

Multi-time scale analysis of hydrogen and oxygen isotope characteristics and influence factors in precipitation in Vienna

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Abstract. Based on isotope and meteorology data at Vienna station from 1972 to 2014 provided by GNIP, the average monthly and annual hydrogen and oxygen stable isotopic compositions and main factors were analyzed by using various trend analysis, periodic analysis and correlation analysis methods. The monthly mean isotopic compositions change slightly, reflecting the fact that although Vienna is affected by the maritime climate and the continental climate, the former impact is more significant. The slope and intercept of the LMWL in Vienna changed significantly from October to March, indicating that it was affected by alternating effects of the two climates. The annual mean isotopes show a trend of enrichment, and it has an obvious temperature effect, but the rainfall amount effect does not exist, and no simple linear relationship was found between isotopes and vapor pressure. The annual mean isotopes also show the periodic variation characteristics with scales such as 9-16 years and 18-29 years, and it is concluded that the isotope values will be enriched after 2011 at the scale 22 years. The multivariate regression relationship established by δD and $\delta^{18}O$ with three climate parameters of temperature, precipitation and vapor pressure can quantitatively estimate the missing value in isotopic data.

1 Introduction

The stable isotopes (δD and $\delta^{18}O$) in natural water are widely used to study the global hydrological cycle and climate change [1-3]. Precipitation is an important part of the natural water cycle, and its hydrogen and oxygen stable isotope relationships play a dominant role in the isotope relationship of the hydrological system. The hydrogen and oxygen stable isotopes in precipitation are a natural tracer for moisture circulation and an indicator of moisture source [4]. Domestic and foreign scholars used the composition of hydrogen and oxygen stable isotopes in precipitation to reveal the moisture source in precipitation [5,6], to explore the influence of monsoon activity on the temporal and spatial distribution of precipitation isotopes [7,8] and analyzed the precipitation law in the region.

The Global Meteoric Water Line reveals the relationship between δD and $\delta^{18}O$ in precipitation which under the conditions of water vapor at its source in non-equilibrium evaporation and equilibrium fractionation during the course of the global decline. Harmon Craig (1961) proposed the global meteoric water line (GMWL) for the first time: $\delta D=8\delta^{18}O+10$ [9]. In fact, the composition of stable isotopes in atmospheric precipitation varies greatly with time and space, and the local meteoric water line (LMWL) in different regions

tend to deviate from the global meteoric water line to varying degrees [10]. In order to quantify the degree of deviation of LMWL with respect to GMWL on slope and intercept, Dansgaard [11] proposed the concept of *d*-excess, defined as: $d=\delta D-8\delta^{18}O$, and it is affected by the temperature of the water vapor source, relative humidity, wind speed and other meteorological conditions. The International Atomic Energy Agency (IAEA) and the World Meteorological Organization (WMO) collaborated to study the temporal and spatial variations in stable isotopes and tritium in atmospheric precipitation starting in 1961 to develop a global precipitation isotope monitoring network (GNIP, the Global Network of Isotopes in Precipitation), and more than 800 precipitation sampling stations have been established around the world.

Due to the miss of monthly measurement value in many stations, most of the current research is aimed at short-term isotope characteristics analysis [12], while the studies on the long-term precipitation isotope variation law are less. However, the composition of the stable hydrogen and oxygen isotopes in precipitation is affected by meteorological factors and has highly nonlinear and multi time scale characteristics [13]. Therefore, the analysis of the interannual variation characteristics of hydrogen and oxygen isotopes in regional precipitation can better reflect the complex time series dynamic process of isotopes. In this study, Vienna, which has the most complete data in GNIP, was selected as the study area to

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analyze the variation characteristics and influence factors of isotopes in precipitation in this area.

2 Data and method

2.1 Research area

Vienna is located in northeastern Austria, at the easternmost extension of the Alps in the Vienna Basin. Vienna is affected by the maritime climate from the west and the continental climate from the east, which is a transitional climate. Precipitation is moderate throughout the year, averaging 550 mm annually.

2.2 Data

The hydrogen and oxygen isotope observations in precipitation from Vienna station have the longest continuous period and the largest number of samples, so the observations from Vienna station are selected to analyze, including: average monthly and annual hydrogen and oxygen isotope data, temperature, precipitation, and water vapor pressure. The research period is from 1972 to 2014. Sample collection, transportation, and standard data are strictly regulated by the International Atomic Energy Agency (IAEA), so data quality and accuracy are reliable and guaranteed.

2.3 Analytical method

2.3.1 The trend analysis method

Linear regression is a trend analysis method, which uses regression analysis in mathematical statistics to determine the quantitative relationship between two or more variables depending on each other. In this paper, we used the linear regression analysis method to analyze the time series changes of hydrogen and oxygen isotopes and meteorological elements in precipitation at different time scales in Vienna. Multiple linear regression analysis method was used to determine the quantitative relationship between isotopes in precipitation and meteorological factors such as precipitation, temperature and water vapor pressure. Mann-Kendall rank correlation method (M-K method) is an effective tool for extracting sequence change trend in time series trend analysis method. It is a nonparametric test method recommended by the World Meteorological Organization and widely used [14], therefore, M-K method is used to statistically test the trend of time series of isotopic and meteorological elements.

2.3.2 The periodic analysis method

Wavelet analysis is a new technique of time-scale analysis and multi-resolution analysis. It can fully reflect the change trend of the system in different time scales, and can estimate the future development trend qualitatively. We used the Morlet wavelet function to analyze the time series

of hydrogen and oxygen isotopes in precipitation.

2.3.3 The correlation analysis method

Correlation analysis is a process of measuring the degree of linear correlation between variables. The most commonly used methods are binary correlation analysis, partial correlation analysis and distance analysis. Among the binary correlation analysis methods, Spearman rank correlation is the most commonly used, which uses rank of two variables to make linear correlation analysis and has a wide range of application. The partial correlation analysis is to analyze the linear correlation between two variables under the condition of controlling the linear influence of other variables. In this paper, Spearman correlation analysis and partial correlation analysis are used to study the correlation between hydrogen and oxygen isotopes in precipitation and influence factors (temperature, precipitation and water vapor pressure).

3 Results and analysis

3.1 Trend analysis of monthly hydrogen and oxygen isotope in precipitation

Based on the data from 1972 to 2014 at Vienna Station, the monthly precipitation is used as the weight to obtain the monthly mean hydrogen and oxygen isotope. The monthly mean values of δD and $\delta^{18}O$ relatively small, which are higher in July and August and lower in December to February (Fig.1).

The frequency of the maximum and minimum δ values of hydrogen and oxygen isotopes in precipitation in each month of each year is analyzed by statistical method, as shown in Tab.1, the maximum of δD and $\delta^{18}O$ occur most frequently in July and August, 10 times in July and 16 times in August, accounting for 23.3% and 37.2% of the statistical years, respectively. The frequency of δ low value appeared highest in December and February, the frequency of δD minimum value was 11 times, 10 times and 13 times respectively, and the frequency of $\delta^{18}O$ minimum value was 12 times 10 times and 10 times respectively, which reached more than 70% of the statistical years. Therefore, the maximum monthly mean hydrogen and oxygen isotopes in precipitation at Vienna station mainly occur in July to August of each year, and the minimum mainly occur in December to February of each year, which is consistent with the results obtained from Fig. 1.

Compared with the global hydrogen and oxygen isotopes in precipitation, the δ value in Vienna is lower, indicating that the moisture sources is mainly marine air mass, and Vienna is mainly controlled by oceanic climate throughout the year. However, the δ value of hydrogen and oxygen isotopes from July to August is higher, which indicates that the contribution rate of moisture from land is large, and during this period, Vienna is mainly controlled by continental climate. It can also be found from Fig.1 that the change of the monthly mean d -excess in precipitation is not obvious, its average value is 6.9‰,

which is much smaller than the global average of 10‰, indicating that the moisture of precipitation in Vienna is relatively stable during the year and is mainly influenced

by warm and wet air mass.

The monthly variation of the slope and intercept of LMWL in Vienna is calculated by using the least

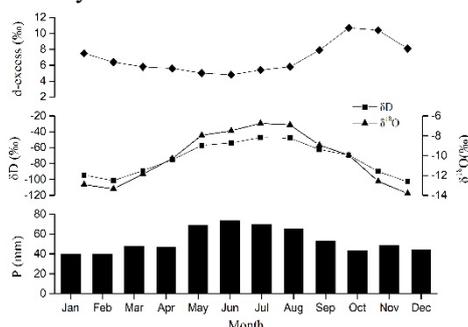


Figure 1. Variation trend of monthly precipitation, *d*-excess and hydrogen and oxygen values

Table 1. Frequency Statistics of monthly δ extremum of precipitation hydrogen and oxygen isotopes

| | | Month | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | Total |
|---------|----------------|--------------|------|------|-----|-----|------|-----|------|------|-----|------|------|------|-------|
| Maximum | δD | Frequency | 0 | 1 | 0 | 0 | 5 | 3 | 10 | 16 | 3 | 5 | 0 | 0 | 43 |
| | | Percentage/% | 0 | 2.3 | 0 | 0 | 11.6 | 7.0 | 23.3 | 37.2 | 7.0 | 11.6 | 0 | 0 | 100.0 |
| | $\delta^{18}O$ | Frequency | 0 | 1 | 1 | 1 | 4 | 3 | 10 | 16 | 3 | 4 | 0 | 0 | 43 |
| | | Percentage/% | 0 | 2.3 | 2.3 | 2.3 | 9.3 | 7.0 | 23.3 | 37.2 | 7.0 | 9.3 | 0 | 0 | 100.0 |
| Minimum | δD | Frequency | 10 | 13 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 11 | 43 |
| | | Percentage/% | 23.3 | 30.2 | 4.7 | 2.3 | 0 | 0 | 0 | 0 | 0 | 7.0 | 7.0 | 25.6 | 100.0 |
| | $\delta^{18}O$ | Frequency | 10 | 10 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 3 | 6 | 12 | 43 |
| | | Percentage/% | 23.3 | 23.3 | 2.3 | 2.3 | 0 | 0 | 0 | 0 | 0 | 7.0 | 14.0 | 27.9 | 100.0 |

square method, as shown in Fig.2, the monthly variation trend of the slope and intercept is basically the same, but the change of slope is relatively small. This is due to the uniform distribution of rainfall throughout the year in the Vienna and the small difference in isotope fractionation caused by evaporation of raindrops during the falling process, which makes the slope of the water line varies little in each month. It is proved that the moisture source in Vienna is mainly controlled by oceanic climate in another perspective. The slope and intercept range of October to March are relatively large, which may be due to the alternating control of oceanic climate and continental climate, high temperature variability and complicated source of moisture.

3.2 Trend analysis of annual hydrogen and oxygen isotope in precipitation

The annual mean values of δD and $\delta^{18}O$ in precipitation at Vienna station are -70.2 ‰ and -9.7 ‰ respectively, and the variation of hydrogen

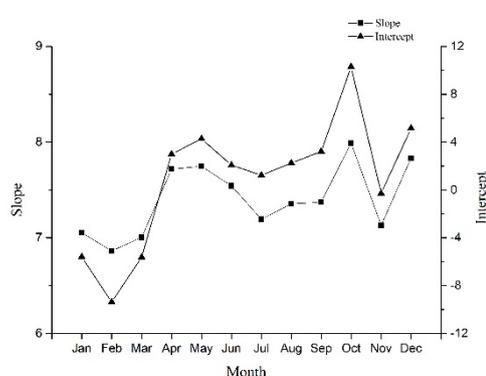


Figure 2. Monthly variation trend of slope and intercept of LMWL in Vienna

and oxygen isotopes in these 43 years is shown in Fig.3. The annual variation of δD and $\delta^{18}O$ is large, which is due to the alternation control of two climatic conditions in Vienna, the time difference of the two climate alternations each year and the difference of the precipitation intensity corresponding to the climate control. It was found from the linear regression made between δD , $\delta^{18}O$ in precipitation and time (Fig.3) that the annual mean δD and $\delta^{18}O$ time series showed an upward trend, and the rising rates were 1.7‰/10a and 0.3‰/10a, respectively, indicating that δD and $\delta^{18}O$ in precipitation were gradually enriched in Vienna from 1972 to 2014. Furthermore, M-K method was used to test the variation trend of annual mean δD and $\delta^{18}O$

(Tab.2). The δD test value Z_c is 1.58, passing the 0.1 significance test, and the $\delta^{18}O$ test value Z_c is 2.42,

passing the 0.01 significant test, indicating that $\delta^{18}O$ is increasing obviously.

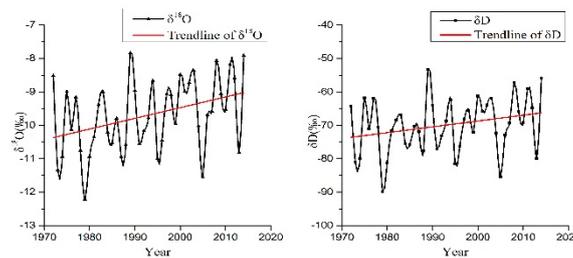


Figure 3. Variation trend of annual precipitation hydrogen and oxygen values

Table 2. Mann-Kendall test of annual mean hydrogen and oxygen isotopic composition

| | δD | $\delta^{18}O$ | d -excess |
|--------------------|------------|----------------|-------------|
| Z_c | 1.58* | 2.42** | -2.91** |
| Slope | 0.17 | 0.03 | -0.08 |
| Variation tendency | upward | upward | downward |

*, ** indicate a significance level of 0.1 and 0.01, respectively

The variation of d -excess during 43 years of precipitation in Vienna is statistically analyzed (Fig. 4). It can be found that the d -excess value is between 3.8‰ and 15.6‰, which average value is 7.5 ‰, and the decline rate is -0.8‰/10a. The MK test value Z_c is -2.91, passing the 0.01 significant test (Tab.2). The average annual d value is small, which indicates that the imbalance between evaporation and condensation in the precipitation process in Vienna is smaller than in other regions, and the precipitation is mostly controlled by marine moisture, which reflects the oceanic climate characteristics. In 1978, the value of d -excess is the highest (15.6‰), far higher than the other years, because the rainfall amount in this year(450mm) is less than that of 43 years, and the moisture evaporation rate was fast, resulting in a very high d value.

Because precipitation isotopes are very sensitive to the process of evaporation-condensation phase transition which is controlled by the temperature, so the slope and intercept of annual meteoric water line can be used to trace the phenomenon of below-cloud re-evaporation during precipitation. As shown in Fig.5, the inter-annual variation trend of slope and intercept in Vienna is basically the same, showing an upward trend, and is the same as that of precipitation, air temperature and water vapor pressure. The inter-annual variation of slope and intercept is evident because Vienna is controlled by both the

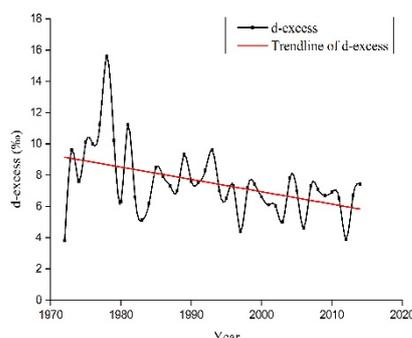


Figure 4. Variation trend of annual precipitation d -excess values

oceanic climate and the continental climate. The slope and intercept were both low in 1972,1998 and 2003. In 2003, the annual precipitation in Vienna was 446 mm, and the average annual temperature was 11°C. The high temperature and low precipitation resulted in strong evaporation and significant isotopic dynamic fractionation effect, so the slope and intercept are low. However, the low slope and intercept in 1972 and 2003 may be due to the below-cloud secondary evaporation caused by small rainfall events.

3.3 The periodic analysis hydrogen and oxygen Isotope in precipitation

Using Morlet wavelet analysis method, the fluctuation characteristics of δD and $\delta^{18}O$ at different

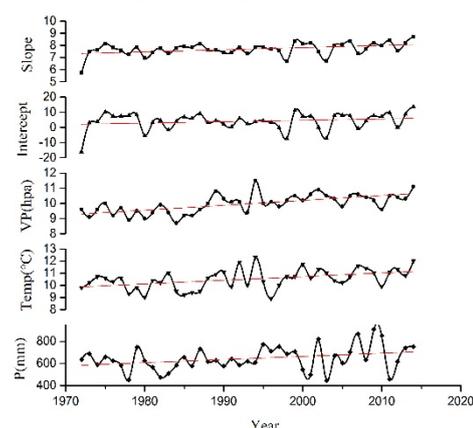


Figure 5. Annual variation trend of precipitation, temperature, vapor pressure, slope and intercept of LMWL in Vienna time scales are analyzed, and the real part isoline graphs (Fig.6) and variance diagrams (Fig.7) of wavelet transform coefficients are drawn according to the results of wavelet transform. The hydrogen and oxygen isotopes in precipitation have multi-time scale periodic variation characteristics, of which 9-16 years is obvious, the scale central is 13 years, and the positive and negative phases

alternately appear. The dashed line in Fig.8 gives the real part variation process of wavelet transform at 13-year scale, and the variation and abrupt point of hydrogen and oxygen isotopes in precipitation can be seen.

3.4 Study on the influence factors of hydrogen and oxygen Isotope in precipitation

The correlation between hydrogen and oxygen isotopes in monthly precipitation and temperature, precipitation and vapor pressure were analyzed by Spearman correlation analysis, and the results are shown in Tab.3.

In the middle and high latitudes of continental region, hydrogen and oxygen isotopes in precipitation have significant temperature effect, of which the principle is that the atmosphere and the fractionation of hydrogen and oxygen isotopes in precipitation are mainly controlled by the temperature during the phase transition [11,16]. It can be seen from Tab.3 that the Spearman correlation coefficients of δD and $\delta^{18}O$ in monthly precipitation and temperature are 0.756 and 0.763, respectively, which are significant correlation at a confidence level of 0.01. Therefore, there is a significant positive correlation between precipitation isotopes and temperature in Vienna.

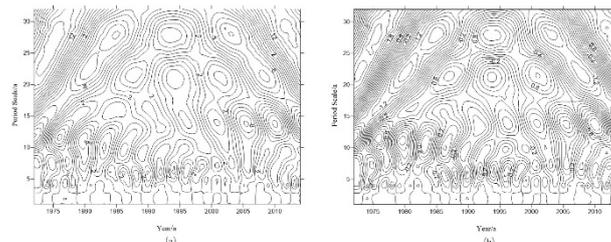


Figure 6. Wavelet transform coefficient contour map of annual mean δD (a) and $\delta^{18}O$ (b)

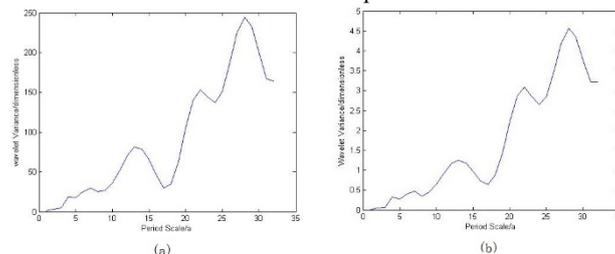


Figure 7. Wavelet transform coefficient variance diagram of annual mean δD (a) and $\delta^{18}O$ (b)

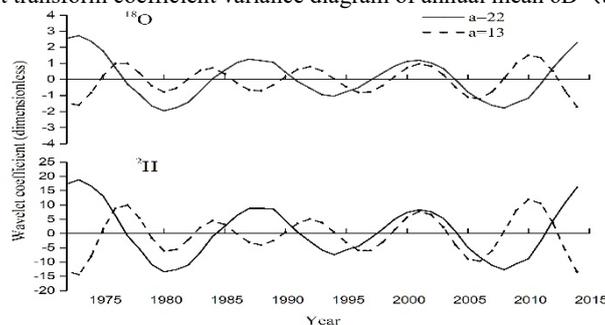


Figure 8. Variation of real part of wavelet transform coefficient of annual mean hydrogen and oxygen isotopic composition

Table 3. Correlation analysis of monthly stable isotope composition and meteorological factors

| Parameter | | Air Temperature | Precipitation | Vapor Pressure |
|----------------|-------------------------|-----------------|---------------|----------------|
| $\delta^{18}O$ | Correlation coefficient | 0.756** | -0.030 | 0.731** |
| | Significant probability | 0.000 | 0.507 | 0.000 |
| δD | Correlation coefficient | 0.763** | 0.004 | 0.745** |
| | Significant probability | 0.000 | 0.933 | 0.000 |

** indicate a significance level of 0.01

As is shown in Fig. 5, the time series of annual average temperature in many years fluctuate periodically, with an overall upward trend of $0.3^{\circ}C/10a$, which is the same as that of $\delta^{18}O$ in Fig.2. So, the precipitation hydrogen and oxygen isotopes in Vienna show significant temperature effect.

The formation mechanism of rainfall amount effect is quite complex, which depends on the evaporation

conditions of the moisture source area, the moisture transport process and the condensation degree during precipitation [17]. In Tab.3, the Spearman correlation coefficients of δD and $\delta^{18}O$ and precipitation are -0.030 and 0.004, respectively, which do not pass the significance test. indicating that there is no simple linear correlation between precipitation isotopes and precipitation in Vienna. The reason for this phenomenon is that the latitude of

Vienna area is higher, the annual precipitation is moderate and the monthly distribution is relatively uniform, and it also may be covered up by temperature effect. In order to eliminate the influence of temperature on the relationship between isotopes and precipitation, the partial correlation coefficient of $\delta^{18}\text{O}$ and precipitation is -0.291, and the correlation is significant at the confidence level of 0.01, which is far greater than the Spearman correlation coefficient -0.035. It can be shown that the relationship between the precipitation and isotopes in Vienna is indeed affected by the temperature effect, but the linear correlation between the two is still relatively weak.

The change of hydrogen and oxygen isotopes in precipitation is the result of the interaction of various climatic factors. The multiple linear regression of temperature, precipitation, water vapor pressure and hydrogen and oxygen isotopes is carried out, and 0.01 significance test is passed. The following linear equations were obtained:

$$\delta^{18}\text{O}=0.456T-0.019P-0.138V-12.13 \quad (R^2=0.601) \quad (1)$$

$$\delta\text{D}=3.273T-0.129P-0.556V-92.782 \quad (R^2=0.605) \quad (2)$$

Where T is temperature ($^{\circ}\text{C}$), P is precipitation (mm), and V is vapor pressure (hPa).

In Fig.3, the Spearman correlation coefficients of δD and $\delta^{18}\text{O}$ in monthly precipitation and vapor pressure are 0.756 and 0.763 respectively, which are significant correlation at a confidence level of 0.01, but the coefficient of vapor pressure in equation (1) and (2) is negative. This is because the Spearman correlation

analysis does not consider whether there is a collinearity or interaction between variables. The magnitude of vapor pressure is closely related to the speed of evaporation, and the speed is mainly controlled by temperature under certain conditions of water supply, so there is a high collinearity between temperature and vapor pressure. The partial correlation analysis of δD , $\delta^{18}\text{O}$ and vapor pressure was carried out with temperature as the control variable. The partial correlation coefficients are -0.84 and -1.22 respectively, and the correlation is not significant. It shows that there is no simple linear relationship between the precipitation isotopes and vapor pressure without considering the temperature.

In the 43-year monitoring data at Vienna station from 1972 to 2014, the monthly mean δD was absent for 17 times and $\delta^{18}\text{O}$ was absent for 14 times. The missing values of δD and $\delta^{18}\text{O}$ are calculated by using equations (1) and (2), and are compared with the corresponding monthly mean values for many years (Tab.4). The relative error between most of the calculated values and the monthly mean value is less than 10%, which indicates that the δ mean value of a certain month can be well calculated by using the temperature, precipitation and vapor pressure according to the equation (1) and (2). However, the individual error is close to 30%, which is because the variation of precipitation isotopes is the result of the interaction of many climatic environmental factors and human activities. The δ value in precipitation can not be accurately determined by only three climatic factors: temperature, precipitation and vapor pressure.

Table 4. The calculated values of missing month and GNIP monthly mean values in Vienna Station

| Date | Air Temperature ($^{\circ}\text{C}$) | Precipitation (mm) | Vapor Pressure (hpa) | Calculated (‰) | | monthly average (‰) | | Relative error (‰) | |
|------------|--|--------------------|----------------------|---------------------------|------------------|--------------------------------|------------------|-------------------------------|------------------|
| | | | | $\delta^{18}\text{O}$ | δD | $\delta^{18}\text{O}$ | δD | $\delta^{18}\text{O}$ | δD |
| 1972-02-15 | 3.1 | 54 | 6.5 | -12.64 | -93.22 | -13.34 | -101.52 | 5.27 | 8.18 |
| 1972-12-15 | 0.6 | 3 | 5.3 | -12.64 | -94.15 | -13.81 | -102.92 | 8.42 | 8.52 |
| 1974-08-15 | 21.5 | 19 | 16.5 | -4.96 | -34.04 | -6.90 | -47.80 | 28.09 | 28.80 |
| 1979-05-15 | 15.4 | 10 | 10.3 | -6.72 | -49.39 | -7.94 | -57.05 | 15.40 | 13.42 |
| 1979-06-15 | 19.8 | 159 | 15.5 | -8.26 | -57.11 | -7.50 | -53.96 | 10.18 | 5.82 |
| 1979-08-15 | 18.4 | 35 | 14.5 | / | -45.14 | -6.90 | -47.80 | / | 5.58 |
| 1980-10-15 | 9.5 | 73 | 9.1 | -10.44 | -76.17 | -9.95 | -69.23 | 4.89 | 10.02 |
| 1982-11-15 | 5.5 | 8 | 7.6 | -10.82 | -80.04 | -12.58 | -89.90 | 14.01 | 10.97 |
| 1987-01-15 | -4.4 | 82 | 3.7 | / | -119.82 | -12.91 | -94.37 | / | 26.96 |
| 1987-02-15 | 0.6 | 74 | 5.3 | / | -103.31 | -13.34 | -101.52 | / | 1.76 |
| 1990-01-15 | 0.8 | 3 | 5.6 | -12.59 | -93.66 | -12.91 | -94.37 | 2.45 | 0.75 |
| 1992-11-15 | 5.5 | 82 | 7 | -12.15 | -89.25 | -12.58 | -89.90 | 3.49 | 0.73 |
| 2000-11-15 | 7.6 | 33 | 8.5 | -10.46 | -76.89 | -12.58 | -89.90 | 16.86 | 14.48 |
| 2003-02-15 | -1.7 | 1 | 3.8 | -13.45 | -100.59 | -13.34 | -101.52 | 0.80 | 0.92 |
| 2003-07-15 | 21.6 | 36 | 16.8 | -5.28 | -36.07 | -6.74 | -47.10 | 21.58 | 23.42 |
| 2006-10-15 | 12.3 | 11 | 11.4 | -8.30 | -60.28 | -9.95 | -69.23 | 16.59 | 12.92 |
| 2014-01-15 | 2.2 | 8 | 6.4 | -12.16 | -90.17 | -12.91 | -94.37 | 5.80 | 4.45 |

4 Discussion

In this paper, the simple and statistical methods are used to analyze the monthly hydrogen and oxygen isotopic changes in precipitation. It is found that the monthly mean precipitation δ value in Vienna has little change in the whole year, but it still shows high value in summer and low value in winter, which is consistent with the change of GNIP's multi-year monthly-weighted average δ value. The monthly d -excess change is not obvious and is much smaller than the global average of 10‰. Therefore, it is considered that the precipitation source in the Vienna area is relatively stable during the year, mainly affected by the maritime climate. This is similar to the previous results. Li Guang [18] studied the precipitation isotopes in wet season from 2009 to 2012 and the value of d -excess is 6.5‰. The precipitation in wet season was mainly controlled by the marine air mass, resulting in a low d value. Hu Haiying et al. [13] believed that the difference in d -excess between the dry season and the wet season in Hong Kong is not significant, reflecting its stable moisture source. The average monthly slope and intercept of the LMWL in Vienna is not large. From another perspective, the result suggests that the annual moisture source in Vienna is mainly controlled by maritime climate.

The inter-annual variation of the δD and $\delta^{18}O$ values in the annual precipitation in Vienna is large, and the slope and intercept variation of the LMWL are also obvious. This is because Vienna is controlled by both the maritime climate and the continental climate. The temporal difference between the two climatic conditions and the precipitation intensity formed by the corresponding climate control are different, which results in large inter-annual variation of δ value and large difference in isotopic dynamic fractionation. This accounts for the significant change of slope and intercept. The results are consistent with the study on the slope and intercept of the 15-year LMWL in Kunming Carried by Wen Xinyu [19]. In addition, both linear regression and MK test indicate that the δD and $\delta^{18}O$ time series are on the upward trend, therefore it is considered that the precipitation isotopes in Vienna are enriched year by year.

Using Morlet wavelet to analyze the fluctuation characteristics of δD and $\delta^{18}O$ at different time scales, it is found that the annual mean precipitation hydrogen and oxygen isotopes in Vienna have multi-time scale periodic variation characteristics, which is most obvious in 18~29 years, and the scale center is 22 and 27 years, respectively. However, the 27-year scale is more than half of the 43-year time series, the accuracy and representativeness of the periodic variation at this time scale are not rigorous. Previous studies have shown that the sunspot has a shock period of 22 years, and sunspot activity has good response relationships with the global climate anomalies and the atmospheric circulation [20]. Therefore, in this paper, hydrogen and oxygen isotopic changes and the distribution of the mutation points at the central time scale of 22 years are focuses on, and it is concluded that the annual mean hydrogen and oxygen isotope values will be partially enriched at the 22-year scale after 2011.

It is found that the variation of the average hydrogen

and oxygen isotope in monthly precipitation in Vienna has significant temperature effect, but no rainfall amount effect. There is no simple linear relationship between isotopic variation and vapor pressure. This is similar to the precipitation hydrogen and oxygen isotope changes of northeast China [21]. The relationship between δ values and temperature, precipitation and vapor pressure is obtained by multiple linear regression. The 0.01 significance test has been passed and the δD and $\delta^{18}O$ of the missing month are estimated.

In this paper, a variety of statistical analysis methods are used to study the monthly, annual and periodic variations of precipitation isotopes in Vienna station, which can predict the changes of hydrogen and oxygen isotopes in precipitation in a certain period scale. In addition, the correlation equations between isotopic values and meteorological factors can be used to estimate and interpolate the missing data of Vienna station to a certain extent. However, the accuracy of the periodic variation of hydrogen and oxygen isotopes obtained by wavelet analysis is limited by the length of the analysis sequence. To predict the periodic variation more accurately, a longer continuous sequence and a more mature analysis method are needed. Moreover, the change of hydrogen and oxygen isotope in precipitation is the result of the interaction of various climatic environmental factors and human activities. It is still impossible to accurately determine the δ value in precipitation by the three meteorological factors of temperature, precipitation and moisture pressure. Therefore, it is necessary to increase the observation sequence and comprehensively consider the interaction of meteorological factors such as temperature with the latitude and longitude and elevation of hydrogen and oxygen isotope changes in the future.

5 Conclusion

Based on the monthly and annual time scales, this paper analyzes the isotopic changes in precipitation in Vienna during 43 years. Its influence factors and the following conclusions are drawn:

(1) The monthly δ value in precipitation in Vienna has not changed much in the whole year. The high value is concentrated from July to August, and the low value is distributed from December to February. It is roughly the same as the temperature change period, indicating that Vienna is located in the transition zone between maritime and continental climate. The impact of maritime climate is more significant, and the control of continental climate mainly occurs from July to August.

(2) The variations of monthly mean d -excess and the slope and intercept of the LMWL in Vienna are closely related to its unique climate. The characteristics of maritime climate controlling the region throughout the year make d -excess a small overall change. The slope and intercept amplitudes are relatively large in October and March, which is due to the large temperature variability and complex moisture sources caused by alternate control of maritime and continental climate in Vienna from October to March.

(3) The precipitation isotopes in Vienna show an inter-

annual trend of annual enrichment, showing significant temperature effects, but no rainfall amount effect, and there is no simple linear relationship between isotopic variation and vapor pressure. The multivariate regression relationship established by δD and $\delta^{18}O$ with three climate parameters of temperature, precipitation and vapor pressure can quantitatively estimate the missing value in isotopic data.

(4) The annual mean precipitation hydrogen and oxygen isotopes in Vienna has multi-time scale periodic variation characteristics, of which 18~29 years are the most obvious, the scale centers are 22 years and 27 years respectively, and it is inferred that the annual mean values of hydrogen and oxygen isotopes will be enriched at the 22-year scale after 2011.

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