AN OPERATIONAL STRATEGY FOR RETRIEVAL OF VEGETATION PRODUCTS FROM SEVIRI & AVHRR-3 DATA

F. Camacho-de Coca, F. J. García-Haro, B. Martínez and J.Meliá

Deptartament de Termodinàmica, Universitat de Valencia
C/ Dr. Moliner, 50 46.100 Burjassot, Valencia, Spain

ABSTRACT

Our aim is the development of robust and operational algorithms for the processing of data from the EUMETSAT MSG and EPS satellites. In particular, we are interested in biophysical parameters such as fractional vegetation cover (FVC) and leaf area index (LAI), which play a critical role in the description of both land-surface processes and land-atmosphere interactions. The behavior of vegetated canopies is mainly controlled by these two variables: FVC refers to the vegetation amounts distributed in a horizontal perspective whereas LAI refers to the leaf layers, i.e. the vegetation accumulated vertically.

The MSG and EPS Vegetation Product provides coverage over the MSG disk (Europe and Africa) for both FVC and LAI at 3-km spatial resolution in a to be determined projection and format. These products will be corrected from uncertainty derived of the view/sun angles and also the surface anisotropic differences for the whole image with the aid of BRDF models. The methodology is based in the complementary use of optimised spectral mixture analysis (SMA) and inversion algorithms supported by BRDF models. The retrieved products will be mutually validated with up-dates in monitoring exercises. In this work, the methodology to retrieve FVC and LAI is presented.

1. IMPORTANCE OF THE VEGETATION PARAMETERS

Vegetation structural parameters such as the Leaf Area Index (LAI) and the Fractional Vegetation Coverage (FVC) play a critical role in the description of and land-atmosphere interactions. In Atmospheric General Circulation Models (AGCMs) and Limited Area Models (LAMs) used for climate and weather forecasting land-surface processes are described by Soil-Vegetation-Atmosphere Transfer (SVAT) models. These models require a detailed representation of soil and vegetation characteristics implemented by means of different surface parameterisation schemes (e.g. TESSEL, ISBA) for an accurate assessment of the radiation and energy budgets at the atmospheric boundary layer. Therefore, vegetation parameters are a necessary input for Numerical Weather Prediction (NWP), regional and global climate modelling, weather forecasting and global change monitoring. Besides, the scientific user communities have expressed the need for timely series of biophysical vegetation parameters, which are relevant for Land Biosphere Applications such us agriculture and forestry, environmental management and land use, hydrology, natural hazards monitoring and management, vegetation-soil dynamics monitoring, drought conditions and fire scar extent.

Remote sensed data is the unique way for monitoring the vegetation on a global scale. Traditional approaches have relied on exploitation of the spatial, temporal and spectral domains of Bidirectional Reflectance Distribution Function (BRDF). Therefore, a bias in the estimates is produced related to the lack of directional information and the surface anisotropic properties, as was shown with AVHRR data (Roujean and Leroy, 1992a). The synergistic use of sun-synchronous (EPS) and geo-stationary (MSG) EUMETSAT sensor systems allows access to the directional information. Therefore, a better determination of the anisotropic properties of Earth's surfaces is expected, thus improving the accuracy of the estimates.

2. PRODUCT DESCRIPTION

Structural properties of the vegetation canopies are mainly characterised by the FVC and LAI parameters. FVC refers to the vegetation amount distributed in a horizontal perspective whereas LAI refers to the leaf layers, i.e. the vegetation accumulated vertically. Vegetation products will be provided on a global coverage over the SEVIRI full disk merging SEVIRI/MSG and AVHRR-3/EPS+NOAA data. FVC is expressed in the range from 0% to 100%, whereas LAI presents values up to 6-7. Vegetation products will be provided at 3-km spatial resolution for two different temporal resolutions (10-days and monthly). These products will be corrected from uncertainty derived of the sun-target-sensor geometry with the aid of BRDF models. The accuracy of the products will be determined in the validation stage. The main characteristics of the MSG and EPS Vegetation Product are summarized in table 1.

Acronym	Spatial Resolution	Temporal Resolution	Projections	Accuracy
FVC	3 km Full disk	10-day period Monthly	UTM Polar stereographic	TBD
LAI	3 km Full disk	10-day period Monthly	UTM Polar stereographic	TBD

Table 1. Main characteristics of FVC and LAI products

The potential users of MSG and EPS vegetation products are mainly the NWP and LBA communities, including national and regional weather services and environmental agencies, governments and university research institutes. Nevertheless, the vegetation product will be first distributed within the LSA SAF Consortium in order to be used as an input of the algorithms for other products. For example, the FVC is an input for the EM and LST products (layer IB) and both FVC and LAI are inputs in the SVAT scheme used to obtain the SM (layer IIIA) and ET (layer IIIC) products (see Sience Plan Document, LSA SAF EUMETSAT)

3. PRODUCT EXTRACTION

3.1 BRDF PRINCIPLES

The BRDF is the basic function that characterizes geometrically the spectral reflectance (Nicodemus et al., 1977). This function can be reconstructed by using a set of reflectance measurements acquired under different sun-target-sensor geometries. The BRDF of the Earth's surfaces is manifestly anisotropic as it was shown from field (Kimes,1983; Deering et al., 1999), airborne (Irons et al., 1991; Staenz et al., 1994) and spaceborne data (Hautecoeur and Leroy, 1998; Bicheron and Leroy, 2001). To understand the canopy radiative regimen, three important features must be considered. They are (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 the observed shadow's pattern with the acquisition geometry results in a high directional dependence of measured reflectance. Consequently, the anisotropy of the BRDF is linked to the 3D structure of the canopy, and is thus a potential source of structural information. For instance, the directional information has been used to improve LAI and fAPAR accuracy (Bicheron and Leroy, 1999), enhance boreal classification (Sandmeier and Deering, 1999) or retrieve clumping index (Leblanc et al., 2001; Lacaze and Roujean, 2001). Conversely, the anisotropy of BRDF can be regarded as a source of noise that must be normalized before applying traditional extraction techniques. Figure 1 shows an example of the BRDF in the red and NIR spectral regions for two solar zenith angles reconstructed from POLDER airborne data.

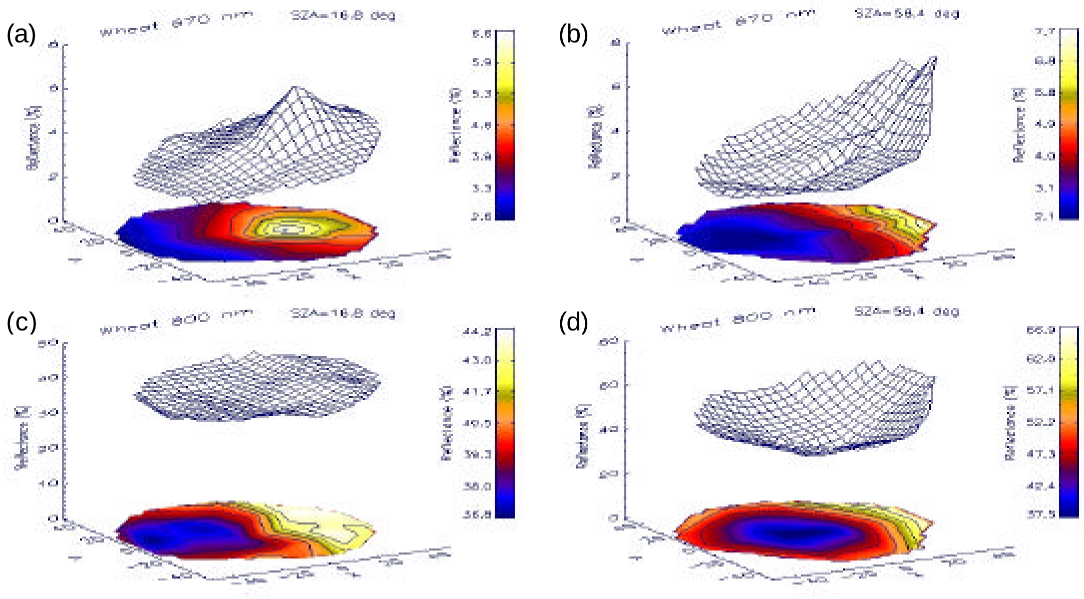

Figure 1. BRDF measurements for a dense wheat cover at 670 nm (a, b) and 800 nm (c, d) and two different Sun Zenith Angles (SZA): 16.8º (a, c) and 56.4º (b, d).

We can observe the effect of the sun zenith angle and optical properties on the anisotropy of BRDF. The multiple scattering in the NIR smooths the anisotropy whereas the high absorption increases the anisotropy due to the higher contrast between shaded and sunlit areas. Thereby, the SEVIRI and AVHRR spectral channels in these regions provide us with complementary directional information. The SZA has also a very important effect since its position determines the gradient of radiation interception in the canopy (Kimes, 1983). Therefore, the higher the SZA the higher the directional effects on the BRDF because of the higher contrast between the top and bottom of the canopy.

3.2 SENSOR CHARACTERISTICS

As shown in figure 2, SEVIRI and AVHRR-3 respectively on-board MSG and EPS present common spectral capabilities (http://www.meteo.pt/landsaf/) that can be used to monitor land surface properties. Although directly designed to improve the observation of meteorological systems, the new generation of EUMETSAT space sensor systems represent a real challenge to improve our knowledge of surface processes. It is expected that combining information between geostationary (MSG) and polar (EPS) systems will bring new insights into the properties of the land surface.

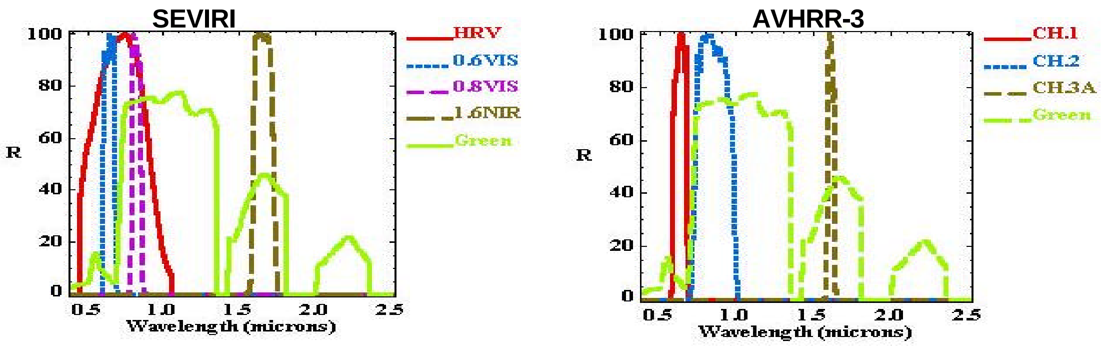

Figure 2. Spectral response of the SEVIRI and AVHRR instrument in the optical region.

MSG and EPS systems will also provide access to directional information on a daily composite basis, allowing a proper sampling of surface anisotropy on the observed radiances. In fact, the SEVIRI instrument will provide multiple illumination angles of the surface whereas AVHRR-3 will allow multi-angular viewing of a given ground target. Besides, the richer the sampling the less additional hypotheses and/or independent data sets are needed to retrieve the physical properties. MSG will also provide an image repeat cycle of 15 minutes offering new opportunities to detect short-term evolution of land resources. Such feature is particularly relevant over areas characterized by a high cloud occurrence as well as for semi-arid ecosystems having short vegetation cycles. On the other hand, the spatial characteristics of both sensors mainly relate to events at the regional to continental scales. In addition, AVHRR-3 on EPS will provide variations of view angles close to the principal plane, the plane containing the sun and the target. The expected view and solar zenith angular that will be included in the data processing steps will be between 0º and 70º. Data acquisitions beyond 70º will be discarded due to their large pixel sizes and difficult atmospheric corrections (Van Leuween and Roujean, 2001). Therefore, MSG & EPS synergy will bring an upgraded level of remotely sensed information thanks to a much better angular sampling.

3.3 ALGORITHM DESCRIPTION

The flow diagram shown in figure 3 describes the main steps of the algorithm. The FVC and LAI product algorithm relies on multi-temporal, multi-angular, multi-spectral, cloud-cleared and atmospherically corrected BRDF data provided by Météo France. The determination of vegetation parameters are based on optimised mixture modelling approaches and model inversion techniques, which are methods especially adequate for global studies, since the spatial variability within pixel is high.

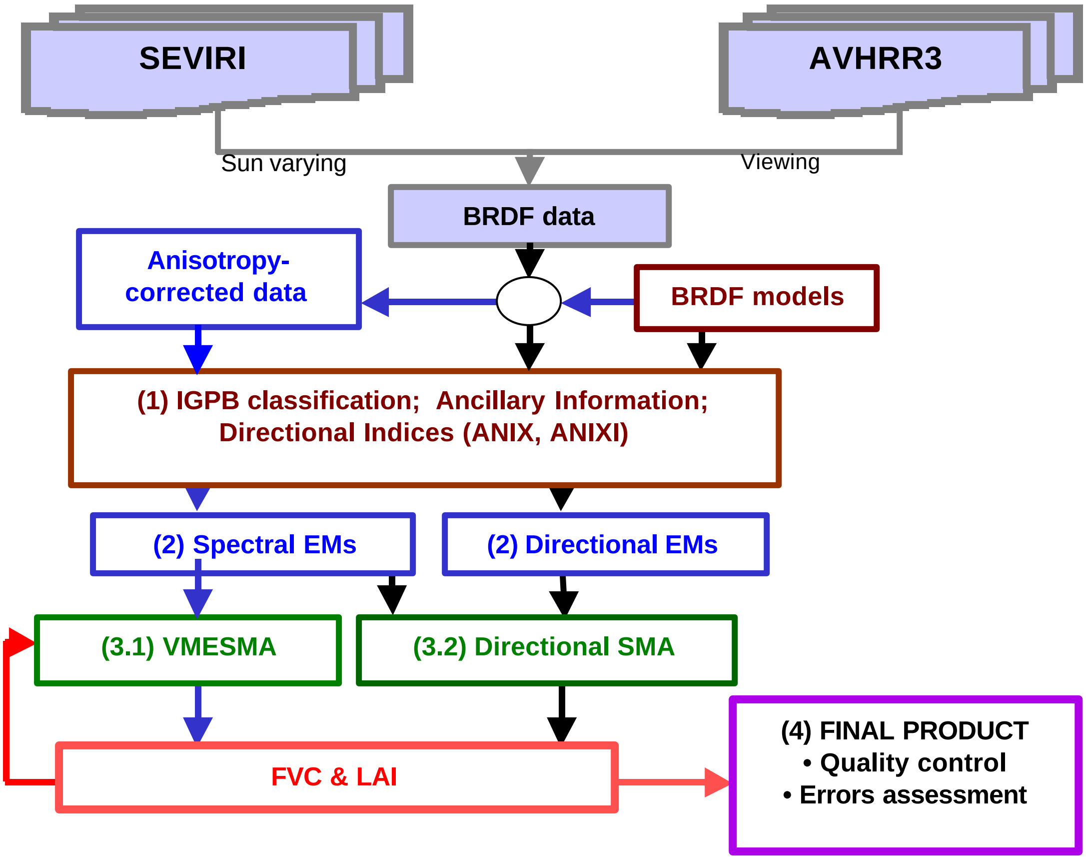

Figure 3. Flow diagram of the methodology for the retrieval of FVC and LAI.

The strategy for retrieval vegetation parameters can be divided into the following main parts:

(1) the **segmentation** of the study area, which allows the partitioning of the scene into different categories as a function of its spectral and directional attributes (e.g. the IGPB land cover classification, anisotropy indices, clumping maps, etc.). BRDF signatures of major biomes cover types, as assessed from models and previous results undertaken on real datasets, will be used to categorise the image. Recently, angular indices based on simple relationship between the maximum and minimum of the directional signature in the principal plane (ANIX) have proved to be effective for enhancing classification of boreal forest (Sandmeier and Deering, 1999). Similarly, anisotropy factors like ANIXI, based on the change of the reflectance with the sun zenith angle have been proposed (Camacho-de Coca et al., 2001). This kind of anisotropy indices will ease to group together the land cover classes with similar anisotropy properties. The stratification of the scene subareas is a critical step to improve the accuracy of the output derived biophysical products. It also allows for selective analysis (e.g. to concentrate the analysis on problematic areas while keeping previous outcomes in well-modeled areas) and eases the iterative improvement of model inputs.

(2) The previous categorisation of the area allows us to employ a **variable strategy** selecting the best EMs (spectral and directional) subset according with landscapes units in order to improve the model performance.

(3)Two complementary **inversion approaches** are considered for the retrieval of FVC and LAI:

(3.1)The inversion of kernel-driven reflectance models (Roujean et al., 1992b) to obtain nadir-zenith reflectance as a sub-product before applying more consistently a technique, namely VMESMA (variable multiple endmember spectral mixture analysis) (Garcia-Haro et al., 2002). The aim is to estimate the sub-pixel abundance of vegetation, soils and other spectrally distinct materials that fundamentally contribute to the spectral signal of mixed pixels. VMESMA enhances the use of standardised thematic interpretation concepts, adapting them to spectro-angular conditions of the main cover types. Moreover, it provides estimates of the FVC very robust against external factors (illumination, soil background) and canopy shade (Brink et al., 2002). Although the primary output will be FVC, some empirical relationships can be then used to derive LAI from estimated FVC based on an optimal configuration in order to reduce the uncertainty derived products with the view and sun angles (Roujean and Lacaze, 2002).

(3.2) The application of a directional SMA strategy, which relates the BRDF of the surface with the directional signatures of vegetation and soil and meaningful biophysical parameters (García-Haro et al., 2002). The aim is to invert the model in order to achieve accurate estimates of the vegetation variables from an optimal set of spectro-angular measurements. Since directional SMA requires a LAI parameter as input, LAI can be retrieved directly. The inversion consists in the definition of a merit function from the difference between spectral/directional measurements and those predicted by the model. However, the merit function will incorporate both *a priori* information and correlation between variables (LAI, FVC, leaf albedo, etc.) to increase the reliability of the estimates. The solutions are obtained using either minimisation algorithms or look-up table methods. The advantage of the use of look-up tables is that the distribution of solutions defines a domain for FVC and LAI around the "true" values, which is also related with the estimation and the correlation between them. The accuracy of the retrieved FVC and LAI will be improved thanks to the synergistic use of MSG and AVHRR3, which allows for an adequate BRDF sampling of the surface.

(4) After the inversion procedure, **error assessments** will be conducted, in which problematic areas will be identified by tying together modelling errors and estimating errors**.** These outputs will aid to improve the products in a feed-back process. This modeling approach enables consistent time series for long-term monitoring the vegetation environments at a global scale.

4. PRELIMINARY RESULTS

Although when multiple angle remote sensing data is available, we will generally regard the BRDF as a source of information, in some cases it may be regarded also as a source of noise. The correction of these effects is hence an important aspect to increase the physical meaning of the vegetation products. The inversion of kernel-driven models is fast and has shown to be robust and effective from airborne and satellite data. Several works have shown the usefulness of the BRDF models to normalise anisotropic properties of the surfaces (Leroy and Roujean, 1994; Leroy and Hautecour, 1999; Hu et al., 2000) and has been recently implemented for normalizing time series of VEGETATION data (Maisongrande et al. 2001). Its inversion provides a set of coefficients $k_{i=0,1,2}$ which stand, respectively, for a nadir-zenith (Lambertian) reflectance, and roughness and volume scattering coefficients.

In order to optimise and validate the methodology, it is being tested on POLDER airborne data. Preliminary results have revealed the potential of the information contained in the directional domain of the BRDF related with the canopy structure. This information was linked by means of appropriate invertible canopy reflectance models with biophysical variables (FVC, LAI, fAPAR), which could be retrieved (García-Haro et al., 2002). In this work, we present preliminary results obtained using the normalisation approach. These analyses have been undertaken on both synthetic data and real data taken from a validation site (see Camacho et al., this issue), which offers a large collection of independent in-situ, aircraft and satellite data. The first example corresponds to POLDER airborne imagery of the Barrax validation area and the second example to MSG synthetic data provided by Météo-France.

4.1 Analysis on POLDER airborne data

Non-accounted anisotropy effects have proved to difficult the discrimination of different community types, even when multi-temporal series are used (Chopping et al., 2000). Figure 4 illustrates how directional effects may reduce the discrimination between communities. Ellipses represent the data cloud variability (1-σ confidence level) of sites corresponding to the main communities and cover types found in the Barrax validation site. The separability is evaluated in the red (SEVIRI 0.6 VIS) and NIR (0.8 VIS) space. In the uncorrected reflectance, the variability is mostly induced by the BRDF, whereas corrected reflectance retains the inherent spectral variability characteristic of each community. Hence when BRDF is regarded as a source of noise, directional effects need to be normalised to increase the intra-class separability.

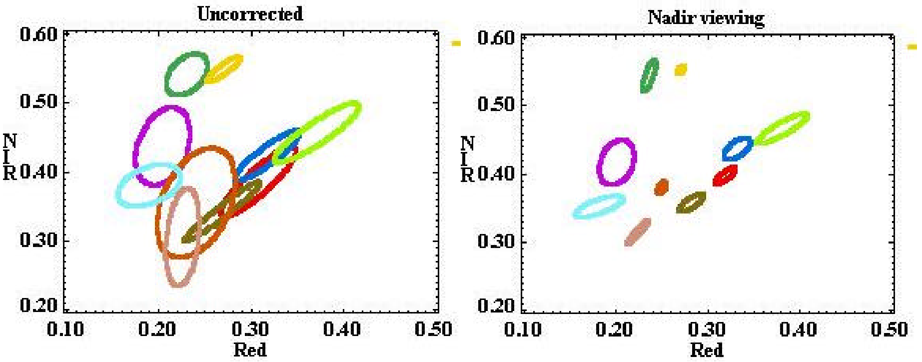

Figure 4. Distributions of community types in the VIS-NIR reflectance space. After normalisation, these distributions are more useful than uncorrected reflectance, because inter-class separability is improved substantially.

For the retrieval of the FVC, the optimal configuration is nadir viewing with the sun at zenith. Two different normalisation methods, nadir interpolation and the Roujean et al. (1992b) kernel-driven model were tested. VMESMA was then applied on normalized POLDER images to retrieve FVC. The reliability of the interpolation method was guaranteed by the adequate BRDF sampling during the acquisition of POLDER data. The results (see figure 5) are quite similar, which confirms the validity of the kernel-driven normalization method. A Graphic User Interface (GUI) enabled us the optimisation of inversion scheme (sampling, model parameters, etc) and an immediate interpretation of modelling/estimating errors. Results compared favourably with field data.

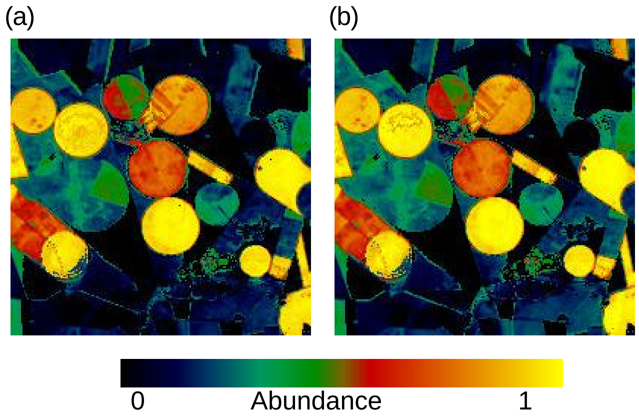

Figure 5. FVC images as obtained from POLDER imagery using two different normalisation methods: (a) k_{iso} from Roujean's kernel-driven model and (b) Normalized nadir POLDER image.

4.2 Analysis on synthetic SEVIRI data

A similar analysis was also undertaken on synthetic SEVIRI data generated by Météo France, corresponding to 12:00 GMT, 166*th* Julian day. In this example, FVC has been estimated from VMESMA for different images along the day (time is expressed in GMT). A variable endmember strategy considering different 2-EM configurations was used. The EMs were extracted automatically from the image. The resulting FVC images are shown in figure 6. A strong relationship has been found between the FVC and the LAI map derived from POLDER data. This suggest the feasibility of the use of semi-empirical relationships to retrieve LAI from FVC, using coefficients that are dependent of the vegetation cover type.

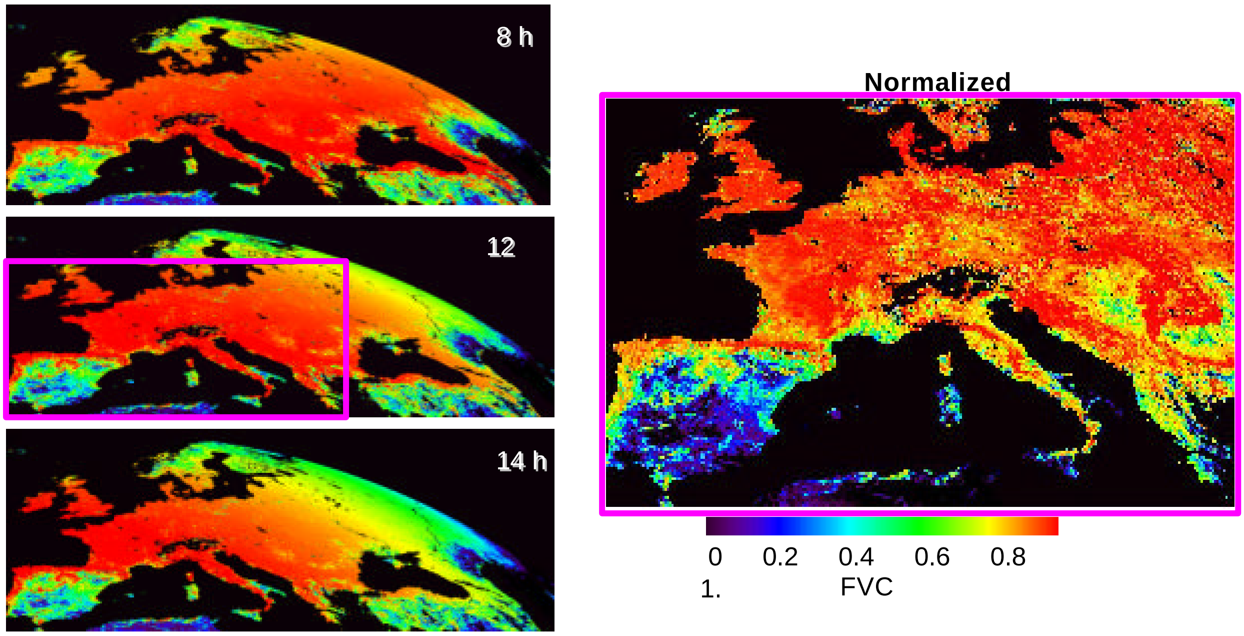

Figure 6 – FVC obtained from VMESMA using both uncorrected and normalised synthetic SEVIRI data.

It is evident that the FVC is highly influenced by the shade variations along the diurnal cycle. Furthermore, the derived product is also influenced by the full SEVIRI disk viewing geometry. In fact, applying VMESMA from single image causes inconsistent estimates of FVC because the vegetation spectral signature does not address the anisotropy of the surface observed from space, and therefore, a bias in the FVC is obtained. For example, the relative contribution of illuminated soil may decrease with the sun angle in the plane orthogonal to the principal plane. This decrease may translate into an overestimation of the FVC. Similarly, the greenness of the vegetation may increase when observing at high off-nadir angles in the backwards direction since the proportion of illuminated and viewed canopy cover is higher. Consequently, FVC could be overestimated at high off-nadir angles.

One possible solution consists in referring pixel reflectance to a nadir-zenith reflectance (e.g. estimated k_{iso}) before applying more consistently VMESMA (see results in figure 6). The correction of the angular view for the full disk is also an important feature of this approach because the large range of view zenith angle involved. This increased the physical meaning of the FVC and made it rather insensitive respect to the anisotropy effects.

5. CONCLUSIONS AND PROSPECTS

An operational strategy is presented for the retrieval of vegetation parameters from SEVIRI and AVHRR-3 data. The more traditional approach will be to normalize the anisotropic behaviour using BRDF models and then apply VMESMA. Another complementary approach will be the inversion of BRDF models, in particular a directional SMA, which characterises the angular dependence of vegetation and soil components for each land cover type. The accuracy will be improved thanks to (i) accumulation of ancillary data for better conditioning the inversion, (ii) zone-dependent selection of methods, supported by well-documented data-bases of major biomes BRDFs and (iii) an appropriate surface BRDF characterisation, which will be improved thanks to the synergistic use of SEVIRI/MSG and AVHRR-3/EPS.

The quality of the operational vegetation products derived from MSG, AVHRR-3 or both will be assessed on the basis of the sensor characteristics (spectral, radiometric and geometric), cloud detection, atmospheric correction and the angular distribution of the observations. The accuracy assessment combines modelling errors, estimating errors and validation ground truth available. The lack of accurate, extensive geometric data on different ecosystems at regional and global scales offered by MSG/AVHRR resolution difficult the validation of prototyping algorithms. Statistical errors and bias of derived products will be also assessed based upon the fluctuations induced by surface anisotropic properties. The retrieved products will be mutually validated with up-dates in monitoring exercises. International efforts will be conducted in order to establish standard methods and protocols for high-level products validation.

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