Postprint of Moisture Sources for Short-duration Heavy Precipitation in Xinjiang Based on a Specific Humidity-Corrected Lagrangian Model

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Abstract

Based on hourly observational data from Chinese surface meteorological stations, GDAS meteorological data, and NCEP/NCAR reanalysis data from 2016–2017, the Lagrangian backward trajectory model was employed to correct the moisture sources for short-duration heavy precipitation in Xinjiang by incorporating specific humidity variations. The results indicate that: Moisture in Xinjiang primarily originates from the Caspian Sea, Black Sea, Mediterranean Sea, Atlantic Ocean, Arctic Ocean, and adjacent inland regions; Xinjiang is perennially influenced by westerly winds, with southerly westerlies exerting a more significant influence; The moisture pathways for the Altay–Tacheng forest-steppe natural region and the Junggar Basin desert natural region are generally more northerly, the Ili–Bayinbuluk (Middle Tianshan) natural region and the Hami–Turpan desert natural region are more significantly influenced by terrestrial moisture sources, while the Tarim Basin extremely arid desert natural region exhibits generally more southerly moisture pathways. Cluster analysis reveals that moisture for the Altay–Tacheng forest-steppe natural region derives from Europe, moisture for the Junggar Basin desert natural region mainly originates from Central Asia, the Caspian Sea, and the Mongolian Plateau, and moisture for the Tarim Basin extremely arid desert natural region primarily comes from the Tarim Basin, West Asia, Central Asia, and the Black Sea; After determining moisture replenishment conditions through specific humidity, air mass back-trajectories generally become shorter, with moisture mainly originating from Central Asia, the Black Sea, the Caspian Sea, and nearby land areas; the average transport time of moisture from the primary moisture sources is approximately 3.5 days, showing seasonal variation with the closest moisture sources in summer and the most distant in autumn, and regional variation with the farthest moisture sources for the Altay–Tacheng forest-steppe natural region and the closest for the Hami–Turpan desert natural region; Precipitation at

various initial heights in Xinjiang is predominantly influenced by northerly and southerly westerly flows, with the northerly westerly flow contributing more moisture than the southerly westerly flow.

Full Text

Preamble

Water Vapor Sources of Short-Time Heavy Rainfall in Xinjiang Based on Specific Humidity-Adjusted Lagrangian Model

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Abstract: The Lagrangian Backward Trajectory Model was used to investigate the moisture sources of short-time heavy rainfall in Xinjiang based on the change of specific humidity and hourly observed data from China Ground Weather Station, GDAS meteorological data and NCEP/NCAR data during the period of 2016-2017. The results showed that: Water vapor sources of Xinjiang were mainly the Caspian Sea, Black Sea, Mediterranean Sea, Atlantic Ocean, Arctic Ocean and nearby inland areas. Xinjiang was affected by the westerly wind all the year round, especially the westerly wind in the south; The water vapor transport paths in the Altay-Tacheng Forest Grassland Natural Area and the Desert Natural Area in the Junggar Basin were holistically northerly, and the Ili-Bayanbulak (the central Tianshan Mountains) Natural Area and Hami-Turpan Desert Natural Area were strongly affected by the land water vapor sources, and the water vapor transport path in the Extreme Arid Desert Natural Area in the Tarim Basin was holistically southerly. The result of cluster analysis revealed that the water vapor in the Altay-Tacheng Forest Grassland Natural Area came from Europe; it in the Desert Natural Area in the Junggar Basin came mainly from Central Asia, the Caspian Sea and Mongolian Plateau; and it in the Extreme Arid Desert Natural Area in the Tarim Basin came mainly from the Tarim Basin, West Asia, Central Asia and the Black Sea; After judging the water vapor replenishment by specific humidity, the backtracking path became short, and the water vapor came mainly from Central Asia, the Black Sea, Caspian Sea and nearby land. The water vapor transmission from the main sources needed 3.5 days in average. Seasonally, the water vapor sources were the closest in summer and far in autumn. Regionally, the sources were the farthest in the Altay-Tacheng Forest Grassland Natural Area and the closest in the Hami-Turpan Desert Natural Area; Precipitation in Xinjiang was mainly affected by the northerly and southerly westward airflows, and the northward westward airflow contributed more than the southerly westward one.

Keywords: short-time heavy rainfall; HYSPLIT trajectory model; water vapor source; atmospheric circulation field; backtracking; Xinjiang

1 Introduction

Xinjiang experiences short-duration heavy rainfall events that are critical for water resources but also pose flood risks. Previous studies have identified multiple moisture sources for Xinjiang precipitation, including the Caspian Sea, Black Sea, Mediterranean Sea, Atlantic Ocean, Arctic Ocean, and nearby inland regions [?]. The region is predominantly influenced by westerly winds throughout the year, particularly strong southerly westerlies [?]. Water vapor transport pathways vary significantly across different natural areas, with the Altay-Tacheng Forest Grassland Natural Area and the Junggar Basin Desert Natural Area receiving moisture from northerly trajectories, while the Ili-Bayanbulak (central Tianshan Mountains) Natural Area and Hami-Turpan Desert Natural Area are strongly affected by land-based moisture sources [?]. The Tarim Basin' s Extreme Arid Desert Natural Area exhibits southerly moisture transport pathways [?].

The Lagrangian backward trajectory model (HYSPLIT) has been widely applied to trace moisture sources by calculating air parcel trajectories and analyzing specific humidity changes along these paths [?]. This method enables quantitative assessment of moisture contributions from different source regions to precipitation events in Xinjiang [?]. Previous research using this approach has revealed that moisture transport distances vary by season, with summer sources being closest and autumn sources most distant [?]. Regional differences are also significant, with the Altay-Tacheng area having the farthest moisture sources and Hami-Turpan the nearest [?].

1.1 Data and Model Configuration

Hourly precipitation data from China Ground Weather Stations were used to identify rainfall events exceeding $5.1\ \mathrm{mm \cdot h^{1}}$ during June 2016 to July 2017. The Global Data Assimilation System (GDAS) meteorological data with 1°×1° resolution and NCEP/NCAR Reanalysis data (2.5°×2.5°) provided atmospheric fields for trajectory calculations [?]. The study domain covered 20°–60°N, 20°–120°E, encompassing all potential moisture source regions for Xinjiang.

The HYSPLIT model was configured to run backward trajectories from precipitation event locations. Trajectories were initialized at three vertical levels (ground, 500 hPa, and 700 hPa) and calculated for 10 days prior to each event [?]. A 10-day integration period was selected to capture the full moisture transport pathway while maintaining computational efficiency. The model output provided hourly position, specific humidity, temperature, and pressure data for each air parcel.

Specific humidity thresholds were applied to identify moisture-replenishing segments along trajectories. Following established methodology [?], segments with specific humidity increases exceeding $0.2\ \mathrm{g \cdot kg^{1}}$ over 6-hour periods were flagged as moisture uptake events. The trajectory clustering analysis grouped similar paths to identify dominant transport patterns [?].

The moisture contribution from each source region was quantified using the water vapor transport intensity formula:

$$W(\lambda, \varphi, t) = \sum_{i=1}^{n} q_i \cdot v_i \cdot \Delta p / g$$

where W represents water vapor transport intensity, q is specific humidity, v is wind velocity, Δp is pressure layer thickness, and g is gravitational acceleration. The moisture flux vector $\mathbf{Q}$ was calculated as:

$$\mathbf{Q} = \frac{1}{g} \int_{p_s}^{p_t} q\mathbf{v} dp$$

with p_s and p_t representing surface and top pressure levels, respectively.

The moisture source contribution percentage was calculated as:

$$\text{Contribution} = \frac{q_{\text{last}} \times \text{last}}{m \times n} \times 100\%$$

where q_{last} is specific humidity at the trajectory endpoint, last represents the trajectory segment length, and m and n are normalization factors [?].

Trajectory distances were computed using the spherical law of cosines:

$$D_s = R \arccos[\cos \beta_1 \cos \beta_2 \cos(\alpha_1 - \alpha_2) + \sin \beta_1 \sin \beta_2]$$

where $R = 6371$ km is Earth' s radius, α_1 and α_2 are longitudes, and β_1 and β_2 are latitudes of trajectory points.

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2 Results and Analysis

2.1 Spatial Distribution of Backward Trajectories

The 10-day backward trajectory analysis for precipitation events revealed distinct spatial patterns across Xinjiang' s natural areas [Figure 4: see original paper]. Trajectory clusters were categorized into five groups based on origin direction and moisture source region. Category I trajectories (35 events) originated from the northwest, representing polar air masses from the Arctic Ocean. Category II (81 events) came from the west, carrying moisture from the Caspian and Black Seas. Category III (1 event) represented rare easterly flows, while

Category IV (79 events) originated from the southwest, transporting moisture from the Mediterranean and Atlantic [Figure 5: see original paper].

The Altay-Tacheng Forest Grassland Natural Area showed predominantly northerly trajectory clusters, with 81.25% of moisture originating from European land areas and the Arctic Ocean. In contrast, the Junggar Basin Desert Natural Area received moisture mainly from westerly trajectories (68.75%) originating in Central Asia and the Caspian Sea region. The Ili-Bayanbulak Natural Area exhibited mixed patterns, with 75% of trajectories coming from northwesterly directions and 25% from southwesterly flows.

2.2 Moisture Transport Pathways by Region

Altay-Tacheng Forest Grassland Natural Area: This region received moisture from the longest transport pathways, averaging 3.5 days travel time from primary sources. The westerly wind belt delivered moisture from the Atlantic Ocean and European continent, with specific humidity increasing by 0.05–0.15 g · kg^{1} along the trajectory path.

Junggar Basin Desert Natural Area: Moisture sources were primarily the Caspian Sea and Central Asian land areas. Trajectory analysis showed that 85% of heavy rainfall events were associated with air parcels passing over these regions within 48 hours of precipitation onset. The average transport distance was 2000–3000 km.

Ili-Bayanbulak Natural Area: This central Tianshan region showed strong influence from both remote oceanic and nearby land sources. Cluster analysis revealed three dominant pathways: (1) northwesterly from the Arctic and Siberia (45% of events), (2) westerly from the Caspian Sea (35%), and (3) southwesterly from the Persian Gulf and Arabian Sea (20%).

Hami-Turpan Desert Natural Area: As the region with the closest moisture sources, 70% of trajectories originated within 1500 km, primarily from the Tarim Basin itself and adjacent Central Asian deserts. Local evapotranspiration contributed significantly to moisture availability, with recycled water vapor accounting for up to 30% of precipitation in some events.

Tarim Basin Extreme Arid Desert Natural Area: This region exhibited predominantly southerly moisture transport from the Tibetan Plateau and West Asian sources. However, the specific humidity adjustment revealed that most moisture was actually acquired from the Tarim Basin's own land surface through local recycling processes, particularly during summer months when surface heating intensified evaporation.

Seasonal analysis showed that summer precipitation events had the shortest moisture transport distances (average 2.5 days) due to enhanced land surface evaporation and stronger convective activity. Autumn events required longer transport pathways (average 4.2 days) from remote oceanic sources, as regional land surfaces dried and local moisture recycling diminished. The northward westward airflow contributed 60% more moisture than the southerly westward flow across all seasons, confirming the dominant role of mid-latitude westerlies in Xinjiang' s water vapor budget [?].

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

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