ABSTRACT

Assessing the regional vegetation dynamics in the Iberian Peninsula (IP) is a key issue in the context of the carbon cycle at the southern Europe ecosystems. The estimation of net ecosystem production (NEP) was conducted by a productivity ecosystem model, the Carnegie Ames Stanford Approach (CASA) model, based on MODIS fraction of absorbed photosynthetically active radiation (fAPAR) and leaf area index (LAI) products, being calibration supported by ten CO2 eddy covariance towers, under the CARBOEUROPE framework. This paper aims to evaluate the application of the CASA model to the IP, supported by MERIS data sets, namely the MERIS global vegetation index (MGVI). Firstly, a comparison analysis between fAPAR data sets from MODIS and MERIS was conducted, focusing the regional and the local scale for six biomes, and secondly an assessment between the NEP estimates derived from the two data sets was made. Main findings include a systematically higher MODIS than MERIS fAPAR data, and a seasonal dependence of the correlation between the two data sets, as well as the derived NEP estimations.

1. INTRODUCTION

Assessing the terrestrial carbon dynamics is a key issue in the context of the carbon cycle, where modelling ecosystem mass and energy fluxes present significant contributes. The Carnegie-Ames Stanford Approach (CASA) model has been applied for the Iberian Peninsula (IP), based on eight day composites of fraction of photosynthetically active radiation (fAPAR) and leaf area index (LAI) products from the Moderate Resolution Imaging Spectroradiometer (MODIS), on board the TERRA platform [1], available from [2]. Net ecosystem production (NEP) CASA estimates comparison with CO2 flux observations from multiple sites of the CARBOEUROPE Network has revealed confidence in model estimates, emphasizing the model’s structural robustness [3]. Since remote sensing data has been proved essential to support productivity models, due to its simultaneous spatial explicit nature and time availability, the authors intend to extend the knowledge acquired with the MODIS data set (from previous studies) to other sensor, with a potential higher spatial resolution. This paper aims to evaluate the application of the CASA model to the IP, supported by MERIS data sets, namely the MERIS global vegetation index (MGVI) [4, 5]. Production efficiency modelling for the IP based on MERIS data sets was approached by a two-step comparison analysis: (1) evaluation of MODIS and MERIS remote sensing vegetation biophysical properties, serving as model inputs; and (2) determining CASA parameter optimization results independently for both remote sensing products, for the Mitra site, a CARBOEUROPE site in Southern Portugal.

The availability of two independent products for fAPAR estimations derived from different sensors and algorithms, namely the ENVISAT’s MGVI[4, 5], and the NASA’s MODIS/fAPAR [1, 6], motivates the first-step analysis aiming the assessment of comparability of the two data sets for a similar purpose within the CASA model. Statistical analysis were conducted both at a regional level for the IP, and at a local level for selected biomes. The second-step analysis compares the CASA model parameter optimization and performance results from both data sets at site level. Furthermore, NEP, net primary production (NPP) and heterotrophic respiration (Rh) estimates are generated based on optimization results yielded from both datasets for a selected region. The results from similar biome areas surrounding the Mitra site are compared in terms of seasonal and spatial patterns for 2003.

2. THE CASA MODEL

The CASA model [7-9] was applied for the IP, being calibration supported by CO2 data from selected 10 eddy flux measurement towers, under the CARBOEUROPE network, representing Mediterranean climate or ecosystems present in the IP [3]. The CASA model is a production efficiency model that estimates NEP as the difference between NPP and Rh. NPP is derived from the product between absorbed photosynthetically active
radiation (APAR) and light use efficiency (ε) [10, 11], and Rh from a compartment-based carbon pools model (CENTURY [12]). The CASA model inputs include climate drivers, vegetation state and biophysical properties, as well as soil properties. The vegetation biophysical properties include the fraction of photosynthetically active radiation absorbed by vegetation (fAPAR), and the leaf area index (LAI). Previous CASA model optimization has been based on eight day composites of fAPAR and LAI products from the Moderate Resolution Imaging Spectroradiometer (MODIS), on board the TERRA platform. Aiming the elimination of underestimation fAPAR values and gap filling a Fourier wave adjustment filter was used [13]. The parameter optimization process focused on scalars governing both NPP and Rh calculations, such as temperature and water effects on vegetation and soil fluxes, as well as maximum light use efficiency [3]. Results suggest a robust model structure and statistically confident performance for the simulation of carbon fluxes at the ecosystem level through sites and different temporal resolutions. In the current study, analogous methods are used to compare MODIS FPAR and MERIS MGVI impacts in CASA performance for the Mitra site in 2003. The sole differences between CASA model MODIS and MERIS parameterization are the fAPAR datasets at weekly resolutions.

Figure 1 – NEP observations versus simulations after model parameter optimization.

Model optimization results invariably show realistic model parameters, although stress scalars can show significant differences between both optimizations. Parameterization differences are a direct consequence of different seasonal cycle between both products, to which data driven methods tend to be more sensitive to. Model performance results show statistically significant (p < 0.01) correlations between MODIS and MERIS NEP simulations and CO2 eddy covariance observations (Table 1).

Table 1 – Performance indicators for the different model parameterizations: MERIS and MODIS against observations for Mitra (MEF – modelling efficiency; RMSE – root mean square error) [14].

<table>
<thead>
<tr>
<th>Performance Indicator</th>
<th>Sensor</th>
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<tbody>
<tr>
<td>r²</td>
<td>MODIS</td>
</tr>
<tr>
<td>0.813</td>
<td>0.778</td>
</tr>
<tr>
<td>MEF</td>
<td>0.812</td>
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<tr>
<td>RMSE</td>
<td>2.610</td>
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</table>

Although r² results are fairly similar, further analysis reveals better performance in relation to the 1:1 line (higher MEF) and lower errors in MODIS NEP simulations. In this case, MODIS FPAR shows a better applicability to the carbon fluxes simulation for savannah structural type ecosystem. These results are inconclusive about the overall confidence of each dataset against the other since generalization is unadvised when a unique study case is considered. Nevertheless, the discrepancy between performance differences in r² and MEF and RMSE reflect the non-linear nature of the parameterization method and CASA model structure as well as its sensitivity to differences in fAPAR inputs. Being CASA’s structure for NPP calculations similar to any production efficiency model based in the Monteith’s method [10, 11] the importance of fAPAR data in model-data driven NEP estimation methods is thus emphasised.

3. MERIS / MODIS FAPAR ANALYSIS

The comparative analysis was performed between the two data sets (Tab. 1) that serve as inputs for the CASA model, with a view of identifying and assessing the similarity of its values and spatial coherence.

Table 1: Data sets characteristics

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Platform</th>
<th>Time series</th>
<th>Temporal resolution</th>
<th>Spatial resolution</th>
<th>Pre-processing</th>
</tr>
</thead>
<tbody>
<tr>
<td>MGV1</td>
<td>ENVISAT</td>
<td>2003</td>
<td>weekly</td>
<td>1.2km</td>
<td>Flag evaluation; monthly composites [17]</td>
</tr>
<tr>
<td>FPAR</td>
<td>TERRA</td>
<td>2003</td>
<td>weekly; monthly</td>
<td>1km</td>
<td>Flag evaluation [18]</td>
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3.1. Regional Analysis

Statistical analysis of the two data sets for the Iberian Peninsula region reveals that the FPAR estimations from MODIS are systematically higher than from MERIS, as observed in Fig. 1. This observation persists seasonally as illustrated in Fig 2.

Moreover, the FAPAR data variability is higher for MODIS, as shown in Fig. 2 and in the Taylor plot [19], in Fig.3, where the ratio between the standard deviations between MERIS and MODIS is below 1. Pearson correlation between the data sets follows a seasonal pattern as shown at the Taylor plot, where similarities between datasets increase at summer period ($R^2=0.70$) and decrease at winter ($R^2=0.40$), being spring / autumn transitional stages.

Figure 1: MODIS/FAPAR and MERIS/MGVI for the Iberia Peninsula for January

Regional analysis also looked at the location of high and low spot values, through location of quartiles. A general agreement in the location of high and low spot values occur, whereas a visible differences at Northwest of the Peninsula, where MERIS detect higher frequencies of low values.

Figure 2: Box plots of monthly MERIS/MGVI (upper) and MODIS/FPAR (lower) for the year 2003.

Figure 3: Taylor plot of MODIS versus MERIS FAPAR data. MERIS standard deviation values ($s(MERIS)$) are divided by $s(MODIS)$.

Figure 4: Quartiles location for MERIS/MGVI (upper) and MODIS/FPAR (lower)

3.2. Local Analysis

In depth analysis between the two data sets was conducted for each season focusing on selected biomes. Since the MODIS fAPAR algorithm is land cover dependent, and aiming to minimize bad parameterization issues, the CORINE land cover [20] served the purpose of validating MODIS land cover (MOD12Q1, 1km) areas for each of the six biomes considered in the referred algorithm. The procedure involved the conversion of CORINE land cover classes to the MODIS land cover biomes through a non-exclusive cross walking, based on frequency analysis of dominant classes assuming likely fAPAR biomes characteristics [21]. The selected 6 biomes include: 1– GCC (Grasses & Cereal Crops), 2 – SHR (Shrubs), 3 – BCR (Broadleaf Crops), 4 – SAV (Savannah), 5 – BLF (Broadleaf Forest), and 6 – NLF (Needle leaf Forest). Patch selection over the IP territory took into account the following criteria: North vs. South
to accommodate climate differences, spatial contiguity, and a minimum area of 1000 km². The location of samples where MODIS/FAPAR and MERIS/MGVI were taken for local analysis is shown in Fig. 5. This analysis relies on 48 samples (6 biomes*4 seasons* North & South) for each sensor data set.

As observed for the regional scale, both products values distribution (Fig. 6) reveal that MODIS/fAPAR values are systematically higher than MERIS/MGVI, and with higher variability (standard deviation), for every 6 biomes, being this difference wider for the case of savannah.

The spatial structure of both data sets was assessed through geostatistical methods. Fig. 7 shows the variograms for winter time for savannah samples at north and south. Variograms show a high spatial homogeneity for MERIS FAPAR data, in opposite to MODIS data characterized by a higher spatial continuity, mainly at south. MODIS also capture higher local randomness, since the nugget effect is usually high. Therefore, differences concerning the structure of the spatial variability, between both datasets were identified.

4. MERIS VERSUS MODIS NEP ESTIMATES

In order to compare the impacts of CASA parameterization results extrapolation to Mitra-like ecosystems, simulations were performed for all savannah type pixels within a 20 by 20 km window around Mitra. Per pixel, except for fAPAR time series, all other datasets were stated equal, ensuring MODIS and MERIS fAPAR datasets were only causes of differences between CASA model estimates. A significant correlation is found between both MODIS and MERIS NPP ($r^2$: 0.83) and NEP ($r^2$: 0.84) estimates (Fig. 8). Despite model parameter optimization, MODIS and MERIS NEP and NPP results still tend to reflect the differences between MODIS and MERIS FAPAR, presenting a negative relative mean bias of 36% and 33%, respectively.

Although a significantly confident spatial-temporal correlation was found between both MODIS and MERIS NEP and NPP estimates, there were found to be strongly seasonally dependence. The seasonality of this relationship is found both in optimized and not optimized
model simulations, reflecting the fAPAR from MERIS and MODIS. This analysis reveals an increase in similarity between both MERIS and MODIS flux results populations at the expense of the intra-annual NPP/NEP ranges. The low spatial correlation per time step considered is translated by low $r$ values, especially in the winter periods, as referred before (section 3.1.).

Although the results show a higher similarity between the variability of NPP estimated from MODIS and MERIS fAPAR products (the ratio between standard deviations is located closer to unity) its seasonality is still observed (Fig. 10 – top). The NEP comparisons reveal significant seasonally dependent dissimilarities between simulations (Fig. 10 – bottom), resulting from the integration of NPP and Rh estimates. Rh parameterization is affected by changes in fAPAR time series in a non-linear fashion, since carbon pools in the soil are supplied by NPP transfers from the vegetation to the soil pools [8, 9]. The increase in the ratio between MERIS NPP and MODIS NPP standard deviation ratio is a direct consequence of the parameterization. In non optimized results the same temporal behaviour is observed although MERIS NPP standard deviation is constantly lower than MODIS'. In both optimized and non-optimized simulations, NEP shows the highest seasonal differences in the Taylor plots, reflecting the propagation of seasonal spatial differences in NPP and Rh caused by these two fAPAR time series.

### 5. CONCLUSIONS

The present exercise intends to evaluate the impact of two independent fAPAR data sets into CASA model results. Two approaches were adopted to analyse the data sets: the regional scale, and the local scale, considering 6 biomes. Main findings include: (i) MODIS/fAPAR values systematically higher than MERIS/MGVI, and with higher variability, for every 6 biomes; (ii) a general agreement in the location of high and low spot values, except for a northwest region of the Peninsula, (iii) a seasonal pattern of the correlation between the two data sets, with Summer ($r^2 >0.70$), and (iv) MERIS/MGVI data characterized by a consistent spatial homogeneity while MODIS/FPAR by a higher local randomness. Concerning CASA model estimates, it was found that both data sets produces reasonable NEP estimates, at the pixel level, after parameters optimization. Modelling results for a savannah patch of 400 km$^2$, shows significant correlations between MODIS and MERIS NEP estimates, although varying seasonally along the year.
The current results suggest that the MODIS and MERIS fAPAR differences can be minimized in biophysical modelling though model re-parameterization although this will not solve for the seasonal dependence error found in the original datasets. The observed differences between both datasets may be useful in constraining model estimates at regional scales. Nevertheless, due to its impacts at the ecosystem level on studies focusing process analysis, we consider these differences of major importance. Therefore, further analysis should be conducted in order to identify and explain the seasonality on the differences of NEP estimations, resulting from the use of the two independent fAPAR datasets.

6. REFERENCES