Postprint of Classification Indices for the Timing and Duration of Climate Seasons in Tibet

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Abstract

To better understand the response mechanisms of seasonal variations on ecology and environment in high-altitude regions under global climate change, research on classification indicators for seasonal timing and duration in Tibet is particularly crucial. Based on daily temperature data from 38 meteorological stations in Tibet from 1981 to 2023, using temperature thresholds of 6 ℃, 17 ℃, 17 ℃, and 6 ℃ for the division of the four seasons, this study investigates the classification indicators for seasonal timing and duration and their evolutionary patterns. The results indicate that: (1) The average start dates of spring, summer, autumn, and winter at the 38 stations are April 21, June 17, July 17, and October 17, respectively, with average durations of 56 d, 29 d, 92 d, and 188 d. (2) The start/end times and durations of climatic seasons overall exhibit the characteristic of "minimum standard deviation in winter and maximum standard deviation in summer". (3) The timing and duration grades of climatic seasons display the pattern of "normal grade days > slightly early/late and early/late grade days > significantly early/late and abnormal early/late grade days", and the A indicator is more consistent with the thresholds for classification indicators of seasonal timing and duration. (4) The start dates of spring and summer in Tibet show an advancing trend, while those of autumn and winter show a postponing trend. (5) The start date of spring, end date of winter, and duration of summer are predominantly classified as normal grade; the start dates of summer, autumn, and winter and the end dates of spring and autumn are predominantly classified as early grade; the durations of spring and autumn are predominantly classified as short grade; the duration of winter is predominantly classified as long grade; and the end date of summer is predominantly classified as late grade. These results can provide a reference for climate resource management, ecological environment protection, and human production and livelihood activities.

Full Text

Preamble

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Division Index of Early or Late and Length Grade in Climate Seasons in Xizang

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Abstract

To better understand the response mechanisms of seasonal changes to ecological and environmental factors in high-altitude regions under global climate change, studying the division indices for early/late onset and duration length of seasons in Xizang is particularly important. Based on daily temperature data from 38 meteorological stations in Xizang from 1981 to 2023, we selected temperature thresholds of $ $6°C for spring onset, $ $17°C for summer onset, and <17°C for autumn onset, with <6°C for winter onset, to explore classification indices and evolution patterns of seasonal timing and duration. The results show: (1) The average start dates for spring, summer, autumn, and winter at the 38 stations were April 21, June 17, July 17, and October 17, respectively, with average durations of 56 days, 29 days, 92 days, and 188 days. (2) The start/end dates and durations of climatic seasons exhibit the characteristic of minimum standard deviation in winter and maximum standard deviation in summer. (3) The timing and duration grades of climatic seasons display a pattern of "normal grade > slightly early/late and early/late grades > significantly early/late and abnormally early/late grades." (4) In Xizang, the start dates of spring and summer show a trend toward earlier onset, while autumn and winter show trends toward later onset. (5) The start date of spring, end date of winter, and length of summer are predominantly classified as normal grade; the start dates of summer, autumn, and winter, along with the end dates of spring and autumn, are mainly early grade; the lengths of spring and autumn are primarily short grade; winter length is mainly long grade; and the end date of summer is predominantly late grade. These findings provide valuable references for climate resource management, ecological environmental protection, and human production and livelihood activities.

Keywords: climate season; early or late and length grade; standard deviation; evolution law; Xizang

China is a sensitive and significantly affected region of climate change, with a warming rate notably higher than the global average during the same period, and Xizang exhibits this trend as well. Rising temperatures directly alter the start and end times of the four seasons and their durations, leading to changes in the timing and length of climatic seasons. These changes not only directly impact daily life and production activities—such as scheduling for agricultural sowing and harvesting and planning for tourism peak seasons—but are also closely related to ecosystem balance and biodiversity. Although previous studies have proposed various division methods and indices, they often have certain limitations or regional adaptability issues. Unified and scientific standards for climatic season division, along with grade indices for seasonal timing and duration, help standardize related business operations and public meteorological services, enabling different regions and industries to better understand and respond to climatic season changes.

Xizang is characterized by the climatic feature of "four seasons in one mountain, different weather every ten miles." Based on existing research, selecting appropriate temperature thresholds for the four seasons in Xizang and exploring classification indices for seasonal timing and duration grades and their evolution patterns can provide theoretical foundations and decision-making support for climatology research, resource management, and environmental protection, promoting better human adaptation and response to the changing climate environment.

1.1 Data Sources

Daily mean temperature data from 38 meteorological stations in Xizang were selected (Figure 1), obtained from the Xizang Meteorological Information Network Center. The stations along the Yarlung Tsangpo River line include Lhasa, Zedang, Xigazê, Gyantse, Nagarzê, Lhatse, Nyêmo, Gonggar, Maizhokunggar, Gyaca, and Namling. The period 1991–2020 was selected as the standard climate period, with its average values serving as climatic means.

Note: The base map was produced using the standard map of the Xizang Natural Resources Department (Approval No. S(2022)004), with no modifications to boundary lines. The same applies below.

[Figure 1: see original paper] Distribution of 38 meteorological stations in Xizang

1.2.1 Calculation of Perennial Climate Seasons

Following the method of Shi Jiqing et al., the common climatic season division method uses 5-day moving average temperatures (T) that satisfy T $\geq$ 6°C as spring onset, T $\geq$ 17°C as summer onset, T $<$ 17°C as autumn onset, and T $<$ 6°C as winter onset. The day before the spring (summer, autumn, winter) start date is taken as the end date of winter (spring, summer, autumn). The number of days between the start and end dates constitutes the duration of the corresponding climatic season.

For the standard climate period (1991–2020), the perennial daily mean temperature sequence is calculated by averaging the same calendar day's temperatures over the 30 years to obtain a 365-day perennial mean temperature sequence. Using the four-season temperature thresholds, the perennial start/end dates and durations are determined. The formula for calculating the 5-day moving average is:

Mj = (tj + tj-1 + tj-2 + tj-3 + tj-4) / 5

where Mj is the 5-day moving average temperature for day j, and tj is the daily mean temperature for day j.

1.2.2 Classification of Climate Season Early/Late and Length Grades

Calculation of Standard Deviations α, β, δ: The standard deviations of start dates, end dates, and durations for each year are calculated as follows:

$\alpha = \sqrt{[\Sigma(Di - \bar{D})^2 / n]}$
$\beta = \sqrt{[\Sigma(Ti - \bar{T})^2 / n]}$
$\delta = \sqrt{[\Sigma(Li - \bar{L})^2 / n]}$

where $\bar{D}$, $\bar{T}$, and $\bar{L}$ are the mean start date, end date, and duration, respectively; Di, Ti, and Li are the start date, end date, and duration for year i; and n is the number of years (30).

Classification of Seasonal Timing and Duration Grades: By analyzing the relationship between the difference in days between the current year's season start/end dates (or duration) and the perennial values, and the standard deviation of the 30-year sequence, the early/late (long/short) grades are determined using standard deviation multiples as thresholds. Two division indices are selected: $±$0.5 standard deviations and $±$1.5 standard deviations. The difference in days (D) between the current year's season start date (D) and the perennial start date ($\bar{D}$) is calculated, and similarly for end dates and durations. The classification follows Table 1.

Index for classification of climate season grade

2.1 Spatial Distribution of Perennial Climate Seasons

Analysis of the spatial distribution of perennial season start dates, end dates, and durations at the 38 stations reveals that 29 stations have all four seasons, mainly distributed in low-altitude areas of Nyingchi City, western Chamdo City, and most areas along the Yarlung Tsangpo River line.

The average start dates for spring, summer, autumn, and winter at the 38 stations are day 112 (April 21), day 169 (June 17), day 199 (July 17), and day 291 (October 17), respectively, with average durations of 56 days, 29 days, 92 days, and 188 days. The earliest spring onset occurs at Amdo (day 77, March

17), the latest at Zayü (day 165, June 13), with the longest duration at Zayü (120 days) and the shortest at Cona and Pali (29 days). Where summer exists, the earliest onset is day 120 (May 29) at Baxoi, the latest is day 214 (August 1) at Bomi, with the longest duration at Zedang (120 days) and the shortest at Zedang (20 days). The earliest autumn onset is day 169 (June 17) at Amdo, the latest is day 241 (August 28) at Zayü, with the longest duration at Amdo (274 days) and the shortest at Zayü (36 days). The earliest winter onset is day 241 (August 28) at Zayü, the latest is day 349 (December 14) at Amdo, with the longest duration at Amdo (272 days) and the shortest at Zayü (113 days).

Early spring start and end dates are concentrated in Nyingchi City and along the Yarlung Tsangpo River, while later dates appear in northwestern Xizang. Longer spring durations are found in Nyingchi City and most areas along the Yarlung Tsangpo River, with shorter durations scattered in northern and southern Xizang. Early summer start and end dates are concentrated in central regions, with later dates in eastern areas. Longer summer durations occur in Nyingchi City, with shorter durations scattered at Zedang, Nyêmo, Gonggar, and Lhorong stations. Early autumn onset is concentrated along most of the Yarlung Tsangpo River, with later onset in Nyingchi City and eastern Nagqu City. Early end dates are scattered in northern and southern Xizang, with later end dates in Nyingchi City. Longer autumn durations are found in northern Xizang, with shorter durations concentrated along most of the Yarlung Tsangpo River. Early winter onset is distributed in northern Xizang, Zayü, Gyaca, Baxoi, and Zedang, with later onset in Amdo, Lhari, Cona, and Pali. Longer winter durations are located in northwestern and southern Xizang, with shorter durations concentrated in Nyingchi City and Baxoi.

[Figure 2: see original paper] Distribution of the start date, end date and duration of the perennial climate season at 38 stations in Xizang
[Figure 3: see original paper] Spatial distribution map of the start time, end time and duration of the perennial climate season

2.2 Standard Deviation of Current Year Climate Seasons

Using the formulas above, the standard deviations of season start dates, end dates, and durations at the 38 stations were calculated (Figure 4). Overall, winter shows the smallest standard deviation (7.0–14.0 days), while summer shows the largest (17.0–20.0 days). Spring, summer, and winter have the smallest standard deviations for start dates, while autumn has the smallest for end dates. The minimum standard deviation values appear in autumn end dates and winter start dates, while the maximum appears in autumn duration. Spring and winter end dates and durations have similar standard deviations, while summer start dates, end dates, and durations are similar, and autumn start dates and durations are similar.

[Figure 4: see original paper] Standard deviation of the start time, end date and duration of the perennial climatic season at 38 stations in Xizang

2.3 Determination of Classification Indices for Climate Season Early/Late Grades

The average frequencies of early/late and length grades at the 38 stations were analyzed under two division indices ($\pm$0.5 and $\pm$1.5 standard deviations). Under both indices, normal grade days are most frequent for start dates, end dates, and durations, followed by slightly early/late and early/late grade days, with significantly early/late and abnormally early/late grade days being least frequent.

The ratio of each grade's occurrence to the total sample size was calculated (Table 2). Summer shows the highest average frequency for start dates, while winter shows the highest for end dates. Based on the condition that average frequencies should satisfy normal > slightly early/late > early/late > significantly early/late, all seasons except summer meet this condition under the $\pm$0.5 standard deviation index. Under the $\pm$1.5 standard deviation index, all seasons satisfy this condition for end dates. Since the $\pm$0.5 standard deviation index yields a maximum frequency (for summer end dates) exceeding the threshold, while the $\pm$1.5 standard deviation index meets all conditions, the latter is more suitable as the threshold for classifying early/late and length grades.

Frequency of average early or late and length grade of climatic seasons at 38 stations

2.4.1 Temporal Variation

Using the $\pm$1.5 standard deviation index to classify seasonal grades in Xizang, the temporal distribution of early 0.05), with climate tendency rates of -8.61 days $\cdot (10a)^{-1}$ and 4.94 days $\cdot (10a)^{-1}$, respectively, indicating an advancing trend in spring onset. The proportion of early start date grades peaks in the 2010s, while late grades peak in the 1980s, showing opposite patterns.

For summer, early (late) start dates show non-significant increasing (decreasing) trends, with a climate tendency rate of -3.60 days $\cdot (10a)^{-1}$, indicating a slight advancing trend. The proportion of early start date grades follows the same pattern as spring. For autumn and winter, early (late) start dates show significant decreasing (increasing) trends ($P < 0.05$), with climate tendency rates of -6.00 days $\cdot (10a)^{-1}$ and -8.81 days $\cdot (10a)^{-1}$, respectively, indicating a delaying trend in autumn and winter onset. Early grade proportions peak in the 1980s, while late grades peak in the 2010s.

For end dates, spring shows a non-significant decreasing (increasing) trend for early (late) grades, indicating a delaying trend in spring end dates. Summer shows a significant decreasing (increasing) trend ($P < 0.05$), indicating a delaying trend in summer end dates. Autumn shows a significant decreasing (increasing) trend ($P < 0.05$), indicating a delaying trend in autumn end dates. Winter shows a significant increasing (decreasing) trend ($P < 0.05$), indicating an advancing trend in winter end dates.

For duration, short (long) grades in spring and summer show non-significant and significant decreasing (increasing) trends, respectively, indicating increasing trends in spring and summer lengths. Autumn and winter show non-significant and significant increasing (decreasing) trends, respectively, indicating decreasing trends in autumn and winter lengths.

[Figure 6: see original paper] Time distribution of the start date early or late grade of the four seasons in Xizang

2.4.2 Spatial Variation

Using the $±$1.5 standard deviation index, the spatial distribution of early/late grade proportions for season start dates, end dates, and durations was analyzed. For spring start dates, normal grade days are most frequent, followed by late grade days, with early grade days being least frequent. Except for Chamdo City and Shannan City, which are dominated by late grades, other regions are primarily normal grade. For end dates, early grade days are most frequent, followed by late grade days, with normal grade days being least frequent. Chamdo, Nagqu, and eastern Nyingchi are dominated by early grades, while Lhasa and southwestern Shannan are primarily normal grade, and other areas are late grade. For duration, normal grade days are most frequent, followed by long grade days, with short grade days being least frequent. Eastern Lhasa, Nyingchi, Zedang, Xigazê, and Lhatse are dominated by normal grades; eastern Nyingchi, Gyaca, Gonggar, and Nyêmo are dominated by long grades; and Mainling, Baxoi, and Lhorong are dominated by short grades.

For summer start dates, early grade days are most frequent, followed by normal grade days, with late grade days being least frequent. Most areas along the Yarlung Tsangpo River, eastern Nyingchi, and Chamdo are dominated by early grades; Gonggar, Lhorong, and Nyingchi are primarily normal grade; and Baxoi and Mainling are late grade. For end dates, late grade days are most frequent, followed by normal grade days, with early grade days being least frequent. Most areas along the Yarlung Tsangpo River, most of Nyingchi, and Chamdo are dominated by late grades; Gonggar, Lhorong, and Nyingchi are normal grade; and Baxoi and Mainling are early grade. For duration, normal grade days are most frequent, followed by long grade days, with short grade days being least frequent. Most areas along the Yarlung Tsangpo River, Nyingchi, and Chamdo are dominated by normal grades; Shannan, most of Xigazê, southeastern Ngari, central-western Lhasa, Amdo, Zayü, and Riwoqê are short grade; and Nagqu, most of Chamdo, northeastern Lhasa, Shiquanhe, Nyingchi, Xigazê, and Nyalam are long grade.

For autumn start dates, early grade days are most frequent, followed by late grade days, with normal grade days being least frequent. Most of Nagqu, most of Chamdo, western Nyingchi, Shiquanhe, Damxung, Xigazê, and Nyalam are dominated by early grades; Ngari, most of Shannan, central-western Lhasa, and Zayü are late grade; and normal grades are scattered in Baxoi, Xainza, Nagarzê, Bomi, Riwoqê, Namling, Cona, and Tingri. For end dates, early grade days are most frequent, followed by normal grade days, with late grade days being least frequent. Most of Xizang is dominated by early grades; normal grades are scattered in Markam, Gyaca, Bomi, Sogxian, Pali, Lhorong, Namling, and other areas; and Mainling and Zedang are late grade. For duration, short grade days are most frequent, followed by long grade days, with normal grade days being least frequent. Most of Chamdo, most of Nagqu, western Ngari, eastern Nyingchi, Damxung, and Nyalam are short grade; southern Shannan and southern Lhasa are normal grade; and other areas are long grade.

For winter start dates, early grade days are most frequent, followed by normal grade days, with late grade days being least frequent. Most of Xizang is dominated by early grades; normal grades are distributed in Markam, Gyantse, Namling, Bomi, Gyaca, Sogxian, Lhorong, and Pali; and Mainling and Zedang are late grade. For end dates, normal grade days are most frequent, followed by late grade days, with early grade days being least frequent. Most of Chamdo, most of Shannan, Shiquanhe, Nagqu, Xainza, Biru, Nyingchi, and Gyantse are late grade; Chamdo and Sogxian are early grade; and other areas are normal grade. For duration, long grade days are most frequent, followed by normal grade days, with short grade days being least frequent. Most of Xizang is dominated by long grades; Pangkog, Nyalam, Namling, Lhatse, Zogang, and Zayü are normal grade; and Mainling, Bomi, Sogxian, and Xigazê are short grade.

[Figure 7: see original paper] Proportion of the time length of the four seasons which in length grade in Xizang

3 Discussion

This study's results differ from those of Cheng Yuqin et al., who first calculated the perennial values and then performed 5-day moving averages. Our approach uses daily mean temperatures from the most recent three decades (1991–2020) to first obtain perennial temperature sequences for each calendar day, then applies 5-day moving averages to derive perennial seasonal values. This method fully considers climatic characteristics over longer timescales and reduces the impact of anomalous temperatures in individual years.

Many methods exist for dividing China's four seasons, with temperature thresholds being the most common. However, these thresholds are not fixed. This study adopts the new four-season division method for Xizang, which fully considers the complexity and particularity of Xizang's climate, providing a reliable prerequisite for exploring classification indices. Our finding that 29 stations have summer differs from Shi Jiqing et al.'s conclusion that all regions of Xizang have four seasons when using altitude-based thresholds, mainly because the latter approach lacks uniformity across Xizang and involves multiple thresholds.

Although summer durations are short (<20 days) in Nyêmo, Gonggar, Zedang, Lhatse, and Lhorong, the distinct characteristics of climatic seasons objectively exist. Compared with natural seasons, Xizang's climatic seasons feature long winters, slightly short springs, extremely short summers, and moderate autumns.

Under global warming, Xizang's climatic seasons have changed significantly, showing advancing trends in spring and summer onset and delaying trends in autumn and winter onset. This aligns with studies by Liu Yulian and Zhang Shixuan on seasonal changes in Heilongjiang and China. The conclusion of increasing summer duration and decreasing winter duration is consistent with Liu Yulian's findings, but the trends of increasing spring duration and decreasing autumn duration differ, possibly due to differences in atmospheric circulation patterns, ecosystems, vegetation cover, and human activities.

The distribution characteristics of seasonal grade proportions show that "spring has more normal, early, and short grade days; summer has more early, late, and normal grade days; autumn has more early, early, and short grade days; and winter has more early, normal, and long grade days." Differences in interdecadal variations and which seasons show these patterns, compared with studies by Yao Yu and Fan Sirui, may arise from different research methods, data, geographic locations, and altitude differences, which affect seasonal changes across Xizang's vast and special climate regions.

4 Conclusions

(1) According to the new four-season division method, 29 stations in Xizang have summer, mainly distributed in low-altitude areas of Nyingchi City, western Chamdo City, and most areas along the Yarlung Tsangpo River line.

(2) The average start dates for spring, summer, autumn, and winter are April 21, June 17, July 17, and October 17, respectively, with average durations of 56 days, 29 days, 92 days, and 188 days.

(3) For perennial climate seasons, early spring and autumn start and end dates are concentrated in Nyingchi City and along the Yarlung Tsangpo River (except autumn end dates in northern Xizang). Early summer start and end dates are concentrated in the central region where four seasons are distinct. Early winter onset is scattered in northern and southern Xizang. Late start/end dates for spring, summer, and autumn appear in northern Xizang, Nyingchi City, and eastern regions, respectively, while late winter onset appears in Nyingchi City. Standard deviations show maximum values for seasonal durations, minimum values for spring, summer, and winter start dates, and minimum values for autumn end dates.

(4) Under the $±$1.5 standard deviation index, normal grade days are most frequent for start dates, end dates, and durations, while significantly early/late and abnormally early/late grade days are least frequent. This index better conforms to the threshold requirements for classifying seasonal timing and duration grades.

(5) Spring and summer start dates show advancing trends, while autumn and winter start dates show delaying trends. Spring, summer, and autumn end dates show delaying trends, while winter end dates show an advancing trend. Spring and summer durations show increasing trends, while autumn and winter durations show decreasing trends.

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