MINISTÉRIO DA CIÊNCIA E TECNOLOGIA
INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS

Workshop on GLOBIO model, Rio de Janeiro, 2009

Land Use and Cover Change Modeling at Brazilian Amazon: How to Model Human Actions?

Tiago Garcia de Senna Carneiro
Universidade Federal de Ouro Preto
http://www.terralab.ufop.br

Gilberto Câmara
Ana Paula Aguiar
Earth System Science Centre, INPE
http://geochange.ess.inpe.br

BRASIL UM PAÍS DE TODOS GOVERNO FEDERAL

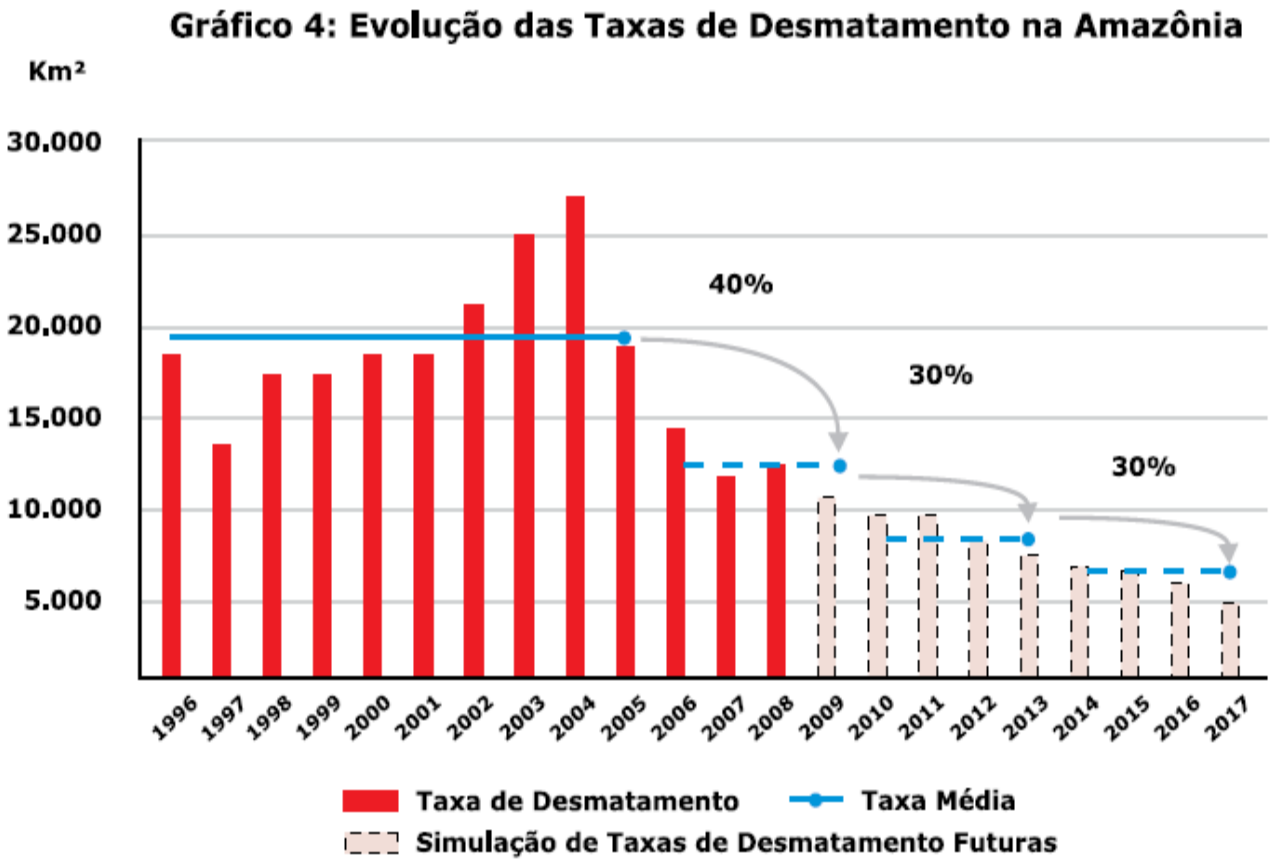
Human actions and global change

photo: C. Nobre

How much change is happening?
Where are changes taking place?
Who is being impacted by the change?

photo: A. Reenberg

National Plan for Climatic Change (Brazil, 2008)



TERÇA-FEIRA, 2 DE DEZEMBRO DE 2008
ESTADO DE S.PAULO

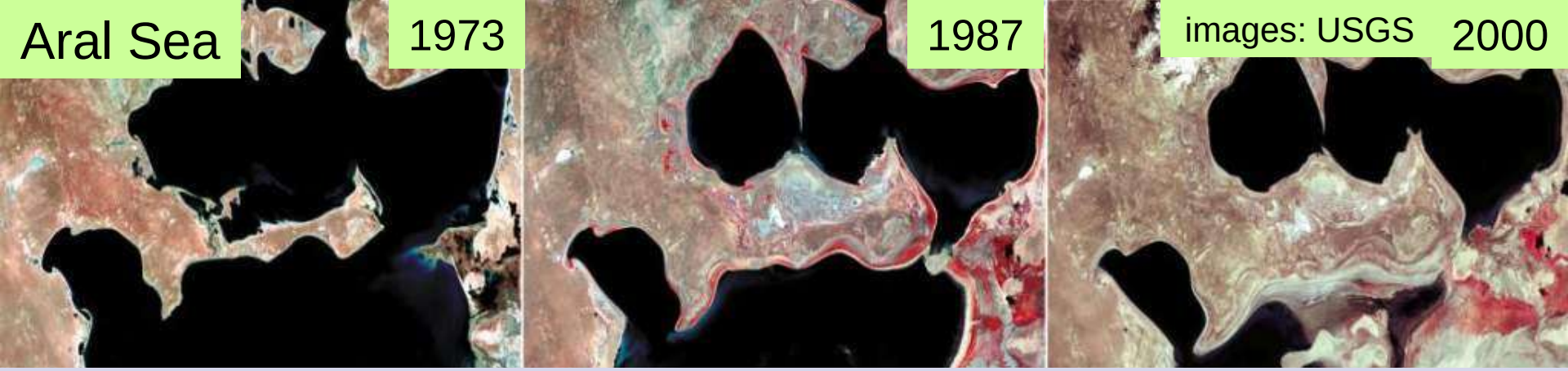
NÚMEROS

9,2 mil km quadrados
é o máximo que o País poderá desmatar no ano que vem para cumprir a primeira etapa da redução progressiva do desmatamento na Amazônia

70 mil km quadrados
é a área total de desmatamento da floresta amazônica que o governo vai tolerar entre 2009 e 2017, uma extensão de matas superior ao território dos Estados do Rio e de Sergipe, somados

5 mil km quadrados
é a taxa de desmate anual esperada para 2017, caso o plano do governo seja bem-sucedido

Are targets of deforestation possible for the Brazilian Amazon?



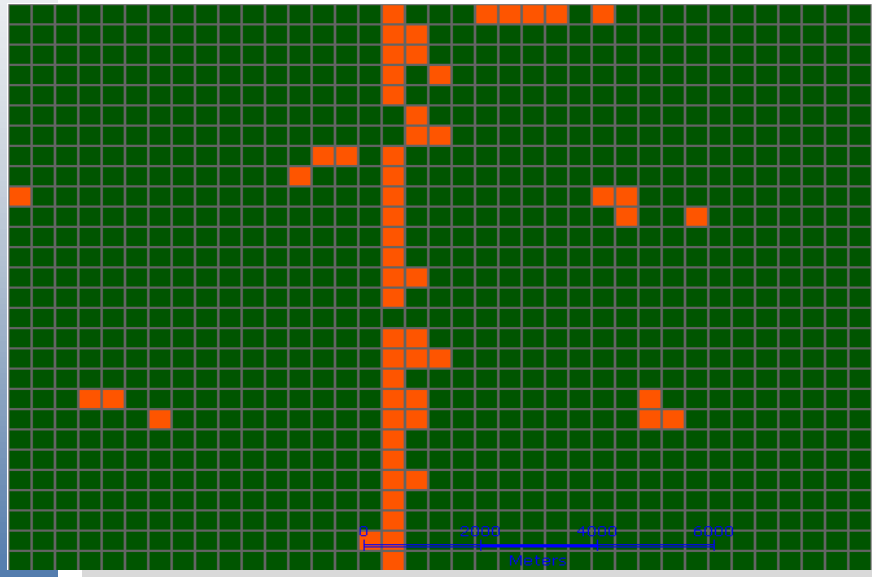
Modelling Nature-Society Interactions

How do humans use space?

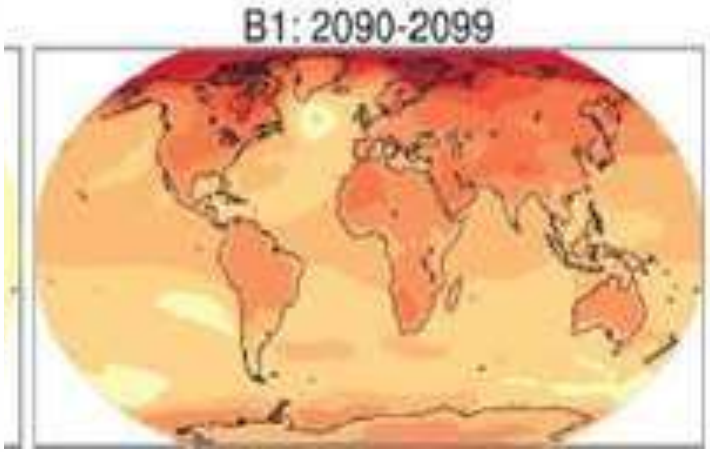
How to describe and predict changes resulting from human actions?

What computational tools are needed to model Modeling the interaction nature-society interactions?

Question #1 for Nature-Society models



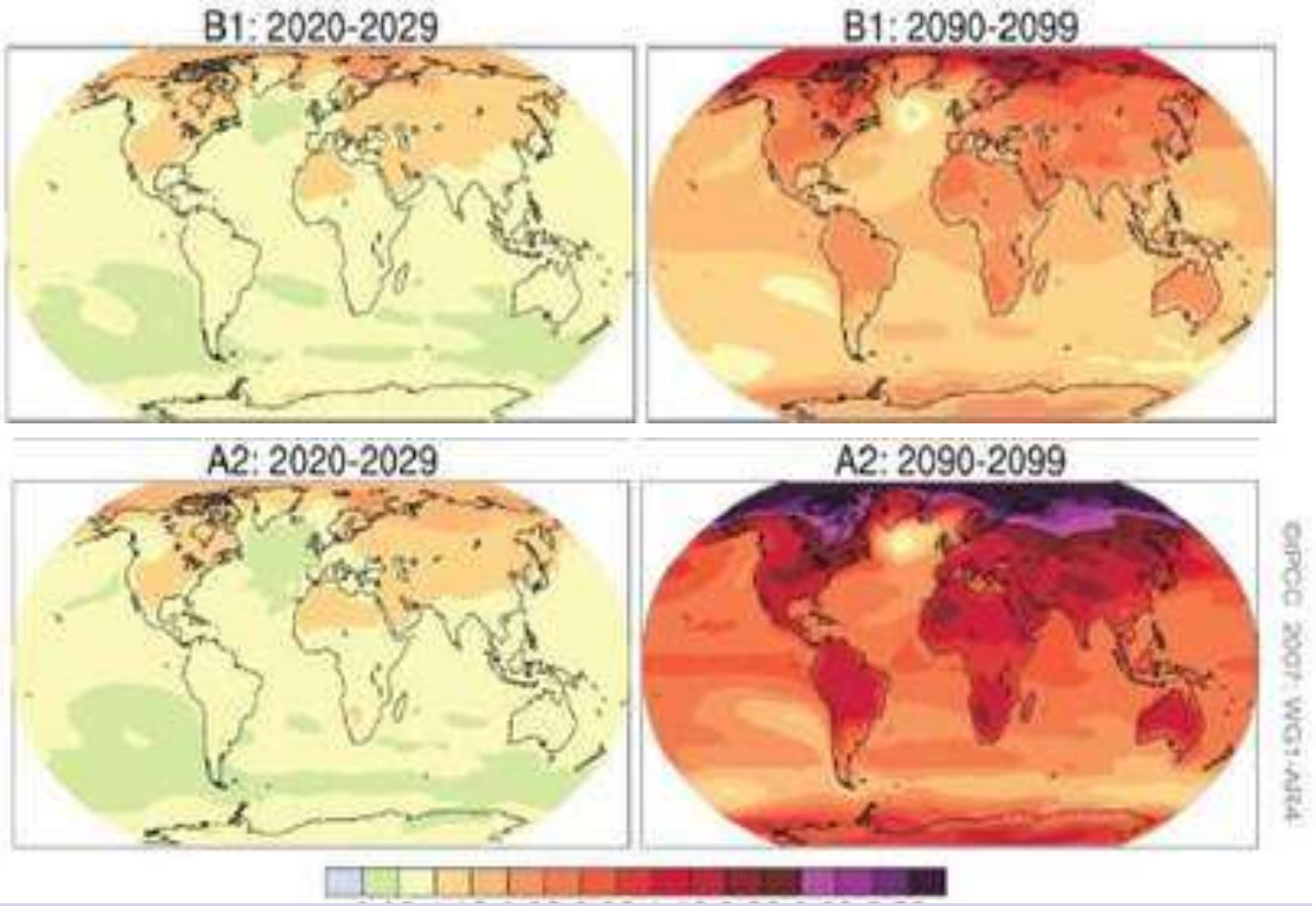
land_cover cells



Loss of Biodiveristy

What ontological kinds (data types) are required for nature-society models?

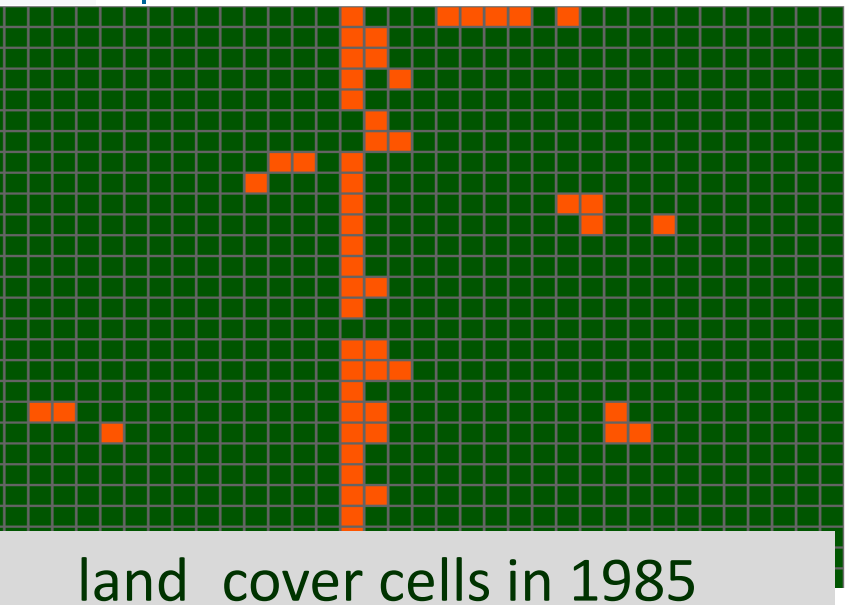
Environmental Change models deals with ST fields



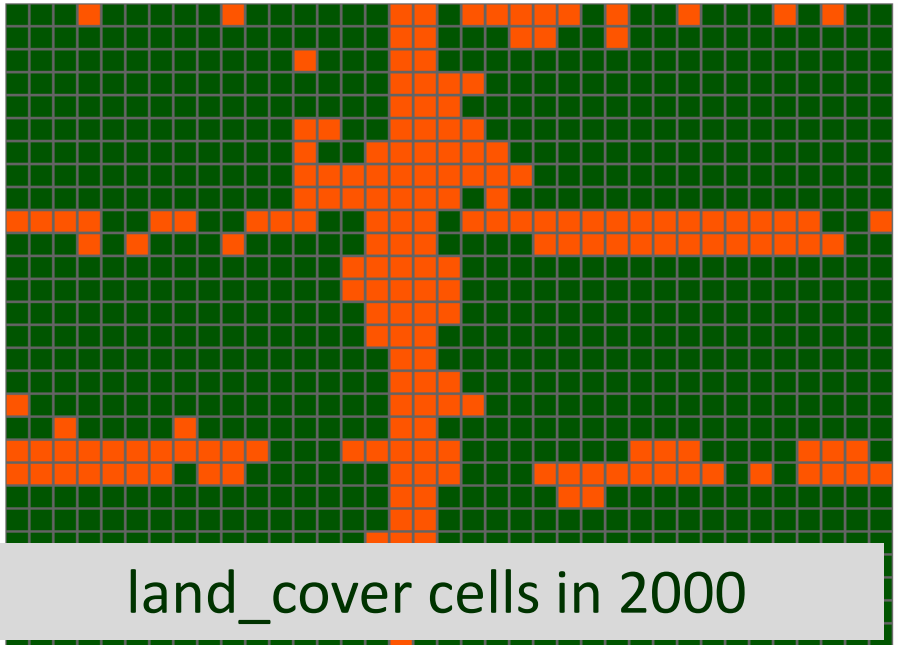
A field is a spacetime continuum

Field: T $\rightarrow$ S $\rightarrow$ A

Societal data are modelled as ST objects



land_cover cells in 1985



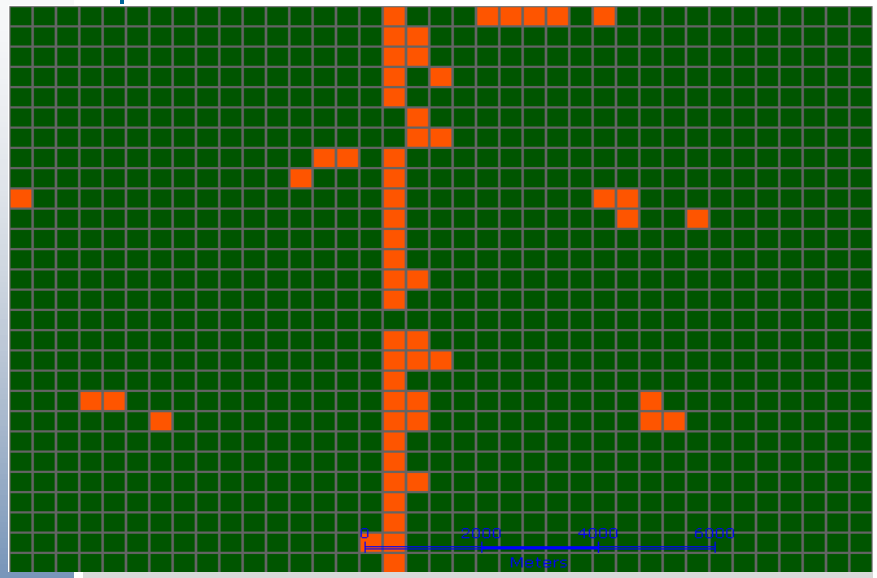
land_cover cells in 2000

attr_id	object_id	initial_time	final_time	land_cover	dist_primary_road	dist_secondary_road
C34L181985-	C34L18	01/01/1985	31/12/1985	forest	7068.90	669.22
C34L181988-	C34L18	01/01/1988	31/12/1988	forest	7068.90	669.22
C34L181991-	C34L18	01/01/1991	31/12/1991	forest	7068.90	669.22
C34L181994-	C34L18	01/01/1994	31/12/1994	deforested	7068.90	669.22
C34L181997-	C34L18	01/01/1997	31/12/1997	deforested	7068.90	669.22
C34L182000-	C34L18	01/01/2000	31/12/2000	deforested	7068.90	669.22
C34L191985-	C34L19	01/01/1985	31/12/1985	forest	7087.29	269.24
C34L191988-	C34L19	01/01/1988	31/12/1988	deforested	7087.29	269.24
C34L191991-	C34L19	01/01/1991	31/12/1991	deforested	7087.29	269.24
C34L191994-	C34L19	01/01/1994	31/12/1994	deforested	7087.29	269.24
C34L19199						
C34L19200						

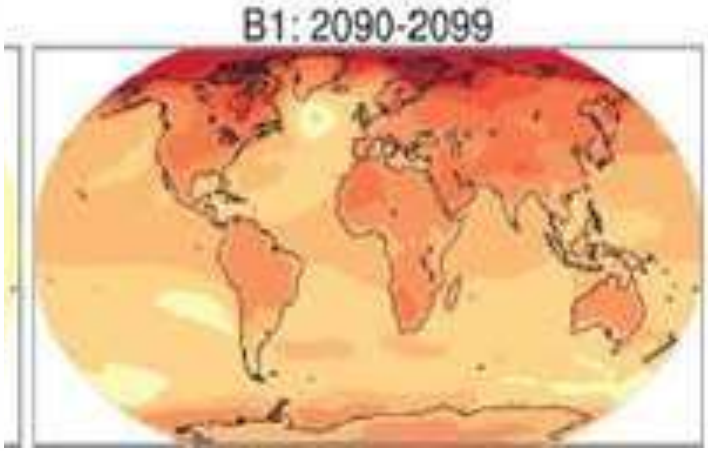
An object is an individual that exists in space and time

(Object: ID $\rightarrow$ T $\rightarrow$ [S,A])

Requirement #1 for Nature-Society models



land_cover cells (objects)



Loss of Biodiversity (fields)

attr_id	object_id	initial_time	final_time	land_cover	dist_primary_road	dist_secondary_road
C34L181985	C34L18	01/01/1985	31/12/1985	forest	7068.90	669.22
C34L181988	C34L18	01/01/1988	31/12/1988	forest	7068.90	669.22
C34L181991	C34L18	01/01/1991	31/12/1991	forest	7068.90	669.22
C34L181994	C34L18	01/01/1994	31/12/1994	deforested	7068.90	669.22
C34L181997	C34L18	01/01/1997	31/12/1997	deforested	7068.90	669.22
C34L182000	C34L18	01/01/2000	31/12/2000	deforested	7068.90	669.22
C34L191985	C34L19	01/01/1985	31/12/1985	forest	7087.29	269.24
C34L191988	C34L19	01/01/1988	31/12/1988	deforested	7087.29	269.24
C34L191991	C34L19	01/01/1991	31/12/1991	deforested	7087.29	269.24
C34L191994	C34L19	01/01/1994	31/12/1994	deforested	7087.29	269.24
C3						
C3						

Nature-society models need to describe fields and objects (and store their attributes in a database)

Question #2 for Nature-Society models

What models are needed to describe human actions?

Modelling Human Actions

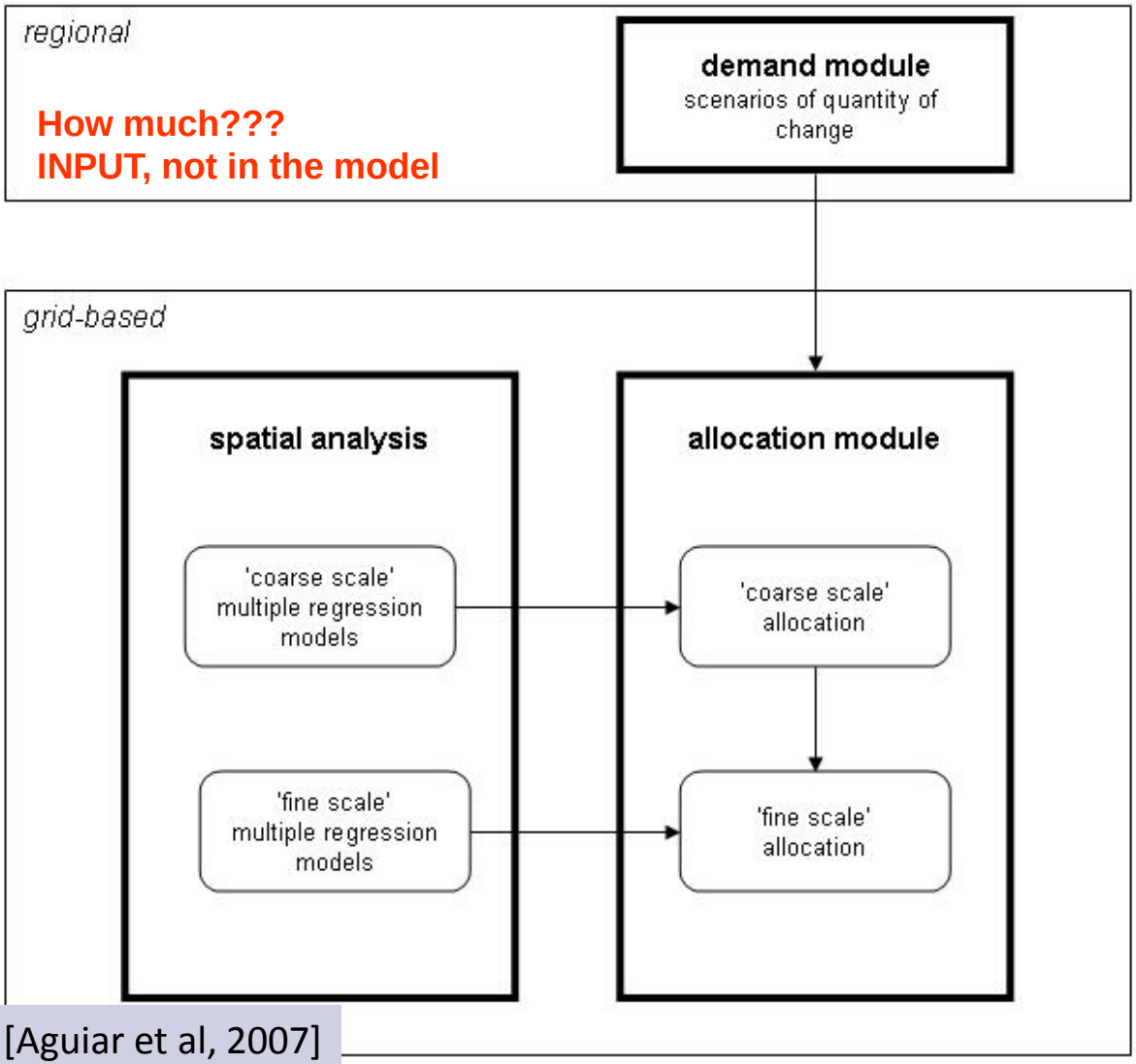
- Models based on global factors
  - Explanation based on causal models
  - “For everything, there is a cause”
  - Human_actions = f (factors,....)
- Emergent models
  - Local actions lead to global patterns
  - Simple interactions between individuals lead to complex behaviour
  - “More is different”
  - “The organism is intelligent, its parts are simple-minded”
  - Example: cellular automata based models, agent based models

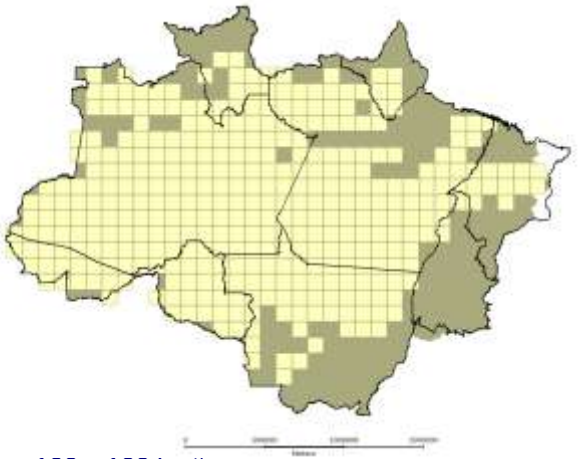
Statistics: Humans as clouds

$$y=a_0 + a_1x_1 + a_2x_2 + \ldots + a_ix_i + E$$

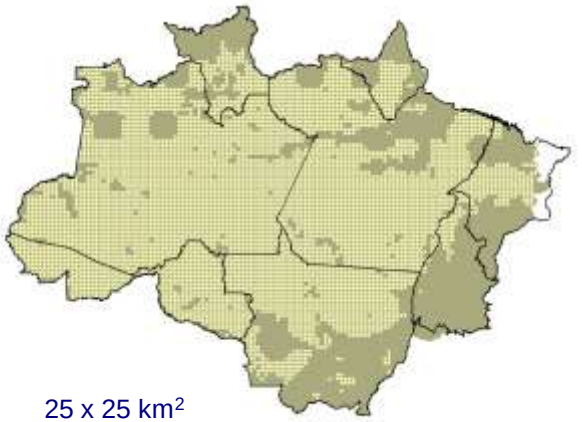
- Establishes statistical relationship with variables that are related to the phenomena under study
- Basic hypothesis: stationary processes
- Examples: CLUE Model (University of Wageningen)

CLUE modeling framework





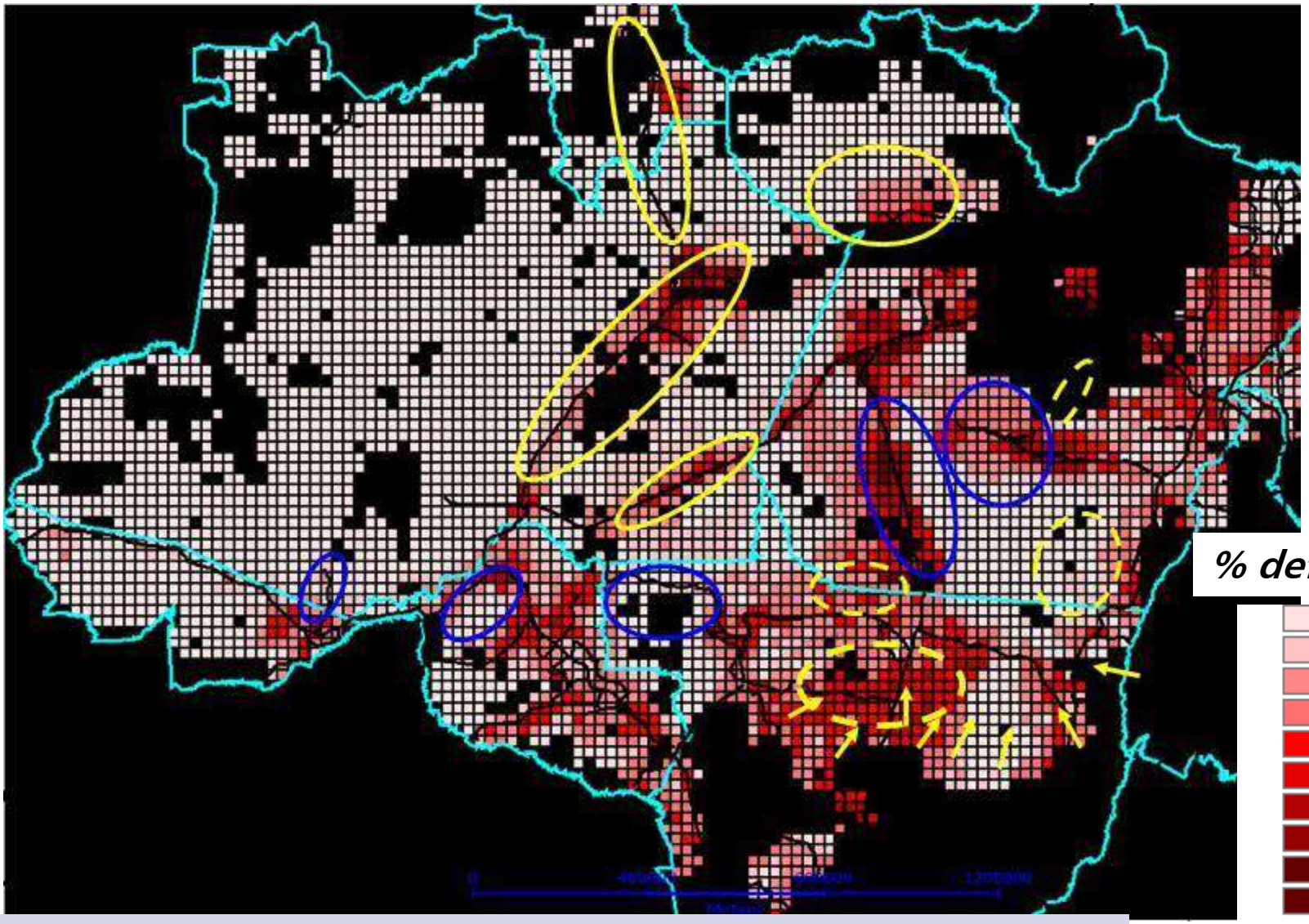
100 x 100 km²



25 x 25 km²

[Aguiar et al, 2007]

Land Change in Amazonia (Scenario for 2015)



TerraME cell space: 90 initial explanatory factors

[Aguiar, 2006]

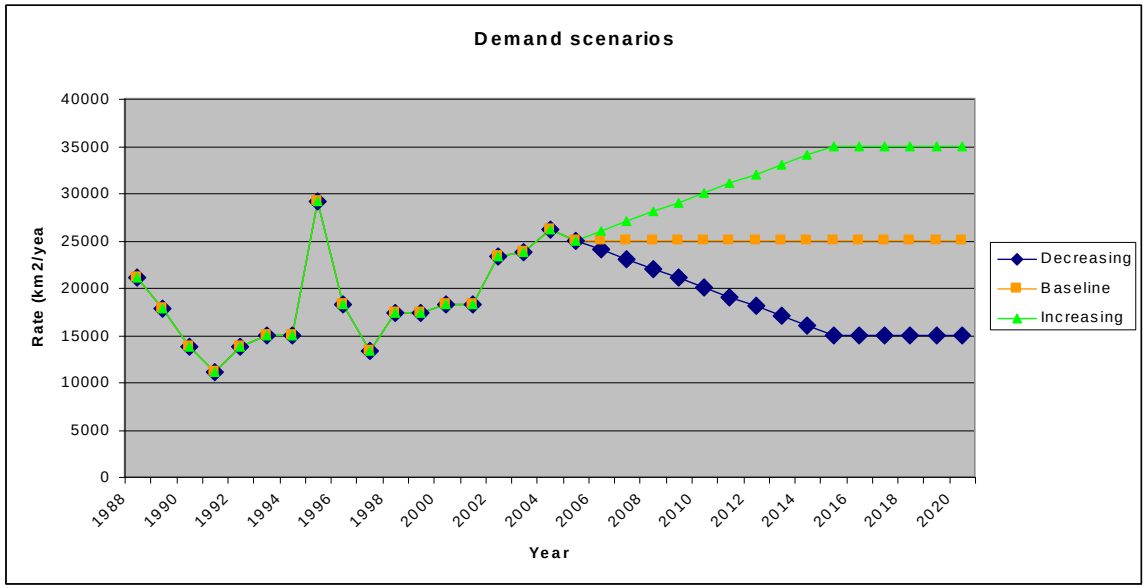
Statistics: Humans as clouds

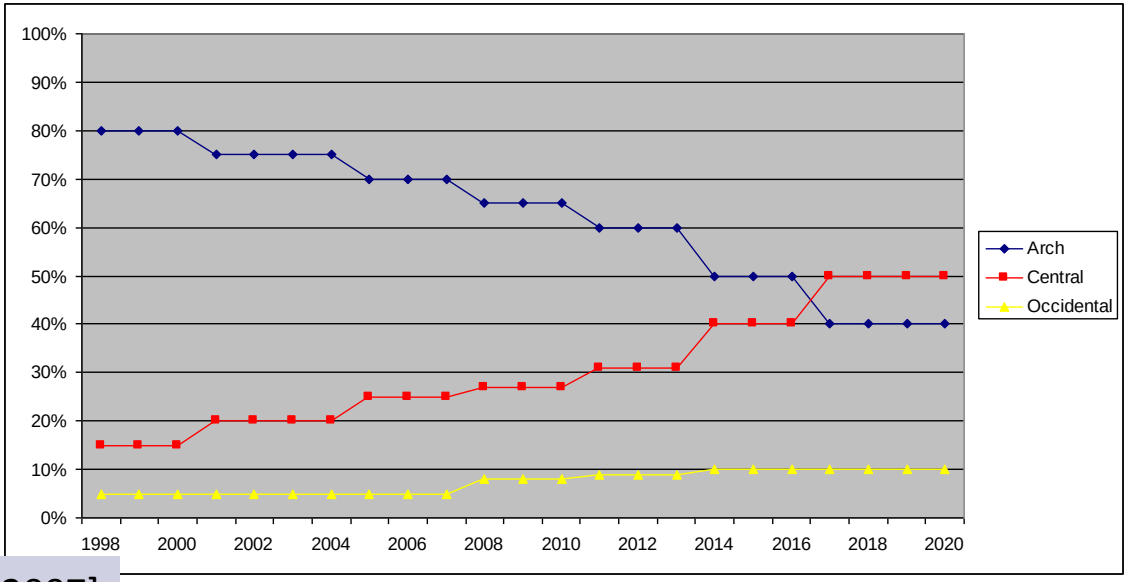
MODEL 7: R^2 = .86			
Variables	**Description**	**stb**	**p-level**
PORC3_AR	Percentage of large farms, in terms of area	0,27	0,00
LOG_DENS	Population density (log 10)	0,38	0,00
PRECIPIT	Avarege precipitation	-0,32	0,00
LOG_NR1	Percentage of small farms, in terms of number (log 10)	0,29	0,00
DIST_EST	Distance to roads	-0,10	0,00
LOG2_FER	Percentage of medium fertility soil (log 10)	-0,06	0,01
PORC1_UC	Percantage of Indigenous land	-0,06	0,01

Statistical analysis of deforestation: 27 alternative regressive models (R^2 = 0.80 to 0.86)

[Aguiar et al, 2007]

Demand scenarios





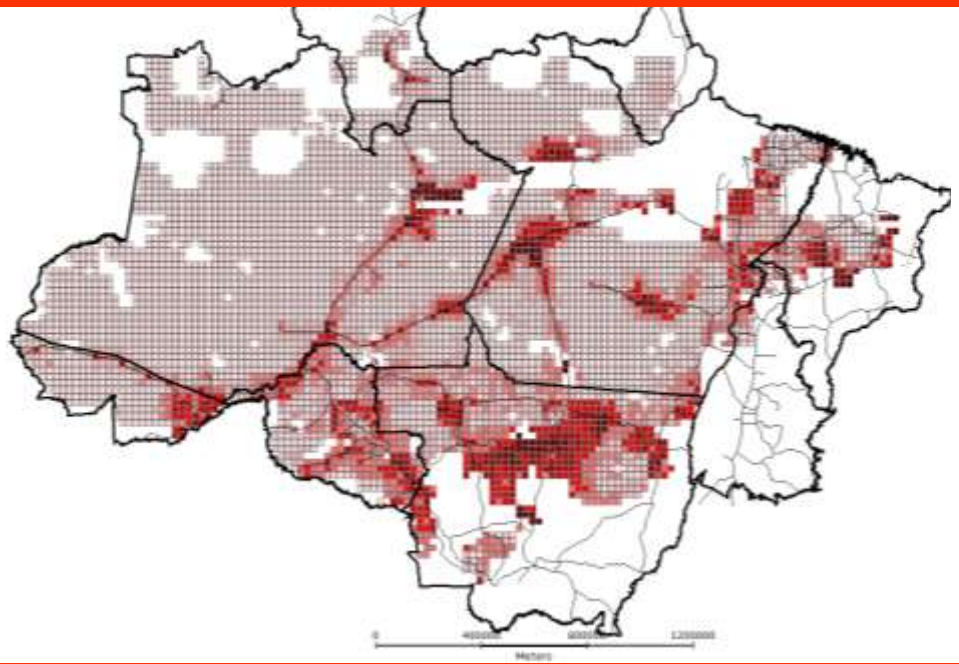
[Aguiar et al, 2007]

Law enforcement scenarios

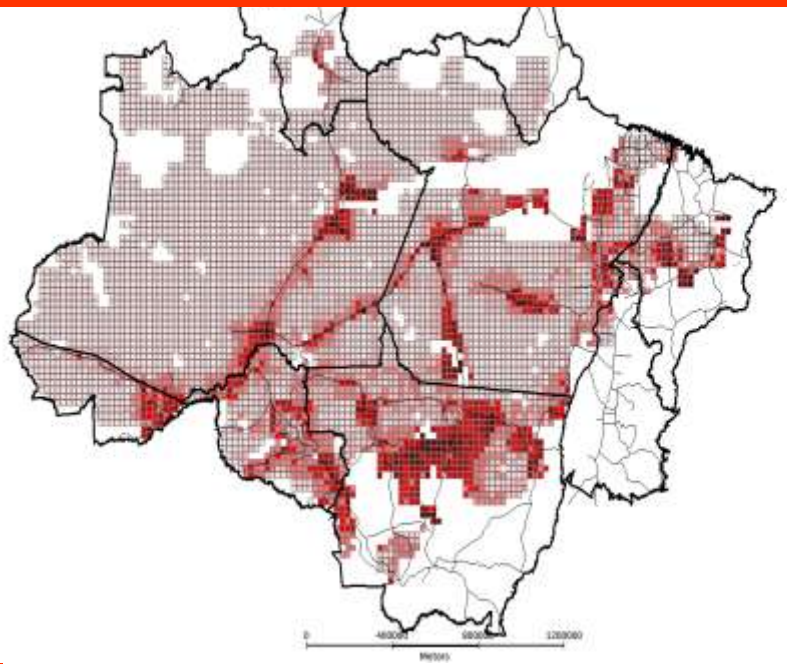
	Forest cover threshold (forest_ threshold)	Maximum allowed change (change_max_lim)
No law enforcement	20%	50%
Private Reserve partial enforcement	50%	50%
Local Command and Control:		
Controlled areas	50%	20%
Outside controlled areas	20%	50%

[Aguiar et al, 2007]

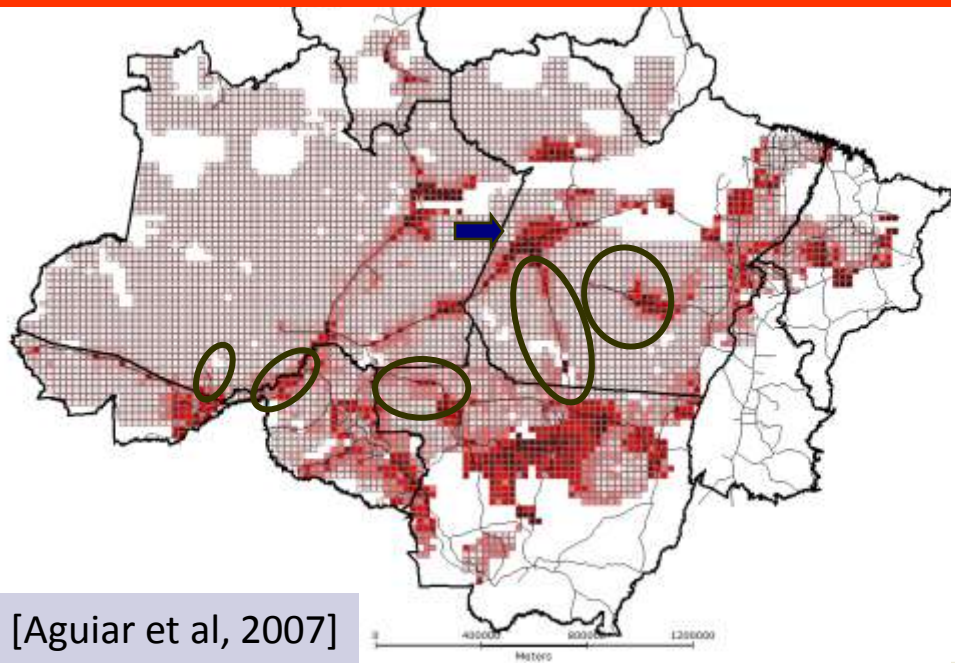
arch_25, central_25, occidental_25

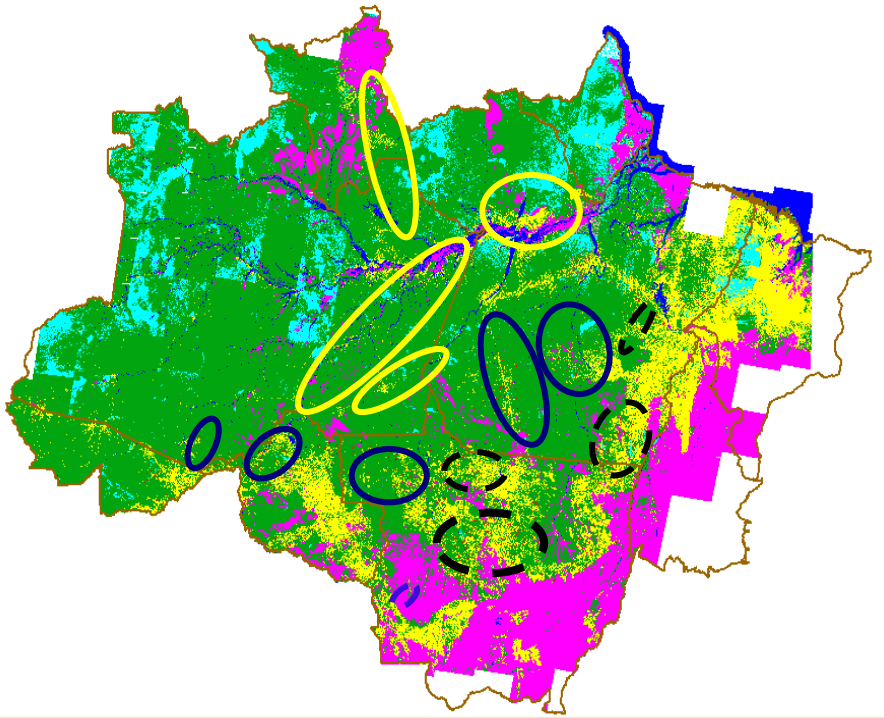


arch_25



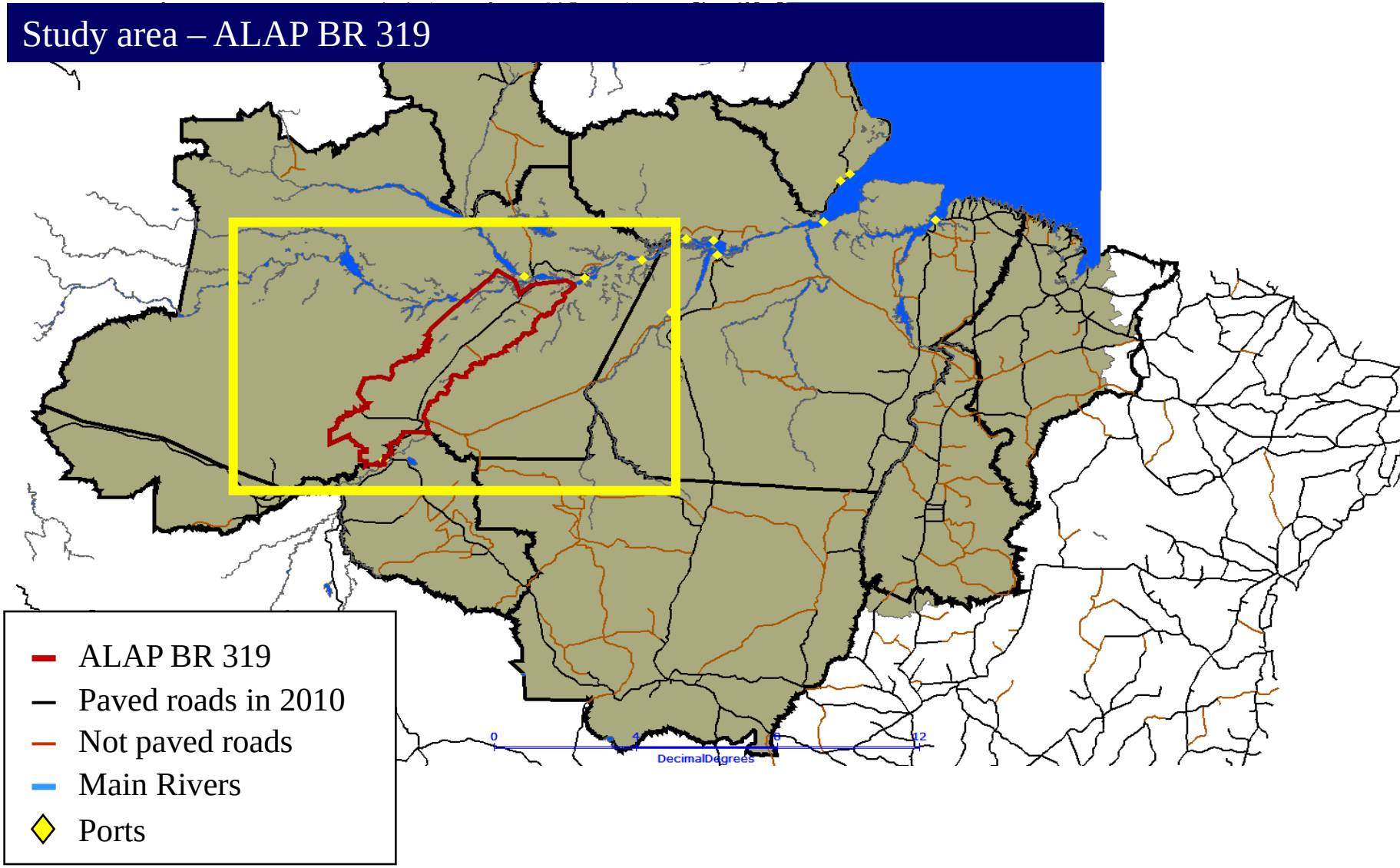
arch_25, central_25, occidental_25



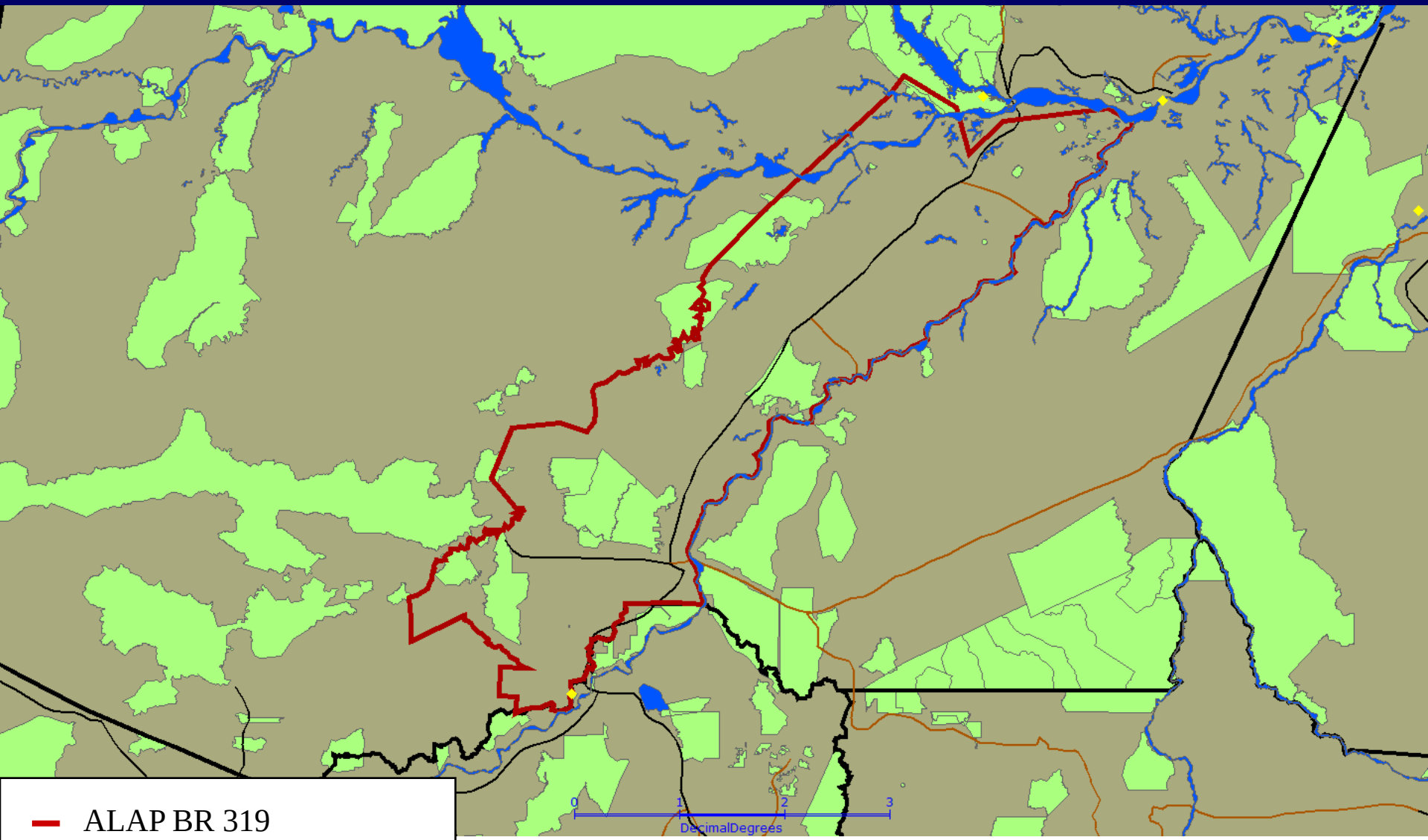


[Aguiar et al, 2007]

CLUE Simulations: protected areas impact



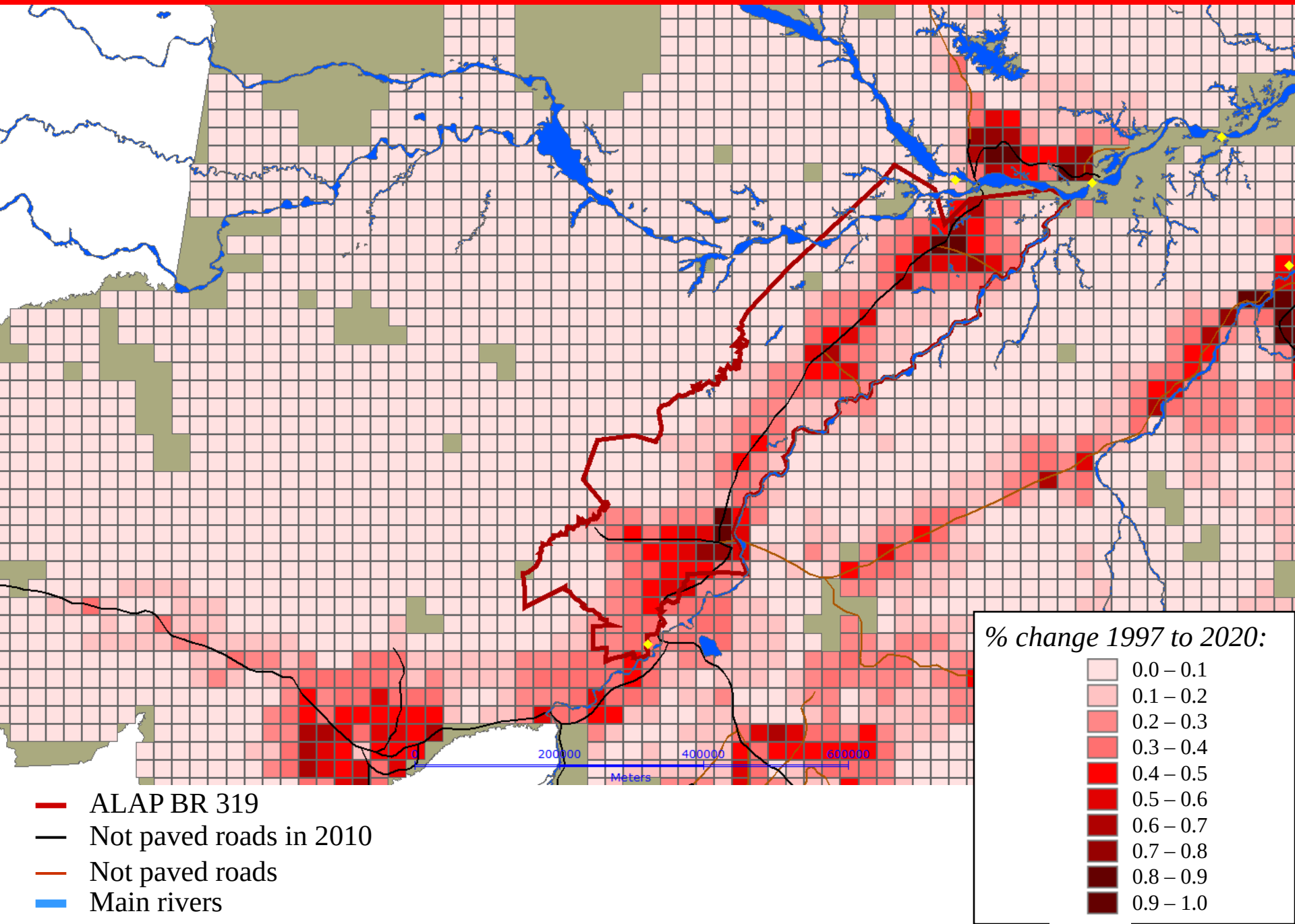
BASE Scenario – Protected areas in 2004



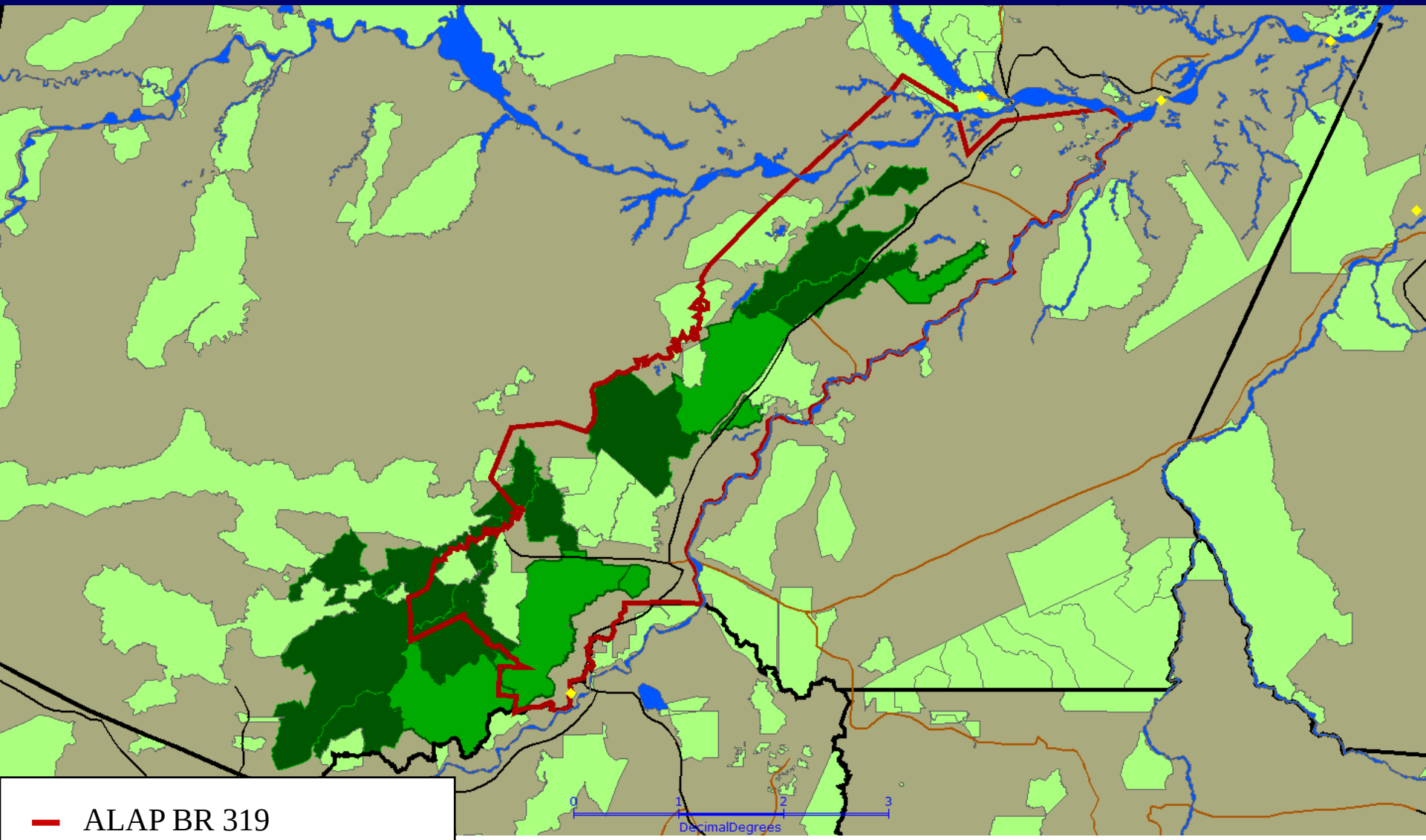
ALAP BR 319
Paved roads in 2010
Not paved roads
Main Rivers
Ports

Protected areas in 2004
New productive areas (2007)
New sustenable use areas (2007)

BASE SCENARIO – *Hot spots* of change (1997 to 2020)



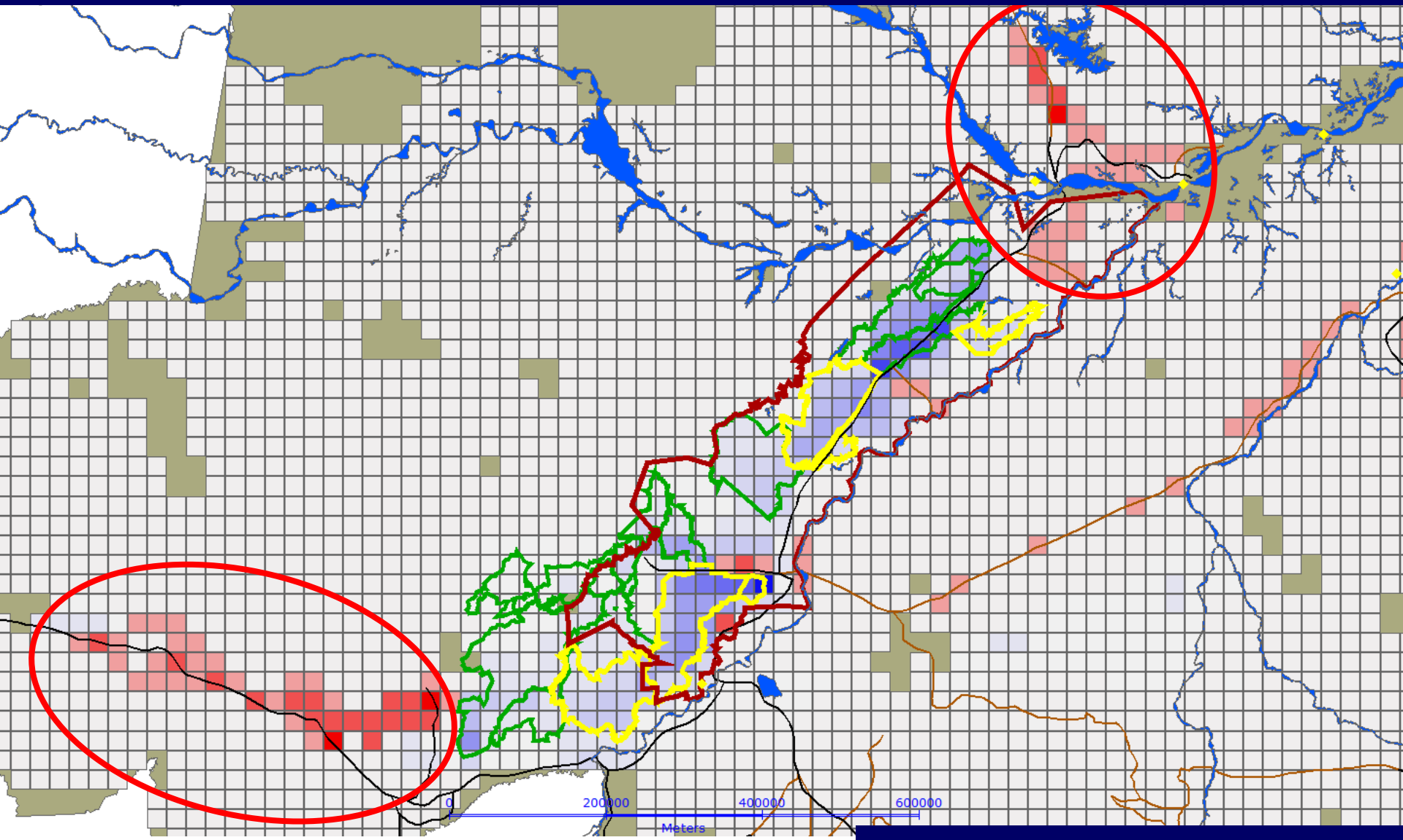
CENÁRIO SIMULADO – Adicionando áreas de proteção integral e uso sustentável (2007)



- ALAP BR 319
- Paved roads in 2010
- Not paved roads
- Main Rivers
- Ports

- Protected areas in 2004
- New productive areas (2007)
- New sustenable use areas (2007)

Simulated Scenario – Differences from the BASE SCENARIO



ALAP BR 319
Not paved roads in 2010
Not paved roads
Main rivers

Protected areas

Sustenable use areas

Deforestation differences:

Decreasing: 0.0 ⇨ -0.50

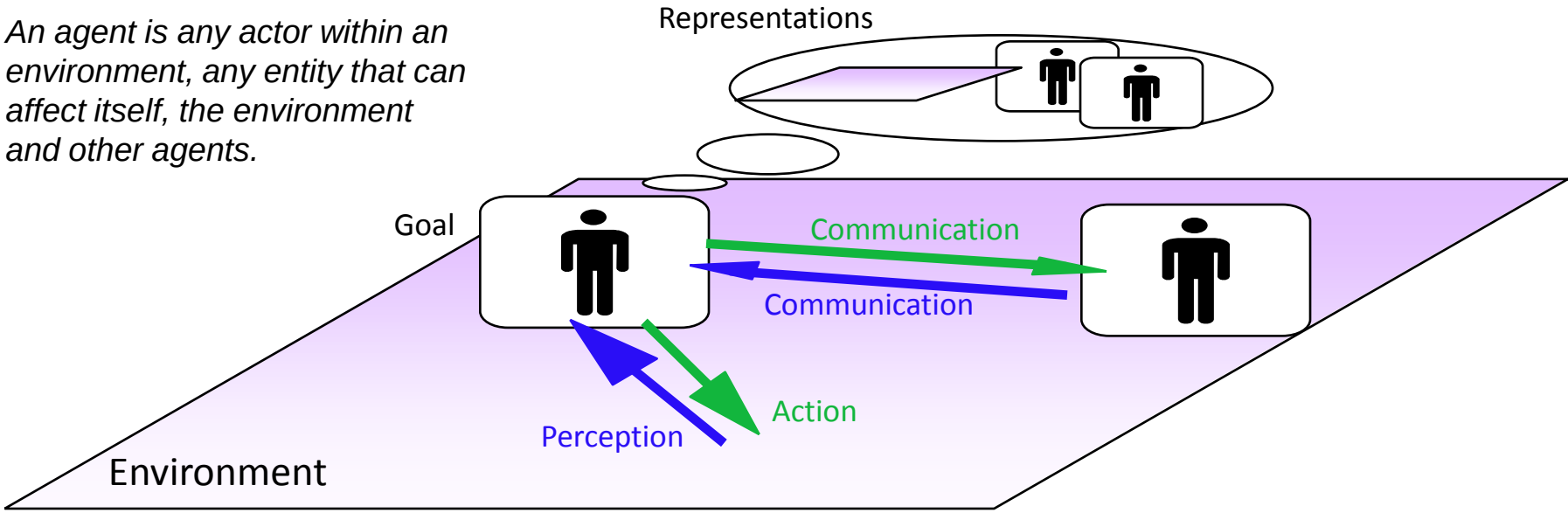
Increasing: 0.0 ⇨ 0.10

Dynamic modeling conclusions

- Most important coefficient: diffusive pattern of deforestation
- Results show that single factor analysis can be misleading: relative importance of **determining factors vary across the Amazonia**
- The main factors identified were:
  - Population density;
  - Connection to national markets;
  - Climatic conditions;
  - Indicators related to land distribution between large and small farmers.
- It is the interaction of connectivity and other factors that influence the intra-regional dynamics and created differentiated conditions in the new expansion axes.
- This intra-regional differences led to differentiated impacts of policies across the region.

Agents as basis for complex systems

An agent is any actor within an environment, any entity that can affect itself, the environment and other agents.



- **Human behavior:**
  - Autonomous and collaborative
  - Goal oriented
  - Based on previous knowledge
  - Planned

source: Nigel Gilbert

Agents: autonomy, flexibility, interaction

Bird Flocking

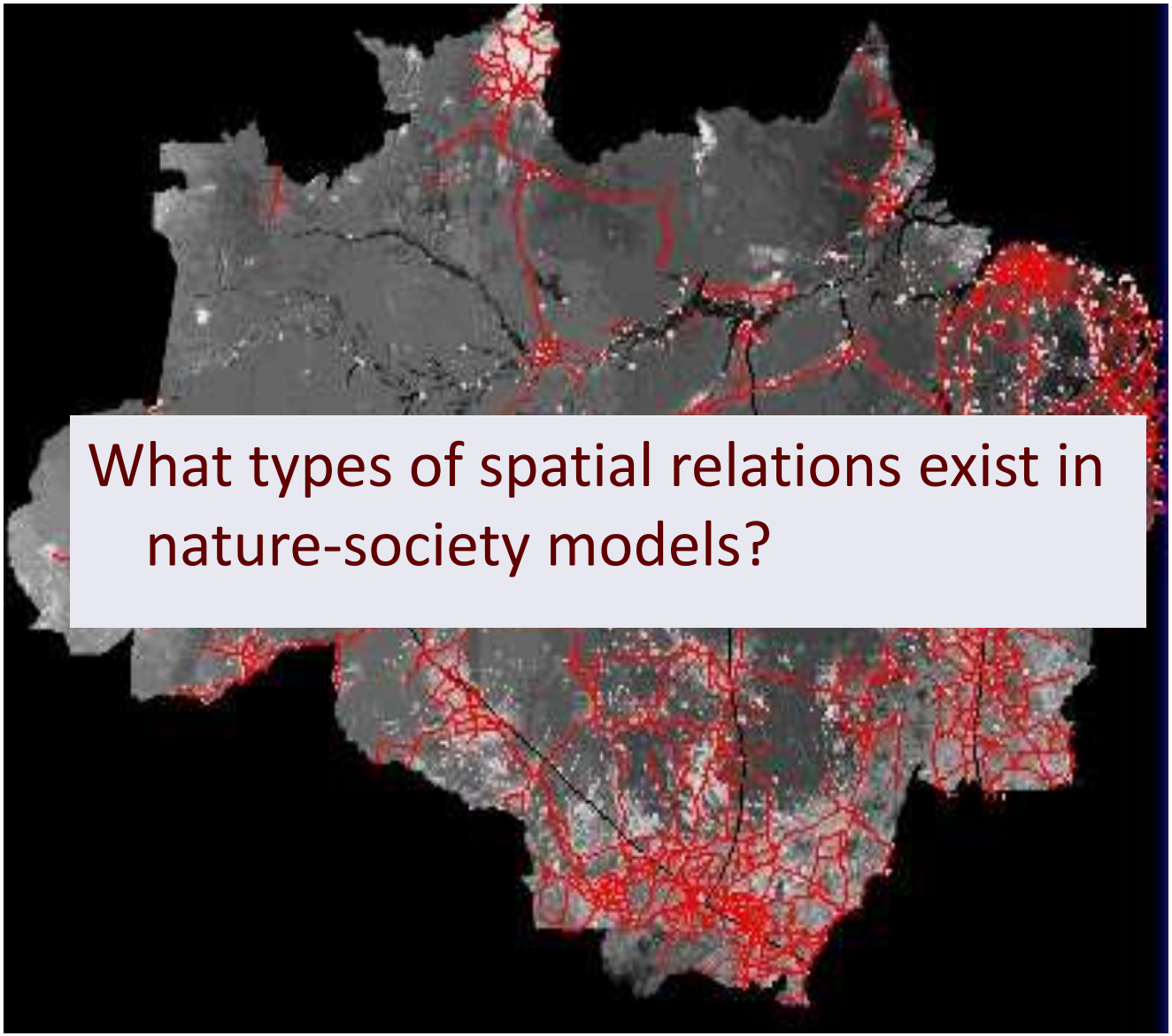
No central authority: Each bird reacts to its neighbor

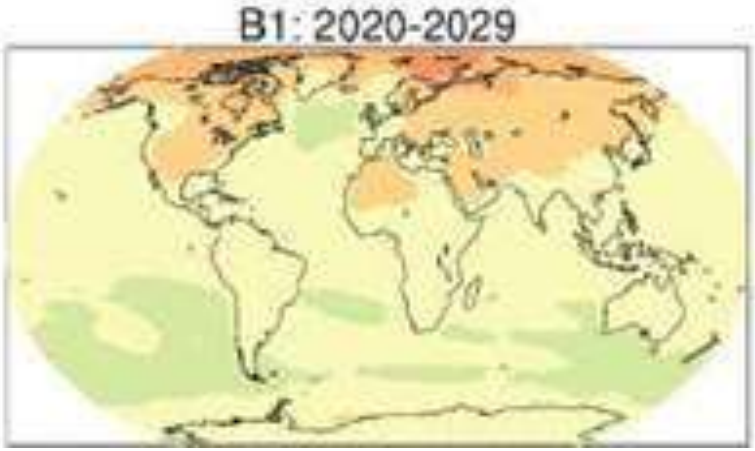
Bottom-up: not possible to model the flock in a global manner. It is necessary to simulate the **INTERACTION** between the individuals

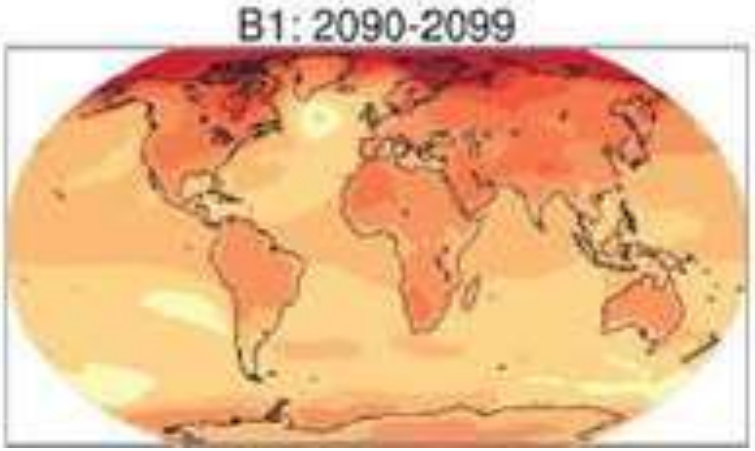
Requirement #2 for Nature-Society models

Models need to support both statistical relations (clouds) and agents (ants)

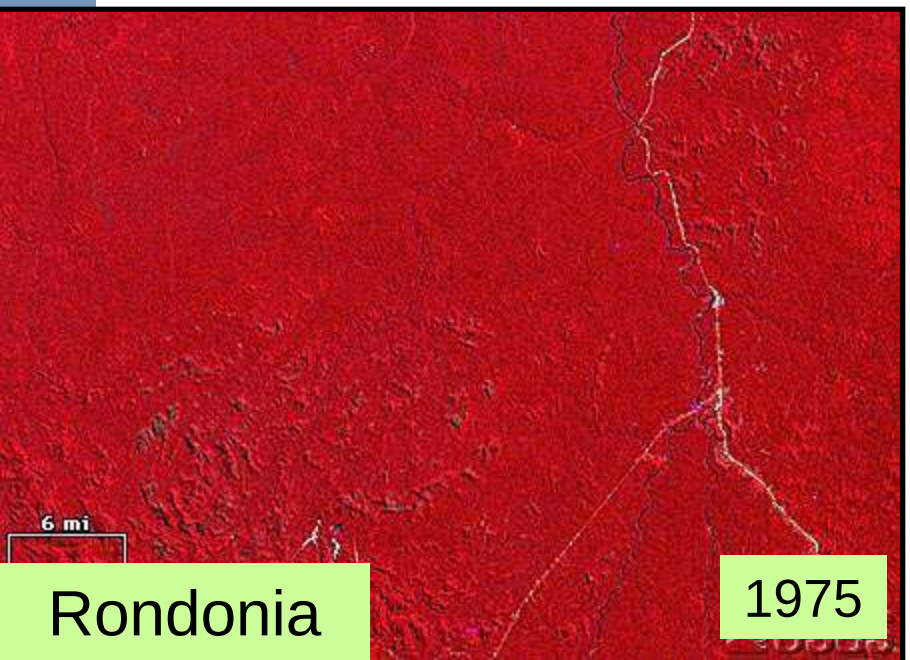
Question #3 for Nature-Society models

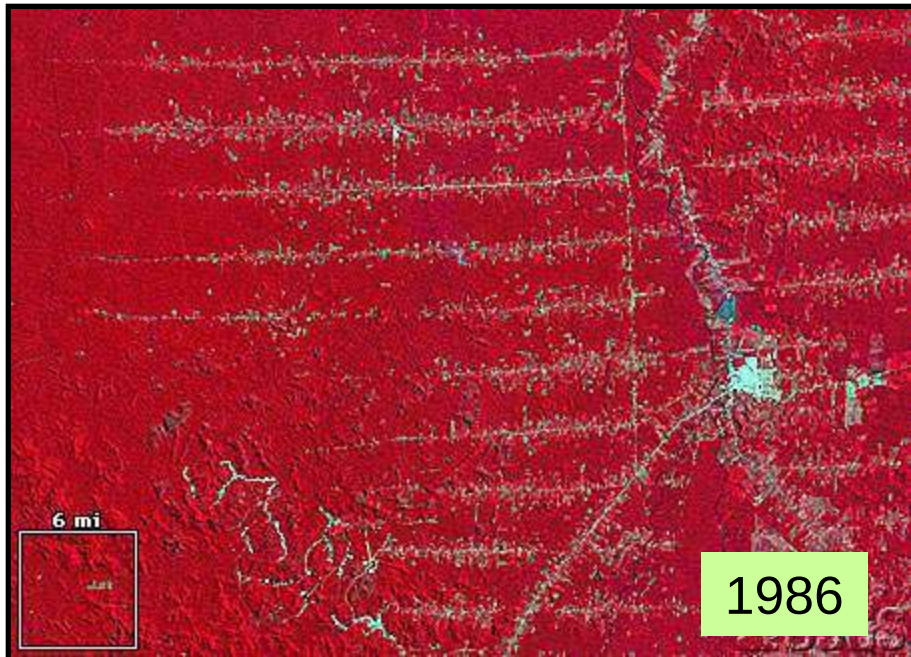






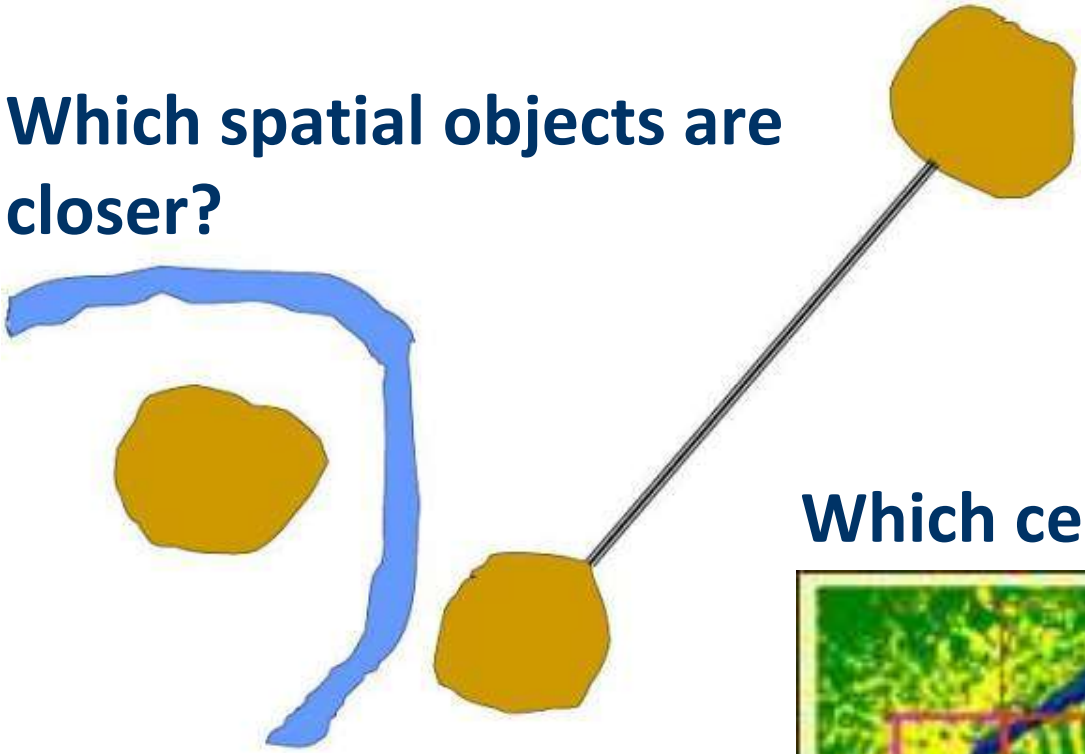
Natural space is (usually) isotropic
Societal space is mostly anisotropic



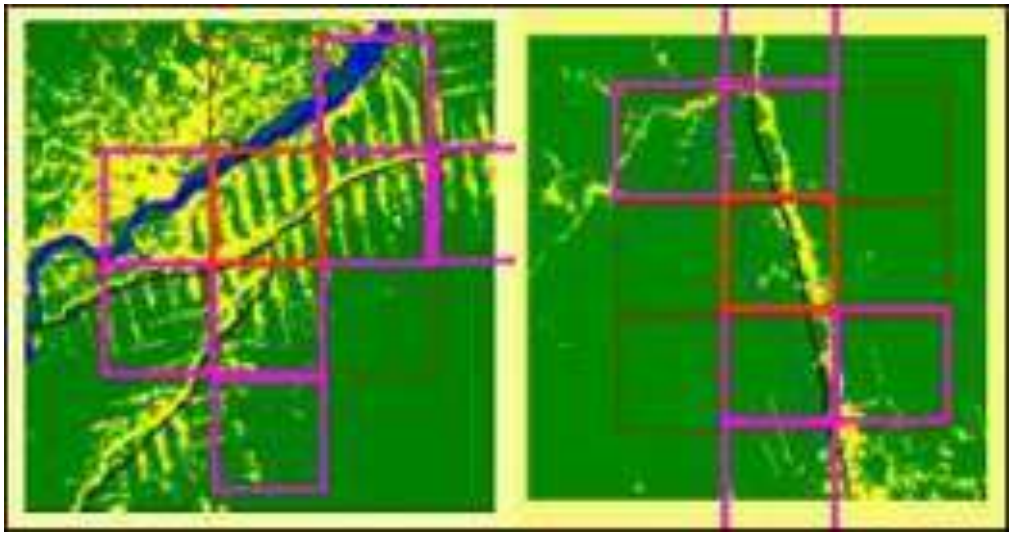


Societal spaces are anisotropic

Which spatial objects are closer?



Which cells are closer?



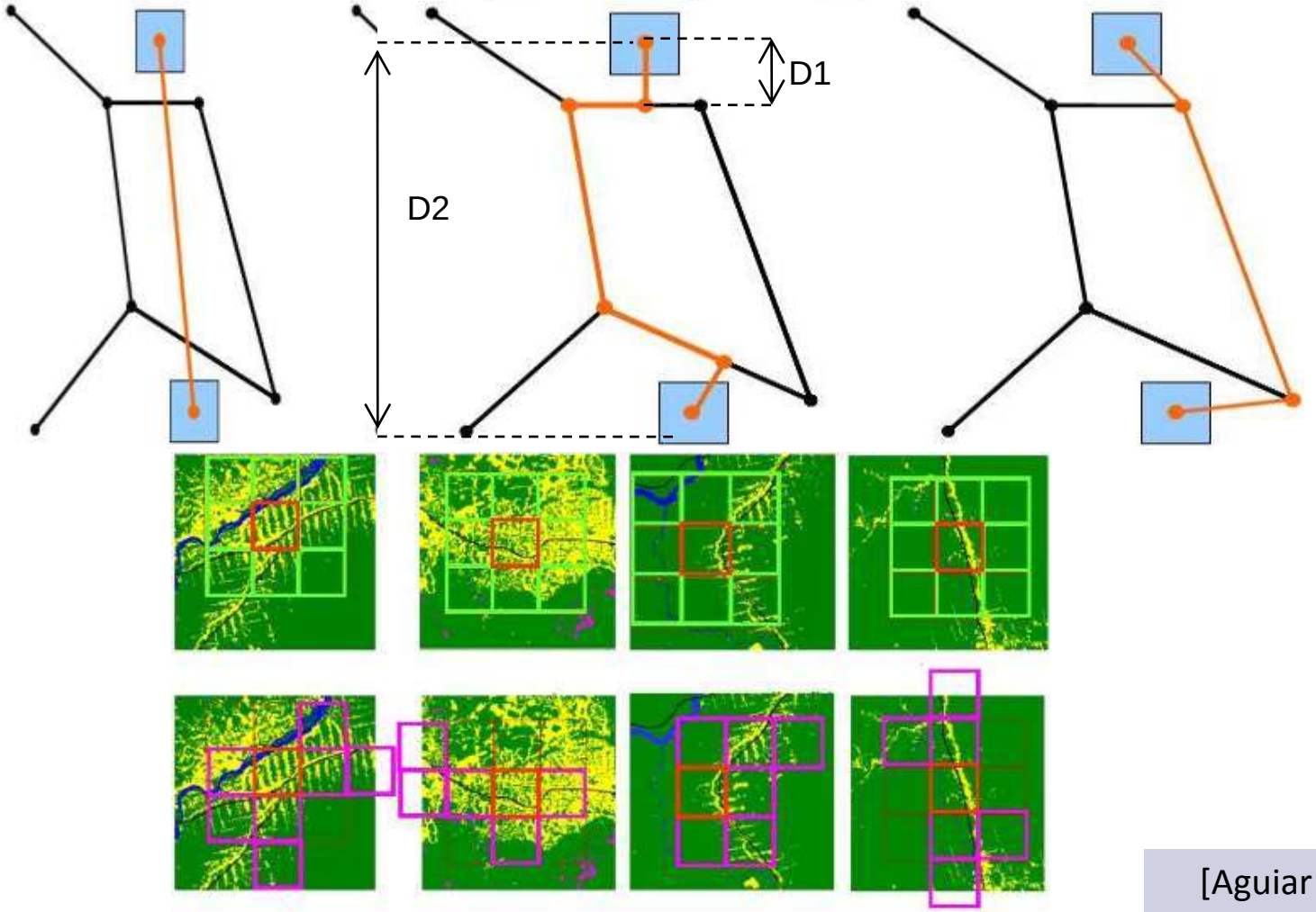
[Aguiar et al., 2003]

Requirement #3 for Nature-Society models: express anisotropy explicitly

Euclidean space

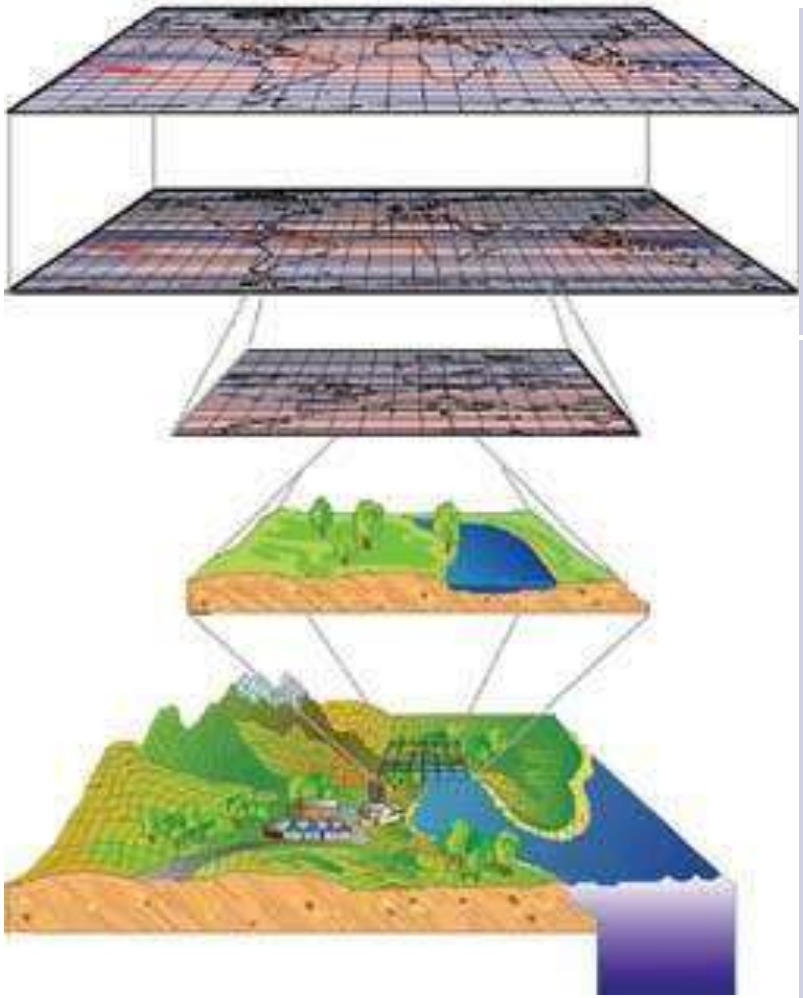
Open network

Closed network



[Aguiar et al., 2003]

Question #4 for Nature-Society models



How do we combine independent multi-scale models with feedback?

Athmosphere, ocean, chemistry climate model (resolution 200 x 200 km)

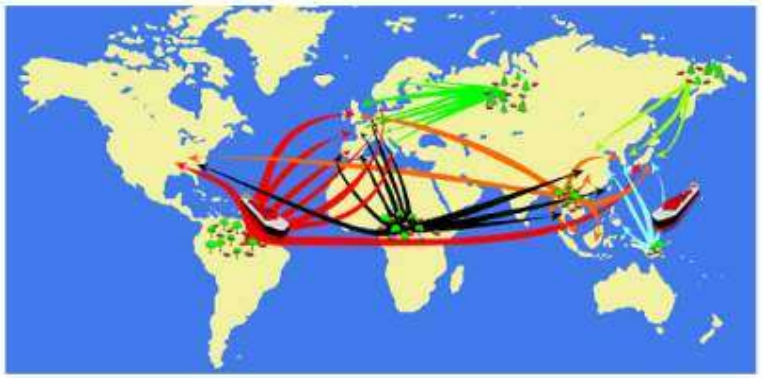
Atmosphere only global climate model (resolution 50 x 50 km)

Regional climate model (resolution 10 x 10 km)

Hydrology, Vegetation
Soil Topography (e.g, 1 x 1 km)

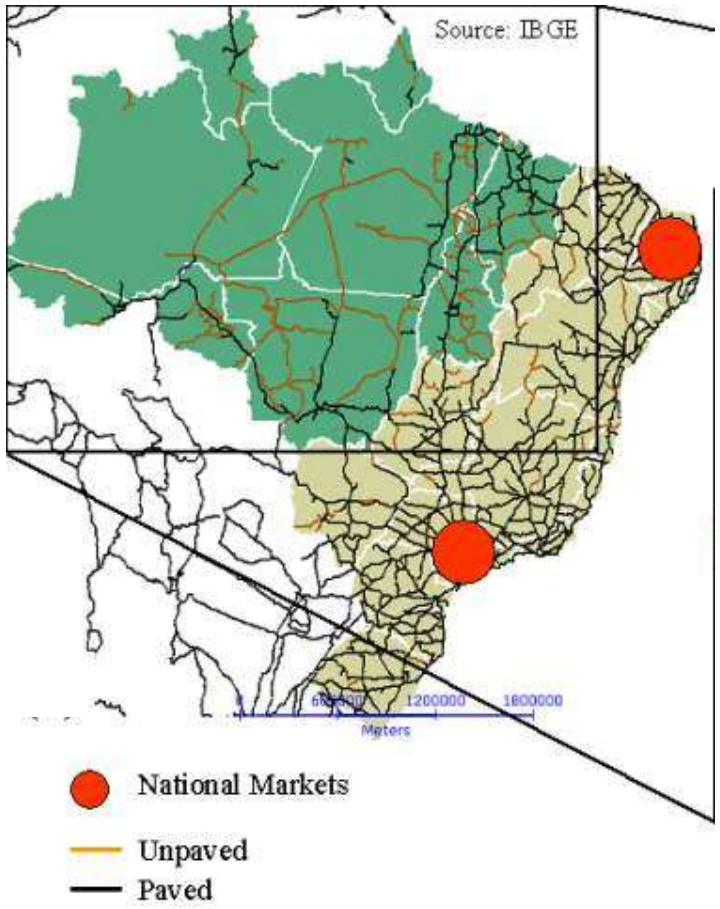
Regional land use change
Socio-economic changes
Adaptation (e.g., 100 x 100 m)

Multi-scale modelling includes networks



Flow of timber from Amazonia

Network-based relations

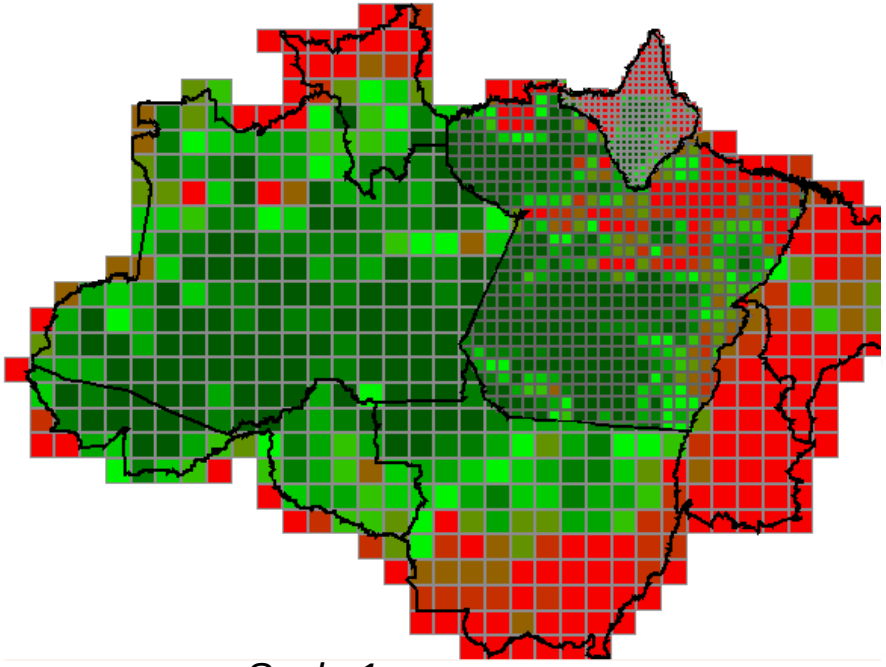


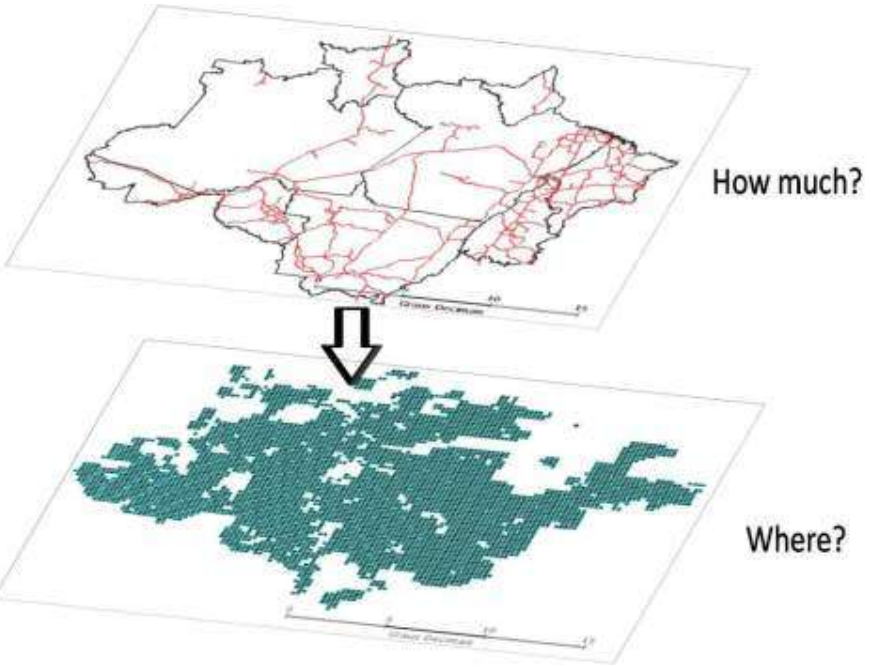
National market chains in Brazil

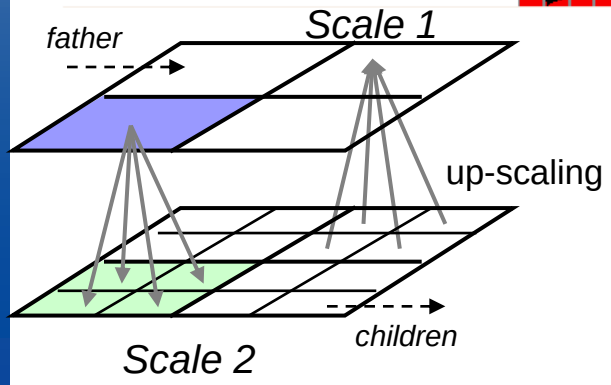
[Moreira et al., 2008]

Requirement #4 for Nature-Society models: support multi-scale modelling using explicit relationships

[Moreira et al., 2008]
[Carneiro et al., 2008]





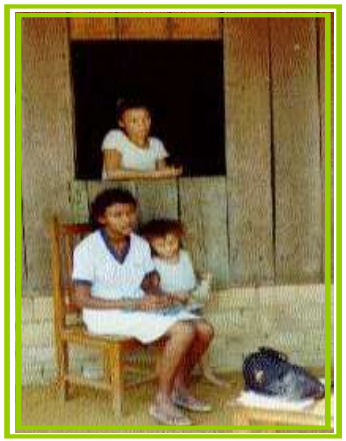


Express explicit spatial relationships between individual objects in different scales

Question #5 for Nature-Society models

photos: Isabel Escada

How can we express behavioral changes in human societies?



Small Farmers

When a small farmer becomes a medium-sized one, his behaviour changes

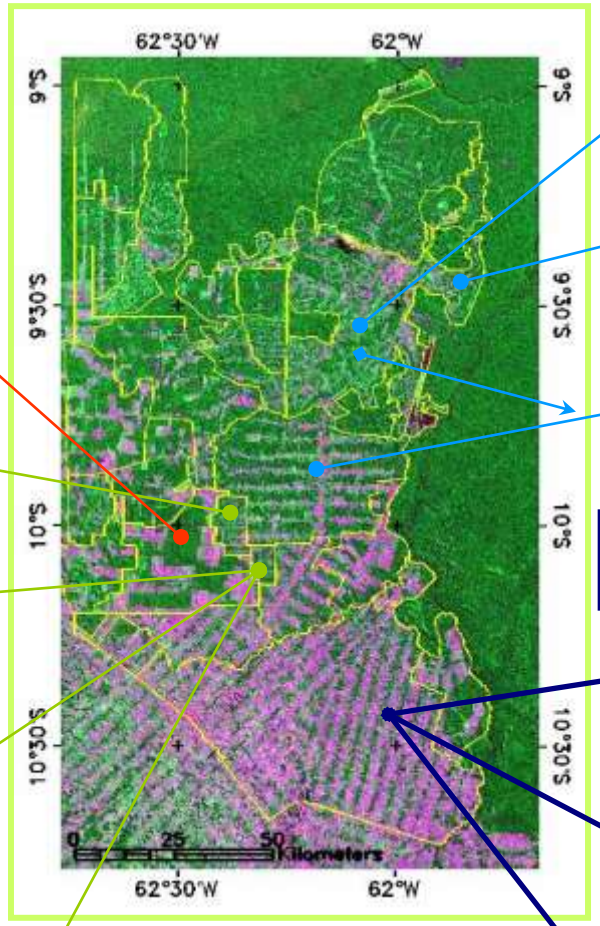
Medium-Sized Farmers

Societal systems undergo phase transitions

Isabel Escada, 2003

Farms

Recent Settlements (less than 4 years)

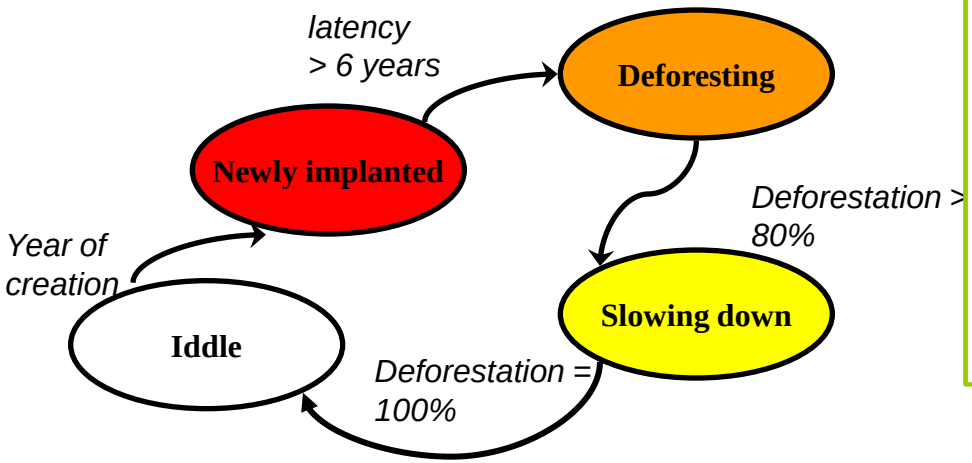


Settlements 10 to 20 years

Old Settlements (more than 20 years)

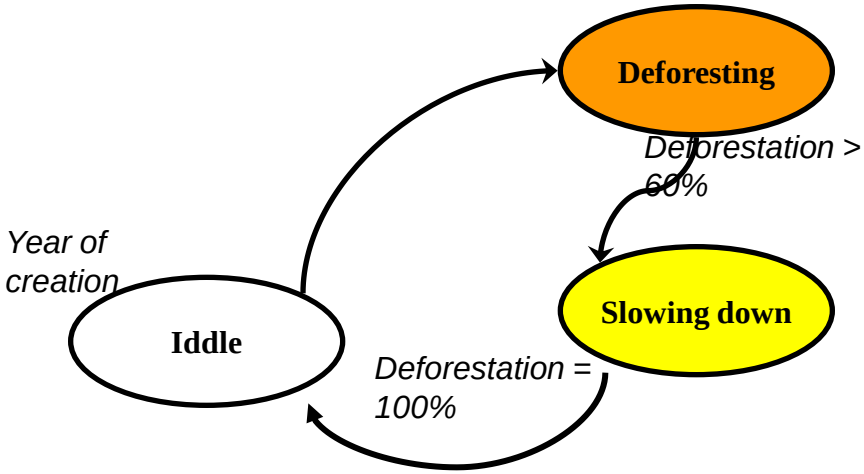
[Escada, 2003]

Requirement #5 for Nature-Society models: Capture phase transitions



Small Farmers

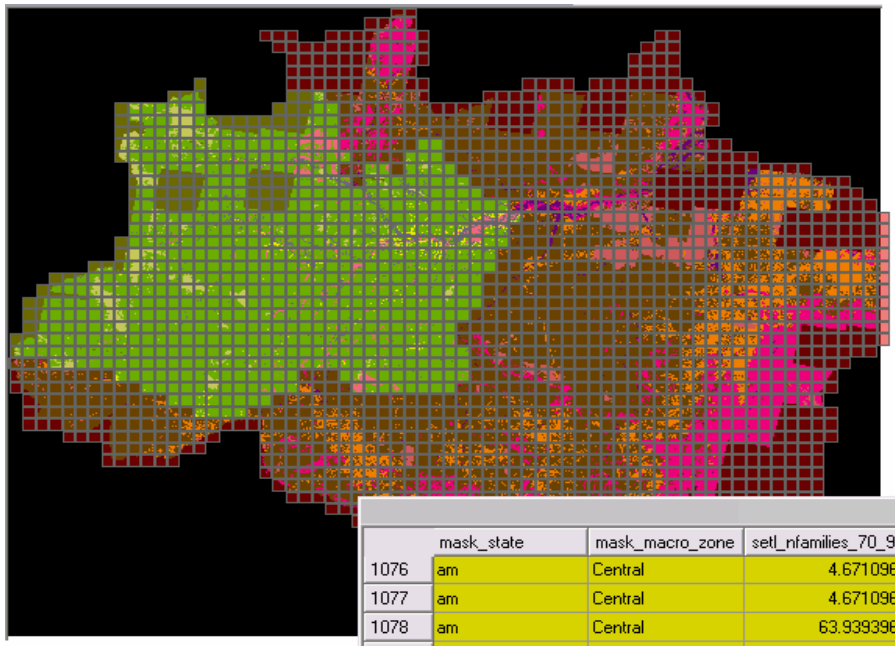
photos: Isabel Escada



Medium-Sized Farmers

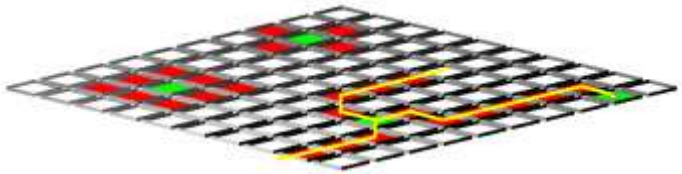
TerraME: Computational environment for developing nature-society models

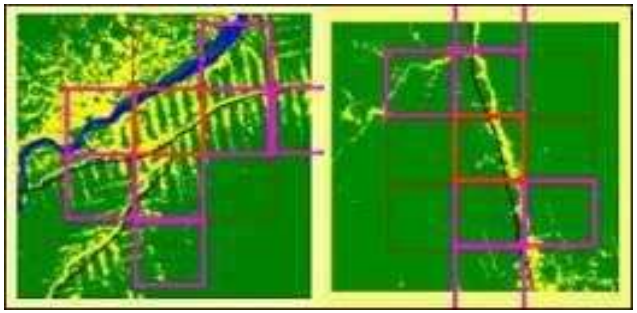
Cell Spaces



	mask_state	mask_macro_zone	setl_nfamilies_70_9	setl_area_70_99	agr
1076	am	Central	4.671096	146.23648	
1077	am	Central	4.671096	146.23648	
1078	am	Central	63.939396	23501.954167	
1079	am	Central	81.582006	29565.766222	
1080	pa	Central	12.805476	1287.076729	
1081	pa	Central	13.10852	1329.578364	
1082	pa	Central	13.10852	1329.578364	
1083	pa	Central	11.466334	1163.013824	

Support for cellular automata and agents

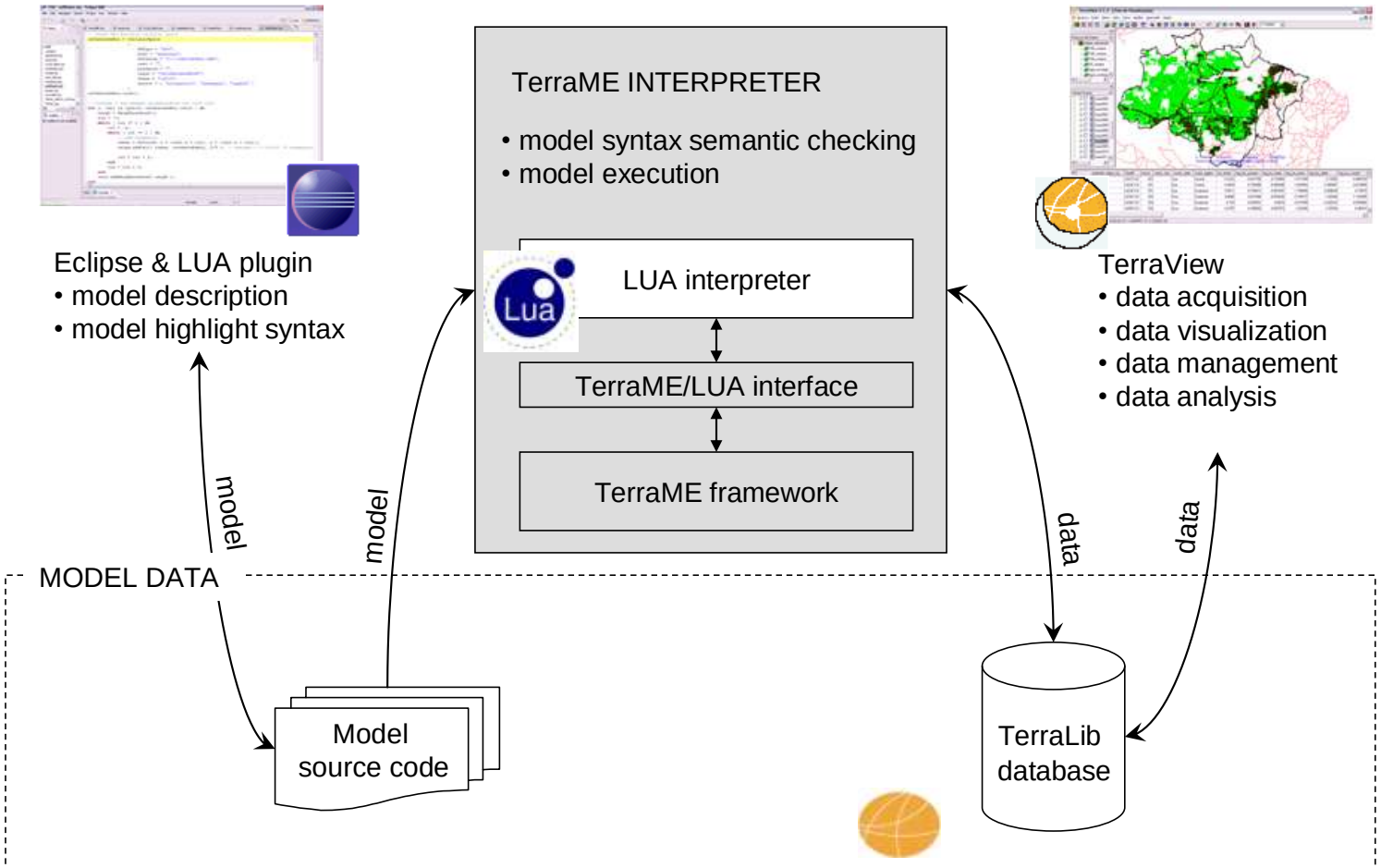




All these requirements have been addressed in TerraME design.

[Carneiro, 2006]

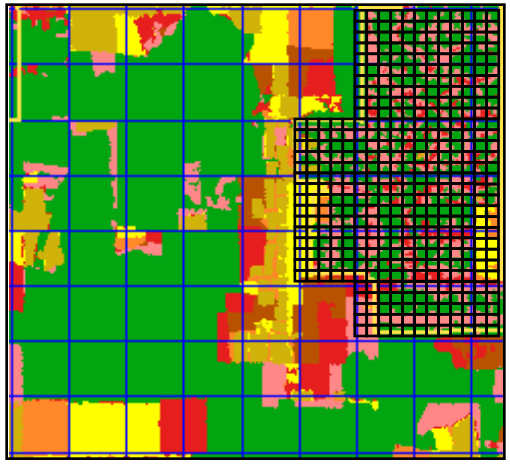
TerraME modelling environment



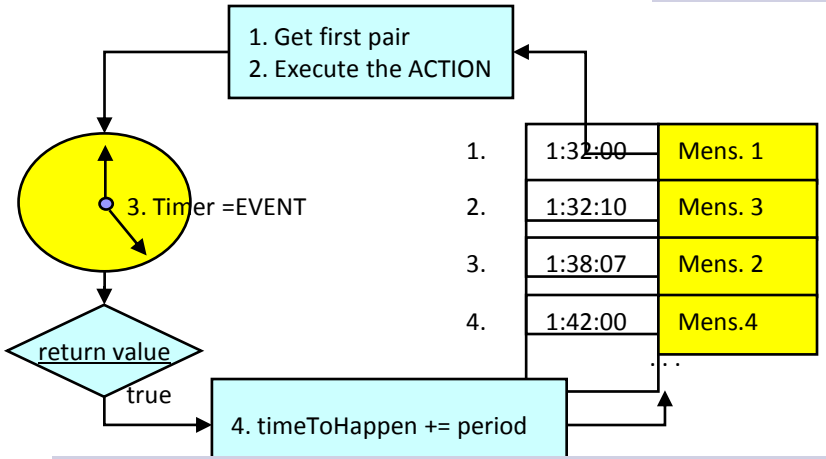
[Carneiro, 2006]

TerraME´s way: Modular components

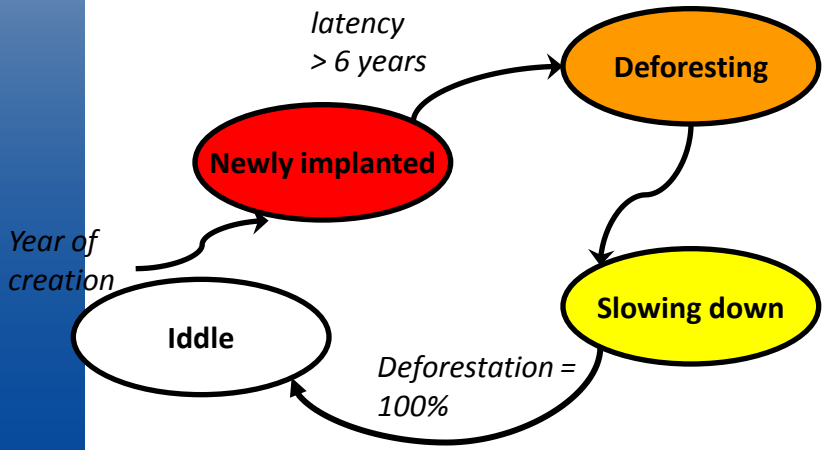
[Carneiro, 2006]



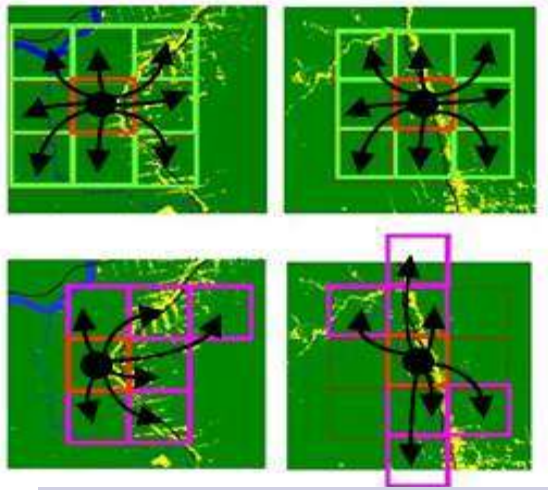
Describe spatial structure



Describe temporal structure

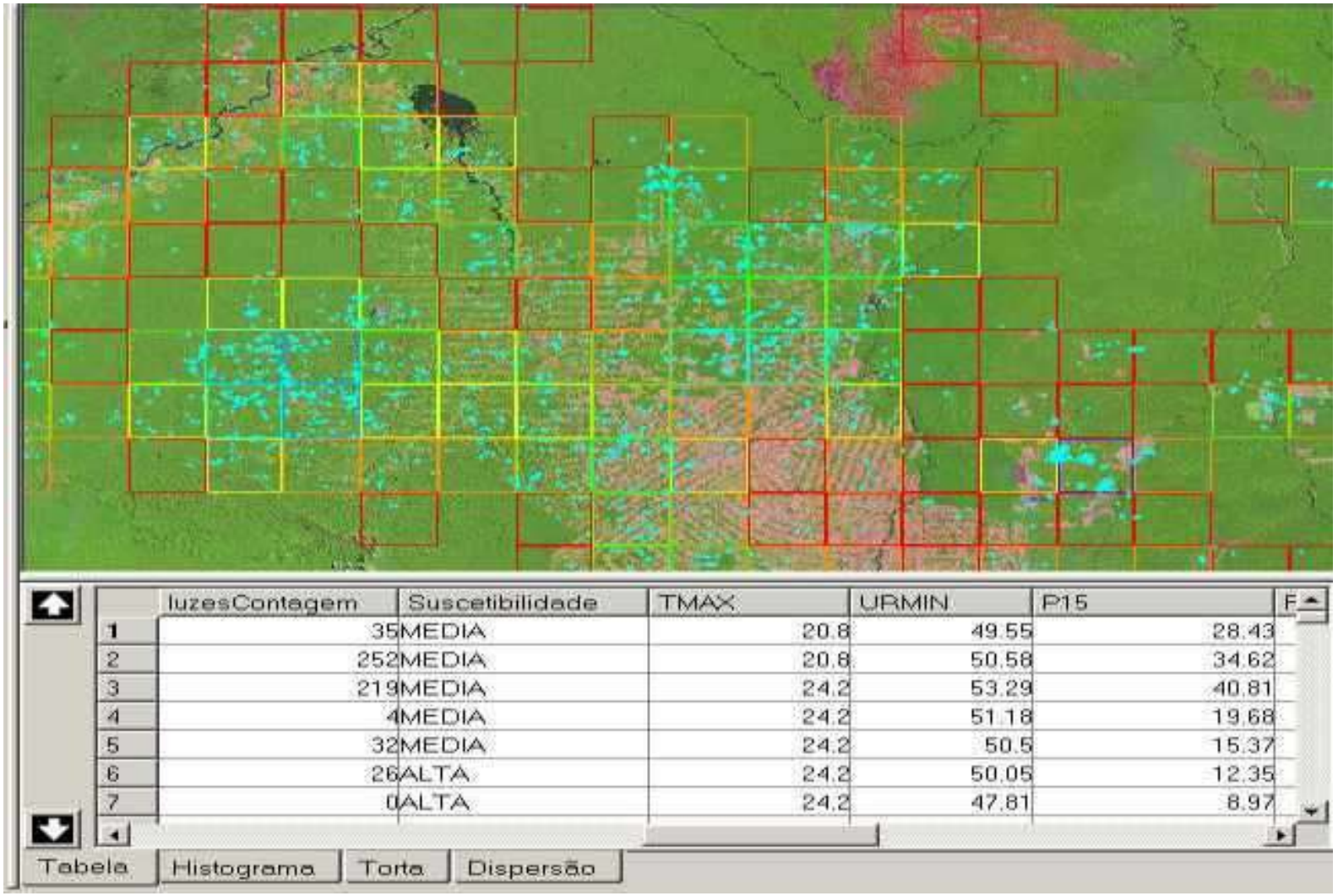


Describe rules of behaviour



Describe spatial relations

TerraME GIS Integration: Cell Spaces integrated with databases

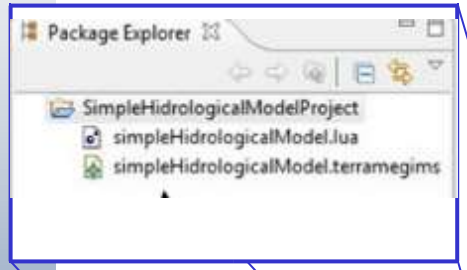


	luzesContagem	Suscetibilidade	TMAX	URMIN	P15	F
1	35	MEDIA	20.8	49.55	28.43	
2	252	MEDIA	20.8	50.58	34.62	
3	219	MEDIA	24.2	53.29	40.81	
4	4	MEDIA	24.2	51.18	19.68	
5	32	MEDIA	24.2	50.5	15.37	
6	26	ALTA	24.2	50.05	12.35	
7	0	ALTA	24.2	47.81	8.97	

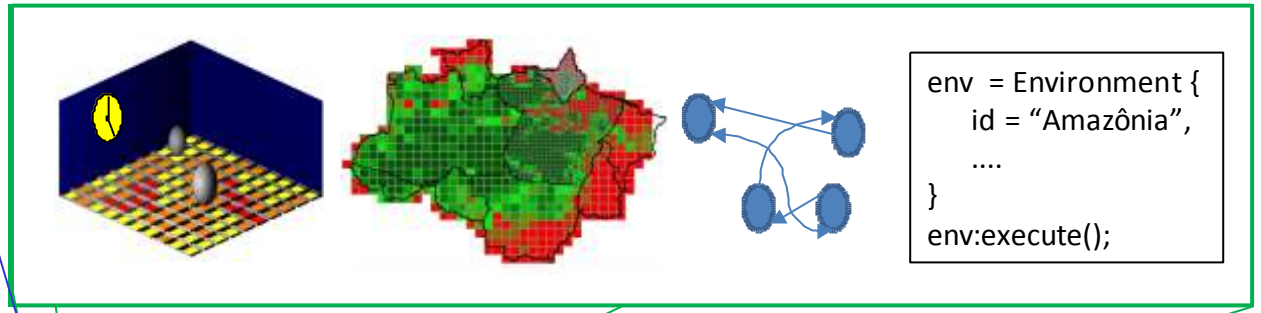
Tabela | Histograma | Torta | Dispersão

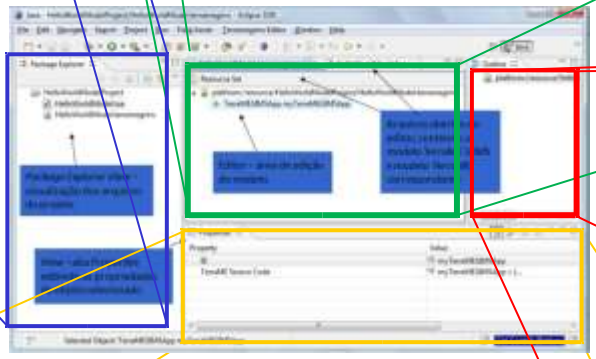
TerraME GIMS – Graphical Interface for Modeling and Simulation

Model Package Explorer

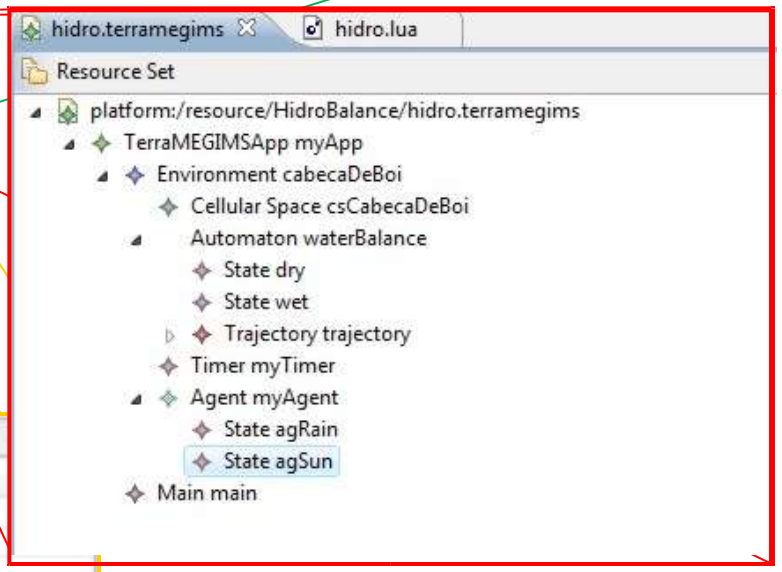


Model Graphical Editor

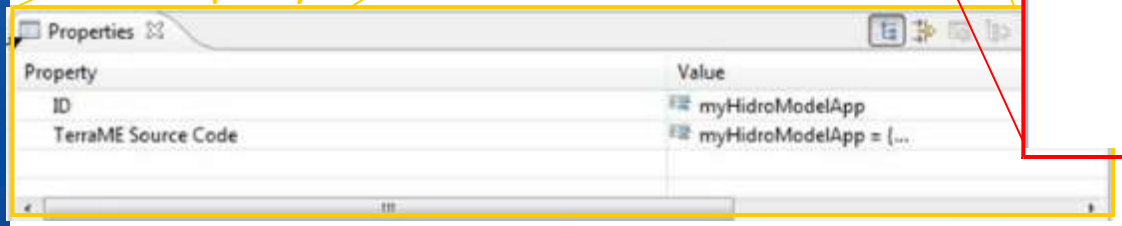




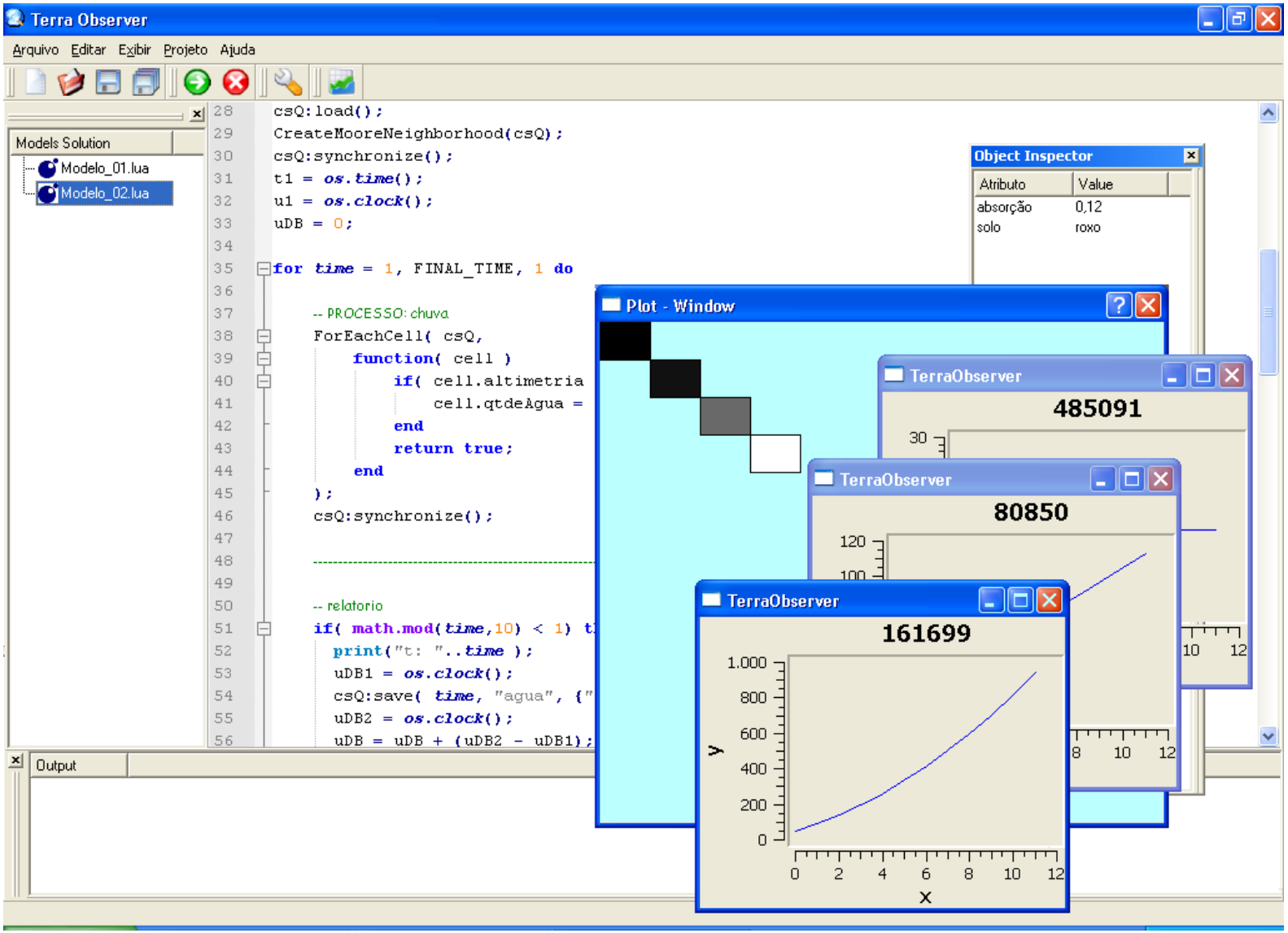
Model Structure Editor



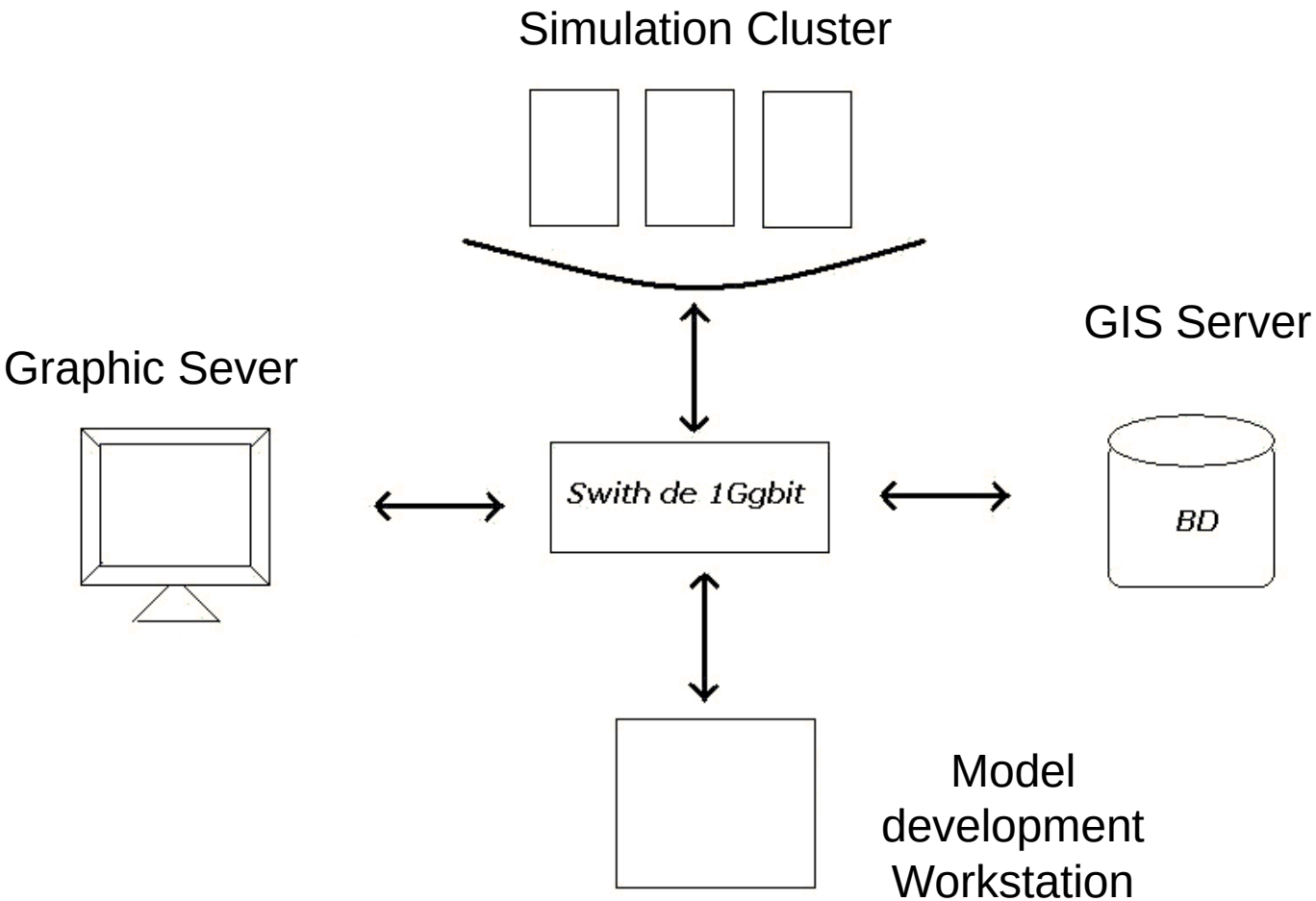
Model Property Editor



TerraME Observer



TerraME HPA
High Performance Architecture



Thank you...

Acknowledgments and thanks to:

Gilberto Câmara (INPE): Land use modeling group leader
Ana Aguiar (INPE): Land use models in TerraME
Miguel Monteiro (INPE): Agent models in TerraME

Sergio Costa, Pedro Andrade-Neto, Karine Ferreira, Gilberto Ribeiro,
Eva Moreira, Giovana Espinola: PhD Students

TerraME TEAM

Tiago Carneiro (UFOP): TerraME architect and chief programmer
Raian Maretto (UFOP): TerraME programmer
Antônio Rodrigues (UFOP): TerraME programmer
Thiago Lima (UFOP): TerraME programmer