BRDF/Albedo retrievals from the Terra and Aqua MODIS systems at 500-meter spatial resolution and 10-day intervals

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ABSTRACT

Surface bi-directional reflectance distribution function (BRDF) and albedo properties are retrieved over the Atmospheric Radiation Measurement (ARM) Program Southern Great Plains (SGP) area. A landcover-based fitting approach is employed by using a newly developed landcover classification map and the MODIS 10-day surface reflectance product (MOD09). The surface albedo derived by this method is validated against other satellite systems (e.g. Landsat-7 and MISR) and ground measurements made by an ASD spectroradiometer. Our results show good agreements between the datasets in general. The advantages of this method include the ability to capture rapid changes in surface properties and an improved performance over other methods under a frequent presence of clouds. Results indicate that the developed landcover-based fitting methodology is valuable for generating spatially and temporally complete surface albedo and BRDF maps using MODIS observations.

Keywords: Surface albedo, bi-directional reflectance, BRDF, MODIS, ARM SGP, landcover-based fitting

1. INTRODUCTION

Surface albedo is defined as the ratio of the total (hemispheric) reflected solar radiation flux to the incident flux upon the ground surface. It is an important parameter in atmospheric radiation studies. Incident radiation is reflected anisotropically over most land surfaces; that is, it is not reflected equally in all directions. These anisotropic properties are often described by the surface bi-directional reflectance distribution function (BRDF)[1]. Surface albedo can be obtained from the BRDF through the hemispheric integration of directional reflectance. However, obtaining the BRDF from observations with limited angular sampling is difficult. Many parametric BRDF models have been developed based on physical characteristics and experimental results observed for various natural surfaces. Semi-empirical linear kernel-driven models are among the most widely used of these models. Kernel-driven models are attractive because of their fast operational implementation and good accuracy [2, 3, 4]. The derivation of BRDF parameters, i.e. the process of model inversion, is achieved through a fitting procedure that tunes the model to observed data points by minimizing mean-square residuals. For a successful inversion of the model, the observation must cover a variety (and, ideally, an entire range) of sun-target-viewer geometries. In practice, however, this requirement is rarely achieved. For a fixed location on the Earth's surface, some satellite systems, such as the Multiangle Imaging Spectro-Radiometer (MISR), can obtain multiple (i.e. nine) angular views virtually instantaneously, while others, such as the Moderate-resolution Imaging Spectroradiometer (MODIS), build up sequential angular views over a period of time (e.g. 16 days). These approaches provide a limited number of data points, especially when there is frequent cloud presence. The quality of BRDF retrieval is also questionable when there is a rapid change in surface properties within a sampling interval.

In this paper, we present a landcover-based fitting (LBF) approach that directly addresses the above issues. The collection of data is based on landcover types within a region rather than an individual pixel. The LBF approach provides improved sampling in terms of the number of observations and range of geometries utilized, it requires less computational resources than other approaches, and it can be implemented for shorter time intervals to capture a rapid change in BRDF characteristics. We retrieve spatially and temporally complete surface BRDF/albedo over the ARM SGP area by applying the LBF approach to MODIS data. The approach employs a recently developed landcover map and MODIS multi-day clear-sky composites of directional surface reflectance (MOD09). Separate datasets for MODIS on Terra and Aqua, as well as their combined data product, are generated at 500-meter spatial resolution and every 10-day interval since March 2000 and July 2002, respectively. Surface anisotropic properties derived from the MODIS cross-track scanning instrument are compared with the along-track multi-angular observations from the MISR system, and validated against both Landsat-7 nadir view data and ground measurements.

2. METHODOLOGY

The landcover based fitting (LBF) approach assumes that the BRDF properties of some pixels are similar if they belong to the same landcover type in a climatic region, and are in a similar biophysical condition. The method uses a multi-day clear-sky composite of surface reflectance, and groups pixels according to landcover types. It then separates the pixels within each landcover class according to their green biomass levels (characterized by the Normalized Difference Vegetation Index (NDVI)). These grouped data – which may include observations at various observational geometries, i.e., solar zenith angle (SZA), view zenith angle (VZA) and Sun-satellite relative azimuth angle (RAA) – are then used to optimally fit the BRDF model parameters for each landcover type. The particular BRDF of each pixel is then determined by adjusting the general landcover-grouped BRDF parameters to the observed reflectances of the pixel. This approach overcomes the major limitations of pixel-based fitting approaches that are associated with a small or insufficient number of observations for the fitting process [5].

The region selected for our study covers a 8° latitude x 10° longitude area centered over the ARM SGP Central Facility (CF) located in North Oklahoma. We used the National Land Cover Dataset to provide an initial landcover map of this region. This dataset is compiled from Landsat TM imagery at a spatial resolution of 30 meters and is supplemented by various ancillary data (http://landcover.usgs.gov/natllandcover.asp). In this paper, we aggregated the Land Cover Dataset to a spatial resolution of 500 meters and re-mapped it onto the ARM-SGP area. The landcover map can be viewed elsewhere [6]. We used surface reflectances from the MODIS 8-day 500m-resolution clear-sky composite data product (MOD09). These data were re-arranged into 10-day intervals for compatibility with other satellite products.

We used the RossThick-LiSparse reciprocal BRDF model because of its good performance with data spanning limited angular distributions, and because of its computational efficiency and linear structure[3]. The model is expressed as a sum of several theoretically constructed kernel functions

$$\rho_\lambda(\theta_s,\theta_v,\phi) = a_0 + a_1 f_1(\theta_s,\theta_v,\phi) + a_2 f_2(\theta_s,\theta_v,\phi)$$

where θ_s, θ_v and ϕ are the SZA, VZA and RAA, respectively. f_1 corresponds to a RossThick kernel, and represents scattering from a dense leaf canopy. This kernel is based on a single-scattering approximation of radiative transfer theory. f_2 corresponds to a LiSparse kernel, which is derived from the geometric-optical mutual shadowing model, and assumes a sparse ensemble of surface objects. Parameters a_0, a_1, and a_2 are the coefficients of the kernels and are related to the isotropic, volumetric, and geometric reflectances, respectively.

The number of pixels that correspond to the dominant landcover classes in the study area (e.g. grasslands) are large, and thus, their distribution with respect to the VZA and RAA is irregular. Unequal weights for different angles may bias the fitted results towards data with most frequently observed angles while ignoring valuable, but less frequently observed angles. To address this problem, we sorted all data points within each given landcover class into small 4-dimension bins with three angular plus the NDVI intervals, e.g. 5°, 5°, 10° and 0.1 for the SZA, VZA, RAA and NDVI, respectively. Data collected within each data bin were statistically processed to eliminate outliers and reduce noise. Only one data point from each bin contributed to the fitting process.

3. RESULTS

The results of fitting MODIS reflectances by the Ross-Li model with the LBF approach are shown in Figure 1. The reflectances are plotted against the VZA, with the Terra and Aqua MODIS red and near infrared (NIR) bands for a major landcover type (grassland) at various levels of green biomass (NDVI). Each square represents one MODIS reflectance data-bin, while the overlaid triangles show the results of fitting the Ross-Li BRDF model. As expected, these figures show that observations are sampled almost continuously against the VZA axis and with approximately equal weights. The observations cover a wide viewing range and clearly produce an anisotropic BRDF shape. The observation and model results are distributed as tight clusters. This indicates that successful fittings have been mostly achieved.

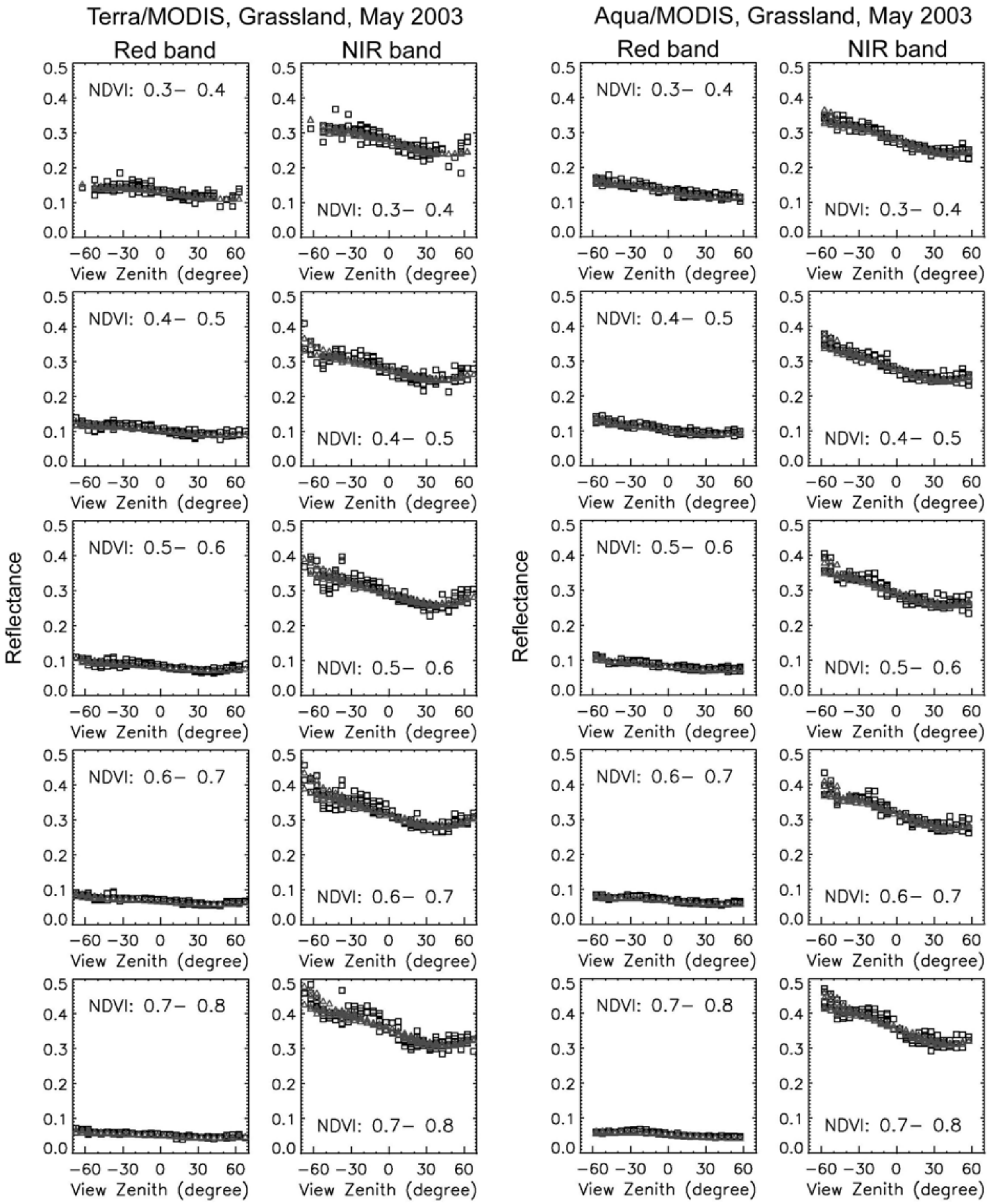

Figure 1. MODIS reflectances for May 2003 in the red and NIR bands plotted against the viewing zenith angles (VZA) for different NDVI levels. A main landcover type (grasslands) is displayed. The square symbols correspond to the observed values from each data-bin. The overlaid triangle symbols correspond to the fitted values based on the RossThick-LiSparse BRDF model.

After deriving the BRDFs for each landcover class, BRDFs were applied to each pixel to obtain the spatially complete BRDFs and albedo for the whole region. Various interpolation procedures were used to fill the data gaps due to cloud presence. These were based on a multi-year observation database and referred to results from other locations that shared similar landcover properties. A seasonal smoothing procedure was also applied to further remove outliers and artefacts from the data series. This is illustrated in Figure 2, where the time series of three BRDF parameters are shown.

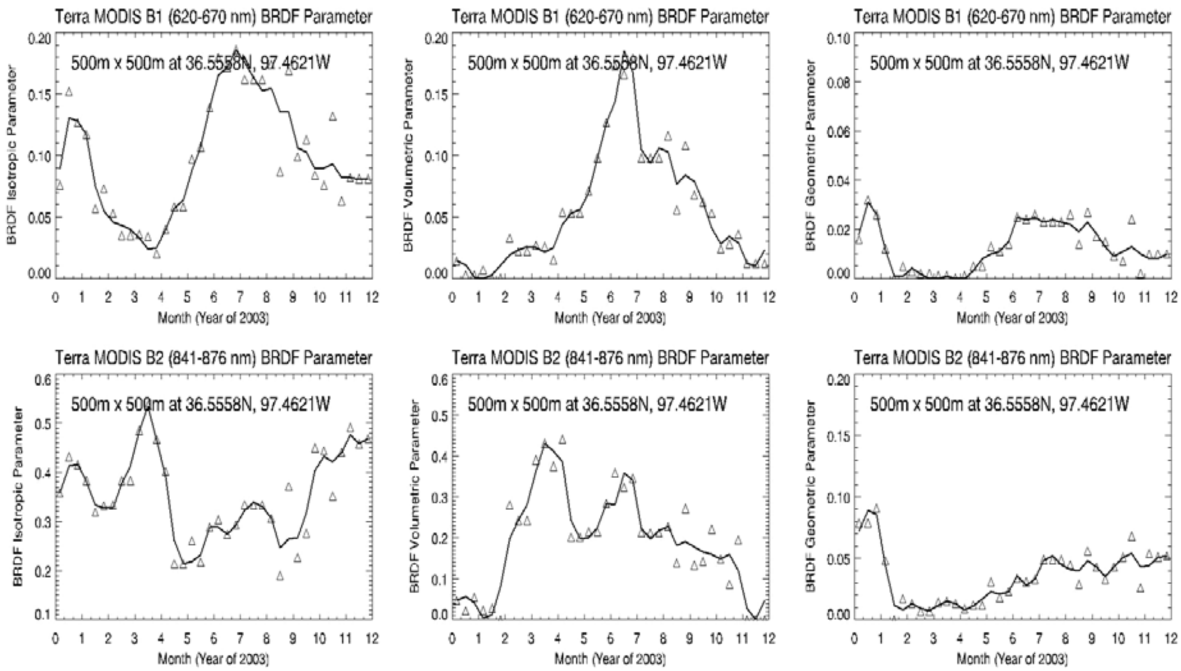

Figure 2. BRDF parameters (i.e. isotropic, volumetric, and geometric from the left to right) as a function of time in 2003. The red (B1) and NIR (B2) bands for a cropland pixel near the ARM-SGP CF are displayed. Each triangle symbol represents a derived value based on a 10-day composite dataset, and the solid curve is a smoothed result of one 12-month cycle.

The hemispheric reflectance – i.e. albedo – was computed using the BRDF parameters. We computed both the direct and diffuse albedo components. Direct albedo is defined as the albedo of the surface illuminated by a direct beam of radiation. Diffuse albedo is defined as the albedo of the surface under a fully isotropic downward radiance field. Both types of albedo can be computed using a linear model by using a look-up table of pre-computed kernel integrals or by using analytical approximations that express albedo as a function of BRDF parameters and SZAs [4,5]. It is worth noting that the albedo of the surface under natural conditions, i.e. the superposition of direct and diffuse radiance fields, could be computed as a combination of direct and diffuse albedo components, which is, in a simple assumption, dependent on the atmospheric aerosol optical depth. Figure 3 shows the direct albedo maps computed at local solar noon for the red band for May of 2003, when an aerosol IOP was conducted around ARM-SGP Central Facility (CF). Albedo maps for 10-day intervals were derived separately from Terra and Aqua MODIS 10-day clear-sky composites. Although these satellites observe the earth in the morning and afternoon, respectively, their derived albedo maps were very similar. This suggests a good stability and reliability of the LBF methodology.

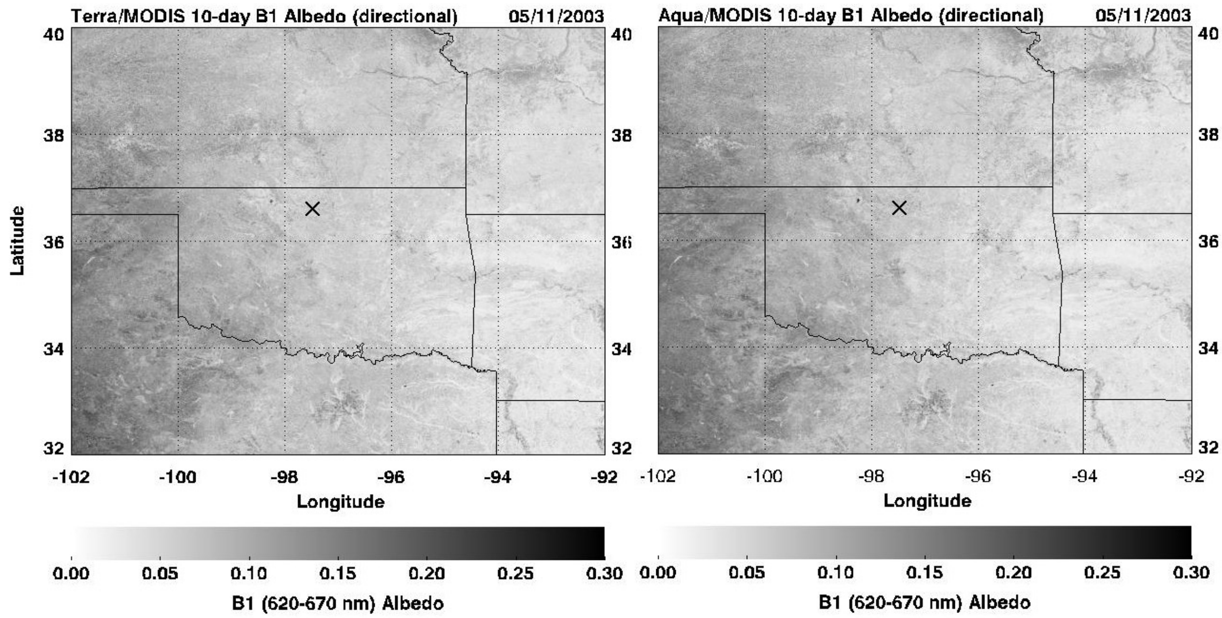

Figure 3. Direct albedo (local noon) for the red band over the ARM-SGP area. The MODIS albedo maps are derived based on the LBF algorithm using data from Terra and Aqua separately. The maps show albedo for the 10-day interval of May 11-20 of 2003.

4. COMPARISONS AND VALIDATIONS

Figure 4 shows the spectral albedos derived from MODIS and the ground-based spectroradiometer (ASD) around the CF (marked by a cross symbol in Figure 3) in May of 2003. We selected three large fields in the study area for measurement and comparison. High-resolution Landsat imagery showed that the landcover of each of these locations was relatively uniform. Figure 4 shows that there is a close correspondence between the MODIS and ASD spectrum in the visible and NIR bands (400-800 nm) for the three fields. The wheat field shows the lowest albedo, which indicates a large and healthy volume of biomass. The albedo of grassland in the visible band is in between, which is due to less amount of healthy vegetation. The young cornfield shows higher albedo in the visible band, which represents sparse vegetation coverage on bare soil. Some discrepancies appear between the 800 and 1500 nm wavebands, where the ground measurements show slightly higher albedos. However, the MODIS derived albedos are generally similar to the ASD values.

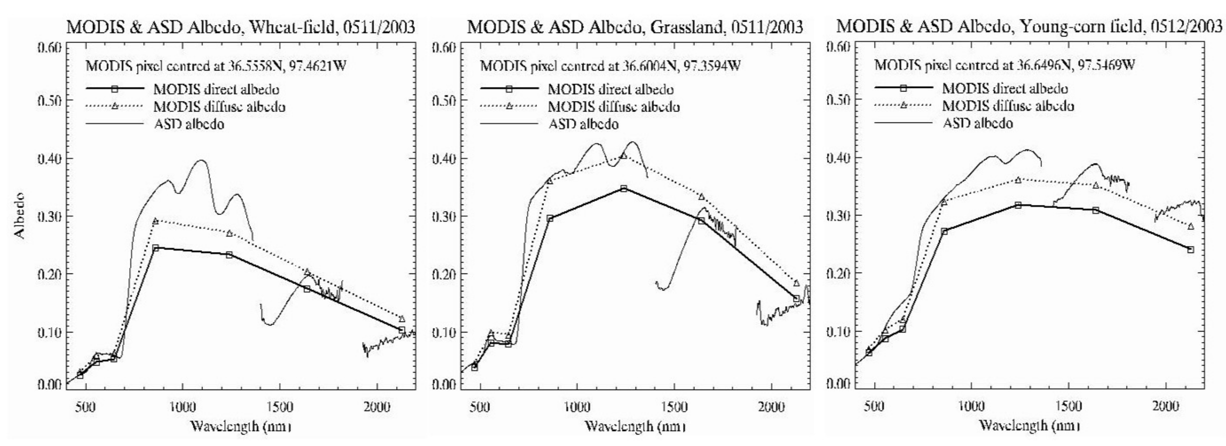

Figure 4. The spectral albedo around the ARM-SGP Central Facility by the MODIS observations and the ground ASD measurements. MODIS albedo is derived for 7 channels. The ASD albedos are almost spectrally continuous except for some bands where strong atmospheric absorptions occur.

Although the above validation suggests that our approach can be used to successfully estimate surface albedo, it is limited because large validation areas are never perfectly uniform, and because the number of landcover types and/or measurements are often not enough for a meaningful statistical analysis. Therefore, a comparison with data from other satellites, such as Landsat and MISR, provides a useful independent assessment of the quality of the BRDF and albedo product derived by different algorithms or based on different BRDF models. Different sensors have a different spectral response function (SRF) (Figure 5), and thus, data from these sensors must be spectrally corrected before any comparisons can be made[7]. Our corrections were based on a linear regression formula, which used the reflectances of six Landsat-7 channels and four MISR channels to predict the reflectance of each MODIS channel. The coefficients of the regression formula were based on each sensor's SRFs, surface solar flux (from the MODTRAN model) and the various surface spectral albedos derived from ground measurements.

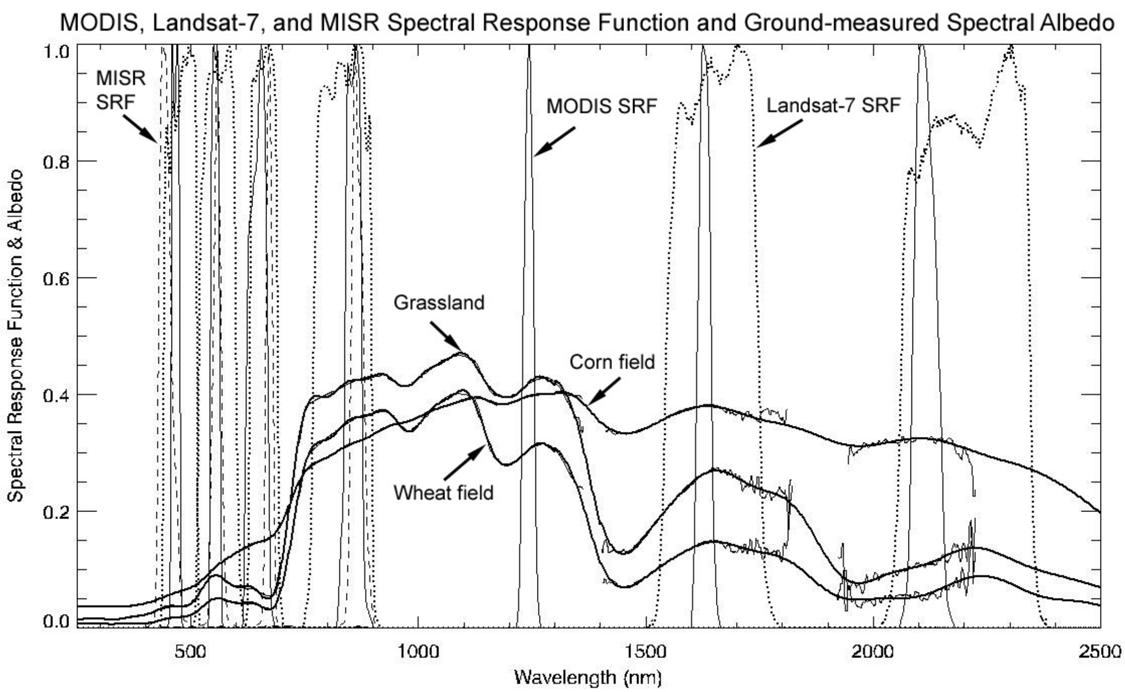

Figure 5. The spectral response functions for the MODIS (solid line), Landsat-7 (dotted line) and MISR (dashed line). Three spectral albedo curves are measured by the ASD instrument at the ARM-SGP site in May of 2003 for the wheat field, the grassland, and the corn field, respectively.

Pixel-by-pixel comparisons between Landsat-7 and MODIS nadir reflectance, and between MISR and MODIS albedo, are presented in Figures 6 and 7, respectively. Figure 6 compares Landsat-7 and MODIS nadir reflectance over an area of cropland and pasture located near the CF. Figure 7 compares MISR and MODIS albedo over the entire study area (as shown in Figure 3) for five major landcover types. It should be noted here that errors in these comparisons might be caused by the re-projection, and subsequent spatial mismatch, between independent products. Despite these limitations, in most cases the data points fall around the 1:1 line of perfect validity. Correlation coefficients (R) between the two data sets vary from 0.55 to 0.92 (most are greater than 0.80). The mean bias ($\overline{\Delta}$) (an average of the differences between two datasets, where a positive $\overline{\Delta}$ means that the Landsat or MISR albedo is greater on average than the MODIS albedo) represents any systematic bias that exists between the two data sets. The mean biases shown in Figures 6 and 7 are mostly small. The standard deviation (δ) of the bias reflects how stable or confident the systematic bias is. The correlation between MISR and MODIS is better than that between Landsat-7 and MODIS. This is probably because the MISR SRFs and spatial resolution are much closer to the MODIS values than those of Landsat. The mean biases show that, in general, the MISR albedo is slightly larger than that derived from MODIS. This systematic bias may be caused by many factors, including differences in calibration and atmospheric corrections. Among all landcover types, the grasslands show the largest correlation between sensors, while the evergreen needleleaf forest shows the smallest correlations. These differences can also be explained, at least partially, by the large overall variability in albedo over grasslands and the relatively small range in albedo over needleleaf forest. Another possible reason for these correlations is the difference in BRDF models used. The RossThickLiSparse model used in the MODIS product is more suitable to a surface of short height vegetation, while the modified Rahman's model used in the MISR product is more accurate for a forest canopy [8]. Based on the albedo comparisons (including results for other months), a good agreement is generally found, with the average biases in the red and near-infrared bands usually being less than 0.005 and 0.01, the standard deviation of biases being less than 0.01 and 0.02, and the correlation coefficients typically being larger than 0.80.

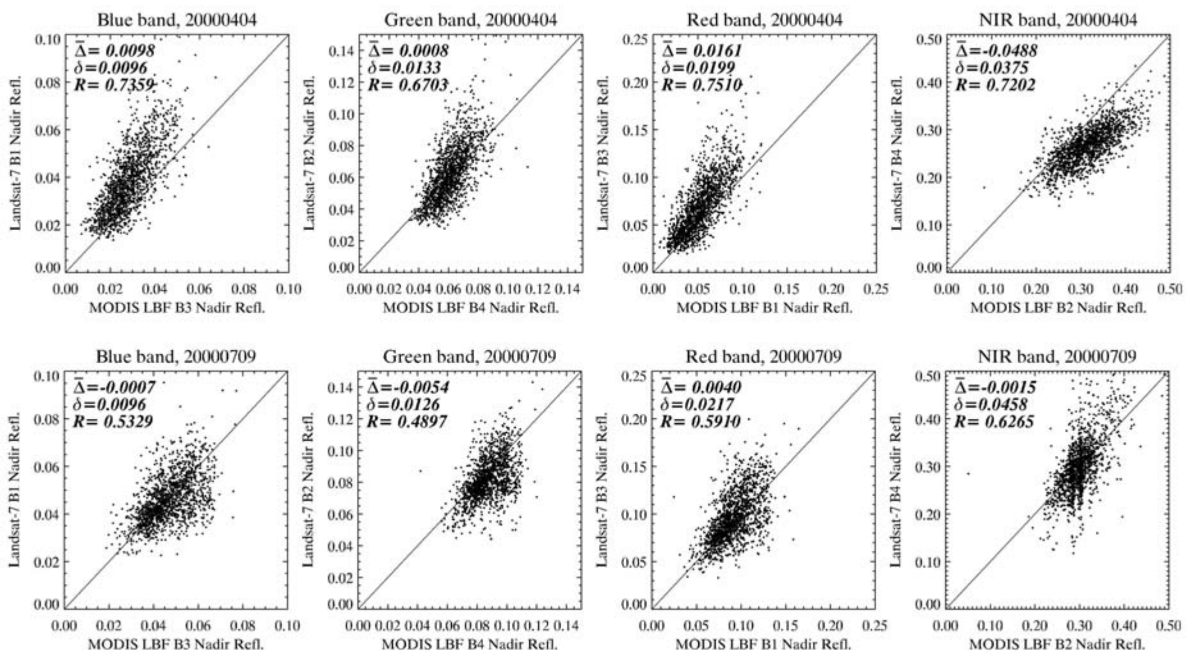

Figure 6. The Landsat-7 nadir reflectance plotted against the MODIS nadir reflectance for four channels and two seasons around the ARM-SGP site.

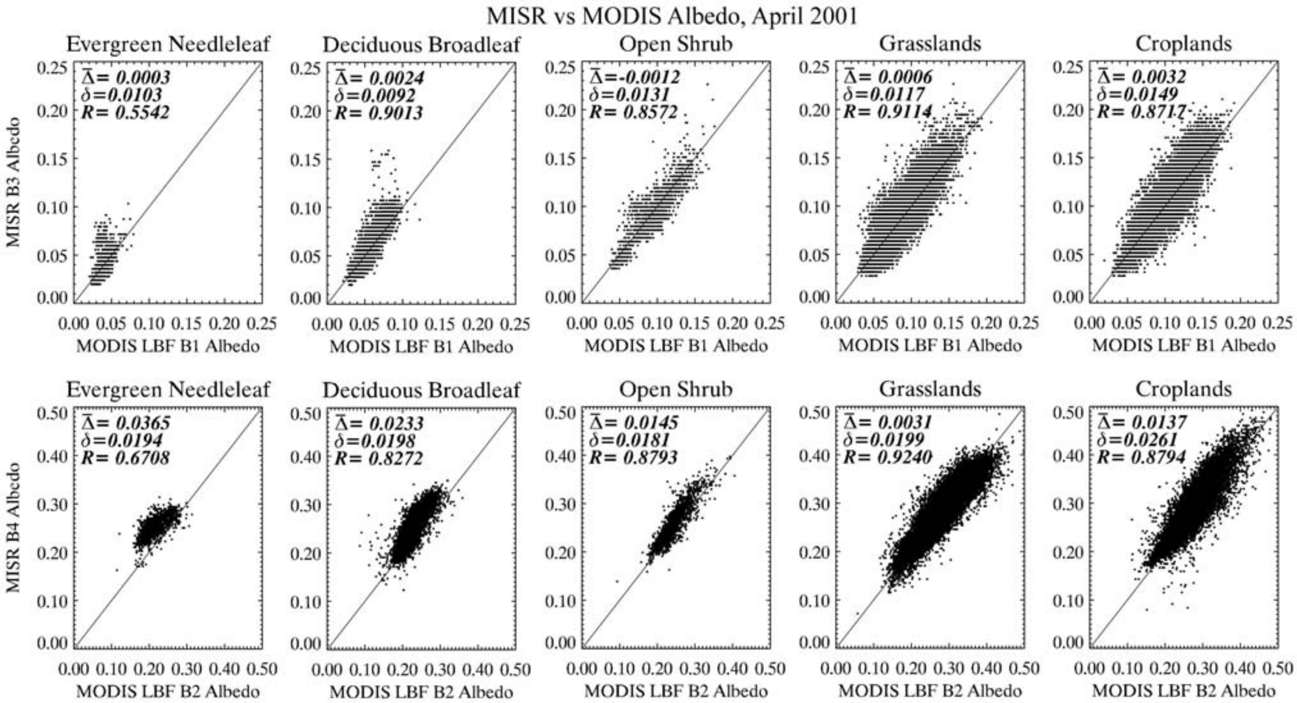

Figure 7. MISR albedo plotted against MODIS albedo derived by the landcover-based fitting algorithm for five major landcover types in April 2001.

5. SUMMARY

The purpose of this work was to develop an approach suitable for generating a surface BRDF/Albedo product using multi-day composite datasets obtained from satellite observations. The proposed LBF approach has four major advantages over a pixel-based method. First, it increases the number of samples used in the BRDF fitting procedure and thus makes retrieval of the BRDF shape more reliable. Second, it performs a data binning process, which reduces noise or outliers and prevents bias due to the uneven distribution of observational conditions. Third, it can generate albedo over short time intervals and capture the rapid variations of surface properties. Fourth, it can be easily applied for joint data processing of multi-day clear-sky composite data assembled from multiple platforms. A spectral correction procedure has to be implemented to merge data from similar but not identical sensors to reduce the spectral response function effect. BRDF/albedo results are validated and compared with ground measurements and observations from other sensors. Generated BRDF model parameters are available through the CCRS ftp site: ftp://ftp.ccrs.nrcan.gc.ca/ftp/ad/CCRS_ARM/Satellites/.

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