Estimación de parámetros biofísicos a partir de datos direccionales de satélites de nueva generación: EPS y MSG
Retrieval of biophysical parameters using directional data from new generation satellites: EPS and MSG

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SUMMARY

The accumulation of directional data in short periods of time permitted by the new generation satellites concept should permit the extraction by inversion of significant information on leaf reflectances, leaf area index and other structural properties of vegetation canopies. However, the question of the behaviour of the inversion process in the general case of heterogeneous pixels has not been addressed yet. Our main objective is the development of a robust methodology for the retrieval of the biophysical parameters of vegetation such as FVC and LAI, which play a critical role in the description of both land-surface processes and land-atmosphere interactions. The estimation of these parameters relies on a highly optimised mixture modelling approach and model inversion strategies, which are methods especially adequate when the spatial variability within pixel is high.

1. INTRODUCCIÓN

This work has been developed in the frame of the Land SAF Project (Satellite Application Facility on Land surface analysis), which will be part of the ground segment for the future EUMETSAT missions METEOSAT Second Generation (MSG) and European Polar System (EPS), developed by the ESA. This new generation of off-nadir satellite sensors will bring an upgraded level of remote-sensed information to the user community thanks to a much better spatial, temporal, spectral and angular sampling of the radiative fields emerging from the Earth's surface. The time resolution and global

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$$R_v(\lambda,\Phi) = EM_{v,j}(\lambda)\cdot CC(\Phi,X)\cdot B_{v,j}(\lambda,\Phi,X) \tag{1}$$

where

- $EM_{v,j}$ refers to vegetation endmember, i.e. the spectral signature corresponding to a dense vegetation canopy (i.e. for LAI=∞) measured under ideal conditions (e.g. θ_s=0 and θ_v=0). The EMs that make up the pixel vary on a per-pixel basis. This multiple endmember configuration based on a dynamic identification of the optimum EM subset for each image pixel provides a more accurate interpretation, improving the fit of the model and reducing the errors of solutions. The index *j* corresponds to the best vegetation endmember among all the possible candidate vegetation endmembers.

A set of *c* candidate vegetation endmembers $EM_{v,j,}$ (j=1,c) can be selected in order to match the possible solutions to the spectral properties and architecture of the main canopy types found in the image. VMESMA offers different techniques to identify appropriate image EMs and interpret them on the basis of a spectral attribute data-base. Alternatively, the EM can be derived with the aid of semi-empirical relationships, e.g.:

$$EM_{v,j}(\lambda, j) = A(j)\tau(\lambda)^{B(j)} \tag{2}$$

where $\tau(\lambda)$ is the transmittance of the leaves, and A and B are structural parameters that can be tabulated to characterize the main different vegetation types (Gilabert et al., 2000).

- B_v parameterizes the angular dependence of the vegetation community labeled *j*, as a function of its spectral, angular and structural parameters.
- $CC(\Phi,X)$ is the sunlit and viewed canopy cover, which varies with the sun and view angles and with canopy parameters, which are symbolized by X. Canopy parameters include the main structural properties such like the LAI, the angular distribution of leaves, the clumping index and the dimensions and spatial distributions of canopy elements. $CC(\Phi,X)$ is usually related with LAI using physically based relationships using coefficients that are dependent of the vegetation cover type. Neglecting the hotspot effect, it can be expressed as the product of the probabilities of the gap fractions in the directions of the sun (θ_s) and the sensor (θ_v), respectively. This function can be approximated by the following expression:

$$CC(\Phi,X) = 1-\exp(-\Delta\cdot LAI_e) \tag{3}$$

$$\Delta = \frac{G_s}{\cos(\theta_s)} + \frac{G_v}{\cos(\theta_v)} \tag{4}$$

where

- $G_{s,v}$ represent the mean foliage projection factors for the sun and view directions, respectively. In general, $G_{s,v}$ depend on the zenith angle, although for uniform (turbid) canopies and assuming that leaves, branches and shoots are randomly distributed, $G_{s,v}$ are equal to 0.5. In heterogeneous canopies, $G_{s,v}$ takes a higher value since the between-crown geometry affects to the light penetration (Lacaze and Roujean, 2001).
- LAI_e is the effective LAI, which is the LAI found assuming a random foliage distribution. We can introduce the clumping in the following way:

$$LAI_e = LAI\cdot\Omega \tag{5}$$

where Ω is the clumping index. Ω=1 means random foliage distribution and Ω<1 means clumped foliage. The clumping index has been found to be dependent on the view zenith angle (Kucharik et al., 1997). Leblanc et al. (2001) found a linear relationship between the Normalised Difference Hotspot Darkspot index (NDHD) calculated at the solar zenith angle of 35 degrees and Ω:

$$\Omega = 1.002 - 1.515\cdot NDHD_{(\lambda=865nm)} \tag{6}$$

Logically, the fractional vegetation cover, FVC, is the canopy cover found under ideal conditions, i.e. $FVC = CC(\theta_s = 0, \theta_v = 0)$. Because the proposed model requires a LAI parameter as input, inversion of this model will allows us to obtain LAI values. Alternatively, some empirical relationships to derive LAI from estimated FVC can be used (eg. Lacaze and Roujean, 2001).

Soil modelling. The spectro-angular characterisation of the soil component is based on the expression:

$$R_s(\lambda,\Phi) = EM_{s,j}(\lambda)\cdot GC(\Phi,X)\cdot B_{s,j}(\lambda,\Phi) \tag{7}$$

where

- $EM_{s,j}$ refers to soil endmember, i.e. the spectral signature of a surface with LAI=0 measured under ideal conditions (e.g. θ_s=0 and θ_v=0), and the index *j* corresponds to the 'best' soil endmember. Although VMESMA provides us with different methods for the retrieval of the spectral signatures of the main soil types, another possible strategy could consists in express the spectral signature of soils using a certain parameterization. For example, Bicheron and Leroy (1999) use two spectral soil parameters, a_1 and a_2 and the following expression:

$$EM_s(\lambda) = a_1\cdot\varphi_1(\lambda) + a_2\cdot\varphi_2(\lambda) \tag{8}$$

where $\varphi_1(\lambda)$ and $\varphi_2(\lambda)$ are the two first basis functions of Price (1990).

- $B_{s,j}$ parameterizes the directional dependence of the soil type labeled j. There are many soil BRDF models available. For example, Bicheron and Leroy (1999) propose a wavelength-independent function given by

$$B_s(\lambda,\Phi) \approx B_v(\Phi) = 1 + w_a\theta_s\theta_v\cos\Phi + w_b\theta_s^2\theta_v^2 \tag{9}$$

where w_a and w_b are two directional soil parameters. Walthall et al. (1985) proposed another empirical formula for soil BRDF which is valid for soils of average roughness. Nilson and Kuusk (1989) modified it to satisfy the reciprocity principle, resulting in a simple (non parametric) model. Other authors propose a more complex soil BRDF models (Hapke, 1993; Jacquemoud et al., 1992).

- $GC(\Phi,X)$ is the ground cover, which varies with the view and sensor zenith angles and with canopy structural parameters, e.g. Lacaze and Roujean, (2001):

$$GC(\Phi,X) = \exp(-\Delta\cdot LAI_e) \tag{10}$$

3. A HIERARCHICAL INVERSION STRATEGY

BRDF signatures of major biomes cover types, as assessed from models and previous results undertaken on real datasets, will be used to categorise the image. Recent studies (Bicheron and Leroy, 2000) have measured from POLDER/ADEOS the BRDF signatures on the basis of 17 land cover classes of the IGBP 1-km land cover classification, called DISCover land cover data set (Loveland and Belward, 1997). These data are available to the science community. The result of our modeling approach will be a hierarchical subdivision of the image for addressing the variations of the level of complexity between the various image sub-areas. All existing multi-source data will be effectively involved in the process. For example, the iterative process will incorporate auxiliar information such a land cover maps. Recently, angular indices (NDHD, ANIX) based on simple relationship between the maximum and minimum of the directional signature in the principal plane have proved to be useful for mapping vegetation clumping (Leblanc et al., 2001), to enhance classification of boreal forest (Sandmeier and Deering, 1999) or to define new vegetation indices (Camacho-de Coca *et al*., 2001a). Similarly, the usefulness of the use of anisotropy factors like ANIF*i*, based on the change of the reflectance with the sun zenith angle, allows for retrieval of structural information of the surfaces (Camacho-de Coca *et al*., 2001b). This anisotropy index, which has been successfully tested using airborne data from the DAISEX

Project, will be used in the categorisation of the scene, allowing us to group together the land cover classes with similar anisotropy properties. Highly efficient methods for selecting the best candidate EM have been proposed and developed, which tie together modeling errors and estimate errors, and moreover allows for a maximum control of the solutions (García-Haro et al., 2001).

4. A SIMPLER APPROACH

The above sections presents a general solution we propose for the estimation of biophysical properties from directional imagery. However, we will also consider a simpler approach based on a two steps:

(1) BRDF models may be used to simulate the reflectance at a common solar zenith angle for all pixels that were taken at different solar zenith angle. Several works have shown the usefulness of the BRDF models to normalise anisotropic properties of the surfaces (Hu *et al.*, 2000; Leroy and Hautecour, 1999). Normalisation bidirectional effects consists in displacing the reflectances values along the shape of the BRDF from their actual acquisition geometry to a reference geometry (Wu et al., 1995; Maisongrande et al., 2001). Schaff et al. (2001) supply nadir BRDF-adjusted reflectances at the mean solar angle of a 16-day period in order to provide a surface bidirectional reflectance at MODIS resolution that has been corrected to a common view geometry. For example, Leroy and Roujean (1994) propose a method to address the directional effect influencing the off-nadir images based on a kernel-driven model (Roujean et al., 1992). Its inversion provides a set of coefficients $k_{i=0,1,2}$ which stand, respectively, for a nadir-zenith (Lambertian) reflectance, and roughness and volume scattering coefficients.

(2) The second step consists in using nadir-zenith reflectance (i.e. estimated k_o) as a sub-product before applying more consistently the traditional VMESMA. The correction of the angular view for the whole of the image (step 1) is also an important aspect to be into account in order to increase the physical meaning of the vegetation products (FVC) retrieved in step 2.

The inversion approach is considerably simpler that the directional SMA described in section 2, and is based on the following assumptions: $B_V=1$ and $B_S=1$, $CC(\Phi, X)=FVC$, $GC(\Phi, X)=1-FVC$. Thus, the approach can be formulated as follows for a 2-EM model:

$$R = FVC \cdot EM_{v,j}(\lambda) + (1-FVC) \cdot EM_{s,j}(\lambda) \qquad (11)$$

where the $EM_{v,j}$ and $EM_{s,j}$ are the best vegetation and soil endmembers. Equation (11) is the basis of the traditional SMA, which can be considered appropriate for analysing unitemporal images comprising relatively small FOVs, and where the influence of off-nadir view angles throughout the scene are not significant. This model can be generalised to allow for solutions including 3-EM and 4-EM models (e.g. García-Haro et al., 2001) although a multiple 2-EM solution might be sufficient to model the major part of the scene variability in vegetated areas, even in semi-arid landscapes (Roberts et al., 1998; Kemper et al., 2001). Finally, semi-empirical methods can be used to retrieve LAI from derived FVC (e.g. Lacaze and Roujean, 2001). Thus the retrieved FVC would be rather insensitive respect to the anisotropy effects. The main drawback of methods that rely on k_o is that they do not explode the physical information contained in the variation of the sun/sensor geometry (e.g. the diurnal signature provided from SEVIRI).

5. ANALYSIS ON SYNTHETIC DATA

In order to aid the examination of the BRDF effects, a preliminary analysis has been undertaken on synthetic data generated by Meteo France (Van Leeuwen and Roujean, 2001), which accurately reproduce the spectral, spatial and directional characteristics of real SEVIRI data. The simulation is based on the SAIL BRDF model (Verhoef, 1984) and a 6S atmospheric model (Vermote et al., 1997), using as inputs spectral libraries (http://speclib.jpl.nasa.gov/) and LAI derived from POLDER/ADEOS. SEVIRI onboard MSG will allow for frequent daily sampling at different solar zenith angles but at a given zenith angle, and mostly in the plane orthogonal to the principal plane. In this study a SEVIRI image (corresponding to 12:00 GMT, 166*th* Julian day). The nadir position of the sun and sensor is shown in figure 1.

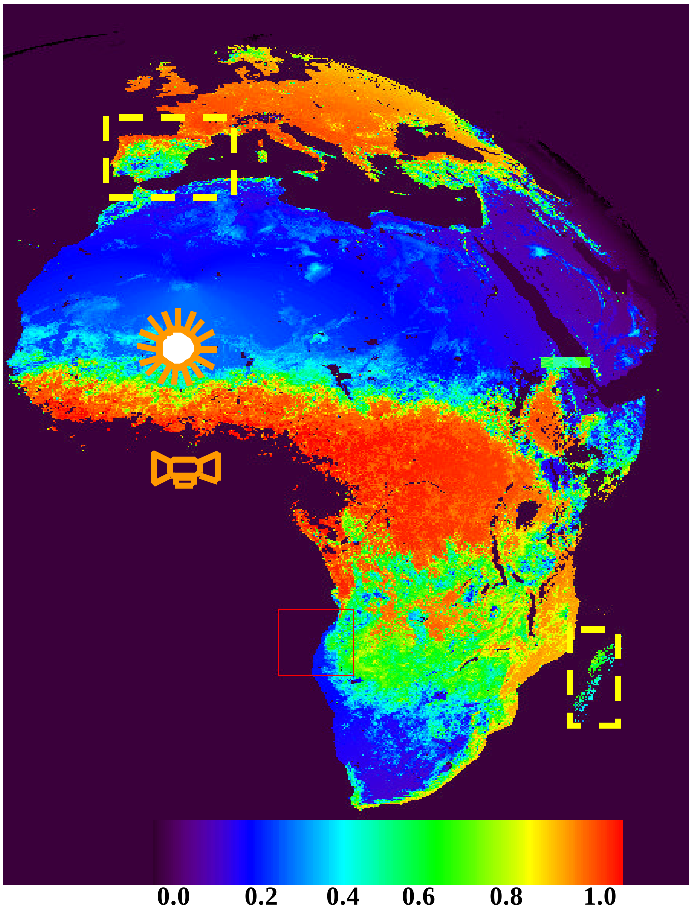

Figure 1 **– FVC derived using VMESMA on SEVIRI synthetic data.**

Since a single image was available for the analysis, the normalisation method described above could not be undertaken. So we have considered the most simple case neglecting the influence of the directional effects (ie., the change of the illumination and view angles throughout the image). Different soil and vegetation EMs were extracted automatically from the image and then VMESMA was applied using a variable 2-EM model strategy. Figure 1 show the resulting FVC image. Finally, FVC was compared with the available information, such like the LAI map derived from ADEOS/POLDER. Figure 2 shows the relationship found between FVC and LAI for two single areas, a Mediterranean area centred in Spain (θ_s=17°; θ_v=45°; Φ= 8°), and an island, Madagascar (θ_s=62°; θ_v=55°; Φ=337°). Both areas, highlighted by dashed boxes in figure 1, are situated near the principal plane, and are characterized by a backwards scattering geometry. The Madagascar area presents considerably higher zenith angles, specially for the illumination.

We can observe a strong correlation between derived FVC and LAI. The data fit very well to the theoretical relationship mentioned above (Eq. 3). Discrepancies between the results obtained for two different scene areas are mainly attributable to the illumination variations not accounted by the unmixing model. Although when multiple angle remote sensing data is available, BRDF is generally regarded as a source of information, in this cases it must be regarded as a source of noise. In fact, applying the traditional VMESMA under non-nadir conditions produces inconsistent EM fractions. In this case, vegetation EMs did not addressed the differences in the viewing/illumination geometry and, therefore, it has resulted in a bias in the FVC estimates. For example, there is an apparent increase in the greenness of the vegetation EM when observing at high off-nadir angles in the backwards direction (i.e. in Madagascar) since the proportion of illuminated and viewed canopy cover is higher. Consequently, it has resulted in an overestimation of the FVC at high off-nadir angles, which is evident in figure 2.

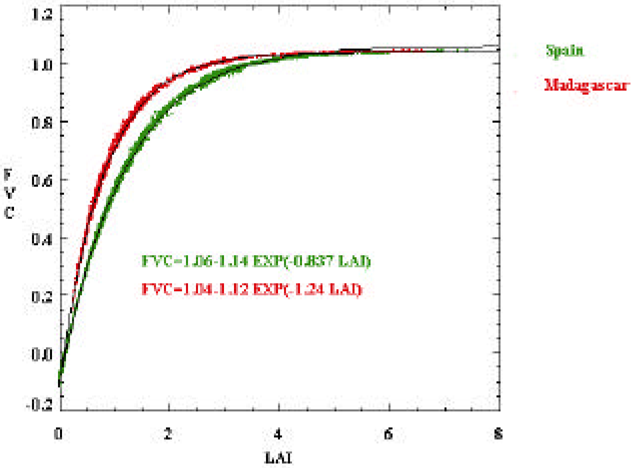

Figure 2 **– Relationship between LAI from POLDER/ADEOS and estimated FVC.**

6. FUTURE WORK

Studies carried out by means of simulation have shown that there is an optimal configuration in order to reduce the uncertainty derived products with the view and sun angles (Lacaze and Roujean, 2001). In future, BRDF models will be adjusted based on BRF satellite sampling corresponding to the optimal configuration using real and simulated data (e.g. García-Haro et al. 2001). A well-documented area, the center of Castilla-La mancha, will be used for the optimisation of the proposed methodology (Camacho-de Coca et al. 2002, *this symposium*).

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