Journal of Global Change Data & Discovery. 2024, 8(3): 311-317
www.geodoi.ac.cn

Dataset Development on Moisture Sources of Precipitation in Southern and Northern Qinghai-Xizang Plateau (1979–2016)

Zhang, C.

Key Laboratory of Land Surface Pattern and Simulation, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China

Abstract: The massive topography of the Qinghai-Xizang Plateau not only influences the climate of Asia and even globally, but also appearances significant climatic variations within itself: the southern plateau is mainly influenced by monsoons, forming a warm and humid plateau monsoon climate; while the northern plateau is primarily affected by westerlies, resulting in a cold and arid plateau continental climate. To quantify the differences in precipitation sources between the southern and northern plateau and reveal their distinct changing characteristics under global warming, the research team used a numerical model to track the moisture sources for seasonal (May–September) and annual precipitation in both the southern (south of 30°N) and northern (north of 35°N) plateau regions over approximately 40 years. The study used ERA-Interim reanalysis data, CMA precipitation and GLDAS evaporation as model drivers, and conducted comparative experiments for validation, ultimately generating precipitation source data for both the southern and northern plateau regions annually and during the rainy season. The dataset includes: (1) the boundaries of southern and northern plateau regions; (2) annual and seasonal precipitation source data for southern and northern plateau regions from 1979–2016, with a spatial resolution of 1°x1°, measured in mm; (3) regional average annual and seasonal precipitation data for southern and northern plateau regions from 1979–2016. The dataset is archived in .nc, .shp, and .xlsx formats, consisting of 17 data files with a total size of 66.4 MB. (compressed into 1 file, 53.7 MB).

Keywords: Qinghai-Xizang Plateau; climate change; precipitation; moisture source; southern and northern; 1979–2016

DOI: https://doi.org/10.3974/geodp.2024.03.08

CSTR: https://cstr.escience.org.cn/CSTR:20146.14.2024.03.08

Dataset Availability Statement:

The dataset supporting this paper was published and is accessible through the *Digital Journal of Global Change Data Repository* at: https://doi.org/10.3974/geodb.2024.08.03.V1 or https://cstr.escience.org.cn/CSTR:20146.11.2024.08.03.V1.

Received: 20-05-2024; **Accepted:** 26-08-2024; **Published:** 25-09-2024

Foundations: National Natural Science Foundation of China (U2243226); Chinese Academy of Sciences (XDA-2006040202)

Author Information: Zhang, C., Key Laboratory of Land Surface Pattern and Simulation, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, zhangchi@igsnrr.ac.cn

Data Citation: [1] Zhang, C. Dataset development on moisture sources of precipitation in southern and northern Qinghai-Xizang Plateau (1979–2016) [J]. *Journal of Global Change Data & Discovery*, 2024, 8(3): 311–317. https://doi.org/10.3974/geodp.2024.03.08. https://cstr.escience.org.cn/CSTR:20146.14.2024.03.08.

[2] Zhang, C., Tang, Q. H., Huang, J. C., *et al*. Precipitation moisture source simulating dataset on southern and northern Qinghai-Xizang Plateau [J/DB/OL]. *Digital Journal of Global Change Data Repository*, 2024. https://doi.org/10.3974/geodb.2024.08.03.V1. https://cstr.escience.org.cn/CSTR:20146.11.2024.08.03.V1.

1 Introduction

The Qinghai-Xizang Plateau plays a crucial role in the global climate system, and its environmental changes have drawn widespread attention from the international climatology community[1–3]. Research has shown that while the Qinghai-Xizang Plateau as a whole shows a wetting trend, precipitation changes display significant regional characteristics[4,5]. There are notable differences in precipitation changes between the northern and southern Qinghai-Xizang Plateau, with increased precipitation in the north and decreased precipitation in the south[1,6]. Yao *et al.* pointed out that the Northern Qinghai-Xizang Plateau (NTP, north of 35°N) is mainly influenced by westerlies, while the Southern Qinghai-Xizang Plateau (STP, south of 30°N) is primarily controlled by the Indian monsoon[7]. Different circulation systems bring moisture from various sources to different regions of the Qinghai-Xizang Plateau, resulting in spatial variations in precipitation.

The contrasting precipitation trends between STP and NTP may indicate changes in both circulation patterns and moisture sources. To reveal the causes of these opposing precipitation changes between the northern and southern plateau, the authors designed water vapor tracking experiments, using a numerical model to track the sources for both seasonal (May–September) and annual precipitation in the southern and northern plateau from 1979–2016. This generated nearly 40 years of moisture source data for annual and seasonal precipitation, providing a solid data foundation for quantifying the precipitation contributions of plateau circulations, and evaluating north-south differences, interannual fluctuations, and climate change impacts on circulation patterns.

2 Metadata of the Dataset

The metadata of Precipitation moisture source simulating dataset on southern and northern Qinghai-Xizang Plateau[8] is summarized in Table 1. It includes the dataset full name, short name, authors, year of the dataset, temporal resolution, spatial resolution, data format, data size, data files, data publisher, and data sharing policy, etc.

3 Methods

3.1 Data Sources

This study uses the 0.5° gridded monthly precipitation data based on ground observations provided by the China Meteorological Administration (CMA)[10]. This gridded data product is derived from quality-controlled observational data from approximately 2,400 national stations across China since 1961, using the thin-plate smoothing spline interpolation method while taking topographic effects into account. The study utilizes data from 1979–2016.

The 3-hourly 1° gridded evaporation data provided by the Community Land Model (CLM) within the Global Land Data Assimilation System (GLDAS)[11] is selected for this study. Data from 1996 contains a suspicious anomaly due to erroneous precipitation[12], and it is recommended to exclude the evaporation and related simulation results for 1996.

Atmospheric data is sourced from the European Centre for Medium-Range Weather Forecasts (ECMWF) reanalysis data ERA-Interim[13], with a spatial resolution of 1°×1°. ERA-Interim provides a series of datasets, including 6-hourly model-level zonal wind, meridional wind, and specific humidity; 6-hourly surface pressure and a set of vertically integrated moisture and flux variables (vertically integrated water, vertically integrated northward/eastward moisture flux, including water vapor, liquid water, and ice fluxes); as well as 3-hourly precipitation and evaporation data.

Table 1 Metadata summary of precipitation moisture source simulating dataset on Southern and Northern Qinghai-Xizang Plateau

Items	Description
Dataset full name	Precipitation moisture source simulating dataset on southern and northern Qinghai-Xizang Plateau
Dataset short name	MoistureSourceNSPlateau
Authors	Zhang, C., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, zhangchi@igsnrr.ac.cn Tang, Q. H., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, tangqh@igsnrr.ac.cn Huang, J. C., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, huangjc@igsnrr.ac.cn Xu, X. M., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, xuxm@igsnrr.ac.cn Gaffney, P. P. J., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, gafppj@igsnrr.ac.cn Zhou, Y. Y., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, zhouyy@igsnrr.ac.cn
Geographical region	Qinghai-Xizang Plateau
Year	1979–2016
Temporal resolution	Annual, monthly from May to September
Spatial resolution	1°×1°
Data format	.nc, .xlsx, .shp
Data size	53.7 MB（after compression）
Data files	The geographical extent of NTP and STP, annual and rainy season monthly precipitation in the NTP and STP, moisture sources for annual and rainy season monthly precipitation in the NTP and STP
Foundations	Chinese Academy of Sciences (XDA2006040202); National Natural Science Foundation of China (U2243226)
Data publisher	Global Change Research Data Publishing & Repository, http://www.geodoi.ac.cn
Address	No. 11A, Datun Road, Chaoyang District, Beijing 100101, China
Data sharing policy	(1) *Data* are openly available and can be free downloaded via the Internet; (2) End users are encouraged to use *Data* subject to citation; (3) Users, who are by definition also value-added service providers, are welcome to redistribute *Data* subject to written permission from the GCdataPR Editorial Office and the issuance of a *Data* redistribution license; and (4) If *Data* are used to compile new datasets, the 'ten per cent principal' should be followed such that *Data* records utilized should not surpass 10% of the new dataset contents, while sources should be clearly noted in suitable places in the new dataset[9]
Communication and searchable system	DOI, CSTR, Crossref, DCI, CSCD, CNKI, SciEngine, WDS, GEOSS, PubScholar, CKRSC

3.2 Model and Experimental Design

This study uses the WAM2Layers (Water Accounting Model using 2 layers) model to track the sources for precipitation over the NTP and STP. WAM2Layers is a quasi-three-dimensional Eulerian numerical tracking model that represents a significant improvement over the first-generation model WAM. The model introduces a layered (two-layer) structure in the vertical direction, effectively addressing the tracking bias issues caused by vertical wind shear. This design significantly improves the accuracy and reliability of moisture tracking, enabling the model to more accurately simulate moisture movement and distribution in complex atmospheric environments[14,15]. The model's main equation is based on the atmospheric water balance equation, as shown in Equation (1):

$$\frac{\partial W_{l,\Omega}}{\partial t} = -\frac{\partial (W_{l,\Omega} u)}{\partial x} - \frac{\partial (W_{l,\Omega} v)}{\partial y} + E_{l,\Omega} - P_{l,\Omega} \pm F_{V,\Omega} + \alpha_{l,\Omega} \quad (1)$$

where *l* represents the upper or lower atmospheric layer, *Ω* represents moisture from a specific source region, the left side of the equation represents the temporal change in atmospheric precipitable water (W), and the right side includes moisture convergence caused by horizontal winds (u, v), moisture supply from surface evaporation (E), moisture loss due to precipitation (P), vertical moisture transport between layers (Fv), and a residual term (α). The model's water vapor tracking algorithm has been described in the previous literature[16] and is therefore omitted here.

This study focuses on comparing the effects of different surface evaporation (E) and precipitation (P) fluxes on moisture tracking. Therefore, the team conducted two sets of experiments using different E and P fluxes. One set uses observation-based data, specifically CMA precipitation and GLDAS evaporation. The other set uses ERA-Interim's E and P, combined with ERA-Interim atmospheric data, forming a complete ERA-based dataset, referred to as ERA-Suite, which has a more self-consistent water cycle. The experiment using ERA-Suite serves as a supplement to compare with the main experiment and verify the reliability of the results.

3.3 Data Pre-processing

When using observational precipitation data, the study calibrates the 3-hourly ERA-Interim precipitation data using CMA monthly precipitation data to preserve diurnal precipitation variation while ensuring monthly values match the CMA data. The specific steps are as follows: First, CMA precipitation data is converted to the same spatial resolution as ERA-Interim by averaging the 0.5° grids that fall within each 1° grid. The monthly precipitation from ERA-Interim is then calculated. Using CMA monthly precipitation as the reference, scaling factors for ERA-Interim are determined. Subsequently, all 3-hourly ERA-Interim precipitation data within each month are scaled proportionally.

Since GLDAS evaporation data only covers land areas, ERA-Interim data is still used for ocean regions' evaporation. To ensure numerical stability in the moisture tracking process, all model input data is discretized to 15-minute time steps. Data with 6-hour or 3-hour intervals is converted to 15-minute intervals using either linear interpolation or equal distribution methods.

3.4 Data Post-processing

The simulation results provide spatiotemporal field data of moisture content from the specific source region (i.e., tagged water) at 15-minute time steps. Using the tagged water content variable W_{Ω_down} in the lower atmosphere, at any time step, $e \times r_{\Omega}$ of the evaporation e will ultimately form direct precipitation in the target area, which can be expressed through Equation (2):

$$E_{con}(t,x,y) = E(t,x,y) \times \frac{W_{\Omega_{\text{down}}}(t,x,y)}{W_{\text{down}}(t,x,y)} \tag{2}$$

The water vapor contributions at monthly and regional scales are obtained through temporal integration and areal integration, respectively.

3.5 Technical Route

In summary, the technical workflow for developing this dataset is shown in Figure 1.

4 Data Results and Validation

4.1 Data Composition

The dataset consists of 17 data files, including: (1) geographical locations of the NTP and

STP (in .shp format); (2) annual and rainy season precipitation data in the NTP and STP from 1979 to 2016 (mm, in .xlsx format); (3) simulated moisture source data for the rainy season and annual precipitation in the NTP and STP from 1979 to 2016, with a spatial resolution of 1°×1° (mm, in .nc format).

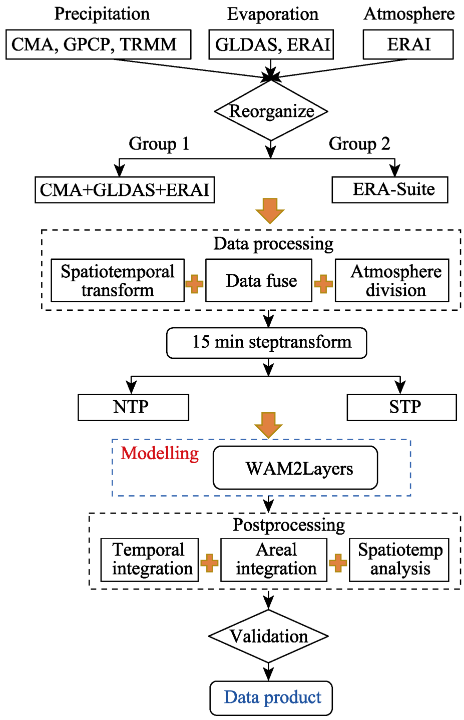

Figure 1 Technical workflow for the dataset development

4.2 Data Results

According to statistics, precipitation during the rainy season (May–September) dominates over the Qinghai-Xizang Plateau, with average rainy season precipitation accounting for 77.1% and 88.4% of annual precipitation in the southern and northern plateau, respectively. The distribution of moisture sources for annual and rainy season precipitation in the northern and southern plateau is shown in Figure 2. There are notable differences between the northern and southern plateau. Precipitation in the northern plateau mainly originates from the northwestern westerlies that traverse the Eurasian continent, while the contribution from southern moisture sources is less extensive for the same intensity. Precipitation in the southern plateau primarily comes from southern moisture sources, including the Indochina Peninsula, Arabian Sea, Bay of Bengal, and the west-central tropical Indian Ocean; the westerlies zone also contributes but is generally weaker. Moisture north of the plateau contributes significantly to the northern plateau but barely affects the southern plateau; similarly, moisture from the tropical Indian Ocean hardly influences the northern plateau.

The comparison between annual and rainy season precipitation moisture source distributions further demonstrates the decisive role of rainy season precipitation. Taking the northern plateau as an example, the annual precipitation source shows a narrow band of moisture contribution over the western Indian Ocean, which comes from the rainy season's contribution to the precipitation (Figures 2a and 2b). When the rainy season begins and the southwest monsoon breaks out, large amounts of moisture from the western Indian Ocean are transported to the northern plateau through the Somali Jet, forming precipitation and leaving a significant imprint.

The northern and southern plateau show different precipitation trends. From a moisture source perspective, the increase in northern precipitation is mainly due to increased moisture contribution from the plateau and monsoon regions. In contrast, changes in moisture sources for southern plateau precipitation are more complex—the decrease in moisture contribution from the Indian Peninsula and westerlies is the direct cause of reduced precipitation in the southern plateau[17].

4.3 Data Validation

Due to the scarcity of ground station data in the northern plateau, there is significant uncertainty in northern precipitation data. Zhang *et al.* introduced the TRMM satellite precipitation product 3B42 to further track and simulate moisture sources in the northern plateau[17]. Results show that during the overlapping time period (1998–2016), despite some

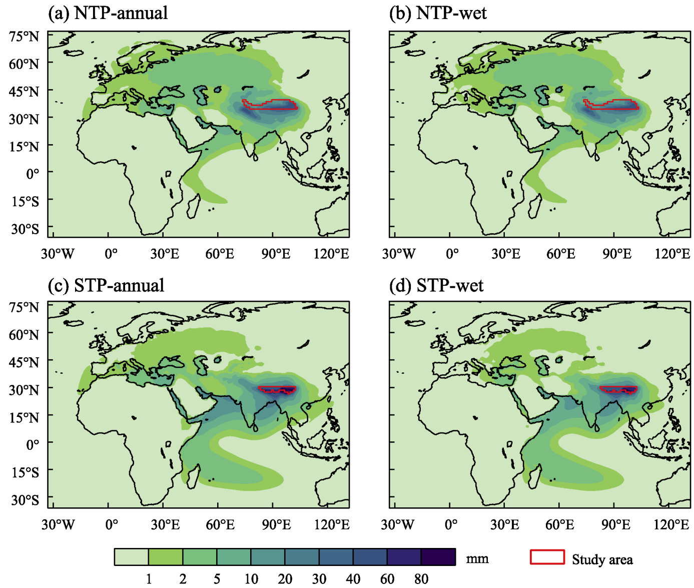

Figure 2 Spatial distribution maps of moisture sources for annual (a, c) and rainy (wet) season (b, d) mean precipitation in the Northern (a, b) and Southern (c, d) Qinghai-Xizang Plateau (NTP and STP)

differences in specific values in certain local areas, the moisture sources and their trend distributions derived from different precipitation datasets demonstrate high spatial structural similarity. This finding indicates that the qualitative conclusions based on CMA data are reliable. Additionally, alongside the main experiment, Zhang also designed control group experiments[17], using complete ERA-Interim data to simulate moisture sources for the northern and southern plateau. By comparing with the main experimental results, they quantified the uncertainty caused by different input data, strengthening the credibility of the main experimental results and research conclusions.

5 Discussion and Conclusion

The northern and southern Qinghai-Xizang Plateau, controlled by different circulation systems, display distinctly different precipitation patterns: the northern region shows significant precipitation increase, while the southern region exhibits a slight decreasing trend. This study employed the numerical model WAM2Layers, using the CMA precipitation product, GLDAS model evaporation data and ERA-Interim atmospheric reanalysis as driving data to track moisture sources for precipitation in the northern and southern plateau regions, thereby establishing a simulation dataset of moisture sources for precipitation in the northern and southern plateau. This dataset has a spatial resolution of 1°×1°, covers the period 1979–2016, and includes moisture source distributions for both annual and rainy season precipitation. The reliability of this dataset has been thoroughly validated through comparative experiments and supplementary precipitation experiments.

Preliminary analysis results show that precipitation sources on the Qinghai-Xizang Plateau exhibit distinct seasonal characteristics and regional differences, with rainy season precipitation playing a decisive role in both precipitation amount and moisture sources. This complex precipitation pattern reflects the unique geographical and atmospheric circulation characteristics of the Qinghai-Xizang Plateau. Based on this dataset, future research directions may include: in-depth analysis of how different circulation changes affect precipitation; investigation of moisture source differences during extreme precipitation years;

and study of the synchronous and asynchronous relationships between northern and southern plateau precipitation systems. These studies will help further reveal the mechanisms of precipitation change and moisture transport processes on the plateau, providing important scientific evidence for understanding the region's water cycle.

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Chen, D. L., Xu, B. Q., Yao, T. D., *et al*. Assessment of past, present and future environmental changes on the Qinghai-Xizang Plateau [J]. *Chinese Science Bulletin*, 2015, 60: 3025–3035.

[2] Yao, T. D., Thompson, L., Yang, W., *et al*. Different glacier status with atmospheric circulations in Tibetan Plateau and surroundings [J]. *Nature Climate Change*, 2012, 2(9): 663–667.

[3] Klein, J. A., Hopping, K. A., Yeh, E. T., *et al*. Unexpected climate impacts on the Tibetan Plateau: local and scientific knowledge in findings of delayed summer [J]. *Global Environmental Change*, 2014, 28: 141–152.

[4] Yang, K., Ye, B., Zhou, D., *et al*. Response of hydrological cycle to recent climate changes in the Tibetan Plateau [J]. *Climatic change*, 2011, 109: 517–534.

[5] Gao, Y., Cuo, L., Zhang, Y. Changes in moisture flux over the Tibetan Plateau during 1979–2011 and possible mechanisms [J]. *Journal of Climate*, 2014, 27(5): 1876–1893.

[6] Jiang, J., Zhou, T., Qian, Y., *et al*. Precipitation regime changes in High Mountain Asia driven by cleaner air [J]. *Nature*, 2023, 623(7987): 544–549.

[7] Yao, T. D., Masson-Delmotte, V., Gao, J., *et al*. A review of climatic controls on $\delta^{18}O$ in precipitation over the Tibetan Plateau: observations and simulations [J]. *Reviews of Geophysics*, 2013, 51(4): 525–548.

[8] Zhang, C., Tang, Q. H., Huang, J. C., *et al*. Precipitation moisture source simulating dataset on southern and northern Qinghai-Xizang Plateau [J/DB/OL]. *Digital Journal of Global Change Data Repository*, 2024. https://doi.org/10.3974/geodb.2024.08.03.V1. https://cstr.escience.org.cn/CSTR:20146.11.2024.08.03.V1.

[9] GCdataPR Editorial Office. GCdataPR data sharing policy [OL]. https://doi.org/10.3974/dp.policy.2014.05 (Updated 2017).

[10] Zhao, Y., Zhu, J., Xu, Y. Establishment and assessment of the grid precipitation datasets in China for recent 50 years [J]. *Journal of the Meteorological Sciences*, 2014, 34(4): 414–420.

[11] Rodell, M., Houser, P. R., Jambor, U. E. A., *et al*. The global land data assimilation system [J]. *Bulletin of the American Meteorological society*, 2004, 85: 381–394.

[12] Zhou, X., Zhang, Y., Yang, Y., *et al*. Evaluation of anomalies in GLDAS-1996 dataset [J]. *Water science and technology*, 2013, 67(8): 1718–1727.

[13] Dee, D. P., Uppala, S. M., Simmons, A. J., *et al*. The ERA-Interim reanalysis: configuration and performance of the data assimilation system [J]. *Quarterly Journal of the Royal Meteorological Society*, 2011, 137: 553–597.

[14] van der Ent, R. J., Tuinenburg, O. A., Knoche, H. R., *et al*. Should we use a simple or complex model for moisture recycling and atmospheric moisture tracking? [J]. *Hydrology and Earth System Sciences*, 2013, 17: 4869–4884.

[15] van der Ent, R. J., Wang-Erlandsson, L., Keys, P. W., *et al*. Contrasting roles of interception and transpiration in the hydrological cycle—part 2: moisture recycling [J]. *Earth System Dynamics*, 2014, 5(2): 471–489.

[16] Zhang, C. Dataset development for water vapor sources of Meiyu Season precipitation in the middle and lower reaches of the Yangtze River (26.5°N–33.5°N, 104.5°E–122.5°E, 1991–2020) [J]. *Journal of Global Change Data & Discovery*, 2024, 8(2): 171–177. https://doi.org/10.3974/geodp.2024.02.07. https://cstr.escience.org.cn/CSTR:20146.14.2024.02.07.

[17] Zhang, C., Tang, Q. H., Chen, D. L., *et al*. Moisture source changes contributed to different precipitation changes over the northern and southern Tibetan Plateau [J]. *Journal of Hydrometeorology*, 2019, 20(2): 217–229.