Dynamic changes in maize NDVI and its response to drought in Liaoning province from 1998 to 2018

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Abstract. In order to study the normalized difference vegetation index (NDVI) of maize and its response to drought, this paper analysed the relationship between maize NDVI and drought in Liaoning province. Based on the meteorological data and NDVI data from 1998 to 2018, this paper analysed the spatial and temporal variation of maize NDVI and identified the drought occurrence in the growing season with the evaporative demand drought index (EDDI). The effect of drought disaster on maize NDVI was carried out by comparing maize NDVI and EDDI. The results could provide a basis for drought loss assessment and drought disaster prevention of maize.

1. Introduction
As a key part in the soil-plant-atmosphere continuum, vegetation is a link connecting the energy exchange, water and material cycle between land surface and atmosphere, and plays an important role in the water cycle and energy conversion [1-3]. The process of vegetation change can provide a basis for the study of climate change [4]. The rapid development of remote sensing technology provides abundant data and new technologies for monitoring the dynamic change of vegetation in a long time series. Normalized difference vegetation index (NDVI) is a vegetation index calculated by the ratio of the reflectance difference between the near-infrared band and the visible band and the sum of the reflectance of the two bands, which can well reflect the difference in vegetation coverage [5]. The evaporative demand drought index (EDDI) is a drought indicator established from the atmospheric evaporation demand, which can provide early warnings and evaluate agricultural drought conditions [6]. Maize is the largest food crop in Liaoning province, with a sown area of more than 20,000 km\textsuperscript{2}. The interannual yield of maize fluctuated greatly due to drought. With the intensification of climate change and human activities, drought would occur frequently and influentially in China. Therefore, in order to understand how crop ecosystems respond to drought, it is of great significance to explore the effect of drought on maize growth.
2. Materials and methods

2.1. Study areas
Liaoning Province (118°53’ E–125°46’ E and 38°43’ N–43°26’ N) is located in the northeast of China, with an area 148,000 km². It belongs to a temperate continental monsoon climate. The annual mean temperature is 8.5°C; the mean annual precipitation is 656mm; and there are 2,520 h of sunshine annually. The average planting area of maize in Liaoning province was about 22,200 km² and the yield was about 1,050,000 kg from 2016 to 2018. The main planting areas are located in Shenyang, Jinzhou, Fuxin, Tieling, Chaoyang and other cities of northwestern Liaoning province.

2.2. Data resources
NDVI products with a spatial resolution of 1 km from 1998 to 2017 were downloaded from the Resources and Environmental Data Cloud Platform (http://www.resdc.cn/Default.aspx) [7]; The meteorological data, which were from the Liaoning Meteorological Bureau, included air pressure, maximum temperature, minimum temperature, vapor pressure, average wind speed and sunshine hours of 55 stations in Liaoning province from 1998 to 2017.

2.3. Data processing
The annual NDVI of maize in Liaoning province was calculated from the mean value of each pixel from 1998 to 2017, using ArcGIS 9.3 software. To obtain raster data of EDDI in each year with a spatial resolution of 1 km, we conducted interpolation calculations on EDDI from 55 meteorological stations in Liaoning province from 1998 to 2017. The correlation between NDVI and EDDI was analyzed by using IBM SPSS Statistics 25 software.

2.4. Methods

2.4.1. Calculation of EDDI. EDDI is a normal normalization index obtained the distribution probability of the evaporation demand \( (E_0) \), which were constructed by sorting the cumulative value of \( E_0 \) within a given time scale. The specific principle and calculation method were shown in the article [6]. When EDDI is equal to 0, it means that the cumulative value of \( E_0 \) is equal to the median of climatology during the study period; negative value means that it is wetter than normal; positive value means that it is drier than normal; and the drought grade increases with the EDDI increasing. Drought grades were divided into five with the values of EDDI [8], which were light, moderate, severe, special and extreme. Table 1 showed the drought categories of EDDI in Liaoning province.

| Drought grade | Description          | EDDI percentiles | Values of EDDI |
|---------------|----------------------|------------------|----------------|
| ED0           | Light drought        | 70%–80%          | 0.511–0.817    |
| ED1           | Moderate drought     | 80%–90%          | 0.817–1.232    |
| ED2           | Severe drought       | 90%–95%          | 1.232–1.555    |
| ED3           | Special drought      | 95%–98%          | 1.555–1.872    |
| ED4           | Extreme drought      | ≥98%             | ≥1.872         |

2.4.2. Analysis of spatial and temporal distribution of drought. The value of the ratio (IOC) between the number of stations recording drought and total stations indicated the occurrence range of drought in the year. The occurrence range of drought was divided into local, regional and large-scale categories; an IOC lower than 20% was a local drought; an IOC from 20% to 50% was a regional drought; and an IOC greater than 50% was a large-scale drought. The occurrence frequency of drought in the period \( (P, \%) \) was the percentage of years with drought out of the total years.
2.4.3. Maize growth evaluation. The annual growth of maize was evaluated by the anomaly percentage of NDVI (ΔNDVI). The growth of maize can be divided into six grades with the values of ΔNDVI (Table 2), as shown in equation (1):

\[
\Delta \text{NDVI} = \frac{\text{NDVI}_{\text{current}} - \text{NDVI}_{\text{average}}}{\text{NDVI}_{\text{average}}} \times 100\%
\]

(1)

Where, \( \text{NDVI}_{\text{average}} \) is the average value of NDVI in a series period.

| Anomaly percentage of NDVI (ΔNDVI) | Grades of maize growth |
|-----------------------------------|------------------------|
| >10%                              | Very better            |
| 3% ≤ ΔNDVI ≤ 10%                  | Better                 |
| 0% ≤ ΔNDVI ≤ 3%                   | Slightly better        |
| -3% ≤ ΔNDVI ≤ 0%                  | Slightly poorer        |
| -10% ≤ ΔNDVI ≤ -3%                | Poorer                 |
| ΔNDVI ≤ -10%                      | Very poorer            |

Table 2. The grades of maize growth

3. Results

3.1. Spatial and temporal variation of NDVI

Figure 3 showed the annual change of mean NDVI of maize planting area in Liaoning province from 1998 to 2018. As can be seen from the figure, the change of NDVI showed an increase trend in volatility in the past 21 years, and the linear rate was 0.041/10a. The mean value of NDVI was the highest (0.819) in 2012. The lowest mean NDVI was 0.688 in 2000. The mean NDVI of maize in 21 years was 0.775. The years when NDVI was less than or equal to the average were in 1998-2004 and 2006, and the other years were higher than the average value.

Figure 1 showed the spatial distribution of NDVI anomaly percentage in maize in Liaoning province in 2000 and 2012, respectively. In the year of 2000, the maize growth in most regions of Liaoning province was poorer than the average growth, and the value of NDVI anomaly percentage was negative. In 2012, maize growth in most regions of Liaoning province was better than the average growth, and the NDVI anomaly percentage was positive, while the growth in some regions was poor.
The maize growth in most areas of Liaoning province was poorer or very poorer in 1998-2002, and the percentage of NDVI anomalies was negative. The percentages of the years from 1998 to 2002 were 83.5%, 88.2%, 96.4%, 83.2% and 95.5%, which were under the poorer grades. The maize growth in most areas of Liaoning province was better or very better in 2007, 2008, 2010, 2012 and 2013, and the percentages under better grades in these years were 89.0%, 96.2%, 85.4%, 93.3% and 52.7%, respectively.

3.2. Drought occurrences identified by EDDI
Figure 4 showed the annual variation of EDDI during the growing season (May to September) in Liaoning province from 1998 to 2018. The interannual change of EDDI was characterized by the alternation of dry-wet-dry in the growing season of maize in Liaoning province. The relatively high EDDI periods were concentrated in 1999-2002, 2009, 2015 and 2017, indicating that drought occurred during these periods. The value of EDDI in 2017 was the largest in the past 21 years. The figure showed that a dry-wet or wet-dry reversal occurred in 1998-1999 and 2008-2010.

Figure 2 showed the change of IOC for drought disaster in Liaoning province from 1998 to 2018. The EDDI values of 55 stations were lower than 0.511 indicating that there was no drought in 1998, 2005-2006, 2008 and 2010. The values of IOC were more than 50% in the years of 2000, 2011, 2002, 2014, 2015, and 2017, which indicating large-scale drought; The values of IOC were more than 20% in 1999, 2004, 2009, 2016, and 2018, which was characterized by regional drought; The values of IOC were less than 20% in 2003, 2007, 2011, 2012, and 2013, which was characterized by local drought.

3.3. NDVI change responses to drought
Figure 3 showed the changes of annual EDDI and NDVI in the growing season of maize in Liaoning province from 1998 to 2018. When EDDI showed wetter, the values of NDVI were generally higher. EDDI was drier from 1999 to 2002, and the values of NDVI were lower than mean NDVI. EDDI showed wet in 2008, 2012 and 2013, and the values of NDVI were also higher. However, although EDDI showed a dry trend from 2014 to 2017, the trend of NDVI did not decline.
Figure 4 showed the annual change of EDDI and NDVI anomaly percentage of maize in Liaoning province from 1998 to 2018. The period from 1999 to 2002 was a concentrated period of poor maize growth (ΔNDVI< -3%), when EDDI was higher and drought occurred. The period of good maize growth (ΔNDVI>3%) was concentrated in 2010-2013, which was consistent with wet EDDI. However, the values of NDVI were higher than mean NDVI, while EDDI showed dry in 2015-2018. The main reason was that EDDI and NDVI used the average value of the whole province, but the average values might eliminate spatial difference. Although maize growth in 2015-2018 was good in most areas, there were still some areas with poor growth and the proportion of NDVI below the average growth in these years were 40.2%, 25.5%, 25.3% and 34.8%. Therefore, although the mean NDVI values were higher, the dry phenomenon of EDDI reflected the drought in some regions.

In general, the response of NDVI to the dry and wet state of EDDI was consistent in most years and inconsistent in a few years. Pearson correlation analysis was carried out between annual EDDI and NDVI, and the correlation coefficient was -0.457. It showed a significant negative correlation between NDVI and EDDI. The NDVI of maize has a response to EDDI and drought, but there were also some other factors affected NDVI.

4. Conclusion and discussion

(1) In general, NDVI change of maize showed an increase trend in volatility in Liaoning province from 1998 to 2018, and the linear rate was 0.041/10a.

(2) The inter-annual change of EDDI was characterized by the alternation of dry-wet-dry in the growing season of maize in Liaoning province from 1998 to 2018. The high EDDI were concentrated in the years of 1999-2002, 2009, 2015 and 2017.

(3) It showed a significant negative correlation between NDVI and EDDI in the maize growing season in Liaoning province in the past 21 years. But the drought was not the only factor affecting the growth of maize.

Acknowledgments

This work was financially supported by Provincial Key R&D Project of Department of Science and Technology of Liaoning Province, China [2017210001, 2019JH2/10200018]; National Key R&D Program of China [2018YFD0300309-02]; the project of Institute of Atmospheric Environment, China Meteorological Administration, Shenyang [2018SY1AEZD1]; and the climate change project of China Meteorological Administration [CCSF201910].
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