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QPhenoMetrics: An open source software application to assess vegetation phenology metrics

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ABSTRACT

Phenology is one of the most reliable indicators of vegetation dynamics. Assessing and monitoring the dynamics of phenology is relevant to support several decisions in order to improve the efficiency of several farming practices. An open source application – QPhenoMetrics - implemented in QGIS software that estimates vegetation phenology metrics is presented, using Earth Observation Systems (EOS) based time-series of Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI) as proxies for phenology. QPhenoMetrics is characterized by freely-usable and updatable code, acceptance of satellite images or text formats, time-series analysis toolbox allowing the selection of region of interest with statistical quality assessment for Vegetation Indices (VI), and estimation of ensemble metrics. The application is structured in three components: (i) input data; (ii) pre-processing of the VI time-series and several fitting methods and (iii) computation of the phenological metrics. QPhenoMetrics produces a plot with the VI time-series and corresponding phenology metrics, and a spreadsheet is created with a list of NDVI or EVI values estimated using the selected fitting method. To evaluate the application, two main Portuguese crops, vineyards and maize, and MOD13 data from MODIS sensor during 2011–2012 were considered. QPhenoMetrics was validated with vineyard phenology observations (2007–2011). A comparative analysis with software products TimeSat and Spirits was also performed. It was concluded that QPhenoMetrics can be very useful for common users to extract phenology information for 16 daily MODIS data in HDF format, text files with NDVI/EVI data and ASCII files, through a simple and intuitive graphic interface. Furthermore, the user can evaluate the quality assessment of VI of the images used. QPhenoMetrics is an effective open source tool that in addition to being free, is readily modifiable by user according to the study requirements.

1. Introduction

Vegetation phenology refers to the seasonal timing of recurring biological events, the causes of their timing, their relationship to biotic and abiotic forces, and the interrelations among phases of the same or different species (Lieth, 1974). Phenology, due to its interaction with the atmosphere, soil, water and land use is one of the most reliable indicators of vegetation dynamics that plays a prominent role in local, regional and global agricultural and ecosystems simulation models.

Assessing and monitoring continuously phenology is relevant for several purposes, including climate change, biodiversity conservation, ecosystem management (e.g. Coops et al., 2009; Lhermitte et al., 2011), or use efficiency in farming practices (Cunha et al., 2015; Vrieling et al., 2011). The development of tools focusing phenology and identifying main phenological events is therefore important, particularly if they promote inclusiveness of broad user communities. Open source applications integrating phenological tools into Geographical Information Systems (GIS) environments are one step further on that direction.

At regional and global scales, time series of Vegetation Indices (VI) based on remotely sensed data provide valuable information for understanding vegetation dynamics and phenological events in space and time (Bayarjargal et al., 2006; Cunha and Richter, 2014; Ma et al., 2013; Xiao et al., 2006). Satellite–derived VIs are spectral indicators of vegetation greenness, photosynthesis and metabolism intensity of vegetation (Ma et al., 2013; Wardlow et al., 2007; Yan et al., 2015). Time series of the Normalized Difference Vegetation Index (NDVI) and

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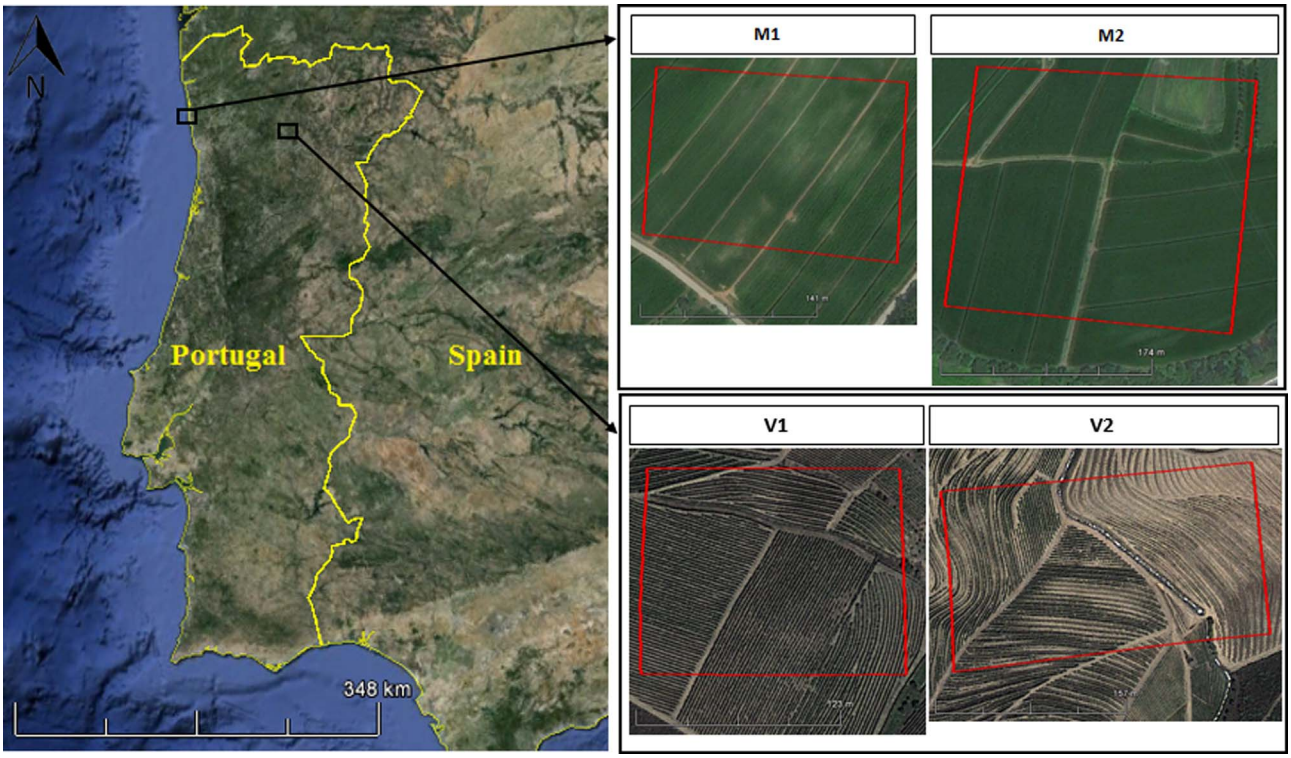

Fig. 1. Locations of the testing sites in Portugal (left image). The two regions selected from the maize fields, M1 and M2, are represented on the upper right images acquired in 18/07/2010. The two regions selected from the rainfed vineyards fields, V1 and V2, are represented on the lower right images acquired in 24/05/2013. Images provided by GoogleEarth®.

Enhanced Vegetation Index (EVI) are the most considered. Different phenology metrics can be extracted from NDVI and EVI time series and the most frequently used are the Start Of the Season (SOS) and the End Of the Season (EOS), which correspond, respectively to the beginning and end of measurable greenness of vegetation canopy. A number of vegetation parameters such as the length of season, maximum seasonal value and duration of photosynthesis activity in the canopy could also be computed. The set of metrics estimated depend on the purpose, vegetation or crop selected (Cunha et al., 2010a; Fraga et al., 2014).

Regarding to remote sensing sensors providing VIs commonly used in phenological studies, it varied with temporal, spatial and spectral resolution considered. The most popular are still the Advanced Very High Resolution Radiometer (AVHRR), Moderate Resolution Imaging Spectro-radiometer (MODIS) and Système Pour L'Observation de la Terre (SPOT)-VEGETATION. In specific, MODIS data provide global high temporal frequency measurements of land surface properties and is, therefore, well suited for monitoring seasonal-to-decadal patterns and trends in regional-to-global phenology (de Beurs and Henebry, 2005; Piwowar, 2011; Reed et al., 1994; White et al., 2005; Zhang et al., 2003). MODIS data from Terra and Aqua satellite platforms increased significantly the availability of VI data. Because the MODIS sensors aboard Terra and Aqua satellites are identical, the VI algorithm generates each 16-day composite eight days apart (phased products) to permit a higher temporal resolution product by combining both data records. MODIS has a large-spatial coverage of land, high temporal resolution, and is downloadable free of charge, thus providing an excellent basis for regional-to-global scale studies of land surface phenology (e.g. Xue et al., 2014; Zhang et al., 2006). With the launch of the MODIS sensor, the use of a long time series was introduced, for example, in studies of crop phenology (Cunha et al., 2010c; Sakamoto et al., 2005), discrimination of agricultural crops (Wu et al., 2014), land cover changes (Clark et al., 2012), and the estimation of vegetation' biophysical parameters (Bandaru et al., 2013).

In order to derive phenology metrics from satellite VI time series several software tools have been developed in recent years: Phenological Parameters Estimation Tool (PPET; McKellip et al., 2010), TimeStats (Udelhoven, 2011), TimeSat (Jönsson and Eklundh, 2004; Eklundh and Jönsson, 2012), enhanced TimeSat (Tan et al., 2011), Phenosat (Rodrigues et al., 2013), Hants (Zhou et al., 2015) and Software for the Processing and Interpretation of Remotely Sensed Image Time Series (Spirits; Eerens et al., 2014). These software tools have important functionalities for the extraction of phenological information. Nonetheless, the selection of an in-season window of interest as well as the option to determine double growing seasons (e.g. Phenosat; Rodrigues et al., 2013) is still a constraint. This feature is typical and relevant for vegetated areas with two or more crops in succession per year originating two or more growing season peaks (e.g. farmland system). In addition, available free and open source tools (e.g. PPET, PhenoSat and Hants) require Matlab, a non-free environment to perform the analysis. By last, none of these tools are available in most used GIS environments (e.g. QGIS or GRASS), which are widely used in environmental and crop management applications.

The main objective of this work was to develop an effectively open source application based on QGIS software able to produce vegetation phenology metrics (QPhenoMetrics), based on a prototype previously developed by the authors (Duarte et al., 2014). The present version was validated with in-situ measurements and includes the following major innovations: (i) development of an open source tool-free to use and to be updated/modified; (ii) acceptance of either satellite images or text files with time series of VI measurements as input; (iii) analysis of both NDVI and EVI time series; (iv) selection of a Region Of Interest (ROI); (v) statistical analysis of the VI quality; and (vi) the inclusion of an "ensemble" method to deal with uncertainty in phenological metrics associated to the chosen algorithm. The performance of QPhenoMetrics is also tested by considering different environmental contexts and establishing comparative analysis with other software tools.

2. Testing sites

Two crops were considered to evaluate the performance of