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GEOV1: LAI, FAPAR essential climate variables and FCOVER global time series capitalizing over existing products. Part 2: Validation and intercomparison with reference products

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ABSTRACT

This paper describes the scientific validation of the first version of global biophysical products (i.e., leaf area index, fraction of absorbed photosynthetically active radiation and fraction of vegetation cover), namely GEOV1, developed in the framework of the geoland-2/BioPar core mapping service at 1 km spatial resolution and 10-days temporal frequency. The strategy follows the recommendations of the CEOS/WGCV Land Product Validation for LAI global products validation. Several criteria of performance were evaluated, including continuity, spatial and temporal consistency, dynamic range of retrievals, statistical analysis per biome type, precision and accuracy. The spatial and temporal consistencies of GEOV1 products were assessed by intercomparison with reference global products (MODIS c5, CYCLOPES v3.1, GLOBCARBON v2 LAI, and JRC SeaWIFS FAPAR) over a global network of homogeneous sites (BELMANIP-2) during the 2003–2005 period. The accuracy of GEOV1 was evaluated against a number of available ground reference maps. Our results show that GEOV1 products present reliable spatial distribution, smooth temporal profiles which are stable from year to year, good dynamic range with reliable magnitude for bare areas and dense forests, and optimal performances with ground-based maps. GEOV1 outperforms the quality of reference global products in most of the examined criteria, and constitutes a step forward in the development of consistent and accurate global biophysical variables within the context of the land monitoring core service of GMES.

1. Introduction

Delivering validated remote sensing surface biophysical products associated to quantitative uncertainties is mandatory for efficiently using this source of information. The products should show a significant level of spatial and temporal consistency for mapping or monitoring the dynamics of vegetation characteristics. Further, these biophysical variables may be integrated with other sources of information within process models. The knowledge of the uncertainties attached to these remote sensing derived products would be exploited to weigh the contribution of this source of information as compared to other possible information including prior information on model parameters and variables, climate variables or soil properties.

The Land Product Validation sub-group (LPV) of the Working Group Cal/Val (WGCV) of the Committee on Earth Observing Satellite (CEOS) was established to define standard guidelines and protocols and to foster data relevant to the validation of land products, focused on the essential climate variables of the Global Terrestrial Observation System (GTOS) (Justice et al., 2000; Morisette et al., 2006). However, the validation is a difficult task for medium resolution global satellite products due to the large range of situations and variability in potential sources of error encountered on a global basis. In addition, the mismatch between the small spatial footprint of ground observations used for independent measurement of the targeted variables and the size of the medium resolution pixels further complicates the uncertainty assessment. Comparison with in-situ measurements (i.e. direct validation) allows quantifying the accuracy of the products. The comparison with ground data is achieved by scaling up the ground measurements using a high resolution imagery (ground sampling distance – GSD – around 20 m), which is later aggregated to the moderate resolution products (Morisette et al., 2006). However, the existing data sets are limited in time and space and, thus, are not representative of global conditions (Baret et al., 2006). The quantification of the spatial and temporal consistencies of the products allows providing estimates of the attached precision over a larger range of situations since this does not require concurrent ground measurements. Further, intercomparison with similar satellite products (i.e. indirect validation) allows analyzing the consistency among several satellite products over a large data set representative of global vegetation conditions and may also provide an independent way to build a community reference. Finally, benchmarking of remote sensing products is essential to identify and

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possibly resolve differences between products, leading to improvement in their accuracy and reliability (GCOS, 2010).

Previous validation activities of global remote sensing biophysical products showed that the seasonality of the products is generally consistent while major discrepancies are observed in terms of magnitude, which are in many situations beyond user's requirements (Camacho et al., 2006; Fang et al., 2012; Ganguly et al., 2008; Garcia-Haro et al., 2008; Garrigues et al., 2008a; McCallum et al., 2010; Weiss et al., 2007). These may be explained by the assumptions embedded in the retrieval algorithm and product definition, the sensor characteristics (spectral function and point spread function) and processing chain including radiometric calibration, geometrical correction, projection, water bodies, snow and cloud detection, and atmospheric correction or directional normalization. Different authors found that CYCLOPES v3.1 (Baret et al., 2007) and MODIS c5 (Knyazikhin et al., 1998) LAI and FAPAR products are the more consistent global products (Garrigues et al., 2008a; McCallum et al., 2010; Weiss et al., 2007). Both products have been widely validated, reaching the Stage 2 validation according to the CEOS hierarchical four-stage validation approach, and some authors have initiated the Stage 3 validation showing uncertainties in LAI around ± 1.0 (Fang et al., 2012). In summary, validation efforts showed that CYCLOPES products were found reliable for the lower vegetation values whereas an early saturation was observed in LAI (Weiss et al., 2007) and FCOVER (Camacho et al., 2006) products. Conversely, MODIS LAI/FAPAR products were found more reliable for the higher vegetation values, showing however an overestimation of the lower FAPAR values (Camacho et al., 2010; McCallum et al., 2010). Moreover, MODIS displayed noisy temporal retrievals and unrealistically strong temporal variations over some regions (Kobayashi et al., 2010).

The GEOV1 LAI, FAPAR and FCOVER products are derived from CYCLOPES v3.1 and MODIS c5 biophysical products based on their associated validation results (see details in the companion paper, Baret et al., 2013-this issue). The aim was to capitalize on the previous efforts spent on their development and validation, taking benefit of the better performances of each product while reducing their main drawbacks. GEOV1 products have been developed within the FP7 geoland2 project (http://www.gmes-geoland.info) aiming to implement the GMES (Global Monitoring for Environment and Security) land monitoring services. One component of the project, the BioPar core mapping service, is setting-up an operational system, fully validated, providing biophysical products at a range of scales relevant to a number of applications including forest and natural resources management, agri-environmental indicators, crop monitoring and food security, or carbon cycle diagnostic and prognostic description. All these applications require long-term global time series of vegetation variables (LAI, FAPAR, FCOVER and albedo) with typical target accuracy and stability (i.e., the extent to which accuracy remains constant with time) around 0.5 and 0.05 for LAI and FAPAR respectively (GCOS, 2006). For the FCOVER, the same accuracy and precision as for the FAPAR are expected.

In this context, the primary objectives of this paper are: (1) to validate the GEOV1 LAI, FAPAR and FCOVER biophysical products (Baret et al., 2013-this issue) by direct comparison with ground measurements processed according to CEOS/WGCV LPV recommendations (Morisette et al., 2006) that were mainly compiled in Garrigues et al. (2008a), (2) to evaluate the spatial and temporal consistencies of the GEOV1 products over large domains by intercomparison with reference products, and (3) to assess the added-value of GEOV1 regarding its two precursor products (CYCLOPES v3.1 and MODIS c5). For the intercomparison, two independent references were used: the GLOBCARBON v2 LAI (Deng et al., 2006) and the JRC SeaWiFS FAPAR (Gobron et al., 2006). This was partly achieved over the BELMANIP-2 (Benchmark Land Multisite Analysis and Intercomparison of Products) network of sites that aim to sample in a representative way the global variability of vegetation types (Baret et al., 2006) for the period 2003–2005.

The next section of this paper briefly describes each remote sensing biophysical product evaluated in this work, and the validation procedure is presented in Section 3. The results are discussed in Section 4, before giving conclusions in the last section.

2. Remote sensing vegetation products

In this section, we provide the main characteristics of the global remote sensing vegetation products investigated in this work. A summary with their main characteristics can be found in Table 1.

2.1. CYCLOPES

The CYCLOPES version 3.1 (http://postel.mediasfrance.org) is produced from the SPOT/VEGETATION sensor at 1/112° (about 1 km at the equator) spatial sampling distance and a 10-day temporal sampling, in a Plate Carrée projection, for the period 1999–2007 (Baret et al., 2007). The algorithm uses as input the red, near-infrared and short-wave infrared snow and cloud free reflectances (Hagolle et al., 2004) normalized to a standard geometry. The normalization is performed by inversion of a BRDF model (Roujean et al., 1992) over data accumulated during a 30-day compositing period. Products are estimated using a neural network trained from a coupled leaf (PROSPECT model; Jacquemoud & Baret, 1990) and canopy one-dimensional radiative transfer model (SAIL model; Verhoef, 1984) simulations without using any parameterization as a function of the biome. Clumping, i.e. heterogeneity in leaf area density distribution in the canopy volume, may occur at several scales as described in Garrigues et al. (2008a, 2008b). Clumping at the plant and canopy scale is not represented in the algorithm, but the landscape clumping is represented by considering mixed pixels made of a fraction of pure vegetation and a complement fraction of pure bare soil. Therefore, the LAI corresponds to an effective LAI rather than an actual LAI. Further, all the green elements in the canopy are considered, including stems when green and green background. The FAPAR is defined as the instantaneous black-sky FAPAR at 10:00 h, referring only to the green elements. The FCOVER is defined as the complementary to the gap fraction in the nadir view, considering also only the green elements. The CYCLOPES products are provided with the corresponding error estimate and a quality flag (only good quality outputs were used for this study).

Several authors assessed the merit of the CYCLOPES products by comparison with available ground truth maps and intercomparison with remote sensing products at a global scale (Fang et al., 2012; Ganguly et al., 2008; Garrigues et al., 2008a; Weiss et al., 2007) or over different regions (Camacho et al., 2006; Garcia-Haro et al., 2008; McCallum et al., 2010; Verger et al., 2009a). An early saturation of the LAI associated to the assumption of the RT model and the saturation of the signal, and an unreliable small dynamic range for the FCOVER with maximum values around 0.7 were the main limitations reported for the CYCLOPES v3.1 products.

2.2. MODIS

Terra MODIS LAI/FPAR (MOD15A2) collection 5, available since 2000 (https://lpdaac.usgs.gov/lpdaac/products/) is produced at 1 km ground sampling distance and 8 day frequency over a sinusoidal grid (Myneni et al., 2002; Yang et al., 2006a). The main algorithm is based on LUTs simulated from a three-dimensional radiative transfer model (Knyazikhin et al., 1998). The MODIS red and NIR atmospherically corrected reflectances (Vermote et al., 1997) and the corresponding illumination-view geometry is used as input of the LUTs. The output is the mean LAI/FAPAR computed over the set of acceptable LUT elements for which simulated and measured MODIS surface reflectances are within specified uncertainties. When the main algorithm fails, a backup solution based on LAI/FAPAR-NDVI relationships is used. In collection 5, parameters of both main and backup algorithms are defined for 8 vegetation types, and a new stochastic RT model was used to better