A Study on the LAI Up-Scaling Based on Mathematic Transformation

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Abstract. How to apply some mathematic transformation in remote sensing scaling is investigated in this paper. The LAI (Leaf Area Index) up-scaling and Fourier and wavelet transformation are taken for example. Commonly, a larger spatial scale process is acquired by averaging the smaller scale remotely sensed process, but the high frequency components are eliminated by the averaging operation. Then Fourier transformation is a low-pass filter in essence, so the outline information of a remotely sensed image with high resolution can be gotten by Fourier transformation. However, some detailed information is also lost at the same time. Therefore, wavelet transformation is applied in now, we can acquire the up-scaled image by combining the detailed information and the outline information. Test results shown that the overall evaluating index suggested in the paper is correct and reasonable. Transfer function related to scale correct factor is also introduced into this up-scaling method to improve the results. But it’s a dependence factor. Further study on the scale correct factor and transformation parameters is doing.

Keywords: LAI, up-scaling, transfer function, Fourier transformation, wavelet transformation.

1. Introduction

Scale is a key concept in both natural and social sciences. It has different definitions in different point of view [1-5]. In landscape ecology, scale refers primarily to grain (or resolution) and extent in space or/and time, and it may be absolute (measured in spatial or time units) or relative (denoted as a ratio). Scale may be also the observer’s measuring stick or viewing window size, a spatial or temporal characteristic of an ecological pattern or process, or a fundamental framework in which diverse ecological phenomena can be more effectively studied and understood individually and collectively. Scaling, on the other hand, is usually defined as the process of extrapolating or translating information from one scale to another, including scaling up and scaling down [6-7]. In this study, scaling refers to the former [8].

As spatial heterogeneity becoming a major theme in a wide range of ecological studies [9], the concepts of scale, scaling, and hierarchy also become more and more important in ecology and other disciplines. Recently, several reviews on scale and scaling seem to suggest that a science of scale is emerging from different disciplines encompassing both natural and social sciences [1, 3-4, 7]. In ecological research and applications, three related but distinctive tasks of scale stand out. Scaling, one of these three, has quickly become a buzzword in ecology in recent years with the focus has clearly been shifted from fine to coarse scales. To emphasize the shift in this paper is inevitable for two reasons. First of all, it is evident that most, if not all, environment and resource management could only be dealt effectively with at large scales (usually the human landscape and above). The second and more profound reason is that ecologists are now acutely aware of that, in order to uncover how nature works, they should understand large-scale pattern and process and relate them to those at fine scales with which we are most familiar. In both cases, transferring
information from one scale to another, i.e. scaling is indispensable. How to scale up or scale down? How does spatial and temporal heterogeneity affect scaling? How do different processes or ecological systems differ in terms of scaling? Are there general rules for scaling? These questions are thus focus in all disciplines of earth sciences [8].

2. Methods and Results

2.1. Data Sources and Preprocessing

The remotely sensed image data used in this paper are ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) image of Dunhua, Jilin Province, China in Sep. 4th, 2001, which resolution is 15m, and MODIS (MODerate resolution Imaging Spectroradiometer) LAI (Leaf Area Index) product composed of 8 days of the first ten days of September, which resolution is 1km. These two data could be treated as in the same time due to in the same area and period. The LAI used in the paper to test the results measured by TRACK in site.

MODIS LAI is a standard product to be delivered from data acquired by the MODIS aboard the Earth Observing System (EOS) Terra platform. ASTER LAI is inversed by statistical model. Radiometric correction, geometric correction and supervised classification are accomplished before acquired ASTER classification image of research region.

LAI is defined as the green leaf area per unit ground area, also as the sum (LAI in full) or the sum of one side of the green leaf area per unit ground area. Chen et al [10] defined LAI as the half of the sum of the green leaf area per unit ground area. The advantage of this definition is that the extinction coefficient could be regarded as a constant 0.5 of all the convex leaves when the leave distribute angle is random. The quantitative remotely sensed method of LAI. are these two in common-optical model and statistical model. The latter is applied in the paper. Four VIs (Vegetation Index) are used in the paper to inverse LAI. They are SR (Simple Ratio), NDVI (Normalized Difference Vegetation Index), RSR (Resistant Simple Ratio) and SAVI (Soil-Adjusted Vegetation Index) as shown in Table 1.

Here, \( R_n \), \( R_r \), \( R_{swir} \) is the reflectance of near infrared, red and shortwave infrared bands respectively. \( R_{swir_{min}} \) and \( R_{swir_{max}} \) is minimum and maximum of the reflectance in shortwave infrared band. Here, they take the reflectance at 1% double ends in histogram of band 4 [11]. \( l \) is the adjusted parameter, and usually 0.5 when vegetation cover is moderate [12].

For each vegetation class, the relationship of VIs and LAI in statistical are applied, then LAI from ASTER can be attained by the above method.

<table>
<thead>
<tr>
<th>VIs</th>
<th>Calculation formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>SR</td>
<td>( R_n / R_r )</td>
</tr>
<tr>
<td>NDVI</td>
<td>( (R_n - R_r) / (R_n + R_r) )</td>
</tr>
<tr>
<td>RSR</td>
<td>( SR * (1 - (R_{swir_{min}} - R_{swir_{max}}) / (R_{swir_{max}} - R_{swir_{min}})) )</td>
</tr>
<tr>
<td>SAVI</td>
<td>( (R_n - R_r) * (1 + l) / (R_n + R_r + l) )</td>
</tr>
</tbody>
</table>

2.2. Methods and Analysis

The grey value of remotely sensed image is random in spatial, but they are spectrum in space-frequency domain. For two images in different spatial resolution in the same area, the difference between them is in low frequency rather than high frequency. Namely, the low frequency part of their spectrum is the same or similar. Thus, low-pass filter of the small scale image can have the most similar spectrum to large scale image. Fourier transformation is a low-pass filter in essence. Then, it is maybe the main tool for transformation from spatial domain to space-frequency domain of remotely sensed image [13]. Test results of Fourier transformation of ASTER image show the relation to MODIS is high to 0.89. So we could get the
outline of the image with high spatial resolution for up-scaling.

However, some detailed characteristic information is also lost in this procedure. Wavelet transformation is developed basing Fourier transformation. It could express detailed information of any function in every extent, in other words, a mathematical microscope \cite{14}. So it is used in this paper to retrieve characteristic detailed information. Coiflets3 wavelet is the choice in this test. Now, LAI up-scaling basing on Fourier and wavelet transformation accomplished. Quantitative evaluate index, such as correlation and norm show it is advantage than the average \cite{15}.

The aim of LAI scaling is that LAI getting from low-resolution image (MODIS) should be equal to the area average of those getting correspondently from the high one (ASTER) \cite{16}. As we known, there exists error between them in fact because of the heterogeneity in lower resolution image. Accordingly, it is necessary to modify the scale effect of LAI due to heterogeneity in order to improve the accuracy of LAI up-scaling above and establish the theoretic base for up-scaling of remote sensing image. So, following is the modify method to errors caused by the land surface heterogeneity. The MODIS up-scaling LAI is correct by this method under the hypotheses that there are no system errors of different sensors.

In mathematics, linear filter is modelled as Fourier spectrum of an image multiplied by a transfer function, which defined in frequency domain. It modifies weight before reconstructing original image by inverse transformation, such as Fourier and wavelet in essence. Therefore, the transfer function is so crisis to correct the up-scaling error due to heterogeneity.

This modified up-scaling method basing on mathematic transformation could be modelled as following,

$$\text{IMAGE}_{\text{SCALE}} = < A_j, D_j, \text{TransFun} >,$$  \hspace{1cm} (1)

$$\text{Scale Proc} = \{\varphi(x, f), \psi(x), (A_j), (D_j) \in \mathbb{Z}, \},$$  \hspace{1cm} (2)

$$\text{TransFun} = R^j.$$  \hspace{1cm} (3)

Here, $\text{IMAGE}_{\text{SCALE}}$ is the image aimed to gained at the given small scale. $A_j$ is the outline information of the given scale basing on the Fourier transformation of the original large scale image. $D_j$ is the detail information basing on the wavelet transformation, acquired by equation (2). $j \in \mathbb{Z}$, belongs to general scale. $R^j$ is the correct factor for error.

Therefore, the operation flow is as follow. Firstly, 2-D DFT (Discrete Fourier Transform) and MRA (Multi-Resolution Analysis); Secondly, multiply frequency spectrum by transfer function point by point; Finally, inverse DFT. It is a effective method as long as the transfer function is available, namely, transfer function is very important.

Transfer function, R, introduced in this paper as following. The base is assuming data in highest resolution could describe the ground truth best. LAI calculated from the above data is regarded as accurate and correct (Fig. 1-A). While LAI calculated or inversed from data with low resolution, or by other methods is inaccurate and having errors to correct (Fig. 1-B). Taking one coarse pixel is composed of several (P) fine pixels as an example. These P fine pixels are maybe many different land cover type, but one dominative land cover type is assigned to the coarse pixel due to heterogeneity; others then neglected. According to the above analysis, scale effect because of heterogeneity in up-scaling could be corrected by the expression (4),

$$\text{LAI}^j_A = \text{LAI}^j_B \times R^j.$$  \hspace{1cm} (4)

Here, $\text{LAI}^j_A$ is LAI calculated in mode A, whose cover type is J; $\text{LAI}^j_B$ is LAI calculated in mode B, whose cover type is also J. $R^j$ is the correct factor for error correct, it is treated as the transfer function after being transformed into frequency domain.

Therefore, target LAI calculated by the method proposed in the paper basing on mathematic transformation should be correct by the R through above method. Finally, LAI up-scaling by wavelet and Fourier transformation (WF is the abbreviation of them) after correction is

$$\text{LAI}^j_{\text{WF, corrected}} = \text{LAI}^j_{\text{WF}} \times R^j.$$  \hspace{1cm} (5)

Here, $\text{LAI}^j_{\text{WF, corrected}}$ is the corrected LAI after modification of up-scaling by using WF proposed in this paper.
2.3. Results and Evaluation
The result of corrected and uncorrected up-scaling LAI by different methods of the above MODIS LAI product is shown. The correlation and the norm is used to evaluate the results of each method. From this test, a conclusion is that the corrected result is better than the result gotten from pixel aggregation and nearest neighbor.

<table>
<thead>
<tr>
<th>Method</th>
<th>Uncorrected</th>
<th>Corrected</th>
<th>Pixel aggregate</th>
<th>Nearest neighbor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correlation</td>
<td>0.22117</td>
<td>0.30996</td>
<td>0.314</td>
<td>0.21997</td>
</tr>
<tr>
<td>norm</td>
<td>4078</td>
<td>2588.2</td>
<td>4069.8</td>
<td>3622.6</td>
</tr>
</tbody>
</table>

Fig. 2 LAI up-scaling results of different method

Fig. 1 sketch map of LAI calculated in different modes
The ground measurement LAI in 24 pixels in the region of interest is used to validate the accuracy of this up-scaling LAI method suggested in the paper. It is described in the figure 3. R is the correlation of the two parameters. In the figure, R² is recorded. RMSE is an abbreviation, which is “Root Mean Square Error”. It is shown that the relativity of corrected LAI and real LAI is higher than that of real LAI and the result gotten from aggregation method. We can see that the relativity of data is enhanced. So the method proposed in the paper is corrected and adaptable to the region of interest. The corrected LAI is improved not only in the accuracy but also in system error because it has the reliable basis in theory and in reality to choose scale corrected factor as transfer function.

Fig. 3  comparison of relativity of LAI gotten from different methods
From above results, we can draw a conclusion that the correlation of modified LAI and real LAI is higher than that of pixel aggregation or nearest neighbour method. It illustrates the adjusted model suggested in the paper for LAI up-scaling is correct.

3. Conclusion and Discussion

Mathematic transformation, such as Fourier and wavelet transformation applied in remotely sensed LAI up-scaling is investigated in this paper. Considering the heterogeneity affects accuracy of LAI up-scaling, TF (Transfer Function) is introduced into the model according to the characteristics of LAI. The test results are satisfactory. Thereby, the method improves the up-scaling accuracy using remotely sense data with middle or coarse resolution, provides theoretic base for the analysis and application of the quantitative remote sensing in large scale at the same time.

But the result is not very ideal maybe because of following several reasons though it realizes LAI up-scaling. In other words, these errors affect LAI up-scaling also need further study.

First, errors caused by angle of sensor and setting of sensor are not considered when calculating the transfer function, but only consider heterogeneity. Second, transfer function calculated assuming aggregation methods with high resolution being true, but the shortage maybe zoomed out in the last results. And these two reasons are all focus on transfer function.

Mathematic transformation applied with some experience, such as, determine of the cut-off frequency of Fourier transformation, and scale of wavelet transformation.

The evaluate index in this paper only are correlation and norm, more effective and correct index need introducing into the results evaluation.

New methods introduced and applied in scaling is one kind of enrichment. However, the difficulty of scaling always exists. Errors must exist when transform among different scales. Therefore, it is necessary to enhance the study of scaling, mechanism of reciprocity among different scales, and so on. These kind results should have great sense to governor and decision-maker. So there are lots of works to do in future which related to above problems.

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5. References

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