Monitoring natural and rural ecosystems using the NDVI anomaly: an application to the Umbria Region

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Vegetation is one of the main components of the terrestrial ecosystems and plays a key role in energy exchanges and in water and biogeochemical cycles of Earth (Peng et al. 2012). Due to the link between soil, atmosphere and humidity, vegetation plays a crucial role in maintaining climate stability, adjusting carbon balance and reducing the greenhouse gases. However, for the same reasons, vegetation is also particularly sensitive to climate change. Therefore, the dynamics connected to vegetation have been recognized as one of the crucial elements for measuring climate change in terrestrial ecosystems (Bachelet et al., 2001).
In particular, they can be a robust and consistent picture of climate change over the Mediterranean area, consisting of a pronounced decrease in precipitation, especially in the warm season. This drying is due to increased anticyclonic circulation that yields increasingly stable conditions and is associated with a northward shift of the Atlantic storm track. A pronounced warming is also projected, maximum in the summer season. Inter-annual variability is projected to mostly increase especially in summer, which, along with the mean warming, would lead to a greater occurrence of extremely high temperature events. (Giorgi et al. 2008).
Vegetation can be an important climate indicator with very high rapidity of response, but itself can be a monitoring object for the protection needs of ecosystems .
Remote sensing via satellite can provide valuable support for monitoring large-scale vegetation dynamics, thanks to the temporal and spatial resolution offered, as well as for the accuracy of the data. The index known as "Normalized Difference Vegetation Index" (NDVI), proposed by Rouse et al. (1973), is based on processing the reflectance data in the red and near-infrared bands. Several environmental and territorial studies applied NDVI because of its high level of correlation with photosynthetic capacity, leaf area index, biomass and primary productivity (Gamon et al., 1995).
The domain of the NDVI is between -1 and 1: values near to 1 mean a high vegetative coverage, with intense photosynthetic activity; negative values indicate the presence of clouds, snow, water or areas without vegetation (Rouse et al., 1973). In the last twenty years, the NDVI has been widely used in several applications; for instance in relation to the net primary productivity (NPP) of the vegetation (Rasmus et al., 204), the coverage of the soil, the photosynthetic activity of plants, the surface of water bodies, the Leaf Area Index (LAI) , as well as an indicator of the effects of climate change at local scale (Piao et al., 2006).
The present study uses not the NDVI itself but its anomaly (DEV_{NDVI}). The DEV_{NDVI} represents the percentage variation of the current NDVI compared to the average one, according to values present in the FAO-Earth observation Database[1], as reported in 1.

$$DEV_{NDVI} = (NDVI_i - NDVI_{average})/DEV_{average} \tag{1}$$

where DEV_{NDVI} is the anomaly of the Normalized Difference Vegetation Index, $NDVI_i$ represents the NDVI in a certain period and $NDVI_{average}$ is the average value estimated on the basis of the FAO Database.

The aim of this work is to present a semi-automatic system that, through the use of a plurality of software tools, is able to obtain data from the satellite MODIS / Terra Vegetation Indices 16-Day L3 250m SIN Global Grid (MOD13Q1), to process them and to provide results (in terms of DEV_{NDVI}) almost in real time. The model is applied to the Umbrian territory, for analyzing the dynamics of the vegetation. The applications proposed are two: the former is on the whole regional vegetation, while the latter considers just one specific agrarian typology, the olive orchards. The analysis of anomalies is possible thanks to a database of data collected since January 1st 2001. The comparison between $NDVI_i$ and $NDVI_{average}$ (the latter taken from the database) allows to identify areas, and the corresponding habitats, which show significant anomalies.
Information obtained from such an analysis can be used for constructing synthetic indicators, representing the response of vegetation to climate variability. These indicators can be very useful to identify suffering areas, within particular habitat or ground coverings, such as vineyard and olive groves for example, or to monitor areas sensitive to climate variability (Sykes,2009).

[1] http://www.fao.org/giews/earthobservation/asis/index_2.jsp

The identification of critical areas allows also the implementation of rapid actions, at regional scale, for protecting vulnerable or priority ecosystems, with the frequency offered by the temporal resolution of the satellite data (16 days). Finally, the information collected can be useful for purposes of sustainable land use and planning, with particular reference to carbon management, due to the role of vegetation in the capture and storage of carbon.
The system proposed for obtaining and elaborating data is based on open source libraries, as pyMODIS and GDAL, and geographical software, like GRASS, linked by several phyton scripts. We chose GRASS GIS for our application because it is an advanced and well-known open-source GIS software (Frigeri et al., 2011), used for geospatial data management and analysis, image processing, graphics/maps production, spatial modelling and visualisation. Since its first release in 1982 (Frigeri et al., 2011), GRASS GIS has been increasingly used by academic and commercial settings all around the world, as well as by many governmental agencies and environmental consulting companies, for a wide range of possible applications.
Ultimately, the system presented can be considered an experimental semi-automatic system of vegetation monitoring, allowing to get information on the state of the vegetation almost in real time. Moreover, it gives information about the response of vegetation in terms of photosynthetic activity and response to climatic variability. The system also allows to get information on specific ground covers, either natural (e.g. wetlands, oak forests, grassland formations, etc.) and artificial (olive groves, vineyards, urban parks). The analysis of data, acquired every 16 days, provides information on the recent evolution of the ground cover by vegetation in a territory.
The results of our case study showed, for Umbria region, a slight increase in the biological activity of the vegetation. However, the absolute value showed significant differences in the time of development of anomaly and depending on the type of vegetal formation. The response of wetlands was particularly interesting because it confirmed as these areas present great vulnerability and poor resilience towards changes in action. Moreover, the DEV_{NDVI} for habitats connected to wetland represented more than 60% of the total anomaly (positive). The importance of this phenomenon, which involves both main wetlands, as Trasimeno Lake, and secondary ones, requires furthers analysis. The application to olive orchards showed a pronounced seasonal trend, with two peaks in spring and autumn and some periods in which NDVI collapsed. Further analysis will be done thanks to the trends analysis.
The information collected can be useful for the regional Decision Maker, in order to promptly identify priority action areas. Furthermore, they can be an indicator of the real effects of climate change on vegetation component, and of how the vegetation itself responds for adapting to change.
Further development of the system will be addressed to improve the efficiency of the code and to increase the data acquisitions for enriching the availability of time series. Moreover, additional indexes will be implemented, using other information available from the MODIS satellite, like for example the EVI index, but also using different sources of data with a higher spatial resolution.

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