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# Improving BRDF normalisation for Landsat data using statistical relationships between MODIS BRDF shape and vegetation structure in the Australian continent

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ABSTRACT

The intra- and inter-annual variability of the Moderate Resolution Imaging Spectroradiometer (MODIS) surface Bidirectional Reflectance Distribution Function (BRDF) products in Australia have been analysed using 10 years (2002 − 2011) of MODIS BRDF Collection 6 data. Root Mean Square (RMS) and Anisotropic Flat Index (AFX) parameters were used as BRDF shape indices to represent the overall BRDF shape. Australian vegetation structure and agro-climate regions were used to separate and analyse different BRDF shape patterns. The results confirmed earlier findings that the intra-annual variation of MODIS BRDF shape is stronger than the inter-annual. High variance in the shape parameters of the base BRDF model as well as poor quality data regions suggest that for spectral data correction, the data are better used as a spatial average of BRDF shape (e.g. over a vegetation structure/climate class patch). This can reduce the spatial variance of shape to similar levels observed in the local variance of spectral data. The within- and between-class variations as well as correlations between some BRDF shape indices and normalized difference vegetation index (NDVI) show that inter-annual relationships between BRDF parameters can be separated using strata based on vegetation structure (basically height, cover and dominant growth form). However, due to the different climate drivers involved, such as rainfall, light and temperature, the intra-annual variation is better analysed if the patches of vegetation structure classes are identified by climate zone for climatic homogeneity. It is found that if long term averages are used to represent stable focal points in the time series, significant relationships exist between BRDF indices and spectral indices such as NDVI. However, there is no satisfactory way to directly relate short term fluctuations of (e.g.) NDVI with short term BRDF changes. All of the indices are significantly related to rainfall, structural characteristics and biomass with lagged relationships providing a more suitable pathway to analysing short variations. It is concluded that for the situation where a high quality BRDF product is available, the best strategy would involve use of a set of vegetation structure class patches to increase the resolution of local differences in BRDF shape for inhomogeneous scenes as well as control the high variance in MODIS BRDF model shape parameters. The partial relationships found between some BRDF indices (in particular RMS) and average rainfall or stable (longer term) NDVI also provide a potential for empirically updating BRDF shape for climate variation in periods before MODIS data were available.



## 1. Introduction and background information

Using surface BRDF with atmospheric correction is an important step in standardizing satellite data, particularly for time series related data applications, such as surface changes and land cover classification (Li et al., 2010, 2012). To apply this step, knowledge of an effective surface BRDF shape is needed for the target surface or area. There is currently an operational time series of band dependent BRDF surface reflectance model parameters derived from MODIS data (Wanner et al., 1997). This is possible because MODIS acquires samples from a wide range of view angles, with varying sun angles and at frequent revisit times, the effects of which are doubled when the MODIS sensors on both AQUA and TERRA are used (Schaaf et al., 2002, 2011). For higher resolution data, such as Landsat, a model for surface BRDF shape cannot be independently derived from its data and separated from atmospheric effects due to the small variation of relative view and solar angles, a consistent sun-synchronous view of a given location and the less frequent revisit period of the sensor. Instead, one must use BRDF information from another source. MODIS BRDF data can and have been used to provide this opportunity to correct BRDF effects and standardize Landsat data (Li et al., 2010, 2012).

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However, in the work reported in these papers and its operational application, it was necessary to address a number of issues. One was the very high fine-scale spatial variation found to be present in MODIS BRDF shape data but not (for example) in Landsat data or MODIS isotropic parameter data. This arises from a number of sources. The first is a combination of factors such as cloud effects, sampling of the sun and view angles and various fundamental issues discussed by Lucht and Lewis (2000) as they affect the operation of converting the base data to BRDF kernel model parameters. Band dependent MODIS BRDF data quality flags are sufficient to manage most of the issues that can be regarded simply as noise but leave gaps that for time series may need to be filled. However, a second source of high variance seems to arise from systematic variation of the observed multi-sun and view angle data from an underlying mean BRDF. Some of this variation has been called BRVF or Bi-directional Reflectance Variance Function in Ni et al. (1999) and Ni-Meister and Jupp (2000) and at a fundamental level affects properties normally assumed for BRDF such as reciprocity (Snyder, 2002; Di Girolamo, 2003). Since the BRDF model parameters are derived from a statistical fitting method to the MODIS data, BRVF may not always be well modelled by such a BRDF function. For this reason, the local shape parameter variance in the product may be high and correlated. This second source of variance is not noise and may provide unique surface information relating to BRDF shape but it does not seem to occur in the isotropic parameters or in other spectral data sources such as Landsat and it seems unwise to introduce it during correction of Landsat data for BRDF effects.

Pragmatically, to reduce the fine-scale shape parameter variance and resolve issues arising from the different scales of MODIS and Landsat as well as fill gaps due to poor quality flags and missing data, Li et al. (2010, 2012) used an average of MODIS BRDF shape over a Landsat scene for the day of overpass to represent BRDF shape. This value was used to correct for a broad scale BRDF effect in Landsat data sensed after 2000 and up to the current time. The main remaining issues were that the scene average did not make allowance for the presence of land covers within a scene with significantly different BRDF shapes; and nor was it clear how BRDF information outside of the period of MODIS data availability (such as prior to 2000) could be selected or estimated. The first needs a stratification consisting of classes that are relatively homogeneous in BRDF shape allowing the averaging to be over homogeneous patches of the strata in a scene and the second needs some means of generating a time series of shape from the present state back in time or forward in time (if necessary). This paper describes progress in addressing these issues.

Using 10 years of MODIS BRDF data over the Australian continent, Li et al. (2013a) found that the inter-annual variation of BRDF shape is generally much smaller than the intra-annual variation. That is, seasonal variation dominated the signal. Based on this, 46 time periods of a year (8-day “weeks”) averaged over 10 years (2002 − 2012) of MODIS BRDF parameters for the Australian continent (500 m resolution data) were used in order to process the Australian Landsat data that were sensed before 2000. However, the assumptions that there is no inter-annual variation and the seasonal signal in any one place is constant from year to year are not true. Single BRDF shape averaged over a scene used in the processing system also limits inclusion of local BRDF variation.

A means of improving this by using some form of updating based on ancillary data is needed for better results. Previous studies based on AVHRR, POLDER, MODIS, airborne and ground data have found that BRDF shape and various shape indices are significantly related to vegetation structure and land cover type. Among many others, pertinent examples are in Wu et al. (1995), Sandmeier and Deering (1999a, 1999b), Jupp (2000), Lovell and Graetz (2002), Luo et al. (2005), Brown de Colstoun and Walthall (2006), Hill et al. (2008), Jiao et al. (2011) and Li et al. (2013b). Several studies have used land cover based information or BRDF archetypes to adjust for the BRDF effect. For example, Shuai et al. (2014) used a disturbance based BRDF Look-Up Table to adjust for the BRDF effect in Landsat data that was sensed before the MODIS era and Strugnell and Lucht (2001) used land cover based BRDF data to correct AVHRR data. If an effective classification based on land cover or vegetation structure and possibly involving climate can be established, available BRDF data could be averaged over patches of land cover/or vegetation structure types within a scene to reduce within-class variance while maintaining within scene BRDF variation. Moreover, when MODIS BRDF data are not available then updates or estimates could also then be modelled by class within scene rather than at a point.

In this study, the relationships between BRDF shape and vegetation structure (defined here in terms of height and cover of dominant growth form) as well as agro-climate classes were analysed using 10 years of MODIS MCD43A Collection 6 data. The aim of the work is: (i) to analyse the time-series relationships between vegetation structure classes, agro-climate classes and BRDF shape indices in greater detail; and (ii) to evaluate BRDF and climate data relationships using an Australian vegetation structure map and agro-climate classes. These were investigated as tools to adjust the annual variation. In a similar way to earlier investigations (e.g. Li et al., 2013a), this has been done by separating intra- and inter-annual variations of the MODIS BRDF shape parameters and then considering options in the two cases. It must be emphasised that the purpose of this study was to build a climatology of BRDF data through the statistical analysis of MODIS BRDF and vegetation/or climate classes for correcting the BRDF effect in Landsat or similar resolution of satellites. The intrinsic characteristics of BRDF, BRDF indices and their causal relationships with vegetation structure/ or climate were not in the scope of this study. Based on this approach, Section 2 introduces the data used and the indices that were derived to analyse the series as well as the time series methods applied, Section 3 outlines the results from inter- and intra-annual correlation analysis for BRDF indices, as well as their relationships with spectral data (such as NDVI) and relationships with some ground data, Section 4 extends the discussion with some new results to include consideration of a continental scale rainfall time series, Section 5 analyses shape homogeneity among the present structure classes and Section 6 summarises the final conclusions.

## 2. Data and methods

### 2.1. Data sets and pre-processing

#### 2.1.1. MODIS BRDF data and pre-processing

The MODIS MCD43 product provides BRDF information as three model parameters ($F_{iso}$, $F_{vol}$ and $F_{geo}$) in seven MODIS spectral bands as well as information bands relating to model quality at 500 m resolution in standard tiles and sinusoidal projection for the world (Schaaf et al., 2002, 2011 and Wang et al., 2014). Starting in 2002, samples from two satellites (TERRA and AQUA) have been available with considerable benefit to the product. For Collections 1–5, the product was the result of fitting a kernel model to samples from a sliding window of 16 days of atmospherically corrected MODIS surface reflectance data and sampling at 8 days step. Collection 6 is sampled at daily time step although still with the 16 day compositing period. In the standard MODIS product, a linear combination of a constant isotropic term, the Ross Thick volume kernel and the Li-sparse Reciprocal geometric kernel is used to fit these data over the period. The BRDF model in each case can be reconstructed from the data using the linear model:

$$\rho_s(\theta_S, \theta_V, \delta\phi) = F_{iso} + F_{vol}K_{vol}(\theta_S, \theta_V, \delta\phi) + F_{geo}K_{geo}(\theta_S, \theta_V, \delta\phi) \quad (1)$$

where $F_{iso}$ is the isotropic contribution. $F_{vol}$ and $F_{geo}$ are the weights for volume-scattering and geometric-optical contributions respectively. $K_{vol}$ and $K_{geo}$ are volume-scattering and geometrical-optical scattering kernel functions. $K_{vol}$ and $K_{geo}$ are defined as functions of $\theta_S$, $\theta_V$ and $\delta\phi$. $\theta_S$ is solar zenith angle and $\theta_V$ is view zenith angle, $\delta\phi$