TerraME-LuccME: an open source framework for spatially explicit land use change modeling

GLP Land Use Transitions in South America: framing the present, preparing for a sustainable future Workshop
Ilhabela, 17-19 November, 2011

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Topics

1. TerraME-LuccME
   - Conceptual proposal
   - Advanced features
   - On-going South America applications

2. Future research directions
CCST LUCC Modeling Group

Scenarios: information to society about alternative land use change under different scenarios

Derived environmental and social indicators: Integration to greenhouse emission and secondary forests dynamics models

Integrated environmental models, coupling to Vegetation (INLAND) and Hydrological Models, aiming at exploring bi-directional feedbacks

Land use projections generated by Spatially explicit dynamic LUCC models (top-down and agent-based)
Figure 4: GLP analytical structure.

Source: Global Land Project Scientific Plan

- **T1.** Dynamics of land systems
- **T2.** Consequences of land system change
- **T3.** Integrating analysis and modelling for land sustainability
Our group modeling tools
(developed at INPE on top of TerraME)

- **TerraME - LuccME**: land use/cell perspective *(the remaining of this presentation)*
- **TerraME - LuccABME**: agents perspective *(next slide)*
- **TerraME - INPE-EM**: land cover change emission model *(next slide)*

www.terrame.org
LuccAEME
Built-in concepts to construct generic agent based models and Example

Institutional Arrangement → Agent → Cell (Polygon) → Cell

Social Network → Neighbourhood → Cell

Territorial arrangements (protected areas)
Non-territorial (soy moratorium)

Farmers

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Farms

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<td>200</td>
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<td>3</td>
<td>2</td>
<td>300</td>
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Cells

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<td>1500</td>
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Source: Assis et al, forthcoming (Relations), Costa et al., forthcoming (Arrangements), Andrade et al, forthcoming (TerraME agents)
INPE-EM
A framework to estimate greenhouse emissions derived from land cover change processes, considering the spatial and temporal heterogeneity of the region. First applied to the Brazilian Amazonia (Aguiar, Ometto et. al, forthcoming).

Biomass spatial distribution (source: Saatchi et al., 2007)
Our tools are built on top of the TerraME and they make model creation easier.

TerraLib

- TerraLib Enviromental Modeling Framework
- C++ Signal Processing librarys
- C++ Mathematical librarys
- C++ Statistical librarys

TerraLib Virtual Machine

- TerraME Language
- TerraME Compiler
- TerraME Virtual Machine

INPE-EM

- Amazonia
- Cerrado
- BR163
- Pará 5 km
- Amazonia 25 km

LuccABME

- SFX
- PA Moju

Amazonia 25 km

Amazonia 5 km

INPE

- Amazonia
- Cerrado
- BR163
- Pará 5 km

LuccABME

- Amazonia
- Cerrado
- BR163
- Pará 5 km

INPE-EM

- Amazonia
- Cerrado
- BR163
- Pará 5 km

LuccABME

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- Cerrado
- BR163
- Pará 5 km

INPE-EM

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- Cerrado
- BR163
- Pará 5 km

LuccABME

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- Cerrado
- BR163
- Pará 5 km

INPE-EM

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- Cerrado
- BR163
- Pará 5 km

LuccABME

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- Cerrado
- BR163
- Pará 5 km

INPE-EM

- Amazonia
- Cerrado
- BR163
- Pará 5 km

LuccABME

- Amazonia
- Cerrado
- BR163
- Pará 5 km

INPE-EM

- Amazonia
- Cerrado
- BR163
- Pará 5 km

LuccABME

- Amazonia
- Cerrado
- BR163
- Pará 5 km
Which are the TerraME main features we use in our tools?

www.terrame.org
TerraME features:
Direct access to database (regular or irregular multi-attribute cellular spaces)

Source: Carneiro 2006
TerraME features: Proximity based on euclidian distance, adjacency and network relations (GPM)

TerraME features:
Environment and Nested Environments

An Environment encapsulates all the components of a model:

- Spatial
- Temporal
- Behavioral

Source: Carneiro 2006
TerraME features:
Nested *Environments* and multiscale modeling

Source: Carneiro 2006
TerraME basic architecture

Model 1
TerraLib Enviromental Modeling Framework

Model 2
C++ Signal Processing libraries

Model 3
C++ Mathematical libraries

Model 4
C++ Statistical libraries

TerraME Virtual Machine

TerraME Compiler

TerraME Language

TerraME

Source: Carneiro 2006
How LuccME was conceived?
A bit of our history...
Application of the CLUE modeling framework for Amazonia (Aguiar 2006)

Regional

Demand module
Scenarios of quantity of change

Grid-based

Spatial analysis

'Coarse scale' multiple regression models

'Fine scale' multiple regression models

Allocation module

'Coarse scale' allocation

'Fine scale' allocation

Source: Veldkam et al., 1996; Verburg et al. (1999)
A version of the CLUE framework was first implemented in TerraME by Carneiro (2006)
Using TerraME Environments we coupled multiscale and multi approach models (Moreira et al, 2009)
We also developed a discrete model based on the CLUE-S (Verburg et al. 2002) ideas.
Then we had the idea:

Couldn’t we design a generic and extensible tool based on a common structure found in several spatially explicitly LUCC, like the Clue family and many others?

Couldn’t we allow the modeler to combine/explore methods proposed by different authors?
Generalization of LUCC spatial explicit models
(Examples: CLUE family, Dinamica, Geomod, and others)

Driving factors of the *quantity* of land use change

Land use change rate and magnitude
*(Demand module)*

Driving factors of the *location* of land use change

Suitability or Transition Potential Maps
*(Potential Transition module)*

Allocation Algorithm
*(Allocation Module)*

Land use at t0

Time Loop

Land use map at t1

Bottom-up calculation

Feedback

Top-down constraint

Source: Adapted from Verburg et al. (2006)
That is LuccME

- A generic open source framework to construct spatially explicit land use and cover change models for different applications and scales.
- Based on the common structure of several well known LUCC models (Verburg et al. 2006, Eastman et al., 2005)
  - Commercial tools: ArcGIS, IDRISI
  - Academic (operational) tools: Clue family (Veldkamp et al. 1996, Verbur et al., 2002), Dinamica (Soares-Filho et al., 2002)
What is a LuccME model?

**Definition of:**

1. Spatial and temporal scale of analysis
2. Database location
3. Land use variables
4. Spatial drivers
5. Potential, Demand and Allocation components *(choice and parameterization)*
6. Output parameters
What is na LuccME model?

Spatial scale: Amazonia, 5 x 5 km²
Temporal scale: 2000-2050, annual
Goal: deforestation scenarios

Spatial scale: Bauru, 500 x 500 m²
Temporal scale: 1990-2010, bi-annual
Goal: urban expansion

Source: Pimenta (2010)
You can compare existing components results, verify which one fits better your application, or even develop new components.
Constraint to interchangeability of components

They must be *inside the same component branch*.

We defined four branches according to fundamental approach differences:

- Continuos or Discrete
- Structural or Transitional
Structural x Transitional

Exemple of transitional tool

*Dinamica*

1. Define land use transitions
2. Define drivers which explain each transition (quantity and location)
3. Compute **potential** for each transition
4. Compute **demand** for each transition
5. Perform **allocation** of the transitions (not the land use themselves)

**Exemple of transition**

*Non-urban->Urban (Recreation)*

**FIGURA 6.6 – Exemplo de um mapa de transição de uso do solo (não-urbano para lazer/recreação) de Bauru no período: 1967-1979.**

Structural models: input land uses at one date

Pasture in 1997

Temporary agriculture in 1997

1. Define land use classes
2. Define drivers which explain each land use pattern/structure (accumulated changes)
3. Compute **potential** for each land use
4. Compute **demand** for each land use
5. Perform **allocation** of land use classes

Temporary agriculture in 1997

Source: Aguiar et al., 2007; Aguiar, 2006.
CONTINUOUS MODELS: PERCENTAGE OF EACH USE IN THE CELLS

Pasture percentage in each 5x5 km²

source: IBGE agricultural census 2006 and PRODES 2007
DISCRETE MODELS: CATEGORICAL LAND USE CLASSES

EACH CELL IS CLASSIFIED AS MECHANIZED AGRICULTURE OR PASTURE OR FOREST

Source: Coelho (2009), Pimenta (2010)
DISCRETE MODELS

LAND USE TRAJECTORIES EXPLICIT REPRESENTATION

Source: Fearnside (2002)
**Available components (LuccME v1.0 Beta)**

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<th>Structural Approach</th>
<th>Continuos</th>
<th>Discrete</th>
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<td></td>
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</tbody>
</table>

Available components (LuCCME v1.0 Beta) ([LuccME](http://www.terrame.org/luccme))

Red components being developed
LuccME advanced features

1. Advanced potential component features
2. Advanced allocation component features
3. Model coupling
1. Advanced potential component features

- **Alternative neighborhood** relations through the Generalized Proximity Matrix (GPM)
  - Spatial Regression analyses
  - CA-like models (attraction/repulsion)

- **Regionalization to represent** heterogeneous rules of territory use
  - Spatial drivers/regressions
  - For discrete models, regionalization of possible transitions
  - Dynamic regionalization (space and time)
TerraME incorporates the GPM concept: neighborhood based on Euclidian distance, adjacency and network relations (GPM)

Source: Aguiar et.al,(2003), Carneiro (2006)
Example of heterogeneous rules of territory use (mosaic of Territorial Units in Amazonia)

Source: INCRA, MMA, FUNAI, elaborated by Ana Aguiar (GEOMA)
Rules of territory use: are they being followed?
Example: land tenure in Santarém, PA

Agrarian situation in 2007:
- FLONA
- PA
- PAE
- PDS
- PAC

Source: Andrea Coelho, Ana Aguiar (GEOMA/IDESP/INPE)
How to incorporate different rules of territory use into this generalized spatially explicit land change models?

Source: adapted from Verburg, 2006.
Allowing multiple rules through dynamic regionalization of the potential module

Driving factors of the quantity of land use change

Land use change rate and magnitude (Demand module)

Top-down constraint

Suitability or Transition Potential Maps (Potential Transition module)

Regions map at time t (Regionalization module)

Region N Possible land use transitions
Region 3 Possible land use transitions
Region 2 Possible land use transitions
Region 1 Possible land use transitions
Driving factors of the location of land use change

Allocation Algorithm (Allocation Module)

Land use map at time t

Land use at time t-1

Source: Pimenta et al. (2008)
How to incorporate different rules of territory use into land change models? *Allowing multiple rules through dynamic regionalization of the potential module.*
How to incorporate different rules of territory use into land change models? *Allowing multiple rules through dynamic regionalization of the potential module.*

**Expansion area**
(no specific rules except Forest Law)

**PA, PAE e PAC:** specific rules of territory use

Source: Andrea Coelho, Ana Aguiar (GEOMA/IDESP/INPE)
2. Advanced allocation component features

- Discrete models:
  - Discrete models: optional change in block, parametrized independently for different land uses (block size and shape).

- Continuos models (features developed for the Brazilian Amazonia by Aguiar (2006), which can be useful in other contexts):
  - Restriction of maximum magnitude change allowed in general and in each cell (to simulate heterogeneous governance levels and command and control actions)
  - Minimum percentage of a given class in a cell, slowed down in allocation speed after this limit is reached (to simulate Brazilian Forest Code enforcement)
3. Model coupling using TerraME Environment

- Multiscale/hierarchical coupling
- Regionalization of demand
- Update of dynamic variables (regions and drivers)
- Natural and social system models
- To combine potential/allocation components sequentilally at the same time step (e.g., like Dinamica combines Expander and Patcher)

(see www.terrame.org/luccme for explanation and details about these items)
Ana Aguiar & colleagues, GLP Workshop, Ilhabela, Nov 2011

Source: Moreira et al. (2009)
LuccME on-going applications in South America

Projects lead by Dr. Ana Paula Aguiar and Dr. Jean Ometto (CCST)
CCST operational models for different biomas (2012-2013)
CCST operational models for different biomas (2012-2013)
Overall CCST Scenario Approach: 2010-2050

- Nesting into existing global scenarios (AR5 RCPs) and storylines
- Downscaling / up scaling through multi-scale participatory approaches

National Storylines (based on Nobre et al., forthcoming)

Global Storylines

Intra-regional Storylines

Main Partners: IPEA, EMBRAPA, and others in different regions.
Local partners:
Museu Goeldi, UFPA, UFOPA, INPE/CRA, IDESP, EMBRAPA Amazonia Oriental
Main Projects: LUA, GEOMA, AmazAlert (EU FP7), PSI
Local partners: UnB (Dr. Mercedes Bustamente) and others
Local partners:
UFRN (Dr. Judith Hoelzemann, UFPE (Dr. Romulo Menezes)
LuccME/MadeiraBasin: goal is also CCST hidrology group model coupling

Main local partner (AmazAlert Project):
Christian Seiler, FAN (Fundación Amigos de la Naturaleza), Bolivia
LuccME/BRAmazonia
LuccME/BRAmazonia
Products and results

Forest, pasture, annual and perennial agriculture, secondary vegetation projections

Integration to greenhouse emission and secondary forests dynamics model (INPE-EM)

Integration to dynamic Vegetation Models (INLAND) and Hydrological Models

Information to society about alternative future land use change under different scenarios
Land Use Classes: combining multiple sources

**Pasture** percentage in each 25x55 km² (source: IBGE agricultural census and PRODES)

1997 ![Map of Pasture in 1997]
2007 ![Map of Pasture in 2007]

**Annual Agriculture** percentage in each 25x55 km² (source: IBGE agricultural census and PRODES)

1997 ![Map of Annual Agriculture in 1997]
2007 ![Map of Annual Agriculture in 2007]

Espindola et al., 2011
LuccME/BRAmazonia
Nested multi-scale analyses using finer resolution cells

Pasture percentage in each 5x5 km² (source: IBGE agricultural census and PRODES)
LuccME/BRAmazônia
Nested multi-scale analyses using finer resolution cells

Pasture percentage in each 5x5 km² using TerraClass/INPE 2008

http://www.inpe.br/cra/projetos_pesquisas/terraclass.php
Acknowledgments

- Dr. Tom Veldkamp, Dr. Peter Verburg, Dr. Kasper Kok (CLUE model framework family) for the long time collaboration.
- Dr. Tiago Carneiro for the brilliant ideas behind TerraME
- Sergio Costa, Paulo Pimenta, Eva Moreira for the LuccME initial development.
- Dr. Gilberto Câmara, Dr. Miguel Monteiro and Dr. Isabel Escada for initiating the LUCC modeling group at INPE.
- Dr. Carlos Nobre and Dr. Jean Ometto for promoting the CCST land use modeling activities, especially the INPE-EM model.

- Funding agencies: GEOMA/CNPq, LUA/FAPESP, PSI
Downloads and documentation

- TerraME: www.terrame.org
- LuccME: www.terrame.org/luccme
“The essence of sustainability is to harmonize economic development with social goals and environmental preservation. At its core is the moral imperative that current generations should pass along an undiminished world to their descendants. To a large degree, sustainability is a challenge to think about the long-range future and, in so doing, to rethink the present. Sustainable development brings the question of the future to the strategic forefront of scientific research, policy deliberation, forward-thinking organizations, and the concerns of citizens.”

(Raskin et al., 2005 – Millennium Ecosystem Assessment)