Study of Land-Use and Deforestation In Central and West African Tropical Forest Using High Resolution SAR Satellite Imagery

Progress Report

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Summary

Deforestation in tropical Africa is driven by a variety of socio-economic and environmental factors, and has resulted in land cover changes that threaten biodiversity, water and energy resources, and contributes to trace-gas emissions. Several conservation and development studies have concluded that the deforestation in Africa is closely tied to demographic conditions such that the greatest loss of rain forests has occurred in countries with higher population growth. However, lack of reliable data and survey information in some countries, has made the estimation of areas of intact forest and/or

under land use change and their relation to economic indicators surprisingly difficult to establish. Consequently, the extent and rate of deforestation in Africa are less well known than other regions of tropics.

In this study, we use high resolution satellite imagery to map areas of forest clearing and general land cover types for the entire Central African tropical region. Images acquired by JERS-1 SAR (Synthetic Aperture Radar) instrument during its global rain forest mapping (GRFM) phase are the main source of data for this study. By using a combination of radar backscatter and texture analysis, and a SAR-specific classifier, we have developed a classifier to segment the JERS-1 images into five general categories of forest, nonforest, savanna, floodplain vegetation, and open water. Approximately 4000 high resolution (12.5 m) images for two periods of dry and wet seasons have been processed and delivered to the NASA/Jet Propulsion Laboratory and the European Commission Joint Research Center in Italy for generating a geocoded 100 m resolution mosaic of image data and a land cover map. The thematic interpretation of JERS-1 data and the validation of the land cover map are supported by available Landsat TM images acquired by NASA pathfinder project, ERS-1 mosaic of Africa generated by ESA TREES (Tropical Ecosystem Environment Monitoring by Satellites) project, and vegetation maps and field data provided by collaborators from national institutions in the region. JERS-1 100 m mosaic image and the derived land cover product will be integrated in the Landsat Pathfinder program in order to generate a complete forest cover map for the 1990s period.

To date, the efforts have been focused on the following items:

1. JERS-1 Data Acquisition and Processing

JERS-l SAR is an L-band spaceborne SAR system launched by the National Space Development Agency of Japan (NASDA) in February, 1992. The system operates at 1.275 GHz with horizontal polarization for both transmission and reception. The spatial resolution of the system is 18 m in both azimuth and range. The swath width is 75 km and the incidence angle of radar at the center of swath is 38.5^{o}. The single-look images have 4.2 m pixel spacing in azimuth and 12.5 m in range and the standard three look image has 12.5 m pixel spacing in both azimuth and range. JERS-l covers the global land surface for several applications such as land survey, agriculture, forestry, fisheries, environmental protection, disaster prevention and coastal monitoring. The satellite flies on sun-synchronous orbits 568 km above the Earth surface with a recurrent period of 44 days.

In late 1995, the JERS-l satellite entered into its Global Rain Forest Mapping (GRFM) phase to collect high resolution SAR data over the entire tropical rainforest. SAR data over central and west Africa, from eastern coast of Kenya and Madagascar, to Liberia and Guinea in the west, were acquired from January to March, 1996. The area covered lies between 9^o N and 9^o S latitude, extends approximately 6000 km along the equator, and amounts to about 2200 NASDA processed scenes or 9 million km^2 . The Congo River basin, about 3.5 million km^2 , was also covered during the October and November 1996 (the high water season of the river). Madagascar data were acquired in January 1997.

The entire data acquired over the African continent have been processed and calibrated. Table 1 shows the status of the data acquisition and processing for the region of Africa. Figure 1 shows the geographical area covered by the JERS-1 SAR during the GRFM project over the African tropical region.

Table 1. JERS-1 data acquisition and processing time table over the African tropical rainforest.

Region	Season/Date	# of Images	Status
Central Africa	High water/14 Oct-25 Nov,1996	1464	Completed
West Africa	Low Water/5 Feb-19 Mar, 1996	390	Completed
Central Africa	Low Water/7 Jan-9 Mar, 1996	1796	Completed
Madagascar	Low Water/14-25 Jan, 1997	264	Completed

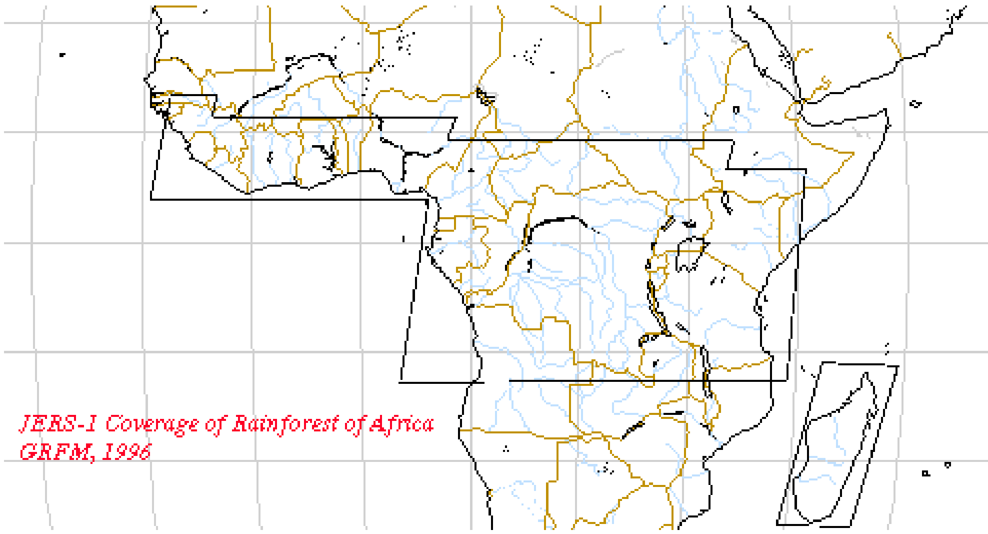

Figure 1. Geographical coverage of JERS-1 data over the African continent during the GRFM project.

2. JERS-1 100 m Mosaic of Central and West Africa:

One of the main problems in using high resolution imagery to provide regional or continental scale maps is the difficulty of mosaicking a large number of images. This is due to inaccurate orbital information, changes in surface feature between two adjacent data takes, and calibration discrepancies among images. In optical imagery, to these problems, one can add the changes of sun angle for each data take, the lack of frequent data takes in one season, and thus spectral changes of landscape. In the case of JERS-1 images, these problems can be readily overcome because 1) all images were acquired in two months, minimizing changes in surface features, 2) JERS-1 data can be cross calibrated to provide uniform calibration over the entire mosaic, and 3) atmospheric conditions do not affect image quality.

We have used 100 m resolution JERS-1 data (8 by 8 averaging of high resolution 12.5 m three-look data) to generate a map of the entire basin . The technique developed for mosaicking the images is based on a mathematical wallpapering approach which minimizes the propagation of errors over the mosaic. The interscene overlaps both in the along-track and cross-track directions were used for individual scene geolocation. The scenes were placed on a global coordinate system with the flexibility of having scenes float freely with respect to one another. The locations of all scenes were calculated simultaneously, avoiding any directional errors. The result is an optimum seamless mosaic. The geometrical accuracy of the mosaic will be checked against control points from local maps. The raw images were processed to level 1 at NASDA, calibration, and image mosaicking were performed at the Joint Recent Center (JRC) in collaboration with the Jet Propulsion Laboratory (JPL). Figure 2 shows the mosaic of JERS-1 data over West and Central Africa.

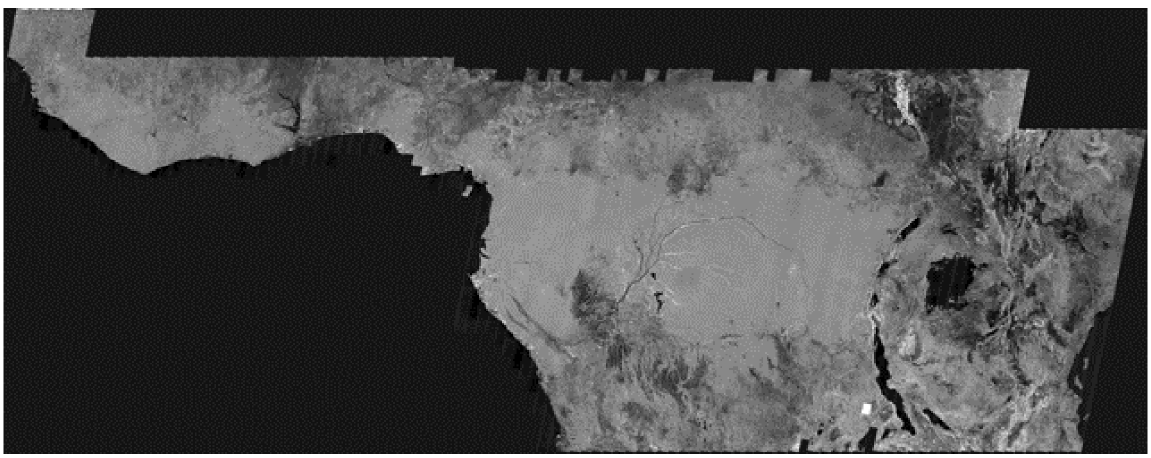

Figure 2. JERS-1 image mosaic of West and Central African rainforest at 100 m resolution.

3. JERS-1 Specific Classifier:

The large scale mosaic of JERS-1 data over tropical forests has provided the opportunity of applying a series of data analysis and classification schemes for mapping and monitoring land cover and land use. The high resolution imagery and the large scale mosaicking allows the visualization of the landscape at both fine and coarse resolution. In other words, more than one scale of the landscape heterogeneity can be observed or analyzed. Therefore, the data and the image mosaic enhance the traditional photogrametry and remote sensing techniques where one resolution and thus one scale is observed. In order to fully exploit the information content of the JERS-1 data, we have developed three types of classifiers: (1) first-order histogram texture based classifier using a combination of maximum likelihood and decision rule based classification, (2) a wavelet based classifier to make use of wavelet coefficients at various scales in conjunction with an automatic decision rule based algorithm developed specifically for the JERS-1 data, (3) a multi-resolution, texture based classification using a Markov random field approach and maximum likelihood technique. These classifiers have already been developed and tested on the 100 m mosaic data over several study areas. The results from the classification study are being reported in conferences and being prepared for journal publications (Saatchi et al., 1999; Simard et al., 1999; and Podest et al., 1999). The following sections summarizes the classification algorithms.

3.1 Multi-resolution classifier

A multiscale approach is introduced to classify the JERS-1 mosaic image over the Central African rainforest. A series of texture maps are generated from the 100 m mosaic image at various scales. The novel feature of the classifier is the exploitation of data in identifying land cover maps as the resolution is varied from coarse to fine. We start by first classifying the image at the coarse resolution using a MAP (Maximum *A Posteriori*) classifier and then proceed progressively to finer resolution. A quadtree and Markov random field approach are used to relate the signal characteristics and classes at various scales (Saatchi et al., 1999). At each scale the classification can be compared and verified with maps and field information and the resulting map is used as an initial condition at the next finer resolution until individual pixels at 100 meter mosaic are classified.

3.2 Wavelet based classifier

A method is developed for semi-automated classification of SAR images of the tropical forest. Information is extracted using the wavelet transform (WT). The WT was adapted to SAR images by normalization of the wavelet coefficients to correct for multiplicative noise. The transform allows for extraction of structural information in the image as a function of scale. Thus, different classes are characterized from their scale properties. In order to classify the SAR image, a Decision Tree Classifier is used. The tree grows using the Gini criterion computed from training data. It allows for estimation of the optimum threshold for separating classes based on the probability of the classes being in a given node (the origin of a split). First, a large tree is grown in order to best separate classes. However, the number of terminal nodes increases. In order to maximize the classification rate versus the tree size, a method called "pruning" is used. The pruning consists in cutting subtrees to reduce the original tree size. This is done using a misclassification cost estimated from an additional test sample (training data).

3.3 First-order texture based classifier

The coherent nature of the radar backscatter signal suggests that the imaging radar data contains two components: one is the speckle due to randomly distributed scatterers in a pixel, the other is the texture resulting from the spatial variability of the scene illuminated by the radar. Speckle often causes uncertainty in interpreting radar data but texture helps identify scene characteristics. There are several filtering techniques to reduce the speckle in SAR data while preserving the texture information. We started our analysis based on the knowledge that textural information enhances the capability of per-pixel classification of SAR data. Textural information or measures can be extracted from different order image histograms using various degrees of signal statistics.

In classifying the JERS-1 SAR data, we developed texture measures from the 100 m JERS-1 mosaic over a variety of window sizes, resulting in multi-scale texture images with independent pixel information, as the windows were shifted in a blockwise fashion in several pixel increments. These first order histogram statistics characterize the frequency of occurrence of grey levels within the window in the single channel radar data and are sensitive to window size which was determined a priori. The JERS-1 mosaic image in figure 2 shows some orbital stripes which are due to slight radiometric discrepancy between the calibration of orbital data takes. These calibration discrepancies which are often less than 0.5 dB in intensity do not affect the texture measures but may influence the classification of the image when the backscatter image is used. To circumvent this problem, one may classify single frame images first and then mosaic the classified images.

In quantifying the texture measures, we use the amplitude mosaic image. The use of amplitude instead of intensity helps separating low vegetation and water classes because of the small dynamic range of JERS-1 data (approximately 18 dB) and low signal to noise ratio. Texture measures calculated for classification were from the first order histograms. They were correlated and did not contribute equally to discriminating known land cover types. In order to evaluate the properties of textures and their effectiveness in separating classes, we used a figure of merit approach. We established a distance between the classes of the image from a training data set in such a way that a large distance implies a better class separability and thus small classification error. The distance is a statistical difference between the probability density functions of two classes i and j, and are often called the B distance (Bhattacharyya distance) or Jeffries-Matusia distance. Assuming that the probability density functions have Gaussian distribution, the B-distance can be calculated analytically. Figure 4 shows and example of the JERS-1 image and the derived land cover classification based on the first order texture measures over the coastal forest of Gabon.

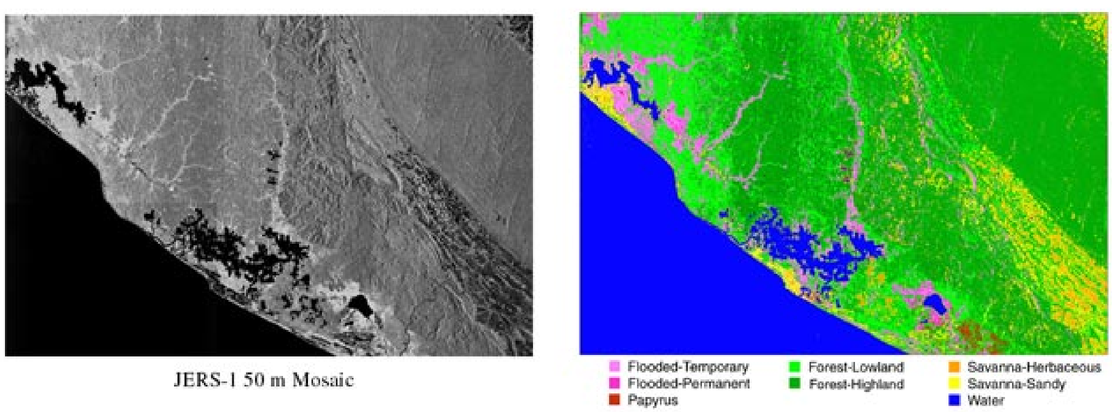

Figure 3. Land cover map of JERS-1 mosaic at 50 m resolution for the validation site in Gamba, Gabon. The class types are chosen to match the existing ground survey-based land cover map. The land cover patterns match the ground data and the pixel based classification accuracy is more 80%.

4. Regional Classification

The choice of land-cover classes on a regional scale is based on (1) the importance of the classes in the global change and land-use change studies, 2) the characteristics and the dynamic range of the JERS-1 SAR backscatter data. The general categories of the land-cover types for global change ecosystem process studies have been suggested by the core project of the International Geosphere Biosphere Program. We used these categories as our guideline to study class reparability in JERS-1 images on a regional scales. The use of texture and backscatter data suggests that six general classes can be separated in JERS-1 data: forest, degraded forest, nonforest, savanna, flooded forest and swamps, and open water. Other classes such as pasture and crop lands and some stages of secondary growth within the rain forest region are important in land use studies but may not be reliably distinguished in the one band JERS-1 data.

The regional maps are first produced on 1km scale for comparison with ground maps and AVHRR data. The results of the comparison will be used to tune the classifier for the 100 m regional land cover maps. Figure 3 is a preliminary classification at a 1km scale for central and west Africa for the low water data. While classifying the images, we noticed that the choice of a large window for example, for transforming 100 m resolution images to 1 km may reduce the accuracy of land cover mapping by introducing mixed information and errors in the definition of edges of land parcels.

During the remaining of the study, we are currently validating the regional maps by using field work and validation test sites and report the accuracy of classification and resulting land cover maps. In addition to regional land cover maps, we are generating a regional floodplain map using the low and high water data sets, and a simple forest/nonforest map to be used in conjunction with the Landsat Pathfinder land cover map for the 1990s period. Filling the gaps of the Landsat data for 1990s is currently underway by our Co-investigators at the University of Maryland, and University of Virginia.

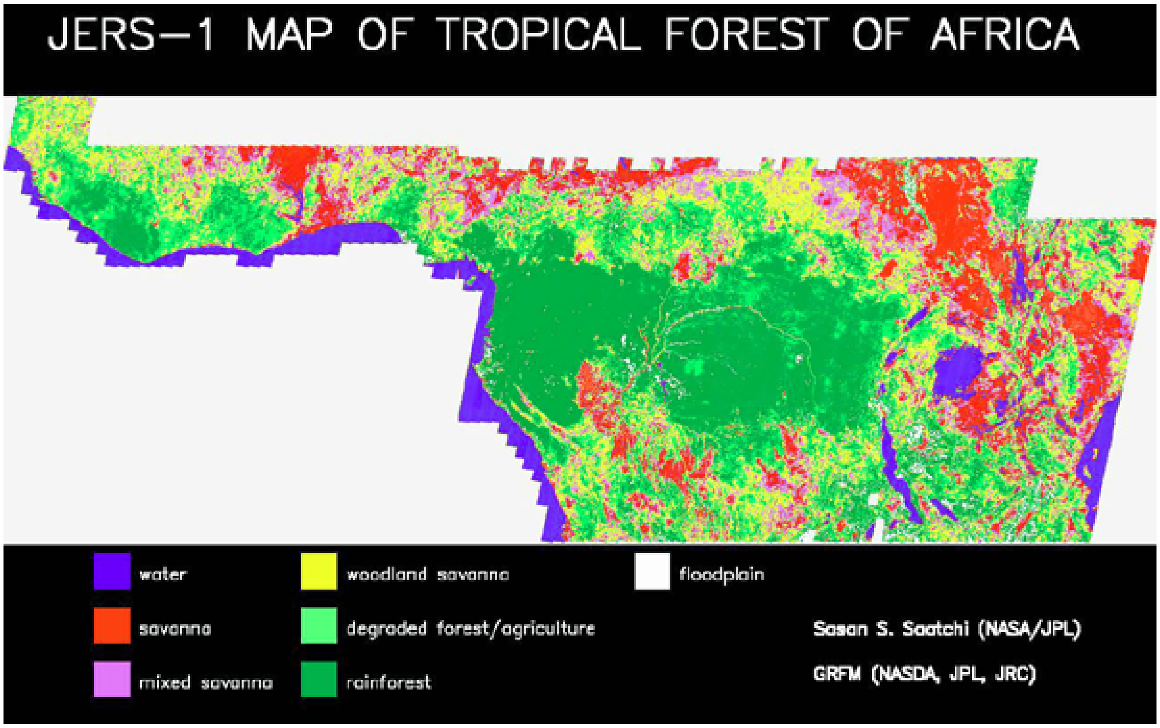

Figure 4. Regional land cover map at 1 km scale generated from the low water data over Central and west Africa. The classification is performed with a maximum likelihood based on backscatter data and one texture measure derived from 100 meter data.

5. Field Work and Validation Data

We have chosen test sites to verify the accuracy of land cover maps. These sites cover a wide range of land cover types: areas representing a cross-section of geographic locations, deforestation and land use practices, undisturbed regions of ecological importance, forest fragments under biodiversity and conservation studies (protected areas and wildlife reserves), areas within the flooded forest of the Congo basin, and areas overlapping the IGBP transects and NASA Landsat pathfinder test sites. We have established these sites in most countries and have worked closely with the IGBP Core projects, START program, NASA Landsat pathfinder, TREES projects, The World Bank environmental and policy departments, and several conservation societies in order to valid the local and regional vegetation maps. The test sites will be chosen from areas where Landsat TM date are available. Depending on the time of data acquisition and intensity of land-use changes, TM images can be used either in the classifier or as for validation purpose. The list of potential sites for validation of the regional land cover map and the corresponding collaborating individuals and agencies are provided by our web site (http://www-radar.jpl.nasa.gov/africamap/). The field data collection and contacts with scientist in each country in Central Africa are coordinated by Central African Regional Program for Environment (CARPE). In 1997, we visited Gabon and Cameroon and collected field data on several sites. During this field trip we also established contacts with local scientists that are currently helping us to validate our test site classifications.

On the regional scale, we are comparing and verifying the land cover map with the AVHRR derived vegetation map of Central Africa produced by TREES project. The comparison will allow us to produce a more accurate map of the region where ambiguities in forest-savanna and secondary regrowth cover types in AVHRR vegetation map are potentially removed.

Figure 5. Geographical location of validation test sites in Gabon. The sites are chosen based on significance in land cover types, human impact and ground data availability.

6. Data Distribution

Based on our initial agreement with NASDA and JRC, the 100 meter resolution JERS-1 data over the entire Central and West Africa for both low water and high water of Congo basin will be released in April of 1999 in CDROM format. The data set include the mosaic images in five-by-five degree sub-frames. The individual 100 meter resolution JERS-1 frame data can be downloaded from our web site at JPL (http://www-radar.jpl.nasa.gov/africamap). In addition to SAR images, at the end of the project, we will release the regional scale land cover mosaic maps in CDROM format including ground and ancillary data useful for further scientific research.

Figure 6. GRFM CDROM for Africa data set.

7. Publications and Presentation

The following is a list of peer-reviewed journal and conference papers submitted for publication which describe the methodology and resulting land cover maps from the GRFM project.

Journal papers:

Saatchi, S., Nelson, B., Podest, E., and Holt, J., 1998, Mapping land cover types in Amazon basin using 1km JERS-1 mosaic, *Int. J. Remote Sens.*, In press.

Saatchi, S., 1999, Change detection approach for monitoring deforestation in tropics using JERS-1 imagery, submitted to *Remote Sens. Environ*, January, 1999.

Conference papers:

Saatchi, S., De Grandi, F. , Simard, M., Podest, E., 1999, Classification of JERS-1 image mosaic of Central Africa using a supervised multiscale classifier of texture features, submitted to Proceeding of IGARSS'99, Hamburg, Germany, June 28-July 2, 1999, pp.

Podest, E. and Saatchi, S., 1999, Application of texture on JERS-1 imagery for tropical forest land cover classification, submitted to Proceeding of IGARSS'99, Hamburg, Germany, June 28-July 2, 1999, pp.

Simard, M., Saatchi, S., De Grandi, F., 1999, Classification of the Gabon SAR mosaic using a wavelet based rule classifier, submitted to Proceeding of IGARSS'99, Hamburg, Germany, June 28-July 2, 1999, pp.

8. Proposals and Related Activities

The GRFM project has provided several opportunities to use the JERS-1 data for various applications such as forest resource management, biodiversity and conservation, and global land cover and land use studies. We have participated with scientists in Universities and other national or international institutions in various interdisciplinary studies. The following is a list of these activities:

1. Forest and Land Cover mapping for Monitoring the Meso American Biological Corridor,
funded by NASA/LCLUC program, March 1999.
PI: Steven Sader (Department of Forestry, University of Maine),
Co-I: S. Saatchi (Jet Propulsion Laboratory)
Thomas Sever (NASA/Marshal Space Flight Center)

2. Integrating field research, satellite tracking and remote sensing into a study of seed disperser dynamics in central African rainforest, submitted to CARPE, November, 1998.
PI: Thomas Smith, Dept. of Biology, San Francisco State University
Co-I: S. Saatchi (Jet Propulsion Laboratory)

3. A Cross-Disciplinary Approach to investigating the evolutionary processes that sustain rainforest biodiversity worldwide. Submitted to the National Science Foundation, Jan. 1999.

PI: Thomas Smith, Dept. of Biology, San Francisco State University

Co-I: S. Saatchi (Jet Propulsion Laboratory)

Chris Schneider (Boston University)

Craig Mortiz (University of Queensland, Australia)

Bob Wayne (University of California, Los Angeles)

Kenton Miller (World Resource Institute)