

Quantitative analysis of cropland's BRDF anisotropy using airborne POLDER data

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ABSTRACT- *During the DAISEX campaigns of the ESA several flights over an agricultural area were performed with the POLDER instrument. In this work, a quantitative analysis of the BRDF anisotropy has been conducted using the anisotropy factor (ANIF) and the anisotropy index (ANIX). The influence of optical properties, sun zenith angle and canopy architecture on the BRDF anisotropy is examined. The analysis shows that the nadir reflectance increases up to 120% in the backscattering direction for a view zenith angle of 45°, whereas the decrease is typically 40% in the forward scattering region. The analysis shows that the anisotropy increase systematically when both sun zenith angle and absorbance increase. The ANIX, which represents the amplitude of the BRDF anisotropy, shows values ranging between 2 and 7 and provides useful information to discriminate the different cover types.*

INTRODUCTION

Canopy structure plays a fundamental role in the interaction of solar radiation and thus for describing the three-dimensional radiation field in vegetation canopies. Besides, the right understanding of this radiation field scattered from vegetation canopies is necessary for interpreting properly remote sensing data, and for developing biophysical parameters retrieval techniques from remotely sensed information.

The basic magnitude to characterize the spectral and directional properties of reflectance is the Bidirectional Reflectance Distribution Function (BRDF). Traditionally, quantitative remote sensing techniques have relied on the exploitation of spatial, temporal and spectral domains of the BRDF. Nevertheless, the new generation of satellite sensors, such as the POLarization and Directionality of the Earth's Reflectance (POLDER) or the Multi-Angle Imaging Spectro Radiometer (MISR), have been conceived to acquire multi-view angle measurements. In addition, the synergistic use of these polar orbiting sensors and geostationary satellites sensors, like the Spinning Enhanced Visible & InfraRed Imager (SEVIRI) on Meteosat Second Generation (MSG), will increase the sampling of the directional domain by combining the sun varying with the view varying measurements.

To understand the canopy radiation regimen, three important features must be considered (Knyazikhin et al, 1998): (1) the canopy architecture; (2) the optical properties of vegetation elements and soil; and (3) the sun zenith angle, which determines joint to the atmospheric conditions the incident radiation field. These features determine the sunlit and shadows areas observed in a scene. The variation of these areas with the sun and view angles results in a

directional dependence of measured reflectance. Therefore, the anisotropy of the BRDF is linked to the 3D structure of the canopy and thereby it constitutes a potential source of information. For instance, the directional signature has been used to retrieve clumping index or foliage density (Lacaze et al. 2002). Nevertheless, the information contained in the directional domain is very influenced by the viewing geometry, optical properties and sun position.

Previous experiments have analysed the anisotropic behaviour of the BRDF (Kimes 1983, Deering et al. 1999, Sandmeier et al. 1998). Two effects are used to explain this behaviour: the gap effect and the backshadow effect. The gap effect is produced when increasing off-nadir view angle produces the increment in the proportion of illuminated upper canopy layers viewed from the sensor. This effect is clearly related to the vertical structure of the canopy and the spatial distribution of elements, which determines the fraction of soil, vegetation and shadows in the scene –for a specific sun zenith angle. Backshadow effect is related to the orientation of the canopy components and the irradiation condition derived from the cosine law and shadow's pattern. Thus, when the normal of the surface is pointing to the sun the surfaces are more irradiated. This effect is very strong in the soils due to the fact that the single scattering governs the dispersion of radiation, and the high contrast between shaded and sunlit areas.

In this work we perform a quantitative analysis of the anisotropy of BRDF of croplands as a function of wavelength, sun zenith angle and structural parameters thanks to the wide BRDF sampling taken during the Digital Airborne Spectrometer EXperiment (DAISEX) campaign. This study has been undertaken in the framework of the Scientific Analysis of the ESA Airborne Multi-Annual Imaging Spectrometer

Campaign DAISEX' project. The main goals have been: (1) to determine the influence of the canopy structure, optical properties and sun zenith angle in the anisotropy of BRDF with the aid of appropriate directional indices, and (2) to understand better the radiative transfer in this kind of herbaceous canopies as a previous step towards the implementation of an innovative directional mixture approach to retrieve structural parameters from multiangular information (García-Haro et al. *this issue*).

In section 2 we briefly present the experiment and methodology. Section 3 shows an example of the BRDF and the quantitative analysis of anisotropy. Finally, conclusions are summarised in section 4.

2 EXPERIMENT AND METHODOLOGY

DAISEX campaigns were performed during the summers of 1998, 1999 and 2000 to demonstrate the feasibility of retrieving biophysical parameters from imaging spectrometer data. The anisotropic effects in surface reflectance were widely considered during all the campaign including the acquisition of the hot spot effect (Camacho-de Coca et al., *this issue*).

The experiment site selected by ESA for the DAISEX campaigns is a 3 km by 3 km area centered at 39° 3' N, 2° 5' W, which is located 28 km from Albacete (Spain), close to the Barrax town (see figure 1 in Camacho-de Coca et al. *this issue*). A supervised classification of the area was made based on field information. The dominant cultivation in the area was approximately 53% dry land (29% barley, 24% fallow) and 42% irrigated land (15% corn, 11% alfalfa, 8% wheat; 2% legumes, 2% sugar beet, and 4% others) with a 5% of unclassified data. Hence, the study area involves different vegetated units, with its own structural characteristics and in its own phenological status. According to the percentage of coverage, barley, alfalfa, wheat and legumes presented full coverage, sugar beet medium coverage and corn, which only presented 3-5 leaves, a very sparse coverage. According to the structural parameters, wheat and barley presented similar characteristics: vertical structure, well-developed spikes, and similar height and LAI. However, the wheat canopy was still vigorous and photosynthetically active whereas the barley canopy was non-photosynthetically active due to its senescent stage. On the other hand, alfalfa and legumes were lower in height, with smaller leaf size and higher LAI than wheat and barley. Sugar beet and corn were markedly row-distributed with large contribution of the bare soil. Vegetation *in-situ* measurements were taken during the campaign corresponding to major agricultural units. NDVI and structural parameters of the major cover types are shown in the next table. FVC was obtained using a

variable endmember spectral mixture analysis (VMESMA) (García-Haro et al., 2002) from HyMAP data whereas LAI was derived from the SAVI vegetation index (ESA, 2001).

Table 1. NDVI and structural parameters of the dominant surface types in the study area. The asterisk refers to field data.

	NDVI	FVC (%)	LAI	Height (m)*
Soil	-	0	0	-
Corn	0,19	25	0,26	0,1-0,2
Sugar Beet	0,32	55	0,6	0,1-0,15
Barley	0,21	92	2,9*	0,55-0,65
Wheat	0,86	97	1,56	0,7-0,85
Legumes	0,76	100	2,22	-
Alfalfa	0,83	100	3,59	0,5-0,6

In the 1999 campaign, the directional capabilities of the POLDER instrument added a new dimension in the acquisition of BRDF measurements. The spectral filters of the POLDER instrument were centered at 443, 500, 550, 590, 670, 700, 720, 800, and 864 nm wavelength. The POLDER field-of-view (FOV) was along track and cross track of $\pm 43^\circ$ and $\pm 51^\circ$ respectively. This resulted in a ground FOV of 7.4x5.6 km² for the flight altitude of 3000 m. At this altitude the spatial resolution was 20 m (Leroy et al. 2001).

Four flights with the ARAT plane carrying POLDER and LEANDRE instruments were performed in the 1999 campaign. They correspond to 3rd June at noon (from 11:29 to 12:31 UT), 4th June in the morning (from 7:16 to 8:15 UT) and in the afternoon (from 13:57 to 15:01 UT), and 5th June in the morning (from 6:57 to 8:02 UT). In this study we have used the data collected in the first three flights, neglecting the last because the time acquisition was very similar to the second one.

In each flight the POLDER instrument records around 140 spectral images, which constitutes a POLDER sequence. One image is acquired within 3 seconds, and the acquisition is repeated every 10 seconds, with an overlap between consecutive images. Thus, in a sequence, every pixel is observed with different viewing directions, typically between 30-60 covering a wide range of the directional space. This rich viewing sampling in addition to 9 spectral channels and three different sun positions allows a good BRDF characterization. The POLDER reflectance images were calibrated, geo-coded and corrected for atmospheric effects as it is specified in Leroy et al (2001).

In order to analyze the influence of the anisotropy regarding the viewing geometry, a simple anisotropy factor (ANIF) or nadir normalized reflectance has been used (Sandmeier et al. 1998):

$$ANIF(\mathbf{l}, \mathbf{q}, \mathbf{j}_i, \mathbf{q}, \mathbf{j}_r) = \frac{R(\mathbf{l}, \mathbf{q}, \mathbf{j}_i, \mathbf{q}, \mathbf{j}_r)}{R_0(\mathbf{l}, \mathbf{q}, \mathbf{j}_i)} \quad (1)$$

where R_0 is the reflectance factor acquired from nadir view.

In addition, to quantify spectrally the anisotropy's degree of the different samples the anisotropy index (ANIX) has been used. The ANIX gives the amplitude of the reflectance variation for a defined sun zenith angle and relative azimuth angle (Sandmeier et al. 1998):

$$ANIX(\mathbf{l}) = \frac{R_{\max}(\mathbf{l})}{R_{\min}(\mathbf{l})} \quad (2)$$

where R_{\max} is the maximum reflectance factor and R_{\min} the minimum. In this work, the ANIX values have been calculated in the principal plane where the anisotropy is manifestly enhanced.

3 RESULTS

3.1 Anisotropy Factor

Firstly, the results of the ANIF, which represents the variation of reflectance factor in percentage regarding the nadir value, are presented. Figure 1 shows the results obtained for two wavelengths, 670 and 800 nm, three different sun positions (17°, 37°, 56°) and four different samples (wheat, legumes, sugar beet and bare soil). The BRDF has been retrieved from a 3x3 pixel area (60x60 m²).

Regarding the optical properties we can observe that for 670 nm the major absorptivity of vegetation and soil translates into a higher anisotropy. The ANIF goes up to 2.2 in the morning for the wheat cover, which represents an increment of the 120% regarding the nadir value. However, at 800 nm the influence of the multiple scattering radiation smoothes the anisotropy of BRDF. The influence of optical properties is evident in dense vegetation canopies (figure 1a and figure 1b) due to the high spectral contrast between red and NIR region. However, for soils (figure 1d) there is no difference in the ANIF at 670 and 800 nm. Therefore, -as a consequence of the optical properties influence on the BRDF anisotropy- the directional information can be used in addition to the spectral information to discriminate soil and vegetation as was pointed in Camacho-de Coca et al (2001). It should be noted that the senescent vegetation (e.g. barley) could present similar optical properties in red and infrared regions then showing a similar directional behavior than the soils.

The sun zenith angle position has a high influence in the anisotropy as it can be observed in the figure 1. When the sun position is nearby zenith, the irradiance of the sample is more homogeneous, resulting in a more isotropic behavior of scattered radiance. Consequently, the lesser variations of the

ANIF take place at noon with values ranging typically between 0.8 and 1.2. However, when the sun zenith angle increases, the differences between the irradiance field in the top and bottom of the canopy becomes greater. This results in an increase the BRDF anisotropy. Hence, the ANIF increases systematically when the SZA increases. This variation is higher in the wheat cover. For the dense wheat cover, the vertical structure implies large differences between nadir reflectance, where the sensor's field-of-view observes the lower canopy layers, and the backscatter radiance, where the sensor mainly collects the radiance coming from the well-illuminated upper layers. In the case of the sparse sugar beet, the increasing SZA results in a lower nadir reflectance value due to the higher fraction of shaded soil.

Concerning the viewing geometry, the ANIF appears symmetric with respect to the solar principal plane, even for the row-distributed sugar beet crop. Conversely, the asymmetry is clearly manifested with respect to the orthogonal plane, and is maximum along the principal plane. In the forward scatter direction large shaded areas are seen resulting in a decreasing reflectance, whilst in the backscatter hemisphere the sunlit areas are predominant and thus the reflectance is enhanced. The maximum value of reflectance occurs in the hot spot geometry. The nadir reflectance increases in this domain up to 120% for a view zenith angle, whereas it decreases typically 20-40% in the forward scattering domain. It should be noted that at this directional resolution the hot spot peak is smoothed (see Camacho de Coca et al. *this issue*) and, consequently, the magnitude of the anisotropy.

Regarding the canopy geometry, the ANIF shows a different behavior that is linked to the influence of the 3D structure on the radiative transfer within the canopy. It is most noticeable at highest sun zenith angle as we can see in the figure 1. Figures 1a and 1b correspond to the ANIF of wheat and legumes cover respectively, both with very similar FVC and LAI values. The differences in the ANIF pattern are connected with the architecture of these samples. The wheat cover presents an erectophile distribution, whilst the legumes cover presents a phanophile distribution. An erectophile distribution favors the gap effect, increasing the anisotropy. This is generally manifested as an increase of reflectance when the off-nadir view angle increase, independently of the azimuth plane, although this trend is reversed if the sun zenith angle is low, typically lower than 20°. The gap effect cause the typical bowl-shape of the BRDF, clearly manifested in the figures 1a corresponding to the NIR, as closed ANIF isolines.

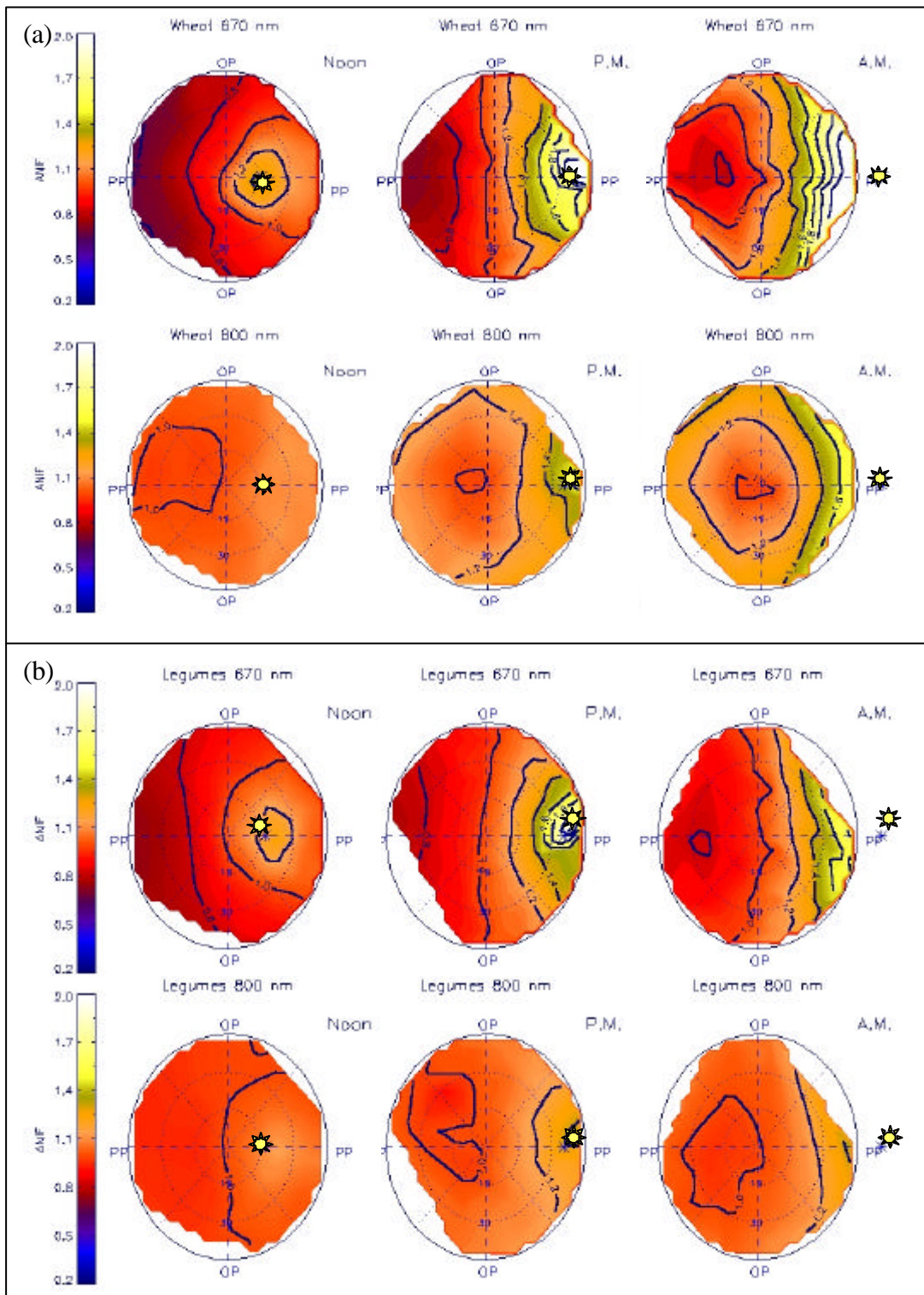


Figure 2. Anisotropy Factors at 670 and 800 nm for three sun zenith angles (17°, 37°, 56°): (a) Wheat, (b) Legumes, (c) Sugar beet and (d) Bare soil.

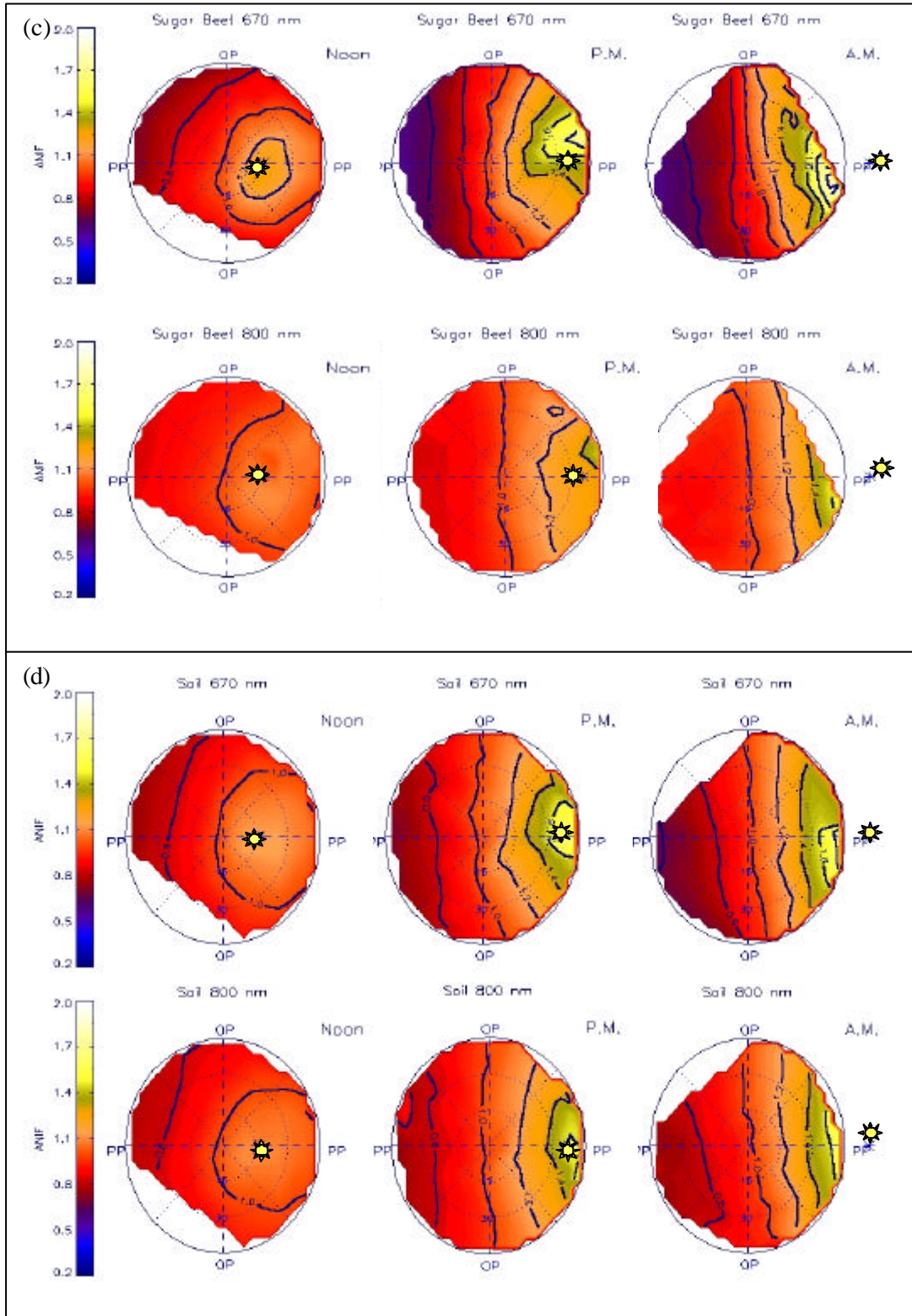


Figure 2 (cont.). Anisotropy Factors at 670 and 800 nm for three sun zenith angles (17°, 37°, 56°): (a) Wheat , (b) Legumes, (c) Sugar beet and (d) Bare soil.

However, in the red region, the high absorbance favors also the backshadow effect, combining thus both effects. This results in a high anisotropy of the wheat cover, especially at high SZA in the red region. The planophile alfalfa cover shows more isotropic values. Both gap and backshadow effects present low influence due to the vegetation is like a bidimensional mat, rather than a tridimensional surface. The different anisotropic behavior of these two covers of very similar structural parameters is well characterized by normalizing the nadir reflectance. Then, the ANIF allows identifying the influence of architecture on the anisotropy of BRDF. In the other two samples (figure 1c and 1d) the ANIF diagrams are influenced by the soil contribution. For soils, the directional behavior is determined by the backshadow effect. This effect is symmetric with respect to the principal plane, thus the isolines appears orthogonal to the solar plane. In addition, in the principal plane, the ANIF values decrease monotonally as the phase angle increase. For the Sugar Beet this effect is stronger in the red band, because of the high absorbance of the vegetation, and the large amount of shadows cast by the plants. Thereby, the ANIF shows the lowest values around 0.6 in the forward scattering region.

3.2 Anisotropy Index

In order to quantify the influence of the canopy geometry on the spectral BRDF anisotropy the ANIX was used. Figure 2 shows the results obtained for the major land cover types existing in the study area. In the noon flight (SZA=17°) the anisotropy index presents similar values for the samples considered. The values range typically between 2 and 3, and go up to 4 at shorter wavelengths. This result shows a small influence of the canopy cover type in the anisotropy index because of the sun position. However, when the sun zenith angle increase, the differences in the spectral anisotropy index between canopy types become more important. In the afternoon (SZA=37°) and in the morning (SZA=56°) flights, the ANIX ranges typically between 2 and 6, and goes up to 8 in the blue. Each canopy cover type presents a slightly different spectral trend, according with its optical properties and structural parameters. For example, sugar beet presents a marked peak in the red region, whereas soil and barley present a decreasing trend with the wavelength, conversely to the multiple scattered radiation. The soil presents the highest ANIX (except at 670 nm) in the morning, associated with the enlargement of the very dark shadows. These results show the influence of the canopy geometry in the anisotropy of the BRDF, showing also the potential of this kind of index to discriminate vegetation types in agricultural areas. Therefore, the ANIX could be considered as a spectral signature directly related with

the anisotropic properties of vegetation canopies and, thus, with its optical and structural characteristics.

We have finally evaluated the relative increment of the ANIX when the sun zenith angle changes from 17° to 56°. This positive variation depends again of the cover type and optical properties and ranges between 30% and 200%. The lowest variation corresponds to the homogeneous legumes crops in the NIR region. For the dense wheat cover, the ANIX variation is twice than for legumes (typically 60%), showing the influence of the canopy architecture.

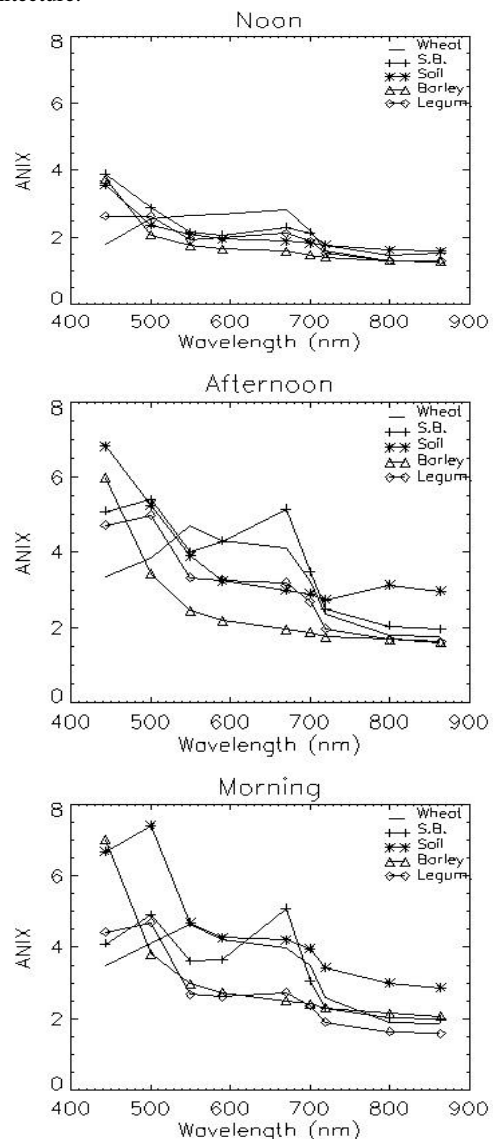


Figure 2. Anisotropy Index of the main cover types for three different SZA: Noon (SZA=17°), Afternoon (SZA=37°), Morning (SZA=56°).

The barley cover shows similar variation than the wheat cover, from 60% in the NIR to 80% in the blue region according with its optical properties. The sugar beet crop shows values from 30% in the NIR to 100% in the red channel, where the spectral contrast between soil and vegetation is more important. Finally, the bare soil shows the highest differences ranging between 100 and 200%. In this case, the low absorbance and the increment of dark shadows in the forward scatter region, produce a very important increment of the anisotropy. The ANIX rise from 2.3 at noon to 7.4 in the morning flight at 500 nm. This result demonstrates the important influence of the sun position in the anisotropy of the BRDF.

4. CONCLUSIONS

Using airborne POLDER data acquired during the DAISEX campaign, a quantitative analysis of the BRDF anisotropy has been performed by means of the ANIF and ANIX anisotropy indices. The ANIF quantify the variation of nadir reflectance with the viewing geometry, whilst the ANIX quantifies the amplitude of the anisotropy, computed as the ratio between the maximum and minimum values. The analysis has allowed evaluating the influence of the canopy structure, optical properties and sun zenith angle on the BRDF anisotropy. The main results were:

(1) The BRDF anisotropy is symmetrical regarding the principal plane. This fact allows us to reduce considerably the sampling necessary to exploit the directional domain. Unlike the orthogonal plane, the principal plane exhibits asymmetry and the highest anisotropy's degree. In this plane, the nadir reflectance increases up to 120% in the backscattering, whereas it decreases around 20-40% in the forward scattering.

(2) The BRDF anisotropy is strongly dependent of the SZA showing a systematic increase with the SZA increase.

(3) Optical properties exert also a strong influence. In general, the multiple scattered radiation (NIR) smoothes the anisotropy whereas a high absorbance (VIS) increases the BRDF anisotropy.

(4) Finally, the structural parameters and the architecture of the canopy determine the anisotropy of the BRDF. The ANIX obtained in the principal plane has shown that the influence of the canopy architecture becomes more important for higher sun zenith angles. The ANIX values ranges between 2 and 7 in the morning ($SZA=56^\circ$), revealing a very marked anisotropic behavior.

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