Modeling Complex Ecodynamics in Mediterranean Landscapes

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A Complex World

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  - Ecological systems are complex

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- But more importantly, it is complex
  - Ecological systems are complex
  - Human social systems are complex

A Complex World

- Socioecological Systems, or SES, compound complexity in human and natural systems

A Complex World

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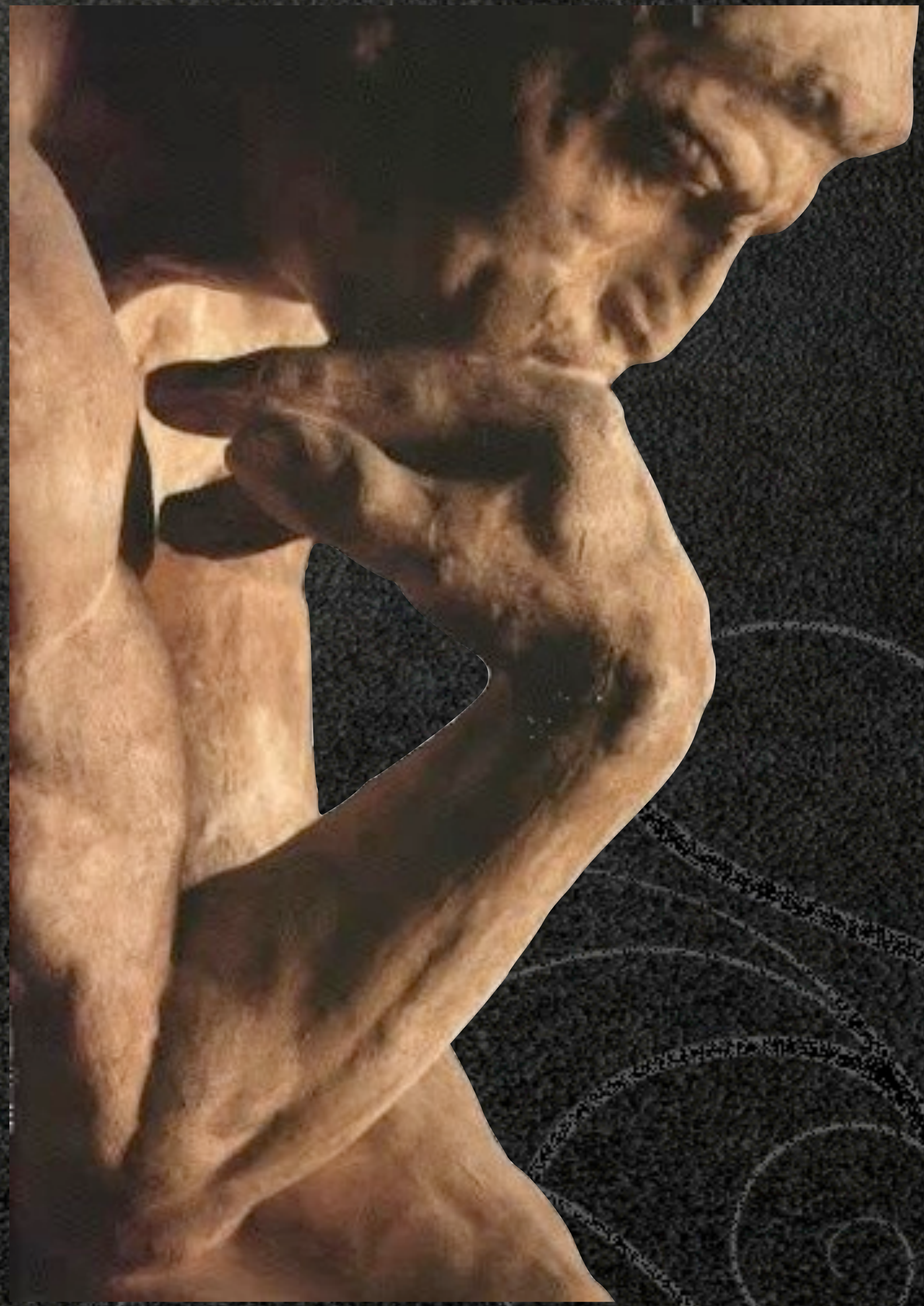
- Manage agro-ecosystems whose biomass exceeds that of all other animals on earth
- Move more terrestrial sediment that all natural processes combined

A Complex World

- Interactions as or more important than the properties of the social and biophysical components.
- Consequences of of human action and non-human environmental change ...
  - Often non-linear
  - Characterized by buffering, thresholds, and unexpected emergent phenomena.
- Present and future of SES are contingent on past

A Complex World

- Linear cause and effect thinking no longer sufficient to anticipate outcomes of social action
- ...even when applied in scientific context
- Need new tools for scientific study of SES



Models for Complex SES

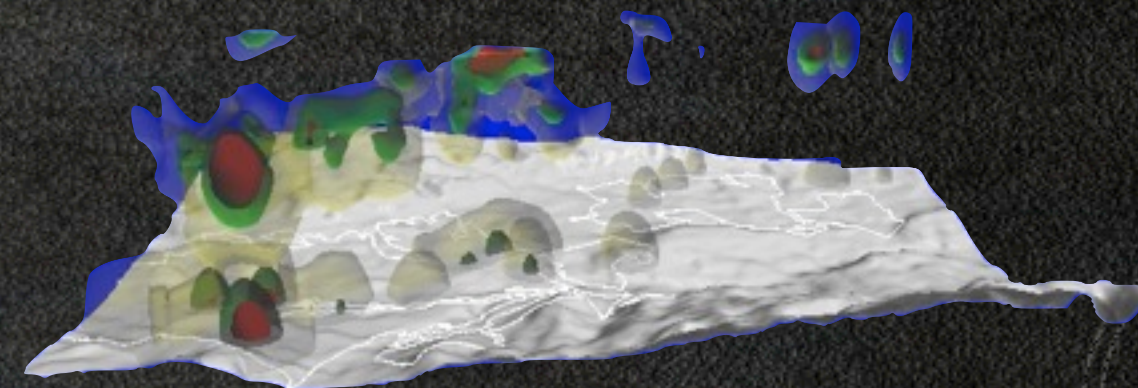
- Models important for understanding SES. Help us to...
  - Understand complex interactions of temporal and spatial dynamics
  - Unravel non-linear causation in highly coupled human and natural systems

Models for Complex SES

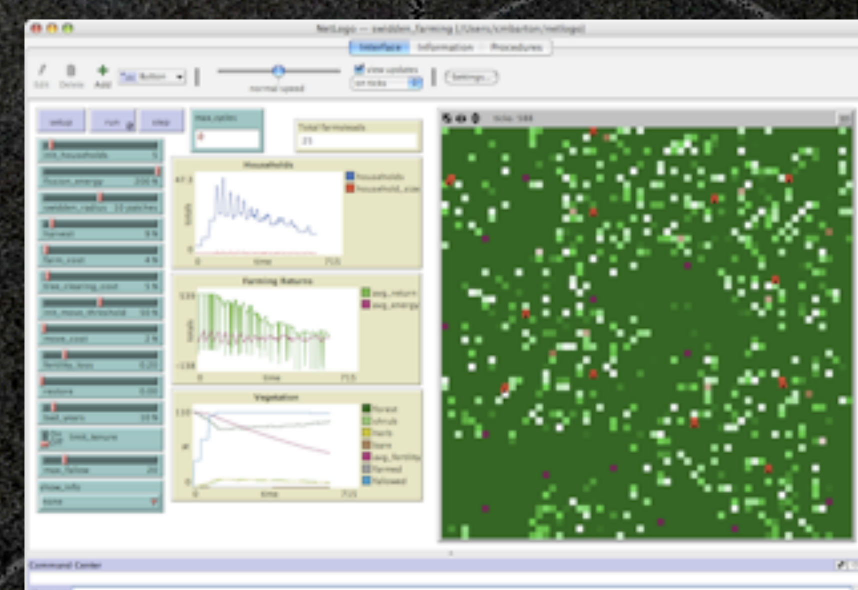
- Most models in archaeology are narratives, inferred from data
- Narratives
  - Easy to understand
  - Inspire imagination
  - Can be useful for describing complex SES, but much less so for explaining their dynamics
  - Tendency for narratives to emphasize linear causation

Models for Complex SES

- New computationally enhanced methods allow us to go beyond normal linear thinking
  - Systems dynamic modeling
  - Dynamic and space/time GIS
  - Agent-based models



Spacetime volume of 100,000 years of human settlement in Polop valley, Spain



Netlogo simulation of swidden agriculture

Mediterranean Landscape Dynamics (MedLanD)

- Coupling different model formalisms to create a computational laboratory for studying the long-term interactions of agropastoral land-use and landscape change in Mediterranean socioecological systems.
- Modeling environment as experimental laboratory
- Archaeological record of early farming provides data for validating and improving model outcomes.

National Science Foundation BCS-410269
Coupled Natural & Human Systems

Arizona State University
Office Knowledge Enterprise & Development

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Study areas in eastern Spain and western Jordan

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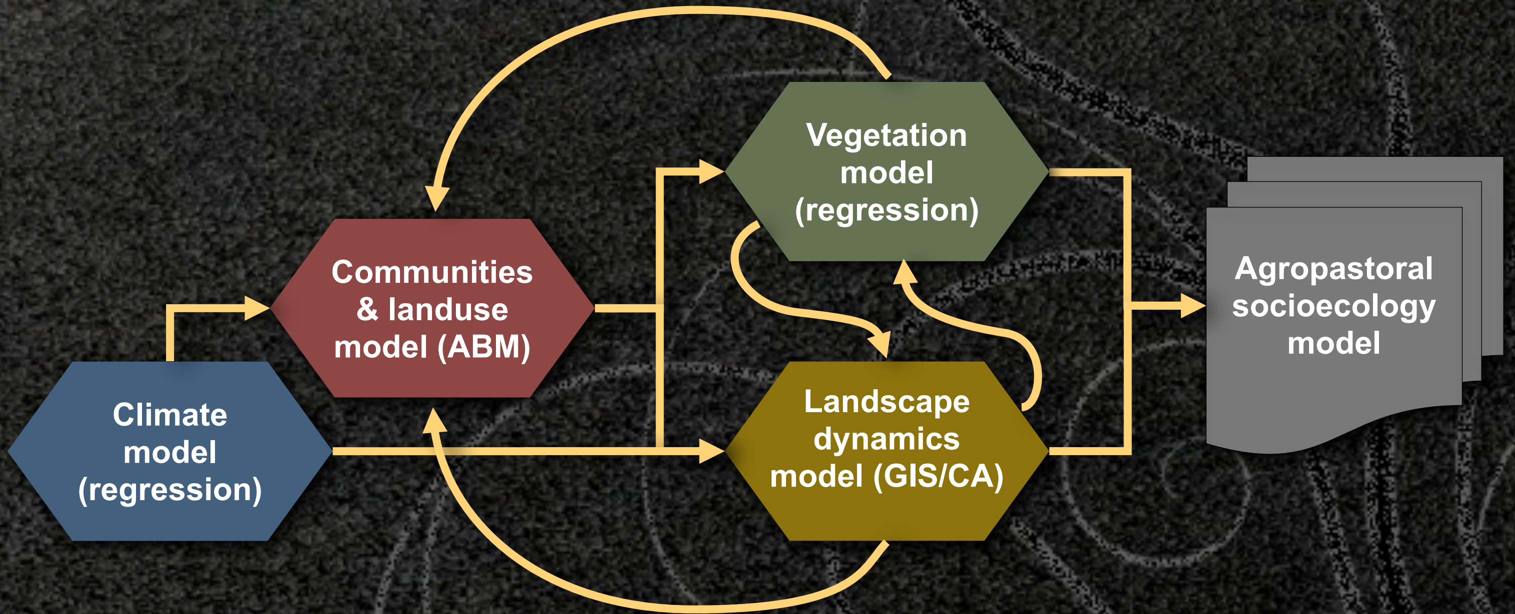
MedLand Modeling Laboratory

- Major components of hybrid modeling laboratory include...
  - ABM of human households and their land-use decisions
  - GIS-based cellular automata of terrain and its changes
  - Regression-based model of local climate
  - Interactive visualization system
- Open source software for research transparency and global accessibility

DEVS Suite (http://www.acims.arizona.edu/SOFTWARE/software.shtml)

GRASS GIS (http://grass.osgeo.org)

World Wind (http://worldwind.arc.nasa.gov/java/)

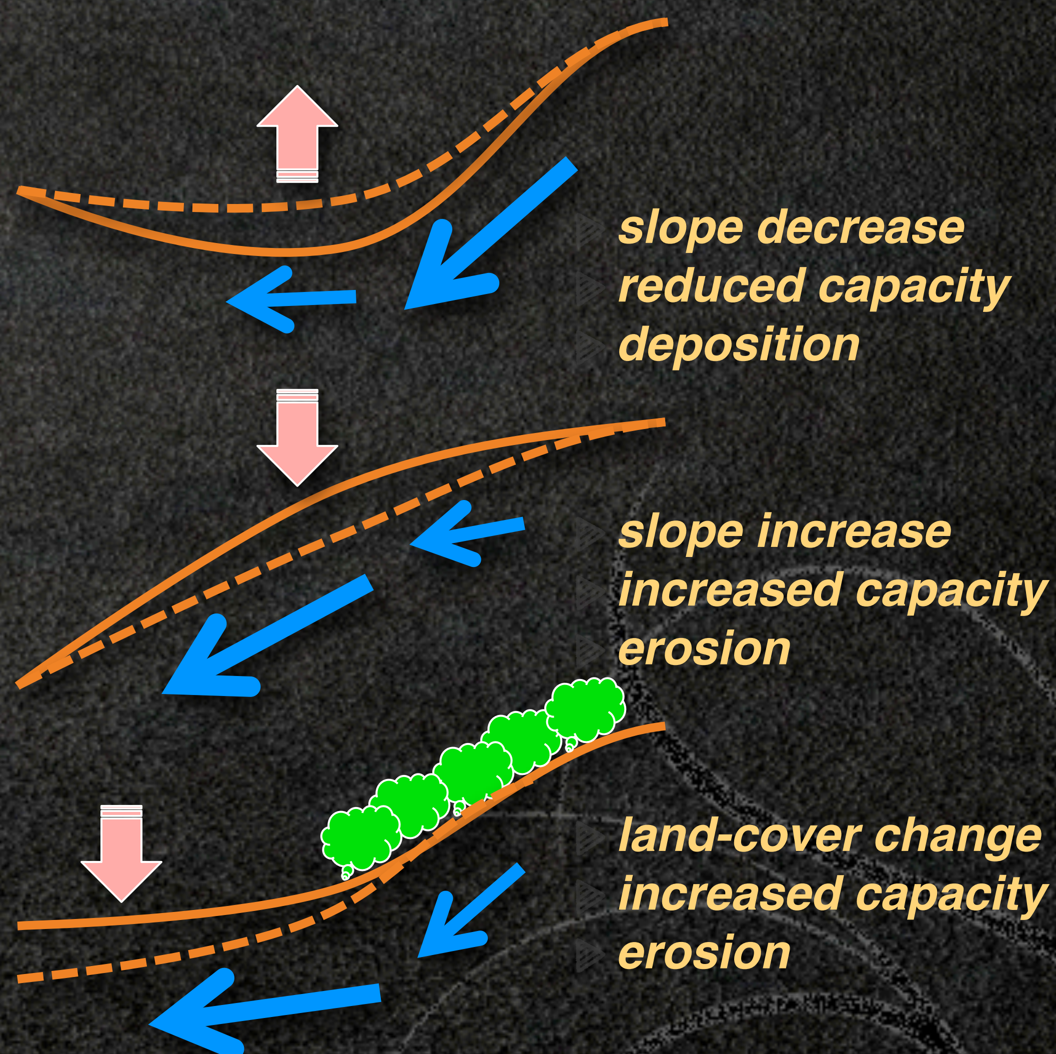


MedLand Modeling Laboratory

- Begin with overview of some of modeling approaches
  - Modeling landscape dynamics
  - Modeling paleoclimate dynamics
  - Modeling human decisions
- Conclude with initial results of experiments with SES associated with beginning of agriculture. Interactions of...
  - Community size
  - Land-use practices
  - Landscapes of northwestern Jordan

Modeling Landscape Dynamics

- Potential sediment flux - sediment-limited process equations
- Basic assumption
  - Flowing water carries sediment at capacity
- Dynamics
  - Changes to hydrology affect transport capacity
  - Water will erode or deposit sediment until its load reaches its new capacity

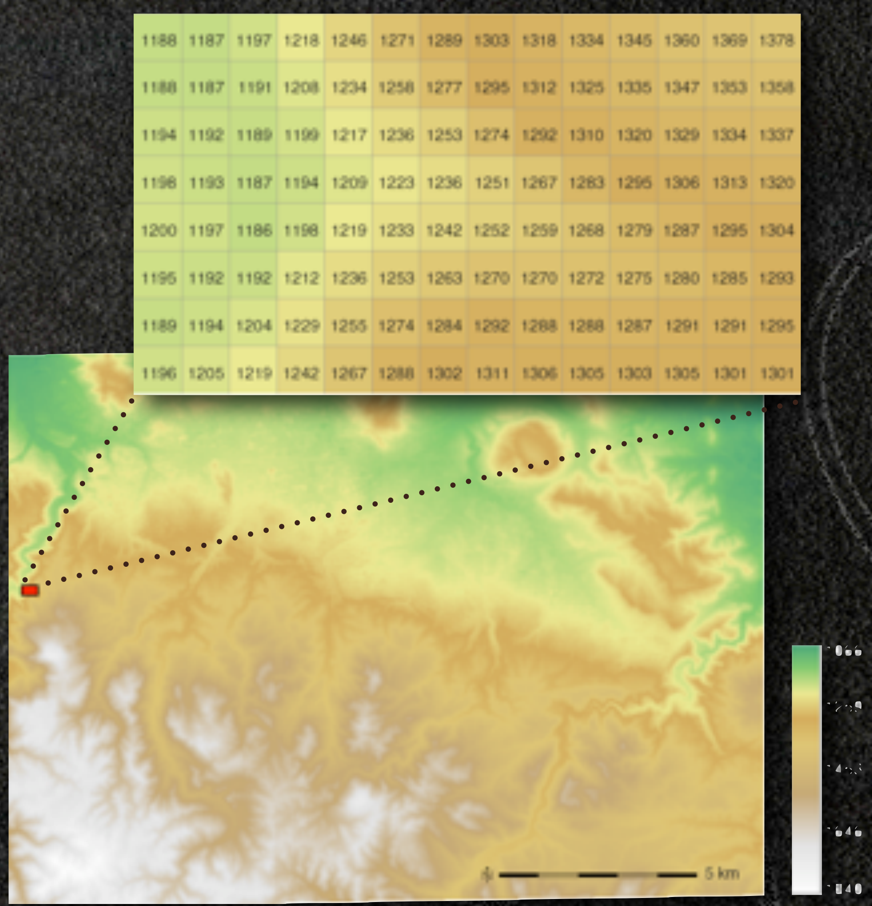


Modeling Landscape Dynamics

- Implemented as recursive scripts in open source GRASS GIS

Modeling Landscape Dynamics

- Implemented as recursive scripts in open source GRASS GIS
  - Start with DEM of topography



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1194	1192	1189	1199	1217	1236	1253	1274	1292	1310	1320	1329	1334	1337
1198	1193	1187	1194	1209	1223	1236	1251	1267	1283	1295	1306	1313	1320
1200	1197	1186	1198	1219	1233	1242	1252	1259	1268	1279	1287	1295	1304
1195	1192	1192	1212	1236	1253	1263	1270	1270	1272	1275	1280	1285	1293
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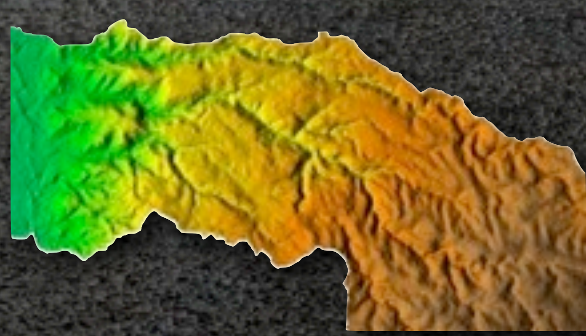
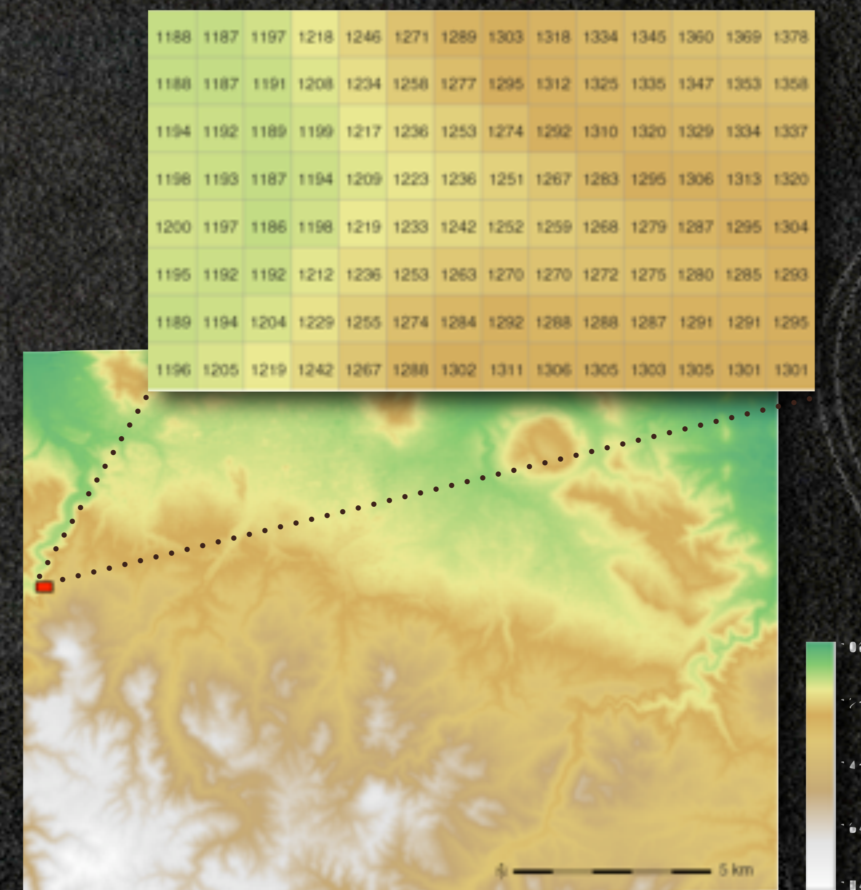


Modeling Landscape Dynamics

- Implemented as recursive scripts in open source GRASS GIS
  - Start with DEM of topography
  - Calculate HED (net erosion/deposition) for each landscape cell



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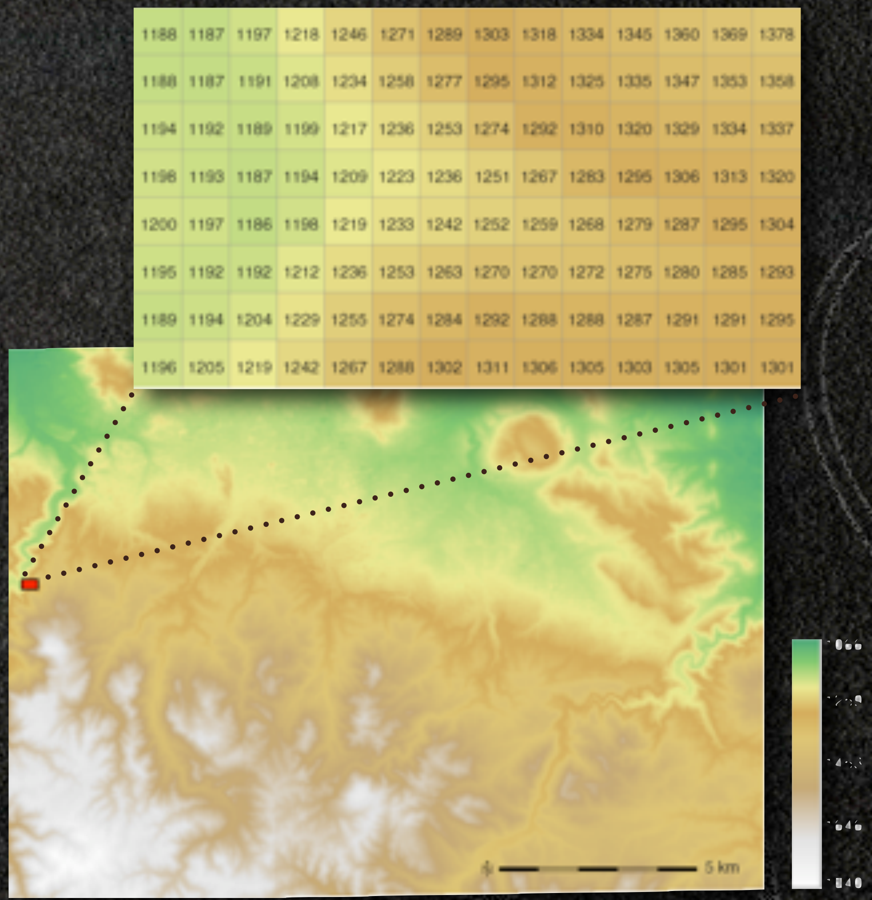

Modeling Landscape Dynamics

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  - Start with DEM of topography
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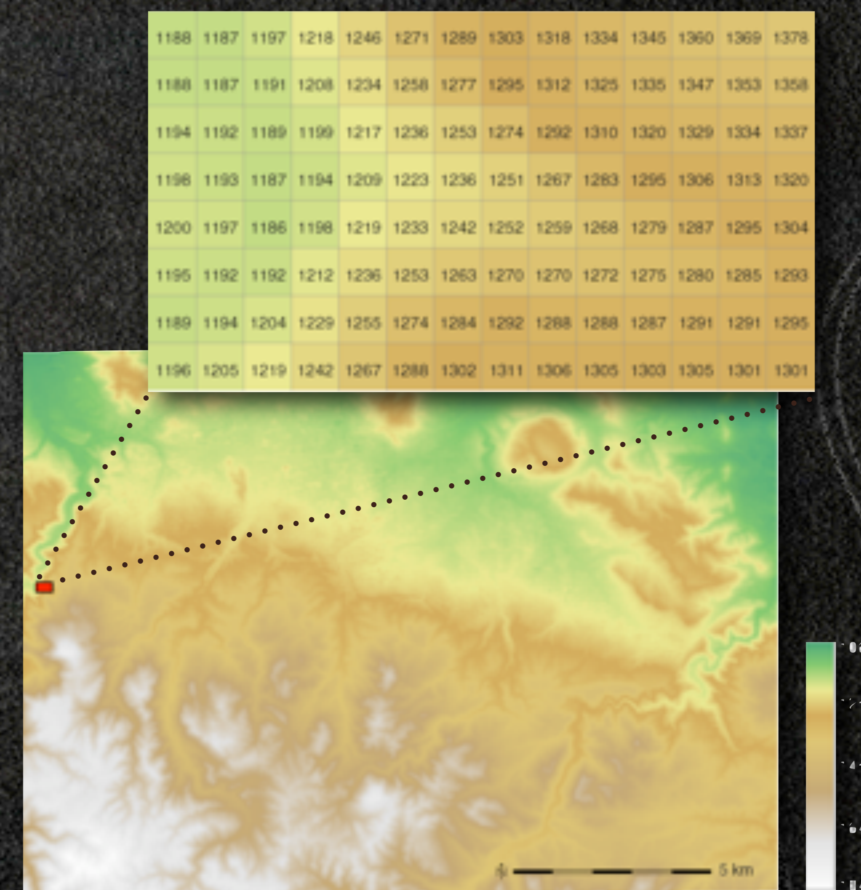
  - Add/subtract net erosion/deposition to DEM
  - Create new DEM of topography



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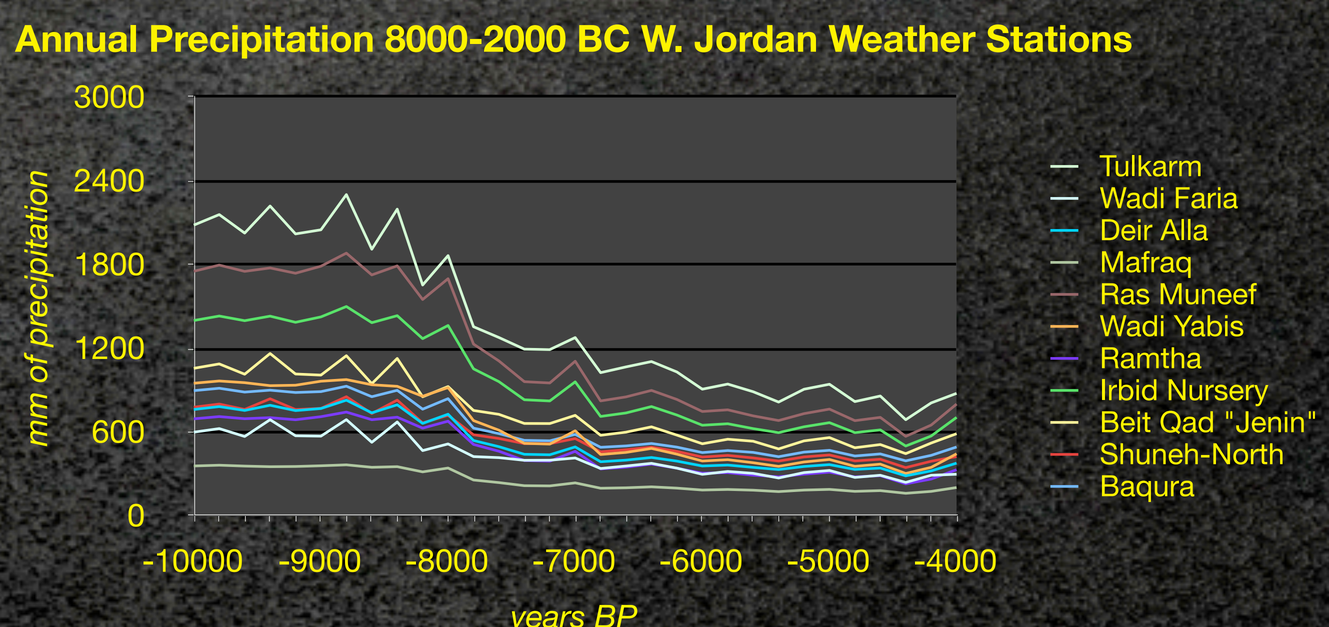
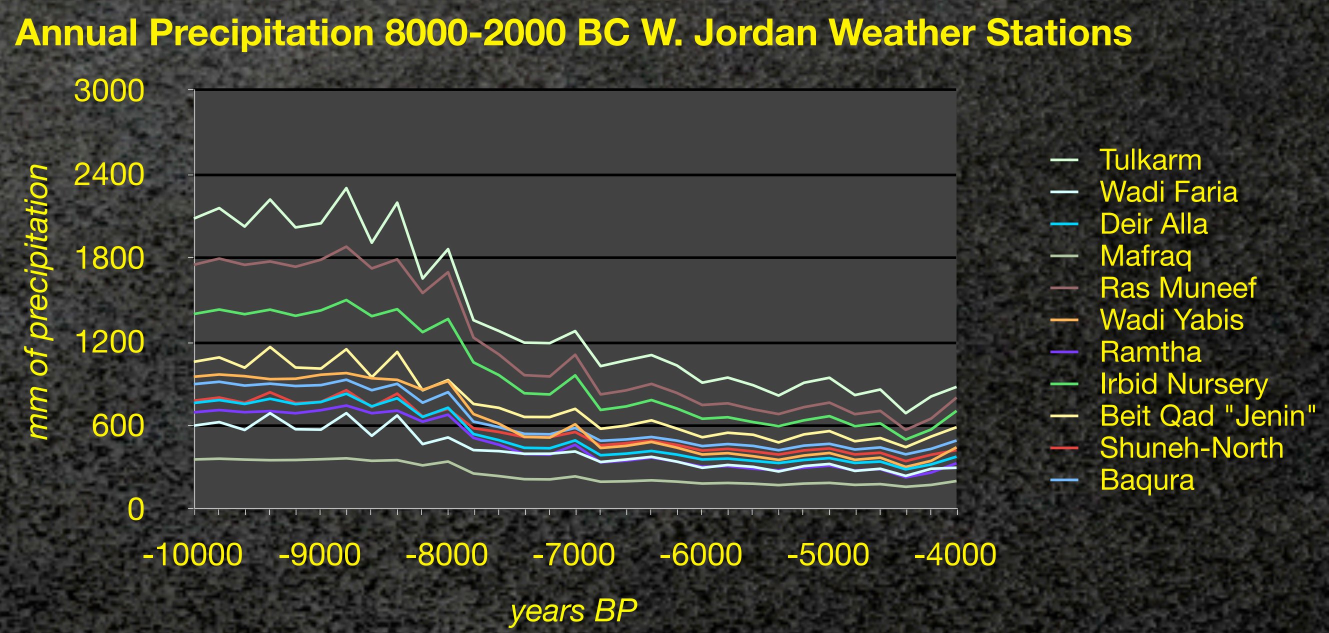
Modeling Climate Dynamics

- Point climate models calculated at weather stations



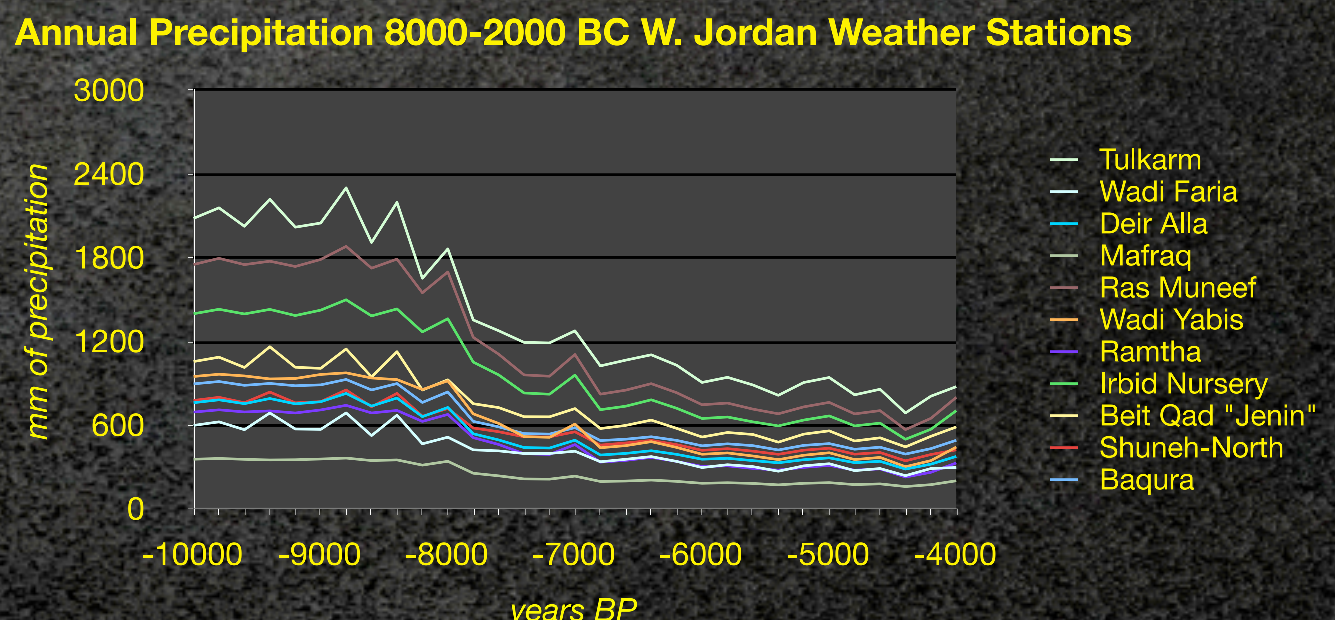
Modeling Climate Dynamics

- Point climate models calculated at weather stations
- Transformed into paleoclimate landscapes using multiple regression

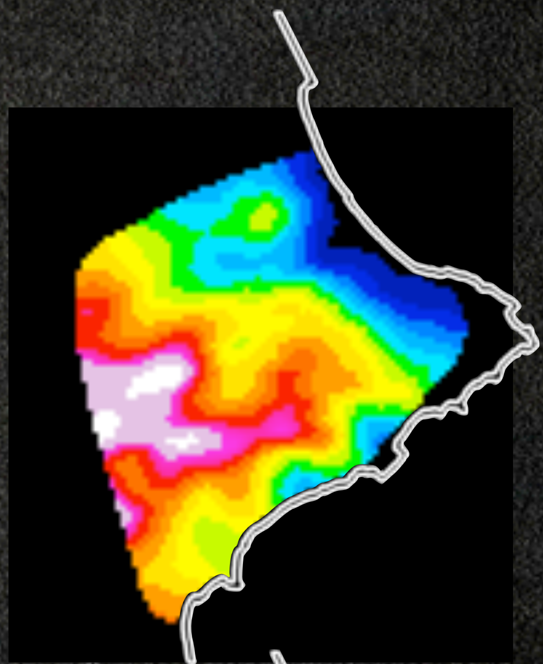


Modeling Climate Dynamics

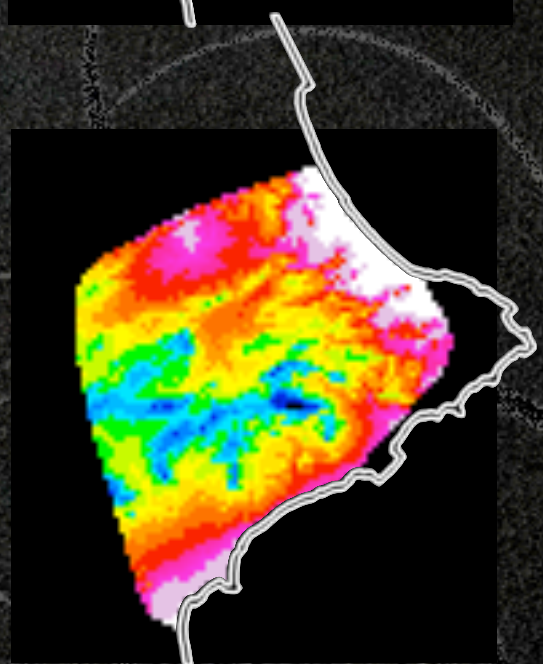
- Point climate models calculated at weather stations
- Transformed into paleoclimate landscapes using multiple regression
- Regression coefficients applied to DEMs to generate climate surfaces



mean annual precipitation



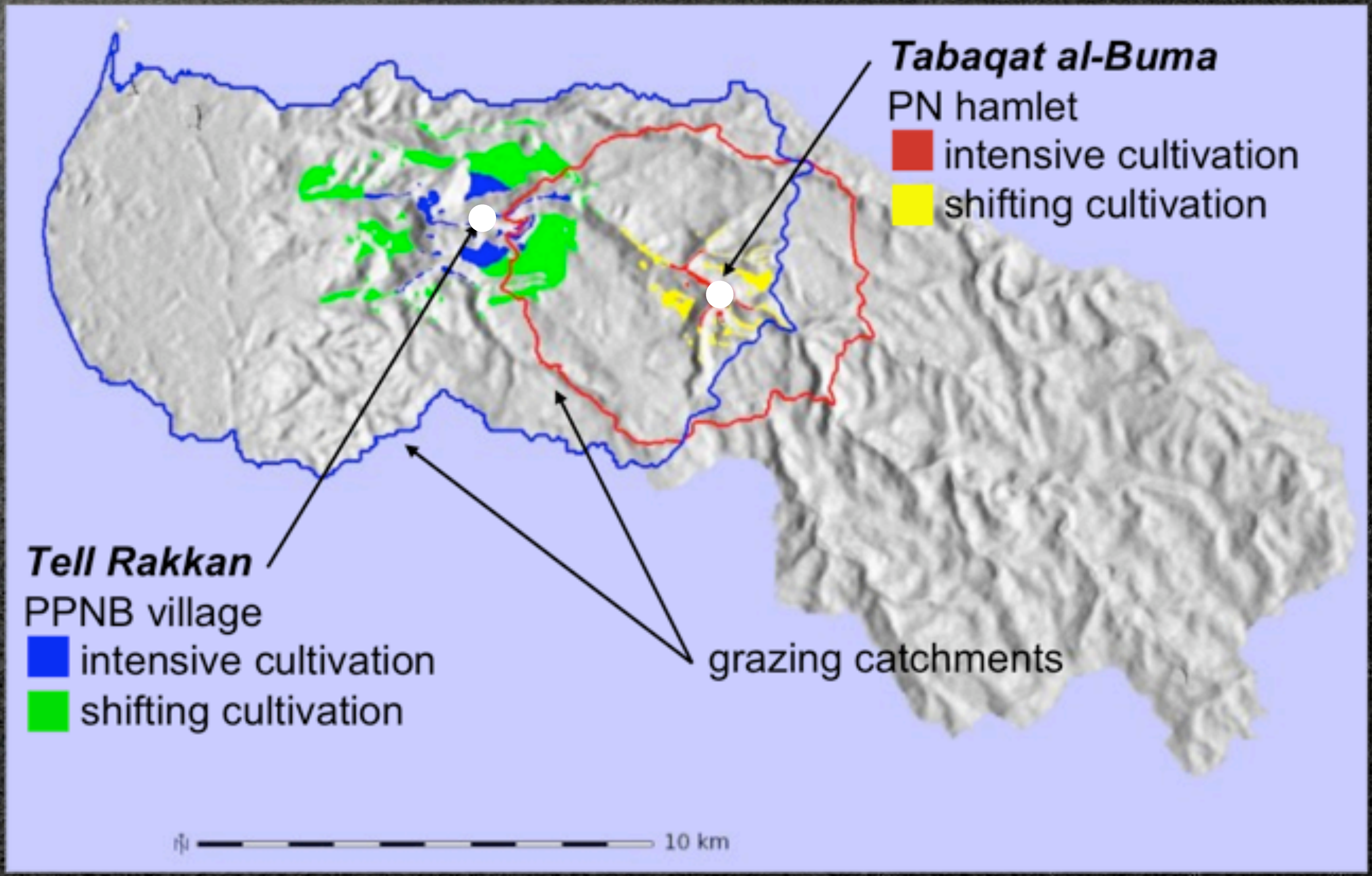
mean annual temperature



Paleoclimates of E.Spain
10,000-3,000 BP

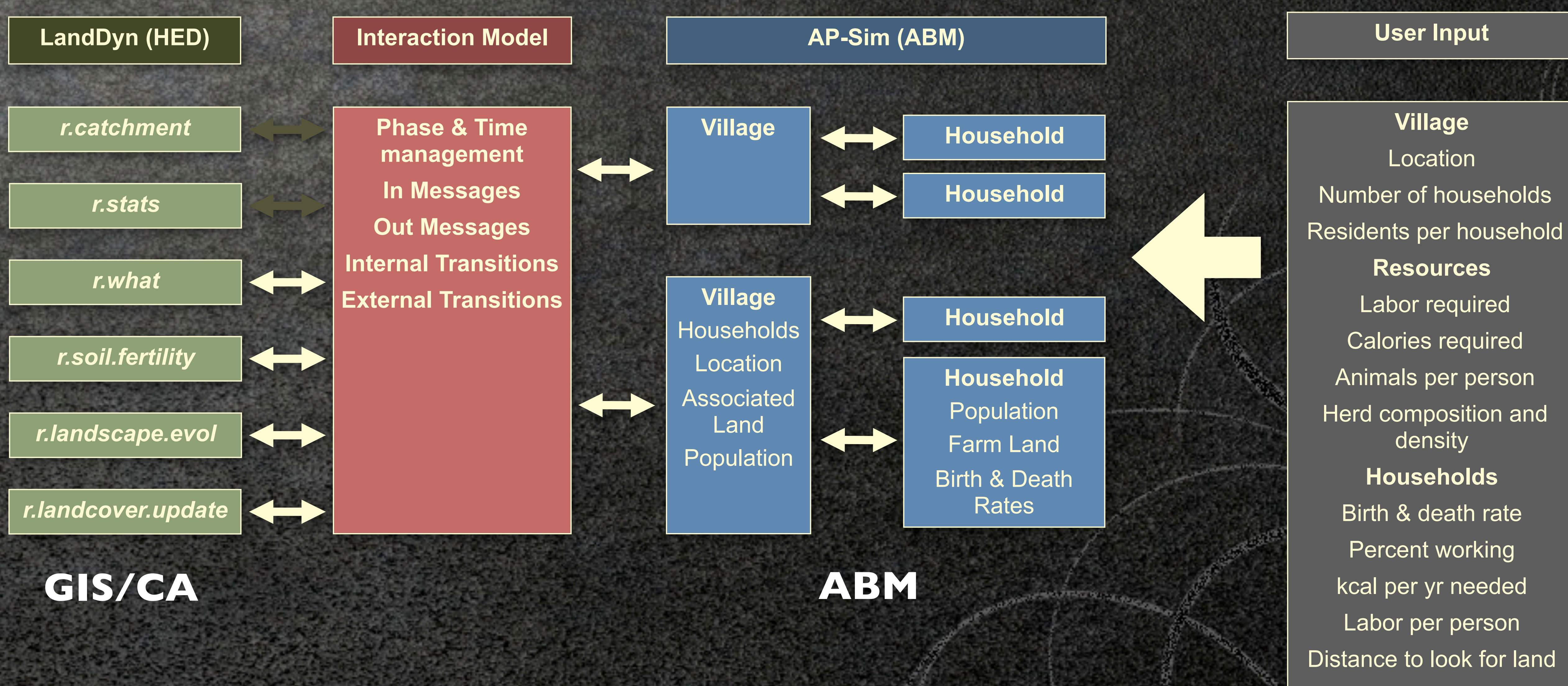
Modeling Land-use

- Stochastic modeling



Modeling Land-use

- Coupled ABM/GIS landscape model



Modeling Ecodynamics

- Visualization of coupled ABM/GIS landscape model using open source WorldWind (NASA)

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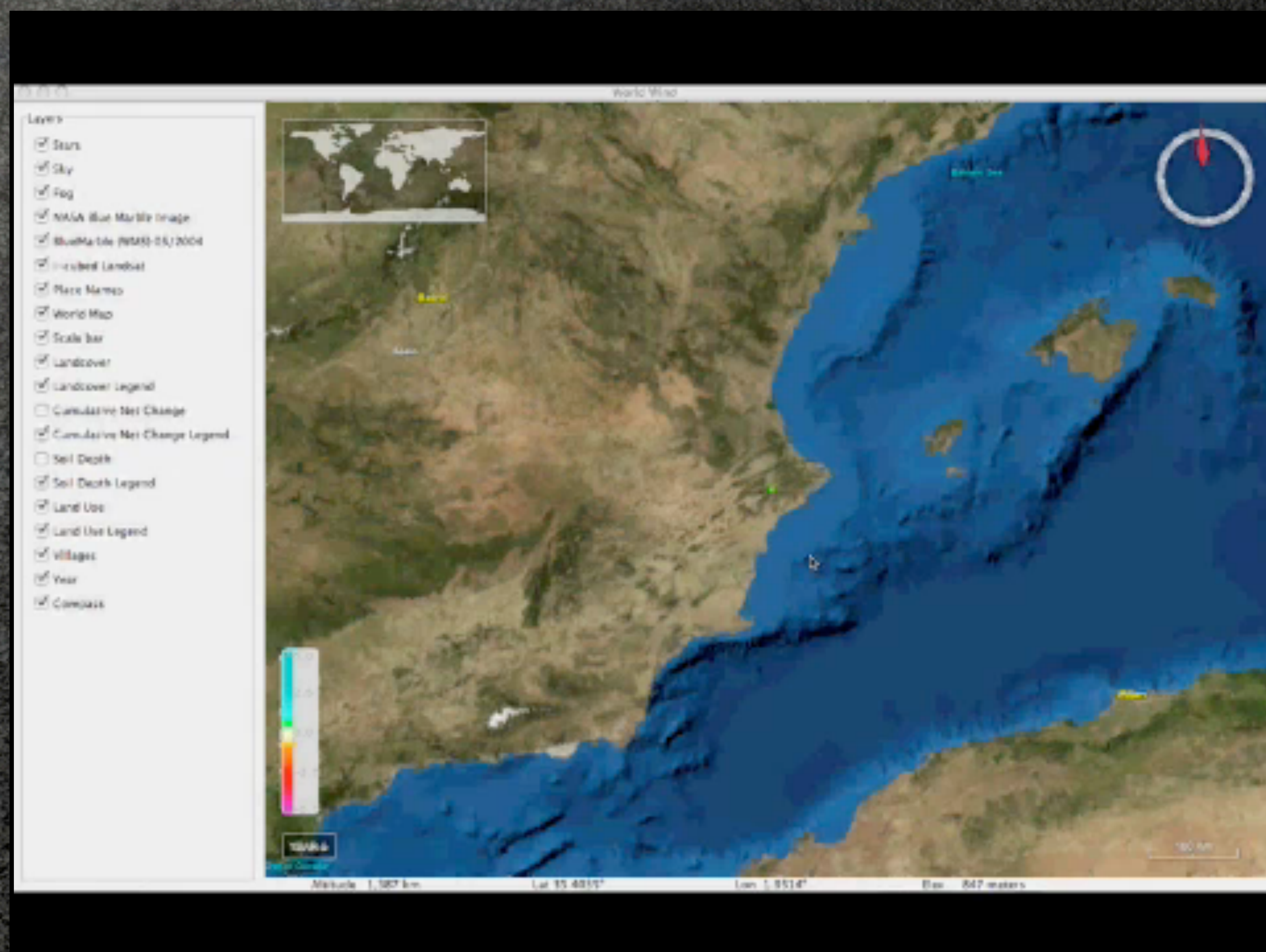

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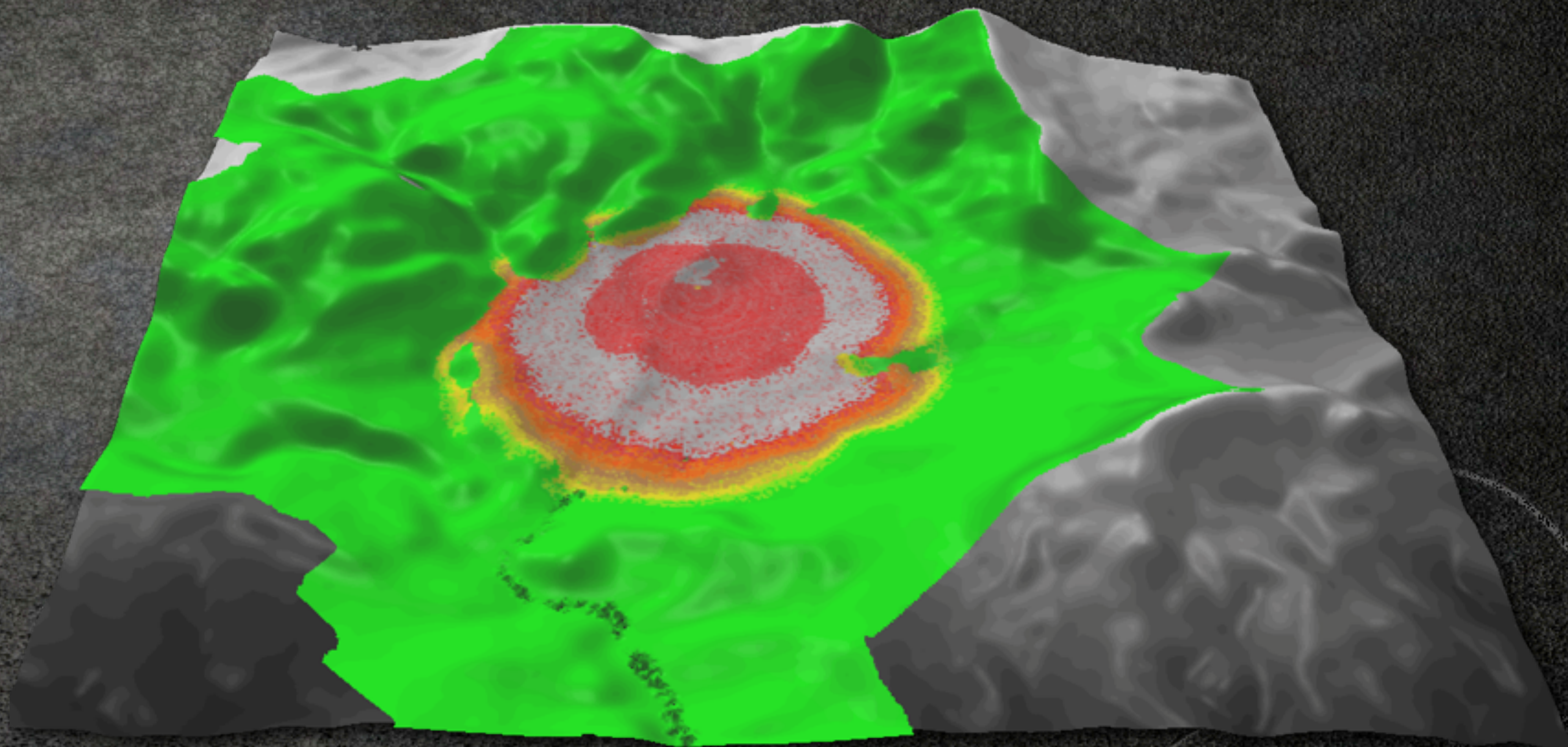

- Coupled model output: 100 years of cultivation and grazing on early Holocene landscape, Penaguila Valley, Alicante Province, Spain.

Experiments in Long-Term Socioecology

- **Results of initial experiments (40 & 200 year simulations) in northwestern Jordan**
- Barton, C. M., Ullah, I., & Mitasova, H. (2010) Computational modeling and socioecological dynamics: a case study from southwest Asia. *American Antiquity* 75(2):364-386.
- Barton, C.M., Ullah, I., & Bergin, S. (2010) Land-use, water, and Mediterranean landscapes: modeling long-term dynamics of socioecological systems. *Phil.Trans.A Royal Society* (in press).

Experiments in Long-Term Socioecology

- Experimental design

Settlement	Precip. & Soil	Agropastoral Land-Use Experiments	
Small village with 5-20 families. Like Tell Rakkan ca. 8400 cal BP (PPNB)	918.5 mm/yr R-factor = 6.69 K-factor = 0.42	No cultivation	No grazing
		Intensive cultivation	No grazing
			Grazing
		Shifting cultivation	No grazing
			Grazing
Hamlet with 1-5 families. Like Tabaqat al-Bûma ca. 7400 cal BP (PN)	783.7 mm/yr R-factor = 5.26 K-factor = 0.42	No cultivation	No grazing
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Experiments in Long-Term Socioecology

- Control model

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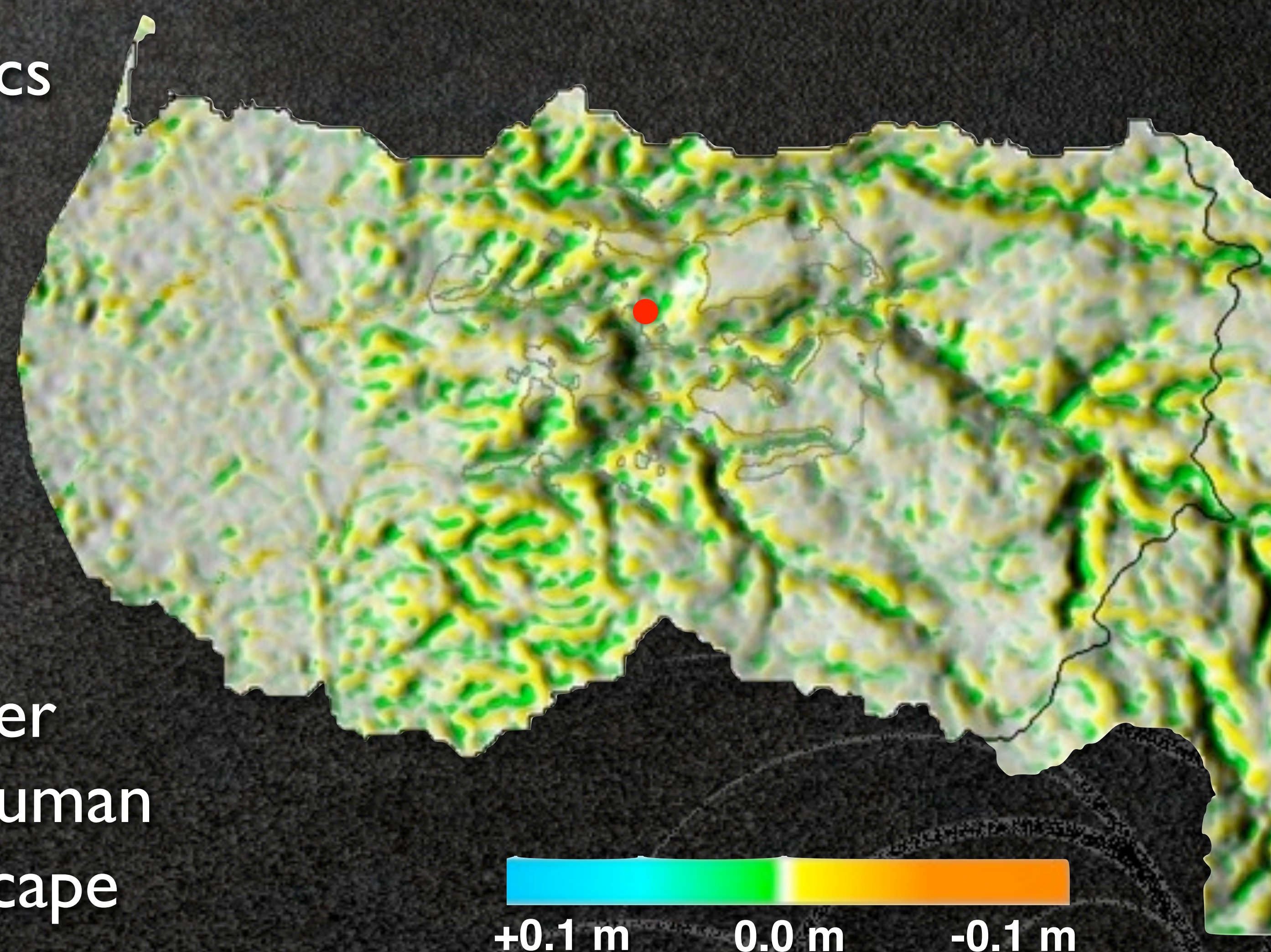
Experiments in Long-Term Socioecology

- Control model after 40 years. Landscape dynamics without people
  - Contrafactual paleoecology
  - Only possible with modeling
  - Used to calibrate other results to show net human contribution to landscape change



Experiments in Long-Term Socioecology

- Comparing consequences of population change

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Experiments in Long-Term Socioecology

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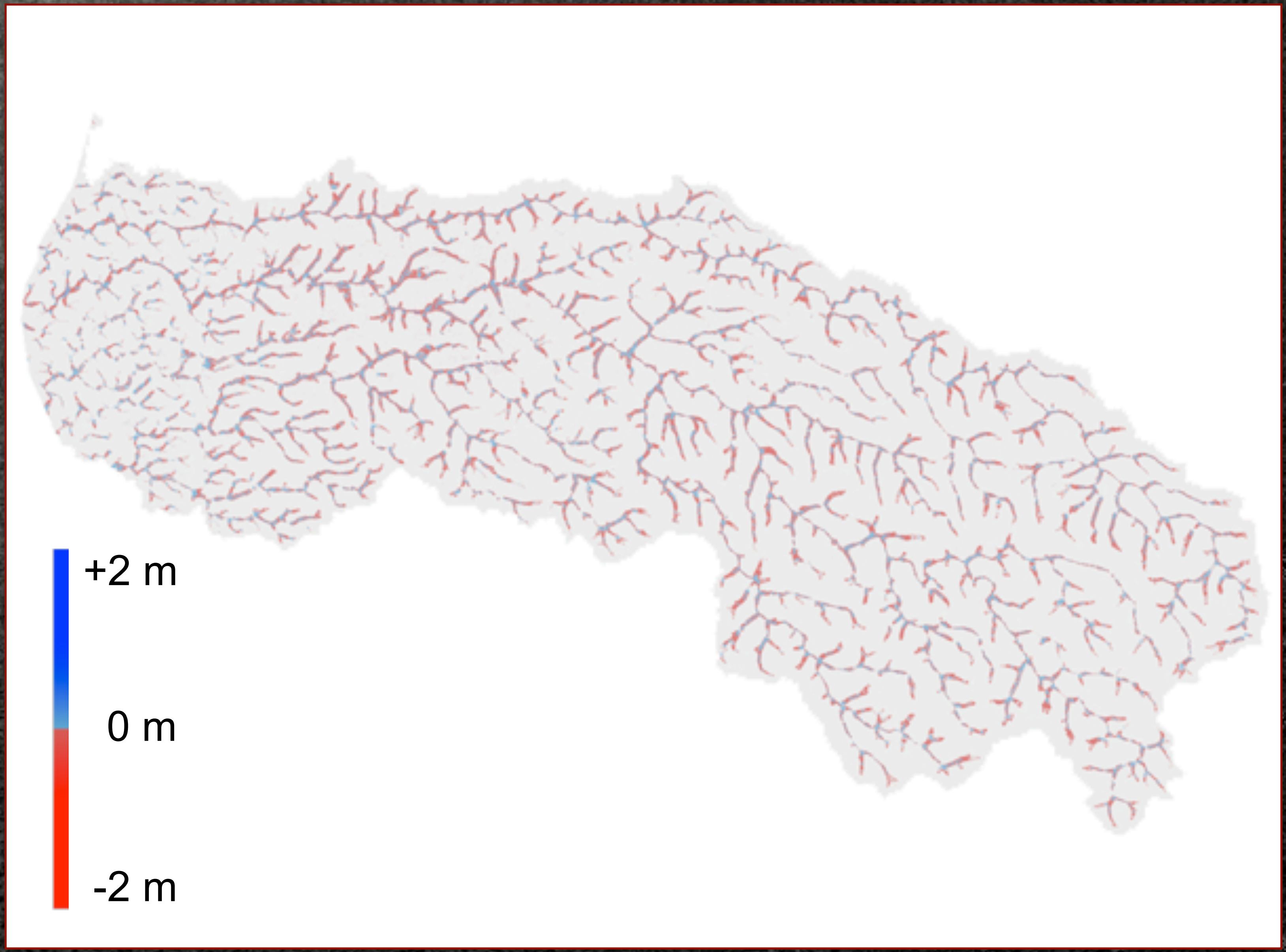

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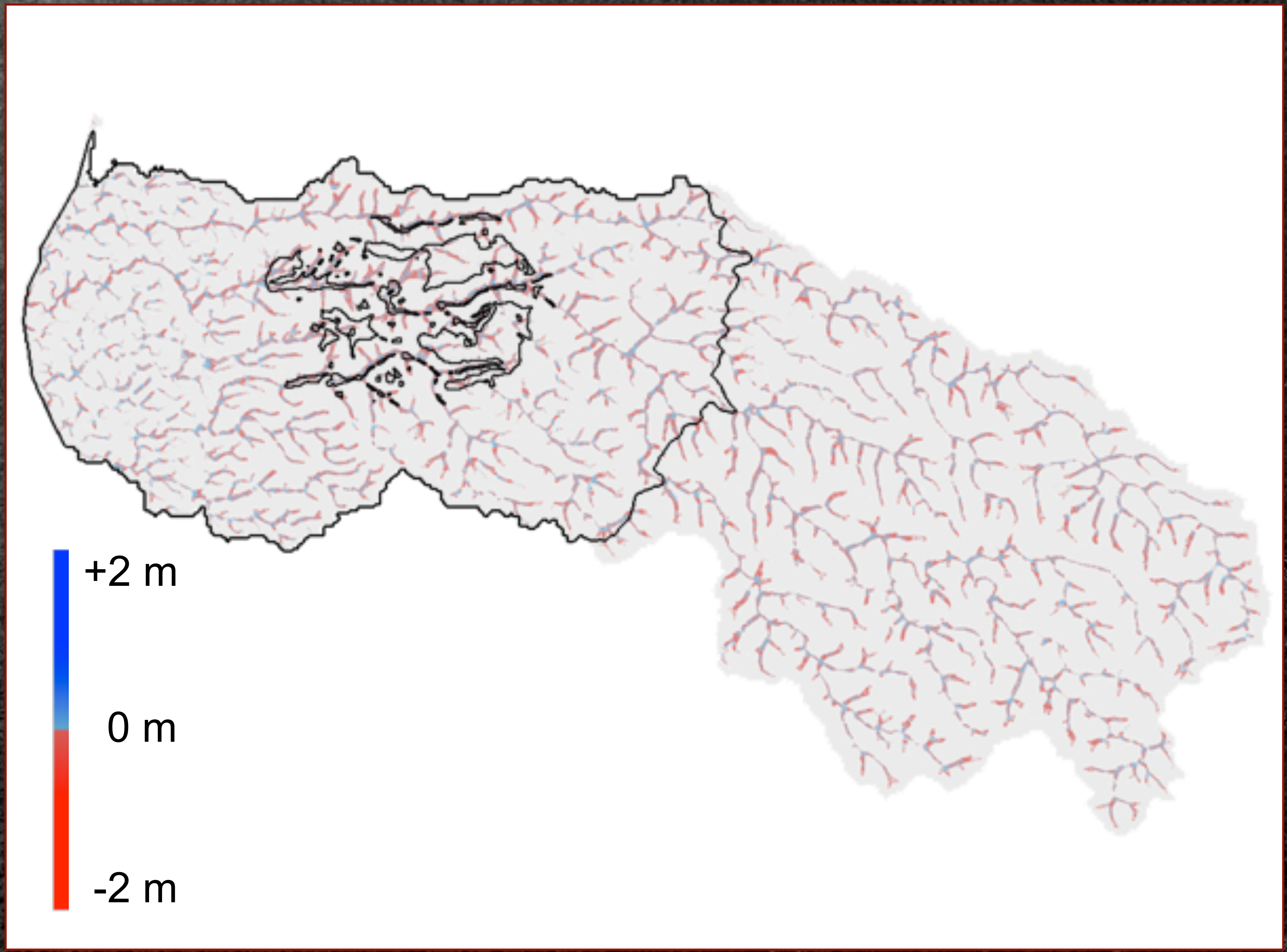
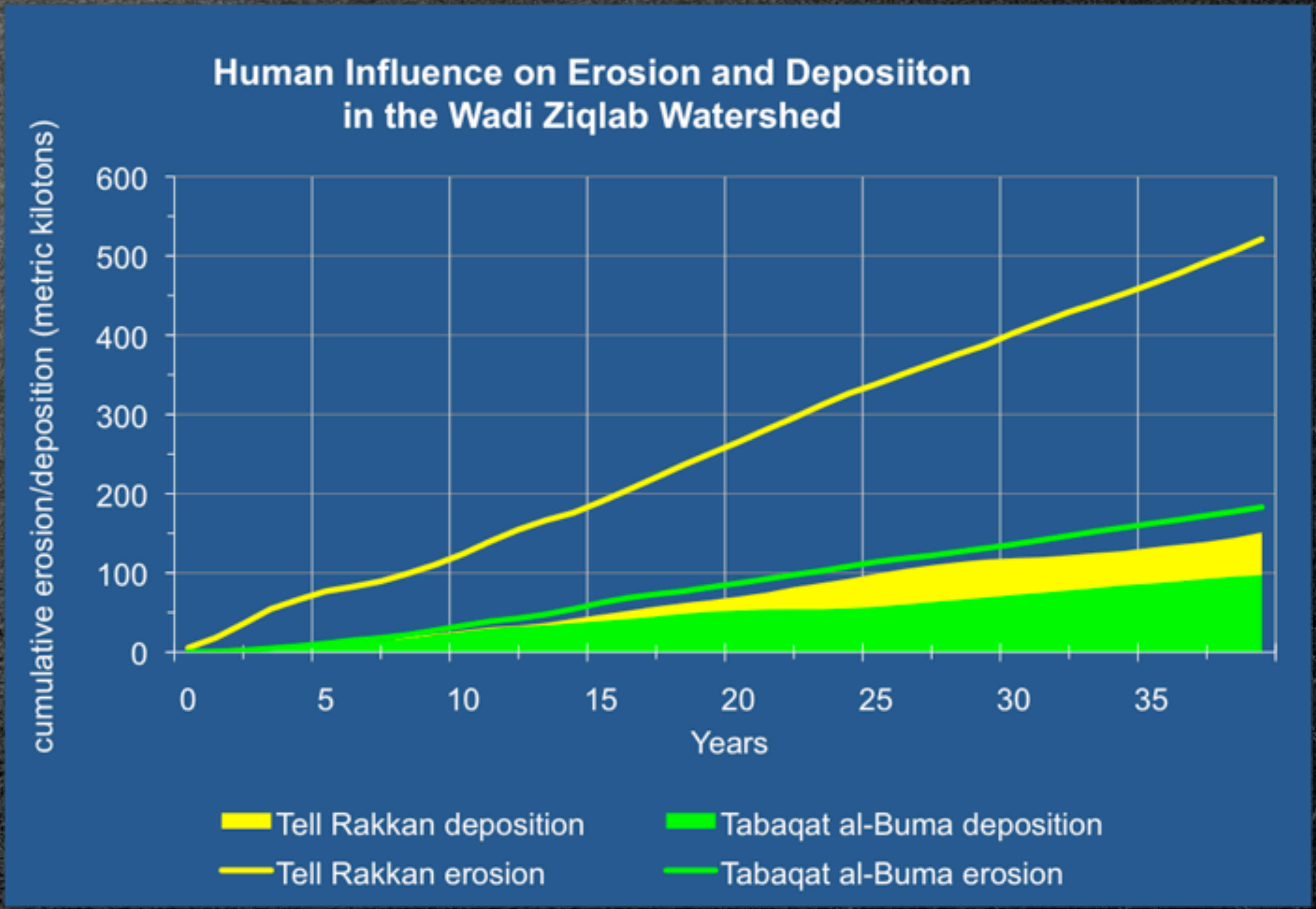


Experiments in Long-Term Socioecology

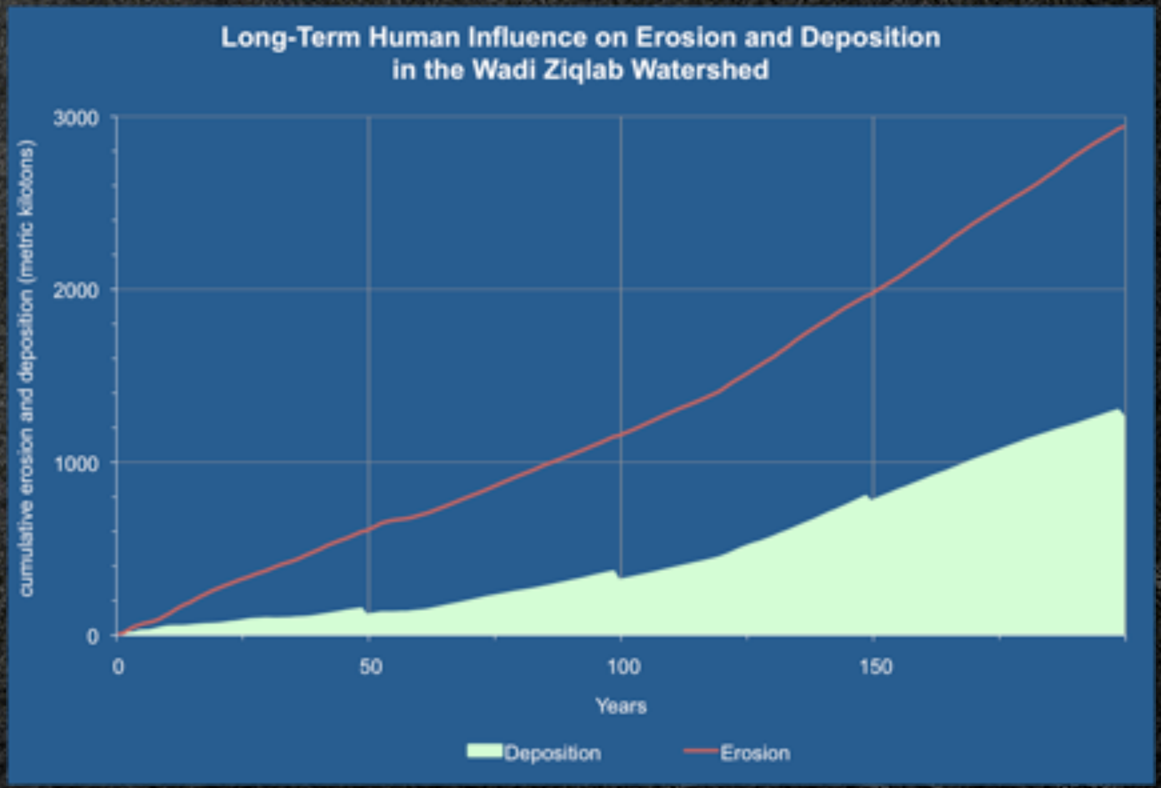


Experiments in Long-Term Socioecology

- Hamlet
  - Cultivation limited to wadi bottoms
  - Grazing causes most erosion
  - Erosion primarily in uncultivated uplands
  - Redeposited sediment in cultivated zones is 53% of erosion
- Village
  - Cultivation in uplands; more extensive grazing
  - Cultivation causes most erosion
  - Erosion in cultivated and uncultivated zones
  - Redeposited sediment only 29% of erosion

Experiments in Long-Term Socioecology

- Long-term outcomes
- 200 years of land-use around village
  - Erosion continues for 200 years
  - Rate of erosion increases
  - Erosion continues to outpace deposition



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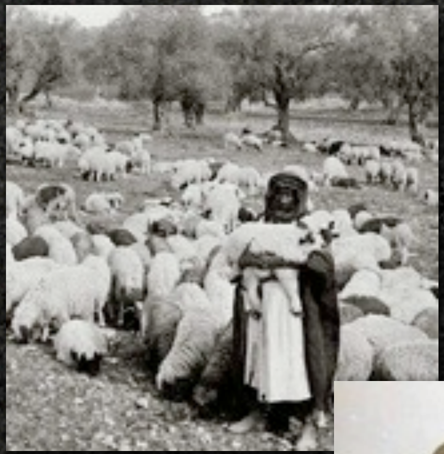
  - Subsequent disappearance of large communities and replacement with smaller communities
  - Initial appearance of pastoralism
  - Initial appearance of significant socioeconomic differentials



Computational Modeling & Social Science

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- Some technologies can even be transformative for science

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Computational Modeling & Social Science

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Computational Modeling & Social Science

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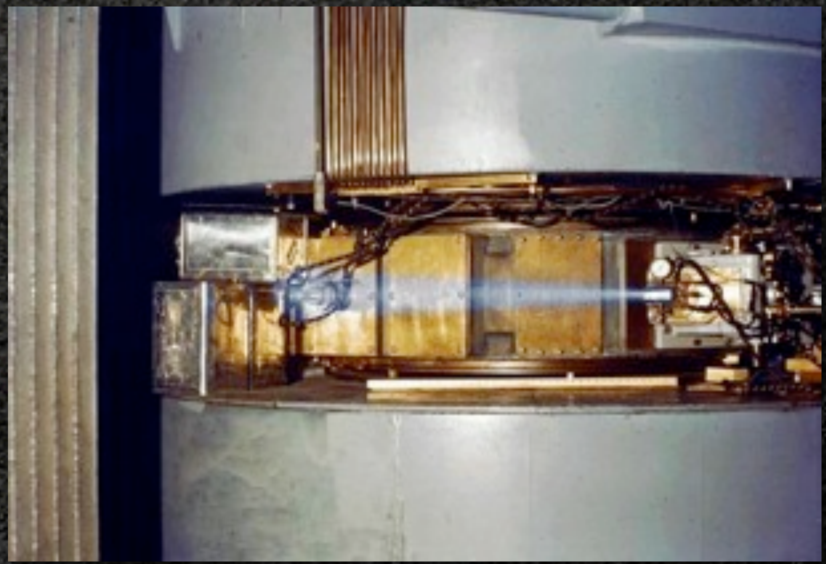
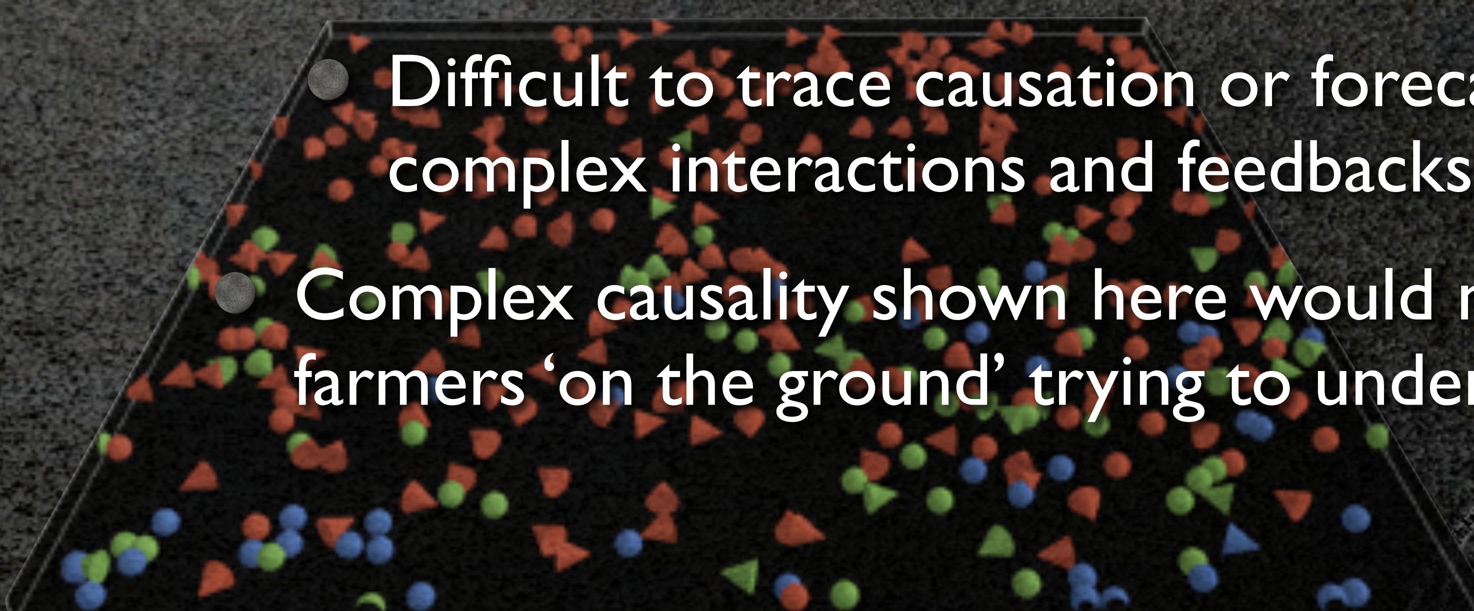
- Particle accelerator



Computational Modeling & Social Science

- Computational modeling a potentially transformative technology in science of socio-ecological systems
- Allows us to express complex interactions and dynamics in quantitative form that can be better communicated across scientific disciplines, and independently evaluated
  - Long-term consequences of decisions and environmental not easily visible in SES
  - Difficult to trace causation or forecast consequences due to complex interactions and feedbacks(couplings)
- Complex causality shown here would not have been apparent to farmers 'on the ground' trying to understand declining productivity



Computational Modeling & Social Science

- BUT requires…
  - "Computational thinking" about social-natural dynamics (models vs. simulations)
  - Familiarity with computer-based tools
  - Investment of time for 'intellectual retooling'
  - Investment of institutional human resources
- SES scientists need to be involved with the development of these important tools for our research
- Need to train our students (and ourselves) in the use of new research methods
- Need to share knowledge of this new technology to jump-start a science of social dynamics.

Interdisciplinary & International Collaboration

- 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
- Partners: Universitat de València, Universidad de Murcia, University of Jordan, North Carolina State University, University of Wisconsin, Hendrix College, Geoarchaeological Research Associates, GRASS GIS Development Team