Dataset Development on Moisture Sources of Increased Precipitation in the Qinghai-Xizang Plateau (1979–2013)

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Abstract: Climate change in the Qinghai-Xizang Plateau has been a focus of international scientific research. From 1979 to 2013, the plateau's precipitation showed a gradually increasing trend, especially in the central and western parts of the plateau. Although precipitation station data is scarce in this region, simulated data, satellite data, and indirect observational data (such as lake area and forest greening) all indicate that the increasing in precipitation is truly happened. So where does the plateau's increasing precipitation come from? The authors identified the areas with significant precipitation increase (covering about 84.7×10^4 km^2) through precipitation trend analysis, then tracked the moisture sources for precipitation in this area using a numerical model. The model used ERA-Interim reanalysis data, the precipitation product by CMA (China Meteorological Administration), and GLDAS (Global Land Data Assimilation Systems) evaporation as data drivers, and set up comparative experiments for validation, ultimately generating annual and rainy season monthly moisture source data for the increased precipitation on the plateau. This dataset includes: (1) geographical extent of the study area; (2) annual and rainy season monthly moisture source data with a spatial resolution of 1.5°×1.5°; (3) precipitation data and rainy season monthly precipitation data from 1979 to 2013. The dataset is archived in .shp, .nc, and .xlsx formats, consisting of 13 data files with a total data size of 46.5 MB (compressed into 1 file, 16.9 MB).

Keywords: Qinghai-Xizang Plateau; climate change; precipitation; moisture source

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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.2024.08.02.V1 or https://cstr.escience.org.cn/CSTR:20146.11.2024.08.02.V1.

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[2] Zhang, C., Tang, Q. H., Huang, J. C., *et al*. Moisture source simulating dataset on increased precipitation area in the Tibetan Plateau (1979–2013) [J/DB/OL]. *Digital Journal of Global Change Data Repository*, 2024. https://doi.org/10.3974/geodb.2024.08.02.V1. https://cstr.escience.org.cn/CSTR:20146.11.2024.08.02.V1.

1 Introduction

The Qinghai-Xizang Plateau, known as the world's "Third Pole", exerts great influence on the climate of East Asia and the Northern Hemisphere. Environmental changes in the Qinghai-Xizang Plateau have also garnered attention from numerous scientists worldwide[1–3]. Existing research indicates that over the past few decades, the Qinghai-Xizang Plateau has experienced rapid warming and overall moistening[3]. Although precipitation changes in the Qinghai-Xizang Plateau exhibit considerable spatial and temporal variability, various sources of surface observational data (station precipitation, lake expansion, forest greening, etc.) and satellite data all support an overall increasing trend in plateau precipitation[1,4,5].

Generally, precipitation requires three essential conditions: moisture source (surface evaporation), transport pathway, and atmospheric uplift[6]. Among these, the most perplexing is the source of water vapor that produces precipitation[7]. The increasing in precipitation in the Qinghai-Xizang Plateau indicates that more evaporated water vapor is participating in precipitation formation, leading to increased precipitation amounts. This water vapor may originate from within the Qinghai-Xizang Plateau (e.g., glacier melting, enhanced evaporation leading to intensified internal hydrological circulation)[8], from outside the plateau (e.g., strengthened South Asian monsoon transporting moist Indian Ocean air to the plateau)[9], or a combination of both. Analyzing plateau precipitation changes from the perspective of precipitation sources can further reveal the influence mechanisms of the plateau's internal hydrological circulation and large-scale circulation system changes. Based on this, this study uses the Eulerian moisture tracking numerical model WAM2Layers to trace the sources of precipitation with marked increase on the Qinghai-Xizang Plateau from 1979 to 2013, generating annual and rainy season monthly moisture source data for precipitation on the plateau, providing a data foundation for studying the mechanisms of plateau precipitation changes.

2 Metadata of the Dataset

The metadata of moisture source simulating dataset on increased precipitation area in the Tibetan Plateau (1979–2013) 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 Model and Algorithm

This study uses the WAM (Water Accounting Model)[12,13] to trace the moisture sources of precipitation on the plateau. WAM is a numerical moisture tracking model based on the Eulerian framework. It can not only forward-track the destination of water vapor but also backward-track its source. The basic equation of WAM is the atmospheric water balance equation:

$$\frac{\partial W}{\partial t}+\frac{\partial (Wu)}{\partial x}+\frac{\partial (Wv)}{\partial y}=E-P+\alpha \tag{1}$$

where W represents the precipitable water in the vertical air column; u and v represent the zonal (x) and meridional (y) wind speeds weighted by water vapor mass, respectively; E is the evaporation; P is the precipitation; α is the residual term, because when using assimilated data or multi-source data, the water balance equation usually cannot be completely closed, and this term is needed to balance the equation. Similarly, water vapor from a

Table 1 Metadata summary of Moisture Source_IPTP

Items	Description
Dataset full name	Moisture source simulating dataset on increased precipitation area in the Tibetan Plateau (1979–2013)
Dataset short name	MoistureSource_IPTP
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	Central-western Qinghai-Xizang Plateau
Year	1979–2016
Temporal resolution	Annual, monthly
Spatial resolution	1.5°×1.5°
Data format	.nc, .xlsx, .shp
Data size	16.9 MB（after compression）
Data files	the study area, annual precipitation and monthly precipitation during the rainy season in the study area, moisture sources for precipitation in the study area
Foundations	National Natural Science Foundation of China (U2243226); China Scholarship Council (202310490002)
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[7]
Communication and searchable system	DOI, CSTR, Crossref, DCI, CSCD, CNKI, SciEngine, WDS, GEOSS, PubScholar, CKRSC

specific source region Ω satisfies the same atmospheric water balance equation:

$$\frac{\partial W_\Omega}{\partial t}+\frac{\partial(W_\Omega u)}{\partial x}+\frac{\partial(W_\Omega v)}{\partial y}=E_\Omega-P_\Omega+\alpha_\Omega \tag{2}$$

From the equation, it can be seen that WAM is a single-layer two-dimensional model. Its moisture tracking algorithm is as follows: consider the inverse process of precipitation, that is, the precipitation P_0 in the target area (central-western plateau) during a specific time period returned to the atmosphere as “tagged water”, and then flows back along the time axis and water vapor transport direction to the initial surface evaporation source. When P_0 enters the atmosphere, it follows the full mixing assumption, meaning that the tagged water is fully mixed with the total water vapor in the air column at that time. Then the tagged water continuously enters the surrounding grid points through horizontal moisture transport and is again fully mixed with the water vapor in the air column where it is located. At a specific time point, if there is an evaporation e at grid point A, and the proportion of tagged water to total water vapor in that air column is r, this means that $e\times r$ of the evaporated water entering the atmosphere from point A will eventually form precipitation in the target area. This part of the water vapor is identified as the direct precipitation contribution of grid point A to the target area and is successfully traced back to its source. The tagged water in the air column at point A needs to be reduced by this amount and continue its "recycling" process until almost all tagged water is traced back to its source.

3.2 Driving Data

The model driving data is divided into two major categories: atmospheric data and surface flux data. The atmospheric data uses the ERA-Interim reanalysis data from the European Centre for Medium-Range Weather Forecasts[14], with a spatial resolution of 1.5°×1.5°. It includes global zonal and meridional wind speeds and atmospheric humidity at 23 pressure levels from 200 to 1,000 hPa every 6 hours, as well as surface atmospheric pressure. The atmospheric precipitable water W and horizontal water vapor flux Q data are calculated using the following equations:

$$W = -\frac{1}{g}\int_{p_{surf}}^{200hPa} q\,dp \tag{3}$$

$$Q = -\frac{1}{g}\int_{p_{surf}}^{200hPa} q\vec{v}\,dp \tag{4}$$

where g is the gravitational acceleration, q is the specific humidity, $\vec{v}$ is the horizontal wind vector, p is the surface atmospheric pressure.

Surface data includes surface evapotranspiration and precipitation. Land evapotranspiration uses output data from the GLDAS land surface model CLM (Community Land Model). This data has a temporal resolution of 3 hours and a spatial resolution of 1°×1°, and has undergone rigorous evaluation on the plateau[15]. Ocean evaporation uses ERA-Interim model data, with a temporal and spatial resolution of 3 hours and 1.5°×1.5°, respectively.

For precipitation on the plateau, authors use the precipitation product from the National Meteorological Information Center of the China Meteorological Administration (CMA)—the China Surface Daily Precipitation Dataset at a 0.5°×0.5° Grid (V2.0)[16]. This dataset originates from daily precipitation records of 2,472 national ground meteorological stations in China since 1961, which have undergone quality control. It uses the thin-plate smoothing spline method for grid interpolation, considers the influence of elevation, and is widely used in China. The study uses the CMA precipitation data as a benchmark, first upscaling it spatially to the ERA-Interim 1.5°×1.5° grid, then comparing it with ERA-Interim precipitation on a monthly scale to obtain correction parameters, which are then used to scale the ERA-Interim 3-hour precipitation data. All driving data needs to be unified to a temporal and spatial resolution of half-hour and 1.5°×1.5° through methods such as time averaging and spatiotemporal linear interpolation.

3.3 Simulation Experiment Description

The study traced the moisture sources of annual precipitation and rainy season monthly precipitation in areas of significant precipitation increasing in the Qinghai-Xizang Plateau from 1979 to 2013. The annual-scale moisture tracing experiment starts from the last day of each year, from December 31, and traces back to January 1 at the beginning of the year, repeating this process for 35 years. The rainy season is defined as May to September each year, with tracing done on a monthly basis. Because monthly precipitation may originate from surface evaporation in the previous month, the experiment traces back an additional month to ensure that the vast majority of precipitation moisture can be tracked. The annual precipitation moisture tracing also faces the issue of January precipitation originating from surface evaporation in December of the previous year. However, because the amount of precipitation in January is small and has a weak impact on annual-scale precipitation, no additional tracing is performed[9].

4 Data Results and Validation

4.1 Data Composition

The dataset consists of 13 data files, including: (1) geographical extent of the study area (in .shp format); (2) precipitation data for the study area from 1979 to 2013 and rainy season monthly precipitation data (in .xlsx format); (3) simulated moisture source data on annual and rainy season monthly scales from 1979 to 2013, with a spatial resolution of 1.5°×1.5° (in .nc format).

4.2 Data Results

Zhang *et al*. (2017) identified the central-western regions of the plateau as having the most significant increase in precipitation during the period 1979–2013 through linear trend analysis of the CMA precipitation data (Figure 1)[9]. Tracing the precipitation source of the extreme regions with increased precipitation on the plateau can effectively represent the overall moisture source status of the plateau, and then analyze and attribute the trend of plateau moisture change from the perspective of moisture source changes. The rainy season precipitation in the central-western plateau accounts for about 90.6% of the annual precipitation, essentially representing the annual precipitation. The climatological average distribution of moisture sources for annual and rainy season precipitation is shown in Figure 1. The spatial patterns of both are similar: the northwestern moisture mainly comes from the Eurasian continent, the western moisture mainly from the Mediterranean-Black Sea-Caspian Sea and the two gulf regions, while the southern moisture is mainly from the direction of the Indian Ocean, transported to the plateau through the Indian monsoon. It can also be observed that the central-western plateau and its adjacent areas in the west and south are moisture sources with high contribution intensity, representing an important source area for precipitation.

The moisture sources for the precipitation in the driest and wettest years selected from 1979–2013 (1984 with 219 mm and 2008 with 420 mm respectively) are displayed in Figure 2. Comparison shows that the difference in moisture contribution between the wettest and driest years in the Eurasian continent is mainly reflected in the spatial pattern. There is no significant difference in intensity in this area. The intensity difference is mainly reflected in the plateau and the region south of it to the western Indian Ocean. The significant differences in moisture contribution from these two regions caused significant differences in precipitation in the target study area. Similarly, analyzing the differences in the distribution of moisture sources during the rainy season between the driest and wettest years (Figure 2), the intensity of moisture contribution from source regions in the wet year is stronger than in the dry year, except in the Eurasian continent. This difference is particularly significant in the local study area, its southwestern adjacent areas, and the western Indian Ocean.

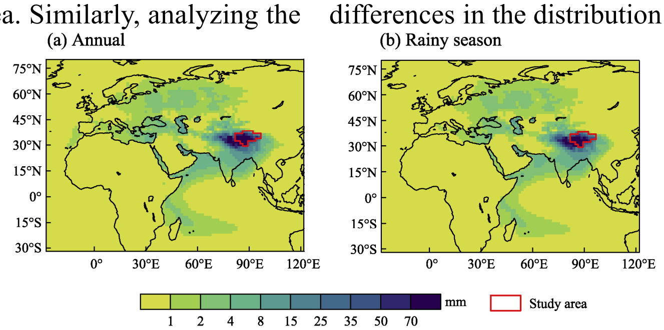

Figure 1 Distribution maps of annual average and rainy season average moisture source contributions

4.3 Data Validation

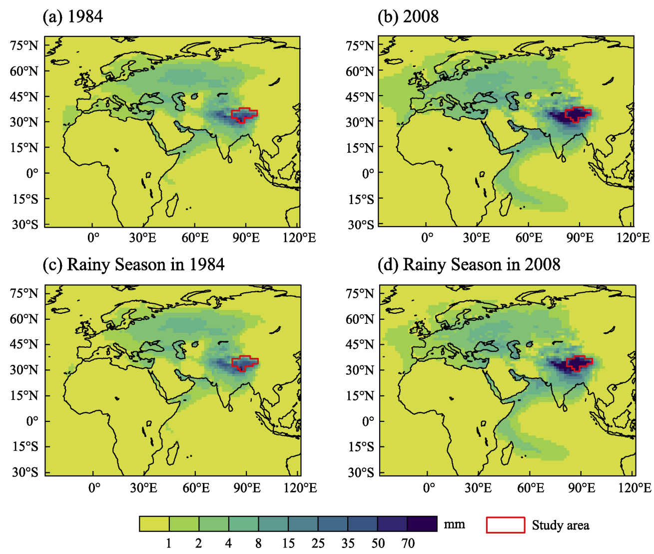

Figure 2 Distribution maps of moisture source contributions for annual precipitation and rainy season precipitation in the driest year (1984) and the wettest year (2008)

The annual-scale moisture tracking experiment shows that the average tracking rate over 35 years was 97.6%, meaning 97.6% of the precipitation water was tracked. In the monthly-scale experiment, the average tracking rate was about 97% which indicates that the experiment successfully traced the vast majority of precipitation in the study area to its surface evaporation sources. To verify the reliability of the results, Zhang *et al.* (2017) conducted a comparative experiment[9]. They used another set of atmospheric reanalysis data, namely the NCEP2 (National Centers for Environmental Prediction–Department of Energy Reanalysis-II) dataset developed jointly by the National Centers for Environmental Prediction (NCEP) and the Department of Energy (DOE). NCEP2 has a spatial resolution of 2.5°×2.5°, which is lower than ERA-Interim; it also has only 10 vertical atmospheric layers in the troposphere, far fewer than ERA-Interim. The auxiliary experiment presented consistent conclusions with the main experiment, including[9]: (1) climatologically, the westerlies and the Indian summer monsoon are the main sources of moisture to precipitation on the plateau; (2) the continuous increasing in precipitation in the Qinghai-Xizang Plateau is mainly attributed to two factors, the enhancement of local moisture recycling on the plateau and the increase in moisture transport from the Indian monsoon. These two key conclusions are not affected by the uncertainty of input data, further confirming the robustness of the research results.

5 Discussion and Conclusion

There is a consensus that the precipitation in the Qinghai-Xizang Plateau has shown an overall increasing trend in recent decades[1,3]. This study used the CMA precipitation and the numerical model WAM to track the moisture sources in areas of significant precipitation increase in the Qinghai-Xizang Plateau. The research ultimately constructed a simulated dataset of moisture sources for the increased precipitation in the Qinghai-Xizang Plateau, demonstrating the contribution of surface evaporation sources from various global regions to precipitation on the plateau, as well as their spatial and temporal patterns. The dataset simulation used multi-source data as model inputs, integrating ERA-Interim reanalysis data, the CMA precipitation, and GLDAS model evaporation. The tracking model, based on strict physical processes and water balance equations, performed calculations at a temporal resolution of 0.5 hours and a spatial resolution of 1.5°×1.5°. The final precipitation tracking rates were 97.6% for annual precipitation and 97.0% for monthly precipitation on average. This indicates that the model successfully traced the vast majority of precipitation back to surface evaporation sources, thereby ensuring the usability of the data. Furthermore, the accuracy of the data was strongly guaranteed through verification by setting up comparative experiments.

This dataset fills a critical gap in the study of precipitation in the Qinghai-Xizang Plateau, laying a solid foundation for a deeper understanding of the complex water cycle processes in the region and their mechanisms of change. It holds multifaceted research value, such as precisely quantifying the proportion of oceanic and terrestrial contributions to plateau precipitation, systematically studying changes in local hydrological cycles, and revealing patterns of monthly, interannual, and trend changes in moisture transport and contribution. Through in-depth analysis of precipitation characteristics in dry and wet years, this dataset helps predict and respond to extreme climate events. These applications have significant scientific and practical implications for advancing climate and hydrological research in the Qinghai-Xizang Plateau and promoting sustainable regional development.

Conflicts of Interest

The author declares 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 Tibetan Plateau [J]. *Chinese Science Bulletin*, 2015, 60(32): 3025–3035.

[2] Yao, T., 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] 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.

[4] Lei, Y., Yang, K. The cause of rapid lake expansion in the Tibetan Plateau: climate wetting or warming? [J]. *Wiley Interdisciplinary Reviews*: *Water*, 2017, 4(6): e1236.

[5] Zhang, G., Zhang, Y., Dong, J., *et al*. Green-up dates in the Tibetan Plateau have continuously advanced from 1982 to 2011 [J]. *Proceedings of the National Academy of Sciences*, 2013, 110(11): 4309–4314.

[6] Gustafsson, M., Rayner, D., Chen, D. Extreme rainfall events in southern Sweden: where does the moisture come from? [J]. *Tellus A*: *Dynamic Meteorology and Oceanography*, 2010, 62(5): 605–616.

[7] Stohl, A., James, P. A Lagrangian analysis of the atmospheric branch of the global water cycle. part I: method description, validation, and demonstration for the August 2002 flooding in central Europe [J]. *Journal of Hydrometeorology*, 2004, 5(4): 656–678.

[8] An, W. L., Hou, S. G., Zhang, Q., *et al*. Enhanced recent local moisture recycling on the northwestern Tibetan Plateau deduced from ice core deuterium excess records [J]. *Journal of Geophysical Research*: *Atmospheres*, 2017, 122(23): 12541–12556.

[9] Zhang, C., Tang, Q. H., Chen, D. L. Recent changes in the moisture source of precipitation over the Tibetan Plateau [J]. *Journal of Climate*, 2017, 30: 1807–1819.

[10] Zhang, C., Tang, Q. H., Huang, J. C., *et al*. Moisture source simulating dataset on increased precipitation area in the Tibetan Plateau (1979–2013) [J/DB/OL]. *Digital Journal of Global Change Data Repository*, 2024. https://doi.org/10.3974/geodb.2024.08.02.V1. https://cstr.escience.org.cn/CSTR:20146.11.2024.08.02.V1.

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

[12] van der Ent, R. J., Savenije, H. H. G. Length and time scales of atmospheric moisture recycling [J]. *Atmospheric Chemistry and Physics*, 2011, 11(5): 1853–1863.

[13] van der Ent, R. J., Savenije, H. H. G., Schaefli, B., *et al*. Origin and fate of atmospheric moisture over continents [J]. *Water Resources Research*, 2010, 46(9): W09525.

[14] 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.

[15] Gao, Y. H., Leung, L. R., Zhang, Y. Changes in moisture flux over the Tibetan Plateau during 1979–2011 and possible mechanisms [J]. *Journal of Climate*, 2015, 28(10): 4185–4197.

[16] Zhao, Y. F., 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.