Bio-geophysical land surface parameters derived from ADEOS-2/POLDER-2 multi-angular measurements

R. Lacaze*[1], F. Maignan[2], B. Miras[1], F. M. Bréon[2], M. Weiss[3], F. Baret[4]

[1] Médias-France, CNES-BPI 2102, 18 av. E. Belin, 31401 Toulouse Cedex 9, France – (lacaze, miras)@medias.cnes.fr
[2] Laboratoire des Sciences du Climat et de l'Environnement, CEA, 91191 Gif sur Yvette, France – maignan@lsce.saclay.cea.fr fmb@cea.fr
[3] Noveltis, Parc Technologique du Canal, 2 av. de l'Europe, 31520 Ramonville, France
[4] INRA/CSE Agroparc, 84014 Avignon, France (baret, weiss)@avignon.inra.fr

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ABSTRACT:

Monitoring of terrestrial vegetation from satellites at global and regional scales requires accurate and frequent measurements of surface reflectance. In this context, the POLDER instrument leads a key improvement providing, at high temporal resolution, measurements of the Bi-directional Reflectance Distribution Function corrected for atmospheric effects. In the frame of the ADEOS-2/POLDER-2 project, advanced Land Surface Level 3 algorithms have been developed to retrieve the spectral Directional-Hemispherical Reflectances (DHR), the Normalized Difference Vegetation Index (NDVI) corrected for directional effects, the Leaf Area Index (LAI) and the Fraction of Vegetation Cover (FVC). The retrieved parameters are validated following a procedure based upon the analyze of the spatial and temporal variability, the comparison with available equivalent products derived from other sensors by similar or different approaches, and finally the comparison with up-scaled in-situ measurements collected over selected areas.

RESUME:

Le suivi de la végétation continentale à l'échelle global et régionale demande des mesures fréquentes et précises de la réflectance de surface. Dans ce contexte, l'instrument POLDER apporte une information inédite en fournissant des mesures journalières de la Fonction de Distribution de la Réflectance Bi-directionnelle (FDRB) corrigées des effets atmosphériques. Dans le cadre du projet ADEOS-2/POLDER-2, des algorithmes améliorés de restitution des paramètres biophysiques des surfaces continentales ont été développés. Ils estiment les réflectances hémisphériques-directionnelles, l'indice de végétation NDVI corrigé des effets directionnels, l'indice foliaire LAI et la fraction de couverture végétale FVC. Les paramètres ainsi restitués sont ensuite validés selon une procédure qui repose sur l'analyse de leur variabilité spatiale et temporelle, la comparaison à des produits équivalents issus d'autres capteurs par des méthodes similaires ou différentes, et enfin la comparaison à des mesures terrains spatialisées acquises sur des sites sélectionnés.

1. INTRODUCTION

The regular increase in greenhouse gases due to anthropogenic emissions in the atmosphere may have a major impact on the Earth' s climate in the forthcoming decades. In order to reduce the uncertainties in forecasting climatic changes, it is necessary to better understand the processes involved in interactions between land surface, aerosols, clouds, radiation and atmospheric circulation.

The exchanges between the land surface and the atmosphere are largely controlled by the physiological characteristics of the surface, which determine energy, water and momentum fluxes. In climatic and weather forecasting models, surface processes are represented by soil-vegetation-atmosphere transfer scheme, which simulate the fluxes at the atmospheric boundary layer (Sato et al., 1989; Calvet et al., 1998). This imposes strict requirements in order to implement global and regional description of soil and vegetation properties which control physical, biological, and hydrological surface processes. Even though climatic and meteorological models are based on large grid cells, a good knowledge of the subgrid landscape variability is necessary to accurately account for surface fluxes of radiation, heat, moisture, and momentum (Henderson-sellers and Pitman, 1992; Noilhan et Lacarrère, 1995). In this context, space-borne sensors play a key role by providing global, long term observations of land surface at appropriate spatial and temporal scale.

The advent of the POLDER sensor providing multiple spectral images at high angular resolutions has lead to investigate the improvement of land surface parameters retrieval using multi-angular measurements. The POLDER radiometer has been designed to measure the directional and polarized reflectances of the surface-atmosphere system (Deschamps et al., 1994). The instrument concept consists in a camera composed of a two-dimensional CCD detector array, wide field of view telecentric optics and a rotating wheel carrying spectral and polarized filters. During a single satellite overpass, a surface target is scanned up to 14 times under different viewing angles. The view illumination directional configuration changes each day as the orbit shifts. Therefore, after a few days, assuming clear atmospheric conditions, the measurements provide a sample of the Bi-directional Reflectance Distribution Function (BRDF) within the sensor field of view.

The POLDER-1 sensor onboard the Japanese satellite platform ADEOS-1 has measured the reflectance of the entire land-atmosphere terrestrial system from November, 1996 to June, 1997. Its successor, POLDER-2, has been launched on the ADEOS-2 platform in December, 2002. It provided BRDF measurements from April to October, 2003.

2. “LAND SURFACE” LEVEL 3 ALGORITHM

The first algorithms of the “Land Surface” processing line, applied to the ADEOS-1/POLDER-1 data, took advantage of the POLDER directionality (Leroy et al., 1997). The Level 3 products are generated over a synthesis period of 30 days with a sliding window to get a temporal resolution of 10 days. Advanced algorithms have been developed to be applied to ADEOS-2/POLDER-2 data. In addition to the Leaf Area Index (LAI) retrieval, the major improvements of the algorithm are:

1) a multi-temporal filtering module that eliminates the observations contaminated by residual clouds and/or aerosols.
2) the application of temporal weighting favouring the data collected in the middle of the synthesis period. Thus, the smoothing of the temporal variations of the biophysical parameters due to the monthly synthesis decreases;
3) the calculation of an error associated with each parameter. This value depends on the noise on the input data (i.e. the measured bi-directional spectral reflectances) and on the retrieval algorithm.

The “Land Surface” Level 3 algorithm relies on 3 major steps as shown on Figure 1.

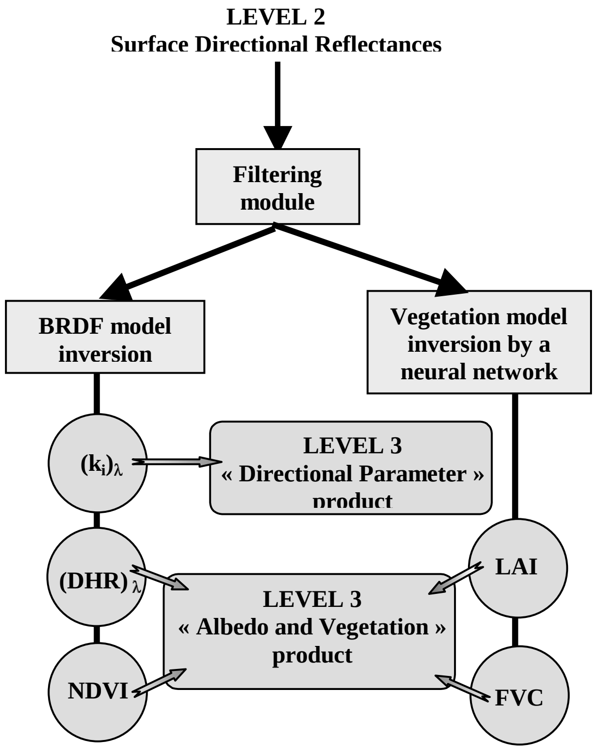

Figure 1. Diagram of the "Land Surface" Level 3 algorithm

2.1 The filtering module

The bi-directional spectral reflectances are the inputs of the “Land Surface” Level 3 processing line. Their quality controls the relevance of biophysical parameters. In order to complete the Level 2 cloud masking and eliminate the disturbed data, a multi-temporal filtering module has been implemented. It determines the type of surface (ground, snow or mixed), identifies the temporal inconstancies of the measured reflectances over the synthesis period of 30 days, and filters the observations contaminated by residual clouds and/or aerosols. This latter point is based on the fitting of the directional model of Walthall et al., (1985) on the reflectances acquired at 443nm under angular configurations close to the perpendicular plane.

The advanced algorithm has been tested on ADEOS-1/POLDER-1 data (Lacaze et al., 2003). The inconsistent spatial variability over cloudy areas is clearly reduced, and the bio-geophysical parameters appear more homogeneous.

2.2 The linear inversion of a BRDF model

A new linear semi-empirical BRDF model proposed by Maignan et al. (2004) has been implemented in the Level 3 processing line to normalize the bi-directional POLDER-2 measurements. This model combines the reciprocal geometric kernel of “Li_sparse” (Lucht et al., 2000) with the volumic kernel of “Ross_thick” (Roujean et al., 1992). The innovation is the merging of the “Ross_thick” kernel with a hotspot module (Bréon et al., 2002) which allows to reproduce more accurately the hotspot phenomenon well described on the POLDER BRDFs. A Gaussian temporal weighting is applied to measured reflectances to enhance the representation of the center of the synthesis period. The resulting spectral directional coefficients are:

- a nadir-zenith reflectance, k0
- a roughness indicator, k1
- a volume scattering indicator, k2.

However, because of the enhanced correlation between the reciprocal “Li-sparse” kernel and the new “Ross_thick_hotspot” kernel, the individual meaning of the directional coefficients as surface indicators should be cautious. Their optimal use is as a set of coefficients to accurately simulate the BRDF. So, they are used for computing the spectral Directional Hemispherical Reflectances (DHR) for the median sun angle of the synthesis period. Then, the NDVI, corrected for the directional effects, is derived from DHR_{670nm} and DHR_{865nm}.

The quality of the inversion remains dependent on the angular distribution of acquisitions in the directional hemisphere. It is estimated through the coefficient of determination R^2 and the root mean square error (rmse) between the measured and simulated reflectances. R^2 and rmse are provided in the Data Quality Index (DQX).

2.3 The inversion of a vegetation model by a neural network

The Leaf Area Index (LAI) is defined as half the total intercepting green foliage area per unit ground surface area (Chen et Black, 1992). The ADEOS-2/POLDER-2 algorithm computes the LAI using a neural network, which inverts the radiative transfer model of Kuusk (1995) considering the vegetation as a turbid medium of leaves with spherical orientation. This model simulates the simple scattering in the canopy (in particular the hot spot phenomenon quantified by the parameter l*, ratio of the leaf size to the canopy height) following the Nilson and Kuusk (1989) approach, and the multiple scattering according the SAIL model (Verhoef, 1984). Furthermore, the leaf optical properties are described by the PROSPECT model (Jacquemoud et al., 1996) whereas the spectral and angular properties of soil are reproduced by the coupling of the functions of Price (1990) and the directional model of Walthall et al., (1985), respectively.

For the specific application to the POLDER data, parameters of the PROSPECT model have been adjusted to account for the chlorophyll concentration, Cab, the senescent pigments concentration, Cs, the dry matter content, Cdm, the water equivalent thickness, Cw, and the effective number of layers inside a leaf, N. More, only director factors, a1 and a2, of the 2 first functions of Price [9], which have been optimized, are considered; others are set to 0. The learning base of the neural network has been produced by sampling LAI [0 - 6.5], Cab [15 - 80µg/cm²], N [1 - 4.5], Cs [0 - 2], a1 [0.1- 0.8], whereas other parameters are fixed (Cw = 0.01g/cm², Cdm = 0.015g/cm², l* = 0.1 and a2 = 1).

The network inputs are a single orbit of 11 directional reflectances in 3 spectral bands (565nm, 670nm, and 865nm) and their angular configurations. The output is the LAI estimated for each POLDER track. Then, a simple merging algorithm, with a Gaussian temporal weighting, averages these retrieved LAI over 30 days to get a monthly value mainly characteristic of the central 10-day period. Then, the Fraction of Vegetation Cover (FVC), defined as the fraction of ground covered by vegetation, is derived following the relationship:

$$FVC = \exp(-0.5 * LAI) \tag{1}$$

3. VALIDATION OF THE BIOPHYSICAL PARAMETERS

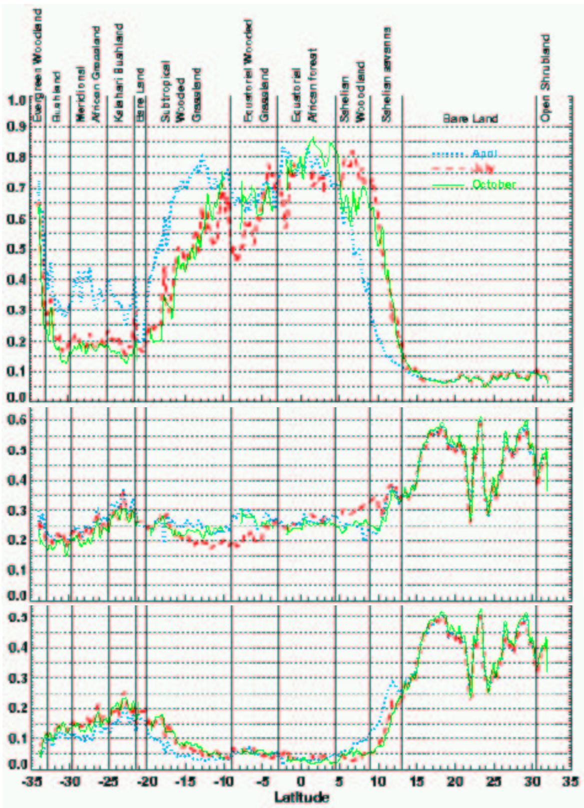

Figure 2 : Spatial variations of visible and NIR DHR, and NDVI along 25°Est over Africa for 3 months (April: blue, July: red, October: green)

The Level 3 biophysical parameters represent the properties of the continental ecosystems. They are dedicated to various environmental studies, whose results are partly controlled by the relevance of the input biophysical parameters. Then, they must be validated, first to estimate their accuracy for the user community, and also to provide feedback so that retrieval algorithm can be improved.

The first step of the validation procedure consists in analyzing the spatial variability of the parameters, i.e. the representation of the gradients at the continental scale, and their temporal evolution over the7 months of acquisition. Figure 2 displays the spatial variations of visible and NIR DHR, and NDVI over Africa. Maxima of DHR appear over the Sahara with DHR 670nm equal to DHR 865nm. We can note the variety of surface on this area, sand with large DHR and rocks with twice lesser DHR. On the both sides of the equator, the season inversion is well marked, especially on the NDVI profile. The minima and maxima values are similar on “Sahelian woodland” on North and “Equatorial Wooded Grassland” on South. These profiles display local ground characteristics such as the Kalahari arid area around 21° South, where the NDVI is rather small in April comparing to the surrounding regions. Over equatorial forest, values are realistic with visible DHR lesser than 0.05 and PIR DHR around 0.25, and NDVI close to 0.8. The NDVI enhances the seasonal variations, especially over intermediate vegetations, woodland, bushland, and grassland.

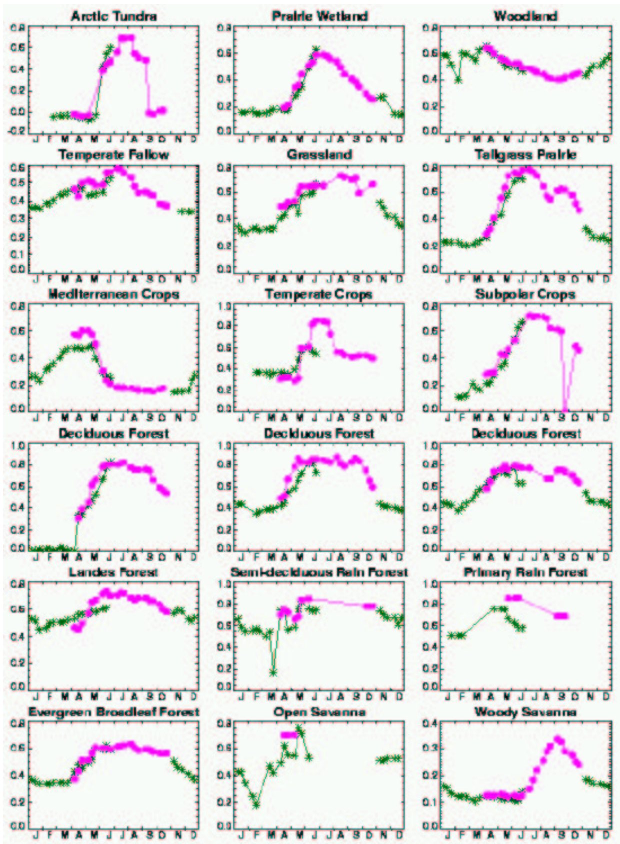

Figure 3 : Temporal variations of NDVI from POLDER-1 (green) and POLDER-2 (magenta)

A second step consists in comparing the POLDER-1 and POLDER-2 parameters. This exercise allow to check the consistency of the products over stable ecosystems and also to display the changes in the vegetation distribution due to climatic variations or anthropogenic actions. Figure 3 shows seasonal variations of NDVI over 18 sites characterizing the main continental biomes. For almost all ecosystems, the POLDER-1 and the POLDER-2 NDVI present a full relevant vegetation cycle. During the northern springtime, when POLDER-1 and POLDER-2 synthesis are available, we can note the differences between the 2 years: in 2003 (POLDER-2) the vegetation growth started some weeks earlier than in 1997 (POLDER-1). This is due to the fact that spring 2003 was warm before a very hot summer. These profiles are regular and smooth what translate a good temporal consistency. Note that NDVI value equal to 0 on sub-polar crop site is due to a single observation contaminated by a cloud. On figure 4, the FVC maps over Africa from POLDER-1 and POLDER-2 measurements display similar spatial features. The main differences appear on the South-West of Africa. In Zambia and Eastern Angola, the FVC is around 0.5 in 1997 and around 0.2 in 2003. The low vegetation development is a consequence of the drought that occurred in this part of Africa in 2003.

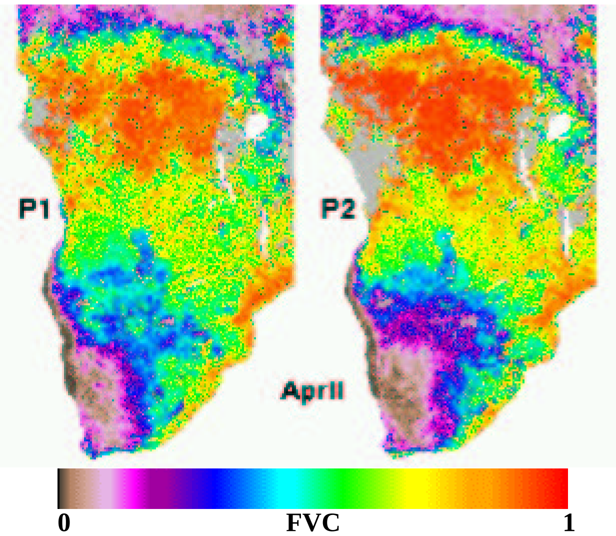

Figure 4: Fraction of Vegetation Cover over Africa retrieved in April 1997 from POLDER-1 (at left) and in April 2003 from POLDER-2 (at right).

The third step of the validation plan consists in comparing POLDER-2 parameters with concomitant products derived from other sensors using similar or different approaches. Then, we performed a comparison between the POLDER-2 DHR and LAI and the MODIS black-sky albedo and LAI.

The methodology applied to retrieve albedos from MODIS observations is similar to the POLDER-2 approach, i.e. based upon the inversion of a kernel-driven, linear BRDF model. Thus, the operational MODIS BRDF/albedo algorithm makes use of the RossThickLiSparse-Reciprocal kernel combination to normalize MODIS data and to calculate the black-sky and white-sky albedos (Lutch et al., 2000). The black-sky albedo is computed for the local noon solar zenith angle for each location. These parameters are provided at the global scale for each 16-day period. We use global black-sky albedo provided in a CGM grid at 0.05° resolution.

More than the differences in the sensors spectral characteristics, the period of synthesis (16 days for MODIS, 30 days for POLDER-2) will imply variations on the parameters, especially when the surface conditions vary quickly, for instance because of snow melting or snow fall. In order to reduce these effects, we relate the POLDER-2 DHR at 565nm, 670nm and 865nm with MODIS black-sky albedo for bands b4 (545-565nm), b1 (620-670nm), and b2 (841-876nm), respectively, over stable desert sites. The profiles are very close with some absolute low differences, around 1% at 865nm and less than 3% in the visible bands. That proves the good consistency of MODIS and POLDER-2 measurements.

The MODIS LAI retrieval algorithm relies on a main procedure which takes advantage of the spectral and angular of the sensor. If this algorithm fails, a back-up procedure is applied to estimate the LAI from vegetation indices (Myneni et al., 1997). The main algorithm is based upon a 3D radiative transfer model which depends on the vegetation structural properties. The measured and simulated bi-directionnal reflectances are compared using a look-up table (Knyazikhin et al., 1998). Here, we use the monthly MODIS LAI available on the Boston University ftp site (www1).

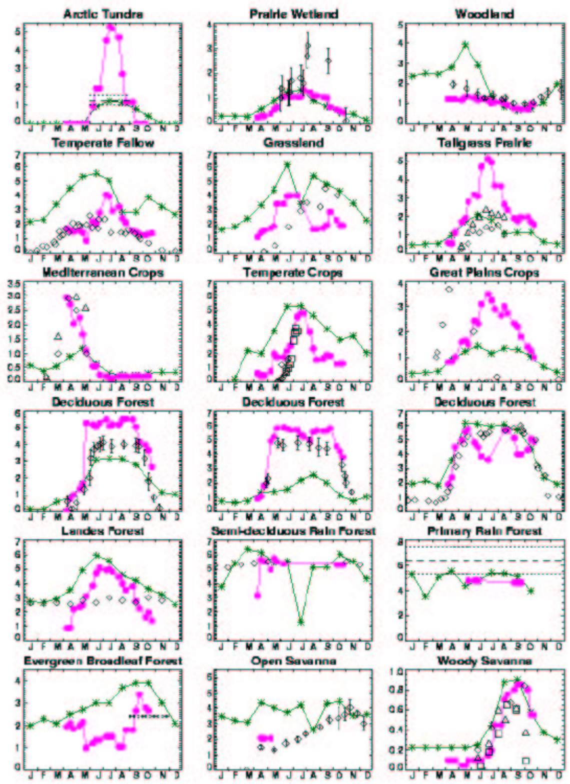

Figure 5: Time profiles of LAI from POLDER (magenta) and MODIS (green) (8km resolution) over some sites characterizing the main continental biomes. Black symbols represent ground measurements collected during previous years.

For most of the sites, the POLDER-2 and MODIS LAI display similar profiles, with difference in magnitude (Figure 5). POLDER-2 shows greater LAI over tallgrass prairie, mediterranean crops, great plain crops, and deciduous forest. Over arctic tundra, it is obviously too large. Over woodland, and temperate fallow, MODIS LAI exhibits much higher values than POLDER-2 and also than ground measurements. In general, POLDER-2 and MODIS LAI profiles suit the time evolution of in-situ data, except for grassland and great plains crops. This is the consequence of the time shift between the year of ground measurement collection and 2003.The profile of the Landes forest of satellite product is clearly controlled by the underwood growth. The lack of POLDER-2 data over open savanna is a consequence of a strict cloud detection. Based upon these comparisons, it is difficult to say which product is the best over sites where large differences are observed.

The last step of the POLDER-2 validation will be the comparison of LAI and FVC to the reference products generated from the ground measurements collected by the VALERI (VAlidation of Land European Remote Sensing Instrument) project (www2). From April to October 2003, 6 sites were instrumented around the world. The data are still under processing.

4. CONCLUSION

The Level 3 algorithms developed to process the POLDER-2 data are based upon the inversion of a linear reflectance model to estimate directional-hemispherical reflectances and NDVI, and upon a neural network inverting a radiative transfer model to calculate LAI and FVC. Before these inversions, a filtering module scans the bi-directional BRDF and removes the contaminated observations.

Directional coefficients, DHR, NDVI, LAI and FVC are generated from Arpil to October 2003. They are validated using temporal and spatial criteria of consistency, comparison with POLDER-1 products, comparison with concomitant MODIS products and, finally comparison with ground measurements. Considering the first three steps, the POLDER-2 biophysical parameters are relevant to characterize the land surface. The spatial distribution and temporal evolution of ecosystems are well reproduced, and the values are realistic. Some discrepancies appears with MODIS products. Final comparisons with concomitant ground measurements from VALERI reference products will be soon performed.

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