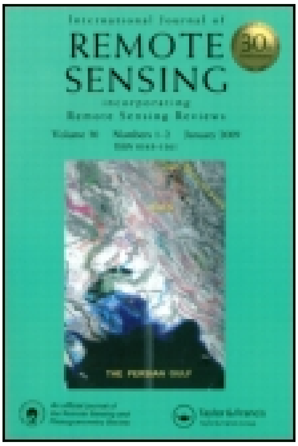

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SPOT-VEGETATION GEOV1 biophysical parameters in semi-arid agro-ecosystems

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The VEGETATION system, which has been delivering global observations of the surface on a daily basis since 1998, provides key information for regional to global climate, environmental and natural resource management applications. Just recently, VEGETATION-derived GEOV1 biophysical products (LAI, FAPAR, and FCOVER) became available for the scientific community and were evaluated in this study for semi-arid forests in the Dry Chaco ecoregion, Argentina. Indirect validation with the MODIS-derived biophysical products (MOD15A2) shows a very good temporal consistency between both products for the period 2000–2011, with a remarkably smooth behaviour of the GEOV1 products. A good relationship between both products was found in the regression analysis with an R^2 of 0.826 and 0.724 for LAI and FAPAR, respectively. Using direct validation with digital hemispherical photography (DHP) and ceptometer ground measurements, a relatively small RMSE ($RMSE_{LAI} \approx 0.31$ and $RMSE_{FAPAR} \approx 0.11$) was found. The novel PASTIS-57 technique, which can derive continuous plant area index (PAI) estimates from light transmittance measurements, shows a similar temporal profile to the GEOV1 LAI product with a relatively high but constant offset for the dry forest study sites and a nearly identical profile for the deforested site (R^2 = 0.86). Overall, PASTIS-57, in combination with satellite-based observations, shows potentials in LAI/PAI research and ecosystem carbon studies in general, but more ground measurements taken over multiple growing seasons and vegetation types are required to confirm these findings.

1. Introduction

In large parts of the world, livestock production is moving to marginal areas such as semi-arid ecosystems, characterized by low-precipitation regimes. The clearing of the dry forest in these areas, spurred mainly by its conversion to agricultural crops or pastures, reaches rates similar to or even higher than those found in tropical forests (Steininger et al. 2001; Zak, Cabido, and Hodgson 2004). Dry forests located in South America have been experiencing the highest deforestation rates over the last two decades (Miles et al. 2006). Traditionally, these forests were used for livestock grazing or wood extraction, but currently, a selective deforestation technique (removal of shrubs and small trees) is used to intensify livestock grazing and to grow irrigated agricultural crops or pastures. These land-use changes are expected to have a significant impact on the carbon and hydrological cycle and on the energy balance in general, at both local and regional scales (Pielke et al. 2002). Spatially and temporally consistent, long-term data on changes and

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trends in vegetation productivity are of great interest for the assessment of environmental conditions in semi-arid regions (Fensholt, Sandholt, and Rasmussen 2004). Low- and medium-resolution remote-sensing imagery has been providing such information on a global scale from the early 1980s onwards. Future programmes, such as the VIIRS, Sentinel 2/3, and PROBA-V missions, will ensure data continuity and trigger constant improvements in sensor, algorithm, and distribution capabilities.

Leaf area index (LAI) and the fraction of photosynthetically active radiation (FAPAR) absorbed by vegetation are identified by the Global Climate Observing System (GCOS) as essential climate variables to characterize ecosystems. LAI corresponds to half the total leaf area per unit of horizontal ground surface area (Chen and Black 1992). It determines the size of the plant–air interface for exchange of energy and matter and as such is a key variable in climate and land-surface models. Directly related to the vegetation primary productivity, FAPAR measures the radiation absorption capacity of the plant systems for photosynthesis, and thus biomass production (Di Bella et al. 2004). In recent years, a number of satellite products have been developed to estimate these biophysical variables at a global scale (MOD15A2 (Myneni et al. 2002), CYCLOPESv3 (Baret et al. 2007), GLOBCARBON (Deng et al. 2006), JRC-FAPAR (Baret et al. 2013), and GEOV1 (Gobron et al. 2006)). Inter-comparison and validation exercises demonstrate that some discrepancies exist between these products (Weiss et al. 2007 and Garrigues et al. 2008). Indeed, significant differences exist between algorithm designs: (i) CYCLOPES does not account for foliar clumping at a plant scale, providing an effective LAI, whereas MODIS is based on a 3-D model accounting for plant and foliar clumping. (ii) GLOBCARBON and MODIS LAI retrievals are land-cover dependent whereas CYCLOPES is not. An incorrect classification of the land cover could lead to differences of up to 50% in the LAI estimation (Myneni et al. 2002). The GEOV1 biophysical products, derived from VEGETATION (Baret et al. 2013) and targeted to leverage these different products, just recently became available, showing promising results for the LAI, FAPAR, and FCOVER products (Camacho et al. 2013).

In this research we investigated the ability of GEOV1 products to provide a time-series analysis of biophysical surface variables in semi-arid regions. The gathering of (continuous) ground measurement data during the 2011 growing season (Figure 2(*b*)) was emphasized for direct validation and for the analysis of the GEOV1 global data products.

2. Study area

The study area is located in the central part of the Argentinean semi-arid region. This area belongs to the Dry Chaco ecoregion, located between 28° and 33° S, and 68° and 66° W (Olson et al. 2001, Figure 1(*a*)). The climate is dry with a mean annual precipitation ranging from 350 to 650 mm from western to eastern areas, and a monthly average temperature ranging from 12°C to 28°C. This region is covered by a dry forest of medium height characterized by the presence of three vegetation layers: an upper layer formed by 3–5 m high trees, a middle shrubby layer of 1 m height on average, and a lower layer (understory) with grasses and herbaceous species (particularly summer growth cycle species). Woody plants more commonly associated with this ecoregion include quebracho (*Aspidosperma quebracho-blanco*) and algarrobo (*Prosopis* spp.). Three sites were selected to represent two major land-cover types present in the area: native forest and deforested areas (Figure 1(*b*)). These sites were quite homogeneous, allowing the building of a relatively simple sampling strategy. Inside each study site, three plots or elementary sampling units (ESUs) of about 20 × 20 m were identified.

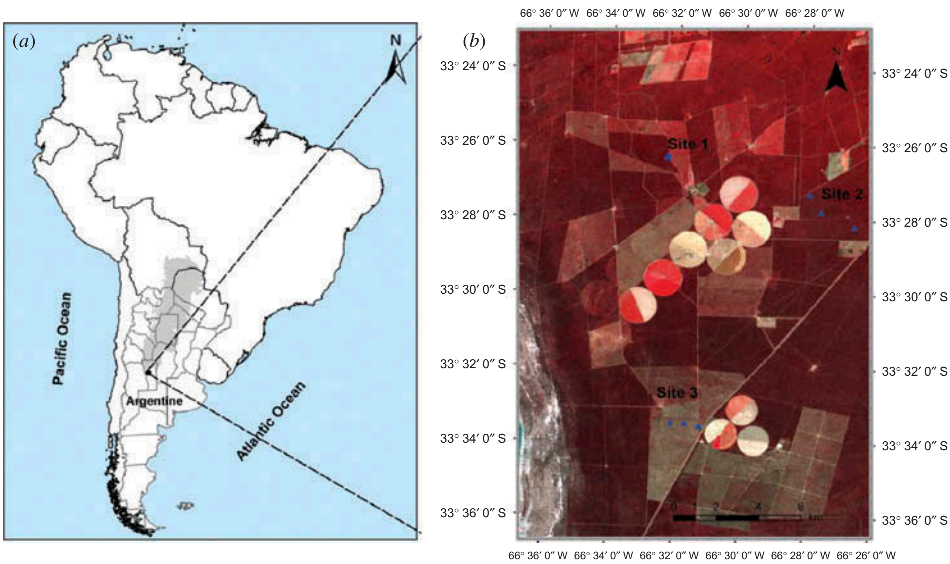


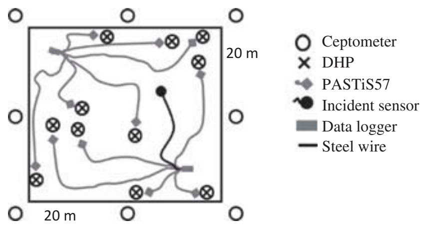
Figure 1. (*a*) South American Dry Chaco ecoregion (grey shaded area) and location of the study area in the Central San Luis province. (*b*) Zoomed view of study sites showing in false colour composite over Landsat TM image (NIR-SWIR-Red) of 5 April 2011, with an indication of the elementary sampling units (ESUs). Site 1 and site 2 are forested sites, and site 3 is deforested.

3. Ground data acquisition

3.1. General remarks

LAI and FAPAR can be measured using various methods as described in Jonckheere et al. (2004) and Garrigues et al. (2008), including direct and indirect, contact and non-contact methods. To validate moderate-resolution remote-sensing products, optical techniques are preferred since they allow larger spatial sampling and are non-destructive. As such, the whole vegetation cycle can be monitored. Optical indirect methods are based on the measurement of light transmission through the canopy, i.e. gap fraction (fraction of background/sky when looking downwards/upwards). Under the assumption of random spatial distribution of vegetation elements within the canopy, the gap fraction measured by optical techniques is related to the effective LAI (LAI_{eff}) by inverting the Poisson model (Weiss et al. 2004). However, generally vegetation elements are not randomly distributed owing to plant and canopy scale structure, and the deviation from the random case should be quantified through the clumping index (Chen and Black 1992). Compared with true LAI measured by direct methods, LAI_{eff} could lead to an underestimation or overestimation in cases of regularly or clumped distributed canopies (Chen, Menges, and Leblanc 2005). Additionally, it must be noticed that these techniques are based on light transmittance in the visible spectral domain, which includes the contribution of both green and non-green elements (branches, stem, trunks, and senescent leaves; Weiss et al. 2004). Thus, it is more straightforward to relate gap fraction to the alternative term plant area index (PAI) rather than LAI (Bréda 2003; Demarez et al. 2008; Baret, De Solan, et al. 2010). PAI was defined as the total developed area of all plant elements (independent of their photosynthetic potential) per unit horizontal ground area (Neumann, Den Hartog, and Shaw 1989; Baret, De Solan, et al. 2010).

(*a*)



(*b*)

Date	DHP	Ceptometer	PASTIS57
4 April 2011	X	X	X
6 June 2011	X		X
21 July 2011	X	X	X
5 October 2011	X	X	X
28 November 2011	X	X	X
Continuous logging			X

Figure 2. Ground measurements setup per ESU: spatial (*a*) and temporal (*b*) distribution of the 2011 field campaigns.

3.2. Ground data collection

Inside each ESU, three different techniques were applied following the sampling scheme described in Figure 2, consisting of randomly selecting 11 points within each 20 × 20 m ESU. All of these techniques are based on gap fraction measurements: DHP, ceptometer, and the novel PASTIS-57 technique (Baret, Lecerf, et al. 2010). The spatial variability was taken into account by averaging over the three ESUs sampled within each site.

The DHP technique uses a digital camera with a fish-eye objective to measure gap fraction over a wide range of viewing angles (Weiss et al. 2007). Using a professional camera, Nikon Coolpix 995, true-colour high-resolution images were taken 15 cm from the ground level, looking upwards, level and aligned with the magnetic south at the same location as the PASTIS-57 sensors. The camera was set to automatic exposure as recommended by Garrigues et al. (2006) to prevent saturation. Although the DHP technique can be performed under varying illumination conditions (direct and diffuse light; Garrigues et al. 2006), all DHP measurements were performed under similar conditions (morning and/or afternoon) over the same ESU and field campaigns. The images were processed using CAN-EYE software (www.avignon.inra.fr\can-eye) to derive actual PAI (true PAI) and FAPAR values. In the computation of the actual PAI, the leaf clumping is taking into account according to the method developed by Lang and Xiang (1986).

The ceptometer uses a line quantum sensor (Cavadevices, Buenos Aires, Argentina) that measures the photon flux between 300 and 1000 nm, and up to 3000 μmol m^{-2} s^{-1}, over a 1 m linear probe. FAPAR was estimated by measuring the incident PAR_i at the top of the canopy and PAR_t transmitted beneath the canopy, at the soil level. Based on these two measurements, FAPAR can be calculated as follows: FAPAR = 1 – PAR_t/PAR_i. Measurements were taken throughout the day.

PASTIS-57 (PAI Autonomous System from Transmittance Instantaneous Sensed from 57°) systems allow continuous monitoring of PAI (Baret, Lecerf, et al. 2010). Each system consists of six photodiodes that measure the light in the blue spectral domain (where the vegetation is almost black and multiple scattering is minimal) plugged into one logger that records data at a sampling rate of five minutes. Sensors positioned directly on the soil measure the light penetrating inside the canopy without interception by canopy elements, and at least one sensor located above the top of the canopy monitors the incoming solar radiation. All sensors were oriented to the south to avoid direct sunlight, and pointed to a zenithal angle of 57° to minimize leaf-angle distribution and plant clumping effects (Baret, De Solan, et al. 2010). PASTIS-57 data were acquired continuously during the vegetation cycle, whereas DHP and Ceptometer data were acquired during specific field campaigns along the vegetation cycle (Figure 2).

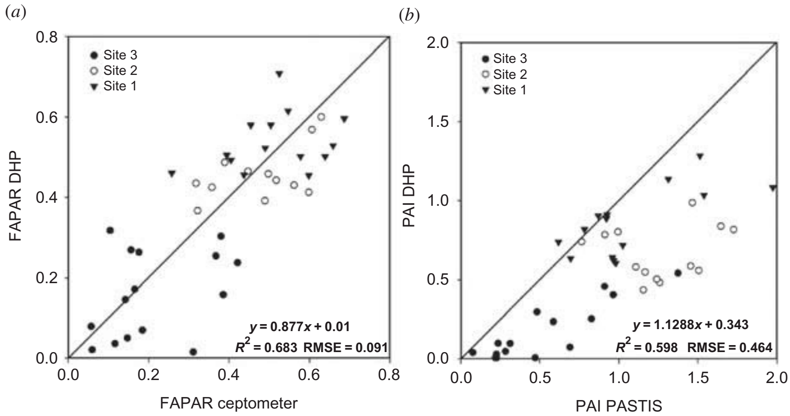


Figure 3. (*a*) Relationship between FAPAR values derived from ceptometer and DHP. (*b*) Relationship between PAI values derived from PASTIS57 and DHP.

3.3. *Ground data inter-comparison*

Analysing the data gathered over the three study sites, FAPAR values derived from DHP and the ceptometer presented a very good agreement (R^2 = 0.68) (Figure 3(*a*)). The major discrepancies are observed for the FAPAR values of site 3 (deforested site). This could be because of the differences in the sensor field of view (fish-eye lens and ceptometer) combined with the high heterogeneity of the deforested site at the ground level. Nevertheless, this result demonstrates that the spatial sampling schemes were well representative of the ESUs. More scattering is observed on the relationship between the PAI values derived from PASTIS-57 and DHPs (Figure 3(*b*)), although PAI data coming from PASTIS-57 are generally higher than PAI estimated from DHP. This overestimation of values derived from PASTIS-57 compared to DHP values can arise from the presence of senescent material such as fallen leaves or small branches lying on the bottom: it contributes to the reduction of light transmittance as measured by the PASTIS-57 systems, whereas the DHP images are generally taken 15 cm from the bottom layer and are less affected. This effect however needs to be further investigated.

3.4. *Homogeneity analysis*

To be able to extrapolate the ground measurements for direct validation of the 1 km-resolution GEOV1 products, a homogeneity analysis was performed on a cloudless Landsat image from 5 April 2011. This image was downloaded from the USGS Global Visualization Viewer Home Page (http://glovis.usgs.gov), radiometrically calibrated, and atmospherically corrected using the QUAC algorithm (Bernstein et al. 2005) implemented in ENVI/IDL. NDVI values were calculated to represent the vegetation status and extracted for the nine different ground measurement locations (three for each site). From these NDVI values, site average and standard deviation (σ) were calculated and compared with the values of the rest of the site, as specified by a 3 × 3 km area of interest. Figure 4 shows these local difference values per site and indicates whether these are higher than σ or 2σ compared with those of the ground measurement locations, indicated as triangles in Figure 4. On an individual (30 m) pixel level, 64%, 82%, and 80% of the pixels of, respectively, sites 1, 2, and 3 have an NDVI value within the 2σ interval and are

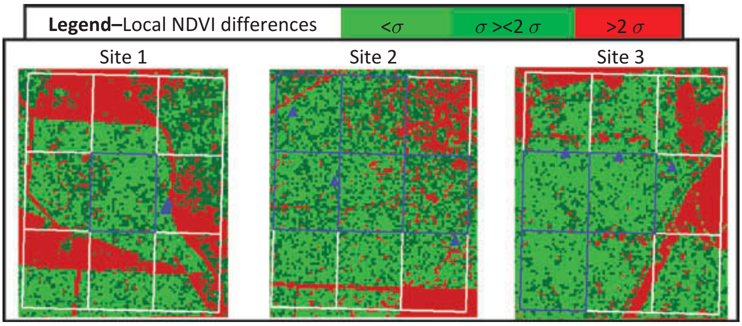


Figure 4. Visualization of NDVI differences with the ground measurement locations for the three sites (site 1, site 2, and site 3). Ground measurement locations are indicated as triangles. The geometric extent of the 1 km resolution GEOV1 pixels that are further considered for the validation is overlaid as blue rectangles.

considered homogeneous. When upscaling this homogeneity analysis to the GEOV1 pixel level, only those 1 km^2 pixel areas that include more than 90% of the homogeneous pixels will be further used for the GEOV1 product validation. These areas are indicated as blue rectangles in Figure 4 and should be well-representing the study site.

4. Biophysical parameters from GEOV1

4.1. VEGETATION and the GEOV1 algorithm

The SPOT-VEGETATION sensors, launched in 1998 and 2002, provide global observations of the surface on a daily basis. The four spectral bands (blue, red, near infrared, and shortwave infrared) are designed specifically to study plant ecosystems from a regional to a global scale. The system and the corresponding products have been described in more details by Henry (1999) and Maisongrande, Duchemin, and Dedieu (2004) and can be ordered online (http://www.vgt.vito.be).

The GEOV1 products (LAI, FAPAR, and FCOVER) are developed in the framework of the GEOLAND-2 European project, which addresses the local, continental, and global components of the GMES Land Monitoring Core Service (LMCS). They can be downloaded at http://www.geoland2.eu/. The GEOV1 (Baret et al. 2013) product algorithm is based on the current CYCLOPESv3 (Baret et al. 2007) and MOD15A2 (Myneni et al. 2002) biophysical products, leveraging their specific performances while limiting the situations where they show drawbacks (Baret et al. 2013). The selected products were re-projected on to the VEGETATION plate carrée 1/112° grid, smoothed through time, and interpolated on a 10 day frequency. Then the fused products were generated for 2003–2004 over the 445 BELMANIP2 set of sites representing the range of vegetation types and conditions observable on the Earth's surface (Baret et al. 2006). Neural networks were then calibrated over this set of sites to relate the fused products to the corresponding VEGETATION L3a top of canopy directionally normalized reflectance using the CYCLOPES preprocessing algorithms (Baret et al. 2007). This study focuses on the GEOV1 LAI and FAPAR products (Figure 5) since no FCOVER data was available from the ground measurements.

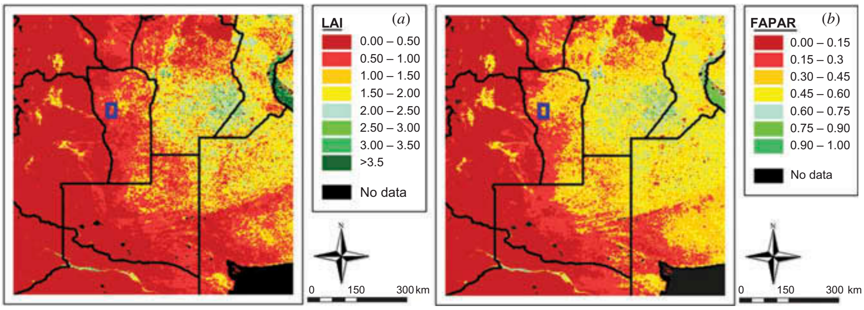


Figure 5. Extraction of the GEOV1 LAI (*a*) and FAPAR (*b*) products for the V12H11 tile (Central Argentina, January 2011). Location of the study area in the San Luis province is indicated as a blue rectangle.

4.2. Indirect validation

The GEOV1 LAI and FAPAR biophysical products were extracted for the period 2000–2011 over the studied sites, considering a spatial window of 3 × 3 pixels. The average GEOV1 LAI and FAPAR temporal profiles of site 3 (Figure 6) show a vegetation peak corresponding to the growing season in the first quarter of the year, at the end of the rainy season. The peak width highly fluctuates from year to year due to irregular rainfall. The vegetation decline occurs generally from March to September, at the end of the dry season. Then onwards, precipitation increases in scattered rainfall events, with an obvious increase in vegetation foliage. When considering specifically the end of 2010 and the beginning of 2011, one can observe a clear drop in the LAI and FAPAR peak values, corresponding to the period of deforestation completed over part of the site 3 study area. As grassland regrowth is fast after deforestation, the LAI and FAPAR recovered their nominal levels around the end of 2011.

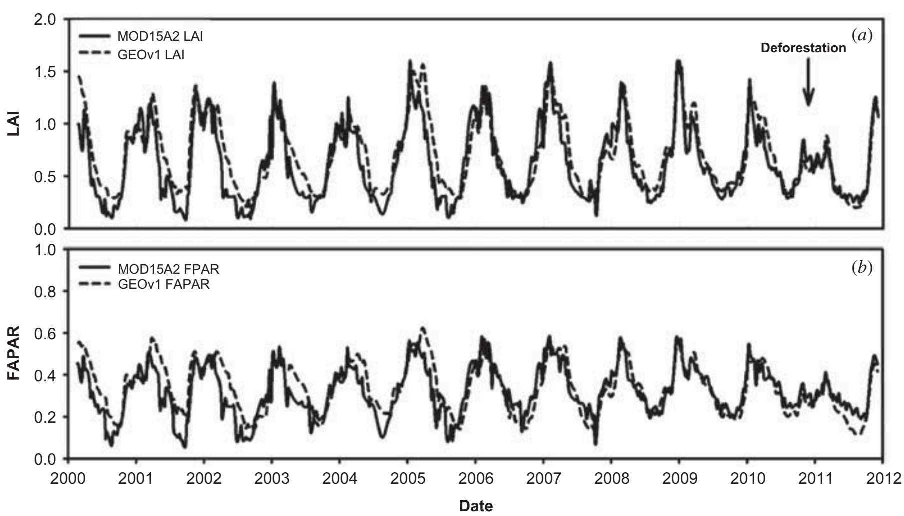


Figure 6. Comparison of the LAI (*a*) and FAPAR (*b*) estimates. VEGETATION (GEOV1) *versus* MODIS (MOD15A2) for site 3 during the period 2000–2011. This site was partly deforested in December 2010.

The GEOV1 products were further compared with the MOD15A2 products. To minimize the effects of geo-location errors and point spread function (PSF) deviations for both sensors, the average and standard deviations for a 3 × 3 km window around the central site location were calculated for both products.

The general vegetation cycle was found to run similarly for both products (Figure 6). The GEOV1 products tend to be smoother than those from MODIS. Similar findings were reported by Camacho et al. (2013) and can be explained by the use of a 30 day VEGETATION synthesis product to derive the GEOV1 products with a 10 day frequency. On the other hand, MOD15A2 is derived from maximum value compositing of daily MODIS imagery using an eight day period. Moreover, they include backup LAI estimates based on NDVI (normalized difference vegetation index) relationships, which tend to be less accurate (Yang et al. 2006.). The regression analysis between GEOV1 and MOD15A2 for the period 2000–2011 (Figure 7) shows that there is a consistent agreement between both products with an R^2 of 0.826 and 0.724 for LAI and FAPAR, respectively. These results are fairly lower than those reported by Camacho et al. (2013) who found a correlation of 0.89 and 0.92 for LAI and FAPAR respectively over the shrubland sites included in their DIRECT comparison database during 2003–2004. This difference can be related to (i) the fact that only a few DIRECT sites correspond to shrublands in 2003 and 2004, which are exclusively composited of low vegetation and poorly represent the vegetation type of our studied site, (ii) the design of GEOV1 products, which was learned on CYCLOPES products for low LAI values and, conversely to the MOD15A2 LAI product, does not take into account the canopy structure and clumping effect. This may not have a significant impact on shrublands similar to grasslands, but can lead to larger deviations for forested ecosystems. This emphasizes the need for more ground campaign experiments for sensor product validation.

4.3. *Validation of biophysical parameters*

The ground data acquired in 2011 for the three sites were used to evaluate the accuracy of the GEOV1 LAI and FAPAR products. As shown in the homogeneity analysis, the ground measurements only partially represent the site's 3 × 3 km main area of interest and as such

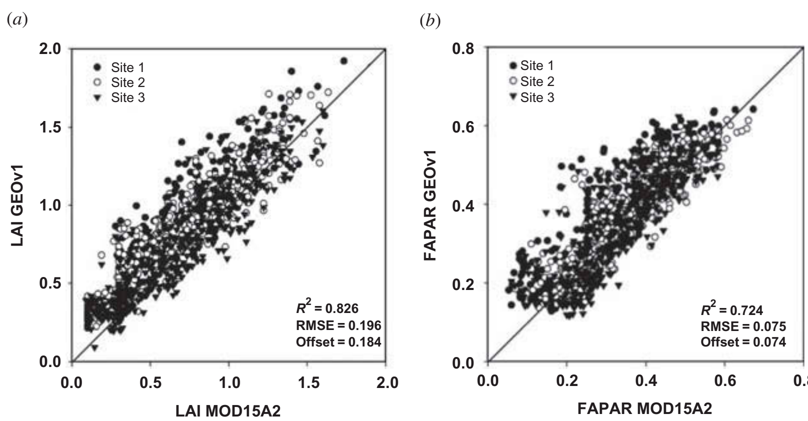


Figure 7. Regression analysis of LAI (*a*) and FAPAR (*b*) data from GEOV1 *versus* MOD15A2.

only the selection of GEOV1 pixels, as indicated in Figure 4 by the blue rectangles, was used further in the validation.

The GEOV1 LAI product was compared with the PASTIS-57 and DHP PAI measurements. The regression analysis shows that GEOV1 products are correlated with ground measurements with an R^2 of 0.61 and 0.35 for PASTIS-57 and DHP, respectively (Figures 8(*a*) and (*b*)). PAI estimates from PASTIS-57 ground measurements are somewhat higher than the GEOV1 LAI product values. This can be due to the amount of senescent vegetation captured by the photodiodes compared to GEOV1 LAI values, which are designed to be sensitive mainly to the green elements of the canopy. This effect is probably enhanced by the specific inclination of the sensors (57° zenith angle) from which more senescent parts are seen compared to more nadir observations. DHP LAI measurements appear to be less sensitive to this artefact since they are generally taken 15 cm from the bottom layer and are calculated from a hemispherical viewing geometry. The disagreement in the magnitude of PAI or LAI values between PASTIS-57 and GEOV1 products is further investigated based on the temporal dynamics of both signals (Figures 9 (*a*)–(*c*)). PASTIS-57 PAI values show a temporal pattern similar to that of the GEOV1 LAI product with an almost constant offset for the forested sites 1 and 2, in which the

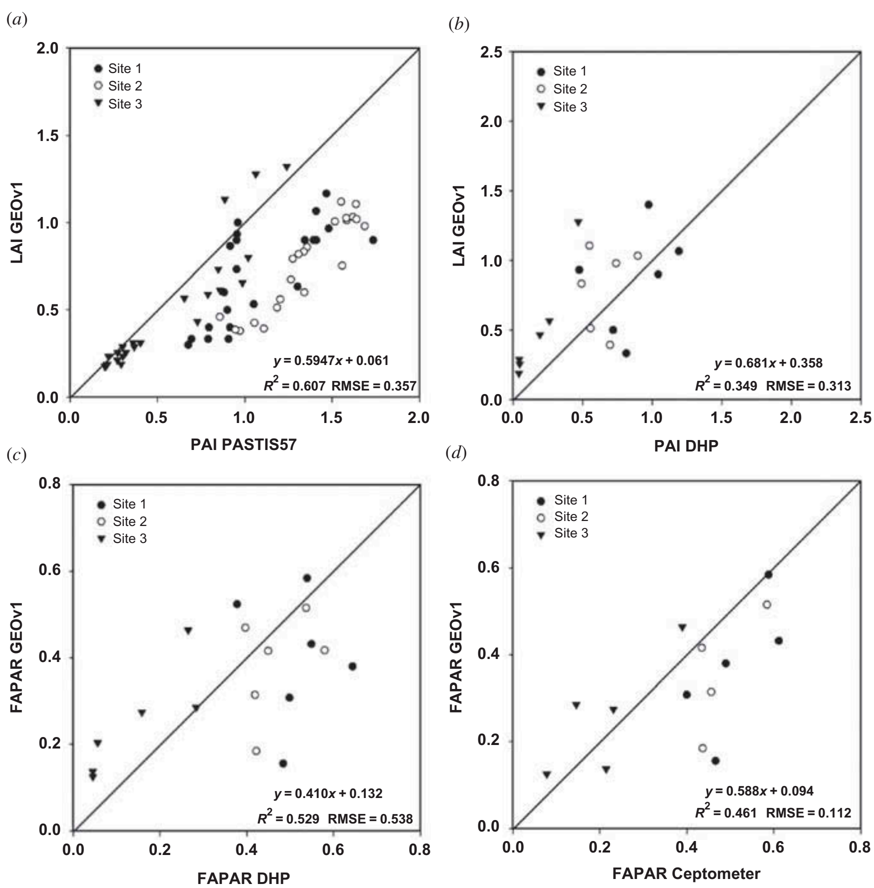


Figure 8. LAI and FAPAR: GEOV1 *versus* ground measurements for the three study areas – regression analysis.

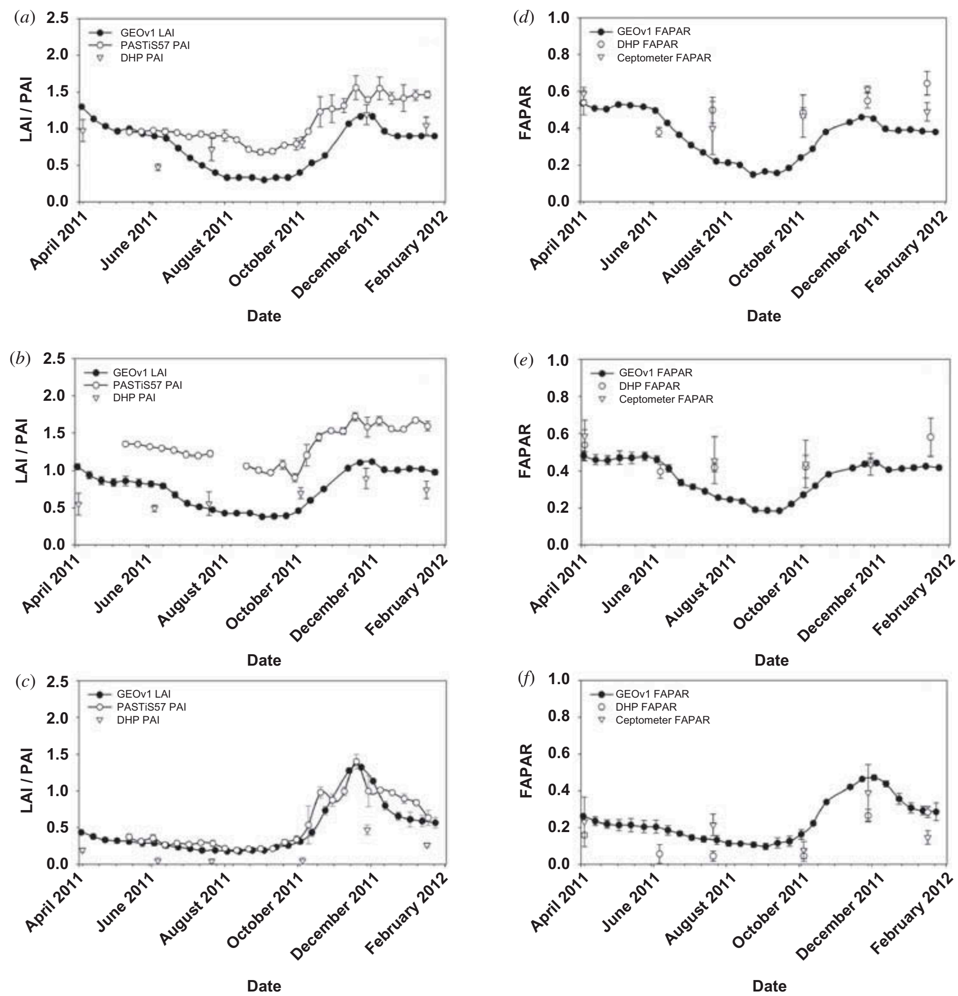


Figure 9. Dynamics of LAI or PAI (*a*), (*b*), (*c*) and FAPAR (*d*), (*e*), (*f*) from GEOV1 products and PASTIS-57, DHP, and ceptometer ground measurements for the forest sites 1 (*a*), (*d*) and 2 (*b*), (*e*) and the deforested site 3 (*c*), (*f*). The error bars correspond to the standard deviation computed across the individual measurements completed for each site.

amount of non-green material is large and relatively constant with time. The temporal profile for the deforested site 3 is, on the other hand, highly similar to the PASTIS 57 and GEOV1 values (Figure 9(*c*)) with low values during the dry winter and one vegetation peak in December. Compared with the forested sites, the amount of senescent plant material present on the bottom layer is low, which can explain the better relationship between GEOV1 and PASTIS-57 (R^2 = 0.86).

The PAI values estimated from DHP along the season did not show a systematic offset with the GEOV1 LAI product but rather some scatter around GEOV1 (Figures 9(*a*)–(*c*)). As noticed by Sprintsin et al. (2011), DHP does not appear optimal for PAI (upwards looking) or LAI (downwards looking) estimations in semi-arid forest stands because the images acquired with the fish-eye lens are complex, combining dry and green vegetation with some shadow effects, inducing uncertainties in the classification process required to compute green fraction (downwards looking) or gap fraction (upwards looking). The high temporal resolution of the PASTIS-57 data allows a more detailed analysis of the dynamics compared with other techniques such as DHP and LAI2000, which are more labour intensive.

The regression analysis in Figures 8(*c*) and (*d*) illustrates that there is a small but significant correlation between DHP and ceptometer FAPAR ground measurements and the corresponding GEOV1 FAPAR product with an R^2 of, respectively, 0.345 and 0.461. The data points are however well balanced around the 1:1 line, i.e. showing little bias. As expected, the dynamics observed on FAPAR (Figures 9(*d*)–(*f*)) is very consistent with that observed on LAI or PAI (Figures 9(*a*)–(*c*)). FAPAR values observed over the forest sites 1 and 2 do not show a clear FAPAR temporal pattern (Figures 9(*d*) and (*e*)), contrary to the GEOV1 product. For the deforested site 3, the vegetation peak is detected by both techniques (Figure 9(*f*)).

5. Conclusions

This study evaluated the potential of SPOT-VEGETATION-derived GEOV1 biophysical products to provide time-consistent biophysical surface variables for a semi-arid area in the dry Chaco ecoregion, Argentina. Comparison with the MOD15A2 products, over the period 2000–2011, shows a good agreement between both products with an R^2 of 0.826 (LAI) and 0.724 (FAPAR) and almost no bias. However, the GEOV1 products are smoother with time whereas the MOD15A2 products show more noisy temporal profiles. Similar instrument inter-comparison efforts on a wide variety of ecosystems are necessary to further evaluate the use of GEOV1 for global biophysical monitoring.

A large effort was put into the gathering of (continuous) ground measurement data for direct validation on two forested sites and one deforested site. For each of these study sites, three different techniques were applied including the novel PASTIS-57 technique, DHP, and ceptometer. PASTIS-57 uses photodiodes that measure the light in the blue spectral domain and has the ability to calculate PAI automatically over a long period of time with a high time sampling rate. A good agreement between the FAPAR values derived from DHPs and the ceptometer (R^2 = 0.68) was found, whereas PAI data arising from PASTIS-57 are generally higher than PAI data estimated from DHP. This over-estimation of values can be the result of the presence of senescent material such as fallen leaves or small branches lying on the bottom: it contributes to reduced light transmittance as measured by the PASTIS-57 systems, whereas the DHP images, owing to the camera and lens design, are generally taken 15 cm from the bottom layer. This effect however needs to be further investigated.

Comparison of these PASTIS-57 PAI measurements with the GEOV1 LAI products shows a similar temporal profile as the GEOV1 LAI product with a relatively high but constant offset for the dry forest study sites and a nearly identical profile for the deforested site (R^2 = 0.86). Overall, PASTIS-57, in combination with satellite-based observations, shows potentials in LAI/PAI research and ecosystem carbon studies in general; however, more ground measurements taken over multiple growing seasons and vegetation types are needed to confirm these findings. Specifically, the inclusion of non-green vegetation and senescent elements in light transmittance calculation should be further investigated and the PASTIS-57 data filtering and smoothing should be improved. Comparison with other techniques must also be conducted over other vegetation types and sites. The DHP and ceptometer-measured values are not consistent enough with time to exhibit a clear dynamics with regard to the GEOV1 products. This was owing to possible changes in illumination conditions from measurements to measurements (ceptometer) and the complexity of the hemispherical images showing a mixture of senescent and green elements. However, the differences found between the GEOV1 and DHP or ceptometer ground measured biophysical values ($RMSE_{LAI} \approx 0.3$ and $RMSE_{FAPAR} \approx 0.1$) are similar to or even better than those reported in the literature (Weiss et al. 2007; Garrigues et al. 2008; Ganguly et al. 2008; Sprintsin et al. 2011). More effort should be dedicated to defining unambiguous guidelines for ground measurements as undertaken by CEOS-LPV (Baret et al. 2009), especially in semi-arid regions, which are sensitive to small changes in vegetation leaf cover over time.

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