

Climate Change Characteristics and Influencing Factors in Shaanxi Based on Pole-Symmetric Mode Decomposition: Postprint

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Abstract

In the context of global warming, climate element responses exhibit nonlinear and non-stationary characteristics under the combined influence of human activities and climate system fluctuations. How to identify multi-timescale information of climate change is currently a hot topic in research. Based on daily temperature and precipitation data from 1970 to 2017, supplemented by methods such as moving average, trend analysis, and Extreme-Point Symmetric Mode Decomposition (ESMD), this study analyzes the spatiotemporal characteristics of climate in the three major geographical units of Shaanxi, and further explores the response relationship between El Niño indices in different ocean regions and temperature and precipitation changes. The results show that: from 1970 to 2017, climate change in Northern Shaanxi experienced a transformation process of “warm-dry to cold-wet to warm-wet”; the climate in Guanzhong and Southern Shaanxi exhibited warming and drying in the late 1980s to 1990s, followed by a hiatus in warming, increased precipitation, and a recent return to warming and drying conditions; using ESMD to decompose temperature and precipitation change signals in Shaanxi, it is found that the regional temperature response hiatus is influenced by decadal fluctuations with a period of approximately 9.2–11.5 years; from trend term analysis, except for the stable fluctuations of temperature in Northern Shaanxi, the warming rate in Guanzhong and Southern Shaanxi has not slowed down; regarding influencing factors, there are differences in the correlations between sea surface temperature anomalies in different ocean regions and temperature and precipitation changes in Shaanxi. Specifically, temperature influences are mainly in the eastern seas of China, showing significant positive correlation with sea surface temperatures in the NINO A region and Kuroshio region; the key ocean region affecting precipitation changes is the equatorial Pacific, i.e., when sea surface temperature anomalies are abnormally high in the central equatorial Pacific, precipitation in Guanzhong and Southern Shaanxi shows a decreasing trend, while when sea surface temperature

anomalies are abnormally high in the eastern equatorial Pacific, precipitation reduction in Northern Shaanxi is more pronounced.

Full Text

Preamble

Spatiotemporal Climate Variation and Its Influencing Factors in Shaanxi Province Based on Extreme-Point Symmetric Mode Decomposition

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Abstract: Against the backdrop of global warming, climate responses exhibit nonlinear and non-stationary characteristics under the combined influence of human activities and climate system fluctuations. Identifying multi-timescale information in climate change has become a critical research focus. Based on daily temperature and precipitation data from 1970 to 2017, this study analyzes the spatiotemporal characteristics of climate across three major geographic units of Shaanxi Province using moving average, trend analysis, and extreme-point symmetric mode decomposition (ESMD) methods. The teleconnection relationships between sea surface temperature anomalies in different oceanic regions and temperature/precipitation variations in Shaanxi are further investigated. Results indicate that from 1970 to 2017, northern Shaanxi experienced a climate transition from warm-dry to warm-wet conditions. In contrast, Guanzhong Plain and southern Shaanxi showed warm-dry conditions in the late 1990s, followed by a warming hiatus and increased precipitation, with recent trends reverting to warm-dry conditions. ESMD decomposition of temperature and precipitation signals reveals that the regional temperature response to the warming hiatus is primarily influenced by decadal fluctuations with a periodicity of approximately 9.2-11.5 years. Trend analysis shows that except for stable temperature fluctuations in northern Shaanxi, the warming rates in Guanzhong Plain and southern Shaanxi have not slowed. Regarding influencing factors, significant differences exist in the correlations between sea temperature anomalies in different oceanic regions and temperature/precipitation changes in Shaanxi. Temperature is primarily influenced by sea surface temperatures in the eastern China seas, showing significant positive correlations with the NINO A region and Kuroshio Current area. Precipitation changes are mainly affected by the equatorial Pacific; when central equatorial Pacific sea temperatures are anomalously high, precipitation in Guanzhong Plain and southern Shaanxi decreases, while anomalously high sea temperatures in the eastern equatorial Pacific lead to more pronounced precipitation reductions in northern Shaanxi.

Keywords: extreme-point symmetric mode decomposition; climate change;

spatiotemporal analysis; Shaanxi Province

Introduction

Global environmental change represents a critical research frontier, particularly regarding extreme weather events triggered by climate change and the dynamic responses of terrestrial natural systems [?]. Under global warming, the rate of increase in global surface temperature reached $0.23\text{ }^{\circ}\text{C} \cdot (10\text{a})^{-1}$, while China's land surface temperature rose at $0.12\text{ }^{\circ}\text{C} \cdot (10\text{a})^{-1}$ [?]. Climate warming has caused temperature zones in China to shift northward significantly, with the cold temperate zone shrinking and glaciers retreating [?]. Most regions in China have experienced drying trends, with precipitation becoming more extreme and frequent summer urban flooding [?]. Compared with temperature increases, China's precipitation has not shown a clear linear trend [?].

In terms of influencing factors, numerous studies have investigated spatiotemporal climate characteristics and driving factors across different basins and geographic units, focusing on teleconnections with ocean-atmosphere circulation anomalies such as El Niño-Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), and Arctic Oscillation [?]. Notably, similar to climate elements, sea temperature circulation anomalies exhibit multi-decadal or interannual variations—for instance, ENSO has a 3–7 year cycle, while PDO shows quasi-20-year variability, both being key drivers of regional climate anomalies [?].

Methodologically, most temperature and precipitation analyses employ linear regression, anomaly analysis, wavelet analysis, and empirical orthogonal function decomposition to examine trends, abrupt changes, or periodicities [?]. However, climate change involves numerous influencing factors, including both natural and anthropogenic components, whose interactions produce nonlinear and non-stationary characteristics [?]. The superposition of different periodic changes makes linear fitting inadequate for capturing regional climate trends [?]. Therefore, signal detection and analysis techniques are essential. Wang Jinliang et al. proposed the Extreme-Point Symmetric Mode Decomposition (ESMD) method as a new development of the “Hilbert-Huang Transform (Empirical Mode Decomposition)” [?]. ESMD has been widely applied in oceanography, atmospheric science, and mechanical signal analysis [?].

Building on this foundation, the present study employs ESMD to analyze the periodic and nonlinear trends of temperature and precipitation time series in Shaanxi from 1970 to 2017. Seventeen sea temperature indices are selected to identify key oceanic regions influencing Shaanxi's climate, providing a theoretical basis for regional climate adaptation.

1. Materials and Methods

1.1 Study Area

Shaanxi Province (105°29' -111°15' E, 31°42' -39°35' N) is located in central China, serving as the gateway to Northwest China and a crucial node on the Silk Road Economic Belt. The province features diverse climate types and complex geomorphic units, including the Mu Us Sandy Land, Loess Plateau, Guanzhong Plain, Qinling Mountains, and Han River Valley from north to south [?]. The Qinling Mountains represent China's north-south climatic divide, while the Great Wall region marks an important agro-pastoral boundary [Figure 1: see original paper]. Among the three geographic units, southern Shaanxi has a north subtropical climate, Guanzhong Plain has a warm temperate climate, and northern Shaanxi represents a transition zone from warm temperate to temperate climate. Annual precipitation decreases from south to north: 400-600 mm in northern Shaanxi, 500-700 mm in Guanzhong Plain, and 700-900 mm in southern Shaanxi [?].

1.2 Data Sources

Temperature and precipitation data for Shaanxi were obtained from the National Climate Center. To ensure data completeness and continuity, the study period was set to 1970-2017. According to the *Brief History of Basic Meteorological Stations in Shaanxi Province*, the Chenggu station relocated to Xiejiajing Village in Chenggu County in 1965, resulting in data loss for earlier periods; thus, its data span 1966-2017. The Wubu station was closed in April 1969 due to institutional streamlining, reopened in Suide in August 1969, and re-established at its original site in August 1971; consequently, Wubu data are available from 1971 onward. Similar situations apply to Mizhi (1971-2017) and Zizhou (1971-2017) stations.

For influencing factors, 17 ocean-atmosphere circulation indices from different sea areas were obtained from the Climate Change and Prediction Research Office of the National Climate Center, China Meteorological Administration. These indices include: Pacific Decadal Oscillation (PDO) with ~20-year periodicity, Quasi-Biennial Oscillation (QBO) reflecting interannual variability, and various NINO indices corresponding to ESMD-derived signals to identify teleconnected oceanic regions affecting Shaanxi's climate anomalies.

1.3 Methods

1.3.1 Extreme-Point Symmetric Mode Decomposition (ESMD) This study employs ESMD to analyze multi-scale oscillation characteristics of temperature and precipitation. ESMD adaptively processes data without requiring predefined basis functions or window lengths. Its decomposed modal frequencies and amplitudes are variable, making it suitable for nonlinear and non-stationary signals. ESMD overcomes the limitation of Empirical Mode Decomposition (EMD) projecting onto fixed frequency points and avoids interference from white

noise addition in Ensemble Empirical Mode Decomposition (EEMD), facilitating analysis of temporal frequency variations [?].

1.3.2 Harmonic Analysis Harmonic analysis represents climate element time series as a superposition of finite sine waves, enabling periodic analysis [?]. This study uses harmonic analysis to quantify periods of ESMD-derived components for temperature and precipitation in Shaanxi, providing a basis for examining impacts of sea temperature anomalies. For a given climate element time series, p major periods (harmonics) are selected through significance testing as estimated values. Regression variance then quantifies each harmonic's variance contribution to determine dominant periods. The method is expressed as:

$$Y_t = A_0 + \sum_{k=1}^p A_k \sin(W_k t + Q_k)$$

where Y_t is the time series signal; A_0 is the mean; A_k is the amplitude of the k -th harmonic; Q_k is the initial phase; $W_k = 1, 2, \dots$ is the harmonic frequency; T is the fundamental period; p is the number of harmonics; and t is time.

2. Results

2.1 Climate Change Trends in Shaanxi

From 1970 to 2017, Shaanxi's mean annual temperature was 12.4 °C, showing a fluctuating upward trend with a rate of $0.29 \text{ }^\circ\text{C} \cdot (10\text{a})^{-1}$, slightly higher than the national average land warming rate of $0.23 \text{ }^\circ\text{C} \cdot (10\text{a})^{-1}$ [?]. All three sub-regions exhibited consistent temperature increases: Guanzhong Plain and northern Shaanxi at $0.31 \text{ }^\circ\text{C} \cdot (10\text{a})^{-1}$, and southern Shaanxi at $0.23 \text{ }^\circ\text{C} \cdot (10\text{a})^{-1}$, all passing significance tests, indicating significant warming across Shaanxi.

Precipitation showed high interannual variability without clear linear trends. Mean annual precipitation was 670.3 mm, decreasing at $-2.34 \text{ mm} \cdot (10\text{a})^{-1}$, though this trend was not statistically significant. Northern Shaanxi precipitation increased at $11.38 \text{ mm} \cdot (10\text{a})^{-1}$, Guanzhong Plain decreased at $-5.43 \text{ mm} \cdot (10\text{a})^{-1}$, and southern Shaanxi showed a slight decline. Overall, Shaanxi experienced warm-dry conditions from 1970 to 2017, but the process was phased.

Specifically, during 1970-1999, mean temperature was 11.6 °C with a slight decline rate of $-0.25 \text{ }^\circ\text{C} \cdot (10\text{a})^{-1}$, while precipitation increased at $111.6 \text{ mm} \cdot (10\text{a})^{-1}$. All three regions showed consistent temperature patterns: initial stable fluctuations followed by decline; precipitation corresponded with early stable fluctuations and later increases. During 1999-2012, mean temperature rose to 11.8 °C with an increase rate of $0.89 \text{ }^\circ\text{C} \cdot (10\text{a})^{-1}$, while precipitation decreased significantly at $-79.5 \text{ mm} \cdot (10\text{a})^{-1}$, indicating intensified warm-dry conditions.

This pattern was consistent across all three regions, particularly pronounced in northern Shaanxi with rapid temperature growth. During 2012–2017, mean temperature reached 12.7 °C with a warming rate of $1.34 \text{ }^\circ\text{C} \cdot (10\text{a})^{-1}$, while precipitation stabilized with continued increases in northern Shaanxi, creating a spatial pattern of “warm-dry in the south, warm-wet in the north.”

2.2 Spatial Characteristics of Climate Change in Shaanxi

Analysis reveals that calculating climate trends over the entire 1970–2017 period masks real change patterns. For example, northern Shaanxi precipitation showed a “V-shaped” pattern—declining before 1999 and increasing afterward—yielding no significant overall trend but obscuring recent precipitation extremes.

Therefore, four characteristic periods were selected: 1970–1999 (fastest temperature increase), 1999–2012 (fastest temperature decrease in northern Shaanxi), 1999–2012 (fastest precipitation decrease in Guanzhong Plain), and 2012–2017 (fastest precipitation increase in northern Shaanxi) to analyze spatial responses.

During 1970–1999, temperatures rose rapidly across Shaanxi, especially in Guanzhong Plain and northern Shaanxi, where increases exceeded those in southern Shaanxi [Figure 2: see original paper]. During 1999–2012, temperature increases slowed or declined across Shaanxi, aligning with the global warming hiatus. Northern Shaanxi showed the fastest temperature decline, more rapid than Guanzhong Plain and southern Shaanxi. During 1999–2012, Guanzhong Plain experienced the fastest precipitation decrease, with sustained temperature increases and precipitation declines creating warm-dry conditions. During 2012–2017, northern Shaanxi showed the fastest precipitation increase, with most stations showing increasing trends, particularly pronounced in northern Shaanxi, moderate in southern Shaanxi, and relatively small in Guanzhong Plain.

In summary, Shaanxi’s temperature changes from 1970 to 2017 showed clear phasing: rapid warming in the mid-1980s to late 1990s with pronounced warm-dry conditions in Guanzhong Plain and southern Shaanxi; early 21st century reversal of warm-dry conditions, especially in northern Shaanxi with cooling-warming transitions and sustained precipitation increases (“warm-dry to warm-wet”), while Guanzhong Plain and southern Shaanxi maintained high temperatures with slight precipitation increases (“warm-dry to warm-wet”) [Figure 3: see original paper].

2.3 Multi-Scale Climate Variation Characteristics in Shaanxi

Climate change results from combined atmospheric and surface influences, with climate element sequences containing both anthropogenic impacts and natural cycles that superimpose or offset each other, forming decadal fluctuation characteristics [?]. ESMD decomposition of Shaanxi’s temperature and precipitation yields periodic signals as follows:

Temperature Variation Characteristics

ESMD analysis decomposes temperature into three modal components and one trend component for Guanzhong Plain and southern Shaanxi, and four modal components plus one trend component for northern Shaanxi, reflecting oscillations from high to low frequencies.

Harmonic analysis of each modal component reveals interannual variation characteristics (IMF1) with dominant periods of 3.7 a, 4.0 a, and 2.2-2.5 a, indicating quasi-3-4 year cycles as primary interannual periods. Decadal variation characteristics (IMF2, IMF3) show periods of 9.6 a, 6.9 a, 16.0 a, and 24.0 a, all significant at the 95% confidence level, representing major temperature variation cycles.

Trend variation (R) shows different patterns across regions: Guanzhong Plain experienced low-level stable fluctuations (1970-1984), rapid temperature increase (1984-1999), and high-temperature fluctuations (1999-2017); southern Shaanxi showed rapid linear warming; northern Shaanxi exhibited “low-level fluctuations –rapid increase–high-level fluctuations” stepwise changes.

Variance contribution rates show that the first three IMF components for northern Shaanxi, Guanzhong Plain, and southern Shaanxi contribute 34.1%, 26.1%, and 26.7% respectively, all lower than the trend component contribution, indicating that warming trends dominate original sequences. Guanzhong Plain's trend R has the highest contribution (42.1%), while southern Shaanxi's is lowest (33.5%).

Notably, the slowdown or deceleration of regional warming rates primarily stems from decadal components in Guanzhong Plain and southern Shaanxi, and IMF2 and trend components in northern Shaanxi. This suggests that regional temperature response to the global warming hiatus is mainly a decadal characteristic with ~9.2-11.5 year periodicity. Trend analysis indicates that except for stable fluctuations in northern Shaanxi, warming rates in Guanzhong Plain and southern Shaanxi have not slowed.

Precipitation Variation Characteristics

ESMD analysis decomposes precipitation into three modal components and one trend component for Guanzhong Plain and northern Shaanxi, and four modal components plus one trend component for southern Shaanxi, reflecting high-to-low frequency oscillations.

Interannual variation (IMF1) shows periods of 2.2-2.5 a, 3.7 a, and 4.0 a, indicating quasi-2-4 year cycles similar to temperature variation periods. Decadal variation (IMF2, IMF3) shows periods of 9.6 a, 6.9 a, 12.0 a, and 6.0 a, all significant at 95% confidence, with 9.6 a as the primary period, consistent with Liu et al.'s findings on Shaanxi precipitation periodicity [?] and matching the quasi-2.0-7.0 a cycle pattern in eastern China's monsoon region [?].

Trend variation (R) shows regional differences: northern Shaanxi and

Guanzhong Plain precipitation decreased before 1999 then increased afterward, especially pronounced in both regions after 1999; southern Shaanxi showed similar patterns but with different decadal fluctuation characteristics and post-1999 trends.

Variance contribution rates show that precipitation trend R contributions are low across all regions, with interannual fluctuations (2–4 year cycles) dominating, indicating that long-term trends are not the primary information source. This contrasts with temperature where decadal fluctuations dominate.

Shaanxi's precipitation concentrates in summer and autumn, influenced by the East Asian summer monsoon whose interannual variability primarily shows 2.0–6.0 year cycles [?], similar to Pang et al.'s findings on multi-gear coupling cycles of East Asian summer circulation [?].

2.4 Influence of Sea Surface Temperature Anomalies on Shaanxi Climate

After removing trend information from temperature and precipitation using ESMD, correlation analysis with 17 sea temperature indices reveals distinct regional differences in climate response to oceanic regions [Figure 5: see original paper].

Temperature Response

Significant positive correlations exist between temperatures in all three sub-regions and sea surface temperatures in the NINO A region and Kuroshio Current area (KCSST). Correlation coefficients are: northern Shaanxi (NINO A: 0.64, KCSST: 0.66), Guanzhong Plain (NINO A: 0.44, KCSST: 0.45), and southern Shaanxi (NINO A: 0.46, KCSST: 0.44). This indicates that when sea temperatures in eastern China are anomalously high, Shaanxi temperatures tend to be higher. Correlations with equatorial eastern Pacific sea temperatures (NINO 1+2, NINO 3.4) are relatively weak.

Precipitation Response

High-correlation regions for precipitation differ from those for temperature, concentrating in the central and eastern equatorial Pacific, with regional variations. Northern Shaanxi shows high correlations with NINO 1+2 (0.45) and NINO 3 (0.23); Guanzhong Plain with NINO 4 (0.36) and NINO 3.4 (0.44); southern Shaanxi with similar regions as Guanzhong Plain. This indicates that when central equatorial Pacific sea temperatures are anomalously high (central Pacific El Niño), precipitation in Guanzhong Plain and southern Shaanxi tends to decrease, while anomalously high sea temperatures in the eastern equatorial Pacific lead to more pronounced precipitation reductions in northern Shaanxi. Conversely, when these regions show anomalously low sea temperatures (La Niña events), the risk of extreme precipitation gradually increases.

3. Conclusions and Discussion

Based on daily temperature and precipitation data from 1970 to 2017, this study employs ESMD decomposition to conduct refined analysis of climate transition characteristics in Shaanxi Province, examining periodic features of temperature and precipitation at different timescales and identifying key oceanic regions affecting interannual climate variability through 17 El Niño indices.

Main Conclusions:

- 1) From 1970 to 2017, Shaanxi's mean annual temperature showed significant stepwise increases, with turning points in 1984, 1999, and 2012. Northern Shaanxi experienced climate transitions from warm-dry to cool-wet to warm-wet conditions. Guanzhong Plain and southern Shaanxi showed warm-dry conditions from 1970 to 1999, followed by a warming hiatus and increased precipitation after 1999, with accelerated warming and decreasing precipitation becoming more evident after 2012.
- 2) ESMD signal decomposition of temperature and precipitation reveals a nonlinear upward trend. Temperature variation is dominated by the trend component, while precipitation variation is dominated by interannual fluctuations. The regional temperature response to the global warming hiatus primarily reflects decadal variability with a periodicity of approximately 9.2-11.5 years. Trend analysis indicates that except for stable fluctuations in northern Shaanxi, warming rates in Guanzhong Plain and southern Shaanxi have not slowed.
- 3) Influencing factors for temperature and precipitation in Shaanxi show spatial differences. Temperature is mainly influenced by sea surface temperatures in the eastern China seas, with significant positive correlations with the NINO A region and Kuroshio Current area. Precipitation influences are concentrated in the equatorial Pacific region. When central equatorial Pacific sea temperatures are anomalously high, particularly during central Pacific El Niño events, precipitation in Guanzhong Plain and southern Shaanxi tends to decrease. When eastern equatorial Pacific sea temperatures are anomalously high, precipitation reductions in northern Shaanxi are more pronounced.

Discussion:

This study examined periodic changes in Shaanxi's temperature and precipitation but did not deeply analyze the causes of these periodic variations, which requires future research combining circulation diagnostics. Different regions experience varying external environmental influences, and multiple circulation factors interact (e.g., PDO, ENSO). Analyzing the relative contributions of various factors to Shaanxi's climate change from an integrated perspective using signal decomposition methods represents a major future research direction.

Methodologically, using ESMD for detrending analysis of temperature and pre-

precipitation across three geographic units is affected by the variance contribution of trend components, creating uncertainty in extracting interannual or decadal fluctuation information. This study cannot fully address whether original versus detrended sequences offer advantages in correlating sea temperatures across different oceanic regions. Future research should aim to identify early warning signals, quantifying the accuracy or false alarm rates of sea temperature anomalies for Shaanxi climate predictions based on both original and detrended sequences.

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