# Discrimination of Africa's Vegetation Using Reconstructed ERS-1 Imagery

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## I. INTRODUCTION

Currently there is an extended international effort to inventory and monitor equatorial vegetation. Because of persistent cloud cover typical of equatorial regions, active microwave imagery such as ERS-1 SAR is preferred over high-resolution visible and near infrared spaceborne sensors for this task. However, no active microwave instrument designed to provide continental coverage at resolutions similar to the popular AVHRR has ever flown -- neither are any planned for the future.

Satellite scatterometers are calibrated active microwave radar instruments originally designed to measure the radar backscatter of the ocean's surface under all-weather conditions. The first spaceborne scatterometer flew as part of the Skylab missions. The European Space Agency (ESA) successfully launched its ERS-1 satellite into a quasi-polar mission-adjustable orbit in the summer of 1991. The instrument payload included the Active Microwave Instrument (AMI) which is capable of operating in a wind scatterometer mode (5.3 Ghz) for the production of wind vector products.

The primary mission of the ERS-1 scatterometer is the determination of ocean surface wind direction and velocity. This is not surprising, because most land imaging applications require spatial resolutions finer than its 50 km footprint appropriate for large ocean expanses. However, an image reconstruction technique developed [1] has improved the AMI scatterometer resolution to 14 km, making it a candidate for coarse monitoring of cloudy global areas such as the Arctic, Antarctic, and continental equatorial forests.

The goal of the research reported in this paper is to evaluate reconstructed ERS-1 scatterometry for discriminating between vegetation classes of continental Africa.

## II. METHODOLOGY

One of the first examinations of ERS-1 scatterometry over land was reported by Mogin *et al.* [2]. As described in that paper among many others, the ERS-1 scatterometer is a C-band instrument consisting of three antennae, one pointing 45° forward, another pointing 45° aft, and one pointing normal to the flight path. The 4.8 kW instrument with VV polarization, orbiting at approximately 785 km, has a swath width of 500 km, incident angle ranges between 18° and 59°, and produces imagery with a spatial resolution of 50 km.

Reconstruction of scatterometry to higher resolutions by using multiple satellite passes is described at length elsewhere [1]. Originally developed for Seasat-A scatterometer data (SASS), reconstruction of ERS-1 data does not produce equally high resolution. Summarizing, the SASS cell on the earth has an irregular hexagon shape with well defined geographic coordinates for each vertex. The generous overlapping of these hexagonal cells of different sizes at a variety of incidence angles allows for high sampling rates in the reconstruction. The result is reconstructed imagery with a cell resolution between 5 and 10 km.

In contrast, the tapered circular footprint of the ERS-1 scatterometer cell, with its $cos^2$ rolloff function provides insufficient definitive locational information for the same high-rate of sampling (with confidence), resulting in a lower resolution image (20 km). The reduced number of measurements produced by the single-sided operation further contributes to the problem.

The ERS-1 data used in the reconstruction for this research was acquired between April, 1992 and May, 1995 and covered 3 seasons. Twelve monthly average backscatter images were reconstructed, corresponding to each of the twelve calendar months. One of the reconstructed scatterometer images used is shown in Figure 1.

Reconstructing the entire African continent created an analysis problem. Since Africa spans both the northern and southern hemispheres, a vegetation class (e.g. tropical woodland) common to both hemispheres would have different backscatter averages dependent on the northern or southern hemisphere season. To rectify this problem, the twelve monthly images were split along the equator, and reconstituted so that corresponding months (*seasonally speaking*) were analyzed together.

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The map database used for this study is produced by the World Data Center-A (WDC-A) for Solid Earth Geophysics in cooperation with the Data Management and Information Systems Working Group of the International Geosphere-Biosphere Program (IGBP). The purpose of the database is to provide a series of digital maps for global change analysis and climatic modeling. The database is used extensively by the United Nations Environmental Program (UNEP) and other international organizations. The database contains several vegetation-related grid-cell maps of continental Africa. Regrettably, none of the digital maps has the same high resolution as the reconstructed ERS-1 imagery, and all are highly tentative. The experiments described in this paper refer to the Matthews Vegetation map. Despite its low 1° cell resolution, it was chosen in preference to the others because of its broad categories of vegetation based on characteristic physiognomic classes. The original map consists of 21 vegetation classes, ranging from tropical evergreen forest to desert. Due to the inaccuracies typical in any map of such coarse resolution, vegetation classes with fewer than 600 cells on the continent were discarded, leaving 13 classes for the discrimination experiments.

The goal of this preliminary analysis was to determine whether sufficient information exists in the reconstructed ERS-1 imagery to distinguish between the Matthews vegetation classes. Three procedures were used:

- Calculation of simple descriptive statistics for each vegetation class for spring, summer, fall, and winter.
- Graphical analysis of backscatter change through the season for each vegetation class.
- Rudimentary discriminant analysis.

To conduct these analyses, the 12 monthly ERS-1 images were registered with the digital vegetation map, and the backscatter values for each underlying vegetation cell were extracted and recorded.

In the discriminant analysis, the vegetation classes were the dependent variables, and pixels from the twelve seasonal images formed the independent variables. In the tests described below, only one-third of the pixels for each of the 13 vegetation formations were used for training. The remaining two-thirds were reserved for testing the discrimination.

The fundamental approach used in the exploratory discriminant analysis was to continually regroup the original 13 vegetation categories into a much smaller set until the classification accuracy produced by discriminant functions reached an acceptable level. An effort was made to maintain logically consistent groupings. For example, while we felt free to combine equatorial forest categories with some woodland categories, we did not combine forest categories with unrelated categories such as desert. The quality of the supervised classification was assessed by a simple percentage of agreement between the map and predicted vegetation class.

## III. RESULTS AND DISCUSSION

Backscatter values for the 13 vegetation classes, calculated for summer and winter seasons, are presented in Table 1. In general, regardless of the season, backscatter is the highest among the tropical forest classes and decreases progressively through the woodland and grassland categories. Desert produces the lowest backscatter.

Figure 2 is a graph of vegetation backscatter changes for the 12 composite months. To improve legibility, only nine of the 13 classes are shown. The graph shows how the backscatter for the equatorial forest classes changes little throughout the year. This is to be expected, since the equatorial forest vegetation is largely evergreen, and does not drop its leaves in response to seasonal changes in temperature or moisture. In fact, most of the evergreen classes show the same general behavior -- consistent backscatter throughout the year. Few of these classes are strongly affected by the shift of the Intertropical Convergence zone (ITC).

The desert class has consistently low backscatter throughout the year -- there is little vegetation to provide seasonally changing surface or volume backscatter.

In contrast to the classes which exhibit little change, the savanna woodlands and grasslands show a profound increase in backscatter during certain months as the grassy vegetation becomes greener, or as the trees leaf-out. As the ITC drifts away from these regions, and these savanna vegetation classes come under the influence of subtropical high pressure, the climate becomes more droughty, the vegetation rapidly browns, and the trees lose their leaves. The backscatter decreases during these months.

Initial attempts to discriminate between all 13 classes were disappointing. Furthermore, a final grouping of four classes produces an overall accuracy of only 63.5%, far less than the accuracy produced when a similar experiment was conducted over South America [3]. Class accuracy figures for this four group solution are presented in Table 2.

As the table shows, the evergreen forest and woodland classes are the most accurately classified, whereas the shrubland and mixed grass-shrubland are correctly classified less than 1/2 the time.

## IV. CONCLUSION

Given the vegetation class seasonality depicted in the ERS-1 imagery, the mediocre classification accuracy is unexpected. Further investigation has indicated that the digital map being used for "ground-truth" is extremely generalized -- the satellite imagery depicts more detail in the vegetation than the map. We think that vegetation mixtures along the vegetative region borders combined with the generalization in the map contributed to the lack of discrimination accuracy. In previous work with higher quality map sources and more selective sampling, classification accuracy exceeded 80%, although the same problems were cited [3].

Given the dramatic seasonal changes in the savanna classes, and the lack of seasonal changes in the tropical forest classes, there is strong evidence that reconstructed ERS-1 imagery can be used for regional vegetation mapping and monitoring. However, other evidence suggests that a single reconstructed image used alone would be insufficient -- a temporal sequence would likely be required. Inclusion of AVHRR or another reconstructed image type would also prove valuable. Mid-latitude and boreal forest research using reconstructed C-band scatterometry may also prove fruitful, especially when combined with high resolution SAR imagery.

## V. REFERENCES

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| Vegetation Formation | Summer | Winter |
|---|---|---|
| Tropical evergreen rainforest | -8.02 | -8.28 |
| Trop. broad-leaved seasonal evergreen forest | -8.44 | -8.93 |
| Evergreen broad-leaved sclerophyllous woodland | -10.22 | -10.23 |
| Grassland with < 10% woody trees | -9.47 | -11.13 |
| Tropical drought-deciduous woodland | -9.86 | -11.15 |
| Grassland with 10-40% woody trees | -10.35 | -11.35 |
| Meadow, short grassland, no woody cover | -10.77 | -11.80 |
| Tall grassland, no woody cover | -10.35 | -12.10 |
| Xeromorphic shrubland | -11.95 | -12.19 |
| Evergreen broad-leaved shrubland | -12.43 | -12.37 |
| Medium grassland, no woody cover | -11.64 | -12.60 |
| Grassland with shrub cover | -12.76 | -13.41 |
| Desert | -15.67 | -15.97 |

*Table 1. Seasonal backscatter averages*

| Vegetation class | Percentage of map pixels accurately classified |
|---|---|
| Evergreen forest and woodland | 82.2% |
| Deciduous woodland and grassland | 64.5% |
| Shrubland and mixed grass-shrubland | 44.6% |
| Desert | 72.2% |

*Table 2. Results from the discrimination analysis.*

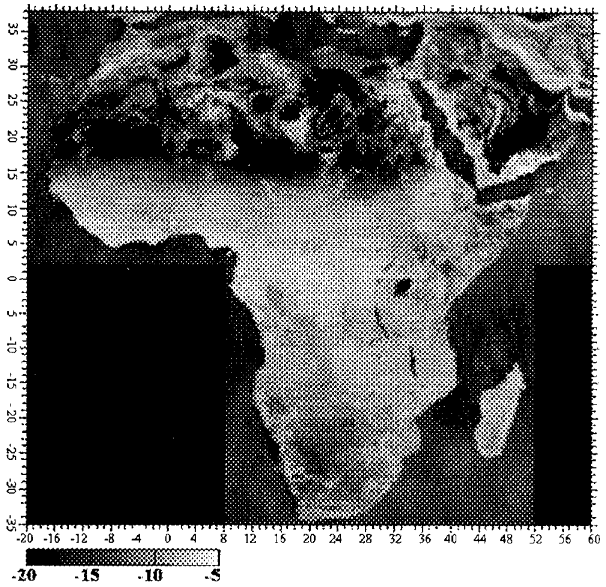

*Figure 1. Reconstructed ERS-1 summer image.*

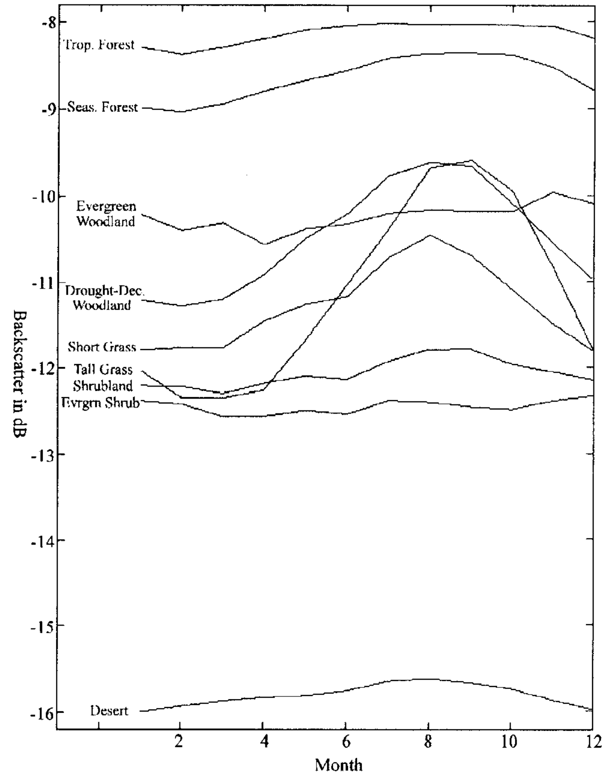

*Figure 2. Seasonal change in backscatter for selected vegetation classes*