

La BRDF en la estimación de la FVC a escala global con los nuevos satélites: MSG y EPS.

The BRDF in FVC retrieval on a global scale with new generation satellites: MSG & EPS.

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SUMMARY

The accuracy of the retrieval of land biophysical parameters, on a global scale is an important issue for the meteorological community due to the fact that vegetation is an input in Numerical Weather Predictions (NWP). The synergistic use of new generation satellites like SEVIRI/MSG and AVHRR3/EPS, allows us to characterise the anisotropic properties of the vegetation by means of the Bidirectional Reflectance Distribution Function (BRDF). Our main objective is to produce maps of fractional vegetation cover (FVC) -on a global scale- from the new SEVIRI and AVHRR3 data using a Variable Multiple Spectral Mixture Analysis (VMESMA). The success of this strategy depends on the adequate election of candidate endmembers (EMs). The main problem in achieving this objective is to determine the set of EMs valid on a global scale considering the high variability in the spectral signature as a consequence of the intrinsic anisotropy properties of land surfaces and the wide range of viewing geometries in the SEVIRI image. In this paper, we discuss -by means of airPOLDER data- the necessity of including 1the Directional Signature of EMs in the methodology, or alternatively to normalise the anisotropic behaviour of BRDF in order to apply the traditional VMESMA technique. For both strategies the combination of polar and geostationary satellite data is fundamental to increase angular sampling and hence to be able to fit BRDF data with the existing BRDF models.

1. INTRODUCTION

Land surfaces are a major component of the climate system and biophysical parameters (FVC, LAI) provide a much-needed information on the boundary conditions that should be specified in General Circulation Models to describe accurately the exchanges of mass, momentum and energy at the biosphere-atmosphere interface (Sellers et al., 1994). Thus, vegetation products on a global scale is an important input for the Numerical Weather Predictions (NWP) community.

Traditionally land surface studies have been emphasised in the exploitation of spectral information although the anisotropic behaviour of the natural surfaces have introduced biases in the results (Roujean *et al.*, 1992). The adequate interpretation of the radiance from land surfaces implies a characterisation of the anisotropy reflecting properties of the surfaces. The basic function that characterises the spectral and directional dependence of the reflectance is the Bidirectional Reflectance Distribution Function (BRDF).

From the last decade to the present, the interest in the characterisation of the BRDF from space has been on the increase in Space Agencies. In particular, the POLarization and Directonality of the Earth's Reflectance (POLDER) optical concept

In this work we discuss how the BRDF of soil and vegetation could be appropriately considered as EMs for the application of the VMESMA to the full Earth disk provided from SEVIRI imagery and by considering the directional signatures provided by AVHRR3/EPS. For this purposes we have used a BRDF dataset over the Barrax area (Albacete) from the airborne POLDER corresponding to the DAISEX'99 campaign.

2. METHODOLOGY

2.1 POLDER data

The POLDER optical system consists of a telecentric lens, a filter wheel and a CCD array (288 x 384 pixels) as a detector. The light is almost vertically incident on the filter wheel after passing through the telecentric lens. The filter wheel contains 10 plots for spectral filters. The first channel is reserved for dark current measurement while the others allow measurements in 9 spectral bands: 443 nm, 500 nm, 550 nm, 590 nm, 670 nm, 700 nm, 720 nm, 800 nm and 864 nm wavelengths.

During the DAISEX experiment four flights were undertaken on 3rd (noon), 4th (morning and afternoon) and 5th (morning) of June 1999. In each flight POLDER took about one hundred images under different viewing geometry with a change in the sun zenith angle of about 10° between the first and the last image.

2.2 Sun/View geometry normalisation

The normalisation of bidirectional effects consists of fitting the real values with a BRDF model and displacing the reflectance values along the shape of the BRDF from their actual acquisition geometry to a reference geometry ($\theta_s=0$, $\theta_v=0$).

Leroy and Roujean (1994) propose a method to address the directional effect influencing 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 an isotropic (Lambertian), roughness and volume scattering contribution to reflectance.

The equations of Roujean's model are expressed as follows:

$$\mathbf{r}(\mathbf{J}_s, \mathbf{J}_v, \mathbf{f}) = k_0 + k_1 f_1(\mathbf{J}_s, \mathbf{J}_v, \mathbf{f}) + k_2 f_2(\mathbf{J}_s, \mathbf{J}_v, \mathbf{f}) \quad (1)$$

$$f_1(\mathbf{J}_s, \mathbf{J}_v, \mathbf{f}) = \frac{1}{2\mathbf{p}} [(\mathbf{p} - \mathbf{f}) \cos \mathbf{f} + \sin \mathbf{f}] \text{tg } \mathbf{J}_s \text{ tg } \mathbf{J}_v - \frac{1}{\mathbf{p}} \left(\text{tg } \mathbf{J}_s + \text{tg } \mathbf{J}_v + \sqrt{\text{tg}^2 \mathbf{J}_s + \text{tg}^2 \mathbf{J}_v - 2 \text{tg } \mathbf{J}_s \text{ tg } \mathbf{J}_v \cos \mathbf{f}} \right) \quad (2)$$

$$f_2(\mathbf{J}_s, \mathbf{J}_v, \mathbf{f}) = \frac{4}{3\mathbf{p}} \frac{1}{\cos \mathbf{J}_s + \cos \mathbf{J}_v} \left[\left(\frac{\mathbf{p} - \mathbf{x}}{2} \right) \cos \mathbf{x} + \sin \mathbf{x} \right] - 1/3 \quad (3)$$

where θ represent the zenith angle, ϕ the relative azimuth angle and ξ is the phase angle between sun and view direction.

3. RESULTS

3.1 BRDF signatures

Figure 1 shows the BRDF in the red region (670 nm) for a very dense alfalfa cover and a bare soil. These surfaces have been selected as they could be representative of both vegetation and soil EMs in a spectral region similar to that of the SEVIRI 0.6 μm channel.

We can observe the typical shape of the BRDF which is characterised in the backscattering by the hot spot effect –the so called opposition effect- (the maximum in the reflectance that

occurs when the sun and view directions coincide and there are no visible shadows). The anisotropic behaviour of the BRDF could be quantified by the anisotropy index ANIX (Sandmeier et al., 1998) defined as the ratio between the maximum and minimum values. For the vegetation cover the anisotropy index is $\text{ANIX}(670\text{nm}) \cong 2.5$ while for the soil is $\text{ANIX}(670\text{nm}) \cong 1.5$. This values depends not only of the 3D structure of land surface (high, roughness, LAI...) but also of the sun zenith angle and of the spectral region. Thus, for the NIR region both soil and vegetation show a similar degree of anisotropy, for vegetation $\text{ANIX}(864 \text{ nm}) = 1.21$ and for soil $\text{ANIX}(864 \text{ nm}) = 1.25$. In general, the anisotropy of the BRDF is higher when the single scattering governs the radiation scattering and this anisotropy decrease when multiple scattering becomes relevant. Consequently, the spectral reflectance of soil and vegetation could present variations higher than 250% due to differences in the viewing geometry. This fact should not be neglected in the SMA procedure on a global scale (or in sensors with a wide FOV like AVHRR, VEGETATION) due to the accuracy of estimations is directly dependent on the correct choice of EMs.

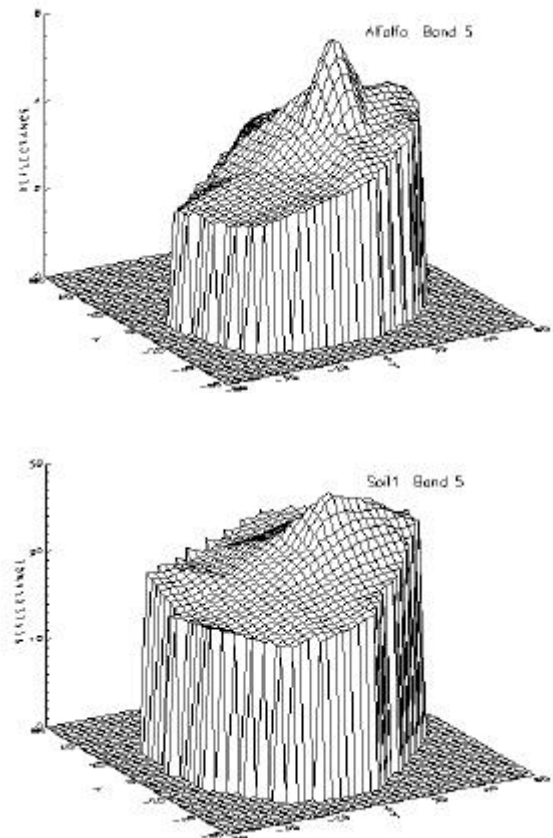


Figure 1. BRDF from POLDER in band 5 (670 nm) for: a) homogeneous alfalfa cover, (b) Bare soil. Sun Zenith Angle from 18.8° to 17.5°. Date 99/06/03.

Therefore, for the satisfactory application of VMESMA to global scale, we have two options: on the one hand we can parameterise the angular behaviour of EMs by using BRDF models, whilst on the other we can normalise this angular behaviour as shown in section 2.2. The first option gives a new bidirectional VMESMA approach and the second one allows the use of the traditional VMESMA (García-Haro et al., 2002).

The viewing geometry variation close to the Principal Plane provided a reflectance gradient that constitutes a directional

signature of the land surfaces. An example of this can be observed in figure 2.

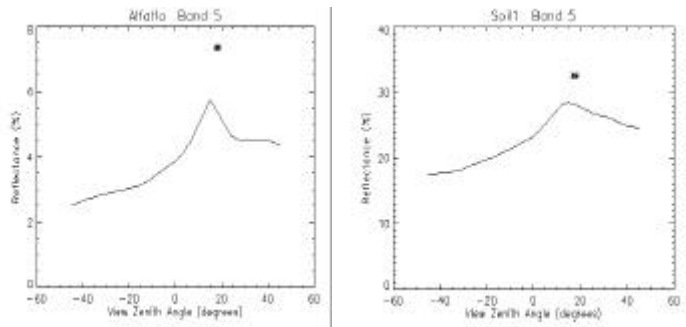


Figure 2. Directional Signatures from POLDER in band 5 (670 nm) for: a) homogeneous alfalfa cover, (b) Bare soil. Asterisk indicates the Sun Zenith Angle position. Date 99/06/03.

These directional signatures are similar to those provided by the AVHRR-3 using a set of consecutive days. In this case, the synergistic use of both sensors allow us to incorporate this signature as additional information in the methodology. For example, the anisotropy index derived from these signatures allows us to improve the stratification of the globe, which is a very important task in the Variable Multiple SMA. This task will allow us to produce a classification based on the anisotropic behaviour, and thereby a better adaptation of the angular dependence of EMs. Furthermore, these viewing variations of polar orbiting EPS will be added to the sun variations provided by the geostationary MSG to increase angular sampling.

For example, the figure 3a shows a modelled soil BRDF using the 7 parameter Hapke model. We can fit the parameters to the experimental data, and therefore characterise the angular dependence of the soil EM. During the DAISEX field campaign directional reflectance measurements were carried out. Figure 3-b shows the directional signature acquired during campaign over a bare soil at 670 and 800 nm, and the modelled soil directional signature with the 7 parameters Hapke model (Hapke, 1981)

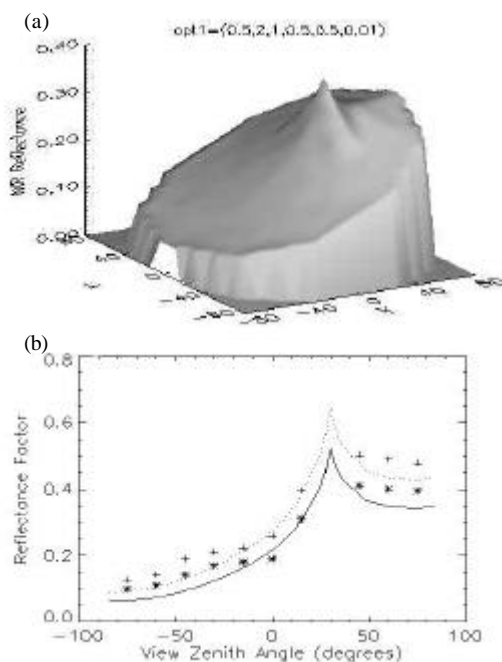


Figure 3: a) NIR BRDF from Hapke soil model, the values of parameters are in the figure, b) Comparison of modelled Directional Signatures (lines) and real data for 670 (asterisk) and 800 (cross) nm

In a similar way to those shown in figure 3, the wide angular range provided by SEVIRI and AVHRR allows us to characterise

the BRDF of major biomes in according with Bicheron and Leroy, (2000). The models chosen must be simple enough for robust inversions but accurate enough to realistically address the major BRDF effects. For example, the recent GHOST model (Lacaze and Roujean, 2001) is suitable to characterise the BRDF of major vegetation types as a function of its structural parameters. This model has been successfully applied to infer structural vegetation attributes from POLDER on ADEOS.

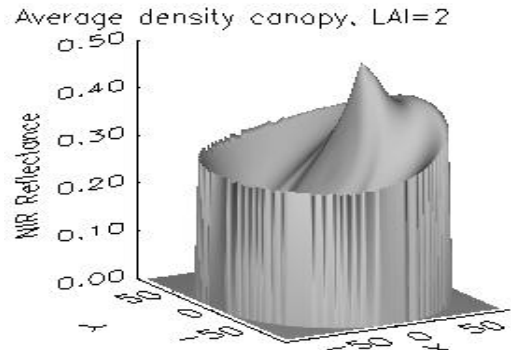


Figure 4: NIR BRDF for dense vegetation cover with GHOST model. SZA=30°

Figure 4 shows the modelled BRDF for an average density canopy of LAI=2. The modelled BRDF reproduced a typical bowl shape and hot spot feature of vegetation cover satisfactorily, as we can observe from POLDER data for alfalfa (LAI=3.0) in figure 1. The advantage in the synergistic use of polar and geostationary satellites reside in the increase of the available angular data that will allow a better fit with the model and a reduction of the *rmse* between modelled and real data.

3.2 Isotropic K_0 signatures

On the other hand, we can consider the anisotropy of the land surface reflectance as a source of noise in the image that must be normalised before applying the VMESMA. In this case we can use the wide angular sampling provided by SEVIRI and AVHRR in order to fit a BRDF model and extrapolate the reflectance of each pixel to the value of reflectance at a common angle, normally corresponding to the sensor at nadir and the sun at zenith. For this purposes, the Roujean et al., (1992) model is widely accepted. This model is based on a kernel-driven approach and the reflectance is expressed as the sum of three functions (ec.1). The inversion of the model provides three coefficients $k_{i=0,1,2}$ related with the lambertian, geometric and volumetric contribution to the BRDF.

Figure 5 shows the directional variability in the spectral signature of soil and pure vegetation. As we can observe in soils and in vegetation the variability is very important. Subsequently, the traditional concept of EM will produce many errors in the estimation of FVC.

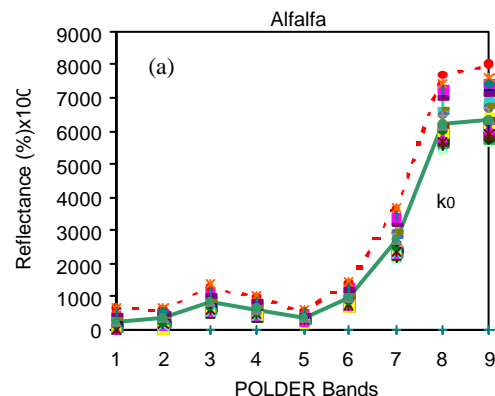


Figure 5: Directional variability in the spectral signatures (in dots) for vegetation (a) and soil (b). Dotted line correspondsto the hot spot. Solid line corresponds to the isotropic k_0 coefficient.

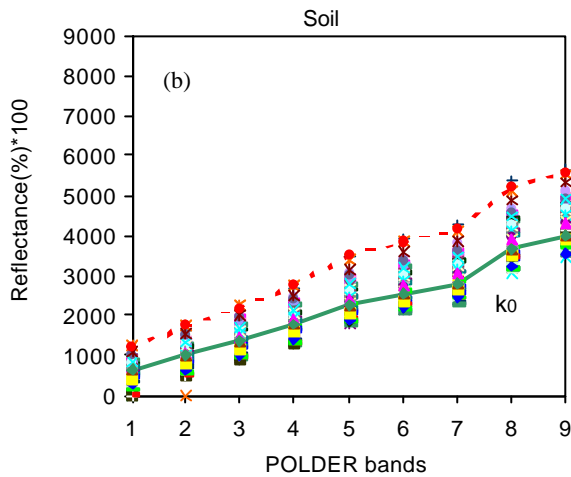


Figure 5: Directional variability in the spectral signatures (in dots) for vegetation (a) and soil (b). Dotted line corresponds to the hot spot. Solid line corresponds to the isotropic k_0 coefficient.

For example, close to the hot spot geometry the spectral signature of vegetation appears as corresponding to a mayor LAI, with a increment in NIR region. This will derive a greater FVC, and the inverse will occur in the forward scattering where the spectral signature shows lower values as a consequence of a major shadow presence.

In figure 5 we can observe the result of the normalisation of anisotropy according the Roujean *et al.*, (1992) model. This correction provides an alternative method to that exposed above and consists of using nadir-zenith derived reflectance (k_0) as a sub-product before applying the traditional VMESMA technique more consistently. This normalisation would supply a SEVIRI image that would be obtained if the MSG was a nadir pointing instrument. Thus the retrieved FVC would be rather insensitive with respect to the anisotropy effects. However, the main drawback regarding methods that rely on k_0 is that they do not exploit the physical information contained in the variation of the sun/sensor geometry.

4. CONCLUSION

The retrieval of FVC on a global scale with the VMESMA methodology has to consider the anisotropic behaviour of the EMs in order to produce accurate estimations. The new generation satellites MSG and EPS, will allow the characterisation of the land surface BRDFs.

In this work we have proved with airPOLDER BRDF data, that the anisotropic influence is very high (higher than 250%) when viewing geometry variations are considered. This anisotropy produces a directional signature of the surfaces, which involves information related with the 3D structure of these surfaces. This Directional Signature is similar to that provided by the new AVHRR3/EPS. Analogously, SEVIRI will provided a Diurnal Directional Signature where the view zenith angle is constant and only the sun zenith angle changes. These directional signatures and the anisotropy indices derived from them will be very useful in order to produce the stratification of the globe according to its anisotropic properties.

There are two possibilities when applying the VMESMA to the full SEVIRI disk. On one hand, the use of the BRDF models to characterise the angular dependence of EMs for each previous land cover type. In order to carry out this task the different vegetation and soil BRDF models must be tested, according to their complexity and robustness. On the other hand, we can use the BRDF models to normalise the anisotropic behaviour. For this task, the increase of angular dimensionality provided by SEVIRI and AVHRR constitutes an important advantage.

Finally, it should be noted that if we consider the angular behaviour of EMs we have to develop a new concept of Directional

VMESMA which exploits the angular information. The normalisation option allow us to apply the traditional VMESMA method although this method does not exploit the information contained in the anisotropy reflectance. Both methods are discussed in this symposium (Garcia-Haro *et al.*, 2001).

5. REFERENCES

- Asner, G.P., Braswell, B.H., Schimel, D.S. and Wessman, C.A., (1998). Ecological Research Needs for Multiangle Remote Sensing Data. *Remote Sensing of Environment*, 63:155-165
- Bicheron, P., Leroy, M., Hauteceur, O. and Bréon, F.M. (1997). Enhanced Discrimination of Boreal Forest Covers with Directional Reflectances from the airborne Polarization and Directionality of Earth Reflectances (POLDER) instrument. *Journal of Geophysical Research*, vol. 102, D24: 29,517-29,528.
- Bicheron, P and Leroy, M. (1999). A Method of Biophysical Parameter Retrieval at Global Scale by Inversion of a Vegetation Reflectance Model. *Remote Sensing of Environment*, 67: 251-266.
- Bicheron, P. and M. Leroy, (2000). Bidirectional reflectance distribution function signatures of major biomes observed from space. *J.Geophys.Res.*,105,26,669-26,681.
- García-Haro, F.J, Sommer, S. and Kemper, T. (2001). "Variable multiple endmember spectral mixture analysis (VMESMA): a high performance computing and environment analysis tool", *Remote Sensing of Environment*, submitted.
- García-Haro F.J., Camacho-de Coca, F. and Gilabert, M.A., (2002). "Retrieval of biophysical parameters using directional data from new generation satellites: EPS and MSG". 3 Assemblée Luso-Espanhola de Geodesia-Geofísica. Valencia, 4-8 Febrero (this issues).
- Hapke, B., and Wells, E. (1981). Bidirectional Reflectance Spectroscopy: 2. Experiments and Observations. *Journal of Geophysical Research*. 86:3055-3060.
- Lacaze, R., and Roujean, J. L. (2001). A Gfunction and Hot Spot (GHOST) reflectance model Application to multi-scale airborne POLDER measurements. *Remote Sensing of Environment*, 76: 67-80.
- Leroy, M and Roujean, J.L. (1994). Sun and View Angle corrections on Reflectances Derived from NOAA/AVHRR Data. *IEEE Transactions on Geoscience and Remote Sensing*, 32(3):684-696.
- Leroy, M. and Hauteceur, O. (1999). Anisotropy-corrected vegetation indexes derived from POLDER/ADEOS. *IEEE Trans. Geosci. Remote Sens.*, 37(3): 1698-1708.
- Roujean, J.L., Leroy, M., and Deschamps, P.Y. (1992). A Bidirectional reflectance model of the Earth's surface for the correction of remote sensing data. *Journal of Geophysical Research*, 97, D18: 20,455-20,468.
- Sandmeier, S., Müller, C., Hosgood, B., and Andreoli, G., (1998) Physical mechanisms in Hyperspectral BRDF Data of Grass and Watercress. *Remote Sensing of Environment*, 66: 222-223.
- Sandmeier, St and Deering, D.W. (1999). Structure Analysis and Classification of Boreal Forest Using Airborne Hyperspectral BRDF Data from ASAS. *Remote Sensing of Environment*, 69: 281-295.
- Sellers, P.J., C.J. Tucker, G.J. Collatz, S.O. Los, C.O. Justice, D.A. Dazlich, and D.A. Randall, 'A global 1° by 1° NDVI data set for climate studies. Part 2 : The generation of global fields of terrestrial biophysical parameters from the NDVI', *International Journal of Remote Sensing*, 15, pp. 3519-3545, 1994.

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