Analysis of Dew Day Variation Trends over the Loess Plateau (Postprint)

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Abstract

Dew days are an important factor in preventing and controlling plant diseases. Investigating dew days under climate change conditions can provide factual basis for regional plant disease prediction and prevention. Based on daily meteorological monitoring data from 52 weather stations from 1961 to 2010, this paper calculated dew days at different spatiotemporal scales on the Loess Plateau, analyzed the trend of dew days changes using the Mann-Kendall method with trend-free pre-whitening (TFPW) and Sen' s slope estimator, and investigated the causes of dew days using correlation analysis. The results show that at the monthly scale, dew occurs from March to November on the Loess Plateau, with a regional monthly average of 7 days, and the longest dew days in September, reaching 8–12 days in the southern, southeastern, and northwestern regions. At 5.77%–25.00% of meteorological stations, dew days increased significantly at a rate of 0.02–0.15 d a 1 in June and August–November; at 17.31% and 7.68% of stations, dew days decreased significantly at rates of -0.09 d a 1 and -0.02 d a 1 in April and July, respectively. At the seasonal scale, dew occurs in spring, summer, and autumn on the Loess Plateau, with a regional seasonal average of 15 days, and the longest dew days in autumn, reaching 14–26 days in the southern, southeastern, and northwestern regions. Only 3.85% and 5.77% of meteorological stations showed significant increases in dew days in summer and autumn at rates of 0.25–0.09 d a 1 and 0.15–0.09 d a 1, respectively, while 5.77% of stations showed a significant decrease in spring at a rate of -0.34 to -0.07 d a 1. Relative humidity and temperature are the most critical factors influencing the spatiotemporal variations of dew days described above.

Full Text

Spatiotemporal Analysis of Dew Days in China' s Loess Plateau

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Abstract: Dew day count is a critical factor for plant disease prevention and control. Investigating dew days under changing climate conditions provides factual evidence for regional plant disease forecasting and management. Based on daily meteorological monitoring data from 52 stations during 1961-2010, this study calculated dew days across various spatiotemporal scales in the Loess Plateau. The trend-free pre-whitening (TFPW) Mann-Kendall method and Sen's slope estimator were employed to analyze temporal trends in dew days, while correlation analysis examined relationships with meteorological factors. The results revealed that at the monthly scale, dew days began in March and ended in November, with a monthly mean of 7 days. Maximum dew days occurred in September in the southern, southeastern, and northwestern regions, reaching 8-12 days. Significant increasing trends (0.02-0.15 d a^{-1}) were detected at 5.77%-25.00% of stations during June and August-November, while significant decreasing trends (-0.09 to -0.02 d a^{-1}) were observed at 17.31% and 7.68% of stations in April and July, respectively. At the seasonal scale, dew occurred in spring, summer, and autumn, with a regional mean of 15 days. Autumn exhibited the longest duration, with 14-26 days in the southern, southeastern, and northwestern regions. Significant increases (0.09-0.25 d a^{-1}) occurred at 3.85% and 5.77% of stations in summer and autumn, respectively, while a significant decrease (-0.34 to -0.07 d a^{-1}) was found at 5.77% of stations in spring. Relative humidity and temperature were identified as the dominant factors influencing these spatiotemporal patterns.

Keywords: Loess Plateau; dew days; trend analysis; Mann-Kendall test; Sen's slope

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Introduction

Global warming induced by the greenhouse effect has altered meteorological variables such as temperature, relative humidity, precipitation, and sunshine duration, posing serious threats to population growth, agriculture, environment, economy, and industry, and even affecting global food security and water resource supply-demand balance. The Loess Plateau in northern China, characterized by a semi-arid to sub-humid climate, is renowned for severe soil erosion, fragile ecological conditions, and high sensitivity to climate change. Climate change significantly impacts the ecological environment and agricultural ecosystems of this region. While previous studies have analyzed the temporal and spatial distribution of meteorological elements in the Loess Plateau, few have focused on dew days—a key parameter in the hydrological cycle and plant disease prevention. Analyzing the spatial distribution, long-term trends, and climatic relationships of dew days can provide a foundation for local plant disease prediction and management.

This study utilized dew day data from 52 meteorological stations (1961-2010) calculated through empirical modeling. The spatial distribution of seasonal and monthly dew days was interpolated using Kriging, temporal trends were examined using trend-free pre-whitening (TFPW) and Sen' s slope estimator, and correlation analysis explained dew formation mechanisms. The findings provide a quantitative basis for understanding dew day distribution and trends under global climate change and offer vital references for future plant disease forecasting, prevention, and risk assessment.

The Loess Plateau, located in the middle and upper reaches of the Yellow River (32°47 N-40°44 N, 106°54 E-114°33 E), extends from Taihang Mountains in the east to Riyue Mountain in Qinghai in the west, bordered by the Qinling Mountains to the south and Yinshan Mountain to the north. Covering a total area of 6.285$×10^{5}$ km^{2} at an elevation of 1,200-1,600 m, the region features a loess layer 30-80 m thick. Spanning seven provinces/autonomous regions (Shanxi, Inner Mongolia, Henan, Shaanxi, Gansu, Ningxia, and Qinghai) across 341 counties, it represents a transition zone from temperate semi-humid to semi-arid and arid climates, making it both climate-sensitive and ecologically vulnerable.

To comprehensively investigate dew days, 52 representative meteorological stations were selected [Figure 1: see original paper]. Meteorological data from the China Meteorological Administration covered 1961-2010 at daily resolution, including precipitation (P, mm), mean/maximum/minimum temperature (Tm, Tmax, Tmin, °C), wind speed (u, $\mathrm{m \cdot s^{-1}}$), relative humidity (RH, %), and evaporation (E, mm). Vapor pressure deficit (VPD, kPa) was calculated as the difference between saturation vapor pressure (es) and actual vapor pressure (ea) using:

$$VPD = es - ea$$

where: - es = saturation vapor pressure (kPa) - ea = actual vapor pressure (kPa) - Td = dew point temperature (°C) - a, b = constants (17.625 and 243.04, respectively) - T = mean air temperature (°C) - RH = mean relative humidity (%) - VPD = vapor pressure deficit (kPa) - $Tmin$ = minimum temperature (°C) - $Tmax$ = maximum temperature (°C)

Methods

Dew Day Calculation

Dew days (DD) were defined as days when air temperature fell below dew point temperature, excluding rainy and frosty days. The Magnus-Tetens equation was used to calculate daily dew point temperature at each station, which was then compared with daily minimum temperature to determine dew occurrence. A day was recorded as having dew ($T_i = 1$) if $P_i = 0$ and $0 < T_i^{min} < Td_i$; otherwise, $T_i = 0$.

Time scales were defined as: monthly (January-December) and seasonal (spring: March-May, summer: June-August, autumn: September-November, winter: December-February).

Monthly dew days (DD_m) and seasonal dew days (DD_s) were calculated as:

$$DD_m = \sum_{i=1}^{N} T_i$$

$$DD_s = \sum_{m=1}^{3} DD_m$$

where Td_i is dew point temperature on day i (°C), P_i is precipitation on day i (mm), and T_i^{min} is minimum temperature on day i (°C).

Trend Analysis

To identify trends in monthly and seasonal dew days, Z-statistics and Sen's slope values were calculated, with stations showing significant changes at 95% and 99% confidence levels quantified. The trend-free pre-whitening (TFPW) Mann-Kendall method was employed to analyze trend significance while accounting for autocorrelation.

Mann-Kendall Test For a stationary time series X_t ($t = 1, 2, \dots, n$), the test statistic S and its variance are calculated. Using two-tailed testing, if $|Z| > Z_{(1-\alpha/2)}$, the null hypothesis of no trend is rejected, indicating a significant upward or downward trend at level α.

TFPW Mann-Kendall Method

1. Calculate linear trend β:

$$\beta = \text{median}\left(\frac{X_j - X_k}{j - k}\right) \quad \text{for } j > k$$

2. Create detrended series: $Y_t = X_t - \beta t$

3. Compute first-order autocorrelation r_1:

$$r_1 = \frac{\sum_{t=1}^{n-1}(Y_t - \bar{Y})(Y_{t+1} - \bar{Y})}{\sum_{t=1}^{n}(Y_t - \bar{Y})^2}$$

   If r_1 is not significantly different from zero, apply standard Mann-Kendall test; otherwise, proceed to remove autocorrelation.
4. Remove autocorrelation: $Z_t = Y_t - r_1 Y_{t-1}$
5. Construct final series: $X'_t = Z_t + \beta t$
6. Apply Mann-Kendall test to X'_t.

Sen' s Slope Estimator To quantify trend magnitude, Sen' s non-parametric method was used: 1. Calculate all pairwise slopes:

$$Q_i = \frac{X_j - X_k}{j - k} \quad \text{for } j > k, \quad i = 1, 2, \ldots, n$$

2. Sen' s slope is the median of all Q_i values.

Correlation Analysis

To assess dew day responses to meteorological factors, correlations were analyzed at 95% and 99% confidence levels. The correlation coefficient R_{xy} between variables x and y was calculated as:

$$R_{xy} = \frac{\sum_{i=1}^{n}(x_i - \bar{X})(y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{X})^2 \sum_{i=1}^{n}(y_i - \bar{Y})^2}}$$

where larger absolute values indicate stronger relationships.

Data Processing

Data were processed using R 3.4.0 and Microsoft Excel 2010, with figures generated in Origin 2016. Spatial distribution maps were created using Kriging interpolation in ArcGIS 10.1, a widely applied method for accurate spatial analysis.

Results

Spatiotemporal Distribution of Dew Days

Monthly Scale: Temporally, dew days increased significantly from March to September ($P < 0.05, 0.01$) and decreased significantly from October to November, peaking in September with a mean of 7 days. Dew was nearly absent in January, February, and December. Spatially, Wugong in the south and Linhe in the northwest showed the earliest onset and longest duration (2-10 days and 2-14 days, respectively). Dew occurred across the entire region from May to October. Spatiotemporally, dew initiated in March in the southern Loess Plateau (2-6 days, maximum 6 days at Wugong), expanded to the southern and southeastern areas in April-May (2-10 days) with simultaneous emergence in the northwest near Linhe (2-6 days). June showed decreasing trends in the south but increases in the northwest (4-14 days). July brought reductions in the northwest (4-10 days) and slight increases in the south (1-2 days). August patterns resembled July, though the southeast increased to 8-12 days. September-October maintained stability in the south and southeast, while the northwest decreased to 6-8 days in October. By November, the northwest fell below 2 days and the south reduced by 2 days.

Seasonal Scale: Temporally, no significant difference existed between summer and autumn dew days ($P < 0.05, 0.01$), with autumn showing the maximum mean of 15 days. Dew was nearly absent in winter. Spatially, Wugong and Linhe again showed the longest durations (20-24 days and 30-34 days, respectively). Spatiotemporally, dew concentrated in the southern and northwestern regions in spring (14-26 days and 14-22 days, respectively), while western and northeastern areas had fewer than 4 days. Summer and autumn dew covered the entire plateau (6-34 days), with the southern, southeastern, and northwestern regions reaching 14-26 days in autumn. Winter dew was negligible [FIGURE:2, FIGURE:3, FIGURE:4].

Trends in Dew Days at Different Temporal Scales

Monthly Scale: Mann-Kendall analysis revealed more stations with increasing than decreasing trends. Significant increases (0.02-0.15 $\mathrm{d \cdot a^{-1}}$) occurred at 5.77%-25.00% of stations during June and August-November, peaking in August (25% of stations). Significant decreases (-0.09 to -0.02 $\mathrm{d \cdot a^{-1}}$) were observed at 17.31% and 7.68% of stations in April and July, respectively, with April showing the largest proportion (17.31%) [Figure 5: see original paper].

Seasonal Scale: At the 95% and 99% confidence levels, 7.69%, 7.69%, and 3.85% of stations showed significant changes in spring, summer, and autumn, respectively. Summer and autumn exhibited significant increases (0.09-0.25 $\mathrm{d \cdot a^{-1}}$) at 3.85% and 5.77% of stations, respectively, while spring showed significant decreases (-0.34 to -0.07 $\mathrm{d \cdot a^{-1}}$) at 5.77% of stations [Figure 6: see original paper].

Factors Influencing Dew Days

Monthly Scale: Mean temperature (Tm), relative humidity (RH), precipitation (P), wind speed (u), evaporation (E), and VPD all significantly influenced dew days. Dew days showed significant positive correlations with RH and P from March to November (50.0%-99.9% and 15.39%-71.15% of stations, respectively) and significant negative correlations with E and VPD (25%-73.08% and

28.84%-90.39% of stations, respectively). Correlations with Tm and u varied by month: Tm was positively correlated in March, April, October, and November (maximum 46.15% of stations) and negatively correlated in May-September (maximum 63.47% of stations); u was positively correlated in May and September (maximum 71.1% of stations) and negatively correlated in other months (maximum 40.39% of stations) .

Seasonal Scale: All meteorological factors significantly affected dew days. Positive correlations with RH and P occurred in spring, summer, and autumn (69.23%-96.16% and 32.69%-76.92% of stations, respectively). Negative correlations were found with u, E, and VPD (21.15%-36.54%, 23.08%-51.92%, and 57.69%-88.46% of stations, respectively). Tm was negatively correlated in spring and summer but positively correlated in autumn (21.16%, 57.69%, and 19.23% of stations, respectively) .

Discussion

Influence of Meteorological Factors on Dew Days

Dew formation is a complex process influenced by numerous meteorological factors related to water vapor distribution, transport, and condensation. While this study estimated dew days using only temperature and relative humidity—representing a limitation—the results demonstrate that RH and precipitation significantly and positively correlated with dew days at both monthly and seasonal scales, with RH correlations reaching 99.9% of stations. Higher RH provides abundant moisture for dew formation, while precipitation increases atmospheric water vapor. Evaporation and VPD showed significant negative correlations because increased evaporation reduces RH, and higher VPD indicates greater difficulty for air to reach saturation. Additionally, RH, precipitation, evaporation, and VPD were all intercorrelated at $P < 0.01$.

Temperature affects dew formation: lower temperatures facilitate surface cooling and condensation, while higher temperatures accelerate evaporation and reduce surface RH. Interestingly, Tm showed positive correlations in March, April, October, November, and autumn (13.47%-46.15% of stations). During these periods, mean temperatures ranged 1.30-10.20°C while dew points were −5.46 to 0.15°C. When dew point falls below 0°C, excess water vapor manifests as frost; increasing Tm can raise dew point above freezing, enabling dew condensation.

Wind speed also critically influences dew formation. Significant positive correlations occurred only in May and September (71.1% of stations) with mean wind speeds of 2.01-2.76 $\mathrm{m \cdot s^{-1}}$, while negative correlations dominated other periods (2.08-2.92 $\mathrm{m \cdot s^{-1}}$). Light winds (<0.5 $\mathrm{m \cdot s^{-1}}$) favor dew formation by facilitating moisture diffusion and maintaining condensation surfaces, while excessive wind promotes turbulent mixing and adiabatic temperature profiles that inhibit dew accumulation. However, wind effects remain uncertain across studies, with optimal speeds ranging from 0.5-2 $\mathrm{m \cdot s^{-1}}$ to thresholds of 4.7-5.7 $\mathrm{m \cdot s^{-1}}$.

Overall, temperature and relative humidity emerged as the most critical factors controlling dew days in the Loess Plateau, consistent with findings from humid regions. The southern and southeastern plateau exhibit higher temperature and humidity than the northwest, explaining their greater dew day frequencies.

Effects of Temperature and Humidity on Dew Day Trends

Temperature serves as a climate change "indicator," while relative humidity affects the biosphere and surface hydrology. In the Loess Plateau, temperature significantly increased at 5.77%-55.77% of stations from April to November (0.018-0.090°C $\cdot\, \mathrm{a^{-1}}$, mean 0.049°C $\cdot\, \mathrm{a^{-1}}$), exceeding global (0.013°C $\cdot\, \mathrm{a^{-1}}$) and national (0.022°C $\cdot\, \mathrm{a^{-1}}$) warming rates. Humidity significantly decreased at 11.54%-23.02% of stations in July-September (-0.3 to $-0.1\% \cdot \mathrm{a^{-1}}$, mean $-0.2\% \cdot \mathrm{a^{-1}}$) and increased at 9.62%-15.39% of stations in April and June (0.1-0.3% $\cdot\, \mathrm{a^{-1}}$, mean 0.3% $\cdot\, \mathrm{a^{-1}}$). Despite these opposing trends, dew days continued increasing because current temperature and humidity ranges remain within favorable thresholds for dew formation (>70% occurrence frequency) [Figure 7: see original paper].

Limitations and Future Directions

As global warming intensifies, creating new intermittent drought and semi-arid zones, dew becomes increasingly vital for plant growth in water-limited regions. The lack of direct dew measurements in the Loess Plateau limits understanding of its ecological effects. Leaf and root water absorption represent two plant water acquisition strategies, with their relative importance shifting under water availability constraints. Given chronic soil water deficits in the Loess Plateau, the extent and sufficiency of foliar water uptake from dew, and the underlying plant-dew interaction mechanisms, warrant future investigation. Additionally, while dew creates conditions for pathogen infection, leveraging this phenomenon for biological pest control requires further research.

Conclusion

Based on long-term meteorological data from 52 stations, this study analyzed spatiotemporal patterns, trends, and drivers of dew days at monthly and seasonal scales in the Loess Plateau.

Monthly scale: Dew initiated in March at Wugong and ceased in November, occurring across the entire region from May to October. September showed maximum dew days (8-12 days in southern, southeastern, and northwestern regions; regional mean 7 days). Significant increases (0.02-0.15 $\mathrm{d \cdot a^{-1}}$) occurred

at 5.77%-25.00% of stations during June and August–November, while significant decreases (-0.09 to -0.02 d · a^{-1}) were observed at 17.31% and 7.68% of stations in April and July, respectively.

Seasonal scale: Dew occurred in spring, summer, and autumn, with no significant difference between summer and autumn. Autumn showed the longest duration (14–26 days in southern, southeastern, and northwestern regions; regional mean 15 days). Significant increases (0.09-0.25 d · a^{-1}) occurred at 3.85% and 5.77% of stations in summer and autumn, respectively, while a significant decrease (-0.34 to -0.07 d · a^{-1}) was found at 5.77% of stations in spring.

Relative humidity, precipitation, evaporation, VPD, and temperature affected dew days differently across temporal scales, but relative humidity and temperature emerged as the dominant factors. This study provides a quantitative basis for understanding dew day distribution and trends under climate change and offers valuable references for plant disease forecasting, management, and risk assessment in the Loess Plateau.

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