

#### EARTH SYSTEMS AS HUMAN SYSTEMS

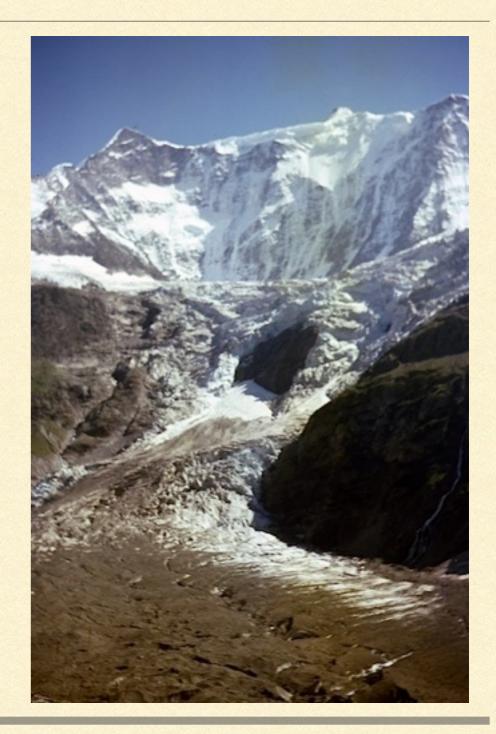
Modeling Interactions Between People & the Environment in the Anthropocene



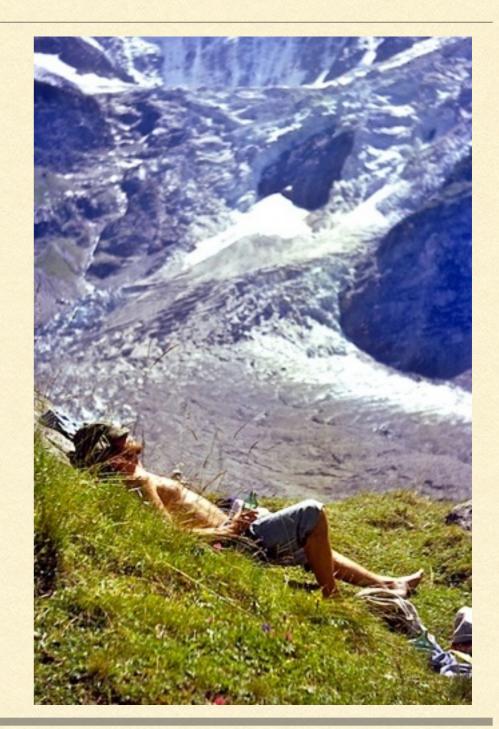
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Modeling Interactions Between People & the Environment in the Anthropocene

 Scientific study often assumes a world without people



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- Incorrect and misleading



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- Incorrect and misleading
- People have altered the earth for a long time





 Anthropogenic contributions may seem small

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





The Anthropocene

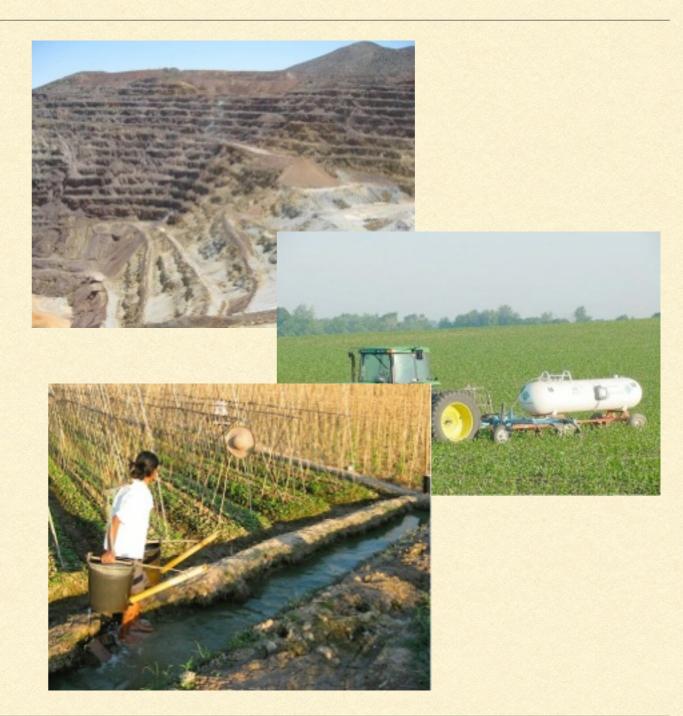
- The Anthropocene
  - More terrestrial sediment moved



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  - More terrestrial sediment moved
  - More Nitrogen cycled



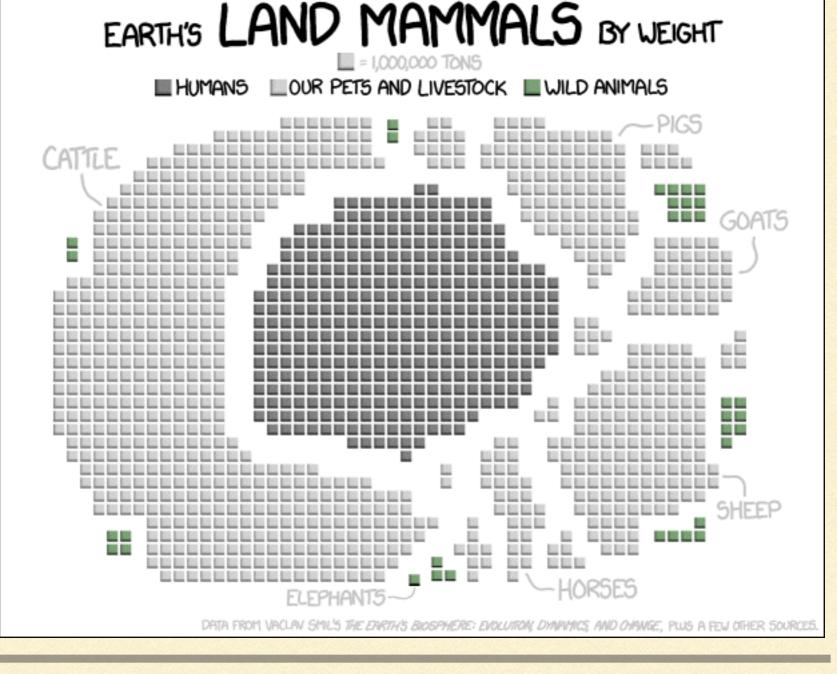
- The Anthropocene
  - More terrestrial sediment moved
  - More Nitrogen cycled
  - Over half of surface fresh water

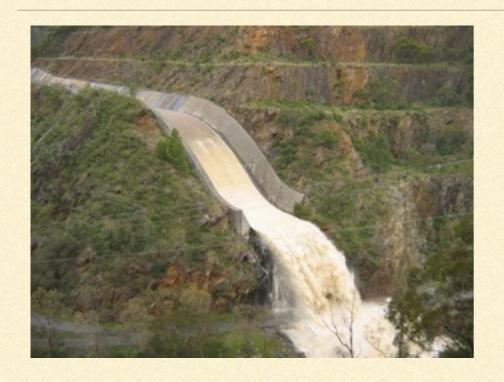


EARTH'S LAND MAMMALS BY WEIGHT OUR PETS AND LIVESTOCK WILD ANIMALS HUMANS -PIGS 888 00000 The Anthropocene LE LE LE LE LE LE LE LE . . . . . . . . . . 12 12 12 13 13 12 15 12 0.0 12 13 12 12 101 103 12 15 12 E E E E E 13 <u>8</u> 8 8 13 10 12 12 10 IO IO 18 18 12 13 12 100 13 DATA FROM VACLAN SMIL'S THE BARTH'S BIOSPHERE: BUOLUTION, DYNAMICS, AND CHANGE, PWS A FEW OTHER SOL

The Anthropocene

 Agro-biomass more than all other animals





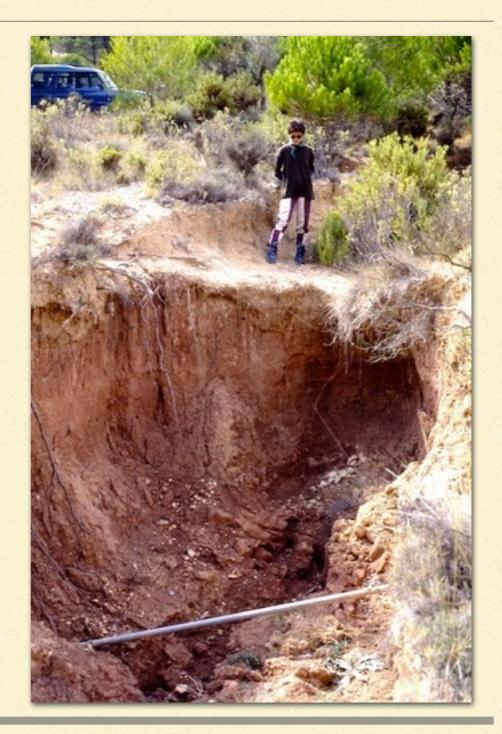
Real-world landscape dynamics today must take into account human contribution



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



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

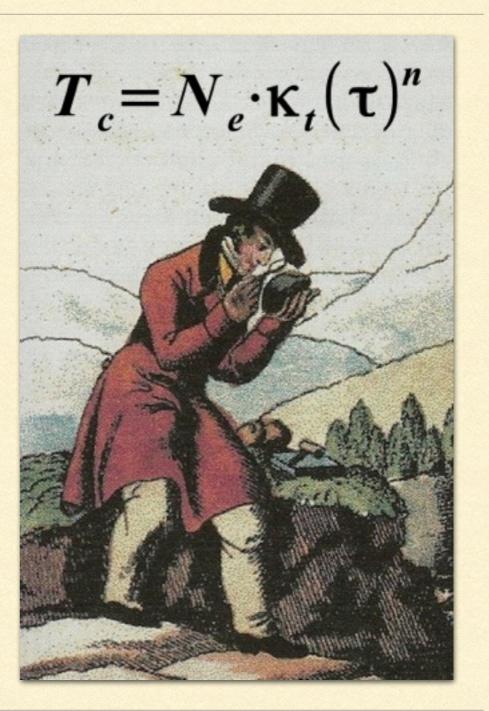


 Shift in characterizing physical landscape formation processes

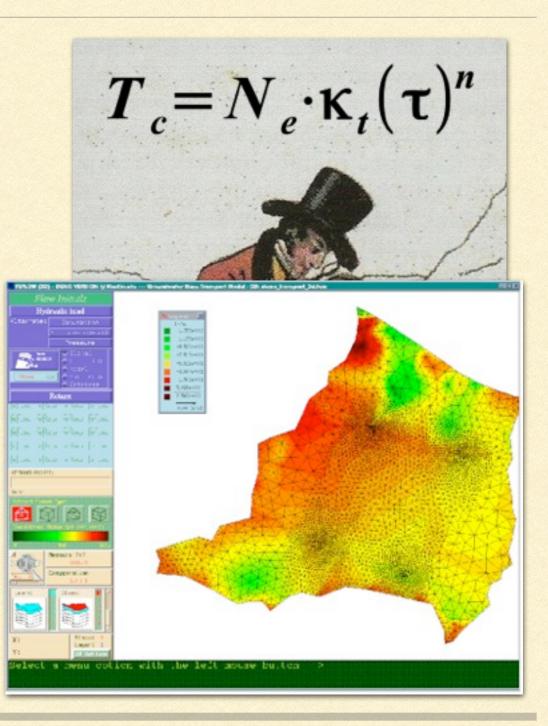
- Shift in characterizing physical landscape formation processes
  - From observation and intuition



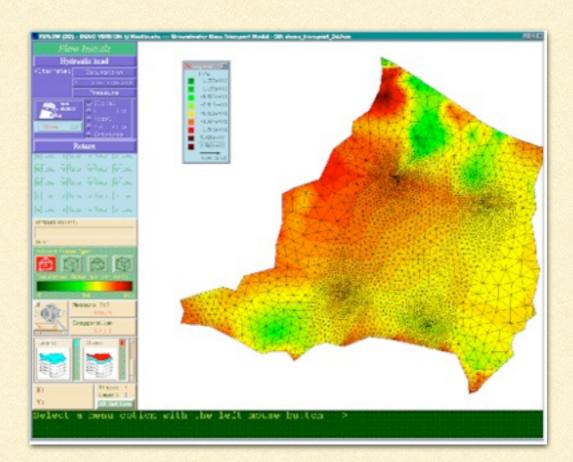
- Shift in characterizing physical landscape formation processes
  - From observation and intuition
  - To numerical equations



- Shift in characterizing physical landscape formation processes
  - From observation and intuition
  - To numerical equations
  - To multidimensional computational models



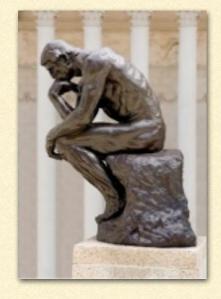
- Shift in characterizing physical landscape formation processes
  - From observation and intuition
  - To numerical equations
  - To multidimensional computational models
- Better explanation and prediction of multidimensional landscape change



- 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

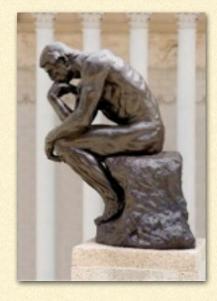
Expressed behavior result of complex decisions

- Expressed behavior result of complex decisions
  - Can be rational or irrational





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  - Can be rational or irrational
  - Economic, ritual, emotional, affective, etc

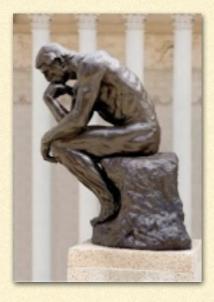








- Expressed behavior result of complex decisions
  - Can be rational or irrational
  - Economic, ritual, emotional, affective, etc
  - Can be modeled as algorithms of decision rules that are activated in different contexts









if energy < move\_threshhold
 [ move ]</pre>

Human behavior highly predictive in many cases.



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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



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  - Variation on how each individual implements culturally common decision rules, given personal history and proclivities

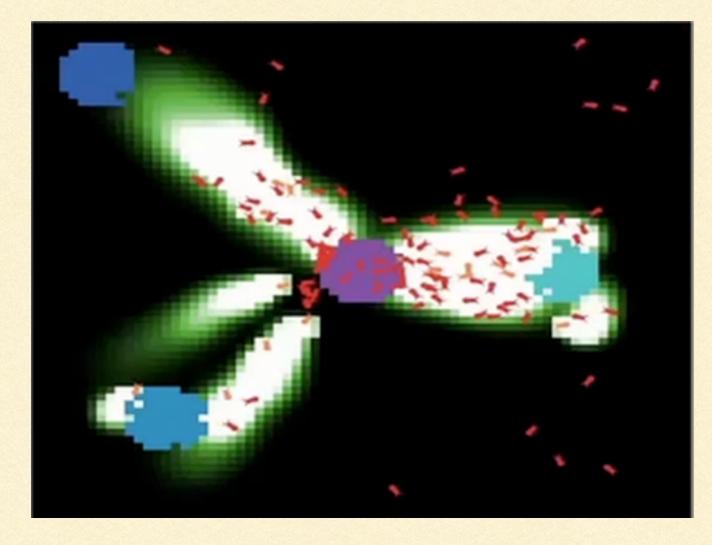


- Human behavior highly predictive in many cases.
- But...
  - Decisions result of interplay of multiple factors that vary from context to context, individual to individual, and with interactions among individuals
  - Variation on how each individual implements culturally common decision rules, given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

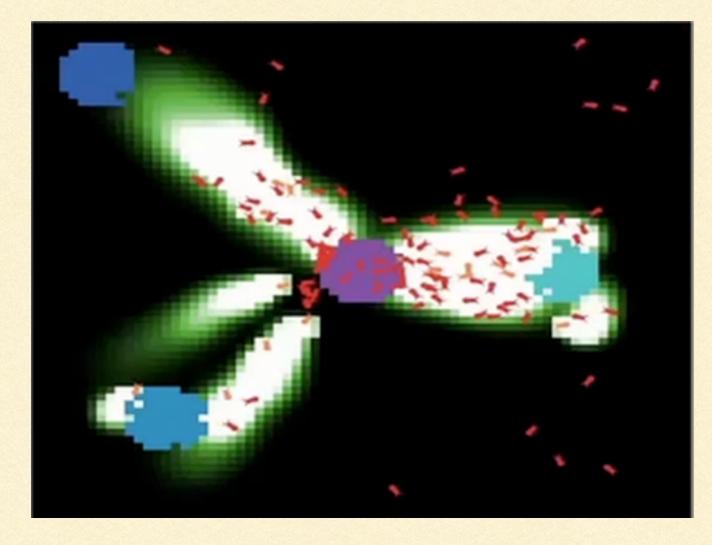


- Calls for modeling framework that...
  - represents behavior as context-specific expression of decisions
  - by discrete social agents
  - individually making decisions and acting
  - in a spatially explicit and variable social and natural environment

- 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)



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



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  - Agents can sense and respond to environment and other agents

- 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



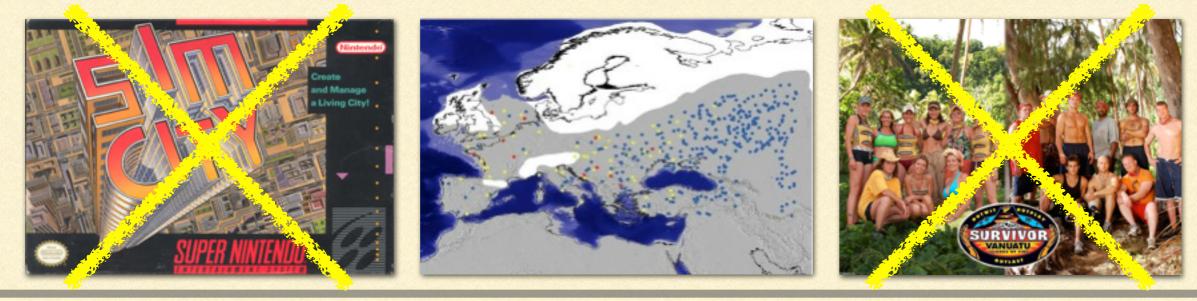
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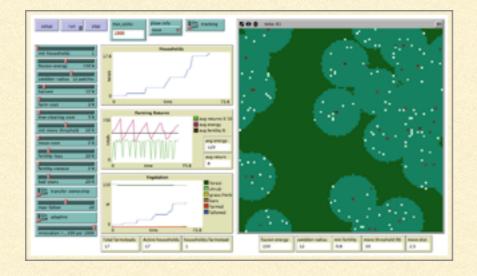


 ABM not an explanatory statement or description of a human system in narrative or equation form

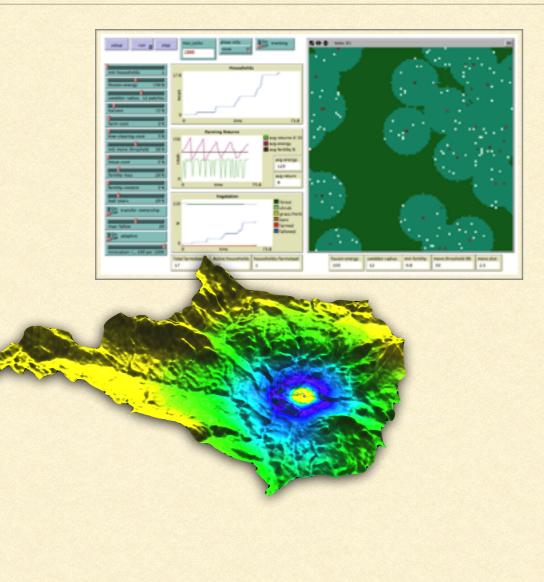
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- ABM is a framework for carrying out bottom up digital experiments in dynamics of complex, multi-component systems

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- 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

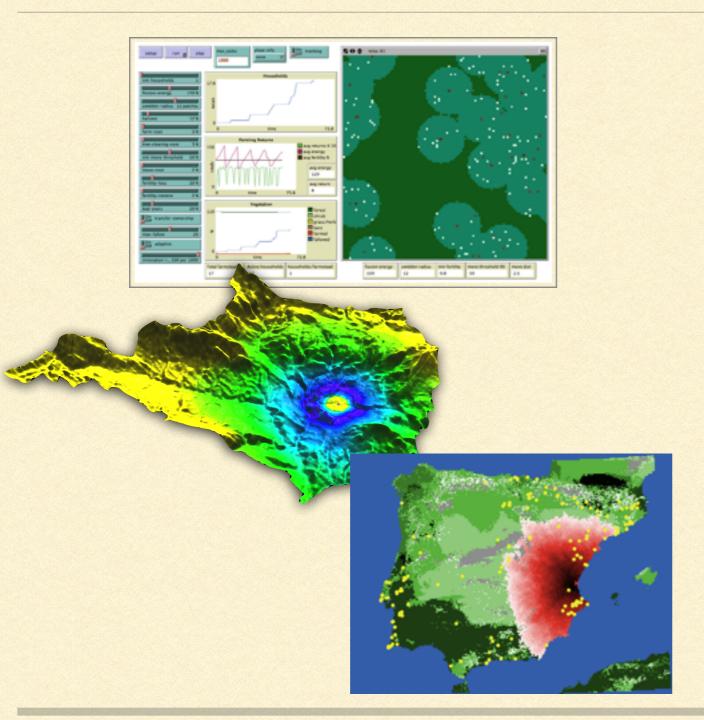




 Agent based model of agricultural land use

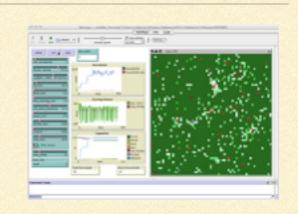


- Agent based model of agricultural land use
- Coupled model of long-term land use and landscape change



- 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

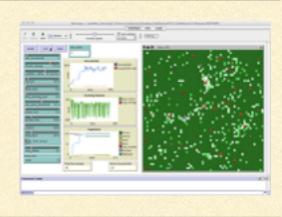


- Agricultural land-use
- Illustrate use of ABM for modeling human behavior. Created in NetLogo
  - Simple, abstract model to explore dynamics of agricultural land-use
  - Primarily economic decision rules; some probabilistic and stochastic rules
  - Agents are households: social decision-making entities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

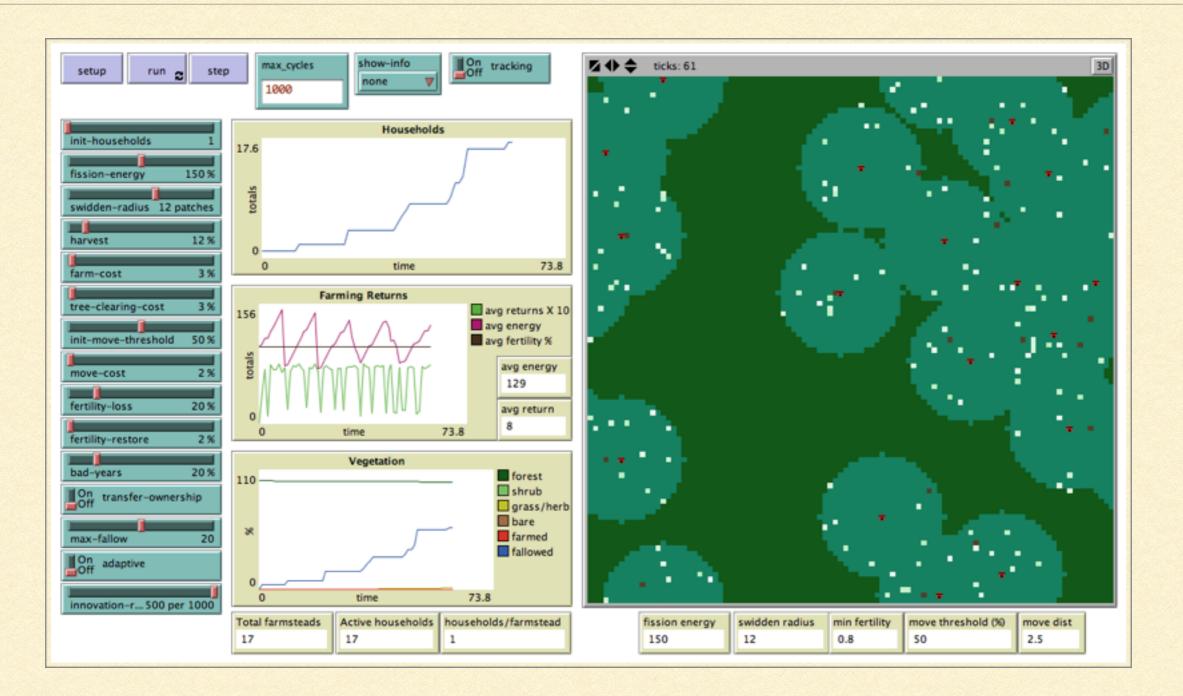
# EXAMPLE OF MODELING HUMAN BEHAVIOR

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

- 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



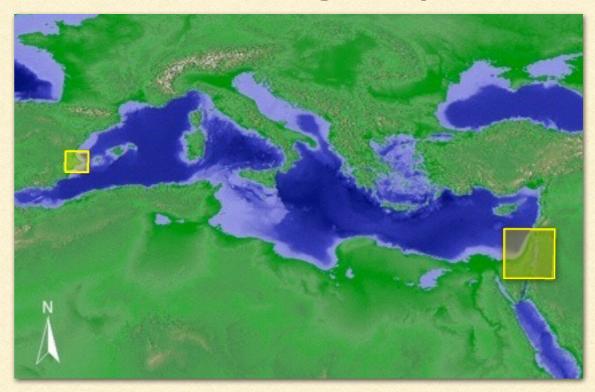
## EXAMPLE OF MODELING HUMAN BEHAVIOR



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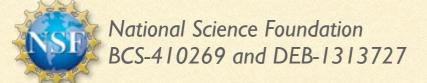
# MEDITERRANEAN LANDSCAPE DYNAMICS (MEDLAND)

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



Arizona State University Office Knowledge Enterprise & Development



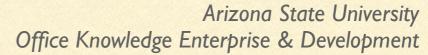


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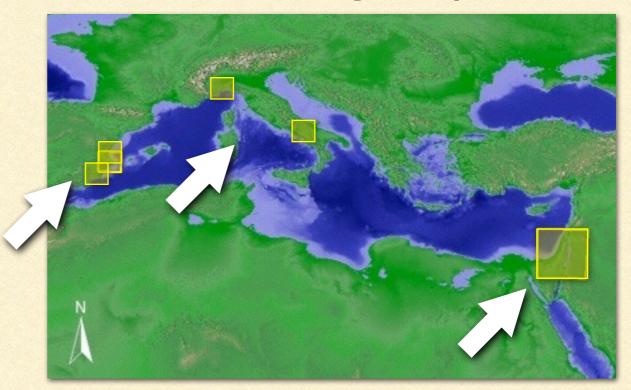
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New areas in Spain and Italy

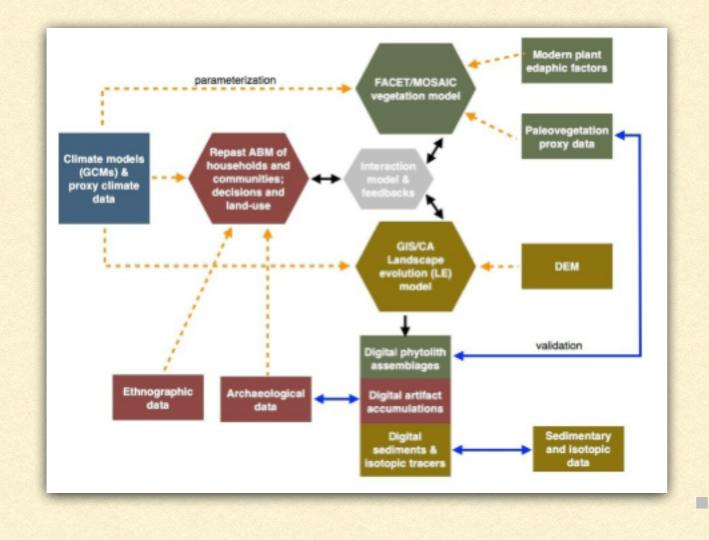
website - http://medland.asu.edu



Arizona State University Office Knowledge Enterprise & Development



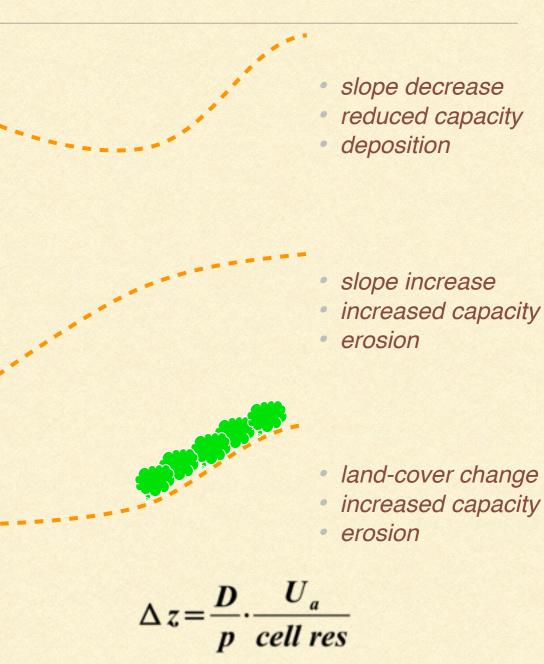
National Science Foundation BCS-410269 and DEB-1313727



- 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

Physical processes

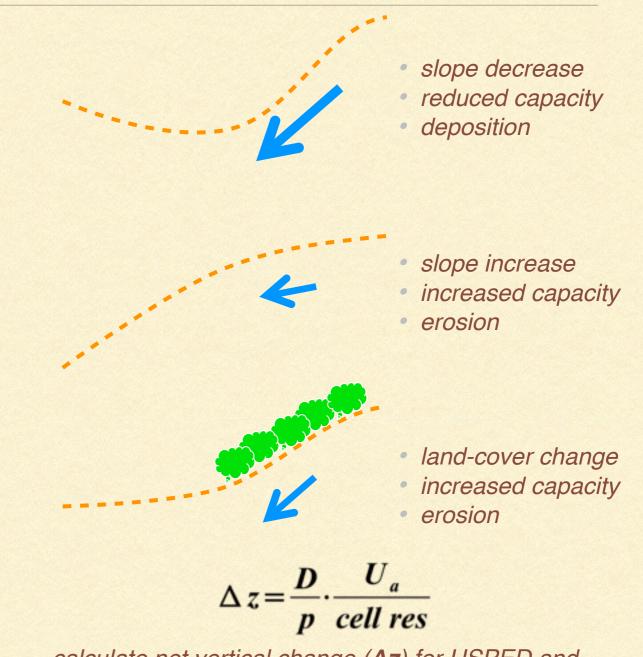


$$D = \operatorname{div} \vec{T}_{c} = \frac{\partial (T_{c} \cos \alpha)}{\partial x} + \frac{\partial (T_{c} \sin \alpha)}{\partial y}$$

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

calculate net vertical change ( $\Delta z$ ) for USPED and shear stress for soil density **p** and areal units **U**<sub>a</sub>

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



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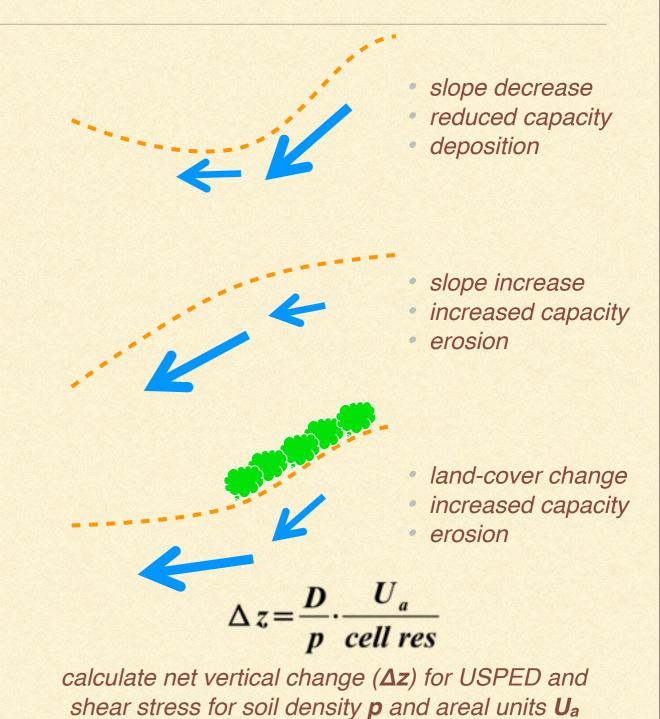
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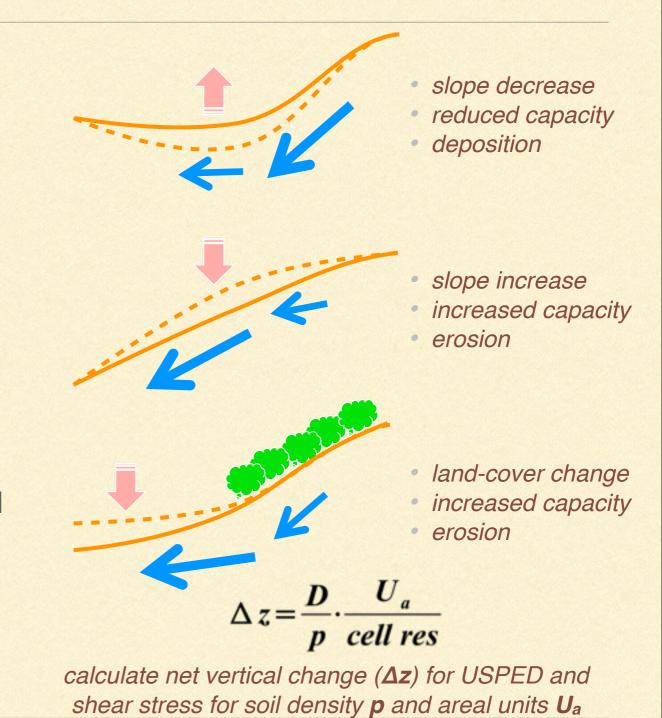
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- Physical processes
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- Dynamics
  - Changes to hydrology affect transport capacity
  - Water will erode or deposit sediment until its load reaches its new capacity

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



Landscape dynamics modeled as recursive Python scripts in GRASS GIS



Landscape dynamics modeled as recursive Python scripts in GRASS GIS

Start with DEM of topography





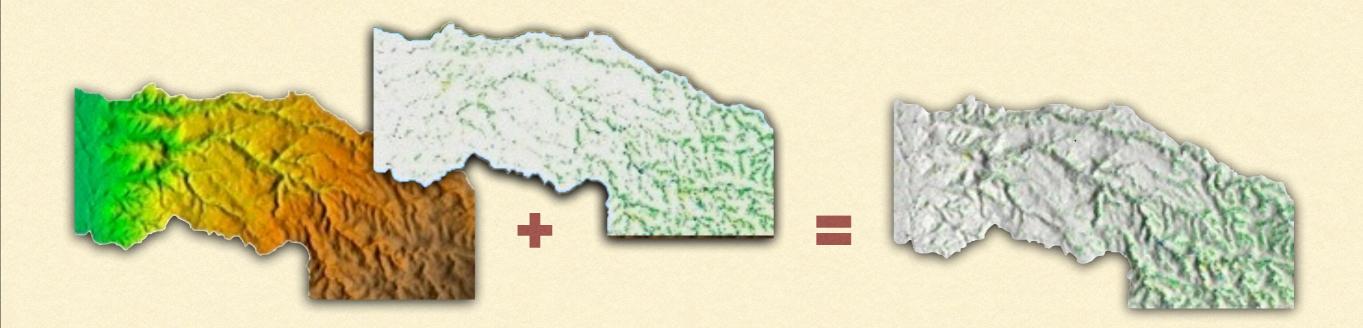
- Landscape dynamics modeled as recursive Python scripts in GRASS GIS
  - Start with DEM of topography
  - Calculate net erosion/deposition for each landscape cell





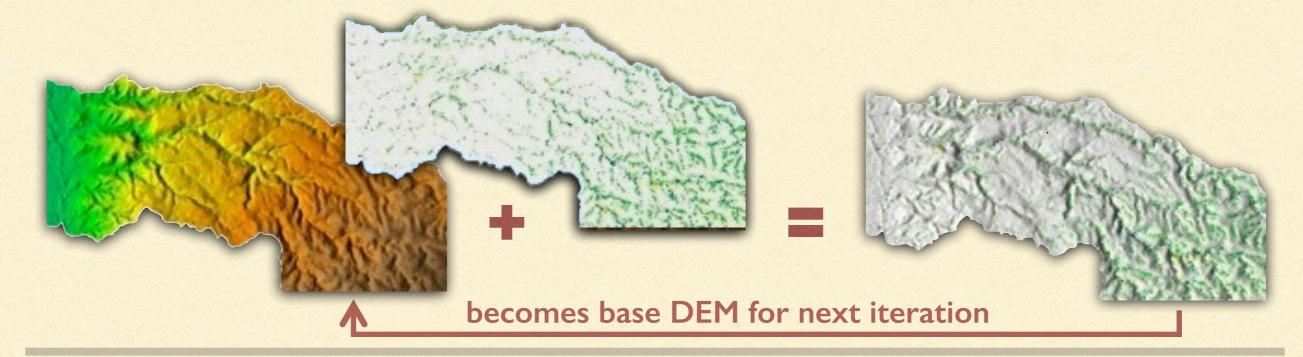
- Landscape dynamics modeled as recursive Python scripts in GRASS GIS
  - Start with DEM of topography
  - Calculate net erosion/deposition for each landscape cell
  - Add/subtract net erosion/deposition to DEM





- Landscape dynamics modeled as recursive Python scripts in GRASS GIS
  - Start with DEM of topography
  - Calculate net erosion/deposition for each landscape cell
  - Add/subtract net erosion/deposition to DEM
  - Create new DEM of topography





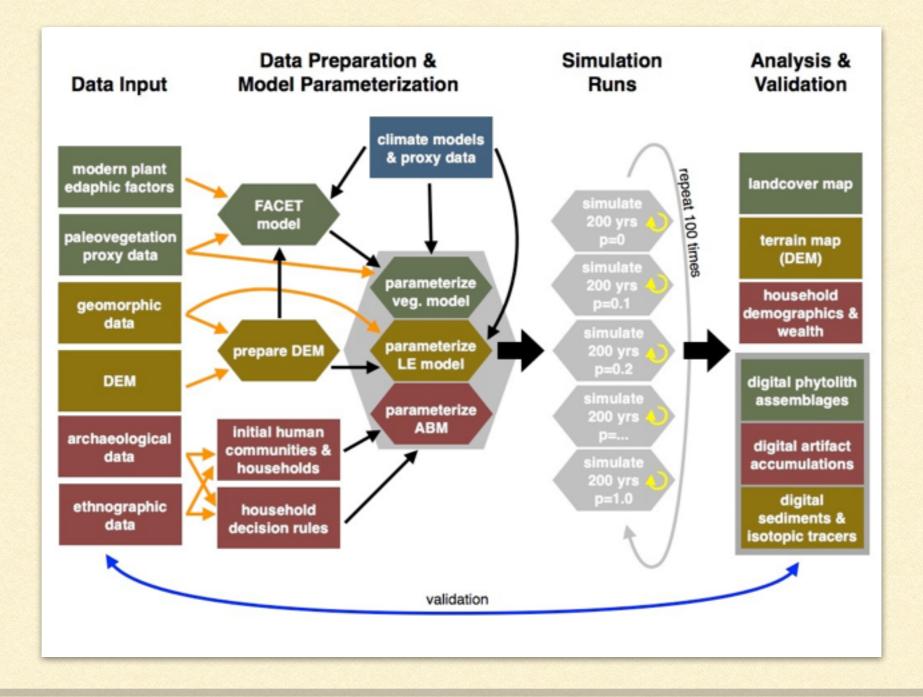
- Parameters set by researcher
  - terrain, soil, vegetation, climate
  - number of villages and households per village
  - village locations
  - caloric costs and returns from raising domesticates
  - ratio of crops to animals, crop types, animal species
  - plant and animal requirements
  - birth and 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

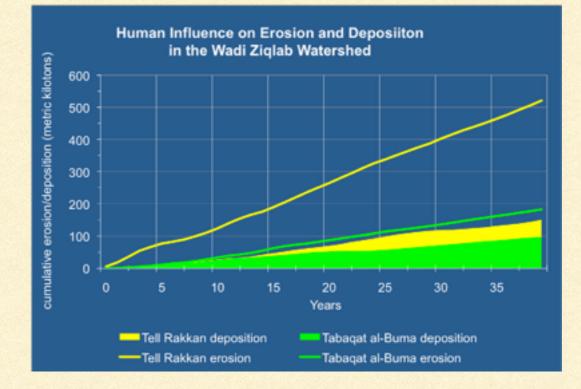
#### Coupled modeling system controlled from Java ABM and interface

Agent Environment Model Interaction Model System Settings	
Villages Resources Households	000
Birth Factors:	Agent Environment Model Interaction Model System Settings
Initial Percent Probability: 3 + % per 6 + people per family	Villages Resources Households
Percent Probability Delta: 1 🔅 % (increase/decrease in a cycle)	
Minimum: 1 🗘 % Maximum: 5 🗘 %	FARMING PARAMETERS Labor Required Initial Expected Yield Calories Provided (man-days/ha/year) (kg/ha/year) (kcal/kg)
Death Factors:	WHEAT 50 450 3500
Initial Percent Probability: 2 3 % per 6 9 people per family	WHEAT 50 450 3500
Percent Probability Delta: 5 3 (increase/decrease in a cycle)	BARLEY 51 456 3501
Minimum: 2 3 % Maximum: 10 3 %	
	NOTE: Barley Is Only Consumed after Being Used as Fodder for Sheep and Goats
Percent of population providing labor: 80 3 % (rounded up to whole person)	OVICAPRID GRAZING PARAMETERS
Food required: 000000 kcal / capita / year Labor provided: 300 man-days / capita / year	Number of Ovicaprids Per Person: 4 Ovicaprid Grazing Density Factor: 1
Maximum distance cost to travel to farm: 2800 Yield Expectation Scalar: 75	Ratio of Sheep to Goats: Sheep : 1 To Goats : 1 Fallow Field Grazing: ON +
0 25 50 75 100 125 150 175	Annual Sheep Fodder Requirement 584 kg Annual Goat Fodder Requirement 894 kg
	Annual Caloric Yield per Sheep 0 kcal Annual Caloric Yield per Goat 0 kcal
ion 3.10, October 2010 Save Configuration Load Configuration Validate Initia	
	GUI version 3.10, October 2010 Save Configuration Load Configuration (Validate Initialize Cancel)

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

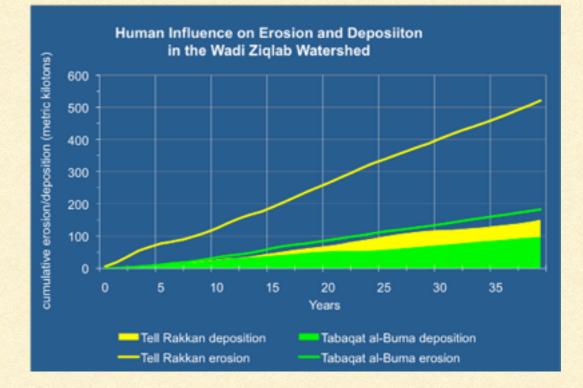


#### Tiny hamlet



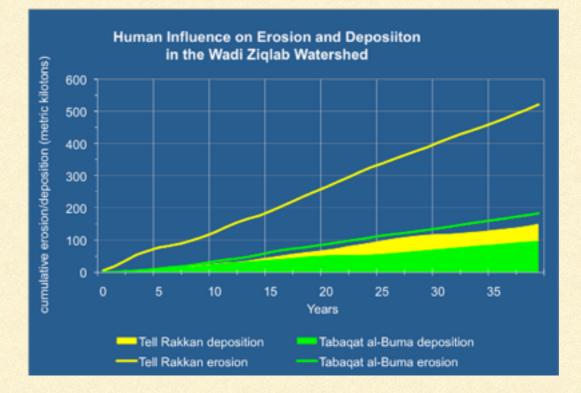


- Tiny hamlet
  - Cultivation limited to wadi bottoms



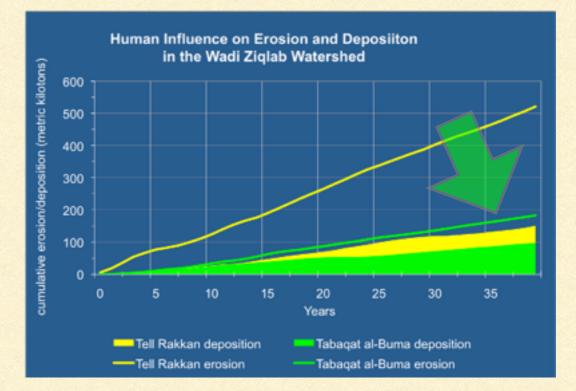


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  - Cultivation limited to wadi bottoms
  - Grazing causes most erosion



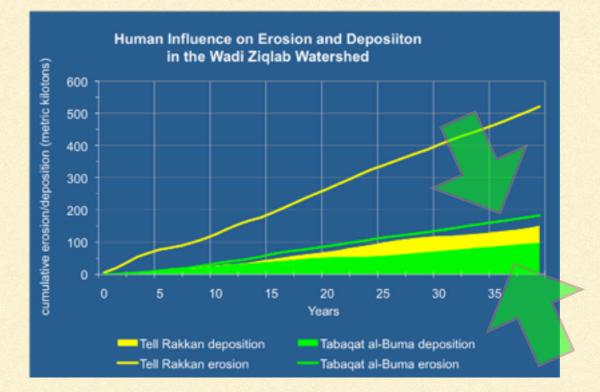


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  - Erosion primarily in uncultivated uplands



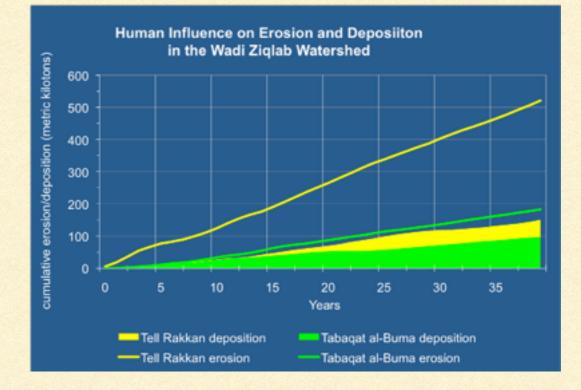


- Tiny hamlet
  - Cultivation limited to wadi bottoms
  - Grazing causes most erosion
  - Erosion primarily in uncultivated uplands
  - Redeposited sediment in cultivated zones is 53% of erosion



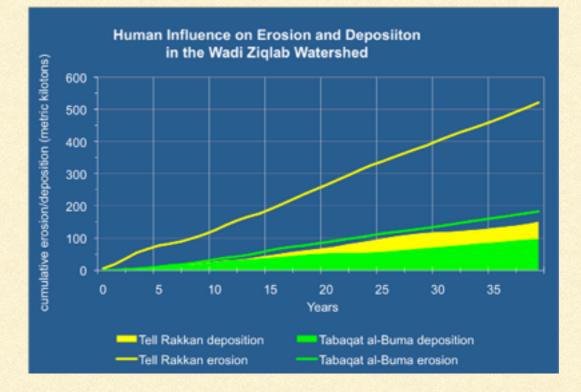


Larger village



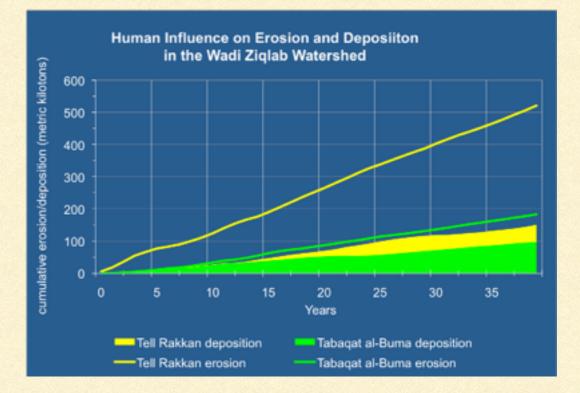


- Larger village
  - Cultivation in uplands; more extensive grazing





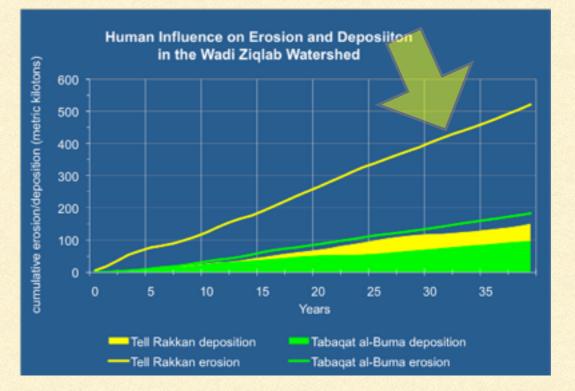
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### LAND-USE & LANDSCAPE DYNAMICS IN NORTHERN JORDAN

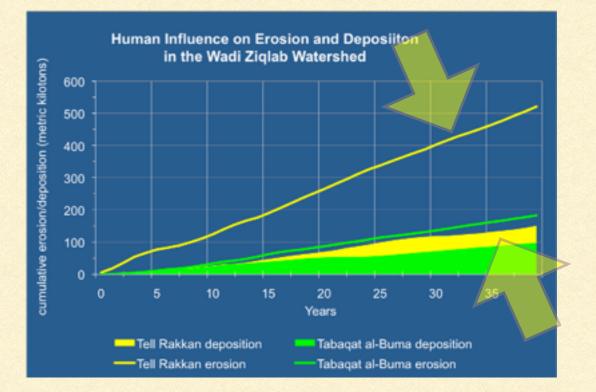
- Larger village
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  - Cultivation causes most erosion
  - Erosion in cultivated and uncultivated zones





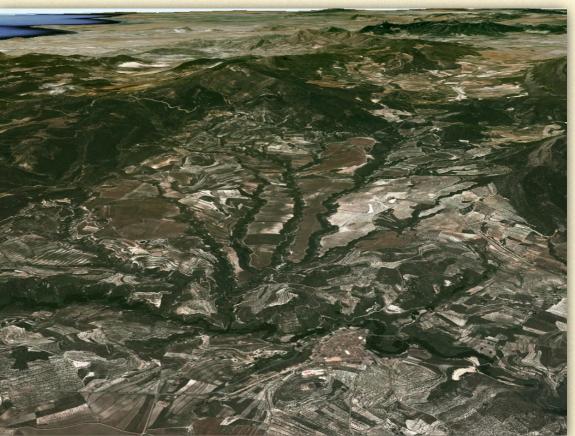
### LAND-USE & LANDSCAPE DYNAMICS IN NORTHERN JORDAN

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







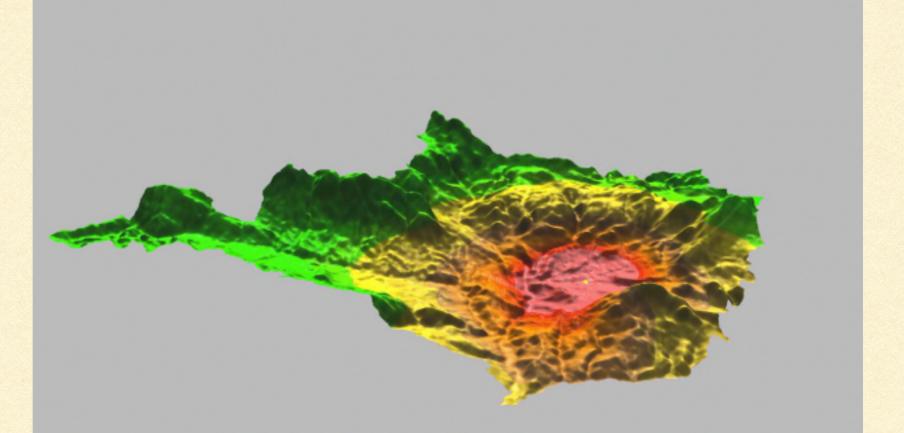




Penaguila Valley, Alicante Province, Spain

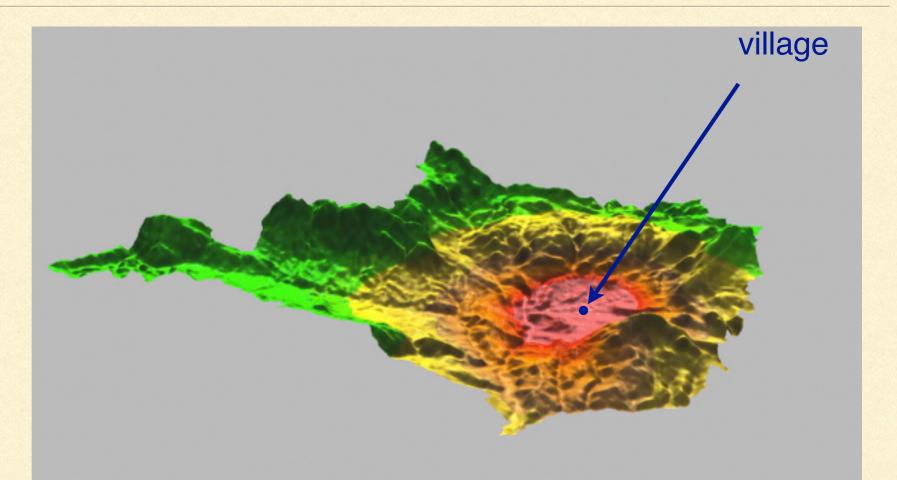


 Begin with paleoterrain of early Holocene



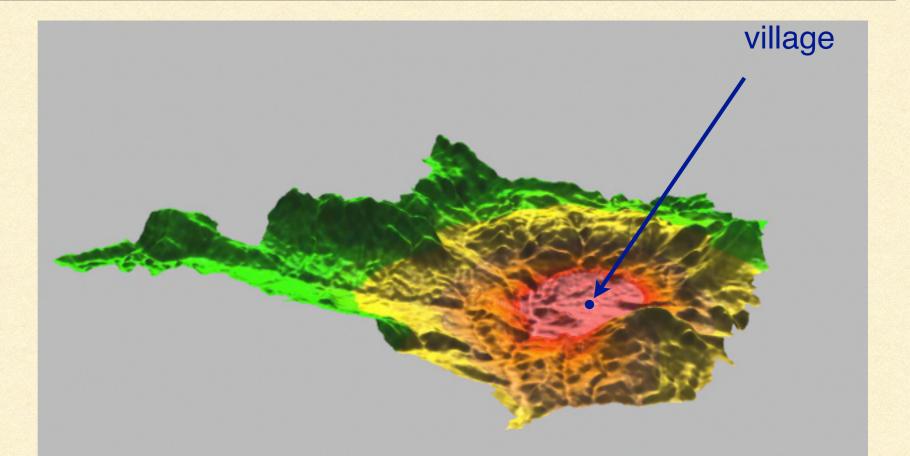
dense woodland (no human impacts) open woodland (grazed) shrubs (grazed or fallowed) grass & cereals (farmed or fallowed) bare (cleared for farming)

- Begin with paleoterrain of early Holocene
- Add ABM of village with households

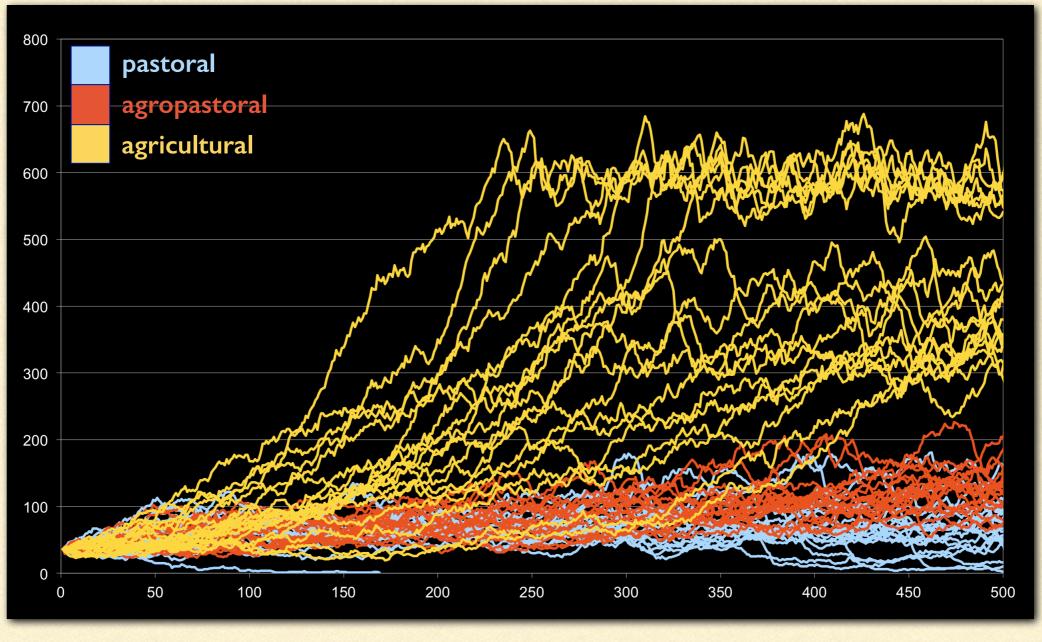


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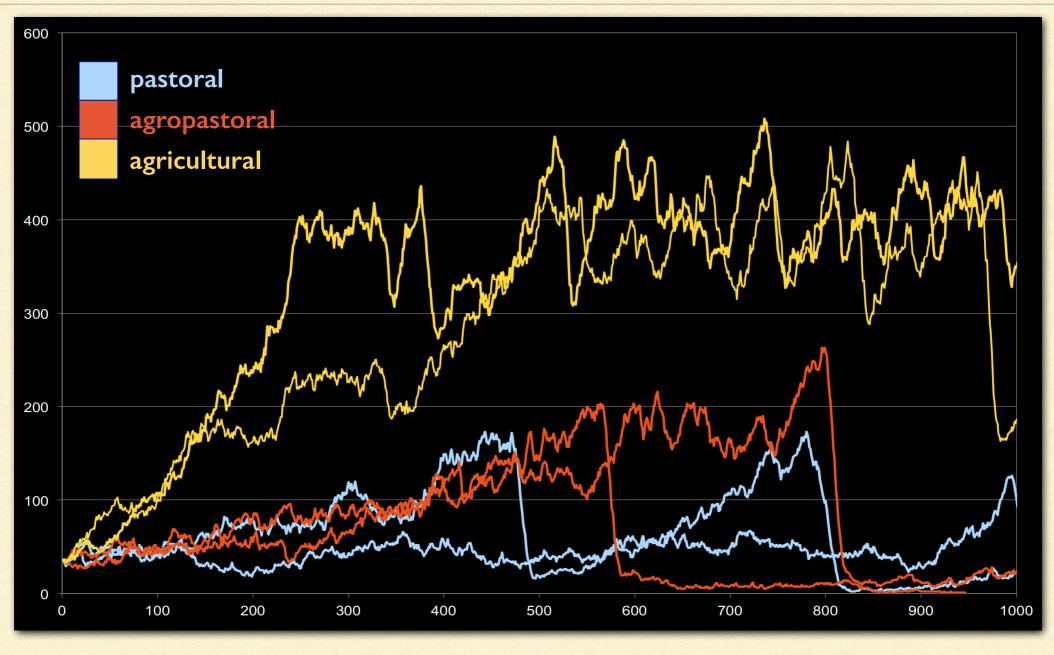
- Begin with paleoterrain of early Holocene
- Add ABM of village with households
- Instantiate 1000 years of agriculture and fuelwood use
- Repeat multiple times for different settings



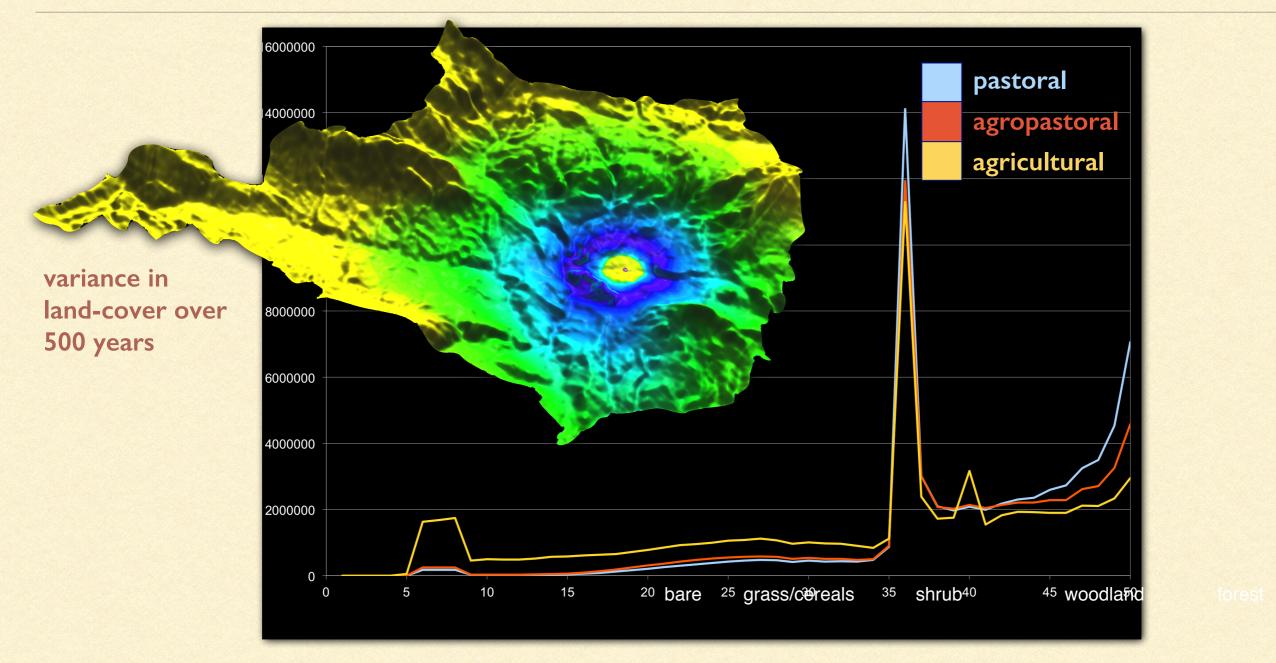
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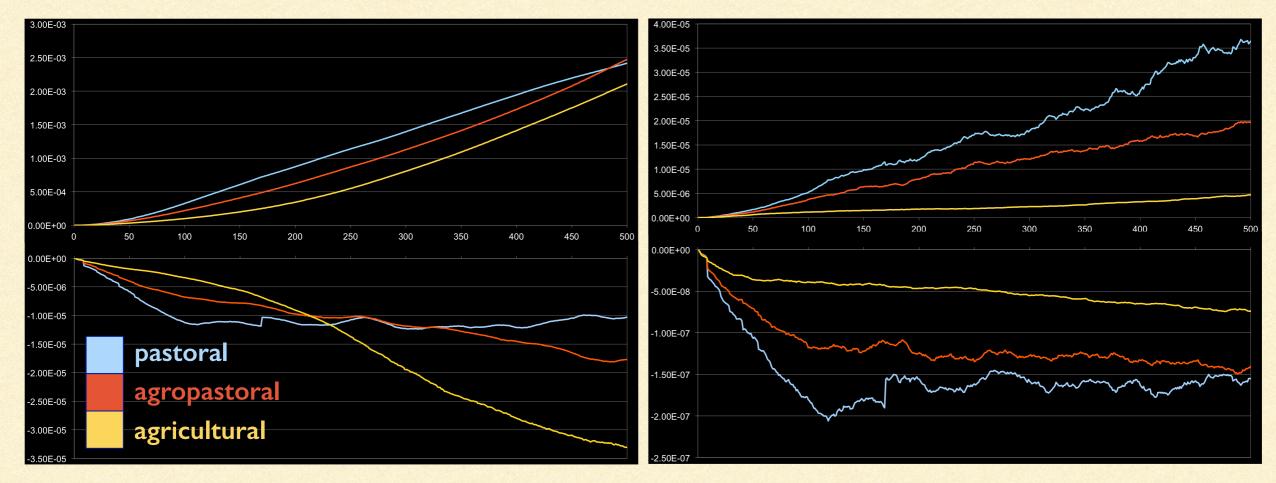
population over 500 years with different subsistence strategies (multiple runs)



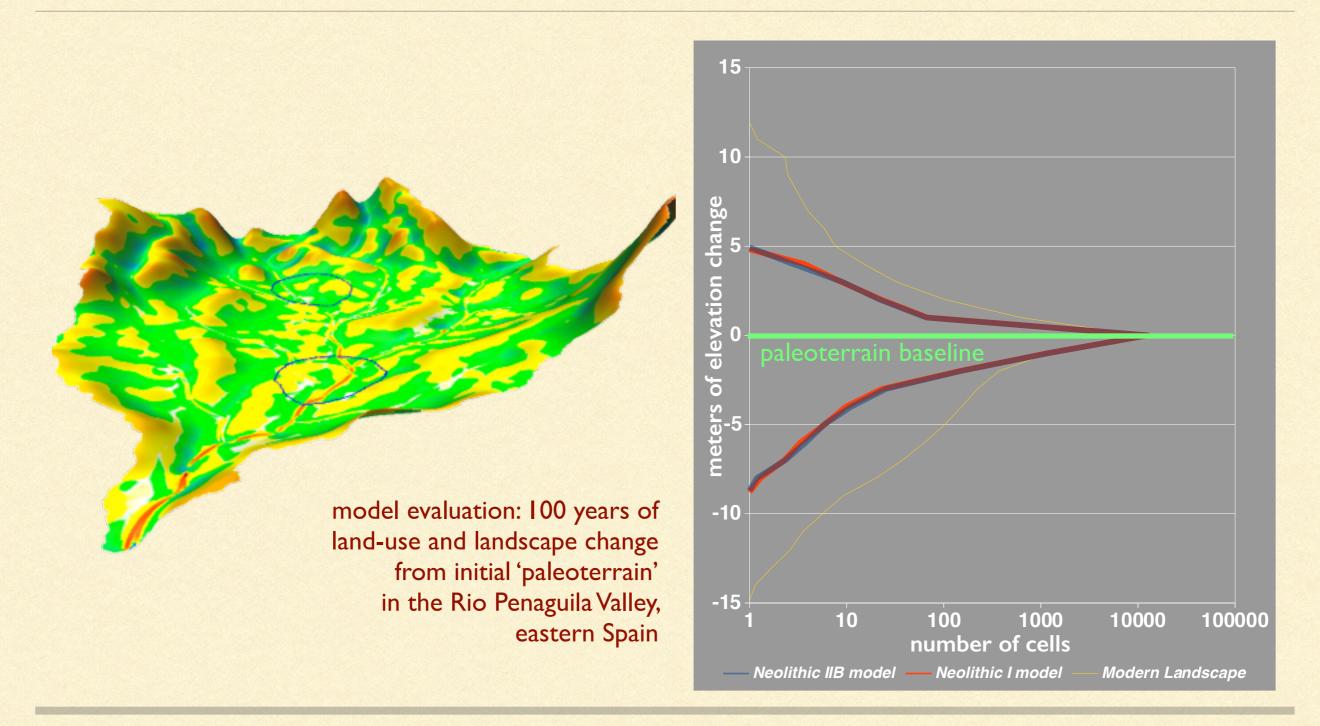
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mean standard deviation in landcover over 500 years with different subsistence strategies

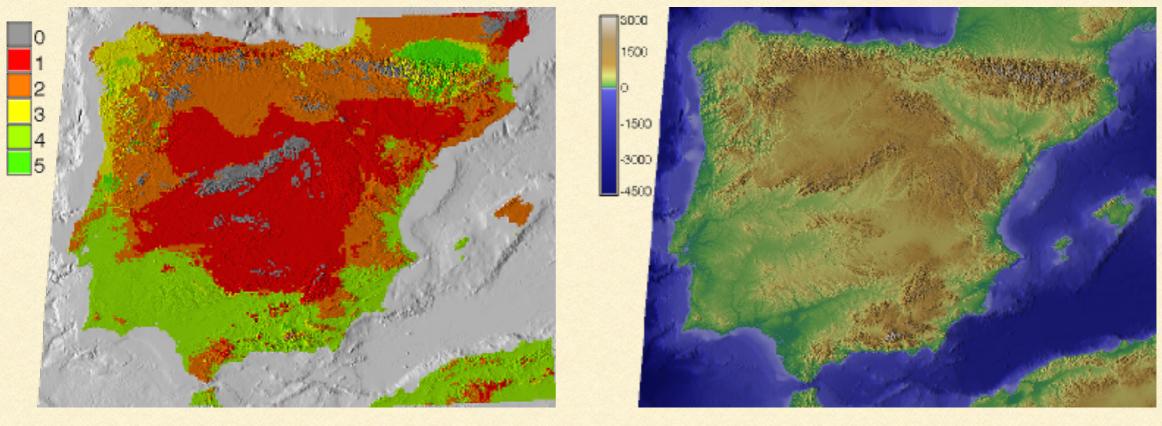


total cumulative erosion/deposition over 500 years with different subsistence strategies (multiple runs combined) per capita cumulative erosion/deposition over 500 years with different subsistence strategies (multiple runs combined)



- 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?

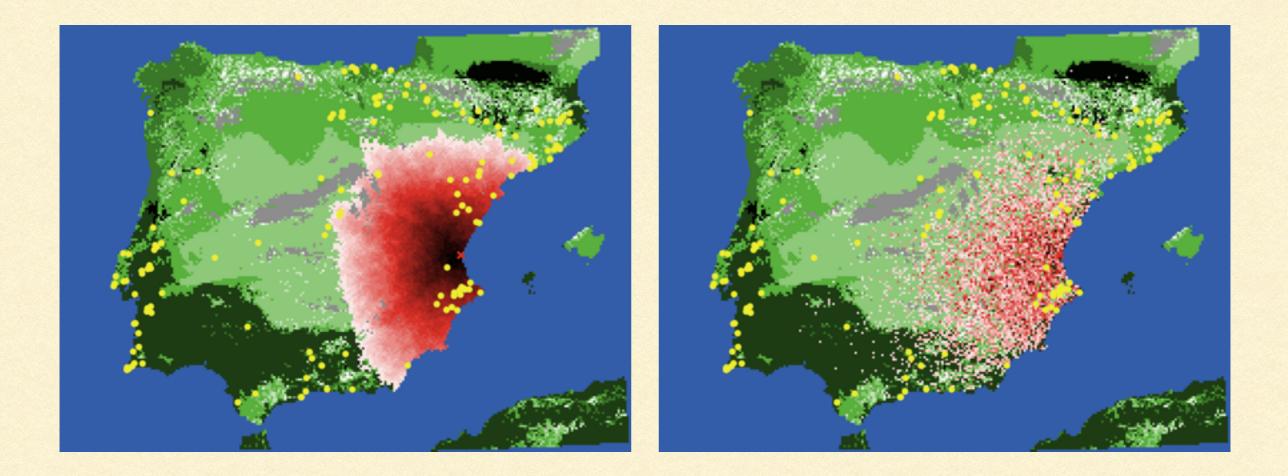
 Estimating suitability for farming from multiple environmental parameters



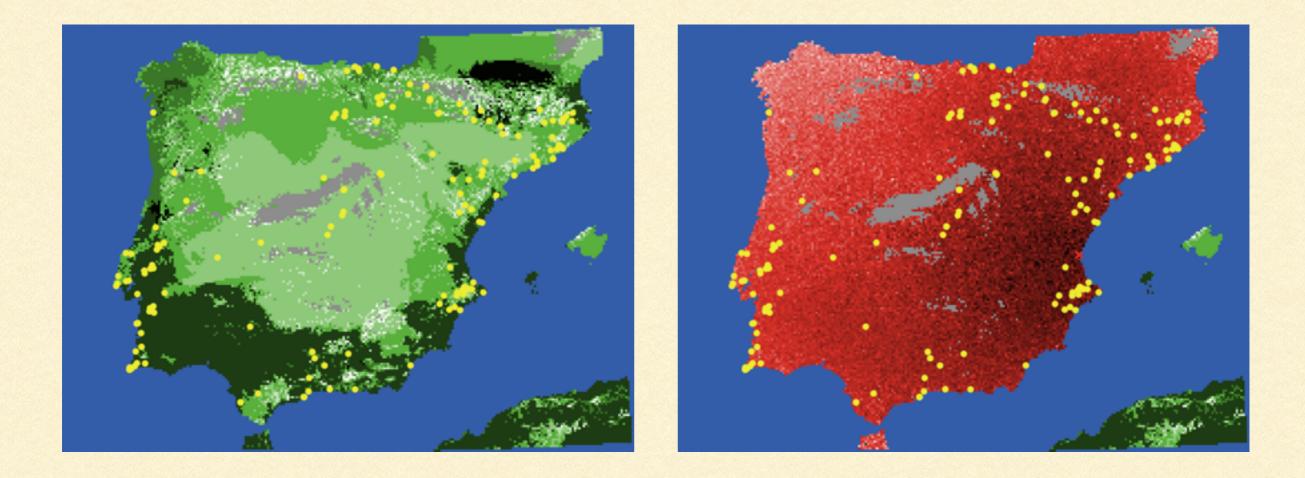
climatic index (cooler colors are better)

topography

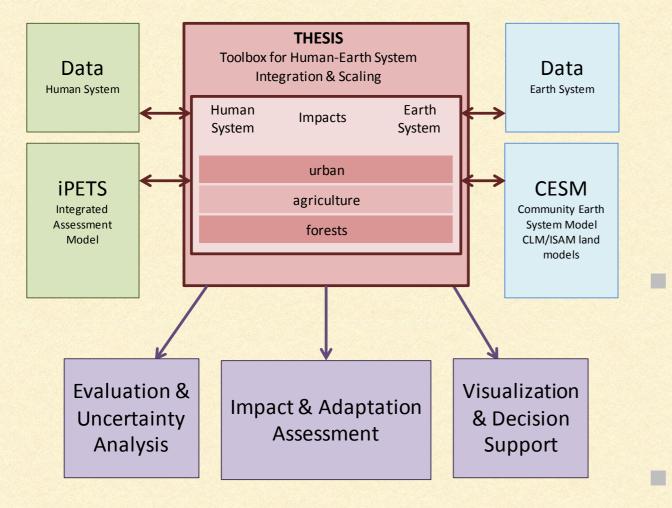
#### Testing different dispersal processes



#### Comparing results with empirical data

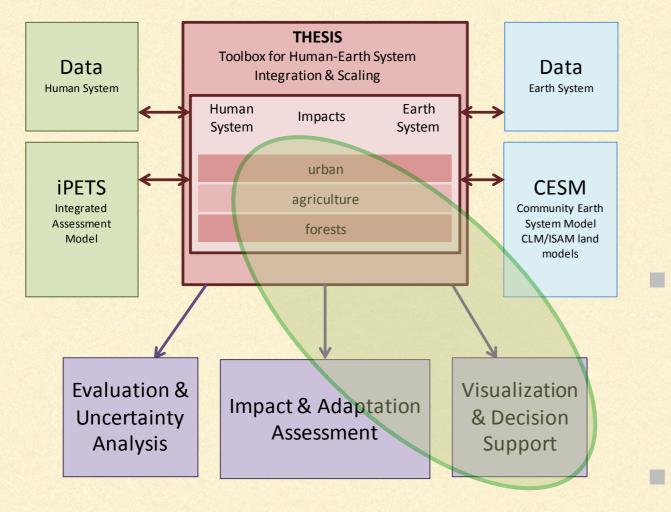


### SOCIAL IMPACTS OF CLIMATE CHANGE



- 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)

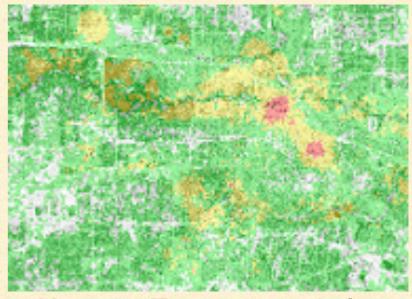
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### SOCIAL IMPACTS OF CLIMATE CHANGE

- 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

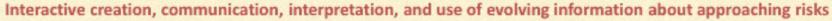


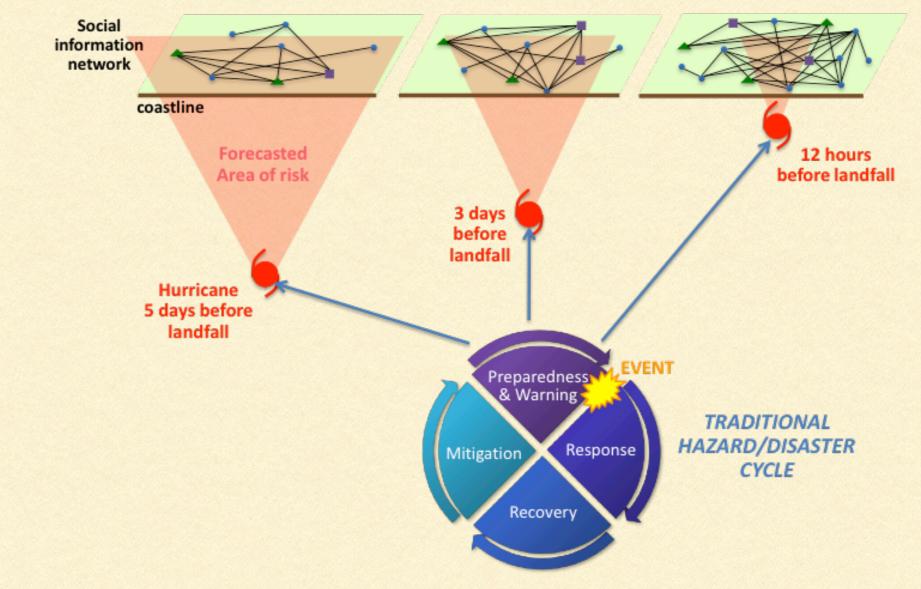
Houston, Tx - city morphology

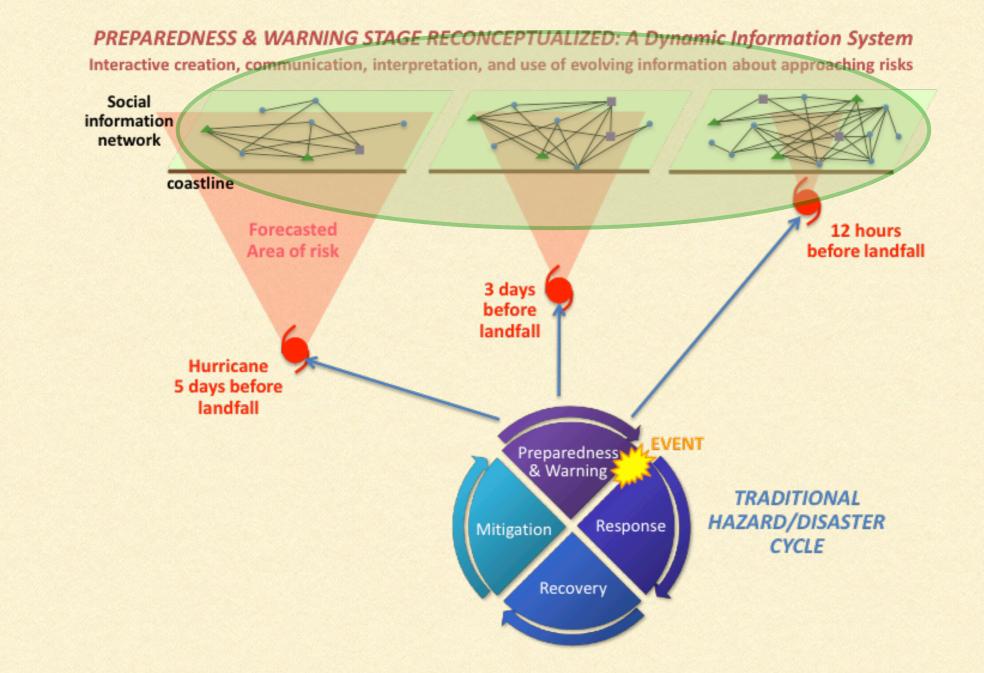


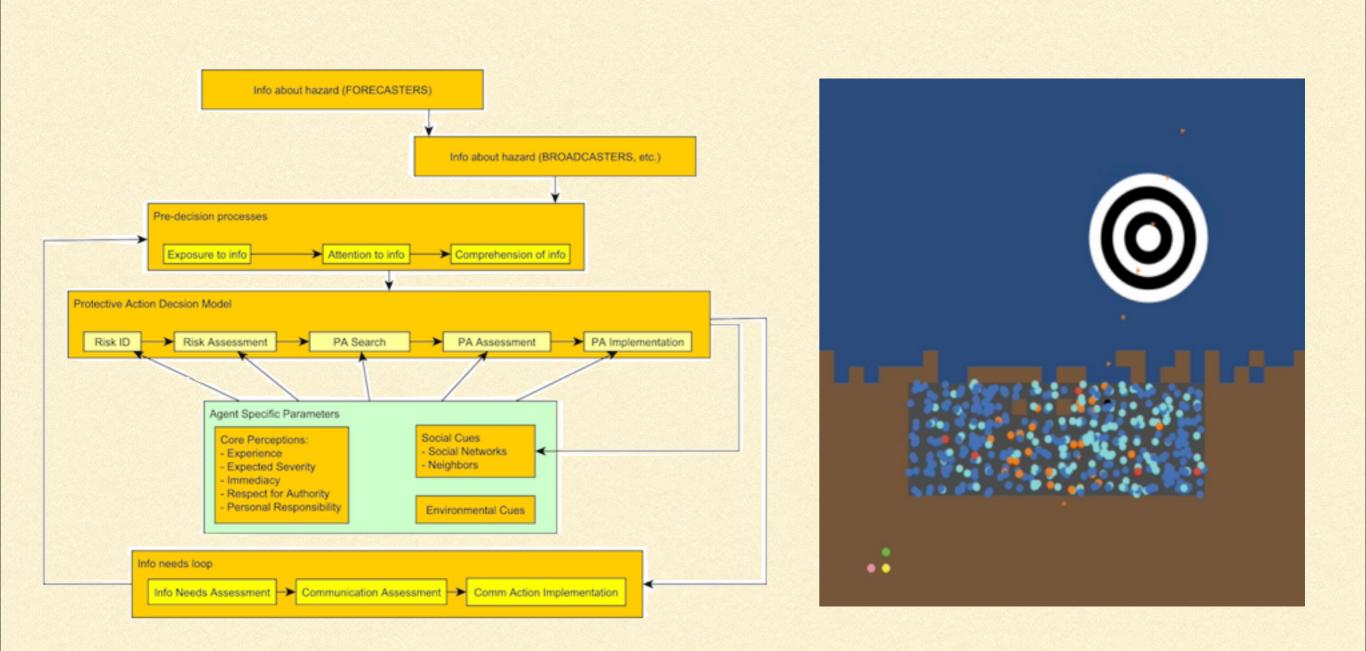
Houston, Tx - Google Earth

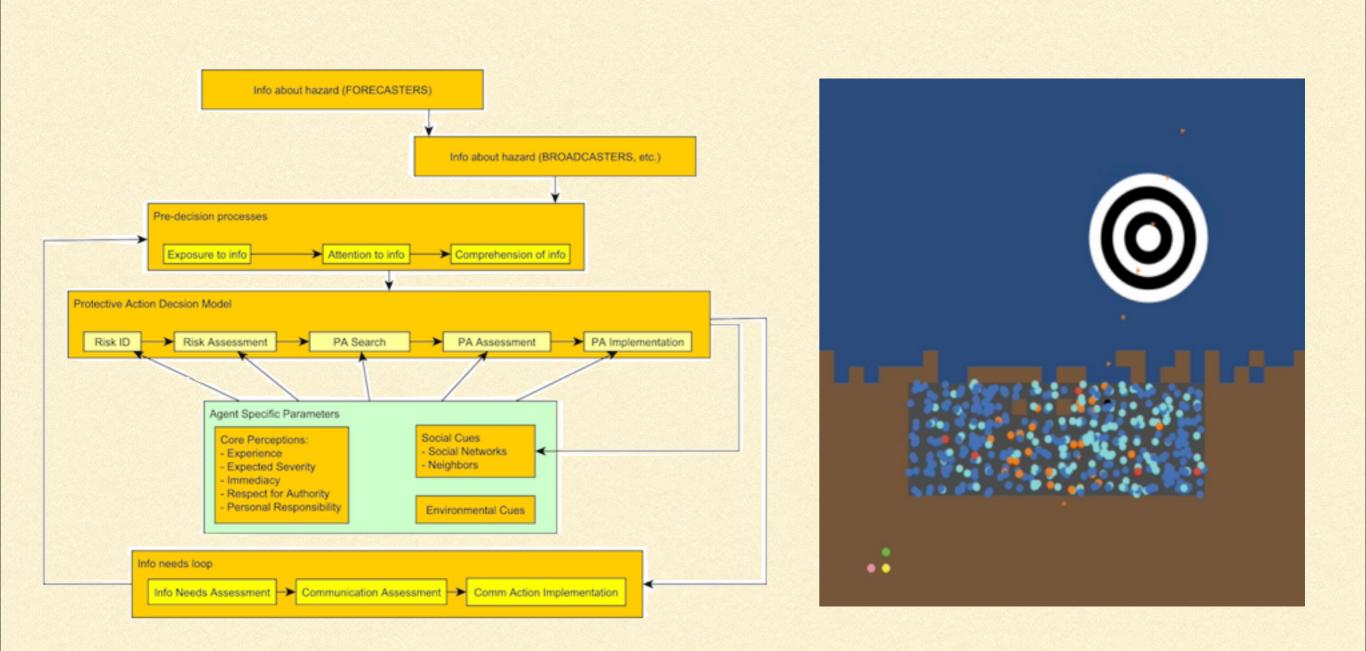
PREPAREDNESS & WARNING STAGE RECONCEPTUALIZED: A Dynamic Information System











# ENABLING TECHNOLOGIES & SCIENCE

 Science is not technology, but some technologies can transform science

### ENABLING TECHNOLOGIES & SCIENCE

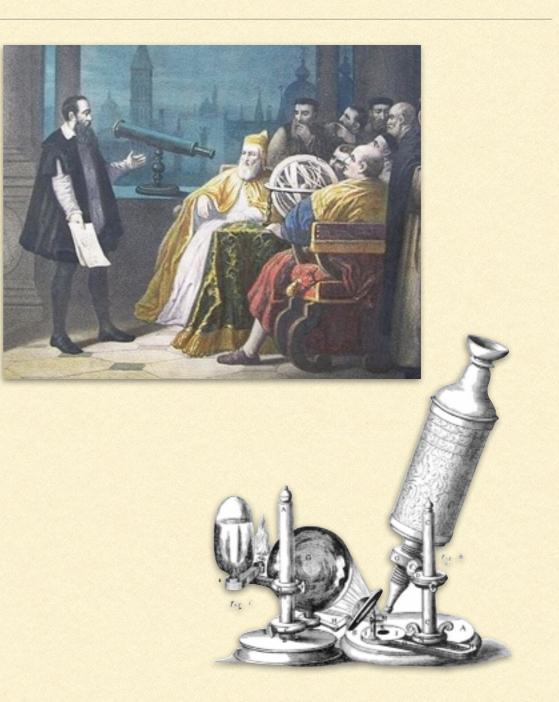
 Science is not technology, but some technologies can transform science



Telescope

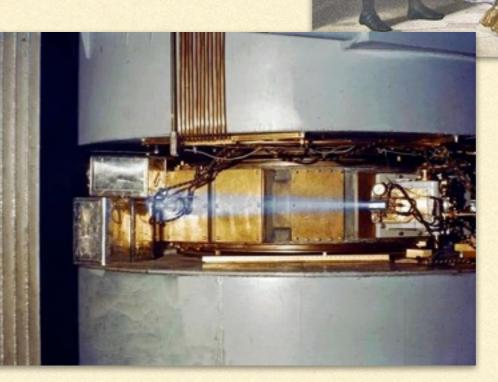
### ENABLING TECHNOLOGIES & SCIENCE

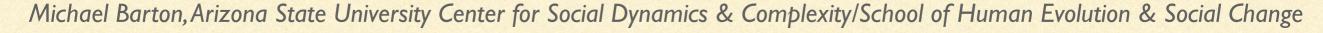
- Science is not technology, but some technologies can transform science
- Telescope
- Microscope



# ENABLING TECHNOLOGIES & SCIENCE

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



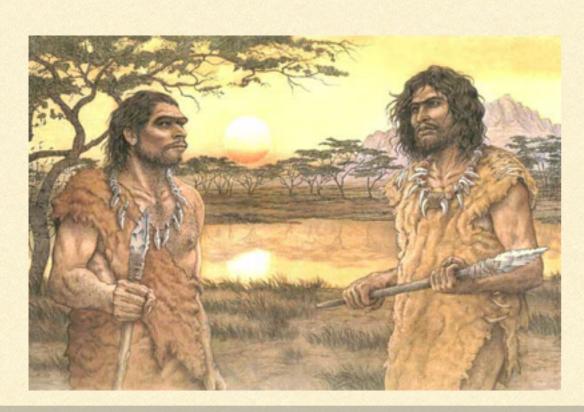


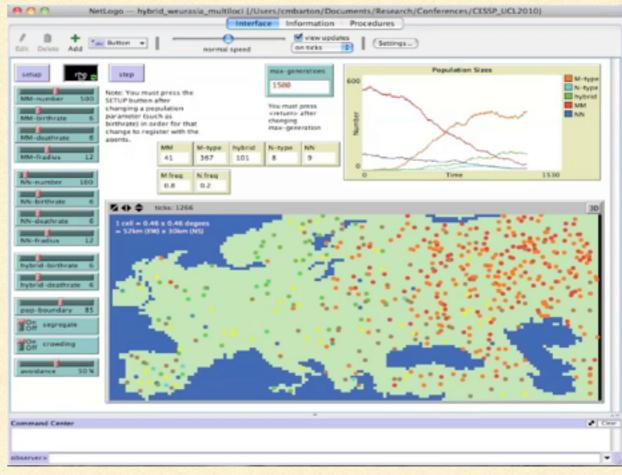
### COMPUTATION & SOCIOECOLOGICAL SYSTEMS

- 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

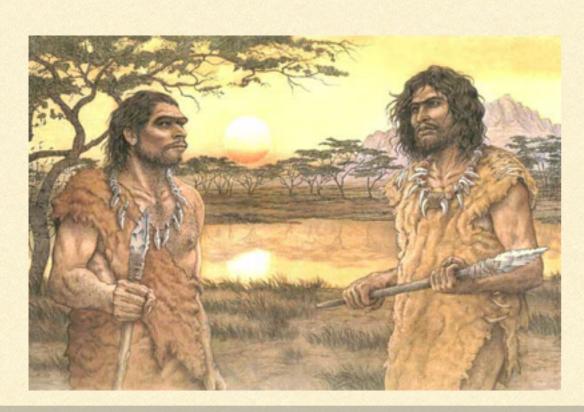
## Transformative technology for science of complex socioecological systems

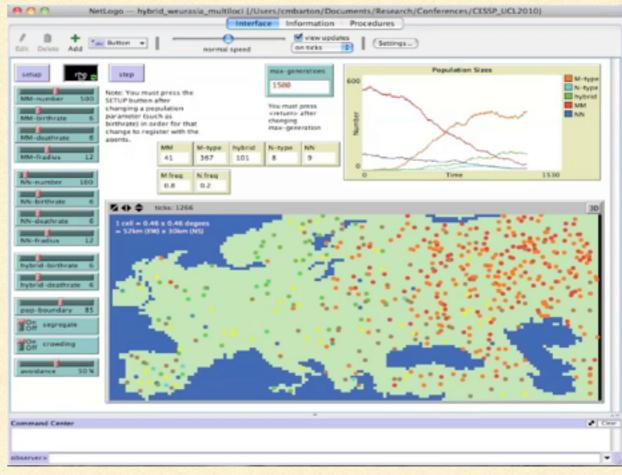




### COMPUTATION & SOCIOECOLOGICAL SYSTEMS

## Transformative technology for science of complex socioecological systems





### 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



### Computational Model Library

onen.	a node in the CoMSES Network	
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Home	CoMSES Computational Model Library	
Model Library	Showing 1 - 15 of 199 models.	
Education		Submitter
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Dibliographic Library	(Policy induced) Diffusion of Innovations - An integrated demand-supply Mode Cournot Competition	I based on
Events Calendar	Objective is to simulate policy interventions in an integrated domand supply model. The underlying	M Plain
Foruma	demand function links both sides. Diffusion proceeds it interactions distribute awareness (Spidemic effect) and rively reduces the market price (	Aug 29, 2011
Jobs & Appointments	9 Maturity levels in Empirical Validation - An innovation diffusion example	
CoMSES Membership	Several taxonomies for empirical validation have been published. Our model integrates different methods to calibrate an investion diffusion model, ranging from simple randomized input validation to complex calibration with the und microbata.	M Rich Out 18, 2011
	A Computational Model of Workers Protest	
	We present an agent based model of worker protect informed by Epstein (2002). Workers have varying degrees of pre-ance depending on the difference between their wage and the average of their neighbors. They protect with probabilities proportional	J Kim May 12, 2011
	A consumer-domand simulation for Smart Metering tariffs (Innovation Diffusion	0
	An Agent based mobili simulates renoumer demand for Smart Metering terffis. It utilizes the Base Diffusion Modet and Regent's adapter categories, Integration of empirical census microdata erables a validated socio-economic background for each	M Rivin Aug 10, 2011
	A Double-Auction Equity Market For a Single Firm with AR1 Earnings	
	This is a final project for the class AML SM at Aroons State University. I have done a small amount of bug checking, but overall the project represents only a half of a semester's work, so proceed w	E Weisbrod Dec 13, 2010
	A Generic Java Learning Classifier Library	
	Complete Library for object oriented development of Classifier Rystems. Ree http://jassa.acc.aurrey.ac.uk/95/9.html for the concept behind.	K Hubulhing Apr 00, 2010
	A land-use model to illustrate ambiguity in design	
	This is an apent-based model that allows is test alternative designs for three model components. The model was built using the 112MX design strategy, while each alternative is in time with the strategy. Using the model, it can be shown that	J Schindler Nox 05, 2012
	A model of groundwater usage by farmers in the Upper Guadiana, Spain	
	An agent-based model to investigate the history of inigated agriculture in the Upper Guadiana librain, Soain, in order to learn about the influence of fermers' characteristics (inter alla profit orientation, risk aversites, skills, evaluate bases	G Hota Jun 30, 2011
	A Modelling4Al/NetLogo model of the Spanish Flu Pandemic	

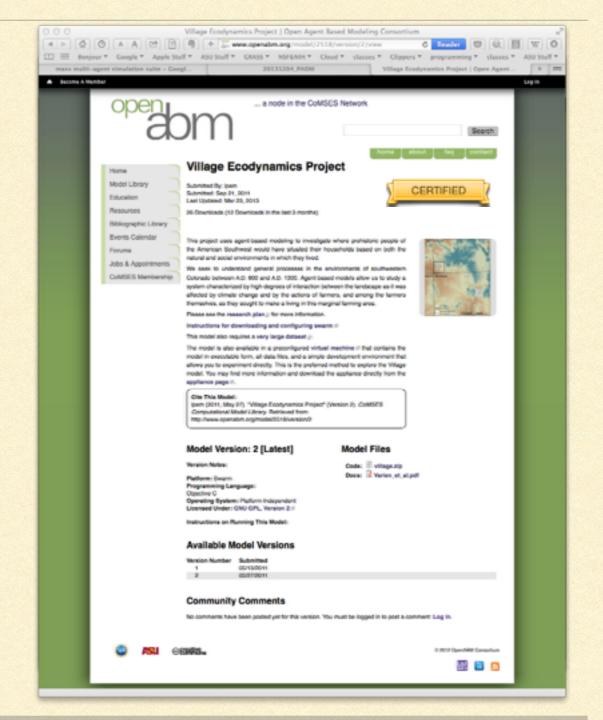
- Computational Model Library
- Open-access publishing of model code

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mass multi-agent simulation sulte - Congl 2011204_PADM Village Ecodynamics Project   Open Agent	-
a node in the CoARSES Network	
Village Ecodynamics Project	
Model Library Submitted By: (pam Education Education Last Updated Mar 25, 2013 Resources 36 Develoads in the last 3 month()	
Bibliographic Library Events Calendar This project uses agent based modeling to investigate where prohibiting people of Forums The American Boutimest would have shaded their households based on both the natural end and event-ments in which they find.	
Jobs & Appointments We assis to understand general processes in the environments of southwestern ColubleSIS Membership Optimum denotational by high degrees of metership between the lendespee as it was effected by climate charge and by the actions of termory, and among the termory	
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Instructions on Running This Model:	
Available Model Versions Version Number Submitted 4 00/32001 2 00/32001	
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- Computational Model Library
- Open-access publishing of model code
- Community standards and best practices for model description and citation

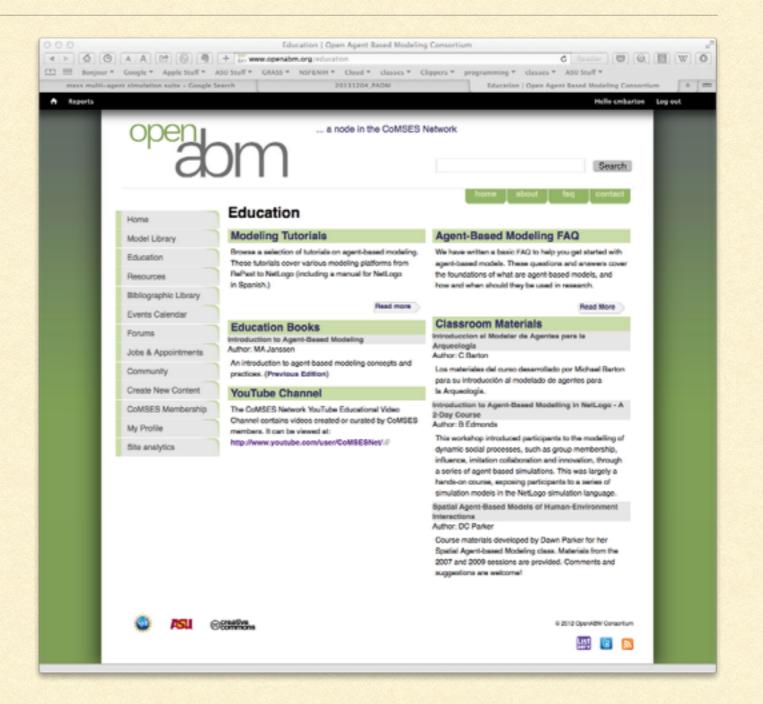
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Events Calendar This project uses agent based modeling to investigate where prehistoric proofs of
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Jobs & Appointments We sake to understand general processes in the anuitoments of acuteuestern
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epplance page 1.
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Model Version: 2 [Latest] Model Files
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- Computational Model Library
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- 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



### ACKNOWLEDGEMENTS

Network for Computational Modeling in the Social and Natural Sciences: National Science Foundation, Coupled Natural and Human Systems Program, grant GEO-909394