

IDENTIFICATION OF CULTIVATED AREA BASED ON PHENOLOGICAL FEATURES IN ARID AND SEMI ARID AREA IN ASIA

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KEY WORDS: Cultivated area, Phenology, MODIS NDVI, Natural vegetation

ABSTRACT:

Remote sensor data has long been provided new means of studying global patterns and dynamics in vegetation. Times series NDVI curves can reflect a real trend of vegetation growth and therefore have been used to interpret seasonal cycle and global land cover classification. Accurate identification of cultivated areas from natural vegetated area is not easy because of their similar characteristics in semi-arid area of Asia. This study proposed a method of discriminating between cultivated areas and naturally vegetated areas based on seasonal phenological features using NDVI data. 250 m spatial resolution, 16-day composite MODIS NDVI data (MOD13Q1) in 2000-2001 year acquired and several phenological parameters including beginning date, ending date and length of growing season are extracted. Non-cultivated natural vegetated area has similar profiles on beginning and ending dates of growing season with cultivated area while length of growing season and time difference between beginning of season to middle of season were longer. Even both parameter have same features, profiles of amplitude and maximum NDVI values were different. Phenological features of cultivated area differ on locations: west areas have early growing season, while east areas late. These results indicate that cultivated area could be identified using several phenological features and the time-series MODIS images have high potential for this analysis.

1. INTRODUCTION

Availability of remote sensing data in last two decades has provided a new means of characterizing changes of land cover and vegetation dynamics in a large scale. Accurate identification of land cover is important task to land use management, land degradation therefore to making social and economic decisions. Vegetation index (VI) data used to interpret seasonal cycle in the phenological characteristics and global land covers classification because it reflects real trend of vegetation growth. Changes in VI data over the growing season are well suites with vegetation seasonal parameters such as greenness onset, senescence and length of the growing season. The most common VI is normalized difference vegetation index (NDVI) computed as follows;

$$NDVI = (NIR - RED)/(NIR + RED) \quad (1)$$

Numerous approaches have been implemented NDVI data to either developing methods for identifying seasonal parameters and providing the evaluation of derived phenological metrics for terrestrial ecosystems at various scales. Remote sensing data with coarse spatial resolution have limits detailed evaluation of phenological changes in specific land cover. Observed physiological growth event can be an integrated response of heterogeneous landscape and can have different phenological characteristics. However launch of Moderate Resolution Imaging Spectroradiometer (MODIS) in December 1999 offers great opportunity for improved evaluation of vegetation phenology information. MODIS data produced at a moderate spatial resolution and high temporal resolution attributes that corresponding to relatively homogeneous land cover types and

major phenological events. Recent studies have indicated that MODIS NDVI images have high potential for mapping crops and estimation of seasonal biophysical changes of vegetation. Most of these studies focused on phenology of the natural vegetated coverage rather than cultivated area, except cropland study in China and Russia.

Northern part of Asia includes large grassland and shrubland environments which vegetated coverage is characterized by a short growing season, with a rapid transition from growth to vegetation dormancy stage. Cultivated area shows similar seasonal characteristics with non-cultivated, naturally vegetated area. Well identification and understanding of seasonal phenological characteristics for similar land covers are important for improved extraction of the land covers. However neither study investigated the seasonal phenological features and regional variation of cropping pattern, even such a study provides important information of cropland mapping for this region.

The objectives of this study are 1) to differentiate cultivated area from non-cultivated, naturally vegetated areas based on their seasonal phenological characteristics using 250 m resolution MODIS NDVI data, and, 2) to investigate the spatial characteristics and regional variations of cultivated area. Phenological features are focus on seasonal variation of vegetated coverage rather than interannual changes and the results will be contribute to better understanding of regional vegetation growth cycles and cropping patterns.

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2. STUDY AREA

Study area covers northern Asia (40°N- 60°N at latitude and 62°15'E – 141°35'E at longitude) incorporating full territory of Mongolia and parts of Russia, Kazakhstan, Kyrgyzstan, Uzbekistan, North Korea and China. The area characterized by an arid to semi-arid climate with strong climatic gradients and variety in land use practices. Climatically, it belongs from continental temperate zone to arid zone that characterized by cold winter and hot summers, have wide daily and seasonal temperature variation. Temperatures range from nearly -30°C in January to 30°C in July. Annual precipitation varies significantly from region to region, with a high of 1200 millimeters and a low of less than 50 millimeters annually. Agriculture productions from this region compose relatively large percentage in Asia. However, climatic and geographic factors limit agricultural activity to small area mostly with single cropping pattern. Growing season is from April/May throughout September/ October. Agriculture is both irrigated and rain-fed with the main crops being wheat, barley, cotton oats, hay, potatoes vegetables and rice.

3. DATA DESCRIPTION

3.1 MODIS NDVI data

16 day composite MODIS NDVI data (MOD13Q1) acquired from Land Processes Distributed Active Archive Center (LP DAAC) located at the USGS Earth Resources Observation and Science (EROS) Center at free of charge. The data consists of 10° x 10° tiles in HDF format at 250 m resolution. This data validated at stage 2 and the composite images are produced using constrained view Maximum Value Composite (MVC) algorithm, which is applied to obtain a higher percentage of clear-sky data. Totally 12 tiles covering for 3 to 4 at vertical line 21, 22 through 26 and 27 at horizontal lines are acquired for 2000 and 2001 year. Sequential data stacks of NDVI were developed and then subset to study region. The tiles are resampled from integerized sinusoidal grid projection (SIN) to geographic projection using nearest neighbor method. Visual examination is carried out for select less snow covered period and thus images of April to October used for further analysis.

3.2 Digital Elevation Model (DEM)

Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) at 90 m (version 4.1) is downloaded and scaled to 250 m spatial resolution to have same resolution with MODIS NDVI data for spatial analysis of cultivated area.

3.3 Landsat ETM+ scenes

50 scenes of 30 m resolution Landsat ETM+ are acquired from EROS Data Center's Global Land Cover Facility, are used for selection of training sites and it distributes in growing season around 2000 year.

3.4 Existing land cover maps

Numerous existing land cover maps at national, regional to global scale are used as reference information for extracting training area of different land covers. Natural vegetated covers are extracted from GLC 2000 global land cover map at 1 km resolution because it includes more detailed vegetative classes.

For cultivated areas the following national and regional level cropland maps are used;

1. Agriculture and forest land in China Mongolia and the states of the FSU
2. Cropland distributions across China, 2000
3. Digital Arable Land Map, 2003
4. Land cover map of Russia, 1998
5. Land use map of China, 2000
6. Mongolian land resource map, Mongolian national atlas, 1990

4. METHODOLOGY

4.1 Mask creation for forest and bare area

Since our study concentrates on vegetation phenology in a single year, the land cover types that have different phenological patterns than main natural vegetation are eliminated from this analysis. It covers sparsely vegetated and non-vegetated (water and snow/ice) areas exhibiting NDVI values less than 0.3 and evergreen forests showing higher NDVI value than 0.4 through whole growing season.

4.2 Preparation of training sites

Training areas are defined for two broad landcovers; 1) cultivated vegetation, and; 2) non-cultivated/natural vegetation. The national and regional levels cropland maps are used to identify cultivated areas. The identified areas are then checked on the Landsat ETM+ images and Google Earth images for further visual examination. Finally, polygons are drawn on the Landsat ETM+ images in areas judged to be homogeneous enough for training cultivated vegetation. For non-cultivated/natural vegetation, most of the training regions are selected based on the GLC 2000 global land cover map and a few on Landsat ETM+ images. Totally 10 subclasses for cultivated area, 19 subclasses for non-cultivated/natural vegetation are extracted as a training sites.

4.3 Extraction of phenological parameters

A 7 month (April to October) time series of 16 day composite MODIS NDVI data (MOD13Q1) in 2000 and 2001 year used to analyse seasonal phenological features with TIMESAT software (version 2.3) that developed for generate smoothed time series of NDVI as well as to estimate the seasonal phenological parameters. Seasonal features are evaluated at 2000 year. We used an adaptive Savitzky-Golay filter, which uses local polynomial functions in the fitting with small moving windows in two fitting steps producing a smoothed curve while capturing rapid phenological changes. Estimated phenological metrics are divided into date and NDVI related parameters (Figure 1) and we selected nine parameters. Date related parameters include beginning of season, end of season, length of season and middle of season while NDVI related metrics compose base level, peak, amplitude, large integral and small integral. Additionally, time differences between the beginning of season and middle of season are extracted for estimating rate of NDVI greenness.

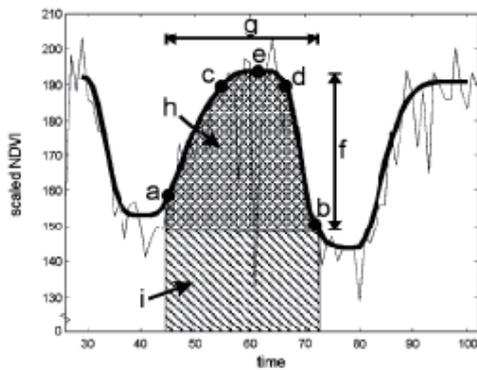


Figure 1. Estimated seasonality parameters using TIMESAT software (a) beginning of season, (b) end of season, (c) peak value and date, (d) amplitude, (e) length of season, (f) integral over growing season giving area between fitted function and average of left and right minimum values, (g) integral over growing season giving area between fitted function and zero level, (h) integral over growing season giving area between fitted function and zero level.

5. RESULTS AND DISCUSSIONS

5.1 Analysis for phenological features

Date related parameters for beginning of season, end of season, middle of season and length of season were inconsistent in each class, except in natural forest. Time intervals are range longer than one month in subclasses of cultivated and non-cultivated natural vegetated area while in natural forest it fluctuates within one month. Beginning of season starts by forest, followed by cultivated area and lasts by non-cultivated natural vegetated area, while end of season had an order of cultivated area, forest and non-cultivated natural vegetated area. The average length of season ranges from 3 month and 28 days to 5 month and 23 days for from April to October. Among of them forest have the longest duration, continuing longer than 5 month. In contrast, cultivated area has the shortest length around 4 month and 20 days and has inconsistent duration with one-month intervals. Non-cultivated vegetated area also shows relatively inconsistent duration and has long length of 4 month and 3 days to 5 month and 23 days. The rate of increase in NDVI during the beginning of the season is theoretically related to the physiognomy of the vegetation and can be estimated by looking at the ratio between the amplitude and the time difference between the season start and the middle of season. For discriminate the cultivated area, time differences between beginning of season and middle of season are extracted. The date differences were longer in the forest and non-cultivated natural vegetated area with 2 months and 16 days, while cultivated area has the shortest time differences of 2 month and 4 days at regional level. NDVI related parameters of base value, peak, amplitude, and large and small integral represent the seasonal vegetation production. Since this study focuses on seasonal characteristics within the growing season, extracted results are effective when data used from April to October. Base and maximum fitted values were higher in forest and cultivated area than non-cultivated vegetated area that included various types of natural vegetation. Amplitudes have an order of forest, cultivated and non-cultivated vegetated area from large to low value as well as in above two parameters. Large and small integrals of annual integrated NDVI show higher value in forest and non-cultivated

vegetation area than cultivated area, which represents total active vegetation cover.

Since plant physiognomy broadly correlated with environmental conditions, the region with similar climate zone tends to have a dominant vegetation of similar life forms. Even average value at regional level shows different profile in date of beginning of season and end of season, many subclasses are overlapped with other land cover types. Therefore it was clear that only one or a few parameters are not enough to identify cultivated area from non-cultivated area. Among of these parameters, length of season, peak NDVI value and time differences between beginning of season and middle of season were the most informative variables. Use any of the two parameters give good opportunity to differentiate cultivated area from non-cultivated area as shown in Figure 2.

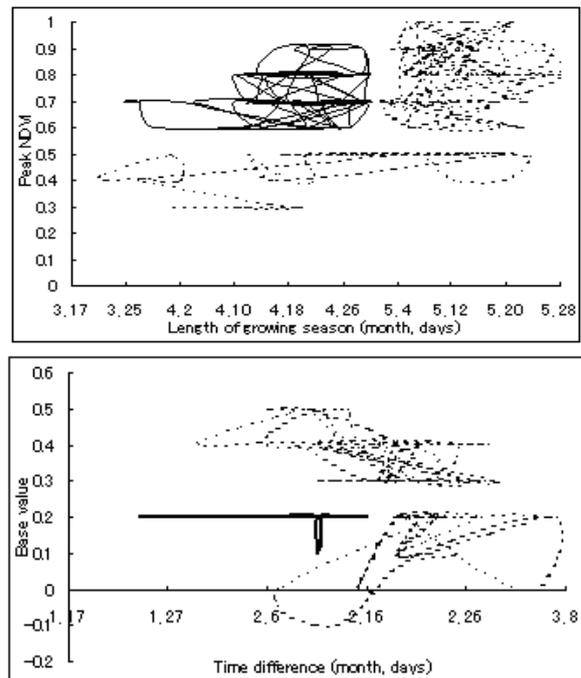


Figure 2. Seasonal parameters, differentiating cultivated area from non-cultivated area. First figure shows relation between peak NDVI and length of season. Second figure shows relation between base value and time differences between beginning of season and middle of season (dotted line shows non-cultivated area, while straight line shows cultivated area)

Graph shows the relation between peak NDVI and length of season in cultivated and non-cultivated area. Peak NDVI value was main parameter to differentiate cultivated area from non-cultivated low vegetated area that have similar length of season, while in non-cultivated dense vegetated area have longer length of growing season. As shown in second graph, cultivated area has short time differences from beginning of season to middle of season, implying that there has rapid increase of growth compare to non-cultivated natural vegetated area.

5.2 Characteristics of cultivated area

Distribution of cultivated area has close relation with geographic location and elevation mainly in semi-arid environment. Four distinct representative types of cultivated area extracted based on date related information (not shown). Type 1 spreads wide area along northern political boundary of Kazakhstan and Russia and southwest of Russia in this study. Average growing season continues from April to September with four month and 23 days of length. Type 2 distributes in several small sites of south and southeastern part of Russia. Growing season starts in May and ends in October and length of season is relatively longer than other types with around five months. Type 3 shows cultivated area in northern Mongolia. Beginning of growing season starts middle of May and ends October with four month 22 days length. Cultivated area in China composes type 4 and it covers large area in northeast side of the country. Compare to other types, growing season starts relatively late around end of May and ends in October and continue with similar length. Each types of cultivated area belong in different countries or locate one's neighbourhood and can conclude that the differences relates with cropping culture in each country. Spatial distributions of training area examined using resampled 250 m DEM SRTM data. Cultivated area locates relatively lower altitude within 1200 m and the highest altitudes were in central part of Mongolia with ranges of 680-1200 m, while in other area have lower elevation of until 800 meters.

5.3 Regional variations of cultivated area

Two date related seasonal phenological parameters for beginning of season and end of season for cultivated area used to examine the spatial gradient of cropping culture. Training sites are averaged by $10^\circ \times 10^\circ$. The earliest dates of growing season were observed in western part between 65°N to 90°N at longitude. This location corresponds to the cultivated area in Kazakhstan and western part of Russia. Beginning of season range from April to beginning of May while ending dates of season show similar profile with starting dates of season that have early senescence at end of August to beginning of October. Those dates gradually become later in Mongolia to eastward. Beginning of season start in May with ending dates of arriving around October 8 in cultivated area of Mongolia. With northward of latitude from central part of Mongolia, there have observable early dates of season starts around beginning of May while no big difference at ending dates, with longer length of season. This area covers the territory of eastern part of Russia and shows different sign of cropping culture. In contrast, eastward sites in China have the latest dates for beginning of season around May 26 and end of season in October 15, respectively. Figure 3 shows the results of regional variation in two dates related parameters. It have clear trends that western parts have earlier dates while eastern areas have later dates on above two date parameters of beginning of season and end of season. The observed changes at two date related parameter show regional variation of growing season and differences of cultivating culture in each country. These date variations can be corresponding temperature and precipitation gradient and crop type differences, which did not include in this study.

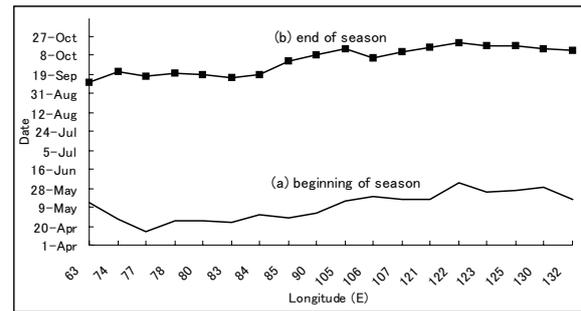


Figure 3. Regional variation of cultivated area on two date related parameters

6. CONCLUSIONS

We discriminated cultivated area from non-cultivated, naturally vegetated area in semi arid region based on their seasonal phenological features using 250 m resolution 16-day composite time series of MODIS NDVI data in 2000 year. Different land covers of forest, cultivated area and natural vegetated area in northern part of Asia show similar features at green-up, senescence period under lasting short growing season that controlled by influence of climate characteristics. Cultivated area were relatively short length of season from 3 month and 28 days to 4 month and 29 days duration while non-cultivated natural vegetated area lasts longer than 4 month and 3 days. Also, time differences between beginning of season and middle date were shorter than other two classes that depicting sudden rise of vegetation production for cultivated area. Some subclasses of non-cultivated, naturally vegetated area have shorter duration and show similar profile with cultivated area. However, total vegetation activity differed above sites and can be conclude that these three metrics give good discrimination. Distribution change analysis of cultivated area at spatial and regional variations is examined using Digital Elevation Map (DEM) and geographic location information. The results show that cultivated areas are located relatively lower altitude (>1200 m). The growing season change to later dates as moving from west to the east direction. One-month interval is found in beginning of season and end of season. The results show that phenological features have potential to discriminating cultivated area from non-cultivated classes that have similar features and analysis of spatial and regional variation of cultivated area. Moreover, we conclude that crop type and cropping patterns can be identified using the phenological features at a large scale.

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