Coupled Models for Coupled Systems

Land-Use and Landscape Dynamics in the Mediterranean

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A model is an abstract representation of real-world phenomena.

Models are pervasive in science.

Models simplify complex reality to make it understandable, and identify key processes and parameters.
Models for CHANS Science

- Models important for CHANS research
- To understand complex interactions of temporal and spatial dynamics
- To unravel non-linear causation in highly coupled human and natural systems
Models for CHANS Science

- Natural systems are complex
- Social systems are complex
- But are complex in different ways
Models for CHANS Science

Multiple modeling approach, each with different strengths and weaknesses

- Mathematical models: simple and robust representation of continuous processes; forecasting trends in aggregate phenomena
- GIS: efficient processing of large, gridded data sets; matrix algebra (map algebra); cellular automata (e.g., hydrology)
- Agent-based modeling: multiple entities that move and interact independently; behavior based on decision rules; interactions among independent agents
Models for CHANS Science

- Coupled social and natural systems compound complexity and dynamics to be modeled
- No single modeling approach adequate to represent all diverse phenomena of complex CHANS
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.

Study areas in eastern Spain and western Jordan

National Science Foundation BCS-410269
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/)
Overview of some of the components of coupled modeling laboratory

- Modeling landscape dynamics
- Modeling paleoclimate dynamics
- Modeling human decisions

Initial results of experiments with CHANS associated with beginning of agriculture

- Interactions of population and land-use practices
- Effects on landscapes of northwestern Jordan
Hillslope erosion/deposition (HED) model

Extension of USPED and RUSLE

\[ HED = \frac{\partial T \cdot \cos(\alpha)}{\partial x} + \frac{\partial T \cdot \sin(\alpha)}{\partial y} \]

HED ➞ net erosion/deposition per landscape cell

\[ T = R \cdot K \cdot C \cdot A^m \cdot \sin(B)^n \]

[modified RUSLE for hillslopes]

Where...

- \( R \) = rainfall coefficient
- \( K \) = soil erodibility coefficient
- \( C \) = landcover coefficient
- \( A \) = upslope area contributing to flow
- \( m,n \) = empirical coefficients for different flow regimes
- \( B \) = slope
Change from sediment-limited to transport-limited process equation for streams

Same HED equation, but $T$ changes to include shear stress of flowing water

$HED = \frac{\partial T \cdot \cos(\alpha)}{\partial x} + \frac{\partial T \cdot \sin(\alpha)}{\partial y}$

$T = K_1 \cdot \tau^n$

Where

$\tau = 9806.65 \cdot B \cdot D$

$D = \frac{(R_m - (R_m \cdot i)) \cdot A}{R_d \cdot 1440}$

$9806.65$ is a constant related to the gravitational acceleration of water

and $R, K, A, m, n,$ and $B$ are the same as for hillslopes
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

- slope decrease
  - reduced capacity deposition
- slope increase
  - increased capacity erosion
- land-cover change
  - increased capacity erosion
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
- Add/subtract net erosion/deposition to DEM
- Create new DEM of topography

becomes base DEM for next iteration
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

**Annual Precipitation 8000-2000 BC W. Jordan Weather Stations**

- Tulkarm
- Wadi Faria
- Deir Alla
- Mafraq
- Ras Muneef
- Wadi Yabis
- Ramtha
- Irbid Nursery
- Beit Qad "Jenin"
- Shuneh-North
- Baqura

**Paleoclimate, E.Spain**

- Annual precipitation
- Annual temperature

10,000-3,000 BP
Modeling Land-Use

Coupled model

LandDyn (HED)
- r.catchment
- r.stats
- r.what
- r.soil.fertility
- r.landscape.evol
- r.landcover.update

Interaction Model
- Phase & Time management
- In Messages
- Out Messages
- Internal Transitions
- External Transitions

AP-Sim (ABM)
- Village
  - Household
  - Household
  - Household
- Household
  - Population
  - Farm Land
  - Birth & Death Rates

GIS/CA

ABM

User Input
- Village
  - Location
  - Number of households
  - Residents per household
  - Resources
    - Labor required
    - Calories required
    - Animals per person
    - Herd composition and density
  - Households
    - Birth & death rate
    - Percent working
    - kcal per yr needed
    - Labor per person
    - Distance to look for land
Coupled model output (yr 5): cultivation and grazing on early Holocene landscape, Penaguila Valley, Alicante Province, Spain.
Visualizing Coupled Models

- Visualization using open source WorldWind (NASA)
Experiments in Long-Term Socioecology

- Results of initial experiments (40 & 200 year simulations) in northwestern Jordan


## Experimental design

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Experiments in Long-Term Socioecology

- Land-use modeling

[Map showing land-use patterns]
## 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

- **Small village, shifting cultivation, grazing**

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|                                   |                | Grazing                           |
Experiments in Long-Term Socioecology

- Small village, shifting cultivation, grazing (40 years)
Comparing consequences of population change

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Experiments in Long-Term Socioecology

Human Influence on Erosion and Deposition in the Wadi Ziqlab Watershed

- Tell Rakkan deposition
- Tabaqat al-Buma deposition
- Tell Rakkan erosion
- Tabaqat al-Buma erosion
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

*Graph: Long-Term Human Influence on Erosion and Deposition in the Wadi Izqlab Watershed*
Experiments in Long-Term Socioecology

- Comparisons with the archaeological record
- Growth of Neolithic communities through the Pre-Pottery Neolithic
- Villages to larger “megasites” by end of Pre-Pottery Neolithic B
- Subsequent disappearance of large communities
  - Prevalence of smaller communities
  - Initial appearance of pastoralism
  - Initial appearance of significant socioeconomic differentials
Without computational modeling...

- Long-term consequences of decisions and environmental not easily visible in CHANS
- 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
Science is not technology, but technology is an important component of mature sciences. Some technologies can even be transformative for science. Telescope, Microscope, Cyclotron.
Computational Modeling & Social Science

- Computational modeling a potentially transformative technology in science of coupled human and natural systems
- Allows us to express complex interactions and dynamics in quantitative form that can be better communicated across scientific disciplines, and independently evaluated
- Transparely build and test theory about process and change in social systems
- Create a robust experimental social science that permits controlled replication of social processes. ‘Re-run the tape’ (S.J. Gould)
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
- CHANS 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.
Computational Modeling for SES CoMSES Network

- New community of practice for researchers in social and ecological sciences
- Improving access to computational tools for complex systems modeling
- Sharing experiences and strategies
- Promoting a science of social dynamics
OpenABM

- Recognition of the importance of computational modeling to the future of CNH science
- But widespread lack of expertise in or access to computational modeling by CNH scientists
- Pilot project and workshop to...
  - ID reasons for lack of use of and access to computational modeling
  - Initiate a community of practice to mitigate these issues
OpenABM

- Launched as Open Agent-Based Modeling Consortium in 2007
- Web based resource center (http://www.openabm.org)
- Highly successful
CoMSES Network

--Launched February 2010 with planning workshop to address barriers to use of computational modeling in normal science practice
  - Standards
  - Logistics of dissemination
  - Evaluation of research
  - University curricula
- Creating an international network for...
  - Promoting standards and best practices
  - Knowledge scaffolding. New ways to continue the practices that have made science successful.
CoMSES Network

- New internet site
  - NSF SES models library to be seeded with CNH projects *(We want your models!)*
  - Educational materials library
  - Cyberinfrastructure for scientific networking and information sharing
- Online journal
- Get involved: http://www.openabm.org
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