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PARAMETERIZATION OF BI-DIRECTIONAL REFLECTANCES FOR VEGETATION BY USING MULTI-TEMPORAL SPOT IMAGES

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ABSTRACT: - In this paper, the parameterization of bi-directional reflectances of vegetation is made possible by using multi-temporal SPOT satellite images. Five SPOT images scanned within two weeks are used. The woods near the Taichung port in central Taiwan are selected. An atmospheric correction model is applied to remove the atmospheric effect of the satellite images. Aerosol optical depth (AOD) is retrieved from dense dark target of the image. The linear bi-directional reflectance model developed by Roujean et al. (1992) is used to parameterization the bi-directional reflectances of woods. The results show that the standard error between simulated reflectance and atmospheric-effect-corrected BRF can be less than 0.01 in all three XS bands. By using this retrieved bi-directional reflectance model of vegetation, the bi-directional effect of vegetation can be reduced.

Keywords: bi-directional reflectance model, SPOT, vegetation

1. INTRODUCTION

The reflective characteristics of vegetation are important for many studies, such as yield estimation of crop, timber volume of forest, global radiation budget estimation. The dynamical changes of reflectance of vegetation can be derived from the multi-temporal satellite images. The surface reflectance image can be obtained, if the proper atmospheric correction model is available. Due to the anisotropy of natural surface, the surface reflectances on multi-temporal images can be different even the atmospheric effect of is corrected. Therefore, parameterization of the bi-directional effect of the vegetation canopy is necessary for studies of vegetation dynamical growth.

Bi-directional reflectance model can be used to model the bi-directional effect of reflectance of vegetation. Many models have been developed based on empirical, semi-empirical and physical approaches as discussed by many researchers (Lucht and Lewis, 2000; Dymond et al., 2001; Kalluri et al., 2001). Selection of models among the different approaches can be based on the application, e.g. inferring surface parameters such as LAI or derivation of albedo. An empirical approach cannot be used to infer physical parameters, whereas it can be applied to compute surface albedo, since the three approaches perform similarly (Kalluri et al., 2001). When the inversion of surface characteristics is a must, speed must be also an important factor to the consideration of the model, since most physical models are complex (with many parameters), non-linear and it's necessary to use high performance computing methodology to speed up the inversion (Kalluri et al., 2001). Semi-empirical approach can, therefore, have the advantage of easiness and speed to model the bi-directional reflectance of vegetation. These semi-empirical models include the kernel-driven model such as Ambrals BRDF model, which is used to generate BRDF datasets from EOS MODIS sensor (Wanner et al. 1995), Roujean model (Roujean et al. 1992) used to generate BRDF dataset from Polarization and Directionality of the Earth's Radiation (POLDER) instrument on ADEOS-1 (Lucht and Lewis, 2000).

The retrieved model parameters can be more sensitive to noises, such as angular sampling, compared to the reflectance and albedo (Lucht and Lewis, 2000). Even the model is accurate and the observed (or measured) bi-directional reflectances are in absence of noises, inaccurate parameters can be obtained when the sampling are in particular angle space (e.g. usually away from the solar principal plane) where the parameters are insensitive to these model parameters. Such a problem may be enhanced, if the model inadequacies and noises present in the bi-directional reflectances.

In this paper, we use multi-temporal SPOT satellite images to monitoring the bi-directional effect of vegetation and parameterize the effect through the use of BRDF model.

2. APPROACHES

2.1 Atmospheric correction of SPOT satellite images

The atmospheric effect is corrected by an image-based retrieval algorithm of aerosol characteristics and surface reflectances (Liu et al. 1996). Dense dark vegetation (DDV) targets are selected to retrieve the aerosol optical depth (AOD) of the SPOT images with (Liu 2001). Since the NDVI used to derive DDV is affected by the aerosol, this approach can be only applicable to the unifo rm atmospheric effect (Holben et al., 1992; Kaufman and Remer, 1994). The retrieved AOD can be as the input to the algorithm to correct the atmospheric effect and the adjacency effect.

2.2 Parameterization of bi -directional reflectances for vegetation

A linear kernel-driven model with three parameters developed by Roujean et al. (1992) is used to parameterize the reflectance differences due to viewing and solar geometries for vegetation. The bi-directional reflectance model can be written as follows:

$$r(\theta_s, \theta_v, \phi) = k_0 + k_1 f_1(\theta_s, \theta_v, \phi) + k_2 f_2(\theta_s, \theta_v, \phi) \tag{1}$$

where θ_s, θ_v, ϕ are the solar zenith angle, viewing zenith angle and relative azimuth angle, respectively. k_0 is the bi-directional reflectance for θ_s=θ_v=0, k_1 is the weight for geometric scattering kernel function f_1 and k_2 is the weight for volume scattering kernel function f_2. Because of its linearity and few parameters (only three), inversion of (1) is simple compared with many complex physical models (Andrieu et al. 1997; Gastellu-Etchegorry et al., 1996; Gobron et al., 1997; Li & Strahler, 1985, 1992). This semi-empirical model can be applicable to heterogeneous surfaces, and it is used to generate BRDF dataset from Polarization and Directionality of the Earth's Radiation (POLDER) instrument on ADEOS-1 (Lucht and Lewis, 2000).

To see the accuracy of the model, the standard error is computed as follows:

$$\text{Standard error} = \sqrt{\frac{\sum_{i=1}^{n} (r_i - \hat{r})^2}{n - p - 1}} \tag{2}$$

where $\hat{r}$ is the modeled reflectance, n is the number of observations and p is the number of parameters in model (Chang, 1994).

2.3 Multi-temporal SPOT satellite images dataset

Five SPOT satellite images, which is near Taichung port in central Taiwan are used in this study (table 1). Since these images are only within 12 days, canopies can be assumed to be invariant. Woods near the port are chosen to the study of the bi-directional reflectance effect and its parameterization of vegetation. Averaged bi-directional reflectance over 200m x 200m is computed to avoid the canopy mixture at the boundary pixels. The solar zenith angle θ_s differences (~4^0) are small compared to the viewing zenith angle θ_v (-19.3^0~30.7^0). Therefore, the differences of bi-directional reflectances of woods among these five images can be mainly attributed to viewing zenith angle effect. If $\phi<90^o$, the viewing direction is in backscattering region ($\theta_v<0$); on the contrary, if $\phi>90^o$, the viewing direction is in forescattering region ($\theta_v>0$).

3. ANALYSIS AND DISCUSSIONS

To retrieve the surface reflectances, the atmospheric effect must be correct and the AOD should be determined from the image if there's no ground measurement. The retrieved AODs range from 0.30~0.84, 0.22~0.68 in XS1 and XS2 bands, respectively (table 1). The corresponding visibility ranges from hazy to clear sky (4.9 km ~ 20.5 km). The retrieved Junge υ parameters range from 2.72~3.77. Nevertheless, these are not validated by the con-current ground measurements.

The estimated bi-directional reflectance of woods near Taichung port are also shown in table 1. Their relation with respect to view angle is also depicted in figure 1. Typical reflectance pattern of vegetation can be obtained after the atmospheric correction, although no ground measurements of surface reflectance are taken. In general, the bi-directional reflectance in back-scattering region (θ_v < 0) is larger than that in fore-scattering region (θ_v > 0).

Such trends are consistent with many researcher's meaurements (Kimes et al., 1985; Deering and Eck, 1987). The largest NIR reflectance(0.190) is at θ_v=-19.3^0 (scene 981102), whereas the smallest NIR reflectance(0.161) is at θ_v=+30.7^0 (scene 981111). Although the woods reflectances (0.060, 0.042 in green and red bands) on scene 98102 are smaller than those (0.068, 0.048 in green and red bands) on scene 981112 (θ_v=-7.3^0), the difference is within the error of the algorithm. Overall, woods bi-directional reflctances range from 0.030~0.068, 0.020~0.048, 0.161~0.190 in XS1-XS3 band. The absolute differences are 0.038, 0.028, 0.030, and the relative differences are 127.7%, 140.0%, 180.1% in three bands respectively. Thus, woods reflectance are sensitive to viewing angle changes.

Table 1. Retrieved aerosol optical depth, visibility (km) and Junge υ parameter and woods bi-directional reflectances from multi-temporal SPOT images.

SPOT images	θ_s [a]	θ_v [b]	ϕ [c]	Retrieved AOD/Bidirectional Reflectance			Visibility (km)	Junge ν
				XS1	XS2	XS3		
981101	39.37	17.88	120.19	0.30/0.053	0.22/0.039	0.14/0.163	20.5	3.77
981102	41.22	-19.25	53.12	0.77/0.060	0.63/0.042	0.46/0.190	5.4	3.18
981103	40.86	0.49	122.98	0.84/0.057	0.68/0.041	0.48/0.186	4.9	3.26
981111	41.88	30.67	116.34	0.52/0.030	0.46/0.020	0.38/0.161	9.1	2.72
981112	43.51	-7.28	56.75	0.58/0.068	0.44/0.048	0.28/0.184	8.0	3.66

[a]solar zenith angle.
[b]viewing zenith angle.
[c]absolute value of the relative azimuth between solar azimuth and viewing azimuth.

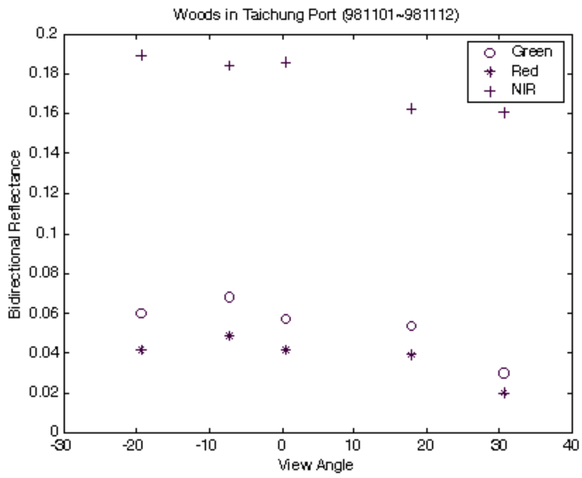

Figure 1. The bi-directional reflectance of woods with respect to view angle in XS1 (Green), XS2 (Red) and XS3 (NIR) bands

Table 2. Retrieved parameters of BRDF model for vegetated surface by using multi-temporal SPOT images.

Band	k0	k1	k2	R2	Standard Error
XS 1	0.1231	0.1124	-0.1124	0.81	0.013
XS 2	0.0944	0.0935	-0.1786	0.82	0.009
XS 3	0.2194	0.0594	0.2959	0.89	0.009

The bi-directional effect can be modeled by the bi-directional reflectance model, such as the linear kernel-driven model (Roujean et al. 1992) used here. Table 2 depicts the retrieved model parameters k0, k1, k2 as well as R2 and standard error which describe the accuracy of the model. The derived bi-directional reflectances after atmospheric correction also compare the simulated reflectance modeled by (1) using the retrieved parameters in table 2 (figure 2, figure 3 and figure 4). Although the k2 (weight of volume scattering component) in XS1 and XS2 bands are negative, the fitting is quite well since R2s are all larger 0.8 and the standard errors are around 0.01 in all bands. Such an error may be due to the noise, e.g. sparse sampling (Lucht and Lewis, 2000), besides the suitability of the model and the accuracy of the atmospheric correction model. Here, we have only use 5 images with one azimuth plane viewed by crossing-track viewing of SPOT satellite. Nevertheless, the retrieved albedo is expected to be more stable with noises as pointed by Lucht and Lewis (2000). By using this retrieved bi-directional reflectance model of vegetation, the bi-directional effect of vegetation can be reduced.

CONCLUSIONS

Through the use of multi-temporal SPOT satellite images and Roujean model, the parameterization of bi-directional reflectance of vegetation is made. In spite of the negative values of the retrieved k2 (weight of volume scattering component) in XS1 and XS2 bands, the modeling is quite well since the standard errors are low (~0.01 in all bands). Bidirectional effect of vegetation reflectance can be reduced through the use of this model.

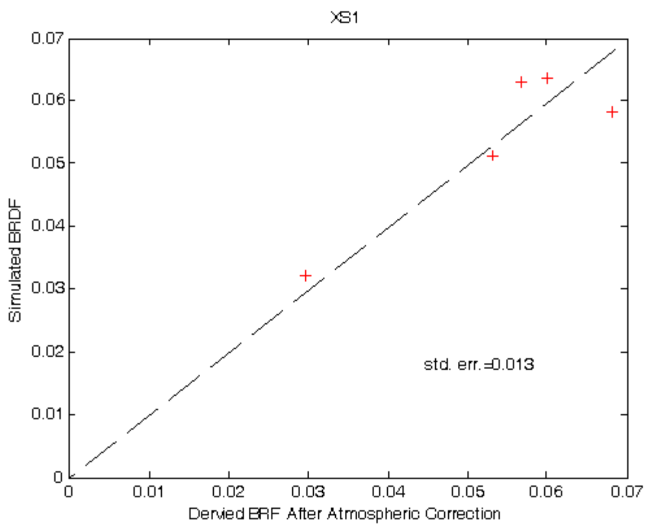

Figure 2. Comparison of derived bi-directional reflectance of woods and simulated bi-directional reflectance using the Roujean model using the retrieved parameters k0, k1, k2 in XS1 band

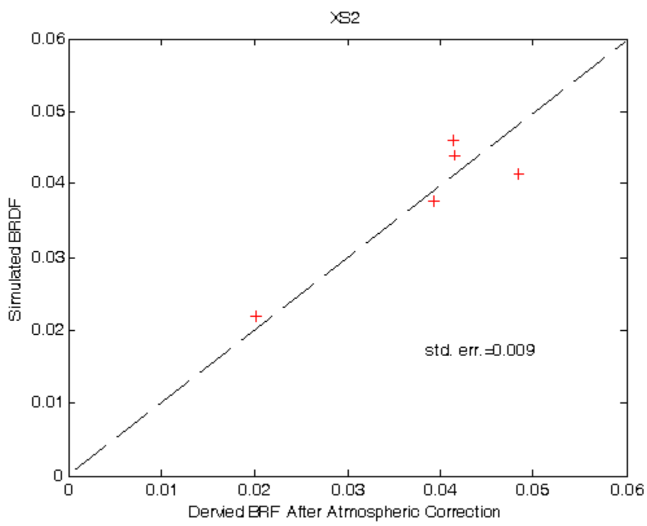

Figure 3. Same as figure 2, except in XS2 band.

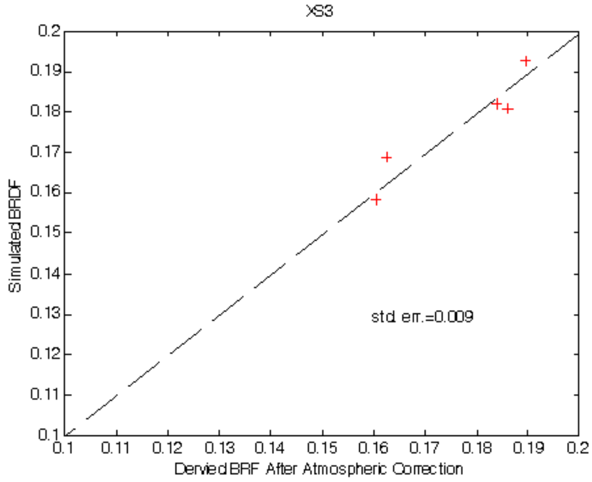

Figure 4. Same as figure 2, except in XS3 band.

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REFERENCES

Andrieu B., F. Baret, S. Jacquemoud, T. Malthus, and M. Steven, 1997, Evaluation of an improved version of SAIL model for simulating bi-directional reflectance of sugar beet canopies. Remote Sensing of Environment, 60, 247-257.
Chang J. B., 1994, Statistics, San-ming, Taipei (Chinese).
Deering, D. W. and T. F. Eck, 1987, Atmospheric optical depth effects on angular anisotropy of plant canopy reflectance, International Journal of Remote Sensing, 8, 893-916.
Dymond J. R., J. D. Shepherd, and J. Qi, 2001, A simple physical model of vegetation reflectance for standardizing optical satellite imagery, Remote Sensing of Environment, 75, 350-359.
Gastellu-Etchegorry, J. P., F. Zagolski and J. Rmoier, 1996, A simple anistropic reflectance model for homogeneous multi-layer canopies, Remote Sensing of Environment, 57, 22-38.
Gobron, N., B. Pinty, M. M. Verstraete, and Y. Govaerts, 1997, A sempi-discrete model for the scattering of light by vegetation, Journal of Geophysical Research, 102, 9431-9466.
Holben B. N., E. Vermote, Y. J. Kaufman, D. Tanre, and V. Kalb, 1992, Aerosols retrieval over land from AVHRR data-application for atmospheric correction, IEEE Transactions on Geoscience and Remote Sensing, 30, 212-222.
Kalluri S. N. V., Z. Zhang, J. Jaja, S. Liang and J. R. G. Townshend, 2001, Characterizing land surface anisotropy from AVHRR data at a global scale using high performance computing, Int. J. Remote Sens., 22, 2171-2191.
Kaufman Y. J. and L. A. Remer, 1994, Detection of forests using mid-IR reflectance: an application for aerosol studies, IEEE Trans. Geosci. and Remote Sens., 32, 672-683.
Kimes D. S. W. W. Newcomb, C. J. Tucker, I. S. Zonneveld, W. van Wijngaarden, J. de Leeuw, and G. F. Epema, 1985, Directional reflectance factor distributions for cover types of Northern Africa, Remote Sens. Environ., 18, 1-19.
Li X. and Strahler A. H., 1985, Geometrical-optical modeling of a coniferous forest canopy, IEEE Transactions on Geoscience and Remote Sensing, 23, 207-221.
Li X. and Strahler A. H., 1992, Geometrical-optical bi-directional reflectance modeling of mutual shadowing effects of crowns in a forest canopy, IEEE Transactions on Geoscience and Remote Sensing, 30, 276-292.
Liu C. H., A. J. Chen and G. R. Liu, 1996. An image-based retrieval algorithm of aerosol characteristics and surface reflectance for satellite images, International Journal of Remote Sensing, 17, 3477-3500.
Liu C. H., 2001, Validation of Aerosol Optical Depth Retrieved from SPOT Satellite Images, ACRS2001, this issue.
Lucht W., and P. Lewis, 2000, Theoretical noise sensitivity of BRDF and albedo retrieval from the EOS-MODIS and MISR sensors with respect to angular sampling, 21, 81-98.
Roujean J-L., M. Leroy and P.-Y. Deschamps, 1992, A bi-directional reflectance model of the earth's surface for the correction of remote sensing data, Journal of Geophysical Research, vol. 97, no.D18, 20455-20468.
Wanner W., X. Li, and A. H. Strahler, 1995, On the derivation of kernels for kernel-driven models of bi-directional reflectance, Journal of Geophysical Research, 100, 21077-21090.