Monitoring of Vegetation Phenology from Satellite Data in Iran

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Abstract: Leaf phenology describes the seasonal cycle of leaf functioning and is essential for understanding the interactions between the biosphere, the climate and biogeochemical cycles. In this study we investigate the climate changes effected on the phenology events in shrubs land, using the AVHRR/NDVI biweekly time-series data collected from 1982 to 1999 and concurrent mean temperature and precipitation data. The NDVI thresholds for the onset dates of green-up (0.151) and dormancy (0.171) occur in grass land. The shrubs land exhibit advanced green-up and shrubs land exhibit advanced delayed dormancy. The growing season length (0.92 days yr$^{-1}$) occurs in grassland. The advance of green up onset (0.56 days yr$^{-1}$) and the delays of dormancy delay (0.39 days yr$^{-1}$) occur in grass land. The onset date of green-up for all vegetation types negatively correlated with mean preseasone temperature for almost all the preseasone periods significant, suggesting that the warmer winters probably benefit an earlier green-up the following spring. The growing season duration of shrubs land was significantly lengthened, primarily through an earlier green-up and a later dormancy during the period of 1982-1999.

Keywords: Green up • Growing season • NDVI • Precipitation • Dormancy • Grass land

INTRODUCTION

Evidence from remote sensing data [1-3] all revealed that the spring advanced and growing season duration significantly lengthened over the past two decades at the middle and high latitudes in the northern hemisphere. Normalized Density Vegetation Index (NDVI), which is derived from infrared channel and near-infrared channel remote sensing data, is a good indicator of photosynthesis (vegetation activity). With a broad spatial coverage and high temporal resolution, the advanced very high-resolution radiometer (AVHRR) of the National Oceanic and Atmospheric Administration (NOAA) NDVI datasets provides unique opportunities for monitoring terrestrial vegetation conditions at regional and global scales [4] and has widely been used in research areas of NPP [5], vegetation coverage [1,3], biomass [6] and phenology [7]. Disease, competition, soil factors and weather conditions can profoundly influence plant phanological status [2]. The spring advanced and growing season duration significantly lengthened over the past two decades at the middle and high latitudes in the northern hemisphere. Satellite remote sensing provides powerful techniques that can monitor and characterize phenological trends at large scales [3]. Investigation on the relationship between phenology and climate may contribute to the understanding of the mechanisms of the vegetation responses to climate changes. A ‘sudden change’ in NDVI can be related to the onset or cessation of ‘significant photosynthetic activity’ [7]. Various biomes require the use of different NDVI thresholds. NOAA AVHRR NDVI data set and climate records were used to examine the recent trends inplant phenology in the selected zone of Iran from 1982 to 1999. The NDVI data set was at a spatial resolution of 8.8km$^2$ and 15-day interval. This study aims to quantify changes in plant phenology of Iran’s vegetation between the years 1982 to 1999 and investigate the relationships between the onset dates of phenology and climatic factors.

MATERIALS AND METHODS

Study Area: The research was conducted in Iran north of about 34°N in latitude as the study region (Fig. 1). A strong west-to-east precipitation gradient results in a decrease in annual precipitation from more than 550 mm. The scope of the study was limited to four vegetation types as follows: grass lands, shrubs (Fig. 1).

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Data: Among the available types of satellite data, AVHRR data is outstanding for its temporal resolution (the satellites pass above each location twice daily). NDVI data at a spatial resolution of 8×8 km² and 15-day interval were acquired from the Global Inventory Monitoring and Modeling Studies (GIMMS) group derived from the NOAA/AVHRR Land data set for the period January 1982 to December 1999. The dataset is known for its high quality, having been calibrated to eliminate noise from volcano eruptions, solar angle and sensor errors and has been widely used in studies on vegetation dynamics at regional and global scales [6,8]. In order to eliminate the impact of bare and sparsely vegetated regions, only grid cells with annual mean NDVI greater than 0.1 during the 18 year period were used in this study.

Biweekly mean temperature and precipitation data were compiled from the 1982-1999 Temperature/precipitation databases of weather stations Iran in whole study area. Vegetation type data were obtained from a digitized 1: 2000000 vegetation map of Iran (Forest, Range and Watershed Organization of Iran) vegetation was grouped as: Deciduous broadleaf forest, shrubs, grasslands, Cultivation, cultivation (Fig. 1). As mentioned above grass lands, shrubs were included in the study.

Method: The onset dates of vegetation green-up and dormancy were determined based on the estimated rates and the NDVI seasonal cycles. procedures used to determine the onset dates of phenological event from (NDVI) time series are shown in Fig 2. For determining the rates of the changes in the average seasonal NDVI curves, we computed the NDVI ratio from (Eq.1). The NDVIratio were computed from the 18-year averaged NDVI seasonal curves for the entire study area and for each biome. The NDVIratio, from the series of consecutive 15-day periods was calculated.

\[ \text{NDVIratio}(t) = \frac{\text{NDVI}(t+1) - \text{NDVI}(t)}{\text{NDVI}(t)} \]  

For Determining the NDVI thresholds associated with the onset dates of vegetation green-up and dormancy, the time \( t \) was detected with the minimum NDVIratio and then the corresponding NDVI \((t+1)\) at time \((t+1)\) as the NDVI threshold for the onset date of vegetation dormancy was used. And also, the time \( t \) was detected with the maximum NDVIratio and then the corresponding NDVI \((t)\) as the NDVI threshold for the onset date of green-up was used.
For fitting a smooth NDVI seasonal curve as a function of time, in general, for a pixel, with increasing Julian day, its NDVI value gradually increases first and then decreases after arriving its maximum. Therefore, a least-square regression analysis of the relationship between the biweekly NDVI time-series data from January to September and from July to December was done and the corresponding Julian day for the entire study area and vegetation types for each year was calculated (Eqn. 2), to represent the seasonal changes in NDVI as a function of Julian day. Mostly, this seasonal NDVI curve can fit an inverted parabola equation.

\[ \text{NDVI} = a_0 + a_1 x + a_2 x^2 + a_3 x^3 + \ldots + a_n x^n, \]  

(2)

Where \( x \) stands for the Julian days. Because of the impact of some non vegetation effects of cloud, atmosphere, solar zenith angle and other factors, some NDVI values are lower than their two adjacent ones. Obviously, using Eqn (2) can help smooth these abnormal values. A sixth degree polynomial function (\( n=6 \)) was applicable to the regression in most cases.

**RESULTS AND DISCUSSION**

The early May was recognized as the mean onset period of vegetation green-up while early November as

<table>
<thead>
<tr>
<th>Vegetation types</th>
<th>NDVI threshold (A)</th>
<th>NDVI threshold (B)</th>
<th>Temperature threshold (°C) (A)</th>
<th>Temperature threshold (°C) (B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shrubs land</td>
<td>0.23</td>
<td>0.25</td>
<td>11.1</td>
<td>8.5</td>
</tr>
<tr>
<td>Grass lands</td>
<td>0.151</td>
<td>0.171</td>
<td>10.5</td>
<td>7</td>
</tr>
</tbody>
</table>

\( a \): Green-up; \( b \): vegetation dormancy.

the mean onset period of vegetation dormancy for the entire national level. Table 1 lists the vegetation green-up and dormancy and their corresponding thresholds of NDVI and temperature for each vegetation type. Figure 3 shows the seasonal variations in the 18-year averaged NDVI and temperature at the interval of 15 days for the entire study area. In contrast, the mean onset dates of dormancy do not differ among vegetation types; all occur in early November. The lowest NDVI thresholds for the onset dates of green-up (0.151) and dormancy (0.171) occur in grassland (Table 1). Grasslands require the lowest temperature thresholds, for the onset dates of green-up 10.5°C and dormancy 7°C and cultivation demands the highest temperature for the onset dates of green-up 12.6°C and dormancy 9.3°C. The mean onset date of green-up over study area has significantly advanced over the past 18 years (\( R^2=0.71, P=0.005 \)), with an annual advance of 0.63 days yr\(^{-1} \) (Fig. 4a).
The mean onset date of vegetation dormancy was delayed from 1982 to 1999 ($R^2=0.44$, $P=0.006$), with an annual delay of 0.32 days yr$^{-1}$ (Fig. 4b). The length of the growing season has increased by 0.94 days yr$^{-1}$ from 1982 to 1999 ($R^2=0.65$, $P=0.002$) (Fig. 4c). All vegetation types exhibit advanced green-up (Fig. 5). All vegetation types exhibit advanced delayed dormancy (Fig. 6). The length of the growing season for different vegetation types are shown in figure 10. The greatest growing season length by grass lands (0.92 days yr$^{-1}$), followed by shrubs (0.9 days yr$^{-1}$). Results of Green-up trends in relation to climate shows, when analyzing the relationships between the onset dates of green-up and the climatic variables, we calculated the average temperature and cumulative precipitation before the onset date of green-up and since preceding date of dormancy. We computed the correlation coefficients between these average climate variables and the onset dates of green-up. We used the term ‘preseason’ to refer to the period before the mean onset dates to analyze the relationships between the onset date and preseason climatic variables. According to such a definition, the length of preseason expands to half month periods, from early May to the preceding November. Figure 6 shows the correlation coefficients between the onset dates of green-up and preseason climatic variables for the 1982-1999. The onset date of green up was significantly and negatively correlated with temperature for all the preseason periods (Fig. 7a). The mean temperature at that time could have the greatest influence in activating the green-up of the study area. The greatest correlation is in the preceding 2 months (Fig. 7a). The preseason precipitation also significantly influenced the onset date of green-up (Fig. 7b). Figure 8 demonstrates the correlation coefficients between onset dates of green-up and mean preseason temperature and precipitation by the vegetation type. The onset date of green-up for all vegetation types negatively correlated with mean preseason temperature for almost all the preseason periods significant (Fig. 8), the warmer winters probably triggers an earlier green-up the following spring.

The onset date of green-up for grasslands negatively correlated with preseason cumulated precipitation (Fig. 8c). The averaged temperature and cumulated precipitation were calculated during the growing season from early May to early November by increasing each half-month from the onset date of vegetation dormancy and the obtained temperature and the precipitation values for 10 periods. The correlation coefficients of these ‘pre dormancy’ climatic conditions with the onset date of vegetation dormancy were computed for the 1982-1999. The results show that the onset dates of vegetation dormancy are positively correlated with the pre dormancy mean temperature for almost all the averaging periods over the whole zone (Fig. 9a). The increased temperature during the preceding growing season postponed the dormancy of vegetation at regional scale. The onset dates of vegetation dormancy did not correlate with the cumulative precipitation during all of the averaging periods (Fig. 9b). The warmer preceding temperatures led to a delay of the dormancy (positive correlation) for all vegetation types (Fig. 10). The relationship between the onset date and the preceding cumulative Precipitation by the vegetation type showed no significant correlation for the broadleaved forest, grasslands, shrubs and cultivation (Fig. 10, b, c).
Fig. 4: Variation in the mean onset dates of (a) green-up, (b) vegetation dormancy, and (c) growing season length.

Fig. 5: Variation in the onset dates of green-up for different vegetation types: (b) shrubs, (c) grasslands.
Fig. 6: Variation in the onset dates of vegetation dormancy for different vegetation types: (b) shrubs, (c) grasslands.

Fig. 7: Correlation coefficients between the onset date of green up and (a) mean preseason temperature and (b) precipitation for different preseason periods.

Fig. 8: Correlation coefficients between onset dates of green-up and mean preseason temperature and precipitation in different preseason periods by the vegetation type: (b) shrubs, (c) grasslands.
Fig. 9: Correlation coefficients between the onset date of vegetation dormancy and (a) preseason mean temperature and (b) precipitation over our study area for different preseason periods.

Fig. 10: Correlation coefficients between the onset date of vegetation dormancy and preseason mean temperature and precipitation for different preseason periods by vegetation type: (b) shrubs, (c) grassland.

Fig. 11: Interannual variations in the onset dates of growing season length for vegetation types in study area from 1982 to 1999.
Disease, competition, soil factors and weather conditions can profoundly influence plant phenological status [9]. Investigation on the relationship between phenology and climate may contribute to the understanding of the mechanisms of the vegetation responses to climate changes. A 'sudden change' in NDVI can be related to the onset or cessation of 'significant photosynthetic activity' [10]. This study estimated that the mean onset date of the green up of the selected zone of Iran advanced on average by 0.63 days yr⁻¹ from 1982 to 1999. Some evidence also indicates a later onset of autumnal phenological events [11,12]. This study estimated that the mean onset date of vegetation dormancy of the selected zone of Iran was delayed with an annual delay of 0.32 days yr⁻¹ from 1982 to 1999. Increasing in growing season length could increase the mean forest net primary production [13]. The length of the growing season duration mainly impacts the interannual variability of plant growth and thereby, also strongly affects the net carbon dioxide uptake [14]. This study estimated that the mean onset date of length of the growing season over study area has significantly advanced with an annual advance of 0.94 days yr⁻¹. The onset date of the green-up is not significantly coupled with preseason cumulated precipitation for the forest and shrub biomes. It may be associated with their growth environments [10]. Based on NOAA/AVHRR NDVI biweekly time-series data and concurrent climate information, it was estimated that the growing season duration of Iran's vegetation was significantly lengthened, primarily through an earlier green-up and a later dormancy during the period of 1982-1999.

REFERENCES