Remote Sensing Forest Phenology and Global Changes

Research Proposal by Biagio Minio

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Phenology has been defined as the study of recurring plant (and animal) life cycle[1]. Through phenology, it is possible to identify the influence of seasonally varying environmental conditions on the timing of plant development stages or phenophases, including germination, flowering and senescence. If, on one hand, the direct phenological observations in the field are useful to provide detailed information on plant phenology at the scale of single individuals or plants, on the other hand, field observations are necessarily limited to small areas and to a limited number of individuals [2]. By contrast, remote sensing represents an effective tool for monitoring the vegetation seasonal dynamics providing a higher temporal resolution and a greater spatial coverage compared to visual observations. However, many specific phenological events cannot be detected directly at the spatial resolution of the satellite images. Therefore, dealing with "Land Surface Phenology" (LSP), other more general descriptors of the vegetation seasonal dynamics are used. De Beurs & Henebry [3] defined LSP as the spatio-temporal development of the vegetated earth surface as revealed by spectral observations from satellite sensors. Thanks to the large amount of data collected on a relatively long period of time, to the high temporal frequency of the observations, and the high quality and internal consistency of data, LSP represents a valid tool for environmental monitoring at the ecosystem level. Remote sensing phenology is generally based on vegetation indices (VIs), such as the normalized difference vegetation index (NDVI, [4]) or the enhanced vegetation index (EVI, [5]). The seasonal dynamics of the VIs shows a strong correlation with some of the typical phases of vegetation growth, such as the start of the greening season (SOS), the peak of growing season, the onset of senescence (or end of season, EOS) and the growing season length [6, 7] (Figure 1).

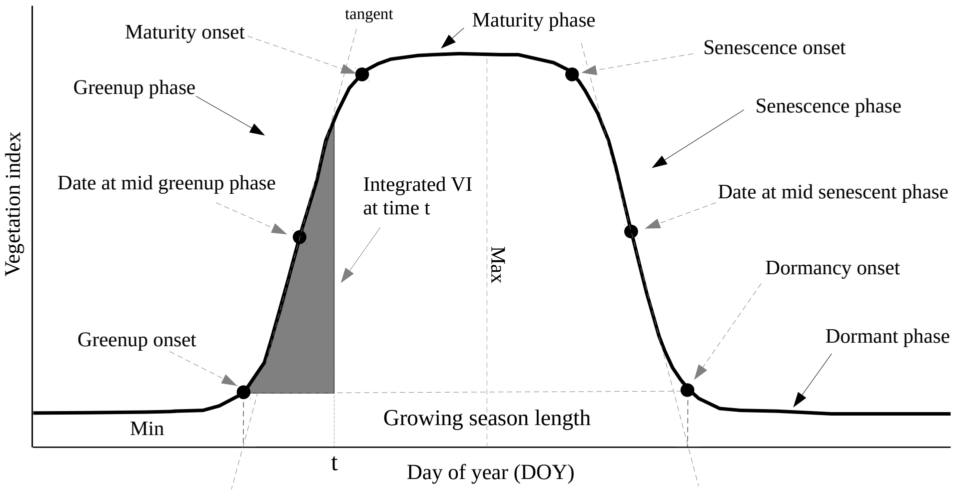

Figure 1: Annual trend of vegetation indices. The main metrics used and the corresponding vegetation phases are shown. The profile is an example of deciduous forests, opposite or constant conditions over time indicate evergreen forests. For real data the growth phases are faster than the decrease.

Recently, Zeng et al. [2] published a very detailed review about the different methods used to extract phenological metrics from satellite time series. Unfortunately, most of these methods suffer from not being general enough to be applied to a wide variety of vegetation types with less pronounced phenological cycles, such as evergreen Mediterranean forests, or Alpine coniferous forests.

Therefore, the general goal of this PhD project is the implementation of a remotely-sensed tool that is able to monitor the phenological dynamics of different forest types in time and space. More specifically, the main objectives of this PhD project are:

- to develop a robust and general method to automatically extract the main phenological metrics from different (Italian and European) forest ecosystems;
- to group the main forest ecosystems into homogeneous phenological types, identifying the composition and the main phenological characteristics of the different phenological types and exploring the role of climate and physiographic variables in the phenological timing of each type;
- to explore the phenological response of forests ecosystems to global change.

To achieve these goals, in the first phase, which corresponds to the first year of activity, we will acquire the annual remotely-sensed NDVI and/or EVI profiles for all points of the Italian forest Inventory and the European ICP forest inventory (International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests , ICP Forest, http://icp-forests.net/). By means of Google Earth Engine, we will download the 23 16-day composite MODIS NDVI and EVI images per year for the period 2001 to 2020 to generate the remotely-sensed phenological profiles of all inventory points at the spatial resolution of 250 m, and to extract the corresponding phenological metrics. To extract the phenological metrics from the satellite profiles, we will use a number of classical multivariate approaches and machine learning algorithms, with the possibility of integrating different methods. In this framework, machine learning methods show great potential in cloud data recovery and time series data reconstruction. Specifically, different machine learning methods such as neural networks, singular value decomposition (SVD), random forest, or support vector machine (SVM) will be tested.

Next, in the second year, based on the phenological metrics, the inventory points will be classified into phenological types. These phenological types represent a special kind of process-based functional groups that are characterized by homogeneous phenological behavior (and hence by a homogeneous response to environmental conditions), irrespective of the structural and compositional differences among the various inventory points within each group [8]. The phenological types will be then characterized in terms of their main climatic and physiographic drivers and represented in map form (i.e. Pheno-maps) to show the phenological patterns of Italian and European forests.

Finally, in the third year, we will explore the influence of global change on the temporal dynamics of the different phenological types. In this case, the main questions are: is it possible to identify variations in the phenological timing of vegetation in the last twenty years? What are the forest types most subject to phenological changes? In particular, by answering these questions, it will be possible to explore the main adaptive strategies of the different forest types in response to global change in terms of changes in the length of the growing season and early or late trends in the greenup and senescence phase. Note that, to date, this latter phase has been poorly understood because the phenological responses to senescence detected both in the field and with remotely sensed tools are much more complex and fuzzier than the start of the growing season. Therefore, by linking vegetation senescence to their environmental drivers, this project will possibly help to clarify some of the most problematic aspects of remotely sensed phenology.

To conclude, the availability of remotely sensed time-series data has enabled a reliable investigation of seasonal vegetation patterns at regional and ecosystem-level scales, thus expanding the concept of vegetation functional groups to phenological types. We hope, this PhD project will improve our understanding of remotely sensed forest phenology for large-scale environmental studies.

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