A MODEL OF TOPOGRAPHIC CORRECTION AND REFLECTANCE RETRIEVAL FOR OPTICAL SATELLITE DATA IN FORESTED AREAS

Cheng Wei[a], [*], Tian Qingjiu[b], Wang Liming[a]

[a]The Center for Earth Observation and Digital Earth, #45, Beisanhuanxi Road, Beijing, China, 100086 - simbla@sina.com, lmwang@ne.rsgs.ac.cn
[b]International Institute for Earth System Sciences, Nanjing University, #22, Hankou Road, Nanjing, China, 210093 - qjtian@nju.edu.cn

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ABSTRACT:

Topographic correction is a necessary step of pre-process in the remote sensing application in rugged terrain. Most of traditional topographic correction methods are empirical and statistical based. These methods have the advantage of facility; however they also have some disadvantages, such as lack of comprehensive physical analysis, subjectivity in operation, separation of atmospheric correction and so on. Instead, the topographic correction model based on radiative transfer theory can overcome these disadvantages in a degree. In this paper, an optical, radiative transfer theory based model for topographic correction and surface reflectance retrieval for forested terrain is developed. This model is established by modifying existing radiative transfer theory based model (developed by Sandmeier et al). The difference between the two models is that the modified model is developed in sub-pixel scale, which SCS correction is also based on. Finally, the model is validated using the ETM imagery and DEM of Lipin County, Guizhou province, China. Visual and statistical methods are used to evaluate the results of the two models. In comparison with existing radiative transfer theory based model, the modified model has a better result in removing the terrain effects of imagery in forested areas.

1. INTRODUCTION

High spatial resolution remote sensing images in rugged areas often have great terrain effects, so besides atmospheric correction, topographic correction is also a necessary step of pre-process in the remote sensing application for rugged areas. In china, nearly 70% of total homeland is mountainous or hilly, so developing topographic correction technique of remote sensing imagery has great importance in forestry survey, resources exploration and other interrelated fields. So far, the scientists in the field of remote sensing have developed many methods of topographic correction, such as cosine correction, C correction, Minarets correction (Smith, 1980; Teillet, 1982, 1986; Colby, 1991; Meyer, 1993 et al.). The three methods are STS (sun-surface-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. This hypothesis is reasonable to bare land, so STS methods are quite applicable to ground surfaces which have no tree crowns covered. However, the hypothesis is not reasonable to tree canopy. Because tree crown is usually in some specific shape and can not be considered as a plane. In addition, tree canopy in the nature is always vertical to the horizontal plane (Figure1 1(a) and (c)), not vertical to the slope. If STS methods are applied in tree canopy, the canopy will be declining after correction (Figure1 1(b)), which is obviously not reasonable. 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.

All methods above are empirical and statistical based and have the advantage of facility, however they also have some disadvantages, such as lack of comprehensive physical analysis, subjectivity in operation, and separation of atmospheric correction. To overcome these shortcomings, Sandmeier (1997) developed a physical, radiative transfer theory based topographic correction model. Compared to empirical and statistical based methods, radiative transfer theory based topographic correction model has a clear physical meaning. Moreover, it can combine atmospheric correction and topographic correction effectively. As these advantages, radiative transfer theory based topographic correction methods may be more adapted to the quantitative remote sensing. Now the model has been embedded in ATCOR3 (2006), the atmospheric/topographic correction module of commercial remote sensing imagery processing software ERDAS. However, like cosine correction, C correction and Minarets correction, the model developed by Sandmeier is also based on STS (sun-surface-sensor) correction. So it is only applicable to bare land and is not reasonable to tree canopy.
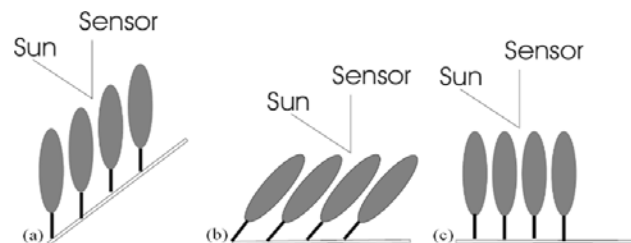

Figure 1. Geotropism of tree canopy (by Scott, 2005)

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[*] Corresponding author: E-mail: simbla@sina.com

In this paper, radiative transfer theory and SCS correction are combined in order to make Sandmeier's model applicable to forested areas where tree crowns predominate. Compared to Sandmeier's model, the main difference is that the modified model is developed in sub-pixel scale, which SCS correction is also based on. The reason why discussing in sub-pixel is that it is more convenient and reasonable to analyze the terrain effects of tree canopy.

2. RADIATIVE TRANSFER THEORY BASED TOPOGRAPHIC CORRECTION MODEL

2.1 Existing Model

Assuming that the surface is Lambertian, the radiance reflected by a level pixel can be divided into two components:

$$L = L_d + L_f \qquad (1)$$

Where L_d = radiance reflected from the direct solar irradiance
L_f = radiance reflected from the diffuse solar irradiance

The topographic influence on remote sensing signal is very complicated. Some scientists have done detailed analysis of this (Proy, et al, 1989). In order to interpreting topographic effects accurately, Sandmeier partitioned the radiance reflected by pixel in rugged terrain into four components:

1. Reflected radiance from the direct solar irradiance, affected by terrain slope and topographic azimuth.

2. Reflected radiance from the isotropic diffuse irradiance, affected by the same factors as the first component.

3. Reflected radiance from the circumsolar diffuse irradiance, affected by terrain shading.

4. Reflected radiance from surrounding terrain irradiance, affected by the radiance of neighbour pixels.

The partition accounts for the anisotropic distribution of the diffuse solar radiance. It is a linear combination of the contribution of the circumsolar diffuse irradiance from the solid angle near the sun and an isotropic contribution for the remaining sky dome. In detail, the partition above is

$$L = b\frac{\cos i}{\cos \theta_s}L_d + b\frac{\cos i}{\cos \theta_s}KL_f + (1-K)VL_f + L_t \qquad (2)$$

Where θ_s = solar zenith angle
i = solar incidence angle
b = binary factor
K = anisotropic index
V = sky view factor
L_t = reflected radiance from terrain irradiance

The solar incidence angle i is the angel between direct solar ray and local terrain surface normal, which can be calculated from the DEM slope and aspect angles and the solar geometry:

$$\cos i = \cos \theta_s \cdot \cos \alpha + \sin \theta_s \cdot \sin \alpha \cdot \cos(\varphi_s - \varphi_n) \qquad (3)$$

Where α = slope angle
φ_s = solar azimuth
φ_n = slope aspect angle

The factor b is one if pixel receives direct solar beam, it is zero if $\cos i < 0$, which means the pixel is completely in shadow and can not receive the direct solar radiation. This applies for the case of self-shadowing. It is also set to zero if shadow is cast from surrounding topography. The factor K is the proportion of circumsolar diffuse irradiance in the total sky diffuse irradiance, which equal to the sun-to-ground direct transmittance. V is defined as the proportion of sky dome that is not shaded by surrounding topography, which is ranged 0-1.

Here, modify equation (2) in the form of reflectance:

$$L = (b\frac{\cos i}{\cos \theta_s}E_d + b\frac{\cos i}{\cos \theta_s}KE_f + (1-K)VE_f + E_t)\frac{\rho}{\pi} \qquad (4)$$

Where E_d = direct solar irradiance
E_f = diffuse solar irradiance
E_t = terrain irradiance
ρ = surface reflectance

According to equation (4), it is easy to obtain ρ:

$$\rho = \frac{\pi L}{b\dfrac{\cos i}{\cos \theta_s}E_d + b\dfrac{\cos i}{\cos \theta_s}KE_f + (1-K)VE_f + E_t} \qquad (5)$$

This is the essential equation of the topographic correction model by Sandmeier and ACTOR3.

2.2 Modified Model for Forested Areas

Strictly speaking, the above model only applies to bare surface; because its illumination correction of direct solar irradiance is derived from STS theory (The situation of circumsolar diffuse irradiance is the same as direct irradiance, so its discussion is omitted here). In STS correction, the up radiance reflected by the surface is the function of the down irradiance; and the direct irradiance depends on the solar incidence angle which changes with the slope and aspect of the surface. Therefore, as implied in equation (3), the rate of reflected radiance from direct irradiance between sloping pixel and level pixel equals the irradiance rate, or the cosine rate of the solar incidence angle:

$$\frac{L_d{}'}{L_d} = \frac{E_d{}'}{E_d} = \frac{\cos i}{\cos \theta_s} \qquad (6)$$

Where L_d' = radiance reflected from direct solar irradiance of sloping pixel

E_d' = direct solar irradiance of sloping pixel

However, tree growth is oriented with the gravitational field and always vertical to the horizontal plane, not vertical to the slope. As a result, the solar incidence angle is constant and the direct solar irradiance received by individual crown is independent with the slope and aspect of the surface, which means the radiance reflected is not affected by topography as well. So equation (6) will be not applicable. But for the case of a cluster of tree crowns, there is another type of topography effect (Gu, 1998). Firstly, because of the mutual shading of tree crowns, the pixel of tree crowns can be partitioned to sunlit part and shadow part. The sunlit part can receive both direct and diffuse irradiance, and the shadow part can only receive diffuse irradiance. Secondly, the mutual shading effect is controlled by terrain since the relative position of trees is affected by topography. As a result, on Sun-facing slopes, the proportion of sunlit tree crowns which exposed to the direct illumination is larger than that on the slopes facing away from the Sun, which eventually lead to the difference of reflected up radiance. So for the case of tree crowns, the rate of reflected radiance from direct irradiance between sloping pixel and level pixel equals the rate of total area of sunlit part of the pixel. By Gu, the rate is:

$$\frac{L_d'}{L_d} = \frac{A'}{A} = \frac{\cos i}{\cos \theta_s \cos \alpha} \qquad (7)$$

Where A' = the total sunlit area of sloping pixel

A = the total sunlit area of level pixel

According to the analysis above, for tree crowns, equation (2) can be modified as (The situation of circumsolar diffuse irradiance is the same as direct irradiance):

$$L = b\frac{\cos i}{\cos \theta_s \cos \alpha}L_d + b\frac{\cos i}{\cos \theta_s \cos \alpha}KL_f + (1-K)VL_f + L_t \qquad (8)$$

From equation (8), the model can be modified as:

$$\rho = \frac{\pi L}{b\dfrac{\cos i}{\cos \theta_s \cos \alpha}E_d + b\dfrac{\cos i}{\cos \theta_s \cos \alpha}KE_f + (1-K)VE_f + E_t} \qquad (9)$$

This is the modified model for forest areas where tree crowns cover, which is the combination of Sandmeier's model and SCS correction.

2.3 Parameter Calculation

The radiative transfer parameters E_d, E_f, K can be calculated by 6S or MODTRAN 4 model etc. The total radiance reflected by level pixel (L) can be calculated by:

$$L = \frac{(E_d + E_f)\rho_a}{\pi} \qquad (10)$$

Where ρ_a = atmospheric corrected reflectance by 6S or MODTRAN 4 etc.

The slope angle and aspect angle can be calculated from DEM; the accurate calculation of E_t and V was discussed respectively by Proy (1989) and Dozier (1990); Sandmeier's model provides the simplified calculation of them (Sandmeier, 1997).

3. MODEL VALIDATION

3.1 Validation Data and Implementation

The modified model in this paper is specifically for forested areas, so it is necessary to use satellite data in forested area to validate the effectiveness of the model. In the experiment, the 30m multi-spectral ETM image of Landsat 7 acquired on May 14th, 2000 as validation data. Lipin County, Guizhou province, China was chosen to be the study area. The study area is typical forest and mainly covered by Chinese fir. DEM with an original spatial resolution of 25m were used here (see Figure 2). The terrain in the area is quite rugged, where the average slope angle is 22 degree and the maximal slope angle is 55 degree.

In this experiment, the radiative transfer parameters in the model were calculated by 6S model. The dark objective method (Kaufman, 1988; Tian Qingjiu, 1998) was used to estimate the aerosol optical thickness, which is a very important input parameter of 6S model. The programming tool of the experiment is IDL.
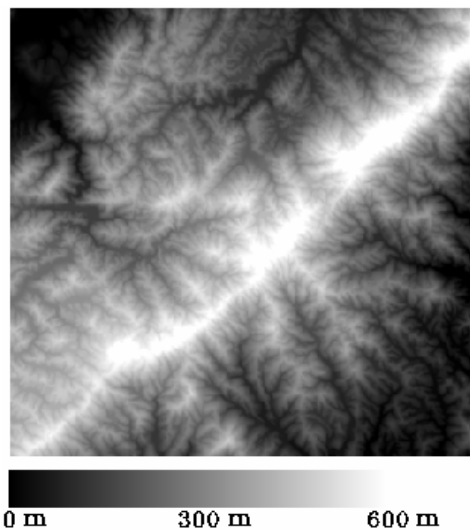

Figure 2. DEM in the study area

3.2 Result and Discussion

In order to evaluate the efficiency of the model, the atmospheric corrected image by 6S model was taken as the comparative image without topographic correction. In addition, Sandmeier's model is also applied to the same data to make comparison with the modified model.
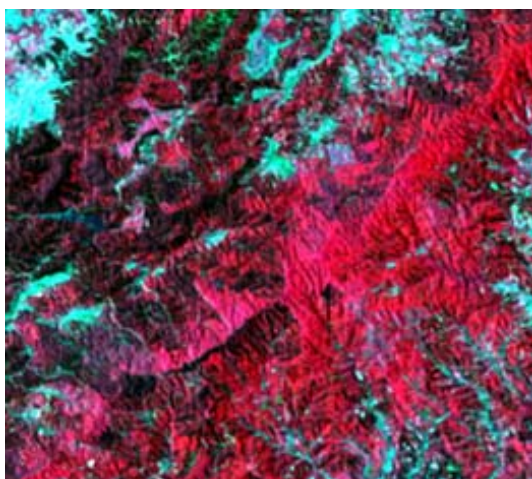
Because tree canopy reflectance is very difficult to measure and it is impossible to make the slope become flat in reality, here only visual and statistical methods can be used to analyse and evaluate the results of the two models.
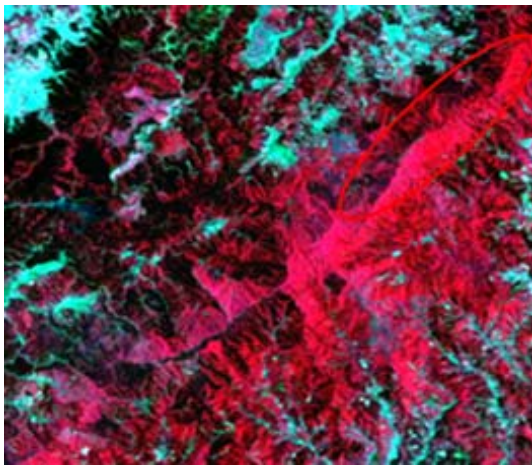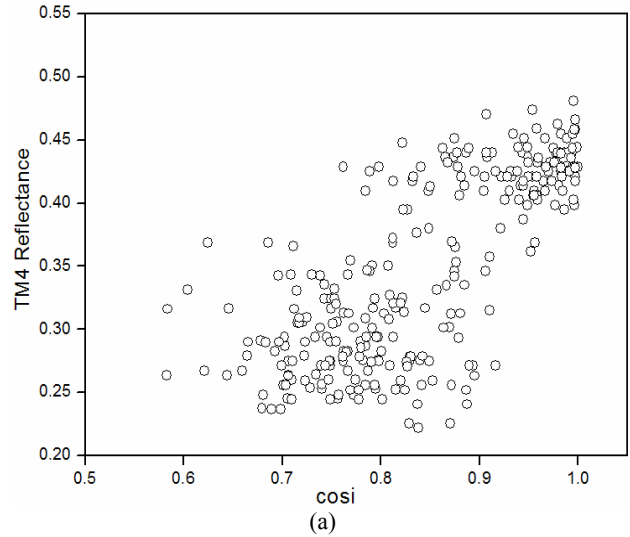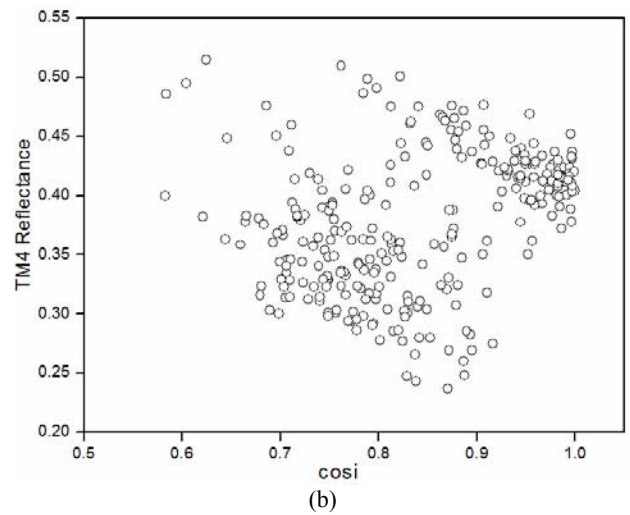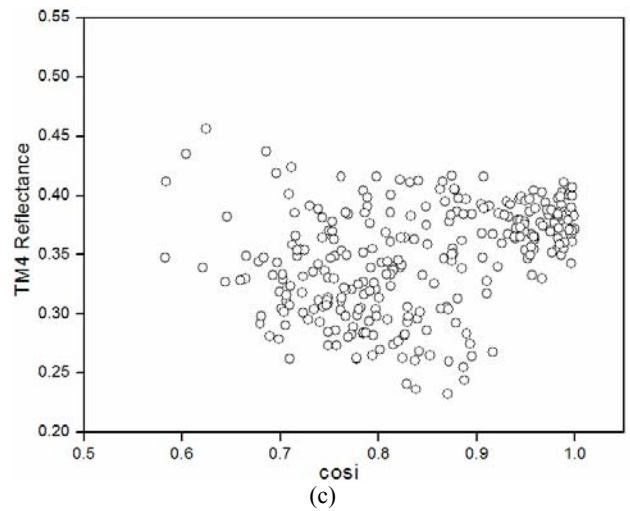

(a)
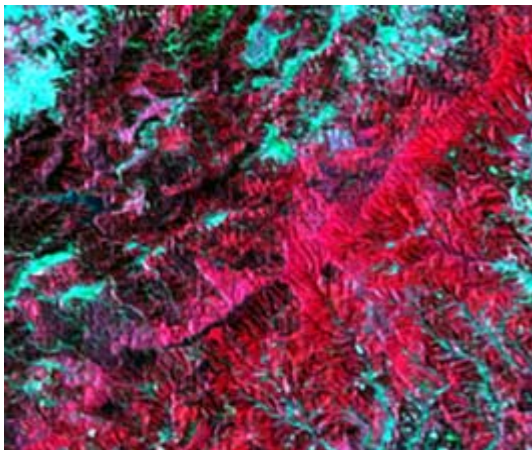
(b)

(c)

Figure 3. Comparison of reflectance false color image (TM4/3/2). (a) Before topographic correction. (b) Sandmeier's model. (c) Modified model.

(a)

(b)

(c)

Figure 4. Comparison of scatter plots of TM 4 reflectance vs. cosine of the solar incidence angle. (a) Before topographic correction. (b) Sandmeier's model. (c) Modified model.

3.2.1 Visual Analysis: Figure 3 presents the false colour images of, respectively, (a) atmospheric corrected image before topographic correction, (b) Sandmeier's model corrected image and (c) modified model corrected image. From Figure 3 (a), we can see a northeast-southwest ridge (labelled with a red circle in Figure 3 (a)). It is easy to distinguish that the southeast side of the ridge is the sun-facing slope and the northwest side is the slope facing away from the Sun. Due to the topographic effect, the brightness of the shaded slope is obviously lower than that of the sun-facing slope. By comparison of the three images, we can see that after correction by the two models, the brightness difference between the two sides of the ridge has been greatly removed. Additionally, in the upper left of the images, the information of some low-brightness pixels in the terrain shadow has been partially resumed. But it seems that the there are no significant visual differences between the results of the two models.

3.2.2 Statistical Analysis: In the experiment, 289 vegetation pixels were selected on the sunlit slopes and shaded slopes as sample pixels to quantitatively evaluate the result. The NDVI of each sample pixel is high that guarantee each of them representative of tree crowns.

The correlation analysis of pixel value (DN or reflectance) and illumination factor is an important method to analyse the terrain effect on remote sensing imagery. Illumination factor here is defined as the cosine of the solar incidence angle, which is the directly affected by topography. Figure 4 displays the relation of TM4 reflectance of the sample pixels and their illumination factors. Pixels with relatively low illumination factor present pixels on shaded slopes; and those with high illumination factor present pixels on sunlit slopes. Figure 4 suggests that:

1. As showed in figure 4 (a), before topographic correction, the reflectance on shady slopes (with illumination factor about 0.5~0.8) is clearly lower than the reflectance on sunlit slopes (with illumination factor about 0.8~1.0). In other words, the reflectance increases from shaded slopes to sunlit slopes. This trend explains the terrain impact on the remote sensing image.
2. After correction by the two models, the reflectance on the shaded slopes increases and the reflectance on the sunlit slopes decrease (see figure 4 (b) and (c)). So the both of the two models can greatly eliminate the topographic control on the reflectance. But by comparing (b) and (c), we can see that the variability of reflectance by Sandmeier's model is much greater than modified model. Considering the sample pixels are of the same cover type, which means the real reflectance of them will have a good coherence, so it can be said that the modified model performs better than Sandmeier's model on the coherence of reflectance.

Coherence of reflectance (or DN of pixel) is a commonly used index to evaluate the topographic correction efficiency. Good coherence of reflectance means low standard deviation of reflectance, so an ideal topographic correction result should mean decreasing of standard deviation of reflectance. Table 1 shows the comparison of mean and standard deviation of reflectance of the sample pixels in different TM bands. From the table, we can see that:
1. After correction by the two models, the mean of reflectance on the shaded slopes increases and that on the sunlit slopes decrease. But in visible band (TM1~ TM3), both of the two models have the problem of overcorrection,

which means the reflectance of shady slopes s higher than that of sunlit slopes after correction.
2. In the visible band, both of the two models (excluding the result by modified model in TM2), especially Sandmeier's model, did not decrease, but increase the standard deviation, which means not ideal topographic correction efficiency. Compared to Sandmeier's model, the degree of standard deviation increasing by modified model is smaller. In the near-infrared band (TM4, TM5 and TM7), both of the two models can decrease the standard deviation and the modified model performs better than Sandmeier's model.

		Before correction	*Sandmeier's model*	*Modified model*
T M 1	μ-sunlit	0.01290	0.01285	0.01197
	μ-shaded	0.01265	0.01531	0.01437
	σ	0.00115	0.00168	0.00165
T M 2	μ-sunlit	0.04084	0.04057	0.03826
	μ-shaded	0.03690	0.04502	0.04201
	σ	0.00400	0.00424	0.00386
T M 3	μ-sunlit	0.02411	0.02381	0.02183
	μ-shaded	0.02438	0.02995	0.02683
	σ	0.00258	0.00401	0.00392
T M 4	μ-sunlit	0.41571	0.40634	0.36933
	μ-shaded	0.29261	0.35214	0.33428
	σ	0.07316	0.05792	0.04437
T M 5	μ-sunlit	0.18850	0.18221	0.16470
	μ-shaded	0.14543	0.18203	0.16684
	σ	0.02679	0.02156	0.01640
T M 7	μ-sunlit	0.07851	0.07578	0.06849
	μ-shaded	0.06537	0.08199	0.07007
	σ	0.00985	0.00969	0.00857

Table 1. Comparison of mean and standard deviation of reflectance. μ-sunlit presents mean of reflectance of pixels on sunlit slopes. μ-shaded presents mean of reflectance of pixels on shaded slopes. σ presents standard deviation of reflectance.

4. CONCLUSION

This paper presents a topographic correction and reflectance retrieval model for optical satellite image of forested areas where tree crowns predominate. The model is developed by modifying Sandmeier's model. In this model, SCS correction is adopted to make the model applicable to tree canopy.

The modified model is validated using the ETM imagery in a forested area. The result of the experiment shows that the modified model can greatly remove the terrain effects on TM imagery, especially in the near-infrared band. Compared to Sandmeier's model, the modified model developed in this paper has a better performance. So we can conclude that the modified model is more applicable to remote sensing imagery in forest areas.

Further studies should be done to validate the modified model with other images and other study areas. Additionally, the two models should be combined to use for areas where there is a concurrence of bare surface and tree canopy.

REFERENCES

Colby, J. D., 1991. Topographic Normalization in Rugged Terrain. *Photogrammetric Engineering & Remote Sensing*, 57 (5), pp. 531-537.

Corporation of GEOSYSTEMS, 2006. User Manual for ATCOR for IMAGINE 9.1. http://www.geosystems.de/atcor/downloads/ATCOR_Manual_V91.pdf

C. Proy, D. Tanre, P. Y. Deschamps, 1989. Evaluation of Topographic Effects in Remotely Sensed Data. *Remote Sensing of Environment*, (30), pp. 21-32.

Gu D, Gillespie A., 1998. Topographic Normalization of Landsat TM Images of Forest Based on Subpixel Sun-Canopy-Sensor Geometry. *Remote Sensing of Environment*, 64, pp. 166-175.

Huang Wei, Zhang Liang-pei, Li Ping-xiang, 2006. A Topographic Correction Approach for Radiation of RS Images by Using Spatial Context Information. *Acta Geodaetica Et Cartographica Sinica*, 35(8), pp. 286-290.

J. Dozier, J. Frew, 1990. Rapid Calculation of Terrain Parameters for Radiation Modeling from Digital Elevation Data. *IEEE Trans. Geosci. Remote Sensing*, 28(5), pp. 963-969.

Kaufman, Y. J., Sendra, 1988. Algorithm for Automatic Atmospheric Correction to Visible and Near-ir Satellite Imagery. *International Journal of Remote Sensing*, 9(6), pp. 1357-1381.

Li Xin, Cheng Guo-dong, Chen Xian-zhang, 1999. A Modified Radiation Model of Rugged Terrain. *Chinese Science Bulletin*, 44(9), pp. 993-998.

Meyer P, Itten K. I., Kellenberger T., Sandmeier S., Sandmeier R., 1993. Radiometric Corrections of Topographically Induced Effects on Landsat TM Data in an Alpine Environment. ISPRS *Journal of Photogrammetry and Remote Sensing*, 48, pp. 17-28.

Smith, J. A., Lin, T. L., Ranson, K. J., 1980. The Lambertian Assumption and Landsat Data. *Photogrammetric Engineering & Remote Sensing*, 46 (9), pp. 1183-1189.

Scott A, Soenen, Derek R, et al., 2005. SCS+C: A Modified Sun-Canopy-Sensor Topographic Correction in Forested Terrain. *IEEE Trans. Geosci. Remote Sensing*, 43 (9), pp. 2148-2159.

Stefan Sandmeier, Klaus I. Itten, 1997. A Physically-Based Model to Correct Atmospheric and Illumination Effects in Optical Satellite Data of Rugged Terrain. *IEEE Trans. Geosci. Remote Sensing*, 18, pp. 1099-1111.

Teillet, P. M., 1986. Image correction for radiometric effects in remote sensing. *International Journal of Remote Sensing*, 7 (12), pp. 1637-1651.

Teillet, P.M., Guindon, B., Goodenough, D.G., 1982. On the Slope-Aspect Correction of Multispectral Scanner Data. *Canadian Journal of Remote Sensing*, 8 (2), pp. 84-106.

Tian Qing-jiu, Zheng Lan-fen, Tong Qing-xi, 1998. Image Based Atmospheric Radiation Correction and Reflectance Retrieval Methods. *Journal of Applied Meteorological Science*, 9 (4), pp. 456-461.

Yan Guang-Jian, Zhu Chong-Guang, Guo Ju, et al., 2000. A Model Based Radiative Transfer Algorithm to Correct Remotely Sensed Image in Mountainous Area. *Journal of Image and Graphics*, 5(1), pp. 11-15.