^{18}O$ values of precipitation increased rapidly during the post-monsoon period (to -10.4‰) (Fig. 2b).

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In summary, during the summer period, moisture over the Nagqu region of the central Tibetan Plateau originates primarily from the southern portion of the Tibetan Plateau, as well as the southern slope of the Himalayas, the coastal regions of Bengal/western India, and the Bay of Bengal, all strongly influenced by the Indian monsoon and convection. In contrast, convection on the northern Tibetan Plateau is weaker than that on the central Tibetan Plateau, and the westerlies prevail on the northern Tibetan Plateau, almost without any influence of the Indian monsoon (Tian et al., 2003; Yu et al., 2008). Different moisture sources cause different effects on the $\delta^{18}O$ values of water vapour and precipitation at the two stations of Nagqu and Delingha, located on the central and northern Tibetan Plateau, respectively. This results in different $\delta^{18}O$ characteristics of water vapour and precipitation from the central and northern Tibetan Plateau and may explain the different $\delta^{18}O$ characteristics

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of ice cores from the central and northern Tibetan Plateau. For example, the $\delta^{18}O$ record preserved in the Dunde ice core from the northern Tibetan Plateau provides a reasonable proxy of summer temperature (Thompson et al., 1989), while the $\delta^{18}O$ record in the Tanggula ice core from the central Tibetan Plateau shows no correlation between average $\delta^{18}O$ values and temperature, probably due to the influence of the Indian monsoon (Joswiak et al., 2010). Accordingly, our findings indicate that the influences of different moisture sources and the activities of the Indian monsoon and convection may be significant when reconstructing paleoclimate variations on the central and northern Tibetan Plateau. Certainly, ice core (or other proxy) $\delta^{18}O$ records do not reflect day-to-day changes of $\delta^{18}O$ in water vapour/precipitation. In order to disprove the presence of a temperature effect over the central Tibetan Plateau, multiple years of data and data that span the entire year will be needed for future studies. Hence, the authors have launched a new project to survey a longer time series of isotopic compositions of water vapour and precipitation ($\delta^{18}O$ and δD), which should provide greater confidence in our findings and gain a better understanding of the links between water vapour and precipitation $\delta^{18}O/\delta D$ values and paleoclimatic records.

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5 Conclusions

This study represents the first simultaneous water vapour and precipitation $\delta^{18}O$ time series for the central Tibetan Plateau. In the study region of Nagqu, the isotopic composition of water vapour has a direct relationship to that of precipitation. In turn, the isotopic composition of precipitation provides a feedback effect on that of water vapour. Hence, an interaction between $\delta^{18}O$ from water vapour and precipitation clearly exists. The $\delta^{18}O_v$ and $\delta^{18}O_p$ variations at Nagqu appear mainly controlled by joint influences of relative humidity, pressure, and precipitation amount, but did not demonstrate a "temperature effect". Moreover, the different $\delta^{18}O$ characteristics of water vapour and precipitation at Nagqu appear to relate to different atmospheric trajectories, especially involving the influences of the Indian monsoon and convection. The enrichment of $\delta^{18}O_p$ relative to $\delta^{18}O_v$ at Nagqu (on the central Tibetan Plateau) is similar to that at the southern station (Bay of Bengal), but differs from that at the northern station (Delingha), due to intense Indian monsoon and convection activities. These results may explain the different $\delta^{18}O$ characteristics obtained from ice cores from the central and the northern Tibetan Plateau. Our findings presented here may provide a basis for reinterpretation of the $\delta^{18}O$ records in ice cores from the central Tibetan Plateau, and suggest that the impacts of different moisture sources, the Indian monsoon, and convection activities all need to be considered.

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PSD, Boulder, Colorado, USA (ftp://arlftp.arlhq.noaa.gov/pub/archives/reanalysis). Some meteorological data were provided by the Climatic Data Center, National Meteorological Information Center, China Meteorological Administration.

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Tables

Table 1. Correlations between $\delta^{18}O_v$ and $\delta^{18}O_p$ at Nagqu. The x and y represent $\delta^{18}O_v$ and $\delta^{18}O_p$ during the same day (Day_n), the y_1, y_2, y_3, and y_4 show $\delta^{18}O_p$ in the following first day (Day_{n+1}), … (Day_{n+2}), …, and the following fourth day (Day_{n+4}), respectively.

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$\delta^{18}O_v$-$\delta^{18}O_p$	Linear regression	Slope	R^2	r	n	p
Day_n - Day_n	$y = 0.90x + 6.9$	0.90	0.65	0.81	86	< 0.01
Day_n - Day_{n+1}	$y_1 = 0.55x - 2.9$	0.55	0.23	0.48	84	< 0.01
Day_n - Day_{n+2}	$y_2 = 0.49x - 4.5$	0.49	0.20	0.45	84	< 0.01
Day_n - Day_{n+3}	$y_3 = 0.36x - 8.1$	0.36	0.11	0.33	83	< 0.01
Day_n - Day_{n+4}	$y_4 = 0.31x - 9.7$	0.31	0.08	0.28	82	< 0.05

Table 2. Correlations between $\delta^{18}O_p$ and $\delta^{18}O_v$ at Nagqu. The x and y represent $\delta^{18}O_p$ and $\delta^{18}O_v$ on the same day (Day_n), the y_1, y_2, y_3, ..., and y_5 represent $\delta^{18}O_v$ in the following first day (Day_{n+1}), … (Day_{n+2}), … (Day_{n+3}), ..., and the following fifth day (Day_{n+5}), respectively.

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$\delta^{18}O_p$-$\delta^{18}O_v$	Linear regression	Slope	R^2	*r*	*n*	*p*
Day_n - Day_n	$y = 0.72x - 14.5$	0.72	0.65	0.81	86	< 0.01
Day_n - Day_{n+1}	$y_1 = 0.61x - 16.4$	0.61	0.47	0.69	86	< 0.01
Day_n - Day_{n+2}	$y_2 = 0.62x - 15.9$	0.62	0.41	0.64	85	< 0.01
Day_n - Day_{n+3}	$y_3 = 0.57x - 16.7$	0.57	0.35	0.59	82	< 0.01
Day_n - Day_{n+4}	$y_4 = 0.38x - 20.2$	0.38	0.17	0.41	83	< 0.01
Day_n - Day_{n+5}	$y_5 = 0.34x - 20.8$	0.34	0.12	0.35	85	< 0.05

Table 3. Correlations between stable oxygen isotope ($\delta^{18}O_v$ and $\delta^{18}O_p$) and meteorological factors (temperature, relative humidity, surface pressure, and precipitation amount) at Nagqu.

	Slope	*r*	*n*	*p*
$\delta^{18}O_v$ – T	–0.33	–0.32	153	< 0.01
$\delta^{18}O_p$ – T	–0.35	–0.27	90	< 0.01
$\delta^{18}O_v$ – RH	–0.20	–0.45	153	< 0.01
$\delta^{18}O_p$ – RH	–0.28	–0.36	90	< 0.01
$\delta^{18}O_v$ – Psfc	1.11	0.41	153	< 0.01
$\delta^{18}O_p$ – Psfc	1.09	0.34	90	< 0.01
$\delta^{18}O_v$ – P	–0.43	–0.44	153	< 0.01
$\delta^{18}O_p$ – P	–0.36	–0.43	90	< 0.01

Figure Captions

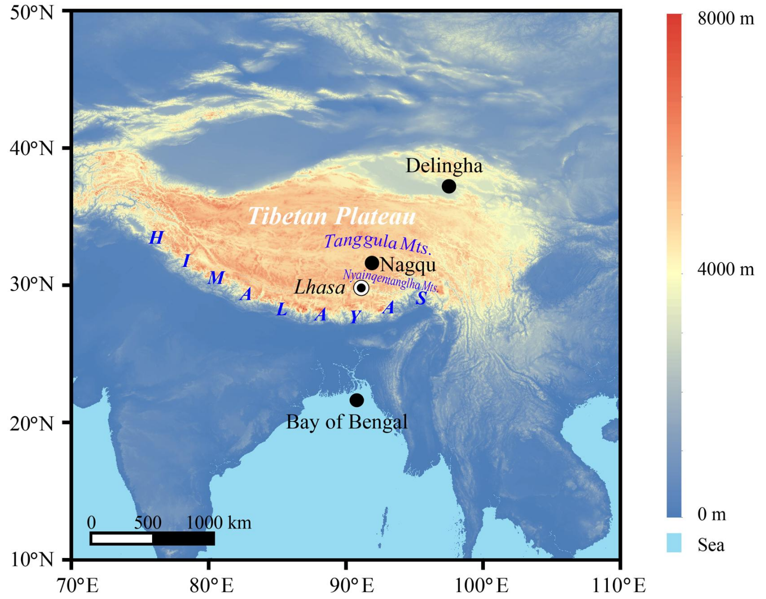

Figure 1. Map showing the sampling site at Nagqu on the central Tibetan Plateau, with the locations of the Delingha and Bay of Bengal stations, and the city of Lhasa.

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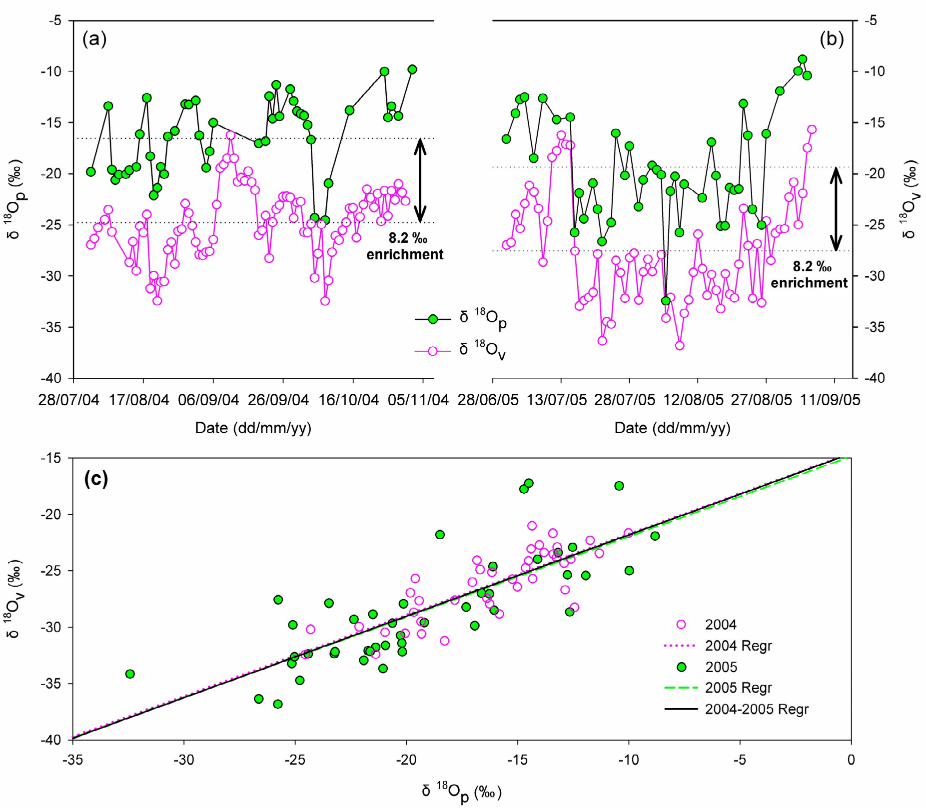
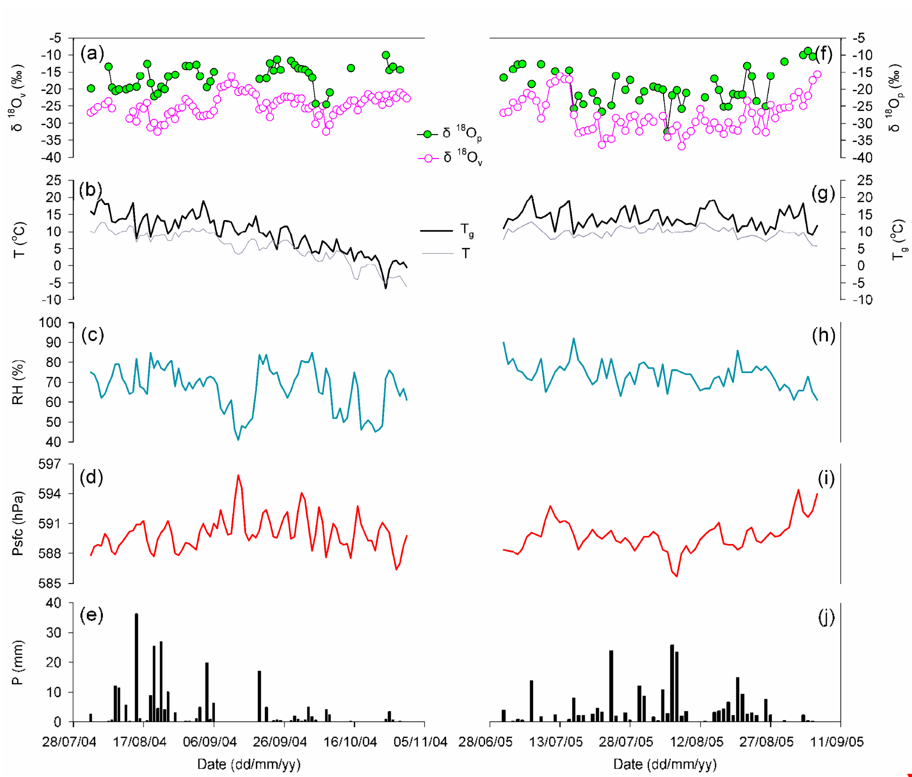


Figure 2. Temporal changes of $\delta^{18}O$ in water vapour ($\delta^{18}O_v$) and precipitation ($\delta^{18}O_p$) and the enrichment of $\delta^{18}O_p$ relative to $\delta^{18}O_v$ at Nagqu in 2004 (**a**) and 2005 (**b**), respectively, and the relationships between $\delta^{18}O_p$ of precipitation and $\delta^{18}O_v$ of water vapour at Nagqu (**c**). Note that in Panel (**c**), the values in 2004 are shown as pink open circles; the values in 2005 shown as green solid dots.



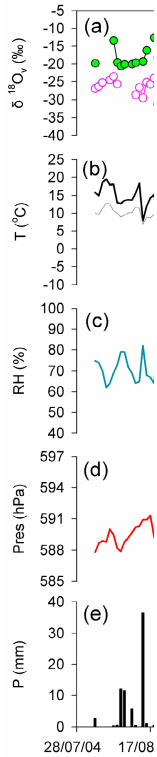


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Figure 3. Daily variations of δ^{18}O in water vapour ($\delta^{18}O_v$) and precipitation ($\delta^{18}O_p$) (**a**, **f**), temperature at 1.5 m (T) and temperature near ground (at 0 m, T_g) (**b**, **g**), relative humidity (RH) (**c**, **h**), surface pressure (Psfc) (**d**, **i**), and precipitation amount (P) (**e**, **j**) at Nagqu over the entire sampling period of 2004–2005.

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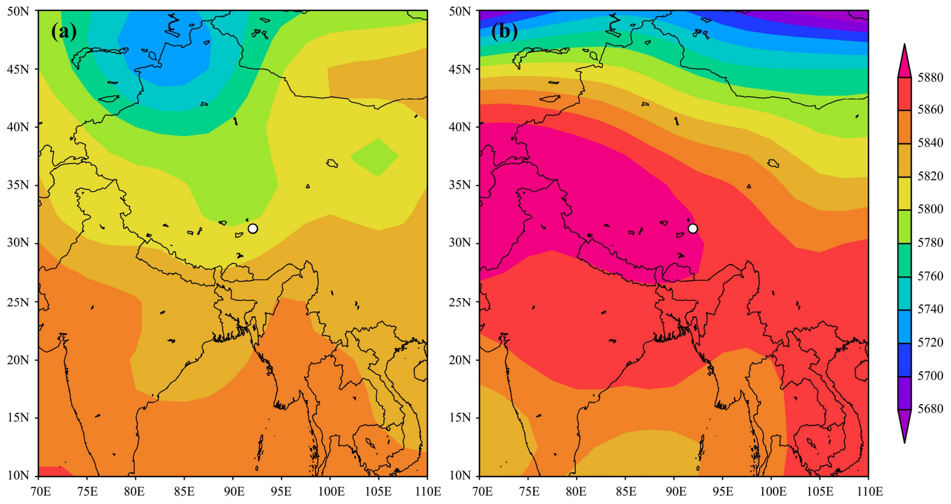

Figure 4. Distributions of the geopotential height (unit: meter) at 500 hPa on 6 August (a) and 5 September (b) 2005 over the Tibetan Plateau and adjacent regions, representing the conditions of low pressure (a) and high pressure (b) over the Nagqu station (white dots).

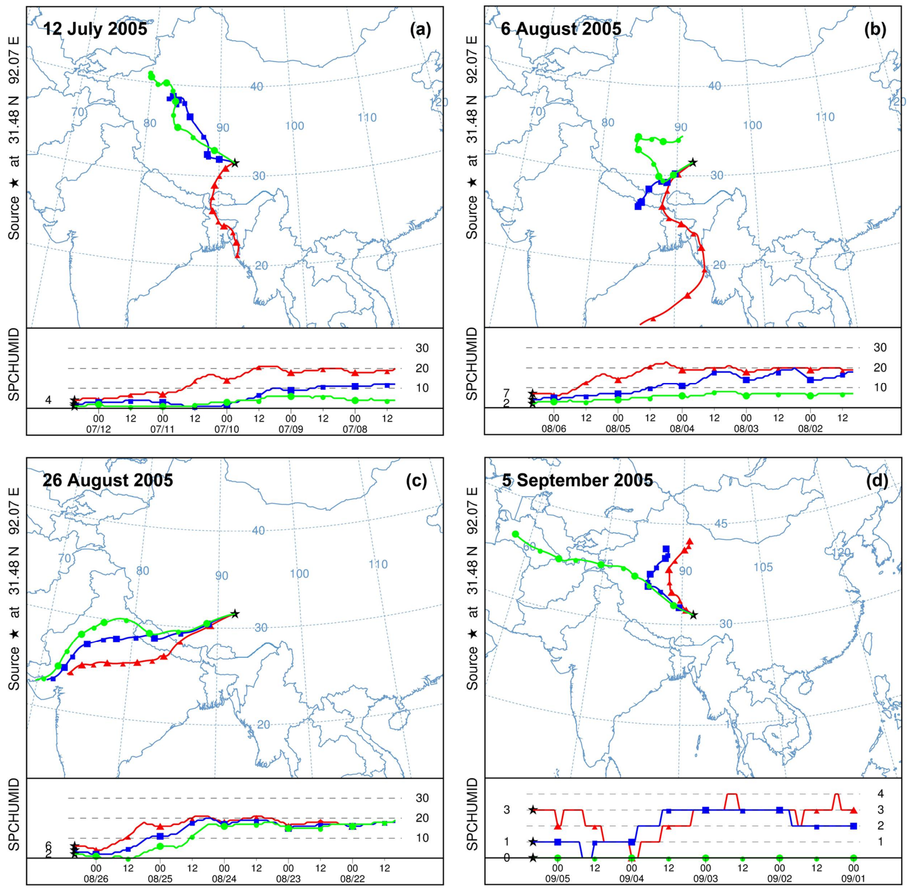

Figure 5. Back trajectories calculated by HYSPLT at 1000 (red lines), 2000 (blue lines), and 3000 m (green lines) a.g.l. on 12 July, 6 August, 26 August, and 5 September 2005, representing the conditions during the weak monsoon (**a**), active monsoon (**b**), late monsoon (**c**), and post-monsoon (**d**) periods, respectively, over the Nagqu station. Note that changes in specific humidity (g/kg) along the air parcel pathways are also shown.

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