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LAI, fAPAR and fCover CYCLOPES global products derived from VEGETATION Part 1: Principles of the algorithm

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Abstract

This article describes the algorithmic principles used to generate LAI, fAPAR and fCover estimates from VEGETATION observations. These biophysical variables are produced globally at 10 days temporal sampling interval under lat–lon projection at 1/112° spatial resolution. After a brief description of the VEGETATION sensors, radiometric calibration process, based on vicarious desertic targets is first presented. The cloud screening algorithm was then fine tuned using a global network of cloudiness observations. Atmospheric correction is then achieved using the SMAC code with inputs coming from meteorological values of pressure, ozone and water vapour. Aerosol optical thickness is derived from MODIS climatology assuming continental aerosol type. The Roujean BRDF model is then adjusted for red, near infrared and short wave infrared bands used to the remaining cloud free observations collected over a time window of ±15 days. Outliers due to possible cloud contamination or residual atmospheric correction are iteratively eliminated and prior information is used to get more robust estimates of the three BRDF kernel coefficients. Nadir viewing top of canopy reflectance in the three bands is input to the biophysical algorithm to compute the products at 10 days sampling interval. This algorithm is based on training neural networks over SAIL+PROPSPECT radiative transfer model simulations for each biophysical variable. Details on the way the training data base was generated and the neural network designed and calibrated are presented. Finally, theoretical performances are discussed. Validation over ground measurement data sets and inter-comparison with other similar biophysical products are presented and discussed in a companion paper. The CYCLOPES products and associated detailed documentation are available at http://postel.mediasfrance.org.

Keywords: LAI; fAPAR; fCover; Biophysical variables; Global products; BRDF; Cloud; Radiative transfer; Neural network

1. Introduction

Many applications require an exhaustive monitoring of surface characteristics including biogeochemical cycle and climate modelling, resource evaluation (water, agriculture or forest production). Surface process models need a large number of inputs and parameters that depend on plant functional types. These relatively complex models need to be validated, calibrated or 'corrected' through assimilation of a number of measured variables. Among those, canopy structure characteristics, LAI (leaf area index) and fAPAR (fraction of photosynthetically active radiation absorbed by the canopy) are key variables that are both used in surface process models and retrieved from remote sensing observations in the reflective solar domain. Other applications such as change detection in land cover due either to hazards, climatic variation or changes in land use (deforestation, aforestation, reforestation, changes in

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species or cultural practices), require a relatively high frequency monitoring of the Earth surface. Variables such as the previous ones in addition to fCover (vegetation cover fraction) retrieved from remote sensing observations, may offer a promising alternative to vegetation indices that are currently used although they did not relate simply to canopy biophysical variables.

For almost 25 years, the Earth surface has been monitored at medium to coarse resolution (not better than 1 km^2 pixels) thanks to the series of NOAA/AVHRR sensors. More recently, new sensors have been launched with improved spectral (e.g. SEAWIFS/VEGETATION/MODIS/MERIS) or directional (e.g. POLDER/MISR) sampling, and higher spatial resolution (e.g. MERIS/MODIS). However, space agencies were used to provide only low level products such as top of atmosphere reflectances, sometimes top of canopy reflectances and vegetation indices, but no true biophysical variables such as LAI, fAPAR or fCover. Biophysical products derived from the observations of a selection of these sensors have just been recently developed, and made available to the scientific community. Modellers may now download these products from service centres and plug them directly into their applications. This is the basis of the success of MODIS products.

The Global Monitoring of the Environment and Security programme was initiated few years ago by Europe to better coordinate the use of satellite Earth observations. This programme is now considered as the European component of GEOSS (Global Earth Observation System of Systems) as defined GEO (Group of Earth Observation). Within GMES, Europe supported projects aiming at the development of biophysical products from currently available sensors. The CYCLOPES project was aiming at the development and actual production of global fields of LAI, fAPAR and fCover for the 1998–2003 period. These products were evaluated by associated users for applications focusing on carbon cycle, climate modelling and change detection.

Although the CYCLOPES project was ultimately targeting to develop products from the fusion of an ensemble of satellites, one of the first tasks achieved was to develop specific products for each series of sensors. This paper present the results obtained for the VEGETATION sensor. After briefly presenting the characteristics of VEGETATION observations, and the way it is radiometrically calibrated, several steps required to derive the biophysical products from the low level products available at VITO (http://www.vgt.vito.be) will be described. It includes cloud screening, atmospheric correction, BRDF normalization, temporal compositing, and the derivation of the biophysical variables and some theoretical validation elements. A companion paper will present the actual validation of these products with some inter-comparison with MODIS Collection 4 (Weiss et al., 2007-this issue).

2. VEGETATION sensors characteristics and radiometric calibration

2.1. VEGETATION sensors characteristics

Europe has launched the first VEGETATION sensor in 1998 aboard SPOT4. A second instrument was launched in 2002 aboard SPOT5 to ensure the continuity of observations. The two instruments are identical and provide global observations of the surface from a sun-synchronous orbit at 822 km altitude, with an inclination of 96.7°, a period of 26 days and an equatorial crossing time of 10:30. Because of the large swath (101°, equivalent to 2200 km), about 90% of the equatorial areas are imaged each day, the remaining 10% being imaged the next day. For latitudes higher than 35° (North and South), all regions are acquired at least once a day. The instrumental concept relies on a linear array of 1728 CCD detectors providing a spatial resolution around 1.15 km with minimum variations for off-nadir pixel size thanks to the telecentric design of the optics. Four spectral bands are available: B0 (450 nm, $\Delta\lambda=40$ nm); B2 (645 nm, $\Delta\lambda=70$ nm); B3 (835 nm, $\Delta\lambda=110$ nm); SWIR (1165 nm, $\Delta\lambda=170$ nm). The stability of the platform, the accurate knowledge on its position and attitude and post processing of the images allow to achieve a multi-temporal registration accuracy around 200 m (rms). (Sylvander et al., 2003). The system and the corresponding products are described with more details in (Henry, 1999) and (Maisongrande et al., 2004).

The P products kindly copied from the archive stored at the VITO processing and archiving centre in Mol (Belgium) were used within this CYCLOPES project. *P* products are extracts of a segment along a single orbit. *P* products are geometrically and radiometrically corrected and correspond thus to top of atmosphere reflectance. These products are delivered under the lat–lon projection at 1/112° spatial resolution.

2.2. Radiometric calibration

CYCLOPES project was aimed at processing data from many sensors with consistent algorithms. The first step consists in obtaining a common calibration reference, thus giving priority to a cross calibration of sensors compared to an absolute calibration. Calibration over desert sites is well suited for this purpose because it provides large extent homogeneous areas to minimise misregistration, a temporal stability, low variability of the overlying atmosphere including low cloudiness, and reduced directional effects. Twenty areas, each larger than 100×100 km^2 in North Africa and Saudi Arabia corresponding to these criteria were selected (Cosnefroy et al., 1996). The POLDER instruments offering a very good characterisation of the site Bi-Directional Reflectance Factor (BRDF) in 8 spectral bands (443 nm to 910 nm) were used as the reference sensors. Each site observed by VEGETATION may be also observed by POLDER under very similar directional configuration. POLDER in-flight calibration has been thoroughly studied (Hagolle et al., 1999) and its accuracy is estimated better than 5% (3 sigma). POLDER 2 instrument was thus used here to cross-calibrate other sensors including VEGETATION. More details on the desert cross calibration method can be found in (Cabot et al., 2000; Hagolle et al., 1999).. However, for VEGETATION SWIR band, it is not possible to use POLDER as a reference since it has no spectral band in the SWIR domain. In this case, the reference sensor is VEGETATION 1 (Hagolle et al., 2004). Continuous monitoring of these desertic sites allows updating the original radiometric calibration coefficients by adjusting an