Simulating the Effects of “Plan Colombia" on Land Use and Land Cover in the Ecuadorian Amazon: A Complex Systems Approach

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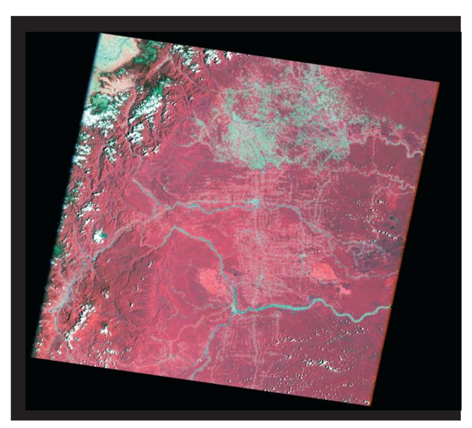
Abstract

This project, using recently developed cellular automaton modeling procedures and a temporally rich case study, develops spatially-explicit model-based simulations of future land use and cover change (LUCC) scenarios for the state of Sucumbios located in the Ecuadorian Amazon along the Colombian border. The research draws heavily upon recent work in remote sensing, complexity theory, and related social and biophysical disciplines. First, a cellular automaton (CA) model representing LUCC will be developed, calibrated, and validated using a time series of remotely sensed images and sketch maps from the region in Northeastern Ecuador linked to spatially referenced biophysical and socioeconomic coverages as input data combined with “rules” derived from empirical analyses of those data. Second, the CA model will be used in dynamic simulations to explore LUCC as both cause and consequence of: a) patterns of village settlement; b) road development; c) agricultural extensification and intensification; and d) the impacts of Plan Colombia (the US based program to eradicate drug production in bordering Colombia). Finally, Complexity Theory will be explored within the spatial and temporal dynamics associated with population/environment interactions.

The project exploits a rich existing collection of interlinked regional data sets including previously analyzed Landsat imagery dating back to 1973, assorted incomplete coverages of IKONOS, JERS, and aerial photographs. Community and household level surveys are available for 1990, 1999 and can be linked to Landsat derived LUCC class maps. Digital coverages showing roads, rivers, elevation, and other spatial-thematic data are also available. After developing, calibrating, and validating the regional CA modeling scenarios, spatially explicit LUCC patterns will be simulated and will illustrate various development scenarios including the hypothesized impacts of Plan Colombia. While prediction is difficult, it seems that the state of Sucumbios and possibly the larger region is poised for substantial social and economic change.

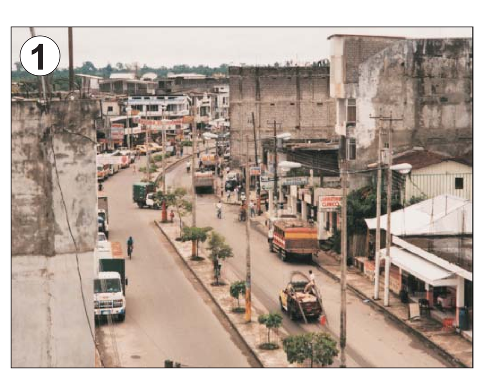
Study Area

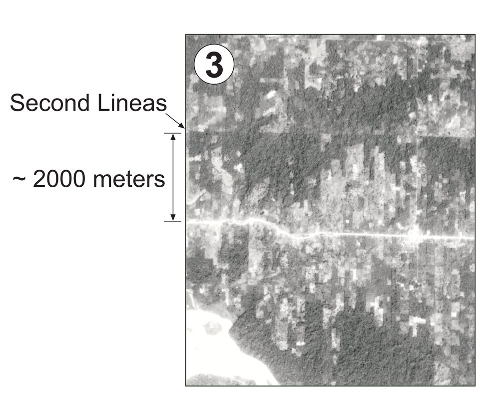


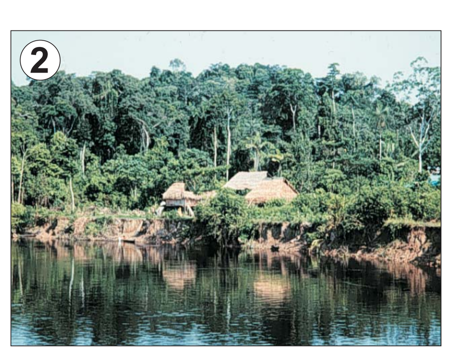
The field study was conducted in and near Coca, Ecuador. This was an ideal area for data collection as there is little season to season vegetation change. Although the vegetation does not vary greatly, the region has seen high levels of development in the last 30 years.

Development Pathways

① Urban Areas (Lago Agrio)
② Along Rivers (Puerto Bolivar)
③ Settlement Patterns







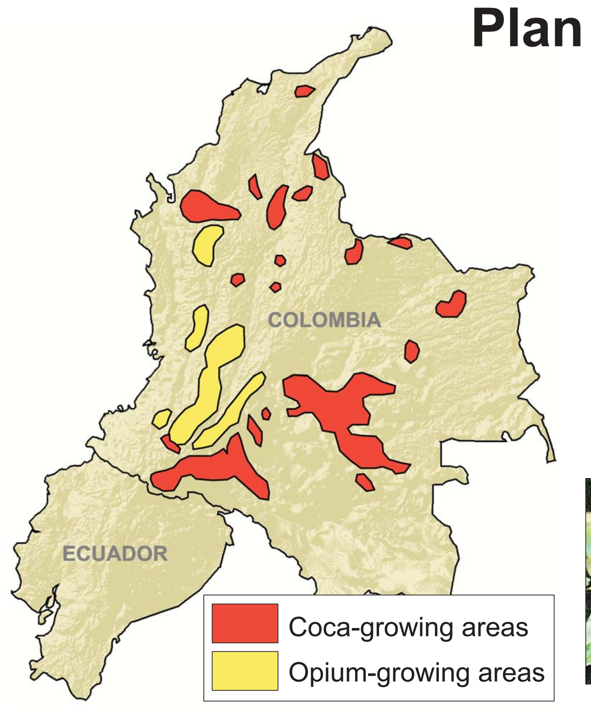
Forests In Transition

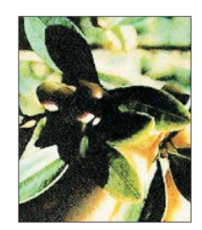
Dense

Secondary

Deforested with African palm

Plan Colombia





Source: UNDCP & Amazon Alliance

Spraying Effects

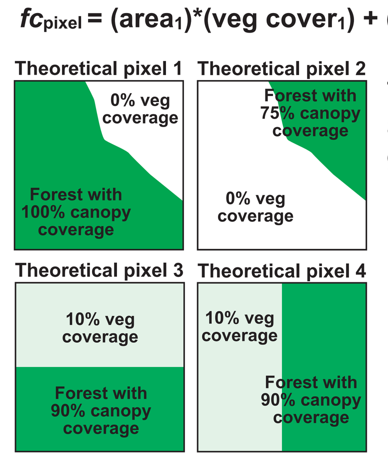
- Intercropping
- Drift

Source: Amazon Alliance

Fractional Coverage

Green Fractional Coverage (***fc***) is the percent of a pixel covered by green vegetation. Considering the heterogeniety existing in most pixels, ***fc*** is a representation of the sum of the percent vegetation cover within the pixel boundary:

$$fc_{pixel} = (area_1)*(veg\ cover_1) + (area_2)*(veg\ cover_2) + \dots (area_n)*(veg\ cover_n)$$



The signal received by the satellite is a mix of the elements present on the ground, thus:

$$fc_{pixel\ 1} = (75\%)*(100\%) + (25\%)*(0\%) = 75\%$$
$$fc_{pixel\ 2} = (75\%)*(0\%) + (25\%)*(100\%) = 18.75\%$$
$$fc_{pixel\ 3} = (50\%)*(90\%) + (50\%)*(10\%) = 50\%$$
$$fc_{pixel\ 4} = (50\%)*(90\%) + (50\%)*(10\%) = 50\%$$

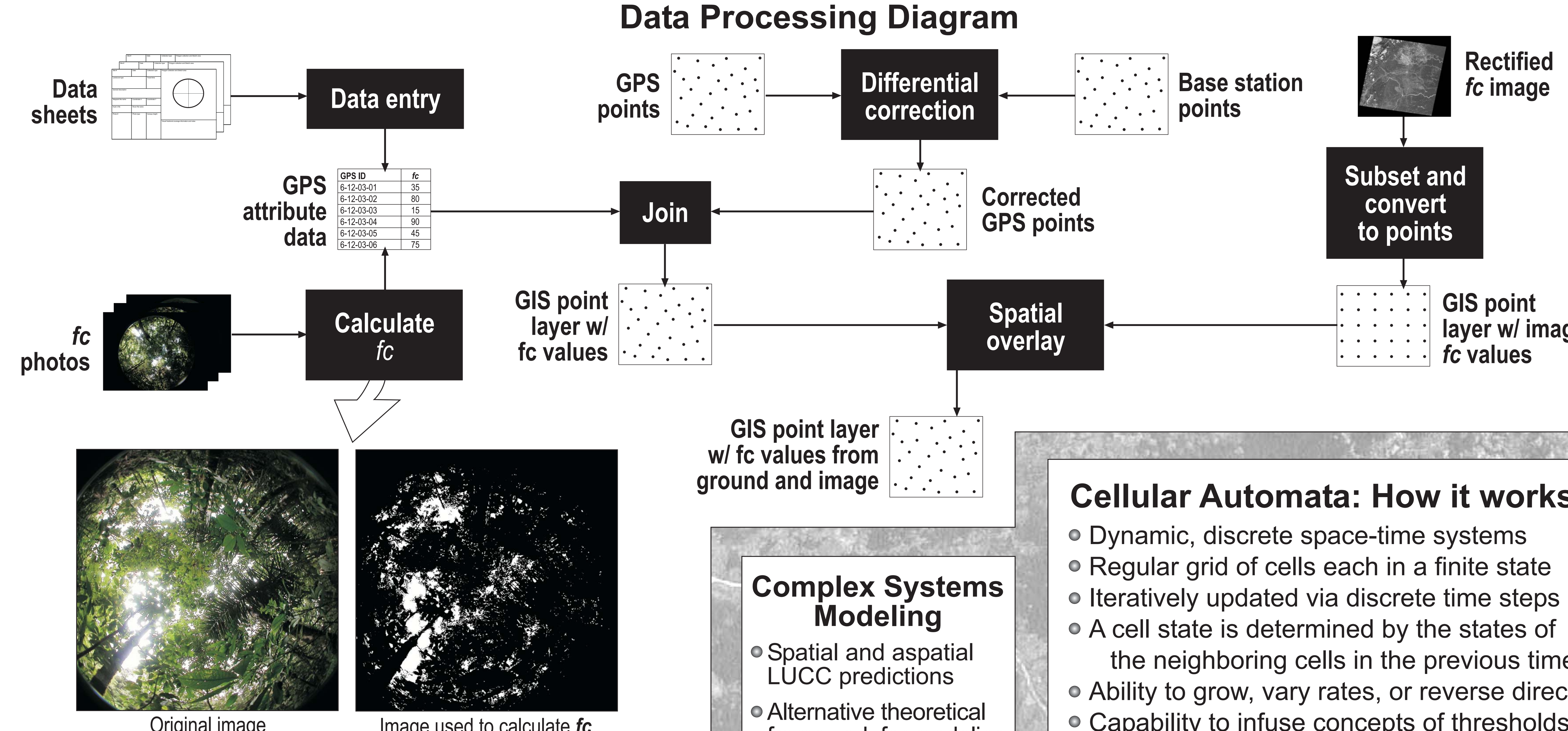
Field Data Collection

GPS Collection Outline / Decision tree

- Use Garmin GPS unit to navigate (by vehicle or on foot) to a predetermined stratified random point location
- Collect coordinates of point with the GeoExplorerII GPS unit
- Collect attribute data
  - If the patch in which the point falls in is homogenous, collect polygon information with the rangefinder and the compass and record fractional coverage and landcover information for the polygon
  - If the patch in which the point falls in is heterogenous, record fractional coverage and landcover information at point
  - If the patch in which the point falls in is forested or has many trees, collect canopy fractional coverage with the digital camera and record fractional coverage of the under story
  - If the patch in which the point falls in is not forested record fractional coverage and landcover information

Acknowledgements:
Francis Baquero, Carlos Mena, Mark Cochrane, Jiaguo Qi, Carolina Population Center

Data Processing Diagram



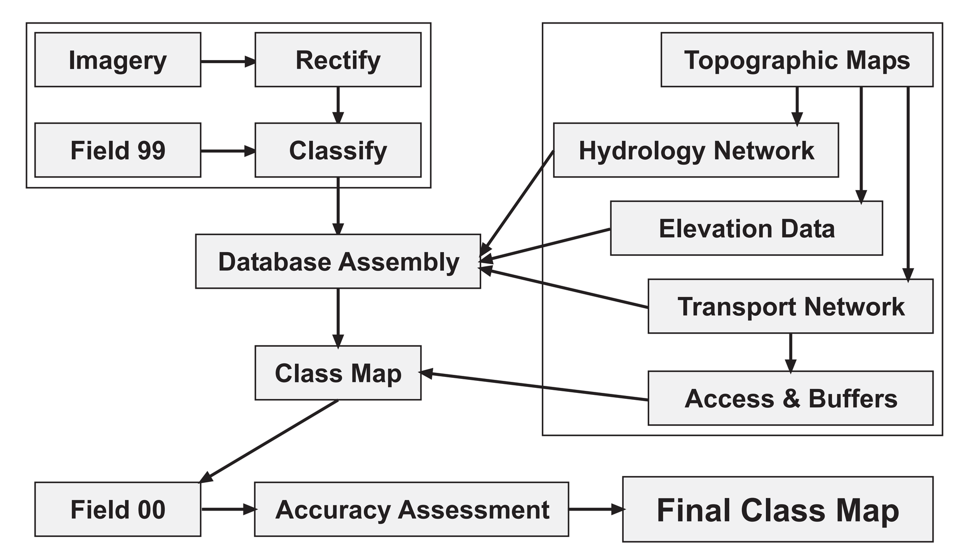
Complex Systems Modeling

- Spatial and aspatial LUCC predictions
- Alternative theoretical framework for modeling the world

Cellular Automata: How it works

- Dynamic, discrete space-time systems
- Regular grid of cells each in a finite state
- Iteratively updated via discrete time steps
- A cell state is determined by the states of the neighboring cells in the previous time step
- Ability to grow, vary rates, or reverse direction
- Capability to infuse concepts of thresholds, feedbacks, and hierarchy

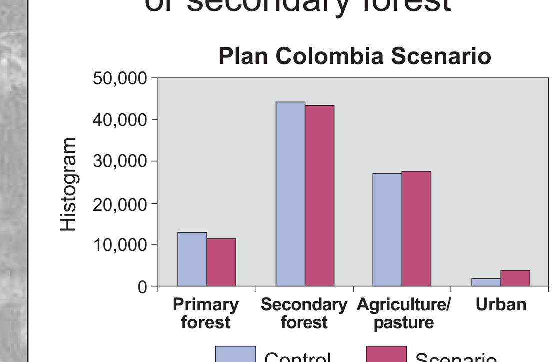
Land Use and Land Cover Classification

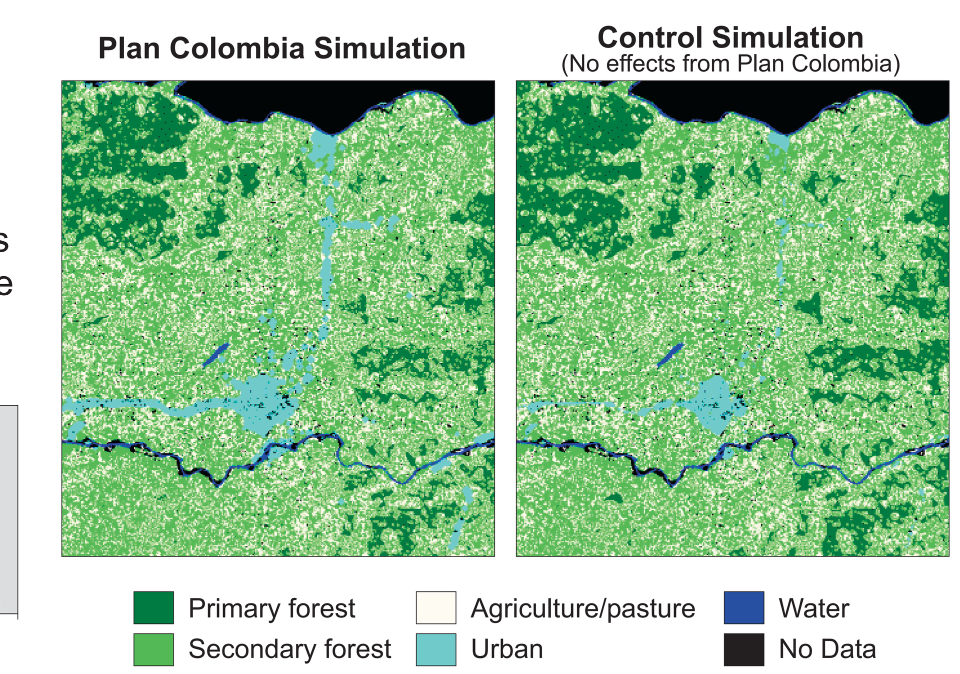


Plan Colombia Comparative Test Simulation through 2010

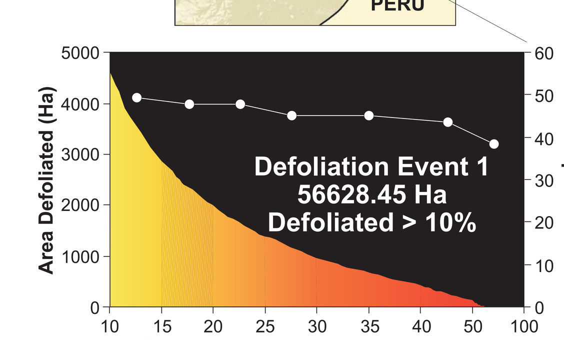
Conditions for Plan Colombia Simulation

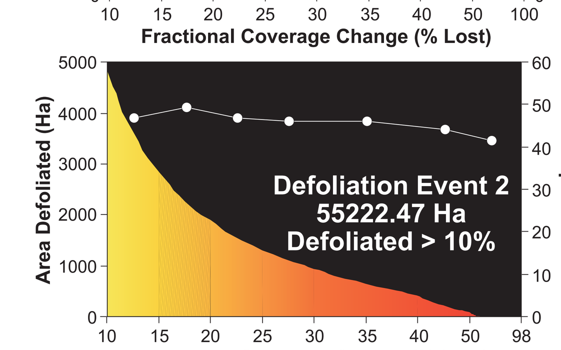
1: Initial 1999
2: Increased urbanization
3: Decreased effect of relief
4: Increased effect of access
5: Equal likelihood of pasture or secondary forest

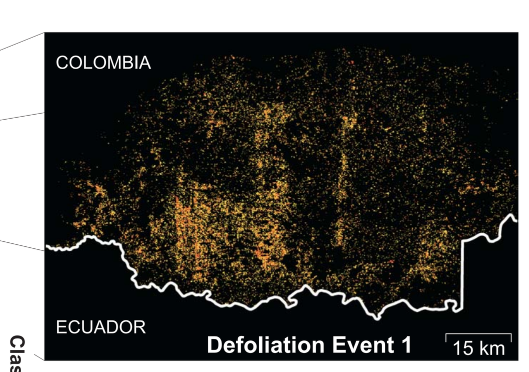


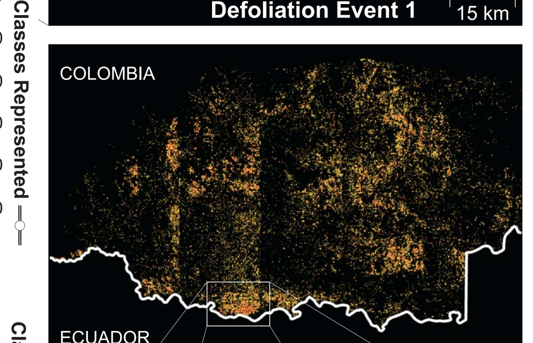


Plan Colombia Defoliation Results

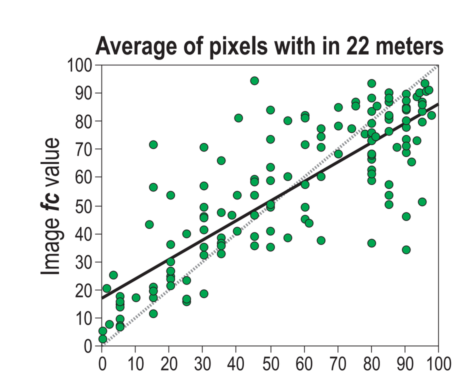








Fractional Coverage Validation



Observations	141
Multiple r	0.8196
r^2	0.6717
Standard Error	14.6477
Slope	0.6909
Intercept	16.5040
t stat (slope)	17.1062
P - value (slope)	$2.083 * 10^{-36}$
t stat (intercept)	6.4602
P - value (intercept)	$1.531 * 10^{-9}$

Significant Milestones

- 7 papers/chapters/proceedings published or in press
- 11 presentations including to the Ecuadorian Minister of the Environment and the Director of Intelligence of the Drug Enforcement Agency
- Field work in 2003
- Graduate Student Thesis (May 2004)
- K-6 teaching materials covering Ecuador

Future Work

- Field work 2004 and 2005
- Acquisition, classification and validation of non-TM imagery
- Completion and distribution of CAPE model version 1 (Cellular Automata Potential Energy)
- Development of complex system rule sets for LUCC along the border between Ecuador and Colombia
- K-12 teaching materials covering Ecuador, Colombia, and Plan Colombia