Project Title

Land Use Change in Amazonia: Institutional Analysis and Modelling at multiple temporal and spatial scales (LUA/IAM)

Name of Principal Investigator: Dr. Gilberto Câmara

Institution: INPE

Proposed start and ending dates: 05/01/2009 to 04/30/2013

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1 Summary

This project aims to understand and model the social processes that contribute to large-scale deforestation in Amazonia. Biomass burning emissions associated with deforestation in the region are responsible for 74% of Brazil's greenhouse gas emissions and have an impact on global environmental changes. We argue that land changes in Amazonia are brought about by social and institutional arrangements that need to be better understood and incorporated into Land Use and Land Cover Change (LUCC) models. Thus we propose to explore the following core scientific question: *How interrelated are the trajectories of land systems and the evolution of institutional arrangements in Amazonia?* We will study how human-induced land change over the past 40 years results from the institutional arrangements that influence how the region´s resources are controlled and owned. These arrangements act upon land tenure, territorial planning, market chains, and public policies. The project incorporates comparative case studies, each organized along four interrelated lines of research, combining methods from different academic areas, including social analysis of institutional arrangements, remote sensing, landscape ecology, and dynamic modelling. Results from the case studies will allow us to establish interrelations between the land systems and the institutional arrangements, and enable an analytical understanding of the driving causes of change at different scales. Findings will be incorporated into multiscale LUCC models to produce scenarios of possible trajectories of deforestation in Amazonia. We expect the project to provide the basis for developing more robust environmental models, which consider the complexity of social interactions in Amazonia, and to allow researchers to study the relations between deforestation and climate change.

2 Results from previous or ongoing funding by FAPESP

Principal Investigator: Gilberto Câmara

Projects funded by FAPESP in the last 10 years:

Project 1

Title: *"Dinâmica Social, Qualidade Ambiental e Espaços Intra-Urbanos em São Paulo: Uma Análise Sócio-Espacial*" (Social Dynamics, Environmental Quality and Intraurban Spaces in São Paulo")

Rôle in the project: Coordinator

FAPESP reference: 00/01965-0

Start and Ending Dates: 2000-2001 (Phase 1) and 2002-2005 (Renewal).

Summary of results: The project made a detailed study of the social exclusion, segregation and urban growth patterns in São Paulo and other important Brazilian cities using spatial analysis methods. The project also developed spatial analysis techniques for modelling regionalization, segregation and urban growth. The project results led to many journal and conference papers and two books: one in Spatial Data Analysis and other on Geoinformatics for Urban Studies.

List of publications: Papers in Journals

1. Claudia Almeida, Michael Batty, Gilberto Câmara, Antonio M. Vieira Monteiro, Britaldo Silveira Soares-Filho, Gustavo Cerqueira, Cássio Pennachin, "Stochastic cellular automata modelling of urban land use dynamics: empirical development and estimation." *Computers, Environment and Urban Systems*, 27(5): 481-509, 2003.
2. Claudia Almeida, Antonio M. Vieira Monteiro, Gilberto Câmara, Britaldo Silveira Soares-Filho, Gustavo Cerqueira, Cássio Pennachin, Michael Batty, "GIS And Remote Sensing As Tools For Simulating Of Urban Land Use Change". *International Journal Of Remote Sensing*, 26(4):759–774, February 2005.
3. Renato Assunção, Marcos Neves, Gilberto Câmara, Corina da Costa Freitas, "Efficient regionalisation techniques for socio-economic geographical units using minimum spanning trees". *International Journal of Geographical Information Science*, vol. 20(7), pp. 797-812, August 2006.
4. Giovana Espínola, Gilberto Câmara, Ilka Reis, Leonardo Bins, Antônio Miguel Monteiro, "Parameter Selection for Region-Growing Image Segmentation Algorithms using Spatial Autocorrelation". *International Journal of Remote Sensing*, vol 27 (14/20), pp. 3035 – 3040. July 2006.
5. Flávia Feitosa, Gilberto Câmara, Antônio Miguel Monteiro, Thomas Koschitzki, Marcelino Santos Silva, "Global and Local Spatial Indices of Urban Segregation", *International Journal of Geographical Information Science*, vol 21(3):299-323, March 2007.

List of publications: Book Chapters

1. Gilberto Câmara, Antônio Miguel Monteiro, Fred Ramos, Aldaiza Sposati, Dirce Koga. "Mapping Social Exclusion in Developing Countries: Social Dynamics of São Paulo in the 90's". In: D. Jonelle, M. Goodchild (eds.), **"***Spatially Integrated Social Science: Examples in Best Practice*" – cap 11, p 223 – 237. New York, Oxford University Press, 2004.

2. Gilberto Câmara, Marília Sá Carvalho, "Análise Espacial na Definição de Políticas Públicas em Grandes Aglomerados Urbanos". (Spatial Analysis in Public Policy Definitions in Large Urban Settlements) In: Elias Rassi, Cláudia Bógus (ed)., *Saúde nos Grandes Aglomerados Urbanos: Uma Visão Integrada (Public Health in Large Urban Settlements)*. Brasília, DF, OPAS, 2003, pg. 137-154.
3. Gilberto Câmara, Antônio Miguel Monteiro, Marilia Carvalho, Suzana Druck, "Análise Espacial e Geoprocessamento" (Spatial Analysis and GIS). In: S. Druck, M. Carvalho, G. Câmara, A. Monteiro, *Análise Espacial de Dados Geográficos (Spatial Data Analysis)*. Brasília, EMBRAPA, 2004 (ISBN 85-7383-260-6).
4. Gilberto Câmara e Marilia Carvalho, "Análise Espacial de Eventos" (Point-pattern analysis). In: S. Druck, M. Carvalho, G. Câmara, A. Monteiro, *Análise Espacial de Dados Geográficos (Spatial Data Analysis)*. Brasília, EMBRAPA, 2004 (ISBN 85-7383-260-6).
5. Eduardo Camargo, Suzana Druck, Gilberto Câmara, "Análise Espacial de Superfícies" (Surface Data Analysis). In: S. Druck, M. Carvalho, G. Câmara, A. Monteiro, *Análise Espacial de Dados Geográficos (Spatial Data Analysis)*. Brasília, EMBRAPA, 2004 (ISBN 85-7383-260-6).
6. Gilberto Câmara, Marilia Carvalho, Oswaldo Cruz, Marcos Neves, Virginia Correa, "Análise Espacial de Áreas" (Areal Data Analysis). In: S. Druck, M. Carvalho, G. Câmara, A. Monteiro, *Análise Espacial de Dados Geográficos (Spatial Data Analysis)*. Brasília, EMBRAPA, 2004 (ISBN 85-7383-260-6).
7. Frederico Ramos, Gilberto Câmara, Antonio Miguel Monteiro, "Territórios Digitais Urbanos" (Digital Urban Territories). In: Cláudia Almeida, Gilberto Câmara, Antônio Miguel Monteiro (org.). *Geoinformação em Urbanismo: Cidade Real x Cidade Virtual (Geoinformatics in Urban Studies: Real City x Virtual City)*. 1 ed. São Paulo: Oficina de Textos, 2007, pp. 34-53.
8. Patrícia Genovez, Antonio Miguel Monteiro, Gilberto Câmara, Corina Freitas, "Indicadores Territoriais de Exclusão Social: Geoinformação como Suporte ao Planejamento de Políticas Sociais" (*Territorial indexes of Social Exclusion: Geoinformatics to Support Social Policies*). In: Claudia Almeida, Gilberto Câmara, Antonio Monteiro (org.), *Geoinformação em Urbanismo: Cidade Real x Cidade Virtual Virtual (Geoinformatics in Urban Studies: Real City x Virtual City)*. 1 ed. São Paulo: Oficina de Textos, 2007, pp.64-85.

9. Flávia Feitosa, Gilberto Câmara, Antônio Miguel Monteiro, Thomas Koschitzki, Marcelino Silva, "De Conceitos a Medidas Territoriais: A Construção de Índices Espaciais de Segregação Urbana" (*From Ideas to Measures: Building Spatial Urban Segregation Indexes*). In: C. Almeida, G. Câmara, A. Monteiro (org.), Geoinformação em Urbanismo: Cidade Real x Cidade Virtual Virtual (*Geoinformatics in Urban Studies: Real City x Virtual City*). 1 ed. São Paulo: Oficina de Textos, 2007, pp. 86-105
10. Patrícia Genovez, Antonio Miguel Monteiro, Gilberto Câmara, Corina Freitas, "Armadilhas de Desigualdade: Detecção e Dinâmica Espacial, Trajetória das Desigualdades Sociais" (*Poverty Traps: Detection and Spatial Dynamics*). In: C. Almeida, G. Câmara, A. Monteiro (org.), Geoinformação em Urbanismo: Cidade Real x Cidade Virtual Virtual (*Geoinformatics in Urban Studies: Real City x Virtual City*). 1 ed. São Paulo: Oficina de Textos, 2007, pp.106-130 (ISBN: 9788586238550).
11. Flávia Feitosa, Antonio Miguel Monteiro, Gilberto Câmara, Compatibilização de Bases de Dados Censitários para Análises Multitemporais com o Auxílio de Imagens Landsat (*Matching Census Databases for Multitemporal Analysis Using Landsat Images*). In: C. Almeida; G. Câmara; A. Monteiro (org.), Geoinformação em Urbanismo: Cidade Real x Cidade Virtual Virtual (*Geoinformatics in Urban Studies: Real City x Virtual City*). 1 ed. São Paulo: Oficina de Textos, 2007, pp.162-170 (ISBN: 9788586238550).

Thesis and Dissertations:

1. Frederico Roman Ramos, "Análise Espacial de Estruturas Intra-Urbanas: O caso de São Paulo" (*Spatial Analysis of Intraurban structures: the Case of São Paulo*). Master Thesis in Remote Sensing, INPE, 2002.
2. Patrícia Genovez, "Estudo da Dinâmica de Exclusão Social no Espaço Urbano em São José dos Campos - SP" (*Spatial Analysis of the Social Exclusion in São Jose dos Campos*). Master Thesis in Remote Sensing, INPE, 2002.
3. Flávia de Fonseca Feitosa, "Índices Espaciais Para Mensurar A Segregação Residencial: O Caso De São José Dos Campos (SP)" (*Spatial Indexes for Residential Segregation*). Master Thesis in Remote Sensing, INPE, 2005.
4. Cláudia Almeida, "Spatial Dynamic Modelling as a Planning Tool: Simulation of Land Use Change in Bauru and Piracicaba (SP), Brazil". Doctor Thesis in Remote Sensing, INPE, 2003.
5. Marcos Neves, "Algoritmos Eficientes de Regionalização de Dados Socioeconômicos em Bancos de Dados Geográficos" (*Efficient Algorithms for Regionalization of Socioeconomic Data*). Doctor Thesis in Remote Sensing, 2003.

Project 2

Title: *OpenModeller: A framework for species distribution modelling*

Rôle in the project: Principal investigator

FAPESP reference: 04/11012-0

Start and Ending Dates: 2004-2009

Summary of results: OpenModeller's project goal is to develop a web-based software to support the work of scientists in predictive modelling of species distribution. INPE´s participation on the project (under Gilberto´s supervision) involves developing TerraLib, a software library that supports quick development of custom-built GIS applications using spatial databases. The TerraLib project aims to creatre a co-operative development network for geoinformatics applications based on open source technology.

List of publications

1. Gilberto Câmara, Fred Fonseca, "Information Policies and Open Source Software in Developing Countries", *Journal of American Society of Information Science and Technology*, 58(1):121–132, January 2007.
2. Gilberto Câmara, Lúbia Vinhas, Karine Ferreira, Gilberto Queiroz, Ricardo Cartaxo Modesto Souza, Antônio Miguel Monteiro, Marcelo Tilio Carvalho, Marco Antonio Casanova, and Ubirajara Moura Freitas. "TerraLib: An open-source GIS library for large-scale environmental and socio-economic applications". In B. Hall and M. Leahy (ed), *Open Source Approaches to Spatial Data Handling*. Berlin: Springer, 2008 (ISBN 978-3-540-74830-4).
3. João Pedro Cordeiro, Gilberto Câmara, Felipe Almeida, "Yet Another Map Algebra", *Geoinformatica*, in press, 2009 (DOI: 10.1007/s10707-008-0045-4).
4. Fernando Gibotti, Gilberto Câmara, Renato Nogueira, "GeoDiscover – a specialized search engine to discover geospatial data in the Web." *VII Brazilian Symposium in Geoinformatics*, Campos do Jordão 2005.
5. Gilberto Câmara, Danilo Palomo, Ricardo Cartaxo Souza, Olga Oliveira, "Towards a generalized map algebra: principles and data types." *VII Brazilian Symposium in Geoinformatics*, Campos do Jordão 2005.
6. Karine Reis Ferreira, Lúbia Vinhas, Gilberto Ribeiro de Queiroz, Gilberto Camara, Ricardo Cartaxo Modesto de Souza, "The Architecture of a Flexible Querier for Spatio-Temporal Databases". *VII Brazilian Symposium in Geoinformatics*, Campos do Jordão 2005.

7. Sérgio Souza Costa, Gilberto Câmara, Danilo Palomo, "TerraHS: Integration of Functional Programming and Spatial Databases for GIS Application Development". *VIII Brazilian Symposium in Geoinformatics*, Campos do Jordão 2006.
8. Karla Fook, Antônio Monteiro, Gilberto Câmara, "Web Service for Cooperation in Biodiversity Modelling". *VIII Brazilian Symposium in Geoinformatics*, Campos do Jordão 2006. In: Clodoveu A. Davis Jr., Antonio Miguel V. Monteiro (eds.) Advances in GeoInformatics. Heidelberg: Springer, 2007. 315p. ISBN 978-3-540-73413-0.

Thesis and Dissertations

1. Sérgio Costa, "Integration of Functional Programming and Spatial Databases for GIS Application Development". Mestrado em Computação Aplicada, INPE, outubro de 2006.
2. Danilo Palomo, "An Algebra for OpenGIS Coverages". Mestrado em Computação Aplicada, INPE, março de 2007.
3. Fernando Reiner Gibotti da Silva, "Geodiscover: Discovering geospatial data on the Web". Doctor´s Thesis in Applied Computer Sciences, INPE, August 2007.

3 Statement of scientific problem

Human-induced Land Use and Cover Change (LUCC) is a major focus of climate change research, because of its role in greenhouse gas emissions and the potential effects of climate change in terrestrial ecosystems (IPCC, 2007; Schimel and Alves, 1996). Changes in land use and land cover can also impact the water flow (hydrology), the energy balance (reflection and absorption of solar radiation), evapotranspiration, and air circulation (surface properties and aerodynamics). In Brazil, biomass-burning emissions associated with deforestation in Amazonia is responsible for 74% of the Brazilian greenhouse gas emissions (MCT, 2005). About 17 per cent of the forest has already been cut, and annual rates of deforestation in the present decade are around 19.000 km^2, although marked by great interannual variations (INPE, 2008).

The social actors affecting the spatial and temporal patterns of deforestation in Amazonia are heterogeneous. In distinct socioeconomic, biophysical and political contexts, multiple actors and institutional arrangements shape the different trajectories of change in the region. As a result, the rates and patterns of land use change also vary in space and time (Alves, 2002; Becker, 2004; Costa et al., 2007; Brondizio 2006; Batistella et al., 2008). To capture the direction, variability, and extent of land use change in the region, we need to understand the underlying social interplays and institutional arrangements working at different scales. Understanding the social and institutional forces is critical for evaluating and proposing deforestation control policies that

also reduce greenhouse gas emissions. Policies aiming at deforestation control based on simplified understanding of the social forces, i.e., neglecting the complexity of social and economic interdependencies in the region, may lead to unexpected negative effects (Aguiar et al., 2008). Thus, we propose the following core scientific problem: *How interrelated are the the trajectories of the land systems and the evolution of the institutional arrangements in Amazonia?*

Our research considers the following definitions and hypotheses. *Institutions* are systems of organized and embedded rules and norms that structure social interaction (Ostrom 1990). *Institutional arrangements* refer to the dynamics within and between institutions. These arrangements include agreements or conventions set up between interest groups, social movements, organizations, and state agencies. Negotiated at different scales (from local to international), they constrain the rules of use of natural resources and territorial occupation, and have potential or observable effects on the trajectories of land systems and in the landscape transformation in Amazonia. The institutional arrangements act upon land tenure, territorial planning, and measures of deforestation control. Our analyses will include specific considerations about how markets influence land change in Amazonia. In this view, markets do not originate from abstract "rules" oriented by demand and supply to an equilibrium state (the "invisible hand"). Markets are created by the embeddedness of economic practices into social networks and institutional arrangements (Granovetter, 1985; Huault, 1998; Williamson, 1996; Brondizio 2008). Our project will then analyse how market arrangements influence the dynamics of land use change in the Amazonia.

Our hypothesis is that the institutional arrangements in Amazonia provide the key to the causes of land change in the region in the last 40 years. These arrangements define how natural resources are controlled and owned and thus define the rules and norms of their use. Often, social exclusion is by-product of such rules and norms of use. Since the 1960s, Amazonia has witnessed the buildup of institutional arrangements often associated to competing ways of using natural resources and to different economic goals. The twin forces of economic globalization and global environmental change, and the growing physical connectivity within the region point to the need of addressing institutional overlaps and interlinkages and how they shape land use, economic activities, and population distribution.

We consider that many institutional arrangements that define use of natural resources in Amazonia reflect the interests of private groups that use social, political, ideological, and legal mechanisms to formalize resource ownership and territorial control. Asserting control over the land, hegemonic groups use institutions and social networks to create mechanisms that reproduce

social inequalities through formal and even legal apparatus. For example, credits granted by state agencies are often used to support political compliances related to private interests. This public-private combination increases in proportion to market value of land and forest products, and to the competition between social groups. Examples include agrarian reform settlements created in areas chosen and controlled by powerful wood companies, the establishment of new municipalities controlled by local elite (Fernandes, 1999), or the control of commodity chains of forest resources by family networks (Brondizio forthcoming).

This perspective can clarify how land seizure by the elite and land expropriation of the poor has been occurring in the region. It also shows why attempts to order occupation since the 1970s produced unexpected results (Bunker, 1985; Araujo et al., 2007a, 2007b), allowing trickery and deception in the rules and norms of land use.

However, recent institutional evolution in Amazonia is increasingly motivated by rules concerned with environmental conservation issues. Since the 1990s, there are new legal limits on the use of natural resources, which include community land rights within and outside protected areas. These laws also mandate formal representation of local populations in city councils and regional development forums. This scenario motivates an important question: *how do competing institutional arrangements for managing resources help to promote or undermine solutions to the problems of land use in Amazonia?* In this context, this project focuses on three dimensions of institutional arrangements:

- *Land Tenure and Planning,* including creation of conservation units and settlements, zonings and concession rules for natural resources exploration. The institutional arrangements in Amazonia bring about rules of land use, which may or may not be followed or enforced. See Figure 1, which shows the relation between land use changes and land tenure in Santarém.
- *Market arrangements,* including how legal (and illegal) market chains affect land use practices. Certification of soybeans, beef and wood products, imposed by market chain consumer (in distant places, even in other countries) may impact land use practices of different actors. Initiatives to value the forest, such as alternative technologies and market chains based on biodiversity products, and payment for ecosystems services may also impact land use practices (Brondizio; 2008; Costa, 2007).
- *Measures for controlling deforestation,* including how monitoring and control practices targeting particular areas have influenced land use. These measures also include the Federal

Forest Code and its enforcement, credit incentives and rules, and law compliance by local actors in the face of growing market pressure for cleared land and commodities.

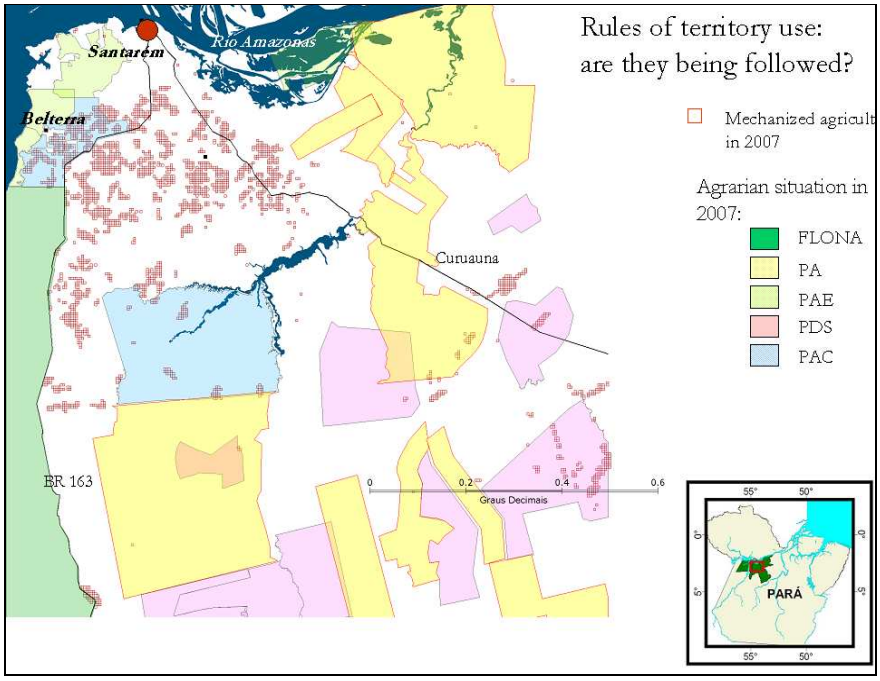

Figure 1 – Are (INCRA) rules of territory used being followed? Mechanized agriculture (soybeans and rice) areas observed inside official settlements (source: Coelho, in preparation).

We will use comparative case studies to explore our research questions. The case studies will be defined inside three large-scale study areas that represent different stages of occupation in the state of Pará (Figure 2):

- *The first area* is known as *Terra do Meio* which follows the PA 279 road from Xinguara to São Felix do Xingu (Escada et al., 2005). São Felix do Xingu is the municipality with the largest deforestation rates in recent years (INPE, 2008). In this area we will focus on the beef and milk market chain and its relations to the land use (Americo et al., 2008; Poccard-Chapuis, xxxx). We will also study how local enforcement actions and new conservation units created in *Terra do Meio* since 2004, as an effort to control deforestation, have affected land use in the area.
- The *second area* is the region of influence of the Cuiabá-Santarém road (BR 163) from Novo Progresso to Santarém. We will examine two major territorial planning measures: the rules of the Ecological Economic Zoning (ZEE) and the new Sustainable Forest District which includes incentives to the logging sector. We will consider whether these measures are

effective to ensure deforestation control, considering past deforestation trajectories associated with legal and illegal logging, agricultural use and land abandonment. This area also includes part of the Transamazonia highway, occupied during the 1970s and 1980s, and part of the municipality of Santarém, where significant changes occurred in the past decade due to expansion of mechanized agriculture (soybeans and rice). Such transformations include the land expropriation of the small-scale agriculture and the creation of several new settlements in the area. Here we will also focus on the soybean market chain and its influence on land use. This includes examining the impact of the so-called "Soybean Moratorium", a trade agreement between NGOs, agricultural commodity exporters, and local soybean producers. This agreement aims at restricting the trade of soybean produced in newly deforested areas or areas of land tenure conflicts. A similar agreement is being negotiated for beef produced in other areas of the state of Pará.

- The *third area* encompasses the western part of the Santarém and Juruti municipalities, the area crossed by the PA 257 (Translagos Road). This includes the Nova Olinda and Mamuru areas where land tenure conflicts have occurred *prior to expansion of deforestation*. This area is under several types of pressure due to the mining prospects of ALCOA, wood extraction, and conflicting views from different governmental sectors about the territorial planning. It also contains extractive reserves, new settlements, and traditional populations, allowing us to study forms of social organization and economic alternatives in face of the multiple pressures the region face.

Figure 2 shows these study areas. During the project´s execution, we may include other areas to explore specific institutional arrangements in other contexts.

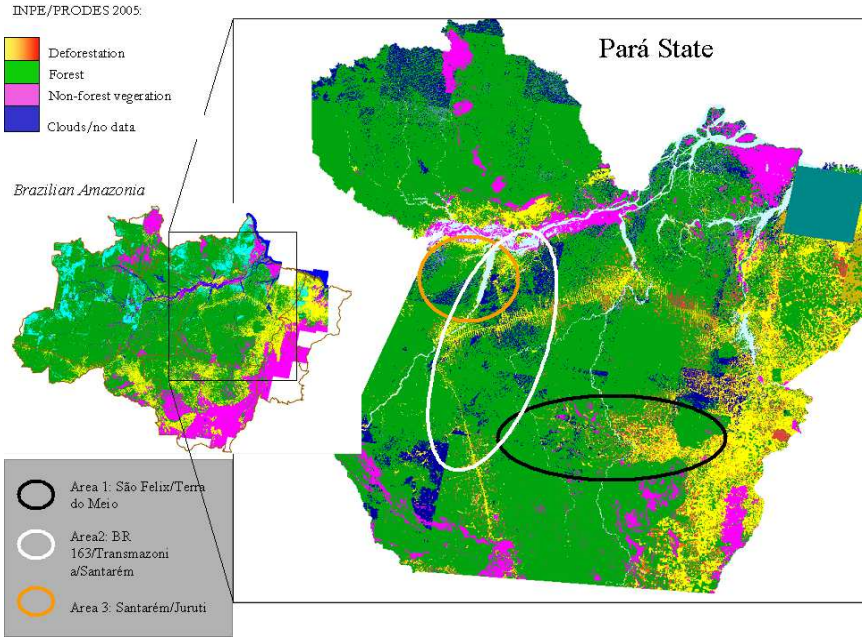

Figure 2: Related study areas in Pará State (source: PRODES/INPE deforestation maps for 2005).

There are interrelations between the study areas, as Figure 2 shows. The municipal government of Santarém and organizations located in the city (such as INCRA, IBAMA, Rural Workers Union) have legal control over much of Areas 2 and 3. A network of roads and rivers connects Areas 1 and 2 through and around "Terra do Meio". We will carry out macro economic and political studies in these different contexts, as they may influence local dynamics in specific ways. Institutional arrangements in one area may affect neighbouring or even distant areas. For instance, creating of a mosaic of protected areas in a region may induce occupation of other areas elsewhere (Aguiar et al, 2008). The project will consider how such intraregional connections work. We will trace a genealogy of institutions and analyse the co-evolution of institutional arrangements and land-use change taking place across sites and scales. We will select *specific questions for each study area, using suitable scales of analysis* (see Section 8), and examine them using a multidimensional perspective, combining social sciences, remote sensing, landscape analysis methods, and dynamic modelling. Each case study will be examined by four different research axis, as Figure 3 explains.

- **Axis 1:** *Identification and analysis of institutional arrangements* that influence land use and cover change (LUCC), using social sciences institutional analysis methods.
- **Axis 2:** *Measurement and mapping of vegetation cover transformation* related to the institutional arrangements, using novel remote sensing and image processing methods.

- **Axis 3:** *Detection and description of occupation patterns and trajectories* in multitemporal image satellite data. These patterns emerge from land changes related to the institutional arrangements mentioned above. We will use data mining and landscape analysis methods to find these patterns and trajectories.
- **Axis 4:** *Construction of computational models and scenarios* that capture how social interactions and institutional arrangements act upon land change trajectories.

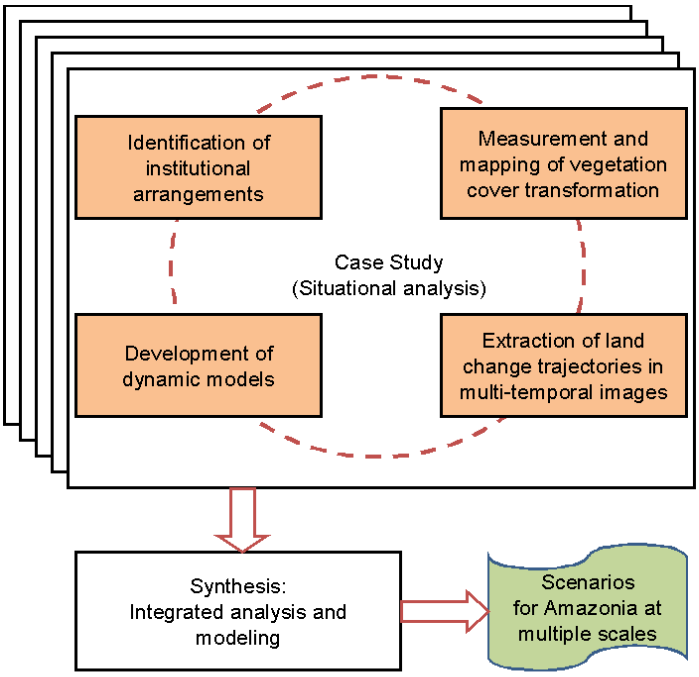

Figure 3 – Relations between project research themes.

Results from the case studies will help us to understand how social and institutional arrangements influence land change at different scales. We will develop models and scenarios, from local to regional scales, incorporating the project findings about institutional arrangements, land change and intraregional interplays[1] (Aguiar, 2006; Moreira et al., 2008; Souza et al., 2008). Our results and methodological advances will provide the basis for developing more robust environmental models that consider the relations between deforestation and climate change, based on the complexity of social arrangements in Amazonia.

[1] We are aware about the contentious on the extents and limits of case studies to inform regional and global scale models. We propose to use them in a comparative and analytical perspective, rather than attempting to generalize results to larger scales (Fox et al., 2003; Geist and Lambin, 2000; Gibson e Ostrom (2005).

4 Justification and rationale

Our rationale for the project is that past and future uses of natural resources in Amazonia are better understood by considering links between the trajectories of land change and the evolution of institutional arrangements. At a regional level, this approach will help to examine how the spatial distribution of institutional arrangements can facilitate or undermine solutions to intricate cross-level problems, such as deforestation, watershed management, and impact of climate change in the Amazon (Brondizio, Ostrom, and Young forthcoming). We use one example to further justify the relevance of our scientific question and rationale behind the approach we propose to answer it. The example concerns how land tenure and territorial planning evolved in the area surrounding the BR 163 road, and how to observe the emerging patterns of land cover change using remote sensing data (see Figure 4).

In the 1970s, the federal government set up agricultural settlement projects in the area under the National Integration Plan (PIN). These official colonization incentive policies – and the associated agricultural and cattle expansion – remained dominant until the end of the 1980s (under the "development-oriented" military government perspective). After the end of the military regime, the José Sarney Government launched the "Nossa Natureza" program and created IBAMA (Brazil´s Environment Institute) in 1989. A new model of collective land tenure ("Concessao de Direito Real de Uso") was brought into force, and applied to some types of settlements. A growing environmentalist trend takes shape during the 1990s, allied with rules enabling local populations to take part in natural resource management. The creation of the National System of Conservation Units (SNUC) introduces a new series of measures, related to development and resource management, logging control, demarcation of indigenous territories, and creation of environmental management in municipalities. Since around 2000, a series of policies for land management have been established by the federal government, including the creation of Conservation Units. As shown in Figure 4, some conservation units recently created as a barrier to agricultural frontier expansion were located in areas where occupation had already started. This creates problems for those enforcement of these units (see the area to the south-west of BR 163).

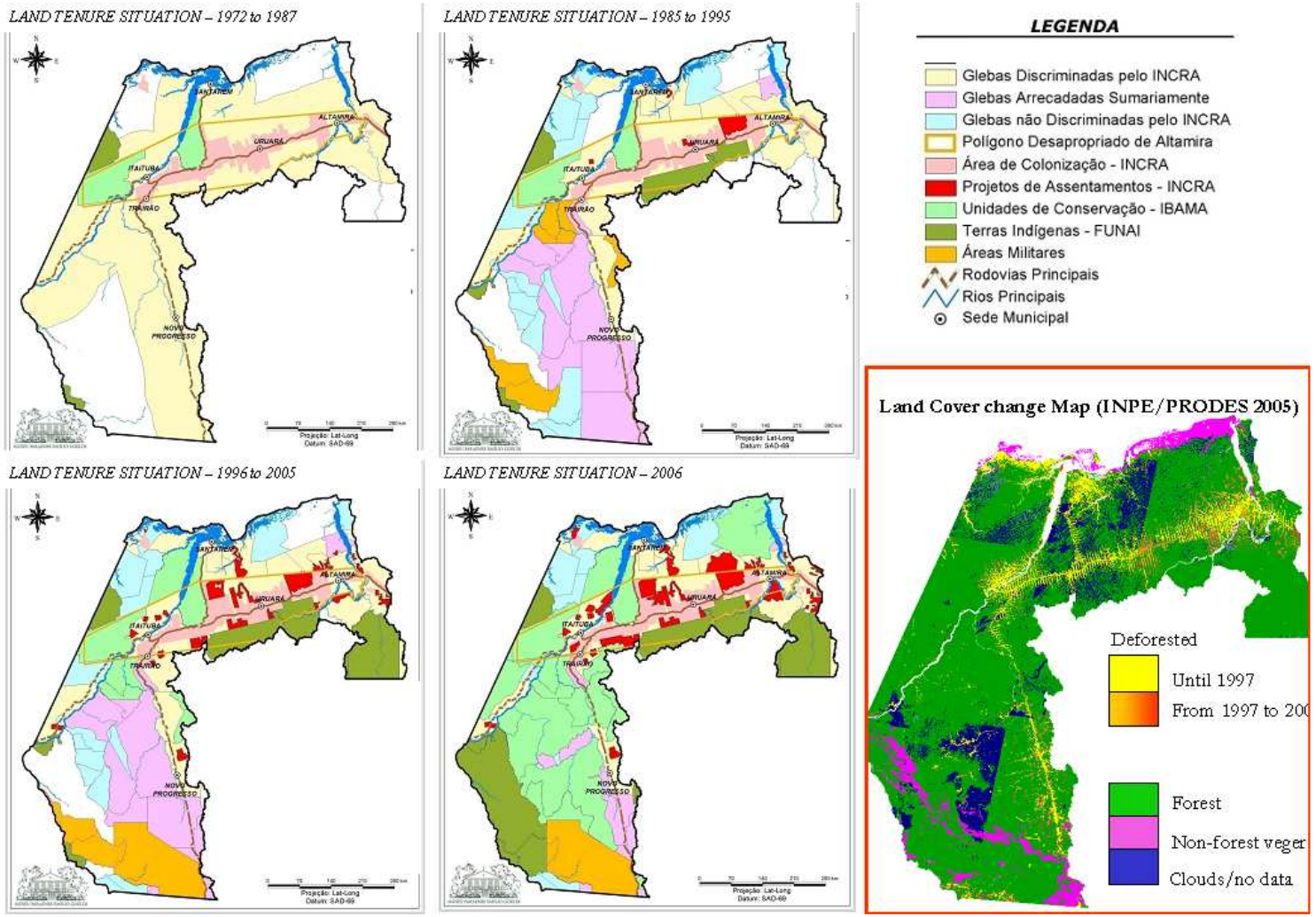

Figure 4 – Evolution of territorial planning and land cover change in Santarém/BR-163.

Figure 4 also shows the patterns of land cover change from 1997 to 2005. Certain spatial patterns of occupation, measurable using Remote Sensing images, *emerge* from rules imposed by governmental plans, such as the fishbone spatial pattern in Transamazonia highway, produced from rules of lot distribution along main and secondary roads. Often, norms imposed by governmental plans are simply not followed. For instance, there are patterns of land concentration in what should be family-scale settlements. Or, as Figure 1 shows, settlements created to promote forest-based activities can be used by other interest groups, such as soybean farmers. This leads to more general questions: *Why and how do actors accept, reject or change legal rules of territorial planning? And how do institutions shape and structure social reality, but not without being - at the same time - structured by institutional arrangements arising from systems of practices?* (Bourdieu, 1980; Araújo e Schiavoni, 2000).

To answer these questions and analyse how land change and institutional arrangements evolve and interact, the research axis mentioned in Section 3 will jointly contribute to the project goals, as shown in Figure 3. The starting point is a timeline of important events relative to both institutional dynamics and landscape transformations. The use of methods of remote sensing and landscape analysis will be complemented in Axis 1 by direct observation through fieldwork, focusing on rebuilding the trajectories of the individuals, social categories, and interest groups involved in land change. These instruments will provide data on the emergence, roles, organization, and interlinkages of institutional arrangements. Computational models will explore hypothesis about the coevolution of land systems and institutional arrangements, and to do so they have to be able to represent such complexity.

Each axis will then contribute to answer the overall project research question, and with innovative methodologies in their own scientific fields. For instance, depending on the temporal and spatial scales chosen for a certain case study, different Remote Sensing data and methods of analysis may be employed, and new methodologies developed. In Santarém, it may be important to study the intraannual variation of agricultural uses to better understand how the land use responds to expanding soybeans market chains. In other cases, data from remote sensing will measure stages of secondary vegetation and pasture degradation. In Axis 3, landscape pattern analysis associated to data mining techniques enables identification and description of different occupation patterns in remote sensing images (Mertens and Lambin 1997, Lambin et al, 2003; Batistella et al. 2003; Escada et al. 2005). Examples of such patterns are shown in Figures 2 and 3 (note the different deforestation patterns along the BR 163 road, Transamazônica road, and São Felix and Santarém cities). Such patterns can be associated to different occupation histories,

social actors, rural settlement and farms, and land use activities, using multitemporal data mining techniques (Silva et al., 2008). Regional and local connectivity and accessibility analysis will also be included in Axis 3 to understand how the networks influence land change in the study areas. Axis 4 will develop new methods to represent this heterogeneity of actors and institutions in dynamic computational models at different scales. A close cooperation between Axis 3 and Axis 4 will enable us to link spatial patterns and underlying processes in LUCC models. The technical contribution of each research line is detailed in Section 8.

5 Significance and relevance for the FAPESP PFPMCG Program

The project responds to the two aspects of this Proposal Call: item (b) *identification of political arrangements and institutional mechanisms related to environmental changes*; and item (f), *observing, modelling and developing Earth System Science* in São Paulo. As for item (b), our goal is to study the coevolution of institutional arrangements and land change, to achieve a broader understanding of their impacts to regional and global environmental changes. This understanding is also critical for setting up deforestation control policies, and other proposals for the region, which may have different impacts on different actors.

As for item (f), we will develop new remote sensing and image classification methods to better identify land use changes in Amazonia. We will also investigate new methods for information extraction from multitemporal images, using data mining computational tools. Further contributions to item (f) are new multiscale land change computational models, capable of better representing the complexity of social interactions in the region. In the future, these models will be coupled to models from other components of the PFPMCG program. Coupling land change and climate change models is necessary for integrated assessments, and to understanding of how changes in Amazonia could affect - and be affected by – climate change.

6 Specific aims

Aim 1: To provide a cohesive understanding about how institutional arrangements are related to the establishment and functioning of land use systems in different contexts in Amazonia.

1.1. To understand how *beef and milk market chain arrangements and deforestation control measures* are related to the establishment and functioning of land use systems at the PA 279 region.

1.2. To understand how *land tenure and territorial planning arrangements*, specially the creation of a *Forest District*, and the soybean market chain, are related to the establishment and functioning of land use systems at BR 163/Santarém area.

1.3. To understand how *land tenure and planning* arrangements are related to the establishment and functioning of land use systems at the Santarém/Juruti areas.

1.4. To elaborate comparative synthesis and integrated models encompassing diverse institutional arrangements and land use systems at multiple scales.

Aim 2: To develop innovative methodologies in Remote Sensing, Landscape Analysis, and Dynamic Modeling to support the core research question and case studies.

2.1. To develop new methodologies for monitoring land change in the Amazon, using data from polarimetric radars and optical sensors, aiming at the identification of secondary vegetation stages, pasture, annual crops, forest degradation and selective logging at different temporal scales.

2.2. To develop methodologies for (a) identifying land change patterns in Amazonia and their relation to institutional arrangements; (b) identify logical and physical networks and evaluate how they interact with the land use patterns; (c) propose new methods of regionalization based on (a) and (b) to support improved land change models.

2.3. To develop new land change models that capture the heterogeneity of actors and institutional arrangements in Amazonia and can be coupled with environmental models at various scales.

7 Expected results

- Scientific articles in national and international journals and technical reports about our core research question, and also about the methods developed in Remote Sensing, Data Mining, and Modelling.
- Synthesis book.
- Geographical databases for the study areas.
- System for data mining (GeoDMA - Geographic Data Mining Analyst).
- Computational models (TerraME) for LUCC, integrating top-down and bottom-up approaches.

Knowledge Transfer:

- Capacity-building, training and education with priority to graduate programs.
- Workshops to promote: (a) integration with other groups that studying LUCC in the Amazon; (b) technology transfer in local universities.

7.A Preliminary results

The proposal is based on previous efforts and the experience of several research teams from INPE-MCT, MPEG-MCT, EMBRAPA and their national (UFOP, UFRN) and international (Indiana University/USA, IRD/France) partners. Such network of researchers was mostly built through GEOMA and LBA programs. Under the GEOMA network, we have been studying the cattle expansion and deforestation processes in São Felix do Xingu (Benatti et al., 2006, Escada et al. (2005), Américo (forthcoming). In GEOMA, we have also been researching land tenure and mechanized agriculture expansion in the Santarém and BR 163 regions (Aguiar, Folhes e Araújo (forthcoming), Pimenta et al. (2008), Coelho (forthcoming), Barreto (2008). In figures 1 and 4, we show preliminary results of these projects. Our plan in this proposal is to integrate a broader group of researchers under a common and clear research question. This joint research teams will allow us to study the dynamics of land use change in Amazonia under the perspective of institutional arrangements, using a multidisciplinary approach. Our goals can contribute for building an Earth System Science scientific network in the State of São Paulo, strengthening both local institutions, and our partnerships with national and international research groups.

8 Scientific challenges and the means and methods to overcome them

As discussed in Section 4, the four axis of research will jointly contribute on the comparative case studies. Each axis will contribute with innovative methods in their own scientific fields, to answer the project overall research question. The integration will happen *around the selected case studies* leaded by Axis 1. The technical challenges and methods in each Axis are:

Axis 1: Identification and analysis of institutional arrangements which influence the land systems *using social sciences methods.*

Challenges:

- Be able to trace a genealogy of the co-evolution of the institutions and land change in the Amazonia, focused on our three Study Areas (Section 3), based on a timeline of important

events. The events include: (a) the relevant milestones for news rules and laws; (b) the thresholds substantial land change; (c) the establishment of new institutions shaping land use. This genealogy will be the basis to defining the specific case studies in each area.

- Be able to perform multiscale modelling and analysis. Since transformations in land-use patterns can be represented in different interlinked scales, a general question follows: *In what scales (local, regional, national, or international) are the actions of specific actors relevant?* Each spatial scale is best suited for representing certain rules of interaction and negotiation between the social and institutional actors, and there are interlinkages between them. Changes at one scale can create unexpected complications at other levels, as when policies that enforce environmental legislation and halt illegal wood-extraction practices also create unemployment, or even induce exploration in other locations (Aguiar, 2006). Successful local management of a territorial unit can, for instance, need cross-level articulations to limit negative environmental impacts resulting from the use of surrounding areas by large commercial plantations (Brondizio, Ostrom, and Young forthcoming; Brondizio 2006). The challenge is thus to understand: *Who are the mediators between these levels? Which are the correlations that exist between groups of actors involved in each situation, and in which way do these power correlations interfere in the rules guiding current institutional arrangements?* Figure 4 shows the multilevel complexity of institutional arrangements.

Discoveries and methods:

We will use situational analysis techniques (Barraqué, 2002; Simon, 1965; Barel, 1971) to consider different elements (such as land change patterns and rules and laws for natural resource use) in the context in which the associated actors also consider themselves to be. This may allow us to find out the conditions that control the existing institutional arrangements without failing to recognize structural focus of tensions and social conflicts.

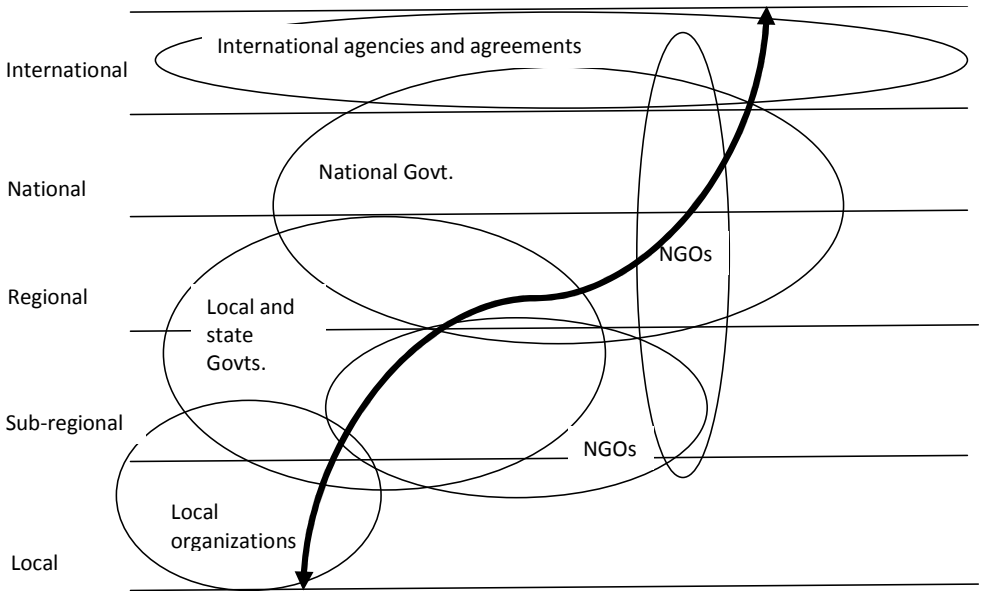

Figure 5 – Institutional levels and complexity of institutional arrangements (Source: Aguiar.Folhes e Araújo, Forthcoming).

- First phase: Genealogy

  The first phase consists of building a genealogy of important events for both institutional arrangements and landscape transformations. We will set up a timeline such as the one presented in Mellilo et al. (xxx), containing both institutional and landscape transformation relevant milestones. This assessment will use INPE deforestation maps and remote sensing images of earlier periods, focusing on the region as a whole, and in the three study areas. We will analyse and map progressively, from the local to the regional scale, how institutional arrangements and land tenure rules have evolved, considering continuity, overlaps, contrasts and spatial fragmentation (as seen in Figure 3 and 4). This genealogy will be established jointly with researchers from Axis 2, 3 and 4, and will provide the necessary support for defining case studies inside the Study Areas.

- Second phase: Case studies

  For each case study, we will define how existing interest groups and arrangements interact with the emerging forms of political representation associated to new land use policies. We will consider to what extent and under which conditions these forms of political

representation provide the basis for new types of institutional arrangement and lead to the buildup of collective *social capital*[2].

We will study the ways for market organization and how markets influence the configuration of the land systems. These market chains will be described according to their actors and their interaction with another production chains. Results of the analysis from Axis 2 and 3 (remote sensing and landscape dynamics analysis) will be complemented by direct observation through fieldwork. We will use data collection in the form of questionnaires and interviews to allow reconstruction of the trajectories of the actors, social categories, and interest groups involved in land change.

These results will help Axis 4 for building land change models for the case studies. These models will use participatory scenario construction methods through which we can explore conflicting perspectives of local interest groups about institutional arrangements and rules for land change.

- Third Phase: Synthesis

  Throughout the project, in periodic group meeting, we will summarizing the results. Our synthesis work will consider how institutional arrangements at different levels influence each study area and how they affect the interrelation between the study areas. We will also look at how the project findings contribute to understanding the land systems in Amazonia as a whole. In collaboration with Axis 4, Axis 1 researchers will contribute to multiscale models and scenarios, from local to regional scales, that incorporate the project findings about institutional arrangements, land change causes and intraregional interactions.

Study areas:

In this Axis of research, the focus will be on all study areas (PA 279, BR 163, PA 235) and through the synthesis phase, results will be generalized to the regional scale.

[2] The paradigm of social capital – partially inspired by an economic neoinstitutionalism– endorses the idea that relationships of trust and reciprocity can contribute to reducing costs of transactions, to produce common goods, and provides a solid background to the development of grassroot management organizations leading to strong civil societies (Durston, 2000). To a detailed discussion on social capital and its role on governance of multi level socio-ecological systems, see (Brondizio, Ostrom, and Young forthcoming).

Axis 2: Measurement and mapping of vegetation cover transformation related to institutional arrangements, *using remote sensing methods*.

Challenges:

We consider four challenges for mapping land cover transformation:

a. Achieving an accurate classification of the secondary vegetation stages, necessary for calculating carbon emissions;

b. Getting information about vegetation cover in humid, tropical, forested regions which are often cloud covered. The issue of clouds also affects identification of agriculture, as the planting season matches the rainy season in parts of Amazonia.

c. Mapping land change in deforested areas, identifying different crops and pasture degradation. These areas use different productive systems, and many farmers adopt rotational practices among different uses.

d. Classifying levels of disturbance in forested areas, due to natural reasons (fires, for instance) and human-activities (selective logging, for instance).

Discoveries and methods

Earlier studies (Lu et al., 2003) have shown that the precision of secondary vegetation classifications is often low when only optical sensors are used. The potential for radar data on bands C and L (such as satellites ERS-1, RADARSAT, JERS-1) for applications in tropical forests has been reported by various researchers (Rignot et al., 1997). Nevertheless, SAR data with a single polarization often fails to identify new areas of deforestation (Almeida Filho et al. 2005). New satellites, all equipped with polarimetric radars, such as RADARSAT-2 (C band) and ALOS/PALSAR (L band), have great potential to improve classification results. Thus, this line of research will develop methods for more precise measurement of changes caused by humans in already deforested areas. These methods combine the new generation of polarimetric radars and improved optical sensors (for example, CBERS/HRC, Terra ASTER). We propose to investigate the following *specific questions*: (a) *can polarimetric radars be combined with optical sensors as a basis for more efficient monitoring systems (without the problems of cloud-cover and with better temporal resolution)?* (b) *What combination of frequencies, polarizations, resolutions, fusion and classification methods best allow distinction between different stages of secondary vegetation and the main agriculture crops?*

The *methodology* we propose is the different combinations of optical images and radar, complemented by high-resolution images (IKONOS, Rapid/Eye, Geoeye, CBERS/HRC, SPOT/HR). We will consider different acquisition frequencies of the polarimetric images and different methods for extracting polarimetric information. Also, we will produce texture information for more precise classification of coverage data and try different methods of fusing radar and optical data. As a result, different methods of classification based on multiple sources will be compared and ranked.

INPE monitoring annually new clear-cut areas in Amazonia uses optical sensor data (INPE, 2008). Recently, INPE and EMBRAPA started a long-term initiative to classify areas already deforested into their specific land use. Mapping the trajectories of land use for deforested areas in Amazonia is important for our project, since it helps to find out what is the impact of institutional arrangements. Thus, we will develop new methods that that will improve land use classification in Amazonia. The method we propose uses multitemporal change detection techniques to monitor the areas already deforested. For this we propose to develop a semi automated change detection algorithm using the SPRING software, using multitemporal image segmentation, unsupervised classification and visual interpretation. This procedure will avoid border effects caused by georeferenced errors between multitemporal images. This analysis uses medium spatial resolution images such as Landsat TM.

Study areas:

In this Axis of research, we will focus on selected sites in Santarém and Altamira, which contain representative cases of diverse productive systems. There are mechanized agriculture and pasture areas in Santarém, familiar agriculture in Altamira, and several areas of wood exploration in both places. Once the methods have been developed, they can be applied to other sites.

Axis 3: Detection and description of occupation patterns and trajectories in multitemporal satellite data, which emerge from land use and cover transformation processes and institutional arrangements mentioned above, *using landscape analysis and data mining methods*.

Challenges:

Land patterns measured in remote sensing images reflect the diversity of the human actions, which occur non-uniformly in geographical space. To analyse these patterns, our methods combine measure from the landscape ecology (Forman, 1990; Turner, 1989; McGarigal, 2002) and to data mining clustering algorithms (Witten and Frank, 2005; Han, 2006). The

challenge we face in this field is how to associate land change patterns identified using RS images to the underlying social processes. Depending on the scale, two different and complementary approaches can be used. For local scale studies, one approach is to use the idea of *landscape objects* (Silva et al, 2008). A *landscape object* is a structure detected in a remote sensing image by an image segmentation algorithm or visual interpretation. For regional scale analysis, another possible approach is based on *cells* that aggregate a set of *landscape objects* representing a distinct occupation pattern. To associated RS spatial patterns to social actors we match the *landscape objects* to a *spatial pattern typology* for the study area (Silva et al, 2008). We use deforestation maps from INPE as the source of land use patterns. Using of multitemporal deforestation data, we carry out spatiotemporal classifications that describe the change trajectories in local and regional scale. We will be able to identify when a landscape pattern was created, how it evolved and what were its trajectories of change.

This line of research will contribute to land change models (Axis 4), which take the heterogeneity of actors and processes into account. One of our results is the partitioning of the space into homogeneous units based on the type of social actors. This partitions provide key information for land change models based on agents, and to integrate of top-down and bottom-up modelling approaches.

Another challenge we face is how to incorporate regional and local connectivity and access networks in the land use pattern analysis. A region can be characterized by its relations of access and connectivity, including, not only roads, but also networks of rivers, landing strips and other types of communication infrastructure. It is essential to identify and characterize these networks (the spatial scale on which they act, their density, diversity and articulation with other networks) in order to determine how they interact with the land use system. In this analysis, we will use the TerraME software.

Discoveries and methods:

The proposed method to extract and describe land cover patterns in multitemporal image data consists of: (i) Collecting and analysing data related to the case studies; (ii) Establishing a land pattern typology associated to human settlements; and (iii) using landscape ecology metrics and data mining to classify the land patterns and describe land change trajectories. A computational tool based on TerraLib Library is under development, the Geographic Data Mining Analyst – GeoDMA (Korting et al, 2008; Silva, 2007).

The regional and local connectivity and access networks will be analyzed in three steps: i) Description of network connections, nodes, and fluxes; ii) Representation of networks in a digital model; iii) Modeling the network system and iv) Analysis of how the networks influence the territory occupation. We will use the TerraME software to model the network system (Carneiro, 2006).

These results will induce new ways to partition the territory for use in land change models. They will also distinguish specific land change trajectories and their relation to the institutional arrangements. Data for these studies include the deforestation data provided by INPE, agriculture and cattle-raising census data (IBGE), high and medium spatial resolution data from the CBERS 2 and LANDSAT sensors, and data about land property (INCRA, ITERPA).

Study areas:

This Axis of research will concentrate on Study Area 1 (PA 279/São Felix do Xingu) and Area 2 (BR 163/Santatém) where the occupation process is in advanced stages, and land use pattern analysis can be applied.

Axis 4: Construction of computational models and scenarios to represent such land use change trajectories and their relation to institutional arrangements at different scales.

Challenges:

The literature includes approaches to modelling (Parker et al., 2002; Verburg et al., 2006). The main approaches to modelling include *top-down* and *bottom-up* methods. *Top-down approaches* start from landscape ecology and analyse land patterns which are based on remote sensing and census data. In this approach, the whole study area is described by a mathematical formula or an empirically defined statistic, based on input data patterns. *Bottom-up approaches* explicitly describe the actors of the changes. Agent-based models (ABM) are examples of such an approach. ABMS provides a bottom-up method for building complex systems, through the dynamical interaction of agents. Agents interacting in the micro level result in the emergence of patterns in the macro level (Matthews et al., 2005). Agents are not necessarily individuals; they can represent organizations, institutions, at several levels. In our project, *one of the challenges we face* is how to represent the diversity of actors, patterns and processes in Amazonia, and their institutional context. Bottom up models present several advantages in this sense. However, bottom-up models need extensive fieldwork to define the rules underpinning agents' behaviour, and normally represent only

smaller areas. On the other hand, top-down models are easier and faster to set up for larger areas, but they can't express the diversity of actors. A second limitation of bottom-up models, in Amazonia or other parts of the world (Verburg et al., 2006) is the lack of officially registered information about property boundaries. This obstructs direct association of actors with patterns of changes observed by means of remote sensing. *One of the challenges* in this scientific area is to combine both approaches in the construction of models. Top-down or bottom-up approaches alone are insufficient to represent the interactions between biophysical and socioeconomic processes at various scales, from the local to the global (Verburg et al., 2006; Moran et al., 2005). We also face the challenge of how to incorporate the institutional arrangements into land use models. Previous land-change modelling exercises in the Amazonia (Laurence et al., 2001, Soares-Filho, 2004, Aguiar, 2006) did not explicitly considerer the fact that the different institutional arrangements induce spatially heterogeneous behavior of land change models. These issues lead to two main challenges: *(a) How represent the heterogeneity of actors and relations of connectivity in the Amazon in bottom-up and top-down computational models? (b) How to incorporate the diversity of institutional arrangements in land change models?*

Discoveries and methods:

Building land change models requires iterative cycles, which start with conceptual workshops to define modelling goals and scenarios with interdisciplinary groups involving researchers and representatives of diverse sectors of society. The next step is fieldwork to help the models construction. Lastly, the computational models are built and validated. The computational models will be developed in the TerraME environment (Carneiro, 2006). Different methods for scenario construction (Janssen, 2002; Alcamo et al., 2006) will be employed, depending on the scale and specific institutional question under scrutiny.

The work will be coordinated through regular meetings to discuss each case study, integrating the different perspectives. We will develop data sets for testing new methodologies in each Axis, so that parallel schedules can be independently organized. Integration will happen through the case studies and synthesis activities (see Section 9).

9 Timetable

		Year 1 2009/2010	Year 2 2010/2011	Year 3 2011/2012	Year 4 2012/2013
Annual Meetings					
Genealogy of institutional and landscape transformations					
Case study definition					
Synthesis: institutional and land use coevolution					
Case Studies	Field work				
	Methodological development				
	Analysis and model development				
Milestones	Technical Reports (1 per year)				
	Research Articles (4 per year)				
	Synthesis Book (1)				

10 Dissemination and evaluation

As presented in Section 7, dissemination will happen through scientific publications and workshops. Evaluation will happen through publication of technical reports, papers and book.

11 Other support

On-going and submitted proposals:

- **Title: Toward Regional Amazonian Forest Structure and Biomass Measurement from Airborne and Spaceborne Remote Sensing -** PI: Robert Truehaft. (JPL/NASA), Agency: NASA, Funds: US 400,000.00 for 3 years (US$ 50,000.00 for Brazilian part), Duration: 36 months (from 05/2007 to 04/2009)
- **Project: Radarsat 2 data for assessing forest structure -** Agência financiadora: Science and Operational Applications Research for RADARSAT-2 (SOAR) - SOAR Project Number: 2517, Coordenador: Yosio E. Shimabukuro
- **Project: AMAZONICA ("Amazon Integrated Carbon Analysis"): A multidisciplinary Consortium to Determine Current and Future Greenhouse Gas Balances of the Amazon Basin -** Period: 2008 to 2012, Agência financiadora: NERC, Coordenador: Manuel Gloor
- **Project: "Mapeamento e monitoramento da Floresta Nacional do Tapajós (PA) utilizando dados de multisensores",** Period: January 2009 to December 2010, Agência financiadora: FAPESP (Submitted), Coordenador: Yosio E. Shimabukuro
- **Project: Producing Composite Imagery and Forest Cover and Change Characterizations for the Humid Tropics - A Contribution to the MDGLS Activity,**

Agência financiadora: NASA (Submitted), Coordenador: Matt Hansen (South Dakota State University)

- **Title: The Performance of Structure and Biomass Estimation from InSAR 3-D Vegetation Missions at L-band over Tropical Forests,** PI: Robert Truehaft. (JPL/NASA), Agency: NASA – Funds: US 800,000.00 for 3 years (US$ 50,000.00 for Brazilian part)
- **Title: GEOMA – MCT**, Coordenator: David Oren, Grant: US$ 600.000,00 yearly from MCT (2004-2008)
- **Title: PIME – INTEGRATED PROJECT OF MCT AND EMBRAPA**, Coordenator: Ana Luiza Mangabeira Albernaz (MPEG), Institutions: INPE, MPEG, INPA, EMBRAPA, Grant: US$ 200.000 from FINEP (2006-2009).
- **Title: "Gestion territoriale de la biodiversité sur les frontières : une méthode de diagnostic et de suivi - Brésil/Colombie/Pérou et Brésil/Guyane française**". Coordinator: Léna, Philippe. Agency: Conseil National de la Recherche Scientifique (CNRS). Funds: 86.000 Euros. Period: 2009-2010
- **Title: Violência, Espaço Público e Dependência Social na Amazônia Oriental** Coordinator: Roberto Araújo. Agency: FINEP. Funds: R$ 350.000. Period: 2007-2009

Support from host institutions:

- Physical installations for researchers and graduate students and administrative services (see item H in the proposal documentation.

12 Broader impacts

This proposal - which aims to better understand the close association between dynamics of cross-level institutional arrangements, and the evolution of land use systems in Amazonia – potentially foster new areas of research linking social and environmental sciences. Exploring innovative methodologies in remote sensing, landscape analysis and dynamic modeling fields, the proposal directly address to a main issue: the study of human purposes and of (individual and collective) intent underlying land cover change. It encompasses the devising of an “overarching land-change theory (that) needs to engage both the behavior of people and society (agency and structure) and the uses to which land uses are put, as well as feedbacks from one to the other”(Lambin and Geist, 2006).

Hence, this proposal provides an interdisciplinary framework to formation of human capital through the participation of graduate students. It allows the strength of a network of scholars and

research institutes, both national and international (see letters of support), stressing these educational aspects. Finally – and for all these reasons together – it fits the near foundation of an Earth System Science Center (CCST) at INPE, bringing a comprehensive core research questions and fieldwork data to the knowledge of socio-environmental issues.

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14 Budget and Timetable spreadsheets

See PROPOSAL DOCUMENTATION – ITEM D.

14.A Consolidated budget by source and by type of expense

See PROPOSAL DOCUMENTATION – ITEM D.

14.B Spreadsheets for items to be funded by FAPESP

See PROPOSAL DOCUMENTATION – ITEM D.

15 Workplans for each of the fellowships requested

15.1 MASTER AND DOCTORAL WORKPLANS

In this proposal, we request 06 scholarships – 03 to a master degree and 03 others for a doctoral degree. These scholarships will contribute to streghthen the postgraduate program of the new Earth System Science Center at INPE (CST-INPE). The aims of this proposal – which the

core research question is to better understand the close association between dynamics of cross-level institutional arrangements, and the evolution of land use systems in Amazonia - are suitable to the lines of research of the postgraduate program in many aspects. These aims encompasses the development of research and formation of human capital on the study of associated changes in *both human and environmental system*, as stated by CST. The scholarships will be equally distributed along the axis 1, 3 and 4 of the proposal3, namely:

- **Axis** 1: Identification and analysis of institutional arrangements that influence land use and cover change (LUCC) processes, using social sciences institutional analysis methods: 01 Master Degree scholarship, 01 oDctoral degree scholarship.
- **Axis** 3: Detection and description of occupation patterns and trajectories in multi-temporal image satellite data, which emerge from LUCC processes and institutional arrangements mentioned above, using landscape dynamic analysis methods: 01 Master Degree scholarship, 01 Doctoral degree scholarship.
- **Axis 4:** Construction of computational models and scenarios to represent the social interactions and institutional arrangements linked to the emergence of these occupation patterns and trajectories, combining different modeling approaches, specially agent-based models based on Complex System Theory concepts: 01 Master Degree scholarship, 01 Doctoral degree scholarship.

The scholarships will apply to the following research themes, and will be assigned in accordance to the student's availability to fit the proposal's case studies, including fieldwork research and collecting data:

1. Land-tenure and land-use land-cover changes.
2. Agents, social structure and process in featuring commodity chains.
3. Modelling land-use and land-cover change.
4. Methodologies for construction of scenarios: from local to global.
5. Analyzing and evaluating the outcomes of public policies responses to environmental changes in several related dimensions: Outcomes on social organization; Outcomes on decision-making process; and outcomes on deforestation.
6. Socio-environmental conflicts: agents, process and institutions in a cross-level analysis.

3 Axis 2 will not be contemplated as INPE has a well-established Remote Sensing Pos-graduation program.

7. Identity, collective action and political representation in dealing with environmental issues.

15.2 POST-DOCTORAL WORKPLANS

Work for a Post-Doctoral Researcher (Axis 1)

Level: PD-BR (FAPESP)

Supervisor: Roberto Araújo (PI), Eduardo Brondizio

Period: 12 months, Project Year 1

During first year of the project a post-doctoral researcher will concentrate on assembling historical data sets and maps featuring institutional arrangements and changes in the study areas. These data sets will serve as a basis for refining a timeline of events, for preparing survey instruments for fieldwork and interviews, and contribute to assembling the project's Geographic Information System. Maps related to changes in land tenure arrangements will be geo-referenced to land cover assessment and prepared for fieldwork and for initial analyses. Existing data (e.g., thematic maps, field data, etc) will be assembled and assessed according to project needs. During this phase, institutional arrangements will be characterized and defined according to type and level, function and extent, and timeframe. This post-doctoral researcher will also be responsible for comparing different methodological frameworks used for institutional analysis: organize and identify relevant variables and units of analysis (different action arenas) that are applicable to the problem. This includes, for instance, adapting the widely used Institutional Analysis and Development Framework (IAD) to this project. Commodity chains will be initially characterized in terms of agents, extent, types of inter-connections, economic return, and intersection with other economic sectors. In parallel to these activities, a detailed characterization of land use will be carried out with the goal of defining land allocation, trajectories and pathways of land use change as well as changes in land use technology. This position will also devote significant time to prepare fieldwork activities, including survey and interview instruments, sampling design, field maps, and initial contact with different groups of stakeholders and individuals. This post-doctoral position will be responsible for visiting regional institutions for interviews with public officials, NGOs, and private enterprises relevant to understand institutional changes and/or representing different sectors of specific commodity chains. In consultation with the larger group, this position will help to coordinate fieldwork plans and activities, organize data entry, data cleaning, and data analysis following fieldwork campaigns, and maintain communication with the research team

about the development of these tasks. This position will also be expected to contribute and lead research articles associated with the project.

Workplan for a Post-Doctoral Researcher (Axis 2)

Level: PD-BR (FAPESP)

Supervisor: Leila Fonseca (PI)

Period: 12 months, Project Year 2

This Post-Doctoral researcher will draw on top of first year results to define a methodology to analyze land-use trajectories across the case studies. The focus will be the analysis of different patterns of occupation that emerge from heterogeneous socio-economic and institutional arrangements. The role of infrastructure networks in connecting different contexts will also be studied, and also the role of cities in relation to these networks. This position will also be expected to contribute and lead research articles associated with the project.

Workplan for a Post-Doctoral Researcher (Axis 4)

Level: PD-BR (FAPESP)

Supervisor: Ana Paula Dutra de Aguiar (PI)

Period: 12 months, Project Year 3

During third year of the project a post-doctoral researcher will analyze the several case studies and their results: This pos-doc will focus in the integration and synthesis activities, connecting case studies results to establish interrelations and an analytical understanding of social and institutional processes of change at different scales. The goal will be to extract subsides to construct multi-scale models based on the case studies project findings, incorporating the project findings about institutional arrangements, land use change processes and intra-regional interactions He will develop methodologies to develop models and scenarios, combining different modeling approaches, from local to regional scales. This position will also be expected to contribute and lead research articles associated with the project.