Monitoring natural disasters and “hot spots” of land-cover change
with SPOT VEGETATION data to assess regions at risk and vulnerability

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1. Introduction

All recent scientific evidences clearly point to the fact that the impact of global change on land surface attributes will not be uniformly distributed geographically. Assessing the regions “at risk” of rapid land-cover changes and/or natural disasters is therefore a priority for global change research and for policies aimed at mitigating the impact of these changes. The objectives of this project are to: (1) Use SPOT VEGETATION data to monitor over large regions the impact on ecosystems of natural disasters such as droughts, fires, floods and vegetation diseases, as well as land-cover change ‘hot spots’; (2) Validate and interpret SPOT VEGETATION-based maps of natural disasters and extreme land-cover changes with collateral data on natural disasters and ‘hot spots’ of land-cover change; (3) Integrate this validated product in the current efforts of the global change scientific community, sponsored by the International Geosphere-Biosphere Programme (IGBP) and International Human Dimensions Programme on Global Environmental Change (IHDP), to assess regions ‘at risk’ of rapid environmental change in order to focus research on most vulnerable areas and support the design of appropriate mitigation policies.

The product can only be generated once two full years of SPOT VEGETATION data will be acquired (i.e. by April 2000). In the meantime, a data processing chain with the change analysis algorithm has been designed, and initial tests over two growing seasons in West Africa (June to November 1998 and 1999) have been conducted. Through these tests, we evaluated the level of data pre-processing required (i.e. geometric registration, compositing period and criteria, combination of spectral bands) to detect different processes of land-cover change. We also evaluated whether the change detection algorithm needs to be adapted to different situations and different biomes. In parallel, we are assembling a database of collateral data on natural disasters and rapid land-cover changes during the period April 1998-April 2000 for validation and interpretation of the VEGETATION-based change maps.

In this report, we will present our first results: a map (available in digital format) which represents the impact of the natural disasters and rapid land-cover changes which have occurred during the growing seasons of 1998 and 1999 in West Africa. For every ‘hot spot’ of change detected (flooding, local decrease or increase of vegetation cover), we have compiled information on the type of change, their cause (heavy rains, drought conditions, deforestation or fires) and their environmental significance.

2. Methodology

The land-cover change detection approach is based on a comparison of the seasonal development curve for successive years of a remotely-sensed land-cover indicator - e.g. a vegetation index or a measure of spatial heterogeneity. When the time trajectory of the indicator over a particular pixel departs from the pixel's reference time trajectory, a change in land-cover is detected. This multitemporal approach is very sensitive to changes in seasonality and ecosystem dynamics, in addition to more abrupt landscape disturbances. It is quite insensitive to atmospheric and sensor noises that only affect isolated periods. The seasonal dynamic of a land-cover indicator can be represented by a multitemporal vector \( p(i, y) \) for pixel \( i \) and year \( y \). Any change in accumulated value and/or in seasonal dynamic of the indicator between the current and reference years can be measured as:

\[
\mathbf{c}(i) = p(i, \text{ref}) - p(i, y)
\]

where \( \mathbf{c}(i) \) is the change vector for pixel \( i \) between the reference year \( \text{ref} \) and the year \( y \). The magnitude of the change vector \( |\mathbf{c}| \) measures the intensity of the change in land cover. It is calculated by the Euclidean distance between the
pixel position, for the current and reference years, in the multitemporal space of the observations (i.e. each
dimension of that space represents the land-cover indicator for one observation period; the coordinates of
a pixel position are the values for that pixels, for that year, of the land-cover indicator for the observation
periods). Note that this arithmetic calculation assumes that the land-cover indicator $I$ is a quantitative
measure which is linearly related to some land-cover attributes. Through this vector difference, all the
input images (decadal or monthly composites for two years) are reduced to a single land-cover change
magnitude map. Tests and validations of this methodology have already been published: LAMBIN E.F.

3. Results
The results are: (1) a digital map representing the impact of the natural disasters and rapid land-cover
changes which occurred during the growing seasons of 1998 and 1999; and (2) a detailed validation of this
map, with collateral data on natural disasters (droughts, floods) and rapid land-cover changes
deforestation), information on the process of change and their environmental significance.

3.1. Map of land-cover changes in West Africa derived from VEGETATION data
The methodology has been applied to the VEGETATION data. There are actually strong perturbations by
clouds on the change image produced from NDVI decadal composites. The change image based on
monthly composites is developed by aggregation (maximum value compositing method) of the decadal
images. This map (Fig. 1) is classified in five classes according to the intensity of changes.

Scale 1: 25 000 000

Fig. 1 Map of land-cover changes in West Africa during the growing seasons of 1998 and 1999

The clouds are represented in white (mask). We can observe that, for the most part, the areas affected by
clouds or with a high risk of cloud contamination are located around the Gulf of Guinea. This is also an
area where high intensity changes are located. We note that different patterns of change are present in this map: (a) linear patterns [1], [2], [3], (b) more patchy patterns [4] and (c) diffuse patterns [5], [6]. These areas of change require interpretation and auxiliary data to be validated.

3.2. Validation of the map
The first areas of change on the change vector magnitude map (fig. 1) are characterised by land-cover changes with linear patterns surrounding rivers and caused by severe floods.

3.2.1 Severe floods in Eastern Mali, Northern Benin and Western Niger [1]
Heavy rains since September 1998 were reported in the region (fig.2a, source: FAO, Global Information and early warning System).

![Fig 2a. Heavy rains in Eastern Mali](image)

The NDVI image (fig.2b) illustrates the spatial impact of the natural disaster. These floods had both human and economic impacts: 20,000 people homeless and hundreds of hectares of agricultural land under water (United Nations, Contributions for natural disasters [318x261]http://www.reliefweb.int/).

3.2.2 Severe floods in Chad [2]
On the change vector magnitude map (fig.1), we can observe change areas surrounding the lake Chad (increase of the lake level) and the different rivers. The anomalous rainfall from June to August 1999 are the causes of this flood. The area affected by heavy rains is located in Southern and Central Chad (fig.3a, source: FAO, Global Information and early warning System, fig. 3b).

![Fig 3a. Heavy rains in Central Chad](image)

![Fig 3b. NDVI image of July 1999 (SPOT VEGE)](image)
This flood had large human and ecological impacts: 128,000 people affected, 5,200 houses destroyed and more than 165,000 ha of agricultural land under water (United Nations, Contributions for natural disasters http://www.reliefweb.int/).

### 3.2.3 Severe floods in Ghana, Togo, Burkina Faso, Benin and Nigeria [3]
A large area has been affected with 117,000 acres of farmland destroyed and with 290,000 people homeless (followed by cholera outbreaks) (United Nations, Contributions for natural disasters http://www.reliefweb.int/). Significant anomalous rainfalls are shown in the figure 4a (source: FEWS Famine Early Warning System).

The interpretation of these three processes of change is also validated by EUMETSAT-derived rainfall estimate (Arteries, FAO project) and Meteosat-derived rainfall estimate (Tamsat project, University of Reading). The monthly difference image based on the NDVI allows for a good detection of the major floods which took place in the region. Nevertheless, because of the short duration of this process of change, it might be necessary to use the decadal composites of VEGETATION data to better follow the flooding and support appropriate policy responses. These three cases of floods show that, even though the spatial impacts of these natural disasters are local, mainly linear and of short duration, the human impacts could be large.

### 3.2.4 Drought in Southern Senegal, Guinea [4]
A patch of change is observed on the difference map (fig. 1) in Southern Senegal. It corresponds to particularly low NDVI values in June, July and August 1998 (fig 5b.). A drought is reported by the Contributions of Natural Disasters (United Nations). Below normal rainfall is shown in figure 5a (source: Africa Dissemination Service – USGS).
This drought has a large spatial impact and is located in a savannah area (IGBP Global Land Cover map). It is associated with a warm anomaly much of the year in the region (Climate Prediction Center, NOAA). Moreover, we note the presence of a large number of fires in June 1999 in the region (source: World Fire Web, JRC) which could increase the value of changes in the difference map.

### 3.2.5 Drought and deforestation in Liberia [5]

The difference map and the NDVI image (fig.6b) show heterogeneous patches of change in Liberia, perturbed by cloud contamination. An important period of drought in 1998 is reported by the Contributions of Natural Disasters (United Nations) and corresponds to the information diffused by the Africa Dissemination Service (USGS). It is located in Liberia in its entirety, from July to September 1998 (fig. 6a.).

![Fig 6a. Below normal rainfall in Liberia 1998](image)

![Fig 6b. NDVI image of August 1998 (SPOT VEGE)](image)

The land cover of the area affected by change in Liberia is a mosaic of savannahs, evergreen broadleaf forests and croplands (IGBP Global Land Cover map). The TREES project (JRC, 1998) has identified the coast of Liberia as being a "hot spot" of diffuse deforestation caused by intensive logging.

The interpretation in this area is particularly complex because of clouds contamination and because of the two driving forces identified: drought and deforestation "hot spot".

### 3.2.6 Deforestation in Cameroon [6]

The land-cover change map shows a large area of diffuse changes located in Cameroon (fig.1). It is certainly a region of clouds perturbation. Up to now, we just found one interpretation: the TREES project (JRC, 1998) has reported a large "hot spot" of deforestation characterised by forest fragmentation occurring along the road network. It is also a place of shifting cultivation with cash crops (coffee, cacao and rubber).

These two last areas for which validation data were collected consisted in mosaics of land-use dynamics. It corresponds on the change map to more diffuse and heterogeneous patterns of change than the first areas affected by flood and drought in Senegal.

### 4. Perspectives and conclusion

In this study, a variety of processes of land-cover change could be detected based on a multitemporal change detection algorithm, that takes into account the changes in the seasonality of a vegetation index. For some patterns of change, the driving forces were complex, with synergetic effects between climate-driven events and anthropogenic events.

This project raises important issues concerning the pre-processing of SPOT VEGETATION data. First, the current cloud masks leaves a large number of clouds unmasked. This forces us to work with monthly composites, to remove remaining clouds by maximising NDVI data. We therefore loose temporal
frequency. A lot of the natural hazards such as droughts or floods would be better detected on decadal composites, given their relatively short duration.

The next step of this research would be to develop a global-scale, routine land-cover change product based on time series of VEGETATION data, for the years to come. Such a product would however gain from: (i) better cloud-masking; (ii) a greater range of more performant vegetation indices.

The main potential end-users of this project are the International Geosphere-Biosphere Programme (IGBP) and International Human Dimensions Programme on Global Environmental Change (IHDP), for the cross-cutting activity on “Vulnerability and regions at risk”. Moreover, the project provides a geographic product for the concluding year of the International Decade for Natural Disaster Reduction (IDNDR), sponsored by the United Nations.

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