Retrieval of Land Surface Albedo from Satellite Observations: A Simulation Study

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ABSTRACT -- Surface albedo retrieved from satellite observations at one atmospheric condition may not be suitable for application to other atmospheric conditions. In this paper the authors separate the apparent surface albedo from the inherent surface albedo, which is independent of atmospheric conditions, based on extensive radiative transfer simulations under a variety of atmospheric conditions. The conversion coefficients of the surface inherent narrowband albedos derived from the MODIS (Moderate-Resolution Imaging Spectroradiometer) and the MISR (Multiangle Imaging Spectroradiometer) instruments to the surface broadband inherent albedo are reported. A new approach of predicting broadband surface inherent albedos from MODIS or MISR TOA (top of atmosphere) narrowband albedos using a neural network is proposed.

I. DEFINITIONS OF ALBEDOS

Let's first define the surface spectral inherent albedo $\rho_I(\theta_i;\lambda)$ at any solar zenith angle θ_i and wavelength λ:

$$\rho_I(\theta_i;\lambda) = \frac{1}{\pi}\int_0^1\int_0^{2\pi} R(-\theta_i,\theta,\phi)\mu d\mu d\phi \qquad (1)$$

where $\mu = \cos(\theta)$, and $R(-\theta_i,\theta,\phi)$ is the bidirectional reflectance factor (BRF). BRF is the sole measure of the surface reflectivity at the viewing direction given specific direct illuminations.

Spectral apparent albedo (ρ_A) is defined as the ratio of upwelling irradiance $F_u(\theta_i;\lambda)$ to downward irradiance $F_d(\theta_i;\lambda)$ at the solar zenith angle θ_i:

$$\rho_A(\theta_i;\lambda) = \frac{F_u(\theta_i;\lambda)}{F_d(\theta_i;\lambda)} \qquad (2)$$

It is a function of the atmospheric conditions.

Apparent albedo in any waveband is defined similarly

$$\rho_A(\theta_i;\Lambda) = \frac{F_u(\theta_i;\Lambda)}{F_d(\theta_i;\Lambda)} = \frac{\int_{\lambda_1}^{\lambda_2} F_u(\theta_i;\lambda)d\lambda}{\int_{\lambda_1}^{\lambda_2} F_d(\theta_i;\lambda)d\lambda} \qquad (3)$$

where Λ is denoted to be the waveband from wavelength λ_1 to wavelength λ_2 ($\Lambda \in (\lambda_1, \lambda_2)$). If $\Lambda \in (0.25\mu m - 5.0\mu m)$, $\rho(\theta_i;\Lambda)$ is the total shortwave broadband albedo. The waverange $\Lambda \in (0.4\mu m - 0.7\mu m)$ and $\Lambda \in (0.7\mu m - 5.0\mu m)$ correspond to visible and near-infrared albedos, respectively. Note that albedo is a dimensionless quantity. From the above definition, we can see that apparent albedo in any waveband is an average of that at every wavelength $\rho_A(\theta_i;\lambda)$ weighted by the proportional spectral downward irradiance:

$$\rho_A(\theta_i;\Lambda) = = \int_{\lambda_1}^{\lambda_2} \frac{F_d(\theta_i;\lambda)}{F_d(\theta_i;\Lambda)}\rho_A(\theta_i;\lambda)d\lambda \qquad (4)$$

Because apparent albedo values are derived under a specific atmospheric condition, we define the surface broadband inherent albedo as the ratio of upwelling irradiance from the surface that is illuminated by an unattenuated direct beam to the surface downward unattenuated irradiance, which is equal to the TOA solar extraterrestrial irradiance $F_0(\theta_i,\lambda)$:

$$\rho_I(\theta_i;\Lambda) = \frac{\int_{F_0}(\theta_i,\lambda)\rho_I(\theta_i;\lambda)d\lambda}{\int F_0(\theta_i,\lambda)d\lambda} \qquad (5)$$

where $\rho_I(\theta_i;\lambda)$ is defined in (1). From above definitions, we can see that surface broadband inherent albedo is completely independent of atmospheric conditions and therefore a measure of surface inherent reflectance properties. It is evident that the surface inherent albedo actually is equivalent to apparent albedo under a perfect clear (no scattering and absorption) atmospheric condition. If the figures/tables/formulae are provided to link apparent albedos with inherent albedos, the user can directly use the inherent albedo products from satellite observations.

II. SIMULATIONS AND DATA ANALYSIS

In this study, we utilize extensive radiative transfer simulations using MODTRAN and SHDOM - Spherical Harmonics Discrete Ordinate Method computer codes. A series of representative atmospheric and surface conditions were input into MODTRAN and the TOA narrowband albedos of MODIS and MISR were related to three broadband surface inherent albedos using polynomial regression and a feed-forward neural network technique.

Fig. 1(A) plots inherent albedo and apparent shortwave albedo under the clear sky conditions for the range of surface spectra, solar zenith angles, visibilities, aerosol models and water vapor profiles. We can see that the difference is too large to be ignored. Smaller shortwave albedos have smaller differences between the apparent and inherent albedos. For snow covered surfaces, the apparent albedos are always larger than the inherent albedos.

It is interesting to note in Figure 1(B) that the apparent and inherent albedos under clear-sky conditions in the visible region are almost identical. The reason is probably that when we change the atmospheric parameters, the shapes of the spectral distributions of downward irradiance are very similar although their magnitudes vary greatly in the visible spectral region.

There are two ways to estimate surface broadband inherent albedos. One is based on surface narrowband albedos. The MODIS science team will generate seven surface narrowband albedos. Based on more than one hundred surface spectra of vegetation, soil, and snow from the USGS spectra library and the measured spectra provided by Dr. J. Salisbury. it is found that a linear combination of these seven MODIS surface narrow band albedos can predict the total shortwave inherent albedo very accurately. In this process, solar TOA extraterrestrial irradiance from MODTRAN and the MODIS seven band spectral response functions were used. The coefficients for converting MODIS narrowband surface inherent albedos to the three surface broadband inherent albedos are given in Table I. MODIS narrowband surface inherent albedos and the three broadband surface inherent albedos were calculated from these surface reflectance spectra and sensor spectral response functions.

For MISR, the corresponding coefficients are given in Table II. Although MISR does not have the same number of narrow bands as MODIS, we found that broadband shortwave and visible inherent albedos can be accurately predicted ($R^2 \approx 1.0$), but R^2 for predicting near-IR inherent albedo is only 0.79 simply because only one near-IR waveband is available for estimation.

The another way of estimating broadband inherent albedos is to use TOA narrowband albedos directly without employing any atmospheric correction. The neural network performs very weel for this purpose (Fig. 2). This demonstrates that a neural network can represent a high-degree nonlinear relation very well.

A similar approach is used for estimating visible inherent albedo using three MODIS narrowband TOA albedos (Fig. 3). However, the prediction is not good enough with either approach. Obviously three bands are not enough to allow us to distinguish between the atmospheric and surface information. However, a primary analysis shows that if aerosol optical depth is known, either approach can predict surface inherent visible albedo very well.

III. ACKNOWLEDGMENTS

We thank Drs. Lex Berk and Gail Anderson for their kind help in modifying MODTRAN codes and Dr. Frank Evans for providing the SHDOM code and other generous assistance. The authors are also grateful to Dr. J. Salisbury for providing surface spectra measurement data. This study was supported in part by the NASA under grant NAG56459 and contract NAS-5-31369.

Fig.1A, shortwave

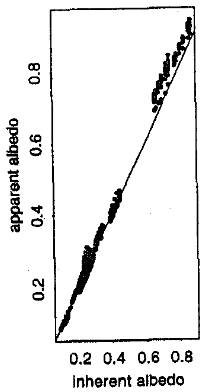

Fig.1B,visible

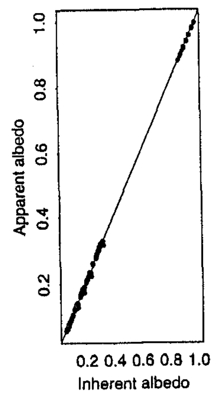

Fig.2, neural network

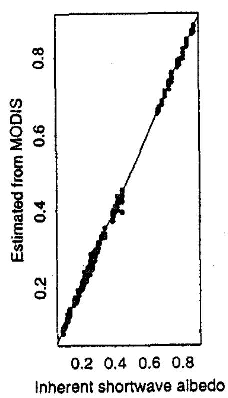

Fig.3 neural network

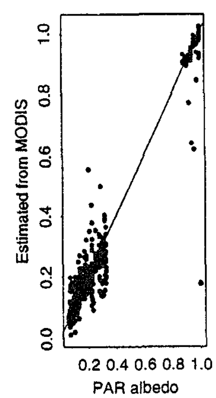

TABLE 1: Weights of converting surface MODIS narrowband albedos to broadband albedos

MODIS bands	wavelength (nm)	visible	near-IR (I)	near-IR (II)	shortwave
band 1	620-670	0.3265	-	-	0.3973
band 2	841-876	-	0.5447	0.5271	0.2382
band 3	459-479	0.4364	-	-	0.3489
band 4	545-565	0.2366	-	-	-0.2655
band 5	1230-1250	-	0.1363	0.1795	0.1604
band 6	1628-1652	-	0.0469	-	-0.0138
band 7	2105-2155	-	0.2536	0.2755	0.0682
intercept	-	-0.0019	-0.0068	-0.0071	0.0036

TABLE 2: Weights of converting surface MISR narrowband albedos to broadband albedos

MISR bands	wavelength (nm)	visible	near-IR	shortwave
band 1	423-458	0.3511	-	0.1587
band 2	543-558	0.3923	-	-0.2463
band 3	663-678	0.2603	-	0.5442
band 4	853-878	-	0.6088	0.3748
intercept	-	-0.0030	0.1442	0.0149