DRAFT-REPORT
NASA LCLUC Program

An Integrated Forest Monitoring System for Central Africa

Progress Report - May 2001 - April 2002

Principal Investigator

- Dr. Nadine Laporte-Goetz
  Dept. of Geography, University of Maryland, College Park, MD 20742
  e-mail: nlaporte@geog.umd.edu, Tel: 301-405-74-75, Fax: 301-314-9299

Co- Investigators

- Dr. Jacqueline Le Moigne
  NASA-GSFC, Applied Information Sciences Branch, Greenbelt, MD 20771,USA
  e-mail: lemoigne@backserv.gsfc.nasa.gov

Collaborators

- Paul Elkan
  Wildlife Conservation Society, Kabo, Rep. of Congo
  e-mail: pelkan@earthlink.net

- Olivier Desmet
  Forest Management Unit - CIB, Pokola, Rep. of Congo
  e-mail: olivier.desmet@cibpokola.com

- Dr. Mike Fay
  Wildlife Conservation Society, Bronx, NY 10460-1099
  e-mail: mfay@ngs.org, Tel: 202 288-9248

- Patrice Gouala
  Ministry of Forest, Brazzaville, Rep. of Congo.
  e-mail: pgouala@yahoo.fr

- Dr. Miroslav Honzák
  Dept. of Cartography and Geoinformatics, Charles University, Albertov 6, 128 43, Prague 2, Czech Rep.
  e-mail: miroslav_honzak@yahoo.com

- Dr. Fiona Maisels
  Research Coordinator, Nouabale-Ndoki National Park, Rep. of Congo
  e-mail: bomassa@uuplus.com

- Dr. Philippe Mayaux
  TREES/Global Vegetation Monitoring Unit, DG Joint Research Centre, Ispra, Italy
  e-mail: philippe.mayaux@jrc.it

Abstract

This project expands on previous work mapping forest types, extent, spatial distribution, and biomass of central Africa. It uses a network of contacts and collaborators in the region to develop a forest monitoring system. The work includes fusion of multiple image data sources and extensive field measurements to map land cover, land use practices, and biomass density at the local and regional scale. This work is based on participation in interdisciplinary programs focused on the region. It provides access to an unprecedented set of remote sensing and field measurements, which are just now available for monitoring regional forest resources and their associated dynamics. A range of land surface variable maps is planned for widespread distribution to an established user community. This will be done in collaboration with the NASA/UMD Deforestation Mapping Group, contingents of the US AID-funded Central Africa Regional Program for the Environment (CARPE), the Africa program of the World Conservation Society and national forest services.

Key words:
Research Fields: Habitat Conversion, Deforestation, Vegetation Mapping
Geographic Area/Biome: Central Africa, Tropical Forest
Remote Sensing: Radar, MODIS, IKONOS, Landsat
Methods/scales: Local to Regional Scale, Data Fusion, Change Detection

Mapping and Monitoring Central African Rainforest

Remote sensing research and applications (75%), Social science (25%)
Carbon (25%), GOFC (50%), Biodiversity Monitoring (25%)

Central African forest is one of the largest carbon reservoirs on Earth, but relatively little is known about the impacts of agriculture and logging on carbon stocks in this region. Changes in forest biomass under different land use scenarios have been addressed in other tropical forest regions (e.g., the Amazon Basin), but the modes of forest harvest and use are very different in Africa. Levels of forest fragmentation and the intensity of forest biomass removal is still largely unknown or poorly documented. During the first 2 years of our project, we developed a strategy to address these needs and made progress on implementing them, as summarized below.

Goals / Science implication

- Better characterization of tropical forest surfaces and their biophysical processes
- Multi-scale/ multi-sensor data integration methods and appropriate validation tools
- Integration of Central African research scientists in regional science activities

Approach / Methods

Develop new forest monitoring approaches under the framework of Global Observations of Forest Cover (GOFC), including:

- Characterization and mapping of Central Africa land cover / land use using multi-sensor, multi-scale satellite data, providing improved vegetation maps for applications at the local and regional scale.
- Development of methodologies to assess and map central Africa biomass using RADAR imagery to support regional carbon modeling.

- Development of forest monitoring techniques integrating new remote sensing information, biodiversity and forestry information in collaboration with international organizations and local stakeholders.

Phase 2 Achievements - Focus on Land Cover Mapping

Characterization and mapping of land cover/ land use in Central African rainforest is complex. This complexity is exacerbated by (1) the diversity of human land use practices and (2) the lack of full and continuous cloud-free coverage by any single remote sensing instrument. In order to provide improved vegetation maps of Central Africa and to develop forest monitoring techniques at the local and regional scales, we have focused our phase 2 activities on: (1) Continuing the integration of multi-sensor remote sensing observations with *in-situ* data for land cover mapping (in protected and logged areas); (2) Assessing the use of JERS-1 mosaics of Central Africa for biomass estimates; (3) Testing new validation methods, including the use of aerial videography, logging inventory, and biodiversity inventory; and, (4) Distributing Landsat imagery, research findings, and map products to our GOFC/CARPE partners for forest monitoring applications (Table 1).

Table 1- Project Milestones May 2001- April 2002

Activity	*2001*								*2002*			
	M	J	J	A	S	O	N	D	J	F	M	A
1-Acquisition of RS data												
2-Application of fusion algorithm to images at regional scale												
3-Develop RS/ biomass relationships using field data												
4-Generate local and regional biomass maps												
6-Validation of maps by in-country collaborators												
7-Acquisition and Analyis of digital aerial videography												
8-Share images with National Forest Services and in-country collaborators												
9-Acquisition of Lidar data (if available)												
10-Participation/ organization of GOFC regional workshop												
11-Collect additional field data												

(1) It would be helpful if the entire data set of Landsat orthorectified images, as well as data from the NASA Landsat Pathfinder archive, were available through the UMD/GLCF website.
(2) VCL launch postponed to ca. 2005.

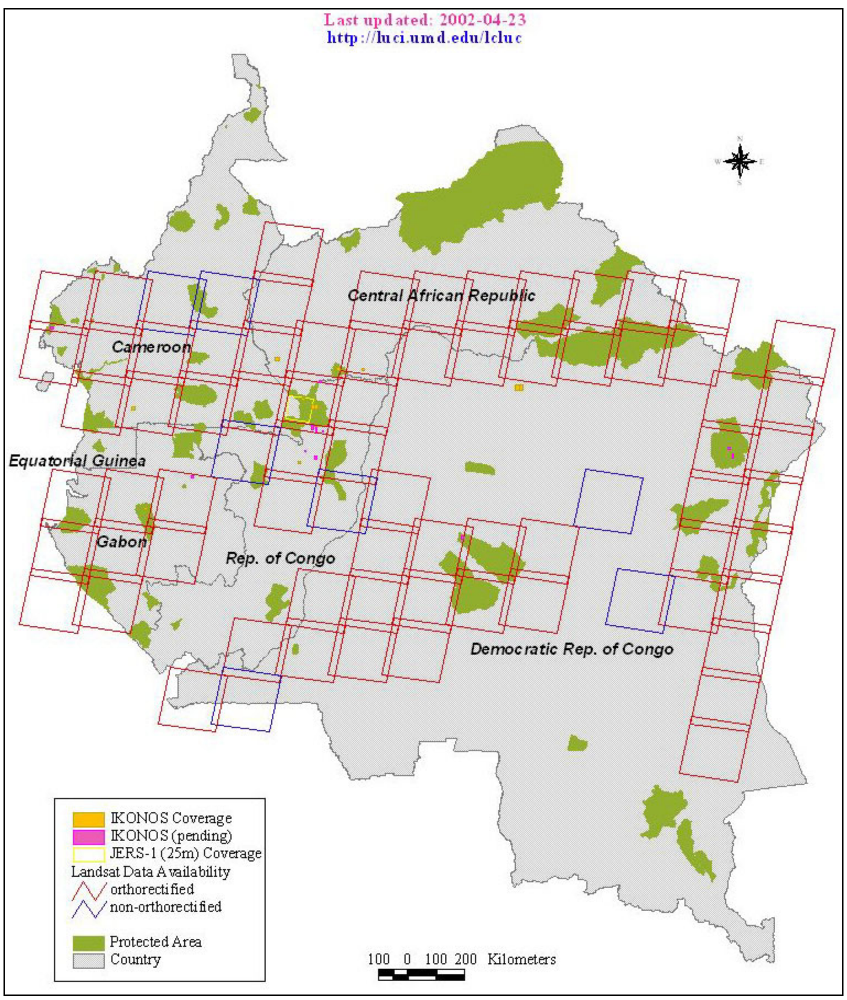
From the 10 activities listed for Year 2, only A4 and A10 were not completed. The regional mapping of biomass (A4) had to be cancelled due to the poor relation found between biomass measurements and JERS-1 amplitude signal; the GOFC/OSFAC workshop (A10) could not be run due to the lack of funding.

New Potentials

- **Image data acquisition, pre-processing, and distribution to GOFC collaborators in Central Africa**

A series of Landsat TM, ETM+ and IKONOS images have been acquired through the NASA Scientific Data Purchase program and distributed to in-country CARPE and GOFC collaborators in order to implement local-scale land cover mapping activities**.** Figure 1 shows the extent of remote sensing data acquired and distributed to collaborators in the region. Since internet access is still a limiting factor in Central Africa (speed and cost), most of the data are still distributed via CD-ROMs. In the future we are proposing to use the OSFAC network (www.osfac.org) to share remote sensing information in the region. The new OSFAC regional POC is Jean Francois Bizenga; he is based in Kinshasa. We now have identified a national POC for Cameroon, Nsoyuni A Lawrence, a GIS/RS officer at the Limbe Botanical Garden. In Gabon, Mr. Antaoine Ndongou from DIARF (Direction des Inventaires, des Aménagements et de la Régéneration des Forêts) was chosen as POC.

Figure 1: INFORMS Central Africa satellite image data availability
Distribution of RS dataset to the CARPE and GOFC networks



- **Outreach: Organization of CARPE-GOFC regional forest monitoring workshops with international NGOs and national forest services**

In collaboration with WCS, we organized a GOFC/CARPE workshop in Gabon (July 2000) to build national capacity for operational forest monitoring. More than 30 in-country researchers participated in the workshop. We focused on practical applications of satellite data to forest monitoring and conservation. The OSFAC follow-up workshop 2001-2002 was cancelled due to the lack of funding. For 2002-2003, CARPE/USAID funds should be available to finance African participation for a workshop at the Limbe Botanical Garden in Cameroon or in DRC.

- **Fusion of SAR and optical data for vegetation mapping**

During phase 1, we developed a wavelet-based fusion method, integrating high-frequency components of the higher spatial resolution data (SAR data at 6m resolution) and low-frequency components of lower spatial resolution data (Landsat-TM at 30m resolution). The fusion provides a new image data set at 6m spatial resolution, which contains more detailed texture features that were used to improve land cover classification. At the same time, the fusion preserves the large homogeneous regions that are observed by the Thematic Mapper sensor (Lemoigne *et al.*, 2001).

During phase 2, we are planning to use the same approach at regional scale to fuse and classify MODIS and JERS imagery (Lemoigne *et al.*, in prep.)

- **New unsupervised clustering for vegetation mapping**

Since field data for an extensive region is either scarce or expensive to acquire, unsupervised clustering methods play a significant role in the pursuit of land cover/ land use classification when relatively little **a priori** ***information is available. Various unsupervised clustering schemes have been proposed and studied over the years. In particular, classical methods such as K-means and ISODATA, which are based on iterative computations of cluster means, have also become standard in the remote sensing community. ISODATA is more involved than K-means, in the sense that it provides additional heuristic procedures, such as cluster merging and splitting, as well as some interactive features. For this study, the unsupervised ISOCLUS clustering scheme is enhanced by developing a fast K-means module. The module is based on a recent improvement to Llyod's K-means algorithm. The basic idea is to gain significant speed-up by pre-processing the data points, such that nearest neighbor computation become much more efficient. The module that is currently under way aims at gaining yet further speed-up by employing the above K-means variant to merely a sample of the image points. Depending on certain distortion criteria, however, the sample may need to be refined (e.g. by attaching stronger weights to certain points) so as to obtain a more "representative" sample. We hope to successfully employ this module to land cover classification where field data is scarce.***

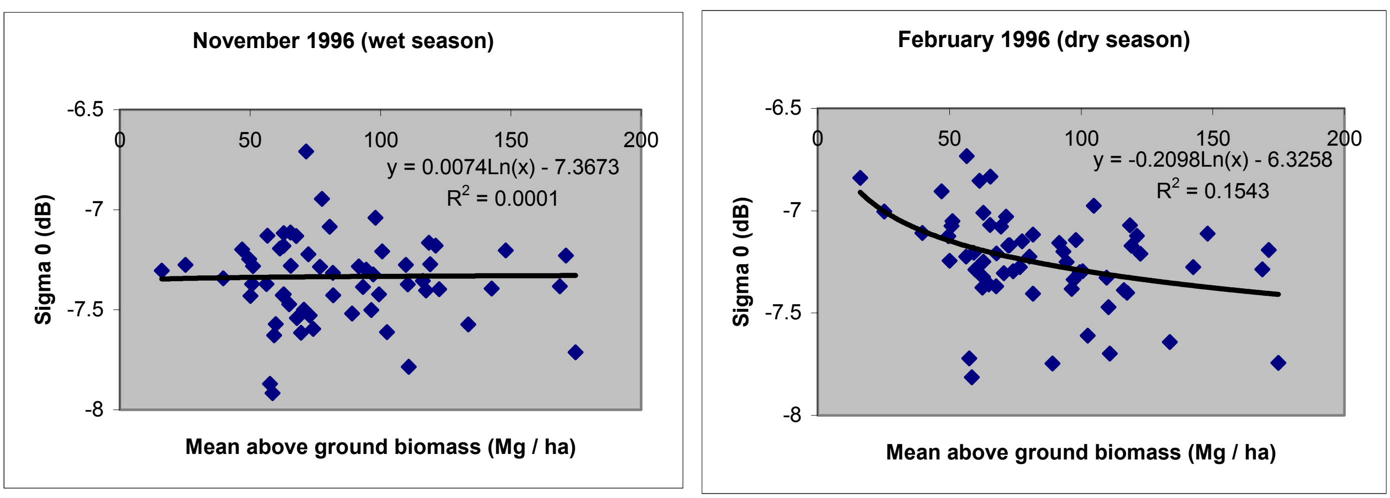
New Products and Results

The new products are posted on a regular basis on the project webpage: http://luci.umd.edu/lcluc Please note that some of the results listed below have been already posted on the site.

- **Assessing biomass using radar imagery (JERS-1 100m mosaics)**

Many studies have shown positive correlation between radar backscatter and total above-ground biomass of different forests in the Northern Hemisphere (LeToan *et al.*, 1992; Ranson *et al.*, 1994). These studies of different forest types confirm that (1) the longer wavelength (L-band) SAR imagery may be used to discriminate between different levels of forest biomass up to a certain threshold and (2) cross polarized backscatter is more sensitive to changes in biomass density. Since tropical forests have more complex structure and higher biomass than northern temperate forests, it was expected that the assessment of south Cameroon forest biomass, using JERS-1 100 m mosaics provided by JPL, would be more challenging. However, the large spectrum of vegetation types and densities of south Cameroon should allow us to better characterize and understand the threshold associated with JERS-1 (SAR L-band) data. But our study found no significant relationship between the existing field biomass measured in 1995 and the normalized backscatter of the JERS-1 mosaic of 1996. The relation was tested for both low and high water mosaics (Figure 2).

Figure 2: Mean above ground biomass v. JERS-1 Normalized backscatter (Sigma 0)



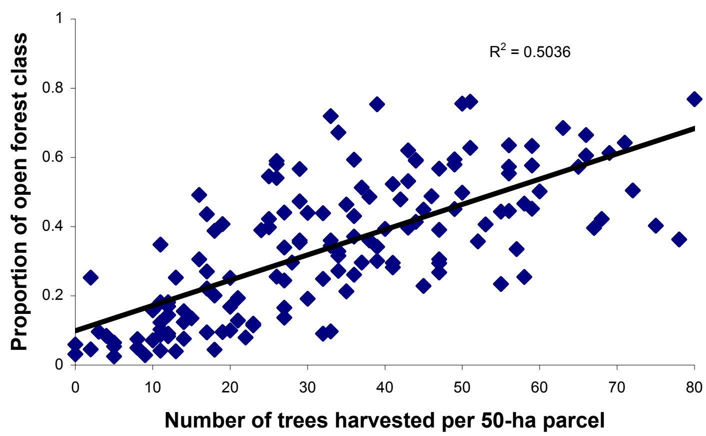
- **Land cover/ land use mapping forest conservation**

Wildlife management requires knowledge of habitat distribution and potential threats. Landsat TM imagery allows us to monitor forest cover around parks. In collaboration with WCS researchers, a vegetation map of the Okapi reserve was produced. The validation of the Okapi land cover map was delayed due to political and financial hardship. The next field validation campaign is planned for July 2002. It will be run by our collaborator Inocent Liengola, a botanist at the CEFROCOF (Centre de Formation et de Recherche en Conservation Forestiere). The validated land cover map will be published and distributed by April 2003.

- **Mapping logging activities in Northern Congo**

In order to identify potential carbon sinks in Central Africa, it is critical to understand the history and projections of logging in the region. Millions of hectares of forestland in the region are under concession (i.e. allocated for logging- ca. 40% of the dense humid forest). To assess the extent of this potential C sink and its implications on carbon modeling in the region, we are analyzing land use changes associated with logging activities in several sites. We have developed a simple "logging index" derived from Landsat satellite imagery. It allows the estimation of harvesting intensity by forest unit. This index needs to be validated in other production units before it can be operationalized (Figure 3).

Figure 3: Developing a logging forest index for Central Africa



- **Assessing rates of deforestation in logging towns**

Northern Republic of Congo is an important area to develop an understanding for the impacts of logging on Central African forests. Logging is the predominant form of land use for this otherwise largely undisturbed natural region. Current rates of deforestation associated with logging in the region are poorly documented. Our mapping of land use change associated with logging at the Pokola site does not show that logging town have a higher rate of deforestation compare to non logging town (1% per year).

It is necessary to analyze deforestation rates in other countries where the deforestation/ logging tandem might have a different outcome due to different traditional use of the land, higher population pressure or different forest policies.

- **Evaluation of IKONOS standard product for geo-location and logging monitoring**

IKONOS imagery was evaluated for geo-location accuracy and its application in the monitoring of selective logging. For the Danzer logging concession in northern Congo, we found that the location of the IKONOS imagery was on average 30m NNE of the GPS reading, with a 5-10m difference between GPS units. This posts a serious challenge in corresponding individual tree measurements from the field to its spectral measurements on the image for forestry and biodiversity applications. The size and form of tree crown is typically species-dependent and is often less than or approximately equal to this 30m spatial uncertainty in the forests of the region. Even on a plot level or transect level, analyzing the relationships between spectral signatures and biophysical characteristics become difficult. It is time-consuming and costly to have adequate samples of field plots that are large enough to render this location uncertainty. This holds true for detecting spectral differences between plots of different harvesting treatments.

Therefore, the feasibility of using IKONOS imagery for logging monitoring largely depends on unambiguous reference points that are spatially well-distributed. Preliminary observations showed that the multispectral image is useful for the identification of general vegetation types as well as the phenology (both vegetative and reproductive) of a forest stand or a forest type. However, the panchromatic image seemed to be more useful in identifying and delineating individual tree crowns in the field. Whether it is for the purpose of georeferencing or spectral analysis, knowledge of the autoecology, particularly tree architecture and phenology, of common tree species in the forests is invaluable in the forestry application of IKONOS products.

In CIB logging concessions, we found a moderate level of positive correlation ($0.4 < R^2 < 0.5$; $p < 0.05$) between logging intensity and the difference in near-IR band of Landsat images 7 years prior to and 2 years post-harvesting. (Calculations were based on relative spectral readings after image-to-image radiometric calibration.) No correlation ($R^2 < 0.01$) was found in other Landsat bands. We expected similar response in IKONOS imagery when examining selective logging of similar forest type in Central African Republic. However, preliminary assessment yielded no significant difference between plot spectral means of IKONOS near-IR band in areas that were logged in 1982 from those that were never exploited. It is hypothesized that any significant change in spectral values of near-IR band as a result of selective logging can no longer be detected 18 years after harvesting.

- **Digital aerial videography for vegetation classification and validation at Ndoki**

The digital video transects acquired in March 2001 in collaboration with WCS are being used for land cover map validation; more acquisitions are planned in collaboration with WCS for 2002. These data sets are invaluable for validating land cover/ land use classifications and for evaluating the spatial variability of vegetation at the local scale. The new transects allow us to improve our vegetation classification and validation activities. We are now preparing to survey our Cameroon and Central

African Republic sites. Flights planned for the Salonga region in the Democratic Republic of Congo could not be done due to security issues. We are still waiting for flight permits for Cameroon.

Next steps (Phase 3) - Focus on result publication and distribution

For the next phase of the project, we plan to focus on the publication and distribution of our results to the national in-country forest services and the scientific community. We already developed a web page for the NASA-LCLUC project (http://luci.umd.edu/lcluc). This web site allows us to share our progress with the scientific community and to present educational materials for students.

Table 2: Project Milestones, May 2002-April 2003

	2002								2003			
Activity	M	J	J	A	S	O	N	D	J	F	M	A
1-Update the project website for data sharing	→	→										
2-Finalize land cover map validation using forestry and biodiversity surveys and videography	→	→	→									
3-Publish results on the development of fusion algorithm at local and regional scale				→	→	→	→					
4-Publish results on JERS/ biomass estimation	→	→	→	→								
5-Publish results on habitat mapping in protected areas							→	→	→	→		
6-Continue the validation/ distribution of land cover maps to in-country collaborators	→	→	→	→	→	→	→	→	→	→	→	→
7-Participation/ Organization of GOFC regional workshop						→	→	→				
8-Continue the acquisition of RS data for OSFAC partners	→	→	→	→	→	→	→	→	→	→	→	→
9-Continue technical support with OSFAC Bureau	→	→	→	→	→	→	→	→	→	→	→	→

Conclusions & Issues

Good progress has been made on satellite land cover / land use mapping activities in several study areas. The preliminary land cover maps were distributed to Forest Services, NGOs, and one logging company for evaluation. We are in the process of improving our land cover classifications and validating areas of identified change in logged forests. We did not find that forest biomass in Cameroon could be predicted using JERS-1 100m mosaics; similar limitation were found for the Amazon forest by Salas *et al.* (2002) IJRS- vol: 23-7). We are planning to organized and run a GOFC remote sensing workshop in the region in collaboration with CARPE (a similar workshop was run in Gabon in 2000).

Peer reviewed papers

Chan J.C.W., Laporte N., Defries R., (2002), Texture classification of logging in tropical Africa using machine learning algorithms, *International Journal of Remote Sensing*, in press.

Report and non peer reviewed papers

Reports and proceedings are posted on our NASA/LCLUC website at:

http://luci.umd.edu/lcluc/

Planned peer reviewed papers

Estimating tropical forest biomass in a fragmented landscape, Laporte N. and Honzack M., in preparation for *International Journal of Remote Sensing*.

An integrated forest monitoring system for central Africa- The Tri-national Park area case study. Laporte N. Lin T., Devers D., in preparation for *Conservation Biology*.

Applying Remote sensing techniques to biodiveristy & conservation monitoring in Central Africa, Laporte N., Devers D., Lin T., Beyers R., in preparation for *Conservation Biology*.

Mapping vegetation dynamics at the forest/savanna interface in Lopé, Laporte N., White L., in preparation for *International Journal of Remote Sensing*.

Deforestation trends in the Democratic Republic of Congo, Laporte N., Devers D., Desh A., in preparation for *Environmental Conservation*.

Literatture cited

Le Moigne J., Laporte N. and Netanyahu N.S. (2001), *Enhancement of tropical land cover mapping with wavelet-based fusion and unsupervised clustering of SAR and Landsat Image Data,* International Society for Optical Engineering (SPIE), Toulouse, 17-21 September 2001, Toulouse, France, 6p.

LeToan T., Beaudoin A., Roim J., Guyon D., 1992, Relating Forest Biomass to SAR data, *IEEE*, *Transactions on Geoscience and Remote Sensing*, 30:403-411.

Ranson K. J. , Sun G., 1994, Mapping Biomass of a Northern Forest Using Multifrequency SAR Data, *IEEE*, *Transactions on Geoscience and Remote Sensing*, 32:388-396.