Analysis of Seasonal Variation Trends in Tibet Under Climate Change and a New Four-Season Division Method (Postprint)

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Abstract

Based on daily temperature data from 38 meteorological stations in Tibet from 1981 to 2023, the new seasonal division method for Tibet is adopted to delineate the four seasons, and the regional variations of climatic seasons, spatiotemporal changes of seasonal onset dates, and seasonal variation trends are investigated. The results show that: (1) The distinct four-season zone in Tibet is concentrated along the Yarlung Tsangpo River and in Nyingchi City, while the indistinct four-season zone (summer-free zone) is mainly located in the western and northern parts of Tibet and the high-altitude regions along the Himalayas. (2) The onset dates of spring and summer in Tibet exhibit an advancing trend, while those of autumn and winter show a delaying trend. The spring onset date underwent a significant abrupt advance in 2000, whereas the autumn and winter onset dates experienced significant abrupt delays in 2003 and 1995, respectively. (3) Regarding onset dates, the first mode (EOF1) of spring and autumn displays characteristics of "low in the northwest and high in the southeast for spring, high in the center and low on both sides for autumn"; the second mode (EOF2) of spring manifests a reversed distribution pattern of "positive in the northwest and negative in the southeast"; EOF2 of autumn exhibits a spatial distribution feature with opposite centers of positive values in the southwest and negative values in the northeast; EOF1 of winter belongs to the "high in the north and low in the southwest" type, while EOF2 of winter shares the same characteristics as EOF2 of spring. (4) In the future, a pattern of delayed onset dates for spring and summer and advanced onset dates for autumn and winter will emerge.

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Full Text

Analysis of Seasonal Variation Trends in Xizang Under Climate Change and New Four-Season Division Methods

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Abstract

Based on daily temperature data from 39 meteorological stations, this study employs the new four-season division method for Xizang to investigate regional climate season variations, spatiotemporal changes in season start dates, and seasonal trends. The results reveal: (1) Areas with four distinct seasons concentrate along the Yarlung Zangbo River and in Nyingchi City, while regions with indistinct seasons (no-summer zones) primarily occupy western, northern, and high-altitude Himalayan areas of Xizang. (2) Spring and summer start dates exhibit advancing trends, whereas autumn and winter start dates show delaying trends. Spring experienced a significant early-shift mutation in 2000, while autumn and winter witnessed significant delayed mutations in 2003 and 1995, respectively. (3) Regarding start dates, the first empirical orthogonal function (EOF) mode for spring and autumn displays a “low in the northwest and high in the southeast for spring, high in the middle and low on both sides for autumn” pattern. The second EOF mode for spring shows a “northwest positive, southeast negative” contrasting distribution, while autumn’s second mode exhibits an opposite “southwest positive, northeast negative” spatial pattern. Winter’s first EOF mode demonstrates a “high in the north, low in the southwest” distribution, with its second mode resembling spring’s second mode. (4) Future projections indicate delayed start dates for spring and summer, and advanced start dates for autumn and winter.

Keywords: start date; wavelet analysis; trend analysis; empirical orthogonal function (EOF); Xizang

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1.1 Study Area Overview

Xizang is located in the southwestern part of the Qinghai-Tibet Plateau, between 78°25 ~99°06 E and 26°50 ~36°53 N, with an average elevation exceeding 4000 m, earning it the title “Roof of the World.” The region features complex and varied topography, fostering rich ecosystem diversity. Its climate is equally diverse, characterized by extreme cold and aridity in the northwest and warmth with humidity in the southeast. The overall climate presents a pattern of long winters without summers and connected spring-autumn transitions, with pronounced vertical climate differentiation. Annual mean temperatures range from -2.4 to 12.1°C. The region experiences abundant water resources, low temperatures, limited accumulated temperature, and substantial diurnal temperature variation. Annual sunshine duration spans 1443.5–3574.3 hours. Data were obtained from the Xizang Meteorological Information Network Center ([Figure 1: see original paper]), encompassing 39 meteorological stations, including 19 national benchmark stations and 20 national general stations.

1.2 Data Sources

The study utilizes daily average temperature data from 39 meteorological stations across Xizang for the period 1981–2022. The dataset comprises records from national benchmark and general meteorological stations.

1.3 Research Methods

The study adopts the "Xizang New Four-Season Division Method" by Shi et al., employing 5-day moving average temperature as the primary indicator with specific temperature thresholds: $ $10°C for spring onset, $ $17°C for summer onset, <17°C for autumn onset, and <10°C for winter onset. Spring begins on the first day when the 5-day moving average reaches $ $10°C; summer starts when it reaches $ $17°C; autumn commences when it falls below 17°C; and winter initiates when it drops below 10°C. The day preceding each season's start date marks the previous season's termination.

2.1 Spatial Variation of Climate Seasonal Regions in Xizang

Based on the new four-season division method and 5-day moving average temperature data from 39 stations, the analysis identifies 18 stations with four distinct seasons, concentrated along the Yarlung Zangbo River and in Nyingchi City. Conversely, 21 stations exhibit indistinct seasonal variations (no-summer zones), located in western, northern, and high-altitude Himalayan regions of Xizang ([Figure 1: see original paper]). Table 1 details the years when summer appears in the four-season distinct areas.

2.2 Interannual Variation of Season Start Dates in Xizang

Both spring and summer start dates demonstrate non-significant decreasing trends, indicating earlier onset, with climate tendency rates of -2.02 $d \cdot (10a)^{-1}$ ($P<0.01$) and -0.86 $d \cdot (10a)^{-1}$, respectively. Autumn and winter start dates show increasing trends, signifying delayed onset, with rates of 2.21 $d \cdot (10a)^{-1}$ ($P<0.01$) and 2.91 $d \cdot (10a)^{-1}$ ($P<0.05$), respectively. Mann-Kendall mutation tests reveal: spring experienced a significant early mutation in 2000; summer showed no significant mutation; autumn exhibited a significant delayed mutation in 2003; and winter displayed a significant delayed mutation in 1995 ([Figure 2: see original paper], [Figure 3: see original paper]).

2.3 Spatial Distribution Characteristics of Season Start Dates

Empirical Orthogonal Function (EOF) decomposition of standardized start date values was performed. Since summer does not occur at all stations uniformly, only spring, autumn, and winter were analyzed. The cumulative variance contributions of the first five eigenvectors reach 68.9%, 62.4%, and 71.1% for spring, autumn, and winter, respectively. The first two modes explain the majority of variance and effectively characterize the primary spatiotemporal distribution patterns.

The first EOF mode for spring and autumn shows consistent positive values across Xizang, indicating uniform early or late trends spatially. Spring's high-value centers concentrate along the Yarlung Zangbo River, the Himalayas, western Nagqu, and eastern Chamdo, with maximum values at Baxiu, Nyingchi, Gyantse, Lhatse, and Lhasa stations, and minimum values in eastern Chamdo and at Biru, Cona, and Pali stations. Autumn's high-value zone centers in central Xizang, representing the most sensitive regions to start date changes, with maximum values in the Yarlung Zangbo River area. The distribution exhibits "low in the northwest and high in the southeast for spring, high in the middle and low on both sides for autumn."

The second EOF mode for spring displays a "northwest positive, southeast negative" contrasting pattern, with negative zones in most of the Yarlung Zangbo River and central Chamdo, and positive zones elsewhere, featuring high-value centers in central-western Nagqu, Ngari, and western Xigazê. Autumn's second mode shows an opposite "southwest positive, northeast negative" distribution, with negative zones in northern Xizang and southwestern Chamdo, and positive zones in southwestern Xizang, centered at Zêtang, Bomi, and Markam stations.

Winter's first EOF mode exhibits a "high in the north, low in the southwest" pattern, while its second mode resembles spring's second mode, showing a "northwest positive, southeast negative" distribution with positive areas in northwestern Ngari and Cona, and negative zones elsewhere, centered at Zêtang and Bomi. The corresponding time coefficient series reveal significant interannual fluctuations with alternating positive-negative phases ([Figure 5: see original paper], [Figure 6: see original paper]).

2.4.1 Variation Cycles

Wavelet analysis reveals distinct periodicities: spring exhibits 22-year main period and 8-year short period, currently in a late phase with delayed trend; summer shows 28-year main period and 6-year short period, with short-term delayed trend; autumn displays 28-year main period and 6-year short period, with short-term early trend; winter demonstrates 22-year main period and 6-year short period, with continuous delayed trend. R/S analysis yields Hurst indices indicating anti-persistence for spring, autumn, and winter (R^2 0.84–0.96), suggesting future trends may reverse past patterns. Summer shows strong anti-persistence (R^2=0.84), indicating intensified delayed trend consistent with its primary 28-year cycle.

3 Discussion

Compared with previous studies using different temperature thresholds, the selected "10°C and 17°C" thresholds effectively resolve limitations of Zhang's method (late spring onset, early winter onset, ignoring low-altitude summers), reconcile Fan's method 矛盾 with Xizang's "long winter, short summer" reality, and address Shi et al.'s shortcomings of prolonged summer/winter durations and biased start dates. Spring and winter start dates generally delay from southeast to northwest, though local climate and topography cause delays compared to same-latitude regions. The advancing spring/summer and delaying autumn/winter trends align with studies on Northeast China, Liaoning, and Heilongjiang. The delayed response of season start dates to temperature changes reflects climate system inertia and stability, requiring adjustment time for atmospheric circulation and ocean temperatures. Large water bodies, mountains, and forests impede or buffer temperature transmission, delaying seasonal onset responses. Human activities may also interfere with temperature-season date correspondence.

Although Shi's "new four-season method" suits Xizang better than alternatives, it considers only temperature, neglecting geographic location, altitude, and climate types, limiting its applicability in high-altitude regions (>4500 m). Future improvements should incorporate altitude-specific thresholds to provide practical guidance for agriculture, animal husbandry, and tourism.

4 Conclusions

1) The new four-season division method more finely captures Xizang's climate nuances than traditional methods, providing more accurate seasonal transition definitions. Long-term data analysis reveals extended seasonal variation patterns, offering robust support for future climate change predictions. Overall, this study achieves methodological and conceptual breakthroughs in understanding Xizang's seasonal changes under climate change.

2) Four-season distinct zones concentrate along the Yarlung Zangbo River and in Nyingchi City, while indistinct zones (no-summer areas) occupy western, northern, and high-altitude Himalayan regions, with an overall warming trend. Spring and summer start dates advance, while autumn and winter dates delay. Spring showed significant early mutation in 2000; summer exhibited no significant mutation; autumn and winter displayed significant delayed mutations in 2003 and 1995, respectively.

3) Regarding start dates, EOF1 for spring and autumn shows "low northwest, high southeast for spring; high middle, low both sides for autumn." Spring's EOF2 presents a northwest-southeast contrasting pattern; autumn's EOF2 shows opposite southwest-northeast distribution. Winter's EOF1 exhibits "high north, low southwest" pattern, while EOF2 resembles spring's EOF2.

4) Future projections indicate: spring will show delayed trend in long cycles but early trend in short cycles; summer will maintain delayed trend in primary cycles but early trend in secondary cycles; autumn will show early trend in primary cycles but delayed trend in secondary cycles; winter will exhibit continuous delayed trend. The anticipated delayed spring and advanced autumn/winter patterns will emerge, with intensified summer delay.

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