Identification of optimal spatial resolution with local variance, semivariogram and wavelet method
— Case studying typical landscape of mountainous area in Southeast China

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Abstract: Understanding the spatial structure of images and selecting optimal spatial resolution has always been an important issue in the application area of remote sensing. The prime objective of this study was to conduct a comparative study of the optimal spatial resolutions for measurement of typical landscape of Mountainous Area in Southeast China, detected with local variance, semivariogram and wavelet analysis. The first principal component of SPOT image was used. The results of local variance demonstrated that optimal spatial resolution of urban, agricultural and forest landscape was around 10-20m, 30-40m and 50-80m respectively. As derived from wavelet transform, it was 40m, 80-160m and 160m respectively. Their values indicated by semivariogram through Exponential and spherical model should be at least less than 160m, 328m and 309m. Although the values we gained from variogram modeling fall within the bound of values derived from wavelet analysis, the values obtained from local variance are relatively small. The values of optimal spatial resolution obtained can vary from the methods and data source we choose and also the prime objects of interest in study areas.

Key words: Optimal spatial resolution; Landscape; semivariogram; wavelet transform; local variance

I. INTRODUCTION

The problem of selecting the appropriate spatial resolution image has been investigated for over twenty years. Woodcock and Strahler (1987) firstly presented the semivariance method and was continuously adopted and applied by many researchers due to its simplicity (Andrefouet et al., 2002; Atkinson and Curran, 1997). But it needs sub-sampling images and those lower resolution images gained may not accurately represent the signal provided by a real sensor (Woodcock and Strahler 1987).

The second type of method incorporates functions relating variance to spatial dependence, generally with variograms (Woodcock et al. 1988). Variogram model can be applied to determine the limit of spatial dependence. It was adopted as an equivalent to the average local variance by Atkinson and Curran (1997). Variogram modeling is proved to be a powerful geostatistical tool and thus is widely used for understanding spatial variability and its change with scale (Atkinson, 1997; Tarnavsky et al., 2008; Garrigues et al., 2008). Spatial variability and spatial structure can both be quantified using variogram modeling. The semi-variance and semivariogram model has a similar rational: optimal resolution was gotten when the nominal spatial resolution equals to the size of features in images.

The third type of method is wavelet analysis, a multi-scale method by itself. In recent years, remarkable progress has been made in the field of wavelet analysis and it is compared to geostatistical procedures (e.g., Chen and Blong 2003). Therefore, in this paper we extend our analysis to include local variation.

The prime objective of this study was to comparative the optimal spatial resolutions for measurement of typical landscape of Mountainous Area in South China, detected with local variance, semivariogram, wavelet method.

II. DATA SOURCE AND METHODOLOGY

A. Data Source

The study area is located coastal eastern area of Fujian province, in the southeast of China. It is characterized as its diversity of climate, mountainous and having few plain. For this study, 10m SPOT image on Dec. 4, 2003 was used. Four typical landscapes were selected representing urban landscape (site A), agricultural landscape (site B), forest landscape (site C) and water landscape respectively (site D) (Fig. 1). Each site has the following characteristics: 5120 by 5120m size. The reflectance was measured in three bands: Green (0.5-0.59μm), red (0.61-0.67μm), NIR (0.78-0.89μm), short-wave infrared (1.58-1.75μm).

B. Data Preprocessing

Principal component analysis was conducted on four bands of SPOT images of four different landscapes to reduce Redundancy. The first principal component of each landscape was used for further calculation. For urban landscape, it was: $Y = 0.484404X_1 + 0.491286X_2 + 0.233391X_3 + 0.685214X_4$. For agricultural landscape, it was: $Y = 0.357873X_1 - 0.528598X_2 + 0.343980X_3 + 0.688613X_4$. For forest landscape, it was: $Y = 0.272710X_1 + 0.453592X_2 - 0.4557425X_3 + 0.715668X_4$. For water landscape, it was: $Y = 0.519410X_1 - 0.849804X_2 + 0.051431X_3 + 0.07327245X_4$. 

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Daubechies wavelet as the wavelet function and produce the low and the high images of the original image in nine levels. Then we extract wavelet coefficients from those images.

IV. RESULTS

Average local variance was calculated on series of spatially aggregated data. The results (Fig. 2) demonstrated that local variances of urban, agricultural and forest landscape reach its maximum value within 100m except water landscape. For the urban landscape, the value of local variance is considerably high at original spatial resolution of 10m, reaching its maximum at 20m and then decreasing very sharply. It could be infer that the optimal spatial resolution of urban landscape is around 20m. However, since the value of local variance is generally low in the case of the size of objects in an image greater than the original spatial resolution. It might suggest that the original spatial resolution of 10m is not small enough to capture the spatial variance of small objects within urban mosaic. For agricultural and forest landscape, the value of local variance is relatively low at 10m, then rises rapidly and drops steadily until 200m. The peak values of them exit at 30-40m, 50-80m individually. It might indicate that optimal spatial resolution of agricultural and forest landscape could be around 30-40m, 50-80m respectively. The value of local variance is considerably high even at coarse spatial resolution of 200m, which suggest large objects within its image. For urban landscape, 10-20m is the average size of buildings, the primary smallest object within the images. For agricultural landscape, 30-40m is the average size of farmland block. For forest landscape, 60-80m is the average size of small topographic unit which causes the light and shadow effect on the image.

The size sequence of semivariogram is generally as follows: forest landscape > urban landscape > agricultural landscape > water landscape (Fig. 3). The varigrams for water landscape are clearly unbounded, i.e. not reaching a sill within the spatial extent of the images. This indicates that their spatial extents relative to spatial resolution are not sufficiently large to encompass the spatial variability of the landscape. Hence, theory variogram modeling for water is meaningless and thus neglected. The range can approximately be used to identify the spatial structure of image. The range of exponential modeling of urban, agricultural and forest landscape is around 160m, 328m and 309m respectively. It indicated that optimal spatial resolution for those three landscapes should be less than 160m, 328m and 309m
respectively. In contrast, the range and sill obtained from spherical modeling is considerably lower. It suggests that appropriate spatial resolution for those three landscapes should be less than 114m, 220m and 236m respectively. The parameters namely range and sill can only be obtained by Variogram modeling. Different theoretical variogram models could be applied. As seen from the above, the values of those parameters gained from them might differ from one model to another.

![Figure 3. Omnidirectional semivariograms for four landscapes](image)

**Figure 3. Omnidirectional semivariograms for four landscapes**

<table>
<thead>
<tr>
<th>Data source</th>
<th>Exponential</th>
<th>Spherical</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$r_l$</td>
<td>$s_l$</td>
</tr>
<tr>
<td>Urban landscape</td>
<td>160.077</td>
<td>0.1897</td>
</tr>
<tr>
<td>Agricultural landscape</td>
<td>328.480</td>
<td>0.0948</td>
</tr>
<tr>
<td>Forest landscape</td>
<td>309.238</td>
<td>0.2652</td>
</tr>
</tbody>
</table>

**Wavelet coefficients is extracted in horizontal, vertical, diagonal directions from those images (Fig. 4~Fig. 7). The values of wavelet variances in the diagonals direction is very small and could be considered as noise.**

For urban landscape, the wavelet variance in the vertical direction is larger which suggest that the structure in this direction is richer than in the horizontal direction (Fig. 4). The values of wavelet variance in horizontal, vertical direction both reach its maximum around 40m and decrease sharply as the spatial resolution increases. Forty meters might be the size of residential patches of urban buildings, green belt and roads.

For agricultural landscape, the wavelet variances in the horizontal and vertical direction have similar maximum values (Fig. 5). It reaches its maximum value at 80m, 160m respectively, and then drop with the increase of spatial resolution. Agricultural landscape is composed of agricultural parcel, irrigation channel and roads between them. Eighty meters, one hundred and sixty meters is roughly the width and length of agricultural parcels separated by non-agricultural landscapes (roads, building or rivers).

![Figure 4. wavelet variance of urban landscape in different direction](image)

**Figure 4. wavelet variance of urban landscape in different direction**

![Figure 5. wavelet variance of agricultural landscape in different direction](image)

**Figure 5. wavelet variance of agricultural landscape in different direction**

![Figure 6. wavelet variance of forest landscape in different direction](image)

**Figure 6. wavelet variance of forest landscape in different direction**

For forest landscape, the wavelet variance in the vertical is relatively greater than in horizontal direction. Both of them reach its peak at 160m (Fig. 6). As seen from the image, variance of forest landscape is primarily controlled by light and shade caused by topography. The width of ridgelines and valley Line may be between 160m.

For water landscape, similar to the results gotten from analysis of local variance and semi-variance, there’s no peak of its wavelet variance in all three directions in the range of 10-1280m (Fig. 7).
V. DISCUSSION AND CONCLUSION

The peak it reaches from analysis of three different methods has similar implication in terms of its spatial heterogeneity or variance is concerned. However, there does exist distinct variations between the values of optimal spatial resolutions gained from three different methods. The optimal spatial resolution of urban, agricultural and forest landscape suggested by wavelet coefficients are 40m, 80-160m and 160m respectively. Their values indicated by semivariogram should be at least less than 160m, 328m and 309m, which still agree with the bound of value gotten from wavelet analysis. Optimal spatial resolution for those three landscapes suggested by local variance was around 20m, 30-40m and 50-80m respectively, which is among the smallest values. It is also stated by that Chen and Blong (2003) that the so-called optimal resolution derived from local variance is usually underestimated and optimistic due to the consequence of sub-sampling. For semivariogram modeling, uncertainty also comes from the theoretical models selected. For this study, the ranges gained from exponential modeling are considerably larger than those from spherical modeling. Combined analysis from those three methods, we can draw a conclusion that multiple optimal spatial resolutions for different landscapes might exist depending on the main objects intended to observe in images. If individual buildings should be classified, the appropriate spatial resolution might be 20m or less. If only mosaics of the residential patches are needed, it could be 40m or less.

This study gives a comparative analysis of these three methods. Local variance is proved to be efficient to derive the small spatial structure of images and thus suitable for small scale observation. Methods of semivariogram and wavelet transform don’t need sub-sampling images and are tight in mathematics. But the optimal values derived from semivariogram of this study are considerably big, although whether it is a general rule or not needs further investigation. Besides, theoretical modeling is needed and parameters gained from them may not be consistent depending on theoretical models we choose. Wavelet transform is more suitable for research on large areas since standard wavelet transform can only be applied to decompose images at spatial resolution levels of two for any integral power, while leaving other resolutions uninvolved. Local variance at original spatial resolution or semivariogram at one-pixel lag could be used to determine whether the spatial resolution of original images is small enough to capture the spatial variation of objects within image.

Except the methods we applied, the original images we use could also make a difference. As seen from the results of all those three methods, the variance of urban landscape at original spatial resolution is already quite high. If higher spatial resolution images were applied, we can safely assume that more detailed information should be gained for urban landscape and we can also confer that optimal resolution from it could be smaller.

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