Arid Land cover change trend analysis with series of satellite images for desertification monitoring in Northern Africa

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Abstract – A time series of 27 Landsat images (MSS and TM) over an ecological study area in Tunisia has been georeferenced and resampled. Conversion of DNs into ground reflectance has been done in two steps: full atmospheric correction of the most recent images and regression method with pseudo-invariant features detected through statistical analysis. Three different approaches of change detection have been tested : change in classes through time, vegetation and colour indices linear trend analysis and Fourier decomposition. Strong degradation and then recovery has been evidenced during the 30 years time span, demonstrating the necessity of long term monitoring for desertification assessment.

Keywords: Land degradation, desertification monitoring, Landsat, time series, intercalibration, trend analysis, Tunisia.

1. INTRODUCTION

Desertification is a very well known threat to the sustainable use of arid lands, and remote sensing is an invaluable source of information over the large areas affected. Despite some local success in delineating degraded areas, the simple 'single date' approaches have been generally disappointing because of the large interannual climatic variability of arid lands. It is now recognised that assessing the degree and extent of desertification affecting a given region requires several years of observations, to be able to detect long term trends, beyond the succession of dryer and wetter years.

In this study, part of a broader euro-mediterranean research project on desertification monitoring, the region of Menzel Habib in southern Tunisia, subjected to ground ecological observations since the 70's, has been used as test area for a long term satellite monitoring experiment. (extension: 34° 02' to 34° 19'N and 9° 33' to 10° E). A 'bottom-up' approach has been developed to establish links between ground features and remote sensing measurements performed in the optical domain. Based on the relationships established three different methods have been tested to assess the long term changes in terms of desertification : areas with worsened, stable or improved ecological condition.

2. LAND SURFACE CHARACTERISATION

Soil and vegetation features related to various degrees of desertification have been characterized on the ground, and along the seasons. On each sampling plot soil colour, texture and condition was recorded as well as plant type and specie, size and development stage. Each land surface sample was subdivided into homogeneous patches such as, sand, gravels, vegetation clump, bare soil with litter, e.g. Spectral reflectance of each of these 'elementary' patches' has been recorded with a portable field spectrometer calibrated versus a reference plate. Simultaneously measurements along transects with the same instrument has allowed to estimate integrated reflectance values at the level of several pixels. Thus a collection of pure and mixed spectral signatures has been established, its analysis has allowed to determine the land surface parameters retrievable from satellite imagery.

Among the striking spectral characteristics of arid land surfaces three may be underlined (Escadafal, 1994) :

1. most of the vegetation is non-green, i.e. displays a weak R/NIR contrast compared to the typical vegetation signature. In that case brightness index is more relevant than classical vegetation indices.
2. soils present a large variability of spectral signatures, specially when taking into account the medium infrared range (e.g. quartzic sand and gypsiferous soils have very contrasted spectral features when comparing visible and MIR parts).
3. land degradation is characterised not only by a decrease of vegetation cover, but also by changes in the soil surface composition (due to wind erosion, e.g.), consequently modifying their reflectance properties.

3. IMAGE SELECTION and PROCESSING

3.1 Building a time series

In order to gather a series of images with the largest possible time span, we focused on the ones collected by the Landsat satellites first the MSS starting in 1972 and then the Thematic Mapper (TM). This combination is rarely used in published satellite time series analysis (Bruzzone et Smiths, 2002).

Despite claims from the satellite images distributors, it is rather difficult to find historical data, among the data theoretically acquired since the launch of the first earth observation satellites, only a few can be actually obtained today. The maintenance of the archive is quite costly and is usually not a priority, as a consequence the Landsat archive is maintained mainly for the United States territory. The Spot images collection is another archive covering the globe, it is more complete but starts only in 1986. In the present study we managed to gather the collection of images listed in table A, showing their uneven time pacing, making the analysis more difficult.

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Table A. List of images of the time series over Menzel Habib (month/year)

Landsat MSS	08/1972 - 02/1973 - 11/1975 - 04/1976 – 06/1976 - 06/1977 - 02/1978 - 07/1979 - 06/1981 - 05/1984 - 09/1987 – 03/1993-
Landsat TM	03/1986 - 04/1989 - 03/1991 - 07/1991 – 03/1993 - 04/1994 - 03/1995 - 03/1996 - 07/1996 - 03/1997 - 03/1999 – 07/1999 - 09/1999 - 12/1999 - 05/2003

Then the sharpest and most recent TM images has been carefully georeferenced with maps and GPS ground control points. The other TM images have been wrapped to the georeferenced one, producing a set of stackable TM images. Then to overcome the resolution difference, with MSS, all images have been resampled with a pixel size of 60 x 60 m. and the MSS have been warped onto the resampled reference TM. At that stage a set of 27 geometrically correct images has been obtained.

To explore the spectral difference between the two type of images, ground collected reflectance spectra have been resampled in the MSS and TM bands allowing to analyse the degree of similarity between equivalent band in the context of the studied area. Results in table B show the strong correlation observed between band pairs. This was expected but **a** and **b** coefficient obtained describe the small difference in spectral range, more noticeable for the first two band pair. It could be used to convert MSS band values into TM values to increase the inter-comparability. However the effect of this correction is modest, and it is in fact not necessary in the pseudo-invariant approach applied for conversion to ground reflectance

Table B. Correlation between ground reflectance data resampled in the similar bands of the two Landsat sensors

	r^2	a	b
TM2 / MSS4	0.993	-0.1315	0.903
TM3 / MSS5	0.999	0.1055	0.980
TM4 / MSS7	1.000	-0.0550	1.0005

3.2 From DNs to ground reflectance values

To be able to compute changes, values contained in the different images of the series must be comparable. The raw images obtained from the provider have values of pixel radiance coded in digital counts. Sensor calibration and atmospheric effects vary from date to date preventing direct comparison of radiance values. A conversion into reflectance at the ground is required. For the recent TM images enough information on satellite calibration was available to use a physical model converting DNs into radiances (ATPRON).

This model is based on some assumption on atmospheric conditions difficult to verify in our context, and as a result the correction was not as good as hoped, significant global differences between some images (offsets) being obviously due to an imperfect intercalibration. To refine it a statistical method for radiometric calibration has been developed based on invariants detection (Schott et al.,1988). A set of areas of minimum temporal variability has been recognised within the time series by computing the variance over time for each band. A resulting set of groups of pixels with very low variance has been established, each one corresponding to an invariant land surface element identified as such on the ground (rocks and soils permanently bare, steppe in stable condition, olive tree plantations, e.g.). When considering each of date pairs a good linear correlation (R2 = 0,8-0,9) is observed between the raw images and the reflectance values (fig.1).

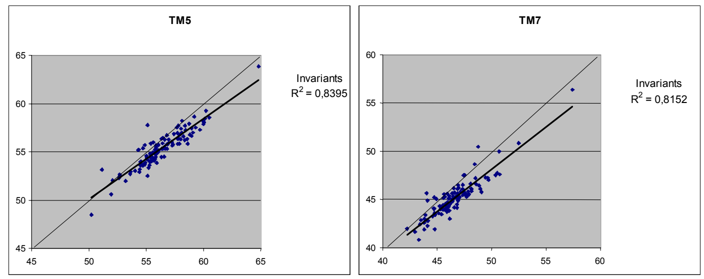

Figure 1. Reflectance of reference image (x) versus values of the other dates (y) for a subset of invariant pixels. The regression coefficients are used to inter-calibrate the images.

Once these invariant are detected, they are used in return to improve the radiometric calibration of the initial 11 TM images. The errors occurring using the physical model appeared to be low but significant, justifying the a further intercalibration applied on the images (Simonneaux et al., 2001). The same process has been applied to the MSS images and at the end of the calibration process we obtain a stack of 27 inter-comparable images of the same size (Xiaojun & Lo, 2000). The bands common to all images are green, blue an near-infrared. Using the results of the ground data analysis, these 3 bands have been used to infer information on soil surface colour, on vegetation greenness (with vegetation index), and on the overall brightness (linked to the global cover).

4. ASSESSMENT of CHANGES

4.1 Classes changes with time

A first attempt to assess changes has been based on a classification technique. In this case a subset of five TM images has been used for a feasibility analysis over a 10 years time span. I this approach each image is classified by maximum likelihood criteria into 10 land surface types according to soil composition and vegetation cover (sandy soil, with low cover steppe, loamy soil with dense cover of annual plants, e.g.).

The classification scheme has been trained on the image of 1999 where detailed ecological observations was done simultaneously on the ground (Jauffret, 2001). The four other images recorded at the same season and being radiometrically equivalent have been subjected to the exact same classification scheme. To make the change analysis more straightforward, in a first exercise the 10 classes have been regrouped under three broader ecological categories: bare soils, soils with low vegetation cover and soils with medium vegetation cover. The objective is to detect trends of changes between these categories through time.

A given pixel has a specific destiny through time, changing (or not) from one class to another between the 5 dates. The number of possible specific pixel movements with time between 3 classes is $5^{3=}$243. However not all situations are significantly represented in reality, thus 65 different time profiles are including 80% of all the pixels. Then the time profiles (or time class changes pattern) have been regrouped on the basis of their significance in terms of desertification : stable condition (no or low changes), degradation (negative changes from medium to low and zero cover) and restoration (positive changes towards higher cover). The resulting map (fig.2) summarizes ecological changes and shows a higher percentage of restored areas compared to degraded, indicating that the previously prevailing desertification trend has been reversed during the 1989-1999 period (Tabarant & Escadafal, 2001).

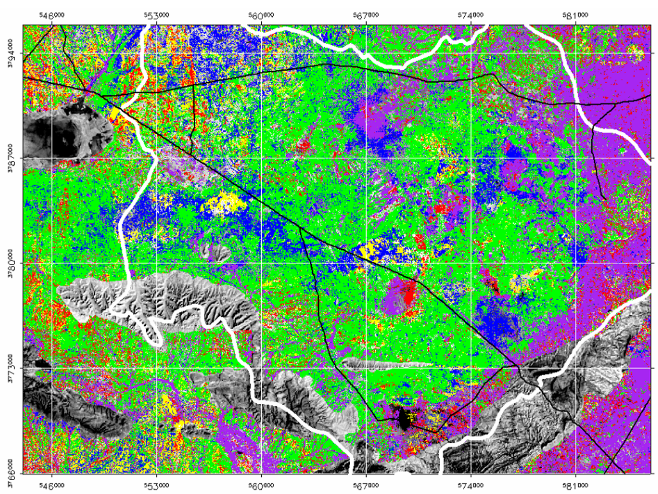

Figure 2. Result of change detection with 5 TM images between 1989 and 1999 (area about 40x60 km)
in red: areas degraded, in blue: areas restored, other colours: stable

This approach showed interesting results but is difficult to apply to large series, as the number of combinations increases with the power of the number of images.

4.2 Linear trend analysis with time

To tackle the objective of processing the whole series of images, a brightness index trend has been computed for each pixel using a linear regression over the 27 dates (Presseq, 2003). However a regression line may have little significance if the values are highly dispersed. The variance has thus been used, considering that when its values are high, the trend is not well defined. The colour scheme of fig.3 is designed to display the two type of results: trend slope (positive or negative) and variance ; note that light grey correspond to null slope, i.e. no trend. Decrease in brightness seem dominant, indicating an ecological trend towards higher vegetation cover (restoration), but in many cases the trend is not very clear (high variance).

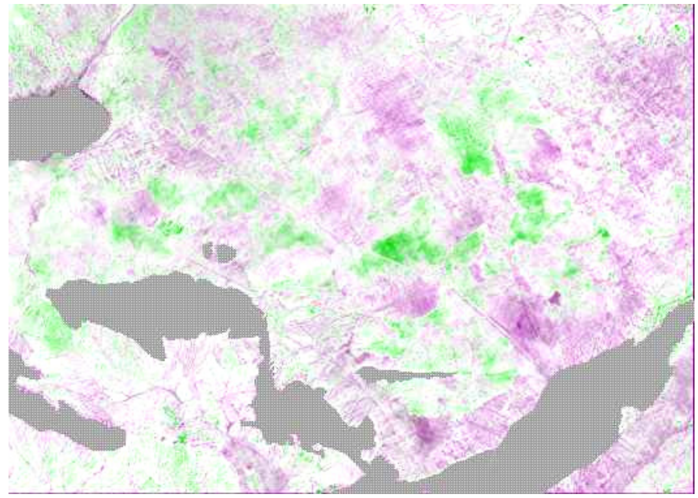

Figure 3. Linear trend analysis of brightness for the 27 images series 1972-2003 (same area) *violin: decrease, green: increase; grey: mask over the mountainous areas*

Some areas display a significant increase in brightness, corresponding to desertification hot spots, as confirmed by ground verifications. However the results obtained by this method are not sufficient to provide an overall diagnosis of the ecological status of the studied region, more should be retrieved from our large data set.

4.3 change frequency analysis

Changes in the studied ecosystem are driven by climatic factors and the behaviour of its users in the wider context, including the socio-economic one. As a result, instead of a regular clear trend, the ecosystem condition fluctuates, with ups and downs. To detect patterns, a frequency analysis using Fourier transform has been applied to the series of 27 images, using again the brightness index.

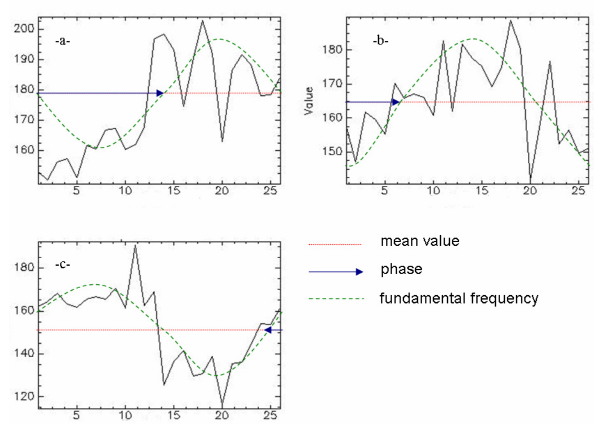

Figure 4. Frequency analysis of the brightness fluctuations in the 27 images time series (3 typical cases displayed on fig.5)

For each pixel the change curve could be deconvolved in fundamental and harmonic frequencies (Albinet, 2004).
Fig.4 displays the curves of three typical cases, mapped on fig.5 :
a) overall increase of brightness (degradation),
b) after a degradation phase, restoration in the last decade (result of exclosure policy),
c) areas protected in the 90's recently turned back to grazing and cultivation..

The other areas have less well defined change patterns and could not be related to one of those three simple categories.

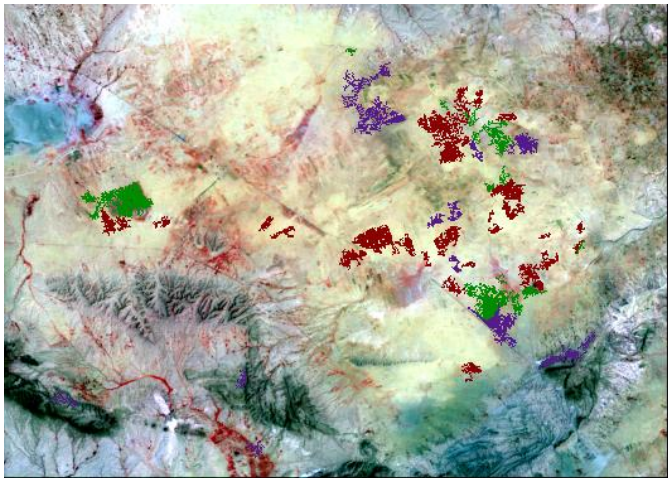

Figure 5 . Three different fluctuations profiles in 27 images series brown: a) , green: b) , violin: c) ; see fig.4 for details (*background: colour composite of June2003 image)*

5. DISCUSSION and CONCLUSION

This change detection study has been based on a laborious process of 27 Landsat MSS and TM images geo-referencing, and two-step radiometric intercalibration. Although rich in ecological content the post-classification method appears better suited for more limited series. A statistically based linear trend showed very global results, interesting but poor in details compared to the amount of data available. The more sophisticated frequency analysis allowed to distinguish among various types of fluctuations, with the example of 3 typical situations, but more could be defined. An overall long term trend has been clearly detected : after the severe degradation alert of the mid 80's, programmes to combat and prevent desertification reversed the tendency and in the last decade the studied areas shows clear recovery.
Future studies of this type will benefit from better archiving and pre-processing of imagery by the providers, and from taking into account the seasonality and climate variability.

Acknowledgements

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