Validation of Kernel-Driven Semiempirical BRDF Models for Application to MODIS/MISR Data

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Abstract–Increasing emphasis on global monitoring makes global modeling of bidirectional reflectance of vegetation an important issue. We study four linear kernel-driven semiempirical models for use in operational production of the BRDF/albedo product for the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument of NASA's Earth Observing System (EOS). In this paper, we use a variety of multiple angle surface reflectance data sets from field and airborne measurements to evaluate these models. The results show that our semiempirical BRDF models provide a good mathematical description of the bidirectional reflectance of the land covers tested.

INTRODUCTION

With the development and wide use of coarse and medium-resolution multiangle sensors especially in global monitoring, the analysis of the BRDF (Bidirectional Reflectance Distribution Function) of each pixel in a remotely sensed image becomes more and more important. It can be used not only to compare observations obtained at different angles or standardize observations to a common geometric situation, but also to provide surface physical parameters and the boundary condition for the atmosphere-earth system. Linear kernel-driven semiempirical models based on physical models were developed [1,2] to meet the needs of global modeling of bidirectional reflectance. Rahman et al. [3] developed a semiempirical model of another type. These models can be applied to inhomogeneous land covers and are readily invertable, making them suitable for low and moderate spatial-resolution remote sensing.

KERNEL-DRIVEN SEMIEMPIRICAL MODELS

Kernel-driven semiempirical models describe the BRDF as a linear superposition of a set of kernels that describe basic BRDF shapes. These kernels are derived from physical models, thus providing a physical basis to the retrievals. The coefficient given to each kernel is determined empirically by fitting to a specific set of observed reflectances. Thus it is the weights of the physically-based kernels that are retrieved, not a set of physical parameters as in physical models. Linear BRDF models scale linearly in space if adjacency effects are assumed to be small, which allows for mixed pixel cases. This advantage is especially important in global processing. Roujean et al. [1] derived the Ross-thick and Roujean kernels, and Wanner et al. [2] the Ross-thin, Li-sparse and Li-dense kernels. For the MODIS/BRDF product [4], we employ four models, Ross-thin–Li-sparse, Ross-thin–Li-dense, Ross-thick–Li-sparse and Ross-thick-Li-dense, based on these kernels.

Like all linear models, these four models can be inverted analytically through matrix inversion, avoiding costly numerical inversion problems. For a given data set in a specific band, a set of model parameters is so selected that

$$\sum_{j=1}^{N} \frac{(R_{obs_j} - R_{model_j})^2}{W_j} \qquad (1)$$

is minimal. Here, N is the number of observation, W_j is a weight which determines the contribution of each measurement to the model inversion, and R is reflectance. Two popular values for W_j are 1 and R^2_{obs}. At present, we set the weight W_j at 1.

VALIDATION OF THE MODELS

We use Kimes' data [5,6,7], Ranson's soybean data [8], soil data from the BRDF Information System [9], PARABOLA data from a boreal forest [10], FIFE data [11] and POLDER data to perform the validation of the kernel-driven semiempirical models. These data sets include a large variety of land cover types with various coverage and leaf area indices.

To evaluate the 4 models, we firstly use them to fit all data sets and to calculate the root mean square error (RMSE) between the predicted and observed values based on all available bands. The results show that all data sets are fit well by at least one of the models. As anticipated, in a number of cases different land cover types prefer different models. For example, bare soil and sparse vegetation are fitted better by models with the Li-sparse kernel than those with the Li-dense kernel. For thick vegetation canopies, such as orchard grass and irrigated wheat (Kimes data), volume scattering is dominant. Thus the selection of Li-sparse and Li-dense kernels in these models does not make much difference. But the models containing the Ross-thick kernel fit better than those with the Ross-thin kernel. A dense forest canopy, such as hardwood (Kimes data), is fitted better by models containing the Li-dense kernel than those with the Li-sparse kernel, because the Li-dense kernel can model the shadow overlapping mechanism which determines the bidirectional reflectance of dense crown canopies. So the relative RMSE of each of the four models can indicate some characteristics of the observed surface.

Secondly, we select the best-fit model based on the RMSE for every data set and calculate the correlation coefficient between the modeled and the measured values. For most data sets, the correlation coefficient is over 0.8 and the RMSE is smaller than 0.043, which indicates a reasonable agreement between the modeled and observed values. Fig. 1 shows the reflectances in the principal plane in the NIR for some land covers, where the points represent the measured data and the solid lines are the modeled data. These data sets have hotspots, as for field and wheat, and bowl shapes, such as hardwood, demonstrating that the models can fit hotspots and bowl shapes well.

Lastly, we compare the best-fit model for every data set with other semiempirical models, such as Roujean's model [1] and Rahman's model [3]. In Fig.1, dashed lines are for Roujean's model and the dash-dotted lines for the Rahman model. From the plots, we can note that our models fit better than the other models, especially for the dense hardwood canopy.

CONCLUSION

In this paper, we evaluated the ability of linear kernel-driven semiempirical models developed for use with MODIS/MISR data to provide adequate mathematical descriptions of the anisotropic reflectance of a variety of natural surfaces. The results show: 1) different land cover types prefer different models; 2) our models can fit a large variety of vegetation canopies well and they fit better than other semiempirical models, especially for dense forest canopies. This is partially due to the fact that they are based on ellipsoidal crown shapes and the shadow overlapping mechanism is modeled realistically. The fit quality can presumably be further improved by reducing the effect of outlier data on the inversion results by giving the appropriate W_j in (1), and by considering more realistic multiple scattering in the models.

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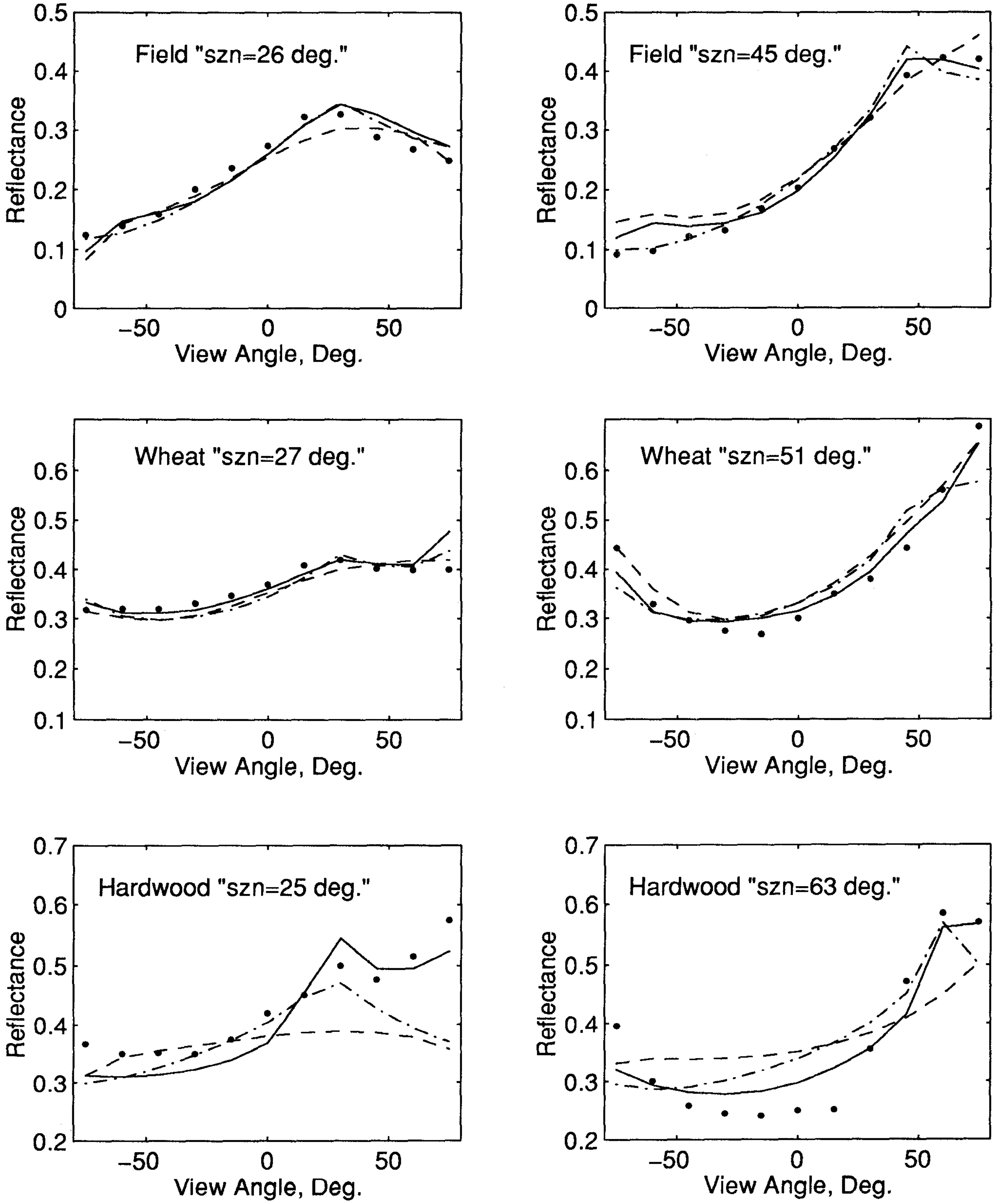

Fig.1 The BRDF on the Principal Plane in the near infrared band for selected Kimes data (szn=sun zenith angle)
dot: observations; solid line: best-fit kernel-driven model dashed: Roujean model; dash-dotted: Rahman model