International Journal of Remote Sensing
Vol. 26, No. 5, 10 March 2005, 1019–1025

VIIRS narrowband to broadband land surface albedo conversion: formula and validation

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(*Received 27 February 2004; in final form 14 June 2004*)

This Letter presents a formula for calculating broadband albedo (0.4–4.0 μm) of land surfaces from Visible/Infrared Imager/Radiometer Suite (VIIRS) spectral albedos. It is based on extensive radiative transfer simulations and multivariate regression analysis. Ground measurements from several test sites confirm that the conversion formula is very accurate. The VIIRS will be launched in 2006, and this formula has been adapted as part of the VIIRS albedo retrieval algorithm.

1. Introduction

Albedo is a critical variable for accurate climate and surface energy balance studies (Liang 2003a). Different sensors have been built which have the capability to map land surface albedo, such as the Advanced Very High Resolution Radiometer (AVHRR), Moderate Resolution Imaging Spectroradiometer (MODIS), the Multi-angle Imaging Spectroradiometer (MISR), the Along Track Scanning Radiometer (ATSR), and Polarization and Directionality of the Earth's Reflectances (POLDER). The Visible/Infrared Imager/Radiometer Suite (VIIRS), the primary visible and infrared sensor, is to be flown onboard the platforms of the National Polar-orbiting Operational Environmental Satellite System (NPOESS) and the NPOESS Preparatory Project (NPP). It follows its predecessor MODIS. The VIIRS albedo algorithm will leverage the algorithm's technological progress to provide an operational albedo product that will build and improve upon an already burgeoning heritage. It uses a two-tiered strategy: a MODIS-like approach for dark surfaces (e.g. vegetation) (Lucht *et al.* 2000, Schaaf *et al.* 2002), and a regression approach for bright surfaces (e.g. desert and snow) (Liang 2003b).

The MODIS heritage algorithm for retrieval of the VIIRS Surface Albedo product over dark surfaces consists of three basic steps: atmospheric correction that converts top-of-atmosphere radiance to surface spectral reflectance; bidirectional reflectance distribution function (BRDF) modelling to convert spectral reflectance to spectral albedo; and statistical conversion from narrowband to broadband albedos. This Letter addresses the last step for all surface types. Since the VIIRS will be the primary sensor for mapping land surface albedo in the next decade, documenting the algorithm development and validation of the conversion formula is

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International Journal of Remote Sensing
ISSN 0143-1161 print/ISSN 1366-5901 online
http://www.tandf.co.uk/journals
DOI: 10.1080/01431160512331340156

valuable for the future algorithm upgrades and also very helpful for the users of the albedo product.

Converting narrowband albedos to broadband albedo has been a research issue in remote sensing for a long time, since most sensors suitable for albedo mapping are outfitted with narrow spectral bands (Liang 2001, 2003a). The broadband albedo mainly depends on surface reflectance spectra, but is also affected by the atmospheric conditions. The main objective of this study is to predict average shortwave broadband albedo (0.4–4.0 μm) of all surface types, under general atmospheric conditions, using VIIRS narrowband albedos.

All previous studies on developing conversion formulae were based on either field measurements of certain surface types or model simulations. It is impossible to develop a universal formula based only on ground measurements because it is so expensive to collect extensive field datasets under different atmospheric and surface conditions. Model simulation is a better approach to develop universal conversion formulae, though ground measurements are certainly valuable for validation. Earlier studies using model simulations consider only a small set of atmosphere and surface conditions. Liang (2001) extended this by taking into account comprehensive conditions for a variety of sensors, and the validation results using ground measurements verify that the resulting formulae are very accurate (Liang *et al.* 2003a). The same algorithm is employed in this study, which is briefly described in §3 after discussing the characterization of VIIRS sensor in §2. The resulting formula and validation results are presented in §4, and a short summary is presented in the last section.

2. VIIRS characteristics

The VIIRS collects radiometric data from the visible to thermal infrared spectrum from a nominal altitude for the NPOESS/NPP satellites of about 833 km. The data will be used for studies of atmosphere, clouds, Earth radiation budget, clear-air land/water surfaces, sea surface temperature, ocean colour, and low light visible imagery. It has multiple bands between 0.4 and 12.5 μm (see table 1), with spatial resolution from 375 m and 750 m at nadir to 800 m and 1600 m at the edge of the scan for Imagery Bands and Moderate Bands, respectively. Shortwave broadband albedo will be derived using the moderate bands M1–M5, M7–M8 and M10–M11. Bands M6 and M9 are not used for the land surface measurement because they are originally designed for ocean observations and the signal will be mostly saturated over land.

The VIIRS scan will extend to 56° on either side of nadir. It is designed and built by Raytheon Santa Barbara Remote Sensing (SBRS), who also built MODIS. The VIIRS will be first flown onboard the NPP satellite, which will be launched by NASA in late 2006.

3. Algorithm development and results analysis

The basic procedure of the algorithm development is composed of two steps. The first step is to conduct extensive radiative transfer simulations using the Santa Barbara DISORT Atmospheric Radiative Transfer (SBDART) code (Ricchiazzi *et al.* 1998). The second step is to perform a multivariate regression analysis.

The key element of the radiative transfer simulation is the inclusion of representative surface reflectance spectra in this study. We employed 279 surface

Table 1. VIIRS band specifications.

Band name	Central wavelength (nm)	Band width (nm)	Wavelength region
M1	412	20	VIS
M2	445	18	VIS
M3	488	20	VIS
M4	555	20	VIS
M5	672	20	VIS
M6	746	15	NIR
M7	865	39	NIR
M8	1240	20	SWIR
M9	1378	15	SWIR
M10	1610	60	SWIR
M11	2250	50	SWIR
M12	3700	180	MWIR
M13	4050	155	MWIR
M14	8550	300	LWIR
M15	10763	1000	LWIR
M16	12013	950	LWIR
DNB	700	400	VIS
I1	640	80	VIS
I2	865	39	NIR
I3	1610	60	SWIR
I4	3740	380	MWIR
I5	11450	1900	LWIR

reflectance spectra, including representative soil (43), vegetation canopy (115), water (13), wetland and beach sand (4), snow and frost (50), urban (26), road (15), rock (4) spectra and those of other cover types (9). Each has different wavelength dependences and magnitudes, from coastal water (low albedos) to snow and frost (high visible albedos). Eleven atmospheric visibility values (2, 5, 10, 15, 20, 25, 30, 50, 70, 100 and 150 km) were used for different aerosol loadings, and five atmospheric profiles of MODTRAN defaults (tropical, mid-latitude winter, sub-arctic summer, sub-arctic winter and US62) that also represent different water vapour and other gaseous amounts and profiles were utilized. A range of nine solar zenith angles was simulated from 0° to 80° at 10° increments. SBDART was run at 231 spectral ranges with the increased wavelength increment from 0.0025 μm at the shortest.

In the second step, a linear regression analysis is used to produce the conversion formula. The simulation outputs include total shortwave albedo and spectral albedos that are calculated by incorporating the sensor spectral response functions. The procedure is straightforward. Although we explored nonlinear regression analysis, linear regression seems sufficient.

Two indices were used to measure the goodness of fit from any standard multiple regression analysis: a multiple R^2 value indicating the correlation between the predicted and the measured broadband albedos and residual standard error (RSE) indicating the deviation of the points from the regression line.

The resulting linear equation for converting the VIIRS narrowband albedos ρ_i to broadband total shortwave albedo ρ is:

$$\begin{aligned}\rho = {} & 0.0948\rho_{M1} + 0.2294\rho_{M2} - 0.2323\rho_{M3} + 0.2785\rho_{M4} \\ & + 0.1580\rho_{M5} + 0.2775\rho_{M7} + 0.0945\rho_{M8} + 0.0939\rho_{M10} + 0.0239\rho_{M11}\end{aligned} \tag{1}$$

The fit with the simulation results is very good (see figure 1): $R^2=0.999$ and RSE=0.0074.

4. Validation

It is evident from figure 1 that linear regression equation (1) can summarize the simulated data extremely well. However, it does not mean this formula is perfect for actual applications. Theoretical simulation may not represent the reality very well, so validation using independent ground measurements is critical.

We need independent datasets to verify the validity of the fitted formula. Two datasets have been used in this study. The first one was collected over Beltsville, Maryland, and used in our previous studies (Liang *et al.* 2003a). The second dataset was collected over Tucson, Arizona, in 2003.

The method and the procedure of the field measurements have been described in our published papers (Liang *et al.* 2002, 2003a, b). The general idea of the field campaign is to use both spectroradiometers for reflectance spectra and albedometers for broadband albedos simultaneously over different cover types. The measured reflectance spectra are converted to broadband albedo using the regression equation (1), which is then compared with the measured broadband albedo.

Note that the VIIRS broadband albedo does not contain ultraviolet (UV) information since it starts from 400 nm, but the albedometers we used are sensitive to the total shortwave from UV. After comparing the VIIRS broadband albedo and the total shortwave albedo from our simulated datasets, we found that their difference is not large, varying from −0.0165 to 0.0282 (see figure 2). The total shortwave albedos generally are larger for soil and vegetation surfaces, and smaller for snow surfaces.

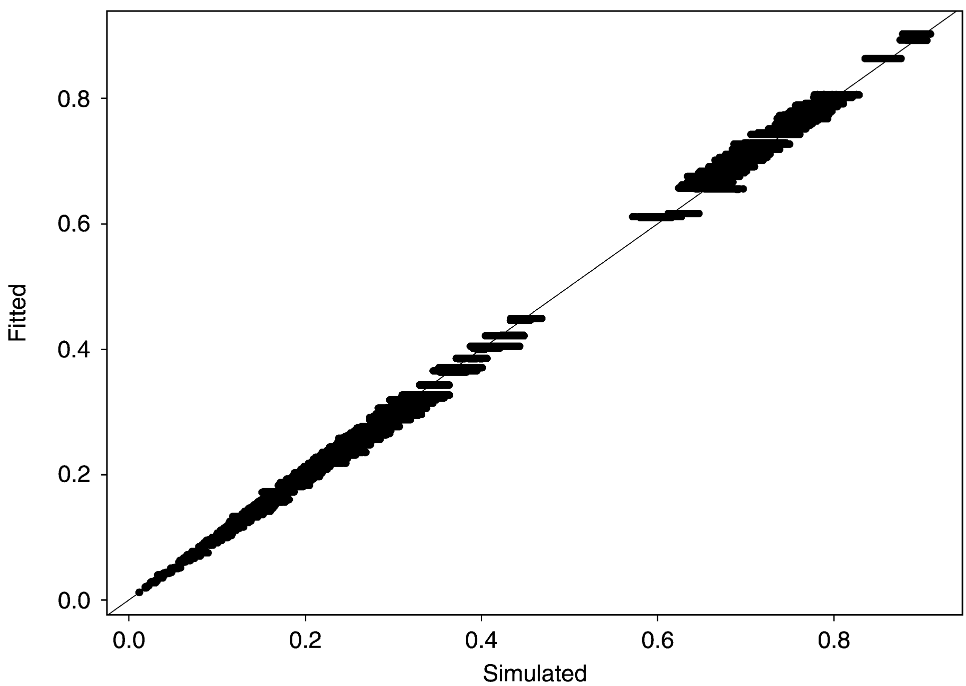

Figure 1. Fitting results of broadband albedo using equation (1).

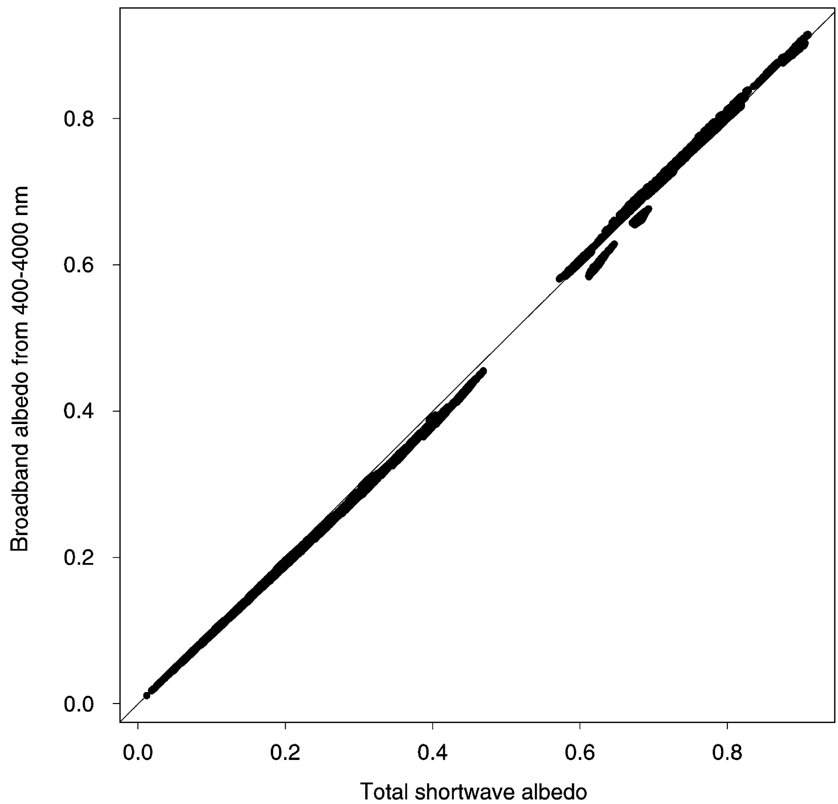

Figure 2. Simulated relationship between the total shortwave albedo and the VIIRS broadband albedo (0.4–4.0 μm).

All field measurements in the first dataset were taken from May 2000 to March 2001 in a validation site located north-east of Washington, DC, covering NASA Goddard Space Flight Center (GSFC) and US Department of Agriculture (USDA) Beltsville Agricultural Research Center (BARC), an area of diverse soils, crops and natural vegetation cover. The second dataset was collected in October 2003, over a semi-arid area also with different cover types. At both sites, two albedometers (one for total shortwave albedo and another for total near-infrared albedo) and the Field Spec Pro, Analytical Spectral Devices (ASD) hand-held spectroradiometer were used to measure surface reflectance spectra and broadband albedos simultaneously over different cover types. Each albedometer consists of two CM21 pyranometers with one pointing up and another down.

After acquiring ground measurements, data analysis is straightforward. The measured reflectance spectra were integrated with sensor spectral response functions to generate the spectral albedos, which were then further converted using the conversion formula (1). The converted broadband albedos were finally compared with the measured broadband albedos.

The results that indicated that the regression formula developed in this study is very good. The two measures of uncertainty are R^2=0.94 and the RSE=0.0195. The details are shown in figure 3. This is consistent with the fitting results from the simulation dataset.

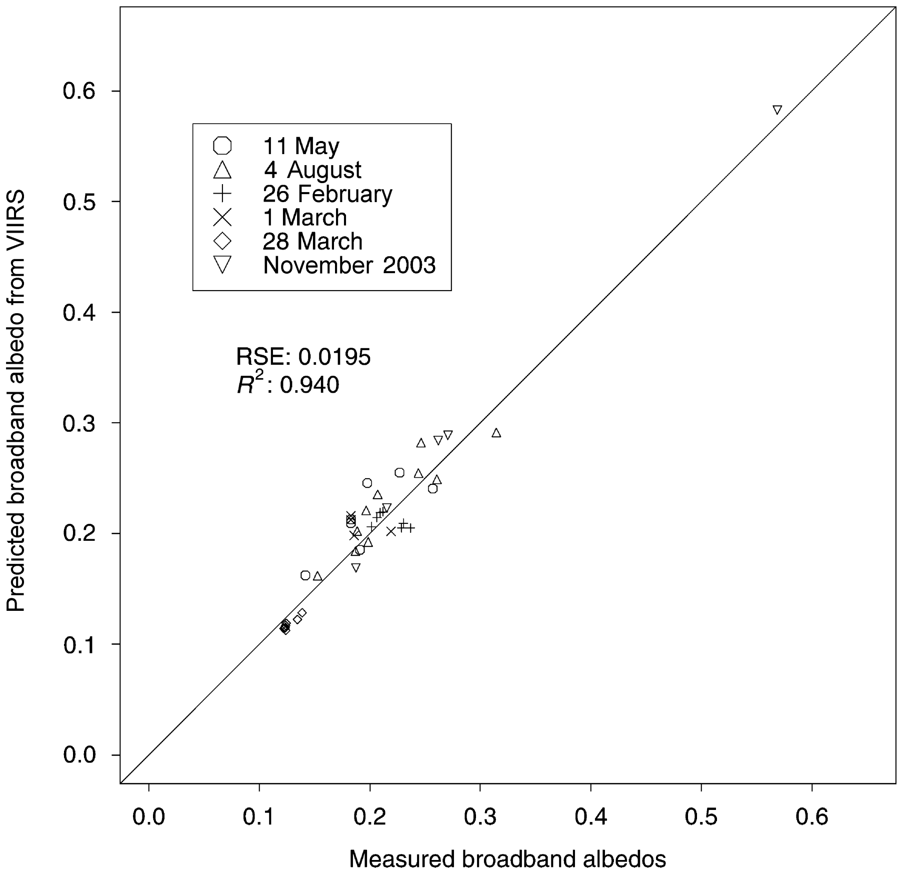

Figure 3. Validation results of equation (1) using ground measurements.

5. Conclusion

The VIIRS narrowband to broadband albedo conversion formula is developed in this study based on extensive radiative transfer simulations and multivariate regression analysis, a procedure that has been used for MODIS, Advanced Land Imager and other sensors. The validation using independent ground measurements verifies that this equation is very accurate with RSE smaller than 0.01 for the simulated data and 0.02 for the ground measurement data.

The formula described in this letter has been adapted by the VIIRS land algorithm team at Raytheon Information Technology Company for implementation of VIIRS surface albedo algorithm.

Acknowledgments

This work is partially supported by the NPOESS VIIRS continuation contract (subcontract no. 47974DGM2S). The authors thank the anonymous reviewers for their valuable comments and suggestions.

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