

QPhenoMetrics GIS application - an improvement

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Abstract: Evaluating and monitoring the dynamics of vegetation phenology is relevant to support several decisions in farming practices and ecosystems. A GIS open source application was already developed by the authors, QPhenoMetrics, in order to estimate vegetation phenology metrics. The vegetation indices most commonly used are the Normalized Difference Vegetation Index (NDVI) and the Enhanced Vegetation Index (EVI). NDVI or EVI values are estimated using a specific fitting method (Delayed Moving Average with 3 points (DMA3), Delayed Moving Average with 5 points (DMA5), Piecewise, Spline, Savitzky-Golay or Ensemble method). The application was developed and prepared to interpret Moderate Imaging Spectroradiometer (MODIS) data. In this work an improvement of QPhenoMetrics application is presented considering the possibility to process and interpret Sentinel-2 data. To evaluate this improvement, a municipality land included in “Serras do Porto” and Valongo’s Nature 2000 Network was considered. The results obtained for Sentinel-2A data were compared with the results obtained for MODIS. This improved version is an open source tool which could be modifiable by the users according to the specific study requirements.

1. Introduction

Geographic Information Systems (GIS) have been relevant in ecology studies. GIS software allows to perform analyses, evaluate the ecosystems and create natural resources management projects (Campo 2012; Larsen 1999). GIS allows to perform ecology studies at different levels of extension and with an accurate analysis (Pereira and Fonseca 2009). Forest resources management is one of the main application areas where GIS can be used. GIS capacities allows to interpret and study the complexity of ecosystems such as the forests (Batchelor 2013, Warnecke et al. 2002). GIS can also be used to evaluate and obtain information about soil types and land use land cover (LULC) (Batchelor 2013). In fact, GIS combined with remote sensing data can lead to the creation of decision plans in order to evaluate the ecosystem conditions particularly in hydrologic resources conditions land cover, biologic and geologic resources cartography (Reddy 2008). In Portugal, one of the dominant species is *Eucalyptus globulus*. This specie is characterized by a large tree trunk, with faster growing, great plasticity and adaptability to different sites (Australian National Botanic Gardens 2011). *Eucalyptus globulus* is one of the most widely planted species in Portugal, given the economic importance (Águas et al., 2014; Maia et al., 2014). In fact, Portugal is the country with the largest areas of planted eucalyptus in the world (Águas et al., 2014). This specie is also one of the contributor to the fires occurrence in Portugal which has severe consequences on biological productivity and negative impacts in ecosystems. Forest management based on sustainability is fundamental in natural or cultivated forests. Nowadays, the concept of sustainable forest management is the base of forests and the practices associated to them (Köhl and Rametsteiner 2007; MCPFE 2003). To the conservation of natural resources, an adequate characterization and understanding of the land cover includes the study of its dynamics (Adamio et al., 2018). So, vegetation dynamics study can provide valuable information to understand the ecosystem behaviour and other purposes such as, climate change or biodiversity conservation (Adami et al., 2018; Duarte et al., 2018). Several tools allow to study the vegetation dynamics such as Software for the Processing and Interpretation of Remotely Sensed Image Time Series -Spirits (Eerens et al., 2014) and TimeSat (Tan et al., 2011). For instance, Gouveia et al. (2010) used VEGETATION sensor on-board of SPOTs 4 and 5 satellites NDVI product to identify burned scars and to monitoring the vegetation recovery in post-fire episodes. MODIS NDVI time-series have also been used to monitoring eucalyptus plantation biomass (Maire et al., 2011; Maire et al., 2014; Gouveia et al., 2010). According to Qiao et al. (2016), the eucalyptus temporal signature is relatively stable during four to six years, called a growth rotation. In a rotation, the eucalyptus reaches the peak around January until June, then the wood is harvested, and the rest of the tree is burned. The land rest for a time and several months later, new eucalyptus trees are planted. The growth is rapid during the first year and remain with high NDVI values for several years (Qiao et al., 2016). Duarte et al. (2018) developed a GIS open source application, under QGIS software, named QPhenoMetrics, which allows to compute vegetation phenology metrics based on MODIS NDVI and EVI products. QPhenoMetrics incorporates six fitting methods: Delayed Moving Average (3 points; DMA3), Delayed Moving Average (5 points; DMA5), Piecewise Regression, Spline, Savitzky Golay and Ensemble method. The main objective of this work was to improve the QPhenoMetrics application with the possibility of process Sentinel-2 images. In order to test the improved version, the municipal lands included in “Serras do Porto” and Valongo’s Nature 2000 Network, were used to study the dynamics of the eucalyptus. Given the fire issues and the concentration of eucalyptus trees in Portugal, this study can help to interpret the eucalyptus behaviour in “Serras do Porto”. The results obtained with Sentinel-2A images were compared with the results obtained with MODIS images for the same time period.

2. Study area and dataset

The study area considered in this project was the municipal lands included in “Serras do Porto” and Valongo’s Nature 2000 network (Figure 1). For decades this area was extensively explored with plantations of eucalyptus in order to produce cellulose for paper industry.

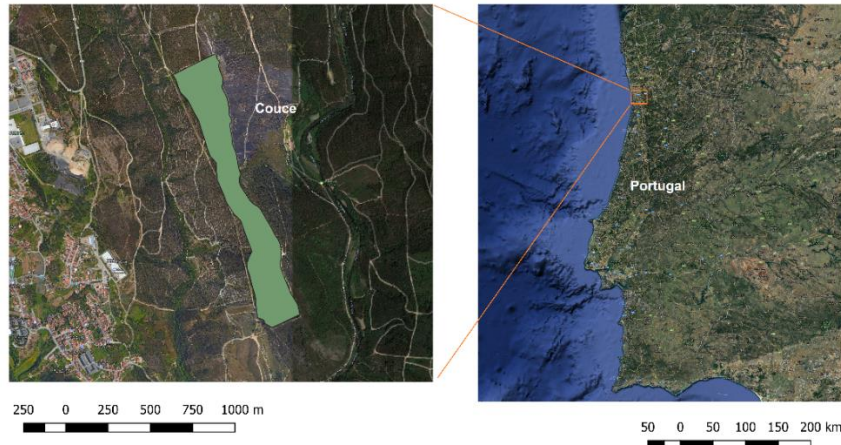


Figura 1 – Study area location.

Twenty-three Sentinel-2A images obtained through Copernicus Open Access Hub, from ESA (<https://scihub.copernicus.eu/dhus/#/home>) between 4th June 2017 and 21st March 2018 with 0 to 10% of cloud cover were used. The images were already atmospherically corrected. To use the QPhenoMetrics application, a Region Of Interest (ROI) must be defined in order to restrict the Sentinel images to the study zone. The ROI window allows to define the longitude and latitude of the centroid (8°29'27.06" W; 41°9'23.94" N), along with the width (840 meters) and the height of the study zone (1600 meters). MODIS images were also used, considering the 16-day temporal interval and 250 meters of spatial resolution of MODIS Terra and MODIS Aqua products (MOD13Q1 and MYD13Q1). Given the fact that MODIS Terra and Aqua satellites are identical, the temporal resolution can be improved using both, Terra and Aqua, simultaneously. The temporal window considered was from 3rd June 2017 until 31st March 2018, in a total of 39 images.

3. Methodology

3.1 QPhenoMetrics

The first version of QPhenoMetrics reads and interpret input data in three different modes: (1) a folder with MODIS images; (2) a text file; (3) an ASCII file with NDVI values already available. It allows the pre-processing of vegetation indices time-series and posterior regression and computation of the phenology metrics based on the six fitting methods: DMA3, DMA5, Piecewise, Spline, Savitzky Golay and Ensemble method (Duarte et al., 2018).

3.2 QPhenoMetrics improved

In the QPhenoMetrics improved tool, a new parameter of choice was added – *Satellite* – with two options: MODIS or Sentinel (Figure 2). In the first version this option was not available, since it only allows to read MODIS data. For that, a combo box was implemented.

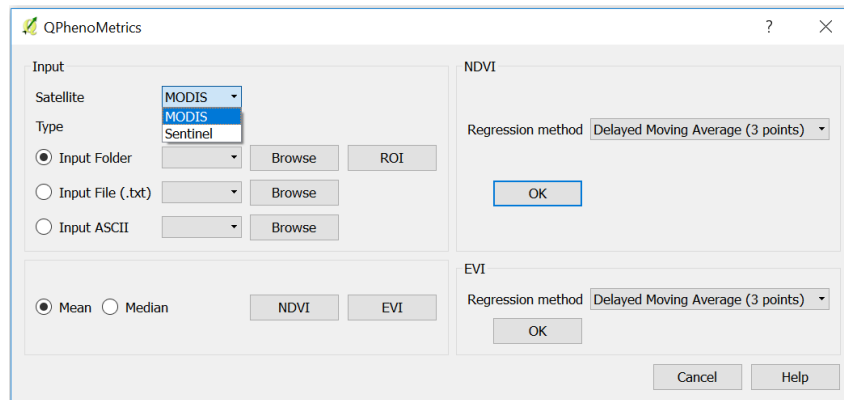


Figura 2 – Graphic interface of improved QPhenoMetrics.

In the code developed of the improved tool, the function *inputValues_ndvi*, belonging to *NDVI* class, was improved with a conditional *if* to connect to the combo box choice. In the case of MODIS images, the application reads each image and process them. In the case of Sentinel-2A images, as they are delivered in a *zip* file with a specific structure of folders, the code was improved in order to interpret the file structure and read the images.

In order to extract the *zip* files and extract automatically the bands, several procedures were incorporated in the application. The *extractall* function from *zipfile* module from Python library was used to extract all the *zip* files present in the folder (Python, 2018). Given the fact that exist more than one folder inside the *zip* file, and the bands of interest are located in *GRANULE* folder, a filter was applied to obtain the *.jp2* extension (the extension of the bands). A list with the name of the bands abbreviated (for instance *AOT* and *B02_10m*) were then created. With this configuration, each image is composed by seven files. It was necessary to distinguish between them, so a *for* loop in steps of 7 was created to run in one file of each image and get the date and time from the file name. Also, in this loop, the differentiation between the vegetation species are performed: *vineyard*, *maize* or *other*. The same procedure was applied to the MODIS images: a temporary folder is created, then a *while* loop was created in order to run through multiple of 7 values, so the vegetation indices were calculated for each image at a time (considering the fact that each image is composed by seven bands in *GRANULE* folder). In the *while* loop, the ROI was identified, and if it exists, the same procedure performed to MODIS images were defined: the individual bands are clipped with the extension defined by the user (ROI). The next step comprised the NDVI calculation. According to Reed et al. (1994), NDVI is estimated as equation 1:

$$NDVI = (NIR + RED)/(NIR - RED) \quad (1)$$

Where NIR is the near-infrared reflectance and RED the red reflectance. Compared to MODIS NDVI product, where NDVI is automatically provided, in the case of Sentinel-2A images, the NDVI must be estimated. This estimation is also performed inside the *while* loop, so it is recorded for each image. First, the image corresponding to each band is founded based on the name of the image (for instance, if the band has *B04* in the name, it corresponds to band 4 of Sentinel image). To calculate the NDVI image, a new function was created – *sentinelNDVI* – with band 4, band 8 and output band as input parameters. In this function, the NDVI map is created through *Raster Calculator* algorithm from SAGA library (SAGA, 2018). The function returns the final result to the *while* loop, where the NDVI values are read and a new function is called – *stats_values* – which allows to estimate the statistics of the raster NDVI values. This function incorporates eight statistics: average, median, standard deviation, coefficient of variation, quartile 25, quartile 75, interquartile range, and amplitude. The final values are returned by the function and recorded in a text file – *Mean_NDVI.txt* – along with the respective date of the image. This procedure is performed in all images and the final text file is obtained based on the statistics of each image processed.

4. Results

4.1 Sentinel-2A

The QPhenoMetrics improved application was used to process the 23 Sentinel-2A images. A text file was obtained with the NDVI values and the statistics provided by QPhenoMetrics improved version. The text file was used again as input in the

application in order to obtain the plots and study the behavior of eucalyptus. The NDVI values estimated in the time period defined varies between 0.500 and 0.535, and 4 outliers identified and removed. The outliers are identified as values less than $m=Q1-1.5\times(Q3-Q1)$ or larger than $M=Q3+1.5\times(Q3-Q1)$, where Q1 and Q3 are respectively the first and third quartiles. DMA3, DMA5, Spline and Savitzky Golay methods were tested. The phenological metrics were difficult to interpret due to the regular behavior of eucalyptus. Figure 3 presents the results obtained with the different methods. The blue dots correspond to the original NDVI values for each image, resulting from an average. The red dots and red lines corresponds to the fitting result according to the method applied. According to Qiao et al. (2016) the eucalyptus trees remain with high NDVI values for several years, so the temporal resolution used in this study is limited regarding the temporal resolution.

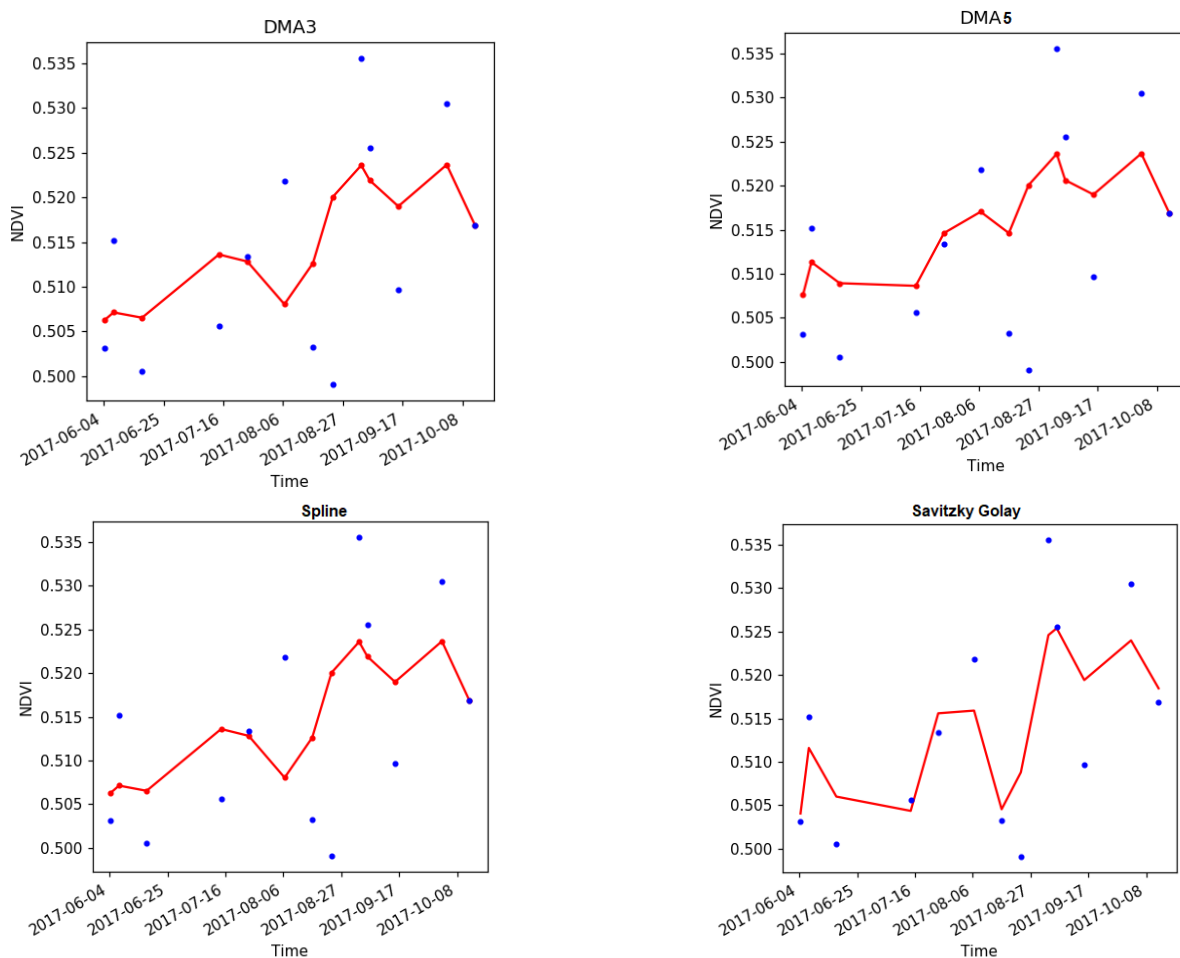


Figura 3 – Sentinel-2A NDVI profiles.

An extraction of the statistics of Sentinel-2A images obtained with the improved QPhenoMetrics are presented in Table 1.

Table 1– Statistics obtained with QPhenoMetrics improved application for Sentinel-2^a images (extraction)

Dates	Average	Median	Standard Deviation	Coef_Variation	Quartil 25	Quartil 75	Interquartil	Amplitude
04-06-17	0.5	0.5	0.2	45.2	0.3	0.7	0.4	0.9
07-06-17	0.5	0.5	0.2	44.4	0.3	0.7	0.4	0.9
17-06-17	0.5	0.5	0.2	42.4	0.3	0.7	0.4	0.8

14-07-17	0.5	0.5	0.2	41.3	0.3	0.7	0.4	0.9
24-07-17	0.5	0.5	0.2	42.3	0.3	0.7	0.4	0.9
06-08-17	0.5	0.5	0.2	34.9	0.4	0.7	0.3	0.8
16-08-17	0.5	0.5	0.2	35.5	0.4	0.6	0.3	0.8
23-08-17	0.5	0.5	0.2	34.2	0.4	0.6	0.3	0.8
02-09-17	0.5	0.5	0.2	31.7	0.4	0.7	0.3	0.8

4.2 MODIS

The same procedure was followed using MODIS images. One outlier was identified considering the same method above described. The results obtained presents a well-defined curve with values varying between 0.424 and 0.681 approximately (Figure 4).

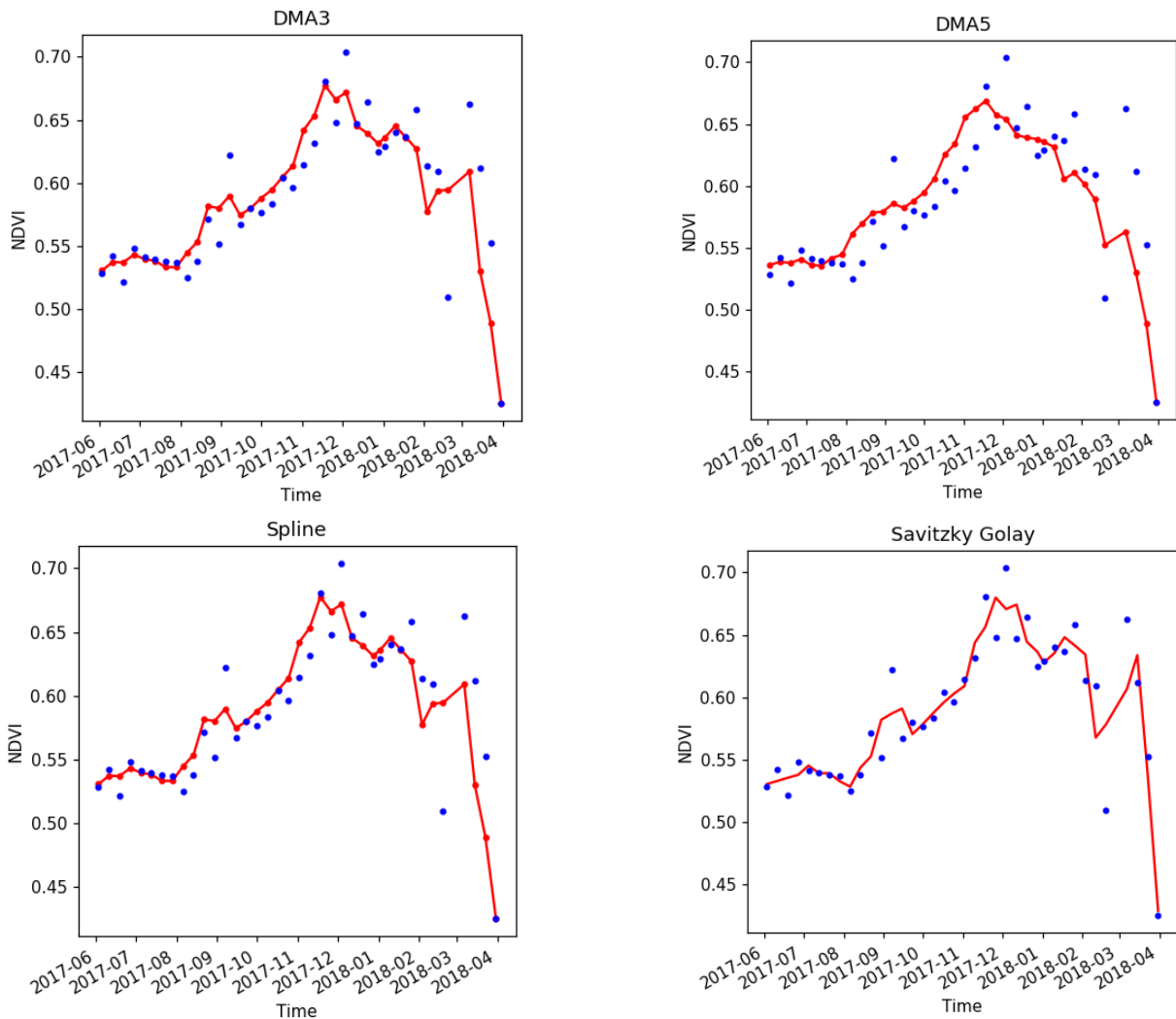


Figura 4 – MODIS NDVI profiles.

5. Discussion and Conclusions

From the results obtained we can conclude that the eucalyptus phenology is constant for the study area considered. It is identified a slightly increase in August probably related to the summer season. Also, in this study case, the forest fire is controlled so there is not a decrease in NDVI values related to this phenomenon. The time interval of the images used correspond to the warm days (early june to early october) so it is expected that the NDVI values are constant in time. Moreover, the summer of 2017 was very dry season without time oscillation's that justify the variations of NDVI. The increasing NDVI values in the end of the period considered could be related with the gradual decreasing of temperature and gradual increasing of humidity with corresponding decreasing of hidric stress. In terms of ROIs, the profiles are very similar because the land cover of the study area is composed by eucalyptus and some scrubs which are very similar. It is important to note, that this work does not test an ecological hypothesis, only compares profiles obtained from two satellites/sensors. Only an annual (incomplete) cycle of vegetation activity was covered, which does not allow for the estimation of inter-annual centrality statistics (average or median) that help to identify spurious values and mitigate the errors. Moreover, the two profiles are very different, namely in the final part (winter-spring 2018), which can be due to many reasons, for instance, due the fact that 2018 was an exceptional year in terms of climate. In the future, a complementary analysis could be performed in order to compare each profile with monthly values of temperature and precipitation for the same period, which could allow to interpret the differences founded between the two profiles. This work presented an improved version of QPhenoMetrics application with the possibility of interpreting Sentinel-2A images. This improvement was tested with eucalyptus species in order to study the phenological behavior of this species. This improvement proved to be very useful in the automatization of use Sentinel images since the file structure is very complex. The great advantage of using Sentinel images is the temporal resolution (5 days) considering the Sentinel A and B in orbit since 2017.

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