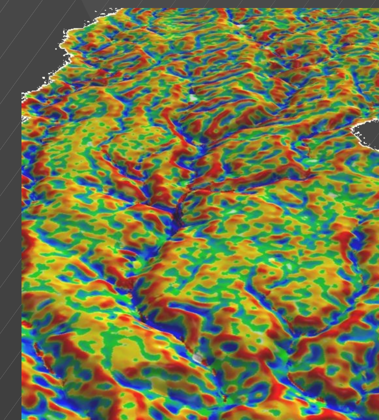
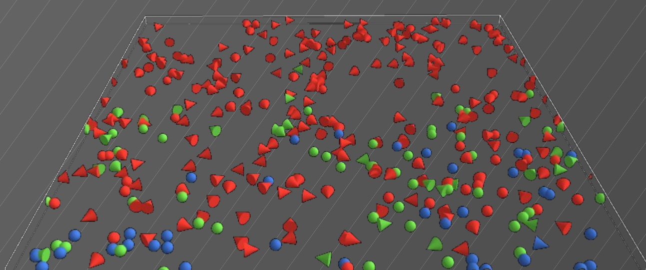


Computational Modeling for Socioecological Systems Science



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Social Systems are Complex

- Even simple social systems are complex
- Complexity has grown at increasing rate since beginnings of urbanism
- Measures of complexity
  - 5,400 mammal species (350 primates)
  - 28,800 occupational titles in USA (820 occupational groups)

Socioecological Systems are More Complex

- Social complexity amplified by interactions with the natural world
- Agriculture (last 10ka)
  - Human manipulation of ecosystems. Now on massive scale.
  - Society recursively impacted by consequences of environmental manipulation
- Result
  - Coupled socioecological systems
  - Dynamics driven by combination of social practice and biophysical process
  - Dominate terrestrial landscapes today

Socioecological Systems are More Complex

- Coupled human-natural systems
  - Non-linear relationships between cause and effect in environmental change (e.g., threshhold and scale-dependent effects)
  - Emergent (often unexpected) ecological effects of human actions
- Ecological consequences may take centuries to play out
  - Different social and biophysical time scales
  - Amplifying vs. dampening effects over time and space

Socioecological Systems are More Complex

- Environmental “problems” are social problems (van der Leeuw)
- Imperative to understand dynamics of socioecological systems
  - Current human-environmental interactions and landscapes
  - Informed environmental (and social) policy
  - Forecasting environmental change and risk

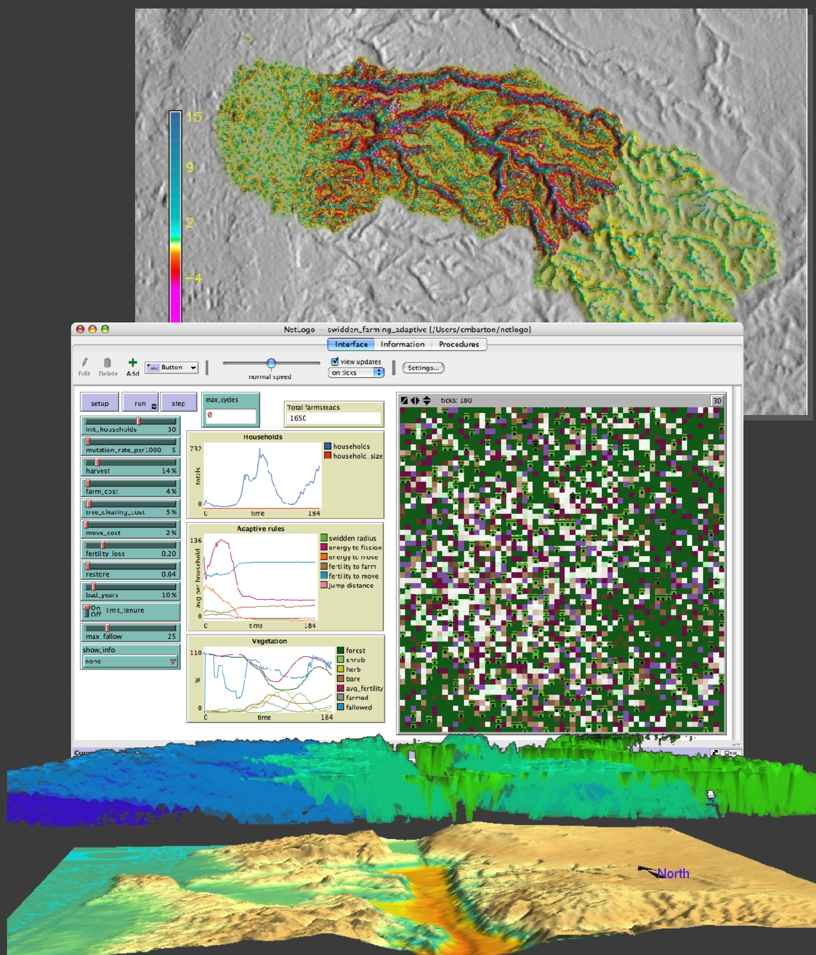
Modeling Socioecological Systems

- Coupled social-natural systems pose special challenges for modeling
- Different components represented by different types of models, operating in different ways, with different timing
- Outcomes often long-term. Make evaluating models difficult with modern data.

Modeling Socioecological Systems

- Human land use
  - Discrete entities, following decision rules, organized in nested hierarchies (individual, household, community, city, etc).
  - Agent-based models
- Surface runoff
  - Landscape cells whose state is influenced by state of adjacent cells
  - Cellular automata
- Stream flow
  - Competence varies continuously with velocity
  - Differential equations

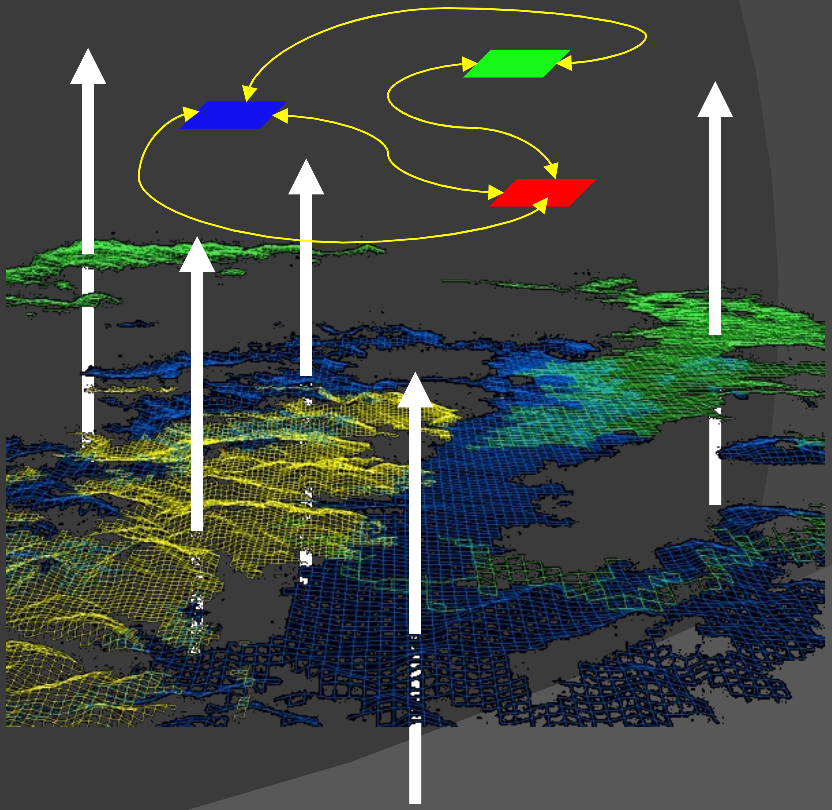
Modeling Socioecological Systems



- New cybertools
  - Permit explicit and quantitative representation of components of social and natural systems
  - Including dynamics across space and time
- Important examples include
  - GIS and geospatial models
  - Agent based models
  - Interactive visualization of multivariate data
- Often must combine to model coupled socioecological systems

Modeling Socioecological Systems

- The past is an effective model testbed, especially for long-term consequences
  - Apply models to archaeological/historical record
  - Rigorous evaluation for models of socioecological dynamics
  - Record of sparse, discontinuous points, scattered in time and space
- Models that can 'pass through' known points of past systems…
  - More robust
  - More confidently applicable in other times and places

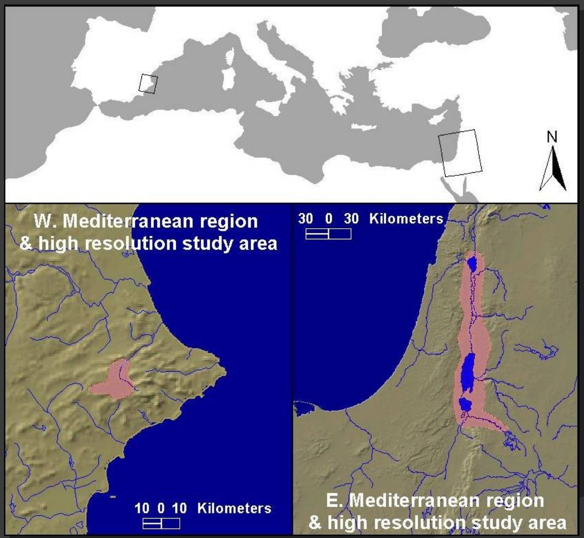


Mediterranean Landscape Dynamics

- Example of research protocols for socioecological modeling
  - Large-scale landscape consequences of small-scale landuse decisions, and their feedbacks, over long time frames.
  - Hybrid modeling laboratory that integrates diverse model classes (ABM, CA, PDE, etc)
  - Uses archaeological data for model parameterization and evaluation. Characterize past system to create more robust general landuse/landscape models
- Interdisciplinary collaboration
  - Archaeology, geosciences, life sciences, climatology, computer science, geospatial methods and statistics
  - NSF Biocomplexity program (BCS-0410269)

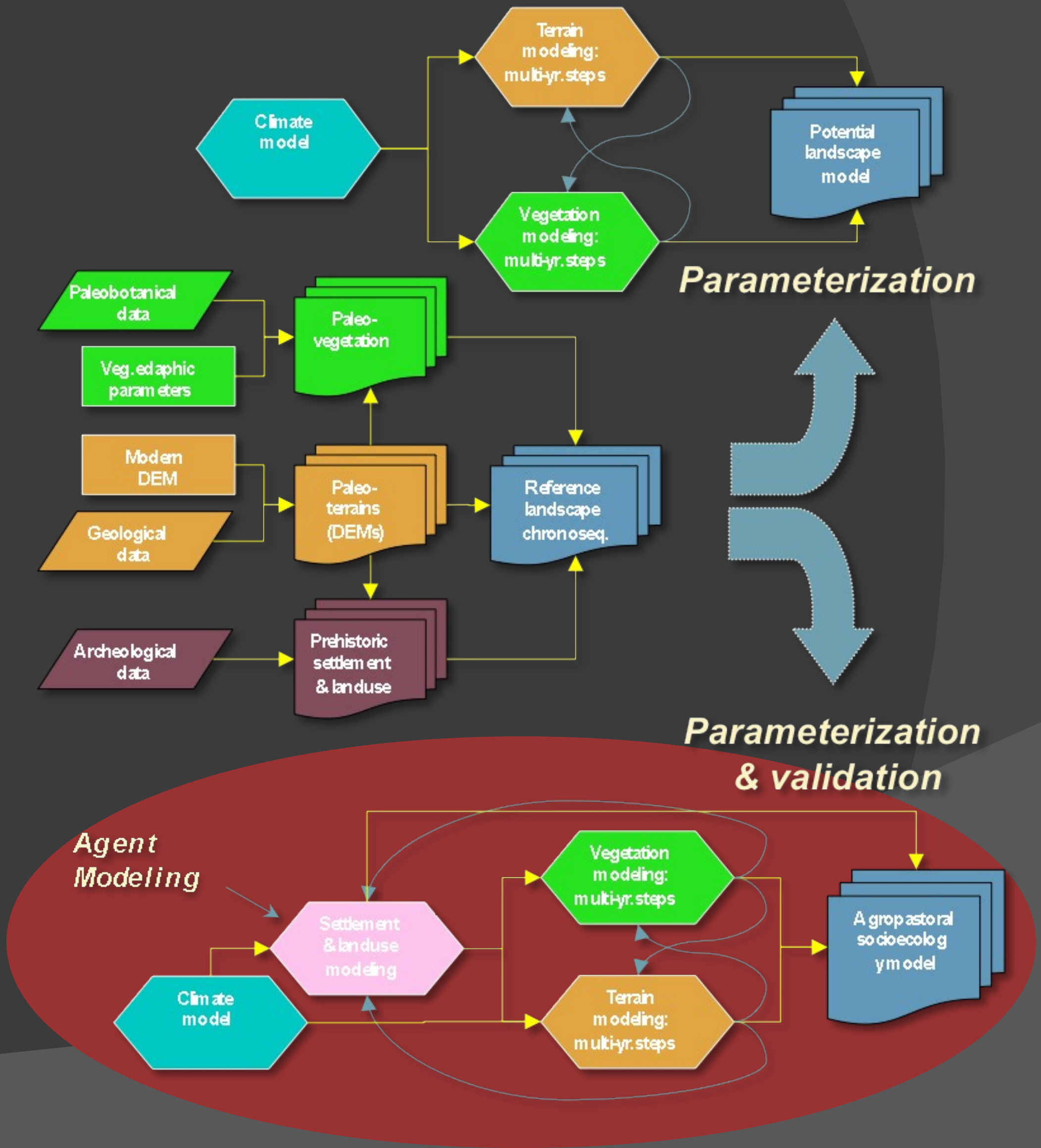
Mediterranean Landscape Dynamics

- Spans Mediterranean socioecosystems
  - Arid East, moister West
  - Range of social configurations
  - Earliest evidence for agriculture



MedLand Modeling Laboratory

- 3 interlinked modeling environments
  - Potential landscape model
  - Archaeological/paleoecological record
  - Coupled agropastoral socioecology model



MedLand Modeling Laboratory

- Dynamically coupled models
  - Landuse ABM:
    - Agents (individuals, households, villages)
    - Behaviors based on decision rules and environmental information
  - Landscape cellular automata
    - Surface processes of erosion/deposition
    - Dynamics derived from differential equations

MedLand Modeling Laboratory

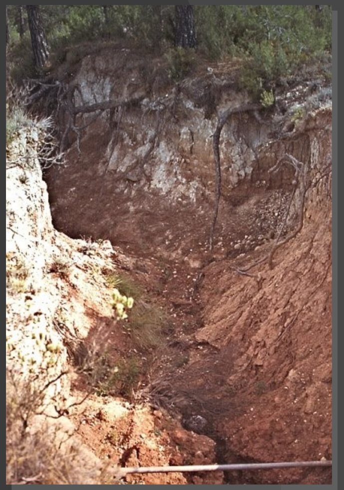
- Models for parameterization
  - Multiple regression
    - Climate: geospatial model
      - Values for each climate station
      - Estimated values between climate stations
    - Vegetation: geospatial model
      - Estimated values based on topography and climate
  - Currently simple algebraic derivation
    - Soils: geospatial model

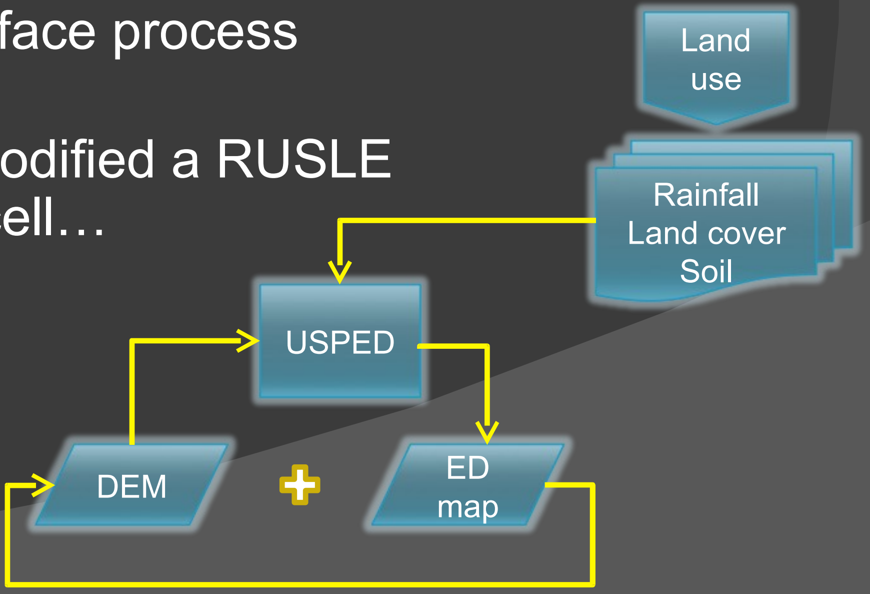
Model Components: Landuse

- ABM in DEVSJAVA
  - Household is basic unit (agent)
  - Organized into villages
- Landuse decisions
  - Potential productivity
  - Distance from village
  - Labor investment needed (e.g., clear land or simply cultivate)
- Landuse activities
  - Clearing land
  - Cultivating crops/herding
  - Fallowing
  - Harvesting crops/animal products
- Returns

Model Components: Landscape

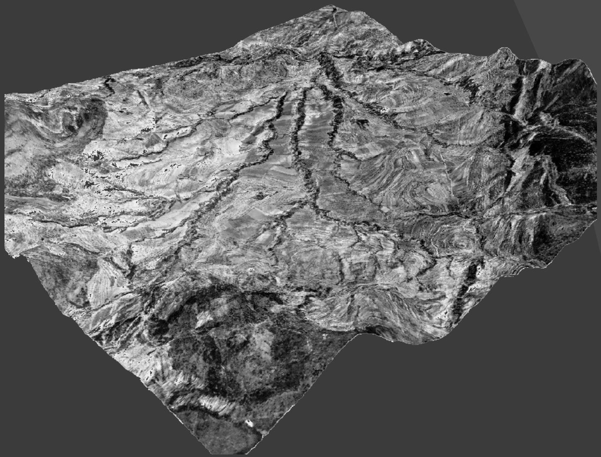
- USPED (as implemented in GRASS GIS)
  - $ED = d(Ep \cdot qsx)/dx + d(Ep \cdot qsy)/dy$
  - ED is net potential erosion or deposition of sediment in any landscape cell
  - qsx and qsy are the sediment transport capacity coefficients in x and y directions (a function of slope, aspect, and flow accumulation) for a given surface process across the cell
  - Ep (potential erodability) is modified a RUSLE value that includes for each cell…
    - rainfall intensity
    - land cover
    - soil characteristics

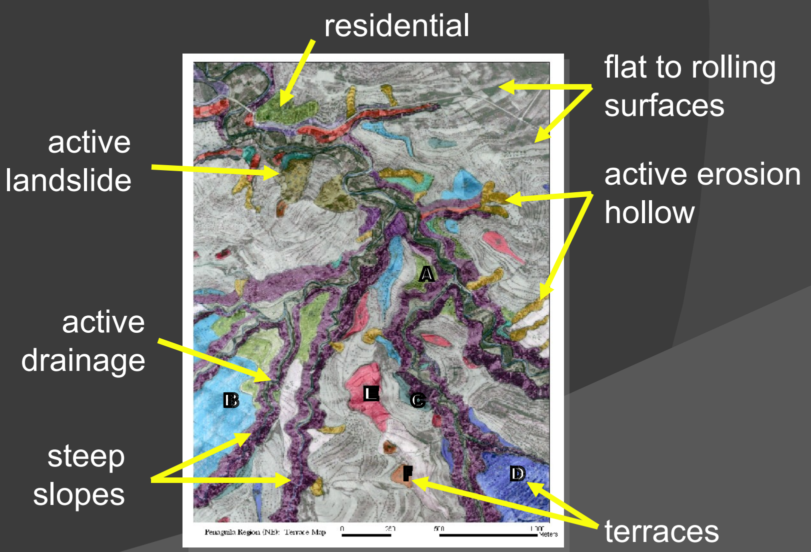




Model Components: Topography

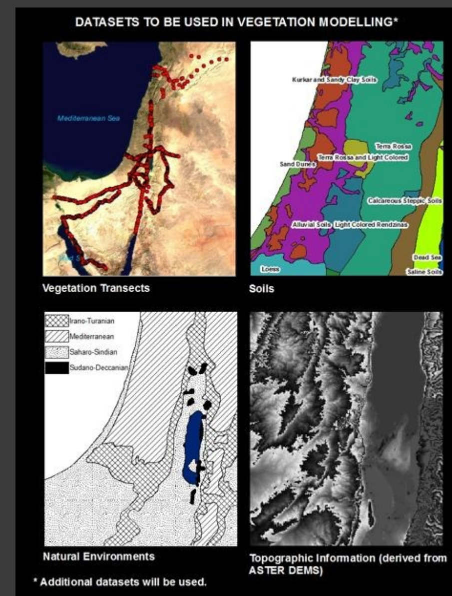
- Paleolandscape reconstruction and verification
- High-resolution DEM created from satellite imagery and stereo aerial photos
- Landform and geomorphic mapping with ground truthing in field

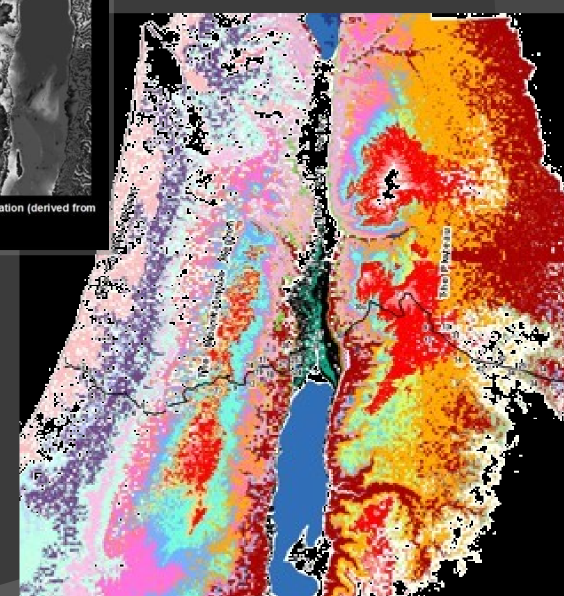




Model Components: Vegetation

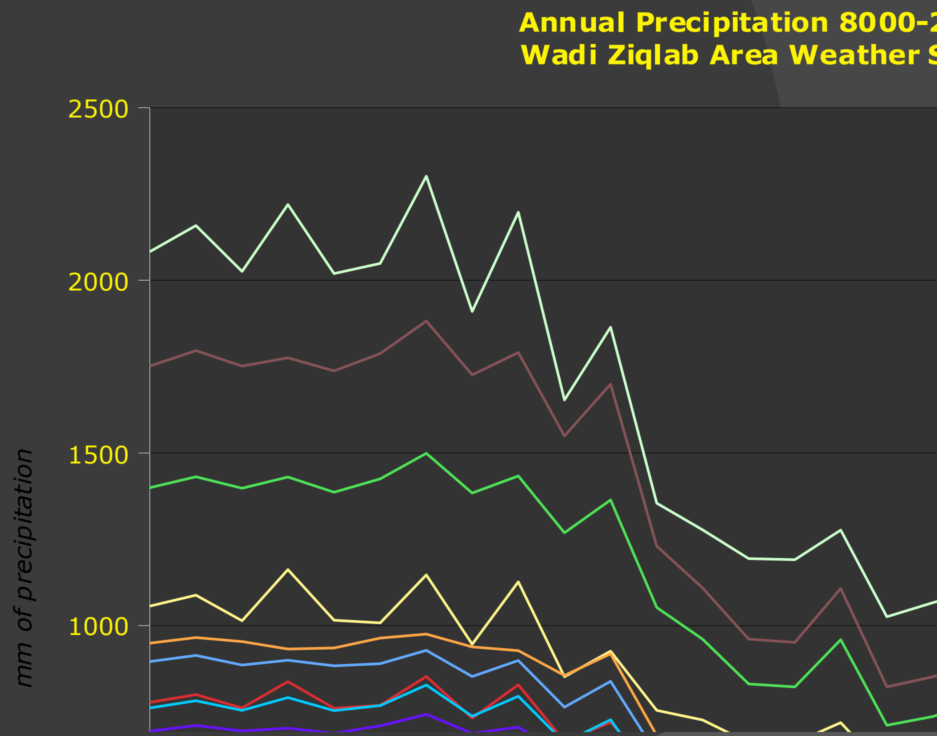
- Potential landcover
- Community models based on
  - climate
  - topography
  - soils
  - vegetation transects
- Successional dynamics





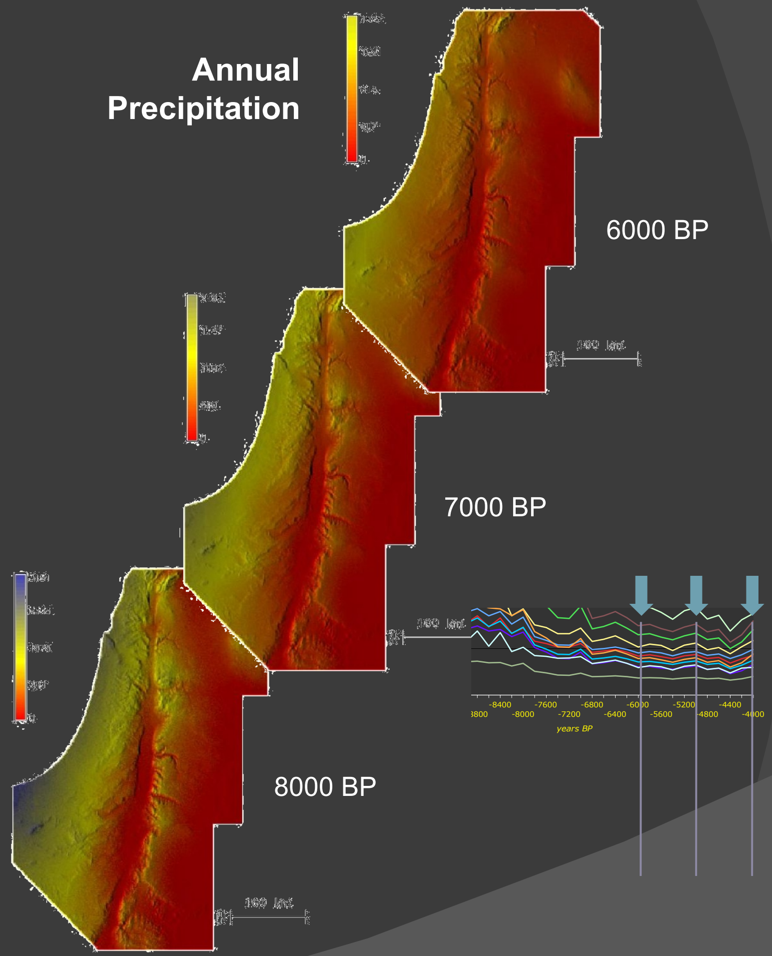
Model Components: Climate

- Paleoclimate at 100 yr intervals for 40 ka
- Macrophysical climate models
- Retrodicted from modern weather station
  - Temperature and precipitation
  - Annual and monthly values



Model Components: Climate

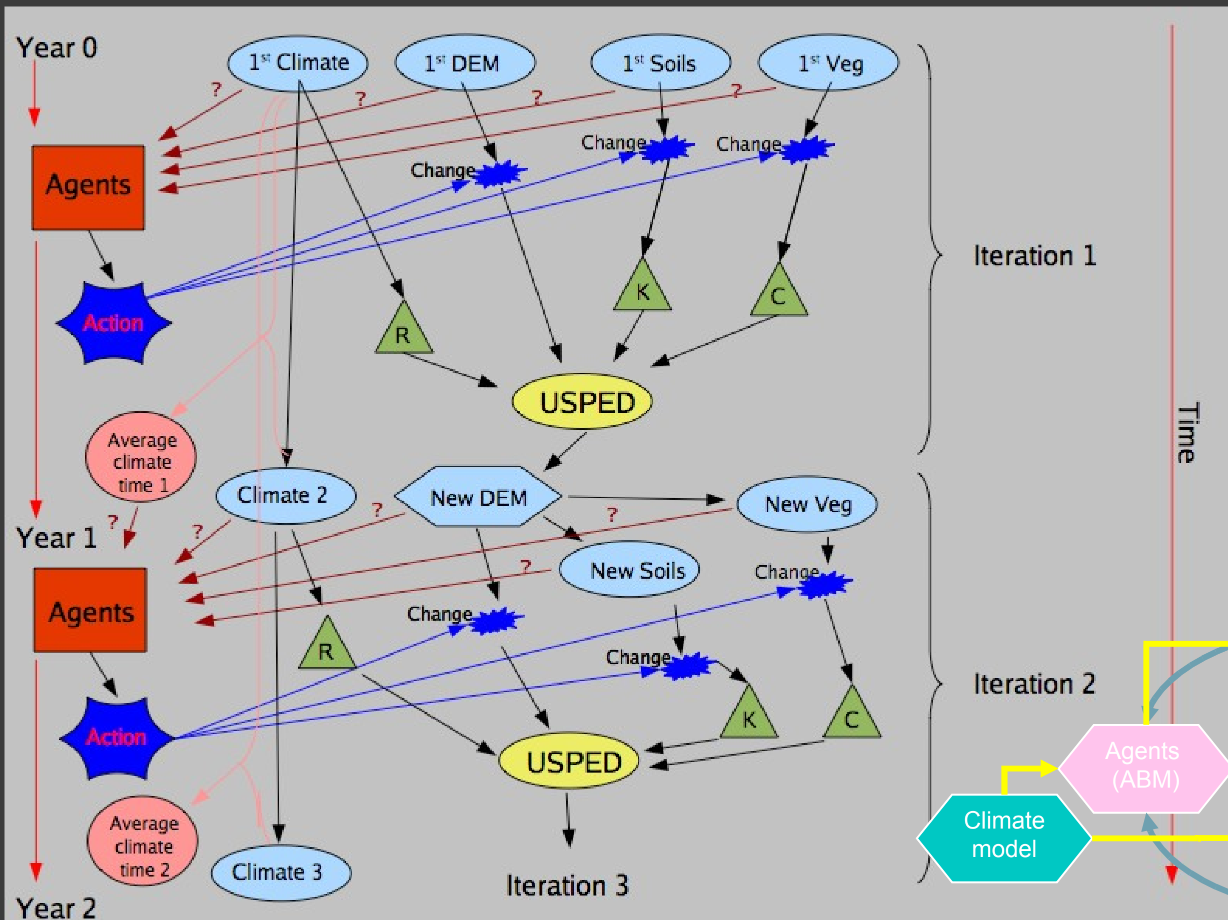
- Calculate multiple regression models for each century using topography/geography
- Apply regression coefficients to DEMs
- Create paleoclimate "landscapes"

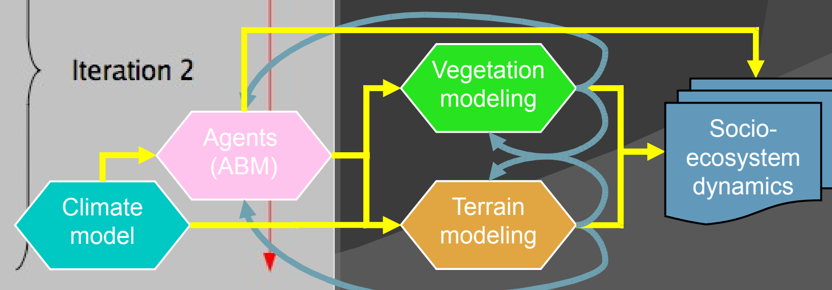


Model Components: Soils

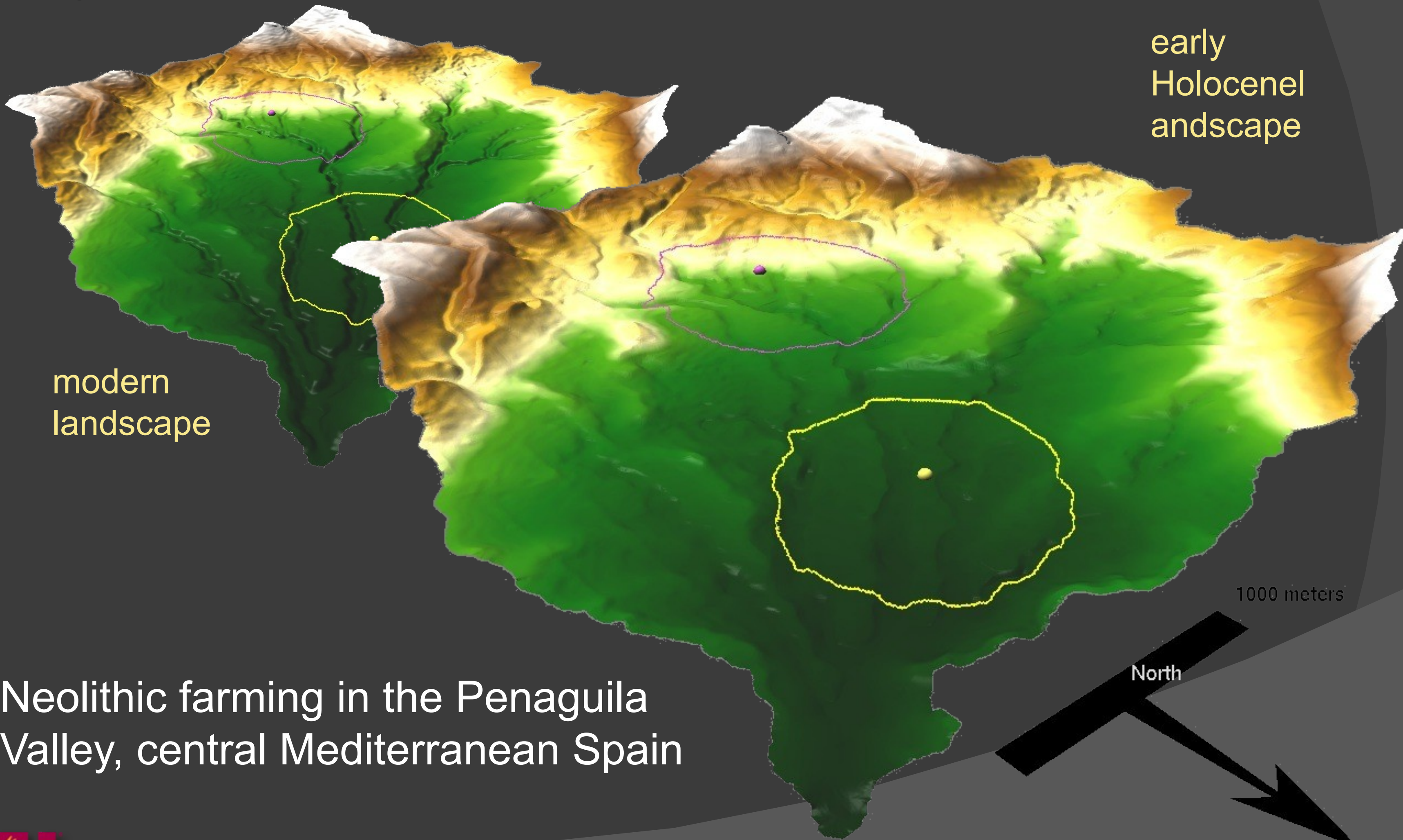
- Initialize as constant thickness
- Calculate K-Factor from sand:silt:clay ratios or bedrock geology
- Dynamically model changing soil thickness and erodability
- Remantle paleosurfaces with Holocene soils.

Coupled ABM & Landscape Model



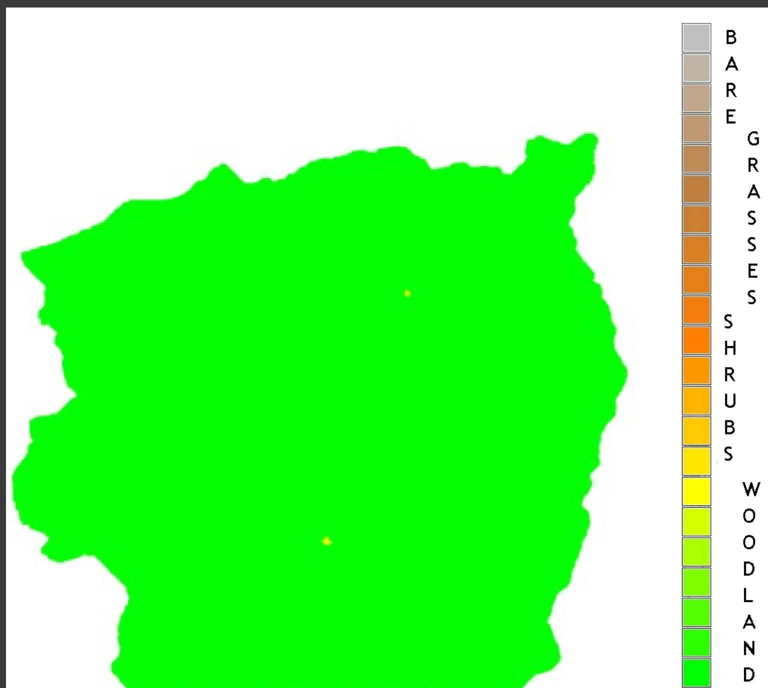


Experiments in Socioecological Dynamics: Spain

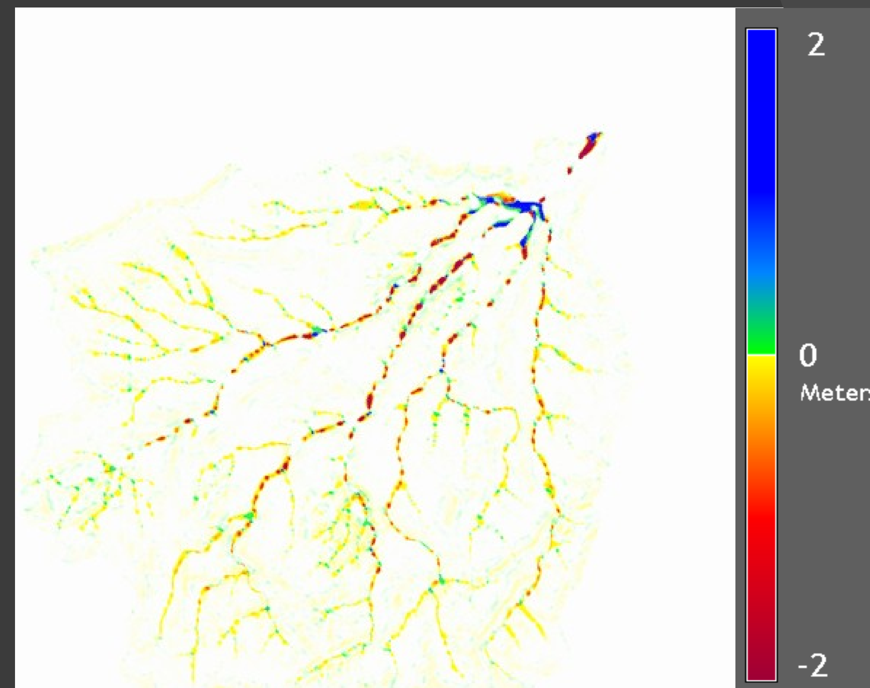


Neolithic farming in the Penaguila Valley, central Mediterranean Spain

Experiments in Socioecological Dynamics: Spain



ABM land cover/landuse

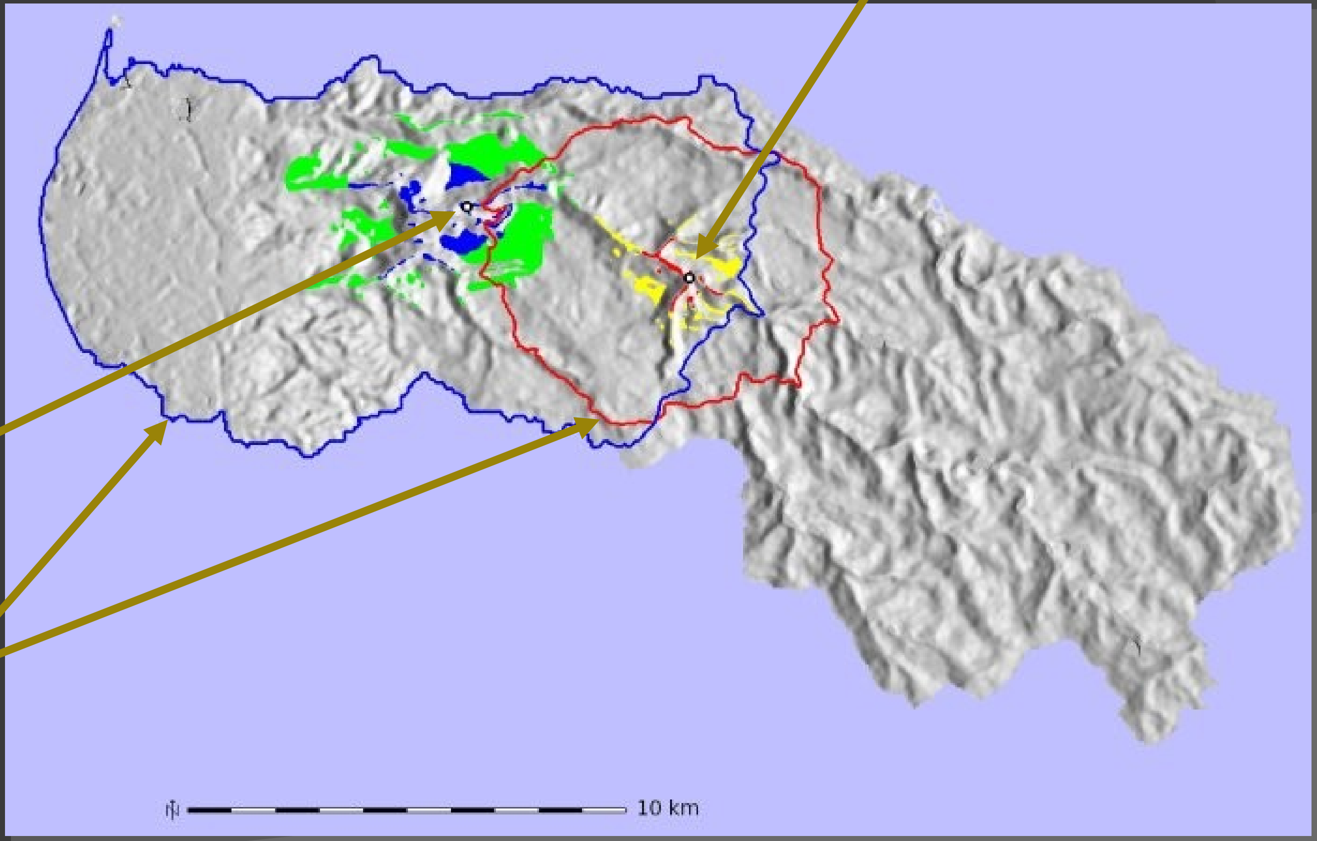


GIS landscape (erosion/deposition)

200 year coupled landuse-landscape simulation

Experiments in Socioecological Dynamics: Jordan

Tabaqat al-Buma PN hamlet
- intensive cultivation
- shifting cultivation



Tell Rakkan PPNB village
- intensive cultivation
- shifting cultivation

grazing
catchments

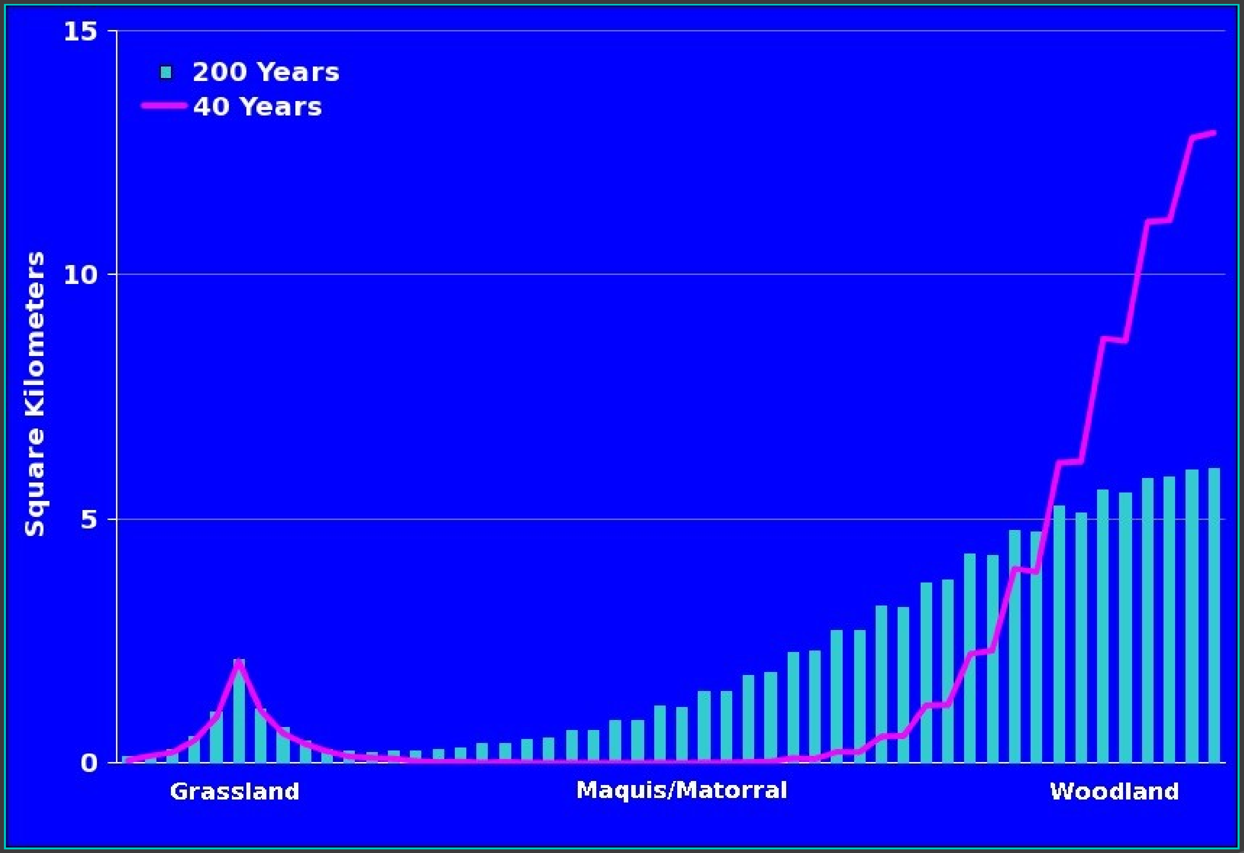
Experiments in Socioecological Dynamics: Jordan


Modeled Wadi Ziqlab. 200 yrs shifting cultivation & grazing


Wadi Ziqlab today

Tell Rakkan: channel incision (shifting cultivation, grazing, low rainfall)

Experiments in Socioecological Dynamics: Jordan



Tell Rakkan: PPNB, high rainfall, vegetation change, 40 yrs vs 200 yrs (swidden agriculture, grazing)

A Science of Social Dynamics

- Socioecological modeling a critical component of new science of social dynamics
- Theory and concepts
  - Reconceptualize societies and environment as closely coupled complex system rather than distinct domains
  - Focus on dynamics of human-environmental interactions rather than their static relationships and results
- Research protocols
  - Requires investment in "computational thinking" to represent human-environmental interaction and change as explicit, algorithmic models
  - Needs emerging cybertools to leverage traditional research protocols of observational data collection and confirmatory statistics
- Benefits in new dimensions in social/natural science and added value for existing approaches and data

Interdisciplinary Collaboration

- ASU: School of Human Evolution and Social Change, Center for Social Dynamics & Complexity, School of Earth and Space Exploration, School of Computing and Informatics, Geographical Sciences, 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

Open Agent Based Modeling Consortium

- Building a community of researchers in social and ecological sciences, to:
  - Improve access to computational tools for complex systems modeling
  - Share experiences and strategies
  - Promote a science of social dynamics
- http://www.openabm.org