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Abstract

Many satellite and information services, such as NOAA STAR, are providing maps displaying data about vegetation indices. Using the time-series that we can obtain from these maps, several analyses are possible. Here we propose the use of recurrence plots. We will show examples based on the data corresponding to three small areas in Italy of the NOAA STAR Vegetation Health Index (VHI), an index used for monitoring and forecasting the status of vegetation. The recurrence plots we obtained seem being able of discriminating different situations.

Article body

Recurrence Plots for the analysis of Vegetation Health Index (VHI)

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Abstract: Many satellite and information services, such as NOAA STAR, are providing maps displaying data about vegetation indices. Using the time-series that we can obtain from these maps, several analyses are possible. Here we propose the use of recurrence plots. We will show examples based on the data corresponding to three small areas in Italy of the NOAA STAR Vegetation Health Index (VHI), an index used for monitoring and forecasting the status of vegetation. The recurrence plots we obtained seem being able of discriminating different situations.

Keywords: Satellite Maps, Satellite Imagery, Recurrence Plots, Vegetation indices, Climate.

Introduction

In 1987, Eckmann, Kamphorst and Ruelle introduced the recurrence plots, which are a simple way to visualize the periodic or chaotic behaviour of a dynamical system through its phase space [1]. These plots have proven being useful for investigating the natural processes, which can have quite distinct recurrent behaviours. Using recurrence plots we can observe short term seasonal periodicities or long term natural cycles, but we can also display the irregular behaviour of El Niño Southern Oscillation [2]. In this framework of environmental analyses we have shown, for instance, the seasonal oscillations of levels of some lakes in Africa [3], and the trend of carbon dioxide concentration in atmosphere, linking it to CO_2 emissions of anthropic origin [4].

In environmental studies, several data are given as time-series of specific quantities, obtained from different sensors. When global data are involved, averages of several observations in different locations are often used. Among devices that are collecting environmental data, we have the satellites equipped with hyperspectral sensors, specific for detecting electromagnetic radiations at different wavelengths. In this manner, besides time-series of satellite images in the visible range, which can be used for investigating the evolution of local landscapes (see for instance, in [5], the monitoring of motion of sand dunes), we have several imageries in other frequency ranges which contain data from remote sensing of temperature, moisture, water use and other environmental parameters. Each pixel of the image is covering a certain geographic area. Therefore, we can use each pixel of these images (or an average of some pixels) as it were a local environmental sensor and use the corresponding time-series of data for monitoring and forecasting. In fact, we can also use them to create recurrence plots of vegetation indices [6]. Besides recurrence quantification analysis [7], the recurrence plots can be a useful tool for identifying specific patterns in environmental phenomena concerning the vegetation indices [8]. Here, we will show and discuss some examples based on NOAA STAR Vegetation Health Index (VHI), an index that was proposed for monitoring the status of vegetation. These examples are concerning three small areas in Italy. We will see that recurrence plots seem being able of discriminating different situations.

Vegetation monitoring

Before showing and discussing recurrence plots from NOAA STAR data, let us shortly revise the satellite method for monitoring vegetation. The green plants are absorbing that part of solar radiation which is in the photosynthetically active spectral range. Plants use it as a source of energy in the process of photosynthesis; moreover, they evolved to have leaf cells scattering solar radiation in the near-infrared spectral region. Hence, live green plants appear relatively dark in the photosynthetically active spectral range and relatively bright in near-infrared [8]. Therefore, leaves strongly absorb visible light (from 0.4 to 0.7 µm) for use in photosynthesis, whereas their cell structure strongly reflects near-infrared light (from 0.7 to 1.1 µm). The more leaves a plant has, the more these wavelengths of light are affected. Since satellites, such as NOAA AVHRR, acquire data in visible and near-infrared, it is quite easy to observe the strong differences in plant reflectance to determine their spatial distribution and prepare some specific maps.

Based on satellite measurements, some vegetation indices can be given; one which is largely used is NDVI (Normalized Difference Vegetation Index), easily defined as follows: NDVI=(NIR−VIS)/(NIR+VIS), where VIS and NIR stand for spectral reflectance acquired in the visible (red) and near-infrared regions, respectively. The remotely sensed spectral vegetation indices are involved in numerous disciplines interested in the assessment of biomass, water use, plant stress, plant health and crop production [9]. However, although vegetation indices were developed to extract the plant signal only, the soil background, moisture condition, solar zenith angle, view angle, as well as the atmosphere, alter the index values in complex ways [9].

The time series of NDVI or other indices can be used to obtain ecological indicators to forecast the ecology of a given region. In fact, as observed in [10], being a crucial component of terrestrial ecosystems, the vegetation dynamic has become one of the key issues in the study of global environmental change, so that many researches have been conducted on vegetation dynamic trend on different periods. In [10], the consistency of these trends after the study period was analysed using Hurst Exponent and R/S analysis. Hurst and Lyapunov exponents have been used also in [11-13]. More generally, Hurst exponent can be involved in fractal analysis of LANDSAT images [14], to investigate the local changes in land uses.

NOAA STAR VH Index

For what concerns the vegetation indices and related maps, several satellite imagery resources are available for investigations. NOAA STAR, a centre for satellite applications and research, provides many of them. This centre is the science arm of NOAA Satellite and Information Service (NESDIS), which acquires and manages Earth-observing satellites. NOAA STAR has the mission to accelerate the transfer of satellite observations from scientific research and development into routine operations. Among the several data provided by the site, we find those concerning the vegetation health, moisture and thermal conditions. For what concerns the Vegetation Health (VH), the satellite observations are principally given by the Advance Very High Resolution Radiometer (AVHRR), flown on NOAA polar-orbiting satellites. Data are global with the resolution 4 km and 7-day composite. The center is providing the following vegetation indices: Vegetation Condition index (VCI), Temperature Condition index (TCI), Vegetation Health index (VHI), Soil Saturation index (SSI), No noise Normalized Difference Vegetation Index (SMN), No noise Brightness Temperature (SMT), Fire risk index (FRI), and other products on drought and malaria. Vegetation Health Index (VHI) is based on a combination of VCI and TCI. It is considered effective enough to be used as proxy data for monitoring vegetation health and drought as discussed in [15]. VHI has been used successfully for detection of vegetation stress and estimation of crop losses in the USA. VHI data showed that large-area drought can be detected up to two months in advance of other techniques, and the impact on grain reduction can be diagnosed long in advance of harvest [15]. Due to the importance of this index, we decided to use it for our analysis with recurrence plots, instead of the NDVI index used in [6].

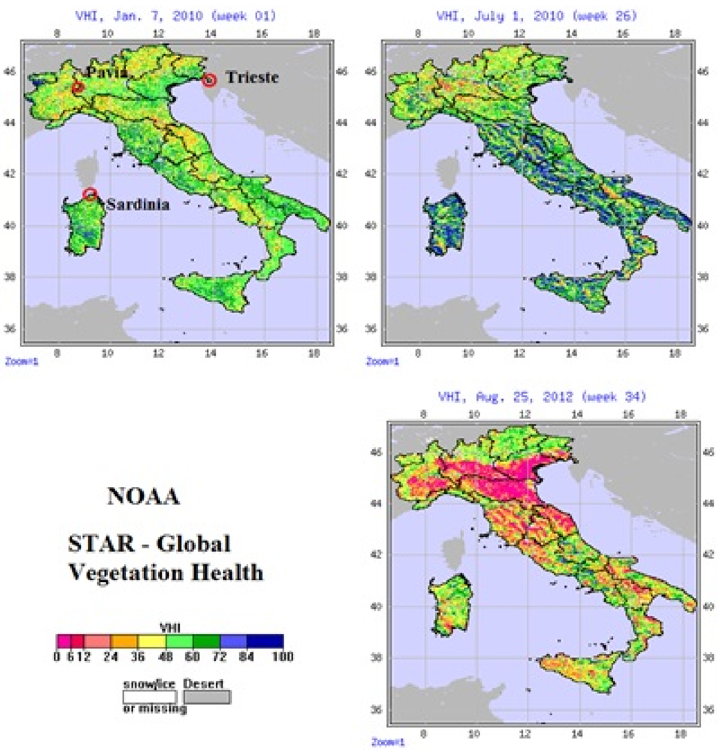

Figure 1: Maps from NOOA STAR of Italy concerning VHI index. The behaviour of this index for the three small areas encircle in the upper/left image is investigated in this paper.

Among the data provided by NOOA STAR, we choose those concerning Italy. In the Figure 1 we can see three maps of VHI for Italy. Note that these maps are not the original satellite images but matrices of processed data. Here, we investigate the behaviour of small regions of a few pixels, corresponding approximatively to 30-square km. There areas are in the northern part of Sardinia (Santa Teresa di Gallura, Rena Majore, Li Lieri and Pulcheddu), Trieste and the wedge of land lying between rivers Po and Ticino near Pavia (San Martino Saccomario, Carbonara al Ticino and Cava Manara). The aim is that of understanding how local environment can influence the behaviour of VHI and, therefore, its forecasting capability at local scale.

The maps from the first week of 2010 to the last available of 2015 have been used. A processing is extracting from each image the color tones of pixels. According to the scale in Figure 1, the highest numerical value is given to the corresponding color tone. An average value on the chosen area is calculated and, as a consequence, a time series is obtained. The result corresponding to the coastal region of Sardinia is given in the graph of Figure 2. High values correspond to healthy vegetation, whereas lower values are corresponding to a stressed situation. In the same Figure, we can find the corresponding recurrence plot. To prepare it, we used E. Kononov software, in the Grey layout [16]. In this plot, black or dark grey pixels correspond to high recurrence, whereas white pixels to low or very low recurrence. A recurrence is a case the time-series datum returns to a value it has attained before. The plot is subdivided in macro areas separated by boundaries. In fact, this plot seems showing a mixture of oscillatory and autoregressive processes (see for instance the examples of these two cases at [17]).

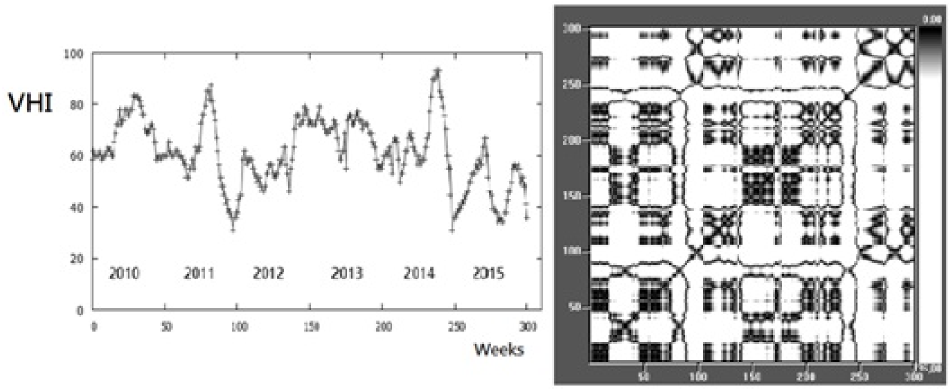

Figure 2: VHI time-series for the coastal region of Sardinia given in Fig.1. High values correspond to healthy vegetation, whereas lower values are corresponding to a stressed situation. On the right, we can find the corresponding recurrence plot. In this plot, black or dark grey pixels correspond to high recurrence, whereas white pixels to low or very low recurrence. This plot looks like a mixture of oscillatory and autoregressive processes.

Of course, it is natural that oscillations are present, due to season effects. However, it seems more relevant the presence of an autoregressive process. In statistics, an autoregressive model is a representation of a type of random process where the output variable depends linearly on its own previous values and on a stochastic term (see [18] and references therein). In an auto-regressive process, a shock affects the evolving variable far into the future. In the case of vegetation, a shock can be represented by anthropic actions too. Shock effects are expected being quite relevant on small areas.

In Figures 3 and 4, VHI time-series for Trieste and Po-Ticino wedge are given, with the corresponding recurrence plots. We observe the same mixture of oscillatory and autoregressive processes. In the case of the area near Pavia, note the strong stress of vegetation, which is connected to that observed for the Pianura Padana as a whole.

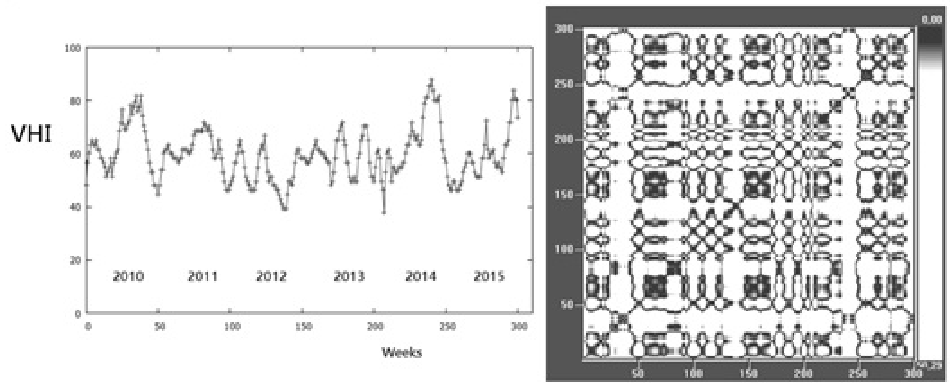

Figure 3: VHI time-series for the coastal region of Trieste and the corresponding recurrence plot. We have, as in the case of Figure 1, a mixture of oscillatory and autoregressive processes.

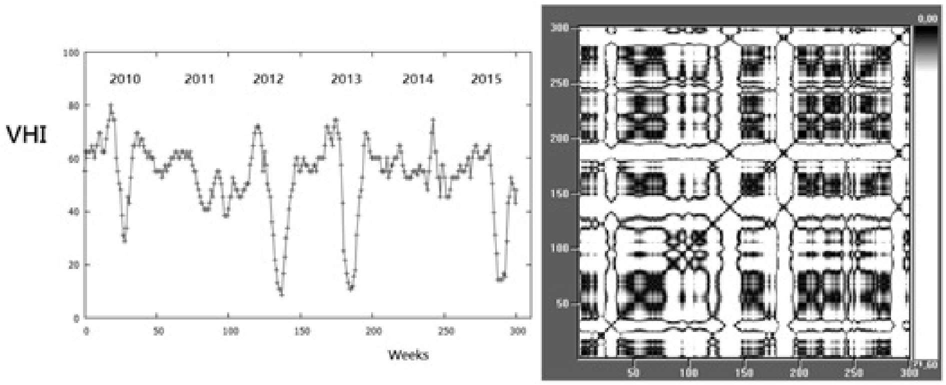

Figure 4: VHI time-series for the Po-Ticino wedge near Pavia and the corresponding recurrence plot. Note the strong stresses of vegetation, which are connected to those observed for the Pianura Padana as a whole.

From Figure 2-4, we can see that, in the recurrence plots, white areas exist which seem separating chessboard textures; these areas are corresponding to the peaks in graphs. In the Figure 5, the three time-series are given for comparison. In Figure 6, the recurrence plots are also shown for easy comparison. Plots are obtained by means of Kononov software in Spectrum layout; using such a layout, the boundary regions between macro areas, which are evidencing peaks in time-series, are clearly visible in green. The recurrence plots shows that the coastal areas of Northern Sardinia and Trieste have a similar behaviour, but the wedge Po-Ticino near Pavia is quite different and typical of the Pianura Padana environment. As a conclusion, we can tell that recurrence plots, and other recurrence calculations based on the time-series of VHI could be interesting for the analysis of local environments.

As previously told, the aim of this research is that of understanding the role of local environments on the behaviour of VH Index. Of course, this paper, with its three examples, is just a preliminary discussion. Further studies are in progress on this subject to collect data from other parts of Italy and compare VHI behaviour to that of other indices.

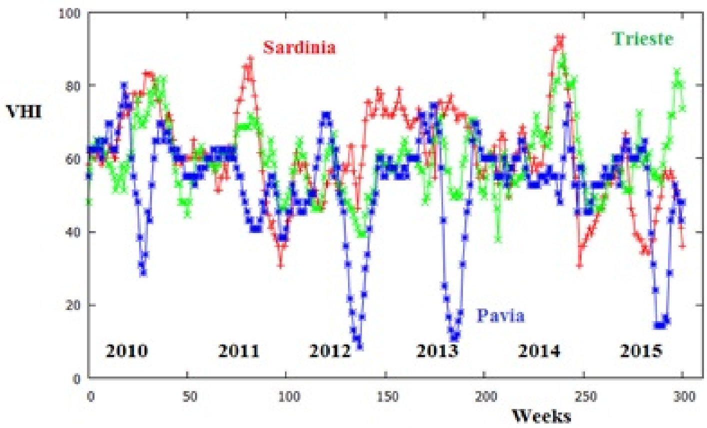

Figure 5: Time-series of the selected areas.

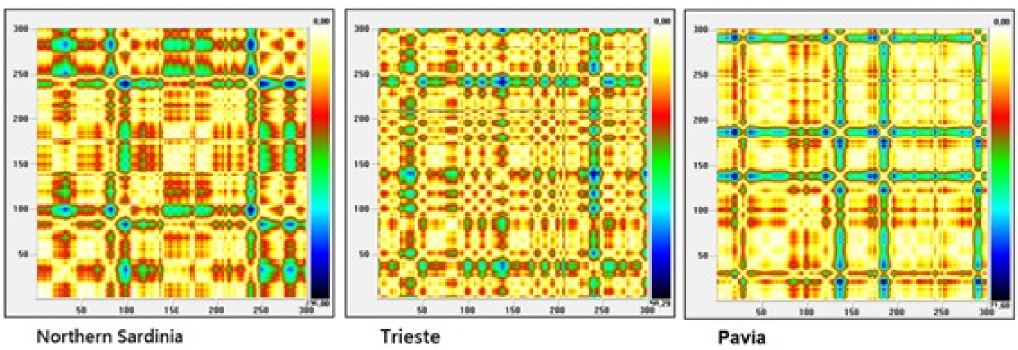

Figure 6: Recurrence plots of the selected areas. Note that the coastal areas of Sardinia and Trieste have a similar behaviour, which is quite different from the wedge between Po and Ticino, near Pavia. This wedge has the typical behaviour of the Pianura Padana.

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