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

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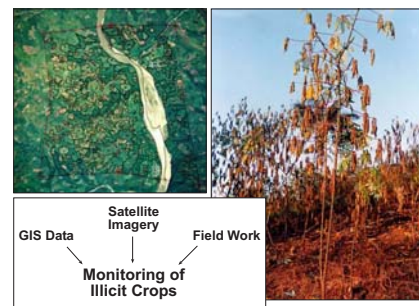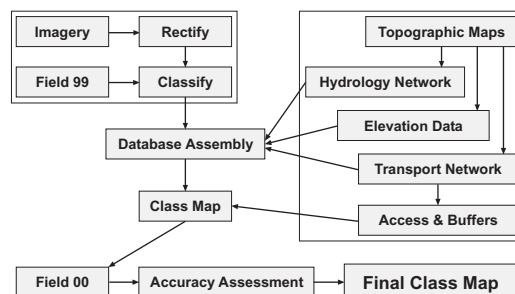CGCEO — Center for Global Change and Earth Observations

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.
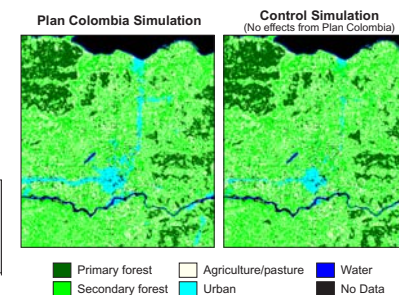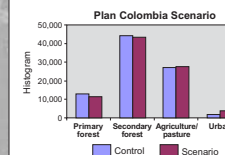
Example GeoSpatial Protocol

GIS Data — Satellite Imagery — Field Work

Monitoring of Illicit Crops

Source: UNDCP

Study Area

Plan Colombia

- Coca-growing areas
- Opium-growing areas

Source: UNDCP & Amazon Alliance

Spraying Effects

- Intercropping
- Drift

Source: Amazon Alliance

Development Pathways

① Urban Areas (Lago Agrio)
② Along Rivers (Puerto Bolivar)
③ Oil Company Roads (Near Colombian border)

Settlement Patterns

Second Lineas
~ 2000 meters
Typical farmhouse
Rio Aguarico

Land Use and Land Cover Classification

Imagery → Rectify

Field 99 → Classify

Topographic Maps

Hydrology Network

Elevation Data

Database Assembly

Transport Network

Class Map

Access & Buffers

Field 00 → Accuracy Assessment → Final Class Map

IDL Model

GIS Layers
LULC | Terrain | Access

Spatial Partitioning

Markov Probabilities

Cellular Coefficients

Model

Access Random Terrain

Flux Class | Cellular Coefficients | Markov Probabilities → Output

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

Existing and Prospective GeoSpatial Data

- Satellite Imagery active and passive sensors
- Aerial Photos
- GPS - Ground truth
- Paper Maps

Landsat ETM+ Scene Bands 4,3,2 9/9/2001

Landsat ETM+ Scene Bands 4,3,2 9/12/2002

Plan Colombia Comparative Test Simulation through 2010
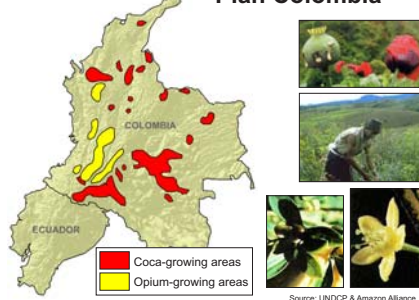
Conditions for Plan Colombia Simulation
1: Initial 1999
2: Increased urbanization
3: Decreased effect of relief
4: Increased effect of access
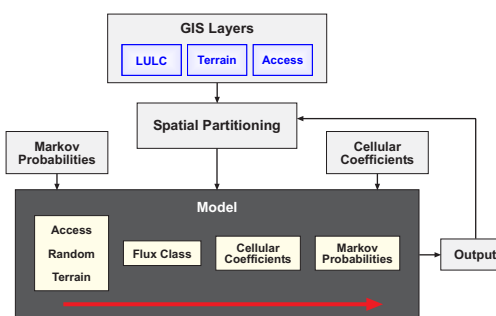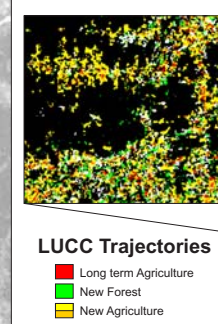5: Equal likelihood of pasture or secondary forest

Plan Colombia Simulation

Control Simulation (No effects from Plan Colombia)

Plan Colombia Scenario

Histogram: 50,000 / 40,000 / 30,000 / 20,000 / 10,000 / 0

Primary forest | Secondary forest | Agriculture/pasture | Urban

Control | Scenario

- Primary forest
- Secondary forest
- Agriculture/pasture
- Urban
- Water
- No Data

Panel Data & Bi-Directional Change, 73-99

LUCC Trajectories

- Long term Agriculture
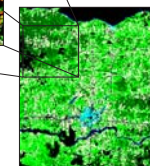- New Forest
- New Agriculture

Complexity Theory and Geography

- Modeling the World
  - Multiple interaction
  - Succinct list of rules
  - Emergent phenomena
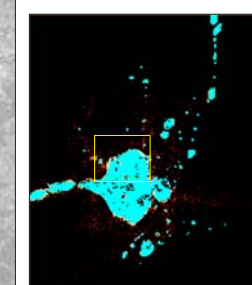 - The whole is more than the sum of the parts
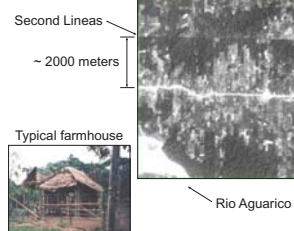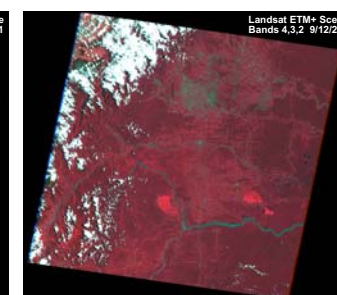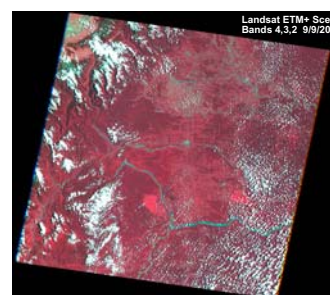
Simulated 2010 Urban

The colors represent different probabilities of change

Plan Colombia

- Spill-over effects in Ecuador
  - Spraying
  - Population displacement
- Measured via Remote sensing, Landscape ecology metrics

Complex Systems

- Accurate and alternative LUCC predictions (spatial and aspatial)
- Sensitivity tests allow for policy development
- Offers an alternative theoretical framework for modeling the world