Diurnal Variations in Water Vapor Isotopes and Water Vapor Source Analysis in the Middle Reaches of the Heihe River in Summer: Postprint

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Abstract

Based on measured water vapor isotope data and related meteorological data from June to August 2012, this study investigated the basic isotopic characteristics of water vapor, its source directions, and potential evaporation sources in the middle reaches of the Heihe River during summer day and night periods. The results show that: the slope of the atmospheric water vapor line is greater during daytime than at night, and the water vapor d-excess value is greater during daytime than at night, which collectively indicates that local evaporation is stronger during daytime than at night; the summer season is significantly influenced by westerly water vapor transport. Specifically, June is mainly influenced by westerly water vapor and Arctic Ocean water vapor, while August is mainly influenced by westerly water vapor and water vapor from the southeast direction, and August is most significantly affected by water vapor from the southeast direction; the underlying surface terrain and the movement of pressure belts along water vapor transport pathways affect the height of water vapor backward trajectories, the water vapor transport channel in the northwest direction is relatively smooth, with higher wind speeds, which facilitates water vapor transport; water vapor evaporation sources are mainly concentrated in the areas surrounding the study region and to its east and north, followed by the northwest. Oases are the main water vapor evaporation sources, followed by urban areas and rivers; local evaporation is stronger and more extensive during daytime than at night.

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Preamble

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Abstract: In this study, we analyzed the basic characteristics of water vapor isotopes in the middle reaches of the Heihe River, Gansu Province, China, mainly based on water vapor d-data. We used PSCF and CWT analysis for the 2012 summer months in the studied area. We identified potential steam source locations during the day and night, and connected this with backward trajectory clustering, maximum wind speed and direction analysis, atmospheric precipitation data, and vapor flux divergence. Our results showed that the slope of the moisture line in the daytime was greater than that at night, with elevated d-values during the day. This suggests that local evaporation is stronger during the day than at night. The values of D and ¹ O in the water vapor increased every month, and were significantly elevated during the day due to the urban heat island effect. The water vapor source was complex, and the d-value of the water vapor decreased throughout the summer. In June, high values reflected relatively humid conditions in the western Pacific, which were significantly affected by arctic and westerly water vapor. In July and August, the arctic vapor was steadily replaced by southeast water vapor. Surface topography and the movement of the pressure zone on the path of water vapor transport both affected the height of the backward trajectory of the water vapor. The water vapor transportation channel in the northwest direction was smooth with high wind speeds, which encourages water vapor transportation. In response to the movement of the pressure belt, the backward trajectory height of water vapor in August was higher than that in June and July. The origins of the water evaporation were mainly concentrated to the east and north of the study area, with lesser contributions from the northwest. Oases were the main source of water evaporation, followed by cities and rivers, with local evaporation being stronger during the day than at night. Indeed, most of the observed features were strengthened by warm daytime temperatures.

Keywords: summer days and nights; water vapor sources; water vapor isotope; middle reaches of Heihe River

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1. Study Area

The middle reaches of the Heihe River (38°51 N, 100°22 E, elevation 1550 m) are located in the continental river basin of Northwest China. From 1961 to 2010, the mean annual temperature was 7.4°C and mean annual precipitation was 128.7 mm, with precipitation concentrated primarily in June–August. The watershed area spans approximately 1300 km^2, characterized by an arid continental climate with mountain-oasis-desert ecosystems.

2. Methods

2.1 Data Sources

Water vapor isotope data were obtained from the Yale vapor isotope monitoring network (https://vapor-isotope.yale.edu/dataset/site-dataset). The dataset includes ^{1} O and D values measured at sampling heights of 0.6–1.6 m and 2.6–3.6 m above ground surface, with measurement precision of ±1‰ for D and ±0.3‰ for ^{1} O. Data were collected during summer 2012 (June–August) at 10:00 and 21:00 daily.

Backward trajectory analysis was performed using the TrajStat plugin and NOAA HYSPLIT model. Meteorological data for trajectory calculation were obtained from NCEP Global Data Assimilation System (GDAS) with 1°×1° spatial resolution. Trajectories were initialized at 10:00, 21:00, 00:00, and 03:00 local time, with a total of 712 trajectories calculated for the study period. Each trajectory was run for 144 hours (6 days) at starting heights of 1000 hPa, 775 hPa, 750 hPa, and 700 hPa.

2.2 Trajectory Clustering and Analysis

Cluster analysis was applied to group backward trajectories into representative paths. Two statistical parameters were calculated: the Spatial Variance (SPVAR) and the Total Spatial Variance (TSV), which quantify the spatial heterogeneity of trajectory clusters. The clustering algorithm minimizes SPVAR while maximizing inter-cluster separation.

2.3 Potential Source Contribution Function (PSCF)

PSCF analysis identifies potential source regions by calculating the conditional probability that a trajectory passing through a given grid cell contains high pollutant (or isotope) concentrations. The study domain was set to 97°E–103°E and 37.5°N–41°N with 0.1°×0.1° grid resolution. The PSCF value for grid cell (i,j) is calculated as:

$$PSCF_{ij} = \frac{W(n_{ij}) \cdot m_{ij}}{n_{ij}}$$

where m_{ij} is the number of trajectory segment endpoints in cell (i,j) associated with high d-values, n_{ij} is the total number of endpoints in that cell, and $W(n_{ij})$ is a weighting function to reduce uncertainty in cells with small sample sizes:

$$W(n_{ij}) = \begin{cases} 1.00 & n_{ij} > 80 \\ 0.70 & 20 < n_{ij} \leq 80 \\ 0.42 & 10 < n_{ij} \leq 20 \\ 0.05 & n_{ij} \leq 10 \end{cases}$$

High d-values were defined as those exceeding the 75th percentile of the dataset.

2.4 Concentration Weighted Trajectory (CWT) Analysis

CWT analysis extends PSCF by incorporating concentration values to identify source-receptor relationships. The method calculates weighted concentration fields using:

$$CWT_{ij} = \frac{\sum_{k=1}^{m} C_k \cdot \tau_{ijk}}{\sum_{k=1}^{m} \tau_{ijk}}$$

where C_k is the measured d-value for trajectory k, and τ_{ijk} is the residence time of trajectory k in grid cell (i,j). This approach provides quantitative estimates of source contributions weighted by observed concentrations.

2.5 Moisture Flux Analysis

Vapor flux divergence was calculated using NCEP reanalysis data at 2.5°×2.5° resolution to identify regions of moisture accumulation or depletion. Divergence fields were computed at 850 hPa, 700 hPa, and 500 hPa pressure levels to characterize vertical moisture transport patterns.

3. Results

3.1 Diurnal Variations in Water Vapor Isotopes

The d-excess values showed clear diurnal patterns, with daytime values significantly higher than nighttime values. This pattern reflects stronger local evaporation during daylight hours due to solar heating and higher temperatures. The slope of the local meteoric water line was steeper during daytime (slope = 7.8) compared to nighttime (slope = 6.9), indicating different moisture source characteristics.

Monthly variations showed progressively decreasing d-values through summer (June: 12.3‰, July: 10.1‰, August: 8.7‰), suggesting temporal shifts in moisture sources from high-latitude (arctic) to low-latitude (monsoonal) origins.

3.2 Source Region Identification

PSCF analysis revealed distinct source regions with seasonal progression. In June, high-probability source areas were located in the northwest (45% of trajectories), with wind speeds of 8-16 m·s^{1}, indicating strong westerly transport. July showed increased contributions from the southeast (35% of trajectories) with similar wind speeds. August exhibited the most complex pattern, with 30% from southeast (4-8 m·s^{1}) and 30% from local evaporation sources.

CWT analysis confirmed these patterns, showing maximum contribution weights of 10-14‰ in source regions east of the study area. The spatial distribution of CWT values indicated that oasis evaporation contributed 30-50% of water vapor in August, while urban and river evaporation accounted for 20-35%.

3.3 Trajectory Height and Transport Efficiency

Backward trajectory heights increased from June (mean: 1500 m) to August (mean: 2800 m), consistent with the seasonal northward migration of the subtropical high-pressure system. This vertical lifting enhanced moisture transport efficiency, as evidenced by stronger vapor flux convergence in August (-3.5×10 g·kg^{1}·s^{1}) compared to June (-1.2×10 g·kg^{1}·s^{1}).

The northwest transport pathway remained the most efficient, with trajectory clusters showing minimal vertical dispersion and sustained high wind speeds (>12 m·s^{1}) throughout the summer. In contrast, southeast trajectories exhibited greater vertical variability and lower speeds, particularly in August when monsoonal influence weakened.

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