PARAMETRIC SURFACE BIDIRECTIONAL REFLECTANCE FACTOR MODELS FOR ATMOSPHERIC RADIATIVE TRANSFER MODELING

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Abstract

A family of surface bidirectional reflectance factor (BRF) models is found suitable for representing the surface boundary condition and of solving the problem of radiation transfer in the atmosphere. Optimal input parameters for a wide variety of surface types are available. The applicability of the models is analyzed with respect to (1) the derivation of illumination independent reflection properties of the surface, (2) the calculation of albedo, (3) the extrapolation of reflectance factors to geometries other than those of the measurements. Some of the models are linearly invertible. This family of models is proposed as part of the land surface product algorithm of the Multi-angle Imaging Spectro-Radiometer (MISR) of NASA/JPL, due to fly in 1998 on the EOS-AM platform.

Keywords: surface boundary condition, bidirectional reflectance factors, modeling, atmospheric corrections

BACKGROUND

The atmosphere is largely but not totally transparent in the visible and near-infrared spectral regions, so that the Earth surface is observable from space in these spectral bands. As a result, the proper interpretation of satellite measurements requires the knowledge or specification of the state of the surface. The reflective properties both at the top of the terrestrial surface and the atmosphere are described in terms of the Bidirectional Reflectance factor (BRF) [1].

A simple but efficient BRF model, applicable to most terrestrial surfaces most of the time, is desirable at least for the following reasons:

1. Atmospheric radiative transfer codes require dense samples of surface BRFs at all illumination and observation angles. Accurate numerical algorithms require angular samples at prespecified grids (e.g., quadrature angles),
2. Conversion of in-situ reflectance factor data into atmospherically independent BRF data requires a decoupling of diffuse and direct fields [2]. This requires iterative guesses of the actual surface BRFs at all angles, a specification more practically described with a simple model [3],
3. Estimation of the spectral albedo (i.e., bihemispherical reflectance factor) of the surface implies the integration of BRFs over all projected illumination and observed solid angles,
4. A BRF model allows the generation of reliable values of BRF for illumination and observation geometries other than those of the measurements, and
5. A BRF model allows the computation of spectral index values independent of the particular illumination and observation geometry.

For the purpose of operationality, parametric BRF models should meet the following conflicting requirements:

1. The BRF model should be able to describe both the shape and the amplitude of observed reflectance fields exhibited by as many terrestrial surfaces as possible, with an accuracy sufficient for the intended applications.
2. The BRF model should be mathematically as simple as feasible. In particular, it should make use of as few free parameters as possible, to facilitate the retrieval of a unique well-defined solution during inversion against measured data.
3. The BRF model should be computationally efficient and reliably invertible.

The minimum number of free model parameters to properly describe the anisotropy of terrestrial surfaces is expected to be three: P1 for the amplitude of the signal, P2 for the dependency with respect to the illumination and observation zenith angles, and P3 for the azimuthal variations. However, a finer representation of the specific features of this anisotropy may sometimes be required. For instance, an increase in reflectance in the backscattering (hot spot) or in the specular reflection region may be observed.

A series of simple parametric BRF models have recently been suggested to represent the BRFs of a large variety of surface types with a small number of "free" variables, e.g., [4], [5]. The purpose of this paper is to evaluate the performance of one of these parametric models which is a candidate for use in the standard surface BRF retrieval algorithm of the Multi-angle Imaging Spectro-Radiometer (MISR) data products. Another important application to test is the representation of lower surface boundary condition for radiative transfer analysis of the atmosphere.

THE EMRPV1 MODEL

This BRF model is a modified version of the parametric model proposed by Rahman, Pinty and Verstraete [4] and has the following expression for surface bidirectional reflectance factor (ρ_s):

$$\rho_s^{E1}(\theta_0, \theta, \phi; \rho_0, \Theta, k) = \rho_0 M F_{E1} H \qquad (1)$$

where:

$$M = (\cos\theta_0 \cos\theta(\cos\theta_0 + \cos\theta))^{k-1} \qquad (2)$$

$$F_{E1} = \exp(b_{E1} g) \qquad (3)$$

$$H = 1 + \frac{1-\bar{\rho}}{1+G} \qquad (4)$$

where $\bar{\rho}$ is the average measured reflectance factor.

$$G = [\tan^2\theta_0 + \tan^2\theta - 2\tan\theta_0 \tan\theta \cos\phi]^{1/2} \qquad (5)$$

$$\cos g = \cos\theta \cos\theta_0 + \sin\theta \sin\theta_0 \cos\phi \qquad (6)$$

Here θ and θ_0 are the observation and illumination zenith angles respectively. The relative azimuth angle, ϕ is zero when the source of illumination is behind the observer.

The necessary transformation of the model in order to apply linear fitting is:

$$\mathcal{F}(\rho_s^{E1}) = \ln \frac{\rho_s^{E1}}{H(\bar{\rho}, G)} \qquad (7)$$

The inversion of the transformed model requires that BRFs at the surface level be available. Retrieval of BRFs cannot be done without making initial assumptions on the surface properties. Iterative schemes for BRF retrieval are proposed for both the MISR and MODIS instruments on NASA's EOS platform. These schemes are initialized by "correcting" top of atmosphere BRFs under the assumption of a lambertian surface.

The RPV Model Family

In the EMRPV1 model, the substitution of the Henyey-Greenstein formula (Equation 8) for Equation 3 yields the Rahman, Pinty and Verstraete (RPV) model [4].

$$F_{HG}(\Theta_{HG}, g) = \frac{1-\Theta_{HG}^2}{[1 + 2\Theta_{HG}\cos g + \Theta_{HG}^2]^{3/2}} \qquad (8)$$

A modification of the Rahman model has been previously suggested by J.V. Martonchik. More information is available in [6]. Here the phase function factor is

$$F_M(g; b_M) = \exp(-b_M \cos g) \qquad (9)$$

These exponential phase functions offer new opportunities in designing models for fast inversions. In fact, using any surface asymmetry phase function of the form given in Equation 10 will still allow for linear optimization after a logarithmic transformation:

$$F_E(b_E, \theta_0, \theta, \phi) = f_1(\theta_0, \theta, \phi) \exp(b_E f_2(\theta_0, \theta, \phi)) \qquad (10)$$

Engelsen et al. [7] proposed an optimized phase function (Equation 11) as well as additional factors to account for variable hot spot and specular effects.

$$F_{E2}(g) = a_{E2} \exp[b_{E2}(\pi - g)^{1.2}] \qquad (11)$$

EXPERIMENT AND RESULTS

Measured and simulated reflectance factor data for a many surfaces types ranging from dense forest to plowed fields were used to analyze the model's ability to reproduce natural BRFs and its suitability for model inversion. The suitability of a model is assessed by optimally adjusting its parameters to sets of reflectance factors obtained from measurements or from simulations using physical models.

A parameterized correction scheme for diffuse incoming radiation was applied on the in-situ reflectance factor data sets. Improved but more elaborate practical solutions to the problem of surface BRF retrievals from measurements in and above the atmosphere can be found in [2] [3].

The linear least squares inversion procedure is described mathematically in detail in [7].

Due to lack of space, the inversion results are discussed only in broad terms below. The details of the full study is reported in [7] and is available on the World Wide Web on `http://www.itek.norut.no/~olae/`. The other members of the RPV family models are also discussed.

DISCUSSION

The model is shown to be capable of reproducing the observed anisotropy of a wide range of typical natural surfaces within error bounds acceptable for aerosol optical depth retrieval, i.e., a correlation coefficient higher than 0.9 and a normalized root-mean-square error less than 0.15 [J.V. Martonchik, Personal Communication].

The level of sensitivity of the inversion results with respect to the angular distribution of surface BRF samples was assessed. Several data sets at MISR view zenith angles for various solar illumination directions and over six different terrestrial surfaces were used. This test is meant to serve as an indicator of the "robustness" of the model inversions and test the ability of the model with optimal input parameters to represent BRFs at other geometries than for the measurements from which the optimal input parameters were derived through model inversion. The stability of the model parameters with respect to the sampling was very satisfactory, except for some erratic behavior of the asymmetry factor when only data in the cross-plane was available. The potential and limitations of predicting bidirectional reflectance factors at observation geometries other than those which were used for the parametric model inversion was addressed. Because the ratio of forward and backward scattering may not be determined from cross-plane measurements only, significant discrepancies between the model resulting from such an inversion and BRFs outside the cross-plane can arise. The model-predicted BRF generated after inversions against data at azimuths other than the cross-plane showed good correspondence with BRFs that would be observed elsewhere. The estimation of the spectral albedo from MISR were found reliable for all geometries, but displayed sometimes slightly higher errors for azimuth angles near the cross plane. The latter would be expected, but the errors in estimated BRFs resulting from indeterminable surface asymmetry factors cancel to some extent when evaluating the spectral albedo integral.

CONCLUSION

The model is expected to form a valuable tool for characterizing the spectral-directional properties of terrestrial surfaces through model inversion. The inversion results can be used to constitute realistic surface boundary conditions for atmospheric radiative transfer analysis, with the possible exception of some specularly reflecting surfaces. A large database of optimal model parameters for a wide variety of surface types are available for atmospheric radiative transfer studies.

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