Estimation of Land-Surface Albedo and Biophysical Properties using SPOT-4 VGT and Semi-Empirical BRDF Models

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Abstract

Estimates of land surface albedo are derived by inverting semi-empirical, kernel-driven BRDF models against moving 16-day and 30-day windows of directional reflectance data recorded by SPOT-VGT. Using images acquired between May 15th and October 1st 1999, spatial data sets of spectral albedo and the BRDF model parameters are generated for part of western Europe. Attention is focused on three main test sites, namely: (i) East Anglia, UK, (ii) Les Landes, France, and (iii) S.E. Spain. Analysis of the temporal variation in the model parameters suggests that the observed trends can be related to changes in surface biophysical properties (e.g., crop development through various stages from biomass accumulation through anthesis to maturity and harvest).

1 Introduction

The objective of this study is to derive estimates of the spectral and broadband albedo of the land surface using data recorded by the SPOT-4 VGT satellite sensor. Since Earth surface materials exhibit anisotropic reflectance behaviour, this is best achieved by acquiring images over a range of solar illumination and/or sensor view angles: in the case of SPOT-VGT, this implies collecting data from a sequence of orbital over-passes taking advantage of the sensor’s wide cross-track field-of-view (Barnsley et al. 1994). A mathematical model is required to interpolate between the resultant sample measurements of directional reflectance and to extrapolate beyond them to unsampled angles. In this study, we use a set of so-called ‘semi-empirical, kernel-driven’ BRDF (Bidirectional Reflectance Distribution Function) models (Wanner et al. 1995). By inverting these against a multi-day window of directional reflectance data, it is possible to derive spatial data sets of the model parameters and, as a
result, spectral albedo. In this paper, we describe the results obtained by applying this approach to a six-month series of image data acquired by SPOT-VGT over part of western Europe.

2 Method

2.1 Data Pre-Processing

The scientific data sets used in this study are extracted from HDF files provided by CTIV. The logical volume descriptor provides additional information from which ENVI image headers are built, enabling the data to be viewed in ENVI and subsequently geo-located. ENVI/IDL is also used to resample the angular and atmospheric data so that the pixel size for these channels is the same as that of the reflectance images. Spatial interpolation of these data values is performed using a nearest-neighbour algorithm. SMAC 2.0 is used to convert the top-of-atmosphere (TOA) reflectance data to their equivalent at-surface values. For the purpose of this study, the sensor coefficients for VGT required by SMAC have been estimated from those derived for other satellite sensors with a similar spectral response: future work will utilize SMAC 3.2 in the atmospheric correction phase, since this version of the code has been designed specifically for use with the VGT sensor. Each image is then masked against the radiometric quality plane extracted from the status map for each of the four spectral channels. These status maps also provide basic cloud-cover and land masks, although these have not been used in this study. Instead, the land mask is determined from a radiometric analysis of the image data, while the cloud mask is based on a simple binary threshold applied to the blue spectral channel. The latter typically removes more pixels than the cloud mask provided in the status map. Preliminary investigations suggest that this is important for subsequent BRDF model inversions, which tend to be sensitive to ‘noise’ induced by residual cloud cover.

2.2 BRDF Model Inversion and Albedo Calculation

The derived bidirectional reflectance data are inverted against a semi-empirical kernel-driven BRDF model of the form originally suggested by Roujean et al. (1992)

$$\rho(\Omega_i, \Omega_o, \lambda) = f_{iso} + f_{vol}k_{vol} + f_{geo}k_{geo}$$

where $\rho$ is the bidirectional reflectance in spectral waveband $\lambda$ at illumination angle $\Omega_i$ and sensor view angle $\Omega_o$, $k_{vol}$ and $k_{geo}$ are the model kernels for volumetric scattering and geometro-optics, and $f_{iso}$ (the component due to isotropic scattering), $f_{vol}$ and $f_{geo}$ are the corresponding kernel weights. The inversion scheme uses LU decomposition to solve the least-squares problem for the over-determined system $Kf = \rho$, where $K$ is the matrix of kernel values for the viewing and illumination geometries which correspond to the observations of surface reflectance in vector $\rho$, and $f$ is the vector of the kernel weights to be found. The kernels used in this study are the same as those selected for the MODIS BRDF/Albedo product (Wanner et al. 1995, Lucht et al. 2000), namely the ‘Ross Thick’ volumetric kernel, which is based on the model developed by Ross (1981), and the reciprocal version of the ‘Li Sparse’ geometric-optic kernel (Li and Strahler 1992, Lucht 1998, Lucht et al. 2000). In addition to estimates of the kernel weights, the model inversion procedure produces a series of other image planes including the root mean squared error (RMSE), the mean error (bias), and the weights of determination associated with the inversion for each spectral channel (Lucht 2000).

It is possible to calculate the so-called spectral, ‘black-sky’ albedo (Lewis and Barnsley 1994) by integrating the kernels across the viewing hemisphere and then summing them. Since analytical
Figure 1: Angular sampling of SPOT-VGT for the period 1/7–30/7/99. Concentric circles denote 15° intervals of view zenith angle. Solar zenith angle is shown via the colour coding. The azimuth angle of the sensor relative to the sun is marked around the edge of the polar plot. White dots indicate samples affected by cloud cover.

Expressions for these integrals probably do not exist, we use the method proposed by Lucht et al. (2000) in which the integral of the kernel across the viewing hemisphere, $\eta_k$, is given by a simple three-term polynomial of solar zenith angle:

$$\eta_k(\theta_i) = g_{0k} + g_{1k}\theta_i^2 + g_{2k}\theta_i^3$$  \hspace{2cm} (2)

where $g_{nk}$ are the polynomial coefficients for kernel $k$ and noting that $\eta$ is wavelength dependent. The ‘black-sky’ albedo then becomes:

$$\alpha(\theta_i) = f_{iso}\eta_{iso} + f_{vol}\eta_{vol} + f_{geo}\eta_{geo}$$  \hspace{2cm} (3)

noting that $\alpha$ is wavelength dependent. The value of the ‘white-sky’ albedo may be calculated in a similar fashion. Since ‘white-sky’ albedo is not a function of solar zenith angle, however, the value of $\eta$ for each of the kernels is a constant. Finally, it is possible to form an expression for the actual (spectral) albedo if the ratio of diffuse to direct illumination is known and the diffuse component is assumed to be isotropic across the illumination hemisphere. Broadband albedo values may be calculated from each of these by spectral extrapolation.

3 Data Sets and Test Sites

The full area considered in this investigation stretches from the UK and Ireland in the north-west to Spain and parts of north Africa in the south-east. All 478 SPOT-VGT images (P products) acquired over this area during the period May 15th to October 1st, 1999 were downloaded from CTIV, although some of these cover only a small fraction of the study area. Three test sites, each approximately 160km x 160km in size, were selected for more detailed analysis, namely: a) East Anglia, UK (arable farmland); b) Les Landes, France (coniferous forest, surrounded by a mixture of agriculture and shrubland); c) south-east Spain (mixture of scrub and forest). The different incidence of cloud cover at each of the sites is reflected in the number of bidirectional reflectance samples available for BRDF model
Figure 2: (a) False-colour composite of spectral ‘black sky’ albedo produced using SPOT-VGT data recorded in the red (B: 0.00–0.07), NIR (G: 0.14–0.44) and SWIR (R: 0.09–0.24); (b) False-colour composite of BRDF kernel weight images produced using SPOT-VGT data from the red spectral waveband — geometric (R: 0.00–0.07), isotropic (G: 0.17–0.47), volumetric (B: 0.04–0.43). These images have been produced using SPOT-VGT data acquired over a 30-day period in July, 1999.

4 Results and Discussion

Figure 2(a) shows an example of the derived spectral albedo data over the UK. The data are presented in the form of a false-colour composite, combining spectral albedo images from the red, NIR and SWIR wavebands. The accuracy of these data is currently being assessed through an intensive programme of field verification. Figure 2(b), on the other hand, presents a false-colour composite of the
retrieved BRDF model kernel weights (i.e., \( f_{iso} \), \( f_{vol} \), and \( f_{geo} \)) for the red waveband alone. Visual inspection of this figure suggests that it is possible to distinguish numerous salient features of the UK landscape on the basis of their bidirectional reflectance behaviour. In particular, there is good contrast between the urban (brownish-red) and non-urban areas, between woodland (dark green) and other vegetation, and possibly even between areas dominated by cereal crops (light blue), moorland vegetation (dark blue) and permanent pasture (light green/cyan). These differences are a result of variations in the relative contributions of the isotropic, volumetric and geometric-optical components of radiation scattering at the earth surface as a function of the differences in the geometrical structure and biophysical properties of the respective land cover types. Work is currently underway to verify these observations using a land cover map of the UK.

While the images presented in Figure 2 are informative, it is also instructive to examine in greater detail the temporal profiles of the retrieved spectral albedo values, as well as the kernel weights, the RMSE of the model fits, and the average number of angular samples used in the BRDF model inversions. Examples of these are shown in Figures 3 and 4 for the red and NIR wavebands, respectively, over an area of cereal crops in the East Anglia (UK) test site. The plots run from approximately the middle of June (JD165) until the end of September (JD275) 1999. These dates refer to the end of the 30-day moving window of data used in the BRDF model inversions; in other words, the actual period of time for which reflectance data were used runs from the middle of May until the end of September. Hereafter, we will use the nomenclature JD_{end,period} (e.g., JD165,30) to refer to the dates used in the inversions. The data in these plots refer to a spatial window of 3 x 3 pixels. The mean values of the spectral albedo, kernel weights, RMSE and number of angular samples used in the inversions within the window are shown by the solid red lines, while the range of values for each property are indicated by the areas shaded in pink. Note that, in general, the temporal profiles for each of the nine pixels in the 3 x 3 window are very consistent (i.e., they tend not to cross one another), so that the width of the area shaded in pink gives an indication of the underlying spatial variability in parameter values rather than a measure of the uncertainty or error in their retrieval.

It is not possible to describe all of the features evident in Figures 3 and 4; instead, we will concentrate on just a few of the most important ones. First, it should be evident that the temporal profile of the spectral albedo values is not necessarily dominated solely by variations in the isotropic kernel weights. This is particularly evident in the red waveband and demonstrates that spectral albedo may only be poorly approximated by individual directional reflectance measurements or an average of these over time. Second, there is evidence of significant changes in the retrieved kernel weights that appear to coincide with known changes in surface biophysical properties. For instance, the marked increase in the value of the volumetric kernel and the somewhat smaller reduction in the value of geometric kernel in the red waveband starting around JD195,30 (i.e., around the middle of July) appears to correspond to the time at which the cereal crops in this region reach maturity (i.e., ripen). This trend is reversed from about JD205,30 (i.e., late July/early August) when the cereal crops are harvested. Corresponding trends are also evident in the data from the NIR channel.

One should, of course, be cautious in terms of reading too much into temporal profiles derived from so few pixels — a more detailed and extensive evaluation is clearly required — but these results suggest that the BRDF models are responding in a predictable way to changes in the biophysical properties of land surface materials. Moreover, results from the Les Landes test site (not presented here) reinforce our confidence in these results. This area, which is dominated by evergreen trees and might therefore be expected to exhibit smaller phytophenological changes over the same period of time, displays much more stable temporal profiles for each of the BRDF model parameters. This suggests that the variation evident for the UK test site is not simply a false positive.
Figure 3: Temporal variation in the spectral albedo, BRDF model kernel weights, RMSE and average number of angular samples for an area of cereal crops in the East Anglia test site (Red channel).
Figure 4: Temporal variation in the spectral albedo, BRDF model kernel weights, RMSE and average number of angular samples for an area of cereal crops in the East Anglia test site (NIR channel).
5 Conclusions

The results of this study suggest that, given a sufficiently long sampling period (e.g., 30 days), data from SPOT-VGT can be used in conjunction with appropriate BRDF models to yield estimates of land surface albedo and other biophysical properties. Preliminary evidence indicates that the spatial and temporal patterns of the retrieved values correspond to anticipated variations in land cover type and phytophenological properties, although rigorous field verification is still required. Due to the accurate radiometric calibration and geometric registration of the SPOT-VGT images, the process of deriving albedo and other biophysical properties through BRDF model inversion is considerably simpler and likely to be much more accurate than with previous ‘coarse’ spatial resolution satellites, such as NOAA/AVHRR.

References


