Investigating satellite SPOT VEGETATION multitemporal NDVI maps for land degradation monitoring in the Basilicata Region: Preliminary Results from the MITRA project

A. Lanorte[1], A. Aromando[1], F. De Santis[1] and R. Lasaponara[1]

[1]*CNR-IMAA, C.da S. Loja 85050 Tito Scalo (PZ), Italy. lasaponara@imaa.cnr.it*

Abstract. In this paper, we focus on the investigations we conducted in the context of the MITRA project focused on the use of low cost technologies (data and software) for pre-operational monitoring of land degradation in the Basilicata Region. The characterization of land surface conditions and land surface variations can be efficiently approached by using satellite remotely sensed data mainly because they provide a wide spatial coverage and internal consistency of data sets. In particular, Normalized Difference Vegetation Index (NDVI) is regarded as a reliable indicator for land cover conditions and variations and over the years it has been widely used for vegetation monitoring. For the aim of our project, we used satellite SPOT-VEGETATION multitemporal NDVI maps which are free available and useful for extracting information on land degradation. The analysis was performed using Principal Component Analysis applied to a temporal series (1999–2011) of the yearly Maximum Value Composite of SPOT/VEGETATION NDVI using open source software codes.

Keywords. GIS; satellite based Analysis; land degradation PCA,; Spatial variation; Moisture index, vegetation index; Basilicata

1. Introduction

The preservation and enhancement of natural and cultural heritage is one of the topics of great economic and social significance. Recently, the debate on strategies for development of integrated environmental and cultural heritage has seen increasing importance. Natural Heritage can be a resource for economic development based on the principles of sustainable use of resources not only for the benefit of society, but also as a useful source of human development. Natural heritage is "increasingly threatened with destruction not only by the traditional causes of decay, but also by changing social and economic conditions which aggravate the situation with even more formidable phenomena of damage or destruction, from the general conference of the United Nations Educational, Scientific and Cultural Organization meeting in Paris from 17 October to 21 November 1972, at its seventeenth session, available on line" (http://whc.unesco.org/en/conventiontext/).

In this scenario, recently the Basilicata region funded a FESR project, MITRA focuses on the development of reliable low cost technologies to preserve and enhance natural and cultural heritage in some relevant areas selected as test cases.

This paper is focused on the results we obtained for the whole Basilicata Region from the Principal Component Analysis applied to a temporal series (1998–2011) of the yearly Maximum Value Composit of SPOT/VEGETATION NDVI maps processed using open source software codes.

Both naturally vegetated areas (forest, shrub-land, herbaceous cover) and agricultural lands have been investigated in order to extract the most prominent natural and/or man induced alterations affecting vegetation behavior. Such analyses can provide valuable information for monitoring the status of vegetation which is an indicator of the degree of stress namely any disturbance that adversely influences plants in response to natural hazards and/or anthropogenic activities

2. Data set and Study area

2.1 Data set

The investigations were performed by using NDVI data derived from the VEGETATION sensor on board the SPOT satellite platforms. Such data are available free of charge at the Vlaamse Instelling voor Technologisch Onderzock (VITO) Image Processing centre (Mol, Belgium) (http://www.vgt.vito.be).

The data were subjected to atmospheric corrections performed by CNES on the basis of the simplified method for atmospheric corrections (SMAC). Moreover, the considered NDVI composition also allows for reducing the contamination effects due to residual clouds, atmospheric perturbations, variable illumination and viewing geometry that are generally present in daily NDVI maps. Additionally, for each considered pixel we carefully checked the absence of residual errors due to cloud edges and shadows, image navigation inaccuracy and changing of viewing-illumination conditions by using a visual inspection and additional information obtained from the four single SPOT-VGT channels and viewing geometry available online from VITO website.

The temporal series 1998–2011 made up of 10-day MVCs of NDVI maps were combined to produce one singular MVC of NDVI map for each year giving a total of 13 NDVI maps. This choice was performed because the yearly MVC of NDVI was found to be a reliable indicator of variations that can affect the state of vegetation cover (Cuomo et al., 2001; Lanfredi et al., 2003). It was found to be able to show the natural interannual variations, the consequences of extreme climatic events and the man-induced damage suffered by ecosystems (Cuomo et al., 2001; Lanfredi et al., 2003, Lasaponara, 2006a,b).

2.2 Study area

The analysis was performed in the Basilicata Region (see Figure 1) that is characterized by typical Mediterranean climate with a pronounced bi-seasonality regime having hot/dry summers and cold/wet winters. Due to a combined effect of natural hazards (drought, wind and rain erosion, floods) and human activity (industry, fires, over tilling, land abandonment), this area recently increased its vulnerability (APAT, 2006).

The environmental equilibrium of the Basilicata is fragile and highly vulnerable to perturbations, as in other Mediterranean regions, and, therefore, it is expected that natural ecosystems, such as forest, shrubland and herbaceous cover, should be more sensitive to the changes that are presently affecting the whole Mediterranean basin.

Figure 1. Basilicata region

3. Method

3.1 Satellite based monitoring using Principal Component Analysis

Nowadays, remotely sensed data has become increasingly available thus offering, at low cost and even also free of charge, a unique tool with great potential for a improving knowledge of both natural (Lasaponara 2005, Lasaponara and Telesca 2006) and cultural heritage (see, for example Lasaponara and Masini 2009, Ciminale et al. 2009 Masini and Lasaponara 2006, Lasaponara et al 2011) quantitative monitoring of risk and damage estimation. In particular, statistical analysis of satellite time series have shown great potential in extracting useful information relevant to detect inter and intra annual variations in vegetation cover. In particular, Lasaponara suggested that (2005) the use of PCA is particular effective for estimating interannual variations in vegetated areas based on using SPOT/VEGETATION NDVI temporal series. For these reason, herein we adopted the PCA for carry out the pre-operational monitoring of vegetation cover in the Basilicata Region.

Principal Component Analysis (PCA) is a linear transformation which decorrelates multivariate data by translating and/ or rotating the axes of the original feature space, so that the data can be represented without correlation in a new component space (see Figure 2). In order to do this, it is first computed: (i) the covariance matrix (S) among all input spectra bands (each element of S is calculated by using formula 1), then (ii) eigenvalues and eigenvectors of S in order to obtain the new feature components.

$$cov_{k1,k2} = 1/nm \sum_{i=1}^{n} \sum_{J=1}^{m} (MVC_{i,j,k1} - \mu_{k2}) (MVC_{i,j,k2} - \mu_{k2})$$

[1]

Where k1, k2 are two input time series dates, MVCij the annual maximum NDVI value in row i and column j , n the number of row, m the number of columns and μ is the mean of all pixel MVC values in the subscripted input dates.

The percent of total dataset variance explained by each component is obtained by formula 2:

$$\%\, i = 100 * \lambda_i / \sum_{i=1}^{k} \lambda_i$$

[2]

where λi are eigenvalues of S.

Finally, a series of new image layers (called eigenchannels or components) are computed (using formula 3) by multiplying, for each pixel, the eigenvector of S for the original value of a given pixel in the input bands

$$P_i = \sum_{i=1}^{n} P_k \times u_{k,i}$$

[3]

where Pi indicates a spectral channel in component i, u_{ki} eigenvector element for component i in input band k, Pk spectral value for channel *k*, number of input band.

A loading, or correlation *R*, of each component *i* with each input band *k* can be calculated by using formula 4.

$$R_{k,i} = u_{k,i} \times (\lambda_i)^{\frac{1}{2}} \times (var_k)^{1/2}$$
[4]

where var_k is the variance of input date k (obtained by reading the k_{th} diagonal of the covariance matrix)

The PCA transforms the input multispectral bands in new components that should be able to make the identification of distinct features and surface types easier. This is a direct result of two facts: (i) the high correlation existing among channels for areas that do not change significantly over the space; and (ii) the expected low correlation associated with higher presence of noise.

The major portion of the variance in a multi-spectral data set is associated with homogeneous areas, whereas localised surface anomalies will be enhanced in later components. In particular, each successive component contains less of the total dataset variance. In other words, the first component contains the major portion of the variance, whereas, later components contain a very low proportion of the total dataset variance. Thus they may represent information variance for a small area or essentially noise and, in this case, it must be disregarded. Some problems can arise from the fact that eigenvectors cannot have general and universal meaning since they are extracted from the series itself.

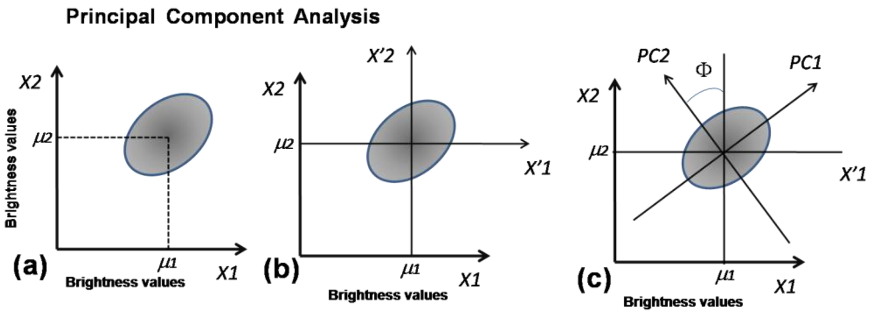

Figure 2. PCA decorrelates multivariate data by translating and/ or rotating the axes of the original feature space.

4. Results

Results obtained from the application of PCA to the NDVI temporal series are shown in Figures 3 and 4.

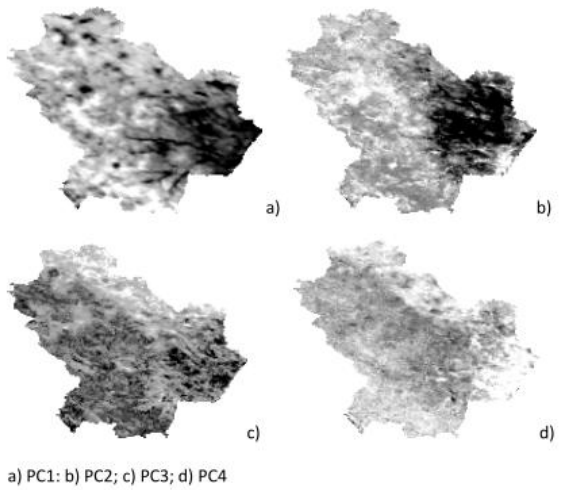

Figure 3. Multiyear principal components (PCs). (a) PC1. (b) PC2. (c) PC3.(d) PC4

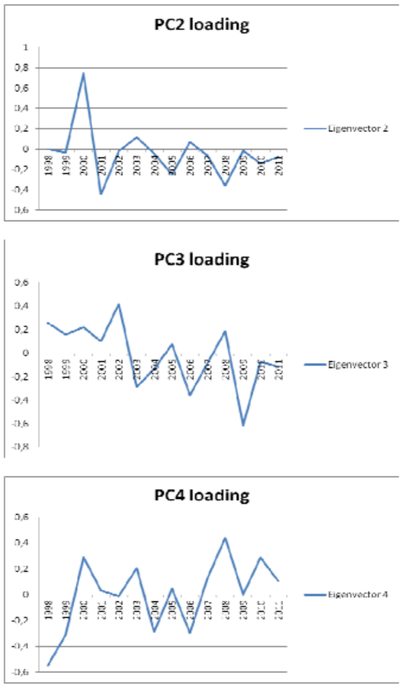

Figure 4. Loadings of PC2, PC3 and PC4

As expected, PC1 exhibits strong correlation values over the considered time window being, in which it clearly represents the mean (or the sum) level of vegetation distributions between the years 1998 and 2011.

Later components obtained from the application of the PCA account for variability that is more limited in space and/or time. The second principal component PC2 image and loading are shown in Figures 3(b) and 4 (above), respectively. PC2 shows a well defined area placed to the south-east of the Basilicata region with remarkable negative anomalies. This kind of anomalies are less important and also more spatially fragmented in PC3 and PC4. The PCs maps (Figure 5) clearly show these results.

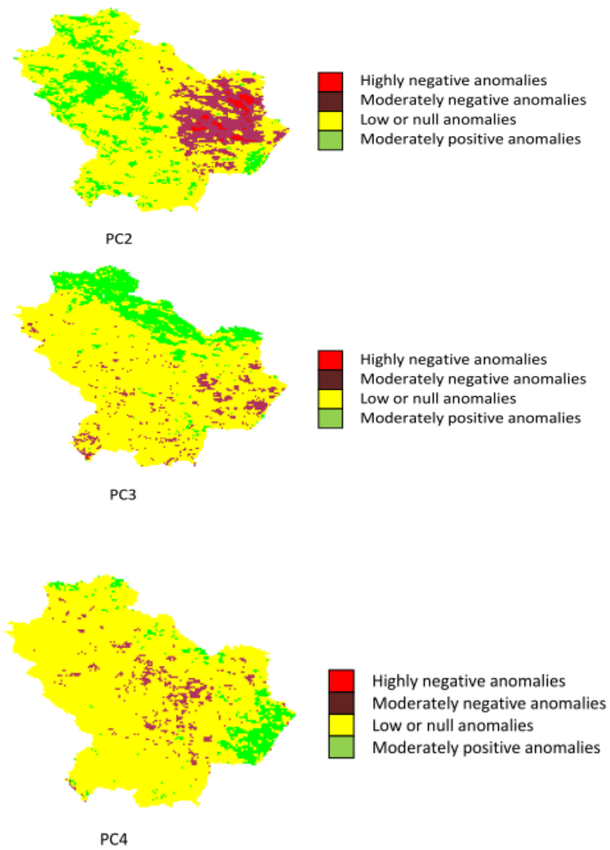

Figure 5. Principal components maps

Although a correct interpretation of PCA results generally requires additional information, such as geographical knowledge, climatological data and field surveys, the main finding of our investigation suggests that PCA can be a feasible tool in order to separately map areas showing quantifiable degrees of interannual variability, so providing valuable information for discriminating unidirectional changes.

Acknowledgments

This work has been supported by the “Regione Basilicata, FESR 2007/2013 – MITRA Project”

Reference

[1] APAT report 2006. La vulnerabilità alla desertificazione in Italia. Manuali e linee guida 40/2006.
[2] Ciminale, M., Gallo, D., Lasaponara, R., Masini, N. 2009. A multiscale approach for reconstructing archaeological landscapes: applications in Northern Apulia (Italy) Archaeological Prospection 16 (3), 143-153
[3] Cuomo, V., Lanfredi, M., Lasaponara, R., Macchiato, M. F., and Simoniello, T., Detection of inter-annual variation of vegetation in middle and southern Italy during 1985–1999 with 1 km NOAA AVHRR. J. Geophys. Res. , vol. 106, no. D16, pp. 17 863–17 876, 2001.
[4] Lanfredi, M, Simoniello, T., Lasaponara, R., Cuomo, V., and Macchiato, M. F., Multiresolution spatial characterization of land degradation phenomena in southern Italy from 1985 to 1999 using NOAA-AVHRR NDVI data. Geophys. Res. Lett., vol. 30, no. 2, pp. 1069–1072, 2003.
[5] Lasaponara, R. (2006a). On the use of principal component analysis (PCA) for evaluating interannual vegetation anomalies from SPOT/VEGETATION NDVI temporal series. Ecol. Model. 194: 429 – 434.
[6] Lasaponara, R., 2006b; Estimating Spectral separability of satellite derived parameters for burned areas mapping in the Calabria Region by using SPOT-Vegetation data Ecological Modelling vol. 196, pp. 265-270.

[7] Lasaponara, R. 2005. Inter-comparison of AVHRR- based fire susceptibility indicators for the Mediterranean ecosystems of southern Italy International Journal of Remote Sensing 26 (5), 853-870

[8] Lasaponara, R., Santulli, A., Telesca, L., 2005. Time-clustering analysis of forest-fire sequences in southern Italy Chaos, Solitons & Fractals 24 (1), 139-149

[9] Lasaponara R, N Masini 2009 Full-waveform Airborne Laser Scanning for the detection of medieval archaeological microtopographic relief Journal of Cultural Heritage 10, e78-e82

[10] Lasaponara, R., Masini, N., Rizzo, E., Orefici, G., 2011. New discoveries in the Piramide Naranjada in Cahuachi (Peru) using satellite, Ground Probing Radar and magnetic investigations Journal of Archaeological Science 38 (9), 2031-2039

[11] Lasaponara, R., 2006. Estimating interannual variations in vegetated areas of Sardinia island using SPOT/VEGETATION NDVI temporal series Geoscience and Remote Sensing Letters, IEEE 3 (4), 481-483

[12] Masini, N., Lasaponara, R. 2006. Satellite-based recognition of landscape archaeological features related to ancient human transformation Journal of Geophysics and Engineering 3 (3), 230

[13] Telesca, L., Lasaponara, R., 2006. Pre and post fire behavioral trends revealed in satellite NDVI time series Geophysical Research Letters 33 (14).