Features of Leaf Area Index Spatial Distribution in Xi´an Using Landsat TM Images

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Abstract

Leaf area index (LAI) is an important ecological parameter. The radiation intensity of Landsat TM/ETM represents the reflectivity of different canopy on the ground, which has a closer relation with leaf area index (LAI). In this paper, Landsat TM/ETM data were used to retrieve canopy reflectivity of Xi´an region in 1998, 2000, and 2003 by 6S model respectively. By correlation analysis of canopy reflectivity, vegetation index (VI) obtained from remote sensing data and field measurements of LAI; a reasonable retrieval model for LAI was established, that is \( \text{LAI} = 6.4967 \times \text{NDVI} + 0.6911 \). Unlike the former research that digital number (DN) of images was usually used to retrieve LAI, in this study, ground canopy reflectivity was used. Theoretically, canopy reflectivity changes according to LAI condition, and it has physical meaning. Based on this, the spatial distribution of LAI in 1998, 2000 and 2003 was retrieved and its feature was also analyzed.

Key words: leaf area index (LAI), vegetation index, 6S model, spatial distribution
Introduction

With the increase of carbon dioxide (CO2) density, many researchers are interested in vegetation, which plays an important role in the process. CO2 produce, moisture evaporating and other major energy change occur on face of leaves (Lars & Andres, 2001). LAI controls many physiological and physical processes of vegetation, such as photosynthesis, respiration, and transpiration, as well as carbon circulating and rainfall interception (Chen & Cihlar, 1996). The spatial distribution feature of LAI in Xi’an region is an important one in many ecological factors. Thus, it is very meaningful to study on it.

Satellite remote sensing provides a unique way to obtain the distribution of LAI over large areas. There are two methods for LAI retrieval, namely statistical model method and optical model method (Fang & Zhang, 2003). The former method setting statistical models uses remote sensing data and field-measured LAI data. It is easy to get input parameters and its form is simple, so statistical model method has been a major method in the estimation of LAI for a long time. Along with the continued development in the technology and theory of remote sensing, new original RS data like VEGETATION on SPOT-4, and Moderate Resolution Imaging Spectrometer (MODIS) that can monitor vegetation condition were used to retrieve LAI (Leonard & Chen, 2000; Wang & Curtis, 2004). There were also different retrieval algorithms according to different RS data, such as MODIS algorithm (Wang & Curtis, 2004). Additionally, as an important parameter in retrieving LAI, better vegetation index were developed. By introducing near infrared information, Restrict Soil Resistant Vegetation Index (RSRVI) improved the retrieving accuracy (Leonard & Chen, 2000). In the application of LAI, in 2000, the second research team of land surface climate project in NASA Goddard Space Flight Center issued the mean monthly LAI data retrieved from NOAA-AVHRR (Zhang & Fu, 2002). Although many deep researches on LAI retrieving methods (Hu & Bin, 2003), parameters and region type were done, there were still a lot of problems about retrieving accuracy, applicability of models in different regions and different kinds of vegetation. Therefore further study on retrieving LAI using remote sensing information is necessary.

It is useful to convert original DN to ground reflection for quantitative analysis, information retrieval and application of remote sensing using RS data. Few researches have been done so in analyzing relation between canopy reflectance and LAI (Zhang & Fu, 2002). In this paper, the digital number images of Xi’an region in Weihe basin were converted to ground reflectance images, and the growth condition and distribution were acquired from ground reflectance. This method is different from customary retrieving way using images with digital number, and its advantage is that it is useful to retrieve LAI according to ground condition and reflectance at that time.
In this research, the spatial distribution of LAI of Xi’an region in October 1998, April 2000 and May 2003 was also obtained. With the seasonal condition and land use data, the influence on LAI spatial distribution of natural environment and socio-economy development since 1998 and the influence of climate on vegetation growth in Qinling Mountain were analyzed.

Data and methods

Study area

Xi’an locates at the Weihe River Basin, which lies in 107°40′-109°49′E and 33°39′-34°44′N. The landform is high in the southeast and low in the northwest, the total area is 9983 km² and the average height above sea level is about 424 m. There are obvious 4 seasons and appropriate rainfall. The average temperature and the average rainfall are 13.1-13.4 °C and 604.2 mm, respectively. To study ecosystem of Xi’an region has to consider the influence of the Weihe River which is the biggest tributary of the yellow river. It runs through the Guanzhong plain from west to east. The Weihe basin belongs to the continental monsoon climate area, so it is cold and dry in winter, hot and rainy in summer.

Data processing

In the paper, Landsat TM/ETM data and field-measured LAI data were used. The orbit of Landsat data was 127/03600. The TM images were obtained on 22 October 1998 and 29 May 2003 and the ETM image was obtained on 26 April 2000. The field-measured LAI data were obtained during 14-25 July 2003 using LAI-2000 (LI-COR). They kept nearly synchronous with TM image of 2003.

Atmospheric correction

6S (Second Simulation of the Satellite Signal in the Solar Spectrum) model describes the influence on sun light by atmosphere in the transmission from the sun to ground and back to remote sensing sensor in different condition like with different sensors or ground covers. 6S model also can simulate the scattering function effect of atmospheric particles and surface directional reflectance (Ghulam, Qin & Zhu, 2004). In our study, 6 images of Landsat TM data (TM1, TM2, TM3, TM4, TM5 and TM7) were corrected atmospherically by 6S model, respectively. To raise the atmospheric correction precision as far as possible, a relatively pure pixel in the Qingling Mountain that was covered with high-density forest was picked out as correcting sample. Other correcting parameters were set as Table 1.
Table 1. 6s input parameters

<table>
<thead>
<tr>
<th>Sensor type</th>
<th>Height/km</th>
<th>Band range/µm</th>
<th>Solar zenith and azimuth</th>
<th>Observation zenith and azimuth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landsat TM</td>
<td>705</td>
<td>0.45-0.52</td>
<td>26.01</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.52-0.6</td>
<td>111.49</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.63-0.69</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.76-0.90</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.55-1.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.08-2.35</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Weather condition

<table>
<thead>
<tr>
<th>Visibility/km</th>
<th>Cloud cover</th>
<th>Atmospheric condition</th>
<th>Average altitude in the study area/km</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>0.00</td>
<td>Mid-Latitude Summer</td>
<td>1.90</td>
</tr>
</tbody>
</table>

Geometric correction

In the paper, we chose ground control points (GCPs) from 1:50000 maps and Landsat TM data. The GCP should be clearly displayed and have accurate orientation in the map, such as corner of rivers or intersection of roads. The GCPs should be set uniformly and randomly. We used 12 ground control points in the geometric correction in the research. The geometric error was less than one pixel. In our research, we also used DEM of 30m-resolution for topographic correction to reduce the solar radiation.

Field-measured LAI data

LAI-2000 (LI-COR) was used to measure field LAI data. The instrument is easy to manipulate and has a good data quality. According to the operation criterion of LAI-2000, the range of every swatch was set 30m*30m, and then we selected 6 samples and got their average as LAI data of this swatch. In the fieldwork, swatches were mostly located at the north of Qinling Mountain, including woodland, orchard and farmland (the important samples were in woodland and orchard). Selecting of samples should take into consideration of different vegetation categories and uniformity of samples. In our fieldwork, we got 69 samples, which included major vegetation types in the study area, and 16 samples were used to validate retrieving models.
Retrieval for LAI

Acquiring canopy reflectance and Vegetation Indexes (VIs)

VIs of each sample and canopy reflectance of single band were achieved by using ENVI4.0 and PCI 9.1 RS software. Statistical regression models between VIs/canopy reflectance and field-measured LAI were established, respectively, and the best model was chosen.

In our research, Normalized Difference Vegetation Index (NDVI), Simple Ratio Vegetation Index (SRVI), and reduced simple ratio vegetation index (RSR) were chosen to acquire a good retrieval result. The expression of RST that introduces short-wave infrared band is follows (Leonard & Chen, 2000).

\[
RST = SR \times \left[1 - \frac{(SWIR - SWIR_{\text{min}})}{(SWIR_{\text{max}} - SWIR_{\text{min}})}\right]
\]

Here, \(SWIR_{\text{max}}, SWIR_{\text{min}}\) represent the maximum and minimum reflectance value in short-wave infrared band, respectively. The statistical analysis takes LAI as attributive variable and spectrum data or its transform (e.g. vegetation index) as independent variable to set up retrieval model, namely \(LAI = f(x)\), \(x\) is spectrum reflectance or VIs. In the paper, the linear regression model is \(y = k \cdot x + b\), here, \(y\) represents LAI and \(x\) represents spectrum reflectance or VIs. Table2 lists the linear regression models between for LAI and VIs.

<table>
<thead>
<tr>
<th>Attributive variable</th>
<th>Linear regression model</th>
<th>Correlation coefficient ((R^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td>TM1</td>
<td>(LAI = -52.351 \cdot TM1 + 6.5444)</td>
<td>0.316</td>
</tr>
<tr>
<td>TM2</td>
<td>(LAI = -33.707 \cdot TM2 + 6.1733)</td>
<td>0.241</td>
</tr>
<tr>
<td>TM3</td>
<td>(LAI = -22.629 \cdot TM3 + 5.9902)</td>
<td>0.332</td>
</tr>
<tr>
<td>TM4</td>
<td>(LAI = 11.711 \cdot TM4 - 0.4407)</td>
<td>0.156</td>
</tr>
<tr>
<td>TM5</td>
<td>(LAI = -7.3694 \cdot TM5 + 4.3949)</td>
<td>0.047</td>
</tr>
<tr>
<td>TM7</td>
<td>(LAI = -14.993 \cdot TM7 + 4.9948)</td>
<td>0.234</td>
</tr>
<tr>
<td>SR</td>
<td>(LAI = 1.2549 \cdot SRVI + 0.2505)</td>
<td>0.453</td>
</tr>
<tr>
<td>NDVI</td>
<td>(LAI = 6.4967 \cdot NDVI + 0.6911)</td>
<td>0.408</td>
</tr>
<tr>
<td>RSR</td>
<td>(LAI = 1.553 \cdot RSR + 0.8663)</td>
<td>0.351</td>
</tr>
</tbody>
</table>

Analysis for LAI retrieval models based on canopy reflectance

From table 2, we can get following results.
(1) The reflectance in red band TM3 was better correlated with LAI than others, which is consistent with other conclusions (Liu & Zhang, 2003; Karin & Stith, 1997). The reason is that chlorophyll of the green vegetation leaves produces photosynthesis and strongly absorbs the red visible light. It showed that the higher of Absorbed Photosynthetically Active Radiation (APAR), the lower (remove to) the red band spectrum reflectance. Therefore good correlation between Band3 and LAI is reasonable.

(2) In the visible bands, the correlation between the reflectance in green band TM2 and LAI was higher than that between the blue band M1 and LAI. But in theory, the absorption of vegetation leaves in blue band is stronger than in green band. Maybe the atmosphere at that time influenced the blue light strongly, which made LAI sensitive to green light. Karin S. (1997) once found that LAI had a good correlation with green light band, which was consistent with our research result.

(3) The correlation between LAI and short-wave infrared band TM5 and near infrared TM4 was poor, which was similar to the conclusion achieved by Peterson et al. (1987) and Spanner et al. (1990).

(4) The reflectance in TM7, the short-wave infrared band with a spectrum range of 2.08-2.35µm, was well correlated with LAI that was only next to red band of the visible bands.

Analysis for LAI retrieval models based on vegetation index

We can also draw several conclusions from Table 2 as follows.
(1) Of these correlations between vegetation indexes with LAI, NDVI was the best one. This is also an example that why NDVI has always been applied in the research of vegetation remote sensing since it was put forward.

(2) The correlation between RSR and LAI was not as good as between SRVI. The reason for this was that \(SWIR_{\text{min}}\) in the formula of RSR should be the minimum reflectance in short-wave band when vegetation canopy is completely closing and \(SWIR_{\text{max}}\) should be the maximum reflectance when the closing of vegetation canopy is 0. However, in fact, it is difficult to realize it. In a whole, the correlation between canopy reflectance in a single band and LAI was lower than that between vegetation indexes and LAI.

(3) The best LAI retrieval model for the Xi’an region in the Weihe basin was 

\[ \text{LAI} = 6.8375 \times \text{NDVI} + 0.3581 \]

16 field-measured LAI data were used to analyze the precision of the model, and the average error was 0.757, the average precision was 74.43%.

Spatial distribution of LAI

The spatial distribution of LAI of Xi’an region on 22 October 1998, 26 April 2000 and 29 May 2003 were achieved based on the model of 

\[ \text{LAI} = 6.8375 \times \text{NDVI} + 0.3581 \] (Fig. 1). And the mean and maximum values of LAI in 1998, 2000 and 2003 were also calculated as Table 4.
Fig. 1. Features of LAI spatial Distribution in Xi’an

Table 4. Mean and Maximum value of LAI in 1998, 2000, 2003

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Average LAI</td>
<td>1.613</td>
<td>1.476</td>
<td>1.794</td>
</tr>
<tr>
<td>Maximum LAI</td>
<td>5.204</td>
<td>4.568</td>
<td>5.983</td>
</tr>
</tbody>
</table>

Fig. 2. Classification of land use in Xi’an

By comparing the LAI spatial distribution (Fig.1) and land use classification in the same area (Fig.2), we could analyze the change features of LAI from 1998 to 2003.
Conclusions and discussion

(1) The average and maximum LAI in 3 years decreased from 2003 to 1998 and further to 2000. The reason for this may be that the end of May or the beginning of June was the time when vegetation was growing fast; in October, the coverage of vegetation remains dense; but April was the early spring in Xi’an, so the LAI in 2000 was the lowest.

(2) The area around Xi’an city, including Zhouzhi, Huxian, Chang’an, Llantian, Lintong, and Gaoling, was mainly covered with farmland and orchard. In 1998, the land use in this region was almost exclusively farmland. However, compared with 2000, in 2003 a lot of farmland was converted to orchard and the LAI changed correspondingly. In addition, the vegetation density in Lishan Mountain was high, so the LAI in this area was also high, especially in 2003.

(3) For the Qinling Mountain that lies in the south of the study area and was covered with high-density forest, LAI of the area was very high in 3 years. Most of the LAI values could reach to 4 and even to 4.5. However, the average LAI of 2003 was bigger than that of 1998, which was 5.983. Because of high altitude of Qinling Mountain, it could be seen from ETM image that some places were still covered with snow which influenced the average value of LAI in April, 2000.

In this research, original DN images were converted to ground reflectance images. It was very helpful and meaningful for us to make quantitative analysis; information retrieval and RS application by using remotely sensed data. The research was just on the foundation of the instantaneous RS data, which were also affected by the temporal atmosphere and many other external factors. So this study could only be representative of the temporal vegetation in Xi’an. The model that was established for retrieving LAI in the Xi’an region of the Weihe basin must be affected by some errors.

To get a better LAI retrieval model, we could try to study further on the factors like weather conditions and ground conditions.

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