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Dataset Development on Moisture Sources of Precipitation on the Qinghai-Xizang Plateau (1998–2018)

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Abstract: The source and transport mechanisms of water vapor for precipitation on the Qinghai-Xizang Plateau have been a focal point of interest in international hydroclimatology. Due to the limited number of ground observation stations and their uneven distribution on the plateau, there are large errors in overall precipitation measurements, leading to significant uncertainties in tracing precipitation sources. The authors introduced satellite precipitation data to compensate for the limitations of station-based precipitation observations, enabling a more accurate assessment of moisture sources for the plateau's overall precipitation. Using a water vapor tracking numerical model, the authors simulated the moisture sources for the plateau's overall precipitation over approximately 20 years. The model was driven by ERA-Interim reanalysis data, TRMM satellite precipitation, and GLDAS-OAFlux evaporation data. Comparative experiments were conducted for validation, ultimately generating monthly-scale data of moisture sources for the plateau's overall precipitation. The dataset includes: (1) the extent of the Qinghai-Xizang Plateau; (2) monthly moisture source data for precipitation from 1998 to 2018, with a spatial resolution of 1°×1°, the unit is mm/mon; (3) monthly and annual precipitation data of the plateau. The dataset is archived in .nc, .shp, and .xlsx formats, consisting of 8 data files with a total size of 55 MB (compressed into 1 file, 40.9 MB).

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

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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.2024.09.02.V1.

1 Introduction

The Qinghai-Xizang Plateau, is the source of several major Asian rivers, with its precipitation constituting the main source of runoff[1]. The sources and transport mechanisms

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[2] Zhang, C., Tang, Q. H., Huang, J. C., *et al*. Simulating precipitation moisture sources dataset on Qingzang Plateau (1998–2018) [J/DB/OL]. *Digital Journal of Global Change Data Repository*, 2024. https://doi.org/10.3974/geodb.2024.09.02.V1.

of water vapor for precipitation over the plateau have long been a focus of international hydroclimatological research[2,3]. However, due to the limited number of ground observation stations and their uneven distribution, there are significant errors in estimating the total precipitation over the plateau[4]. This uncertainty not only affects the accurate assessment of precipitation but also poses challenges in tracing water vapor sources.

To address the problem of sparse and unevenly distributed precipitation observation stations on the plateau, this study introduced the satellite precipitation data product TRMM (Tropical Rainfall Measuring Mission) to compensate for the limitations of surface observations. TRMM data showed high consistency with measured data in areas with dense ground observation stations in the eastern plateau, strongly confirming its applicability across the entire plateau[4]. The successful introduction of satellite precipitation has made it possible to conduct comprehensive and accurate source tracking of overall precipitation on the plateau. This study used ERA-Interim reanalysis, TRMM satellite precipitation, and GLDAS/OAFlux evaporation data as inputs to drive a water vapor tracking numerical model, simulating moisture sources for total precipitation over the plateau from 1998 to 2018, ultimately generating a monthly-scale dataset of moisture sources for plateau precipitation. This achievement provides a solid data foundation for accurately assessing the moisture sources, seasonal variations, and water vapor transport mechanisms of total precipitation over the plateau.

2 Metadata of the Dataset

The metadata of Simulating precipitation moisture sources dataset on Qingzang Plateau (1998–2018)[5] 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

This study selected the new generation Eulerian numerical model WAM2Layers (Water Accounting Model with Two Layers) as the primary tool for tracking moisture sources of total precipitation over the plateau. This model has been significantly optimized from the original WAM model, notably by introducing a dual-layer structure to refine vertical simulation. This design effectively overcomes the tracking errors of the previous model under conditions of vertical wind direction changes, greatly improving the accuracy of dynamic moisture tracking[7,8]. The main model equation is:

$$\frac{\partial W_l}{\partial t}+\frac{\partial (W_l u)}{\partial x}+\frac{\partial (W_l v)}{\partial y}=E_l-P_l\pm F_V+\alpha_l \tag{1}$$

where W represents atmospheric precipitable water (mm), l represents the upper or lower atmospheric layer, u, v represent horizontal wind speed (m/s), E represents surface evaporation (mm), P represents precipitation (mm), Fv represents vertical moisture transport between layers (mm), and α represents the residual term. Moisture from the specific source region follows a similar atmospheric water balance equation:

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

Where Ω represents moisture from a specific source region (mm).

Table 1 Metadata summary of MoistureSourceQZP_1998–2018

Items	Description
Dataset full name	Simulating precipitation moisture sources dataset on Qingzang Plateau (1998–2018)
Dataset short name	MoistureSourceQZP_1998–2018
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 Zhou, Y. Y., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, zhouyy@igsnrr.ac.cn Gaffney, P. P. J., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, gafppj@igsnrr.ac.cn Xu, X. M., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, xuxm@igsnrr.ac.cn
Geographical region	Qinghai-Xizang Plateau
Year	1998–2018
Temporal resolution	Month
Spatial resolution	1°×1°
Data format	.nc, .xlsx, .shp
Data size	40.9 MB (after compression)
Data files	The Qinghai-Xizang Plateau region, monthly precipitation, monthly moisture sources for precipitation in Qinghai-Xizang Plateau
Foundation	Chinese Academy of Sciences (XDA2006040202)
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 percent 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[6]
Communication and searchable system	DOI, CSTR, Crossref, DCI, CSCD, CNKI, SciEngine, WDS, GEOSS, PubScholar, CKRSC

3.2 Data Sources

The atmospheric data used in this study comes from the European Centre for Medium-Range Weather Forecasts' ERA-Interim reanalysis[9], with a spatial resolution of 1°×1°. It includes zonal wind, meridional wind, and specific humidity at model levels at 6-hour intervals, surface atmospheric pressure at 6-hour intervals, and a series of vertically integrated water and flux variables.

For precipitation, the study used the surface station-calibrated TRMM research product 3B43 (V7)[10], which covers the global range of 50°N–50°S and provides monthly data from 1998 to 2018 on a 0.25°×0.25° grid. For land surface evaporation, the study selected the 3-hourly 1°×1° evaporation product produced by the Community Land Model (CLM) of the Global Land Data Assimilation System (GLDAS)[11]. CLM is a rigorously evaluated physics-based model. Its forcing data, including precipitation, temperature, and radiation, are all observational data. Over the oceans, the Objectively Analyzed Air-sea Fluxes (OAFlux) product[12] was used, with a temporal and spatial resolution of monthly 1°×1°. The OAFlux product has assimilated satellite data since 1985. Additionally, 3-hourly precipitation and evaporation data from ERA-Interim were incorporated to provide diurnal variation information.

3.3 Data Processing

Apart from the GLDAS land surface evaporation data, surface fluxes are primarily monthly data. The values of precipitation and evaporation in ERA-Interim are too high to be used directly[13], but they contain diurnal variation information at 3-hour intervals. To preserve this diurnal variation information of ERA-Interim's precipitation and evaporation while conforming to observational data, the team used monthly observational precipitation and evaporation data to recalibrate the ERA-Interim data. The specific steps are as follows:

First, the TRMM precipitation was converted to the same spatial resolution as ERA-Interim by integrating the 0.25° grid values that fall within a 1° grid. Meanwhile, monthly precipitation from ERA-Interim was calculated. Using monthly TRMM data as the baseline, the ratio of TRMM precipitation to ERA-Interim precipitation was calculated for each grid and each month. Then, ERA-Interim precipitation for each grid was recalibrated by multiplying the 3-hourly ERA-Interim precipitation data by the ratio for each month.

For ocean evaporation, the 1°×1° OAFlux values were first linearly transformed to ERA-Interim's 1°×1° grid. Then, using a procedure similar to TRMM, the 3-hourly ERA-Interim evaporation fields were recalibrated to match the OAFlux data. In grids where OAFlux data was missing, ERA-Interim values were retained; Over land, GLDAS evaporation data was linearly interpolated to ERA-Interim's 1° grid. Since GLDAS evaporation data was already at 3-hour resolution, the interpolated data was used directly.

To ensure numerical stability in moisture tracking, each set of input data was discretized to 15-minute time steps. The 6-hourly or 3-hourly data was converted to 15-minute intervals using linear interpolation (for state variables) or equal distribution (for cumulative variables). After the model completed the run, the 15-minute scale moisture contribution data was integrated to the specified time scale as needed.

4 Data Results and Validation

4.1 Dataset Composition

The dataset consists of 8 data files in 3 data groups, including: (1) Geographical extent of the Qinghai-Xizang Plateau (in .shp format); (2) Monthly precipitation data for the plateau from 1998 to 2018 (mm/mon, in .xlsx format); (3) Simulated moisture source data on a monthly scale from 1998 to 2018, with a spatial resolution of 1°×1° (mm/mon, in .nc format).

4.2 Data Results

The moisture sources for precipitation over the Qinghai-Xizang Plateau exhibit significant seasonal variations (Figure 1). In winter, January shows the lowest contribution from evaporative sources throughout the year, in stark contrast to July in summer, when evaporative source contributions reach their annual peak. Notably, the westerlies play a crucial role throughout all seasons of the year. Even in July, when the South Asian monsoon dominates, the westerlies remain an important source of moisture for plateau precipitation, highlighting their persistent influence.

In spring (April), the moisture contribution to plateau precipitation mainly comes from the westerlies, while the Arabian Sea and Bay of Bengal also provide significant contributions. In contrast, the situation in autumn (October) differs, with moisture for plateau precipitation primarily originating from the Bay of Bengal to the south, even exceeding the contribution from the Arabian Sea. This phenomenon reflects subtle changes in the circulation patterns south of the plateau during autumn.

July represents the month with the most abundant total precipitation over the plateau, resulting from the combined effects of multiple circulation systems. The prevailing South Asian monsoon transports large amounts of Indian Ocean moisture to the plateau, while simultaneously, due to the moist Eurasian continental surface, the westerlies also bring considerable moisture contribution to the Qinghai-Xizang Plateau. Additionally, active convection over the plateau during summer strengthens the internal circulation, making local evaporation an important contributor to precipitation, forming a notable center of strong contribution in the southern plateau.

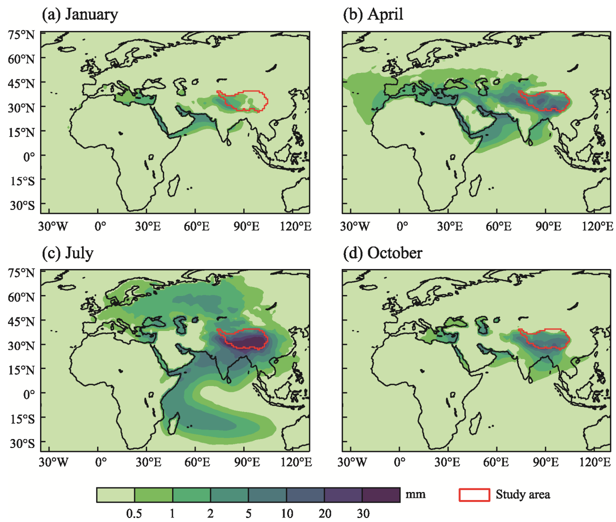

Figure 1 Maps of average seasonal variations in moisture sources for the plateau precipitation

4.3 Data Validation

Due to the sparse and uneven distribution of meteorological stationson the plateau, there exists significant uncertainty in data of the plateau precipitation. A comparison between the China Meteorological Administration's (CMA) station-based precipitation product and TRMM satellite precipitation data (Figure 2) shows that from 1998 to 2017, CMA's estimated overall average annual precipitation for the plateau was approximately 12% lower than TRMM's estimation, with a correlation coefficient of 0.40 between the two. Although this passed the 0.10 significance level test (but not the 0.05 level), substantial differences can be observed in their variations (Figure 2).

To verify the applicability of TRMM precipitation data in Qinghai-Xizang Plateau, Zhang selected a validation area in the eastern plateau with dense surface observation stations to analyze the relationship between surface-observed precipitation and satellite-retrieved precipitation[4]. The results showed that from 1998 to 2017, TRMM data indicated an average annual precipitation of 676.6±40.4 mm in the eastern plateau, which accounted for approximately 93% of the measured precipitation. More importantly, TRMM data demonstrated high consistency with measured data in interannual variations, with a correlation coefficient as high as 0.92. This result strongly confirms the usability of TRMM data under the complex terrain conditions of the Qinghai-Xizang Plateau and supports its application across the entire plateau region. In contrast, the CMA precipitation product has more uncertainties over the plateau due to station-related issues and should be used with caution.

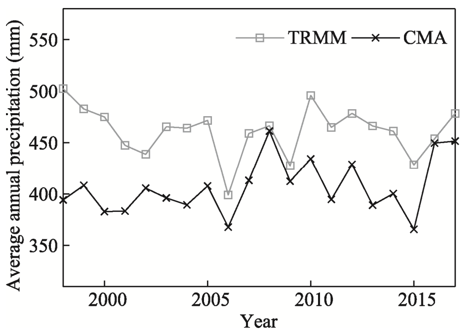

Figure 2 Comparison between remote sensing observation (TRMM) and surface station observation (CMA) precipitations over the Plateau (1998–2017)

5 Discussion and Conclusion

The total precipitation and its moisture sources on the Qinghai-Xizang Plateau have long been a research focus in the global climatology community. However, due to sparse and uneven distribution of ground observation stations on the plateau, there are significant errors in estimating total precipitation, which leads to more uncertainties in tracing precipitation sources. This study introduces satellite precipitation data, taking full advantage of its broad coverage, validating it in areas with dense observations on the plateau, and extending it to the entire plateau region. This method effectively addresses the lack of ground observation data on the plateau and provides a more reliable data source for studying precipitation moisture sources. The model uses multi-source observational data as driving inputs, including TRMM precipitation, GLDAS/ OAFlux model/remote sensing evapotranspiration data, and ERA-Interim reanalysis. Based on strict physical processes and water balance equations, calculations are performed at 15-minute time scales, ultimately providing monthly global gridded moisture contribution data at 1°×1° spatial resolution. The annual precipitation tracking ratio reaches 96.5%, indicating high reliability.

Seasonal variation analysis of this dataset shows that moisture sources for Qinghai-Xizang Plateau precipitation exhibit significant seasonal characteristics. The westerlies influence persists throughout the year, while the abundant July precipitation results from the combined effects of multiple circulation systems, including the South Asian monsoon, plateau internal circulation, and westerlies. This complex moisture transport pattern highlights the crucial role of the Qinghai-Xizang Plateau's unique geographical location and topographical features in regulating regional water cycles, while also emphasizing the synergistic effects of multi-scale atmospheric circulation systems in shaping plateau precipitation characteristics.

Conflicts of Interest

The authors declare no conflicts of interest.

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