https://doi.org/10.5194/essd-2025-805
Preprint. Discussion started: 10 March 2026
© Author(s) 2026. CC BY 4.0 License.

Open Access Earth System Science Data Discussions

Correspondence Authors:

Name： Guofeng Zhu[1,2*]

Institution:

[1] *College of Geography and Environment Science, Northwest Normal University, Lanzhou 730070, Gansu, China*

[2] *Shiyang River Ecological Environment Observation Station, Northwest Normal University, Lanzhou 730070, Gansu, China*

Address:

College of Geography and Environment Science of Northwest Normal University, 967，East Road, Lanzhou, Gansu, China 730070.

Tel: +86-13909310867

E-mail: zhugf@nwnu.edu.cn

https://doi.org/10.5194/essd-2025-805
Preprint. Discussion started: 10 March 2026
© Author(s) 2026. CC BY 4.0 License.

Open Access Earth System Science Data Discussions

Global Water Vapor Stable Isotope Dataset

Dongfei Yang[a,b,c], *Guofeng Zhu*[a,b,c,d,*], *Jiangwei Yang*[a,b,c], *Rui Li*[a,b,c], *Qinqin Wang*[a,b,c], *Xiaoxiao Su*[a,b,c], *Yitian Lei*[a,b,c], *Yurou Zhang*[a,b,c], *Wenjing Liu*[a,b,c], *Kang Ning*[a,b,c],*Xinyue Wang*[a,b,c],*Yaxin Li*[a,b,c]

Affiliations:

[a] *College of Geography and Environment Science, Northwest Normal University, Lanzhou 730070, Gansu, China*

[b] *Shiyang River Ecological Environment Observation Station, Northwest Normal University, Lanzhou 730070, Gansu, China*

[c] *Key Laboratory of Resource Environment and Sustainable Development of Oasis, Gansu Province, Lanzhou 730070, Gansu, China*

[d] *Lanzhou Branch, Remote Sensing Application Center, Ministry of Agriculture and Rural Affairs, Lanzhou 730070, Gansu,China*

[*] *Correspondence to: Guofeng Zhu (zhugf@nwnu.edu.cn)*

Abstract: Stable isotopes in atmospheric water vapor (reported as δ^2H and δ^{18}O relative to VSMOW) provide valuable constraints on moisture sources, transport, and phase-change fractionation. Yet available observations remain fragmented across platforms, regions, and time periods, and cross-study comparison is often hindered by inconsistent metadata, calibration reporting, and quality-control practices. Here we compile and harmonize a global near-surface water vapor isotope dataset from three sources: the WaterIsotopes Database (wiDB; http://wateriso.utah.edu/waterisotopes),

https://doi.org/10.5194/essd-2025-805
Preprint. Discussion started: 10 March 2026
© Author(s) 2026. CC BY 4.0 License.

PANGAEA (https://www.pangaea.de), and peer-reviewed literature. The dataset spans 1981–2021 and contains 87,138 records from 112 sites/platforms. We standardized coordinates to WGS84, timestamps to UTC when possible, isotope units to per mil (‰) in delta notation, and compiled measurement metadata (instrument, method, and model where explicitly reported; e.g., Picarro CRDS, LGR OA-ICOS, IRMS following cryogenic trapping, and satellite retrieval products). A transparent quality-control workflow was applied to identify duplicates, inconsistent metadata, and implausible or poorly documented values, while preserving traceability to original sources. The resulting product provides a consistent observational basis for model evaluation and for comparative studies of water vapor isotope variability across climates and observation strategies. The Global Water Vapor Stable Isotope Dataset is available at https://doi.org/10.6084/m9.figshare.30893984 (Zhu and Yang, 2025).

Keywords: atmospheric water vapor; stable isotopes; dataset; Spatiotemporal Patterns；quality control

1 Introduction

The water cycle is a central component of the Earth's climate system, and its dynamic variations directly influence the global energy balance, ecosystem succession, and water resource distribution (Shi et al., 2022). Under global change, the water cycle is undergoing significant alterations, with its spatial–temporal distribution and variability showing new characteristics (Ren et al., 2024), such as enhanced evaporation, restructured precipitation patterns, and more frequent extreme hydrological events (Bingham and Bayler, 2025; Colman and Soden, 2021). Stable

https://doi.org/10.5194/essd-2025-805
Preprint. Discussion started: 10 March 2026
© Author(s) 2026. CC BY 4.0 License.

isotopes, as natural tracers of water vapor transport and phase change processes (Shang et al., 2024), provide a unique perspective for understanding the dynamic mechanisms of the atmospheric water cycle (Gimeno et al., 2020). The fractionation effects of isotopes are closely related to temperature, humidity, vapor source regions, and transport pathways (Xu et al., 2022), making them a link between microscopic phase-change processes and the macroscopic climate system (Galewsky et al., 2016).

In recent years, advances in laser absorption spectroscopy have enabled high-frequency and continuous measurements of water vapor isotopes (Wei et al., 2019), while satellite retrievals have made it possible to observe their three-dimensional global distribution (Yang et al., 2023); Multi-platform collaborative observations have preliminarily integrated precipitation, surface water, and water vapor isotope data (Chen et al., 2024; Li et al., 2025); Isotope-enabled general circulation models (iGCMs) (Jouzel et al., 2013; Peng et al., 2020) enhance the analysis of source regions, transport, and phase-change processes by explicitly simulating isotope fractionation (Leroy-Dos Santos et al., 2023). However, inconsistencies in sampling strategies, quality control, and calibration systems among different data sources make cross-regional and intertemporal comparisons susceptible to systematic errors (Voglar et al., 2019).

At present, the driving mechanisms underlying variations in water vapor isotopes remain inadequately understood (Galewsky et al., 2023; Xing et al., 2023; Xu et al., 2024). Under global warming, the combined effects of source-region relative humidity, land – sea thermal contrast, convective depth, and re-evaporation cause stable

https://doi.org/10.5194/essd-2025-805
Preprint. Discussion started: 10 March 2026
© Author(s) 2026. CC BY 4.0 License.

isotopes in water vapor to exhibit pronounced nonlinear responses and spatiotemporal heterogeneity to climatic forcing; Isotopic signals are further modulated by the interplay between multi-scale circulation modes and boundary-layer processes (Saranya et al., 2018), forming complex feedback mechanisms. Without a unified and comparable data framework, it is difficult to robustly disentangle the contributions of source-region conditions, transport pathways, and cloud microphysical processes, or to quantify the marginal role of water vapor recycling in extreme events (Wang et al., 2023a). This theoretical gap constrains the examination of the formation mechanisms and interdecadal variations of the “first-order spatial framework” (low-latitude enrichment–high-latitude depletion and progressive depletion from ocean to land). Moreover, recent studies (Gimeno et al., 2021; Lu et al., 2024; Smith and Lacey, 2024; Zhu et al., 2023) show that arid regions exhibit systematic isotope enrichment and rising d-excess, whereas responses in high-latitude and oceanic regions are relatively subdued. Such regionally differentiated responses require integrated analyses based on unified datasets to disentangle multi-process interactions, clarify causal relationships, and identify the critical thresholds and strengths of feedback mechanisms.

In arid and semi-arid regions, intensified precipitation variability and evapotranspiration imbalance have exacerbated conflicts between water supply and demand. Isotopic data can be used to identify re-evaporation intensity and the contribution of upstream moisture transport (Fang et al., 2022), providing a scientific basis for drought monitoring and water allocation decisions; In monsoon–westerly

https://doi.org/10.5194/essd-2025-805
Preprint. Discussion started: 10 March 2026
© Author(s) 2026. CC BY 4.0 License.

interaction zones, phase shifts in moisture pathways and convective activity amplify precipitation extremes. Coupling analyses of d-excess and isotope – climate indicators can identify source-region transitions (Tharammal et al., 2023) and enhanced vapor recycling in advance, which is valuable for early warning of extreme precipitation events; In high-latitude and polar regions, sea-ice melting and the expansion of open water modify local evaporation and boundary-layer structure (Rozmiarek et al., 2025). Abnormal d-excess values provide independent constraints on ice – atmosphere interactions and freshening effects, which are crucial for assessing the hydrological and climatic impacts of sea-ice decline (Klein et al., 2015). The combination of regional challenges and societal demands — such as intensified droughts, greater precipitation variability, and more frequent extreme events — calls for the rapid establishment of standardized datasets and comparable analytical frameworks to support water resource management, extreme event attribution, and climate resilience building (Baijuan et al., 2023).

To address the above challenges and demands, this study aims to solve the following core issues: (1) to establish a high-resolution global water vapor isotope dataset; and (2) to identify the dynamic processes of the atmospheric water cycle based on the global water vapor isotope data. The outcomes of this study will provide essential validation benchmarks for global hydroclimate models and support sustainable water resource management and the development of climate-resilient societies.

2 Data and methods

https://doi.org/10.5194/essd-2025-805
Preprint. Discussion started: 10 March 2026
© Author(s) 2026. CC BY 4.0 License.

112 2.1 Data sources and collection

113 The dataset consists of three main components: data from the Global Network of
114 Isotopes in Water (http://wateriso.utah.edu/waterisotopes), data from the World Data
115 Center PANGAEA (https://www.pangaea.de), and isotopic data retrieved from
116 published literature. The dataset includes 87,138 records from various continents.
117 Literature-based data were systematically retrieved from the Web of Science database
118 using keyword combinations such as “isotope” and “atmospheric water,” along
119 with Boolean logic (Wang et al., 2023b). Based on quality control, targeted selection
120 and supplementation were carried out for underrepresented regions, thereby filling
121 spatial gaps and enhancing the dataset’s global representativeness and regional
122 coverage. We selected academic papers providing isotopic data in text, table, or figure
123 formats as the main data sources to improve data accuracy. The selected studies
124 explicitly identified the water type as "atmospheric water." In addition to isotopic data,
125 we also collected spatiotemporal information of sampling sites, including geographic
126 coordinates (latitude and longitude), exact sampling time, and elevation.

127 Moreover, the global climate classification data used in this study were derived
128 from the Köppen Global Climate Classification (Beck et al., 2018).

129

130

https://doi.org/10.5194/essd-2025-805
Preprint. Discussion started: 10 March 2026
© Author(s) 2026. CC BY 4.0 License.

Open Access Earth System Science Data Discussions

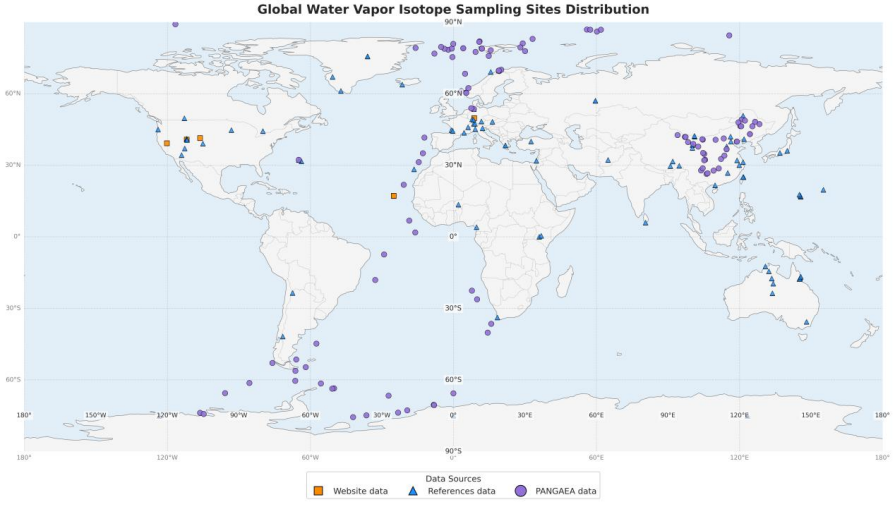


Figure 1: Spatial distribution of sampling sites in the global atmospheric water vapor stable isotope dataset.

2.2 Instrumentation and measurement uncertainties

Atmospheric water vapor isotope observations included in this compilation originate from heterogeneous measurement approaches. Because the dataset aggregates values reported by different research groups rather than reprocessing raw spectroscopic or mass-spectrometric signals, we document the instrumentation and measurement method as reported in the original sources and summarize major uncertainty drivers that users should consider when comparing records across sites and platforms (Table S1).

2.2.1 In situ laser spectroscopy (Picarro CRDS and LGR OA-ICOS)

A substantial fraction of near-surface, high-frequency observations are based on laser absorption spectroscopy, mainly cavity ring-down spectroscopy (CRDS) analyzers from Picarro (e.g., L1102-i, L1115-i, L2120-i, L2130-i, L2140-i; model

https://doi.org/10.5194/essd-2025-805
Preprint. Discussion started: 10 March 2026
© Author(s) 2026. CC BY 4.0 License.

146 names as reported) and off-axis integrated cavity output spectroscopy (OA-ICOS)
147 analyzers from Los Gatos Research (LGR) (e.g., WVIA series and related LGR
148 instruments; model names as reported). These instruments measure water vapor
149 mixing ratio and isotopic composition continuously, but their effective precision and
150 accuracy depend on humidity level, inlet configuration, calibration strategy, and
151 maintenance.

152 Key uncertainty sources for laser-based vapor isotope measurements include:

153 (i) humidity dependence of isotopic retrievals (especially at low water vapor
154 concentrations),

155 (ii) instrument drift and calibration-scale transfer to VSMOW,

156 (iii)memory effects caused by adsorption/desorption in tubing and internal
157 surfaces,

158 (iv)spectral interferences and pressure/temperature sensitivity, and

159 (v) condensation risks in sampling lines (which can induce fractionation).

160 Many source studies mitigate these effects using multi-point or two-point
161 calibration with laboratory standards and frequent checks; when such information is
162 explicitly reported, it is captured in the metadata fields of this dataset.

163 **2.2.2 Cryogenic trapping followed by IRMS**

164 Some records are derived from cryogenic trapping of atmospheric water vapor
165 (e.g., trapping at very low temperatures) followed by laboratory isotope-ratio mass
166 spectrometry (IRMS) of the condensed water (e.g., Finnigan/Thermo IRMS systems
167 such as DELTA V Plus with GasBench; other models as reported). IRMS typically

https://doi.org/10.5194/essd-2025-805
Preprint. Discussion started: 10 March 2026
© Author(s) 2026. CC BY 4.0 License.


provides high analytical precision for $\boldsymbol{\delta^{18}}$O and $\boldsymbol{\delta^{2}}$H under controlled laboratory conditions, but the overall uncertainty also reflects the vapor collection procedure.

Major additional uncertainty sources include:

(i) collection efficiency and representativeness of time-integrated samples,

(ii) potential fractionation during sampling/storage if evaporation occurs, and

(iii)blank effects or contamination in field handling.

Accordingly, IRMS-based values may be analytically precise yet temporally averaged and method-dependent.

2.2.3 Satellite retrieval products

A limited subset of isotope information may come from satellite retrieval products (e.g., TES on Aura retrieving $\boldsymbol{\delta D_v}$ from nadir-viewing infrared Fourier transform spectroscopy). Satellite products represent retrieval-based estimates with vertical sensitivity characteristics and averaging kernels; near-surface layers (e.g., 900 hPa products used in some studies) should therefore be interpreted as retrieval estimates rather than direct in situ measurements. Users should consider reported retrieval precision, degrees of freedom of signal, and recommended quality flags in the original product documentation.

2.2.4 Practical implications for cross-study comparability

To support reuse, we (i) record method class (in situ laser, cryogenic+IRMS, satellite retrieval) and (ii) capture instrument/method/model information when explicitly provided. Users conducting quantitative syntheses should account for method-specific uncertainties and sampling representativeness, and are encouraged to

https://doi.org/10.5194/essd-2025-805
Preprint. Discussion started: 10 March 2026
© Author(s) 2026. CC BY 4.0 License.

apply additional filters (e.g., humidity thresholds for laser instruments or product quality flags for satellite retrievals) consistent with their scientific objectives.

2.3 Data processing and quality control

To ensure consistency across heterogeneous sources, we applied a standardized harmonization and quality-control workflow to all records. This workflow focuses on metadata and value integrity and preserves traceability to the original source.

(1) Data ingestion and formatting. Records were collected from wiDB, PANGAEA, and peer-reviewed literature (tables, supplementary files). All fields were converted into a unified tabular format with consistent variable names and units.

(2) Coordinate and time standardization. Site coordinates were harmonized to WGS84 (latitude/longitude). Sampling time information was standardized to UTC when sufficient information was available; otherwise, the reported local time and its context were retained and flagged in metadata.

(3) Isotope notation and derived variables. Isotopic composition was stored in delta notation in per mil (‰) relative to VSMOW as reported by the source. When both δ^2H and δ^{18}O were available, d-excess was computed as $d = \delta^2\mathrm{H} - 8\,\delta^{18}\mathrm{O}$. We did not interpolate missing isotope values; missing entries remain as missing in the dataset.

(4) Duplicate detection and traceability. Potential duplicates across sources (e.g., identical site/time/value combinations appearing in multiple repositories or publications) were identified and consolidated while keeping the original source references.

(5) Plausibility checks and QC flags. We screened for inconsistent metadata (e.g., impossible coordinates, swapped latitude/longitude, unrealistic elevations), unit inconsistencies, and implausible isotope values. Records failing mandatory metadata requirements or showing clear formatting errors were corrected when the original source allowed unambiguous correction; otherwise, they were flagged. The dataset includes QC indicators to allow users to filter data according to their tolerance for uncertainty.

https://doi.org/10.5194/essd-2025-805
Preprint. Discussion started: 10 March 2026
© Author(s) 2026. CC BY 4.0 License.

Open Access Earth System Science Data Discussions

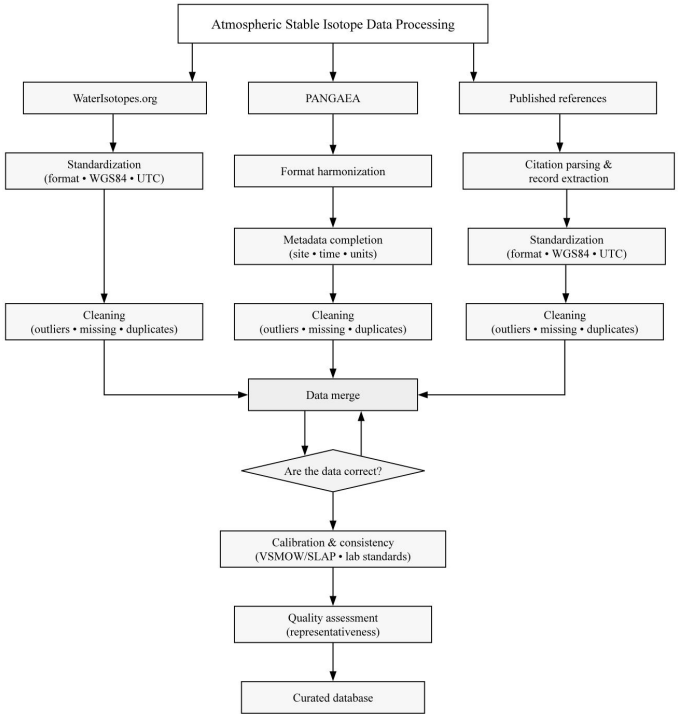


Figure 2: Data processing workflow of the global atmospheric water vapor stable isotope dataset.

3 Dataset Description

3.1 Dataset Overview

This dataset comprises 87,138 measurements of hydrogen and oxygen stable isotopes in atmospheric water vapor from 112 observation sites (Fig. 3). Specifically, it includes 53,617 isotope records from 6 observation sites on the Global Water Isotope Website, 29,100 records from 21 sites in the PANGAEA database, and 4,421 literature-derived records from 85 observation sites. We standardized and compiled the scattered observational data into a unified dataset, achieving spatial coverage from low to high latitudes and from continents to oceans. Importantly, the dataset covers

https://doi.org/10.5194/essd-2025-805
Preprint. Discussion started: 10 March 2026
© Author(s) 2026. CC BY 4.0 License.

regions traditionally lacking observations, including Greenland, Iceland, Africa, Antarctica, and adjacent oceanic areas, while maintaining dense observation sites in key regions such as North America, the Mediterranean coast, and the western Pacific margin, thus significantly enhancing global representativeness. The literature-derived data span a wide temporal range, encompassing both high-frequency short-term sequences and multi-year station or experimental observations. The PANGAEA data are mainly distributed in the Atlantic Ocean and adjacent coastal regions, with sampling largely derived from cruises or continuous station observations; these data are temporally concentrated and highly continuous. Data from the Global Water Isotope Website are more geographically clustered, primarily in mid-latitude inland urban regions, with high sampling frequency and relatively continuous temporal coverage.

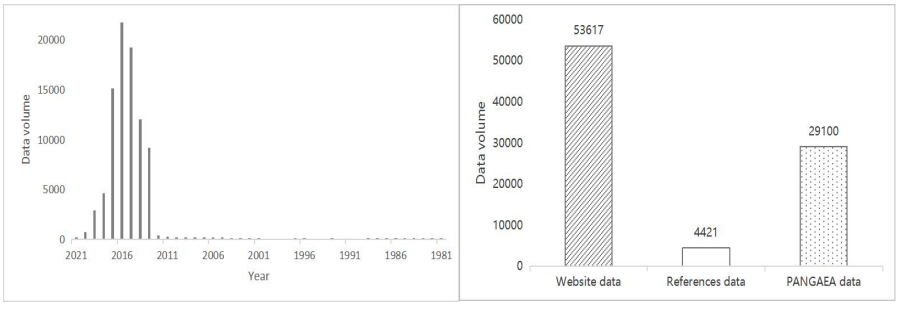


Figure 3: Time series and categories of the global atmospheric water vapor stable isotope dataset.

3.2 Spatiotemporal Patterns in Atmospheric Water Vapor Isotopes

Based on water vapor isotope data collected from global observation stations and reanalysis datasets, we standardized the data format and applied quality control, calculated the deuterium excess (d-excess), and aggregated annual data by taking the median within 3° grid cells. Spatial mapping employed segmented discrete color

https://doi.org/10.5194/essd-2025-805
Preprint. Discussion started: 10 March 2026
© Author(s) 2026. CC BY 4.0 License.

scales to enhance regional comparability and suppress the influence of outliers. Figure 4 presents the global distributions of $\delta^{2}H$, $\delta^{18}O$, and d-excess under annual conditions, while Figure 5 shows boxplot statistics for tropical, arid, temperate, continental, and polar regions across the four seasons.

Spatially, both $\delta^{2}H$ and $\delta^{18}O$ exhibit a "double gradient": enrichment at low latitudes and depletion toward high latitudes; enrichment near the coastlines and gradual depletion inland (Fig. 4). High values over subtropical to tropical oceans indicate enrichment in warm, high-evaporation source regions; along the main transport pathways extending inland and poleward, isotope ratios become progressively lighter with decreasing temperature and stronger condensation (Ruan et al., 2023), reaching the lowest values in polar regions. Pronounced gradients appear in the transition zones between monsoon and westerly circulation systems and at continental–oceanic boundaries. The d-excess demonstrates a complementary pattern: it is higher over arid continents and subsidence zones, indicating enhanced non-equilibrium evaporation and re-evaporation; it is lower over humid oceans and deep convective regions, reflecting dominant near-equilibrium evaporation and strong condensation processes.

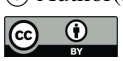
Seasonally, all climate zones exhibit clear annual cyclic patterns, though differing in amplitude and phase. The tropics show the smallest seasonal differences, with slight enrichment in summer and depletion in winter. Arid regions exhibit the largest amplitudes, with marked enrichment during summer due to non-equilibrium evaporation, and depletion in autumn and winter as temperature and evaporation

https://doi.org/10.5194/essd-2025-805
Preprint. Discussion started: 10 March 2026
© Author(s) 2026. CC BY 4.0 License.

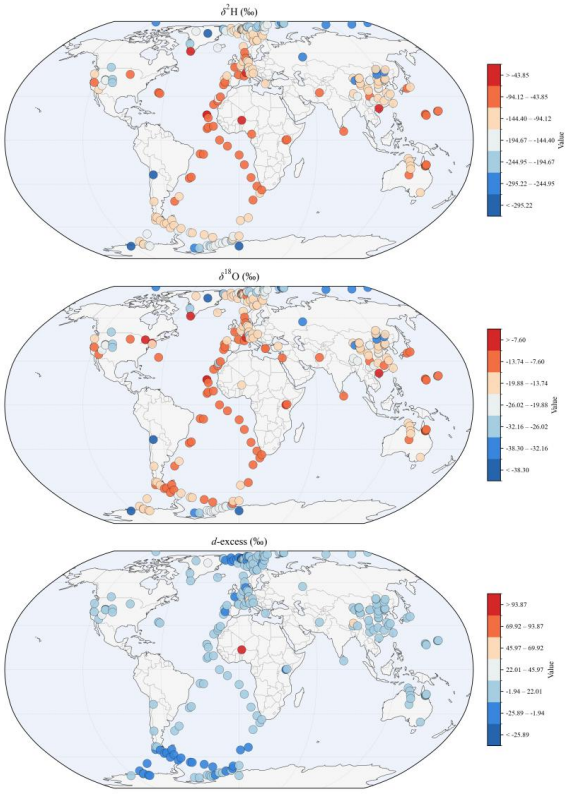
decrease. Temperate regions display a "summer-enriched, winter-depleted" pattern, consistent with their regional annual temperature variations. In continental regions, long-range transport and re-evaporation amplify the seasonal amplitude, with the lowest values in winter and secondary maxima in summer; spring shows increased dispersion due to snowmelt and circulation transitions (Hua et al., 2017). Overall, polar regions are the most depleted, with small amplitude — slight enrichment in summer and the lowest values in winter under strong low-temperature fractionation.

In terms of dispersion, arid and continental regions display the widest boxplots, indicating a higher likelihood of extreme values under interannual climate variability and surface heterogeneity (e.g., lake/river evaporation, irrigation recharge, anthropogenic water use). The tropics and polar regions show smaller dispersions, corresponding respectively to near-equilibrium processes under high humidity and stable fractionation dominated by low temperatures. $\delta^{2}H$ and $\delta^{18}O$ display high consistency in seasonal phase and stable amplitude ratios, indicating co-control by evaporation–condensation processes. However, in arid regions and during summer, $\delta^{2}H$ is more sensitive to non-equilibrium evaporation, showing stronger responses than $\delta^{18}O$.

https://doi.org/10.5194/essd-2025-805
Preprint. Discussion started: 10 March 2026
© Author(s) 2026. CC BY 4.0 License.

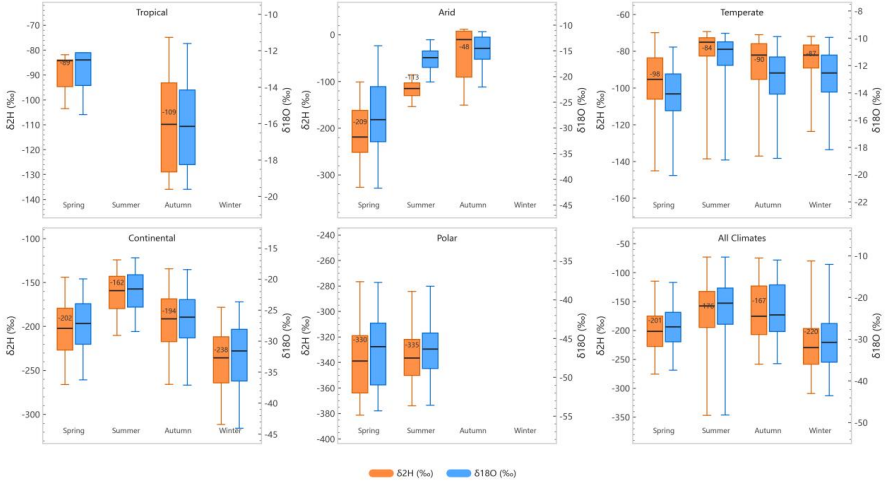


Open Access Earth System Science Data Discussions



289

290 **Figure 4:** Spatial distribution of δ²H and δ¹⁸O in global atmospheric water vapor.



291

292 **Figure 5:** Seasonal variations of δ²H and δ¹⁸O in atmospheric water vapor across different climate

293 zones.

https://doi.org/10.5194/essd-2025-805
Preprint. Discussion started: 10 March 2026
© Author(s) 2026. CC BY 4.0 License.

294 In summary, global atmospheric water vapor isotopes exhibit a spatial pattern of
295 “enrichment in low-latitude and arid regions, and depletion in high-latitude and inland
296 areas.” Temporally, isotope variations are coupled with temperature and evaporation:
297 amplitudes are larger in arid and continental regions, but smaller in tropical and polar
298 regions.

299 3.3 Uncertainty and outlook

300 At present, limited by sampling technologies and methods, the sampling
301 frequency, observation duration, and analytical procedures vary across different
302 climatic regimes. The spatial distribution of observation sites is uneven, and the
303 establishment of long-term continuous monitoring is constrained by cost, labor,
304 equipment, and environmental conditions. Consequently, data continuity and
305 completeness across spatial and temporal scales remain limited—especially in
306 high-latitude regions and harsh environments such as deserts and rainforests, where
307 observations are sparse—thus constraining the reliability of regional comparisons
308 (Smedsrud et al., 2022). In addition, differences in sample preservation conditions,
309 analytical techniques, and instrument precision may introduce systematic errors,
310 reducing the comparability and overall reliability of multi-source datasets. Although
311 the present study applies unified calibration as far as possible, achieving consistency
312 and precision at a global scale remains a significant challenge.

313 In the future, continuous high-frequency observation networks could be
314 established in data-sparse regions such as arid zones and polar areas to reduce
315 uncertainties in quantifying nonequilibrium processes and moisture recycling (Zhu et

https://doi.org/10.5194/essd-2025-805
Preprint. Discussion started: 10 March 2026
© Author(s) 2026. CC BY 4.0 License.

al., 2022). Unified standards for sampling, preservation, analysis, and quality control should be established and promoted. In addition, metadata cataloging and traceable data sharing should be improved to build a high-quality global atmospheric water isotope database. On this basis, multi-source integration of ground-based, remote-sensing, and reanalysis datasets should be advanced (Li et al., 2024). By coupling artificial intelligence with reanalysis products (e.g., ERA5, MERRA-2) and applying multivariate decomposition and causal inference frameworks, contributions of driving factors can be quantitatively assessed. Consequently, this would enable robust characterization of evaporation–transport–condensation linkages and recycling processes, narrowing structural and parametric uncertainties, improving predictability from event to decadal scales, and elevating isotopes from "tracer information" to "decision variables." Such progress would provide traceable evidence for drought early warning, extreme precipitation attribution, ecological water allocation, and cross-regional coordination—thus supporting higher-quality water and climate governance with reduced uncertainty(Grafton et al., 2013).

4 Data availability

The global atmospheric water vapor stable isotope dataset has been publicly released and is available at https://doi.org/10.6084/m9.figshare.30893984 (Zhu and Yang, 2025). Files and accompanying metadata (e.g., variable definitions, source references, and processing notes) are provided on the repository landing page. Users are encouraged to cite the DOI and the original data sources when reusing the dataset.

5 Conclusion

https://doi.org/10.5194/essd-2025-805
Preprint. Discussion started: 10 March 2026
© Author(s) 2026. CC BY 4.0 License.


This data description paper delivers a traceable, harmonized compilation of near-surface atmospheric water vapor stable isotopes (reported as δ^2H and δ^{18}O relative to VSMOW) by integrating three complementary sources: the WaterIsotopes Database (wiDB), PANGAEA, and peer-reviewed literature. The primary contribution is not a new interpretation of vapor isotope variability, but a documented workflow that converts heterogeneous observations into a single product that is easier to discover, filter, and reuse across disciplines and regions.

To construct the dataset, we consolidated records from repositories and publications into a unified tabular structure and preserved links to original sources for each entry. We standardized spatial metadata by harmonizing coordinates to WGS84 and checked for common geolocation issues. We harmonized temporal information by converting timestamps to UTC when sufficient time-zone information was available, while retaining and flagging records whose time reference could not be unambiguously converted. Isotope values were stored consistently in delta notation in per mil (‰) on the VSMOW scale as reported by the source, and d-excess was computed where both δ^2H and δ^{18}O were available. Importantly, We did not attempt to enforce data continuity by filling gaps (e.g., via interpolation or other imputation methods); instead, we retained missing entries as missing to preserve the original values and their reported accuracy.

Because comparability depends strongly on measurement strategy, we compiled instrumentation metadata (instrument/method/model when explicitly reported) and categorized observations by method class, including in situ laser spectroscopy

https://doi.org/10.5194/essd-2025-805
Preprint. Discussion started: 10 March 2026
© Author(s) 2026. CC BY 4.0 License.


(Picarro CRDS; LGR OA-ICOS), cryogenic trapping followed by IRMS, and satellite retrieval products. We applied transparent quality-control checks to identify duplicates across sources, inconsistent metadata, unit/format issues, and implausible or poorly documented records, using QC flags to support user-defined filtering while maintaining traceability.

The resulting dataset is intended to support (i) evaluation and benchmarking of isotope-enabled models, (ii) cross-site comparisons under different climates and observation protocols, and (iii) synthesis studies of boundary-layer and land–atmosphere water-cycle processes. Users are encouraged to account for method-dependent uncertainties and sampling representativeness using the provided metadata and QC indicators. Future updates can extend temporal coverage, incorporate newly published datasets, and improve the completeness of instrument and calibration documentation where available.

Author contributions

Dongfei Yang: Writing-Original draft preparation; Guofeng Zhu: Writing-Reviewing and Editing; Jiangwei Yang: Methodology; Rui Li: Methodology; Qinqin Wang: Validation; Xiaoxiao Su: Investigation; Yitian Lei: Investigation; Yurou Zhang: Investigation; Wenjing Liu: Investigation; Kang Ning: Investigation; Xinyue Wang: Investigation; Yaxin Li: Investigation;

Conflict of Interest Statement

The authors declare that they have no known competing financial interests or

https://doi.org/10.5194/essd-2025-805
Preprint. Discussion started: 10 March 2026
© Author(s) 2026. CC BY 4.0 License.

382 personal relationships that could have appeared to influence the work reported in this
383 paper.

384 **Disclaimer**

385 Publisher's note: Copernicus Publications remains neutral with regard to
386 jurisdictional claims made in the text, published maps, institutional affiliations, or any
387 other geographical representation in this paper. While Copernicus Publications makes
388 every effort to include appropriate place names, the final responsibility lies with the
389 authors.

390 **Acknowledgments**

391 The authors would like to thank Gabriel J. Bowen for his contributions to the
392 wiDB database and the International colleagues for their outstanding contributions
393 with respect to the World Data Center PANGAEA dataset. Finally, the authors thank
394 all of the researchers and institutions that provided data.

395 **Financial support**

396 This research was financially supported by the National Natural Science
397 Foundation of China (42371040), the Key Natural Science Foundation of Gansu
398 Province (23JRRA698), the Western Light Young Scholars Program of the Chinese
399 Academy of Sciences(25JR6KA001),the Key Research and Development Program of
400 Gansu Province (22YF7NA122), the Gansu Provincial Basic Research Innova ion
401 Group Project (22JR5RA129), the Water Resources Science Experimental Research
402 and Technology Promotion Project of Gansu Provincial(25GSLK062), the Cultivation
403 Program of Major key projects of Northwest Normal University

https://doi.org/10.5194/essd-2025-805
Preprint. Discussion started: 10 March 2026
© Author(s) 2026. CC BY 4.0 License.

(NWNU-LKZD-202302), the Oasis Scientific Research achievements Breakthrough Action Plan Project of Northwest normal University (NWNU-LZKX-202303), the Special Project on Rural Revitalization and Food Security of he Ministry of Agriculture and Rural Affairs.

https://doi.org/10.5194/essd-2025-805
Preprint. Discussion started: 10 March 2026
© Author(s) 2026. CC BY 4.0 License.

References

Baijuan, Z., Zongxing, L., Qi, F., Baiting, Z., and Juan, G.: A review of isotope ecohydrology in the cold regions of Western China, Sci. Total Environ., 857, 159438, https://doi.org/10.1016/j.scitotenv.2022.159438, 2023.

Beck, H. E., Zimmermann, N. E., McVicar, T. R., Vergopolan, N., Berg, A., and Wood, E. F.: Present and future Köppen-Geiger climate classification maps at 1-km resolution, Sci. Data, 5, 180214, https://doi.org/10.1038/sdata.2018.214, 2018.

Bingham, F. M. and Bayler, E.: Intensifying Seasonality of the Global Water Cycle as Indicated by Sea Surface Salinity, Geophys. Res. Lett., 52, e2024GL111608, https://doi.org/10.1029/2024GL111608, 2025.

Chen, L., Wang, Q., Zhu, G., Lin, X., Qiu, D., Jiao, Y., Lu, S., Li, R., Meng, G., and Wang, Y.: Dataset of stable isotopes of precipitation in the Eurasian continent, Earth Syst. Sci. Data, 16, 1543–1557, https://doi.org/10.5194/essd-16-1543-2024, 2024.

Colman, R. and Soden, B. J.: Water vapor and lapse rate feedbacks in the climate system, Rev. Mod. Phys., 93, 045002, https://doi.org/10.1103/RevModPhys.93.045002, 2021.

Fang, L., Gao, R., Wang, X., and Liu, T.: Isotopes-based characterization of precipitation compositions and atmospheric water vapor sources over typical Eurasian steppes in south mongolian Plateau, J. Hydrol., 615, 128724, https://doi.org/10.1016/j.jhydrol.2022.128724, 2022.

Galewsky, J., Steen-Larsen, H. C., Field, R. D., Worden, J., Risi, C., and Schneider, M.: Stable isotopes in atmospheric water vapor and applications to the hydrologic cycle, Rev. Geophys., 54, 809–865, https://doi.org/10.1002/2015RG000512, 2016.

Galewsky, J., Schneider, M., Diekmann, C., Semie, A., Bony, S., Risi, C., Emanuel, K., and Brogniez, H.: The Influence of Convective Aggregation on the Stable Isotopic Composition of Water Vapor, AGU Adv., 4, e2023AV000877, https://doi.org/10.1029/2023AV000877, 2023.

Gimeno, L., Vázquez, M., Eiras-Barca, J., Sorí, R., Stojanovic, M., Algarra, I., Nieto, R., Ramos, A. M., Durán-Quesada, A. M., and Dominguez, F.: Recent progress on the sources of continental precipitation as revealed by moisture transport analysis, Earth-Sci. Rev., 201, 103070, https://doi.org/10.1016/j.earscirev.2019.103070, 2020.

Gimeno, L., Eiras-Barca, J., Durán-Quesada, A. M., Dominguez, F., Van Der Ent, R., Sodemann, H., Sánchez-Murillo, R., Nieto, R., and Kirchner, J. W.: The residence time of water vapour in the atmosphere, Nat. Rev. Earth Environ., 2, 558–569, https://doi.org/10.1038/s43017-021-00181-9, 2021.

Grafton, R. Q., Pittock, J., Davis, R., Williams, J., Fu, G., Warburton, M., Udall, B., McKenzie, R., Yu, X., Che, N., Connell, D., Jiang, Q., Kompas, T., Lynch, A., Norris, R., Possingham, H., and Quiggin, J.: Global insights into water resources, climate change and governance, Nat. Clim. Change, 3, 315–321, https://doi.org/10.1038/nclimate1746, 2013.

https://doi.org/10.5194/essd-2025-805
Preprint. Discussion started: 10 March 2026
© Author(s) 2026. CC BY 4.0 License.

451 Hua, L., Zhong, L., and Ma, Z.: Decadal Transition of Moisture Sources and
452 Transport in Northwestern China During Summer From 1982 to 2010, J.
453 Geophys. Res. Atmospheres, 122, https://doi.org/10.1002/2017JD027728, 2017.
454 Jouzel, J., Delaygue, G., Landais, A., Masson-Delmotte, V., Risi, C., and Vimeux, F.:
455 Water isotopes as tools to document oceanic sources of precipitation, Water
456 Resour. Res., 49, 7469–7486, https://doi.org/10.1002/2013WR013508, 2013.
457 Klein, E. S., Cherry, J. E., Young, J., Noone, D., Leffler, A. J., and Welker, J. M.:
458 Arctic cyclone water vapor isotopes support past sea ice retreat recorded in
459 Greenland ice, Sci. Rep., 5, 10295, https://doi.org/10.1038/srep10295, 2015.
460 Leroy-Dos Santos, C., Fourré, E., Agosta, C., Casado, M., Cauquoin, A., Werner, M.,
461 Minster, B., Prié, F., Jossoud, O., Petit, L., and Landais, A.: From atmospheric
462 water isotopes measurement to firn core interpretation in Adélie Land: a case
463 study for isotope-enabled atmospheric models in Antarctica, The Cryosphere, 17,
464 5241–5254, https://doi.org/10.5194/tc-17-5241-2023, 2023.
465 Li, R., Zhu, G., Chen, L., Qi, X., Lu, S., Meng, G., Wang, Y., Li, W., Zheng, Z., Yang,
466 J., and Gun, Y.: Global Stable Isotope Dataset for Surface Water, Earth Syst. Sci.
467 Data, 17, 2135–2145, https://doi.org/10.5194/essd-17-2135-2025, 2025.
468 Li, S., Han, Y., Li, C., and Wang, J.: A novel framework for multi-layer soil moisture
469 estimation with high spatio-temporal resolution based on data fusion and
470 automated machine learning, Agric. Water Manag., 306, 109173,
471 https://doi.org/10.1016/j.agwat.2024.109173, 2024.
472 Lu, S., Zhu, G., Meng, G., Lin, X., Liu, Y., Qiu, D., Xu, Y., Wang, Q., Chen, L., Li, R.,
473 and Jiao, Y.: Influence of atmospheric circulation on the stable isotope of
474 precipitation in the monsoon margin region, Atmospheric Res., 298, 107131,
475 https://doi.org/10.1016/j.atmosres.2023.107131, 2024.
476 Peng, P., John Zhang, X., and Chen, J.: Bias correcting isotope-equipped GCMs
477 outputs to build precipitation oxygen isoscape for eastern China, J. Hydrol., 589,
478 125153, https://doi.org/10.1016/j.jhydrol.2020.125153, 2020.
479 Ren, Y., Yu, H., Huang, J., Peng, M., and Zhou, J.: The Projected Response of the
480 Water Cycle to Global Warming Over Drylands in East Asia, Earths Future, 12,
481 e2023EF004008, https://doi.org/10.1029/2023EF004008, 2024.
482 Rozmiarek, K. S., Dietrich, L. J., Vaughn, B. H., Town, M. S., Markle, B. R., Morris,
483 V., Steen-Larsen, H. C., Fettweis, X., Brashear, C. A., Bennett, H., and Jones, T.
484 R.: Atmosphere to Surface Profiles of Water-Vapor Isotopes and Meteorological
485 Conditions Over the Northeast Greenland Ice Sheet, J. Geophys. Res.
486 Atmospheres, 130, e2024JD042719, https://doi.org/10.1029/2024JD042719,
487 2025.
488 Ruan, K., Lin, Y., Yang, P., and Zhou, W.: Condensation matters, Nat. Chem. Biol., 19,
489 1180–1182, https://doi.org/10.1038/s41589-023-01415-1, 2023.
490 Saranya, P., Krishan, G., Rao, M. S., Kumar, S., and Kumar, B.: Controls on water
491 vapor isotopes over Roorkee, India: Impact of convective activities and
492 depression systems, J. Hydrol., 557, 679–687,
493 https://doi.org/10.1016/j.jhydrol.2017.12.061, 2018.
494 Shang, B., Gao, J., Chen, G., and Wu, Y.: Stable isotopes in atmospheric water vapour:

https://doi.org/10.5194/essd-2025-805
Preprint. Discussion started: 10 March 2026
© Author(s) 2026. CC BY 4.0 License.

Patterns, mechanisms and perspectives, Sci. China Earth Sci., 67, 3789–3813, https://doi.org/10.1007/s11430-023-1410-6, 2024.

Shi, M., Worden, J. R., Bailey, A., Noone, D., Risi, C., Fu, R., Worden, S., Herman, R., Payne, V., Pagano, T., Bowman, K., Bloom, A. A., Saatchi, S., Liu, J., and Fisher, J. B.: Amazonian terrestrial water balance inferred from satellite-observed water vapor isotopes, Nat. Commun., 13, 2686, https://doi.org/10.1038/s41467-022-30317-4, 2022.

Smedsrud, L. H., Muilwijk, M., Brakstad, A., Madonna, E., Lauvset, S. K., Spensberger, C., Born, A., Eldevik, T., Drange, H., Jeansson, E., Li, C., Olsen, A., Skagseth, Ø., Slater, D. A., Straneo, F., Våge, K., and Årthun, M.: Nordic Seas Heat Loss, Atlantic Inflow, and Arctic Sea Ice Cover Over the Last Century, Rev. Geophys., 60, e2020RG000725, https://doi.org/10.1029/2020RG000725, 2022.

Smith, A. C. and Lacey, J. H.: Tracing anthropogenic climate and environmental change using stable isotopes, Quat. Sci. Rev., 346, 109028, https://doi.org/10.1016/j.quascirev.2024.109028, 2024.

Tharammal, T., Bala, G., and Nusbaumer, J. M.: Sources of water vapor and their effects on water isotopes in precipitation in the Indian monsoon region: a model-based assessment, Sci. Rep., 13, 708, https://doi.org/10.1038/s41598-023-27905-9, 2023.

Voglar, G. E., Zavadlav, S., Levanič, T., and Ferlan, M.: Measuring techniques for concentration and stable isotopologues of CO2 in a terrestrial ecosystem: A review, Earth-Sci. Rev., 199, 102978, https://doi.org/10.1016/j.earscirev.2019.102978, 2019.

Wang, D., Tian, L., Risi, C., Wang, X., Cui, J., Bowen, G. J., Yoshimura, K., Wei, Z., and Li, L. Z. X.: Vehicle-based in situ observations of the water vapor isotopic composition across China: spatial and seasonal distributions and controls, Atmospheric Chem. Phys., 23, 3409–3433, https://doi.org/10.5194/acp-23-3409-2023, 2023a.

Wang, Y., Sun, Q., Yu, J., Xu, N., Wei, Y., Cho, J. H., and Wang, Z. L.: Boolean Logic Computing Based on Neuromorphic Transistor, Adv. Funct. Mater., 33, 2305791, https://doi.org/10.1002/adfm.202305791, 2023b.

Wei, Z., Lee, X., Aemisegger, F., Benetti, M., Berkelhammer, M., Casado, M., Caylor, K., Christner, E., Dyroff, C., García, O., González, Y., Griffis, T., Kurita, N., Liang, J., Liang, M.-C., Lin, G., Noone, D., Gribanov, K., Munksgaard, N. C., Schneider, M., Ritter, F., Steen-Larsen, H. C., Vallet-Coulomb, C., Wen, X., Wright, J. S., Xiao, W., and Yoshimura, K.: A global database of water vapor isotopes measured with high temporal resolution infrared laser spectroscopy, Sci. Data, 6, 180302, https://doi.org/10.1038/sdata.2018.302, 2019.

Xing, M., Wang, Z., and Dong, J.: The premise of temperature effect playing in regions with complex moisture sources – Evidence from high-resolution water vapor isotopes, J. Hydrol., 623, 129827, https://doi.org/10.1016/j.jhydrol.2023.129827, 2023.

Xu, T., Pang, H., Zhan, Z., Zhang, W., Guo, H., Wu, S., and Hou, S.: Water vapor isotopes indicating rapid shift among multiple moisture sources for the

https://doi.org/10.5194/essd-2025-805
Preprint. Discussion started: 10 March 2026
© Author(s) 2026. CC BY 4.0 License.

2018–2019 winter extreme precipitation events in southeastern China, Hydrol. Earth Syst. Sci., 26, 117–127, https://doi.org/10.5194/hess-26-117-2022, 2022.

Xu, W., Xia, X., Piao, S., Wu, D., Li, W., Yang, S., and Yuan, W.: Weakened Increase in Global Near-Surface Water Vapor Pressure During the Last 20 Years, Geophys. Res. Lett., 51, e2023GL107909, https://doi.org/10.1029/2023GL107909, 2024.

Yang, G., Xiao, Y., Wang, S., Qian, Y., Li, H., and Zhang, M.: Satellite-Based Distribution of Inverse Altitude Effect of Global Water Vapor Isotopes: Potential Influences on Isotopes in Climate Proxies, Remote Sens., 15, 4533, https://doi.org/10.3390/rs15184533, 2023.

Zhu, G. and Yang, dongfei: Global Water Vapor Stable Isotope Dataset, https://doi.org/10.6084/M9.FIGSHARE.30893984, 2025.

Zhu, G., Liu, Y., Shi, P., Jia, W., Zhou, J., Liu, Y., Ma, X., Pan, H., Zhang, Y., Zhang, Z., Sun, Z., Yong, L., and Zhao, K.: Stable water isotope monitoring network of different water bodies in Shiyang River basin, a typical arid river in China, Earth Syst. Sci. Data, 14, 3773–3789, https://doi.org/10.5194/essd-14-3773-2022, 2022.

Zhu, G., Liu, Y., Wang, L., Sang, L., Zhao, K., Zhang, Z., Lin, X., and Qiu, D.: The isotopes of precipitation have climate change signal in arid Central Asia, Glob. Planet. Change, 225, 104103, https://doi.org/10.1016/j.gloplacha.2023.104103, 2023.