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Influence of DEM resolution on topographic correction models using spot satellite image

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Abstract: Topographic correction models (TCMs) are valid on satellite image data preprocessing steps. The illumination angle may be sensitive to different terrain slope and aspect conditions base on sun-terrain-sensor geometry. Although the topographic correction is influenced by the sun azimuth and zenith angle, the correction result can be equally in the same image status. By contrast, the terrain factors change with different digital elevation model (DEM) resolution in the topographic correction equations and cause a significant effect. Slope is sensitive in rugged terrain, and aspect is impressionable at flat surface at a coarse DEM resolution data. As the DEM resolution lead a distinct result on TCMs, this research is aimed to examine the impact of DEM resolution on the accuracy of terrain representation and of the gradient determined. In this study, five TCMs, including cosine correction, C correction, SCS correction, SCS+C correction and Minnaert correction models are compared by different resolutions using SPOT image data. The 5 meter DEM obtained from Ministry of the interior will be resampled to 10 to 500 meters to test those topographic models sustainability on Lienhuachih Research Center. The accuracy of five topographic correction models base on different DEM resolution will be evaluated by root-mean-square error (RMSE).

Keywords: DEM resolution; Topographic correction model (TCM); Terrain effect; Root-mean-square error (RMSE)

1. Introduction

Remote sensing data are widely used in surface monitoring, and can be combining with other data to address a specific practical problem, such as land-use planning, mineral exploration, or plantation detection. Taiwan is a mountainous island; there are still dense forests in deep mountains which human activities cannot reach to them. Nevertheless, it is necessary to the authority or researchers to investigate those unconquered landforms. Nowadays, scientist can draw support from remote sensing image data to overcome the difficulties came from the rugged terrain. There are other problems should be concentrating on, that is the variation in elevation will create some environment parameters bias derived from satellite data, or different quantitative measurements affected from the resolution on Digital Elevation Model (DEM) data. Therefore, topography variance can seriously affect the radiometric quality of remote sensing data. Base on sun-terrain-sensor geometry, solar illumination effects may cause variations in reflectance of similar ground features due to different topographic positions. So, carrying through topographic correction is an important data pre-processing step when quantitative analysis of multispectral data is carried out in mountainous regions.

There are many physical methods discussing the radiometric influence between surfaces and atmosphere. However topographic correction, such as Cosine correction, C correction, Minnaert correction (Smith, 1980; Teillet, 1982, 1986; Colby, 1991; Meyer, 1993 *et al.*) was developed in the field of remote sensing. The three methods are STS (Sun-Terrain-Sensor) methods, which have an assumption (Scott, 2005) that a pixel in rugged terrain can be considered as a declining plane to handle, and all the illumination correction is based on the assumption. So Gu (1998) developed a new method called SCS (Sun-Canopy-Sensor) correction. Gu analyzed the topographic effects of forest canopy in sub pixel scale and given the new correction method. However, the SCS model, similar to the cosine correction, cannot avoid an overcorrection problem. To address this problem, an empirical parameter C has been introduced into the SCS algorithm to form the SCS+C model (Soenen *et al.*, 2005). This study shows that different DEM resolution compare with topographic correction models used, may cause a changing value in RMSE. To avoid overcorrecting the remote sensing image data, the constant C act as the main factor on Lienhuachih Research Center.

2. Materials and methods

2.1 Study Area

To compare the effectiveness on DEM resolution, five topographic correction models are used in Lianhuachi Research Center. This study area is located in central Taiwan, is about 548 ha. It situates 576 to 925 meters above the sea level with an average altitude of 701 meters. The site is characterized as a humid subtropical forest with an annual mean temperature of 21.1℃ and mean annual rainfall of 2,211 mm. The major forest type is natural hardwood evergreen forest intermixed with artificial plantations (Figure 1.).

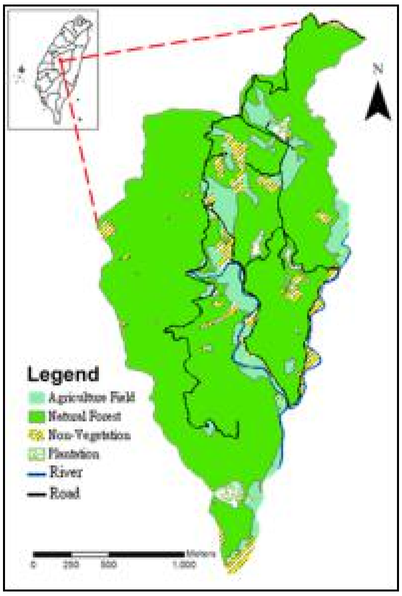

Figure 1. Study area land cover types.

2.2 Satellite Image

The SPOT image taken on March 6, 2010 is used in this study. Each band will be topographic corrected separately, then composite together in order to compare with the original image data. Table 1. list the metadata table of SPOT image data taken on March 6, 2010, which is used for topographic correction.

Scene Parameters	Incidence Angle	Orientation
Value	-28.536017	11.7952
Scene Parameters	Azimuth	Elevation
Value	137.33707	49.877141

Table 1. Image data metadata table

2.3 Digital Elevation Model

In order to compute the slope gradient and aspect using ArcGIS 10.2 software, 5 meter resolution DEM obtained from Ministry of the Interior was used. The DEM will be resampled to 10, 15, 20, 25, 30, 35, 40, 45, 80, 100, 160, 200, 320 and 500 meter.

2.4 Topographic Correction Models

2.4.1 Cosine Correction

Irregular shape of the terrain causes variable illumination angles and diverse reflection values in different aspect. In this mode the equation for the radiance observed by a satellite sensor is based on the assumption that the reflecting surface is horizontal and a Lambertian reflector (Teillet *et al.*, 1982). The equation (1) shows the band correcting step by the equation (2).

$$L_h = L_t \times \frac{\cos Z}{\cos i} \tag{1}$$

$$\cos i = \cos Z \cos S + \sin Z \sin S \cos (A - As) \tag{2}$$

where i = incident angle with respect to surface normal
Z = solar zenith angle
S = terrain slope
A = solar azimuth
As= terrain aspect
L_h= reflectance of the horizontal surface
L_t= reflectance of an inclined surface

If the incidence angle approaches to 90°, the reflectance will become larger and the image may be brighten in shadow areas with low illumination while the terrain effect is corrected by cosine TCM.

2.4.2 C Correction

To reduce the over-correcting pixels in cosine correction, an empirical parameter C is added to the equation in order to avoid abnormally bright (Teillet *et al.*, 1982). Parameter C is calculated in equation (5) by simple linear relationship between the spectral data and the cosine value of incident angle, which is also used in cosine correction. In other words,

$$L_h = L_t \times \frac{\cos Z + C}{\cos i + C} \tag{3}$$

$$L_h = a + b \times \cos i \tag{4}$$

$$C = \frac{a}{b} \tag{5}$$

According to equation (3) parameter C can increase the denominator and cut back the overcorrection of illuminated pixels.

2.4.3 SCS Correction

Topographic correction base on digital terrain models or photometric models are on the basis of the relationship through Sun-Terrain-Sensor (STS) geometry. Although STS has some degree of success, there is a Sun-Canopy-Sensor (SCS) way to participate in correcting procession especially in forests (Gu *et al.*, 1998). The equation is shown in (6).

$$L_h = L_t \times \frac{\cos S \times \cos Z}{\cos i} \tag{6}$$

2.4.4 SCS+C Correction

The aim to combine parameter C to act as the other correction model has the same reason while the angle i approaches 90° in cosine correction. C is derived using equation (4) and (5).

$$L_h = L_t \times \frac{\cos S \times \cos Z + C}{\cos i + C} \tag{6}$$

2.4.5 Minnaert Correction

In most natural surfaces, cosine correction relied on Lambertian assumption are not applicable (Soenen *et al.*, 2005). This model can solve the overcorrecting problem in cosine correction (Smith, 1980). The terrain has a light reflection among diffuse, which is Lambertian, and specular. The Minnaert parameter K ranges from 0 to 1, representing specular to diffuse reflection.

$$L_t \times \cos e = (\ ) L_h \times \cos^k i \times \cos^k e \tag{7}$$

The parameter K not only indicates the terrain roughness, but also reduces the weight of overcorrection (Law, Nichol, 2004). However, the K value depends on the nature land cover, topographic factor, and wavelength.

3. Result and discussion

3.1 The variation of terrain indicators in different spatial resolutions

The slope, aspect and the incident angle are the main factors that effect the TCMs. The variations of the terrain effects on different spatial resolutions are showed in Figure 2. and Figure 3. The values are declining with resolution on both slope and aspect. The cosine value of the incident angle also dependent on the resolution (Figure 4.).

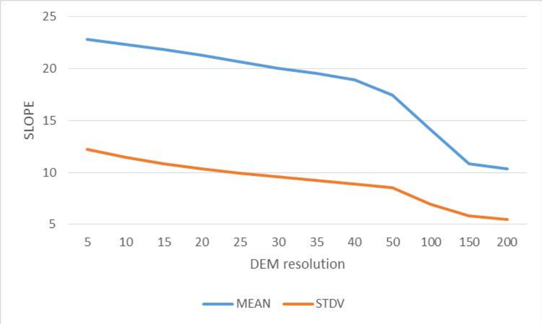

Figure 2. Slope in different DEM resolution

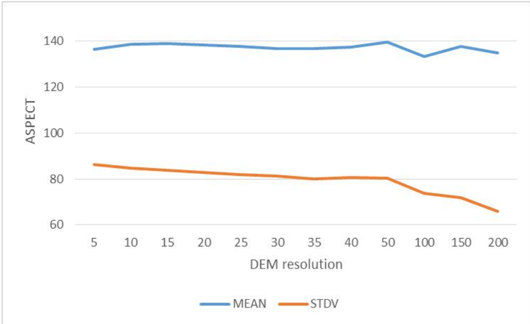

Figure 3. Aspect in different DEM resolution

So, it is necessary to investigate how TCMs interact with the quality of terrain data.

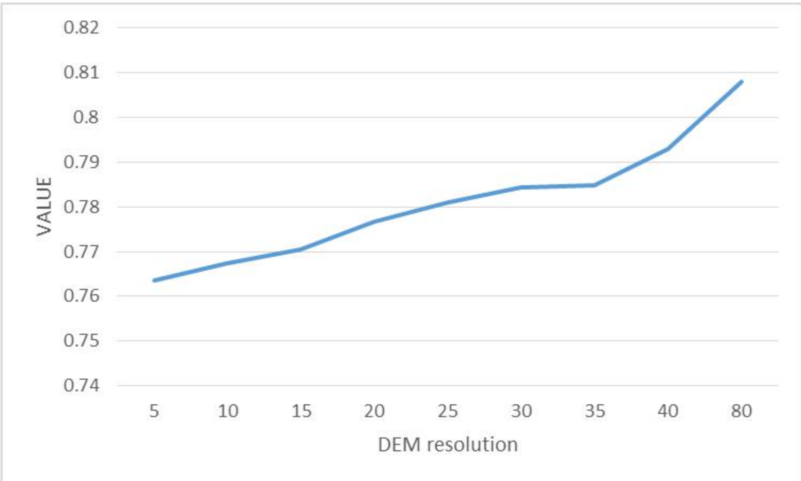

Figure 4. The cosine value of incidence angle in different DEM resolution.

3.2 TCMs' RMSE in different spatial resolutions

To identify the correlation between TCMs and DEM resolution, the Root-Mean-Square-Error (RMSE) was calculated using equation (8) to compare with the original SPOT image data. The RMSEs of five TCMs under different DEM resolution conditions were showed in Figure 5.

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(\overline{x_i} - x_i)^2} \quad (8)$$

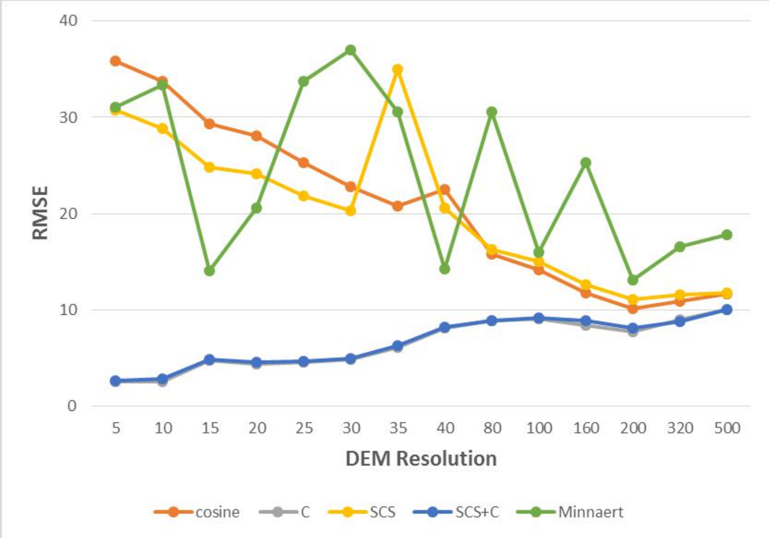

Figure 5. RMSE value in five topographic correction models on different DEM resolution data source.

All of those TCMs are affected by the DEM resolution. According to the Figure 5, they can be separated into three main groups. One group is the C and SCS+C correction models,with the lowest RMSE. It indicates that they are much more stable than the others TCMs when the DEM resolution was changed. It shows that TCMs with the parameter C, can avoid the image data been overcorrected by the TCMs, but it become significant in coarse DEM resolutions. The similar results can be observed on Table2. The parameter C also decreases with DEM resolution in each image. That is to say, the image may be overcorrected in fine DEM resolution data. Another group is cosine and SCS TCMs, their RMSE value decreased while the spatial resolution becomes lower, and there is a peak on SCS TCM in 35m DEM resolution. The other group is the Minnaert correction model. It has an unstable performance among the different DEM resolutions. In Table 3. The parameter K also has shown an unregulated pattern with the DEM resolution.

resolution	5	10	15	20	25	30	35	40	80
B1	4.985	4.787	4.568	4.47	4.328	4.296	4.125	4.176	3.775
B2	2.966	2.841	2.683	2.618	2.515	2.495	2.386	2.407	2.18
B3	2.389	2.206	2.049	1.931	1.831	1.766	1.688	1.651	1.368
B4	1.844	1.691	1.556	1.469	1.378	1.324	1.255	1.23	1.036

Table 2. Parameter C changes with DEM resolution in different image bands.

resolution	5	10	15	20	25	30	35	40	80
B1	0.123	0.164	0.018	0.073	0.185	0.224	0.161	0.038	0.187
B2	0.167	0.145	0.188	0.18	0.142	0.17	0.184	0.228	0.271
B3	0.194	0.362	0.107	0.206	0.046	0.036	0.112	0.297	0.248
B4	0.249	0.451	0.167	0.27	0.091	0.076	0.168	0.366	0.296

Table 3. Parameter K changes with DEM resolution in different image bands.

3.3 TCMs' RMSE difference on slope in the same spatial resolution

There is an obviously change between the RMSE and different DEM resolution by using those five TCMs. The 30m DEM was selected to test how the RMSE changed with different slope condition. The result is presented on Figure 6. We can see that C and SCS+C still have the least influence on different slope classifications. Cosine, SCS and Minnaert correction models show that the RMSE were increasing while the slope degrees grow in number. It represents that overcorrection may occur in cosine, SCS and Minnaert correction models, and the C and SCS+C topographic correction models may be much stable in steep slope.

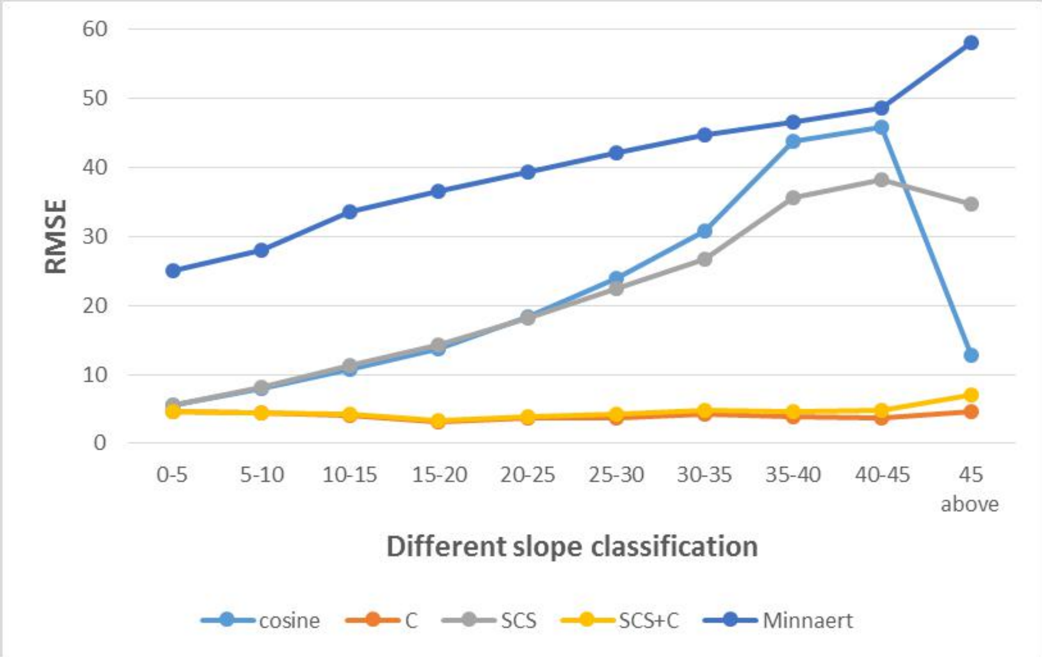

Figure 6. RMSE change in five topographic correction models on different Slope classification.

4. Conclusion

The slope and aspect change with DEM resolution, thus the performance of TCMs were evaluated by RMSE under different resolution in this study. The following major conclusions can be drawn from the study.

1. Overcorrection was observed in the Cosine and SCS TCM, especially when the high resolution DEM data was used in TCM.
2. Overcorrection also occurs when Cosine and SCS TCM were applied in steep slope condition.
3. The parameter C is a key factor that can prevent overcorrection, but it isn't effective if the DEM resolution is low enough.
4. The RMSEs of C and SCS+C TCM are relatively stable under different DEM resolutions and slope conditions. They are suggested as better TCM in all kinds of situations.

Acknowledgements

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