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Analysis of the Characteristics of Soil Moisture Change in Nearly 36a in Hetao Plain Area

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Abstract

In order to explore the characteristics of soil moisture changes in the Hetao Plain, this study uses soil moisture data from 1981 to 2017 to analyze the characteristics of soil moisture changes in the Hetao Plain through linear trend estimation, filter analysis, mutation analysis, and wavelet analysis. The results show that: In the time domain, the overall soil moisture in the Hetao Plain showed a slight downward trend, with a rate of 0.002 m^3/m^3/10a; in the frequency domain, the inter-decadal changes in soil moisture were obvious. The soil moisture in spring changes differently from other seasons. The sudden change of soil moisture in the Hetao Plain occurred in 2004, which was mainly affected by the change of summer soil moisture. On a long-term scale, the soil moisture in the Hetao Plain shows a dry-wet-dry-wet change trend, showing a change of about 10 years;Small-scale interannual variability is the main oscillation period of soil moisture in the Hetao Plain, and it will be in a wet period in the future.

Keywords

Soil moisture, hetao plain, M-K mutation test, anomaly analysis, wavelet analysis.

1. Introduction

Soil moisture refers to the amount of water stored in unsaturated soil[1]. As an important indicator of surface hydrological processes, it contains a lot of information and is a key part of many climate variables. At the same time, soil moisture is also a key element for the growth of various plants, and it has a great effect on soil productivity. It is a very important one of the many land surface factors of climate change [2, 3]. As an important climatic factor, soil moisture affects the surface albedo, heat capacity, photosynthesis, evaporation and transpiration, and changes the sensible heat and latent heat flux transmitted to the atmosphere, thereby affecting climate change [4, 5]. Therefore, studying the change characteristics of soil moisture and analyzing its change rules are of great significance to the rational use of soil moisture, climate change, and agricultural production.

The changing characteristics and changing laws of soil moisture have been studied and concerned by many scholars. Ma Zhuguo et al. [6] found that the soil moisture in each thickness layer of the soil becomes wet in the deep layer, while the shallow layer becomes dry; and it increases with the increase of precipitation, and decreases with the increase of temperature. Relevant studies also show that soil moisture is still at a low level after the 1990s [7], and aridification occurs in the spring [8]. Ji Yanghui et al. [9] found through mutation analysis that although different regions of the Songnen Plain show a downward trend, there are obvious differences in the year of occurrence of the mutation. Deng Biao et al. [10] analyzed the characteristics of soil moisture changes in different seasons in the Sichuan Basin and found that the seasonal changes of soil moisture in the basin showed a bimodal characteristic. In terms of climate influencing factors, many studies have shown that soil moisture is positively correlated with precipitation and negatively correlated with temperature [11-14]; although changes in soil moisture are not determined by only one factor, land use, weather, soil, and topography , Human activities have an impact on it, but for a specific area alone, there are major influencing factors and key scales [15].

The Hetao Plain in Inner Mongolia is an important commercial grain and edible oil production base in the Inner Mongolia Autonomous Region. The crops are mainly spring-sown wheat and corn [16]. There are two types of typical ecological fragile areas in this area, the fragile area in the northern part of the Loess Plateau and the arid and semi-arid fragile area. The ecosystem is more sensitive to climate change [17]. At present, there are few related researches on the analysis of soil moisture change characteristics in the Hetao Plain. Therefore, this paper analyzes the characteristics and change characteristics of soil moisture in the Hetao Plain in order to provide a scientific basis for the Hetao Plain to deal with climate change and agricultural production management.

2. Materials and Methods

2.1. Data Sources and Processing

The reanalysis of data has a long time span, and the data quality in China is relatively high. Relevant studies have shown that ERA5 soil moisture can better reproduce the inter-annual and seasonal cycles of soil moisture [18]. This paper selects the ERA5 soil moisture data released by ECMWF as the research data source, with a time resolution of months, a spatial resolution of 0.1°, and a time span of 1981-2017.

2.2. Methods

2.2.1. Anomaly and Linear Tendency Estimation

Anomaly is a commonly used method to intuitively judge the trend of change from the curve. For sequence X, the anomaly at a certain time t is expressed as:

$$\bar{X}_i = X_i - \bar{X}(i = 1, 2, \ldots, t) \tag{1}$$

The cumulative anomaly curve shows an upward trend, which means the anomaly increases, and a downward trend means that the anomaly value decreases. From the ups and downs of the curve, the long-term significant evolution trend and continuous changes can be judged, and the approximate time of sudden change can even be diagnosed.

Linear tendency estimation is a one-variable linear regression equation of a certain meteorological variable changing with time. The simplest form of linear regression is[19]:

$$x = a + bt \tag{2}$$

In the formula, a is the regression constant, b is the regression coefficient, and x is the meteorological element variable that changes with time.

2.2.2. Filtering Method

In this paper, the Butterworth high-pass filter is used to analyze the spectral characteristics. The Butterworth high-pass filter can filter out low-frequency information, and by retaining high-frequency information, it can analyze interdecadal changes from a spectrum perspective[20]. The transfer function of the Butterworth high-pass filter can be expressed as:

$$H(u,v)=\frac{1}{1+\left[\frac{D(u,v)}{D_0}\right]^{2n}} \tag{3}$$

Among them, D0 is the cutoff frequency, and the parameter n is the order, which is used to control the steepness of the filter.

2.2.3. Mann-Kendall Method

In this study, the non-parametric Mann-Kendall method was used for the mutation test of soil moisture time series changes [21]. The Mann-Kendall method is one of the commonly used test methods to assess the trend of climate elements in time series. According to the time series X reverse order Xn, Xn-1, Xn-2,..., X1, calculated by the corresponding formula, and at the same time make UBk=-UFk(k=n,n-1,...,1), UB1= 0. A value of UFk or UBk greater than 0 indicates an upward trend in the sequence, and a value less than 0 indicates a downward trend. A value of UFk or UBk greater than or equal to U0.05=±1.96 indicates that it has passed the 95% confidence significance test. The moment of intersection of the two curves of UFk and UBk is the time when the sudden change begins.

2.2.4. Wavelet Analysis

Wavelet analysis[22] is the expansion of a one-dimensional signal in both time and frequency directions, which can reflect the local change characteristics of the time series, analyze the time-frequency structure of the signal in detail, extract valuable information, and objectively analyze climate change The hierarchical rules and characteristics.

If function $\psi(t)$ is any function that satisfies the following conditions:

$$\begin{cases} \int_R \psi(t)\mathrm{d}t=0 \\ \int_R \frac{|\hat{\psi}(t)|^2}{|\omega|}\mathrm{d}\omega<\infty \end{cases} \tag{4}$$

The continuous wavelet can be obtained by stretching and shifting the mother wavelet to a certain extent, as:

$$\psi_{a,b}(t)=\frac{1}{\sqrt{a}}\psi\left(\frac{t-b}{a}\right),a,b\in R;a>0 \tag{5}$$

For any function $f(t)\in L12(R)$, the continuous wavelet transform is:

$$\mathrm{W}_f(\mathrm{a,b})=\frac{1}{\sqrt{\mathrm{a}}}\int_R \mathrm{f(t)}\psi\left(\frac{\mathrm{t-b}}{\mathrm{a}}\right)\mathrm{dt} \tag{6}$$

Among them, a is the frequency parameter, b is the time parameter, and $Wf(a,b)$ is the wavelet coefficient. In this study, the basic function of the Mexican hat is used as the mother wavelet of the wavelet transform, and its expression is as follows:

$$\psi(\mathrm{t})=\left(1-\mathrm{t}^2\right)\frac{1}{\sqrt{2\pi}}\mathrm{e}^{-\frac{\mathrm{t}^2}{2}},\quad -\infty<t<\infty \tag{7}$$

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In order to accurately diagnose the oscillating intensity of different periods, the wavelet variance is calculated to determine the main period of the temperature sequence change.

$$Var(a) = \int_{-\infty}^{\infty} \left|\omega_f(a,b)\right|^2 db \tag{8}$$

3. Results and Analysis

3.1. Soil Moisture Trend Analysis

Based on the statistical calculation of the surface soil moisture anomaly sequence in the Hetao Plain area from 1981 to 2017, this study draws a multi-time scale distribution map of monthly average soil moisture, and further analyzes the linear change trend of soil moisture in each year and each season. The results showed that the annual average soil moisture in the Hetao Plain from 1981 to 2017 was 0.169m^3/m^3, the lowest soil moisture appeared in May, which was 0.098 m^3/m^3, and the highest soil moisture appeared in August, which was 0.296 m^3/m^3. Fig. 1shows the monthly average soil moisture time distribution from 1981 to 2017. This figure intuitively reflects the seasonal and interannual overall trend of changes in the past 36 years. The Hetao Plain area has distinct characteristics of soil moisture changes during the year, showing a wet-dry-wet distribution, with the driest in late spring and early summer (April to June), and the wettest in late summer and early autumn (August to October); it can be seen from the inter-annual changes. From the 1980s to the 1990s, the distribution of soil moisture in the spring, autumn, and winter tended to become wet, and from the 1990s to the present, it has shown a drying trend and entered a relatively dry period.

The soil moisture anomaly sequence shows that the annual average soil moisture in the Hetao Plain has shown a slight downward trend in the past 36 years, with a decline rate of 0.002 m^3/m^3/10a ($P>0.05$), and the overall change is relatively stable (Fig. 2a); The linear trend changes in winter are also relatively weak ($P>0.05$), with a decrease in spring at a rate of 0.003 m^3/m^3/10a, and an increase at a rate of 0.002 m^3/m^3/10a and 0.001 m^3/m^3/10a in autumn and winter (Fig. 2b,d,e); Summer soil moisture showed a significant downward trend ($P<0.05$), and the decline rate was 0.008m^3/m^3/10a (Fig. 2c). Although the overall trend change is not obvious, the inter-annual variation of soil moisture is strong, and the fluctuations are obvious. The annual average soil moisture has a positive and negative change of 3-5 years before the 1990s. The soil moisture first increased and then decreased. The soil moisture in the 1990s It has been in a state of increasing fluctuations. During this period, the Hetao Plain was in a wet period; after a dry-to-wet transition from 1999 to 2005, it was at a negative anomaly most of the time, indicating that the influence of factors such as increasing temperature and decreasing precipitation At present, the Hetao Plain is in a dry period. The fluctuations of the soil moisture anomaly sequence in spring, autumn and winter are consistent with the annual average soil moisture anomaly height. The spring soil moisture will continue to get wet after 2017, and the soil moisture anomaly fluctuates sharply in autumn and winter, especially in 1993-1999, the range of soil moisture changes was huge. It is considered that it has been affected by the atmospheric circulation in recent years, and the climate change is strongly caused by it. Before the 21st century, most areas of summer soil humidity were at a positive anomaly, showing a fluctuating and rising state. It was in a wet period. Entering the 21st century, due to global warming, temperature rise, precipitation reduction, human influence and other factors, most of the period is In the dry period, the soil moisture decreases, showing a trend of rapid aridification, which has adverse effects on agricultural production and soil and water conservation, which requires special attention.

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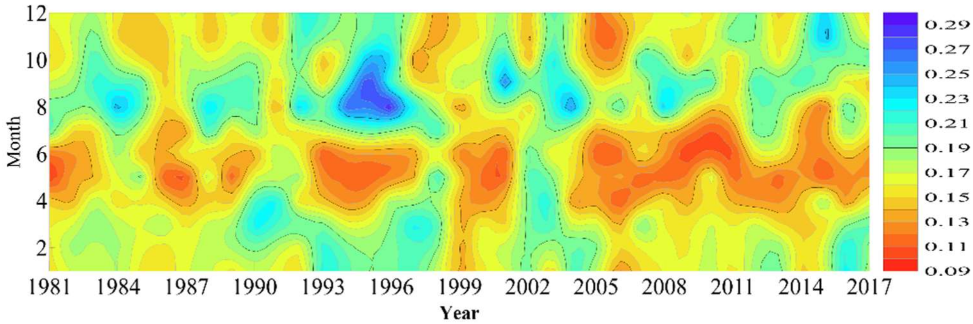

Fig. 1 Monthly average soil moisture anomaly time distribution from 1981 to 2017

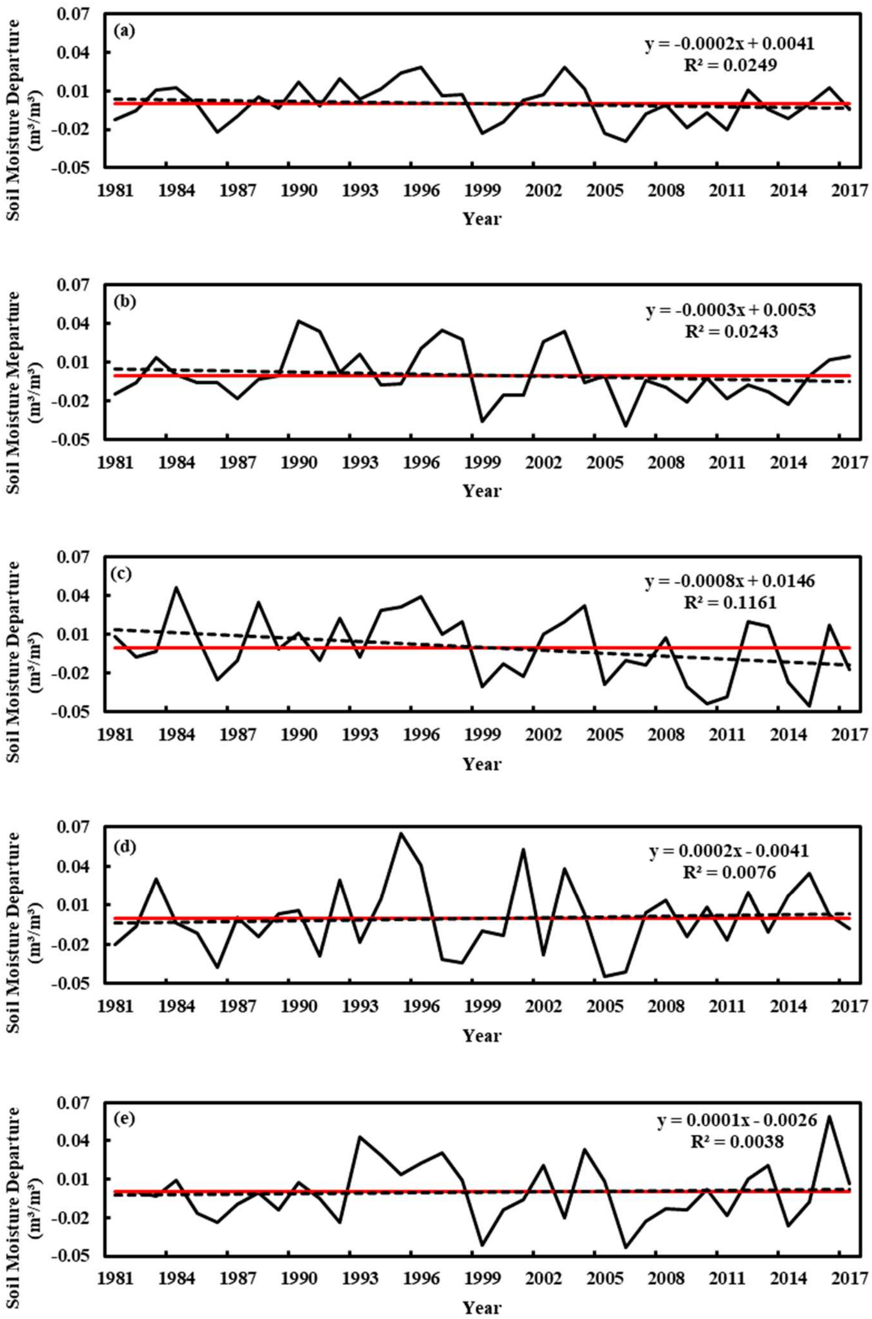

Fig. 2 The sequence of soil moisture anomalies in the Hetao Plain from 1981 to 2017(year(a), spring (b), summer (c), autumn (d), and winter (e) ,the red line is zero line, and the dashed line is the trend line)

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The anomaly analysis and linear trend analysis in the time domain are not significant for long-term soil moisture series and interdecadal changes. Therefore, the soil moisture is filtered and analyzed, transferred into the frequency domain, and high-pass filters are used to remove high values. Frequency noise, analysis of interdecadal changes. The results showed that before 2011, the soil moisture in the Hetao region showed an interannual change of about 10 years throughout the year, with a peak-like fluctuation in amplitude. The amplitude reached its peak (0.185dB) around 1994, which was the highest year in the wet period. After the soil moisture changes around 5 years, there will be a 5 year duration, indicating that the change of soil moisture will be stagnant. After 2011, there will be a small peak in soil moisture around 2015, and there will be a decline thereafter, and will continue to decline. Surface soil moisture has been in a dry period in recent years, and due to various factors, it is difficult to increase very high, so we need to be vigilant. Disaster caused by drought. The overall change trend in summer and winter is highly consistent with the change throughout the year. In winter, due to the freezing of the cold surface soil, the soil moisture is higher than that in the whole year; while the amplitude of soil moisture in summer is the smallest, and the results are consistent at the same time, which is in a dry period; the soil moisture in autumn is in 2014 There is a peak around the year, and the soil moisture rises significantly. The increase in soil moisture during this period may be caused by the increase in soil moisture in autumn; the change in the frequency domain of soil moisture in spring is very different from other seasons, and the increase in amplitude does not appear to be stagnant for 5 years. The amplitude has increased significantly, and soil moisture has increased significantly after 2011, and will continue to increase (Fig. 3).

In general, the soil moisture in the Hetao Plain has significant inter-annual changes in the time domain, while the inter-decadal changes are not strong, and the summer soil moisture is significantly reduced; in the frequency domain, the inter-decadal changes in soil moisture are obvious, and the changes are consistent throughout the year and in summer, autumn and winter. , Spring soil moisture has continued to increase in recent years.

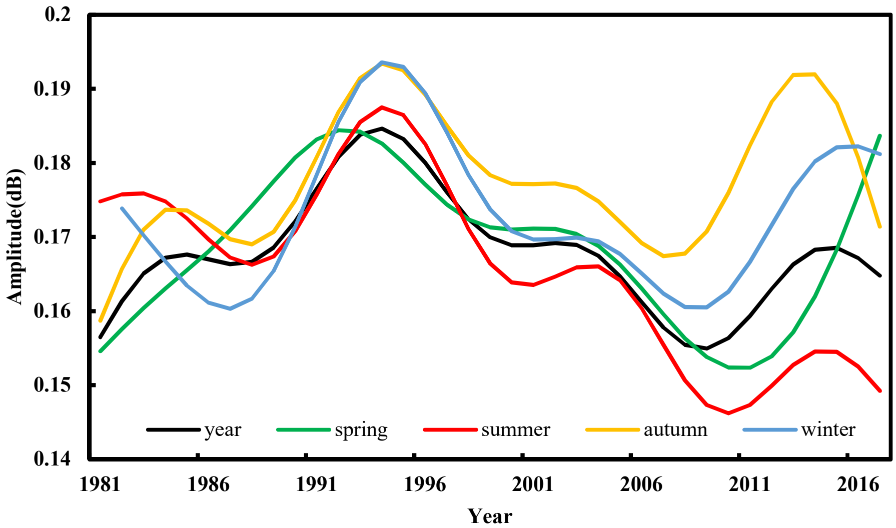

Fig. 3 Distribution of the filter sequence of the annual and seasonal average soil moisture in the Hetao Plain from 1981 to 2017

3.2. Analysis of Soil Moisture Abrupt Change

According to the soil moisture data in the Hetao Plain, the Mann-Kendall method was used to detect the abrupt changes of the annual and seasonal average soil moisture in the Hetao Plain. It can be seen from the annual average soil moisture UF curve (Fig. 4a) that there was a significant increase in soil moisture from 1986 to 1997, and it exceeded the significance level of 0.05. It appears that the soil moisture increased significantly during this time period; the annual average soil moisture continued to decline in the 21st century , But did not pass the 0.05 significance level, and the decline was not significant. The UF-UB curve crossed in 2004, which was a sudden year. The spring soil moisture sequence change is consistent with the annual average soil moisture, but it does not pass the 0.05 significance level, the change is not obvious, and there is no obvious mutation year (Fig. 4b). The summer soil moisture sequence mutation test surface (Fig. 4c) shows that the summer soil moisture in the 21st century has dropped significantly. In recent years, it has passed the 0.05 significance test. So far, there is no trend of wetness. The mutation year is 2006. Summer soil moisture changes have an impact on the annual soil moisture changes, making the Hetao region into a dry period. The UF-UB curve in autumn and winter soil moisture tests did not show a significant increase or decrease trend, with multiple intersections, and did not pass the 0.05 significance level (Fig. 4d, e). It shows that the linear change of soil moisture in autumn and winter is not obvious, but shows a non-linear change.

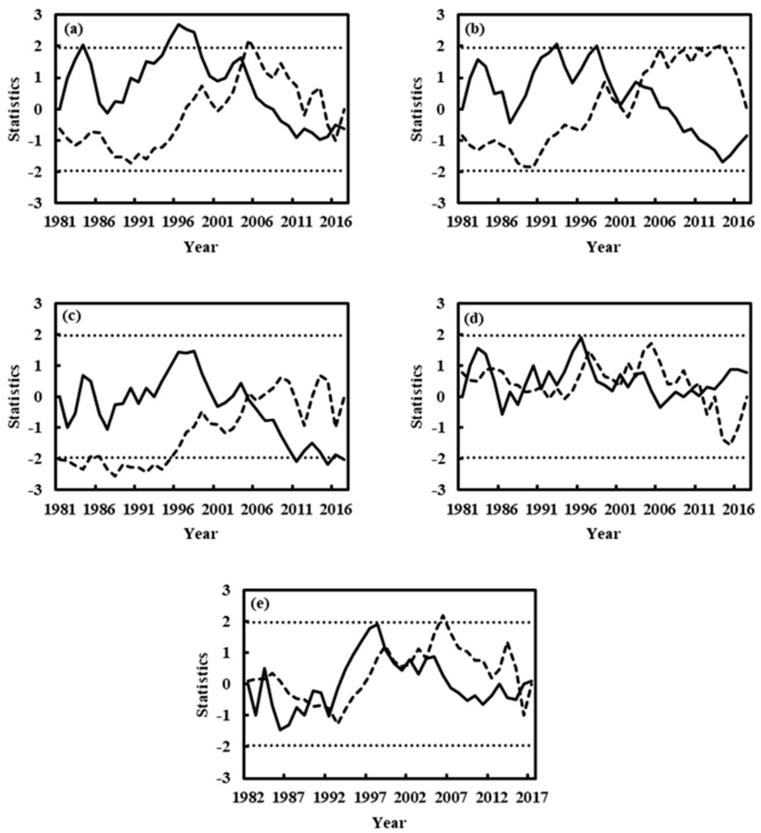

Fig. 4 The Hetao Plain area from 1981 to 2017 (a) annual average, (b) spring average, (c) summer average, (d) autumn average, (e) winter average soil moisture mutation test (the black solid line is the UF curve, The black dotted line is the UB curve, and the black dotted line is the 0.05 significance level)

3.3. Soil Moisture Cycle Analysis

Soil moisture is complex and changeable, and it is usually expressed as multi-frequency and quasi-periodic vibrations in the time domain. Therefore, the use of wavelet transform helps to understand the regularity of the soil moisture cycle and predict the response to changes in soil moisture. According to the soil moisture data in the Hetao Plain, the wavelet changes are calculated. In the soil moisture wavelet power spectrum, the larger the wavelet power, the denser the isolines. The wavelet analysis results show that on the long-term scale of 14-22 years, both the annual average soil moisture and the seasonal average soil moisture show a dry-wet-dry-wet trend, and the isoline is not completely closed, and the wet trend is It will continue (Fig. 5a, b, c, d, e). The annual average soil moisture formed the oscillation center in 1985, 1995, and 2008 respectively, which further proved that the soil moisture exhibited a periodic change of about 10 years in the interannual variation (Fig. 5a). Although the seasonal average annual soil moisture oscillation center is advanced or lagging to different degrees, it maintains a 10-year period change as a whole. The change of soil moisture in the Hetao area is relatively stable on an interdecadal scale. On a short time scale of 2-8a, the change trend of soil moisture accelerates, and dry-wet changes occur almost every 2 years, forming multiple oscillation centers, and the change of soil moisture is intensified, indicating that soil moisture changes significantly on a short time scale (interannual change) , It plays a pivotal role in short-term climate change. Before 2000, spring soil moisture oscillated most on a short-term scale, indicating that the overall soil moisture change was mainly affected by spring soil moisture (Fig. 5b). After 2000, summer soil moisture showed regular oscillations, which had a significant effect on soil moisture changes (Fig. 5c).

It can be seen from the wavelet variance diagram (Fig. 5f) that the first major period of the annual and seasonal oscillations of soil moisture in the Hetao area is 2a, the second major period is 6a, and the third major period is 22a. The soil moisture in the Hetao area mainly changes in Small-scale interannual changes. The wavelet power spectrum shows that the oscillation center of the interdecadal variation runs through the entire cycle, indicating that the interdecadal oscillation of soil moisture in the Hetao area is mainly affected by the year when the interannual variation is the strongest. This can be used to focus on the long-term soil moisture change in the Hetao area and provide assistance in production.

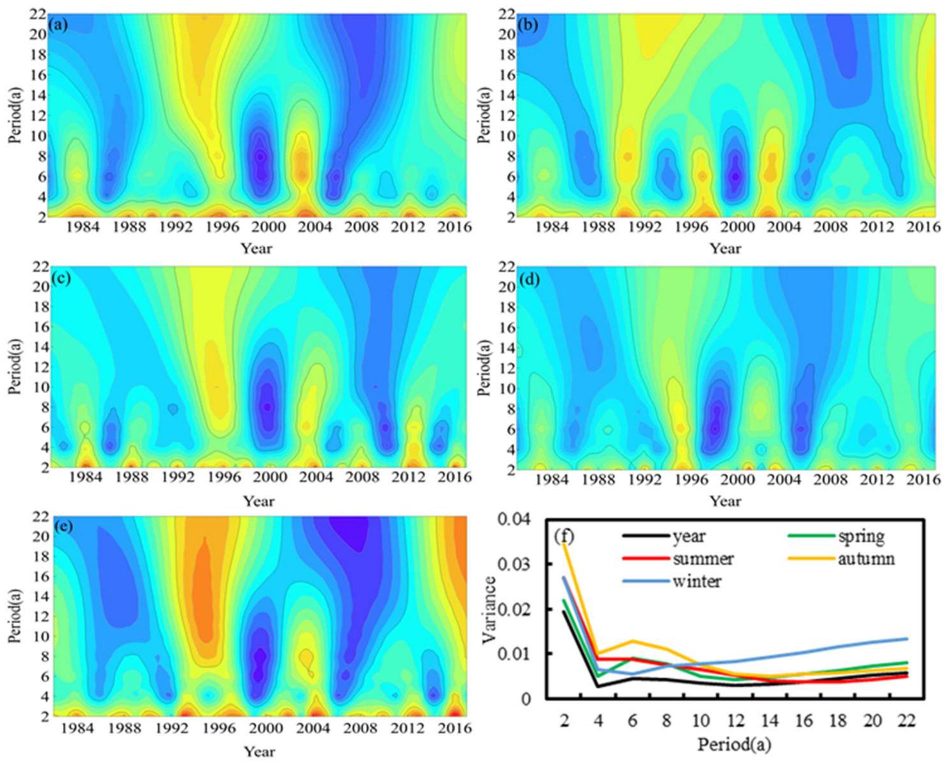

Fig. 5 The Hetao Plain area from 1981 to 2017 (a) year, (b) spring, (c) summer, (d) autumn, (e) winter soil moisture wavelet power spectrum and (f) wavelet variance

4. Conclusion

The annual average soil moisture in the Hetao Plain from 1981 to 2017 was $0.169 m^3/m^3$, the lowest soil moisture appeared in May, which was $0.098\ m^3/m^3$, and the highest soil moisture appeared in August, which was $0.296\ m^3/m^3$. The average drop rate of soil moisture is 0.002 $m^3/m^3/10a$, and there is no significant change; however, the interannual variation of soil moisture is strong, and it has been in a dry period in recent years. It is necessary to be alert to the occurrence of drought events caused by this. In the frequency domain, the interdecadal variation of soil moisture is obvious, and the soil moisture in spring has continued to increase in recent years. The sudden change of soil moisture in the Hetao Plain occurred in the early 21st century and was mainly affected by the sudden change in summer. The Hetao Plain is still in a dry period. Pay attention to the impact of drought on agricultural development.

The soil moisture in the Hetao Plain is very active in inter-decadal and inter-annual changes. The first main period of the soil moisture annual and seasonal oscillations is 2a, the second main period is 6a, and the third main period is 22a. On a short time scale of 2-8a, the trend of soil moisture change accelerates, with dry-wet changes occurring every 2a, forming multiple oscillation centers, and soil moisture changes intensified, which is very important in climate change; on the long-term scale of 14-22a Above, both the annual average soil moisture and the seasonal average soil moisture show a dry-wet-dry-wet change trend. The annual average soil moisture forms the oscillation center in 1985, 1995, and 2008, respectively. The soil moisture changes in the interdecadal period. Shows a periodic change of about 10a.

As a basic research work, this research focuses on the long-term sequence of soil moisture change trends and internal multi-scale laws in the Hetao Plain. Its purpose is to provide valuable information for local agricultural production. At present, drought and water shortage are the primary factors affecting agricultural production in this area, and this research work is undoubtedly meaningful to solve this problem.

References

[1] Seneviratne S I, Corti T, Davin E L, et al: Investigating soil moisture–climate interactions in a changing climate: A review, Earth-science reviews, Vol. 99(2010) No.3, p.125-161.

[2] Anagnostopoulos V, Petropoulos G P, Ireland G, et al: A modernized version of a 1D soil vegetation atmosphere transfer model for improving its future use in land surface interactions studies,Environmental Modelling & Software, (2017), p.147-156.

[3] J Lin, X M Chen, Y Zhang: Research progress on the relationship between climate change and soil moisture, Chinese Journal of Soil Science, Vol.43(2012) No.5, p.1271-1276.

[4] Z G Ma, C B Fu, L Xie, el: Some problems in the study of the relationship between soil moisture and climate change, Advances in Earth Science, (2001) No.4, p.563-568.

[5] Z Y Zuo, R H Zhang: Temporal and spatial changes of soil moisture in eastern China in spring, Science in China (Series D: Earth Sciences), (2008) No.11, p.1428-1437.

[6] Z G Ma, H L Wei, C B Fu: Changes in soil moisture in eastern China and its relationship with climate variability, Acta Meteorologica Sinica, (2000) No.3, p.278-287.

[7] W D Guo, Z G Ma, Y H Yao: Regional evolution characteristics of soil moisture in northern China in the past 50 years, Acta Geographica Sinica, (2003) No.S3, p.83-90.

[8] Z Y Zuo, R H Zhang: The relationship between summer precipitation and spring soil moisture in eastern China, Chinese Science Bulletin, Vol.52(2007) No.14, p.1722-1724.

[9] Y H Ji, C Y Wang, H X Zhu, et al: Time-series characteristics of soil moisture change in Songnen Plain, Chinese Agricultural Science Bulletin, Vol.29(2013) No.2, p.154-159.

[10] B Deng, T G Xiao: Temporal and spatial variation characteristics of surface soil moisture in Sichuan Basin, Journal of Chengdu University of Information Technology, Vol.28(2013) No.1, p.49-55.

[11] X Z Zhang, X Y Wu, J H He: Vertical change characteristics of soil moisture in China, Acta Meteorologica Sinica, Vol.62(2004) No.1, p.51-61.

[12] L X Jiang, S Li, Y H Ji, et al: The response of soil moisture in Songnen Plain to climate change from 1980 to 2005, Chinese Journal of Applied Ecology, Vol.20(2009) No.1, p.91-97.

[13] J J Han, Y G Gao, R Nan, et al: Variation characteristics of soil moisture in main agricultural areas of Heilongjiang Province from 1984 to 2005, Chinese Journal of Agricultural Meteorology, Vol.30 (200 9) No.1, p.41-44.

[14] F Wang, Y Zhang, J Liang: Changes of Soil Moisture in Sanjiang Plain and Its Response to Meteorological Conditions, Research of Soil and Water Conservation, Vol.27(2020) No.5, p.172-176.

[15] Y Qiu, B J Fu, J Wang, et al: Spatiotemporal variation of soil moisture and its relationship with environmental factors,Chinese Journal of Ecology, Vol.26(2007) No.1, p.8.

[16] W X Yan, X L Sun, C Yin: Risk Analysis of Main Crop Meteorological Output in Hetao Irrigation District of Inner Mongolia, Chinese Agricultural Science Bulletin, Vol.29(2013) No.30, p.73-80.

[17] K H Sun, X D Zeng, F Li: Analysis of the characteristics of climate change in China's ecologically vulnerable areas from 1980 to 2014, Climatic and Environmental Research, Vol.24(2019) No.4, p.455-468.

[18] Y X Wang: Research on China's Highly Sensitive Areas Based on Multi-source Soil Moisture Data(MS., Nanjing University, China 2019), p.11.

[19] S S Chen, S Y Zang, L Sun: Dynamic Changes and Effects of Soil Moisture in Permafrost Regions, Research of Soil and Water Conservation, Vol.27(2020) No.3, p.113-118.

[20] J L Xiao: Application research of Butterworth low-pass filter in image enhancement, Intelligent Computers and Applications, Vol.11(2021) No.5, p.179-182.

[21] C X T A B, B K W A, B Y Y A, et al: Quantifying the effectiveness of ecological restoration projects on long-term vegetation dynamics in the karst regions of Southwest China, International Journal of Applied Earth Observation and Geoinformation, Vol.54(2017), p.105-113.

[22] F Y Wei: Modern Climate Statistics Diagnosis and Prediction Technology (Second Edition)(Beijing: Meteorological Press, China, 2007), p.37-39.