

Enhanced Discrimination of Boreal Forest Covers Using Directional Signatures Measured by the Airborne POLDER Instrument

P. Bicheron, M. Leroy, O. Hautecoeur

(CESBIO, UMR CNES-CNRS-UPS, 18, av. E. Belin, 31055 Toulouse Cedex, France)

Abstract The POLDER instrument (POLarization and Directionality of Earth Reflectances) flew during the BOREAS experiment on-board a C-130 aircraft from NASA. BRDF measurements were obtained by POLDER on various supersites in the South area of the BOREAS. Large hot spot features over forest covers, and specular components over fen areas are described. The paper quantifies with airborne POLDER data the improvement of classification and discrimination of various forest covers when remotely-sensed directional signatures are added to the more conventional spectral signatures. When using non supervised classifications, the terms of inter-class confusion matrices are much lower (by a factor between 2 and 5) when directional information is added to the conventional spectral information. This proves that directional signatures enhance the discrimination of boreal forest covers by remote sensing.

Key words POLDER instrument (POLarization and Directionality of Earth Reflectances), Hot spot, Directional signatures

1 INTRODUCTION

Remote sensing observations of the surface reflectance anisotropy have received increasing attention in recent years. Anisotropic effects have been evaluated on times series of the Advanced Very High Resolution Radiometer (AVHRR), for which the viewing zenith angle is highly variable in successive observations^[1,2]. There have been also measurements in the field over bare soils, cultures or natural grasslands^[3]. Directional signatures of forest covers are inherently more difficult to measure because of the cover size. They can be measured from high towers^[4]. Aircraft or helicopter measurements are another option developed recently with the airborne Polarization and Directionality of Earth's Reflectances (POLDER) instrument^[5-7].

Land cover classifications are an important application of remote sensing observations of natural surfaces in the solar spectrum. Although the temporal information is sometimes used, most classification works only use the spectral information. The poten-

tial of the directional information to classify cover types has been suggested in the past^[8,9]. However this was not demonstrated so far due to the lack of appropriate directional data sets. This paper documents new measurements of the spectral and directional reflectances of various boreal forest covers of the Southern Study Area of the BOREAS experiment, acquired by the airborne POLDER onboard a C-130 airplane operated by NASA during the two first Intensive Field Campaigns (IFC-1 and IFC-2) from May to July, 1994. The unique capability of the POLDER concept to derive directional measurements on each grid point of extended areas^[6] is used to quantify the improvement of classifications of boreal cover types when the directional signature is used in addition to the more conventional spectral signature.

2 THE POLDER INSTRUMENT

The airborne POLDER instrument is a radiometer designed to measure the directionality and polarization of the sunlight scattered by the ground-atmosphere system^[5]. The instrument produces bidimen-

sional pictures of the ground on a CCD matrix (288 lines \times 384 columns) through a wide field of view optics. Therefore, a given pixel may be observed under different viewing angles in consecutive images acquired during the sensor overflight. The airborne instrument has an angular coverage of $\pm 43^\circ$ in the crosstrack direction and $\pm 51^\circ$ in the along track direction. The ground pixel size is proportional to the instrument altitude, which was typically 5500 m. It is $6 \times 6 \text{ m}^2$ for an altitude of 1 km. A rotating filter wheel that carries spectral filters and polarizers allows measurements in several spectral bands: 443 nm, 550 nm, 670 nm, 864 nm, and 910 nm. A sequence of images, corresponding to the positions of the filter wheel, is performed within 3 seconds, and is repeated every 10 seconds. The processing of successive images permits the reconstruction of the BRDF for each pixel. For a typical C-130 flight altitude and speed, an angular resolution of approximately 10 degrees is obtained along track.

3 DATA ACQUISITION AND PROCESSING

The POLDER/C-130 flights over «tower sites» of the South Study Area in both IFC-1 and IFC-2 campaigns took place on the so-called Fen, Old Jack Pine, Old Aspen, Young Jack Pine, and Old Black Spruce sites. Each target was overflown several times, each time at a different heading, so that multiple images could be collected in the principal, perpendicular, and oblique planes. For each image acquisition, POLDER recorded the aircraft position and altitude. This gives the approximate position of a given pixel in any POLDER image. Ground control point techniques were used to fine-tune the geometric multi-image registration of the whole set of images for each flight. Images were then processed to derive the BRDF over tower sites, at a resolution of 5×5 pixels ($175 \times 175 \text{ m}^2$), or to produce BRDF data sets on each pixel of georeferenced images of size $5 \times 5 \text{ km}^2$ at a spatial resolution of 100 m.

Calibrations of the POLDER instrument were made before and after the BOREAS experiment at

Laboratoire d'Optique Atmosphérique (Lille) with an integrating sphere. The atmospheric correction algorithm $6S^{[10]}$ was applied to the measured reflectances to produce corrected reflectances. A midarctic summer atmospheric model and a continental aerosol model were selected to characterize the atmosphere above the BOREAS sites. The total and below aircraft aerosol optical thickness at 550 nm are inputs of the algorithm. These measurements were obtained from the BORIS database, and interpolations were made to derive values at 550 nm.

Examples of bidirectional spectral reflectances, corrected for atmospheric effects and averaged on $175 \times 175 \text{ m}^2$, are presented in Fig. 1 for two different «super sites» of the BOREAS experiment, Old Black Spruce (May 31) and Fen (July 24) at 670 nm and 864 nm. The radius of the polar diagrams represents the viewing zenith angle θ_v , and the polar angle is the relative azimuth ϕ between view and Sun direction. Fig. 1 aside data points represent bidirectional reflectance measurements in percents. The aligned data points correspond to successive measurements of a given flight axis.

The measurements show an important gradient in the principal plane, and only small variations in the perpendicular plane. A peak of reflectance is found in the so-called «hot spot» direction, where the viewing direction approaches the solar direction. The directional signature of the Fen contains in addition an energetic component in the neighborhood of the specular direction. The Fen surface is made of high grasses imbedded in water, and this water gives rise to the specular signature.

4 ENHANCED DISCRIMINATION OF VARIOUS FOREST COVERS USING THEIR DIRECTIONAL SIGNATURE

The strong anisotropies observed above suggest that the discrimination by remote sensing of forest covers should be enhanced if some directional information is added to the spectral information. The goal of this section is to provide a quantitative basis to this statement.

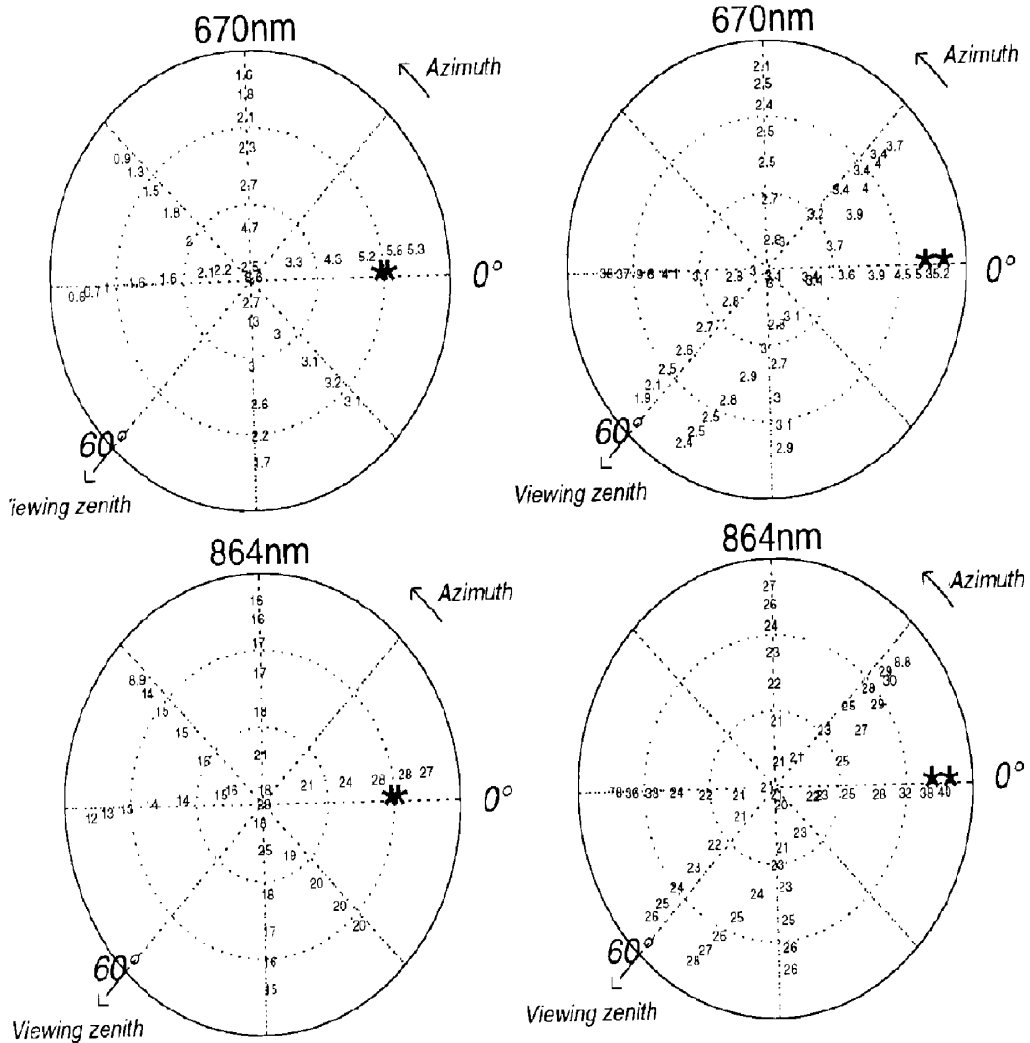


Fig. 1 Directional and spectral diagram for the Old Black Spruce (left) and Fen (right) sites at 670nm and 864nm, corrected for atmospheric effects. Icons represent the range of sun zenith angles during experience

Experimental protocol

A BRDF is extracted, on each $100 \times 100 \text{m}^2$ grid pixel of two $5 \times 5 \text{km}^2$ areas surrounding the «super sites» sites Young Jack Pine and Old Black Spruce, from the POLDER data acquired on July 21, 1994. The number of directional measurements associated to each pixel depends on its position in the study area and on the number of flight axes. It is equal to about 40 at the center of the area and decreases slightly towards its corners. For each pixel, the BRDF measurements acquired by POLDER are adjusted against the 3-parameter semiempirical model of Rahman *et*

al.^[11]. From the 3 model parameters retrieved through the adjustment between model and observations, the reflectance of each $100 \times 100 \text{m}^2$ pixel is reconstructed in 3 different viewing directions (and the same sun zenith angle as in the original data set) : nadir, hotspot, and in the perpendicular plane for $\theta_v = 50^\circ$.

On the other hand, we use subsets of forest cover georeferenced maps, available in the BORIS database, covering the same $5 \times 5 \text{km}^2$ areas mentioned above. These maps describe various attributes such as density, height, primary species, secondary species, third species. The format and resolution of

these maps were made compatible with those of the BRDF. On the basis of the land cover maps, one selects a large number of pixels pertaining to 5 different classes of forest covers. Each class contains 30 pixels.

Then, one compares the results of a non supervised classification on all selected pixels, using as input, either the reflectances at nadir only (this simulates the case of conventional spectral signature), or reflectances reconstructed in the three directions men-

tioned above (this simulates the case of spectral and directional signatures). The number N of dimensions per pixel may be 1 (1 spectral band, 1 direction), 3 (3 spectral bands, 1 direction or 3 directions, 1 spectral band), or 9 (3 directions, 3 spectral bands). Each class is adjusted in N -dimensional space against an ellipsoid centered on the class barycenter. The ellipsoid is determined using a standard Principal

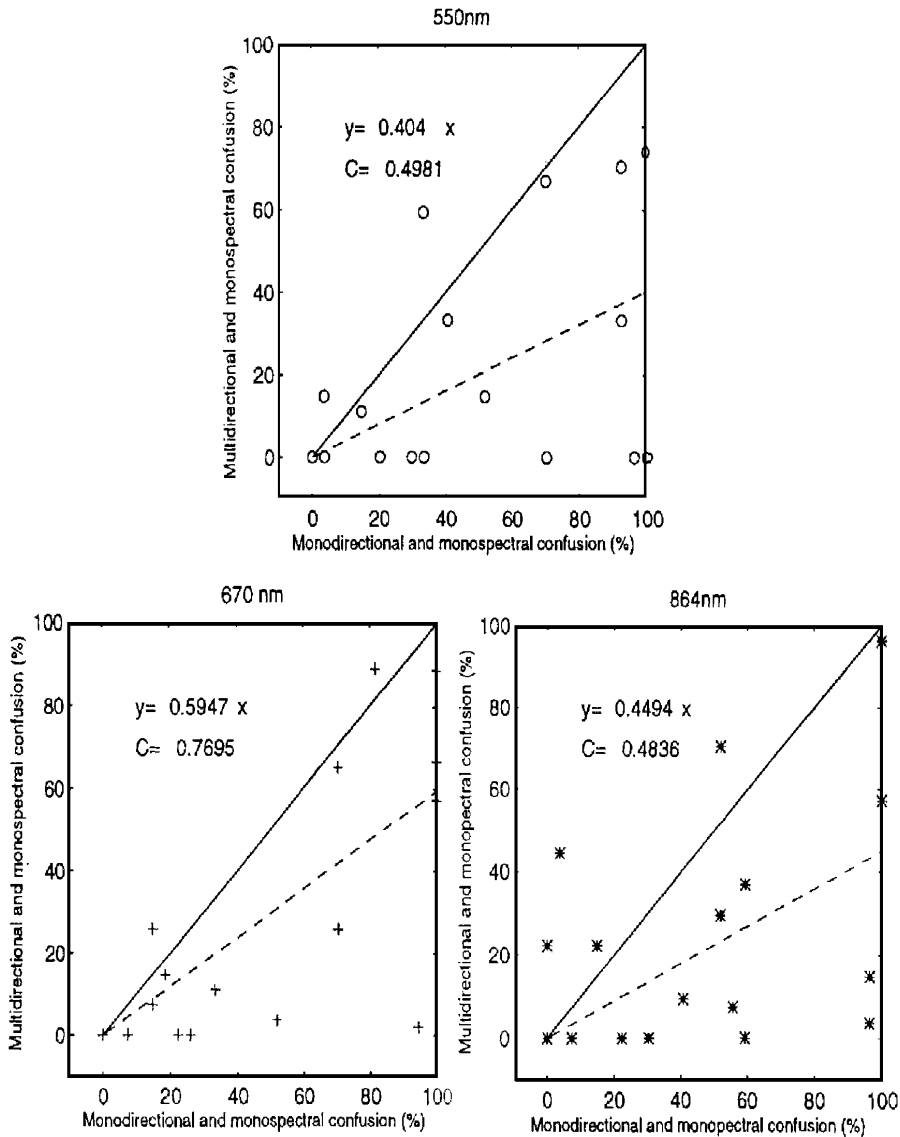


Fig. 2 Scatter plots of the non diagonal elements of the confusion matrix in multidirectional and monospectral space versus those in monodirectional and monospectral space at 550nm, 670nm, and 864nm

Components Analysis. The eigen values of the Principal Component Analysis, which represent the half-axes of the ellipsoid, are then multiplied by a coefficient in such a way that the ellipsoid contains exactly 90% of the pixels of the considered class. By definition, a class C_i is the ensemble of elements of class i contained in the ellipsoid. The non supervised classification efficiency is quantified by its confusion matrix C_{ij} , which describes for two classes C_i and C_j the number of pixels belonging to class C_i which are present in class C_j . The confusion matrix is not symmetric.

Results

A general view of the results is given in Fig. 2, which represents the scatter plots of the non diagonal elements of the multidirectional and monospectral confusion matrix versus those obtained for the monodirectional and monospectral confusion matrix, for each available wavelength. Plots of Fig. 2 show some random scatter, and also general trends, represented by the regression lines. The scatter may be quantified by the correlation coefficient between data points and the regression line. It is not very high, but sufficient to consider the results of the linear regression acceptable. It is concluded from Fig. 2 that, on average, the confusion between classes is about twice as smaller in multidirectional space than in monodirectional space, at each wavelength. Many matrix coefficients reach values close to 0 in multidirectional space, demonstrating the contribution of the directional information. These results show that forest species discrimination is enhanced when directional information is added to the spectral information.

Furthermore, it is possible to compare situations where 3 spectral bands are available with only one direction (3 dimensions), and where 3 spectral bands are available with 3 directions per spectral band (9 dimensions). The improvement of classes discrimination is then spectacular, as shown in Fig. 3. On average, the confusion is about 5 times smaller when all

directions and spectral bands are taken into account, than when only spectral information is considered.

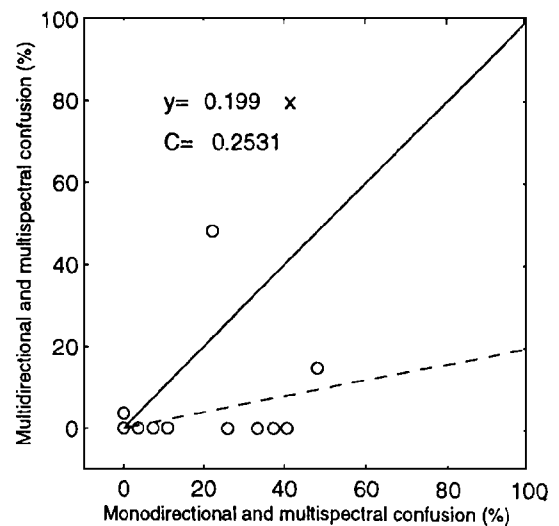


Fig. 3 Scatter plot of the non diagonal elements of the confusion matrix in multidirectional and multispectral space, versus those in monodirectional and multispectral space

5 CONCLUSION

The study presented here has analysed the anisotropy of reflectance signatures of various types of forest covers using the airborne POLDER instrument in the framework of the BOREAS experiment. Several examples of directional and spectral signatures have been documented over coniferous forests and fen areas. All signatures were found to be highly anisotropic, with, however, only slight variations in the perpendicular plane. A key point of this work was to quantify, using a non supervised classification procedure, the improvement of land cover classifications brought by the directional signature in addition to the more usual spectral information. It is concluded that the account of directional information enhances significantly the ability to discriminate forest covers by remote sensing.

REFERENCES

- [1] Leroy, M., J.-L. Roujean. Sun and view angle corrections on reflectances derived from NOAA/AVHRR data. *IEEE TGRSS*, 1994, **32**, 684–696.
- [2] Wu A., Z. Li, J. Cihlar. Effects of land cover type and greenness on advanced very high resolution radiometer bidirectional reflectances analysis and removal. *J. Geo. Res.*, 1995, **100**, 9, 179–192.
- [3] Kuusk A. Determination of vegetation canopy parameters from optical measurements. *Rem. Sens. Env.*, 1991, **37**, 207–218.
- [4] Deering D. W., E. M. Middleton, T. F. Eck. Reflectance anisotropy for a spruce-hemlock forest canopy. *Rem. Sens. Env.*, 1994, **47**, 242–260.
- [5] Deschamps P. Y., F. M. Bréon, M. Leroy, A. Podaire, A. Bricaud, J. C. Buriez, G. Sêze. The POLDER mission; instrument characteristics and scientific objectives. *IEEE Trans. Geosc. Rem. Sens.*, 1994, **32**, 598–615.
- [6] Leroy M, F. M. Bréon. Surface reflectance angular signatures from airborne POLDER data. *Rem. Sens. Env.*, in press, 1996.
- [7] Bréon F. M., V. Vanderbilt, M. Leroy, P. Bicheron, C. L. Walthall, J. E. Kalshoven. Evidence of hot-spot signature from airborne POLDER measurements. *IEEE Trans. Geosc. Rem. Sens.*, in press, 1996.
- [8] Goel N. S., N. E. Reynolds. Bidirectional canopy reflectance and its relationship to vegetation characteristics. *Int. J. Rem. Sens.*, 1989, **10**, 107–132.
- [9] Running, S. W., C. O. Justice, V. Salomonson, D. Hall, J. Barker, Y. J. Kaufman, A. H. Strahler, A. R. Huete, J. P. Muller, V. Vanderbilt, Z. M. Wan, P. Teillet, D. Carneggie. Terrestrial remote sensing science and algorithms planned for EOS/MODIS. *International Journal of Remote Sensing*, 1994, **15**, 3, 587–3, 620.
- [10] Vermote E., D. Tanré J. L. Deuzé J. J. Morcrette. Second simulation of the satellite signal in the solar spectrum; an overview. *IEEE Trans. Geosc. Rem. Sens.*, 1996.
- [11] Rahman H., B. Pinty, M. M. Verstraete. A coupled surface atmosphere reflectance (CSAR) model. Part 2: a semi-empirical model useable with NOAA/AVHRR data. *J. Geophys. Res.*, 1993, **98**, 20, 791–20, 801.

AUTHOR

Patrice Bicheron, 25, graduate student, Marc Leroy, 41, PhD, engineer from CNES, and Olivier Hautecoeur, 30, research engineer. Their research field is remote sensing physics. They are currently working on radiative transfer models and vegetation parameters retrieval from space and airborne sensors.

用航空 POLDER 测量仪获取的方向性信息增强对北方森林冠层的识别

P. Bicheron, M. Leroy, O. Hautecoeur

(CESBIO, UMR CNES-CNRS-UPS, 18, av. E. Belin, 31055 Toulouse Cedex, France)

摘要 POLDER (地球反射极化和方向) 仪器在 BOREAS 实验中曾搭载 NASA 的一架 C-130 飞机飞行。在 BOREAS 的南部地区, POLDER 获取了各种实验场地上的 BRDF 测量值。森林覆盖地区的大热点特征, 以及十个地区上的镜面反射分量得到了描述。该文通过 POLDER 的测量数据, 对向常规的光谱特征中加入通过遥感获得的方向性特征后, 对各种森林覆盖的分类和区分能力的提高给出了定量化的解。当将方向信息加入常规光谱信息后, 采用无监督分类时, 类间耦合矩阵的各项显著减小 (减小倍数为 2–5 倍)。这一事实证明了用遥感方向特征可以增强对 BOREAL 森林覆盖的区分能力。

关键词 POLDER 测量仪 (地球极化与方向反射测量仪), 热点, 方向性信息