

## Fourier analysis of time series of NOAA-AVHRR NDVI composites to map isogrowth zones

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### Abstract

A measurement of the quality of vegetation zones in dynamic terms is provided by the Fourier analysis of time series of AVHRR/NDVI monthly observations over 10 years. The present approach is shown to be a powerful way to classify and extract various dynamic parameters of the vegetation in Southern Africa. The resulting *map of isogrowth zones* of Southern Africa was highly correlated to a radiational index of dryness or Budyko ratio as well as to the spatial distribution of vegetation types according to White vegetation map.

### 1. INTRODUCTION

The timing and distribution of phytophenological events reflect the dynamic nature of the biosphere. Phenology is an extremely sensitive indicator of the many factors, such as climate, soils, and land management, that affect natural vegetation as well as agricultural crops.

Satellite remote sensing provides a way to measure and monitor phytophenology on a global scale: time series of monthly values of NOAA-AVHRR Normalized Difference Vegetation Index (NDVI) extending over 10 years (1981-1992) for Southern Africa and South America were used in this study. The main constraint remains how to summarize the huge quantity of satellite information: time series analysis techniques provide an opportunity to identify and describe coherent structures in the observations using few parameters. The NDVI is obtained with the radiances observed by the Advanced Very High Resolution Radiometer (AVHRR) on board the polar meteorological satellites of the NOAA series. Radiances in the red (Ch1) and near-infrared (Ch2) spectral regions are used:

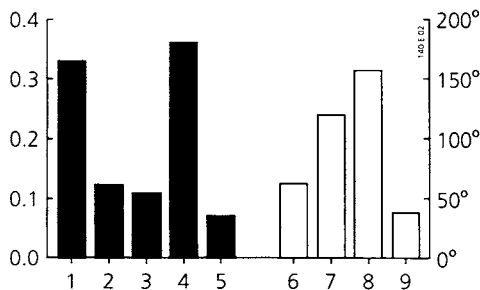


Figure 2. Measurements of different attributes obtained by the FFT algorithm analyzing monthly NDVI data from August 1981 till July 1990 from the same subarea of Figure 1. 1 = average NDVI value, 2 = value of amplitude at 9 years, 3 = value of amplitude at 4.5 years, 4 = value of amplitude at 1 year, 5 = value of amplitude at 6 months, 6 = value of phase in degrees at 9 years, 7 = value of phase at 4.5 years, 8 = value of phase at 1 year, 9 = value of phase at 6 months.

## 2.2. Classification of isogrowth zones

The Fourier transform of the NDVI time series gives a rather large number of possible choices of attributes, viz. amplitude and phase values in different combinations, to apply either numeric classification or qualitative interpretation. A detailed intercomparison of classification results is necessary to understand which attributes (amplitude, phase, frequency) are most significant and whether the latter depends on differences between ecosystems. A classification test has been developed to establish which attribute combination and which classification procedure give the best classification performance.

This test establishes the efficacy of the classifier and of the pattern features used to train the classifier. The performance of the classifier is measured in terms of separability, accuracy and reliability.

The separability indicates if  $n$  spectral vectors can be distinguished in  $i$  classes. Separability is quantified by estimating signature divergences. Accuracy indicates how many pixels have been classified correctly whereas reliability indicates the probability that a spectral vector actually belongs to the class to which has been assigned. An optimal classifier should maximize the values of separability, accuracy and reliability.

Briefly, the procedure to map isogrowth zones was based on the following steps:

- selecting dominant components in the observed Fourier spectra (amplitude values vs. period) e.g. 1 year, 6 months;
- defining classes; class attributes are amplitude and phase values;
- applying different numerical classification methods;
- analysing the statistical significance of classification results.

The assessment of classification procedures was done by considering each procedure to be a vector  $C_i$  with three coordinates:

# *Reliability* was calculated as the integral of the curve obtained by plotting the

$$\text{NDVI} = \frac{\text{Ch2} - \text{Ch1}}{\text{Ch2} + \text{Ch1}} \quad (1)$$

NDVI values fall in the range (-1, 1) and are rescaled to (0, 1023) for binary codification (10 bits).

Spectral vegetation indices, like the one given in Eq. (1), provide a measure of the amount of green (photosynthetically active) vegetation [1,2]. Some authors [1,2] observed simple relationships between NDVI and primary productivity.

Because of seasonality in forcing environmental parameters, e.g. rainfall, time series is a quasi-periodic signal as illustrated by the example given in Figure 1.

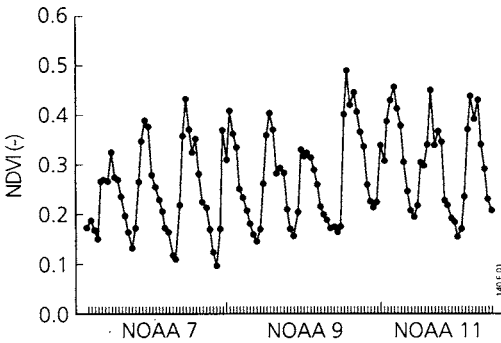


Figure 1. Time series of monthly average values of NOAA-AVHRR NDVI from August 1981 till July 1990 for a sub-area in Africa (Okavango Delta, Botswana).

## 2. METHODOLOGY

### 2.1. Algorithm

A time series of NDVI images,  $I(x,y,t)$  can be represented as a Fourier series of the form:

$$I(x,y,t) = \sum_n A_n(x,y) \exp(i(\omega_n t - \phi_n(x,y))) \quad (2)$$

When a Fast Fourier Transform (FFT) algorithm is applied to the time series of NDVI images, these images are decomposed pixelwise in a set of periodic functions with different periods (or frequency). The amplitude of each component  $A_n(x,y)$  accounts for a portion of the observed NDVI variability; for each function the phase lag (readily converted into a time-lag taking the period into account),  $\phi_n$  with respect to the origin of time in the observations is obtained. The amplitude values of different periodic functions for a given area are objective measures of variability of vegetation growth. Finally, time-lag values provide a measure of earliness or lateness of vegetation growth. Since the technique is applied on a pixel by pixel basis, images of amplitude and time-lag are obtained for each period [3]. Figure 2 shows values of different attributes obtained by the FFT algorithm analyzing monthly NDVI data from August 1981 till July 1990.

fraction of pixels classified at a given confidence level vs. the confidence level. Values ranged between 0 and 1.

# *Separability* was the signature divergence (calculated with Jeffries-Matusita distance). Values ranged between 0 and 1.414.

# *Accuracy* was obtained as (1-error) where the error is the number of pixels in the training set not correctly classified divided by the number of pixels in the training set. It is assessed by calculating the error of the classified pixels. Values range between 0 and 1.

Next, a performance indicator (IP) was calculated as:

$$IP = \frac{\vec{C}_i \cdot \vec{C}_{ref}}{C_{ref}^2} \tag{3}$$

where  $C_{ref}$  is the classification vector with coordinates equal to the maximum values (1, 1.414, 1).

### 3. RESULTS

The results of 15 different classifications have been compared assessing the performance indicator via the methodology of Section 2.2. The results are shown in Figure 3; scores of Procedures 1, 2, 6, 7, 9 and 12 were rather high.

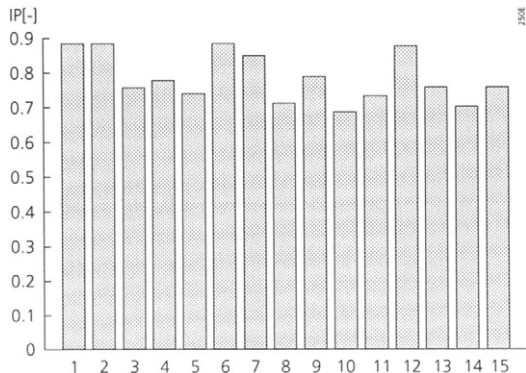


Figure 3. Values of the classification performance indicator (IP) for 15 classification procedures.

The map shown in Figure 4 was obtained by applying the classification procedure 2, combining a high classification performance with a good qualitative performance. Qualitative performance was assessed by comparing the outcome of

the numerical classification with: the map of Budyko index (ratio net radiation/precipitation on the surface) [4], the White map (vegetation map) [5] and the Global GRASS database [6].

Since the qualitative correlation, especially of the  $A_n$  images for the yearly and half-yearly components, was rather good, a regression analysis was done to assess more precisely the relationship of the NDVI time series with aridity (Budyko values) and vegetation type.

High correlation was found between amplitude values at 6 and 12 months with the distribution of the types of the vegetation and the Budyko index values. The highest regression coefficients were calculated for the values of amplitude at 6 months. Figure 5 shows these results obtained using the best fitting curves ( $a$ ,  $b$ ). The correlation values for  $a$ . and for  $b$ . were 0.93 and 0.87 respectively.

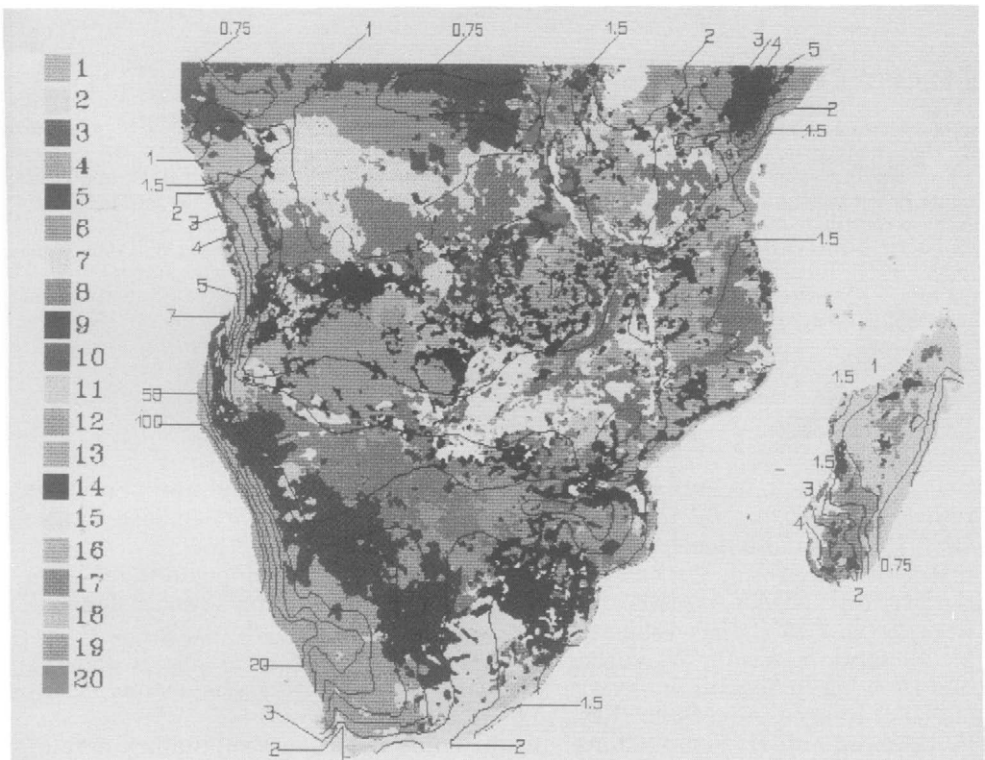


Figure 4. Map of isogrowth zones in Southern Africa; contour lines (black) indicate Budyko index values.

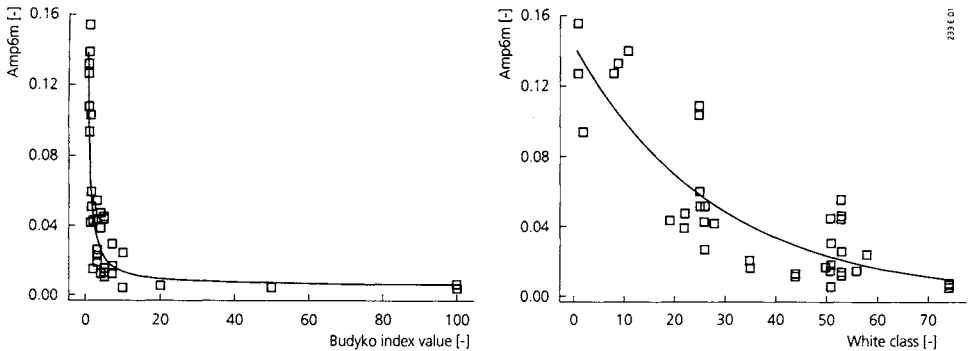


Figure 5a. Best fitting curve (linear divided by linear) of the amplitude values at 6 months vs. Budyko index values; b. Best fitting curve (exponential) of amplitude values at 6 months vs. vegetation classes according to White.

#### COOPERATIVE FRAMEWORK

Satellite data sets have been provided by C.J. Tucker, NASA, Goddard Space Center, USA. Data elaboration, methodology and results have been performed in the Netherlands by M. Menenti and S. Azzali at the DLO-Winand Staring Centre (SC-DLO) and by W. Verhoef and R. van Swol at the National Space Laboratory (NLR). D. Fuller and S. Prince (Dept. of Geography, Univ. of Maryland, USA) have contributed in the data interpretation on African natural ecosystems.

Results are being evaluated in consultation with several international partners: UNEP-GRID in Nairobi, Kenya; CRICYT in Mendoza, Argentina, and others in six Latin American countries.

This research is being sponsored by the Netherlands Board of Remote Sensing (BCRS) and by the Commission of European Communities.

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