

Vegetation Phenology Dataset in Mongolia (2001–2019)

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Abstract: Vegetation phenology reflects the growth status of vegetation and is a biological indicator of climate change. Mongolia is an important part of the Mongolian Plateau and an important response region for global ecological and environmental changes. The change of vegetation phenology in Mongolia can reflect global climate change. The normalized vegetation index of the MOD13Q1 product dataset, uses the dynamic threshold method to obtain the vegetation phenological parameters in Mongolia. The dataset is archived in .tif format, with a spatial resolution of 250 m, and includes remote sensing monitoring data of the start of growing season (SOS), end of growing season (EOS), and length of growing season (LOS) in Mongolia from 2001 to 2019. The dataset consists of 60 files with a data size of 944 MB (compressed into three files, 844 MB). It reveals differences in the temporal and spatial distribution of vegetation phenology in Mongolia, and provides basic reference data for the study of vegetation phenology and climate change in the Mongolian Plateau.

Keywords: vegetation phenology; Mongolia; climate change; Mongolian Plateau

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Dataset Availability Statement:

The dataset supporting this paper was published and is accessible through the *Digital Journal of Global Change Data Repository* at: <https://doi.org/10.3974/geodb.2022.03.05.V1> or <https://cstr.science.org.cn/CSTR:20146.11.2022.03.05.V1>.

1 Introduction

Vegetation phenology refers to a seasonal phenomenon in which vegetation interacts with different climatic, geographical, and other environmental factors. It indicates that under the prolonged influence of surrounding environmental conditions, vegetation growth and development will show a specific periodic law^[1]. Vegetation phenology is a sensitive and

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key feature of vegetation change that plays a crucial role in regulating climate-biosphere interactions, and is closely related to global climate change. It is essential to examine the seasonal and interannual dynamic changes of carbon exchange between vegetation and atmosphere. Therefore, vegetation phenology has attracted increasing attention^[2–4]. Under the background of global climate change, the climate of Mongolia is also changing, and climate change will inevitably lead to drastic changes in vegetation phenology. Therefore, obtaining a vegetation phenology dataset specific to Mongolia and analyzing its temporal and spatial changes are crucial for a detailed understanding of how Mongolia's vegetation ecosystem responds to global climate and environmental change.

The traditional method of obtaining phenological data is observation of ground vegetation, which can provide accurate and objective vegetation phenological data; however, the work efficiency is low and the monitoring range is relatively small, making monitoring over a large-scale range difficult. Novel and advanced remote sensing technology has been utilized to invert vegetation phenology data^[5–7]. Remote sensing technology can dynamically monitor the growth of plants in regions (including overseas regions) that cannot be reached in a short period of time, and help realize the transition from traditional spot monitoring to large-scale regional monitoring on the ground, and of observation objects from a single plant to entire vegetation communities. In many remote sensing applications, MODIS data products have proven to be reliable sources for studying vegetation dynamic evolution data^[8–10]. There are few field phenological observation stations in Mongolia and continuous and systematic measured phenological observation data are lacking, resulting in a dearth of accurate reference materials and data for the study of temporal and spatial variation characteristics of vegetation phenology in Mongolia and the response of vegetation phenology to global climate change. To address this demand, this dataset is based on MODIS data products and remote sensing technology has been efficiently used to obtain the annual vegetation phenology dataset of Mongolia from 2001 to 2019.

2 Metadata of the Dataset

The metadata summary of the Vegetation phenology dataset based on MOD13Q1 in Mongolia (2001–2019)^[11] is shown in Table 1, which includes the dataset's full name, short name, author(s), year, temporal resolution, spatial resolution, data format, data size, data files, publisher, sharing policies, etc.

3 Methods

The dataset was mainly generated based on the Terra/MODIS NDVI data product (MOD13Q1), which has a spatial resolution of 250 m and a temporal resolution of 16 d. Mongolia has nine scenes: h22v03, h23v03, h23v04, h24v03, h24v04, h25v03, h25v04, h26v04, and h27v049. Data from 2001 to 2019, consisting of a total of 3,933 scene data (19 years \times 23 issues /year \times 9 scene) amounting to a total data size of 1,071 GB, was downloaded from the official website of National Aeronautics and Space Administration (NASA) (<https://ladsweb.modaps.eosdis.nasa.gov>).

3.1 Algorithm Principle

(1) Dynamic threshold algorithm

To obtain the phenological period data of Mongolia, the dynamic threshold algorithm^[13] was used to extract phenological parameters from the normalized difference vegetation index (NDVI) time series data, with the following formula:

Table 1 Metadata summary of the Vegetation phenology dataset based on MOD13Q1 in Mongolia (2001–2019)

Items	Description
Dataset full name	Vegetation phenology dataset based on MOD13Q1 in Mongolia (2001–2019)
Dataset short name	VPD_Mongolia_2001–2019
Authors	Shao, Y. T. Institute of Geographic Sciences and Natural Resources Research, CAS, shaoyt@lreis.ac.cn Wang, J. L. R8881-2016, Institute of Geographic Sciences and Natural Resources Research, CAS, wangjl@igsnr.ac.cn
Geographical region	41°35'N–52°09'N, 87°44'E–119°56'E
Year	2001–2019
Temporal resolution	Year
Spatial resolution	250 m
Data format	.tif
Data size	944 MB (844 MB, after compression)
Data files	The dataset contains 60 documents, including the 19-year annual data of the start of growing season, end of growing season, length of growing season and the mean value of 19-year vegetation phenological period in Mongolia
Foundation item	National Natural Science Foundation of China (32161143025, 41971385); Chinese Academy of Sciences (XDA2003020302)
Computing environment	ENVI, ArcGIS
Data publisher	Global Change Research Data Publishing & Repository, http://www.geodoi.ac.cn
Address	No. 11 A Datun Road, Chaoyang District, Beijing 100101, China
Data sharing policy	Data from the Global Change Research Data Publishing & Repository includes metadata, datasets (in the <i>Digital Journal of Global Change Data Repository</i>), and publications (in the <i>Journal of Global Change Data & Discovery</i>). Data sharing policy includes: (1) Data are openly available and can be free downloaded via the Internet; (2) End users are encouraged to use Data subject to citation; (3) Users, who are by definition also value-added service providers, are welcome to redistribute Data subject to written permission from the GCdataPR Editorial Office and the issuance of a Data redistribution license; and (4) If Data are used to compile new datasets, the ‘ten per cent principal’ should be followed such that Data records utilized should not surpass 10% of the new dataset contents, while sources should be clearly noted in suitable places in the new dataset ^[12]
Communication and searchable system	DOI, CSTR, Crossref, DCI, CSCD, CNKI, SciEngine, WDS/ISC, GEOSS

$$NDVI_{ratio} = (NDVI_t - NDVI_{min}) / (NDVI_{max} - NDVI_{min}) \quad (1)$$

where $NDVI_{ratio}$ is the threshold ratio, $NDVI_t$ is the NDVI value at t time, $NDVI_{max}$ is the maximum value of NDVI in a year, and $NDVI_{min}$ is the minimum value of NDVI in the process of rising (or falling). The difference between $NDVI_{max}$ and $NDVI_{min}$ represents the change in NDVI amplitude in the stage of vegetation growth or decline, and t is the Julian day (d).

(2) Trend analysis

The trend analysis method^[14] was used to analyze the temporal and vegetation phenology data to obtain the change trend of vegetation phenology in Mongolia from 2001 to 2019 using, the following formula:

$$b = \frac{\sum_{i=1}^n [(x_i - \bar{x})(y_i - \bar{y})]}{\sum_{i=1}^n (x_i - \bar{x})^2} \quad (2)$$

where b is the change trend, $b < 0$ indicates that the vegetation phenological period is advanced, $b > 0$ indicates that the vegetation phenological period is delayed, and x_i is the year, with the values 1, 2, 3...19 representing 2001, 2002, 2003...2019 respectively. y_i is the phenological data of different years, \bar{x} is 10, \bar{y} is the multi-year mean value of phenological

data, and n is the number of samples (here $n = 19$).

3.2 Technical Route

The main process for the dataset development include: MODIS data preprocessing, time-series data fitting and reconstruction, extraction of vegetation phenology parameters, and vegetation phenology temporal and spatial change analysis, as shown in Figure 1.

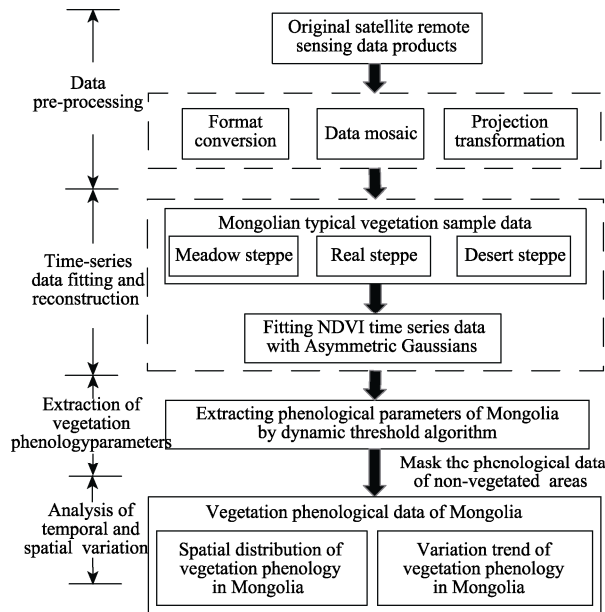


Figure 1 Research and development process of the Mongolian vegetation phenology dataset

(1) Data pre-processing

The original satellite remote sensing data product MOD13Q1 in this dataset is in the international standard Hierarchy Data Format (HDF). The MODIS Reprojection Tool software is used to perform data format conversion, data mosaic, projection transformation and other pre-processing operations on the original data products and finally extract the NDVI data in Geotiff format. Before extracting vegetation phenological data, pixels with NDVI value less than 0.1 were removed. Areas with very low NDVI values are usually called non-vegetated areas^[15].

(2) Time-series data fitting and reconstruction

To suppress the influence of noise on NDVI time-series data, it is necessary to filter and smooth the data^[14]. First, the pre-processed MODIS-NDVI data was loaded in the TIMESAT data import interface, after which samples of different grassland types were obtained according to the Mongolian land cover classification data^[16], Google image data and field survey sample point data. Finally, the asymmetric Gaussians (A-G) model was used to filter and smooth the NDVI time series data in the sample area^[14], obtain the vegetation growth season curve with good quality, and then fit and reconstruct the NDVI time series data of Mongolia.

(3) Extraction of vegetation phenology parameters

Many scholars have used the dynamic threshold method to extract phenology data. Cong and Shen^[17] set the threshold to 0.5 to extract vegetation phenology in the middle and high latitudes of the Northern Hemisphere. Zu *et al.*^[18] found that thresholds of 0.2 and 0.3 can better extract the vegetation phenology of the Qinghai-Tibet Plateau. Fu *et al.*^[19] set thresholds of 0.2 and 0.5, respectively, to extract the beginning and end of vegetation growth

season in Qaidam Basin. Huang *et al.*^[20] compared the extraction results of vegetation phenology in Inner Mongolia when the thresholds were 0.2, 0.3, 0.4 and 0.5, and finally selected 0.5. Due to the lack of long-term series of phenological ground observation data in Mongolia, based on previous studies, the dataset thresholds were first set as 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.45, 0.5, and 0.55, to extract phenological information of typical grassland and forest vegetation in Mongolia. It was found that the results of SOS and EOS were more effective when the threshold was 0.5 and 0.55. Therefore, based on the TIMESAT platform, the dynamic threshold method was used to set the thresholds to 0.5 and 0.55, respectively, to extract the SOS and EOS of vegetation in Mongolia. When NDVI reaches 50% of the amplitude change in the process of NDVI rising, vegetation begins to turn green, and the date corresponding to this pixel value is the SOS. When NDVI reaches 55% of the amplitude change during the NDVI decline process, the vegetation begins to turn yellow, and the date corresponding to the pixel value is considered to be the EOS. Since non-vegetated areas (including water, barren, desert, build area, and sand) are meaningless for the study of phenology, the phenological data of all non-vegetated areas were masked in combination with the land cover data of Mongolia to obtain Mongolian vegetation phenology data.

4 Data Results and Validation

4.1 Data Composition

The vegetation phenology dataset based on MOD13Q1 in Mongolia (2001–2019) includes 60 documents which includes SOS, EOS and LOS (Table 2).

Table 2 List of files in the “Time series of land surface phenology dataset in Central Asia (1982–2015)”

Composition file	Naming method	Description	Format	Number of files	Data size
Phenological raster data	VPD_SOSyyyy.tif	SOS	.tif	19	280 MB
	VPD_EOSyyyy.tif	EOS	.tif	19	280 MB
	VPD_LOSyyyy.tif	LOS	.tif	19	347 MB
	VPD_SOSmean.tif	19-year mean value of SOS	.tif	1	11.3 MB
	VPD_EOSmean.tif	19-year mean value of EOS	.tif	1	11.0 MB
	VPD_LOSmean.tif	19-year mean value of LOS	.tif	1	12.7 MB

In this dataset, the data formats of SOS, EOS and LOS were set as VPD_SOSyyyy.tif, VPD_EOSyyyy.tif, and VPD_LOSyyyy.tif, respectively. VPD (Vegetation Phenology Dataset) represents the vegetation phenology data and yyyy represents the year of the data file.

4.2 Data Results

The dynamic threshold method was used to extract the annual vegetation phenology dataset of Mongolia from 2001 to 2019, and to calculate the 19-year average vegetation phenology data. It was found that the vegetation of Mongolia began to turn green from early April to late May, and began to turn yellow from mid-September to late October. That is consistent with the research findings of Bi^[21] and Sun *et al.*^[22] in Mongolian permafrost regions of grassland vegetation in the SOS and EOS. Thus, the vegetation growing season in Mongolia lasts about 165 days on average. By analyzing this dataset, we can understand the spatial distribution characteristics of vegetation phenology in Mongolia. As shown in Figure 2, its spatial distribution characteristics are similar to the research findings of Li^[23] and Jiang^[24] on the Mongolian Plateau. Under the influence of geographical elements such as precipitation, air temperature, surface temperature, topographic elements, and snow depth and so on, there are obvious differences in the distribution characteristics of vegetation phenology in different regions.

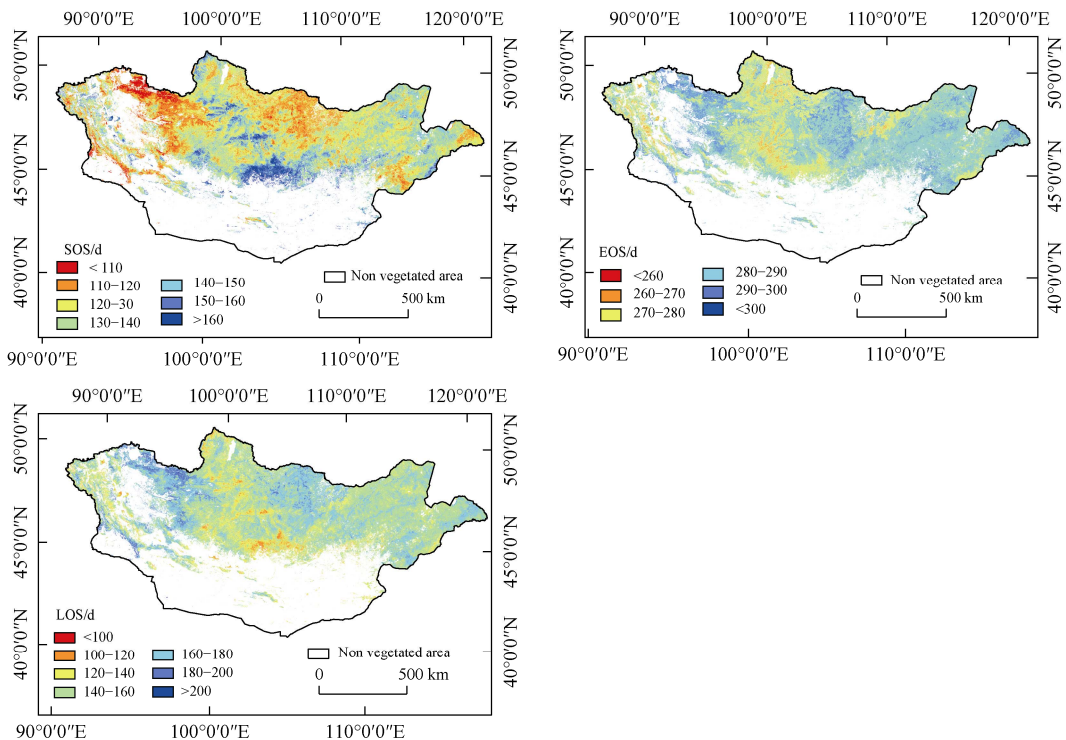


Figure 2 Spatial distribution of vegetation phenology in Mongolia from 2001 to 2019

The trend line analysis method was used to analyze the changes in vegetation phenology in Mongolia from 2001 to 2019. It can be seen that the overall trend of vegetation SOS in Mongolia is typically delayed, which is consistent with the same as the research findings of Jiang *et al.*^[25]. The vegetation EOS showed an advancing trend and the vegetation LOS showed a decreasing trend. Affected by extreme climate events, the trend of vegetation phenology changes abruptly in a certain region at a certain time, and grassland vegetation phenology in the typical transitional region of Mongolia is quite different^[7].

4.3 Data Validation

The analysis of the data in the above section shows that this dataset is consistent and comparable with the research findings of some scholars. At present, few field observation sites and remote-sensing phenological data products are available in Mongolia. The Terra/MODIS NDVI data product MCD12Q2 provides a global surface phenological dataset with a spatial resolution of 500 m, which is one of the few publicly published phenological datasets worldwide. Therefore, the quality of this dataset was evaluated based on the MCD12Q2 data product and the phenological studies conducted by other scholars in Mongolia. MCD12Q2 data were downloaded from NASA's official website and pre-processed to obtain the phenological data of SOS and EOS in Mongolia. This dataset was resampled to obtain phenological data consistent with the spatial resolution and projection of MCD12Q2, and linear correlation analysis was conducted. The results showed that the correlation coefficient between SOS was 0.570,86, and the correlation coefficient between the EOS was 0.550,38, both of which passed the $p < 0.001$ significance test. Therefore, the dataset was comparable and positively correlated with MCD12Q2, as shown in Figure 3. The product of the dataset is a 16-d composite with a spatial resolution of 250 m, but MCD12Q2 is an 8-d composite with a spatial resolution of 500 m. Generally speaking, inconsistencies are expected in the accuracy,

temporal and spatial resolution, temporal continuity, and data processing methods of remote sensing data products, and the phenological values of the same location obtained at the same time cannot be completely consistent^[6,26]. There were some errors, but the threshold range of the phenological period was relatively consistent.

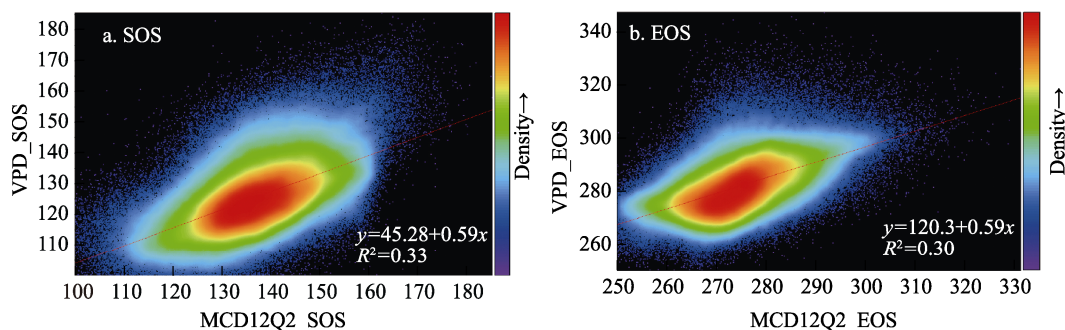


Figure 3 Correlation analysis between vegetation phenology data in this dataset and MCD12Q2 phenology products (Note: VPD_SOS, the SOS in this dataset; VPD_EOS, the EOS in this dataset)

5 Discussion and Conclusion

Mongolia is an important and unique geographical location, and its vegetation distribution has been affected by climate change and human activities on the Mongolian Plateau for a long period of time. The interannual trend variation of Mongolian vegetation phenology was evaluated using a trend analysis, where in the vegetation phenological dataset from 2001 to 2019, including the 19-year average annual distribution map, were derived from the time-series MODIS image data based on remote sensing. Results showed that the average start of growing season (SOS) of Mongolian vegetation was 110–150 days with a general pattern of delay, whereas the end of growing season (EOS) had an average of 270–300 days but with earlier onset patterns. The length of growing season (LOS) ranged between 120–200 days with general shortening patterns, such that the maximum shortened time was two days. As phenological characteristics of different Mongolian grasslands vary, the LOS of the desert grassland vegetation particularly had the highest LOS. The spatial distribution of vegetation phenology in the area was found to be highly responsive to terrain, precipitation, and surface temperature, especially in areas with sparse vegetation. For instance, SOS occurred the earliest southwest Mongolia due to its characteristics of high temperature and relatively low precipitation. Meanwhile, SOS would tend to be delayed with surface temperature increases, similar to that of EOS which would normally occur late in this region, leading to the extension of LOS. This dataset enables a comprehensive understanding of the characteristics of vegetation phenology changes in Mongolia, which in turn allows us to analyze the response of vegetation phenology to climate change under the influence of extreme drought and cold climate, thus providing basic data for the study of climate change in Mongolia. In the future, more multi-source remote sensing and ground data can be combined to obtain additional phenological datasets of the Mongolian Plateau.

Author Contributions

Wang, J. L. developed the total design of the experiment and final dataset; Shao, Y. T. is responsible for the collection, processing and verification of MODIS13Q1 data; Wang, J. L., and Shao, Y. T. jointly wrote the paper.

Conflicts of Interest

The authors declare no conflicts of interest.

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