

Monitoring of Winter Wheat and Summer Corn Phenology in Xiong'an New Area Based on NDVI Time Series

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Abstract—Studying the phenophase of crops is an important way to identify crop planting patterns and extract crop areas. It is also of great value for crop growth monitoring and yield assessment. Based on the ESTARFM model, the MODIS and Landsat image data of the Xiong'an New Area in 2006-2010 are combined to make the data have high spatial and temporal resolution advantages. The Savitzky-Golay (SG) filtering method and the dynamic threshold method are used to perform NDVI on the obtained fusion data set. The time series data was reconstructed, and the key phenophase of winter wheat and summer corn in Xiong'an New Area was compared with the local actual crop planting system. The results show that: (1) Before using Savitzky-Golay filtering method, the NDVI time series is not well-formed, and there is more noise information. After smoothing with Savitzky-Golay filter, the NDVI time series curve can maintain the original curve shape. On the basis of this, the irregular fluctuation of the original data is eliminated, and the details of the curve are well preserved. At the same time, the curve exhibits a distinct bimodal morphology and also conforms to the growth characteristics of winter wheat and summer corn. (2) Through years of research data, it is known that the winter wheat returning green period is usually in the middle of March, the heading period is generally in early May and mid-May and the mature period is mostly in early June and mid-June. The summer corn seeding period is generally in mid-June, the jointing period is in mid-July, the tasseling period is mid-August and late August, the mature period is generally mid-October. Comparing the actual crop planting system in Huang Huai Hai plain, the identification and extraction results of winter wheat and summer corn phenological information are consistent with the practical situation, it may provide a scientific basis for the transformation of agricultural industry in Xiong'an New Area.

Keywords—Savitzky-Golay filtering; NDVI; threshold method; phenological extraction

I. INTRODUCTION

Wheat and corn are important food crops in China, and the North China Plain is the main producing area.

Xiong'an New Area is located in the North China Plain of Baoding City, Hebei Province. It is a new district of national significance after the Shanghai Pudong New Area and the Shenzhen Special Economic Zone, which is facing a major regional transformation. Study the phenological difference, temporal and spatial characteristics of crops and the response relationship with related factors is of great significance to study

the similarities and differences between crops and natural vegetation evolution, crop yield estimation and agricultural time prediction[1].

At the same time, as a kind of remote sensing earth observation technology on a large range of phenological monitoring has more obvious advantages over traditional methods, it has been widely used to monitor crops. At present, there are four methods commonly used in, that is the threshold method, the sliding average method, the derivative method and the curve fitting method. These methods have many research results. Yuke Zhou et al[2] based on the threshold method and the derivative method, in conjunction with cubic splines, double logistic function method and Singular spectrum analysis method to reconstruct the NDVI time series data, then to compare and analyze the differences and applicable conditions of the extraction results of the six methods. The results show that the threshold method has strong stability and adaptability. Wang et al[3] extracted the sowing date and harvest period of rice in Jiangsu Province based on curve fitting method, and found that the effective extraction area in the sowing period was higher than the harvest period. Duchemin B et al[4] proposed to extract the phenological period of temperate deciduous forest by sliding average method. Since the moving average process can be monitored continuously plurality of reproductive phenology but the selection of moving average time interval may cause the returning green period have become unable to monitoring, coupled with the influence by the spring thaw, the results were earlier than that of the actual vegetation returning green period. Xuehui Hou [5] carefully compared the dynamic threshold method, logistic function fitting method, delay moving average method and derivative method, and concluded that the accuracy of logistic function fitting and dynamic threshold method was similar to that of monitoring the greening period of winter wheat.

In summary, in order to obtain more precise phenological information, in this study, NDVI time series extraction was performed on the high-temporal resolution image dataset from 2006 to 2010 based on the ESTARFM fusion model combined with MODIS and Landsat TM data, and reconstruct the NDVI timing curve using Savitzky-Golay filtering. Finally, using the threshold method with strong stability and adaptability to extract the phenological period of wheat and corn in Xiong'an New Area, and compare the actual crop planting system in

Huang Huai Hai plain, to supply a scientific basis for the transformation of agricultural industry in Xiong'an New Area.

II. RESEARCH AREA OVERVIEW AND DATA PROCESSING

A. Survey of Research Area

Xiong'an New Area (38°43'-39°10'N, 115°37'-116°20'E) is located in Baoding City, Hebei Province, and was established as a national new district by the Central Government and the State Council on April 1st, 2017, designed to find the new patterns for development planning in China's densely populated areas. At the junction of Tianjin, Beijing and Baoding, Xiong'an New Area has obvious advantages in transportation and location. It is a new driving force for realizing the transformation and development of the country and solving the predicament of harmonious development between Beijing and Tianjin. [6].

The planning scope of Xiong'an New Area covers three small counties and surrounding areas such as Xiong county, Rongcheng county and Anxin county in Hebei Province. According to the yearbook data of Baoding City in 2015, the total grain output of Xiong'an New Area is 711,830 tons, its main crops are bring in one or two harvests a year. Beyond that, the new area has a flat and wide terrain, northwest high and southeast low. The north side is the Yongding River alluvial fan, and the south side is the alluvial fan of the Ziya River and the Dasha River. The land is a warm temperate monsoon continental climate, the average annual precipitation is 522.9 mm and the annual average temperature is 11.7 °C.

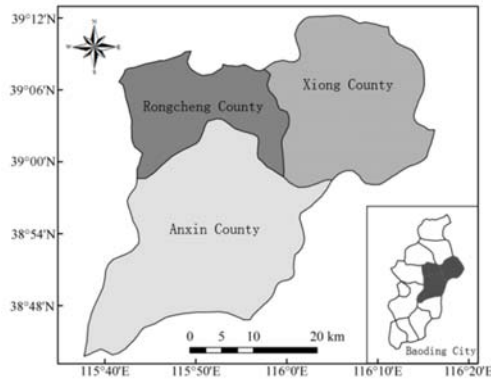


FIGURE 1. GEOGRAPHIC LOCATION MAP OF STUDY AREA
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B. Data and Preprocessing

1) Research data

MODIS is an important sensor on the Terra and Aqua satellites, which have 36 discrete spectral bands, covering full spectrum from 0.4μm (visible light) to 14.4μm (thermal infrared). The MODI09GA and MODI09A1 products with spatial resolution of 500m were selected. The product strip numbers are h26v05 and h27v05, of which MODI09A1 has a temporal resolution of 8days, MODI09GA has a temporal resolution of 1day.

Landsat 5 is the longest-running optical remote sensing satellite in orbit. It is the most widely used and most effective in the world. This paper selects Landsat 5 TM L1T data

products that have undergone system radiation correction, terrain correction and ground control point geometry correction. Its spatial resolution is 30m, track number is 123/033, and the temporal resolution is 16 days.

Based on the ESTARFM model, this study combines MODIS and Landsat TM satellite imagery from 2006 to 2010 to obtain a fusion dataset as a source of subsequent research data, which have high temporal resolution (8days) and high spatial resolution (30m).

2) Data preprocessing

The MODIS raw data is HDF format and needs to be re-projected by the MODIS Reprojection tool (MRT). All MODIS daily reflection products are re-projected into the UTM WGS84 coordinate system, and the nearest neighbor sampling method is used to splicing the image. The image is resampled to a spatial resolution of 30m and then saved as a Geo tiff format output. Because the MODIS data and the Landsat TM data sensor have certain differences in parameters and system characteristics, the MODIS data needs to be adjusted according to the order set in Table 1, in order to achieve both individually corresponding to the respective bands[7], and to use the ESTARFM model-based fusion method to perform subsequent fusion processing on images.

TABLE I. LANDSAT TM AND MODIS BAND SETTINGS AND CORRESPONDING RELATIONSHIP

Spectral range	TM band (resolution/m)	Sensor spectrum segment / μ m		MODI09A1/ MODI09GA band
		TM	MODI09A1/ MODI09GA	
Visible light (blue)	B1 (30)	0.450-0.520	B3 (500)	0.459-0.479
Visible light (green)	B2 (30)	0.520-0.600	B4 (500)	0.545-0.565
Visible light (red)	B3 (30)	0.620-0.690	B1 (250)	0.620-0.670
Near infrared	B4 (30)	0.760-0.900	B2 (250)	0.841-0.876
Mid-infrared	B5 (30)	1.550-1.750	B6 (500)	1.628-1.652
Thermal infrared	B6 (120)	10.40-12.50	B5 (500)	1.230-1.250
Mid-infrared	B7 (30)	2.080-2.350	B7 (500)	2.105-2.155

Secondly, using the boundary vector of Xiong'an New Area as a mask, the Landsat TM and MODIS image data are batch-cut by the program, and to make it become the initial data of the ESTARFM fusion model. The image data obtained after the fusion processing has high temporal resolution (8day) and spatial resolution (30m), the fidelity of the spectral data is also good. Finally, according to formula (1), to calculate the normalized difference vegetation index (NDVI) by using the near-infrared reflectance (NIR) and red band reflectance (Red) . the fusion image NDVI time series data set from 2006 to 2010 was obtained.

$$NDVI = (\rho_{NIR} - \rho_R) / (\rho_{NIR} + \rho_R) \quad (1)$$

In the formula, ρ_{NIR} is the near-infrared reflectance, and ρ_R is the red band reflectance.

III. RESEARCH METHODS

A. Savitzky-Golay Filtering

Savitzky-Golay filtering is a weight moving average filtering method, which based on least squares convolution fitting method, and proposed by Savitzky and Golay in 1964. The weight is mainly determined by the number of polynomials obtained based on least-square polynomial fitting in a filter window[8]. According to previous studies, this method is based on local fitting, which can clearly describe the data complexity and the subtle changes of the reconstruction curve. It can better describe the dynamic changes and local micro-mutation information of NDVI under the one-year multi-cropping system [9]. The formula is as follows:

$$I'_i = \frac{\sum_{j=-n}^n (C_j I_{i+j})}{N} \quad (2)$$

In the formula, I is the primitive NDVI value before unsmoothing; I' is the fitted NDVI value; C_j is the j th convolution coefficient; N is the convolution number, which is numerically equal to the number of data contained in the sliding window $2n+1$. When smoothing with Savitzky-Golay filtering, two parameters of smooth window size and smoothing polynomial order need to be selectively modified. The smoothing window size is represented by n . The larger the value of n is, the smoother the result is, the more peaks and valleys are smoothed. The lower the value of the parameter of the smoothing polynomial order, the smoother the result is, but some exceptions are retained, when the order is high, the outliers can be removed, but the results may be over-fitting resulting in more noise.

B. Threshold Method

The threshold method is to confirm the beginning and end dates of the vegetation growing period in each pixel range by setting threshold conditions for vegetation index (NDVI, EVI, etc.)[5]. The threshold method is mainly divided into two categories, wherein the fixed threshold method uses the preset vegetation index threshold to extract the phenological information of the crop. This method works well for specific areas, but it cannot be applied to areas with different land cover types and soil backgrounds. In the condition of comparing with the traditional fixed threshold method, the dynamic threshold method has a close relationship with the seasonal variation of NDVI per pixel. The threshold can be dynamically adjusted according to the difference between the study areas, in order to eliminate the effects of different soil background values and vegetation types[10].

The calculation method of dynamic threshold $NDVI_{lim}$ is usually as follows:

$$NDVI_{lim} = (NDVI_{max} - NDVI_{min}) \times C \quad (3)$$

Among them, the maximum value of NDVI is $NDVI_{max}$, the minimum value of the NDVI is $NDVI_{min}$ rise or fall phase, C is the set threshold.

Based on the morphological characteristics from time series of NDVI, the key phenological periods of winter wheat and summer corn in the study area from 2006 to 2010 were extracted. Among them, the turning green period of winter wheat is equal to 10% of the rising period of NDVI time series curve; the heading period is equal to the time point when the NDVI curve reaches its maximum value; and the maturity period is equal to the time when the NDVI curve reaches 50% of the declining period [12].

Summer maize seedling-pulling stage is equal to the inflection point where the NDVI curve begins to rise; jointing stage is equal to 50% of the rising period on the left side of NDVI; earing stage is equal to the peak position; maturity stage is equal to 75% of the peak value of the declining period of NDVI[9].

IV. RESULTS AND ANALYSIS

A. NDVI Time Series Data Smoothing Effect

In order to compare the differences before and after NDVI time series curve filtering more clearly and intuitively, this study randomly selected a cultivated land pixel (column number 687,689) in Xiong'an New Area to observe the smoothing effect of S-G filtering.

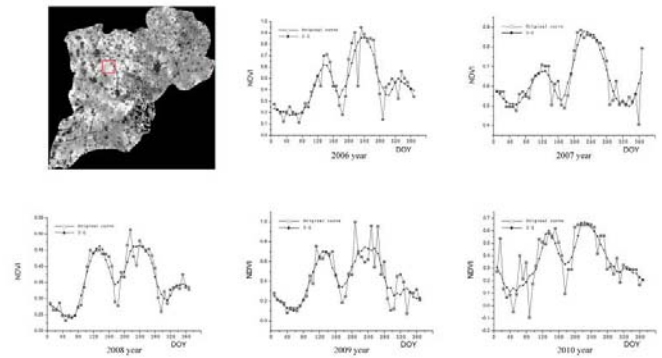


FIGURE II. COMPARISON OF THE EFFECTS OF S-G FILTERING SMOOTHING IN THE STUDY AREA FROM 2006 TO 2010

It can be seen from Fig. 2 that the original data shape before filtering is not perfect enough, and has obvious short-term jagged fluctuations, which greatly affects the shape of the entire NDVI time series curve. The curve processed by Savitzky-Golay filtering basically maintains the original curve shape, and eliminates the irregular fluctuation of the original data, which becomes smoother and retains the detail part well. At the same time, the apparent bimodal morphology of the curve is also consistent with the growth characteristics of winter wheat and summer corn.

B. Crop Phenological Information

Based on the NDVI time series curve after Savitzky-Golay filtering smoothing and the extraction method of winter wheat and summer corn phenology, The returning green, heading and mature periods of winter wheat (Table 2) and the seeding, jointing, tasseling and mature periods of summer corn were extracted from 2006-2010 in the study area.

TABLE II. RESULTS OF WINTER WHEAT PHENOLOGICAL PERIOD EXTRACTION FROM 2006-2010 IN THE STUDY AREA

Years	Returning green period	Heading period	Mature period
2006	March 21	May 16	June 9
2007	March 5	May 8	June 1
2008	March 13	May 16	June 9
2009	March 13	May 8	June 17
2010	March 13	May 16	June 9

TABLE III. RESULTS OF SUMMER CORN PHENOLOGICAL PERIOD EXTRACTION FROM 2006-2010 IN THE STUDY AREA

Years	Seedling period	Jointing period	Tasseling period	Mature period
2006	June 25	July 19	August 28	October 15
2007	June 17	July 19	August 12	October 23
2008	June 25	July 27	August 28	October 15
2009	June 25	July 27	August 20	October 15
2010	June 25	July 27	August 12	October 7

Through years of research data, it is known that the winter wheat returning green period is usually in the middle of March, and the heading period is generally in early May and mid-May, and the mature period is mostly in early June and mid-June. The summer corn seeding period is generally in mid-June, the jointing period is in mid-July, the tasseling period is mid-August and late August, and the mature period is generally mid-October. Comparing the actual crop planting system in North China Plain, the identification and extraction results of winter wheat and summer corn phenological information are conform to reality.

V. CONCLUSIONS AND DISCUSSION

Accurate and rapid acquisition of phenological information of winter wheat and summer corn in the region is of great significance for the implementation of fine field management and yield prediction. In this study, the S-G filtering was used to smooth the NDVI time series curve of Xiong'an New Area from 2006 to 2010, and the key phenological period of winter wheat and summer corn was extracted by dynamic threshold method. The main draw the following conclusions:

(1) At present, the MODIS data commonly used in phenological extraction is a product which spatial resolution is 250 m, and the phenological period observed on the ground is from the visual observation of individual or local crop groups. Remote sensing image data reflects pixel information. A pixel may contain many different types of land use. The whole pixel or even multiple pixels represent the characteristics of local crops, which will lead to a decrease in the accuracy of the remote sensing extraction. The image data used in this study is a fusion data set with high temporal and spatial resolution, which is combined with MODIS and Landsat TM satellite images by ESTARFM model. The high spatial resolution of the data can significantly improve the accuracy of remote sensing extraction results.

(2) The Savitzky-Golay filtering process can effectively correct the irregular fluctuations of the NDVI time series curve and remove the invalid noise, so that it becomes smoother on the basis of maintaining the original shape. At the same time, it can fit the local details of the time series curve, maximize the

phenological features and better extract the phenological information of the crop.

In addition, there are some shortcomings in the research. Firstly, the dynamic threshold method is adopted and its threshold is set to 10% and 50% respectively. This is only limited to the large-area scale, ignoring the spatial variation of the threshold. Second, there are many factors affecting the phenology of crops, such as climate, topography, varieties, planting patterns and so on, their combined effects will lead to significant time and space differences. Therefore, in the future research, the above factors should be considered comprehensively to make the extraction of phenophase more accurate and scientific.

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