Spatiotemporal Characteristics of Drought in Shanxi Province
Based on SPEI

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Abstract. All Drought is one of the most complex natural disasters affecting agriculture, water resources, natural ecosystems and society. The paper used the drought index SPEI to quantify the drought events. Based on the average temperature and monthly rainfall data of 15 meteorological stations in Shanxi Province from 1957 to 2017, the SPEI index was calculated at different time scales, and the drought changes at different time scales were analyzed. In the year, the applicability of SPEI index to drought response in Shanxi Province was verified, and the distribution of drought spatial distribution in Shanxi Province was graphically displayed. The results showed that the SPEI index had good applicability to the drought scenario in Shanxi Province. The overall drought degree was higher in summer and summer, and the distribution of drought was uneven with seasonal variation. The degree of drought changed with time in 1960s-2010s, especially in 2000s.

1. Introduction
As one of the most common and complex natural disasters, drought has a relatively broad impact on human society [¹], usually lasting for months or even years, causing a reduction in food production, hunger and land degradation, resulting in huge economic losses [²]. According to the 4th and 5th reports of the IPCC, in the past century, the global surface temperature has increased by 0.56 to 0.92 °C, and warming will increase the frequency and intensity of extreme meteorological disasters, thus affecting the agro-ecosystem. Therefore, quantitative research on the characteristics of drought change in temporary space and its formation mechanism is of great significance for the scientific management and meteorological warning of agro-ecosystem.

Due to the complex causes of drought and obvious impacts on human activities [³], the drought index is commonly used to describe drought scenarios. The commonly used drought indices are PDSI [⁴], SPI [⁵] and custom drought intensity index. The PDSI index is calculated based on a fixed time scale, so it is impossible to analyze the characteristics of drought spatial-temporal changes at multiple time scales; SPI is a drought-based drought index, which is simple to calculate. It can reflect the drought changes at different time scales well. The input data only needs precipitation, so it can not reflect the drought situation caused by temperature changes; The standardized precipitation evaporation index (SPEI) has the advantage of multiple time scales, which can compare the drought and flood conditions at different time scales and has good stability.
Shanxi Province suffers from drought disasters all the year round. This paper describes the drought in Shanxi Province by SPEI index, and qualitatively and quantitatively describes the spatial and temporal distribution of drought in Shanxi Province on multiple time scales.

2. Overview of the study area
Shanxi Province is located at 34°34′-40°44′N, 110°14′-114°33′E, the total area is 156,700 km². Shanxi Province is located in the eastern wing of the Loess Plateau in western North China. The overall landscape is a mountain plateau widely covered by loess. Most of the areas are above 1000 meters above sea level, which is a strong uplifting situation compared with the eastern North China Plain. The climate type of Shanxi Province belongs to the temperate continental monsoon climate. The annual average temperature in all parts of Shanxi Province is between 4.2 and 14.2 °C; The annual precipitation in the whole province is between 358 and 621 mm, and the seasonal distribution is uneven, and the precipitation distribution in the province is greatly affected by the terrain.

3. Data sources and research methods
The data used in this paper are monthly precipitation and average temperature, all from the China Meteorological Science Data Sharing Service Network (http://data.cma.cn/). The DEM data comes from the Geospatial Data Cloud (http://www.gscloud.cn/).

The SPEI indicator was proposed by Vicente-Serrano. The index was constructed mainly from the difference between precipitation and evapotranspiration. It was also described by log-logistic probability distribution function. Finally, it was normalized by normalization and graded by the cumulative frequency of the difference (Table 1).

| Drought level       | SPEI     |
|---------------------|----------|
| Extremely dry       | <-2      |
| Severe drought      | -2~-1.5  |
| Moderate drought    | -1.5~-1  |
| Basically normal    | -1~1     |
| Moderate wetting    | 1~1.5    |
| Severe wetting      | 1.5~2    |
| Extremely humid     | >2       |

4. Results and analysis
4.1 Analysis of multi-scale characteristics of drought in Shanxi Province
As can be clearly seen in Fig. 1, the sensitivity of SPEI values at different time scales is significantly different with time. The smaller the time scale, the larger the variation of SPEI value. The monthly scale SPEI value is affected by the monthly mean temperature and rainfall changes, which can better reflect the soil water content. The SPEI-1 value fluctuates greatly and the change is most obvious. The seasonal scale SPEI value is affected by seasonal temperature and precipitation changes, which can better reflect the soil moisture content of the lower layer. The SPEI-3 has a longer fluctuation period, which reflects the seasonal drought variation law. The annual scale SPEI value is affected by the annual temperature and rainfall, and can better reflect the river runoff. Therefore, the SPEI-12 values are relatively concentrated, which can reflect the variation characteristics of interannual drought time. In general, SPEI-1 and SPEI-3 can reflect the change of drought condition with time in a short period of time, and the response to interannual change is not obvious. SPEI-12 obviously reflects the law of drought on large spatial scale.

According to the China Meteorological Disaster Code-Shanxi Volume, the drought in Shanxi Province has a high probability of occurrence, a wide geographical range and a long duration. The
monthly scale SPEI value has a high fluctuation frequency and a large fluctuation range, which fully reflects the frequent alternating characteristics of drought and flood in the scale of Shanxi Province. The drought characterized by the annual scale SPEI value is consistent with the historical drought year of Shanxi Province: in 1965, there was heavy drought in Shanxi, and there was a drought in 1972, 1986, 1997 and 2001. The average drought in the province was 1974, 1991 and 1999. The seasonal scale SPEI value and the annual scale SPEI value maintain a large negative value in these periods, which has a good correspondence with the larger drought in the historical record. In summary, the SPEI values on multiple time scales can effectively reflect the degree of drought in Shanxi Province.

![Figure 1. Dynamic characteristics of SPEI index of multiple time scales](image1)

4.2 Distribution characteristics of arid space in Shanxi Province

4.2.1 Spatial distribution of dry season in Shanxi Province. Based on SPEI-3, the SPEI values of the four seasons are calculated respectively. The spatial distribution of drought frequency is calculated to analyze the spatial distribution characteristics of drought frequency at different seasonal scales in Shanxi Province. As shown in Figure 2, the distribution of drought in the spring is relatively uniform, and the frequency of droughts in Yangquan City and Linfen City is relatively high. The summer drought frequency is increasing from north to south, and the higher frequency is distributed in the junction area of Yuncheng, Jincheng and Linfen, in the autumn, the frequency of drought in the south
is generally higher than that in the northern region. The frequency of drought is higher than 12%, mainly distributed in Jinzhong City, while the frequency in the northern part of winter is higher than that in the south. With the change of seasons, the frequency distribution of the occurrence frequency of the middle drought is not the same. In terms of the frequency coverage area of the moderate drought, the dry area in spring and summer is much larger than that in autumn and winter. The frequency of heavy drought in spring decreased from north to south, and the frequency of heavy drought in Shuozhou and Lvliang City was high, the frequency of heavy drought in summer is greater in the northern region than in the southern region, and the frequency of heavy drought in Shuozhou is still higher than in other cities, the heavy drought in autumn is mainly distributed in the central part of Shanxi Province, such as Jinzhong, Linfen and Changzhi, heavy drought in winter is mainly distributed in the northwestern part of Shanxi Province, such as Datong, Shuozhou, Lvliang Cities. The frequency of heavy drought in the northern part of Shanxi Province is higher than that in the south, and the frequency of heavy drought in Shuozhou is high. It also verifies the fact that the perennial drought in Shuozhou City is seriously affected.

The frequency of extreme drought is generally low, and there are few areas with extreme drought in autumn and winter. They are distributed in the west and north of Shanxi Province, and the frequency is within 4%. Most of the extremely dry areas in summer are distributed in the south-central part of Shanxi Province. The frequency of occurrence is also within 4%, and the frequency and area distribution of extreme drought in spring are more serious than those in the other three seasons. Most areas in the province have experienced extreme drought events in spring.

![Image of temporal and spatial distribution of drought season frequency in Shanxi Province](image)

**Figure 2. Temporal and spatial distribution of drought season frequency in Shanxi Province**

4.2.2 Spatial changes in the dry years of Shanxi Province. The spatial distribution of SPEI indices in different ages in Shanxi Province at multiple time scales is shown in Figure 3. It can be seen from the figure that the average SPEI values of the 1960s in different provinces are in the normal range. In 1965, the province's drought was severe, but the average SPEI value was not obvious. Among them, only SPEI6_1960s showed two drought points. The other years of the 1960s and the overall average drought were weak; The average SPEI values of 1970s, 1980s, and 1990s are still in the normal range. The drought was the most serious at the SPEI3 scale, and the drought points that appeared at the same time on five different time scales covered the areas of Yangcheng and Xinzhou, indicating that the frequency of drought occurred in this area was higher; In 2010s, the drought in most areas of the
province was relieved compared with 2000s. At the junction of Yangcheng and Zhangzhou, there were
droughts at the SPEI-1 and 12 scales, but the area was reduced compared with 2000s.

5. Conclusion
Based on the SPEI drought index, this paper analyzes the spatial and temporal
distribution characteristics of drought conditions at different time scales in the 61-year time range of Shanxi
Province, and based on the frequency of droughts at each site, spatial analysis of different drought
degrees in different seasons is carried out. The following conclusions:

(1) To verify the applicability of the SPEI method in response to drought in Shanxi Province, in
comparison with the drought year in which the actual drought year occurred in Shanxi Province and
the SPEI index;

(2) From the spatial distribution of seasonal drought frequency, the frequency of drought in spring
and summer is generally higher than that in autumn and winter, and the frequency of occurrence in
moderate drought and heavy drought exists everywhere. From the perspective of the spatial
distribution of drought in the age, the frequency of drought has gradually increased with the passage of
time, especially in 2000s.

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