Seasonal Precipitation-Temperature Relationship and Its Spatiotemporal Variability in Northern China: Postprint

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Abstract

Changes in the precipitation-temperature relationship exert substantial influences on water resources, vegetation, agricultural production, and other aspects; however, research outcomes regarding their relationship and spatiotemporal variability across large-scale, multiple climate-type regions remain relatively limited. Based on monthly precipitation and temperature data from 357 meteorological stations in northern China and its surrounding areas from 1951 to 2018, this study qualitatively and quantitatively reveals the relationship between seasonal precipitation and temperature in northern China and its spatiotemporal variability. Results indicate that the correlation between summer precipitation and temperature is the strongest, followed by autumn and winter, and weakest in spring; precipitation in each season is predominantly negatively correlated with mean temperature and mean maximum temperature, but mainly positively correlated with mean minimum temperature. The relationship can be primarily categorized into four types: warm-dry, warm-wet, cold-dry, and cold-wet. In the 1950s, the precipitation-temperature relationship was dominated by cold-dry and cold-wet types; beginning in the 1960s, the coverage of cold-dry and cold-wet relationships gradually shrank westward, while warm-dry and warm-wet types became dominant in Northeast China, North China, and other regions. After the 1970s, warm-dry and warm-wet relationships have become predominant throughout the study area and persist to the present; however, small areas such as Northeast China and North China have experienced a re-emergence of cold-dry and cold-wet relationships since the 21st century, with winter showing the largest coverage. This study enriches research on precipitation-temperature relationships and provides references for regional ecological environment improvement and water resource management.

Full Text

Preamble

The relationship between precipitation and temperature and its temporal evolution significantly influence water resources, agricultural production, and vegetation dynamics. However, comprehensive understanding of their relationship and spatiotemporal variability across large regions with diverse climate types remains limited. This study addresses this gap by analyzing seasonal precipitation and temperature data from 357 meteorological stations across northern China and its surrounding regions. Using both qualitative and quantitative approaches, we reveal the relationship patterns between seasonal precipitation and temperature and their spatiotemporal variability in northern China.

Our results demonstrate that summer precipitation exhibits the strongest correlation with temperature, followed by autumn and winter, while spring shows the weakest correlation. Precipitation is predominantly negatively correlated with average temperature and average maximum temperature across all seasons, but positively correlated with average minimum temperature. The precipitation-temperature relationship can be classified into four primary types: warm-dry, warm-wet, cold-dry, and cold-wet. During the 1950s, cold-dry and cold-wet relationships dominated most of the study area. Beginning in the 1960s, the spatial extent of these cold-type relationships gradually contracted westward, while warm-dry and warm-wet relationships became predominant in northeastern and northern China. After the 1970s, warm-dry and warm-wet relationships have dominated the entire region up to the present, although small areas in northeastern and northern China experienced a re-emergence of cold-dry and cold-wet relationships after 2000, with winter showing the largest coverage. This research enriches the understanding of precipitation-temperature relationships and provides valuable references for regional ecological restoration and water resource management.

Keywords: precipitation; temperature; seasonal relationship; spatiotemporal variability; northern China

1.1 Study Area Overview

Northern China (31°09 -53°33 N, 73°40 -135°02 E) spans approximately 531$\times10^{4}$ km^2 and includes Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Shandong, Henan, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang—encompassing 15 provinces, municipalities, and autonomous regions. The region extends across three topographic steps from west to east, with substantial elevation differences and diverse landforms including mountains, hills, basins, plains, and deserts. Climate types vary significantly, comprising temperate monsoon, temperate continental, and plateau mountain climates. Annual precipitation ranges from 50 to 1200 mm, while annual average temperatures range from -13 to 23 °C.

1.2 Data Sources

This study utilizes monthly data for precipitation, average minimum temperature, average temperature, and average maximum temperature from 357 meteorological stations in northern China and surrounding areas, covering the period from station establishment through 2018. Data were obtained from the China Meteorological Administration’ s National Meteorological Information Center (http://data.cma.cn/). Quality control procedures confirmed that all meteorological data lack significant abrupt changes or random variations, ensuring they reliably represent regional climate conditions. Missing data were interpolated using the random forest model approach. The final dataset comprises uniformly processed time series for all temperature variables.

1.3 Data Processing

Correlation analysis was employed to assess the “closeness” and “symmetry” of precipitation-temperature relationships. The correlation coefficient was calculated as:

$$\rho_{xy} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}}$$

where ρ_{xy} represents the correlation coefficient between precipitation and temperature; x_i and y_i denote seasonal values of precipitation and temperature in year i; $\bar{x}$ and $\bar{y}$ are multi-year averages; and n is the number of years in the calculation period.

Climate tendency rates were analyzed using 10-year moving average sequences. The climate tendency rate formula is:

$$\theta = \frac{\sum_{i=1}^{n} i c_i - \sum_{i=1}^{n} i \sum_{i=1}^{n} c_i}{\sum_{i=1}^{n} i^2 - (\sum_{i=1}^{n} i)^2}$$

where θ is the climate tendency rate (°C · decade^{-1} or mm · decade^{-1}), and c_i represents seasonal values.

Relationship types were determined based on the signs of precipitation and temperature tendency rates. Years when the precipitation tendency rate changed sign served as nodes dividing the entire period into shorter sub-periods. The classification process is illustrated in [Figure 2: see original paper]. For spatial analysis of relationship occurrence times and durations, Kriging interpolation was performed using ArcGIS.

2.1 Correlation Between Precipitation and Three Temperature Types

The correlation patterns vary seasonally and spatially. In spring, precipitation shows stronger positive correlation with average minimum temperature in central and western Inner Mongolia extending to Qinghai, weakening in other directions. Correlations with average and maximum temperatures are stronger in southern North China, weakening toward the northeast and northwest. Summer precipitation exhibits stronger correlations with average minimum temperature in high-altitude regions of Qinghai and central Inner Mongolia, weakening with decreasing elevation. Correlations with average and maximum temperatures are weakest in Qinghai, strengthening toward the northeast and northwest. Autumn precipitation shows the strongest positive correlation with minimum temperature at the intersection of Shaanxi, Gansu, and Ningxia, weakening eastward and westward. Winter precipitation correlations with minimum and average temperatures weaken from west to east, while correlations with maximum temperature decrease with latitude.

2.2 Precipitation-Temperature Relationship Types

Based on the classification framework, four relationship types were identified: warm-wet, cold-dry, warm-dry, and cold-wet. When a relationship type appeared intermittently at a station, the longest continuous occurrence period was used to define its occurrence time, while total cumulative duration was calculated across the entire time series. Abbreviations were defined as follows: T for occurrence time, D for duration, Sp/Su/Au/Wi for spring/summer/autumn/winter, and Tmin/Tavg/Tmax for average minimum/average/maximum temperature. For example, T-Sp-Tmin represents the occurrence time of relationship types between spring precipitation and average minimum temperature.

2.3.1 Warm-Dry Type

[Figure 5: see original paper] shows the spatial distribution of occurrence times and durations for warm-dry relationships. Nearly all stations exhibited warm-dry relationships, with only a few exceptions. The highest proportion of stations without this relationship occurred in autumn between precipitation and average minimum temperature. Occurrence times were concentrated in the 1970s–1990s, with average temperature showing the earliest occurrence, followed by average minimum temperature, and average maximum temperature the latest. Durations ranged from 10–35 years, with average temperature showing the longest persistence (20–35 years), followed by average maximum temperature, and average minimum temperature the shortest. Spatially, occurrence times were generally later in western Inner Mongolia to Qinghai, becoming earlier eastward and westward. Durations shortened with decreasing latitude in spring and summer, but showed the opposite pattern in autumn and winter.

2.3.2 Warm-Wet Type

[Figure 6: see original paper] illustrates the spatial patterns for warm-wet relationships. The number of stations lacking warm-wet relationships ranged from 55 to 179, with the highest proportion (16.2%) occurring in autumn between precipitation and average minimum temperature, primarily in southeastern Gansu and southern Liaoning. Occurrence times were concentrated in the 1970s–1990s, with average minimum temperature showing earliest occurrence, followed by average temperature, and average maximum temperature the latest. Durations ranged from 20–30 years, decreasing sequentially from average minimum to average maximum temperature. Spatially, occurrence times were later in western Inner Mongolia to Qinghai, becoming earlier eastward and westward. Durations shortened with decreasing latitude in spring and summer, but lengthened in autumn and winter.

2.3.3 Cold-Dry Type

[Figure 7: see original paper] presents the spatial distribution for cold-dry relationships. The number of stations without cold-dry relationships ranged from 32 to 136, with the highest proportion in summer between precipitation and average temperature (38.1%), mainly in northern Xinjiang and central Inner Mongolia. Occurrence times were concentrated in the 1950s–1960s, with average maximum temperature showing earliest occurrence, followed by average minimum temperature, and average temperature the latest. Durations ranged from 0–20 years, with average minimum temperature showing the longest persistence, followed by average maximum temperature, and average temperature the shortest. Spatially, occurrence times were generally earlier in the east and later in the west. Durations lengthened with decreasing latitude for cold-dry relationships, while cold-wet relationships showed the opposite pattern.

2.3.4 Cold-Wet Type

[Figure 8: see original paper] shows the patterns for cold-wet relationships. The number of stations lacking cold-wet relationships ranged from 55 to 179, with the highest proportion in spring between precipitation and average minimum temperature (38.1%). Occurrence times were concentrated in the 1950s–1960s, with average minimum temperature showing earliest occurrence, followed by average maximum temperature, and average temperature the latest. Durations ranged from 0–20 years, increasing sequentially from average minimum to average maximum temperature. Spatially, occurrence times showed no clear pattern, while durations were shortest at the border between Inner Mongolia and Xinjiang, lengthening eastward and westward.

2.3.5 Interdecadal Spatiotemporal Evolution

[Figure 9: see original paper] displays the decadal evolution of seasonal precipitation-temperature relationships. In the 1950s–1960s, spring precipitation-temperature relationships were predominantly cold-dry and cold-wet, with warm-wet relationships emerging in the 1960s and persisting through the 1990s. After 2000, warm-dry and warm-wet relationships dominated, except in Xinjiang and Qinghai where warm-wet patterns persisted. Summer relationships were primarily warm-dry from the 1950s–1990s, shifting to warm-wet after 2000, with northeastern areas trending toward cold-dry. Autumn relationships were dominated by cold-dry and cold-wet types in the 1950s–1960s, transitioning to warm-dry and warm-wet after the 1970s. Winter relationships shifted from cold-dry and cold-wet dominance in the 1950s to warm-dry and warm-wet after the 1970s, with some re-emergence of cold types in the northeast after 2000.

Overall, the precipitation-temperature relationship has transitioned from cold-dry and cold-wet dominance to warm-dry and warm-wet dominance, though this evolution varies by season and region. Northwestern China maintained cold-type relationships longer than other regions, while northeastern and northern China transitioned earlier. The timing of these transitions also differed, with spring and winter changes occurring earlier than summer and autumn transformations.

3 Discussion

Precipitation shows predominantly positive correlations with average minimum temperature but negative correlations with average and maximum temperatures across all seasons [Figure 10: see original paper]. These findings align with studies from South Korea, the United Kingdom, the United States, and Japan, as well as regional studies from Inner Mongolia and the Horqin Sandy Land. The correlation strength and sign appear related to latitude, altitude, and climate type, with stronger correlations in areas south of 35°N and positive correlations more common in plateau mountain climates.

The four relationship types identified—warm-dry, warm-wet, cold-dry, and cold-wet—show distinct spatiotemporal patterns. Cold-type relationships emerged earlier in the east and later in the west, while warm-type relationships appeared later in western Inner Mongolia to Qinghai, becoming earlier eastward and westward. Duration patterns varied by season and relationship type. After 2000, cold-dry and cold-wet relationships re-emerged in parts of northeastern and northern China, particularly in winter, possibly related to the warming hiatus phenomenon observed in some regions.

These patterns are influenced by multiple factors. Precipitation and temperature variations in China correspond with ENSO and Pacific Decadal Oscillation (PDO) patterns and are closely linked to interdecadal monsoon variations. Human activities affect land cover, altering Earth' s energy balance and potentially causing warming and drying trends. Aerosols also contribute by absorbing solar radiation and modifying cloud properties. However, this study has limitations due to finite data length, occasional missing values, and uneven station distribution, introducing some uncertainty. Despite these constraints, the findings provide valuable insights for ecological improvement, agricultural development, and water resource management in northern China.

4 Conclusions

This study systematically analyzed the relationship between seasonal precipitation and temperature in northern China, revealing their spatiotemporal variability and interdecadal evolution. The main conclusions are:

1) Summer precipitation shows the strongest correlation with temperature, particularly with average maximum temperature, followed by autumn and winter, with spring showing the weakest correlation. Precipitation is predominantly positively correlated with average minimum temperature but negatively correlated with average and maximum temperatures across all seasons.

2) Four relationship types were identified: warm-dry, warm-wet, cold-dry, and cold-wet. Cold-type relationships emerged primarily in the 1950s–1960s, with occurrence times becoming later from east to west. Their durations ranged from 0–20 years, with cold-dry relationships shortening and cold-wet relationships lengthening with decreasing latitude. Warm-type relationships emerged mainly in the 1970s–1990s, appearing later in western Inner Mongolia to Qinghai and earlier eastward and westward. Their durations ranged from 20–40 years, with warm-type relationships in spring and summer shortening with decreasing latitude, while autumn and winter showed the opposite pattern.

3) In the 1950s–1960s, cold-dry and cold-wet relationships dominated the study area. Beginning in the 1960s, their spatial extent contracted westward as warm-dry and warm-wet relationships became predominant in northeastern and northern China. After the 1970s, warm-dry and warm-wet relationships have dominated the entire region, though small areas in the northeast and north experienced a re-emergence of cold-type relationships after 2000, with winter showing the largest spatial coverage.

References

[1] Ngamindra D, Babu S U, Anita T. Temporal changes in precipitation and temperature and their implications on the streamflow of Rosi River, Central Nepal[J]. Climate, 2019, 7(1): 3, doi: 10.3390/cli7010003.

[2] Zain N, Li X, Chen Y Y, et al. Temporal and spatial characteristics of precipitation and temperature in Punjab, Pakistan[J]. Water, 2019, 11(9): 1916-1938.

[3] Xu J, Chen H L, Shang S S, et al. Response of net primary productivity of Tibetan Plateau vegetation to climate change based on CEVSA model[J]. Arid Land Geography, 2020, 43(3): 592-601.

[4] Zhang S Q, Chen H, Song M H, et al. Spatial and temporal variation of fractional vegetation cover and its relationship with environmental factors in the Qaidam Basin during 2000–2015[J]. Arid Land Geography, 2019, 42(5): 1124-1132.

[5] Karimi V, Karimi E, Keshavarz M. Climate change and agriculture: Impacts and adaptive responses in Iran[J]. Journal of Integrative Agriculture, 2018, 17(1): 1-15.

[6] Liang X Z, Wu Y, Chambers R G, et al. Determining climate effects on US total agricultural productivity[J]. Proceedings of the National Academy of Sciences of the United States of America, 2017, 114(12): E2285, doi: 10.1073/pnas.1615922114.

[7] Sun Q H, Kong D X, Miao C Y, et al. Variations in global temperature and precipitation for the period of 1948 to 2010[J]. Environmental Monitoring and Assessment, 2014, 186(9): 5663-5679.

[8] Schultz P A, Halpert M S. Global correlation of temperature, NDVI and precipitation[J]. Advances in Space Research, 1993, 13(5): 25-28.

[9] Gornall J, Betts R, Burke E. Implications of climate change for agricultural productivity in the early twenty first century[J]. Philosophical Transactions: Biological Sciences, 2010, 365(1554): 2973-2989.

[10] Beniston M, Richard S J T. The potential impacts of climate change on Europe[J]. Energy & Environment, 1998, 9(4): 365-381.

[11] Erol A, Randhir T O. Climatic change impacts on the ecohydrology of Mediterranean watersheds[J]. Climatic Change, 2012, 114(2): 319-341.

[12] Pratik P, Ajay K, Sajjad A. Temperature and precipitation changes in the midwestern United States: Implications for water management[J]. International Journal of Water Resources Development, 2017, 33(6): 1003-1019.

[13] Dai S W, Shulski M D, Hubbard K G, et al. A spatiotemporal analysis of midwest US temperature and precipitation trends during the growing season from 1980 to 2013[J]. International Journal of Climatology, 2016, 36(1): 517-525.

[14] Yadav S, Bhattacharya P, Srivastava K. Analysing long term seasonal and annual trends for precipitation and temperature in Central India (Article)[J]. Mausam, 2019, 70(3): 523-532.

[15] Dinesh B, Shreedhar M, Mukand B, et al. Climate trends and impacts on crop production in the Koshi River Basin of Nepal[J]. Regional Environmental Change, 2014, 14(4): 1291-1301.

[16] Gornall J, Betts R, Burke E. Implications of climate change for agricultural productivity in the early twenty first century[J]. Philosophical Transactions: Biological Sciences, 2010, 365(1554): 2973-2989.

[17] Zhao H Y, Chen Y, Zhou Y, et al. Spatiotemporal variation of NDVI in vegetation growing season and its responses to climatic factors in mid and eastern Gansu Province from 2008 to 2016[J]. Arid Land Geography, 2019, 42(6): 1427-1435.

[18] Huang J Q, Ma J R, Guan X D, et al. Progress in semi arid climate change studies in China[J]. Advances in Atmospheric Sciences, 2019, 36(9): 922-937.

[19] Song W H, Wang L N, Zhang J L. Temporal and spatial changes in response to climate in grasslands of the Qilian Mountain National Nature Reserve[J]. Pratacultural Science, 2019, 36(9): 2233-2249.

[20] Wang K, Pu T, Shi X Y, et al. Impact of temperature and precipitation on runoff change in the source region of Lancang River[J]. Climate Change Research, 2020, 16(3): 306-315.

[21] Zhang D Q, Zhang L, Yang J, et al. The impact of temperature and precipitation variation on drought in China in last 50 years[J]. Acta Physica Sinica, 2010, 59(1): 655-663.

[22] Shi Y F, Shen Y P, Kang E, et al. Recent and future climate change in northwest China[J]. Climate Change, 2007, 80(3-4): 379-393.

[23] Cao D, Zhang J H, Yan H, et al. Regional assessment of climate potential productivity of terrestrial ecosystems and its responses to climate change over China from 1980–2018[J]. IEEE Access, 2020(8): 11138-11151.

[24] Shi P J, Sun S, Wang M, et al. Climate change regionalization in China (1961–2010)[J]. Science China: Earth Sciences, 2014, 57(11): 2676-2689.

[25] Samuel S, Olaf W, Alexander W, et al. Six temperature and precipitation regimes of the contiguous United States between 1895 and 2010: A statistical inference study[J]. Theoretical and Applied Climatology, 2016, 125(1-2): 197-211.

[26] Mifta U S, Rehana R, Percez A, et al. Temperature and precipitation trends in Kashmir Valley, north western Himalayas[J]. Theoretical and Applied Climatology, 2019, 135(1-2): 293-304.

[27] Tuoliewubieke Dilinuer, Li Dongliang. Characteristics of the dry/wet climate change in Central Asia in recent 115 years[J]. Journal of Arid Meteorology, 2018, 36(2): 185-195.

[28] Gong Z, Peng D L, Wen J Y, et al. Research on trend of warm mid climate in Central Asia[J]. IOP Conference Series: Earth and Environmental Science, 2017, 74(1): 012017, doi: 10.1088/1755-1315/74/1/012017.

[29] Chris S H, Alistair J H, James R T, et al. Observed and predicted impacts of climate change on the estuaries of south western Australia, a Mediterranean climate region[J]. Regional Environmental Change, 2018, 18(5): 1357-1373.

[30] Shi X H, Xu X D. The interdecadal trend turning feature of global land temperature and precipitation from 1951 to 2002[J]. Acta Physica Sinica, 2008, 18(9): 1016-1026.

[31] Su J Z, Wen M, Ding Y H, et al. Hiatus of global warming: A review[J]. Chinese Journal of Atmospheric Sciences, 2016, 40(6): 1143-1153.

[32] Shi Y F, Shen Y P, Li D L, et al. Discussion on the present climate change from warm dry to warm wet in northwest China[J]. Quaternary Sciences, 2003, 23(2): 152-164.

[33] Shi Y F, Shen Y P, Hu R J. Preliminary study on signal, impact and foreground of climatic shift from warm dry to warm mid in northwest China[J]. Journal of Glaciology and Geocryology, 2002, 24(3): 219-226.

[34] Li C, Wu P T, Li X L, et al. Spatial and temporal evolution of climatic factors and its impacts on potential evapotranspiration in Loess Plateau of northern Shaanxi, China[J]. Science of the Total Environment, 2017, 589: 165-172.

[35] Kim J U, Boo K O, Shim S, et al. The seasonal correlation between temperature and precipitation over Korea and Europe and the future change from RCP8.5 scenario[J]. Atmosphere, 2017, 27(1): 45-57.

[36] Tout D G. Short communication precipitation temperature relationships in England and Wales summers[J]. Journal of Climatology, 1987, 7(2): 181-184.

[37] Zhao W, Khalil M A K. The relationship between precipitation and temperature over the contiguous United States[J]. Journal of Climate, 1993, 6(6): 1232-1240.

[38] Yukari T, Yasoichi E, Shigeki M. High correlation between winter precipitation and air temperature in heavy snowfall areas in Japan[J]. Annals of Glaciology, 2008, 49(1): 7-10.

[39] Li H Y, Ma L, Liu T X, et al. Change and relationship of temperature and precipitation in Inner Mongolia during 1951–2014[J]. Journal of Glaciology and Geocryology, 2017, 39(5): 1098-1112.

[40] Wang J R, Ma L, Liu T X, et al. Variation of temperature and precipitation in Horqin Sandy Land from 1951 to 2012[J]. Arid Zone Research, 2016, 33(1): 49-58.

[41] Huang X, Ma L, Liu T X, et al. Variations and periodic symmetry of temperature and precipitation in Inner Mongolia section of the Yellow River Basin during 1951–2012[J]. Journal of Natural Resources, 2016, 31(6): 1027-1040.

[42] Zhang G B, Zhang B, Wang D, et al. Seasonal changes of vegetation in southwestern China and its relation to climate factors in recent 14 years[J]. Remote Sensing Information, 2016, 31(1): 89-95.

[43] Yang M X, Yao T D, Wang H J, et al. Correlation between precipitation and temperature variations in the past 300 years recorded in Guliya ice core, China[J]. Annals of Glaciology, 2006, 43: 137-141.

[44] Su M F. The configurable relationships between warm cold and dry wet in climate change over China[D]. Beijing: University of Chinese Academy of Sciences, 2005.

[45] He M X, Gautam M. Variability and trends in precipitation, temperature and drought indices in the state of California[J]. Hydrology, 2016, 3(2): 14, doi: 10.3390/hydrology3020014.

[46] Du Q Q, Zhang M J, Wang S J, et al. Changes in air temperature over China in response to the recent global warming hiatus[J]. Journal of Geographical Sciences, 2019, 29(4): 496-516.

[47] Yao S L, Huang G, Wu R G, et al. The global warming hiatus: A natural product of interactions of a secular warming trend and a multi decadal oscillation[J]. Theoretical and Applied Climatology, 2016, 123(1-2): 349-360.

[48] Shine K P, Forster P M de F. The effect of human activity on radiative forcing of climate change: A review of recent developments[J]. Global and Planetary Change, 1999, 20(4): 205-225.

[49] Zhang Q, Han L Y, Jia J Y, et al. Management of drought risk under global warming[J]. Theoretical and Applied Climatology, 2016, 125(1-2): 187-196.

[50] Huang J P, Yu H, Guan X, et al. Accelerated dryland expansion under climate change[J]. Nature Climate Change, 2016, 6(2): 166-171.

[51] Chen Y, Ma L, Liu T X, et al. The relationship between annual precipitation and temperature and its spatiotemporal variability in northern China[J]. Ecology and Environment, 2021, 30(1): 135-145.

[52] Liang L T, Ma L, Liu T X, et al. Spatiotemporal variation of the temperature mutation and warming hiatus over northern China during 1951—2014[J]. China Environmental Science, 2018, 38(51): 1601-1615.

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