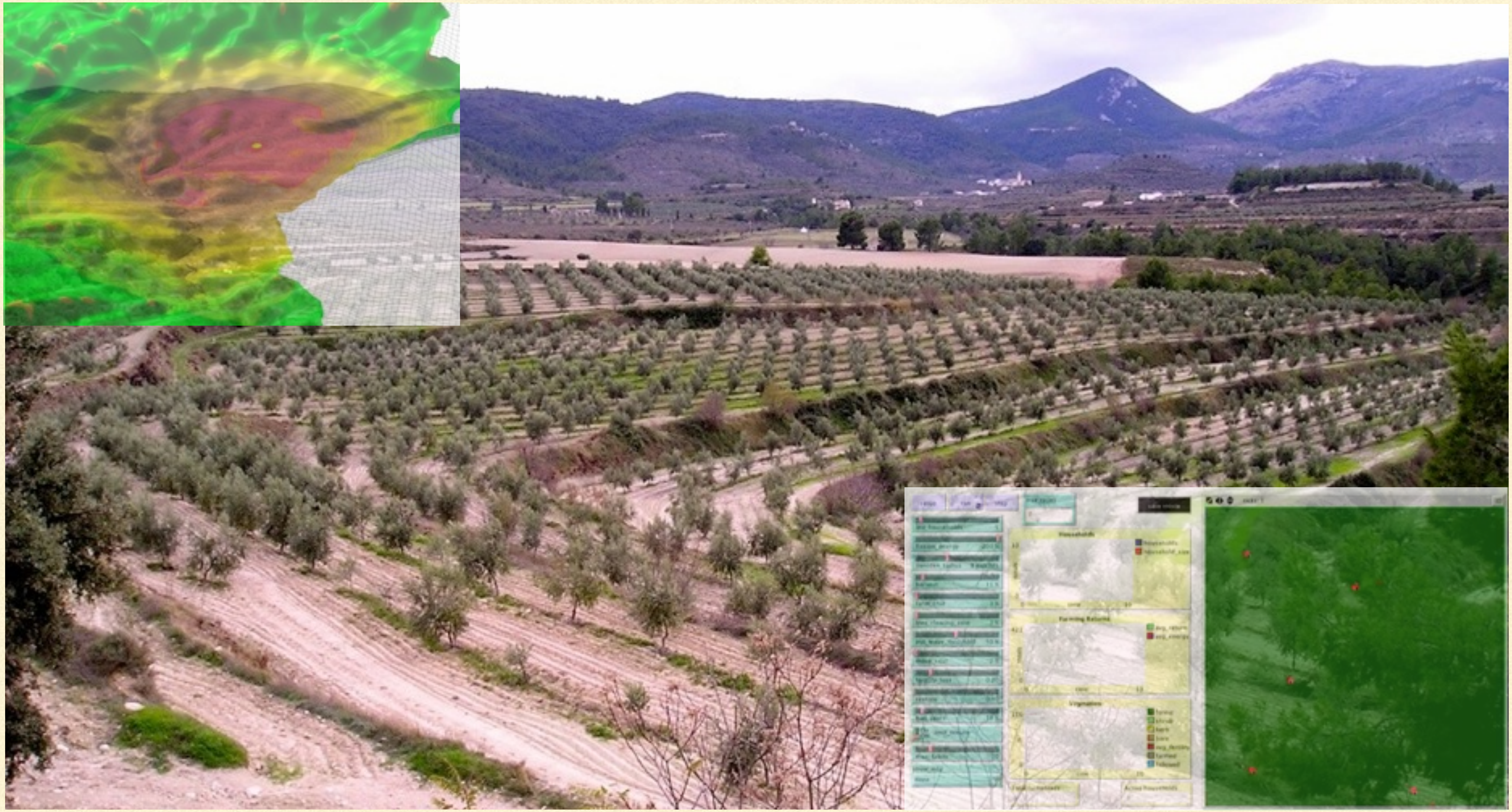
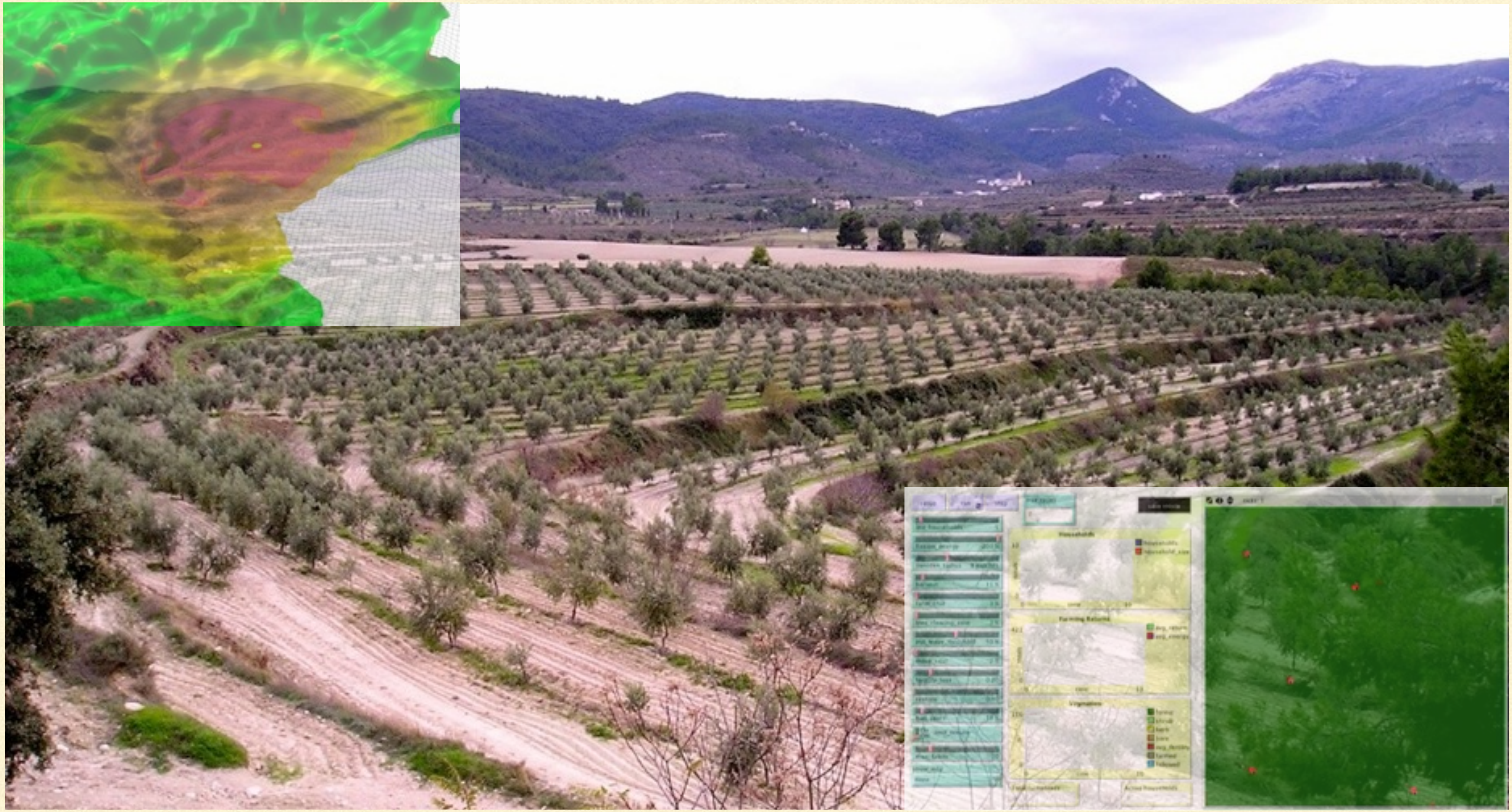


EARTH SYSTEMS AS HUMAN SYSTEMS

Modeling Interactions Between People & the Environment in the Anthropocene

Michael Barton, Arizona State University Center for Social Dynamics & Complexity/School of Human Evolution & Social Change



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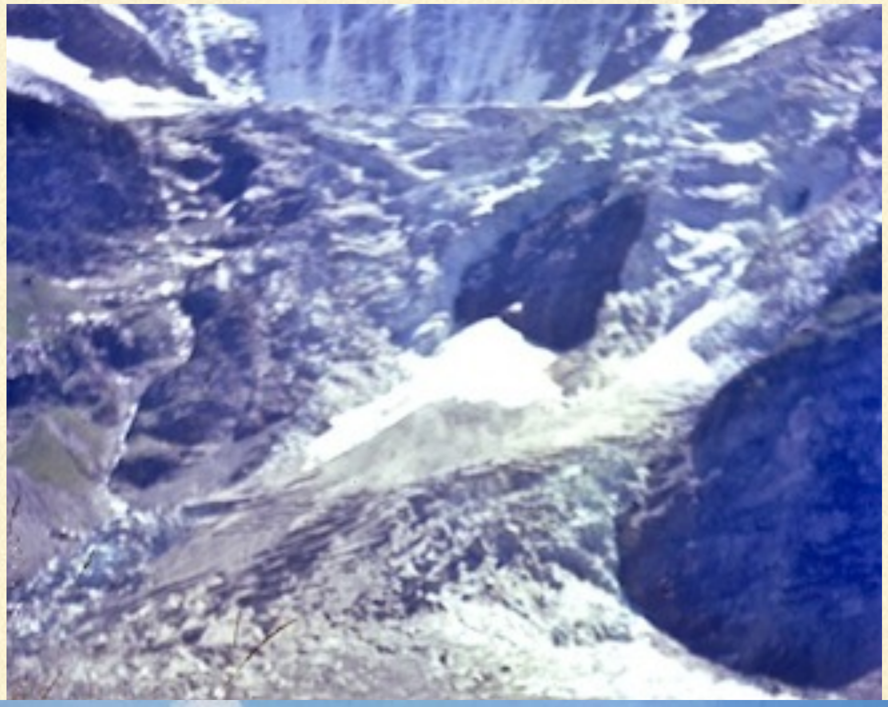
HUMAN PROCESSES SHAPE THE EARTH'S SURFACE

- Scientific study often assumes a world without people
- Incorrect and misleading
- People have altered the earth for a long time



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- Anthropogenic contributions may seem small
- But already transformed much of earth's surface in profound ways

HUMAN PROCESSES SHAPE THE EARTH'S SURFACE

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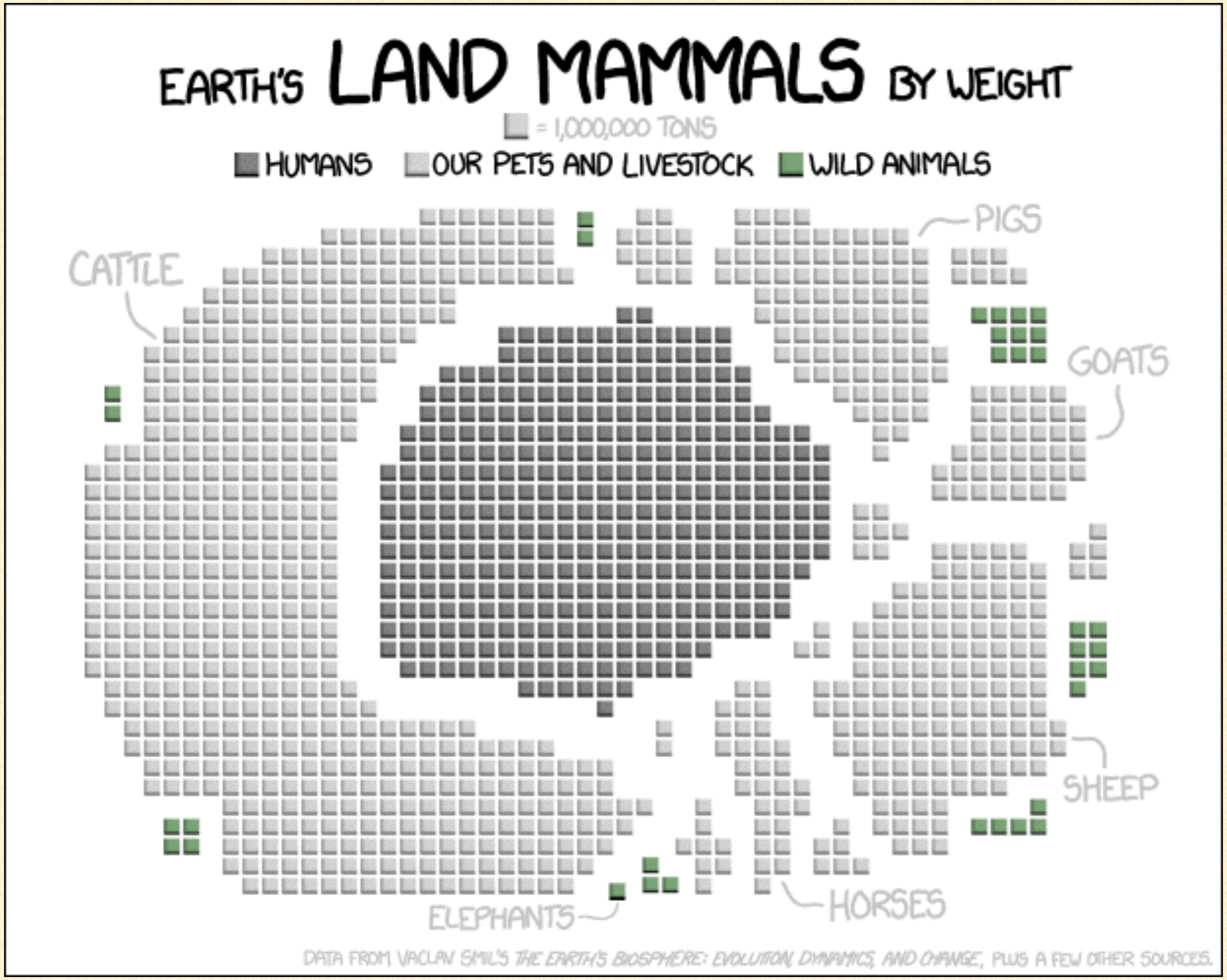
  - More terrestrial sediment moved
  - More Nitrogen cycled
  - Over half of surface fresh water

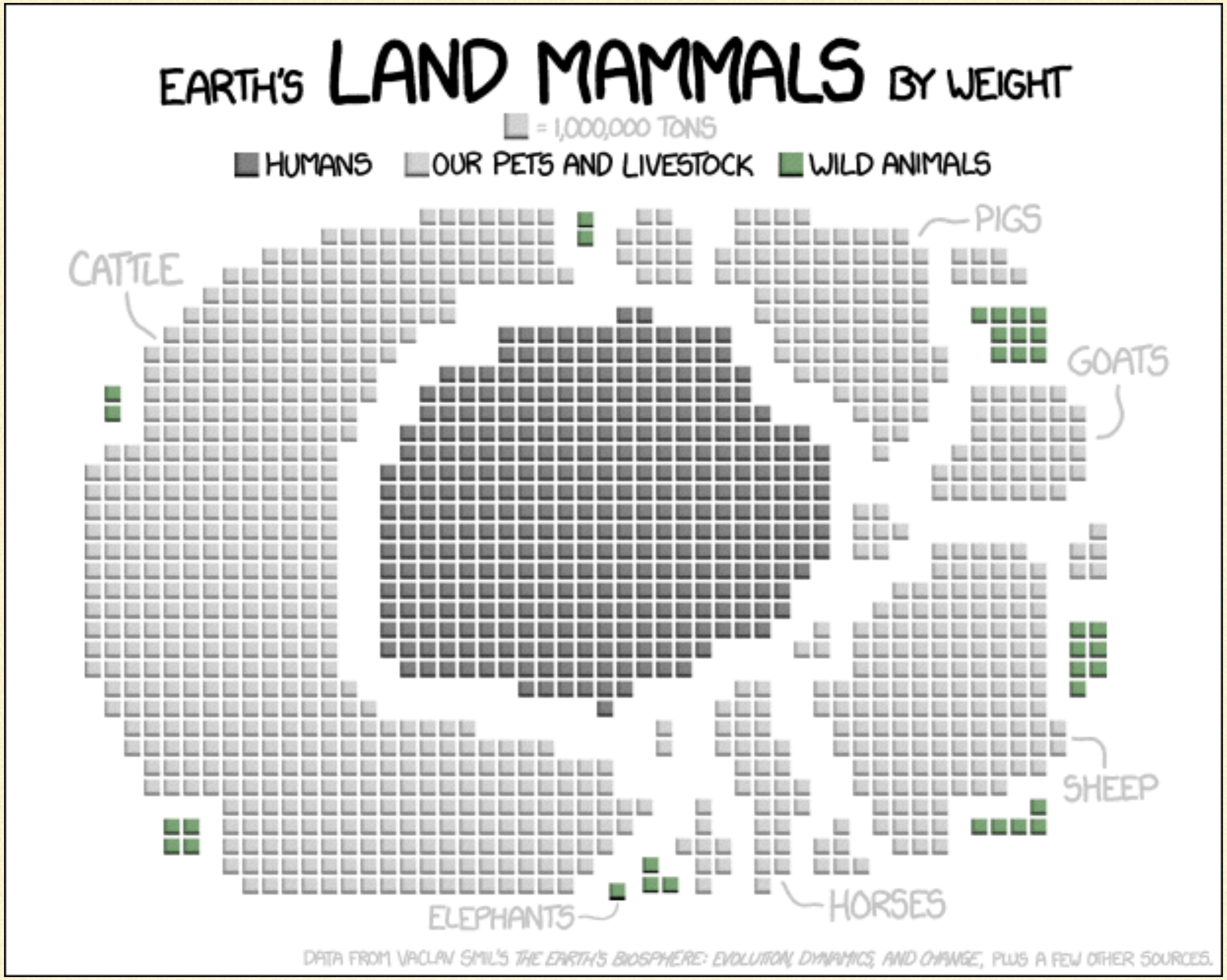
HUMAN PROCESSES SHAPE THE EARTH'S SURFACE

- The Anthropocene



HUMAN PROCESSES SHAPE THE EARTH'S SURFACE

- The Anthropocene
  - Agro-biomass more than all other animals



HUMAN PROCESSES THAT SHAPE THE EARTH'S SURFACE

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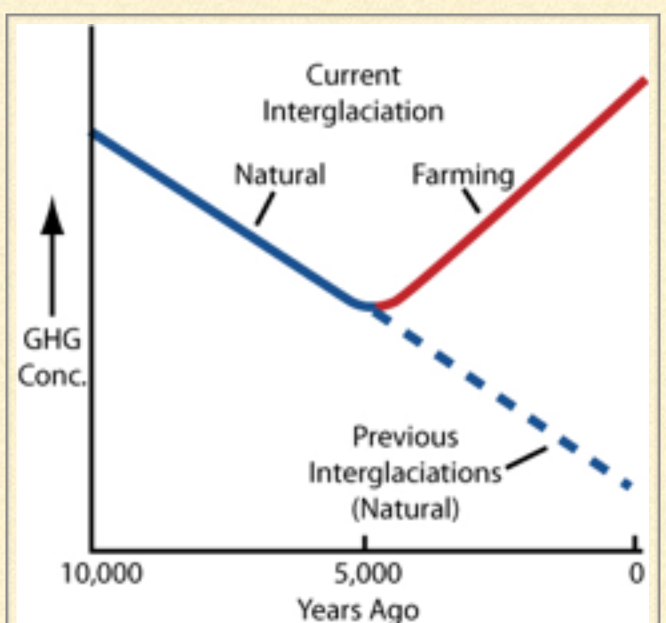
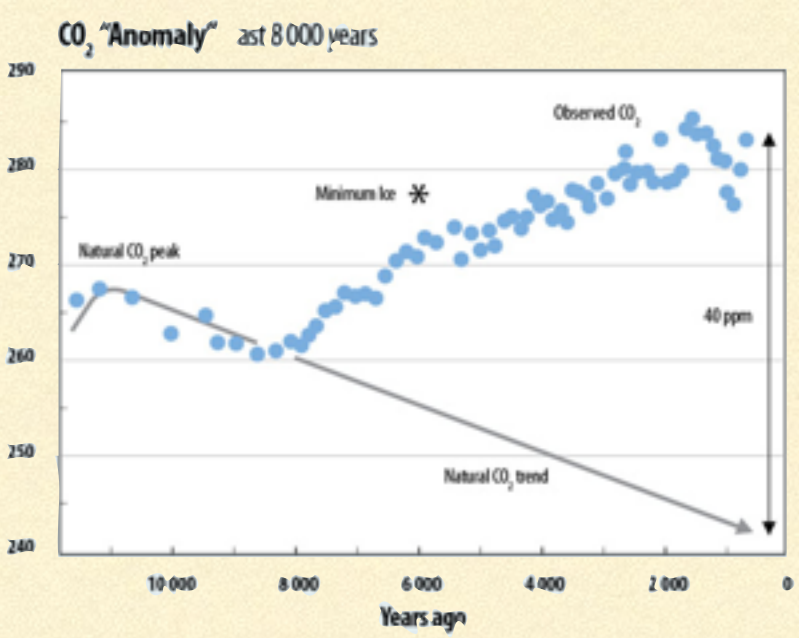
HUMAN PROCESSES THAT SHAPE THE EARTH'S SURFACE

- Real-world landscape dynamics today must take into account human contribution
- Also true to an important extent in the past





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LANDSCAPE DYNAMICS ARE COMPLEX

- Even physical processes that shape landscapes are complex
- Biological and social processes multiply complexity
- Difficult to distinguish social and natural processes

LANDSCAPE DYNAMICS ARE COMPLEX

- Shift in characterizing physical landscape formation processes

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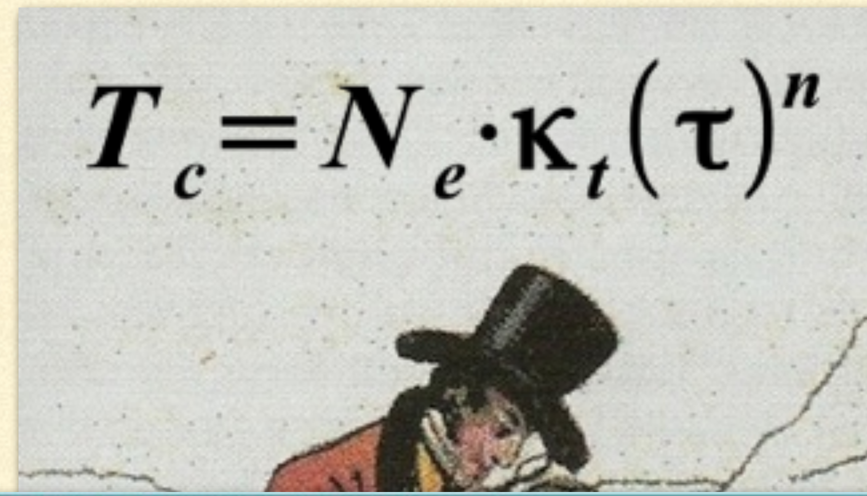
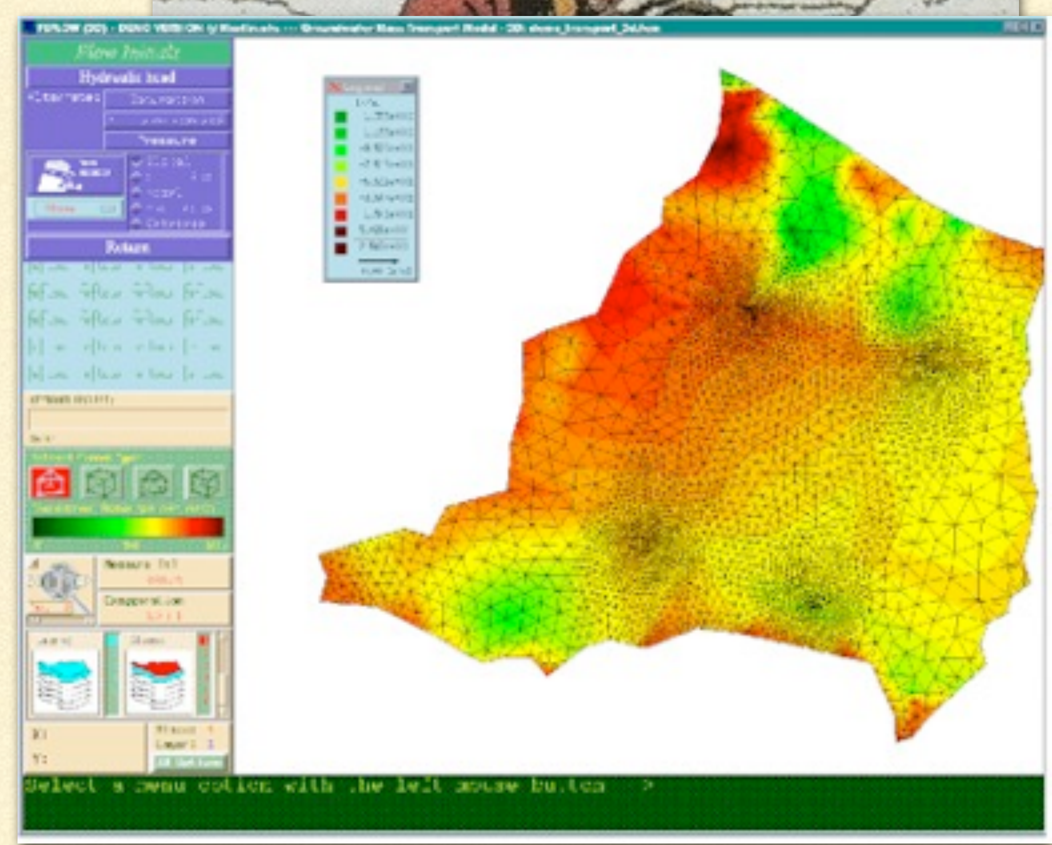
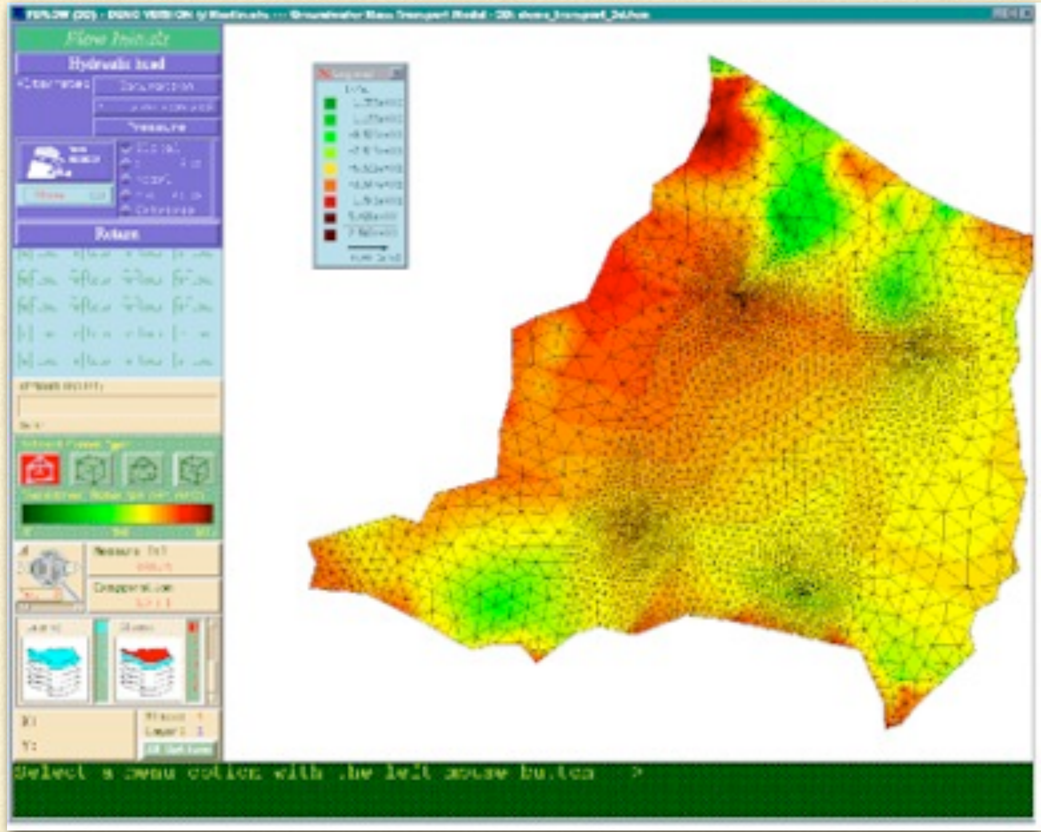
  - To multidimensional computational models





LANDSCAPE DYNAMICS ARE COMPLEX

- Shift in characterizing physical landscape formation processes
  - From observation and intuition
  - To numerical equations
  - To multidimensional computational models
- Better explanation and prediction of multidimensional landscape change



LANDSCAPE DYNAMICS ARE COMPLEX

- Similar shift is beginning for biological and social processes that are equally important as physical drivers in complexly coupled socioecological systems
- Both biological and social dynamics require different kinds of models than physical processes. People are not particles!
- Diversity of processes operating in socioecological systems means that coupling different types of models is important

MODELING SOCIAL BEHAVIOR

- Expressed behavior result of complex decisions

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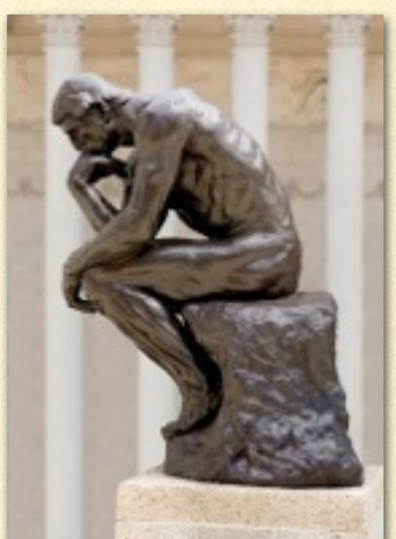
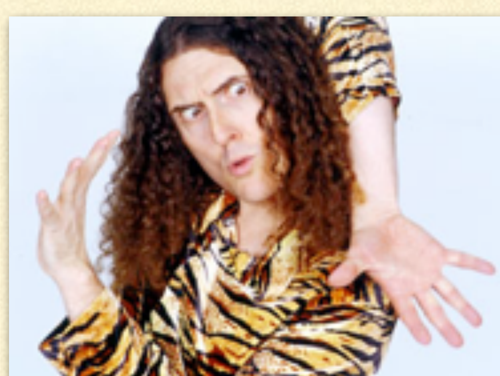
  - Economic, ritual, emotional, affective, etc
  - Can be modeled as algorithms of decision rules that are activated in different contexts





if energy < move_threshhold
[move]

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- But...
    - Decisions result of interplay of multiple factors that vary from context to context, individual to individual, and with interactions among individuals
    - Variation on how each individual implements culturally common decision rules, given personal history and proclivities
- Even though predictable, **human social behavior is a complex system** and **modeling is difficult**

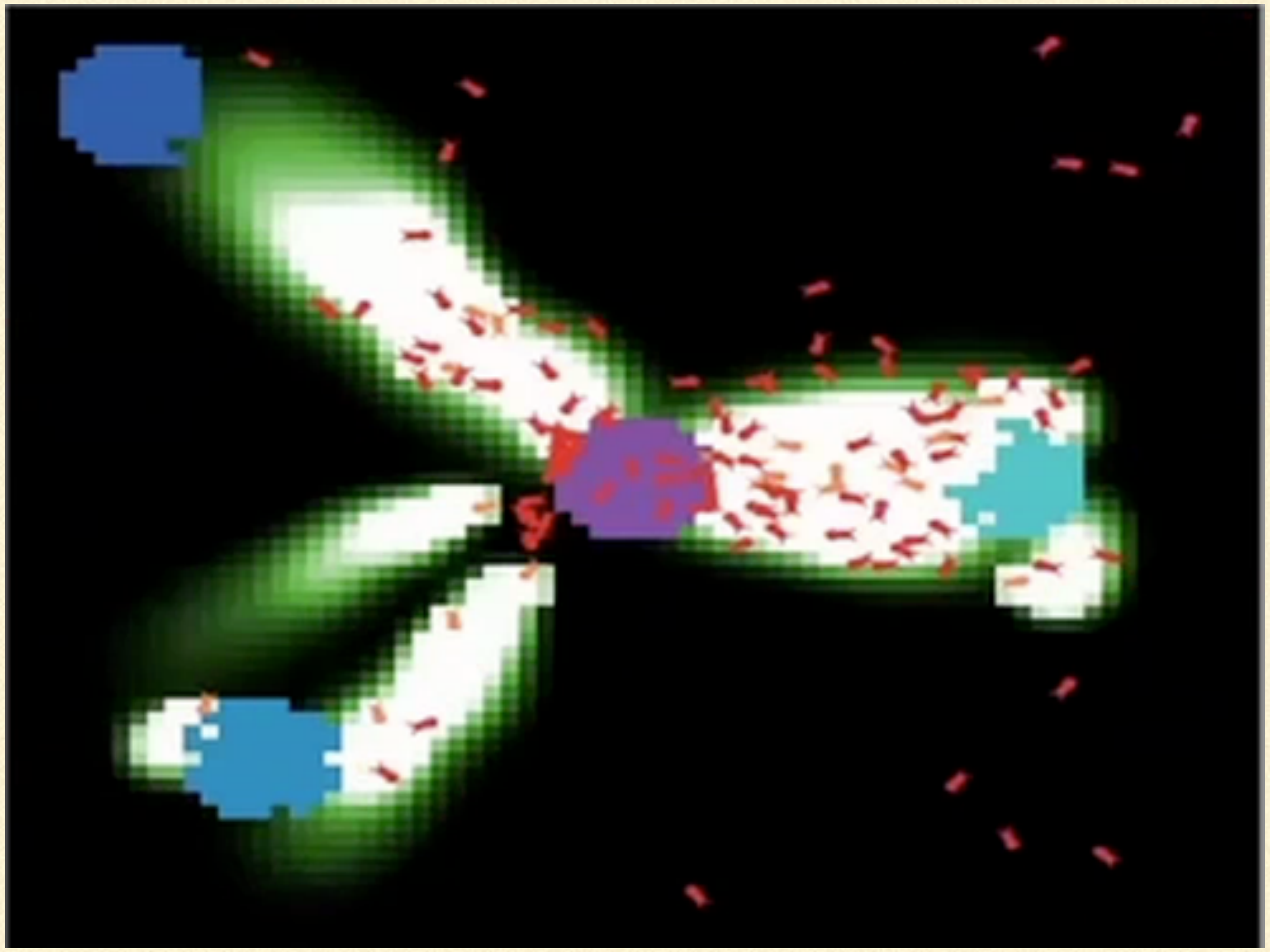
MODELING SOCIAL BEHAVIOR

- Calls for modeling framework that…
  - represents behavior as context-specific expression of decisions
  - by discrete social agents
  - individually making decisions and acting
  - in a spatially explicit and variable social and natural environment

MODELING SOCIAL BEHAVIOR

- Agent Based Modeling (ABM)
  - Provides such a framework.
  - Equivalent to Individual Based Modeling (IBM) used in life and ecological sciences.
- Can more closely represent the way social systems operate than other formal approaches (e.g., equations that aggregate social practice)

MODELING SOCIAL BEHAVIOR



- Multiple computational **agents** = independently acting entities
  - Agents can process information
  - Agents can sense and respond to environment and other agents

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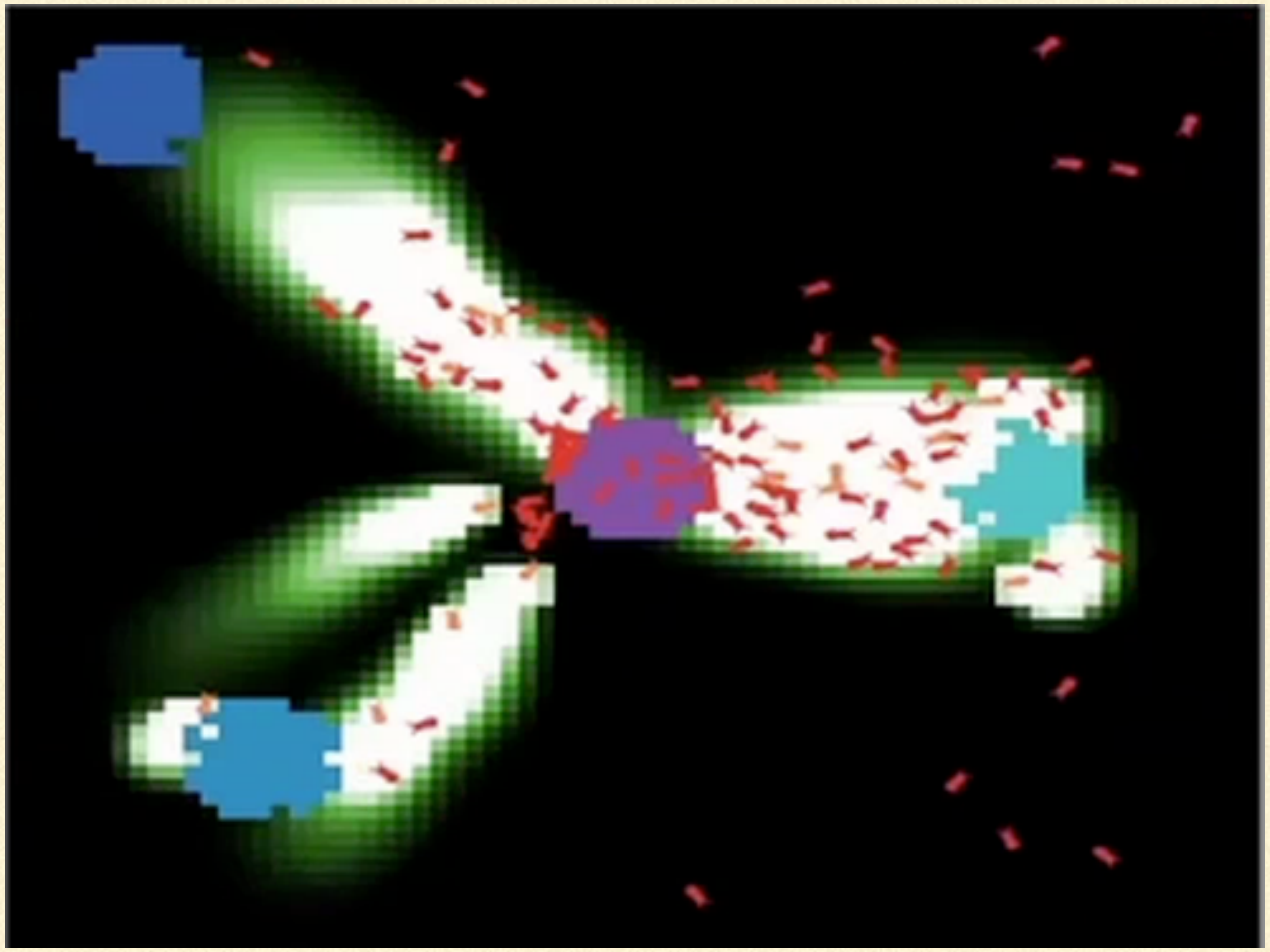

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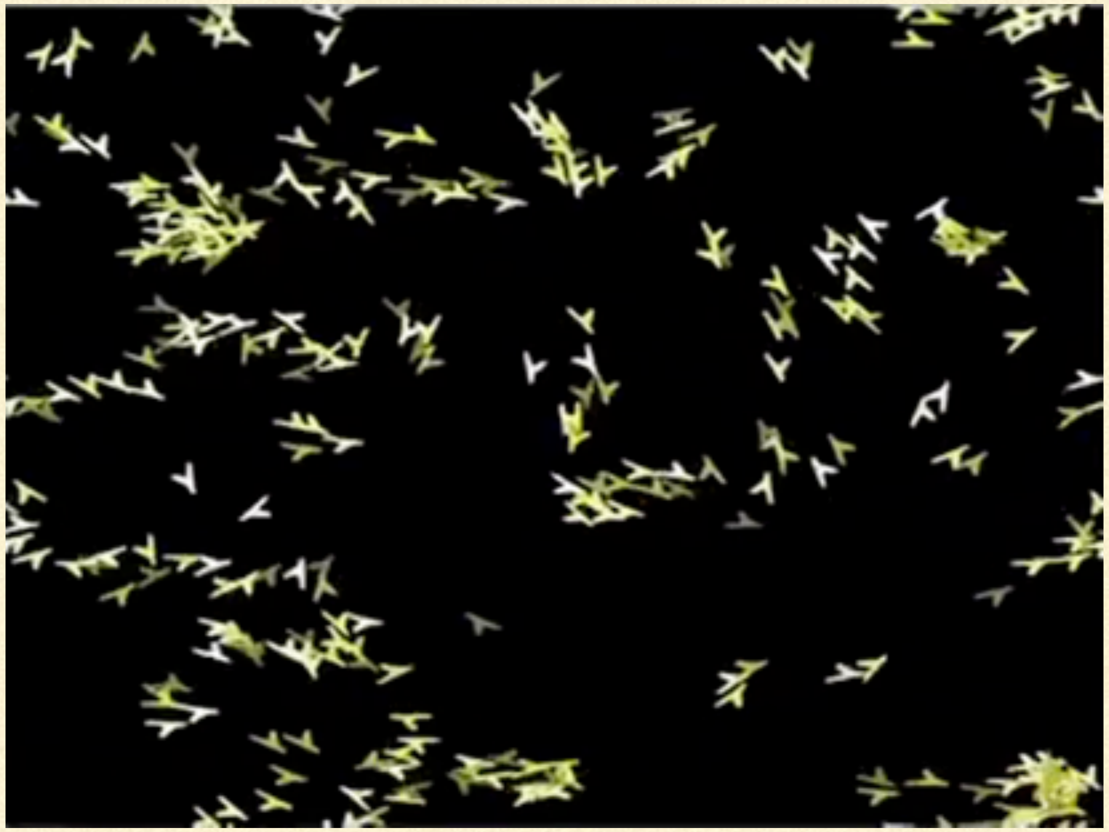
MODELING SOCIAL BEHAVIOR

- Agent behavior governed by decision rules represented as computational algorithms ('recipes for behavior'). Can be ...
  - Deterministic, probabilistic, or stochastic
  - 'Rational' or 'irrational'
  - Based on prior knowledge (including biased and incorrect knowledge)
- Once created, placed in virtual world, and instantiated, agents operate independently without further input or control from researcher



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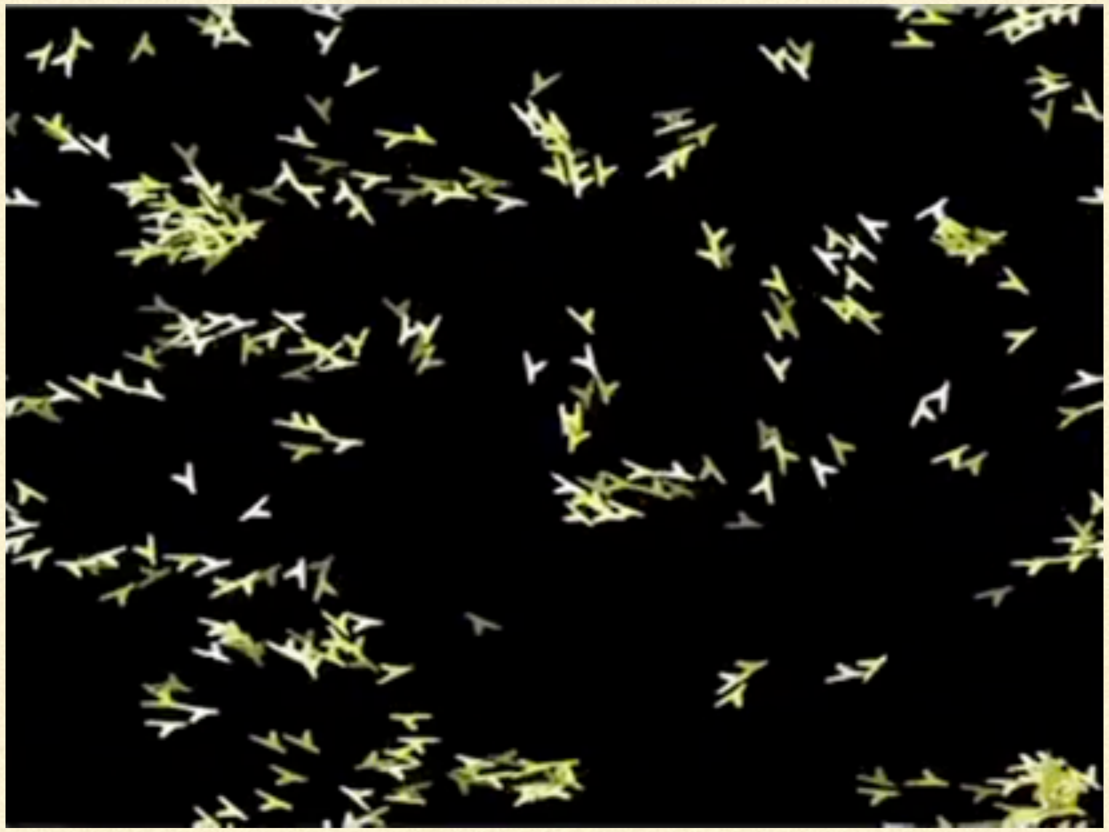

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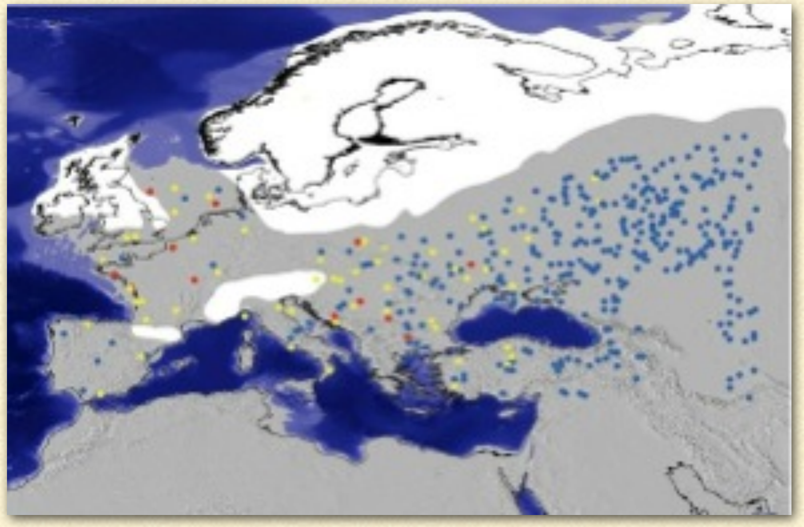
MODELING SOCIAL BEHAVIOR

- ABM not an explanatory statement or description of a human system in narrative or equation form
- ABM is a framework for carrying out bottom up digital experiments in dynamics of complex, multi-component systems
- Controlled experiments vs. virtual reality - experiments that are not possible in real-world settings




EXAMPLES TO STIMULATE DISCUSSION

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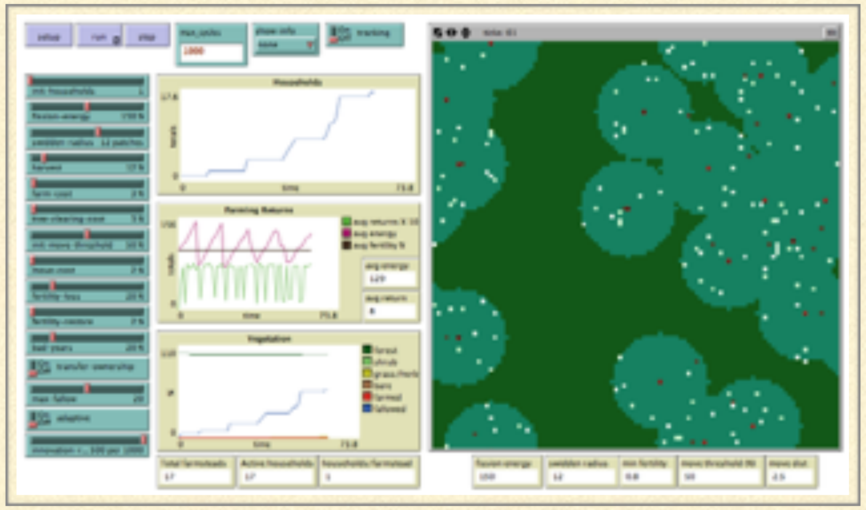
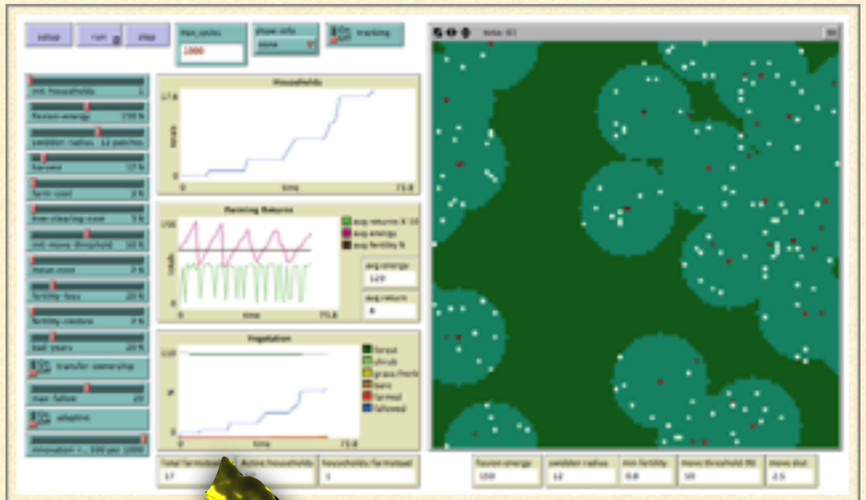
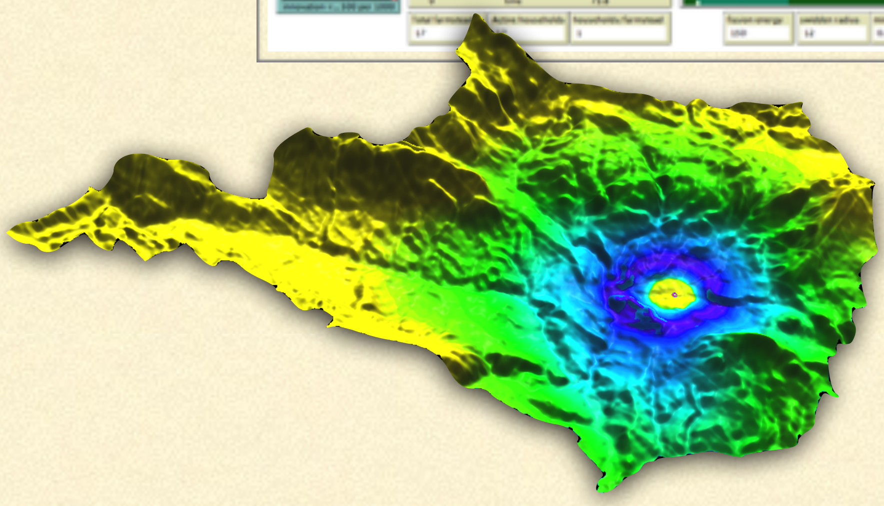


- Agent based model of agricultural land use

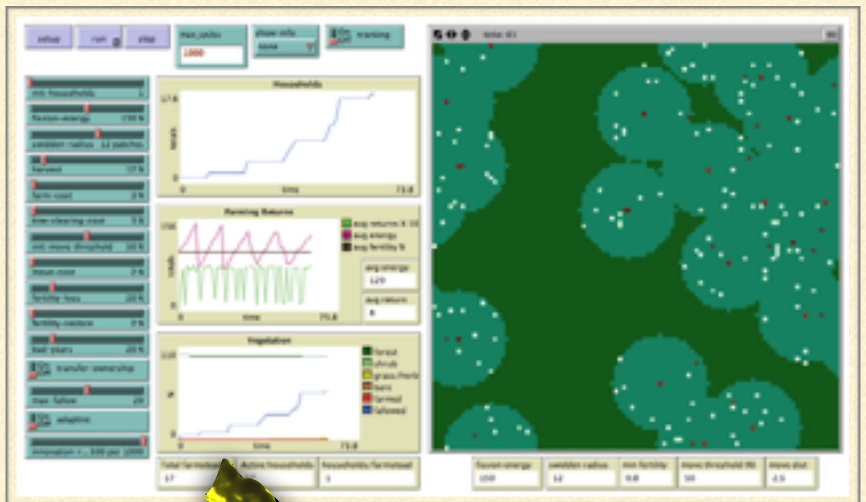
EXAMPLES TO STIMULATE DISCUSSION

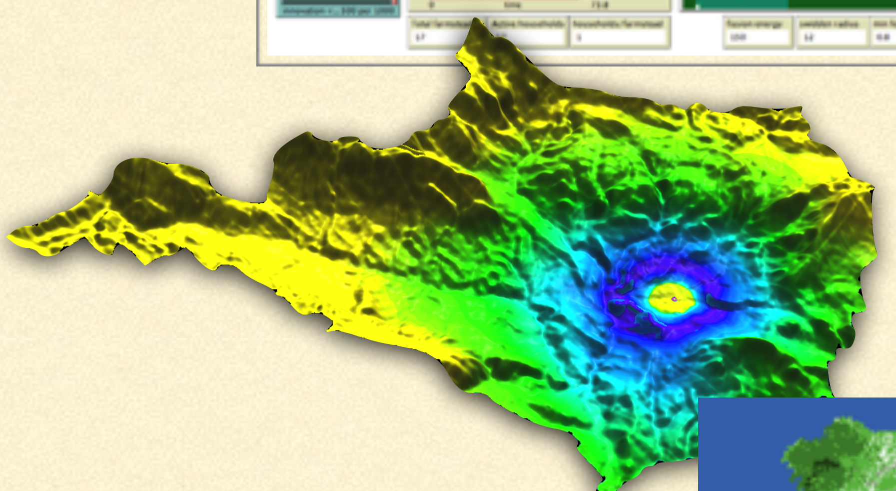


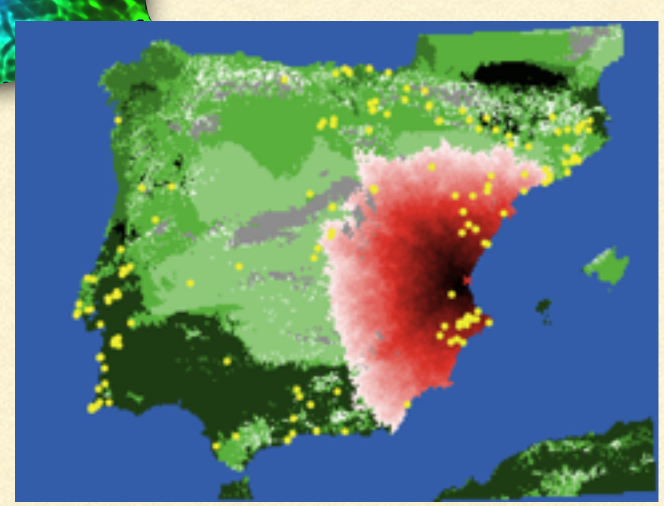


- Agent based model of agricultural land use
- Coupled model of long-term land use and landscape change

EXAMPLES TO STIMULATE DISCUSSION

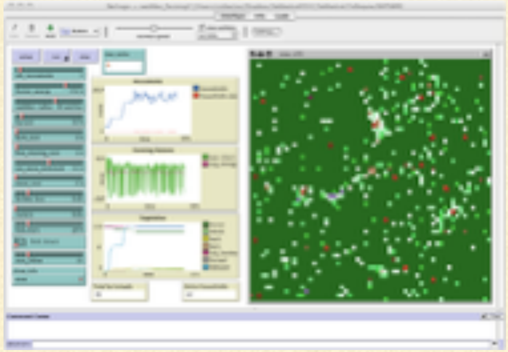






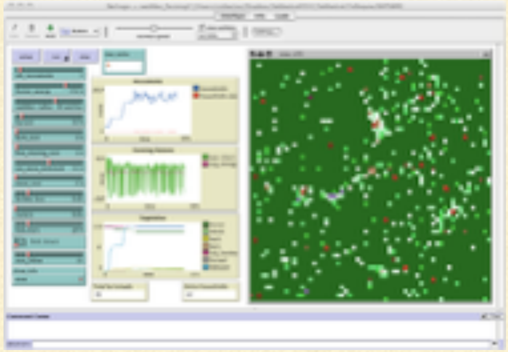
- Agent based model of agricultural land use
- Coupled model of long-term land use and landscape change
- Additional brief examples
  - spread of farming,
  - interactions between society and climate

EXAMPLE OF MODELING HUMAN BEHAVIOR



- Agricultural land-use
- Illustrate use of ABM for modeling human behavior. Created in NetLogo
  - Simple, abstract model to explore dynamics of agricultural land-use
  - Primarily economic decision rules; some probabilistic and stochastic rules
  - Agents are households: social decision-making entities for small-scale subsistence farming

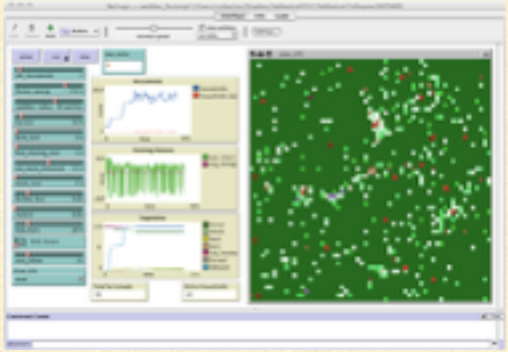
EXAMPLE OF MODELING HUMAN BEHAVIOR

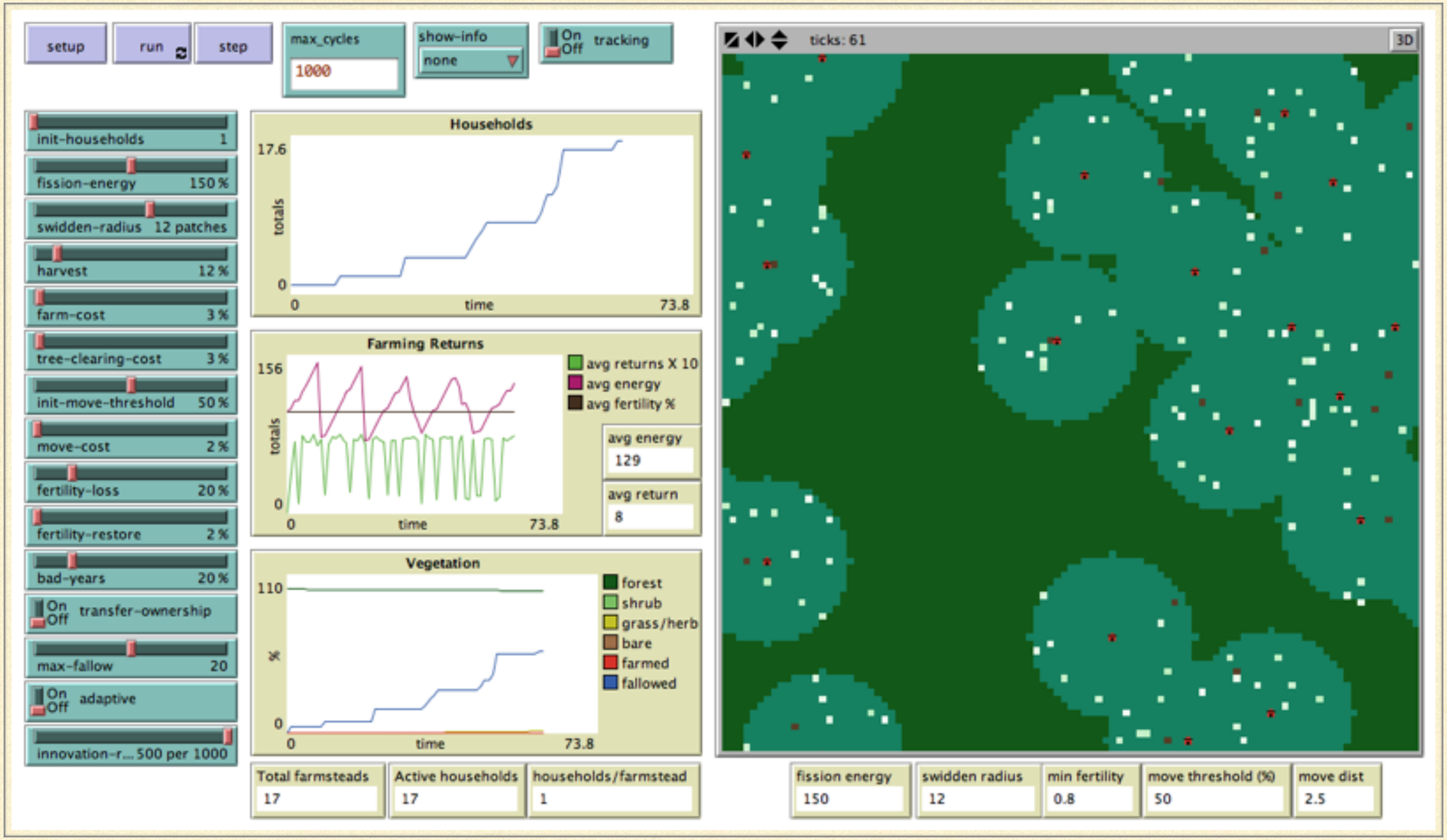


- Parameters set by *researcher
  - # initial households
  - energy for household reproduction
  - size of area farmed
  - harvest return
  - farming and land clearing cost
  - abandonment threshold and cost to move
  - rate of soil depletion and restoration
  - environmental change
- Agent decisions
  - where to farm around settlement
  - whether to fission/reproduce
  - whether to abandon farm
  - where to settle after abandonment or fissioning

**can be set by household agents in adaptive mode*

EXAMPLE OF MODELING HUMAN BEHAVIOR





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MEDITERRANEAN LANDSCAPE DYNAMICS (MEDLAND)

- Combining empirical field research with computational modeling to study the emergence and subsequent dynamics of coupled human and natural landscapes in Mediterranean socioecological systems.

National Science Foundation
BCS-410269 and DEB-1313727

Arizona State University
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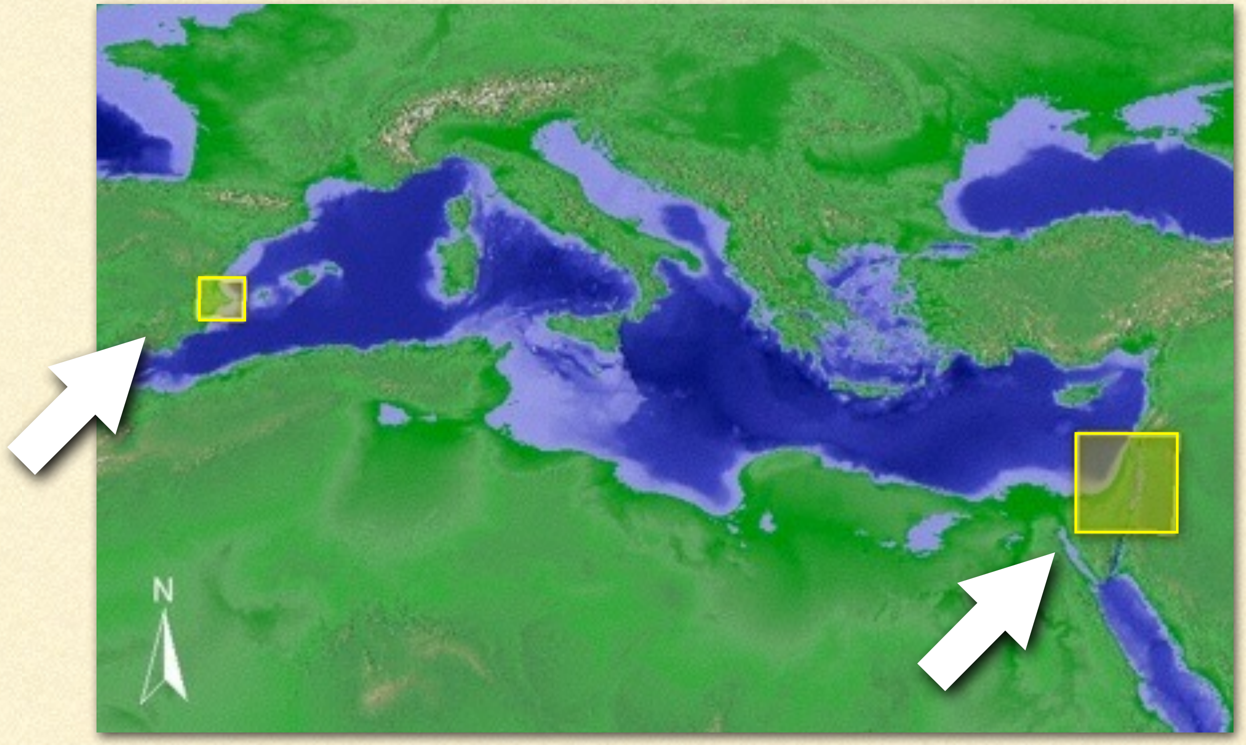

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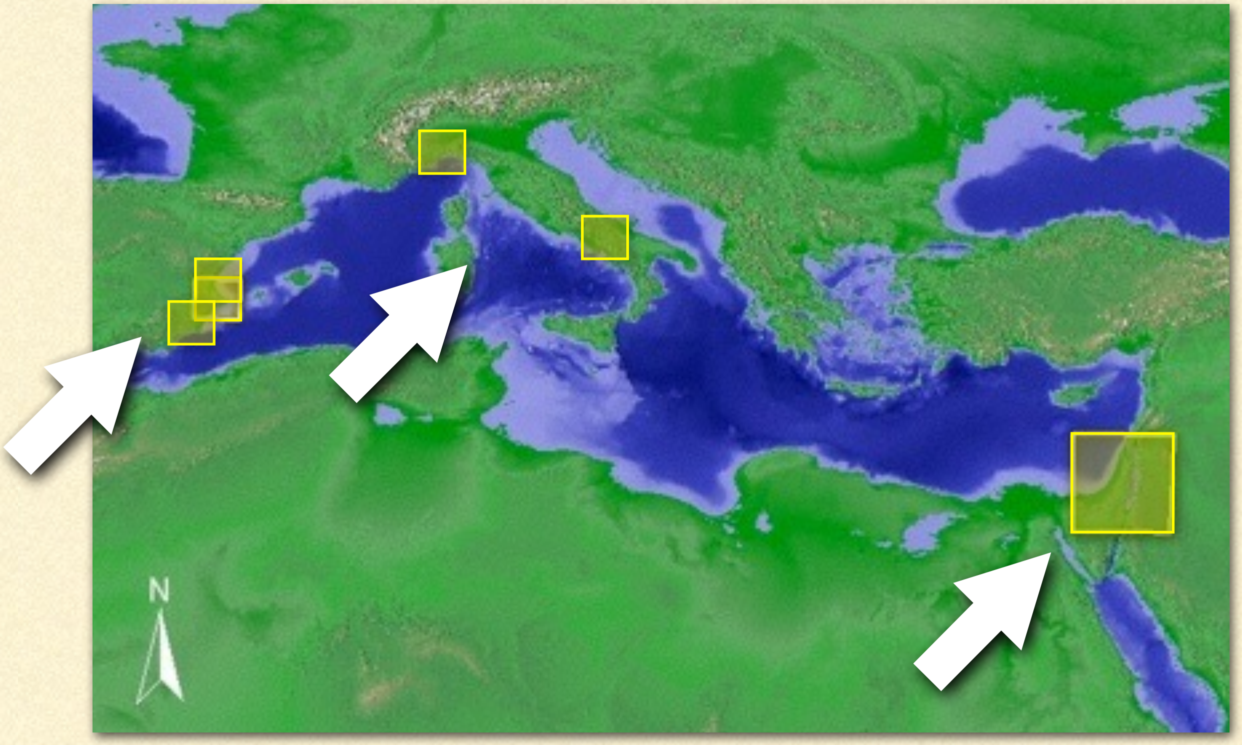
New areas in Spain and Italy

website - http://medland.asu.edu



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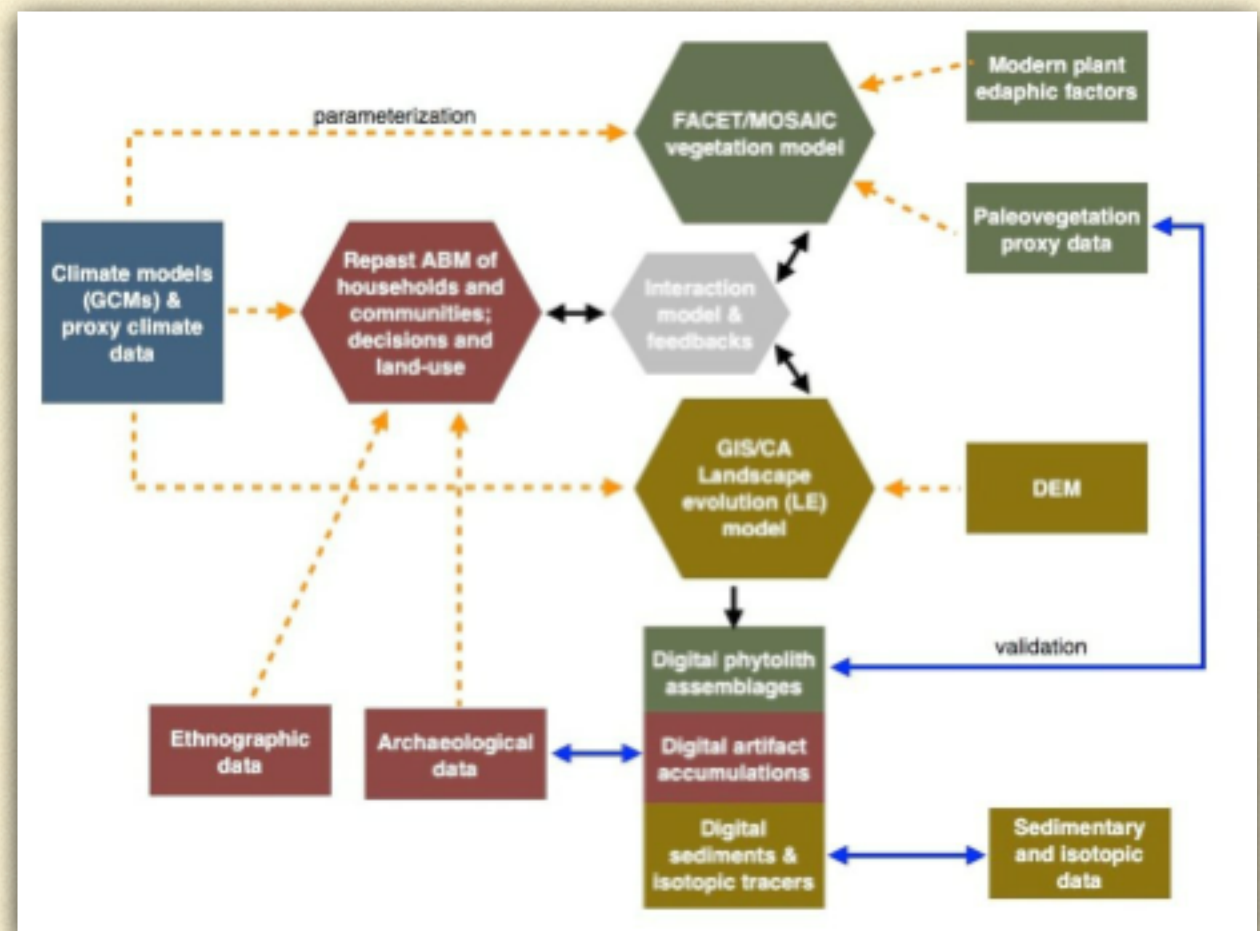
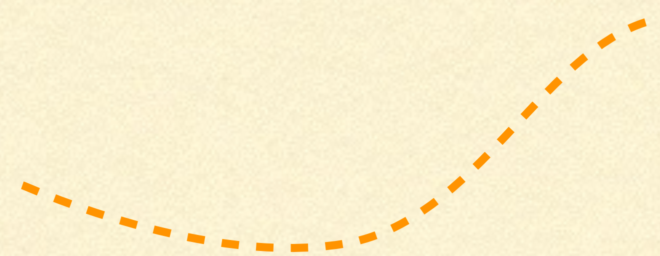
MEDLAND MODELING LABORATORY



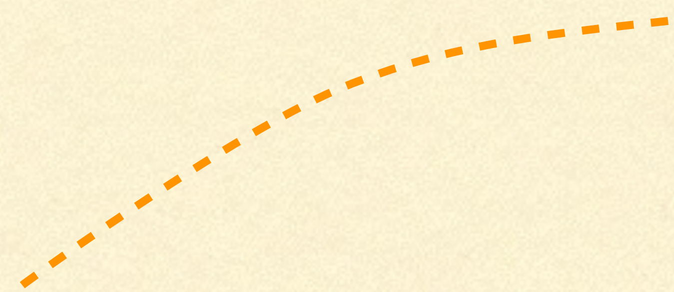
- MedLanD hybrid modeling laboratory includes...
  - Java ABM of human households and their land-use decisions (Devs Suite & Repast)
  - GRASS GIS-based model of landscape dynamics
  - ABM and Regression-based models of local climate and vegetation
- Open source software for research transparency and global accessibility

MEDLAND MODELING LABORATORY

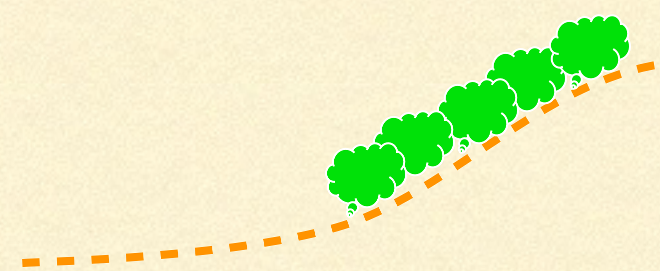
- Physical processes



- *slope decrease*
- *reduced capacity*
- *deposition*



- *slope increase*
- *increased capacity*
- *erosion*



- *land-cover change*
- *increased capacity*
- *erosion*

$$D = \mathrm{div}\,\vec{T}_c = \frac{\partial (T_c \cos \alpha)}{\partial x} + \frac{\partial (T_c \sin \alpha)}{\partial y}$$

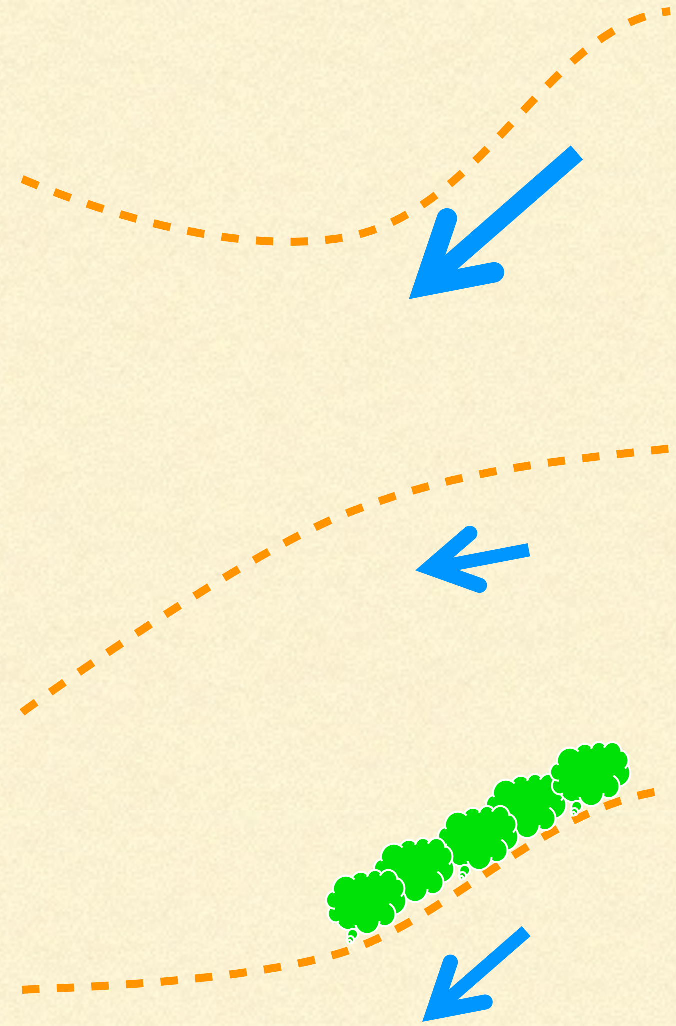
*calculate erosion/deposition **D** as divergence of sediment flow where **α** is the direction of flow*

$$\Delta z = \frac{D}{p} \cdot \frac{U_a}{cell\ res}$$

*calculate net vertical change (**Δz**) for USPED and shear stress for soil density **p** and areal units U_a*

MEDLAND MODELING LABORATORY

- Physical processes
- Basic assumption
  - Flowing water carries sediment at capacity ($T_c \approx Q_s$)



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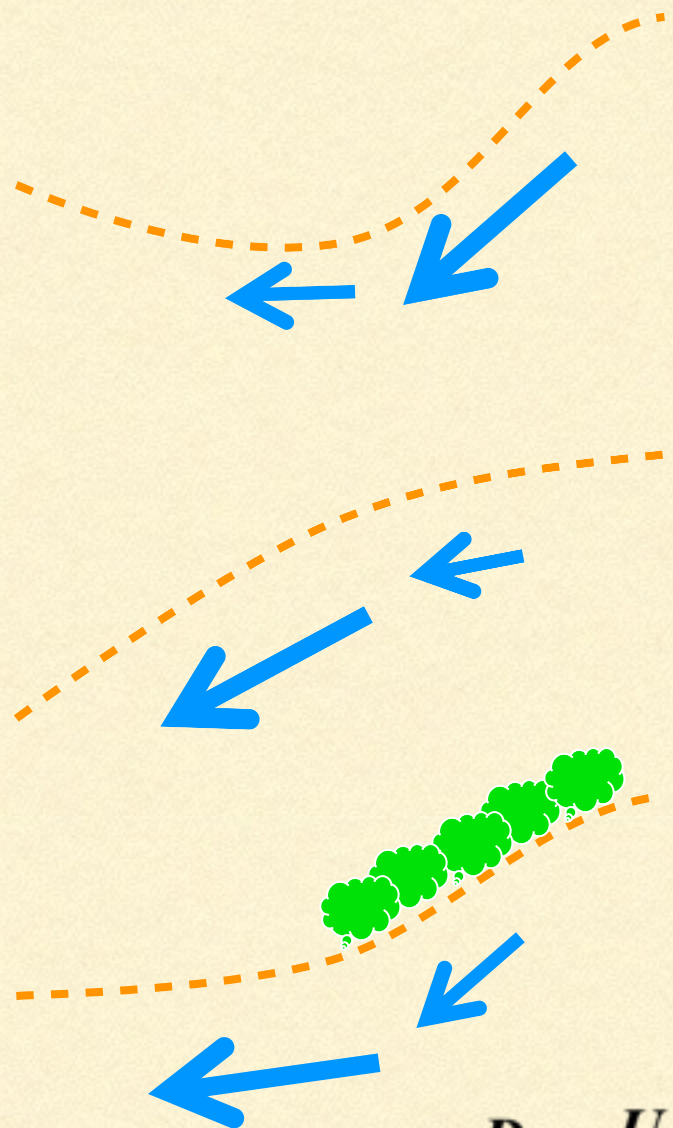
  - Changes to hydrology affect transport capacity



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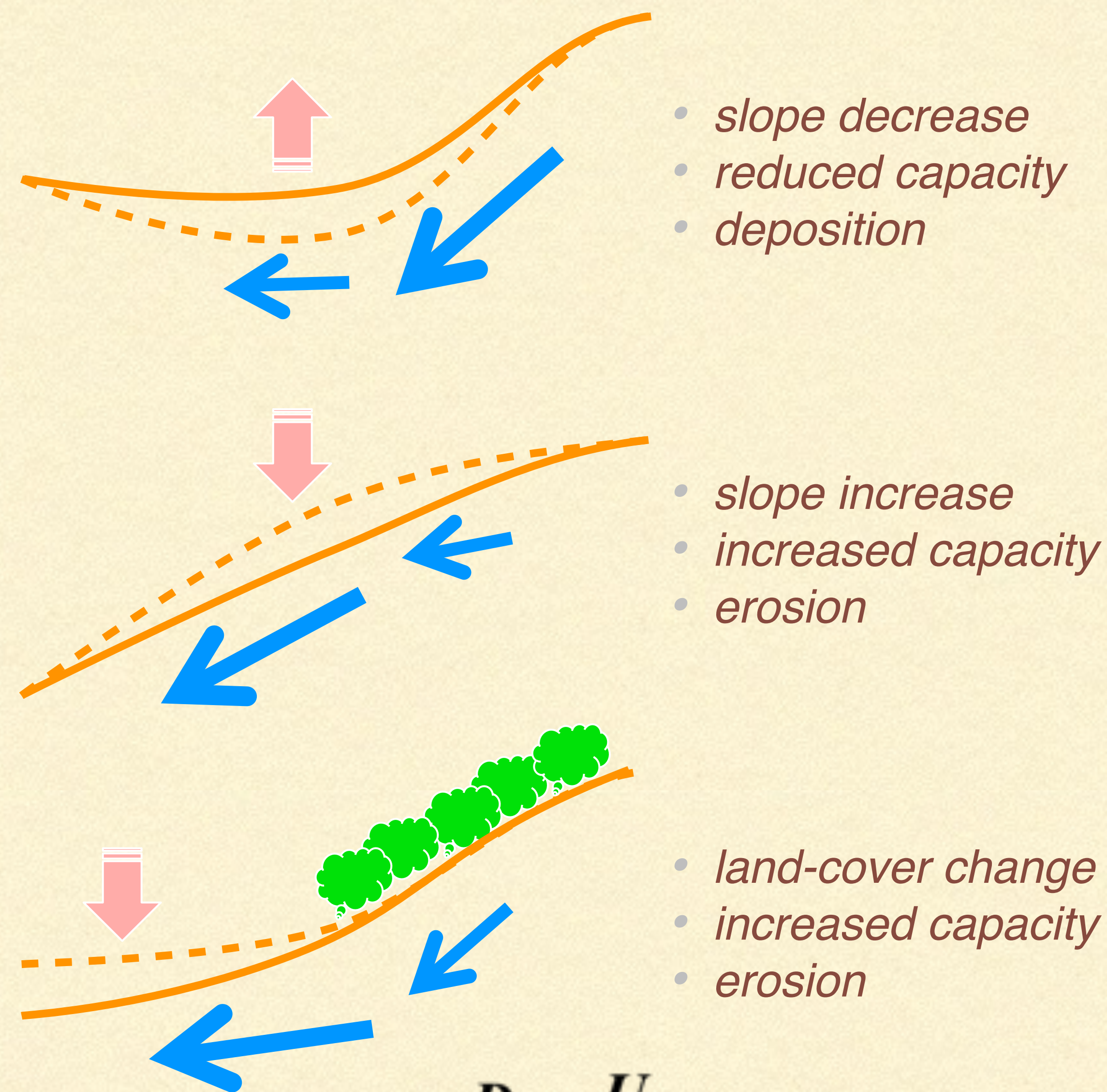
  - Water will erode or deposit sediment until its load reaches its new capacity



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MEDLAND MODELING LABORATORY

- Landscape dynamics modeled as recursive Python scripts in GRASS GIS

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MEDLAND MODELING LABORATORY

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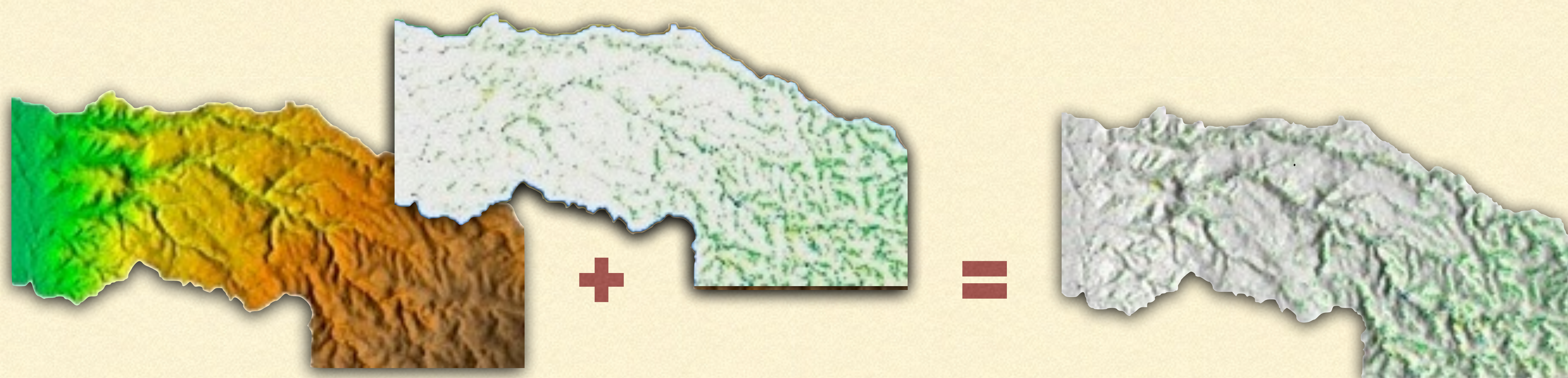

MEDLAND MODELING LABORATORY

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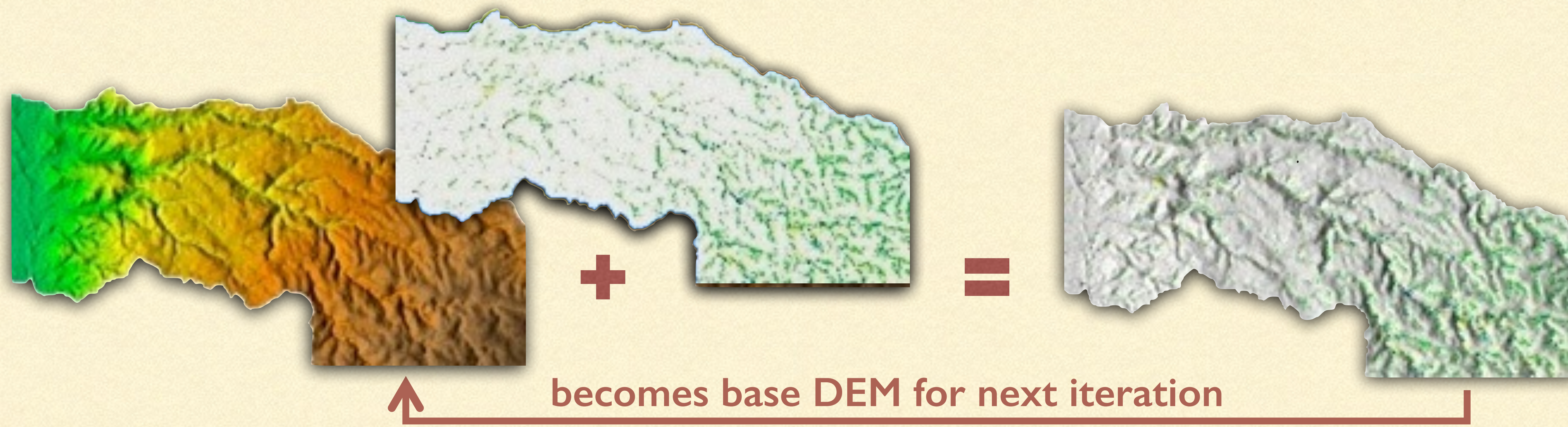
    - Create new DEM of topography

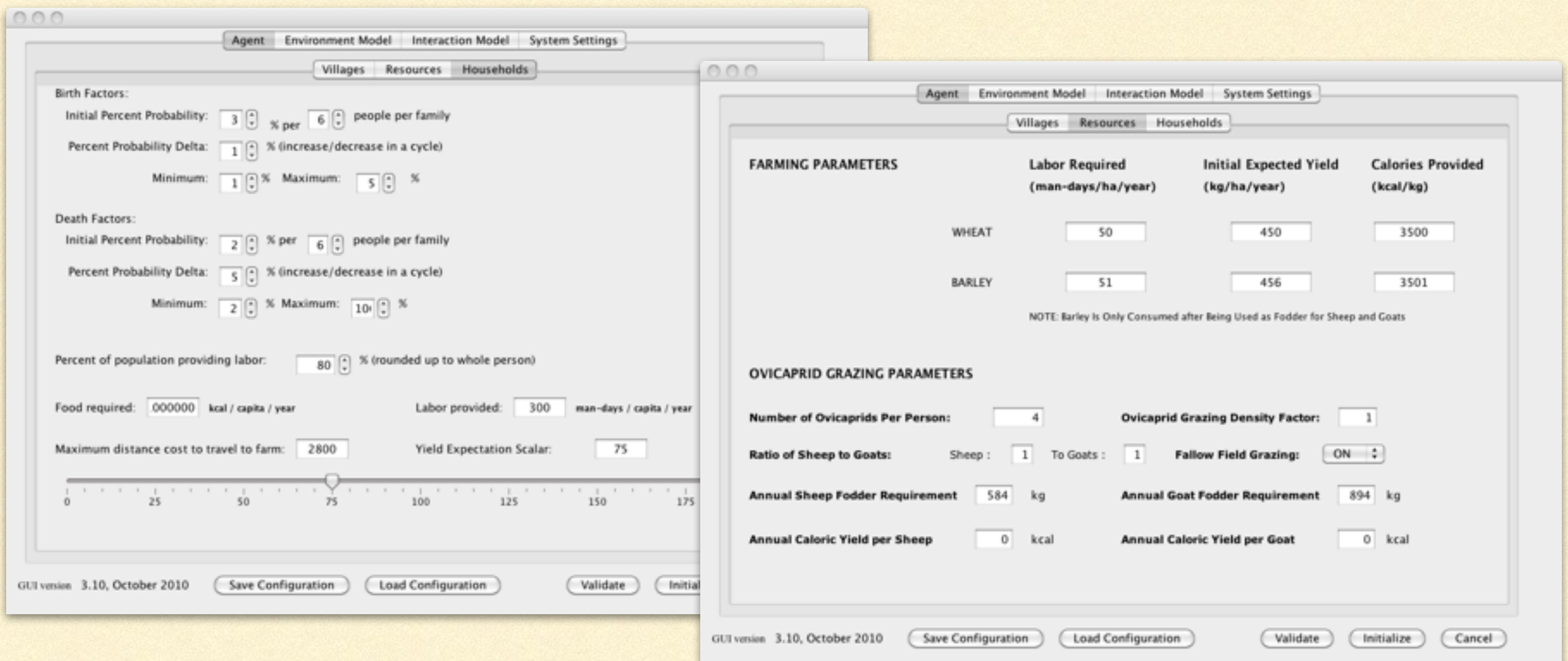


MEDLAND MODELING LABORATORY

- Parameters set by researcher
  - terrain, soil, vegetation, climate
  - number of villages and households per village
  - village locations
  - caloric costs and returns from raising domesticates
  - ratio of crops to animals, crop types, animal species
  - plant and animal requirements
  - birth and death rates
  - fuel needs per household
- Agent decisions/behaviors
  - choose land (amount and location)
  - decide land-use (cultivated, fallow, pasture, wood gathering)
  - farm wheat/barley
  - raise sheep/goats
  - gather wood
  - reproduce
  - die

MEDLAND MODELING LABORATORY

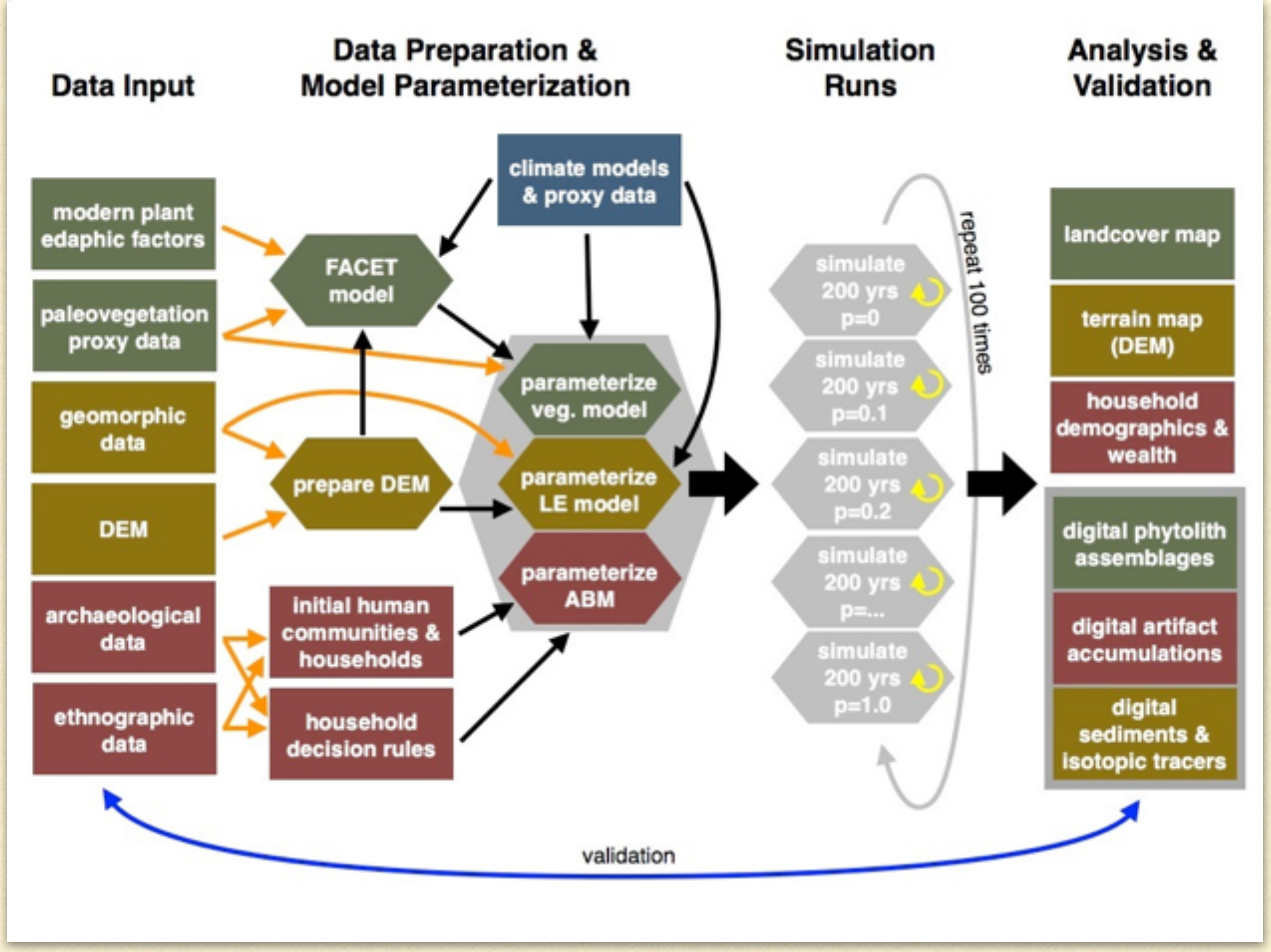
- Coupled modeling system controlled from Java ABM and interface



MEDLAND MODELING LABORATORY

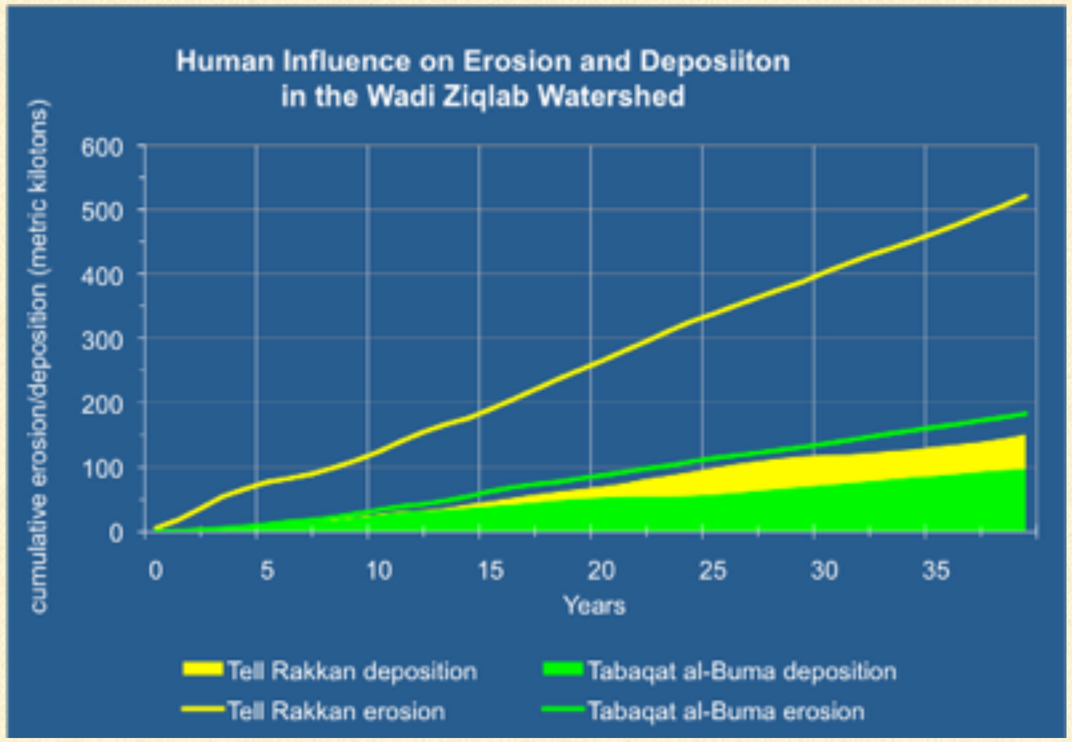
- Experiments in complex interactions of socioecological systems
- Investigating long-term anthropogenic change in Holocene landscapes
- Providing new insights into coupled human & natural processes

MEDLAND MODELING LABORATORY



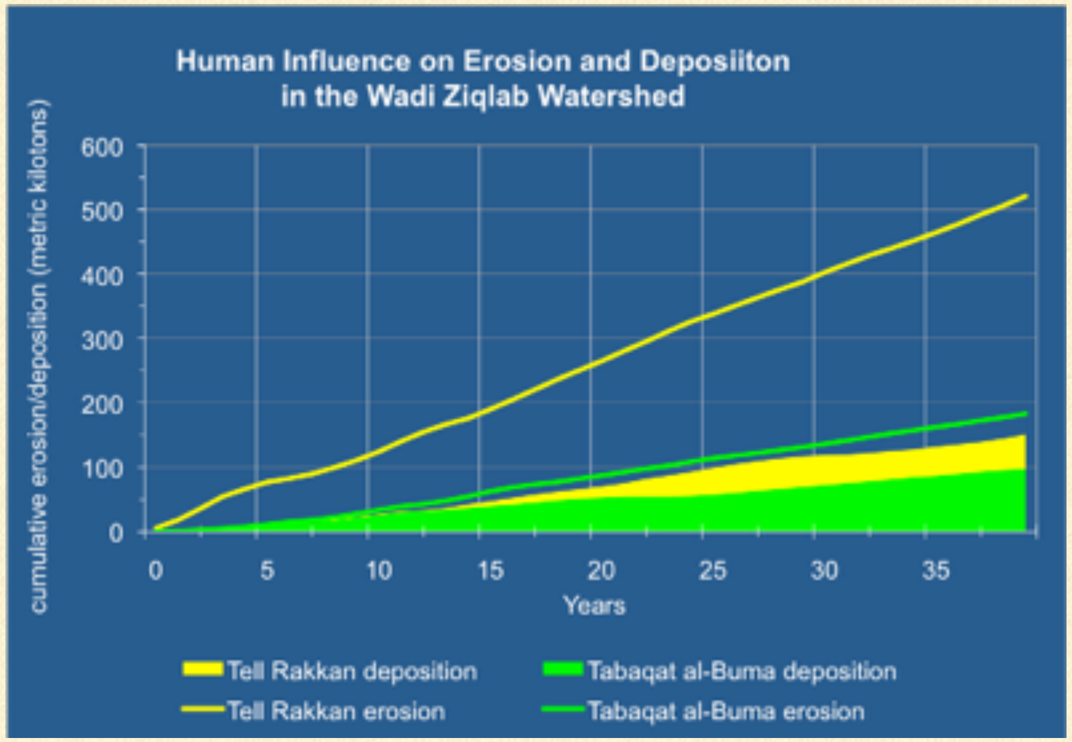
LAND-USE & LANDSCAPE DYNAMICS IN NORTHERN JORDAN

- Tiny hamlet



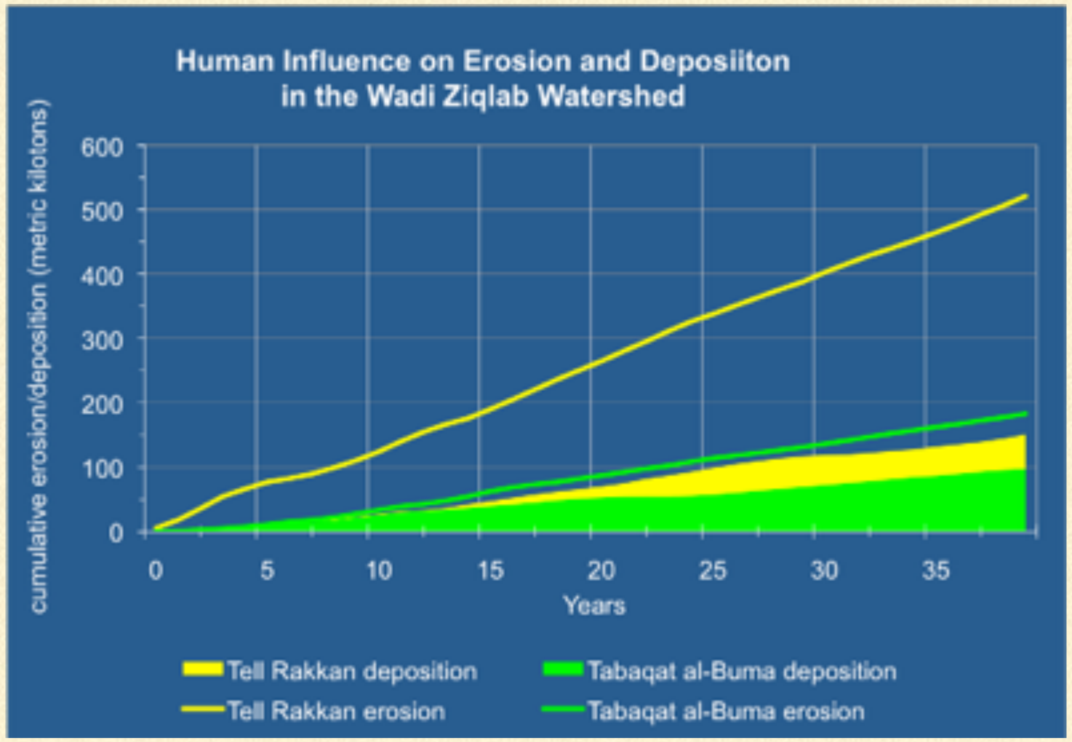
LAND-USE & LANDSCAPE DYNAMICS IN NORTHERN JORDAN

- Tiny hamlet
  - Cultivation limited to wadi bottoms



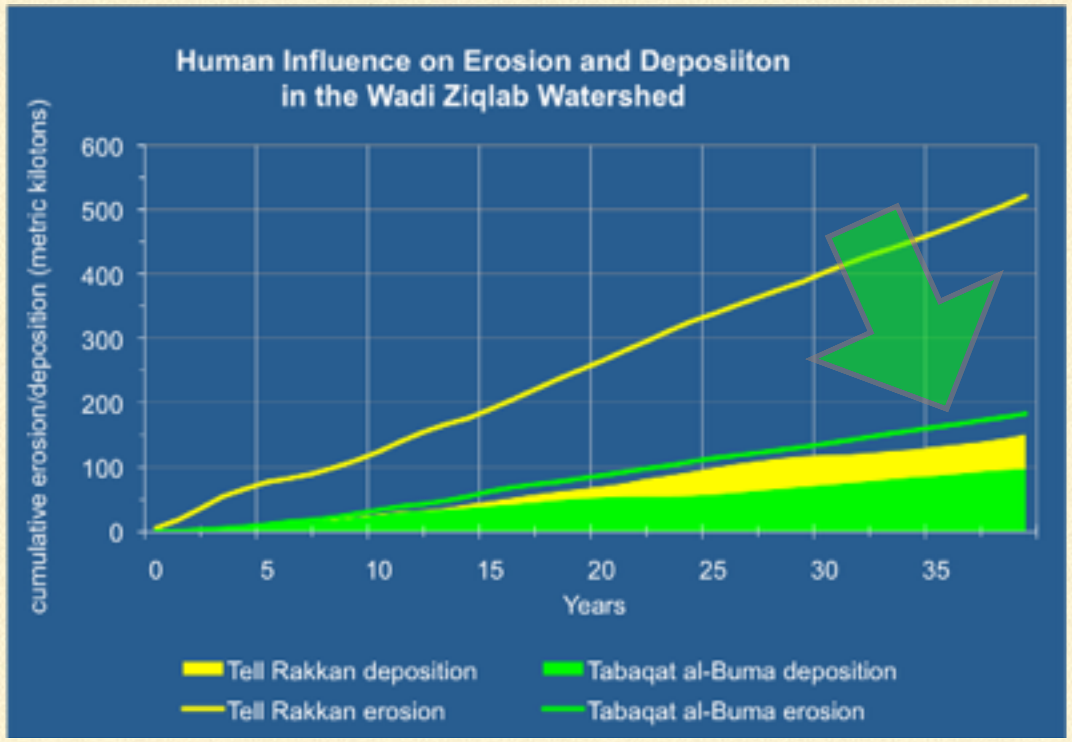
LAND-USE & LANDSCAPE DYNAMICS IN NORTHERN JORDAN

- Tiny hamlet
  - Cultivation limited to wadi bottoms
  - Grazing causes most erosion



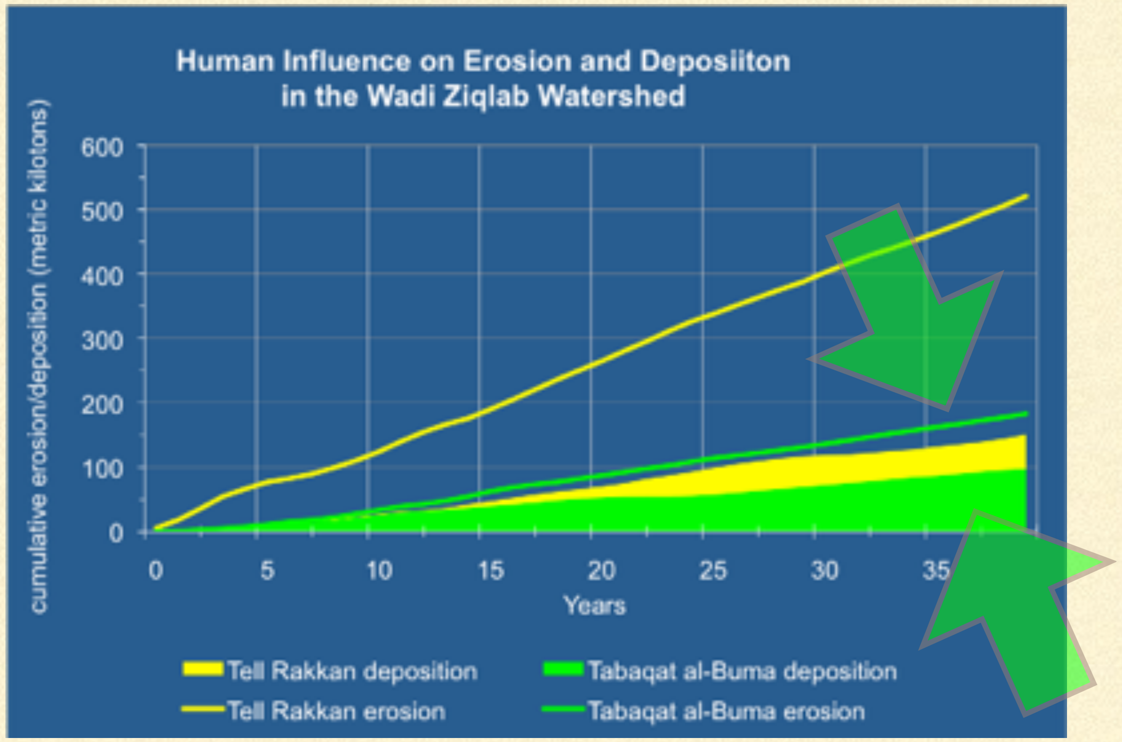
LAND-USE & LANDSCAPE DYNAMICS IN NORTHERN JORDAN

- Tiny hamlet
  - Cultivation limited to wadi bottoms
  - Grazing causes most erosion
  - Erosion primarily in uncultivated uplands



LAND-USE & LANDSCAPE DYNAMICS IN NORTHERN JORDAN

- Tiny hamlet
  - Cultivation limited to wadi bottoms
  - Grazing causes most erosion
  - Erosion primarily in uncultivated uplands
  - Redeposited sediment in cultivated zones is 53% of erosion



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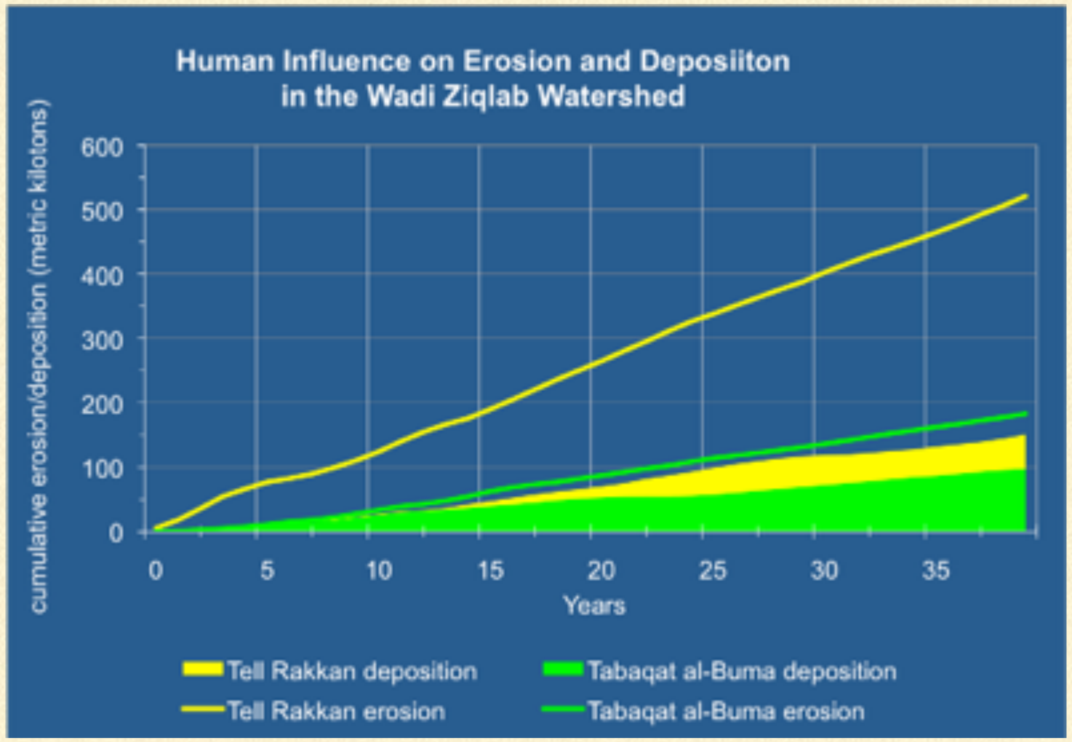
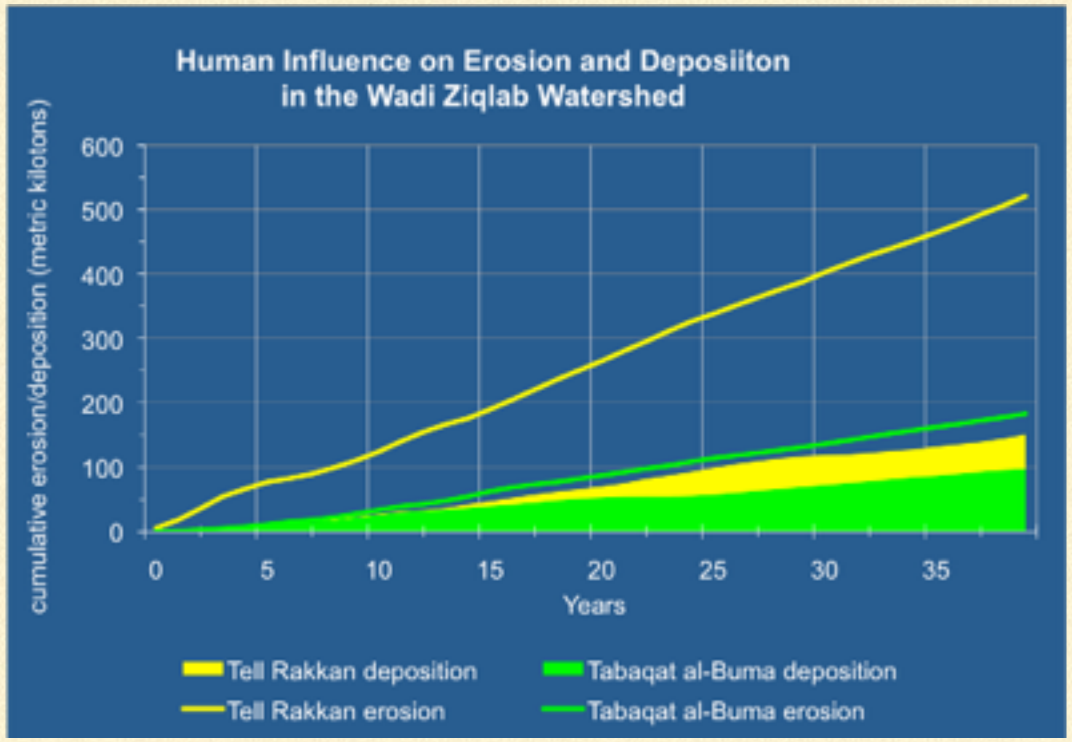
LAND-USE & LANDSCAPE DYNAMICS IN NORTHERN JORDAN

- Larger village



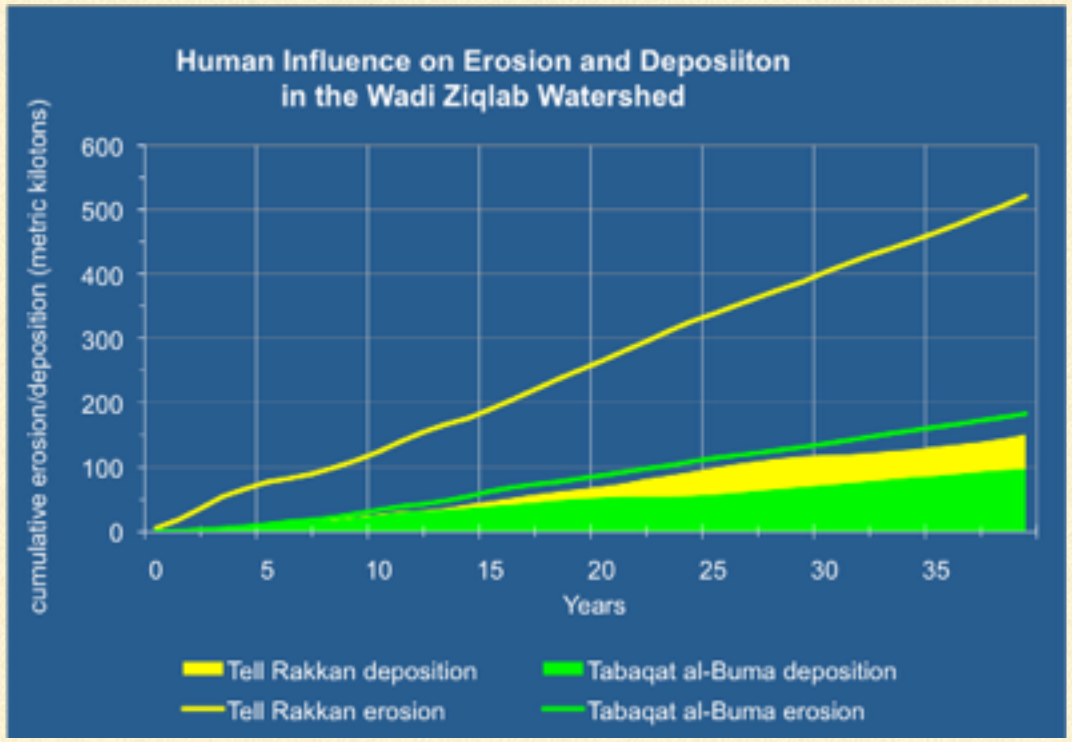
LAND-USE & LANDSCAPE DYNAMICS IN NORTHERN JORDAN

- Larger village
  - Cultivation in uplands; more extensive grazing



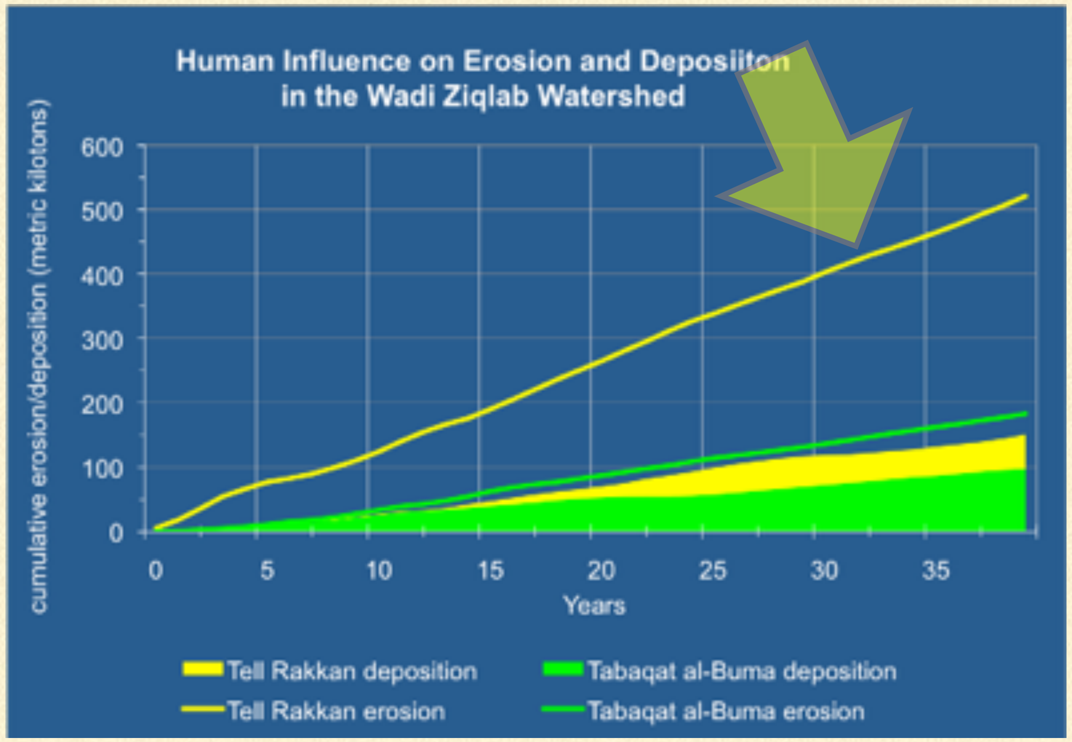
LAND-USE & LANDSCAPE DYNAMICS IN NORTHERN JORDAN

- Larger village
  - Cultivation in uplands; more extensive grazing
  - Cultivation causes most erosion



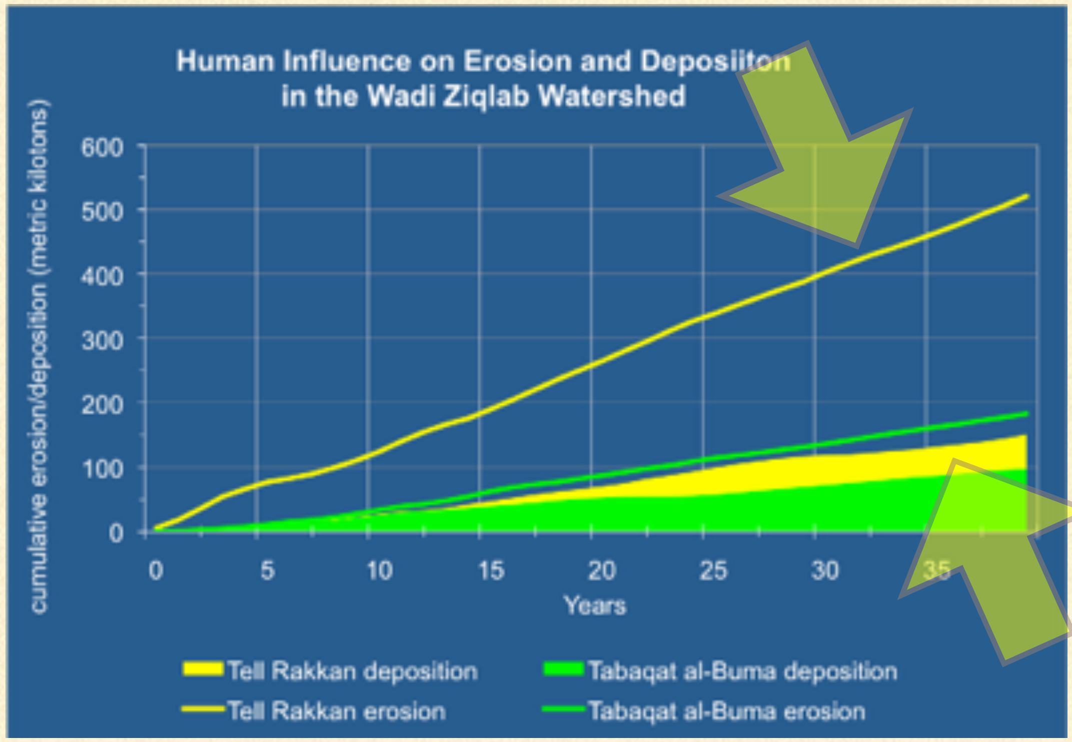
LAND-USE & LANDSCAPE DYNAMICS IN NORTHERN JORDAN

- Larger village
  - Cultivation in uplands; more extensive grazing
  - Cultivation causes most erosion
  - Erosion in cultivated and uncultivated zones



LAND-USE & LANDSCAPE DYNAMICS IN NORTHERN JORDAN

- Larger village
  - Cultivation in uplands; more extensive grazing
  - Cultivation causes most erosion
  - Erosion in cultivated and uncultivated zones
  - Redeposited sediment only 29% of erosion



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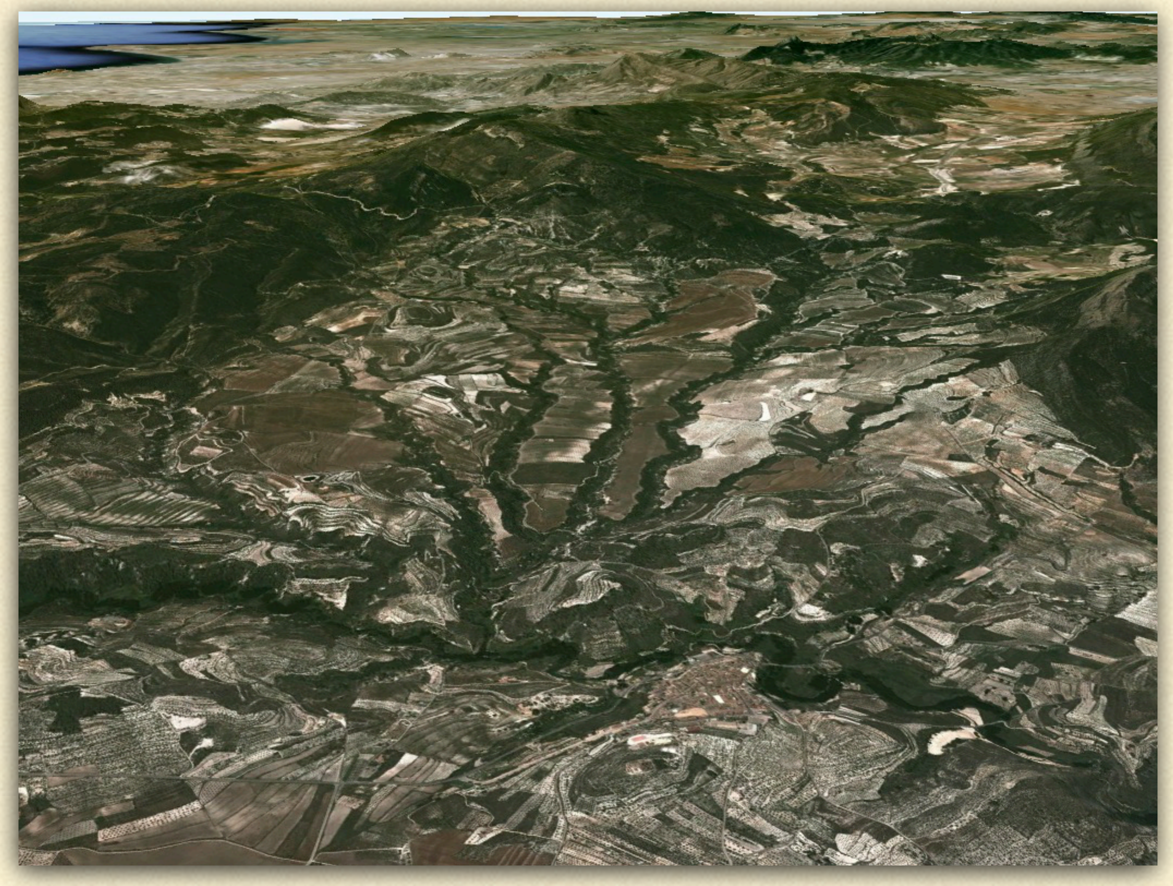
LAND-USE & LANDSCAPE DYNAMICS IN EASTERN SPAIN



Penaguila Valley, Alicante Province, Spain

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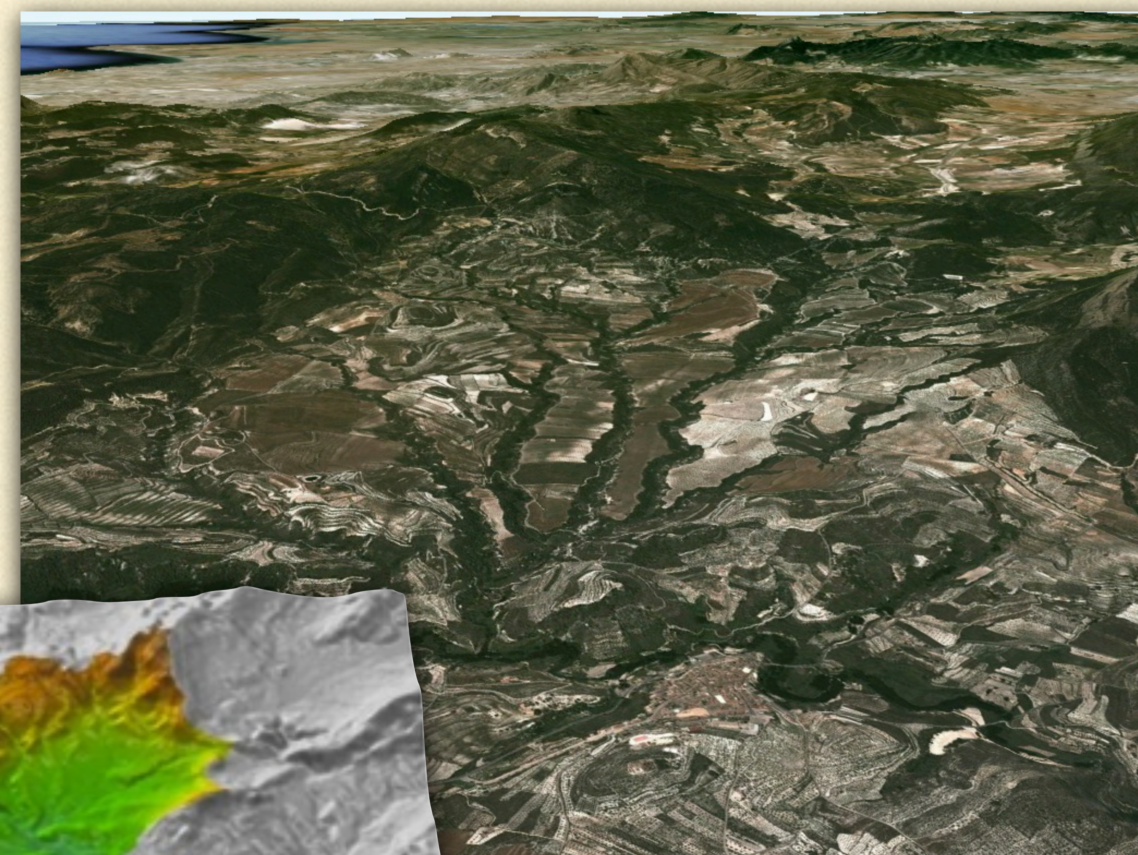
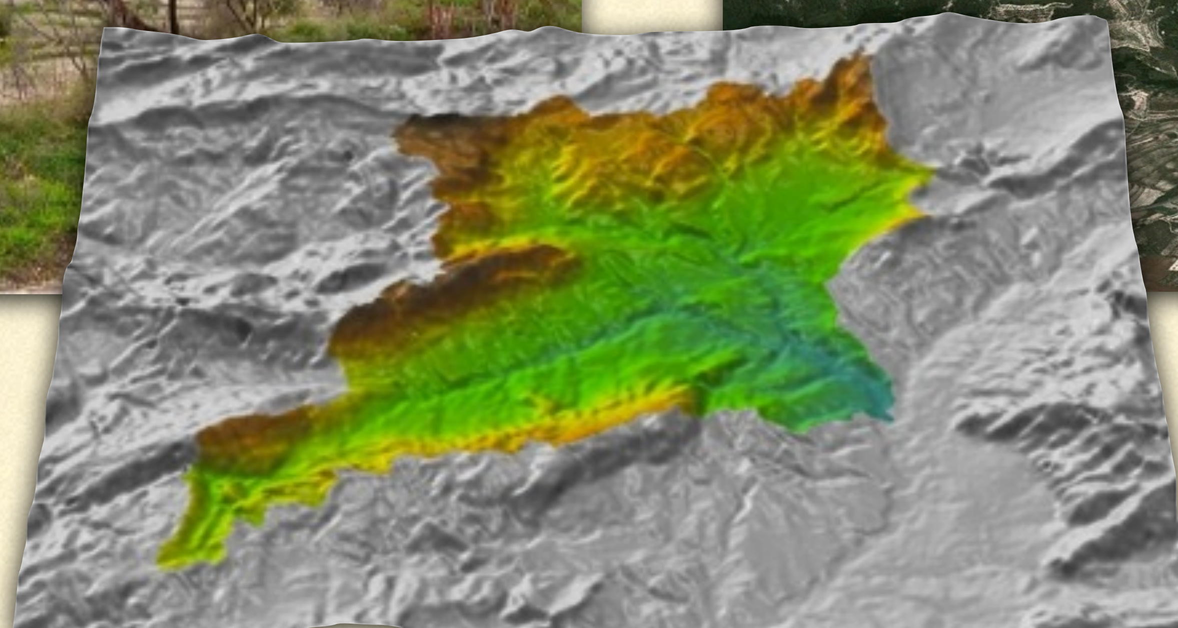
LAND-USE & LANDSCAPE DYNAMICS IN EASTERN SPAIN





Penaguila Valley, Alicante Province, Spain

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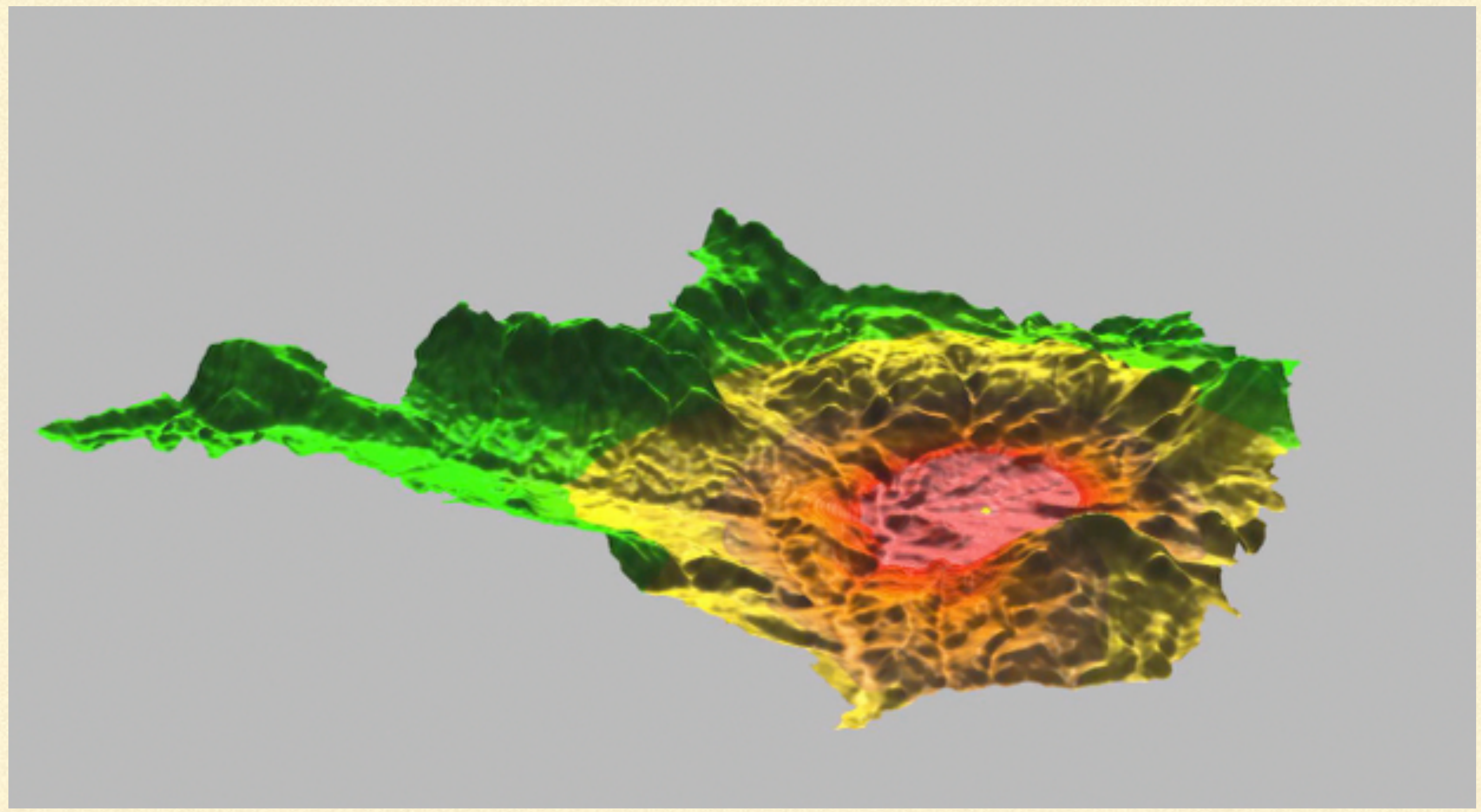
LAND-USE & LANDSCAPE DYNAMICS IN EASTERN SPAIN

- Begin with paleo-terrain of early Holocene



dense woodland (no human impacts)
open woodland (grazed)
shrubs (grazed or fallowed)
grass & cereals (farmed or fallowed)
bare (cleared for farming)

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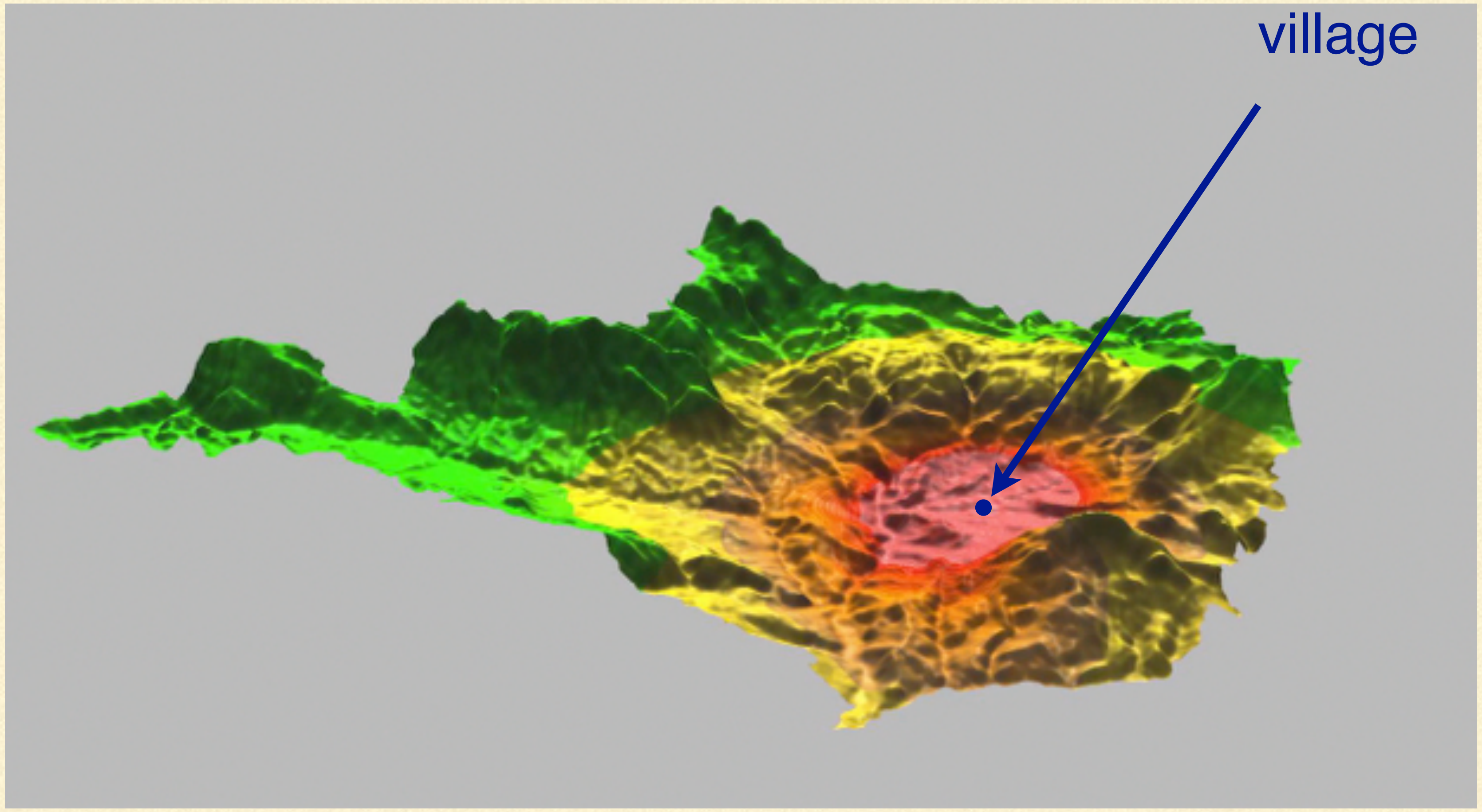
LAND-USE & LANDSCAPE DYNAMICS IN EASTERN SPAIN

- Begin with paleo-terrain of early Holocene
- Add ABM of village with households



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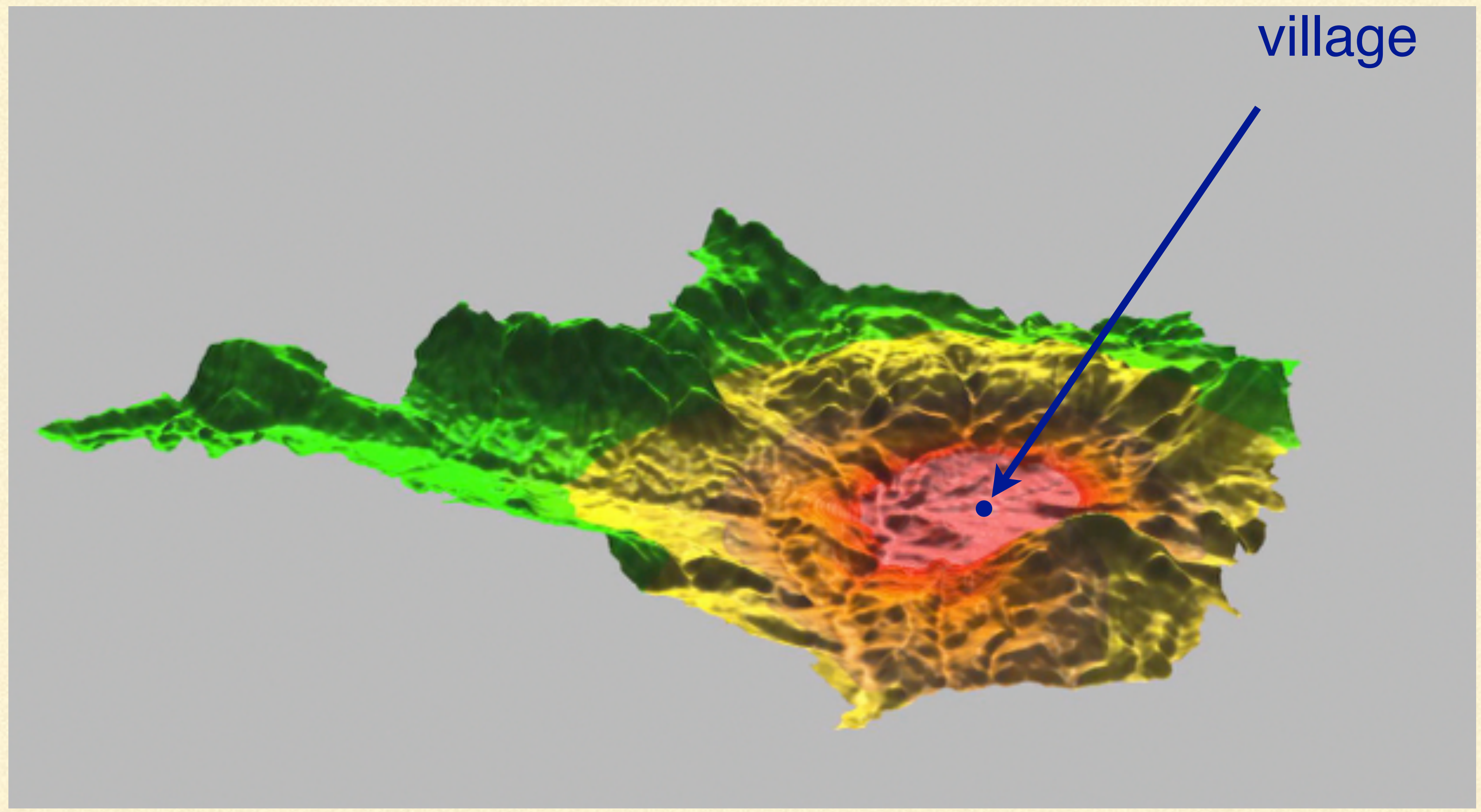
open woodland (grazed)
shrubs (grazed or fallowed)
grass & cereals (farmed or fallowed)
bare (cleared for farming)

LAND-USE & LANDSCAPE DYNAMICS IN EASTERN SPAIN

- Begin with paleo-terrain of early Holocene
- Add ABM of village with households
- Instantiate 1000 years of agriculture and fuelwood use
- Repeat multiple times for different settings



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grass & cereals (farmed or fallowed)
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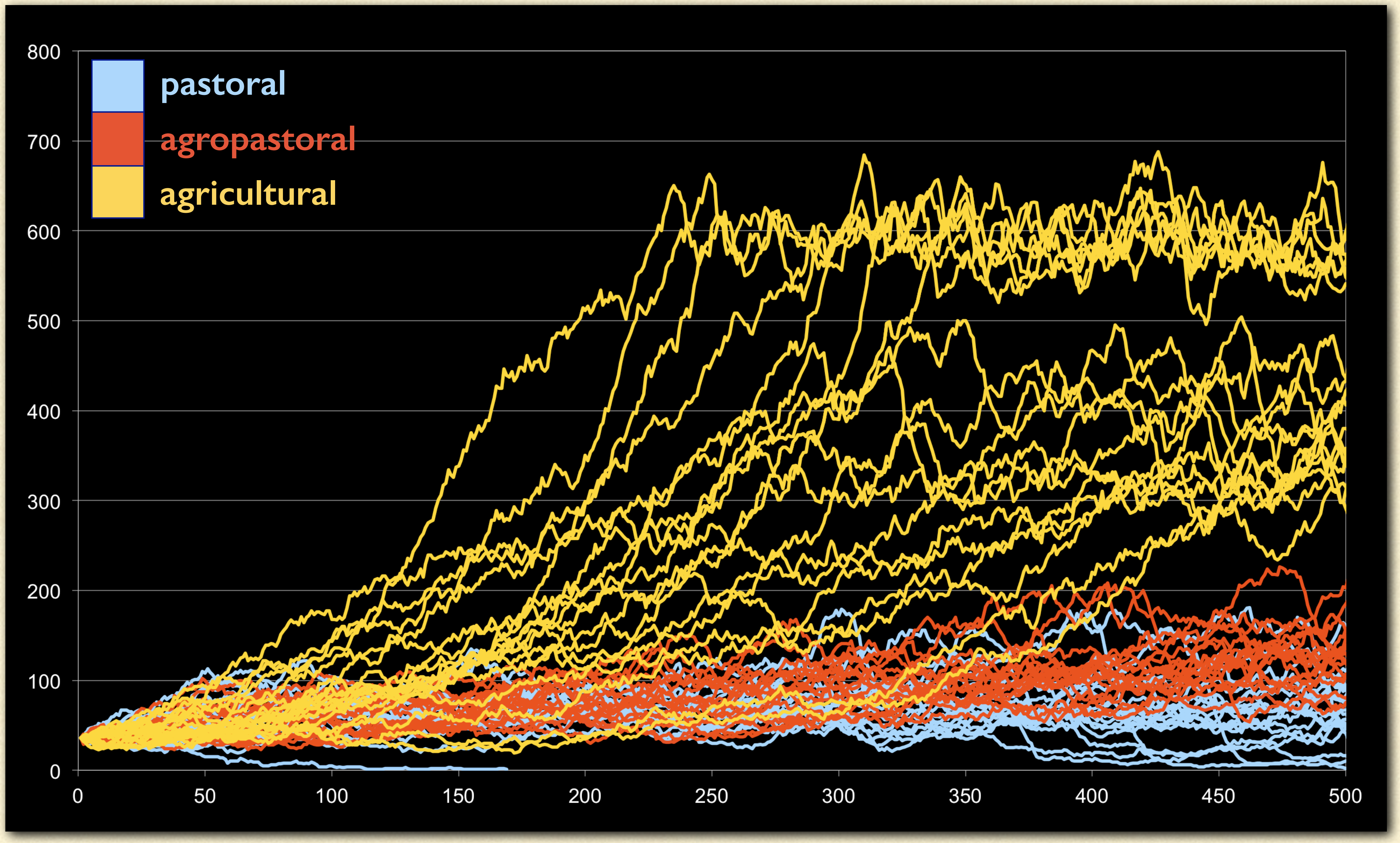
LAND-USE & LANDSCAPE DYNAMICS IN EASTERN SPAIN



population over 500 years with different subsistence strategies (multiple runs)

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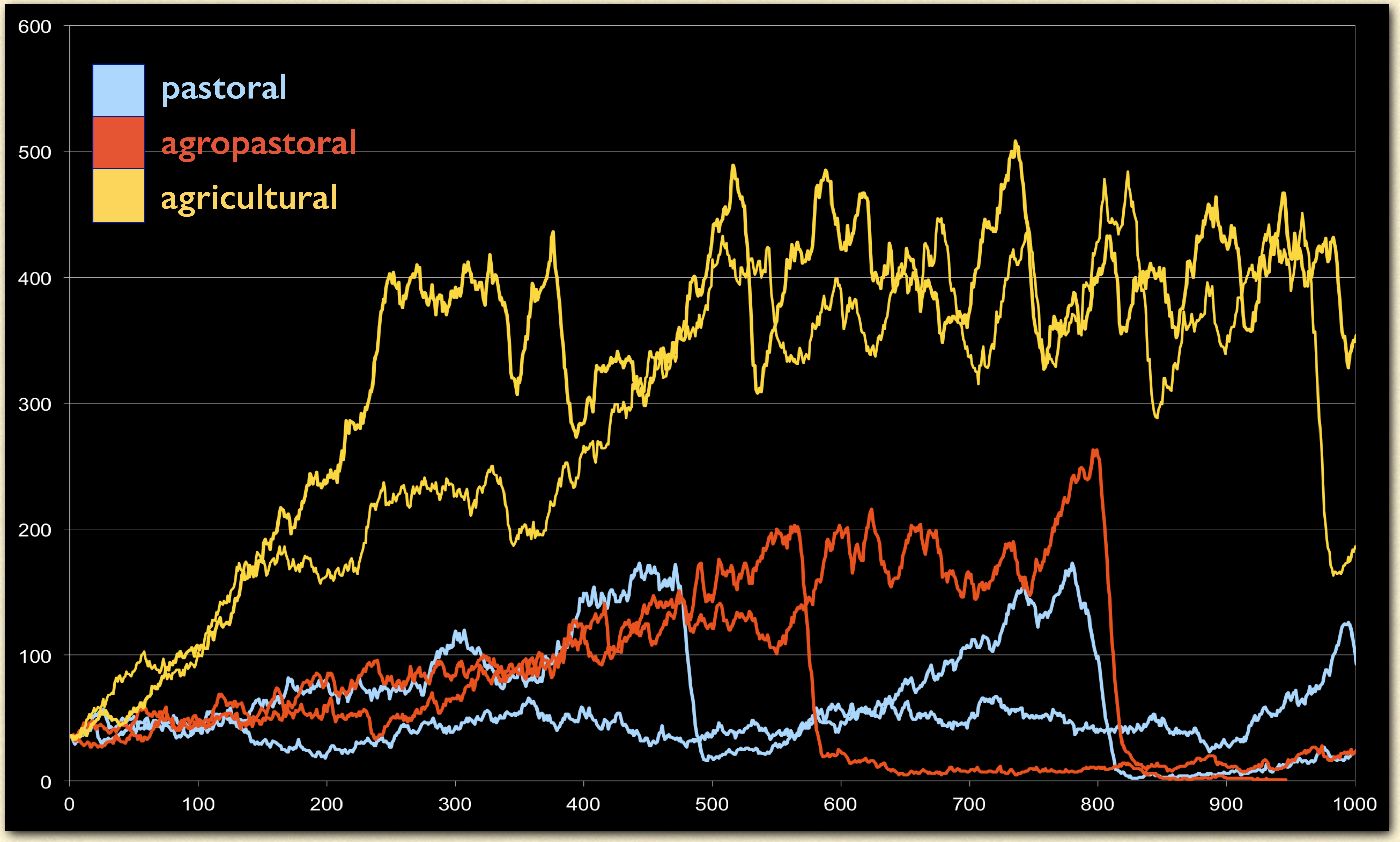
LAND-USE & LANDSCAPE DYNAMICS IN EASTERN SPAIN



population over 1000 years with different subsistence strategies (multiple runs)

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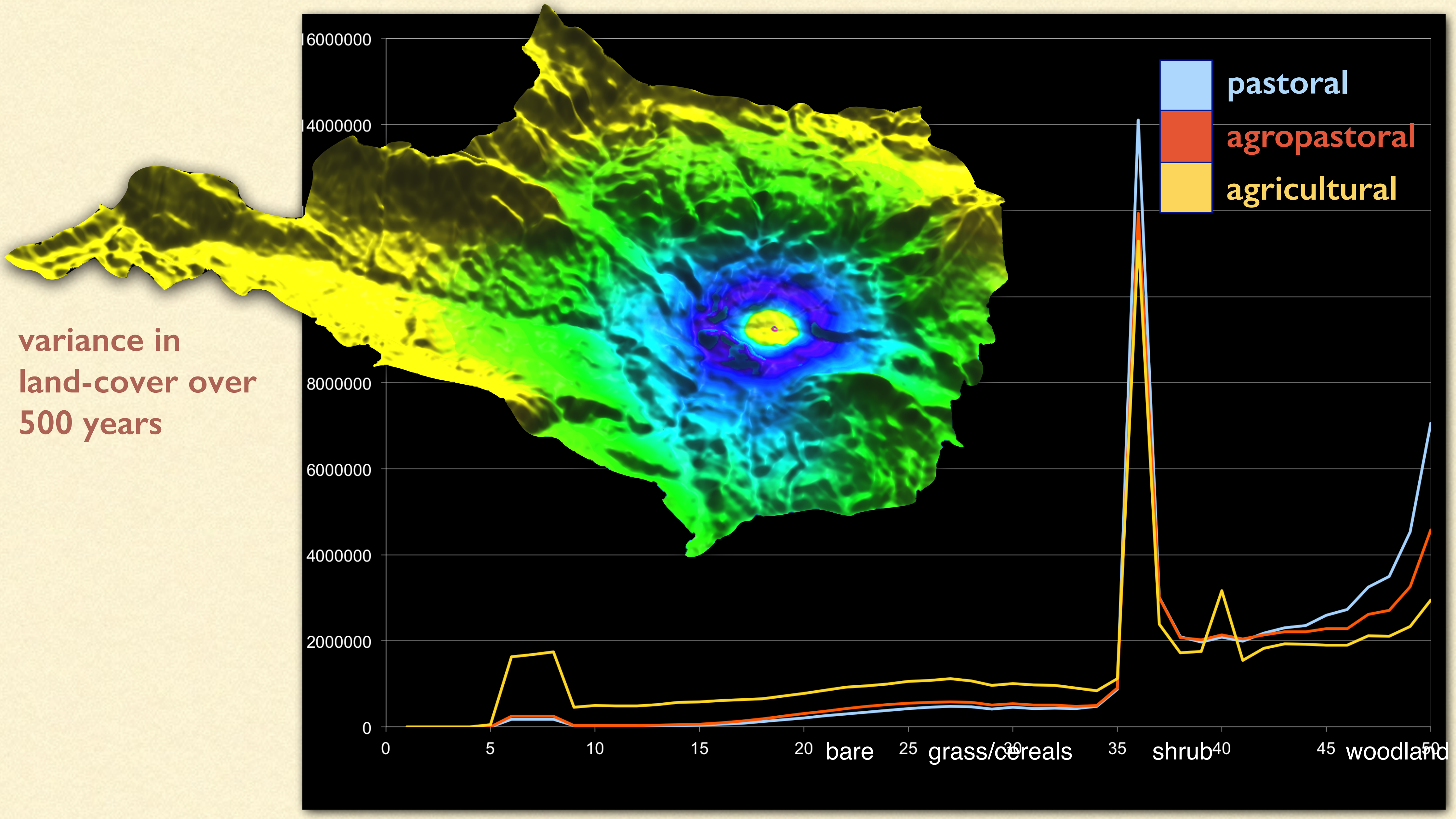
LAND-USE & LANDSCAPE DYNAMICS IN EASTERN SPAIN

variance in land-cover over 500 years



mean standard deviation in landcover over 500 years with different subsistence strategies

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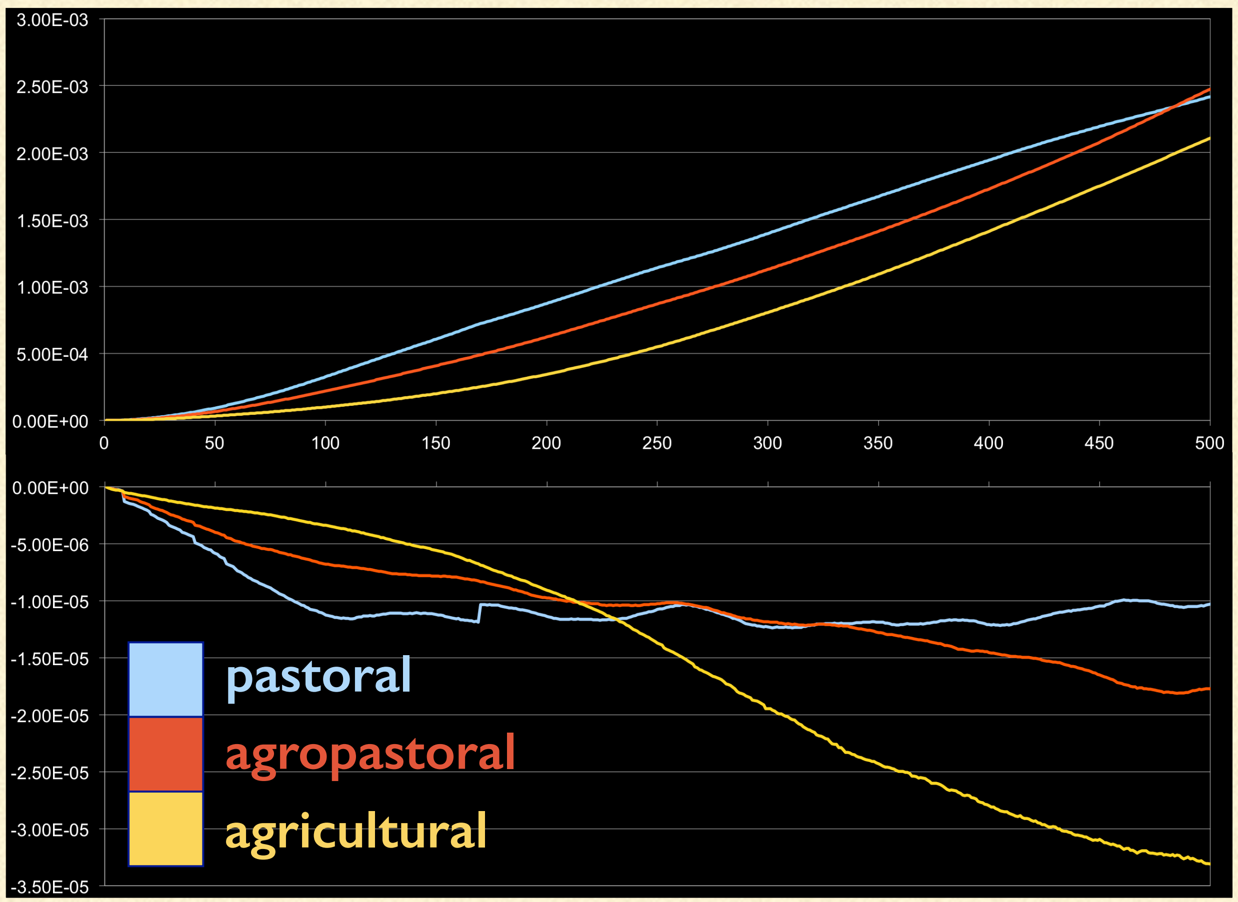
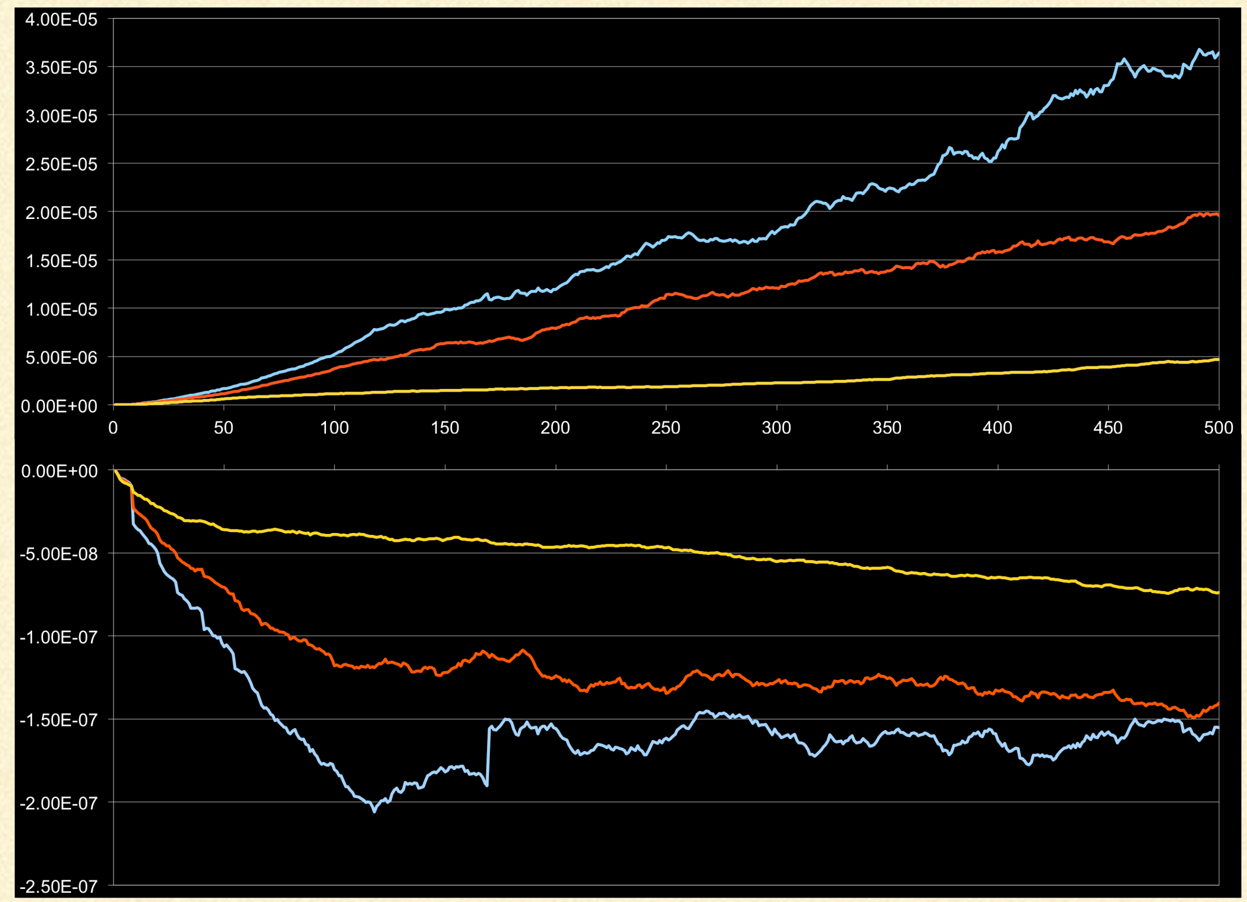
LAND-USE & LANDSCAPE DYNAMICS IN EASTERN SPAIN



total cumulative erosion/deposition over 500 years with different subsistence strategies (multiple runs combined)



per capita cumulative erosion/deposition over 500 years with different subsistence strategies (multiple runs combined)

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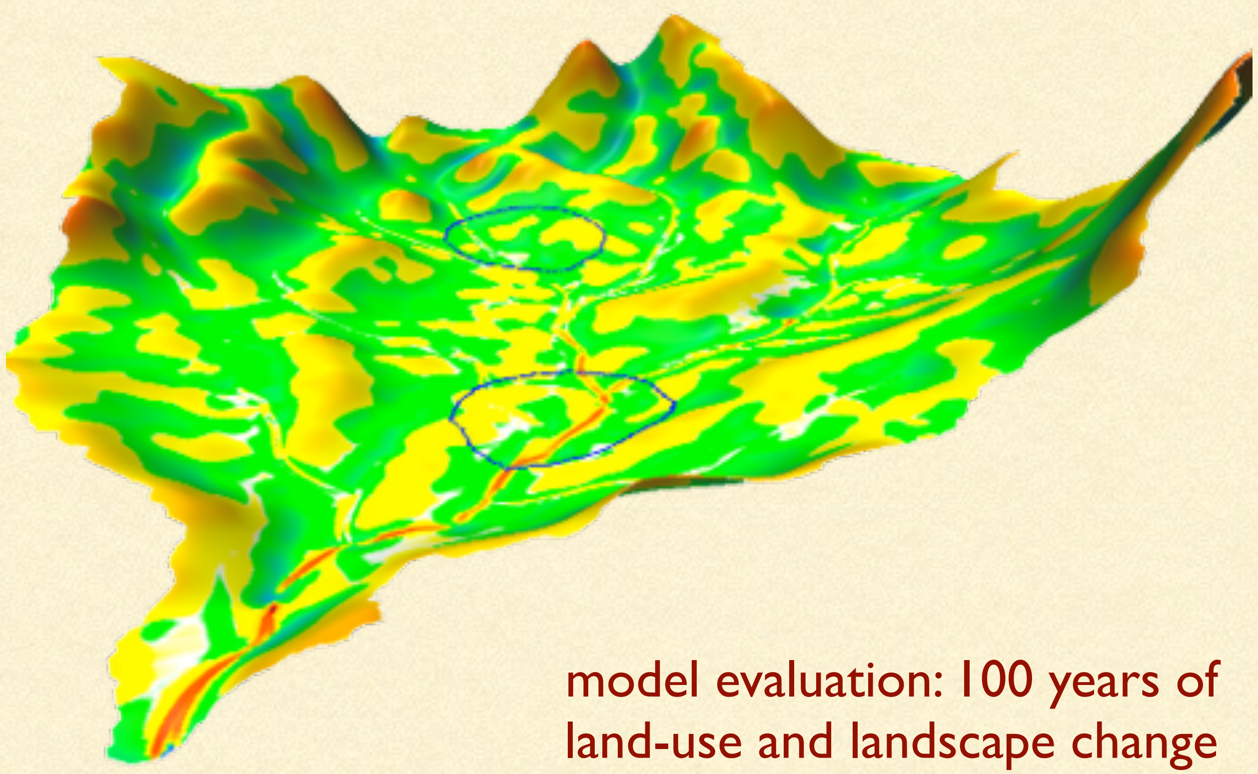
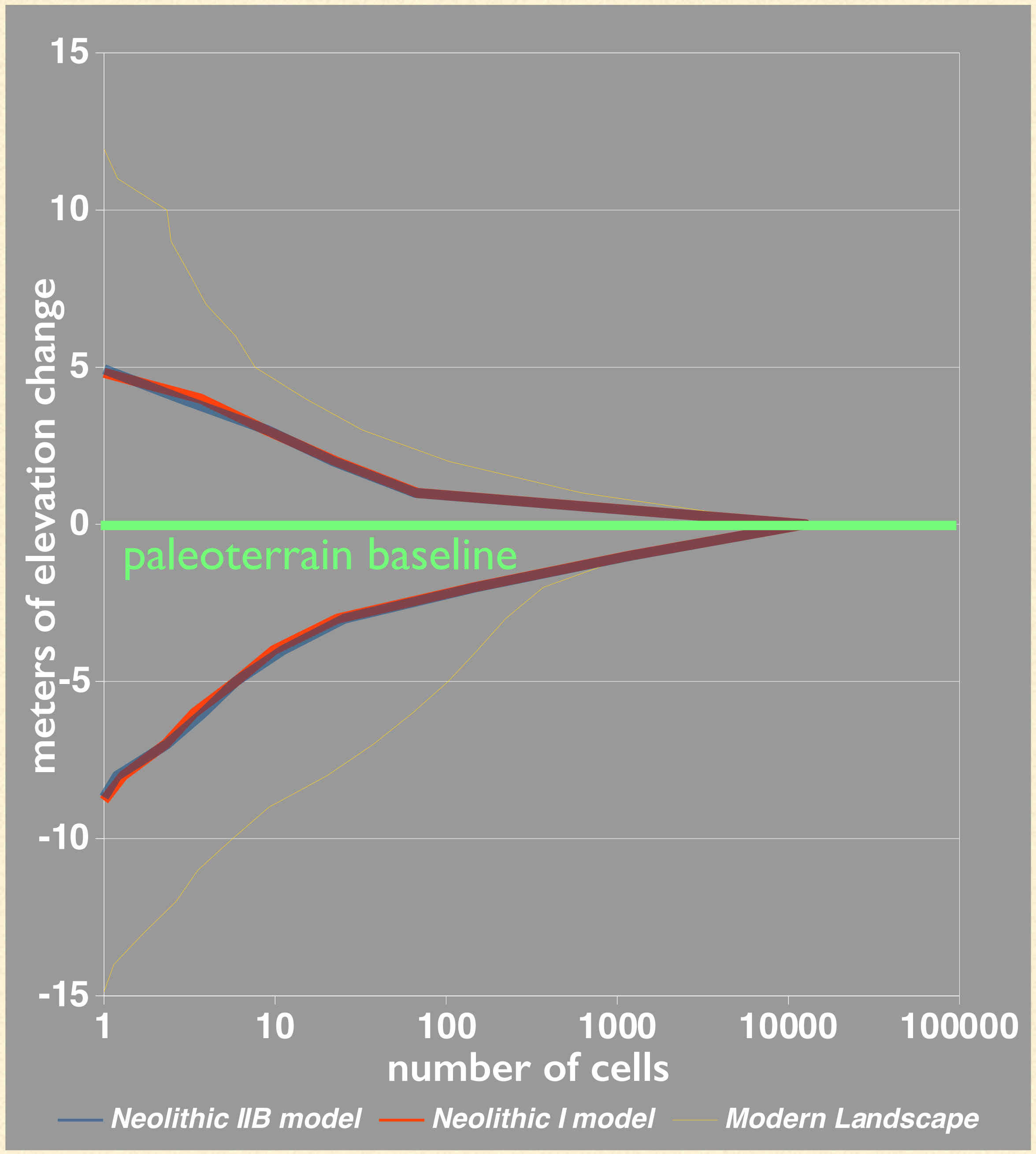
LAND-USE & LANDSCAPE DYNAMICS IN EASTERN SPAIN



model evaluation: 100 years of land-use and landscape change from initial 'paleoterrain' in the Rio Penaguila Valley, eastern Spain

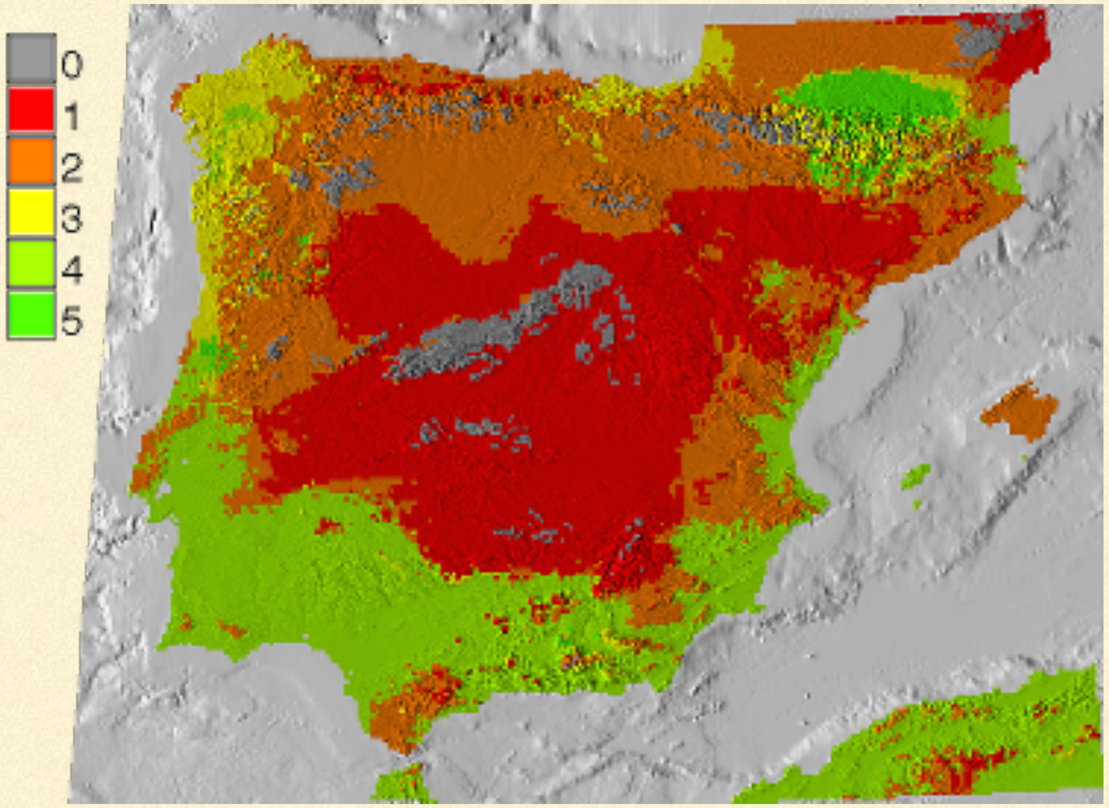


SPREAD OF FARMING IN THE WESTERN MEDITERRANEAN

- Social and demographic changes with recursive impacts on environment
- Questions about processes of socioeconomic change
  - Spread of people vs. spread of ideas?
  - Interactions between farmers and foragers?
  - Continuous diffusion-like spread vs. discontinuous punctuated spread?
  - Land-based, sea-faring, both?

SPREAD OF FARMING IN THE WESTERN MEDITERRANEAN

- Estimating suitability for farming from multiple environmental parameters

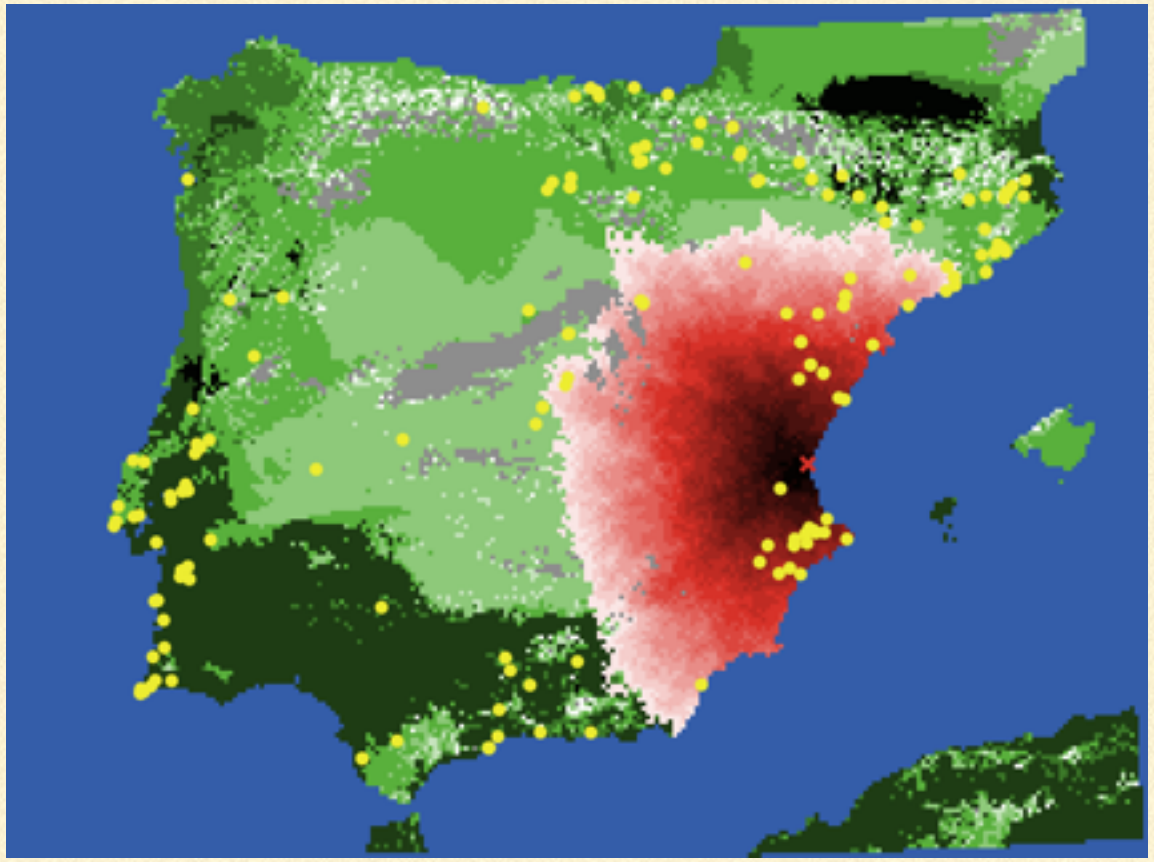


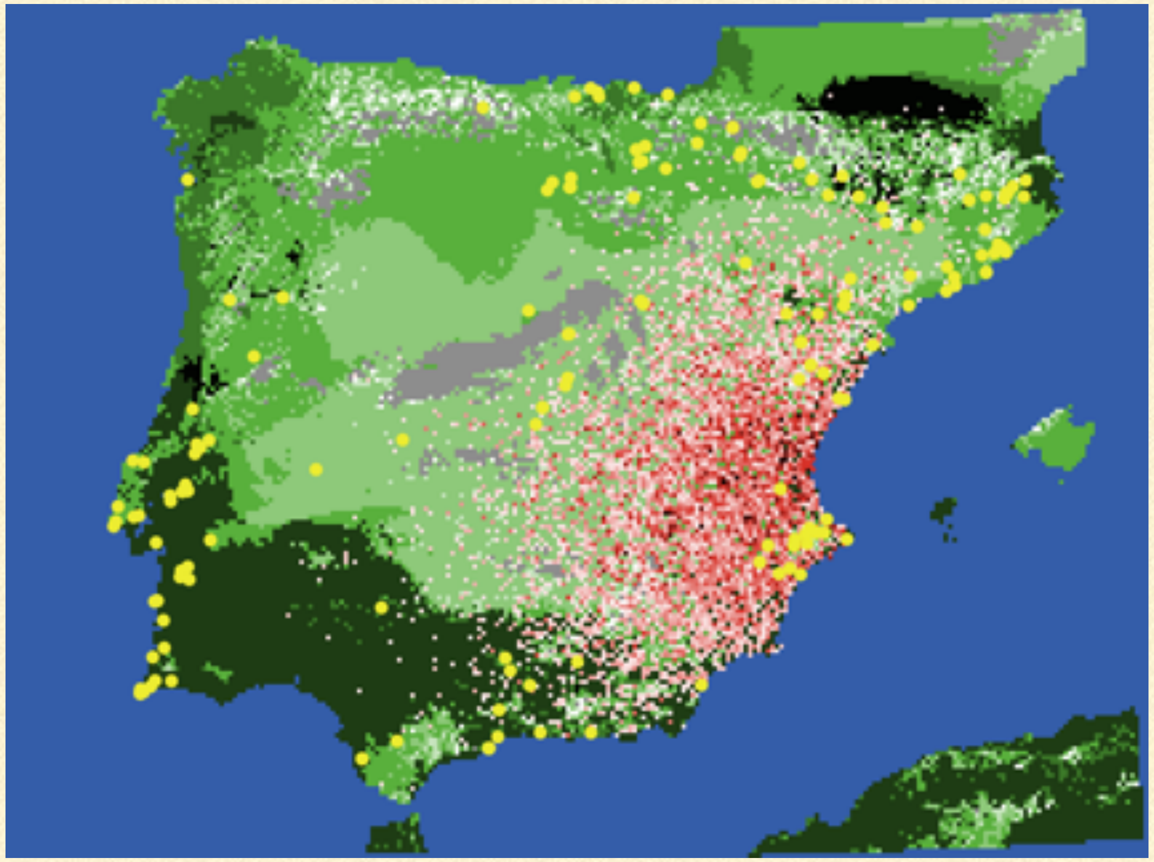
climatic index (cooler colors are better)

topography

SPREAD OF FARMING IN THE WESTERN MEDITERRANEAN

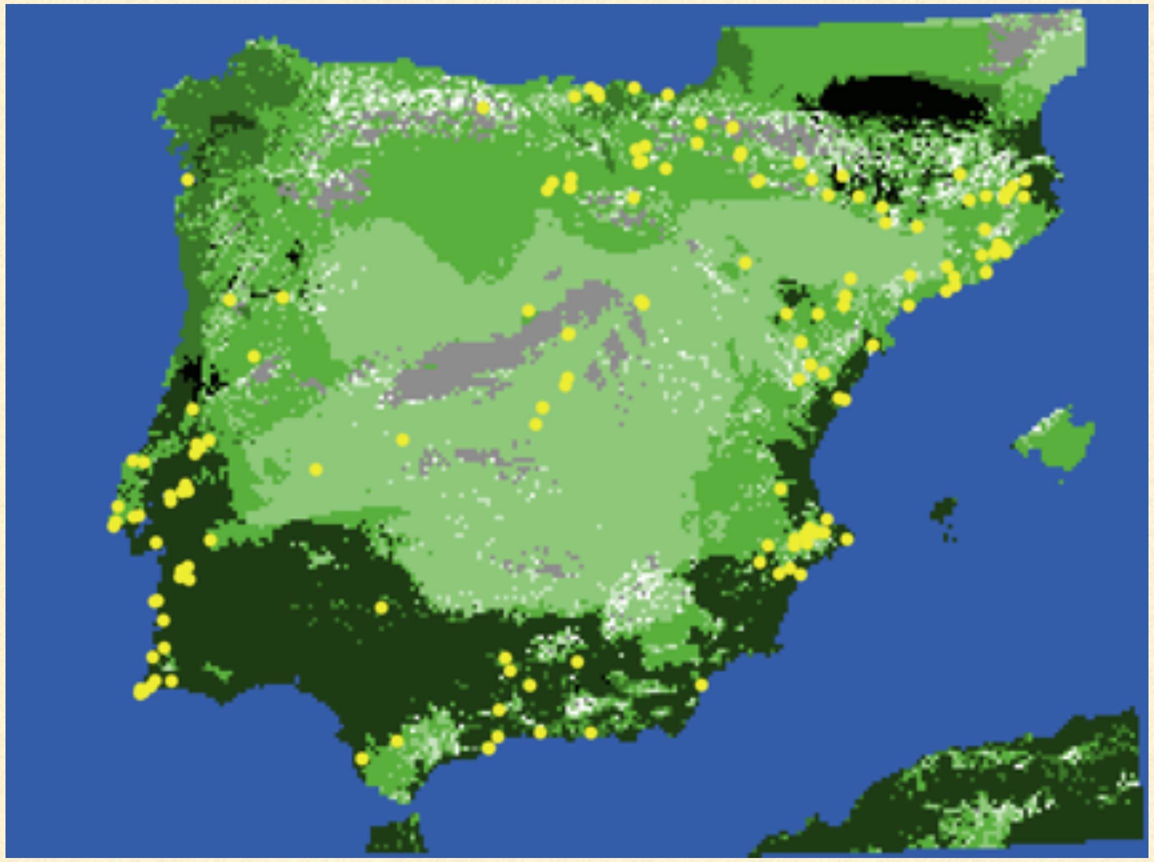
- Testing different dispersal processes

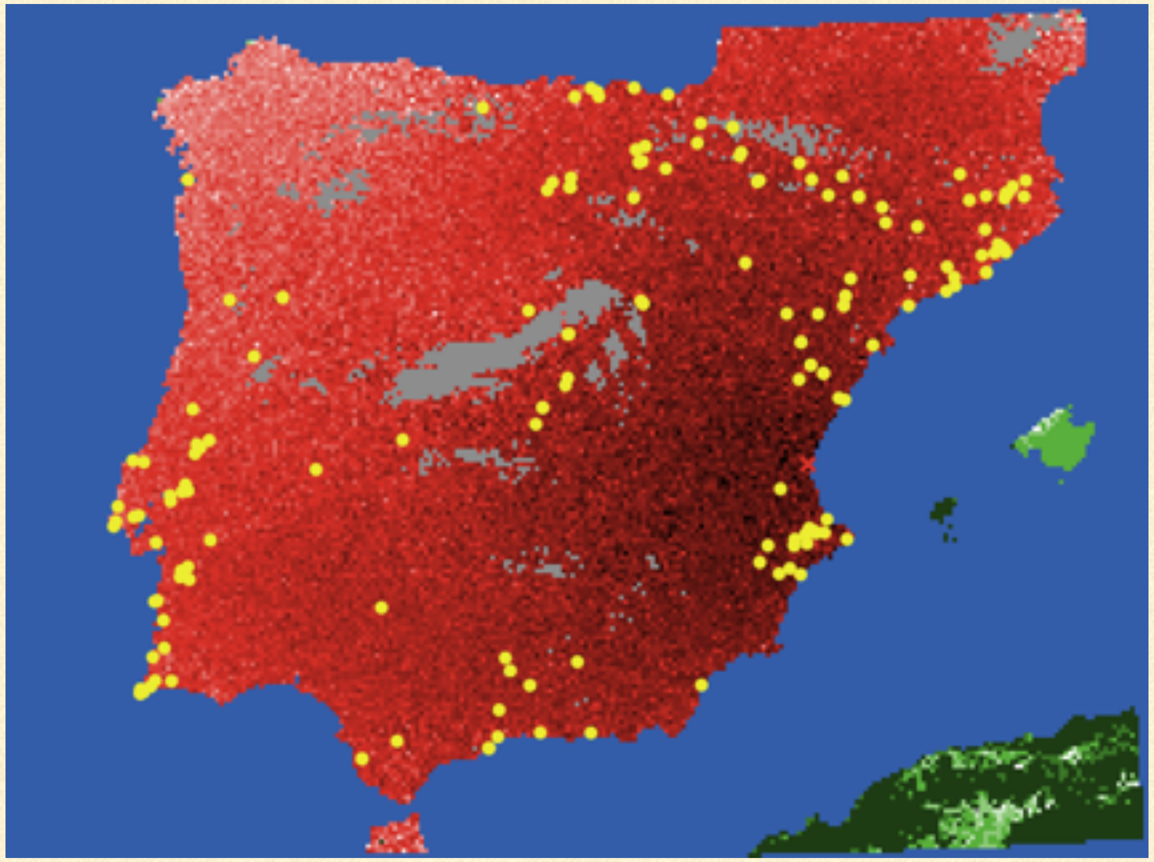




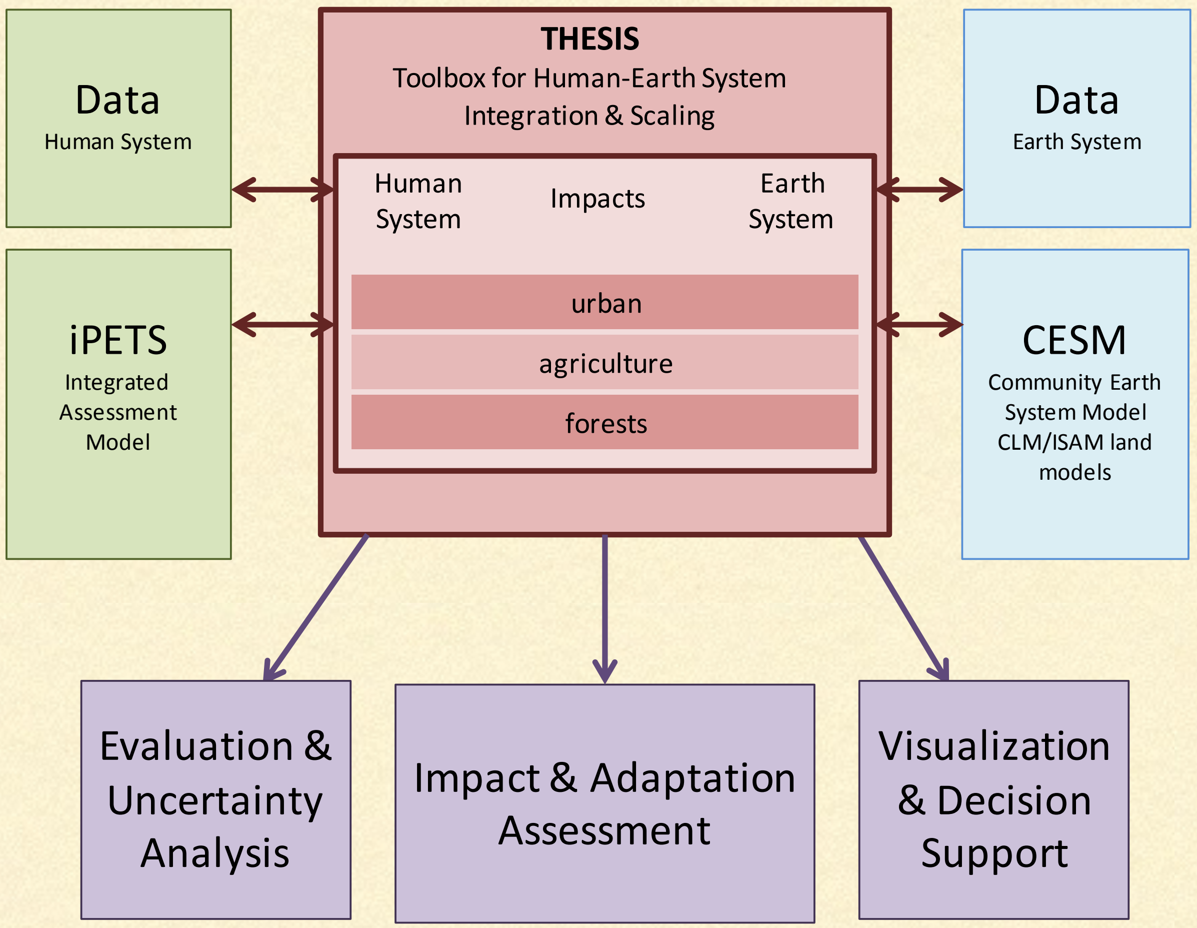
SPREAD OF FARMING IN THE WESTERN MEDITERRANEAN

- Comparing results with empirical data



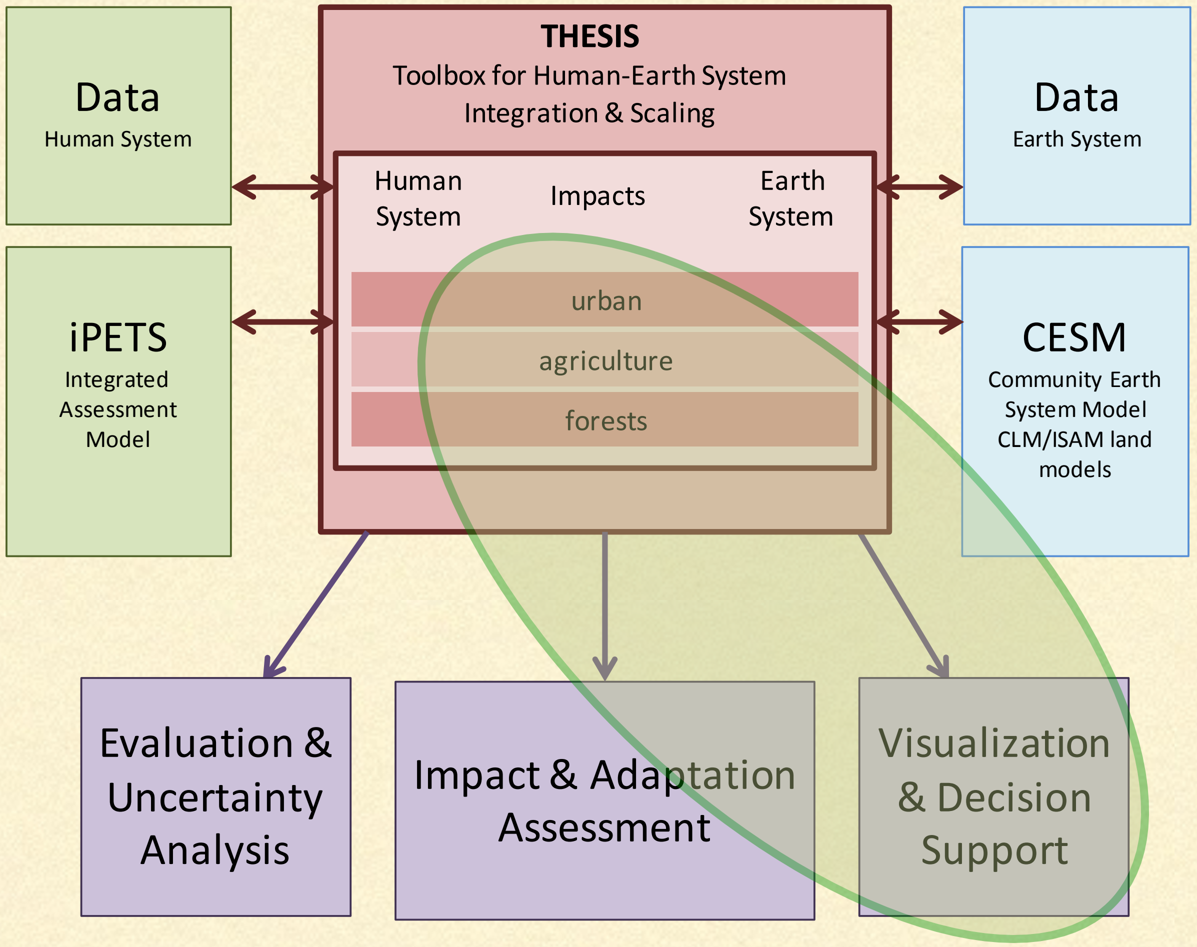


SOCIAL IMPACTS OF CLIMATE CHANGE



- Linking human and earth system models to assess regional impacts and adaption in urban systems and their hinterlands
- Creating decision-support tools to make modeling more useable for planning and policy
- Focus on developing world (BRIC)

SOCIAL IMPACTS OF CLIMATE CHANGE

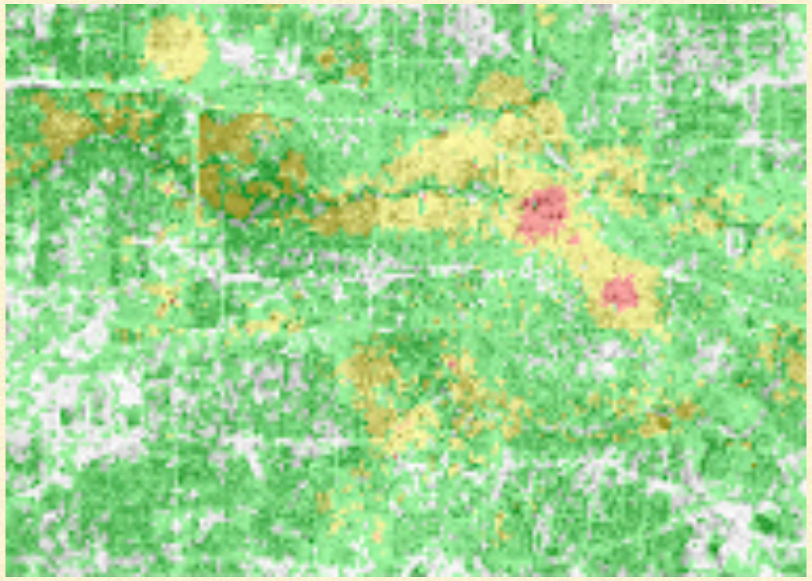


- Linking human and earth system models to assess regional impacts and adaption in urban systems and their hinterlands
- Creating decision-support tools to make modeling more useable for planning and policy
- Focus on developing world (BRIC)

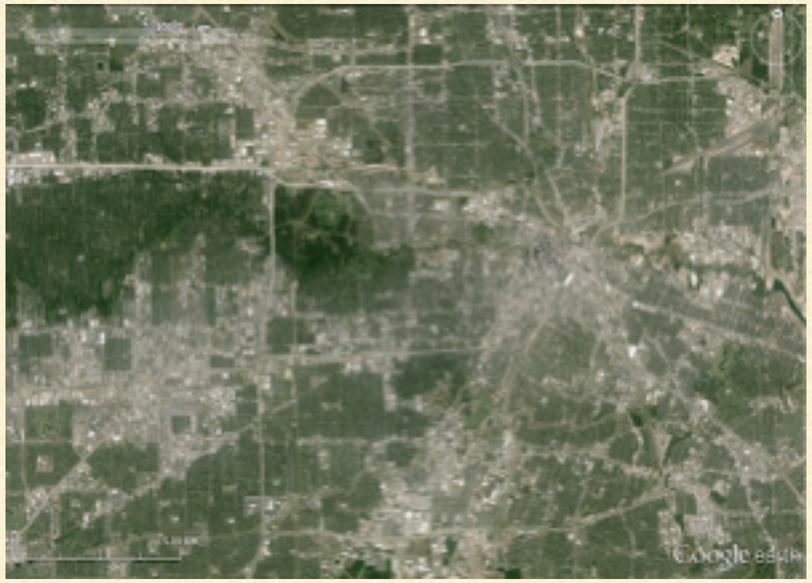
SOCIAL IMPACTS OF CLIMATE CHANGE

- Current work developing a way to quantitatively and systematically map city morphology from remote sensing data

- Collaborating with ASU GeoDA Center to develop visualization and decision support tools

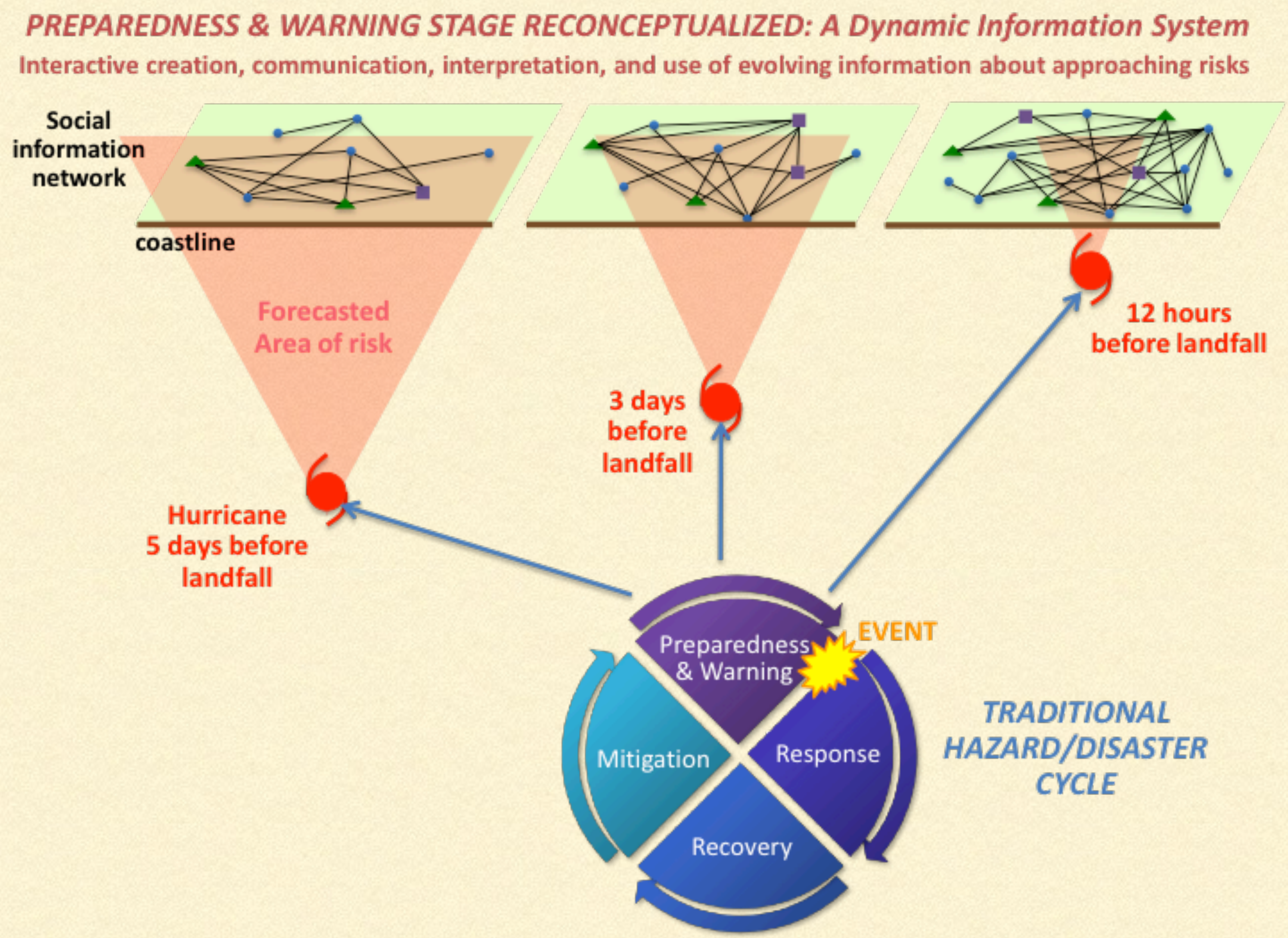


Houston, Tx - city morphology



Houston, Tx - Google Earth

SOCIAL INFORMATION NETWORKS & HAZARDS WARNINGS



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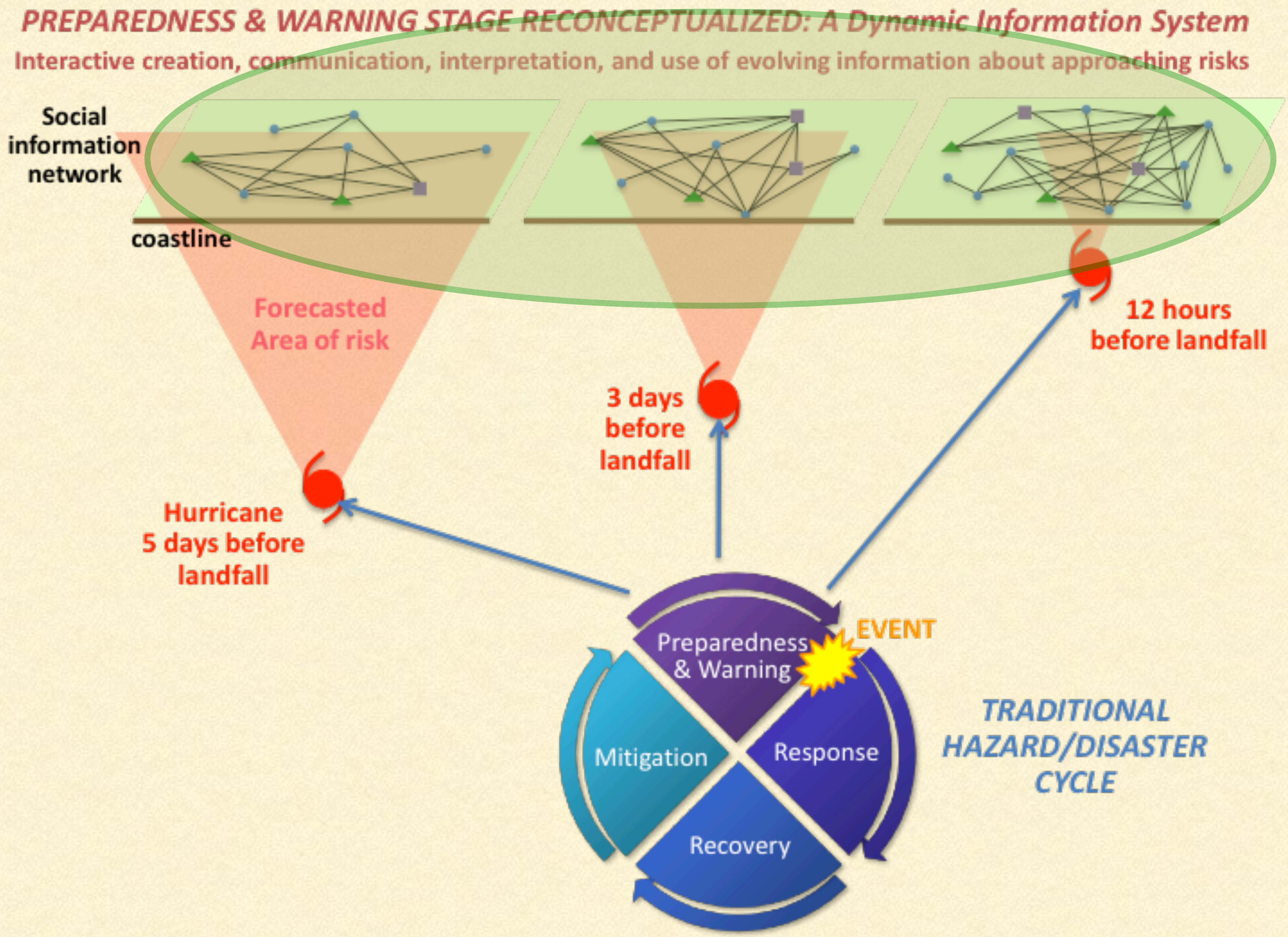
SOCIAL INFORMATION NETWORKS & HAZARDS WARNINGS



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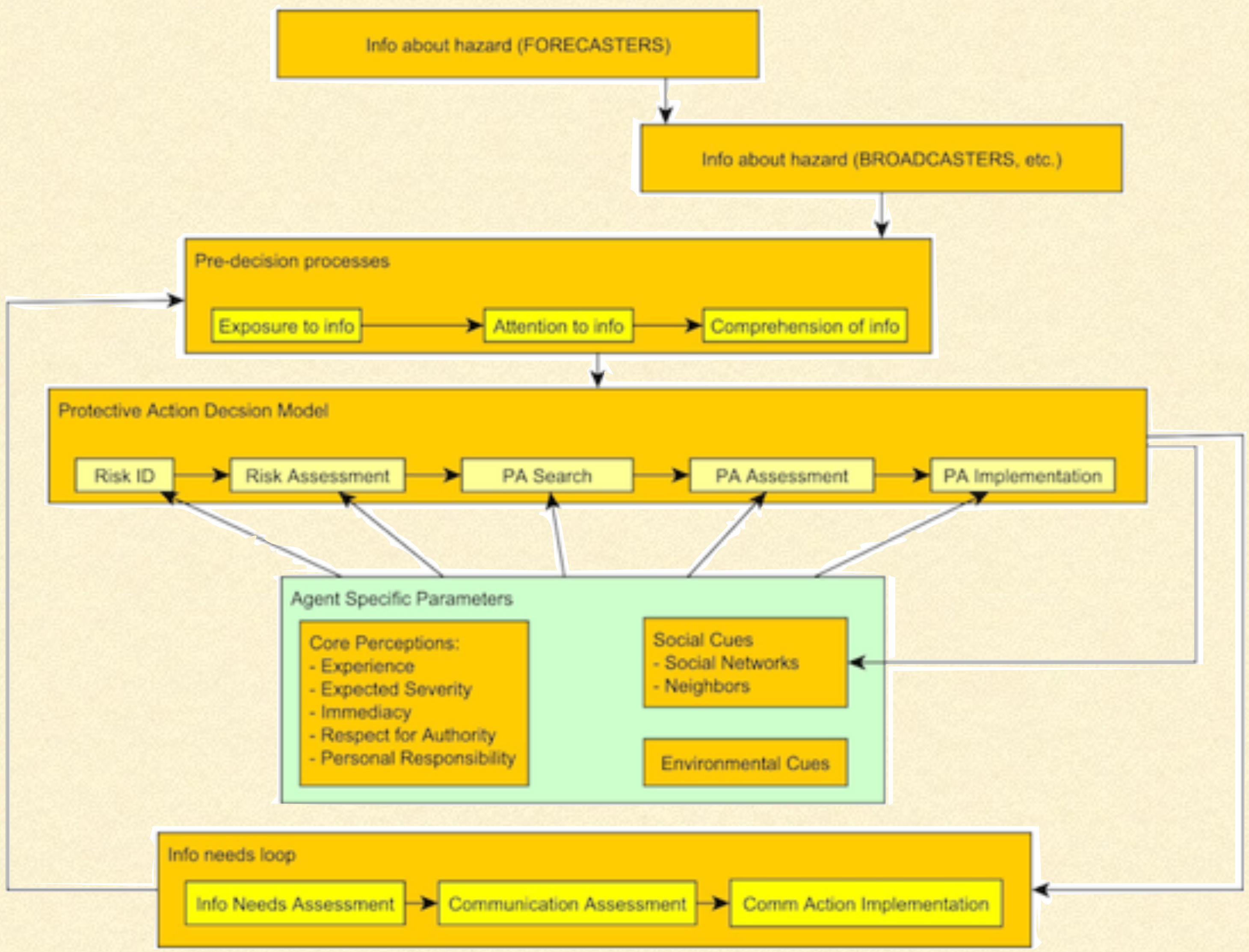
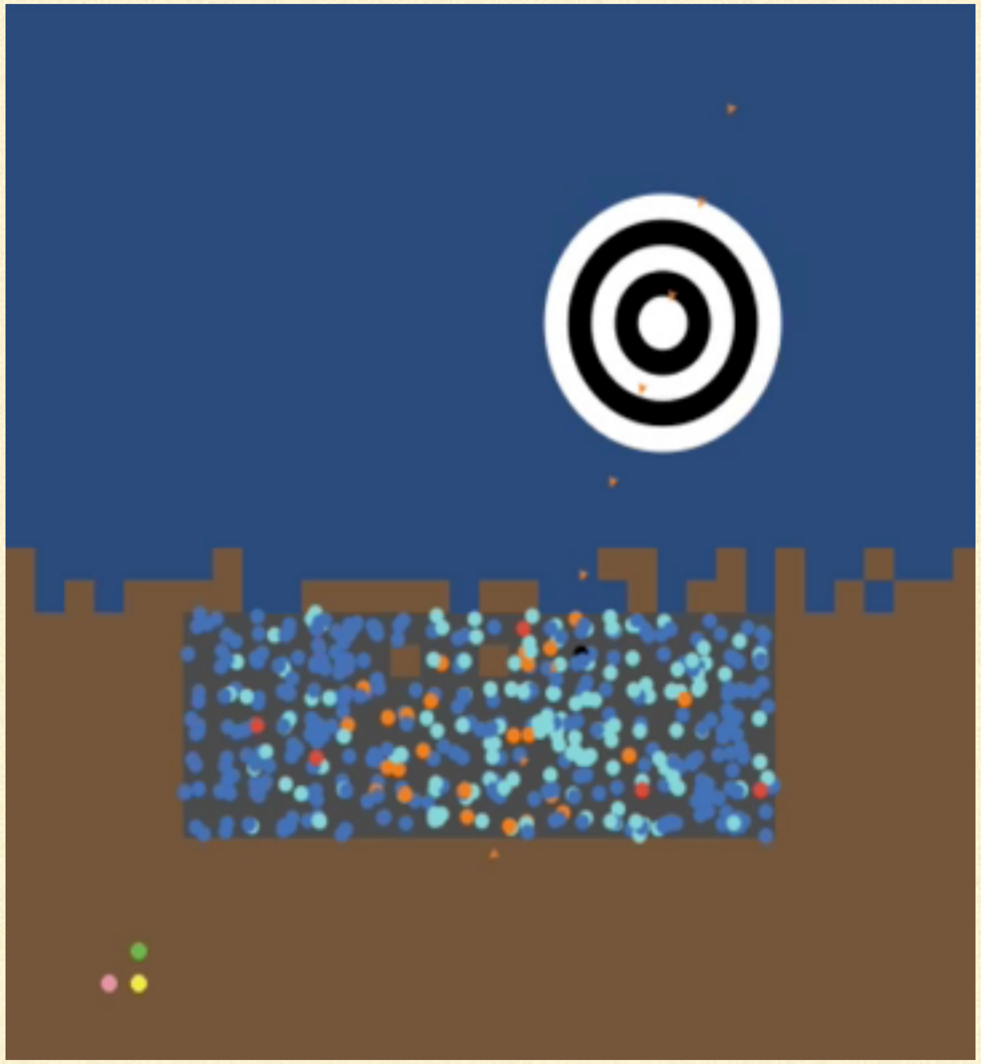
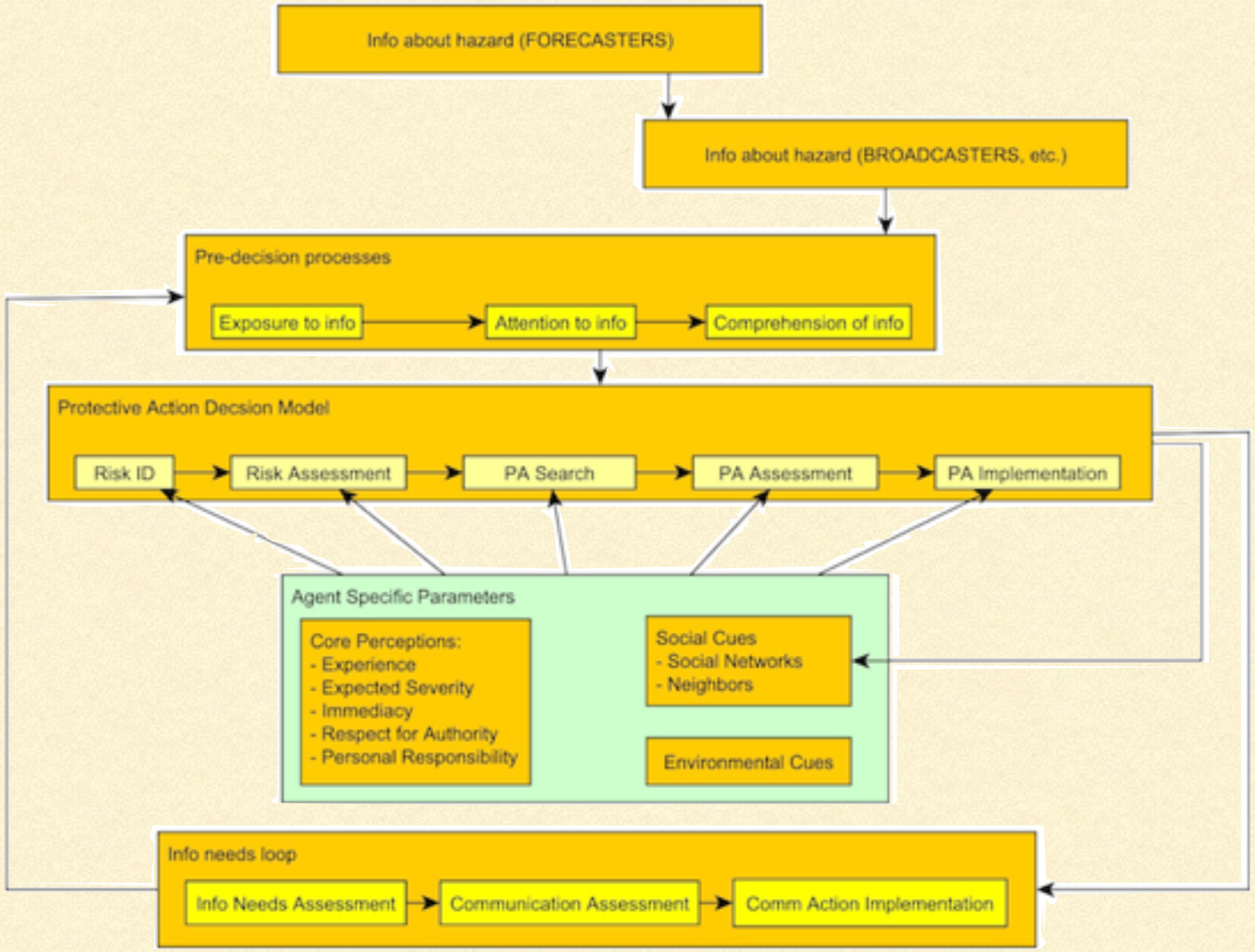
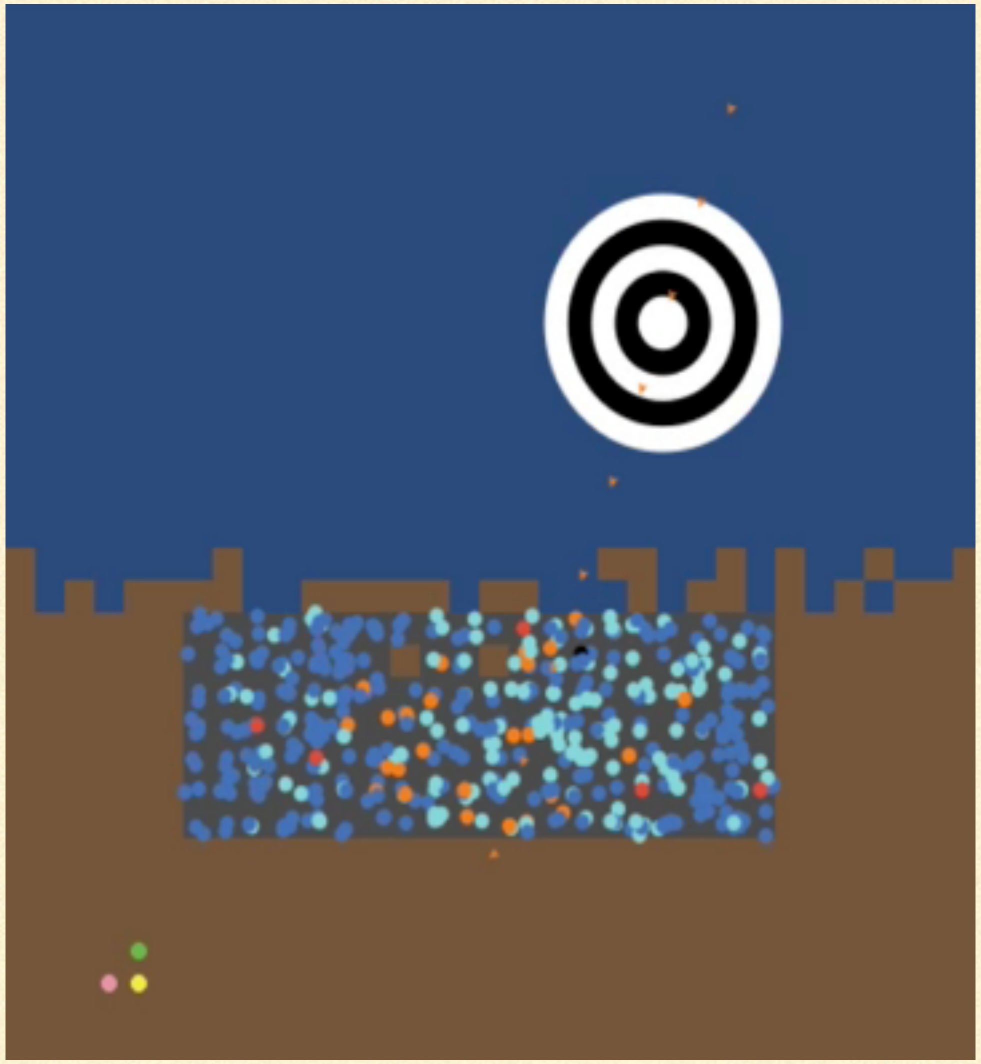




SOCIAL INFORMATION NETWORKS & HAZARDS WARNINGS





ENABLING TECHNOLOGIES & SCIENCE

- Science is not technology, but some technologies can transform science

ENABLING TECHNOLOGIES & SCIENCE

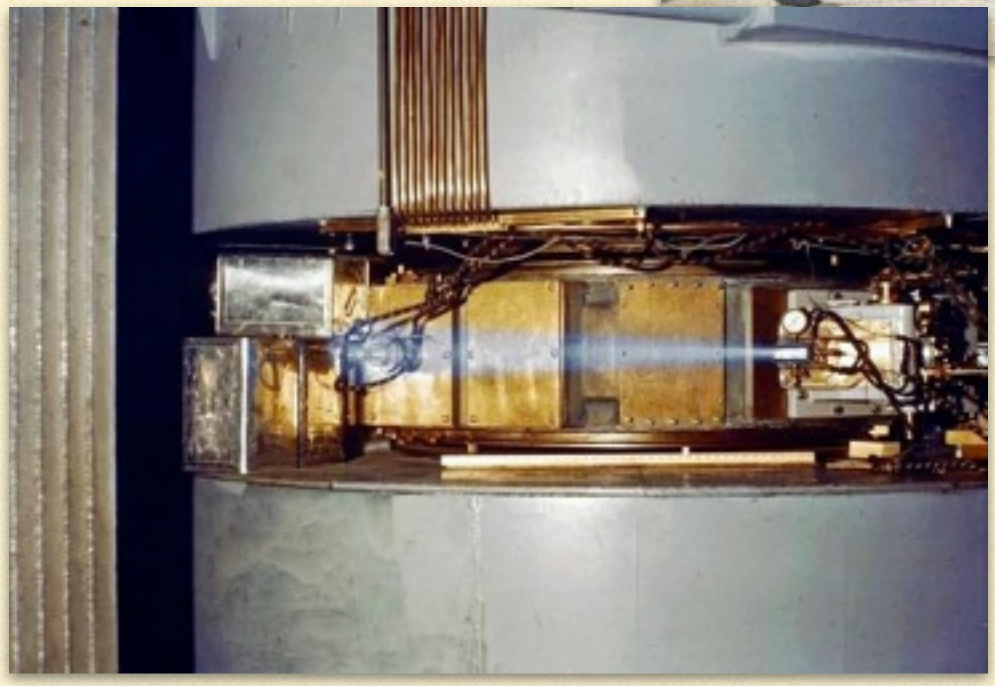
- Science is not technology, but some technologies can transform science

- Telescope

ENABLING TECHNOLOGIES & SCIENCE

- Science is not technology, but some technologies can transform science
- Telescope
- Microscope

ENABLING TECHNOLOGIES & SCIENCE



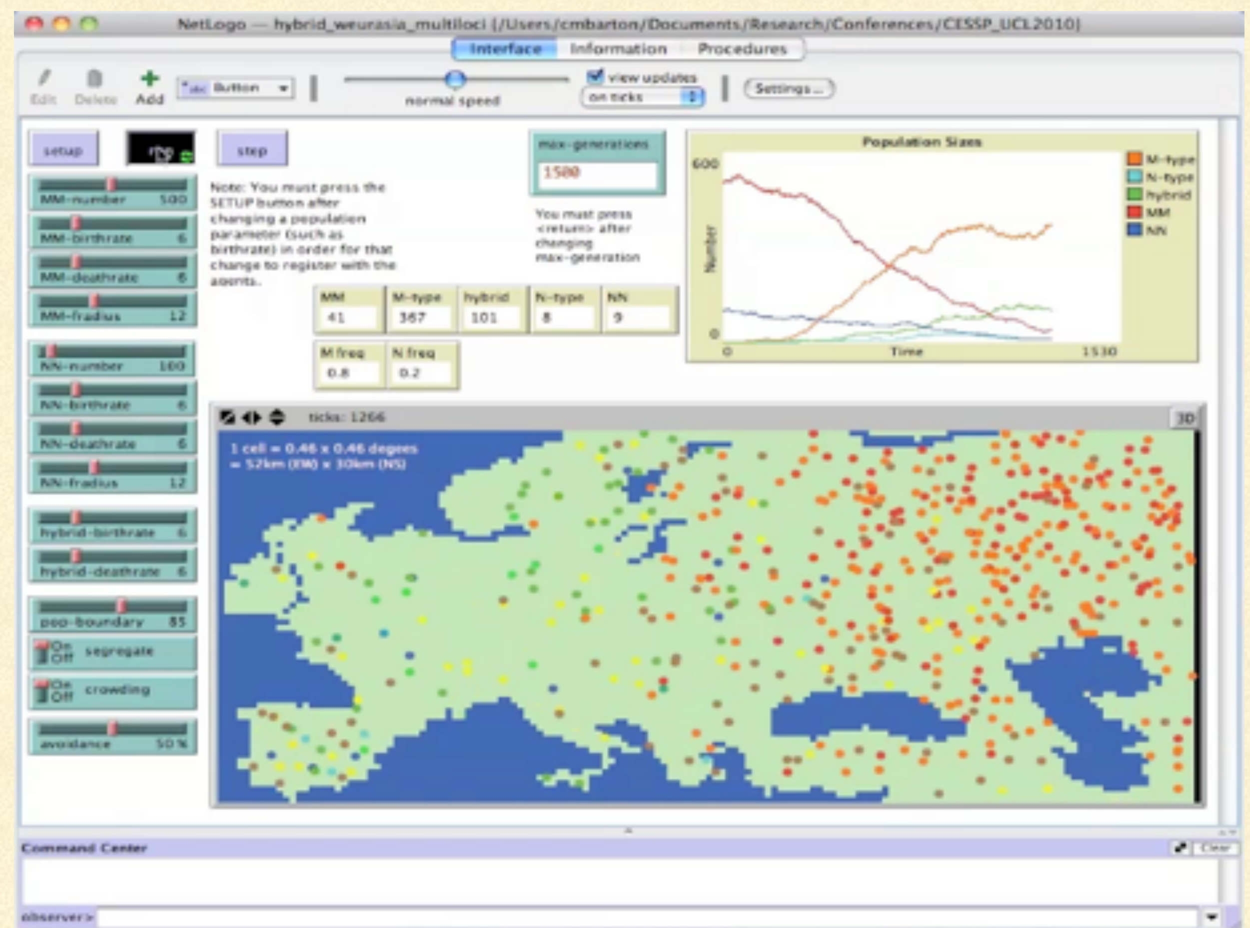
- Science is not technology, but some technologies can transform science
- Telescope
- Microscope
- Cyclotron

COMPUTATION & SOCIOECOLOGICAL SYSTEMS

- New computational tools to help understand and anticipate dynamics of complex world we have created
- Trace causation that is hidden in complex interactions and feedbacks
- Anticipate long-term consequences of decisions and environmental not easily visible in socioecological systems
- Express complex interactions and dynamics in quantitative form for better communication across scientific disciplines
- Create a robust experimental social science that permits controlled replication of social processes. 'Re-run the tape' (S.J. Gould)

COMPUTATION & SOCIOECOLOGICAL SYSTEMS

- Transformative technology for science of complex socioecological systems



COMPUTATION & SOCIOECOLOGICAL SYSTEMS

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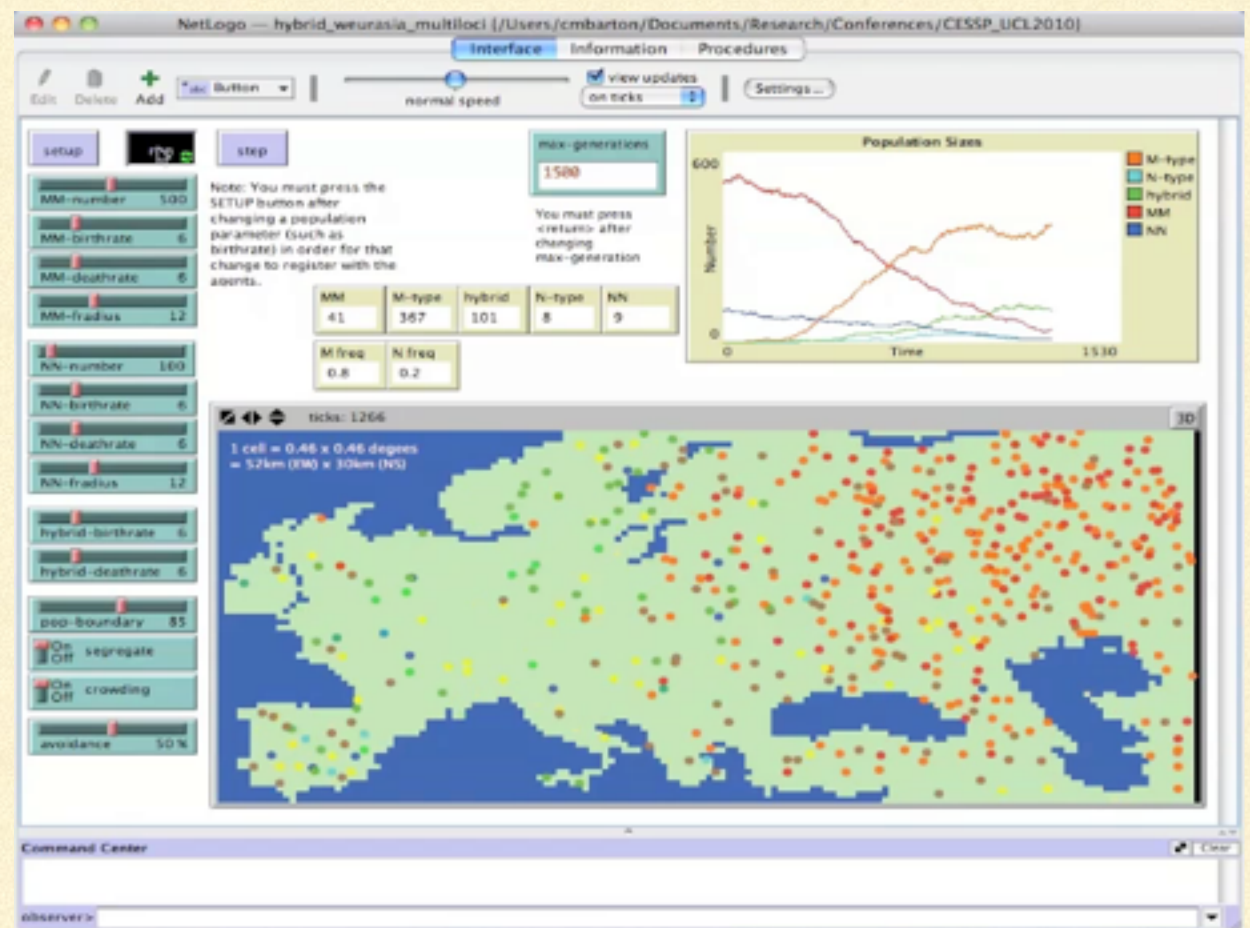


ACKNOWLEDGEMENTS

- Mediterranean Landscape Dynamics: National Science Foundation, Coupled Natural and Human Systems Program, grants BCS-410269, DEB-1313727
- Social Impacts of Global Climate Change: National Science Foundation, Earth Systems Modeling 2 Program, grant AGS-1243089
- Modeling dynamic social information networks: National Science Foundation, Hazard SEES Program, grant DEB-1313727

ACKNOWLEDGEMENTS

- ASU: School of Human Evolution and Social Change, Center for Social Dynamics & Complexity, School of Earth and Space Exploration, School of Computing Informatics and Decision Systems Engineering, School of Geographical Sciences and Urban Planning, School of Sustainability, Decision Theater Alliance

- Partners: Universitat de València, Universidad de Murcia, University of Jordan, University of Colorado Denver, University of North Texas, North Carolina State University, Argonne National Laboratory, University of Wisconsin, Hendrix College, Geoarchaeological Research Associates, GRASS GIS Development Team, National Center for Atmospheric Research, University of Illinois Urbana-Champagne, University of Kansas, University of Colorado Boulder

COMSES NET

http://www.openabm.org

- **Network for Computational Modeling in the Social & Ecological Sciences**
- NSF sponsored *Research Coordination Network*
- A collaborative community of practice to share knowledge about modeling social & ecological systems

A KNOWLEDGE MARKETPLACE

ASCAPE

SWARM

NetLogo

StarLogo on the web

repast

MODGEN

Jason Agent Programming

Modelling 4 All

SOARS

SeSAm Multiagent Simulation

Jason Induction of Logical Decision Trees

MOBIDYC

LABORATORY FOR SIMULATION DEVELOPMENT ...because open source matters

Cormas Natural resources and agent-based simulations

Sugarscape Growing Artificial Societies

MATSim Multi-Agent Transport Simulation

M A S O N

MimOsa

amp

DEVS-Suite Simulator

EcoLab

ENVISION Integrated Modeling Platform

A spatially explicit, distributed, multiagent-based framework for policy assessment and alternative futuring

MADeM: Multi-modal Agent Decision Making

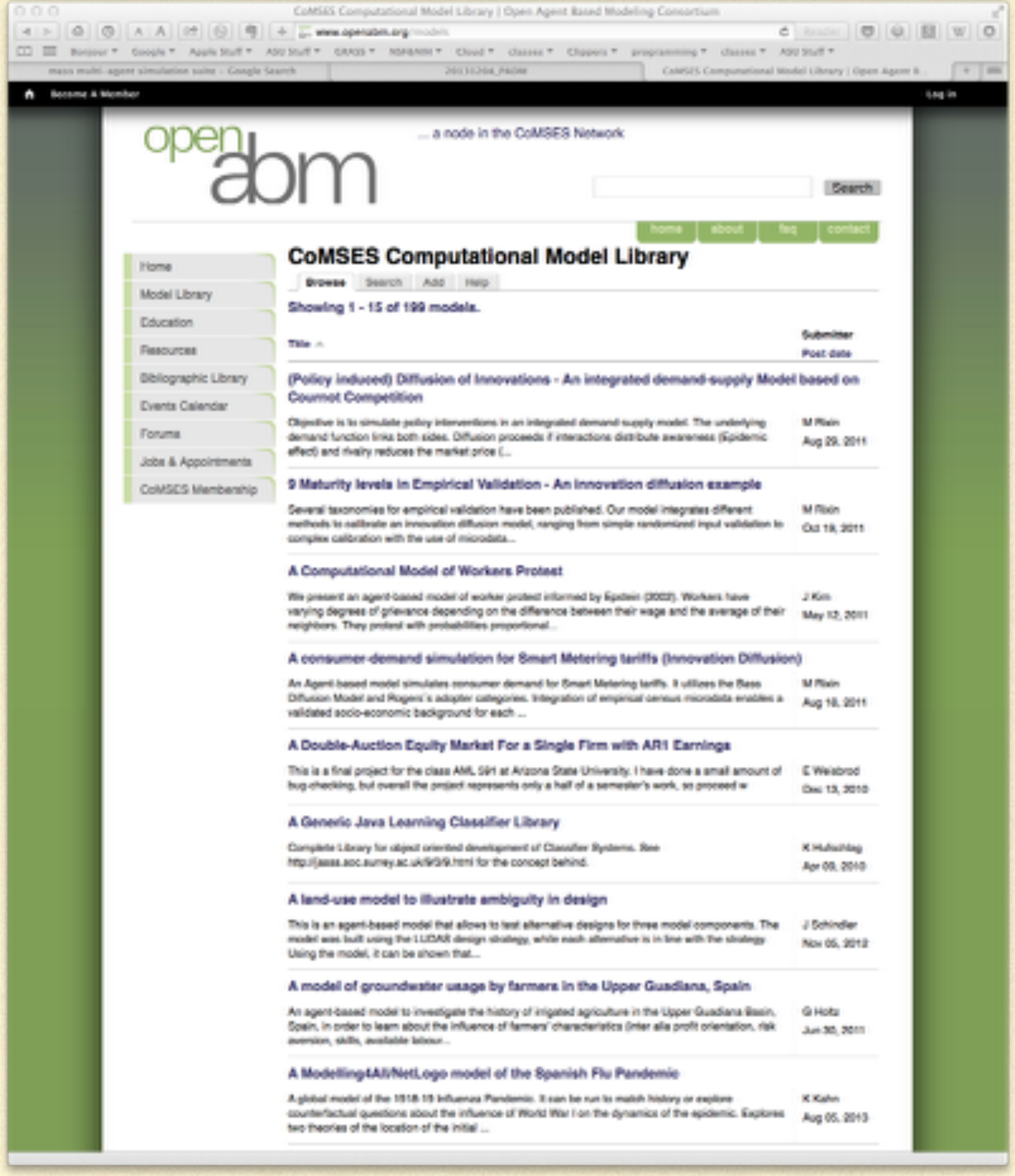
AnyLogic

TerraME

OpenStarLogo

PROMOTING TRANSPARENCY IN SCIENTIFIC COMPUTING

- **Computational Model Library**



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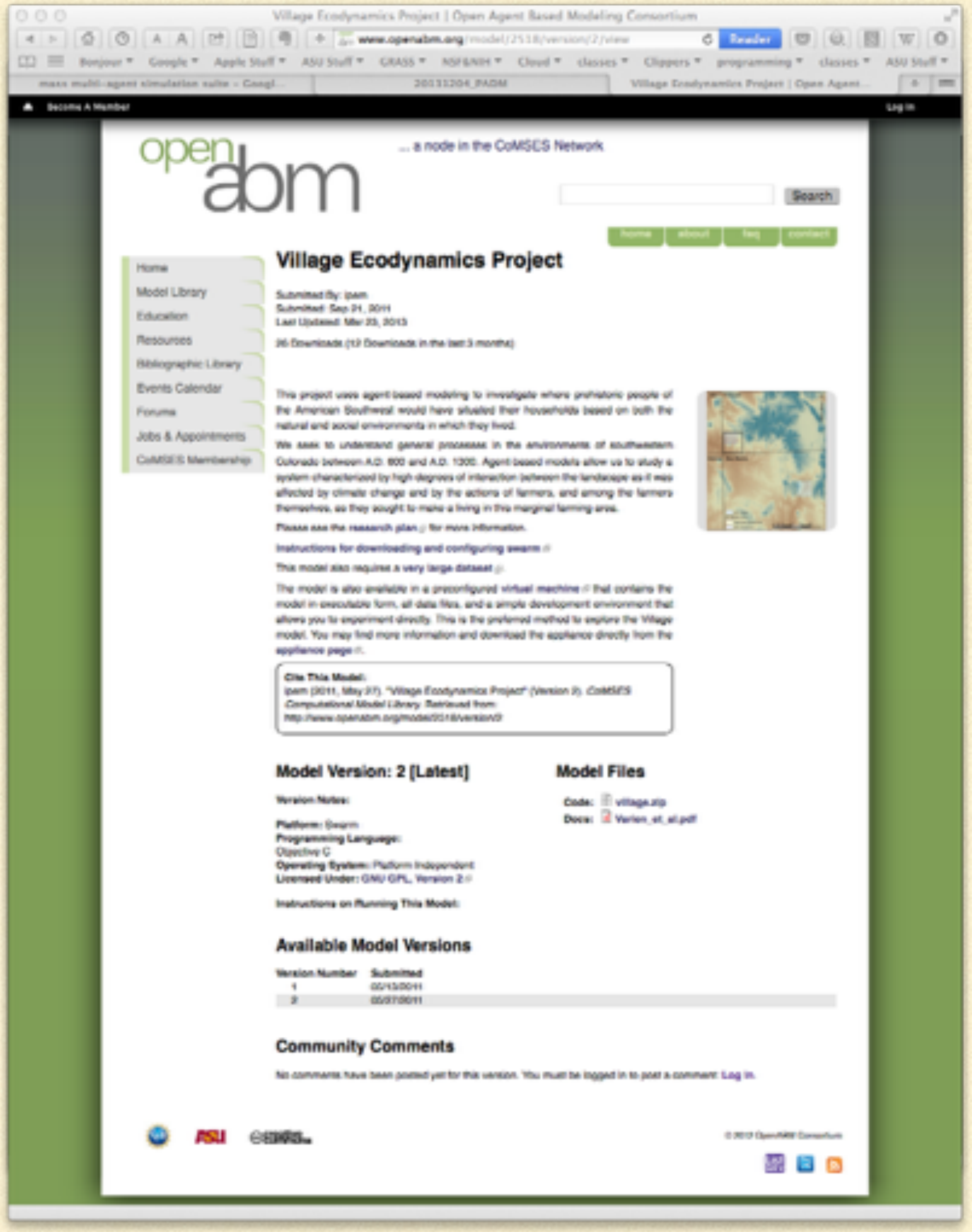
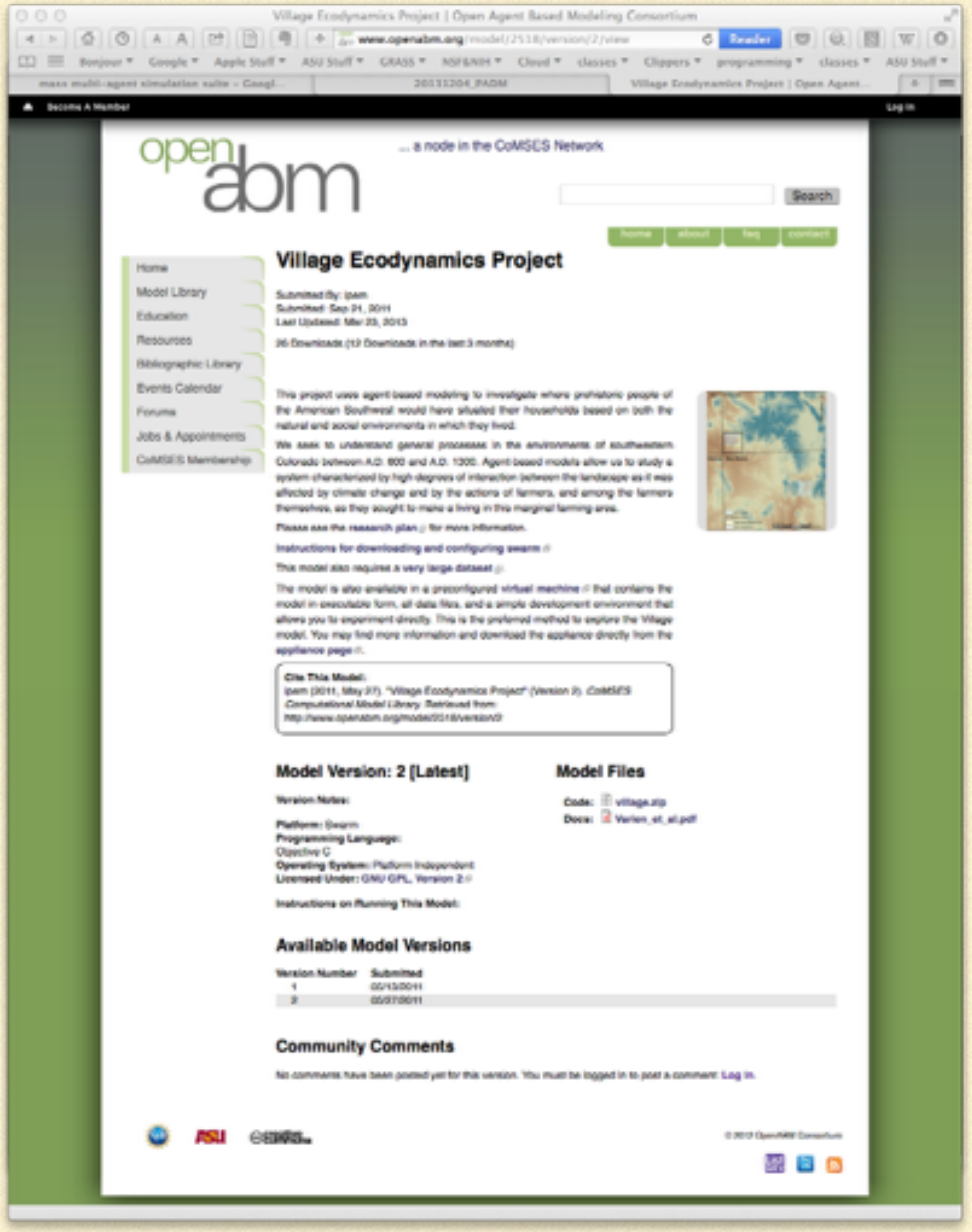
PROMOTING TRANSPARENCY IN SCIENTIFIC COMPUTING

- **Computational Model Library**
- Open-access publishing of model code



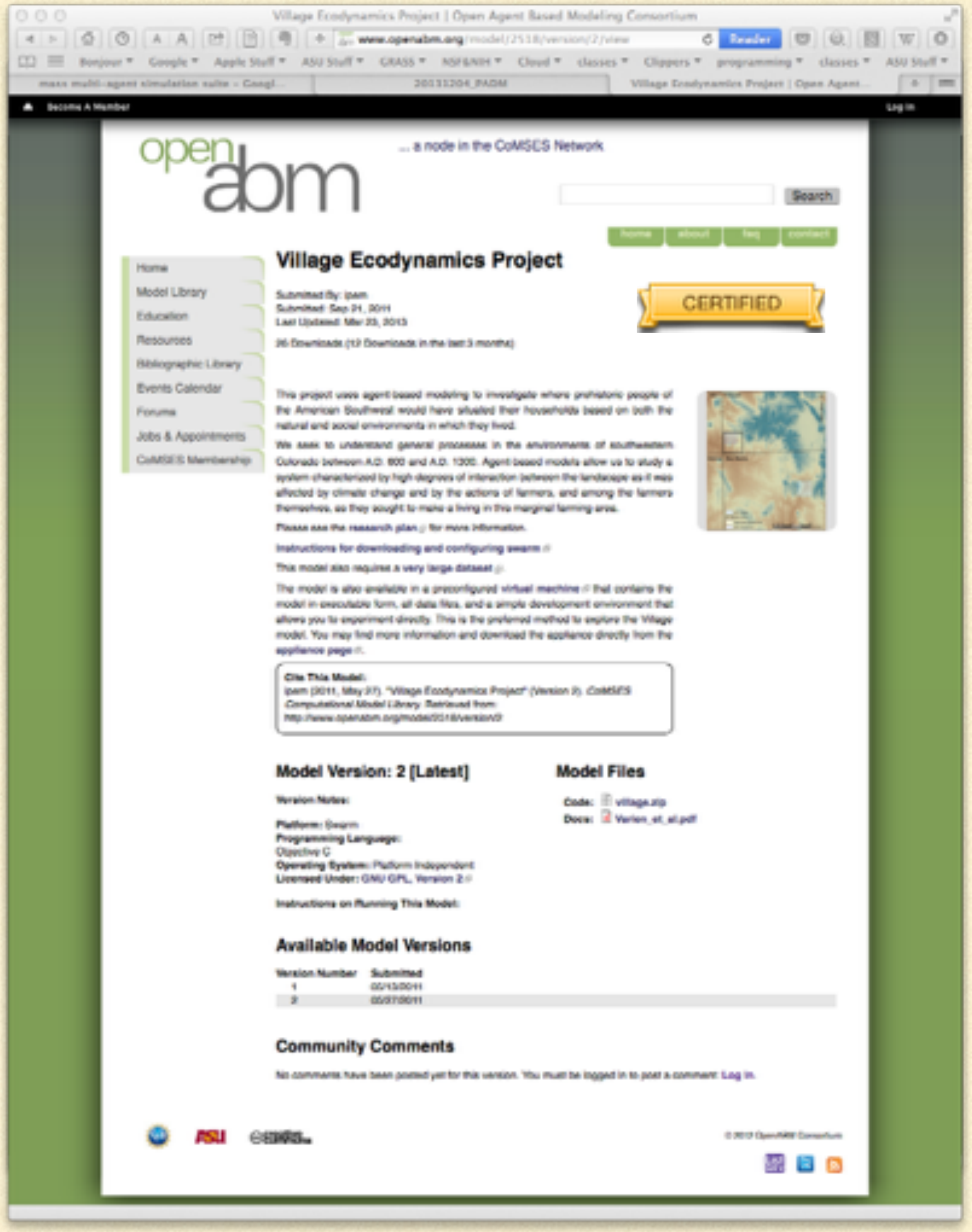
PROMOTING TRANSPARENCY IN SCIENTIFIC COMPUTING

- **Computational Model Library**
- Open-access publishing of model code
- Community standards and best practices for model description and citation



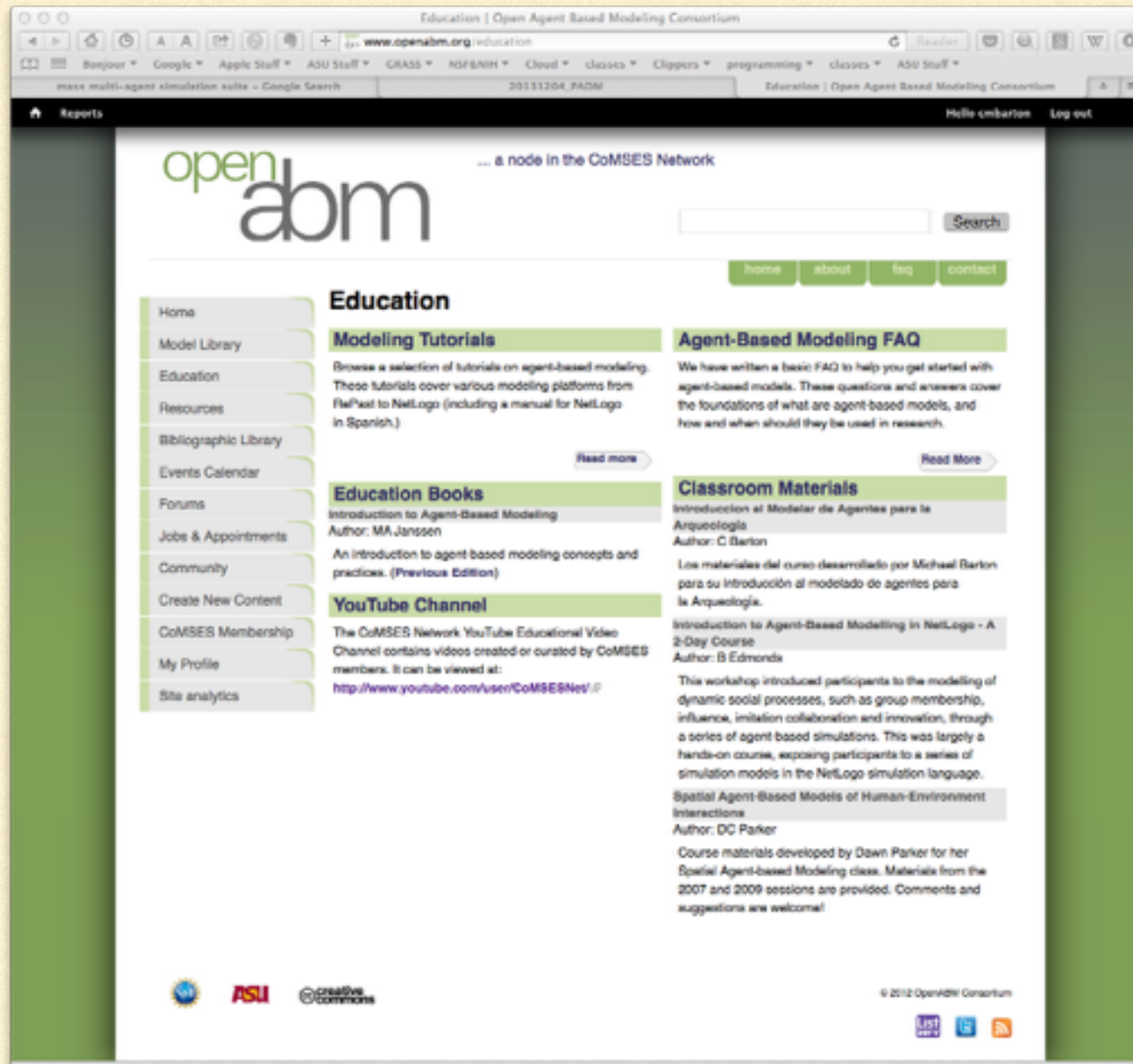
PROMOTING TRANSPARENCY IN SCIENTIFIC COMPUTING

- **Computational Model Library**
- Open-access publishing of model code
- Community standards and best practices for model description and citation
- Peer review of models



EDUCATION FOR COMPUTATIONAL THINKING

- Developing educational curricula for embedding modeling and computational thinking



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