SIMULATION OF BRDF DATA TO SUPPORT BIOPHYSICAL PARAMETER RETRIEVAL IN THE LSA SAF CONTEXT

F. J. García-Haro, F. Camacho-de Coca and M.A. Gilabert

Departament de Termodinàmica, Universitat de Valencia
C/ Dr. Moliner, 50 46.100 Burjassot, Valencia, Spain

ABSTRACT

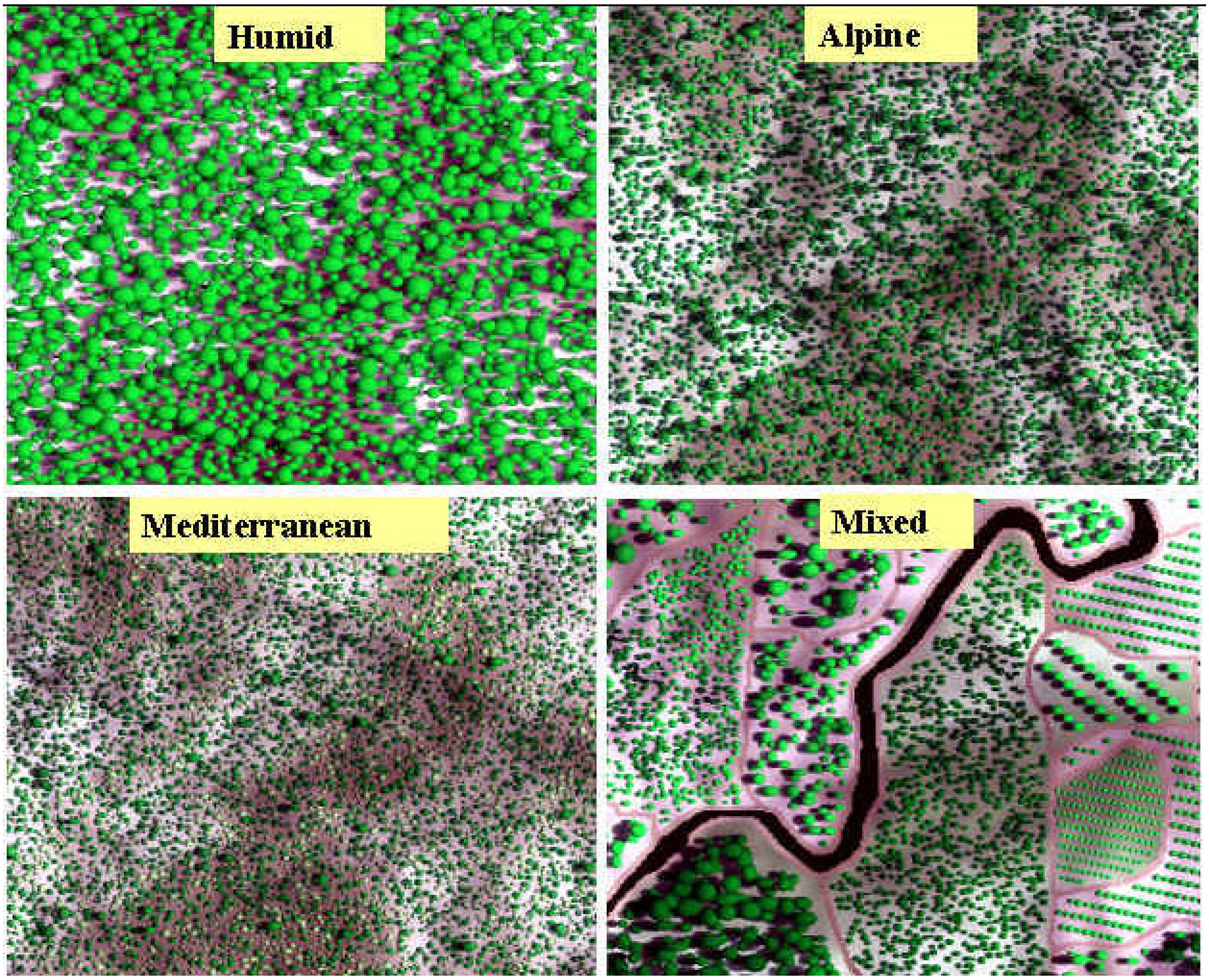
The current development of satellite technology of future EUMETSAT MSG and EPS missions provides improved spatial and spectral resolution of remote sensing data, which requires their careful interpretation with the aid of canopy reflectance models. By introducing appropriate ecological data to the models, they are valuable tools to determine the driving factors of optical images. They may also improve the estimation of parameters by inversion, once prevailing effects have been determined.

In this work, a model for light interaction to compute spectral and bidirectional reflectance from discontinuous canopies is presented (see details in García-Haro and Sommer, 2002). The model attempts to describe the bidirectional reflectance of heterogeneous surfaces offered by coarse scale pixels, i.e. to simulate the reflectance at the kilometre scene. Canopy is approximated by an arbitrary configuration of plants. The model describes directional reflectance properties of vegetation canopies in terms of canopy architecture parameters and optical scattering properties of leaves, resulting in a robust and fast canopy reflectance model of heterogeneous canopies. New capabilities have been incorporated to the model, giving a particular emphasis to the reproduction of SEVIRI (sun varying) and AVHRR-3 (view varying) geometry. The model is presented as a tool that will support the retrieval of vegetation products in the context of LSA SAF. In particular, it will contribute to (i) evaluate the influence of the view/sun angles in order to normalise the directional effects, (ii) describe the angular pattern of sunlit crown/ground using variables connected with the canopy structural parameters in order to support the inversion, (iii) optimise the choice of model/parameter and BRDF sampling for inversion, and (iv) control and assess the potential errors of retrieved vegetation products under a variety of conditions.

1. INTRODUCTION

A number of canopy bidirectional reflectance models of different complexity have been developed in the past decades (Verhoef, 1984; Ross and Marshak, 1988; Li and Strahler, 1992; Borel and Gerstl, 1994; Gastellu-Etchegorry et al., 1996; Chen and Leblanc, 1997; García-Haro et al. 1999; Kuusk and Nilson, 2000; Shabanov et al., 2000). However, though very realistic, they are too intensive computationally for regional scale analysis. Moreover, although relatively large scale scenes have been simulated, the excessive requirement in the number of parameters makes inversion difficult. For some applications such as the evaluation of different ecosystems at different spatial, directional and spectral resolutions or for inversion purposes it is necessary to have fast, but still realistic models.

In this work, forward modelling of physical scenarios was undertaken using a canopy reflectance model (García-Haro and Sommer, 2002). The model predicts the basic features of the BRDF, i.e., bowl shape and the hotspot, but is also well suited to address the spectral and spatial domains. It provides a fast and efficient strategy to derive images at appropriate spatial resolutions (e.g., regional scale) over a wide range of ecosystems (see figure 1).



1. **Examples of simulated images corresponding to different secondary forest ecosystems. The inputs were: 0.5m spatial resolution, SZA=30°, clear atmospheric**

conditions and background composed of two or more soils with a certain pattern of roughness.

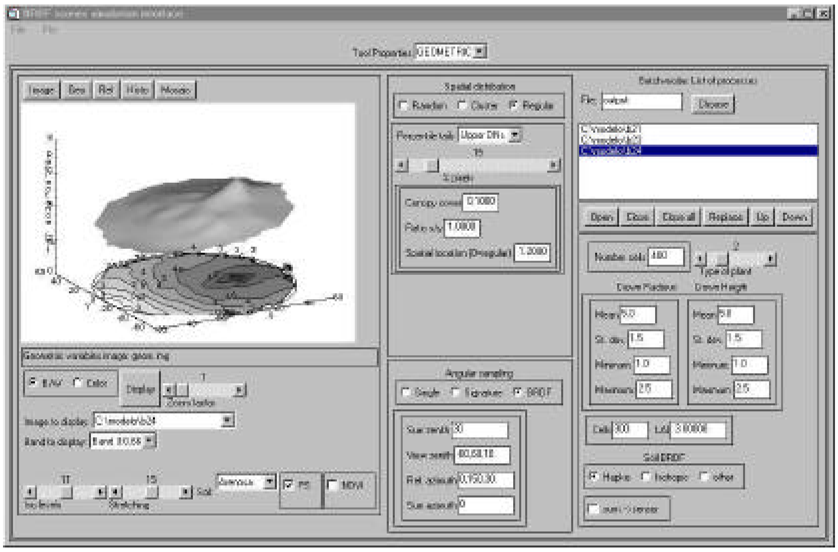
The model is based on geometric-optical principles but uses an average canopy transmittance theory to compensate for errors due to multiple scattering in vegetation canopies that lead to non-linear mixing. This enables us to investigate the capability of space-borne data for heterogeneous vegetated land covers on large areas at appropriate resolutions. The model is well suited for shrublands, croplands and broadleaved deciduous semi-natural ecosystems. However, equations are quite general and thus can be adapted to the conditions of a particular type of canopy.

Figure 1 shows a few examples of simulated images. Different backgrounds presenting variable topography and comprising different landscape features on imported real images were considered: (1) humid climate, with big green broadleaved trees, (2) South Alpine conditions, with higher density of bushes and some dominant trees in between, (3) Mediterranean climate with poor rainfall, dominated by shrubland, with alternation of different species of green and dry shrubs, and some sparse broadleaved trees, and (4) forest map, composed by a set of different stands, as imported from a real distribution. There is a variety of diverse structures, ranging from mixed forest to regular plantations.

The next section describes new features that were incorporated to the model in the LSA SAF context. Section 3 describes the model as a tool to assess the errors of retrieved parameters. Finally, section 4 demonstrates its ability to describe the contribution of shaded and illuminated ground and crown, even when overlapping complicates the generalisation for denser canopies.

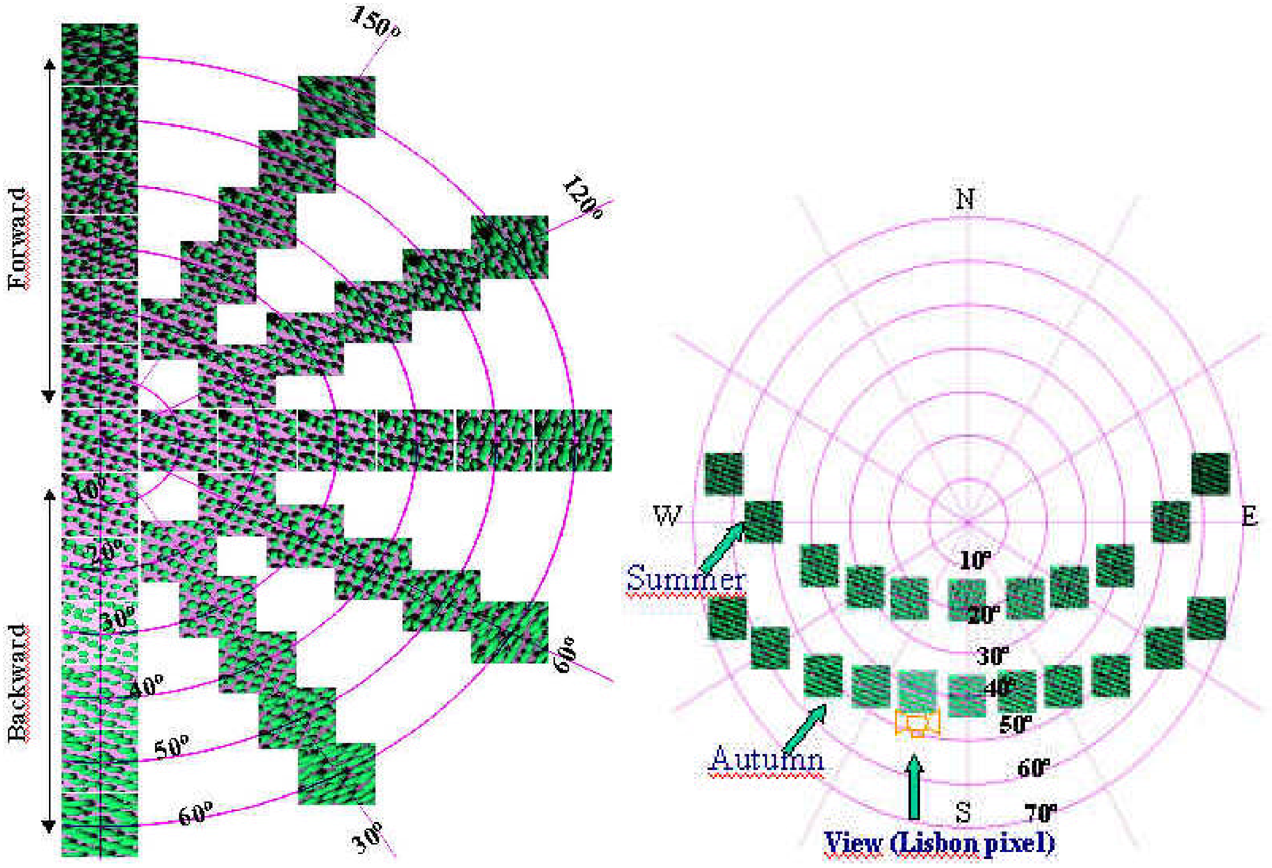
2. MODEL IMPROVEMENTS FOR LSA SAF

New features have been incorporated to the model. For example a more accurate representation of the soil BRDF has been obtained using anisotropic soil reflectance as imported either from real images or from a theoretical model, e.g. the six-parameter SOILSPECT model (Jacquemod et al., 1992). A graphic user interface (GUI) has been developed, which simplifies the simulation of multi-angular and multi-spectral data sets while offering a rank of modelling schemes (see figure 2).



2. The Graphic User Interface provides a robust modular expandable frame and graphical means of interacting with menus and data.

The GUI also facilities the sensitivity analysis of the main scene variables. In particular, emphasis has been given to simulate directional signatures and BRDF sampling adapted to the geometric/spectral characteristics and AVHRR-3 (view varying, see figure 3a) and of SEVIRI (sun varying, see figure 3b) geometry.

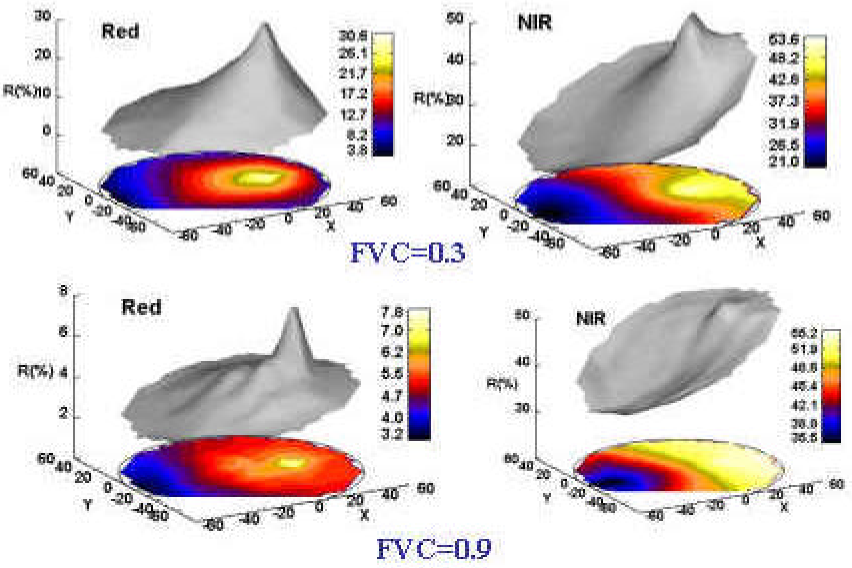


3. Mosaic of simulated images superimposed within a polar diagram. Individual images are displayed as RGB compositions (red, NIR, MIR). (a) View varying full disk. The BRDF was sampled at 10^o intervals in zenith and 30^o in azimuth. The inputs for the simulation are: FVC=0.30 (sparse canopy), plant LAI=3, q_s=30^o, bright soil and random plant distribution. (b) Simulated SEVIRI trajectories corresponding to a particular pixel situated in Lisbon (view angles: q_v=45^o, f_v=193^o), and for two seasons, summer and autumn. The inputs for the simulation are: FVC=0.40 (intermediate canopy), LAI=3, bright soil and random plant distribution with a certain clumping.

AVHRR-3 on EPS will provide variation of view angles using a set of number of days to accumulate observations. The observations will be close to the principal plane using, where the directional effects are more pronounced (see figure 3a). Figure 3b allows us to understand SEVIRI on MSG sampling, i.e. a frequent daily sampling at different solar angles but at a given view zenith angle, and mostly in the plane orthogonal to the principal plane. Simulated images allowed us to investigate the directional diurnal trajectories. The analysis will contribute to normalise the anisotropy associated with the sun angle changes in SEVIRI data (see section 4). In addition, simulated SEVIRI diurnal trajectories in the spectral space will enable an optimal choice of the sampling scheme for better discriminating the major biome types.

2. SENSITIVITY ANALYSIS

The retrieval of vegetation parameters is vulnerable to measurement noise such as soil substract effect, atmospheric effects, and specially bidirectional properties of the vegetation and the soil, effects that have to be considered. Sensitivity analyses using the modelling frame allowed for quantifying the relative contribution of the different canopy biophysical parameters to the simulated spectral and bidirectional reflectance (see examples in figure 4). Simulated images show that LAI and FVC control the canopy reflectance. We can observe a strong anisotropy of the canopy reflectance in all regions. This anisotropy is highly dependent of spectral channel and sun position. The results also demonstrate the critical influence of scene background, even in dense canopies. In general, when the soil is brighter, the directional effects such as the hot spot are more pronounced due to the increased importance of the visibility and brightness variations of scene objects. Logically, at high off-nadir view angles the BRDF becomes rather insensitive to background reflectance since it is usually occulted by the scene objects. The analysis also reveals the strong influence of the plant shapes and clumping.



4. Simulated BRDF with varying view geometry. Input parameters are: LAI=3; SZA=30^o and bright soil. Two different plant densities, FVC=0.3 (sparse) and FVC=0.9 (dense), are considered.

The simulated BRDF data compared favourably with real POLDER data corresponding to cropland. Moreover, one main strength of the model comes from the characterisation of the spectral behaviour of canopies uniquely from a reduced number of dominant parameters, including some meaningful properties (FVC, LAI) that might be retrieved by inversion strategies. Canopy geometry and spatial, spectral and angular resolutions may be systematically altered to examine and validate the proposed algorithms for retrieval of FVC and LAI. In general, errors in one biophysical component, such as LAI, translate into other key parameter, such as FVC. While potentially a weakness, this fact provides a tool for assessing and reducing potential errors in remote sensing estimates of FVC and LAI under a variety of conditions.

3. OPTIMISATION OF DIRECTIONAL SPECTRAL MIXTURE ANALYSIS

Our main concern is the retrieval of surface information using measurements at a few angles using directional spectral mixture analysis (García-Haro et al., 2002). In order to achieve this goal, an accurate description of the single scattering and between-crowns light penetration is necessary. This description can be improved with the aid of the proposed model, as it is shown as follows.

For homogeneous Poisson distribution, the probability P_{ig} of observing the sunlit ground under the tree crowns in any given pixel approaches to (Jasinski and Eagleson, 1989):

$$P_{ig} = (1 - g_c)^{(\eta_s + 1)} \tag{1}$$

where g_c denotes the fractional vegetation cover and η is defined as the ratio of shadowed area to plant area. Consequently, a functional relationship can be found between subpixel shaded ground P_{sg} and fractional vegetation cover:

$$P_{sg} = 1 - g_c - (1 - g_c)^{(\eta_s + 1)} \tag{2}$$

Replacing the sun by the sensor, a similar expression is found for the subpixel viewed ground P_{vg}:

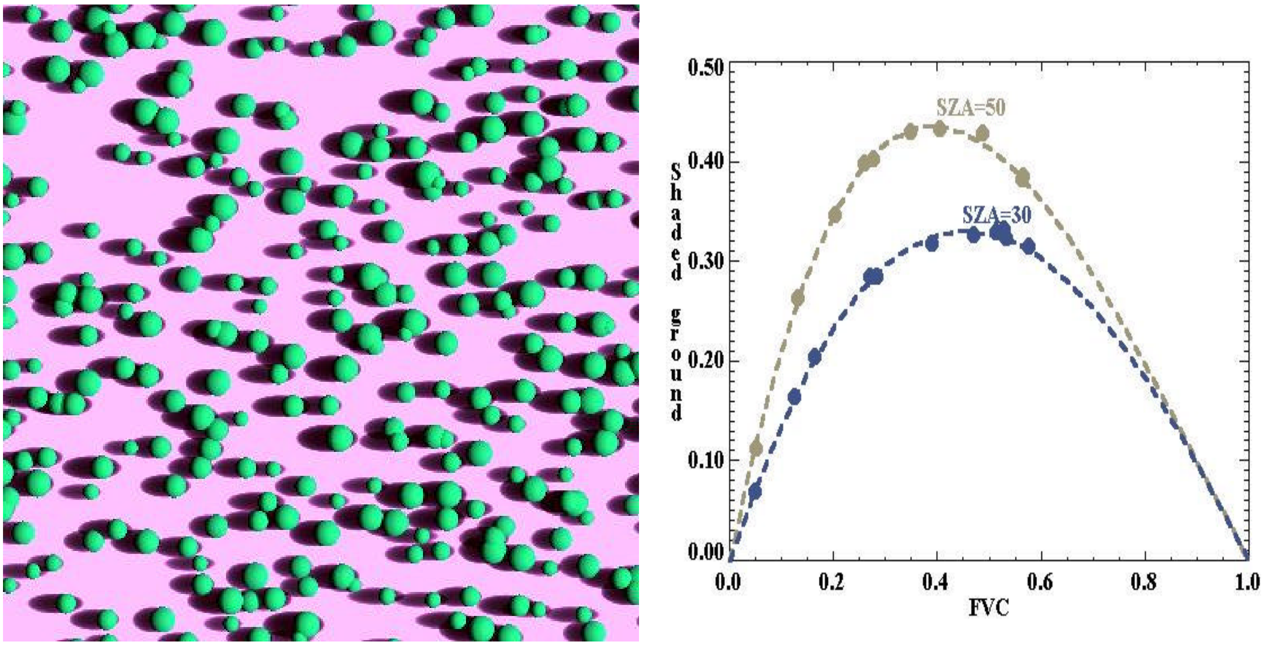
$$P_{vg} = (1 - g_c)^{(\eta_v + 1)} \tag{3}$$

η absorbs all the geometric factors which relate canopy area to shadowing area into only one variable. Its analytical expression for the most common geometrical bodies is provided in Jasinski and Eagleson (1990). For example, for the case of square cylinders, we have:

$$\eta_{s,v} = \tan\theta_{s,v} / b \tag{4}$$

Equations (1-4) are applicable at large sampling scales when imaging stands resolutions greater than the size of the tree crowns. In order to confirm these mathematical relationships, different nadir images were simulated varying the main scene parameters. Figure 5a shows an example corresponding to a 200m pixel scene characterised by FVC=0.3, $\theta_V=50^o$ and Poisson plant distribution. Similar simulated images were obtained varying FVC and SZA. Figure 5b shows the relationship found among subpixel shaded ground and FVC. The dashed lines correspond to the relationships predicted by equation (1). We can observe that the curves are nearly coincident.

Different simulations were undertaken varying the plant distribution (regular, clumped, etc.). The relationships found for these (non-Poisson) distributions differed from those predicted by Eq. (2). This exercise shows that the model is valuable tool to determine the angular pattern of optical images, linking the BRDF with the main structural parameters of the canopy. In fact, forest reflectance is dominated by the contrast between the sunlit and shaded components, especially in the visible parts of the spectrum.



(a) (b)

5. (a) Example of nadir image. Input parameters are: q_V=50^o, Poisson plant distribution, FVC=0.30 and elongated plants (b=2.5). (b) Shaded ground (P_{sg}) as a function FVC, for two different sun zenith angles. The figure reveals a close agreement between P_{sg} obtained from simulations (symbols) and P_{sg} proposed by Eq. (2) (dashed line).

The main problem is the computation of the proportions of sunlit ground and sunlit crown viewed by the sensor. The probability of observing sunlit ground when P_{ig} and P_{vg} are not correlated (i.e. when the viewer sees the sunlit ground trough a gap different from that of illumination) is simply the product of both probabilities: $P_{ig}P_{vg.}$ However, the probability of observing sunlit crow or sunlit ground increases due to the correlation between P_{ig} and P_{vg}. Hotspot kernels are used to account for the dependence between the two gap probabilities along sun and view directions. They are unity when the sun and view positions align (i.e. at the hotspot) and zero when the illumination and view angles are far apart. However, direct calculations for the joint probability are very complicated, and require the use of certain simplifications. For example, the gap size distributions inside and between tree crowns is assumed known (Chen and Leblanc, 1997) or a simple prescribed representation of subcanopies sizes, shapes and distributions is used (Li and Strahler, 1992; Qin et al., 1996). The proposed model offers an alternative and more general method to determine the between crown gap probability and hotspot kernel for a wide range of biomes and spatial resolutions.

4. CONCLUSIONS

The canopy reflectance model presented here is appropriate for investigating the multi-angular, multi-spectral and spatial domains of remotely sensed data. New features have been incorporated to obtain directional signatures and BRDF data sets reproducing the acquisition geometry of SEVIRI and AVHRR-3 instruments. The model is presented as a tool in support of vegetation products retrieval within the context of LSA SAF. For example, it will allow improving our ability to model the BRDF of vegetation canopies and optimise the inversion scheme for the retrieval of surface information using measurements at a few angles. In particular, its accurate description of the single scattering and between-crowns light penetration provide a physical basis which is necessary to parameterize the surface reflectance from the directional signatures of ground and vegetation, e.g. using directional spectral mixture analysis (García-Haro et al., 2002).

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