A Dynamical System Perspective of Multi-temporal Remote Sensing: Analysis of MODIS Spectral Index Time Series from Forest Wildfires

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Abstract— Land surface satellite time series can be interpreted as the output of a dynamical system which generates a process of interest. In this research, the qualitative theory of dynamical systems is applied to understand seasonal time series, which correspond, respectively, to spectral indexes and to the reflectance of single wavelengths from Alpine areas affected by wildfire.

A collection of 293 images acquired from MODerate resolution Imaging Spectroradiometer (MODIS) sensor aboard the NASA-Terra satellite platform was analysed in order to study the dynamics of mountain vegetation (broadleaf, needleleaf and prairies) before and after wildfires in the Alps. Satellite images of the Normalized Difference Vegetation Index (NDVI), the Enhanced Vegetation Index (EVI) and the Normalized Burnt Ratio (NBR) with spatial resolution of 250 m and time resolution of 16 days in the years 2000–2012 were used. Wildfire affected areas (> 40 ha) in Lombardy between 2000 and 2010 were selected. For each burned area, an undisturbed adjacent control site was located on the basis of a digital elevation model (DEM), historical aerial orthophotographs and land-use/land-cover maps.

A set of multi-dimensional arrays (multi-temporal imagery) was created for each spectral index (NDVI and EVI), single band (red, blue, near infra-red, short wave infra-red, all in units of radiance) and for each of the MODIS acquisition meta data (Quality Assurance, Usefulness Index, Shadow, Pixel Reliability, Sun Zenith angle, View Zenith angle and Day Of Year). The time series of these variables thus become available for each pixel of the area. Data pre-processing consisted in the smoothing of MODIS time series for noise removal; in this procedure a SAVITZKY-GOLAY recursive filter was applied, where the weighting scheme is based on the quality parameters of MODIS acquisitions.

Due to the periodic energy input to ecosystems, the vegetation growth cycle in Alpine environments exhibits marked seasonal oscillations. The optical properties vegetation and the related spectral indices are affected accordingly. The process is therefore modelled by a stable periodic orbit of a dynamical system. Wildfire is a perturbation, which alters the system parameters, hence its phase portrait. The effect of the perturbation was visualised by creating a set of yearly scatter plots of different spectral indexes and single wavelengths, extracted from burned and reference areas. Each plot is a sequence of points on the plane, which are the vertices of a generally self-intersecting polygonal chain; these were characterized by a set of morphological descriptors (area, perimeter, centroid coordinates, moments and tensor of inertia). Principal Components Analysis of these descriptors was applied and some representative wildfires could be qualitatively analyzed in the plane of the first two components.