

# **Use of SLC-Off Landsat Image Data for Monitoring Land Use / Land Cover Trends in West Africa**

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## **Introduction**

Landsat 7 imagery is one of the pillars of an ongoing program to monitor and map land use and land cover trends across West Africa. The program has a continuing need for Landsat data. When the SLC-Off problem occurred on Landsat 7 in May 2003, basic questions were raised by program scientists and counterparts in Africa as to the usefulness of SLC-off image data for future efforts to monitor land use and land cover. In an effort to help evaluate these concerns, we participated in an evaluation of SLC-off image data over southern Senegal, comparing it to original (SLC-on) imagery. In this paper we begin by describing the general project background and objectives, and methodologies used (they are described more fully in Tappan et al., in press. This is followed by a specific analysis of the SLC-off product for five target areas within a single Landsat scene in southern Senegal. We conclude with a discussion of results.

## **Project Background**

The countries of West Africa are experiencing rapid change at many levels – climatic, natural resources, agricultural, demographic, political, and socioeconomic. They are endowed with a highly diverse, yet fragile environment. For centuries, humans have been a trivial force in the environmental equation, but this changed dramatically in the 20th century, particularly in the last 50 years. As West Africans enter the 21st century, environmental changes are predicted to accelerate, with unknown and potentially serious implications for both its people and the environment. The West Africa Land Use and Land Cover Trends Project represents a unique and unprecedented effort to document and quantify the impacts, detailed in both time and space, of the environmental and land resource trends that are sweeping across West Africa. The project is being carried out through the AGRHYMET Regional Center and its national partners across West Africa, the Sahel Institute (INSAH), with technical assistance from the US Geological Survey's EROS Data Center, and with support from the USAID/West Africa Regional Program. Through this program, AGRHYMET has been able to obtain complete, detailed satellite images (from the Corona and Landsat satellite systems) covering all of West Africa at four points in time: the 1960s, 1970s, 1980s, and 2000s. The program is providing training to environmental scientists from 15 West African countries in the analysis of this rich image archive, allowing them to map and quantify land use and land cover changes that have occurred across the region in the last 35 to 40 years.

## **Project Objectives**

The overarching goal is to promote awareness and use of spatially explicit and graphic information on natural resource trends among national and regional decision-makers, and engage them in modeling future scenarios that will help them formulate sound and sustainable policy responses leading to better natural resource management, conservation, food security and human well being. The results of this program will be shared with West Africa's political leaders, environmental decision-makers, and the broader scientific community in countries throughout the region.

The complete collection of historical and current satellite imagery is allowing West African scientists to document for the first time spatially explicit alterations and transformations of the natural resource base, much of it at the hands of humans. Only by seeing and understanding how humans (and climate) are modifying the land resources can West Africans get a sense of what they had, what they have, where they are going.

The program has already equipped AGRHYMET with the complete satellite data archive of West Africa from the 1960s to the present. Starting in 2000, geographers and remote sensing specialists from the EROS Data Center and their colleagues at AGRHYMET have conducted a series of training sessions for West Africa agricultural and environmental scientists in the interpretation and analysis of the satellite image data. Land resource trends, particularly changes in land use and land cover, have been quantified for most of the Sahelian countries from 1965 to 2002.

Through this program AGRHYMET and the EROS Data Center will continue to provide unique and valuable training in exploiting the vast satellite image record of West Africa to help national land management institutions effectively map and monitor land resource changes, and to understand and predict some of the fundamental impacts of these changes on the environment and human well-being. The results will be valuable for decision-makers as they face the serious challenges of balancing food production while protecting the environment from degradation.

## **Stratification of West Africa into Ecoregions and Sampling Approach**

The land use and land cover trends program covers most of West Africa, involving some 180 Landsat scenes. Our approach was to stratify the vast geographic area into ecological regions, or ecoregions. Ecoregions are generally considered to be regions of relative homogeneity in ecological systems involving interrelationships between organisms and their environment (Omernik 1987). Ecoregions have been used in Senegal for decades as a regional land use planning tool. While several ecoregion stratifications exist, we adopted the version published by the Direction de l'Aménagement du Territoire (DAT *et al.* 1984). The ecoregions were defined through the integration of various components of the natural and socioeconomic landscapes of Senegal, including both

biophysical (climate, geology, hydrology, soils, vegetation) and human factors (settlement patterns, land-use). Using Landsat images, and the vegetation maps published in Stancioff *et al.* (1986), we made slight modifications and aggregations of the original classes, resulting in 13 ecoregions.

Although we had full Corona and Landsat coverage of Senegal (and West Africa), practical considerations of time and cost precluded mapping the entire country over the three time periods. We chose a sampling strategy, using a random sample of 10-km by 10-km area frames stratified by ecoregion. Each sample frame was randomly selected within each ecoregion (see figure 1). The frames were selected from a fixed 10-km grid that was placed over the entire country.

## **Land Use and Land Cover Mapping**

We defined 13 general land-use and land-cover classes applicable to the West African region (Tappan *et al.*, in press). The classes needed to be general enough that they could be readily identified on Landsat and Corona imagery. This meant that the classes needed to be rather general in definition, and their total number kept to a minimum. This approach led to better interpretation accuracy and consistency. The classes are:

- Agriculture: irrigated, flood recession, garden, rain-fed
- Water bodies
- Natural sandy barren
- Natural rocky barren
- Bare soil, disturbed or degraded
- Settlements and urban
- Vegetation: steppes
- Vegetation: savannas, wooded savannas, open woodlands
- Vegetation: gallery forests and forests
- Vegetation: wetlands
- Vegetation: desert oases
- Vegetation: mangroves
- Vegetation: plantations

Several classes are not found in Senegal, although they do occur in the greater Sahelian region. The class represented by 'vegetation: savannas, wooded savannas, open woodlands' encompasses a broad spectrum of vegetation types defined by varying ranges of percent woody cover.

## **Image Preparation, Interpretation, and Analysis (Overall LULC Project)**

For each 10-km frame, image data were extracted from the full Landsat scenes. False color composite digital and hardcopy images were produced from TM and ETM+ bands 3, 4, and 5. The corresponding 10-km frames were accurately located on Corona black-and-white film positives, and their boundaries were temporarily marked. Next, the area

frame Landsat images were interpreted, mainly from the hardcopy prints at a scale of 1:100,000. A manual interpretation approach was used to identify and delineate the land-use and land-cover classes on image overlays. After testing manual and automated techniques for mapping change, we found that the manual approach gave much more reliable results. First, the manual method lends itself well to working with analog, film-based photographs (Corona). Second, manual photo-interpretation is effective for integrating the photographic elements of tone, hue, texture, shape, size, pattern, shadow and geographic context, whereas these elements are often disregarded by more automated mapping techniques. Third, we were better able to integrate our intimate field knowledge into the interpretation process. Fourth, we were able to disregard such potentially confusing ephemeral features as annual grass fires, and ground reflectance changes related to seasonal influences. In most cases, the dates of imagery corresponded to early-to-mid dry season. The Corona photography, with its very high (2-m) resolution, was often used as a crosscheck when interpreting the Landsat frames. We think all of these factors contributed to providing good local mapping accuracy.

After completing a detailed delineation of each 10-km frame, the area of each class was measured by randomly placing a fine dot grid over the frame. Dot counts were tallied for each class, and converted to a percentage of the frame area. The results were entered into a database, where the area of each class was summarized by ecoregion and by period.

## **Analysis of an SLC-Off Landsat ETM+ Image of Southern Senegal**

Our analysis of the SLC-off image data and its comparison to an original (non SLC-off) image was limited to a scene in southern Senegal (Path 203, Row 51). This area was selected owing to the author's familiarity with the region, the availability of supporting maps and field data, and because the land use and land cover types are representative of those found generally throughout the southern fringes of many Sahelian countries. The targeted area falls within the Casamance Ecoregion of southern Senegal. We selected five target areas or sites based on diverse land use / land cover characteristics, and the presence of significant gaps in the SLC-off image. The data gaps ranged from 26.7 to 35.0 percent of the target areas (see table 1). The primary image of analysis was acquired on January 11, 2001. This date represents the mid-dry season in southern Senegal. An image acquired in February 2001 was used to fill the gaps in the January image. The main analysis was based on comparing the gap-filled January 11 image with the original January 11 image.

Our approach to land use and land cover analysis was similar that used by the overall West Africa trends project. The analysis sites represent 10 X 10 km frames identical to the randomly selected frames in each ecoregion. We used a manual photo-interpretation method of identifying the land use / land cover types, using the classes adopted by the overall project. Rather than prepare detailed land use / land cover maps of each site, we quantified the area within each class using a fine dot grid superimposed digitally on the frames. Each frame contained 400 dots. The land use / land cover was identified at the position of each dot, and these were tallied for the entire frame. Dot counts for each class

were converted to percent area of the frame. The exercise was conducted using both the SLC-off and original images. The area results were compared. Table 1 presents the results of this analysis for four of the five frames.

<b>Table 1</b>	<b>Original Image, % Area</b>	<b>SLC-Off Image, % Area</b>
Site 1: Agriculture	21	20.75
Site 1: Gallery Forest	3	3.25
Site 1: Savanna	76	76
Site 1: Burned Area	33.75	35.25
Site 1: Non-Burned Area	66.25	64.75
Site 1: Gap Area (percent)	0	35
Site 2: Agriculture	19.5	19.5
Site 2: Gallery Forest	3	3
Site 2: Savanna	77.5	77.5
Site 2: Gap Area (percent)	0	27.5
Site 3: Agriculture	27	27.5
Site 3: Water (river)	2.5	2.5
Site 3: Wetland	5.25	5.25
Site 3: Savanna	65	64.5
Site 3: Settlements	0.25	0.25
Site 3: Gap Area (percent)	0	26.7
Site 4: Wetland	1.25	1.25
Site 4: Gallery Forest	3.25	3.25
Site 4: Water (river)	2.25	2.25
Site 4: Savanna	93.25	93.25
Site 4: Gap Area (percent)	0	31.5

The four sites represent much of the diversity in land use / land cover found in the scene. Site 4, for example, is dominated by savanna vegetation, with no agriculture, typical of much of the eastern part of the scene, while agriculture is a significant component of the other sites. All sites contained major areas of burned savanna. Mapping burned areas have not been a goal of the overall trends project. However, for the SLC-off analysis, we quantified burned area for one site (site 1). It contained only recent burns which could be easily classified into burn / non-burn. In the other sites, burn scars of various ages were present, making the analysis more subjective.

## **Discussion**

The results from Table 1 present the percent area of land use / land cover in each of the four 10 X 10 km study sites. The difference in results between the original and SLC-off images is minimal, ranging from zero in many cases to 1.5 percent area. In site 4, no

differences were found among any of the classes, even though the gaps represented 31.5 percent data loss for this site. Thus, we remain optimistic about using gap-filled imagery for photo-interpretation based analysis of land use and land cover.

An immediate question is whether the area differences were due to the tendency of photo-interpretation to be somewhat subjective. We do not think this is the case. First, the classes are general, and their representation on the imagery is distinct enough that manually classifying each point was fairly straightforward. We are also very familiar with the landscapes in the region, having conducted extensive fieldwork intermittently between 1984 and 2002. Second, we compared the interpretation between the paired images, point by point. The differences are due to alterations of the original image by the gap-filling process, resulting in apparent land use / land cover class shifts at specific point locations. Examples of this can be seen in Site 2, Figure 1 (see short arrows). In this case, the indicated dots in the original image fell on agricultural fields, whereas the gap-filled image indicated burned savanna (note: the dots in this figure are much larger than those used during the actual analysis). The long arrow at right points to a common occurrence of hue, texture and pattern perturbations in the gap-filled image. While these often don't result in a land cover class shift, they alter the structure of the image, a potential problem for users doing vegetation canopy density analysis.

Figure 2 shows the paired images from site 1 (with gaps covering 35 percent of the area). In this figure, the burned area in the gap-filled image was found to be greater than in the original image. The long arrows point to the problem. The gap-filled image tends to significantly smudge the burned areas, extending their apparent area. This may be due to additional burns from the alternate fill image. Figure 2 also gives another example of a land use shift anomaly (short arrow). The original image shows an area of cultivation (pink, mottled), whereas the gap-filled image shows a green area that could be interpreted as open savanna.

Figure 3 presents the paired results from site 4, representing a protected area devoid of human activity. Two anomalies are indicated: a non-burned savanna area that has been replaced by a burned savanna signature in the gap-filled area (arrow at left), and a change in the apparent amount of standing water in a small wetland (arrow at right). Numerous other anomalies can be seen, resulting in slight changes in the hue, texture and pattern of the complex savanna vegetation types. Nevertheless, in terms of general land use and land cover, the original and gap-filled images are basically identical.

Figure 4 shows a more extreme example of how the gap-filling altered and extended the shape of a distinct area of burned savanna. In the original image we see an active burn, ringed with fire. The gap-filled image introduces several problems. It alters the shape of the burn, extending the area along the gaps. It also introduces problems of cloud cover and shadow, which were features carried over from the replacement image of February 2002.

## **Conclusion**

The test image we selected in southern Senegal represents a fair degree of land use / land cover complexity, further complicated by patterns of burn scars. The five specific study sites within this image fell near the left and right margins of the image, in areas where the data gaps are wide. The gap filled imagery resulted in quite visible perturbations of the landscape features within a given land use / land cover class, but produced only slight differences in the area of the various classes, amounting to no more than 1.5 percent change in area within 100 km<sup>2</sup> study sites. For most classes, the area differences were negligible. Thus, we remain optimistic that gap-filled Landsat images will be useful for approaches that use photo-interpretation to quantify and map land use / land cover in West Africa.

## References

DAT, PNUD, DTCD (1984) Schéma national d'aménagement du territoire, version préliminaire. SEN 82.016, 749 pp

Omernick J (1987) Ecoregions of the Conterminous United States, *Annals of the Association of American Geographers*, 77: 118-125

Stancioff A, Staljanssens M, Tappan G (1986) "Mapping and Remote Sensing of the Resources of the Republic of Senegal: A study of the geology, hydrology, soils, vegetation and land use potential." SDSU, Remote Sensing Institute, SDSU-RSI-86-01, 655 pp

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# Figures

## SLC-OFF Sample Site Comparison Velingara ETM Scene p203 r051

Senegal, Africa

Samples site: 10km x 10km

Projection: UTM  
Zone: 28  
Units: Meters  
Datum: WGS84

## Sample Site Center Coordinates

Sample #2  
x = 556122; y = 1440216

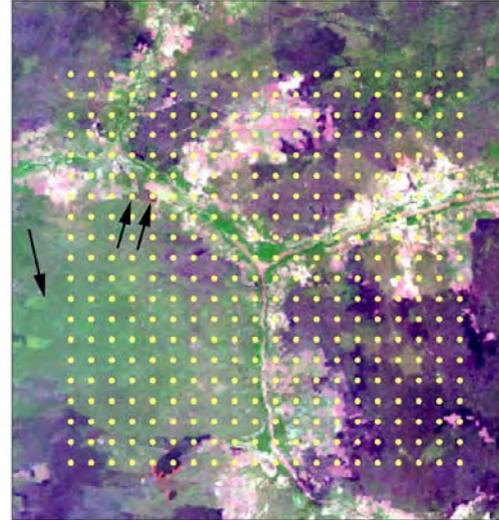
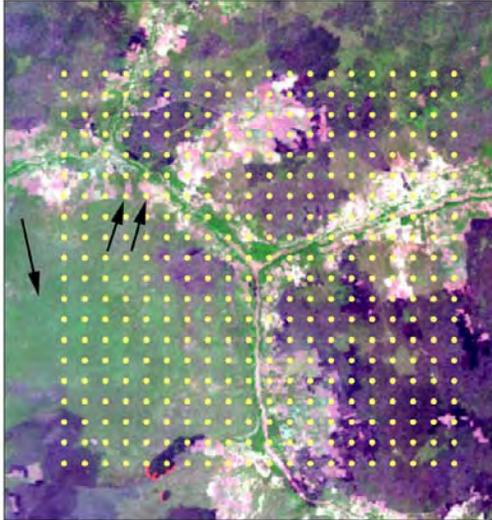
Scale: 1:100,000



## Sample site 2

Original Scene

Gap Filled Scene



Map produced: 04/23/2004

Figure 1.

SLC-OFF Sample Site Comparison  
Velingara ETM Scene p203 r051

Senegal, Africa

Samples site are 10km x 10km

Projection: UTM

Zone: 28

Units: Meters

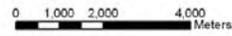
Datum: WGS84

Sample Site Center  
Coordinates

Sample #1

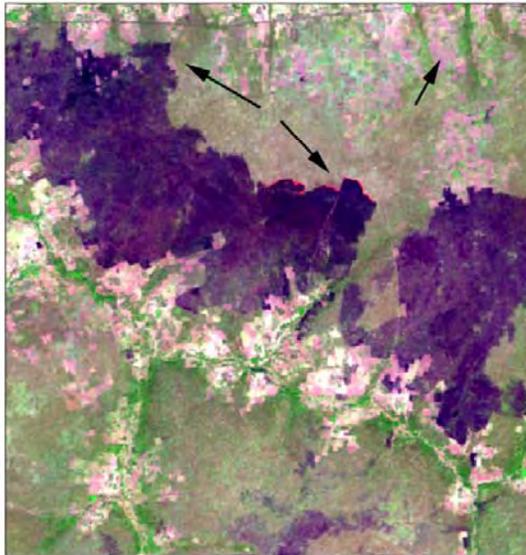
x = 534629; y = 1414041

Scale: 1:100,000

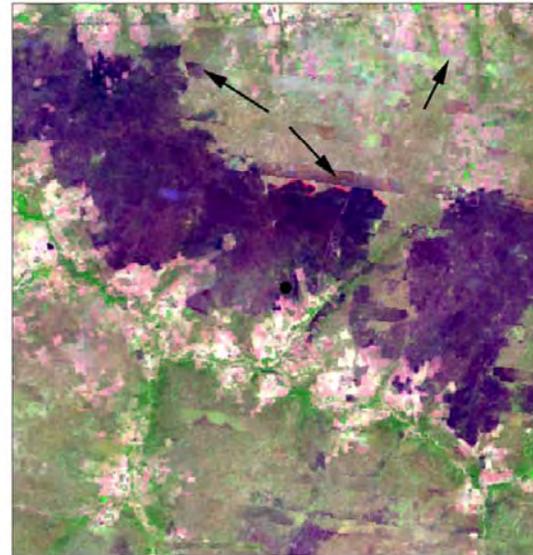


Sample site 1

Original Scene



Gap Filled Scene



Map produced: 04/23/2004

Figure 2.

SLC-OFF Sample Site Comparison  
Velingara ETM Scene p203 r051

Senegal, Africa

Samples site: 10km x 10km

Projection: UTM  
Zone: 28  
Units: Meters  
Datum: WGS84

Sample Site Center  
Coordinates

Sample #4

x = 687767; y = 1440229

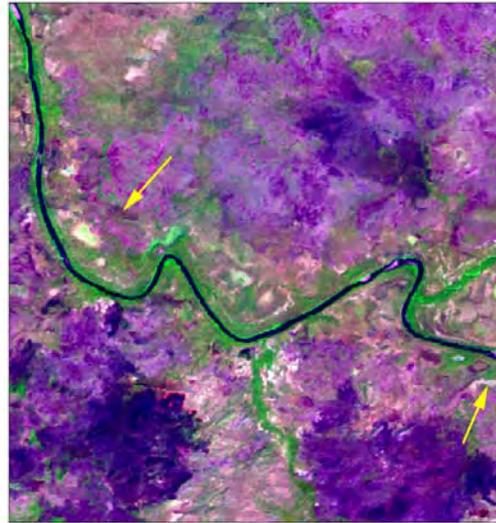
Scale: 1:100,000



Sample site 4

Original Scene

Gap Filled Scene



Map produced: 04/23/2004

Figure 3.

SLC-OFF Sample Site Comparison  
Velingara ETM Scene p203 r051

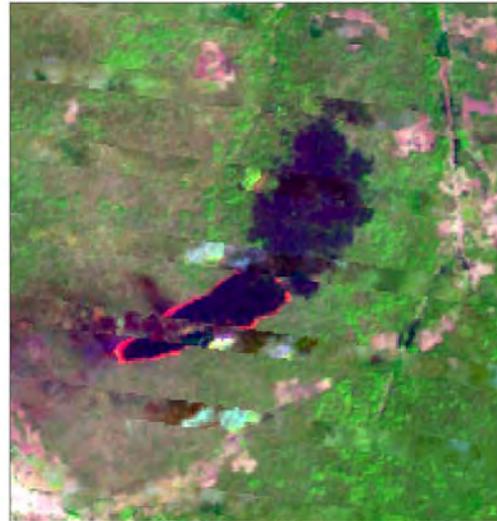
Senegal, Africa  
Projection: UTM  
Zone: 28  
Units: Meters  
Datum: WGS84

Fire Example

Original Scene

Scale: 1:50,000  
0 1,000 2,000 Meters

Gap Filled Scene



Map produced: 04/23/2004

**Figure 4.**