VERIFICATION OF AN ALGORITHM TO ESTIMATE LAND SURFACE ALBEDO USING BRDF MODEL FOR GCOM-C/SGLI PRODUCT

Junichi Susaki[1], Ryota Miyagaki[1], Amane Kuriki[1]
[1]Kyoto University, C1-1-206, Kyotodaigaku-katsura, Nishikyo-ku, Kyoto 615-8540, Japan,
Email: susaki.junichi.3r@kyoto-u.ac.jp

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ABSTRACT: In this paper, we report the results of verifying terrestrial albedo estimated by using bidirectional reflectance distribution function (BRDF) model from the bidirectional reflectance factor (BRF) data measured in situ. Our goal is to develop an algorithm used for the product of Global Change Observation Mission – Climate 1 (GCOM-C1) / Second generation Global Imager (SGLI), that is scheduled to launch in 2016 by Japan Aerospace Exploration Agency (JAXA), Japan. We started in situ measurement of terrestrial albedo and BRF from visible to infrared wavelengths, and examined the application of an algorithm used for Moderate Resolution Imaging Spectroradiometer (MODIS) product to the data. We estimated BRDF for bare land and grassland, respectively, and used the BRDF model parameters to estimate terrestrial albedo. It was found that the algorithm to estimate terrestrial albedo via kernel-driven BRDF model is effective for the bands designed for MODIS. Because the data available are not enough to derive a regression model of albedo for SGLI, in near future, we'll do it after we increase the number of samples and investigate the effectiveness of the approach to generate terrestrial albedo.

1. INTRODUCTION

Japan Aerospace Exploration Agency (JAXA) initiated "Global Change Observation Mission" (GCOM) to observe data on a global-scale for analyzing global climate change and water circulation mechanisms. Global Change Observation Mission – Climate 1 (GCOM-C1) is scheduled to launch in 2016, and the Second generation Global Imager (SGLI) onboard GCOM-C1 is expected to measure reflectance and radiation in the region of visible to infrared wavelengths.

Land covers have anisotropic reflectance characteristics, called the bidirectional reflectance distribution function (BRDF). Analysis of BRDF might contribute to the derivation of albedo from an angular integration of the BRDF. The albedo products of Moderate Resolution Imaging Spectroradiometer (MODIS) sensor are generated by taking this BRDF-driven approach for estimating terrestrial albedo. Among many BRDF models proposed, kernel-driven BRDF models are regarded as robust semiempirical BRDF models and are applicable to any type of land cover. The kernel is a function determined by viewing and illumination geometries. The current common estimation approach from multispectral satellite observations is composed of a series of processing steps, typically including atmospheric correction for estimating land surface directional reflectance, angular modeling for calculating spectral albedos, and narrowband-to-broadband albedo conversions. In this paper, we report the measurement of terrestrial albedo and bidirectional reflectance factor (BRF) and validation of the albedo estimated via kernel-driven BRDF model. Section 2 describes an algorithm to estimate albedo. Section 3 explains study areas in this research. After the experimental results are reported in Section 4, they are discussed in Section 5. Finally, Section 6 concludes this paper.

2. ALBEDO ESTIMATION ALGORITHM

Albedo can be defined as a ratio of the upward flux to the downward flux on a semi-sphere over a point of interest. The range of wavelength depends on the type of albedo. For example, shortwave albedo usually targets a range of 0.3 to 5.0 μm. Figure 1 shows the flowchart of an algorithm to generate broadband albedo from spaceborne multi-angular data. Top-of-atmosphere (TOA) radiance is converted into surface spectral reflectance via atmospheric correction, e.g. second simulation of the satellite signal in the solar spectrum (6S) (Vermote et al., 1997). Spectral albedo is generated by referring to BRDF angular model. Finally, broadband albedo is estimated as a linear combination of multiple spectral albedos. This conversion is expressed as narrowband-to-broadband (NTB) conversion. Hereafter, the terminologies and ideas to achieve the broadband albedo estimation are described.

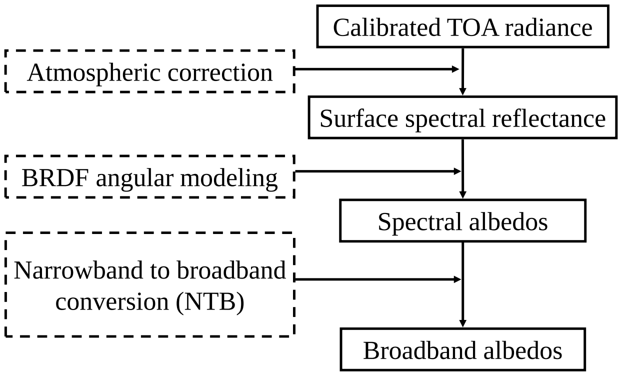


Figure 1. Algorithm for estimating broadband albedo using kernel-driven BRDF model from spaceborne sensor

2.1 Kernels

A kernel used for estimating BRDF and terrestrial albedo is a function of bidirectional reflectance determined by viewing and illumination geometries. In general, we consider two types of scatterings observed from an object on the terrestrial surface: volumetric and geometric scatterings.

2.1.1 Volume scattering kernel: Ross (1981) developed a kernel of the directional reflectance above a horizontally homogeneous plant canopy. Roujean *et al.* (1992) derived the Ross-Thick kernel, expressed by Equation (1):

$$K_{vol}(\theta_i, \theta_v, \phi) = \frac{(0.5\pi - g)\cos g + \sin g}{\cos\theta_i + \cos\theta_v} - \frac{\pi}{4}. \quad (1)$$

Here, θ_i, θ_v and ϕ are solar zenith angle, viewing zenith angle and relative azimuth angle of solar and viewing directions, respectively. g is a phase angle of scattering expressed by Equation (2):

$$\cos g = \cos\theta_i \cos\theta_v + \sin\theta_i \sin\theta_v \cos\phi \quad (2)$$

This Ross-Thick kernel is designed to apply to the areas with large LAI values, and it does not consider hotspot effects.

2.1.2 Geometric scattering kernel: Geometric scattering kernel calculates scattering from sunlit objects, shaded objects, sunlit background and shaded background. For example, tree crowns are approximated as spheroids, and the surface scattering can be calculated. We introduce as a popular geometric scattering kernel Li-Sparse kernel expressed by Equation (3):

$$K_{geo}(\theta_i, \theta_v, \phi) = O(\theta_i, \theta_v, \phi) - \sec\theta_i' - \sec\theta_v' + \frac{1}{2}(1 + \cos g')\sec\theta_i' \sec\theta'. \quad (3)$$

where

$$O = \frac{1}{\pi}\left(\arccos X - X\sqrt{1 - X^2}\right)(\sec\theta_i' + \sec\theta_v') \quad (4)$$

$$X = \frac{h}{b}\frac{\sqrt{D^2 + (\tan\theta_i' \tan\theta_v' \sin\phi)^2}}{\sec\theta_i' + \sec\theta_v'} \quad (5)$$

$$D = \sqrt{\tan^2 \theta_i' \tan^2 \theta_v' - 2\tan\theta_i' \tan\theta_v' \cos\phi} \tag{6}$$

$$\cos g' = \cos\theta_i' \cos\theta_v' + \sin\theta_i' \sin\theta_v' \cos\phi \tag{7}$$

$$\theta' = \tan^{-1}\left(\frac{b}{r}\tan\theta\right) \tag{8}$$

Here, h is the height of the center of the spheroid. b and r are the vertical and horizontal radii of the spheroid, respectively. In MODIS products, h/b and b/r are set to 2 and 1, respectively.

2.2 Estimation of Kernel-driven BRDF Model Parameters

Semi-empirical kernel-driven BRDF model, expressed by Equation (3), has been used for the operational BRDF and albedo products of MODIS:

$$R(\theta_i, \theta_v, \phi) = f_{iso} + f_{vol}K_{vol}(\theta_i, \theta_v, \phi) + f_{geo}K_{geo}(\theta_i, \theta_v, \phi) \tag{9}$$

Here, f_{iso}, f_{vol} and f_{geo} are unknown coefficients. Users can select any combination of kernels of volume and geometric scatterings. In this research, we select a popular combination, i.e. Ross-Thick kernel for volume scattering and Li-Sparse kernel for geometric scattering. Values of kernels can be determined once illumination and viewing geometry are given. Three unknown coefficients are determined by minimizing the least squares error function, expressed by Equation (10):

$$\frac{1}{n}\sum_{j=1}^{n}\varepsilon_j^2 = \frac{1}{n}\sum_{j=1}^{n}\left(r_j - \left(f_{iso} + f_{vol}K_{vol}(\theta_{i,j}, \theta_{v,j}, \phi_j) + f_{geo}K_{geo}(\theta_{i,j}, \theta_{v,j}, \phi_j)\right)\right)^2 \tag{10}$$

Here, n denotes the number of samples, and r denotes the observed reflectance. In operational application, MODIS BRDF products are produced in the following procedure. If at least seven cloud-free observations of the surface are available during a 16-day period, a full model inversion is attempted. The available data are first evaluated in order to discard outliers, and additional checks are performed in order to assure that the kernel weights are positive. If the data pass these evaluations, a full inversion, or a normal inversion, is performed in order to establish the BRDF parameter weights that provide the best RMSE fit (Strahler *et al*., 1999).

2.3 Narrowband Albedo Estimation

With the estimated BRDF model parameters, we estimate black-sky and white-sky albedos. The black-sky albedo is a virtual albedo in the absence of a diffuse component. The white-sky albedo is also a virtual albedo in the absence of a direct component when the diffuse component is isotropic. The black-sky and white-sky albedos are expressed by Equations (11) and (12), respectively.

$$a_{bs}(\theta_i, \lambda) = \sum f_k(\lambda) h_k(\theta_i) \tag{11}$$

$$a_{\mathrm{ws}}(\lambda) = \sum f_k(\lambda) H_k \tag{12}$$

where

$$h_k(\theta_i) = g_{0k} + g_{1k}\theta^2 + g_{2k}\theta^3 \tag{13}$$

$$H_k = 2\int_0^{\pi/2} h_k(\theta_i) \sin\theta \cos\theta d\theta \tag{14}$$

The coefficients used in Equations (13) and (14) are shown in Table 1.

Table 1. Coefficients used for calculating black-sky and white-sky albedos (Lucht *et al.*, 2000)

Term g_{ik} for kernel k	k=Isotropic	k=RossThick	k=LiSparse
g_{0k}	1.0	-0.007574	-1.284909
g_{1k}	0.0	-0.070987	-0.166314
g_{2k}	0.0	0.307588	0.041840
white-sky integral	1.0	0.189184	-1.377622

As shown in Equation (15), actual albedo a (λ) at wavelength λ is expressed as a linear combination of black-sky and white-sky albedos by using atmospheric optical depth τ (λ).

$$a(\lambda) = S(\theta_i, \tau(\lambda))a_{\mathrm{ws}}(\lambda) + (1 - S(\theta_i, \tau(\lambda)))a_{bs}(\theta_i, \lambda) \tag{15}$$

Here, S denotes a fraction of diffuse skylight.

2.4 Narrowband-to-Broadband Conversion

Broadband albedo is estimated as a linear regression model of several narrowband albedos (Liang, 2000). Liang (2004) introduces conversion formulas for various optical sensors. The broadband albedos produced by these formulas achieve the uncertainty of approximately 0.02 (Liang *et al.*, 2002). For example, the formula for estimating shortwave albedo from MODIS data is expressed by Equation (16):

$$a_{\mathrm{SW}} = 0.160a_1 + 0.291a_2 + 0.243a_3 + 0.116a_4 + 0.112a_5 + 0.081a_7 \tag{16}$$

Here, a_i denotes narrowband albedo derived from reflectance of band i.

4. DATA USED

We selected school yards in Kyoto, Japan as study areas because they are homogeneous. Two of them are bare soil and one is covered with short grass, approximately 2 to 3 cm height of grass. The details of the study areas are listed in Table 2. For the reference, we measured volumetric soil moisture. The images of the areas are shown in Figure 2.

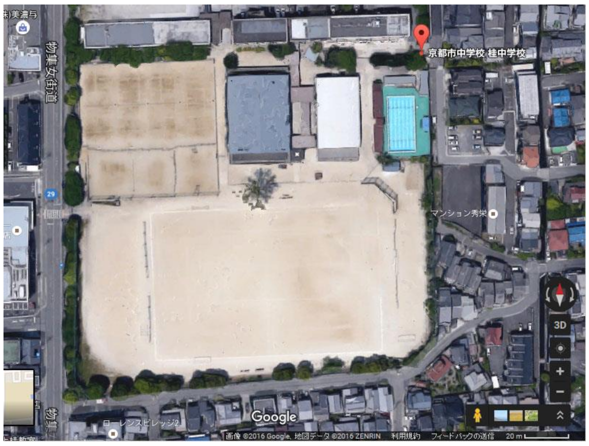
Table 2: Details of study areas

Name of school	Arashiyama Elementary School	Katsura Junior High School	Kuretake Special Support School
Measurement date	August 19, 2016	August 18, 2016	August 1, 2016
Landcover	Bare soil	Bare soil	Grassland
Volumetric soil moisture (%)	9.0	4.9	19.4

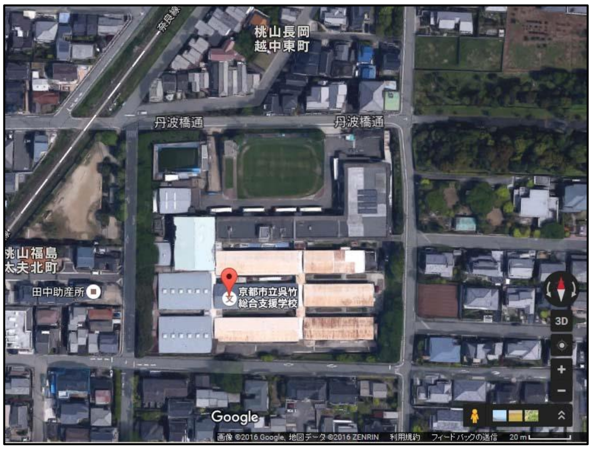
5. RESULTS

We measured BRF from 300 nm to 2,500 nm of wavelength by using Field Spec 3 in three study areas. In the measurement of BRF, we set relative azimuth angle of solar and viewing directions to 15°, 45°, 90°, 135° and 180° to save the measurement time. The reason why we set it to 15° instead of 0° was to avoid contamination of shadow of the equipment. We also measured broadband albedo from 300 nm to 3,000 nm of wavelength by using MR-60, a spectrometer manufactured by EKO Instruments, Japan. Table 3 shows broadband albedo measured and estimated by kernel-driven BRDF model. The wavelengths of bands correspond to those of MODIS.

(a)



(b)



(c)

Figure 2. Study area. (a) Arashiyama, (b) Katsura, and (c) Kuretake (GoogleEarth)

Table 3: Broadband albedo measured and estimated by kernel-driven BRDF model. The wavelengths of bands correspond to those of MODIS.

Albedo		Arashiyama (bare soil)	Katsura (bare soil)	Kuretake (grassland)
Narrowband (Measured)	Band1	0.264	0.340	0.048
	Band2	0.298	0.408	0.425
	Band3	0.162	0.223	0.029
	Band4	0.227	0.304	0.073
	Band5	0.344	0.438	0.460
	Band6	0.366	0.481	0.319
	Band7	0.356	0.422	0.142
Broadband	Estimated	0.262	0.297	0.209
	Measured	0.230	0.315	0.203

6. DISCUSSION

In this research, we estimated shortwave albedo from in situ measured BRF data. Table 3 shows the errors between the estimated albedos and the measured albedos are acceptable. It means that the algorithm to estimate shortwave albedo via kernel-driven BRDF model is applicable.

In this occasion, we measured three points, and it is not enough to derive a NTB conversion formula designed to SGLI bands. In future, we will increase the number of observations at bare soil and vegetated areas. With these data sets, we'll derive the formula and assess the performance. Note that the BRDF model parameter estimation is not always stable, depending on the number of observations and angular sampling. It is possible that some coefficients estimated of Equation (9) are negative, which is theoretically impossible. We will investigate an approach to improve the stability of the BRDF model parameter estimation.

7 CONCLUSIONS

In this paper, we report the results of verifying terrestrial albedo estimated by using BRDF model from the BRF data measured in situ. We estimated BRDF for bare land and grassland, respectively, and used the BRDF model parameters to estimate terrestrial albedo. It was found that the algorithm to estimate terrestrial albedo via kernel-driven BRDF model is effective for the bands designed for MODIS. In near future, we'll derive a formula designed for SGLI after we increase the number of samples and investigate the effectiveness of the approach to generate shortwave albedo.

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