

# Comparison of isotope-based linear and Bayesian mixing models in determining moisture recycling ratio

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**Abstract:** Stable water isotopes are natural tracers quantifying the contribution of moisture recycling to local precipitation, i.e., the moisture recycling ratio, but various isotope-based models usually lead to different results, which affects the accuracy of local moisture recycling. In this study, a total of 18 stations from four typical areas in China were selected to compare the performance of isotope-based linear and Bayesian mixing models and to determine local moisture recycling ratio. Among the three vapor sources including advection, transpiration, and surface evaporation, the advection vapor usually played a dominant role, and the contribution of surface evaporation was less than that of transpiration. When the abnormal values were ignored, the arithmetic averages of differences between isotope-based linear and the Bayesian mixing models were 0.9% for transpiration, 0.2% for surface evaporation, and -1.1% for advection, respectively, and the medians were 0.5%, 0.2%, and -0.8%, respectively. The importance of transpiration was slightly less for most cases when the Bayesian mixing model was applied, and the contribution of advection was relatively larger. The Bayesian mixing model was found to perform better in determining an efficient solution since linear model sometimes resulted in negative contribution ratios. Sensitivity test with two isotope scenarios indicated that the Bayesian model had a relatively low sensitivity to the changes in isotope input, and it was important to accurately estimate the isotopes in precipitation vapor. Generally, the Bayesian mixing model should be recommended instead of a linear model. The findings are useful for understanding the performance of isotope-based linear and Bayesian mixing models under various climate backgrounds.

**Keywords:** moisture recycling; stable water isotope; linear mixing model; Bayesian mixing model; China

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## 1 Introduction

The recycled moisture, including the moisture from local surface evaporation and transpiration, relative to advected moisture, plays a vital role in terrestrial hydrological circulation (Trenberth, 1999; van der Ent et al., 2010; Theeuwens et al., 2023; Xiao et al., 2023). The fractional

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contribution of recycled moisture in local precipitation is a spatially varying parameter, reflecting the climate conditions and the underlying surface (Xiao et al., 2018; Tuinenburg et al., 2020; Dominguez et al., 2022; Harrington et al., 2023). Under changing climate, the moisture recycling ratio reflects both natural and human processes at various scales, and provides information on water resource management (Keune and Miralles, 2019; Li and Wang, 2020; te Wierik et al., 2021).

Stable isotope tracers of hydrogen ( $\delta^2\text{H}$ ) and oxygen ( $\delta^{18}\text{O}$ ) have been widely considered in hydrology (Gimeno et al., 2012; Bowen et al., 2019). When stable isotope compositions of each end member of potential water sources of local precipitation are available, moisture recycling ratio can be determined using an isotope mixing model. From a mathematical perspective, we expect to find the unique solution to linear equations, no matter whether three (advection, surface evaporation, and transpiration as sources of local precipitation) or two (advection and surface evaporation as sources of local precipitation) contributions are assumed (Kong et al., 2013; Zhang and Wang, 2016; Gui et al., 2022).

In most conditions, a linear method is applied in most studies (Peng et al., 2011; Li et al., 2016; Sun et al., 2020; Gui et al., 2022), but linear equations often do not provide a reasonable fractional contribution solution ranging from 0.0% to 100.0%, which constrains the application in wider spatial and temporal scopes (Wang et al., 2016; Zhao et al., 2019; Zhu et al., 2020). For example, in an arid riparian forest, there were negative contributions of evaporation, ranging from  $-23.9\%$  to  $-5.6\%$ , and monthly contribution of advection ranges from 61.4% to 119.3% using isotope-based linear mixing model (Zhao et al., 2019). The Monte Carlo method was also used in this riparian forest, but the results were still abnormal. In another case, when three-component mixing models were applied, 19 in 20 monthly evaporations had no reasonable result with contributions between 0.0% and 100.0% in the mountains in Northwest China (Qiu et al., 2021). If the most negative contribution was removed, i.e., the two-component mixing models were used, 8 cases still have abnormal contributions ( $<0.0\%$  or  $>100.0\%$ ). Some recent studies showed that the Bayesian estimate may have the potential in quantifying moisture recycling (Moore and Semmens, 2008; Parnell et al., 2010; Stock et al., 2018; Qiu et al., 2021; Wang et al., 2022). For example, Qiu et al. (2021) found that the Bayesian model always has fractional contributions between 0.0% and 100.0%. However, the difference in the performance between linear and the Bayesian mixing models under various climates has not been thoroughly studied yet.

In this study, we selected four areas (including 18 sampling stations) from the coastline to the inland in China and then obtained the moisture recycling ratio using linear and the Bayesian mixing models. This work aims to understand the performances of isotope-based linear and the Bayesian mixing models from various climates in China. Through this study, we can better understand the hydrological cycle process in China and provide scientific basis for water resource management and sustainable development.

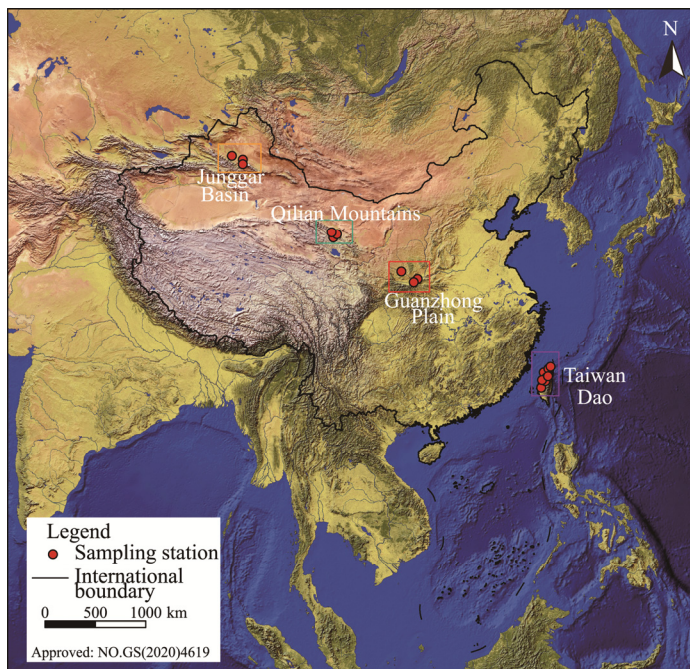
## 2 Materials and methods

### 2.1 Data collection

Four sampling areas in China from eastern coastline to western inland were selected, namely the Taiwan Dao, the Guanzhong Plain, the Qilian Mountains, and the Junggar Basin (Fig. 1; Table 1). The selection criteria of the study area include: (1) the stable isotope compositions of  $\delta^2\text{H}$  and  $\delta^{18}\text{O}$  in precipitating vapor, surface evaporation vapor, transpiration vapor, and advection vapor had to be publicly available; and (2) at least three neighboring stations (interior distance  $<200$  km) had to be available in a single area to eliminate the influence of station selection. The isotope compositions are all expressed using the delta notation relative to the Vienna Standard Mean Ocean Water (V-SMOW).

The Taiwan Dao faces the western Pacific Ocean in the east, and the Tropic of Cancer crosses the island. This area has a tropical and subtropical monsoon climate. The mean annual precipitation amount exceeds 2000 mm. In the Taiwan Dao (Peng et al., 2011), the samples were

collected at nine stations (Xinshan, Wuling, Taibei, Taichung, Puli, Lishan, Hsinchu, Feitsui, and Chiayi) in the summer months (June–September) during 1993–2008.



**Fig. 1** Sampling stations in China. Four typical sampling areas are marked in squares, i.e., the Taiwan Dao (purple), the Guanzhong Plain (red), the Qilian Mountains (green), and the Junggar Basin (brown) from eastern coastline to western inland in China. Note that the figure is based on the standard map (GS(2020)4619) of the Map Service System (<https://bzdt.ch.mnr.gov.cn/>), and the standard map has not been modified.

**Table 1** Latitude, longitude, and altitude of the sampling stations used in this study

Study area	Station	Latitude	Longitude	Altitude (m)	Reference
Taiwan Dao	Xinshan	25°07'N	121°44'E	27	Peng et al. (2011)
	Wuling	24°21'N	121°19'E	1800	
	Taibei	24°59'N	121°31'E	5	
	Taichung	24°07'N	120°41'E	34	
	Puli	23°58'N	120°59'E	732	
	Lishan	24°16'N	121°10'E	1980	
	Hsinchu	24°45'N	121°00'E	34	
	Feitsui	24°54'N	121°34'E	150	
	Chiayi	23°29'N	120°18'E	27	
Guanzhong Plain	Xi'an	34°13'N	109°00'E	460	Li et al. (2020)
	Weinan	34°29'N	109°27'E	413	
	Changwu	35°14'N	107°41'E	1220	
Qilian Mountains	Yeniugou	38°42'N	99°38'E	3320	Zhao et al. (2019)
	Pailugou	38°34'N	100°17'E	2720	
	Hulugou	38°15'N	99°52'E	3020	
Junggar Basin	Urumqi	43°47'N	87°39'E	935	Wang et al. (2016)
	Shihezi	44°19'N	86°03'E	443	
	Caijiahu	44°12'N	87°32'E	441	

The Guanzhong Plain is a west-eastern plain bounded by the Loess Plateau in the north and the Qinling Mountains in the south. The region consists of alluvial plains along the Weihe River, a branch of the Yellow River. It has a temperate monsoon climate, and the mean annual precipitation amount ranges approximately from 400 to 900 mm. In the Guanzhong Plain (Li et al., 2020), we used summer month samples (June–August) at three stations (Xi'an, Weinan, and Changwu) during 2010–2018.

The Qilian Mountains, a mountain range at the northeastern margin of the Qinghai-Tibet Plateau, lie to the south of the Hexi Corridor. Many inland streams and rivers originate from the mountains, and the wind regime is mainly controlled by the mid-latitude westerlies. In the Qilian Mountains, we selected three stations (Yeniugou, Pailugou, and Hulugou) with elevations ranging from 2720 to 3320 m a.s.l. in the upper reaches of the Heihe River (Zhao et al., 2019). Summer month samples (May–September) were collected at the three stations during 2008–2014.

The Junggar Basin is a low-lying basin surrounded by the Altay Mountains to the north and the Tianshan Mountains to the south. It belongs to a temperate continental climate and is governed by westerly moisture (Wang et al., 2016). In the Junggar Basin, samples were collected at three stations (Shihezi, Caijiahu, and Urumqi) in the summer months (April–October) during 2012–2013.

The stable  $\delta^2\text{H}$  and  $\delta^{18}\text{O}$  isotope compositions were analysed using an isotope ratio mass spectrometer (VG SIRA 10 and VG MM602D, IsoPrime Inc., Manchester, UK) and laser spectrometer (Picarro L2130-i, Picarro Inc., Sunnyvale, USA; DLT-100, Los Gatos Research Inc., Mountain View, USA), in which Picarro L2130-i was used in the Guanzhong Plain and the Qilian Mountains; and LGR DLT-100 was used in the Junggar Basin. Measurement precision is generally comparable.

To understand the comparability of different years, we assessed the precipitation isotopes during sampling years and long-term period using an isotope-incorporated Global Spectral Model v.2.0 (isoGSM2) (Yoshimura et al., 2008), which has been widely used in global and regional hydrological studies (Chiang et al., 2020; Kathayat et al., 2022; Wang et al., 2024). The grid dataset of monthly precipitation isotopes from May to September at a spatial resolution of  $1.905^\circ$  (latitude)  $\times$   $1.875^\circ$  (longitude) is used here, and the monthly data are then weighted to a mean using precipitation amount. For each region, the closest grid of simulated isotope to the location with average latitude and longitude was selected. As shown in Figure 2, the simulations during the sampling period are close to the long-term climatology during 1979–2020, indicating the data compiled from different periods generally reflect the isotope characteristics of long-term precipitation.

## 2.2 Methods

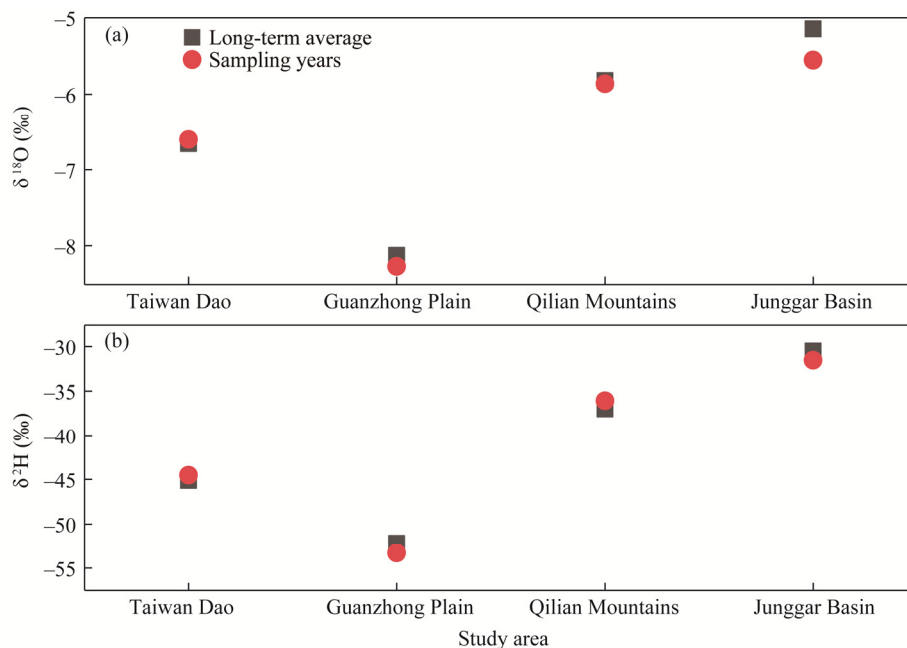
In an isotope-based three-component mixing model (Fig. 3), the precipitating vapor is usually assumed to originate from three sources, i.e., advection vapor, surface evaporation vapor, and transpiration vapor, with the vapor from these three sources assumed to be fully mixed in the atmosphere. When stable isotope compositions of precipitating vapor and the three sources are known, we can determine the fractional contributions for each source (Peng et al., 2011). We described this basic framework using the delta notation of isotope compositions as follows:

$$\delta_{\text{Pv}} = f_{\text{Adv}}\delta_{\text{Adv}} + f_{\text{Tr}}\delta_{\text{Tr}} + f_{\text{Ev}}\delta_{\text{Ev}}, \quad (1)$$

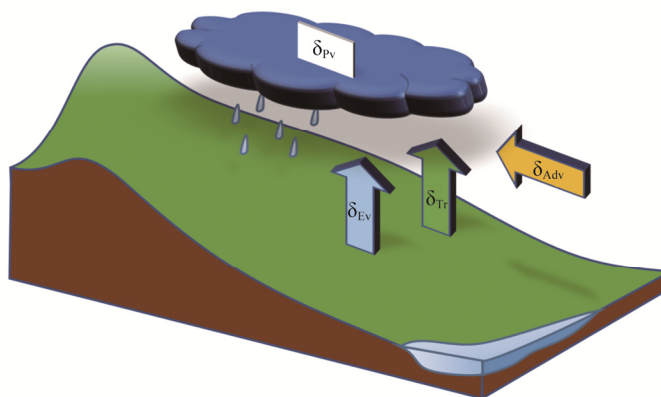
$$f_{\text{Adv}} + f_{\text{Tr}} + f_{\text{Ev}} = 1, \quad (2)$$

where  $\delta_{\text{Pv}}$  is the isotope composition of precipitating vapor (‰);  $f_{\text{Adv}}\delta_{\text{Adv}}$  (‰),  $f_{\text{Tr}}\delta_{\text{Tr}}$  (‰), and  $f_{\text{Ev}}\delta_{\text{Ev}}$  (‰) are the fractional contributions and the isotope compositions of advection, transpiration, and surface evaporation, respectively. Here the sum of contributions from surface evaporation and transpiration vapor is also known as the moisture recycling ratio ( $f_{\text{Re}}$ ):

$$f_{\text{Re}} = f_{\text{Tr}} + f_{\text{Ev}}. \quad (3)$$



**Fig. 2** Precipitation-weighted oxygen ( $\delta^{18}\text{O}$ , a) and hydrogen ( $\delta^2\text{H}$ , b) isotopes in summer months from May to September during long-term average (1979–2020) and sampling years in the four areas



**Fig. 3** Schematic of isotope-based three-component mixing model. Three arrows show the isotope compositions of three vapor sources, i.e., advection ( $\delta_{\text{Adv}}$ ), transpiration ( $\delta_{\text{Tr}}$ ), and surface evaporation ( $\delta_{\text{Ev}}$ ). Isotope composition of precipitating vapor is marked as  $\delta_{\text{pV}}$ .

All the isotope compositions of precipitating, advection, transpiration, and surface evaporation vapors are acquired from the publications in original mixing models (Peng et al., 2011; Wang et al., 2016; Zhao et al., 2019; Li et al., 2020).

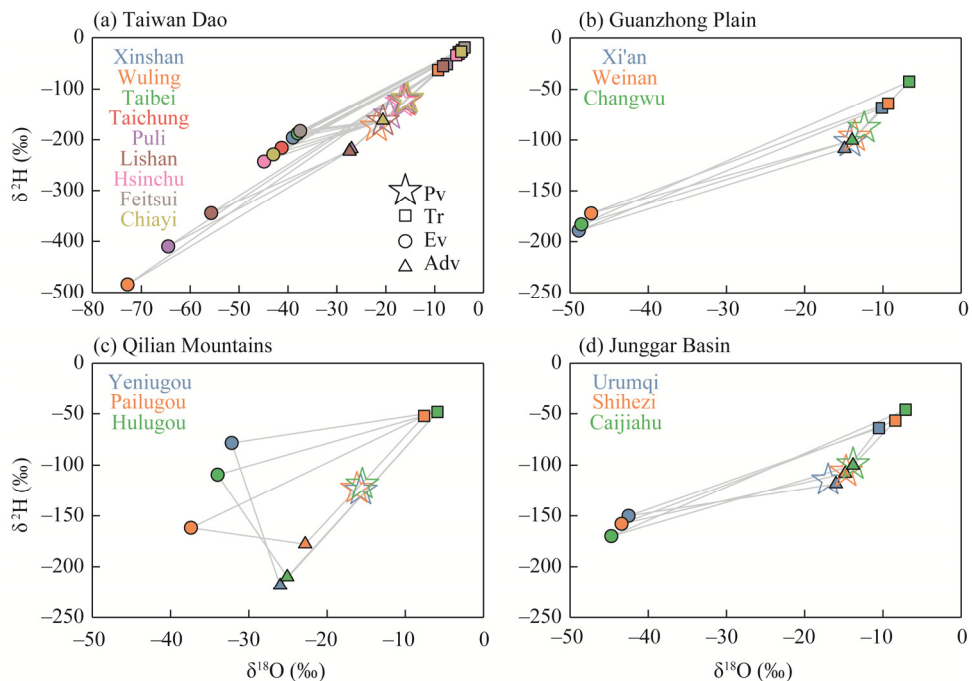
To determine the solution of isotope-based mixing model, we used the Microsoft Excel-based software IsoError v.1.04 (Genereux, 1998; Phillips and Gregg, 2001, 2003). The software provides the estimated proportions and standard errors for each moisture source as well as the confidence intervals.

We also used the MixSIAR (the Bayesian mixing model in R software) v.3.1.12 (Moore and Semmens, 2008; Stock et al., 2018). The Bayesian estimate gives the probabilistic prediction of contributions from potential sources, which has been widely used in isotope mixing models (Evaristo et al., 2017). The model provides the mean value, standard error, and confidence intervals for each source. The number of the Markov chains is three, and the chain length is set as normal, i.e., 100,000.

### 3 Results and discussion

#### 3.1 Relationship among source water isotopes

Relationship of stable isotope compositions for each component is shown in Figure 4. The Taiwan Dao had the largest range of stable isotope compositions among the four areas. Difference for  $\delta^2\text{H}$  values was larger than 400‰ in the Taiwan Dao, and the other areas usually had a  $\delta^2\text{H}$  range smaller than 200‰. That is, the three potential sources have quite different isotope compositions from precipitating vapor in the Taiwan Dao. Similarly, the range of  $\delta^{18}\text{O}$  values (approximately 70‰) in the Taiwan Dao was also larger than those in the other areas. For the areas with complex topography, there was a relatively large difference in humidity and temperature within one area, which might cause a divergence of stable isotopes in recycled moisture. According to the geographic information shown in Table 1, the Taiwan Dao had higher variation in altitude ranging from 5 to 1980 m. In the mountainous stations of the Taiwan Dao with elevations between 732 and 1980 m (Peng et al., 2010), the surface air temperature (16.9°C–22.0°C) and relative humidity (79.0%–85.0%) were different from the other nearby plain stations lower than 150 m (28.0°C–28.7°C for temperature and 74.0%–78.0% for relative humidity, respectively), and precipitation isotopes were more depleted in the mountains than those at the plain.



**Fig. 4** Relationship between stable hydrogen ( $\delta^2\text{H}$ ) and oxygen ( $\delta^{18}\text{O}$ ) isotope compositions of Pv (precipitating vapor), Tr (transpiration), Ev (surface evaporation), and Adv (advection) vapors for different sampling stations in the four study areas. (a), Taiwan Dao; (b), Guanzhong Plain; (c), Qilian Mountains; (d), Junggar Basin. The symbols of  $\delta^2\text{H}$  and  $\delta^{18}\text{O}$  isotope compositions correspond to the sampling stations with the same color. The abbreviations are the same as in the following figures.

Among the three sources of advection, transpiration, and surface evaporation vapors, precipitating vapor was usually close to advected vapor, except in the Qilian Mountains (Fig. 4). In the Taiwan Dao, the Guanzhong Plain, and the Junggar Basin, the distance from selected upwind station to target stations was less than 500 km, indicating strong similarity of water vapor isotope along a transport path. Usually, the recycling ratio increases as study domain increases (Hua et al., 2017). In the Qilian Mountains, the advection vapor had more depleted isotopes, which was consistent with relatively long distance of moisture transport in the original setting (Zhao et al., 2019).

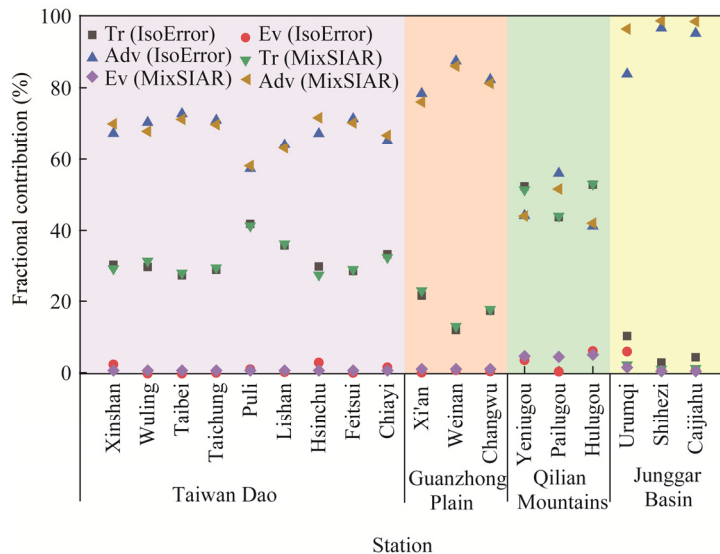
Between transpiration and surface evaporation vapors, precipitating vapor was relatively close to transpiration vapor (Fig. 4). From a global perspective, the contribution of transpiration vapor was usually larger than that of surface evaporation vapor (Rothfuss et al., 2020), and then transpiration vapor played a dominant role in recycled moisture. In addition, there was a commonly-used assumption in isotope mixing model that no isotopic fractionation occurred from soil and xylem water to transpiration vapor, especially in a stable condition, and precipitation isotopes were close to soil water isotopes (Peng et al., 2010).

### 3.2 Comparison between linear and the Bayesian mixing models

The results of means for each fractional contribution using linear and the Bayesian models are shown in Figure 5. Regarding the spatial pattern, the order of fractional contribution of recycled moisture was the Junggar Basin<the Guanzhong Plain<the Taiwan Dao<the Qilian Mountains. Generally, there was no clear linear trend in the moisture recycling ratio from eastern coastline to western inland.

For the results using linear model in 3 stations (Wuling, Taibei, and Feitsui) among 18 stations, fractional contribution had no reasonable values between 0.0% and 100.0% (Fig. 5). The calculated contributions from surface evaporation were below 0.0% at these 3 stations, which actually constrained the application of linear model. The fractional contribution of advection ranged from 41.2% to 96.6%. Contribution of recycled moisture was relatively less than that of advection, including transpiration vapor ranging from 2.8% to 52.8%, as well as surface evaporation ranging from  $-0.3\%$  to 6.0%. The arithmetic averages were 28.0%, 1.4%, and 70.7%, respectively. The medians were 29.4%, 0.6%, and 70.7%, respectively.

For the MixSIAR-based results (Fig. 5), all the components had a contribution between 0.0% and 100.0%. Specifically, the fractional contributions of transpiration, surface evaporation, and advection vapors ranged from 1.0% to 53.0%, from 0.5% to 5.0%, and from 42.0% to 98.6%, respectively. The arithmetic averages were 27.3%, 1.4%, and 71.3%, respectively. The medians were generally similar to the arithmetic averages, i.e., 29.2%, 0.6%, and 70.2%, respectively.



**Fig. 5** Fractional contributions of Tr, Ev, and Adv vapors for each sampling station using IsoError and MixSIAR methods

Generally, among the three sources, advection played a dominant role in most cases, and recycled moisture had less contribution than advection. For recycled moisture, surface evaporation usually showed a fractional contribution of less than 6.0%, and the importance of transpiration vapor was usually larger than that of surface evaporation. This study provides an

integrated comparison of the four areas from coastline to inland. Two western areas (the Junggar Basin and the Qilian Mountains) were mainly affected by westerly advection, while eastern areas (the Guanzhong Plain and the Taiwan Dao) were affected by monsoon advection. Contribution of advected moisture was larger than recycled moisture in all study areas. In a warming climate, water cycle is considered to be intensified in the East Asia (Markonis et al., 2019; Zhang et al., 2019), and evaporation intensity has exhibited an increasing trend in most areas during the last three decades (Shen et al., 2022). However, in this study, even in an arid climate with relatively weak moisture transport, advection vapor always plays a dominant role. Although recycled moisture may contribute to precipitation variability, we should not overrate the role of moisture recycling.

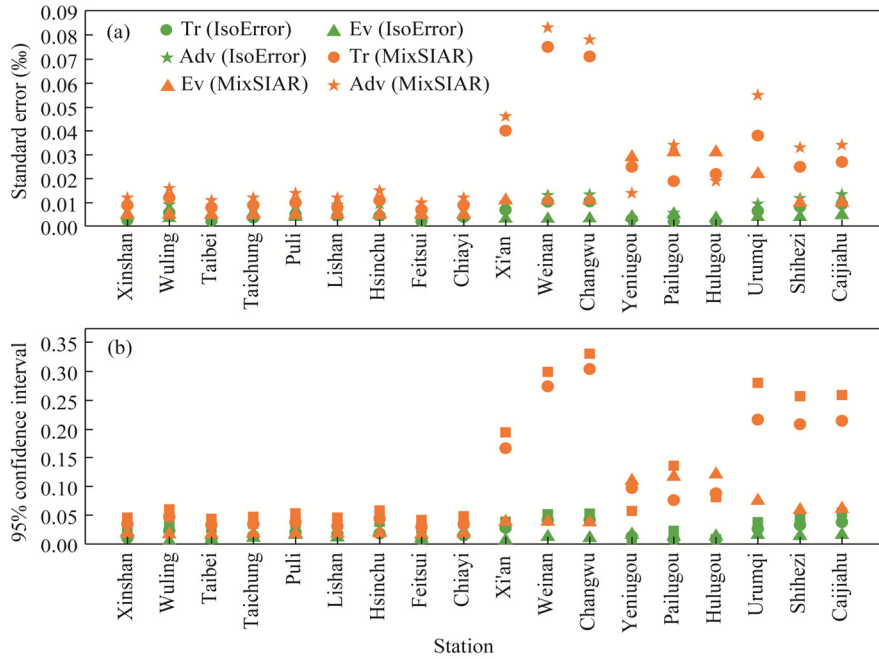
When the three abnormal values (Wuling, Taibei, and Feitsui stations) were ignored, the arithmetic averages of differences between IsoError and MixSIAR methods (i.e., IsoError minus MixSIAR) were 0.9% (ranging from -1.4% to 8.1%) for transpiration vapor, 0.2% (ranging from -4.1% to 4.4%) for surface evaporation vapor, and -1.1% (ranging from -12.4% to 4.4%) for advection vapor, respectively. The medians were 0.5%, 0.2%, and -0.8% for transpiration, surface evaporation, and advection vapors, respectively. That is, the importance of transpiration vapor is slightly less for most stations when MixSIAR is applied, and then that of advection is relatively larger. We compared the findings with that of Qiu et al. (2021), and found that three-component mixing model did not have reasonable solutions for most cases. Considering the existing cases without reasonable solutions using linear model in this study, the Bayesian model was relatively effective in determining the isotopic mixing model. Actually, many cases without solutions were exhibited in previous studies such as Zhao et al. (2019) and Qiu et al. (2021), so the Bayesian model should be recommended especially for the situations without reasonable solution.

Some parameters about uncertainties were also available for the two models (Fig. 6). For IsoError, the output included the proportion contribution, standard error, and 95% confidence interval of each source. For MixSIAR method, the software provided the proportion of water vapor source contribution, standard deviation, and 95% confidence interval. For IsoError-based result, the standard errors of advection vapor (ranging from 0.2% to 1.4%) were usually larger than those of transpiration vapor (ranging from 0.2% to 1.1%) and surface evaporation vapor (ranging from 0.3% to 0.5%). The arithmetic averages (and medians) were 0.4% (and 0.4%), 0.4% (and 0.5%), and 0.9% (and 0.9%) for transpiration vapor, surface evaporation vapor, and advection vapor, respectively. For MixSIAR-based results, the standard deviations for advection vapor were also usually higher. The arithmetic averages (and medians) were 2.4% (and 1.6%), 1.2% (and 0.8%), and 2.8% (and 1.6%) for transpiration, surface evaporation, and advection vapors, respectively. Due to the calculation method, we did not recommend to directly compare the values of standard errors and deviations of the two methods. However, the correlation analysis indicated there was no statistically significant correlation between the two values for each source at  $P < 0.050$  level, and the significance levels were 0.058, 0.095, and 0.690, respectively. The standard error of advection was usually high, while the standard errors of transpiration and surface evaporation vapors were relatively low. This may reflect the complexity of advection process and the influence of isotopic fractionation effects. In MixSIAR method, the standard deviation of advection vapor also showed a higher trend. These results suggest that there may be significant uncertainty in the contribution of water vapor sources to isotopic ratios, and further research and explanation are needed (Davis et al., 2015; Liu et al., 2023). Although we did not recommend directly comparing their standard error and standard deviation, some trends could still be observed. For example, MixSIAR model typically exhibited higher standard deviations, which might be related to their more complex handling of water vapor sources. However, further research is needed to determine the specific reasons for these differences.

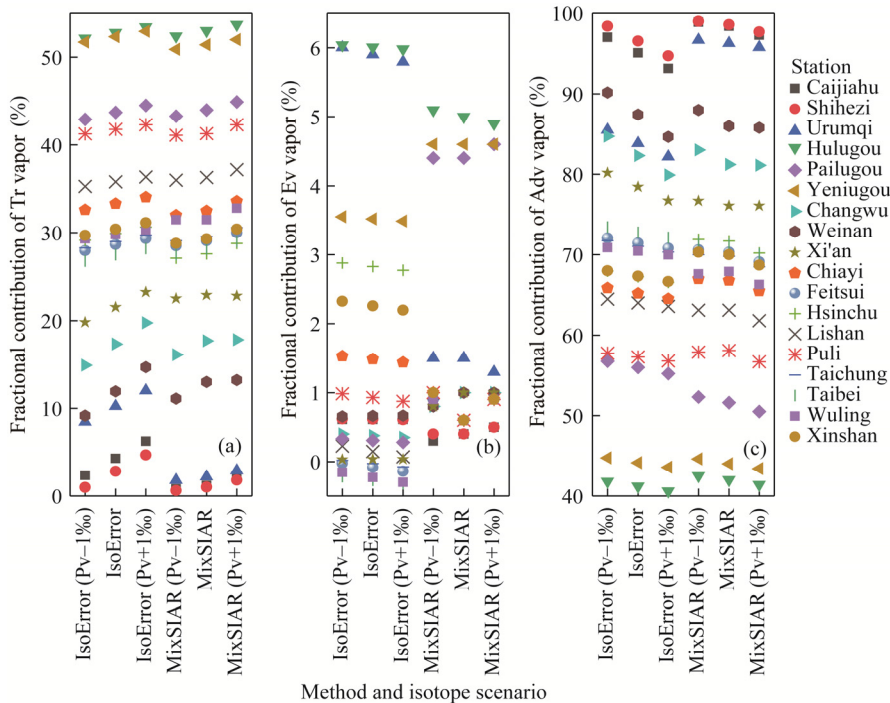
### 3.3 Sensitivity of linear and the Bayesian mixing models

Here we examined the sensitivity of fractional contributions using linear and the Bayesian mixing models. Two isotope scenarios were selected, i.e., increases by 1‰ (+1‰) and decreases by 1‰ (-1‰) to  $\delta^2\text{H}$  in vapor isotopes (Figs. 7–10). Since stable  $\delta^2\text{H}$  isotope ratios in natural water

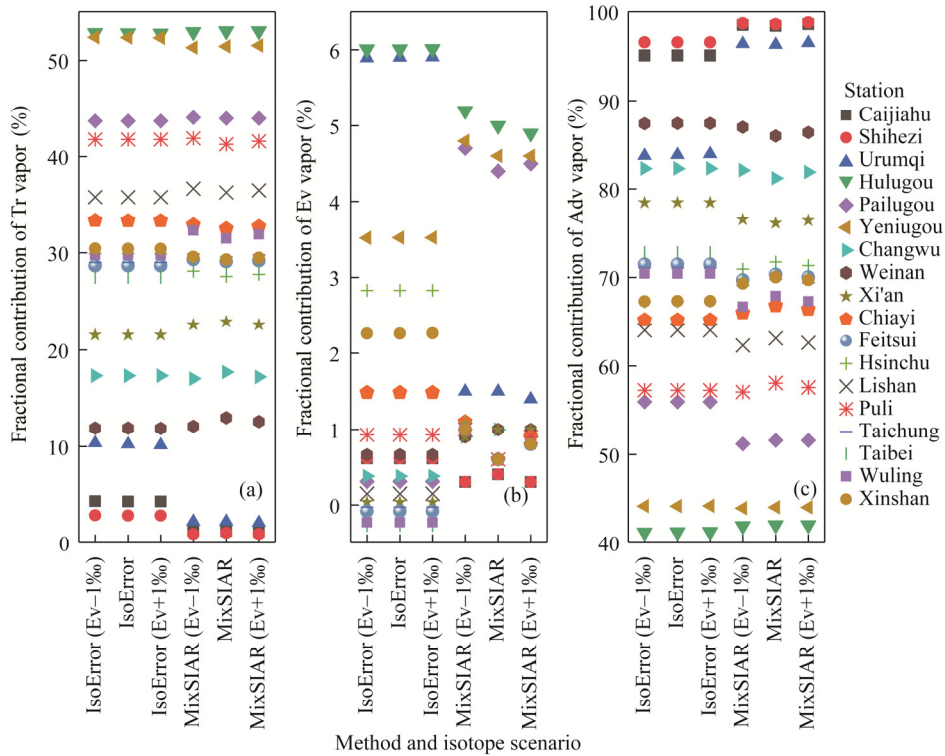
usually correlate positively with stable  $\delta^{18}\text{O}$  isotope ratios (Crawford et al., 2014; Putman et al., 2019), we modified the value of  $\delta^{18}\text{O}$  according to the linear relationship between  $\delta^2\text{H}$  and  $\delta^{18}\text{O}$ . When the linear model works (except at Wuling, Taibei, and Feitsui stations), the basic relationships between advected and recycled moisture in most cases were similar.



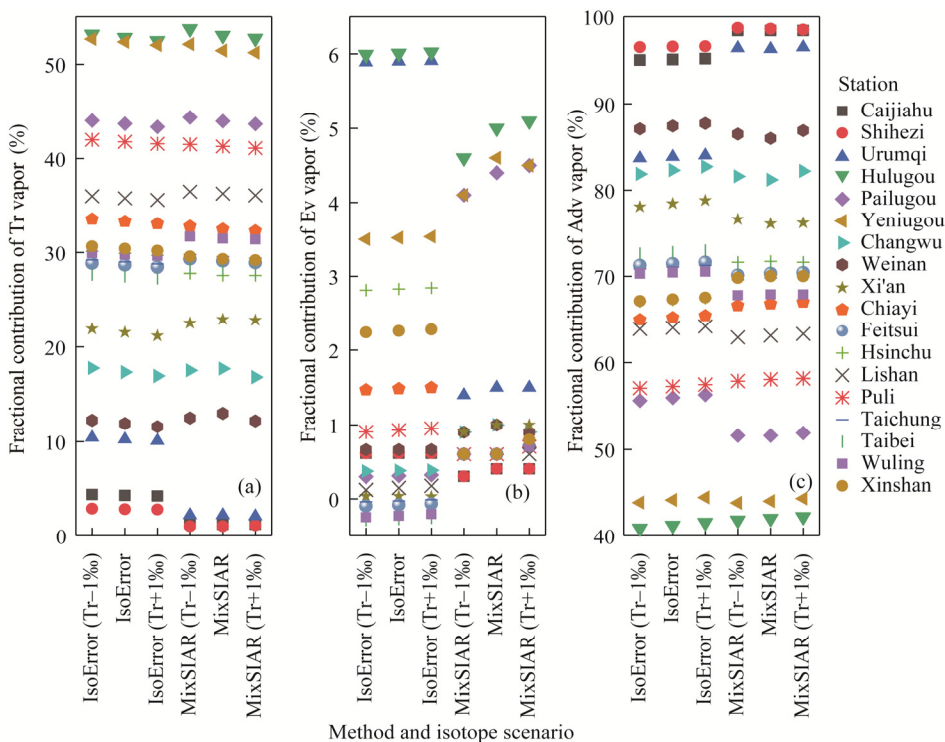
**Fig. 6** Standard errors (a) and 95% confidence intervals (b) of Tr, Ev, and Adv vapors for each sampling station using IsoError and MixSIAR methods



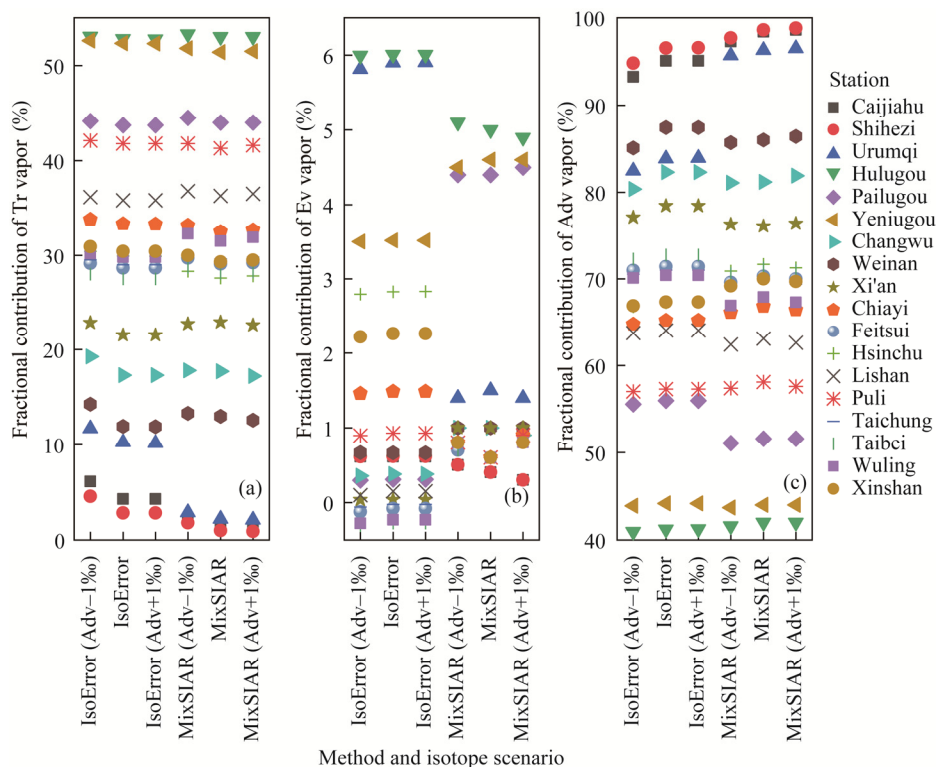
**Fig. 7** Sensitivity of fractional contributions for each vapor source when  $\delta^2\text{H}$  value in Pv increases by 1% (+1%) or decreases by 1% (-1%) using IsoError and MixSIAR methods. (a), Tr vapor; (b), Ev vapor; (c), Adv vapor.



**Fig. 8** Sensitivity of fractional contributions for each vapor source when  $\delta^2\text{H}$  value in Ev vapor increases by 1‰ (+1‰) or decreases by 1‰ (-1‰) using IsoError and MixSIAR methods. (a), Tr vapor; (b), Ev vapor; (c), Adv vapor.



**Fig. 9** Sensitivity of fractional contributions for each vapor source when  $\delta^2\text{H}$  value in Tr vapor increases by 1‰ (+1‰) or decreases by 1‰ (-1‰) using IsoError and MixSIAR methods. (a), Tr vapor; (b), Ev vapor; (c), Adv vapor.



**Fig. 10** Sensitivity of fractional contributions for each vapor source when  $\delta^2\text{H}$  value in Adv vapor increases by 1‰ (+1‰) or decreases by 1‰ (-1‰) using IsoError and MixSIAR methods. (a), Tr vapor; (b), Ev vapor; (c), Adv vapor.

Regarding the sensitivity under different precipitating vapor isotope signatures (Fig. 7), as precipitating vapor isotope ratio increased, the fractional contribution of transpiration vapor usually increased greatly, and that of advection vapor decreased. The changes using linear model were slightly larger than those using the Bayesian mixing model, indicating the Bayesian mixing model might have slightly lower sensitivity for most cases. In Figures 8–10, the results were not as sensitive as the above changes in precipitating vapor, indicating that it was important to accurately estimate the isotopes in precipitating vapor.

## 4 Conclusions

Stable  $\delta^2\text{H}$  and  $\delta^{18}\text{O}$  isotopes provide a useful tool to quantify the fractional contributions of recycled and advected moisture to precipitation. This is of great help in understanding the land-air interaction and natural and human impacts on the regional water cycle. In this study, four typical areas along the precipitation gradient from coastline to inland in China were selected to assess the performance of isotope-based linear and the Bayesian mixing models. When the abnormal values were ignored, the arithmetic averages of differences between IsoError and MixSIAR methods were 0.9% for transpiration vapor, 0.2% for surface evaporation vapor, and -1.1% for advection vapor, respectively. The importance of transpiration vapor was slightly less for most stations when MixSIAR method was applied, and then that of advection vapor was relatively larger. The Bayesian mixing model was more effective in determining a reasonable solution than linear model since linear model sometimes resulted in abnormal contribution rates (<0.0% or >100.0%). The sensitivity of the Bayesian mixing model to the changes in isotope-related input is slightly less than linear model. As precipitating vapor isotope ratio increased, the fractional contribution of transpiration vapor usually increased greatly, and that of advection vapor decreased. Generally, Bayesian mixing model should be recommended especially when a reasonable positive contribution cannot be determined using the traditional linear model.

## Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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