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SURFACE HETEROGENEITY: A FACTOR TO IMPROVE THE NET PRIMARY PRODUCTIVITY ESTIMATION

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Abstract

This study concerns the integration of remote sensing data at high temporal resolution associated with agro-meteorological data in the modelization of vegetal production, at regional scale. Therefore, the objectives are :
i- The passing from a regional analysis of vegetation monitoring to a vegetation component analysis during the vegetative cycle,
ii- The quantification of vegetal production thanks to on adding of radiometric elements (calculated at the previous step) in a productivity model, coming from Monteith model,
iii- The spatialization of production data thanks to the use of satellite imagery.
The inversion of Linear Mixture Modelling enables to retrieve temporal profiles of reflectances (in visible and near infrared) for each type of vegetation from NOAA-AVHRR data. These reflectances are used to estimate the Net Primary Productivity (NPP) for the maize, millet, fallow and savannas.

1- Introduction

One of the major problem for the net primary productivity estimation from the satellite data lies on the characterization of the different vegetal formations present in sahelian regions or temperate ones (such as south of France). The most studies which aim to estimate net primary productivity use data with large view angle and a low spatial resolution such NOAA-AVHRR (Tucker et Sellers, 1986 [20]) because of their high temporal resolution. At the observation scale of about one kilometer, the response of the sensor corresponds to an integration of vegetal formations which have different biophysical properties and then a none identical contribution to the primary productivity (Pech et al., 1986 [14]; Settle et Drake, 1993 [19]). This is frequent particularly in sahelian zone where the vegetation is very heterogeneous at the scale of NOAA-AVHRR. This leads to the notion of mixed pixel. An average productivity information is therefore obtained, using radiometric measurements in the red and near-infrared channels. Furthermore, such a model does not allow primary productivity and associated physiological processes to be quantitatively monitored during the growing season.

In order to approach the biological reality, the modelling must be based on the sum of the productivities of these different constituent elements such as vegetation communities or vegetation categories.

This means that the problem of individual productivities modelling for the p components of an ecosystem must be solved. It is then important to be able to monitor the spectral behavior of each object of a given site and to find a good characterization of the spatial distribution of the vegetation cover inside the mixed pixel.

When several autors (Quarmby et al, 1992 [16]; Cross et al., 1991 [5]; Holben et al., 1993 [10]) retrieved the fractional cover after they have extracted the pure spectral responses (endmembers) for a maximum of four types of vegetation. It is not the same objectif presented in this paper. The aim of this paper is to retrieve the reflectance for different types of vegetation present in the mixed pixel.

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A method for radiometric unmixing coarse resolution signal of NOAA-AVHRR was developed through the inversion of linear mixture modelling. The autors (Cherchali et al. (1993[3] , 1995 [4]); Vignolles et al., 1993) have shown the potential of the linear mixture modelling to retrieve temporal profiles of reflectances. To verify its interest and reliability, it has been performed over a spatially complex area in Burkina-Faso using simulated coarse resolution data by the degradation of SPOT images. The simulation gave the opportunity to quantify the level of accuracy of the retrieved time profiles of reflectances and to provide indications on the limits of faisability of this method (Cherchali et al., 1994).

Therefore, in this paper, the model developed was applied to a temporal set of NOAA images acquired in 1992 on the Niamey region and to a classification (70 x 70 km) which contains the east and the west super sites of HAPEX : site of Banizoumbou. To show the transposability of the model, it has been also tested on a temperate region (Orthez site) with simulate kilometric data obtained by the degradation of SPOT images.

The acquiring of pure reflectances of the different components of the mixed pixel allows then to estimate separetly the net primary productivity of the corresponding objects. Therefore, the simplified Monteith model was used using adapted individual parametrization for the maize, millet, grass fallow and Guierra fallow.

2- Unmixing linear mixture model

Given a multispectral image, it is possible to model each pixel spectrum of this image as a linear combination of a finite set of components for a given date and particular waveband (Pech et al, 1986 [14]) and (Hanan et al, 1991 [7]). We can then numerically approximate the response by:

$$R_i = \sum_{j=0}^{p} f_j \times r_{ij} + E_i \qquad (1)$$

where:

- f_j : proportion of the jth component for a pixel i; $\sum_{j=0}^{p} f_j = 1$,
- R_i : measured satellite sensor response for a pixel in spectral band i,
- r_{ij} : spectral reflectance of the jth mixture component in the pixel for the ith spectral band,
- P : number of vegetation components,
- E_i : error term for ith spectral band.

The approach presented here consists in extracting from the mixed pixels the radiometric information needed to calculate all the individual contribution of each cover type present in the coarse spatial resolution radiometric measurement. The aim is to find an inversion method of the model (1), which applied to a set of coarse resolution images, allows to retrieve temporal profiles of representative parameters such NDVI by type of vegetation. The goal is often to extract more finer information than the observation scale. So, with a knowledge of fractional cover for each type of vegetation in the coarse resolution pixel (j), it then becomes possible from the measures R_i to calculate r_{ij}.

The method is applied to multi-temporal data, provided the proportions of each cover do not change between images; and cannot be applied to a sequence of images in which cover varieties changed.

Taking into account the hypothesis that, in the scene on a given date, the radiometry of each cover is identical on the scale of the coarse resolution images, we can write that $r_{ij} = \bar{r}_j$ (general mean effect of each class of landuse j).

Equations (1) becomes:

$$R_i = \sum_{j=0}^{p} f_j \times \bar{r}_j + E_i \qquad (2)$$

For a given scene, it is possible to decompose the observed landscape in n elementary "cells" (i=1,...., n) where their surfaces correspond to the size of coarse resolution image. In the case of NOAA-AVHRR images , the radiances measured by the AVHRR sensor at 1.1km give the values R_i whereas the fractional cover for each type of vegetation in all AVHRR pixels is obtained from a map of landuse. This one which covers all the studied zone is realized from a classification of SPOT-HRV images (high spatial resolution). It then becomes possible to inverse

the model (2) and to extract the individual contributions $\bar{r}_j$.
This time, the mean response $\bar{r}_j$ of each component contributing to the coarse resolution radiometric response (R_i) is estimated from the known percentages of landuse for the various cover in the low resolution pixel.

3- Study area and data

3-1 Sites of study

The first study area includes the West supersite (2°33'E, 13°31'N) and the East supersite (2°42'E, 13°31') of the HAPEX-Sahel. The Sahel is the region where the annual precipitations are comprise between 100 and 600 mm. The rainy season entend from June to September with a maximum at August.
The second one (Orthez) is situated on 0°23' West and 43°39' North. The site is structured in bocage landscape with small and middle size parcels. Agriculture in this region is dominated by maize and natural grasslands. Climat is distinguished by a mean 750 mm/year rainfall which can be variable from one year to another because of storms.

3-2 Data

200 images NOAA-AVHRR where acquired during 1992 for the west Africa, covering the period of 1st May to 25th October. The quality of the registration between the different bit-map and images (classified images and coarse resolution images) constitutes a source of variations for the quality of inversion and for the stability of the model (Cherchali et al., 1994). The images must be well superimposed. These superimposed images were cloud-free over the study area by applying the GAPF filter (Amram et al., 1994 [1]).
Satellite data in 1994 are 4 SPOT-HRV images for the site of Orthez (between March and October). They are geometrically and radiometrically corrected. The degradation of these images made low spatial resolution data. The simulation of low spatial resolution pixel is made by calculating the mean reflectances of high spatial resolution pixels within 1.21 km2 window [15], [22], [3]].
The mixture model must be calibrated such that for any given pixel, we can determine the proportions of each ground cover type. Radiometry unmixing can not be undertaken until the information on the proportions is known. We superimposed a grid reproducing the coarse resolution pixels on the land use map in order to calculate the percentages of the various themes in each of complete low resolution pixels thus defined (explanatory variables f_j).
A mosaïc of 6 SPOT images (acquired on 25/09/1992) covering the square degree of HAPEX site (13°N-14°N, 2°E-3°E) has been classified to map the landuse (D'Herbes et al., 1992) and then validated by ground measures.
A supervised classification of the 4 SPOT-HRV images for Orthez site provides landuse maps for any site. The ground surveys used in classifications (1% of the total area) give information concerning mean NDVI per site for any crop, this will help for controling values.

4- Retrieval of average reflectances

4-1 Banizoumbou site

The temporal profiles restitution of average reflectances have been obtained through the inversion of the model (1) (Cherchali et al., 1994) using the NOAA-AVHRR data filtered.
Reflectances in the visible and near infrared have been measured from a plane on the east and west supersite of HAPEX (Hanan et al., 1992) in 1992.
These reflectances allow to calculate the corresponding NDVI (Figure 1). Meanwhile, this validation must be interpretated with care because the spectral characteristics of the aireborne radiometer correspond to the one of Thematic Mapper and are then different of the AVHRR radiometer.
In general, the graphs of the Figure show the NDVI values regularly higher than the ones which result from the average reflectances retrieved. This difference can be attributed to the fact that the areas overfly are not automatically representative of the average reflectances.
For the six cases presented, the shape of the cycles are identical to the ones of the indexes obtained from the AVHRR. However, the late starting of the millet production cycle appears clearly shifted in comparison to the satellite signal. Otherwise, the increasing of the overflight measures for the savannas and fallow classes correspond to the information obtained from the satellite signal.

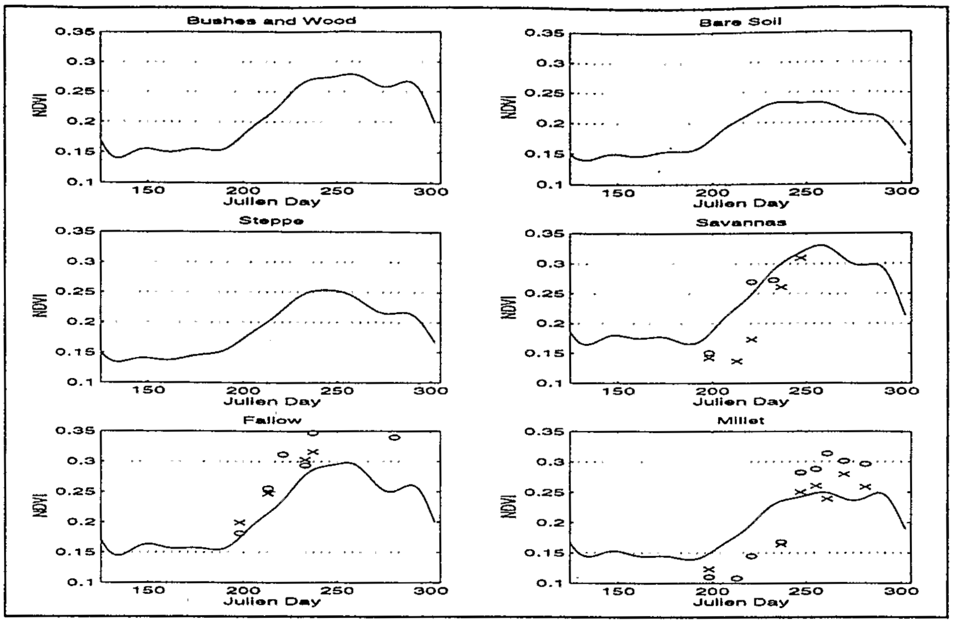
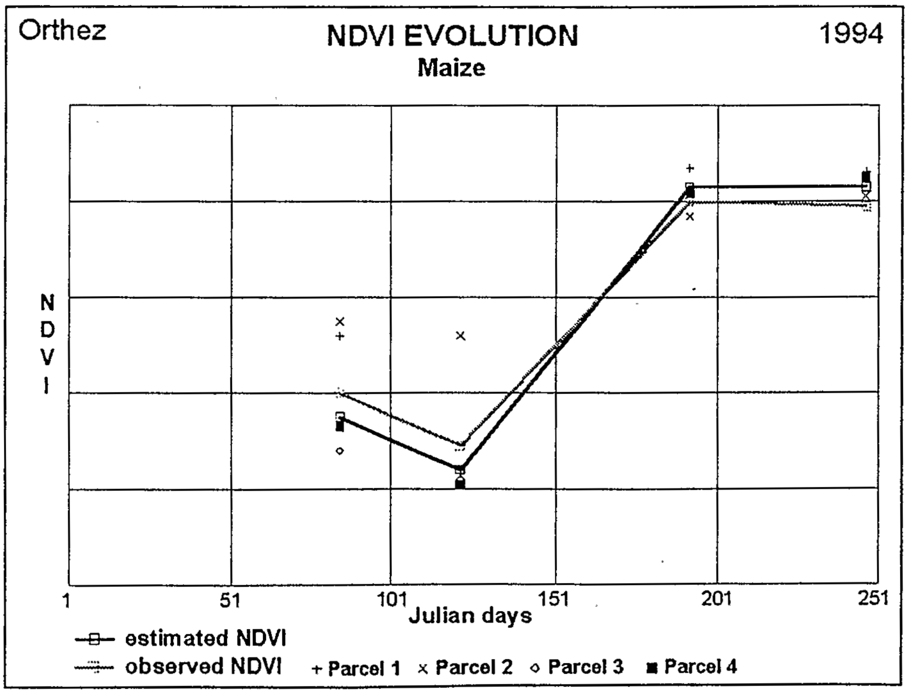


Figure 1: retrieved NDVI compared to the measured ones.

4-2 Orthez site

Whatever the site of study, the year taken into account, the chosen date and channel, it is notable that the determination coefficient remains high. The part of variation in reflectance values of low spatial resolution pixels defined by the variation of landuse percentage of the themes present in these pixels is greater than 60% (often between 70% and 90%).

In 1994, comparison of observed and model calculated NDVI, shows that |estimatedNDVI - observedNDVI| is less than 0.11 for a given crop if it takes up more than 5% of the studied territory. These results are consistent with the agronomic crop behaviour:



5- Estimation of dry matter

To estimate the net primary productivity for a given period, typically a vegetation season, it is necessary to integrate the simplified Monteith's [12,13] model ((3)) (Varlet-Grancher et al., 1982 [21]). The discretisation of the model is formulated as follow:

$$PPN = \sum_{t = deb}^{fin} \varepsilon_c \cdot \varepsilon_a \cdot \varepsilon_b \cdot Rg \cdot dt \quad (3)$$

PPN: total dry matter on stalk (g/m2); Rg: global incident radiation (MJ/m2); ε_c: climatic efficiency (%) proportion of photosynthesis activity radiation PARi in Rg; ε_i: interception efficiency (%) of PARi radiation by vegetal canopy; ε_b: conversion efficiency of the absorbed radiation by canopy in dry matter (g/MJ/m2/)
We have to calculate the different parameters at the step of daily time and to determine the integration period (deb, fin).

5-1 Climatic efficiency estimation (ε_c)

The value of this parameter does'nt vary a lot whatever the considered place, climatic conditions and the integration time. Stanhill et Fuchs (1977) have obtained daily values of 0.47 ± 0.07 and monthly values of 0.49 ± 0.02. We have used the mean value measured by Bégué (1991 [2]) for Niamey during the wet season : 0.466 ± 0.006. For the Orthez site, The mean value retained is 0.48 (Varlet-Grancher et al., 1982 [21]).

5-2 Absorption efficiency estimation (ε_a)

Several autors have used global relation between NDVI (measured from AVHRR) and ε_a to estimate the productivity (Heimann et Keeling, 1989 [9]; Ruimy, 1991 [18]; Loudjani, 1993 [11]) at regional scale.
The globale relation used consists to correspond to the NDVI of soil ($NDVI_s$) a null absorption , and to the maximal NDVI of 0.9 a maximal absorption of 0.95.
The bare soil vegetation index estimation is obtained taking the minimal value of the retrieved NDVI from the linear mixture model, for each class.
The linear connection between instantaneous ei and NDVI has been used [21]: ei = a (NDVI - soilNDVI) with soilNDVI = NDVI for a bare soil. It has been supposed that ei maximum (closed to 0.9) corresponds to (NDVI - soilNDVI) maximum. In our conditions of the whole studied parcels, the mean value of a has been defined to 1.4. In this study, soilNDVI has been considered to be equal to minimum NDVI calculated from the 4 images.

5-3 Conversion efficiency estimation (ε_b)

A bibliographic analysis allow to collect some values of ε_b for the studied types of vegetation. They are summerized in the following table:

Types of vegetation	Autors	ε_b (gMJ^{-1})
maize	Ruget (1990)	4.00
millet	Bégué (1988)	2.7
millet	Bégué (1990)	2.35
millet	Bégué (1991)	2.26
millet	Ouadrairi (1994)	2.44
cultivated plant	Loudjani (1993)	2.26±0.70
wood (trees)	Loudjani (1993)	0.52
fallow	Bégué (1991)	1.60
herbaceous savannas	Loudjani (1993)	2.39

Table 1: conversion efficiency values

5-4 Integration period: estimation of the vegetatif cycle length

To determine this period, some autors use the vegetation index:
- The begining of the growing is assimilated to the minimum of the vegetation index computed for each type of vegetation which preceeds the period where its slope is maximal. This means that the minimum of the vegetation index corresponds to the one of bare soil.
- The determination of the end of integration period is the most difficult. We consider that this date coïncides with

the maximum of chlorophyllian activity which can be determined on the profile of the retrieved vegetation index.

5-5 Production estimation

dry matter(kg/ha)	millet	fallow	savannas	maize
estimated	1280	1447	1375	1977
measured	1234.7	1586.6	1620.0	2301

6- Conclusion

This study confirms the advantages of the unmixing model of low spatial resolution signal (agronomic hardiness, extrapolation in time and space) when the studied theme takes up more than 5% of landuse surface.

Remote sensing data coming from the previous step are interesting for their integration in production models of dry matter. But new experiments with more measures (more reference parcels and more satellite data during vegetative cycle) will be necessary in order to assess the model.

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