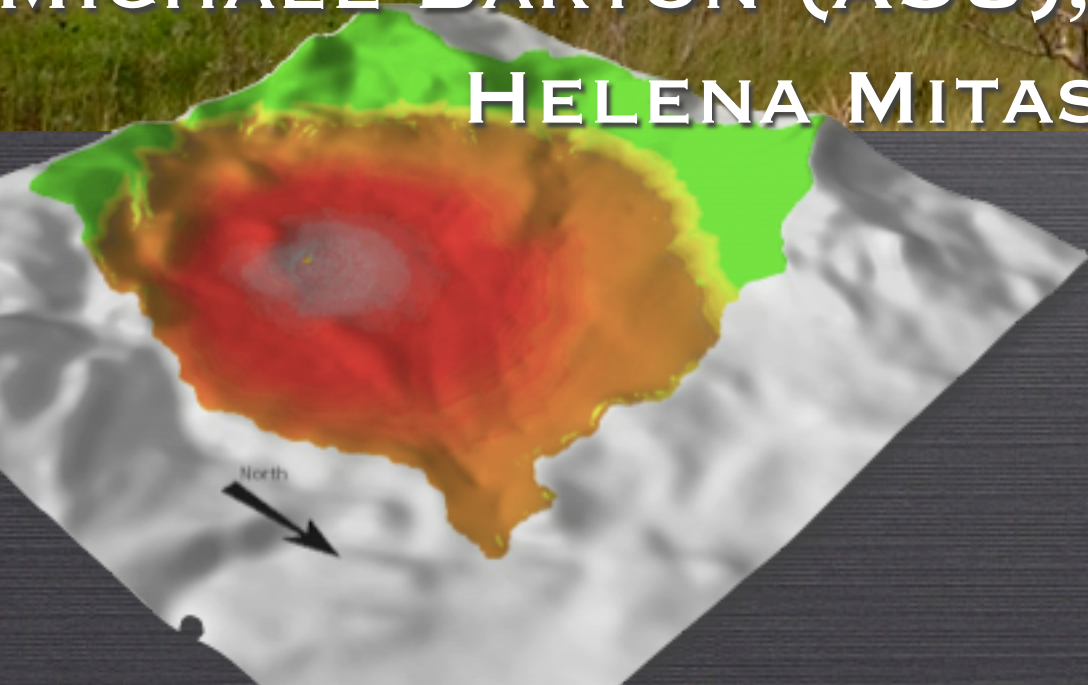


# HIGH RESOLUTION SURFACE PROCESS MODELING IN A GRASS GIS ENVIRONMENT

MICHAEL BARTON (ASU), ISAAC ULLAH (ASU), &  
HELENA MITASOVA (NCSU)





# ANTHROPOCENE LANDSCAPES

- Modeling surface processes requires simulating changes across both space and time
- To understand the role of humans in surface dynamics requires modeling at human scales





# ANTHROPOCENE LANDSCAPES



- What temporal / spatial scales relevant to modeling anthropogenic landscape change
- Anthropocene
  - Last 10k years
  - Begins with farming
  - Increasingly important anthropogenic component of surface processes
- Spatial / temporal scales of human impacts
  - Lifetimes to millennia
  - Household to global



# ANTHROPOCENE LANDSCAPES

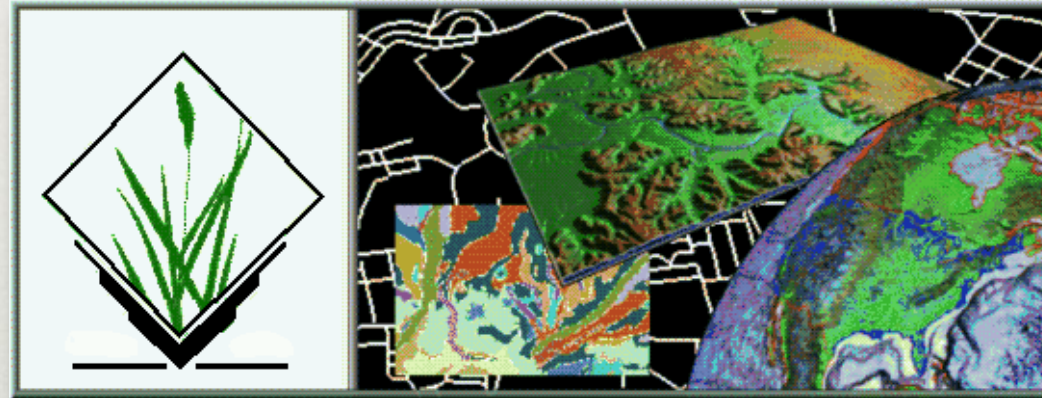
- Research focus
  - Impacts of agropastoral land-use on landscapes and societies
  - Origins of agriculture
  - Socio-ecological systems with feedbacks between social and biophysical drivers
- Modeling platform
  - GRASS GIS
  - Python
  - Java





# PROCESS MODELING

- GRASS = Geographic Resource Analysis Support System
- Full featured GIS and spatial modeling platform
- Open source
- Multi-platform
- Earth scientists well-represented among user base and on dev team

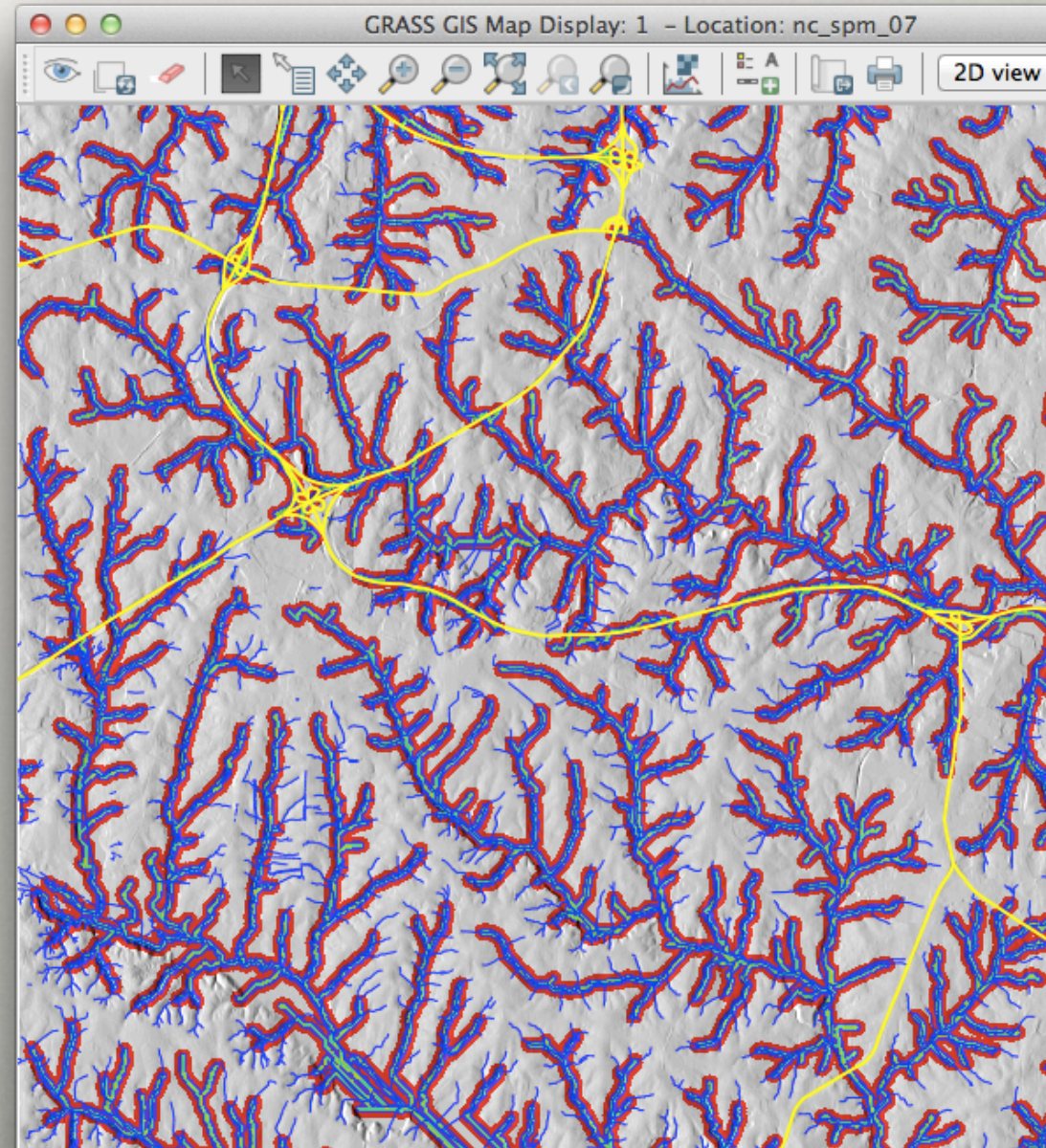
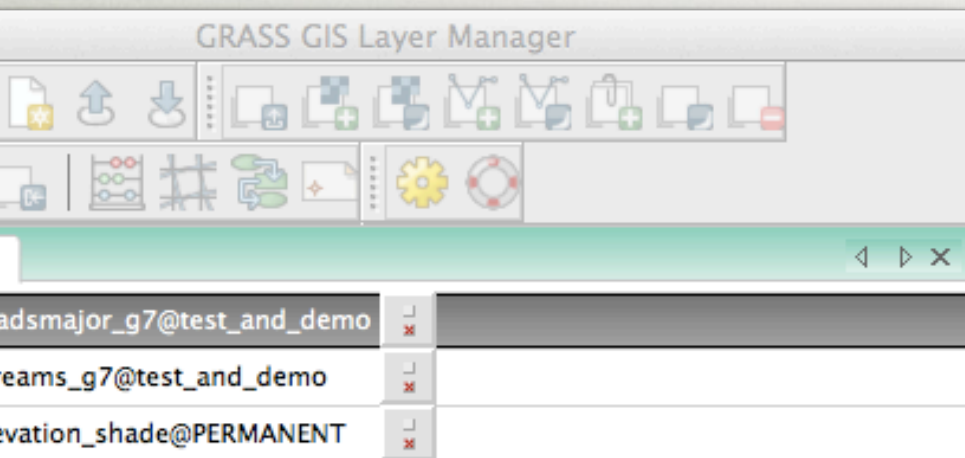




# PROCESS MODELING

raster buffers around streams over relief m

- Raster / grid support

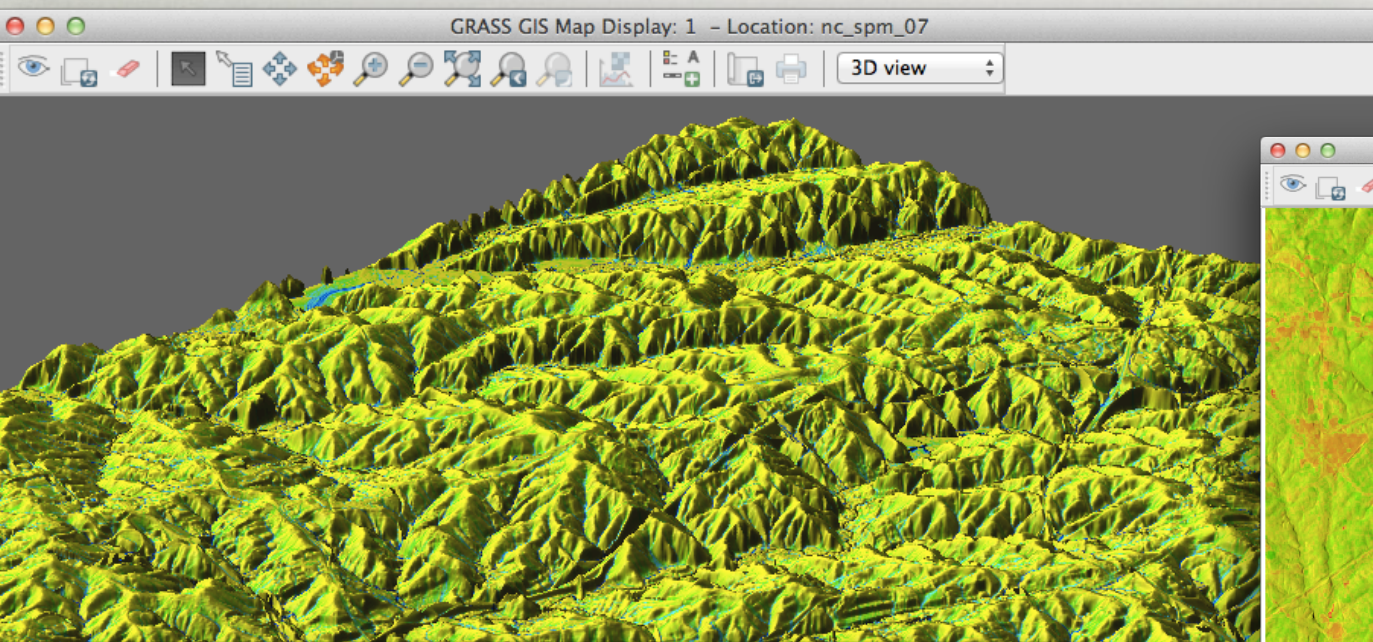




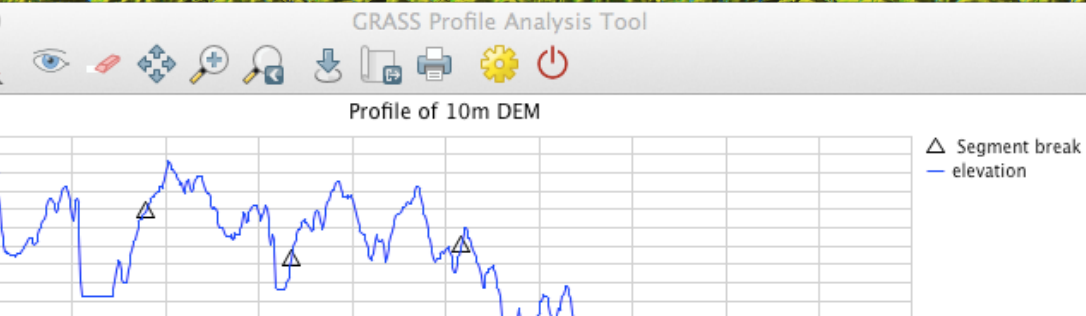
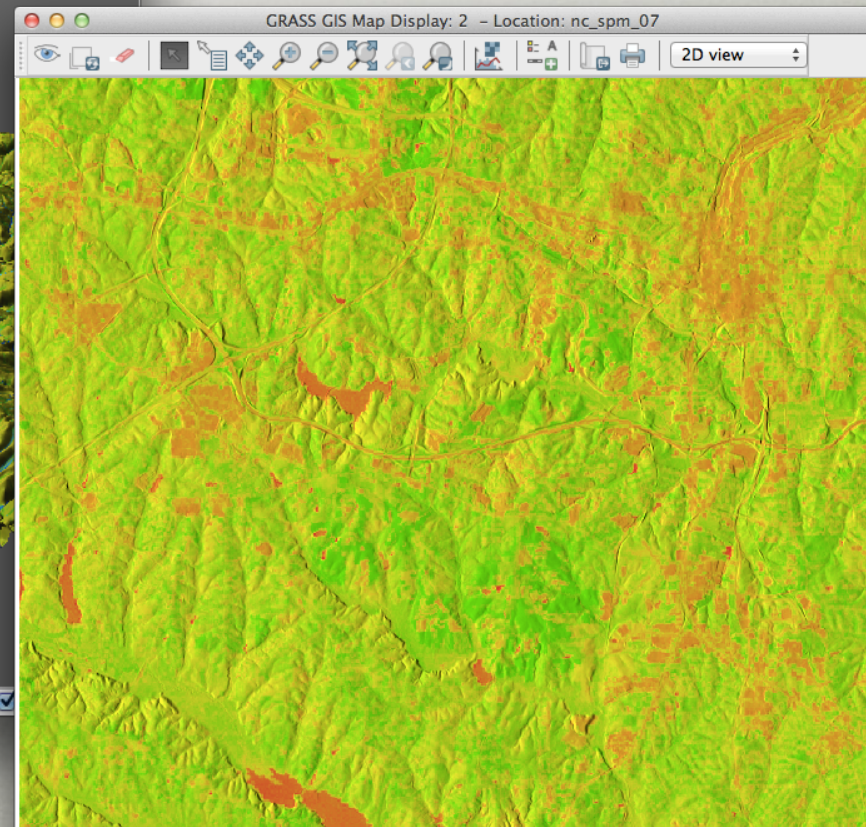
# PROCESS MODELING

- Many tools for surface process modeling and analysis

flow accumulation over 2.5D terrain



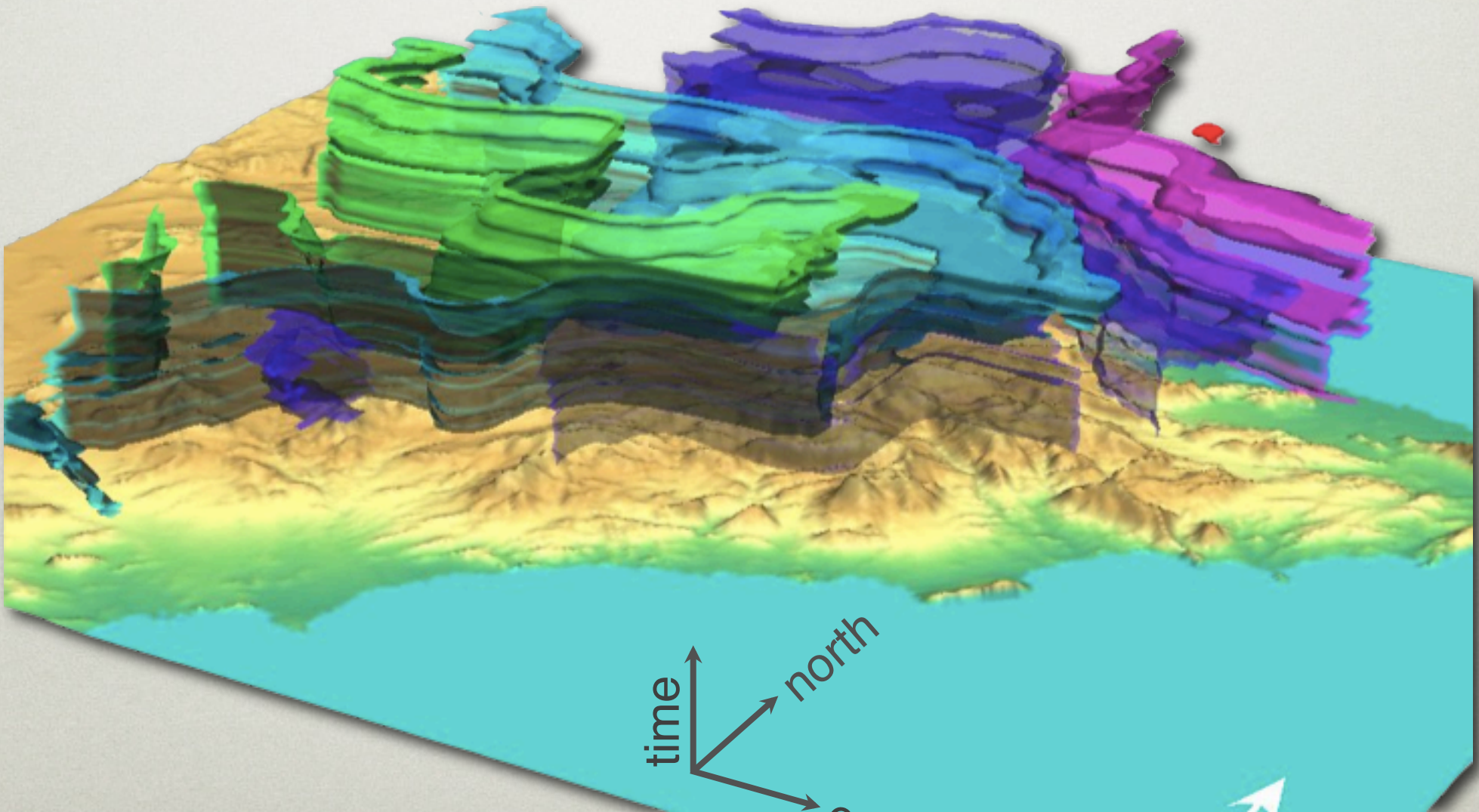
Landsat NDVI over relief map





# PROCESS MODELING

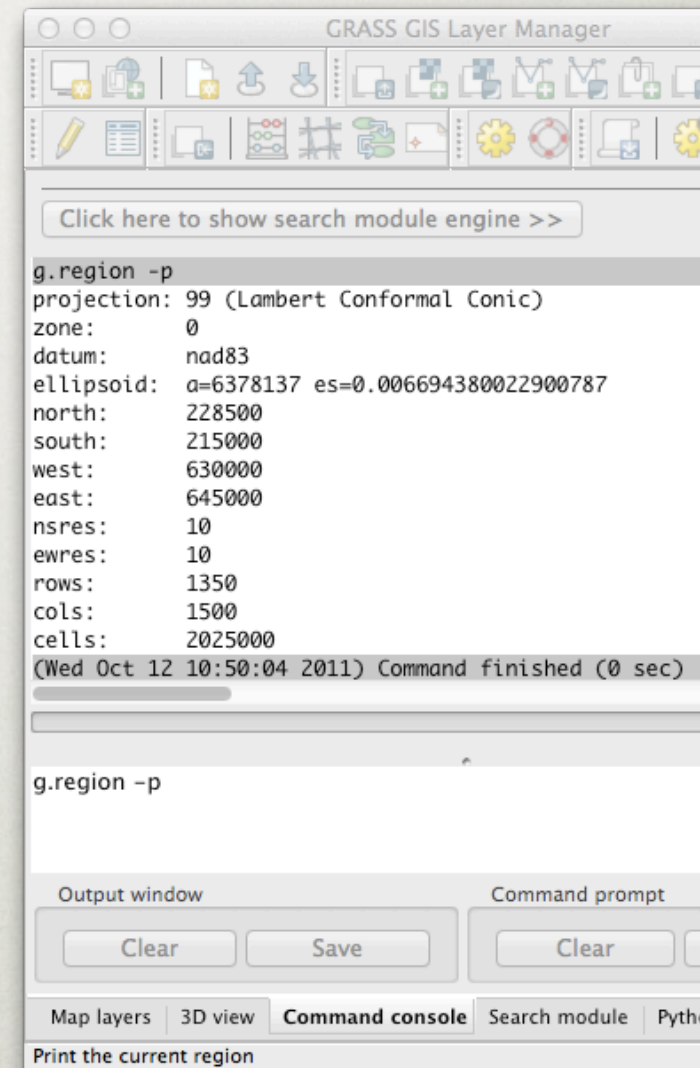
- Voxel support





# PROCESS MODELING

- All geospatial functions available as command-line modules
- Scriptable in many languages
- Strong Python support
- Source code modifiable (written in C and Python)



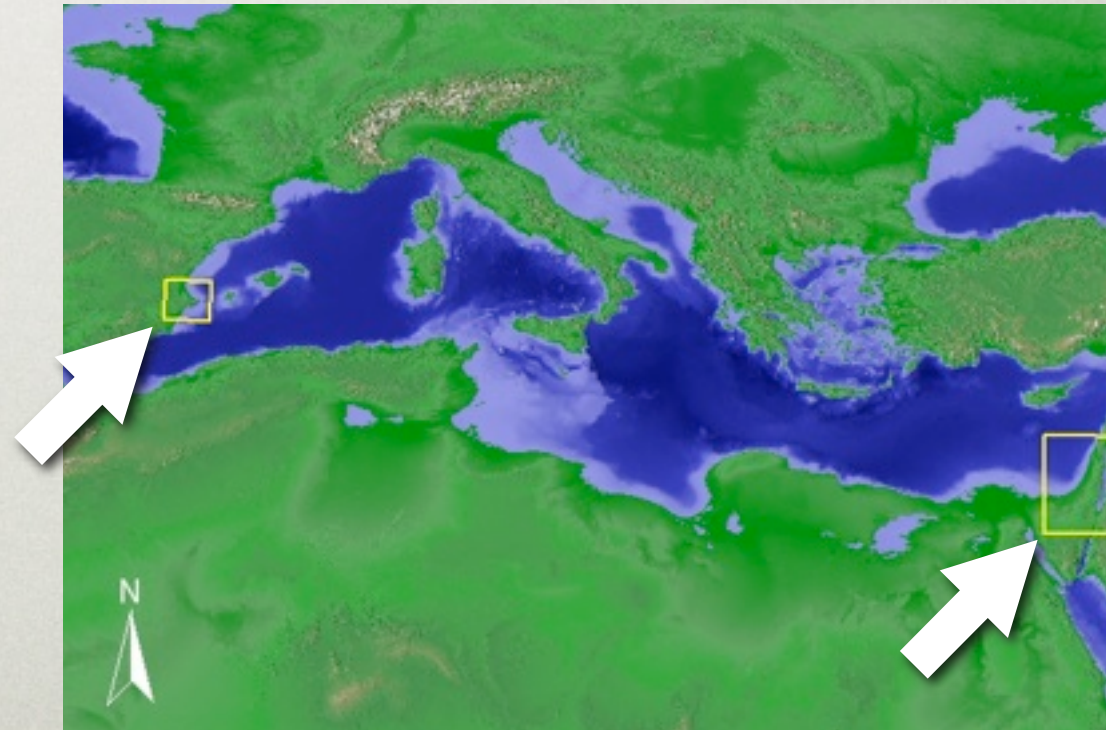


# DYNAMICS (MEDLAND)

- 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.

Study areas in eastern Spain  
and western Jordan

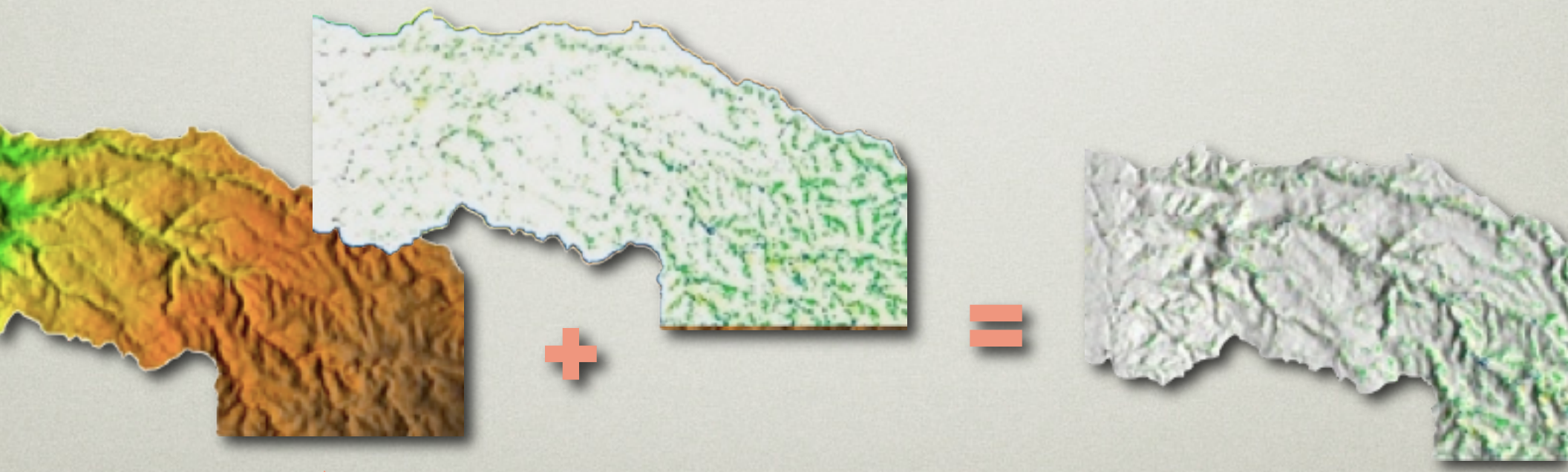
Website - <http://medland.asu.edu>





# MEDLAND SPM OVERVIEW

- Will focus first on surface process modeling aspects of MedLand laboratory
- Implemented as recursive 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

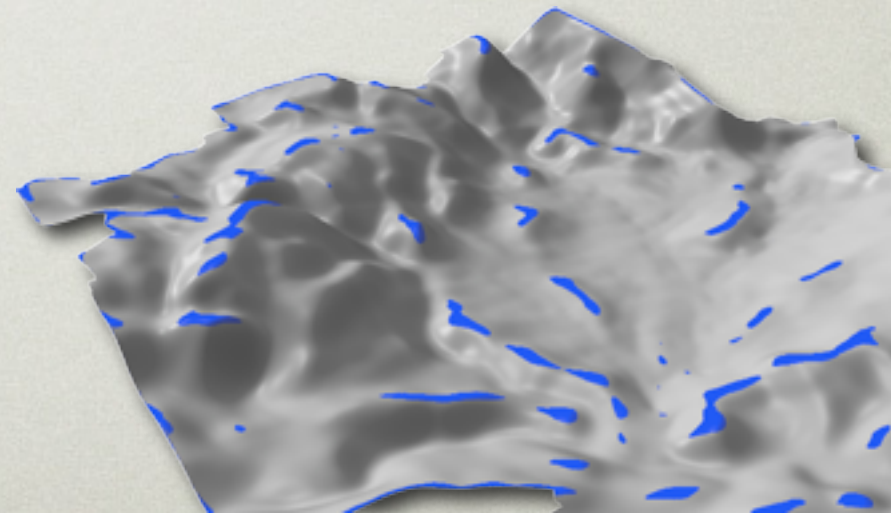




# MEDLAND SPM OVERVIEW

- Different algorithms used for modeling processes in different topographic settings
- Diffusion equation for drainage divides, ridge tops, hill tops
- Where  $\Delta z$  is net vertical change (erosion / deposition),  $\beta$  is slope, and  $\kappa$  is an empirically derived constant for different substrates

$$\Delta z = \kappa \cdot \sin(\beta)$$

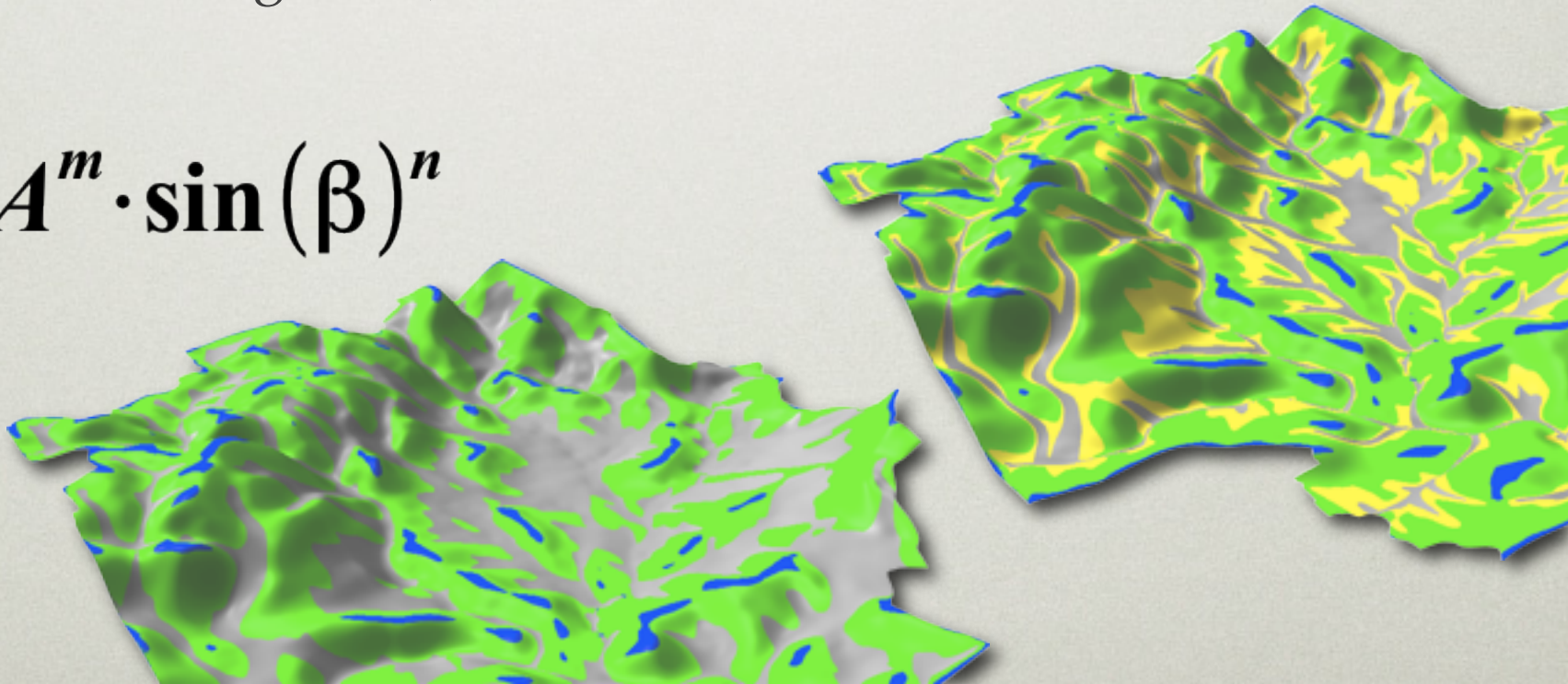




# MEDLAND SPM OVERVIEW

- USPED equation modified for 3D landscapes (transport limited) for hill slopes, rills, and gullies
- Where transport capacity  $T_c$  is estimated from sediment flux ( $T_c \approx Q_s$ );  $R$  (rainfall),  $K$  (soil), and  $C$  (land cover) are empirically derived RUSLE constants;  $A$  is upslope contributing area;  $m$  and  $n$  are empirically derived constants for different flow regimes (hill slopes vs. rills / gullies).

$$R \cdot K \cdot C \cdot A^m \cdot \sin(\beta)^n$$

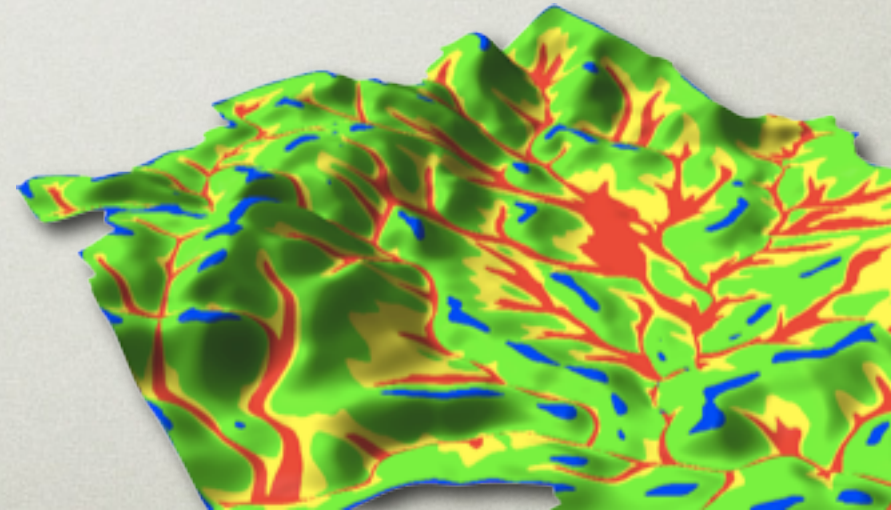




# MEDLAND SPM OVERVIEW

- Shear stress equation for channels
- Where  $\kappa$  is an empirically derived constant for different substrates  
 $\tau$  = shear stress, and  $N_e$  is number of storm events per year

$$T_c = N_e \cdot \kappa_t (\tau)^n$$



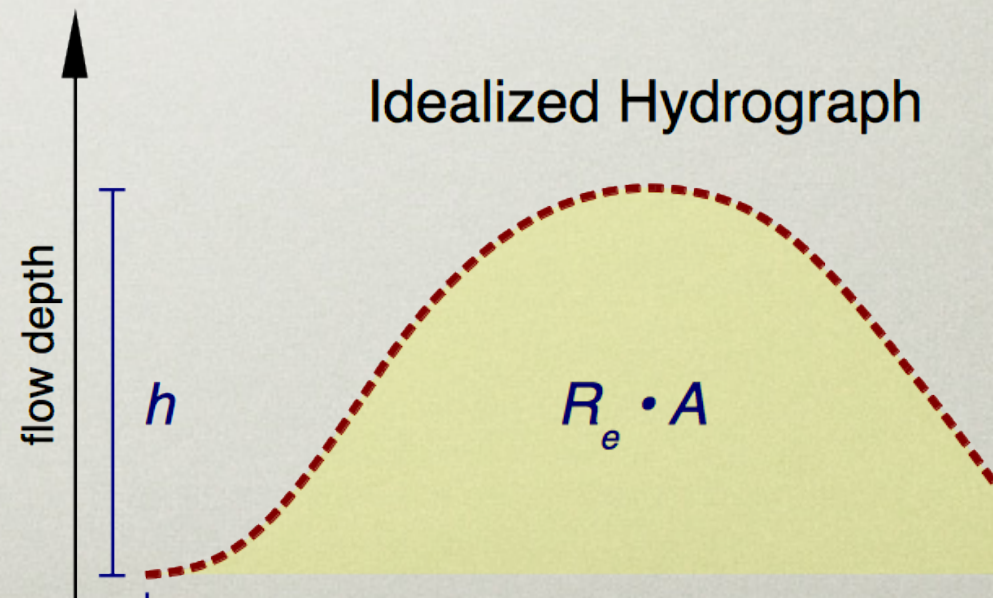


# MEDLAND SPM OVERVIEW

- Calculation of shear stress ( $\tau$ ) for channels, where  $h$  = water depth per storm event, and 9806.65 is a gravitational constant for falling water
- $h$  is calculated on the basis of an idealized hydrograph, where  $t$  is the duration of a storm event in hydrographic instants and is equivalent to the flow velocity of water (calculated by the Manning equation) divided by the cell resolution.  $R_e$  is the rainfall per event and  $A$  is the upslope contributing area for each cell

$$\tau = 9806.65 \cdot \beta \cdot h$$

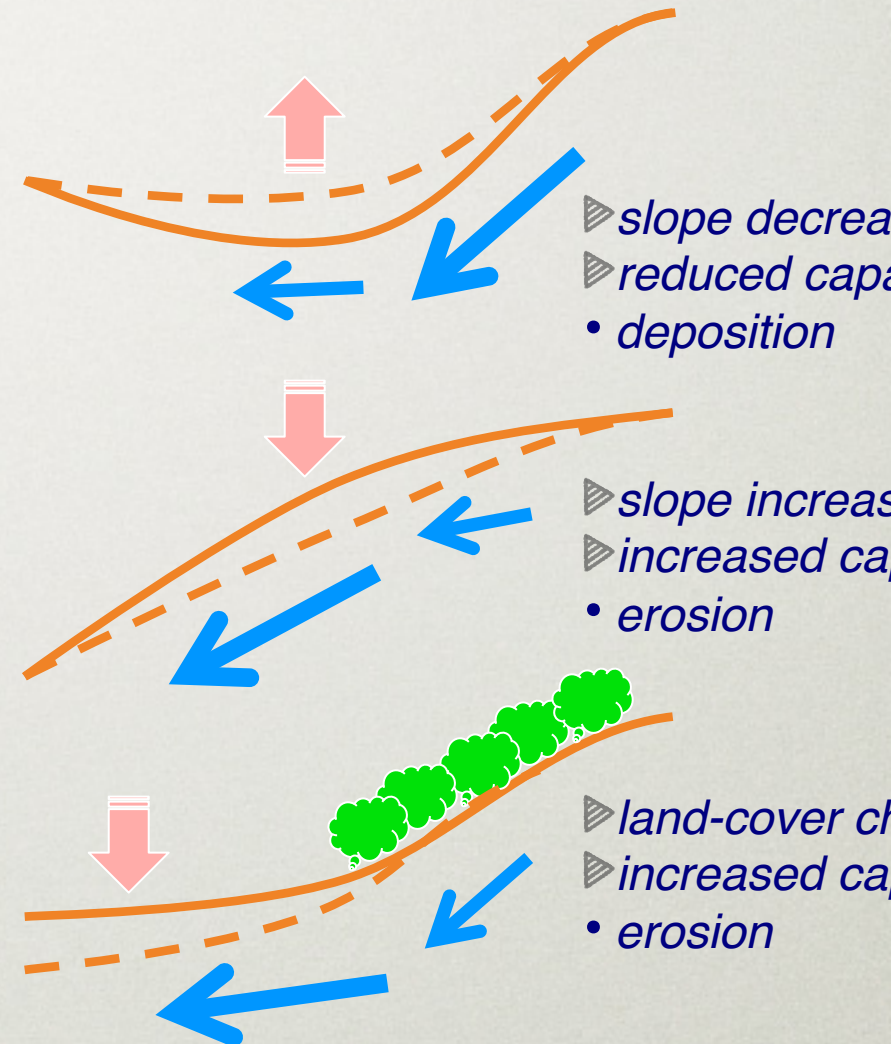
$$h = \frac{R_e \cdot A}{0.595 t}$$





# CHANGE

- Basic assumption
  - Flowing water carries sediment at capacity ( $T_c \approx Q_s$ )
- Dynamics
  - Changes to hydrology affect transport capacity
  - Water will erode or deposit sediment until its load reaches its new capacity

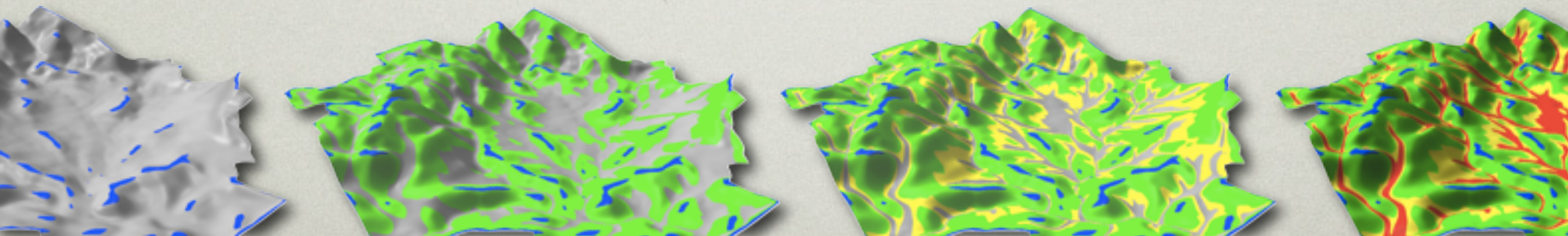
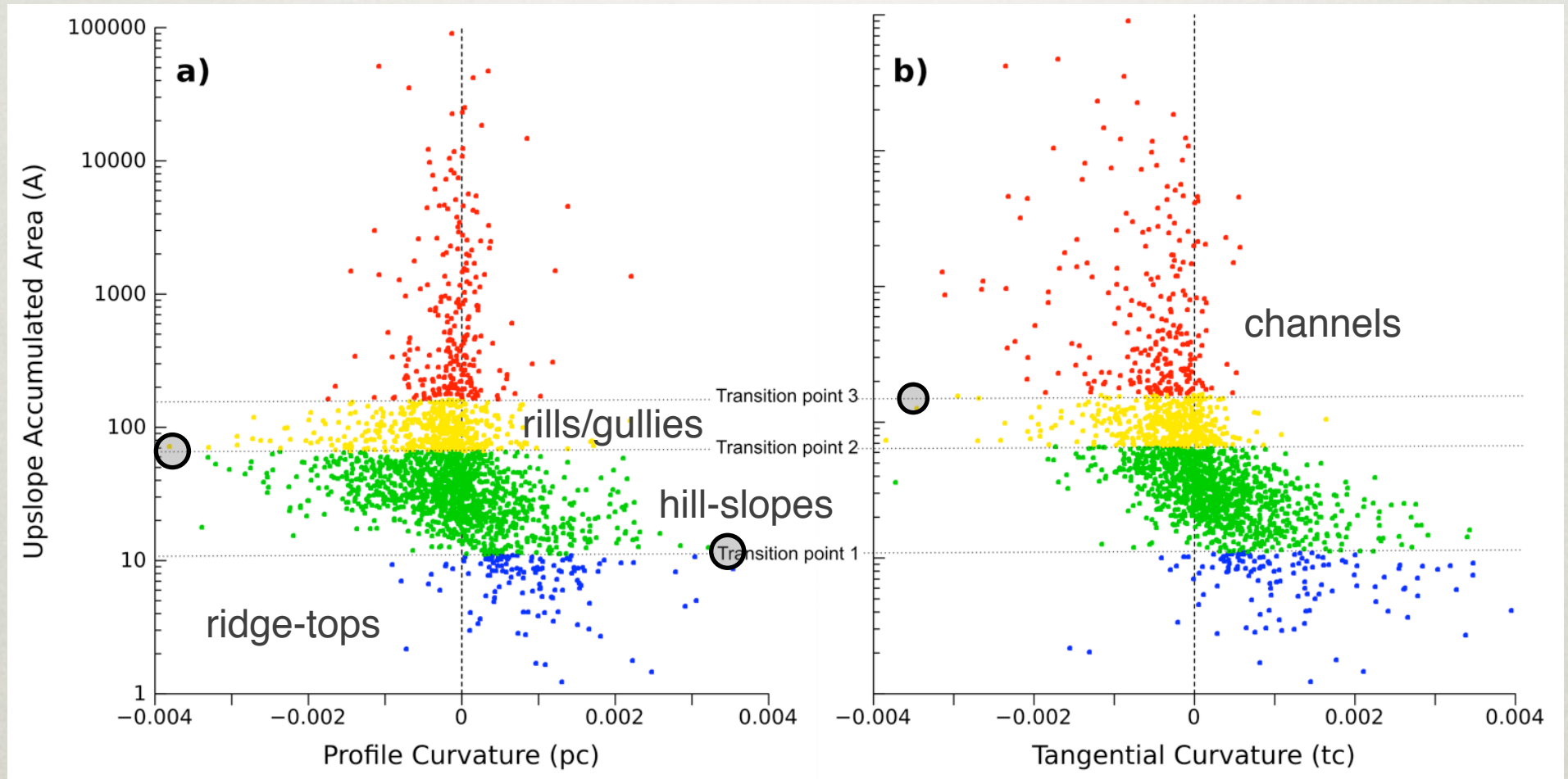


$$\text{div } \vec{T}_c = \frac{\partial (T_c \cos \alpha)}{\partial x} + \frac{\partial (T_c \sin \alpha)}{\partial y}$$

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

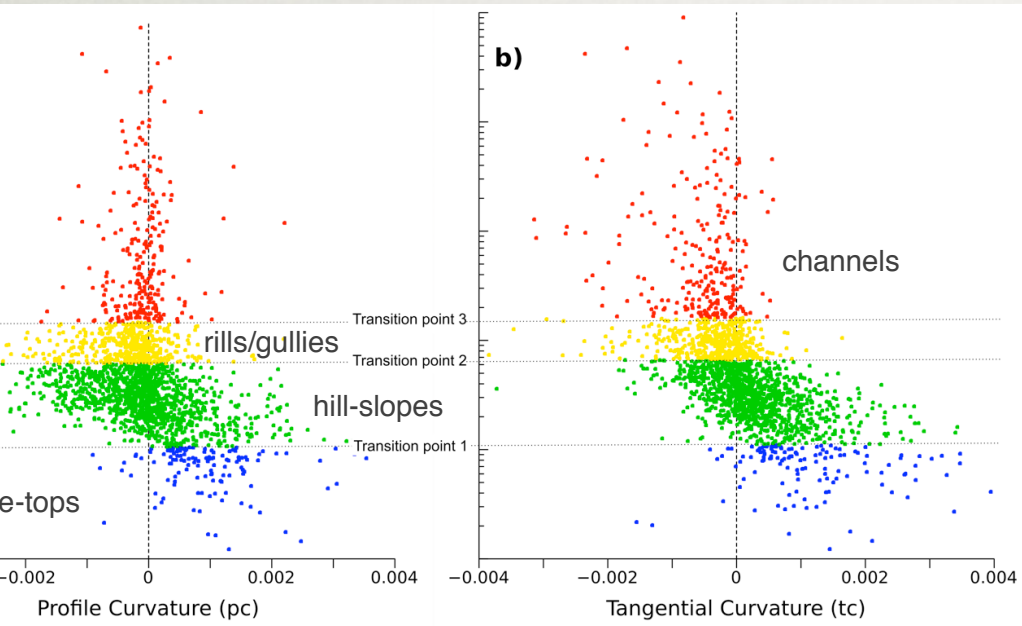


# PHASE SHIFTS

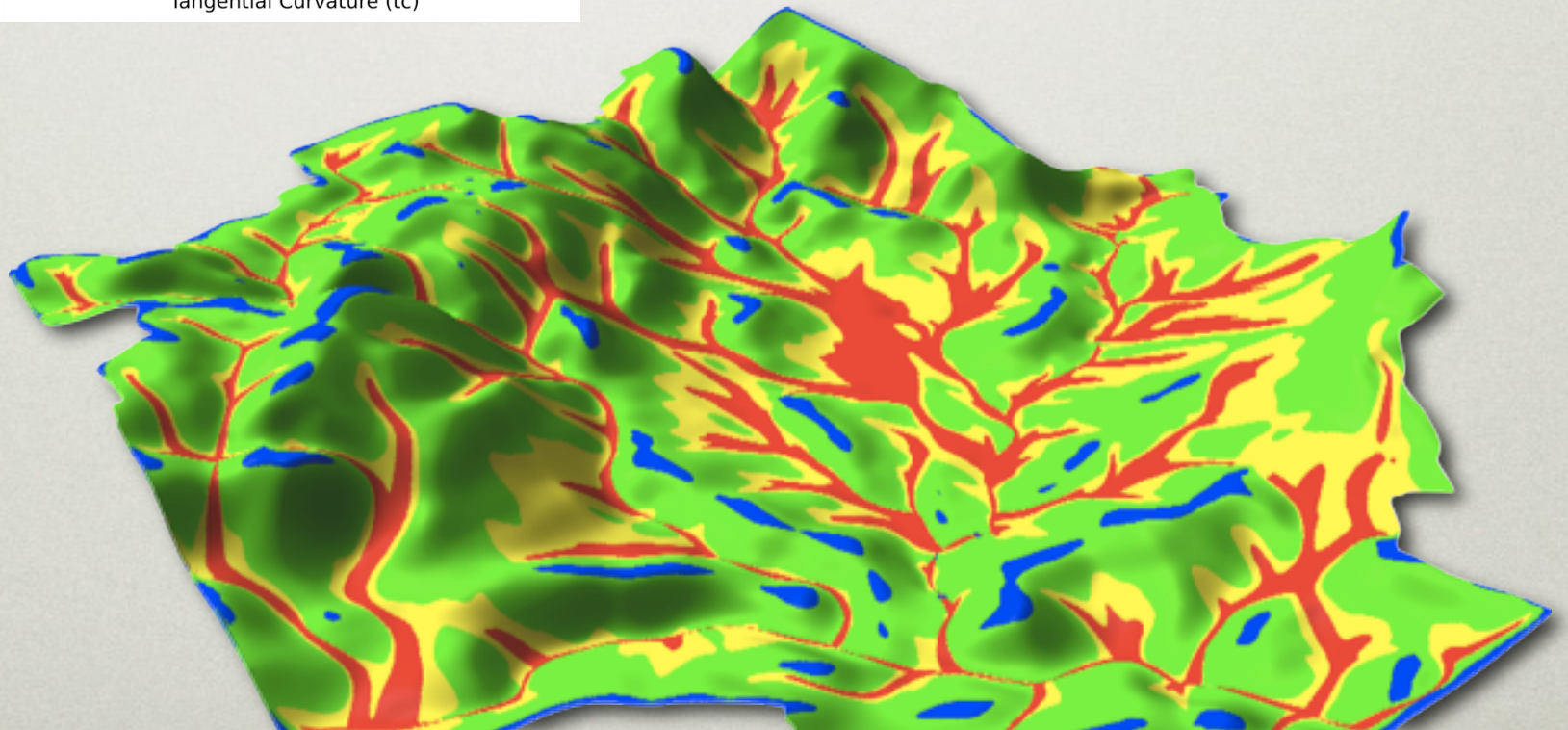




# PHASE SHIFTS



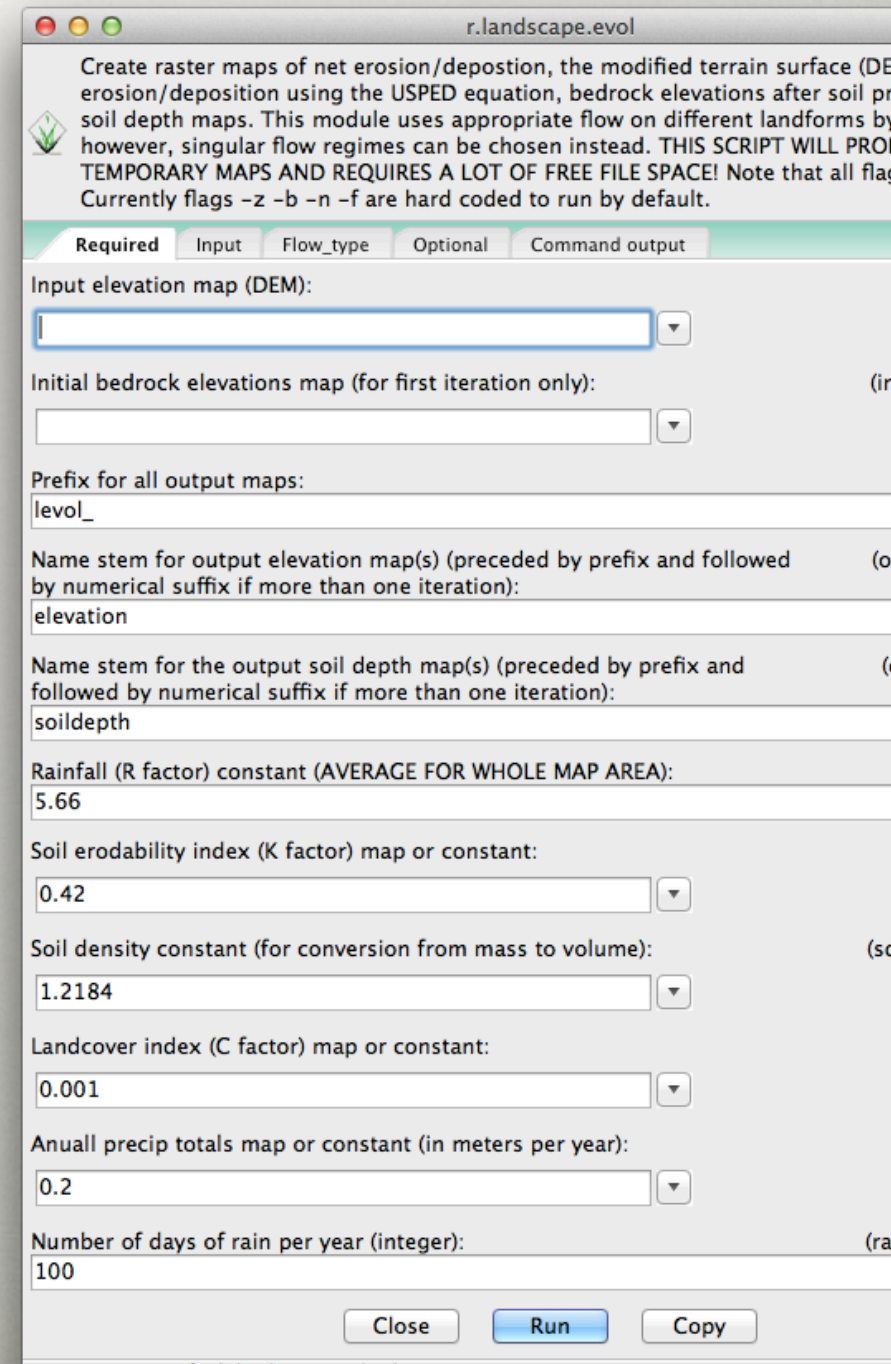
- Each process phase modeled separately
- Resulting maps patched together





# MODELING IN GRASS

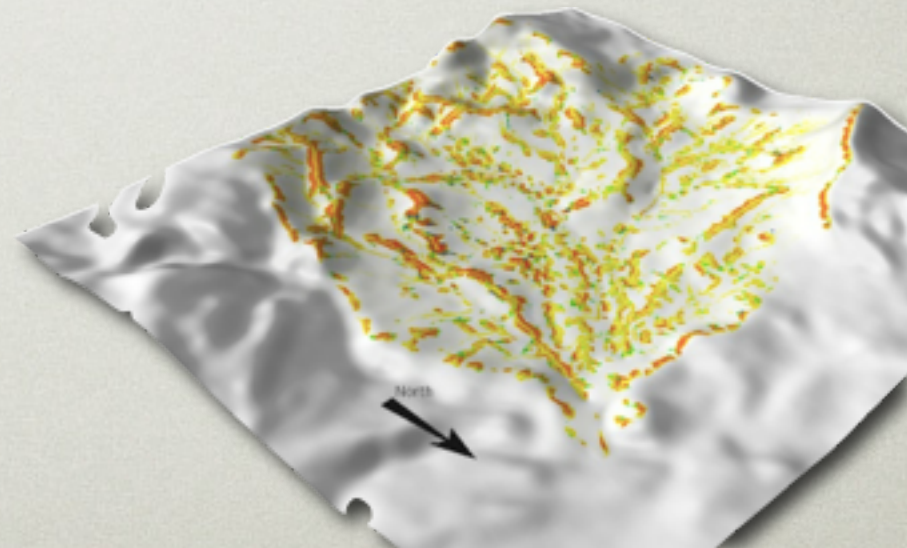
- MedLand terrestrial surface process model is implemented as a Python script in GRASS: `r.landscape.evol.py`
- Easily run from within GRASS GIS environment
- Takes advantage of fast, efficient GRASS modules in C





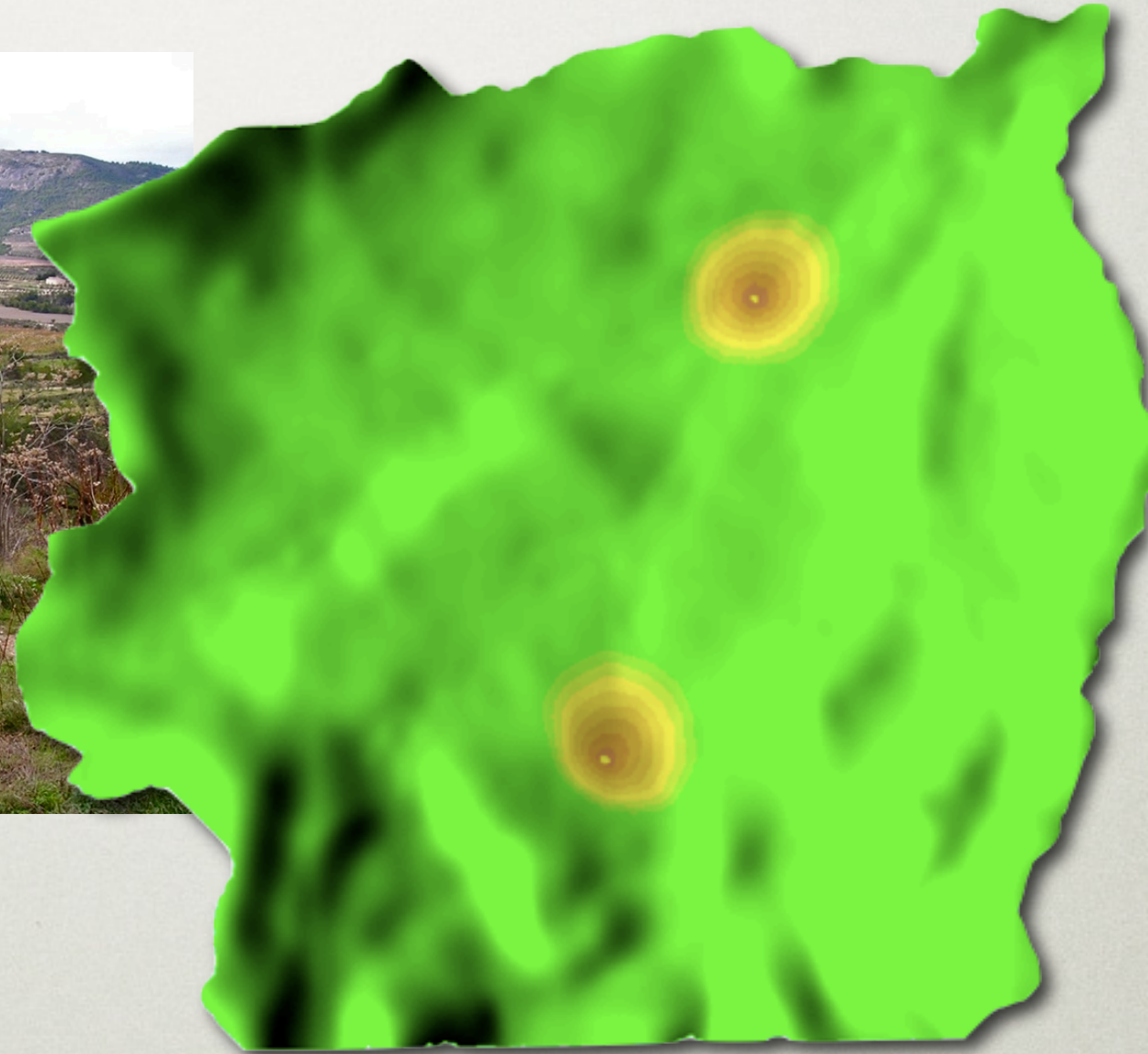
# MODELING IN GRASS

- Can complete 1 modeling cycle in under 1 minute for 1 million cells
- Tuned for annual cycles
- Could be retuned for monthly, daily, or event-based cycles



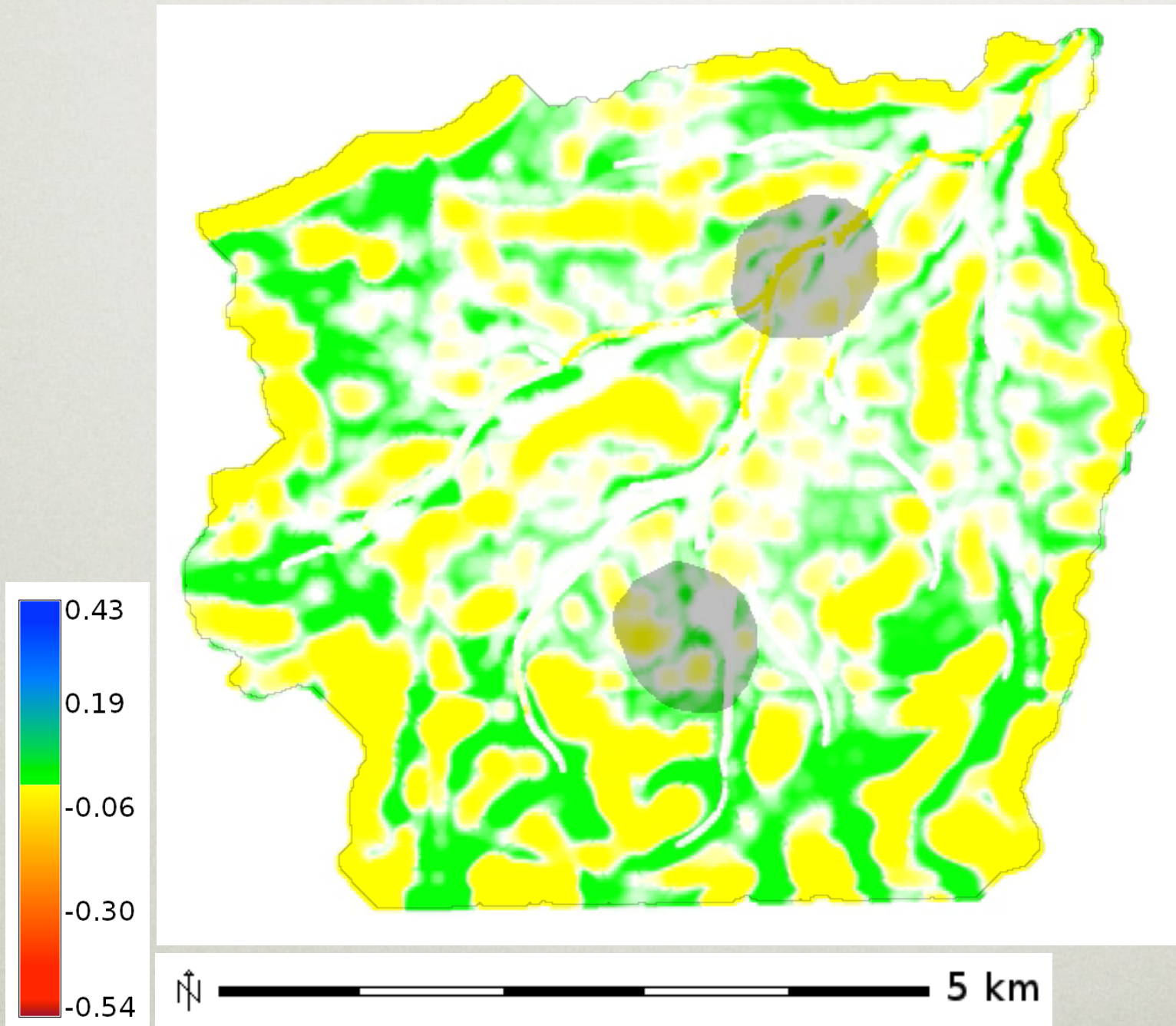


# MODELING IN GRASS



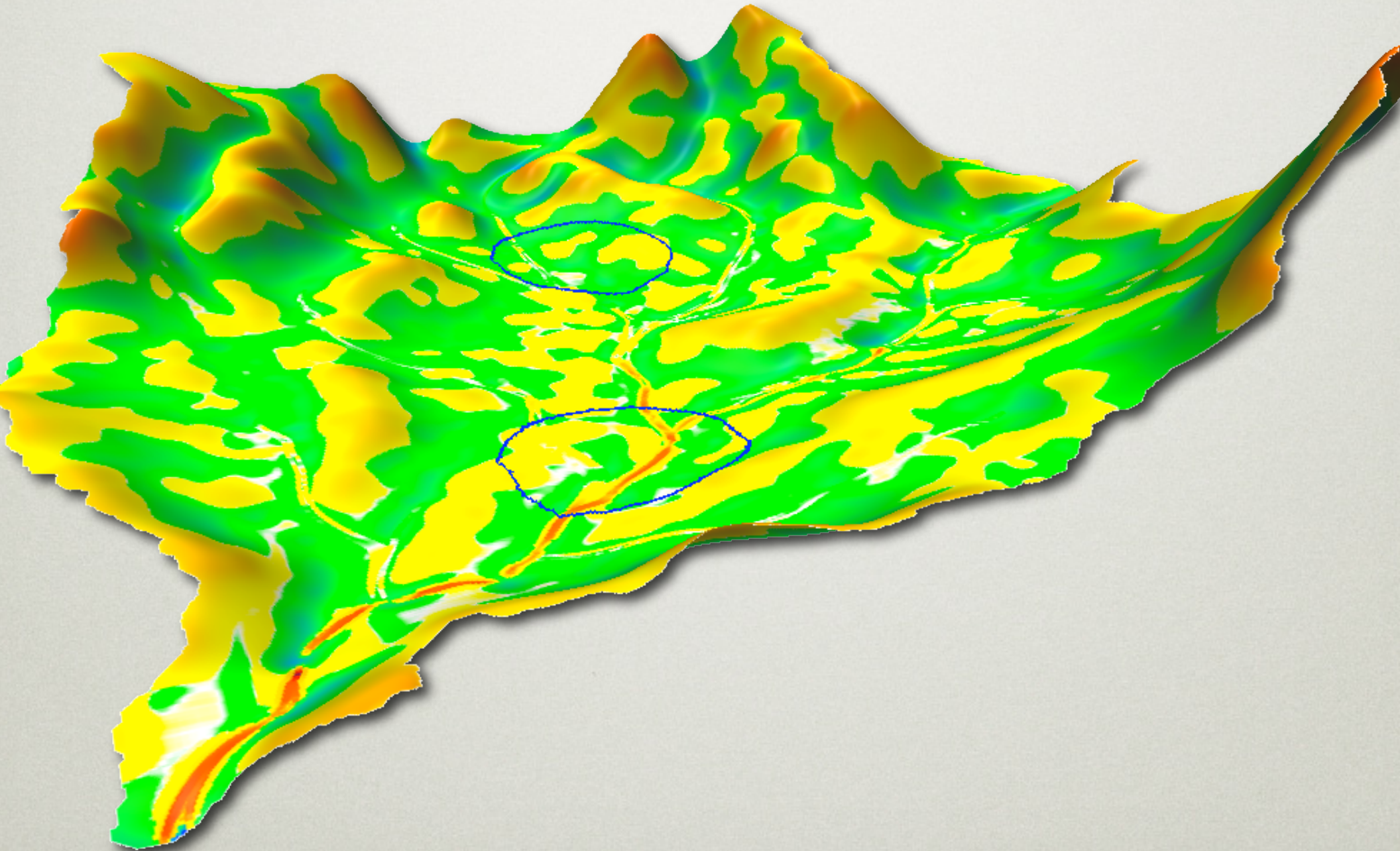


# MODELING IN GRASS





# MODELING IN GRASS





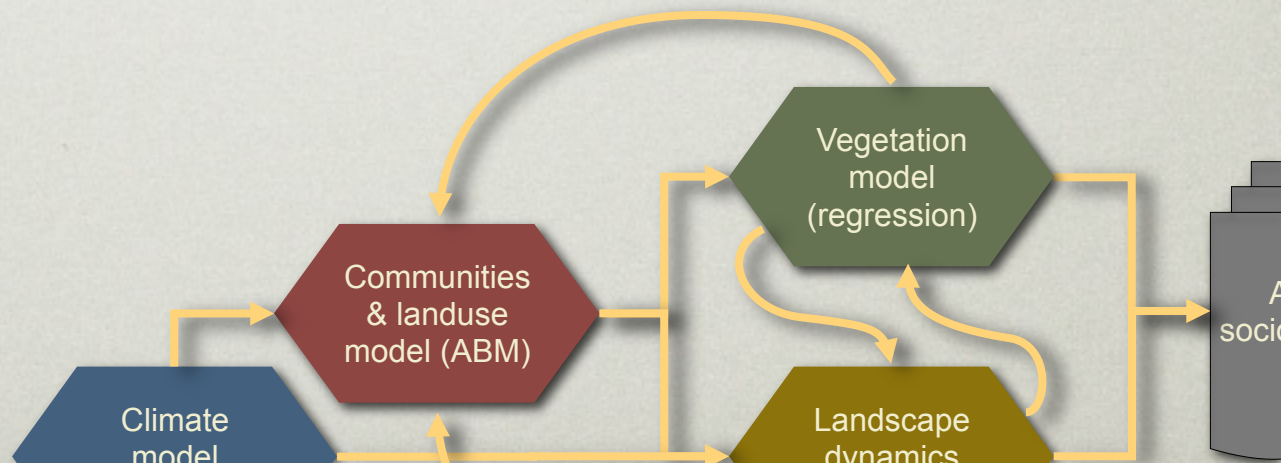
# LABORATORY

- r.landscape.evol one component of hybrid modeling laboratory that includes...
  - Java ABM of human households and their land-use decisions
  - GRASS GIS-based model of landscape dynamics
  - Regression-based models of local climate and vegetation
- Open source software for research transparency and global accessibility

e (  
[acims.arizona.edu/  
E/software.shtml](http://acims.arizona.edu/E/software.shtml))



S ([http://  
o.org](http://o.org))





# LABORATORY

- Coupled modeling system controlled from Java ABM and interface

The screenshot displays the Laboratory software interface, which is a Java-based agent-based modeling system. The interface is divided into several panels and sections:

- Navigation Tabs:** Agent, Environment Model, Interaction Model, System Settings (top); Villages, Resources, Households (middle).
- Configuration Parameters:** Includes sliders and input fields for various parameters such as "Probability", "Fertility Delta", "Minimum", and "Maximum" for different agents.
- FARMING PARAMETERS:** A table showing labor requirements and yields for different crops.
- OVICAPRID GRAZING PARAMETERS:** Parameters related to sheep and goat grazing, including density factors and fodder requirements.
- Visual Elements:** A horizontal slider at the bottom is set to 75, and a progress bar at the bottom left shows 000000 kcal / capita / year.
- Buttons:** Save Configuration, Load Configuration, and Validate are visible at the bottom.

Crop	Labor Required (man-days/ha/year)	Initial Expected Yield (kg/ha/year)	Calories (kcal/kg)
WHEAT	50	450	350
BARLEY	51	456	350

Parameter	Value
Number of Ovicaprids Per Person	4
Ovicaprid Grazing Density Factor	1
Ratio of Sheep to Goats (Sheep : To Goats)	1 : 1
Fallow Field Grazing	ON
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

# LABORATORY

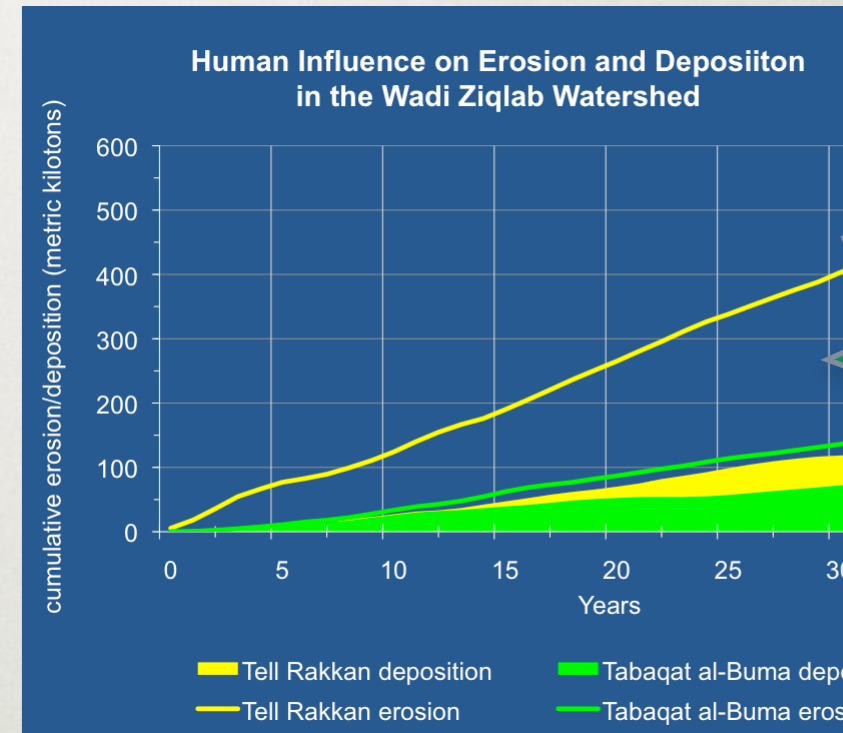
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- Experiments in complex interactions of socioecological systems
- Investigating long-term anthropogenic change in Holocene landscapes
- Providing new insights into coupled human & natural processes



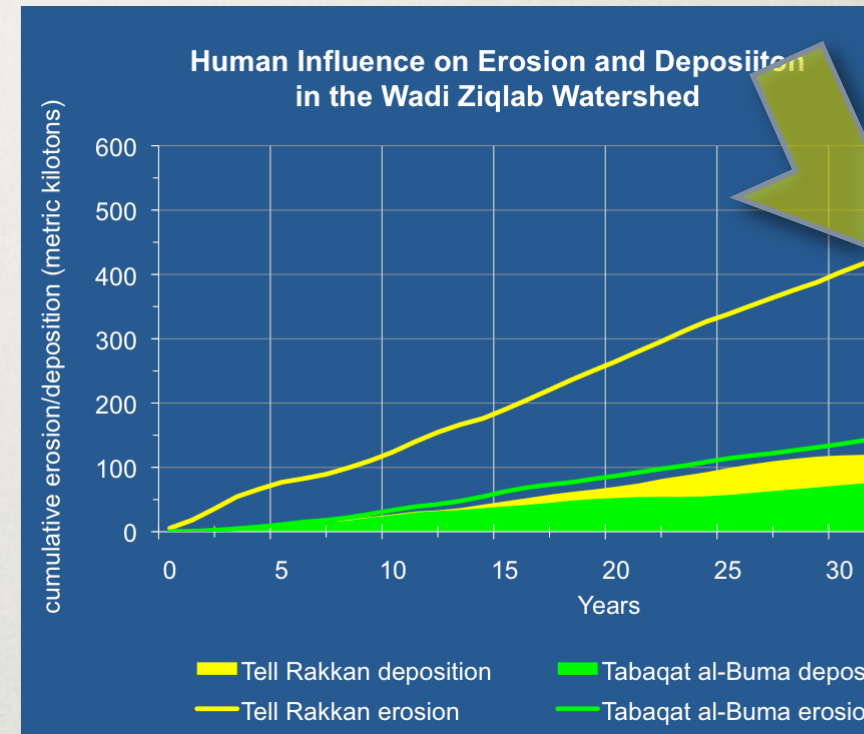
# IN NORTHERN JORDAN

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



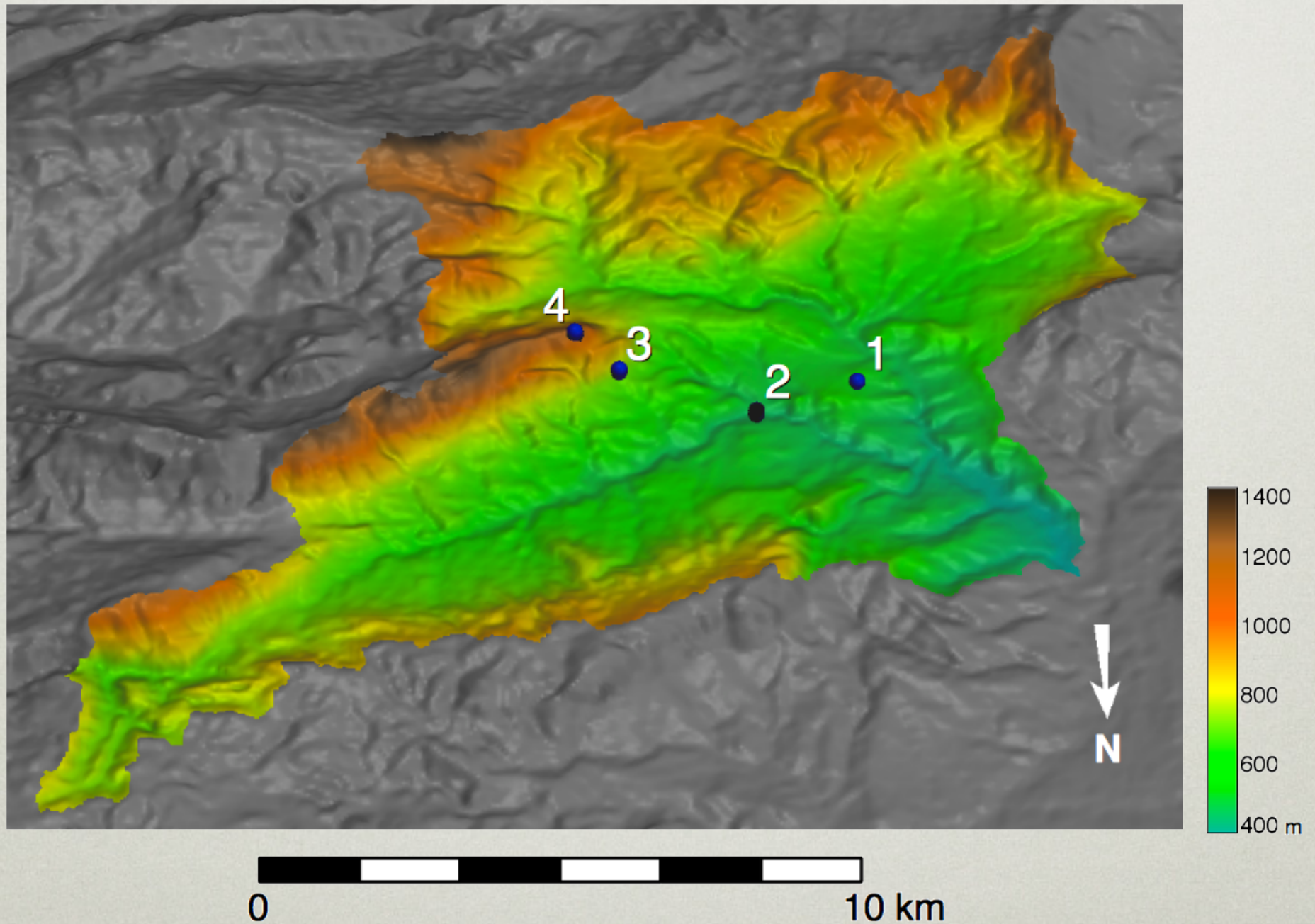
# IN NORTHERN JORDAN

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

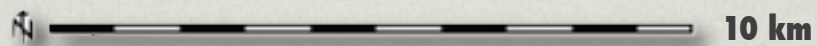
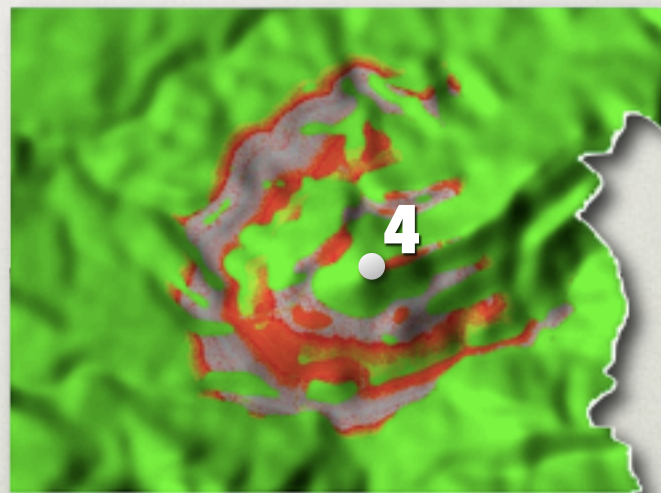
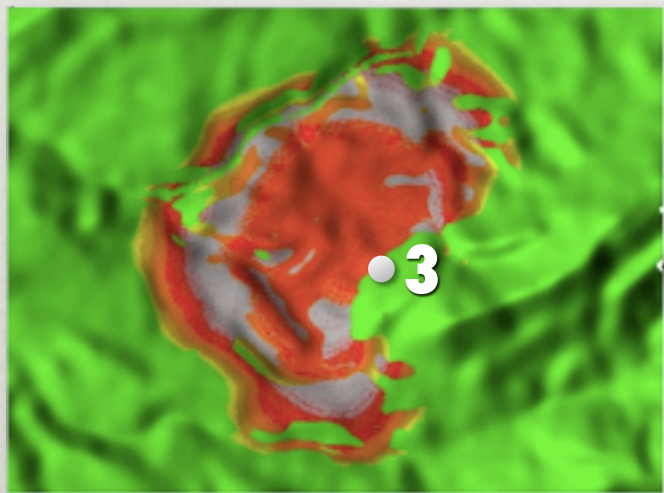
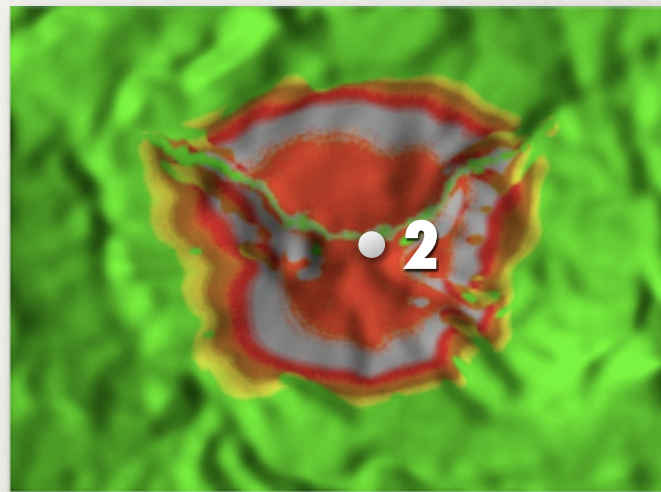
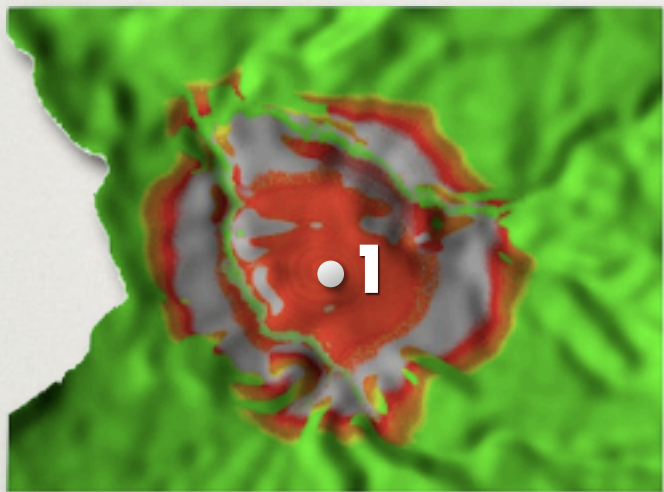




# DYNAMICS IN EASTERN SPAIN



# DYNAMICS IN EASTERN SPAIN



bare grasses shrubs open woodland woodland



# RELEVANT PUBLICATIONS

- Barton, C. Michael, Isaac I.T. Ullah, Sean M. Bergin, Helena, Mitasova, Hessam Sarjoughian (In Press). Looking for the future in the past: long-term change in socioecological systems. *Ecological Modelling*.
- Mitasova, Helena, Russell S. Harmon, Michael Barton, & Issac Ullah (In Press). Geospatial information science-based erosion modeling. In *Treatise in Geomorphology: Vol. 3 Remote Sensing and GI Science*. Elsevier, Amsterdam.
- Barton, C. Michael, (In Press). Stories of the Past or Science of the Future? Archaeology and Computational Social Science. In *Computational Approaches to Archaeological Spaces*, edited by A. Bevan and M. Lake.
- Ullah, I.I., & Sean Bergin (In Press). Modeling the consequences of village site location: Least Cost Path Modeling in a coupled GIS and Agent-Based model of village agropastoralism in Eastern Spain. In *Least Cost Analysis of Social Landscapes: Archaeological Case Studies for Beginners and Experts Alike*, edited by D.A. White and S. L. Surface Evans.
- Ullah, I.I., (2010). A GIS method for assessing the zone of human-environmental impact around archaeological sites: a test case from the Late Neolithic of Wadi Ziqlâb, Jordan. *Journal of Archaeological Science*, 33(6):623-632. Corrected Proof.
- Barton, C. Michael, Isaac Ullah, and Sean Bergin (2010). Land use, water, and Mediterranean landscapes: modelling long-term dynamics of complex socio-ecological systems. *Philosophical Transactions of the Royal Society A*, 368:5275-5297.
- Barton, C. Michael, Isaac Ullah, and Helena Mitasova (2010). Computational modeling and Neolithic socioecological dynamics: a case study from southwest Asia. *American Antiquity*, 75(2):364-386.
- Mayer, G.R., H.S. Sarjoughian, (2009). Composable cellular automata, *Simulation*, 85(11-12): 735-749. [PDF \(1 Mb\)](#)
- Mayer, G.R., H.S. Sarjoughian, (2008). A composable discrete-time cellular automaton formalism, *First International Workshop on Social Computing, Behavioral Modeling, and Prediction*, pp. 187-196, Springer, April, Phoenix, AZ.
- Mayer, G.R., Hessam Sarjoughian (2007). Complexities of simulating a hybrid agent-landscape model using

# COMSES NETWORK

- A new community of practice
- Building capacity and promoting best practices for computational modeling

Open Agent Based Modeling Consortium | ... a node in the CoMSES network

http://www.openabm.org/

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Welcome to the OpenABM website. The OpenABM site includes a growing collection of tutorials on computational modeling, frequently asked questions about computational modeling, a modeling library intended to provide a locus for authors and modelers to share their models, and forums for modeling related discussion and job postings. [More »](#)

**Upcoming Events**

**Feb 21, 2011 - Feb 25, 2011** - Winter School Netlogo

**Mar 31, 2011 - Apr 01, 2011** - Simulating Knowledge Dynamics in Innovation Networks

**Apr 01, 2011** - Spatial agent-based models for socio-ecological systems

**Apr 01, 2011 - Apr 03, 2011** - Epistemology of Modeling and Simulation

**Apr 03, 2011 - Apr 08, 2011** - Geomorphology and agent models at EGU [More »](#)

**OpenABM Announcements**

**New Content Feature: Classroom Materials**  
OpenABM has added a new content section, Classroom Materials, where teaching materials on ABM can be shared with the community.

**2010 OpenABM and CSSS Modeling Competition**  
OpenABM.org and the Computational Social Science Society (CSSS) will be holding a competition for agent-based models to determine a model that best predicts the behavior of subjects in a foraging experiment.

**Paper Submission Deadlines**

**Mar 15th, 2011** - 2nd ESSA Summer School on Agent-Based Modelling

**Apr 1st, 2011** - Simulating the Social Processes of Science

**Apr 4th, 2011** - 12th International Workshop on Computational Logic in Multi-Agent Systems

**Apr 7th, 2011** - Evolutionary Computation and Multi-Agent Systems and Simulation Workshop

**Jun 1st, 2011** - 2nd International Conference on Reputation (ICORE 2011)

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# COMSES NETWORK

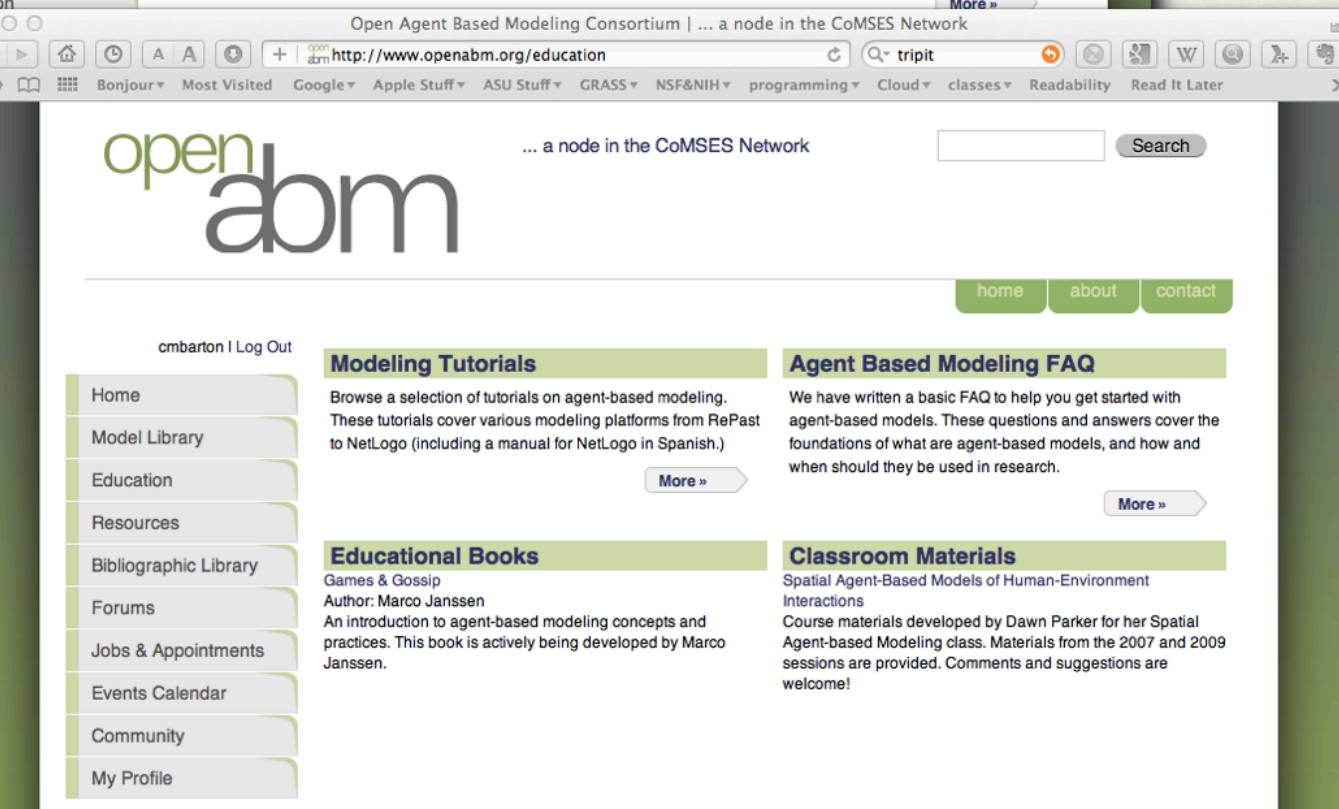
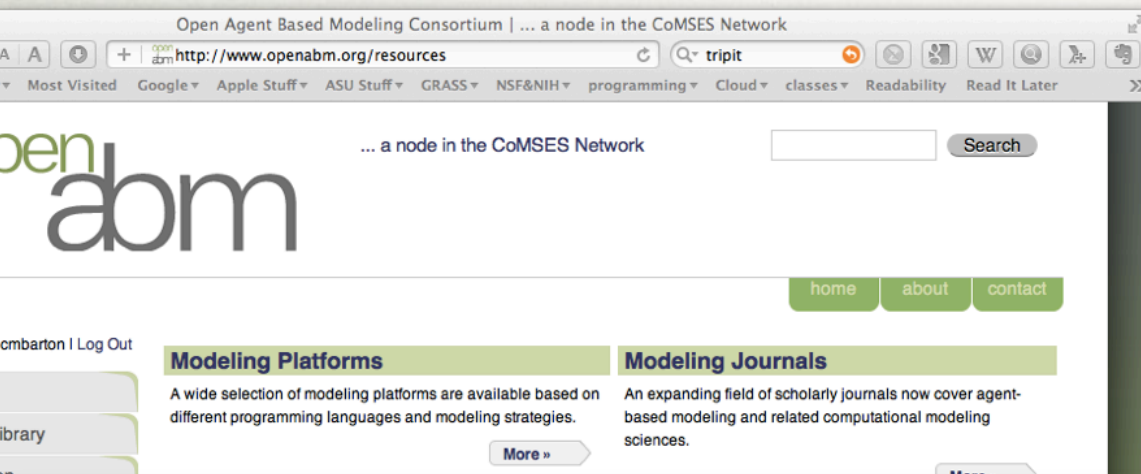
- Computational Models Library
- Linking models to publications
- Permanent Handle for published models
- Model certification
- NSF data sharing requirement

The screenshot shows a web browser window displaying the OpenABM website. The browser's address bar shows the URL: <http://www.openabm.org/model/2609/version/2/view>. The page title is "(Policy induced) Diffusion of Innovations - An integrated demand-supply...del based on Cournot Competition | Open Agent Base". The website header includes the OpenABM logo and the text "... a node in the CoMSES Network". A navigation menu on the left lists: Home, Model Library, Education, Resources, Bibliographic Library, Forums, Jobs & Appointments, Events Calendar, Community, and My Profile. The main content area features the title "(Policy induced) Diffusion of Innovations - An integrated demand-supply Model based on Cournot Competition" by martin.rixen, with a last update of 09/19/2011. Below the title are tags for "innovation adoption", "innovation diffusion", "product diffusion", "policy", "induced diffusion", "market entry", and "market exit". There are also sub-tags for "epidemic" and "probit". An HD video link is provided: <http://www.youtube.com/watch?v=9JNTI7TioLM>. The video description states: "The model integrates both demand and supply in a single model. The underlying demand function is the crucial element that links both sides. It is determined by consumer's learning status, the awareness for the new technology, and consumer's individual price thresholds, their willingness-to-pay. Diffusion proceeds in our model, if interactions distribute awareness (Epidemic effect) and rivalry reduces the market price (Probit effect). Endogeneity is given due to the fact that consumer awareness as well as their willingness-to-pay drives supply-side rivalry. Vice versa, rivalry determines pricing and therefore consumer adoption and awareness. Market entry and exit decisions as well as quantity and price settings are driven by the underlying demand function. We utilize Cournot competition to calculate competitive dynamics. Suppliers compete on the quantity of output they will produce. Firms ...". A list of assumptions follows: 

- produce a homogeneous product, there is no product differentiation.
- do not cooperate, there is no collusion.
- have market power, each output decision affects market price.

 On the right side of the page, there is a small inset window showing a simulation interface with various graphs and data points.

# COMSES NETWORK



- Links to data archives for parameterization, testing, and validation
- Standards for metadata and model description
- Educational resources
- Special interest groups
- High performance computing access



# ACKNOWLEDGEMENTS

- **National Science Foundation:** grants BCS-410269 (MedLand), GEO-909394 (CoMSES)
- **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, University of Alaska, Geoarchaeological Research Associates, GRASS GIS Development Team

