NDVI fluctuations from 1995 to 2006 in South Italy and North Africa: a search for a climate change indicator

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ABSTRACT

Seasonal and interannual vegetation trends in the last eleven years were analyzed for two macro-regions, South Italy and North Africa, in search for evidence of climate changes and associated desertification processes. The South Italy macro-region comprises Apulia, Campania, Basilicata, Calabria and Sicily regions, while the North Africa one covers the northern part of Lybia. Vegetation index data for the whole Europe and North Africa can be retrieved from the DLR archive of thematic maps in the form of monthly composite Normalized Difference Vegetation Index (NDVI) maps. The DLR archive dates back to 1995, thus the analysis could only be carried out for the last eleven years. The analysis of temporal vegetation variations was performed by implementing specific routines which provide objective measurements of vegetation trends and anomaly. Rainfall data for the same periods and geographic areas, were also analyzed in order to investigate the correlation between the two phenomena. Results for the two selected macro-regions, from 1995 to 2006, are presented and discussed. In a successive phase, this study will focus on distinguishing vegetation variations at regional level, in order to compare different local trends.

Keywords: NDVI, Vegetation Index, Vegetation Anomaly Analysis, NDVI fluctuations

1. INTRODUCTION

The Normalized Difference Vegetation Index (NDVI) used in this study is the index derived from measurements made by AVHRR sensor onboard of NOAA polar orbiting satellites; it is calculated from the measurements in channel 1 (visible) and channel 2 (near infrared) as:

$$NDVI = (\rho_{nir} - \rho_v)/(\rho_{nir} + \rho_v) \tag{1}$$

where ρ_v) and ρ_{nir} are the surface reflectances in the 550-700nm and 730-1000nm regions of the e.m. spectrum, respectively.

NDVI temporal series at global or continental scale are made available by several data centres around the world and provide a valid tool for monitoring vegetation trends. A large amount of literature on the use of NDVI have been published in the in the last twenty years. This paper presents an analysis of NDVI dynamics in two macro-regions, South Italy and North Africa, in the last eleven years. For both selected areas, characterized by a Mediterranean ecosystem, our aim is the search for a climate change indicator. Recently Cuomo et al.[1] have published a study of interannual vegetation variation in Southern Italy from 1985 to 1999; the study shows a clear contraction in vegetation activity in the period. The study presented here extends the work of Cuomo et al. to the most recent year and considers, in addition, an area of North Africa inside the same longitude range of the former one. A notable difference with Cuomo et al. work is that, rather than starting from raw AVHRR data, the availability of archived and verified NDVI data sets was exploited. Our analysis is based on two simple methods, similar to those described by Myeni et al.:[2] the first one provides the mean trend of vegetation, while the second one describes vegetation anomaly behaviour. The results will then be compared with rainfall time series for the corresponding periods. The two macro-regions selected for this study are shown below: the South

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Italy one extends from 42°N to 36°N in latitude and from 12°E to 18.5°E in longitude (Fig.1), while the North Africa one extends from 33.4°N to 29.8°N in latitude and still from 12°E to 18.5°E in longitude (Fig.2).

The paper is organized as follows: Section 2 describes the datasets used while Section 3 discusses the analysis methods; Section 4 illustrates the achieved results and, finally, Section 5 concludes the paper discussing the results and outlining future research directions.

2. DATA SETS

2.1. DLR MVC NDVI Dataset

The NDVI dataset employed in this study was retrieved from the DLR/EOWEB data archive[3] . EOWEB provides access to different earth observation data sets: among these are NOAA AVHRR products which cover the whole Europe and North Africa in the form of composite daily, weekly and monthly NDVI[4] . In particular, the Level 3 product Maximum Value Composite (MVC) monthly NDVI was chosen, as it ensures a good quality by excluding atmospheric alterations by clouds and aerosols[5] . The AVHRR images of DLR archive are related to Central Europe, the geometrical resolution of the instrument is approximately 1,1 km at nadir but reduced, because of the large swath and earth curvature, to about 6 km near the pass edges. The data are remapped onto a Mercator projection with a geometrical resolution of 1.1132 km at the center of the satellite map at 51°N,15°E. The "nearest neighbour" technique is applied for resampling the pixels onto the map whose size is 4300 lines x 4100 samples. The NDVI maps are then calibrated, with clouds and water detected and labelled.

The whole monthly dataset from 1995 to 2006 was retrieved from the DLR web archive. Because of NOAA satellite or AVHRR failures, the data set is not continuous and few monthly maps, mainly in year 1999, 2000 and 2001, are missing. NDVI maps are downloaded in HDF-4 format; they consist of 1 layer at 8-bit resolution (256 grey levels) and must be converted to "raw" in order to be converted to NDVI values for later processing. In the Level 3 NDVI products, value 0 refers to water, value 255 refers to clouds and no valid data (like snow and ice). The NDVI range starts from -0.0968454 and refers to Grey value 1. The radiometric resolution is 0.0031546, GreyValue 254 thus refers to NDVI value 0.7 (maximum NDVI). To obtain NDVI values from GreyValues, the following expression must be applied:

$$NDVI(x,y) = GreyValue(x,y)/3.17 - 0.1 \tag{2}$$

The NDVI monthly sequences for the macro-regions under study have been extracted from the full product (see Fig.1) by means of a specific procedure which makes use of the commercial software TeraScan[6] . This procedure consists of the following steps:

1. HDF-4 to "raw" conversion of the full product;
2. geo-referencing of the full product;
3. extraction of the two areas of interest on their original Mercator projection;
4. application of eqn.(1) and production of the final NDVI map to be used in the later analysis.

2.2. GPCC Rainfall Dataset

Rainfall data are obtained from the Global Precipitation Climatology Centre (GGPC)[7] which provides global precipitation analyses and data sets for Earth's climate monitoring and research. The rainfall dataset, which spans the period from 1951 to 2004, is based on quality-controlled data from a large number of stations, with irregular coverage in time and space. The GPCC provides global gridded precipitation data at 2.5°, 1.0° and 0.5° resolution. The data related to the two regions of interest were extracted from the global file containing one year of precipitation data at the maximum resolution, 0.5°, for the twelve years from 1993 to 2004.

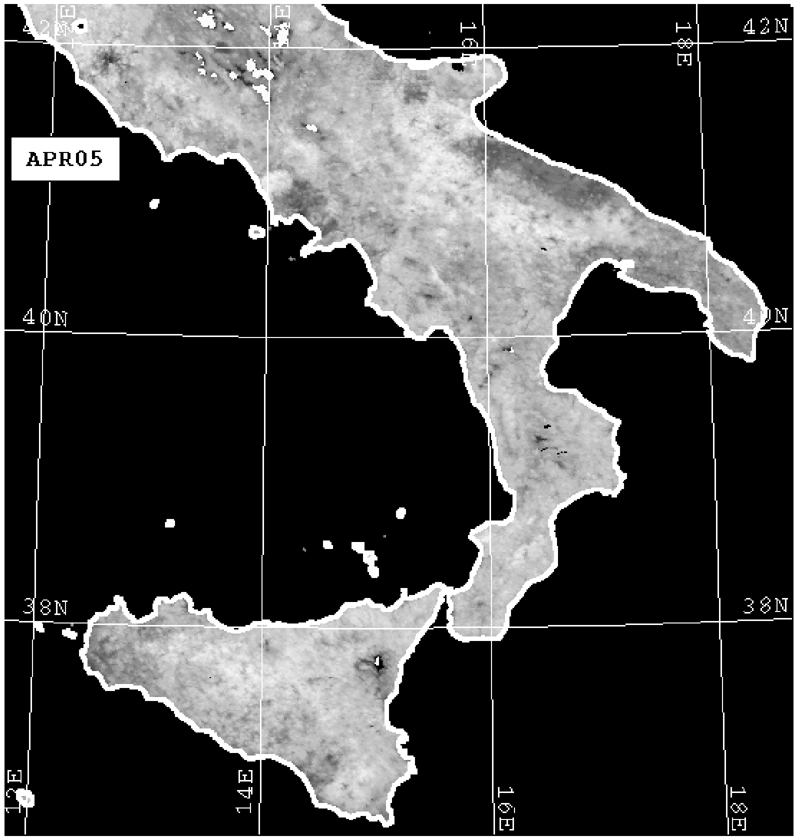

Figure 1. Sample NDVI map for the macro-region South Italy (April 2005).

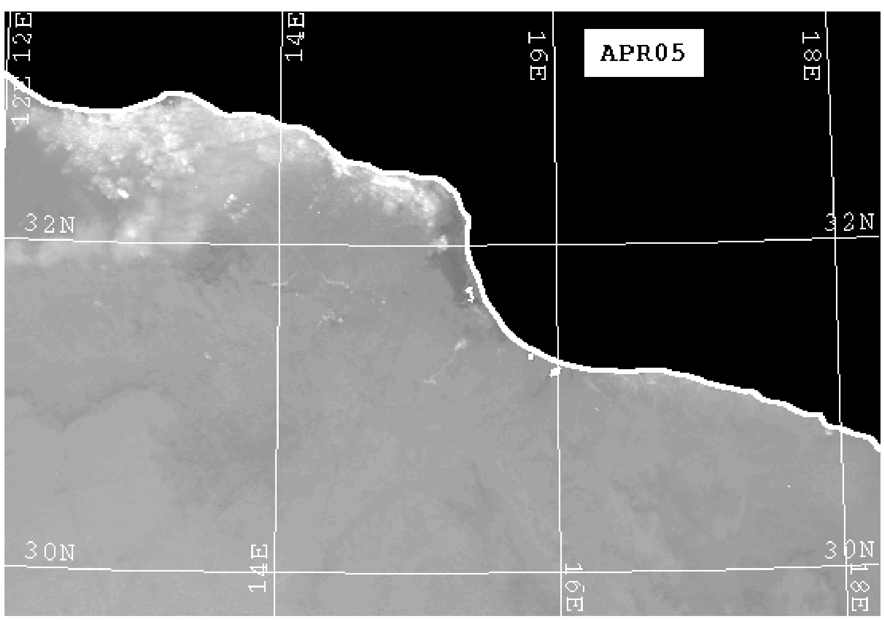

Figure 2. Sample NDVI map for the macro-region North Africa (April 2005).

3. ANALYSIS METHODS

Two methods of analysis were applied in this work to both areas under study:

- an evaluation of vegetation trend, obtained by analyzing the total NDVI and its spatial average for each month and year;
- an estimation of spatial average of long term NDVI anomaly, according to the analysis methods described by Myneni et al.[2] .

For the first method: let $x(k,m,y)$ be the MVC monthly NDVI of pixel k in month m and year y, the spatial average can be computed as

$$\tilde{x}_k(m,y) = 1/N_p \sum_{k=1}^{N_p} x(k,m,y) \tag{3}$$

where N_p is the number of pixel of the analyzed area. This spatial average is performed by only considering the pixels not corresponding to water, clouds or snow/ice covers, these being easily identified in the NDVI maps.

For the second method: a modification of Myneni et al. methodology for long term monthly NDVI anomaly evaluation, was developed; this new method is based on the use of the *median*, rather than of the *mean* as in Myneni et al. The NDVI monthly value of a pixel in the study area, in a given year, can be considered a continuous random variable belonging to a given distribution. The *median* is the value p such that the probability is at least 1/2, or 50%, that a randomly chosen point on the function will be less than or equal to p, and the probability is at least 1/2 that a randomly chosen point on the function will be larger than or equal to p. Thus, let $\hat{x}(k,m)$ be the long term monthly *median* value of pixel k in month m, the monthly NDVI anomaly $x'(k,m,y)$ is computed as:

$$x'(k,m,y) = [x(k,m,y) - \hat{x}(k,m)]. \tag{4}$$

The monthly anomaly represents a simple measure of the offset of NDVI, for a given pixel, month and year, with respect to its long term mean behaviour. The long term NDVI anomaly can be spatially averaged in order to achieve a vegetation trend indication.

Before starting to describe how the monthly NDVI anomaly can be analyzed, a motivation of the use of the *median*, rather than the *mean* as used by Myneni et al., is given. The long term monthly average NDVI of a given pixel, in a month m and year y, can by computed as the arithmetic mean; in this way, if some spike occurs, the anomaly evaluation can be altered because the value representing the mean behaviour is altered. On the contrary, the *median* is not influenced by spikes and gives a better description of the long term mean behaviour.

Like in Myeni et al., two approaches were adopted for the spatial averaging of the anomaly. Being $x'(k,m,y)$ the long term monthly anomaly of pixel k, in month m and year y, the spatial averaging operation can be performed in two ways:

1. by only considering those pixels having a corresponding $\hat{x}(k,m)$ long term monthly median value larger then the fixed threshold: with this method the pixels taken into account will vary from month to month but will remain almost constant from year to year (see discussion below); this method is called Vary Month Constant Year (VMCY) and is best suited to study climate-induced variations in NDVI.
2. by only considering those pixels having a corresponding $\hat{x}(k,m)$ long term monthly median value larger then the fixed threshold in May ($k = 5$). This method is called Constant Month Years (CMY) because the pixels involved in the average is constant from month to month and from year to year. The spatial average of NDVI anomaly performed according to this method highlights NDVI seasonality. In this definition, the month of May was chosen as the "greenest" month of the year for the study areas.

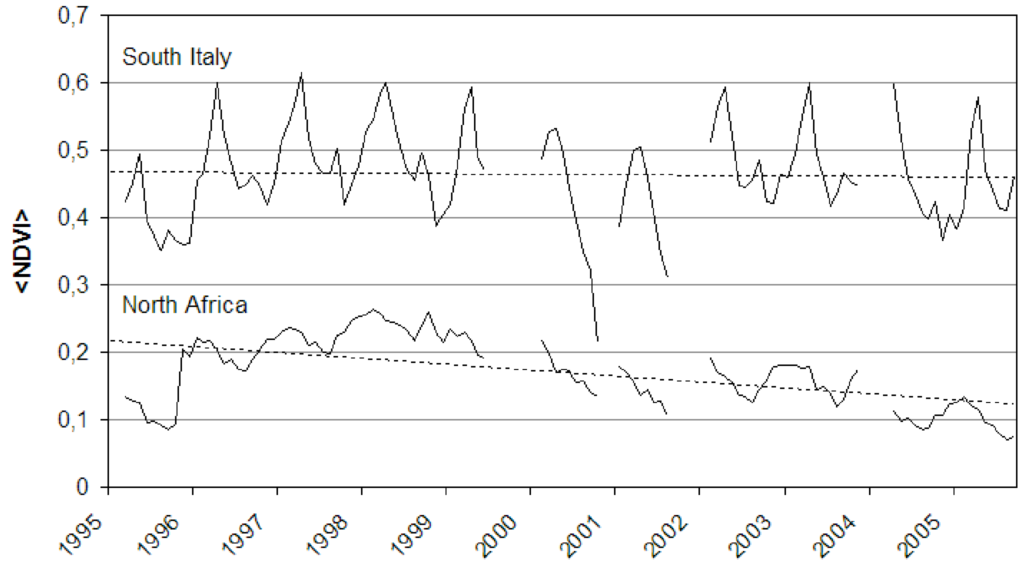

Figure 3. Time series of averaged NDVI for South Italy and North Africa. The dashed lines are the regression lines of the two curves, representing their long term trend.

In both cases, the pixels taken into account must satisfy a further criterion:

$$x'_s(k, m, y) < |3\sigma| \tag{5}$$

where x'_s, the standardized anomaly, is defined as:

$$x'_s(k, m, y) = [x(k, m, y) - \hat{x}(m, y)]/\sigma(k, m) \tag{6}$$

where the long-term monthly NDVI standard deviation of pixel k in month m, $\sigma(k, m)$, is defined as:

$$\sigma(k, m) = \{\frac{1}{N_y - 1}\sum_{y=1}^{N_y}[x(k, m, y) - \tilde{x}_y(k, m)]^2\}^{1/2} \tag{7}$$

and $\tilde{x}_y(k, m)$ is the average over years. As a consequence, the pixels for which $x'_s(k, m, y) \geq |3\sigma|$ are not included in the spatial average and are considered as outliers.

All the analysis methods described in this section were implemented in MATLAB language[8] .

4. RESULTS

The two curves of the average NDVI value, for the analyzed areas and for the study period (1995-2006), are shown in Fig.3. The upper curve, regarding South Italy, displays marked seasonal oscillations, with low values in the autumn of year 1995, 2000 and 2001. For both areas the regression lines indicating the long term trend, are decreasing, with a steeper slope for the North Africa data set.

Fig.4A and B show the time series of averaged NDVI anomaly for South Italy, computed according to VYCM and CMY methods. The two plots look very similar and this demonstrates that the two methods are almost equivalent. Fig.5A and B are the correspondent of Fig.4A and B for North Africa.

As vegetation development is clearly linked to rainfall, the time series of precipitation data retrieved from the GPCC were plotted against NDVI time series for South Italy (Fig.6A) and North Africa (Fig.6B). The visual inspection of Fig.5A and B reveals a strong, lagged, correlation between rainfall and NDVI curves, with a time-lag of 1-2 months; in order to obtain an objective measure of the time-lag between the two curves, the cross-correlation function[9] must be computed: this will be part of a successive, extended, study.

5. DISCUSSION AND CONCLUSIONS

Aim of this work was to investigate the possibility to identify, by means of series of NDVI maps ranging from year 1995 to 2006, a climate change indicator for the two selected macro-regions.

The analysis of average NDVI long term trend shows a moderate decline for South Italy but a more marked one for North Africa. The same can be said for NDVI anomaly computed by both methods described above: a steep decrease for North Africa and a modest one for South Italy. It can be concluded that both indexes, average NDVI and NDVI anomaly, can be used as climate change indicators: this holds in particular for North Africa macro-region, with NDVI anomaly being especially sensitive to climatic variations.

Some issues still remain to be investigated:

- the steep declines of NDVI in South Italy in the autumn of years 2000, 2001 and 2002 and their relation with environmental factors;
- the marked negative peaks of NDVI anomaly for South Italy in the autumn of year 2001 and in January 2005 and their relation with environmental factors;
- the time lag between rainfall and NDVI curves by means of the cross-correlation function.

These points will be dealt with in a successive paper which will also include the analysis of the current year 2006.

As a concluding remark we wish to stress the great advantage of exploiting the large ammount of remote sensing data made available nowadays by public archives (DLR, NASA, NOAA, JRC-IES, etc.). The study presented here was indeed made possible thanks to the generosity of DLR archive.

ACKNOWLEDGMENTS

The authors wish to thank the German Aerospace Center (DLR) for the free access to its archive of NDVI thematic maps, and the Global Precipitation Climatology Centre (GPCC) of the German National Meteorological Service (DWD) for the free access to its global precipitation data sets.

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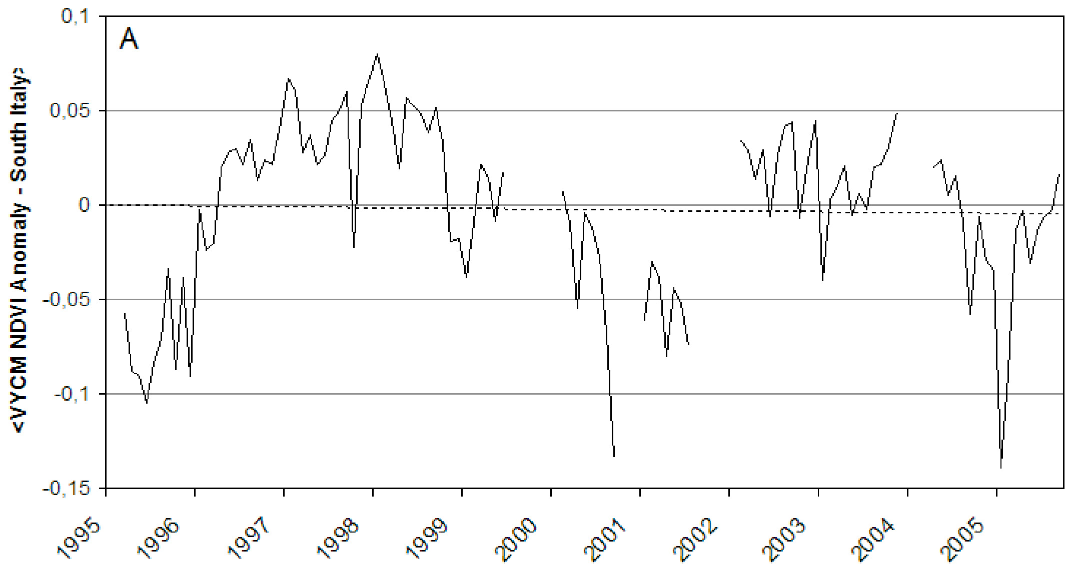


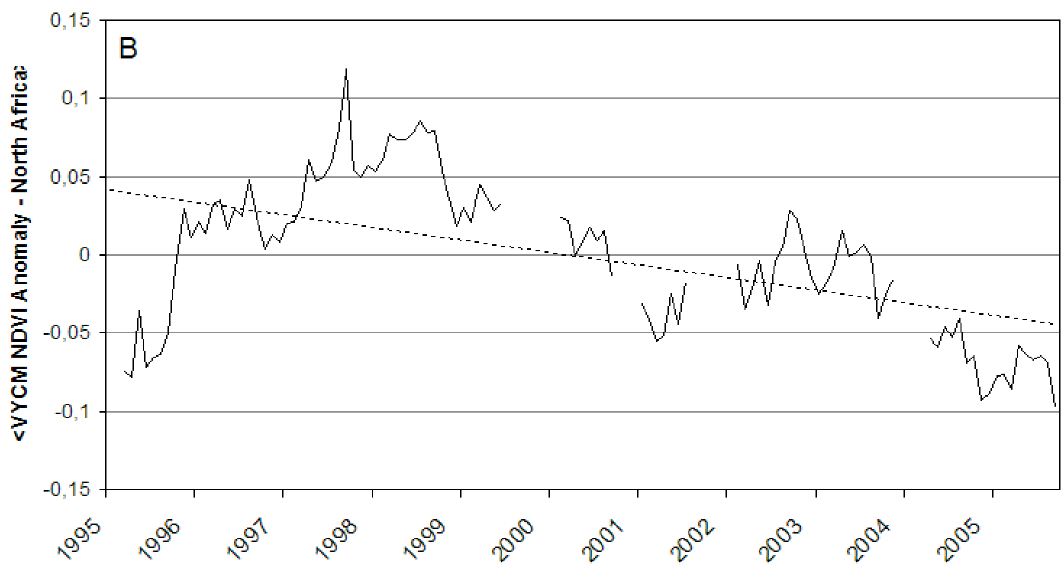
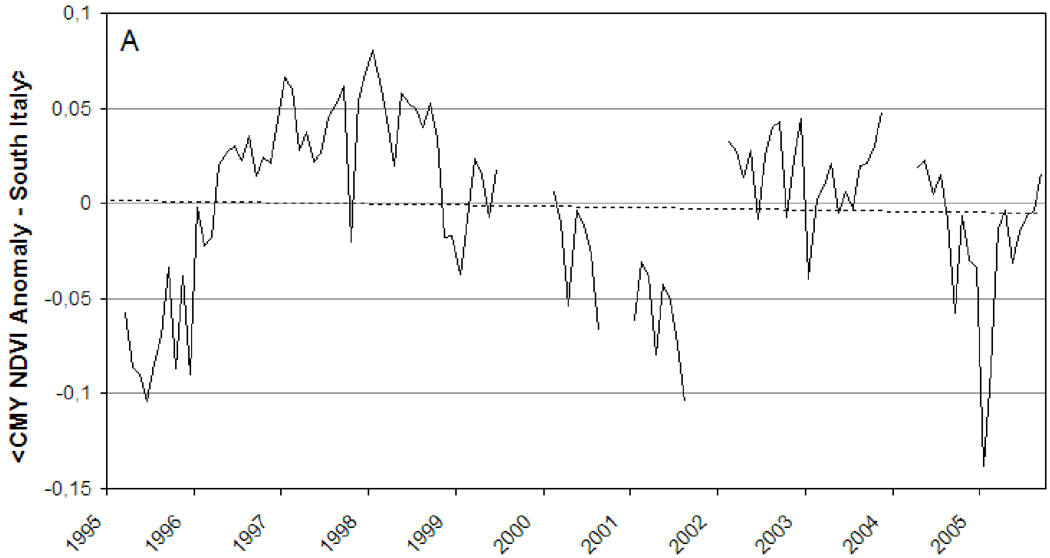


Figure 4. Time series of averaged NDVI anomaly for South Italy. A: Computation according to VYCM method. B: Computation according to CMY method.



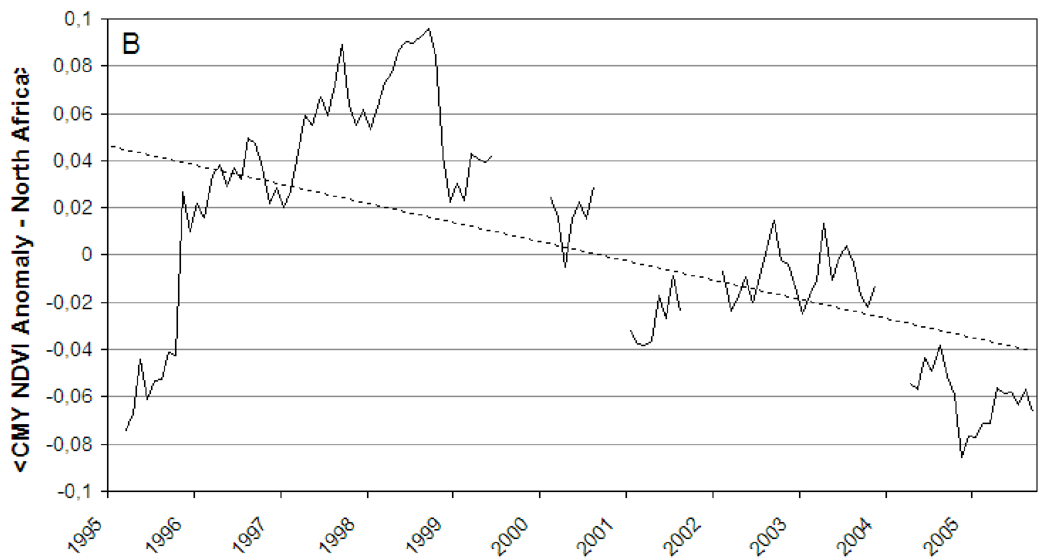


Figure 5. Time series of averaged NDVI anomaly for North Africa. A: Computation according to VYCM method. B: Computation according to to CMY method.

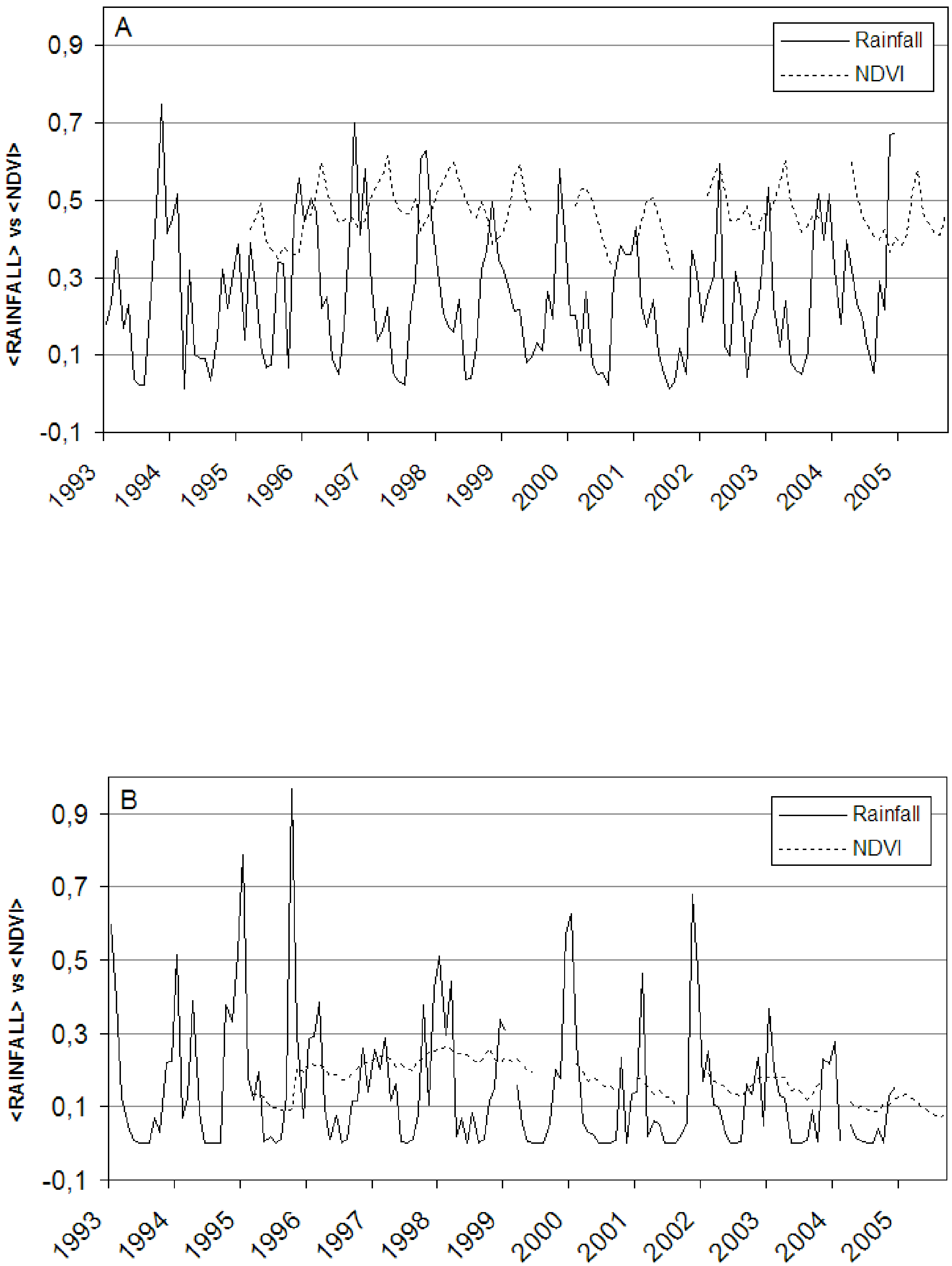


Figure 6. Time series of averaged rainfall and NDVI: both curves are normalized with respect to their maximum value in order to facilitate the comparison. A: South Italy. B: North Africa.