

Application of Figure-CWT Method in Identifying Water Vapor Sources of Summer Precipitation in China: Postprint

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Abstract

Using the backward trajectory calculation module in TrajStat software and the Concentration Weighted Trajectory (CWT) method, we analyzed the water vapor sources of summer precipitation at event scale in western China (Urumqi in Xinjiang, Qilian and Maduo in Qinghai) and eastern China (Changsha in Hunan and Guangzhou in Guangdong), with supplementary analysis using water vapor flux. The results show: Summer precipitation in Urumqi, Qilian, and Maduo is significantly influenced by westerly water vapor, while summer precipitation in Changsha is significantly influenced by Western Pacific water vapor, and summer precipitation in Guangzhou is significantly influenced by Indian Ocean water vapor. All five stations involve local recycled water vapor in summer precipitation. In the western region, the recycled water vapor affecting summer precipitation is mainly distributed in mountainous areas and basins with relatively high relative humidity, as well as regions with high evaporation. In the eastern region, the recycled water vapor affecting summer precipitation is mainly distributed in areas where surface water bodies are concentrated. In the western region, due to large undulations of the underlying surface during water vapor transport, changes in the water vapor d-value of air masses are influenced not only by surface evaporation water vapor but also by terrain undulation of the underlying surface. In the eastern region, due to small undulations of the underlying surface during water vapor transport, changes in the water vapor d-value of air masses are generally only influenced by surface evaporation water vapor.

Full Text

Application of CWT Method in Identifying Water Vapor Sources of Summer Precipitation in China

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The Concentration Weighted Trajectory (CWT) method calculates the concentration field using the formula:

$$C_{ij} = \sum_k C_k T_{ijk} \cdot W(n_{ij})$$

where C_{ij} is the concentration at grid cell (i,j), C_k is the concentration of trajectory k, T_{ijk} is the residence time, and $W(n_{ij})$ is a weighting function.

Abstract: The water vapor sources of summer precipitation in western China (Urumqi, Qilian and Maduo) and eastern China (Changsha and Guangzhou) were analyzed using the backward trajectory calculation module and Concentration Weighted Trajectory (CWT) method of TrajStat software, combined with water vapor flux analysis. The results showed: (1) Summer precipitation in Urumqi, Qilian and Maduo was significantly influenced by westerly water vapor transport, while Changsha was predominantly affected by Western Pacific water vapor and Guangzhou by Indian Ocean water vapor. (2) Local recycled water vapor contributed to summer precipitation at all five sampling sites. In western China, recycled water vapor primarily originated from mountainous areas and basins with high relative humidity and substantial evaporation capacity. In eastern China, recycled water vapor mainly came from regions with concentrated surface water bodies. (3) In western regions, changes in air mass water vapor content were influenced by both evaporated water vapor and underlying surface conditions, as the underlying surface underwent significant changes during water vapor transport. In eastern regions, changes in air mass water vapor content were primarily influenced by evaporated water vapor due to minimal changes in the underlying surface.

Keywords: summer precipitation; backward trajectory; CWT; water vapor source

[Figure 1: see original paper]

[Figure 2: see original paper]

1. Introduction

The CWT method is an effective approach for identifying water vapor sources and their spatial distributions. This study investigates summer precipitation

across five sampling sites representing different climatic regimes in China. The analysis integrates backward trajectory modeling with isotopic and meteorological data to quantify contributions from different moisture sources.

2. Data and Methods

2.1 Data Sources and Processing Isotopic data for summer precipitation were obtained for the years 2003 and 2009. The isotopic composition was calculated using standard equations for water vapor isotopic fractionation:

$$\begin{aligned}\delta^{18}O_{PV} &\approx \delta^{18}O_P - 10^3(\alpha_{w-v}^{18} - 1) \\ \delta D_{PV} &\approx \delta D_P - 10^3(\alpha_{w-v}^2 - 1)\end{aligned}$$

where α_{w-v}^{18} and α_{w-v}^2 are fractionation factors for ^{18}O and deuterium, respectively, between water and vapor.

The fractionation factors are temperature-dependent, calculated as [26-27]:

$$\begin{aligned}10^3 \ln \alpha_{w-v}^{18} &= 1.137 \left(\frac{10^6}{T^2} \right) - 0.4156 \left(\frac{10^3}{T} \right) - 2.0667 \\ 10^3 \ln \alpha_{w-v}^2 &= 24.844 \left(\frac{10^6}{T^2} \right) - 76.248 \left(\frac{10^3}{T} \right) + 52.612\end{aligned}$$

The mixed isotopic composition of evaporated vapor is calculated by:

$$\delta(w) = \sum P_i \delta_i$$

where $\delta(w)$ is the mixed isotopic composition, P_i is the proportion, and δ_i is the isotopic composition of each component.

2.2 Trajectory Calculation Backward trajectories were calculated using the TrajStat software package [28], which utilizes NOAA's HYSPLIT model [29]. Trajectories were computed for summer months (June-August) at 00:00 and 12:00 UTC, with a duration of 144 hours (6 days). Starting heights were set at 2000 m, 1500 m, and 1000 m above ground level for different sites.

The trajectory calculation follows the equation:

$$P(t + \Delta t) = P(t) + 0.5 \cdot [V(P, t) + V(P', t + \Delta t)] \cdot \Delta t$$

where $P(t)$ is the position vector, $V(P, t)$ is the velocity vector, and Δt is the time step.

Meteorological data were obtained from the Global Data Assimilation System (GDAS) with $1^\circ \times 1^\circ$ spatial resolution and NCEP/NCAR Reanalysis data with $2.5^\circ \times 2.5^\circ$ resolution [23-25].

Table 1. Basic information of the sampling sites in this study

Site	Latitude	Longitude	Altitude (m)	Temperature (°C)	Precipitation (mm)
Urumqi	43°06 N	86°50 E	401.4	[18]	[18]
Qilian	38°42 N	99°38 E	1427.5	[19]	[19]
Maduo	34°55 N	98°16 E	[20]	[20]	[20]
Changshu	28°12 N	112°54 E	[21]	[21]	[21]
Guangzhou	23°09 N	113°21 E	[22]	[22]	[22]

2.3 CWT Method The Concentration Weighted Trajectory method calculates potential source contributions by weighting trajectory residence times with associated concentrations [30]. For each grid cell, the CWT value is calculated as:

$$C_{ij} = \frac{\sum_{k=1}^m C_k \cdot t_{ijk}}{\sum_{k=1}^m t_{ijk}} \cdot W(n_{ij})$$

where C_{ij} is the average concentration in grid cell (i, j) , C_k is the concentration observed at the receptor site from trajectory k , t_{ijk} is the residence time of trajectory k in grid cell (i, j) , and $W(n_{ij})$ is a weighting function based on the number of trajectories passing through the cell.

3. Results and Discussion

3.1 Water Vapor Source Analysis at Urumqi Analysis of 2003 summer data for Urumqi shows that westerly water vapor transport dominates precipitation sources. CWT analysis with a $0.5^\circ \times 0.5^\circ$ grid resolution reveals high-concentration centers distributed across Central Asia and northwestern China. The method effectively identifies spatial patterns of moisture sources, with recycling ratios reaching 16.2% in areas with high relative humidity [36].

3.2 Water Vapor Source Analysis at Qilian in 2009 The backward trajectory analysis for Qilian in the summer of 2009 demonstrates that water vapor primarily originated from westerly transport [Figure 2: see original paper]. CWT analysis reveals high-concentration centers mainly distributed across Central Asia and the western portions of Northwest China. Previous studies have established that westerly water vapor transport constitutes the principal moisture source for precipitation in the Qilian Mountains region [37-39].

Underlying surface conditions along transport pathways significantly modulate air mass water vapor content. As air masses traverse regions with elevated relative humidity or substantial evaporation capacity, water vapor content increases via surface evaporation. Conversely, passage over arid regions with low relative

humidity results in decreased water vapor content. The complex terrain of the Qilian Mountains region causes water vapor transport to be influenced by both large-scale atmospheric circulation and local topographic effects.

Model simulations confirm the dominance of westerly water vapor transport in summer precipitation for this region. The CWT method effectively identifies spatial distributions of water vapor sources, with recycling ratios reaching 16.2% in mountainous areas characterized by high relative humidity, while basin areas exhibit recycling ratios of approximately 5% [36].

[Figure 3: see original paper]

3.3 Water Vapor Source Analysis at Maduo in 2009 CWT analysis for Maduo in the summer of 2009 indicates that water vapor derived mainly from westerly transport, supplemented by local evaporation [Figure 3: see original paper]. High-concentration centers were situated in the plateau region west of Maduo. Transport pathways cross areas with pronounced topographic variations, inducing substantial changes in underlying surface conditions.

Local recycled water vapor in the Maduo region occurs primarily in areas with concentrated water bodies and high relative humidity. Evaporation from plateau lakes and wetlands contributes significantly to local water vapor recycling. Research indicates that the water vapor recycling ratio in this region can reach 16.2% [40], demonstrating that local evaporation plays a crucial role in precipitation formation.

Isotopic characteristics of precipitation reflect these water vapor sources. $\delta^{18}\text{O}$ values in summer precipitation at Maduo range from -3.07‰ to -14‰ , with a deuterium excess of approximately 14‰ , suggesting derivation primarily from westerly water vapor with some local evaporation influence [41-42].

[Figure 4: see original paper]

3.4 Water Vapor Transport Characteristics Analysis of water vapor transport characteristics reveals distinct regional patterns across China. In western China, westerly water vapor transport dominates summer precipitation, while in eastern China, monsoonal moisture from the Pacific and Indian Oceans plays a critical role. Local water vapor recycling assumes greater significance in western China due to complex terrain and substantial evaporation capacity in certain areas.

[Figure 5: see original paper]

3.5 Water Vapor Source Analysis at Guangzhou in 2008 CWT analysis for Guangzhou in the summer of 2008 shows that water vapor originated primarily from the Indian Ocean and South China Sea [Figure 5: see original paper]. High-concentration centers were located in tropical ocean regions. Wa-

ter vapor transport was associated with summer monsoon circulation, delivering abundant moisture from ocean to land.

Isotopic composition of precipitation at Guangzhou exhibited $\delta^{18}\text{O}$ values ranging from -3.07‰ to -14‰ , with a deuterium excess of about 14‰ . These values indicate precipitation derived mainly from oceanic water vapor with minimal local evaporation influence [43]. The water vapor recycling ratio in this region was relatively low, generally less than 5% [36].

Despite underlying surface conditions characterized by dense vegetation and abundant water bodies in the Guangzhou region, their impact on monsoon air mass water vapor content remained limited due to strong moisture advection from the ocean.

[Figure 6: see original paper]

3.6 Comparative Analysis of Water Vapor Sources Comparative analysis across different stations reveals significant regional differences. In western China (Urumqi, Qilian, Maduo), westerly water vapor transport dominates summer precipitation, with local recycled water vapor contributing 5-16.2% of total precipitation. In eastern China (Changsha, Guangzhou), monsoonal water vapor from the Pacific and Indian Oceans represents the primary source, with local recycling playing a minor role.

These differences in water vapor sources are determined primarily by large-scale atmospheric circulation patterns and regional geographic features. Complex terrain in western China enhances local water vapor recycling through orographic lifting and increased evaporation in mountainous areas. In contrast, flat terrain in eastern China and strong monsoon advection limit development of local water vapor recycling.

4. Conclusions

- (1) The CWT method effectively identifies spatial distributions of water vapor sources for summer precipitation across China. Western regions are dominated by westerly transport, while eastern regions receive moisture primarily from monsoonal sources.
- (2) Local water vapor recycling contributes significantly to precipitation in western China (5-16.2%), particularly in mountainous areas with high relative humidity. In eastern China, recycling ratios are lower ($<5\%$) due to strong advection of oceanic moisture.
- (3) Underlying surface conditions play a crucial role in modulating air mass water vapor content, particularly in western China where topographic complexity enhances evaporative contributions.

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Note: Figure translations are in progress. See original paper for figures.

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