Analysis of Water Vapor Recycling Rate in the Arid Region of Northwest China Based on the LMDZ Model (Postprint)

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Abstract

Local water vapor recycling represents a critical component of the terrestrial water cycle. In the arid regions of Northwest China, although the absolute magnitude of water vapor recycling is limited, its contribution to regional precipitation (i.e., the water vapor recycling rate) cannot be neglected. Based on simulation data from the LMDZ model with a nested isotope module and utilizing an isotope mixing model, this study analyzes the spatiotemporal characteristics and mechanistic underpinnings of water vapor recycling rates in the arid regions of Northwest China from 1979 to 2007. The results demonstrate that during the study period, the contribution rate of external water vapor to precipitation was substantially higher than that of recycled water vapor at both monthly and annual timescales, exhibiting a seasonal pattern of higher values in summer and lower values in winter, along with an interannual trend of gradual increase. In contrast, the contribution rate of recycled water vapor was relatively low, characterized by lower values in summer and higher values in winter with a declining interannual trend (the contribution rate of plant transpiration water vapor during the winter half-year showed an increasing interannual trend). The contribution rate of external water vapor to precipitation displayed spatial heterogeneity, with values typically elevated in proximity to mountainous areas and reduced in desert plain regions. Regarding surface evaporation and plant transpiration, the contribution rate of surface evaporation to precipitation was generally lower than that of plant transpiration, although the opposite pattern was observed in certain localized areas. The spatial distribution characteristics of contribution amounts for external water vapor and surface evaporation water vapor were essentially consistent with their respective contribution rates, whereas the contribution amount of plant transpiration water vapor was greater in mountainous regions than in desert plain areas.

Full Text

Contribution of Moisture Recycling to Precipitation in the Arid Region of Northwest China Based on the LMDZ Model

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Abstract

As a critical component of the terrestrial water cycle, the contribution of local moisture recycling to precipitation in the arid region of Northwest China cannot be ignored, although its absolute magnitude is relatively limited. Based on isotopic data simulated by LMDZ simulations, this study analyzes the spatiotemporal distribution characteristics and mechanisms of the contribution proportion of recycled moisture during the period from 1979 to 2007 in the arid region of Northwest China using an isotopic mixing model. Results show that the monthly and interannual contribution rate of advected moisture to precipitation was significantly higher than that of recycled moisture during the study period, being high in summer but low in winter, with a gradual increasing trend at the annual scale. Conversely, the monthly and interannual contribution rate of recycled moisture to precipitation was relatively low, being low in summer but high in winter, with a decreasing trend year by year (the interannual contribution proportion of plant transpiration moisture increased during the winter half-year). Spatially, the contribution proportion of advected moisture exhibited distinct patterns, being high in mountainous areas but low in desert plains. The contribution proportion of evaporation vapor was lower than that of plant transpiration vapor in most areas, though the opposite pattern was observed in some regions. The spatial distribution of the contribution amount of advected vapor and surface evaporation vapor was consistent with their contribution rates, while the contribution amount of plant transpiration vapor was higher in mountainous areas than in desert plains.

Keywords: moisture recycling; precipitation contribution proportion; spatial distribution; isotopic mixing model; LMDZ model; arid region of Northwest China

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1.2 Isotopic Mixing Model for Precipitation Sources

The isotopic mixing model decomposes precipitation into three components: transpiration moisture, evaporation moisture, and advected moisture. The model is based on mass balance principles and isotopic conservation. The fundamental equations are:

_pv = _tr f_tr + _ev f_ev + _adv f_adv
f_tr + f_ev + f_adv = 1

where f_tr, f_ev, and f_adv represent the fractional contributions of transpiration, evaporation, and advection to precipitation, respectively; _pv, _tr, _ev, and _adv denote the isotopic compositions of precipitation, transpiration moisture, evaporation moisture, and advected moisture, respectively.

For simplified cases, the model can be reduced to two components:

_pv = _re f_re + _adv f_adv
f_re + f_adv = 1

where _re represents the isotopic composition of recycled moisture (combined transpiration and evaporation), and f_re is the recycled moisture fraction.

1.3 Isotopic Calculations

Isotopic fractionation calculations were performed using the Hydrocalculator model (version 1.03) . The isotopic composition of precipitation (_pv) is calculated as:

_P-k + / 1+k +

where _P is the isotopic composition of precipitation, k is the fractionation factor, and + represents the equilibrium fractionation coefficient.

The equilibrium fractionation coefficient is temperature-dependent and calculated using established relationships for oxygen-18 and deuterium fractionation between water vapor and liquid water.

1.5 Local Evaporation Lines

Local evaporation lines in and around the arid region of Northwest China were established based on observational data from multiple stations. Table 1 summarizes the geographic locations and isotopic characteristics of these evaporation lines.

1.6 Isotopic Composition of Moisture Sources

The isotopic composition of different moisture sources was determined using standard procedures. The isotopic signatures of advected moisture, transpiration moisture, and evaporation moisture were distinguished based on their distinct isotopic fractionation processes.

[Figure 6: see original paper]

Figure 6 shows the interannual variations and monthly distributions of precipitation contributed by advected vapor, surface evaporation vapor, and plant transpiration vapor in the arid region of Northwest China, derived from LMDZ (free) and LMDZ (nudged) simulations during 1979–2007.

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