

Hot Spot Signature Dynamics in Vegetation Canopies with varying LAI

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

*Departamento de Termodinàmica. Facultat de Física. Universitat de València
Dr. Moliner, 50. 46100 Burjassot (Valencia) Spain
e-mail: Fernando.Camacho@uv.es*

ABSTRACT- *The hot spot directional signature provides us an additional information to that obtained from the nadir view and which is related to the structural parameters of the vegetation canopies, like the LAI (Leaf Area Index), the height of the canopy or the size of the leaves. On the other hand, the hot spot signature shows a spectral variability consequence of the optical properties of the samples and is also dependent of the illumination zenith angle.*

*In this work we have designed a laboratory experiment to analyse the dynamics, within the range of 400 to 1000 nm, of the hot spot signature with varying LAI, and remaining the illumination zenith angle fixed at 40°. In order to achieve this, we have made different LAI level samples from bare soil to dense cover for two different vegetation species, *Rosmarinus Officinalis* and *Pinus Pinaster*. Our main goal was to obtain those spectral channels that show higher sensibility to the LAI changes, and to analyse the utility of the hot spot angular signature to retrieve vegetation parameters derived from reflectance.*

The analysis has proved that the hot spot signature shows high variability in the red and NIR regions, and that the hot spot magnitude and gradient can be very useful to obtain biophysical parameters like the LAI or to normalise soil contribution, especially in arid or semiarid landscapes.

1- INTRODUCTION

Traditionally, optical remote sensing methods and techniques related to vegetation canopy studies have been developed based on the wavelength dependence of the Bidirectional Reflectance Factor (BRF) -simply called reflectance (R), which allows us to define a spectral signature of the surfaces. Nevertheless, the BRF depends strongly on the geometry of incident and reflected radiation fluxes. Therefore, the correct spectral utilisation of the remote sensing data should be applied taking into account these directional characteristics. Directional information can be used in order to: a) normalise directional effects for ameliorating the physical meaning of bio-physical parameters retrieved, b) exploit increasing intrinsic dimensionality of data incorporating the off-nadir reflectance into the vegetation algorithms.

Previous works have demonstrated from hyperspectral data that the anisotropic behaviour of the BRF in homogeneous vegetation canopies depends on the illumination and viewing geometry, structural parameters and optical properties of the canopy [Cama 00; Sand 98]. This anisotropic behaviour reaches its maximum expression in the principal plane, showing a maximum in the retro-solar direction, which is called the hot spot peak, and a minimum in the forward scattering near nadir-view [Kime, 83]. Both effects, the hot spot peak in the backscattering and the minimum in the forward scattering, produce a reflectance gradient with the view zenith angle that constitute a directional signature named *hot spot directional signature* or, simply, *hot spot signature*.

Theoretical models have shown that the hot spot magnitude and the angular width depend on the ratio of the horizontal and vertical scale of the canopy, the size of the leaves and the LAI [Qin, 94; Jupp, 91]. On the other hand, hot spot signature has been used to enhance discrimination of the forest [Bich, 97] and recently an anisotropy index (ANIX), derived directly from the maximum and

the minimum ratio of the hot spot signature, has been useful in ameliorating boreal forest classification [Sand, 99]. This ratio, or index of anisotropy can be directly related to the *backshadow effect* [Sans, 98], which mainly depends of the leaf angle distribution, height of the trees, LAI and optical properties. Therefore, an erectophile canopy like *Pinus Pinaster* exhibits a higher *backshadow effect* than a planophile canopy like *Rosmarinus Officinalis*, due to the fact that horizontal oriented leaves favour isotropic scattering of the radiation. On the other hand, for sparse vegetation, both the height and LAI of the plants determines the shadow's pattern, while absorbance governs the 'darkness' of the shadows.

Consequently, the hot spot signature provides us an additional information to that obtained from the nadir view, which is related to landscape and canopy structure. This information, with the MISR and POLDER instruments, will play an important role in improving vegetation studies from optical spectral data.

The present investigation examines the dynamics of the hot spot signature for homogeneous canopies with different LAI values from laboratory data and analyses the relationship among the biophysical parameter LAI, the structural parameters and the optical spectral regions with the hot spot signature. The objective of our work is to study if the hot spot signature can be relevant for improving both the biophysical parameter retrieval and discrimination of vegetation canopies.

2-INSTRUMENTATION AND METHODOLOGY

2.1 Experiment Setup

Reflectance laboratory measurements were carried out with a Goniometer made by the Remote Sensing Unit of the University of València. Bidirectional Reflectance Factor data were taken with a GER-3700 spectroradiometer with a field of view of 6°. The Bidirectional Reflectance Factor was calculated as the ratio of the radiant flux reflected by a target to that reflected by an ideal diffuse reference surface, irradiated and viewed in the same way as the sample. The illumination zenith angle was fixed to 40°, corresponding to an expected sun position in the field campaigns. We used tungsten 1000 W halogen lamp as a light source.

Bidirectional measurements were taken for zenith viewing angles between -50° and 50° every 10°. The measurement of the hot spot signature was carried out very close to the principal plane, with an azimuth relative angle lower than 5°. The hot spot in the principal plane could not be measured in the laboratory due to problems related to the sensor shadow. The solution adopted for this experiment was to fix both the lamp and the sensor at the same level of the structure, and to calculate the relative azimuth angle between the lamp centre and the centre of the sensor field of view.

Two typical Mediterranean vegetation species were selected for their structural parameter differences: (a) *Pinus Pinaster* and (b) *Rosmarinus Officinalis*. These structural parameters showed strong differences mainly in leaf angle distribution and leaf size parameter [Cama 00]. We used as background a red clay soil, also very common in the Mediterranean environments. Once the vegetation and soil were selected, we prepare several samples varying number of plants, and consequently the LAI of the samples. Therefore, we studied the off-nadir reflectance near the principal plane from bare soil (LAI=0.0) to dense canopies (LAI≈2.2). The measured LAI of each sample is shown in table 1. Our intention was to achieve similar levels of LAI for both vegetation species to contrast hot spot signature. The LAI was measured with the LICOR-2000 LAI Canopy Analyser.

For this study, we are going to analyse the dynamics of the hot spot signature in broad bands corresponding to *Blue*, *Green*, *Red* and *NIR* regions. Spectral windows have been defined according

to Landsat-7/ETM+ channels. Finally, we have also used the first derivative reflectance to show the increase of the green biomass contribution to radiometric response with the view zenith angle.

TABLE I. LAI values of the different samples studied in this experience

<i>P. Pinaster</i>	<i>R. Officinalis</i>
2.38±0.08	2.17±0.16
1.69±0.09	1.61±0.17
1.1±0.2	1.2±0.3
0.8±0.2	0.7±0.3

3-RESULTS

3.1 Soil hot spot signature

First of all, we have acquired off-nadir measurements of the soil background used in this experiment, which corresponds to the lower LAI level.

Figure 1 shows -for the four spectral bands selected- the hot spot signature in broad bands.

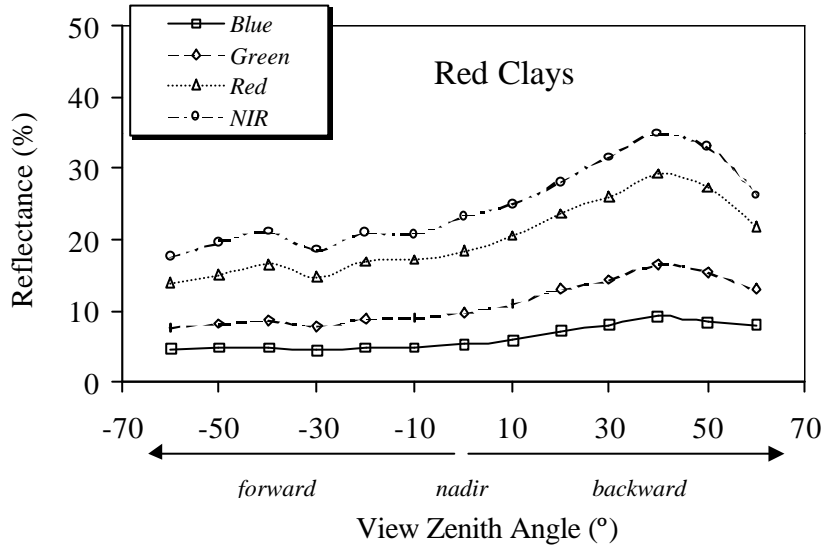


Fig. 1: Hot spot directional signature in the four spectral channels selected for red clay soil in the Principal Plane, Illumination Zenith Angle 40°.

Figure 1 reveals a very clear hot spot peak at 40 ° backward and another peak at -40° forward corresponding to the specular contribution. This reflectance variation, in the principal plane, with the view zenith angle determines the hot spot directional signature. The hot spot signature for soils exhibits a very similar trend in the four channels, which is a consequence of their similar optical properties along the optical region characterised by a very low transmittance. The clear hot spot is attributed to the roughness, which together with low transmittance produces very dark shadows. Shadows' hiding is completed when view and illumination zenith angles coincide, and the reflectance reaches its maximum value, called the hot spot. Although in the forward scattering shadows are visible, the specular contribution of the reflected beam produces a visible increase in the forward reflectance.

3.2 Hot spot signature vs LAI

In this section, we have compared the hot spot signature for the spectral channels as a function of the LAI value. The preliminary inspection of the angular behaviour reveals that the hot spot signature in the blue and green channels shows low sensitivity to the LAI level, i.e. that the hot spot signature does not change with the LAI. This is an expected result because both the red clay soils used as background soil and the vegetation have very close reflectance values in these bands.

Consequently, optical spectral regions where spectral signatures of soils and vegetation have low radiometric contrast will also exhibit low contrast in the hot spot signature. On the other hand, the red and NIR regions, where spectral signature has high contrast, should show the highest dynamic range of the hot spot signature with the LAI. This is showed in the following figure.

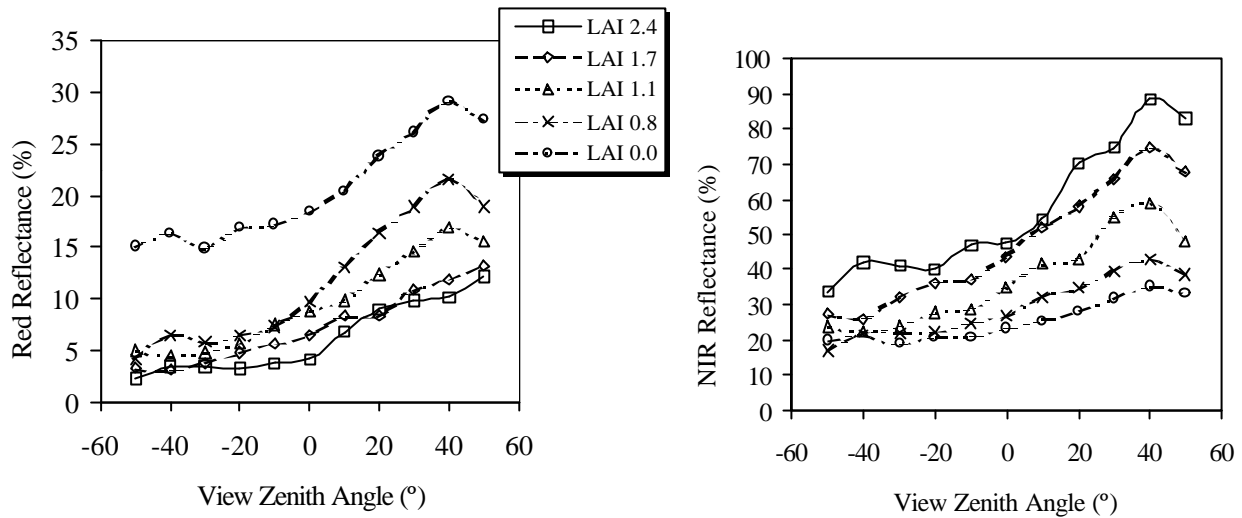


Fig. 2: Hot Spot signature in *Red* and *NIR* bands for the *Pinus Pinaster* samples with varying LAI

Figure 2 reveals dynamic hot spot signature behaviour in both analysed bands. In the Red band, the backscattering contribution increases when the LAI decreases, while in the NIR band this trend is inverted and the hot spot signature reaches the maximum values for the densest vegetation cover. This inverse trend has been analysed in order to achieve useful information to quantify vegetation. Consequently, we have studied the gradient between the nadir value and the hot spot value, that we have named *hot spot gradient*, in the Red and NIR regions.

The hot spot gradient in the Red and NIR bands reflects an adjusted linear trend, although obviously this adjustment depends on the angular, spatial and spectral resolution. Therefore, the relationships derived from radiometry data cannot be extrapolated to higher scales, although similar relationships will be found on airborne or satellite scales. As we can see in figure 2, the dynamic of this gradient is opposite in both bands. In the Red one, the slope of the line increases when LAI varies from densest cover to bare soil. While in the NIR band the slopes decrease when LAI varies from densest cover to bare soil.

Figure 3-a shows the hot spot gradient *vs* LAI in the NIR region and figure 3-b shows the hot spot gradient in the NIR and Red bands only for the bare soil (LAI=0.0) and densest cover (LAI=2.4), both graphs relate to the *Pinus Pinaster* Samples. A similar trend is shown for the *Rosmarinus Officinalis* samples. In the figure 3-a we can see as in the NIR region, when LAI increases both the magnitude of the hot spot and the slope of the gradient increase too, as does the interception which correspond with the nadir magnitude. We have studied the regression line, and we have found that although hot spot magnitude correlates very well with LAI, with $R^2=0.95$ ($R^2=0.91$) for *P. Pinaster* (*R. Officinalis*), there are no significant differences when we use the nadir value where $R^2=0.94$ ($R^2=0.89$) respectively.

On the other hand, figure 3-b reveals a relationship between Red and NIR hot spot gradient that could be useful to quantify vegetation. The trend shown for bare soil is that both Red and NIR hot spot gradient lines have a similar slope, and both lines appears as parallels (slopes $a=0.27$ and $a=0.3$ for Red and NIR bands). This effect can be explained by the fact that in the Red and NIR regions the optical properties of the soils are similar, and no change is produced in the hot spot gradient when it moves from the Red to NIR region.

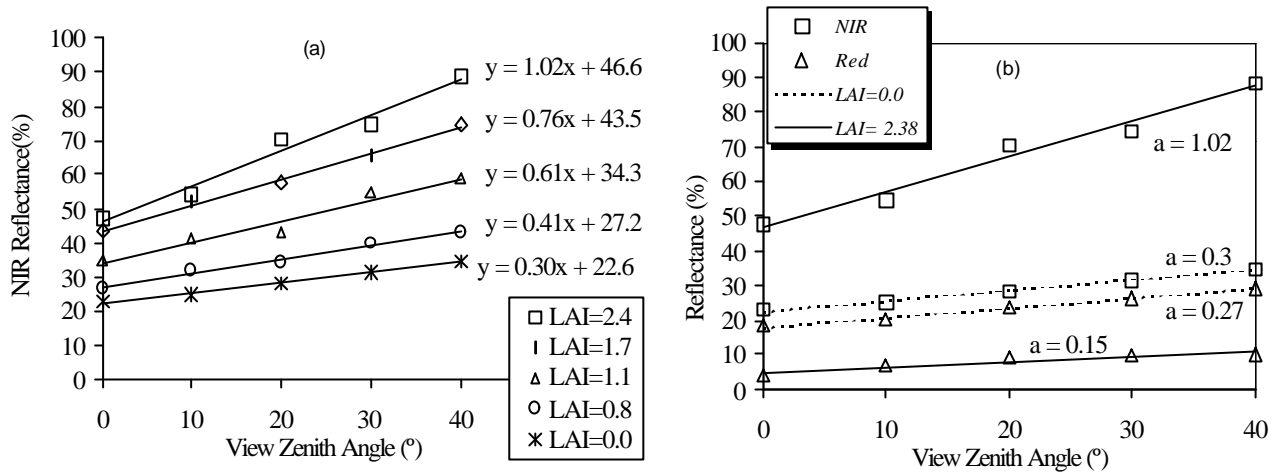


Fig. 3: (a) Linear trend of the NIR hot spot gradient between 0° and 40° -view zenith angle- in the backward scattering contribution. (b) Linear trend of the NIR and Red hot spot gradient, dotted lines correspond to bare soil (LAI=0.0) and continuous lines correspond to densest sample (LAI=2.4), 'a' indicates the slope of the line.

However, when the LAI increases, the lines correspond to both the Red and NIR hot spot gradients become divergent. For the Red band, the slope decreases from $a=0.27$ to $a=0.15$ (0.22) when LAI changes from LAI= 0.0 to LAI=2.4, while for the NIR band the effect is opposite and the slope increases from $a=0.3$ to $a=1.02$ (0.94) when the cover changes from bare soil to the densest cover of *Pinus Pinaster* (*Rosmarinus Officinalis*) samples. This information can be used to estimate vegetation amount in a similar way to that of vegetation indexes, for example by using the angle between lines or the normalised ratio of the slopes. Both values have been also studied showing a very high degree of correlation of around 95% with the LAI. However, we have obtained the same degree of correlation with the traditional NDVI that only use nadir information.

Therefore, is the hot spot signature improving the traditional vertical information, or is it only providing us redundant information? In order to answer this question we have obtained the first derivative reflectance that we can see in figure 4.

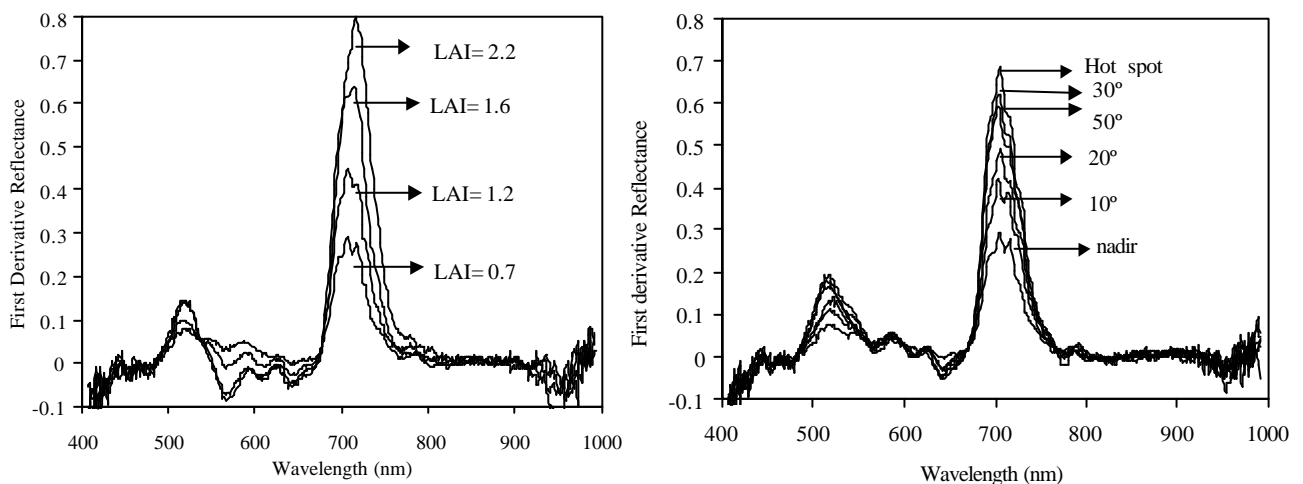


Fig. 4: (a) First Derivative Reflectance from nadir data vs. LAI for *Rosmarinus Officinalis* samples. (b) First Derivative Reflectance for lowest LAI cover (*Rosmarinus Officinalis* LAI=0.7) vs. view zenith angle at backscattering.

Figure 4 (a) shows a peak in the red edge zone (around 700nm) which increases with the LAI. The magnitude of this peak is directly related with the green biomass, and appears as a consequence of the high spectral contrast that green vegetation has in this region. Figure 4 (b) shows the same trend

for an LAI=0.7 when view zenith angles approach the hot spot view angle as when LAI increases for the nadir view. This effect, which also occurs for the other LAI levels, is a consequence of the shadows' hiding and an increase in the upper levels of the canopy seen by the sensor's field of view when the view zenith angle is increased -an effect known as the *gap effect*. Consequently, at the hot spot view zenith angle, no shadows are seen and there is a greater contribution of vegetation than in the nadir view. Therefore, the hot spot configuration is the best configuration to retrieve vegetation bio-physical parameters, and should improve the sensitivity of remote sensing to the vegetation cover in arid or semiarid landscapes.

4. CONCLUSIONS

In this work, the dynamic of the hot spot directional signature with varying LAI has been analysed in order to determine those spectral channels where the hot spot signature can be most useful for improving vegetation parameter retrieval.

Both Blue and Green channels have showed no dependence on the LAI. However, Red and NIR channels exhibit a clear and opposite trend with the LAI. On one hand, in the Red band both the hot spot magnitude and the slope of the hot spot gradient decrease when LAI increases. On the other hand, in the NIR band, the trend is inverted increasing the hot spot magnitude and the slope when the LAI decreases. The linear relationship has been checked between the hot spot magnitude and LAI showing a high degree of correlation for both vegetation species used in the experiment. We have also found that the gradient of the hot spot at the backscattering in the Red and NIR channels are parallels for bare soil, and became more divergent when the vegetation amount increase. However, these angular relationships with the LAI by themselves do not imply an improvement regarding the traditional relationships derived from nadir.

Finally, the first derivative reflectance has clearly shown that the off-nadir viewing reflectance increases the contribution of the green vegetation. In particular, the hot spot view zenith angle maximises the vegetation contribution to the radiometric response, so it is *a priori* the best configuration to retrieve vegetation bio-physical parameters, and for increasing the sensitivity of remote sensing methods to vegetation cover in arid or semiarid landscapes.

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