High resolution surface process modeling in a GRASS GIS environment

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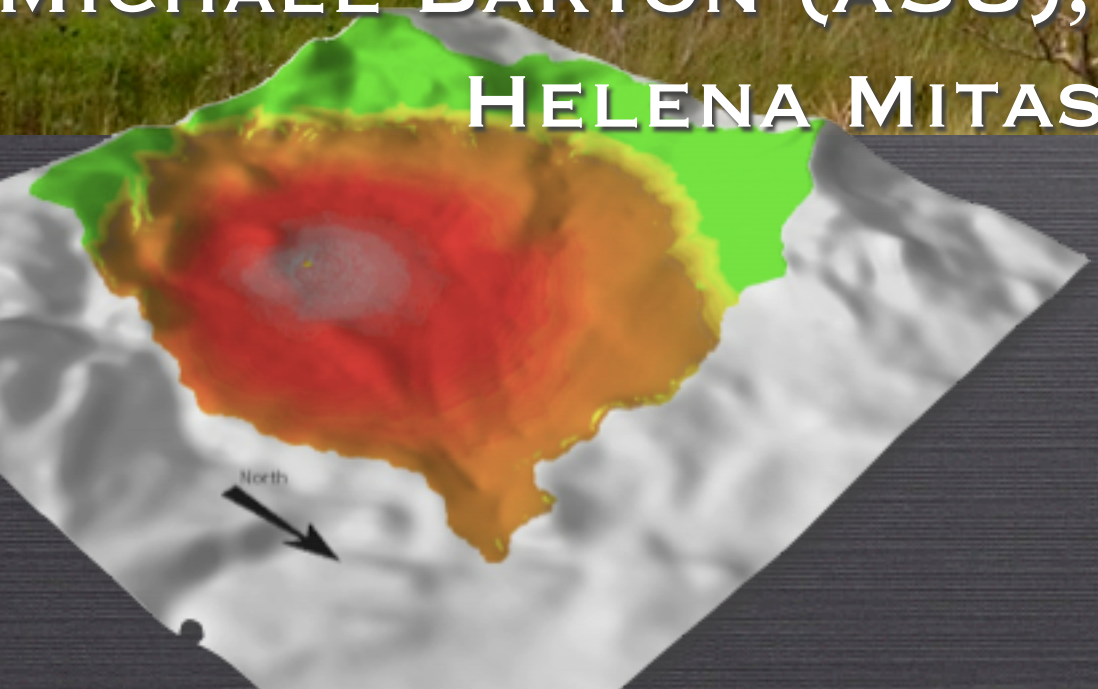
Helena Mitasova (NCSU)



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

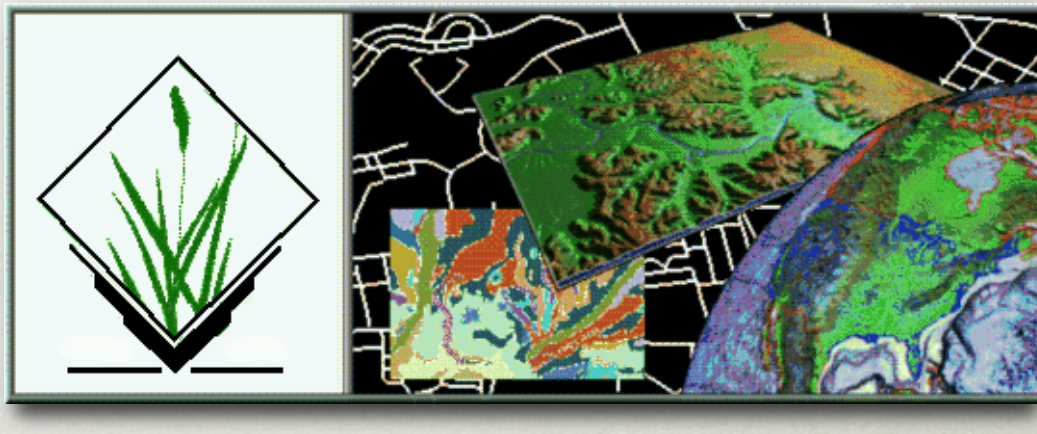
- What temporal/spatial scales relevant to modeling anthropogenic landscape char
- Anthropocene
  - Last 10k years
  - Begins with farming
  - Increasingly important anthropogenic componen surface processes
- Spatial/temporal scales of hu impacts
  - Lifetimes to millennia
  - Household to global

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

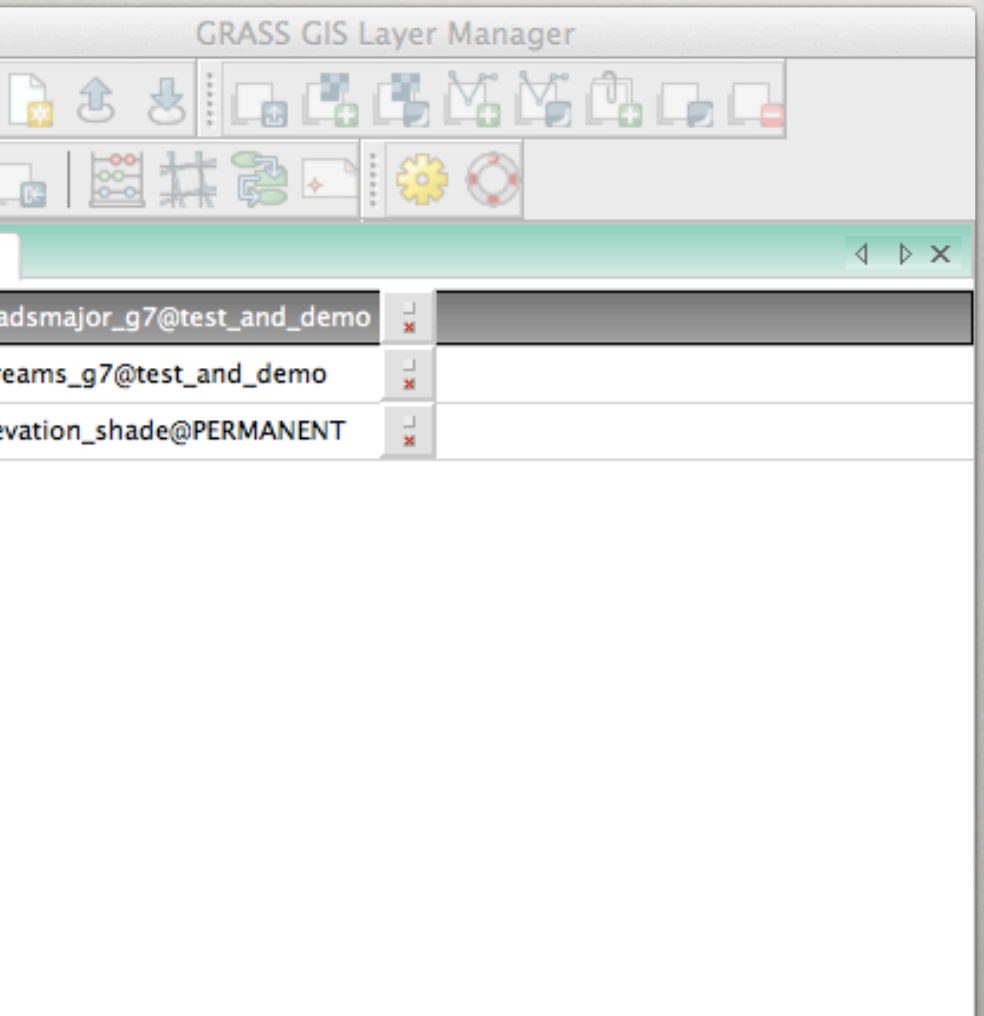
Process Modeling

- 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

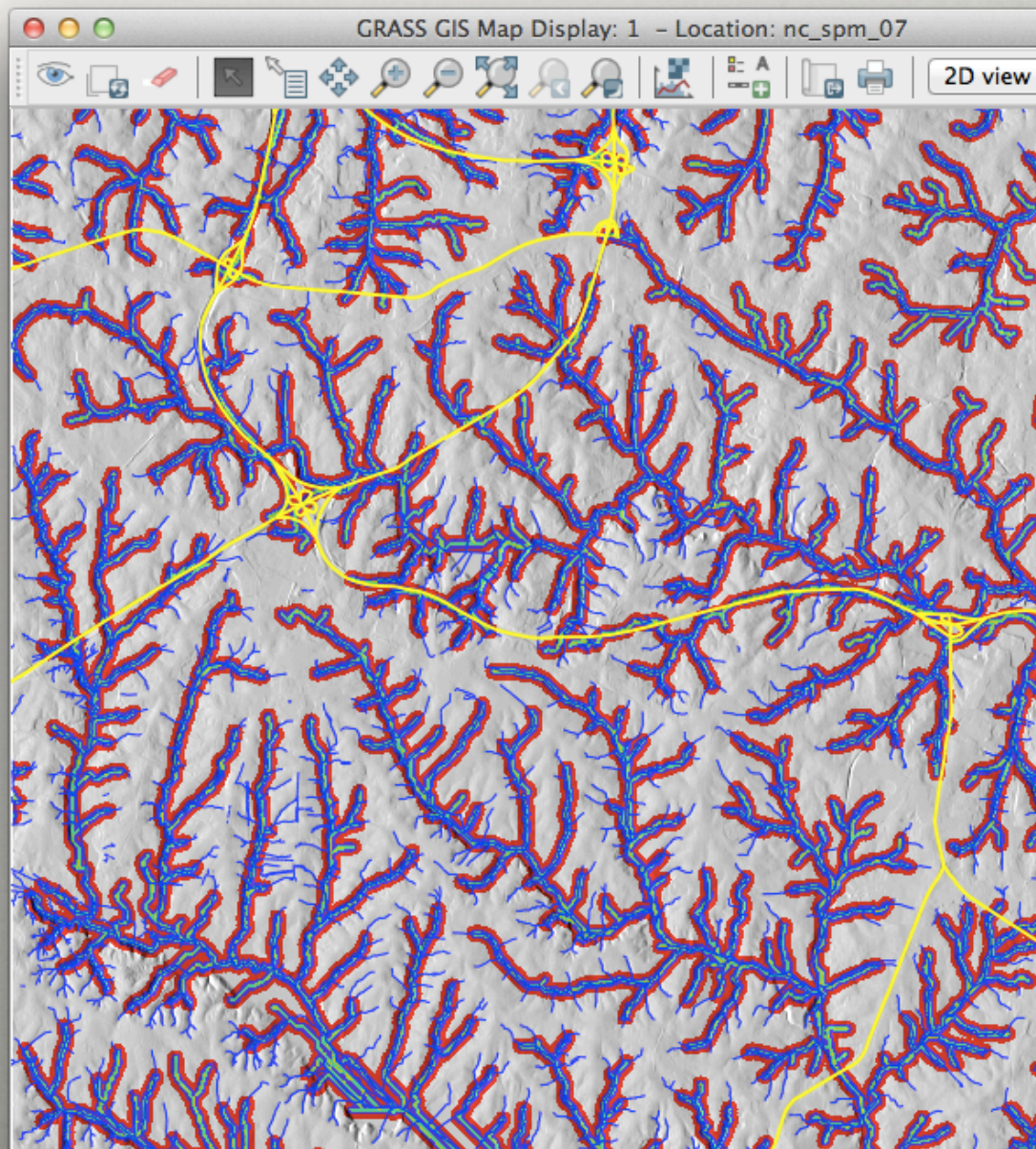


Process Modeling

- Raster / grid support



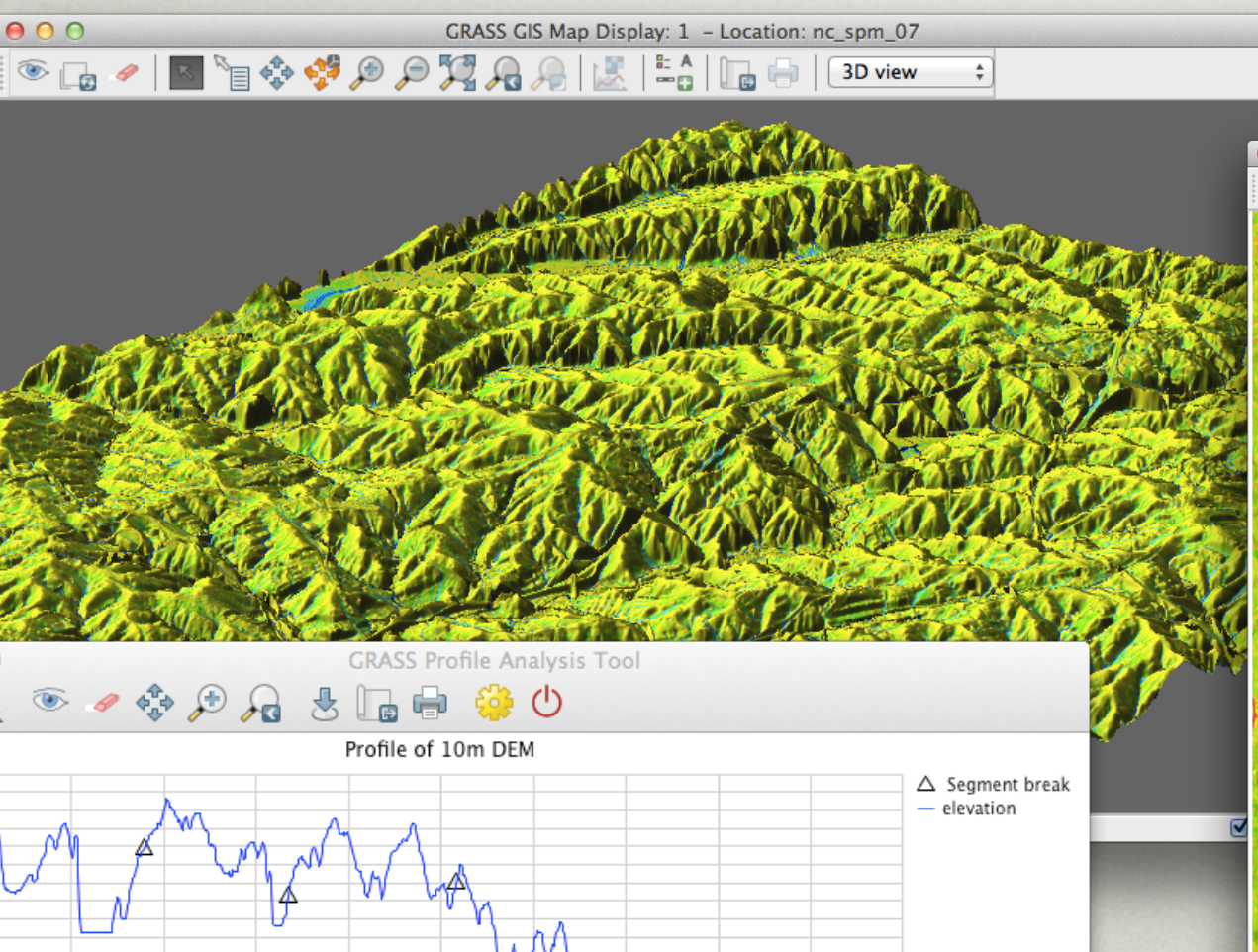
raster buffers around streams over relief m



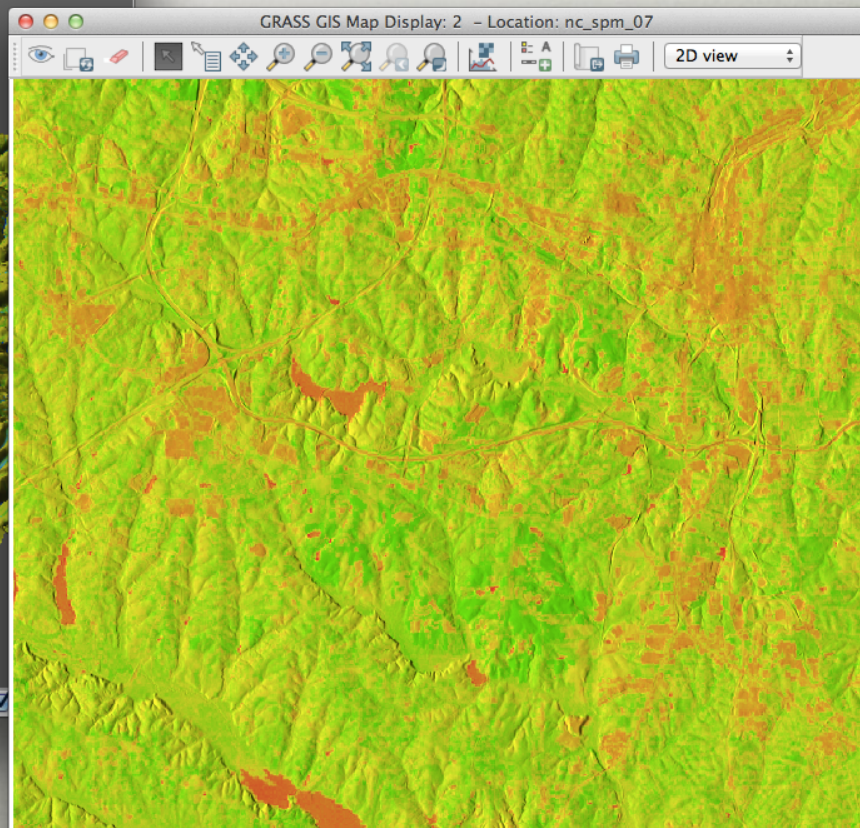
Process Modeling

- Many tools for surface process modeling and analysis

flow accumulation over 2.5D terrain

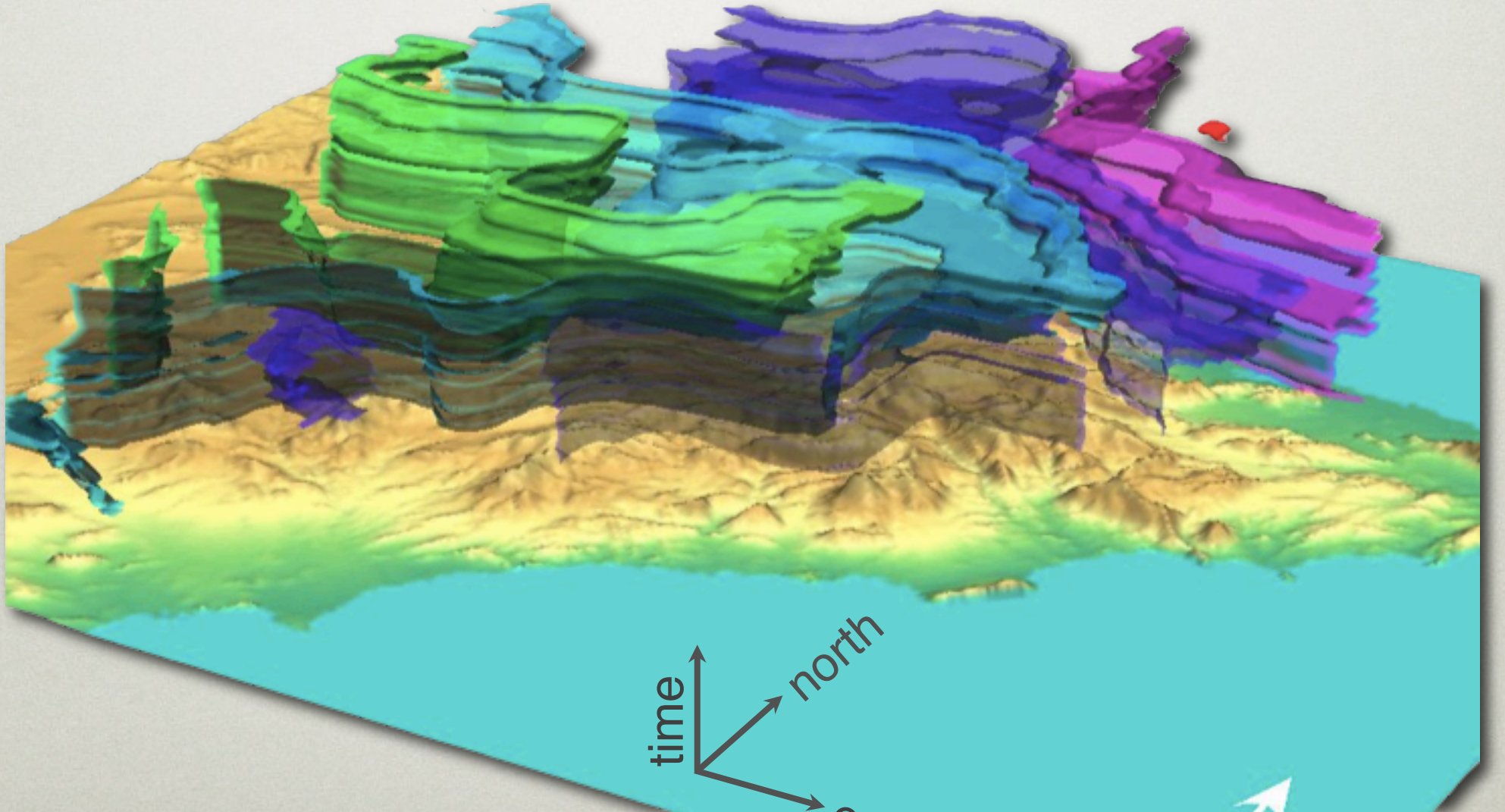


Landsat NDVI over relief map



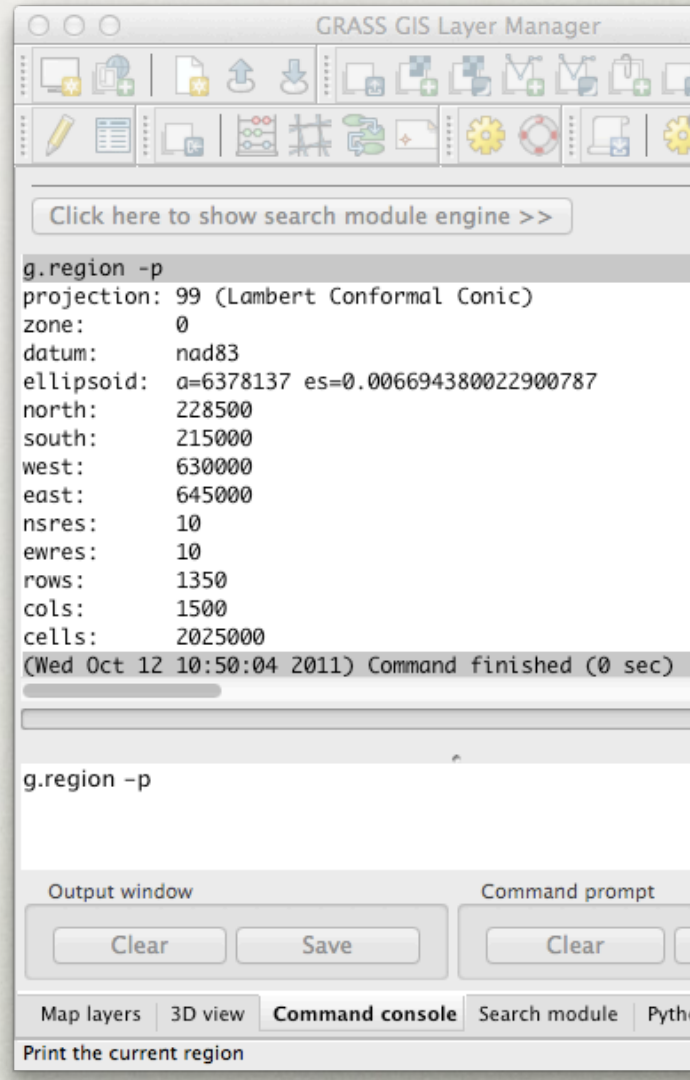
Process Modeling

- 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)

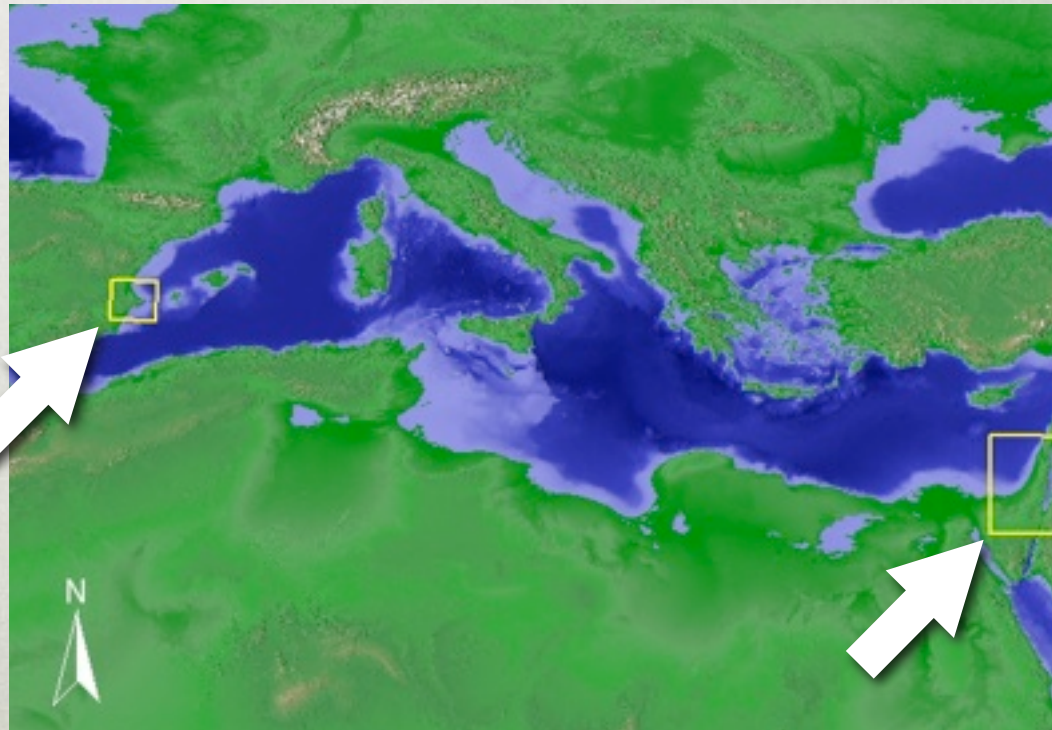


Dynamics (MedLanD)

- 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

ebsite - http://medland.asu.edu



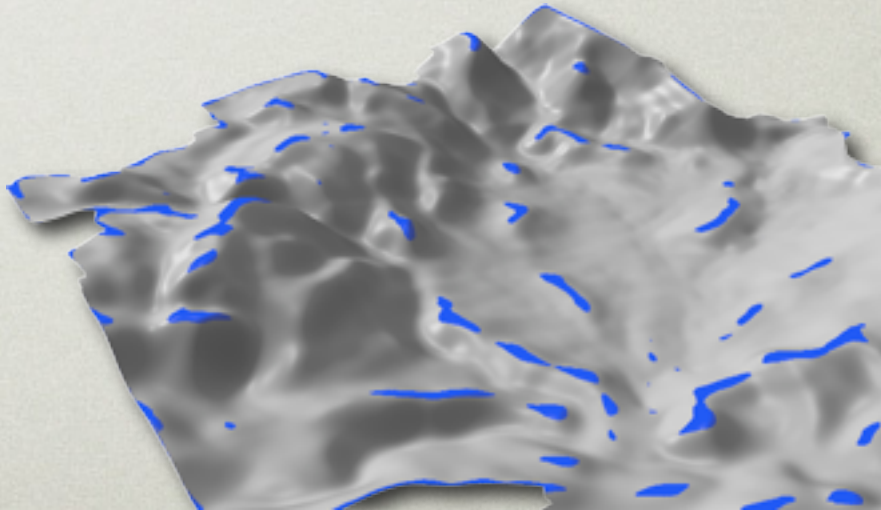
MedLand SPM Overview

- 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 **Δz** is net vertical change (erosion/deposition), **β** is slope, and **κ** is an empirically derived constant for different substrates

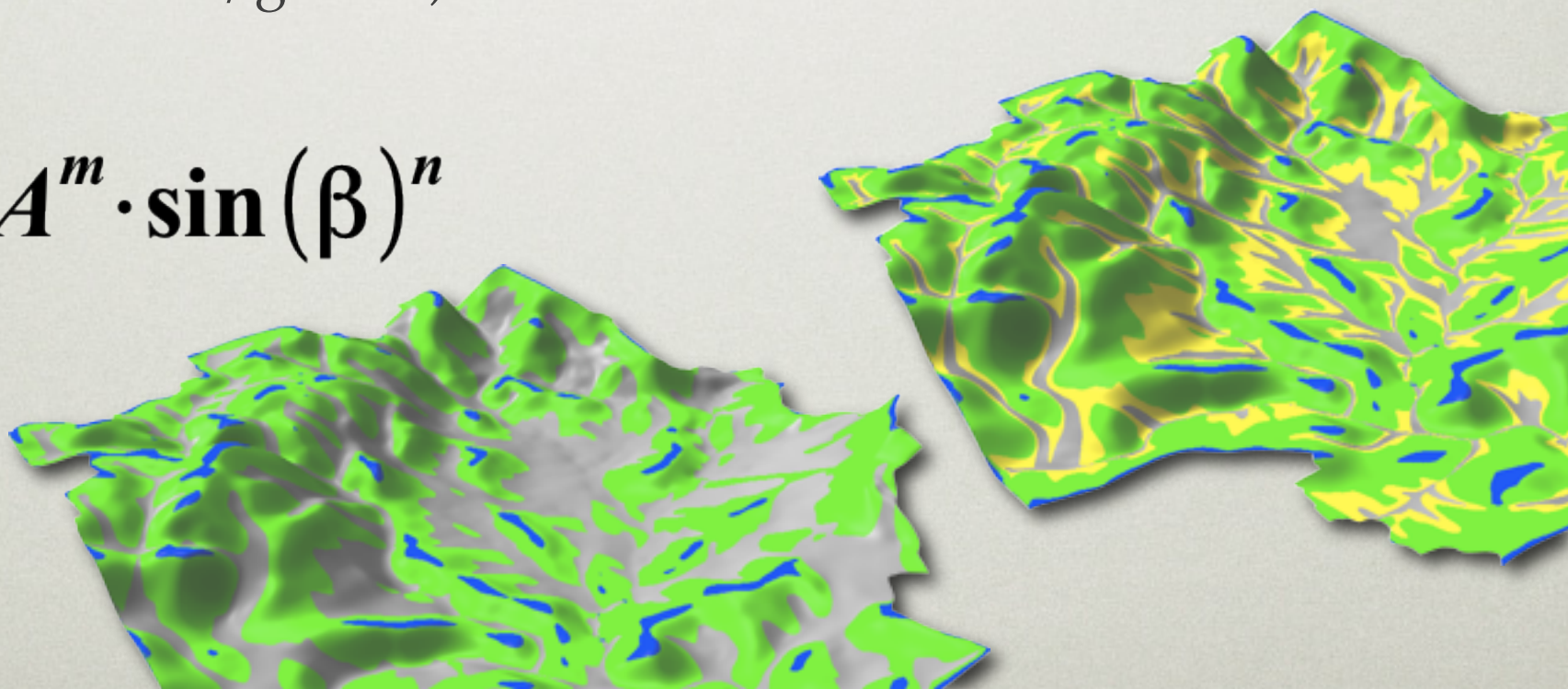
$$\Delta z = \kappa \cdot \sin(\beta)$$



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 derive RUSLE constants; A is upslope contributing area; m and n are empirically derived constants for different flow regimes (hill slopes vs. rills/gullies).

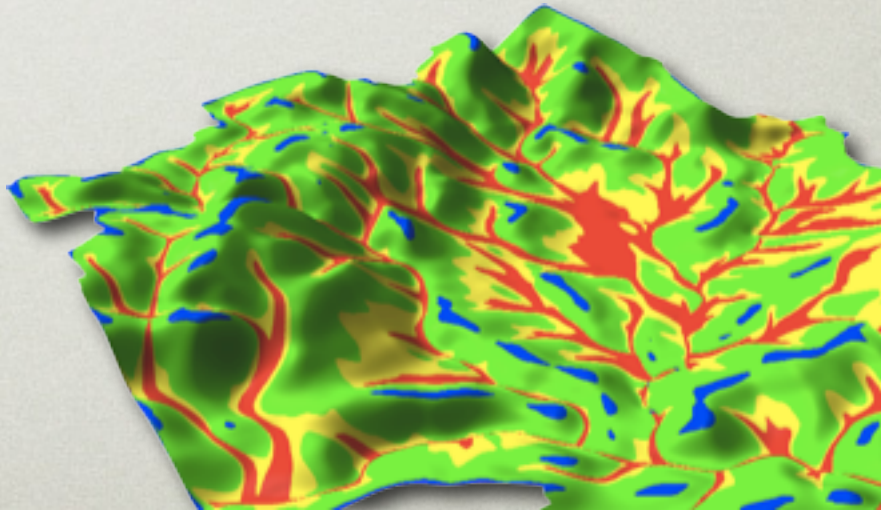
$$R \cdot K \cdot C \cdot A^m \cdot \sin(\beta)^n$$



MedLand SPM Overview

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

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

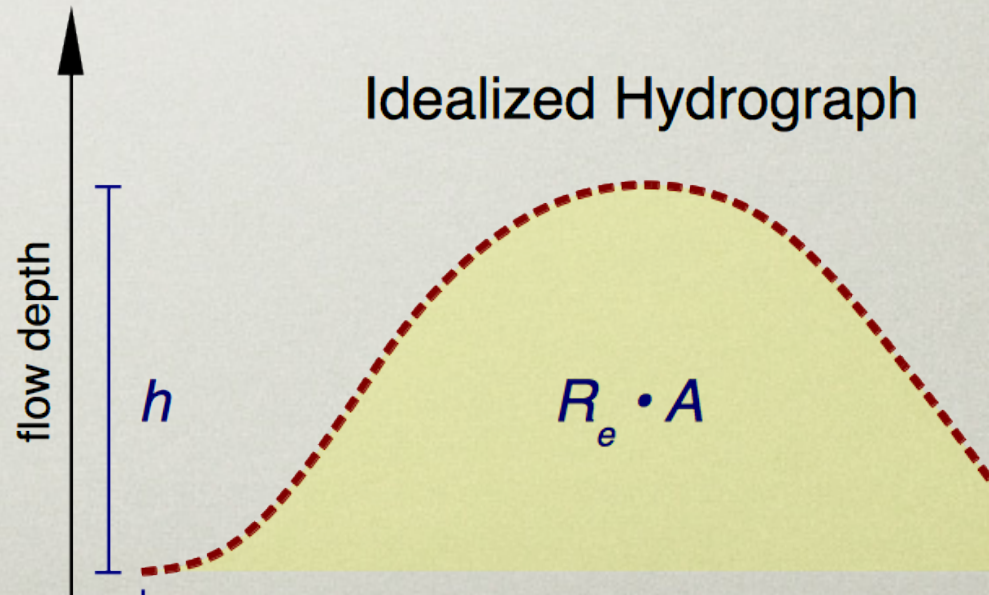


MedLand SPM Overview

- Calculation of shear stress (τ) 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

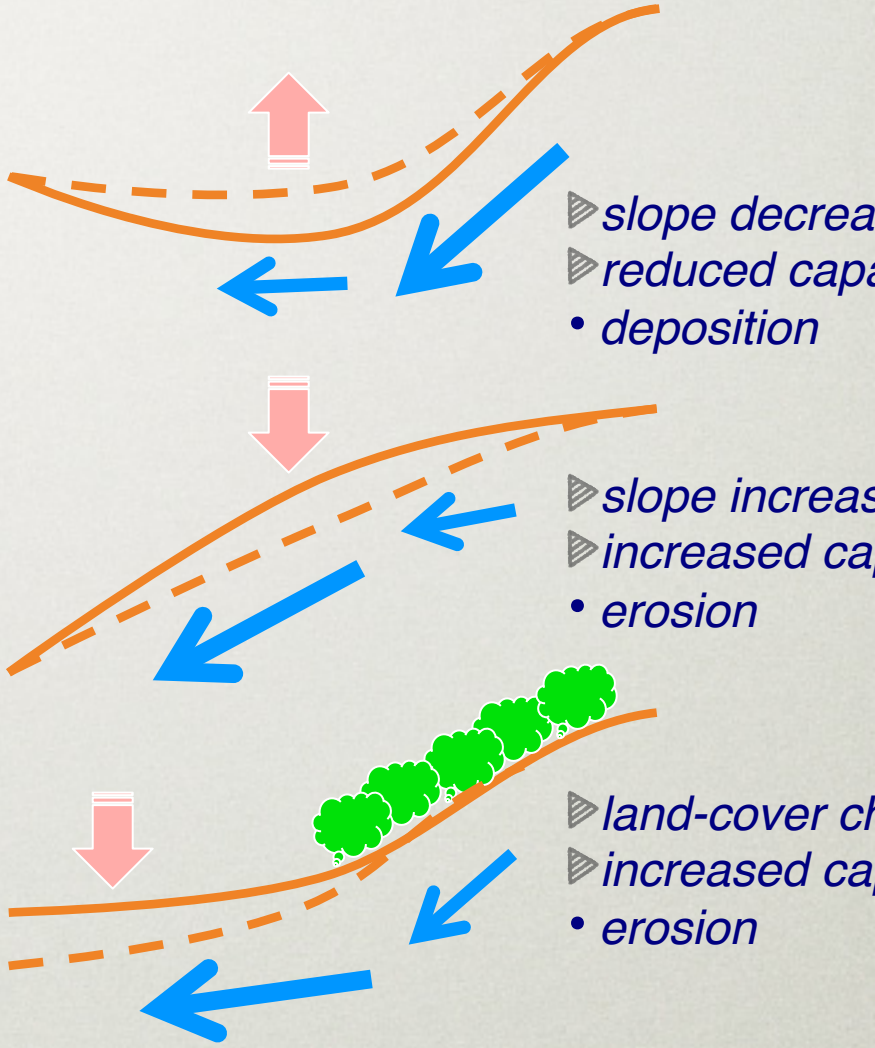
$$\tau = 9806.65 \cdot \beta \cdot h$$

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



Change

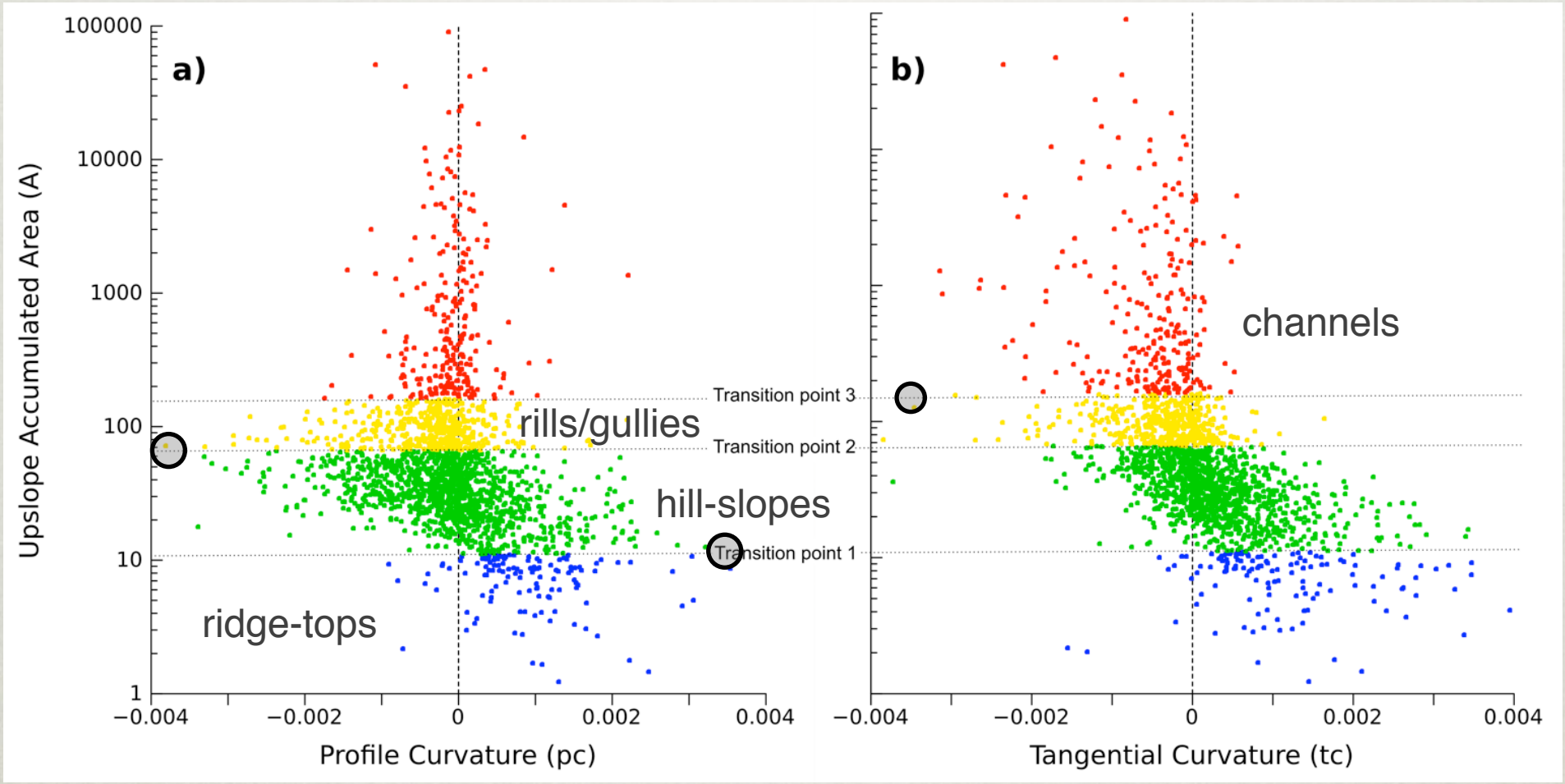
- Basic assumption
  - Flowing water carries sediment at capacity ($T_c \approx Q_s$)
- Dynamics
  - Changes to hydrology affect transport capacity
  - Water will erode or deposit sediment until its load reaches its new capacity

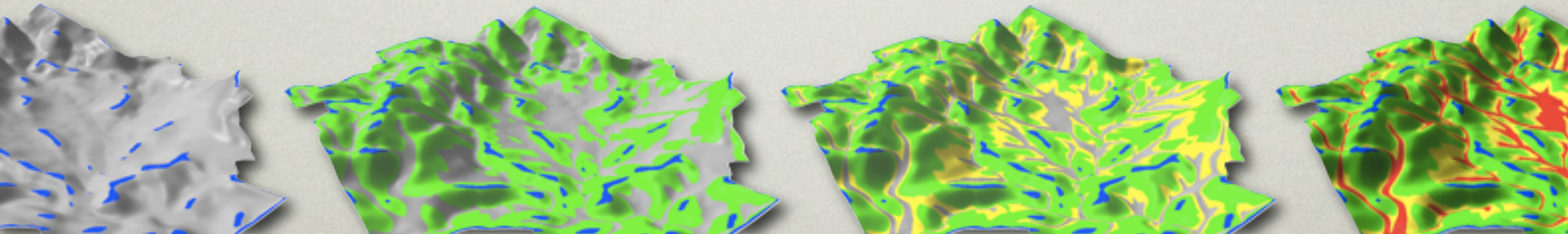


$$\operatorname{div} \vec{T}_c = \frac{\partial (T_c \cos \alpha)}{\partial x} + \frac{\partial (T_c \sin \alpha)}{\partial y}$$

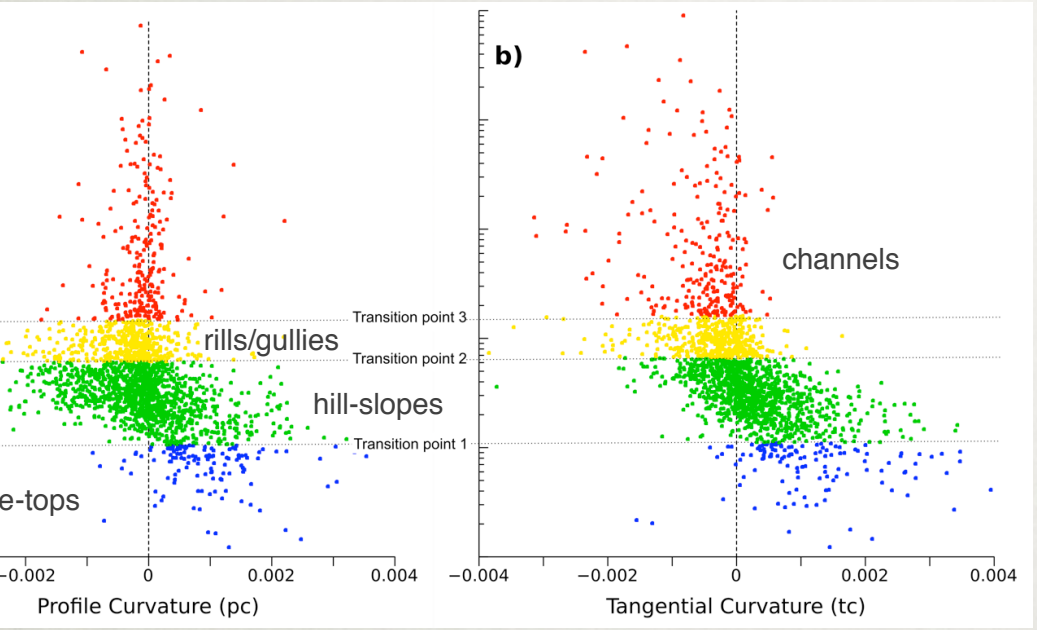
$$\Delta z = \frac{D}{p} \cdot \frac{U_a}{cell\ res}$$

Phase Shifts

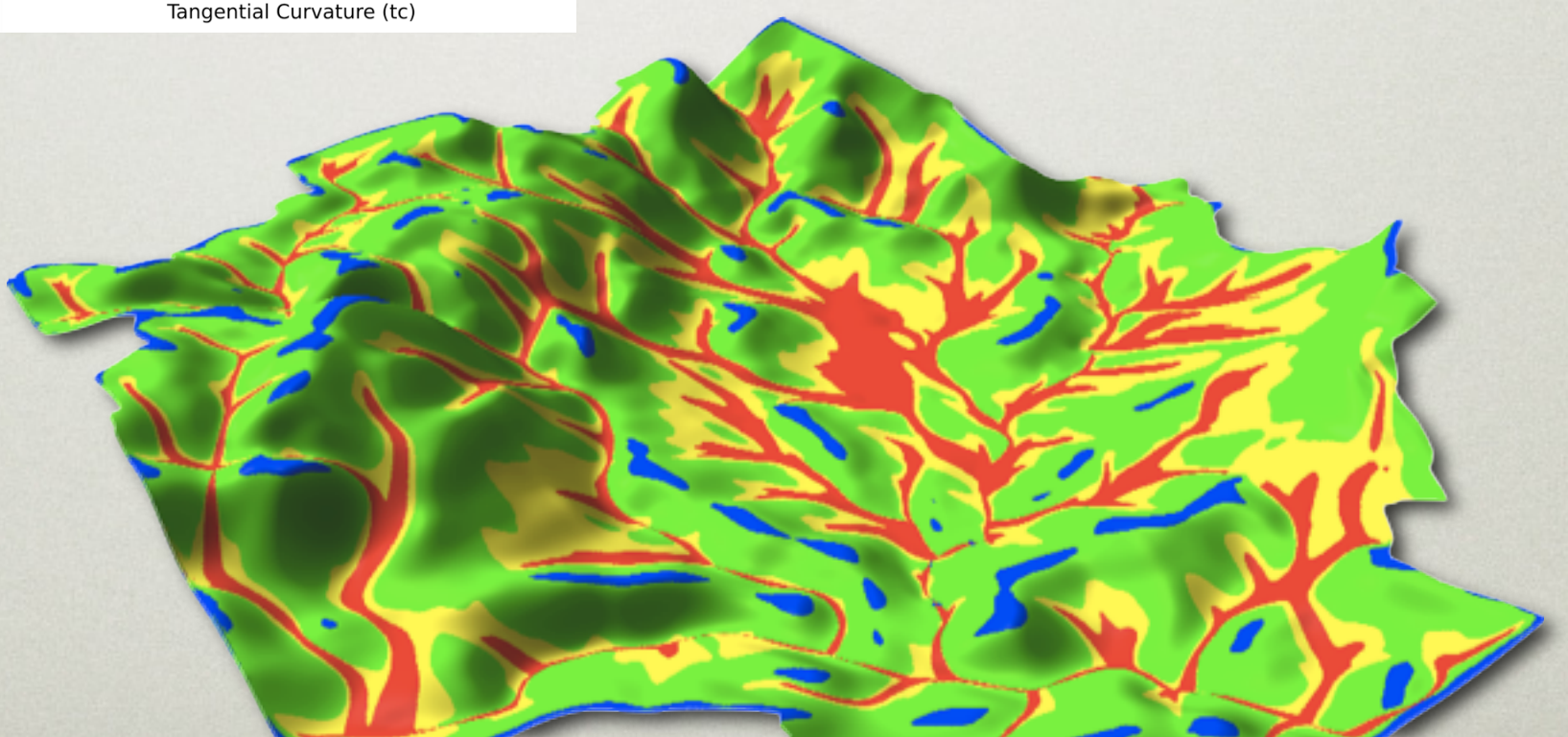




Phase Shifts

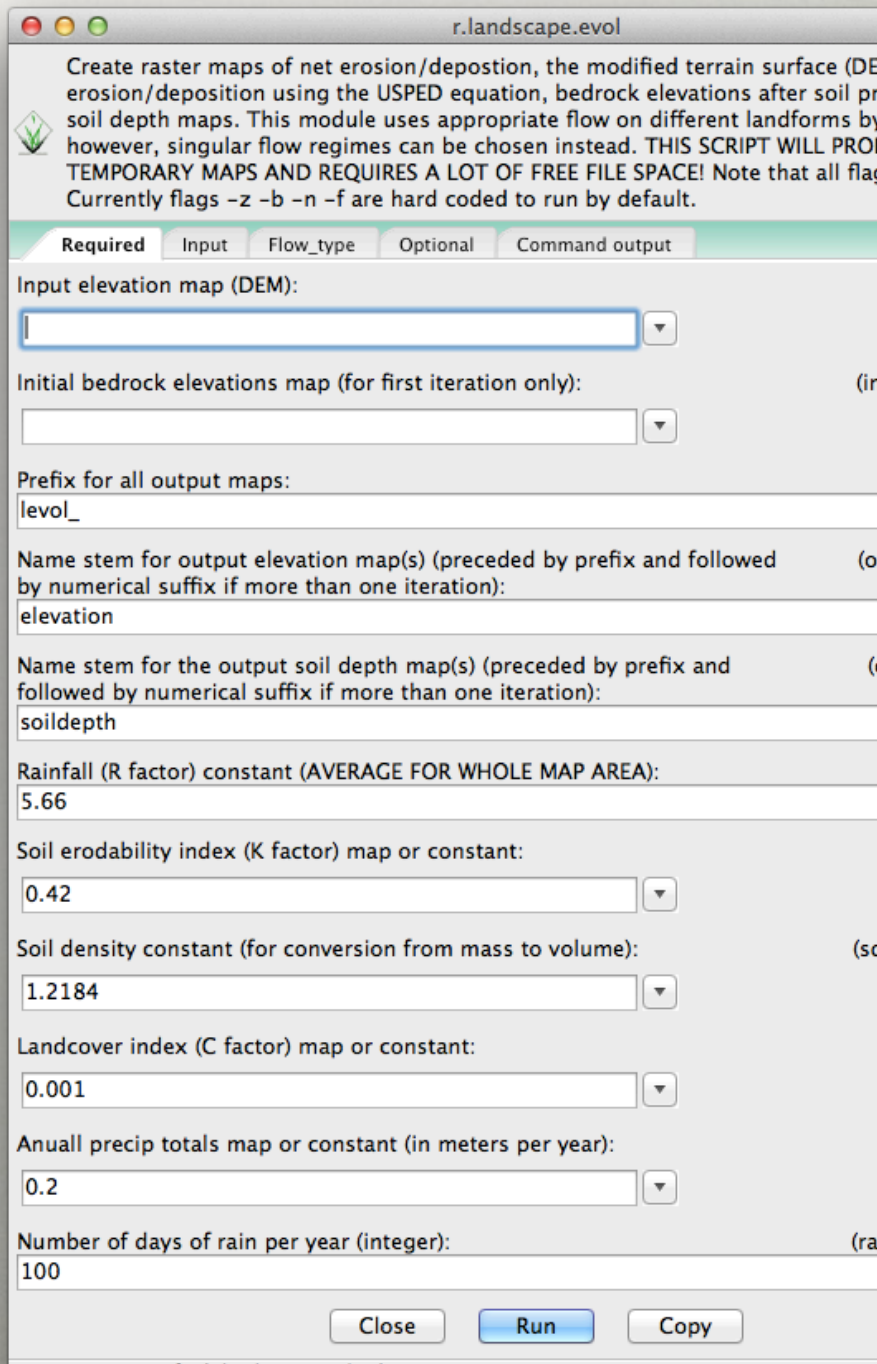


- Each process phas
  modeled separatel
- Resulting maps
  patched together



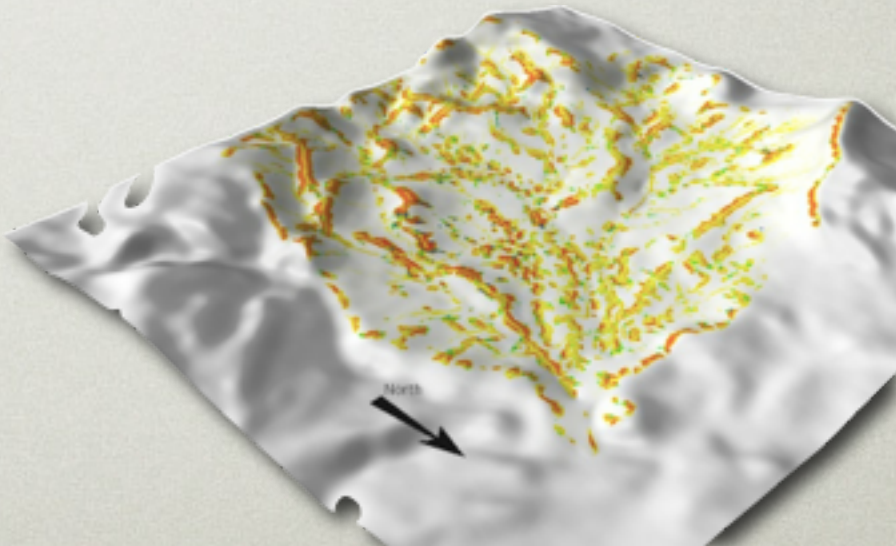
Modeling in GRASS

- 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

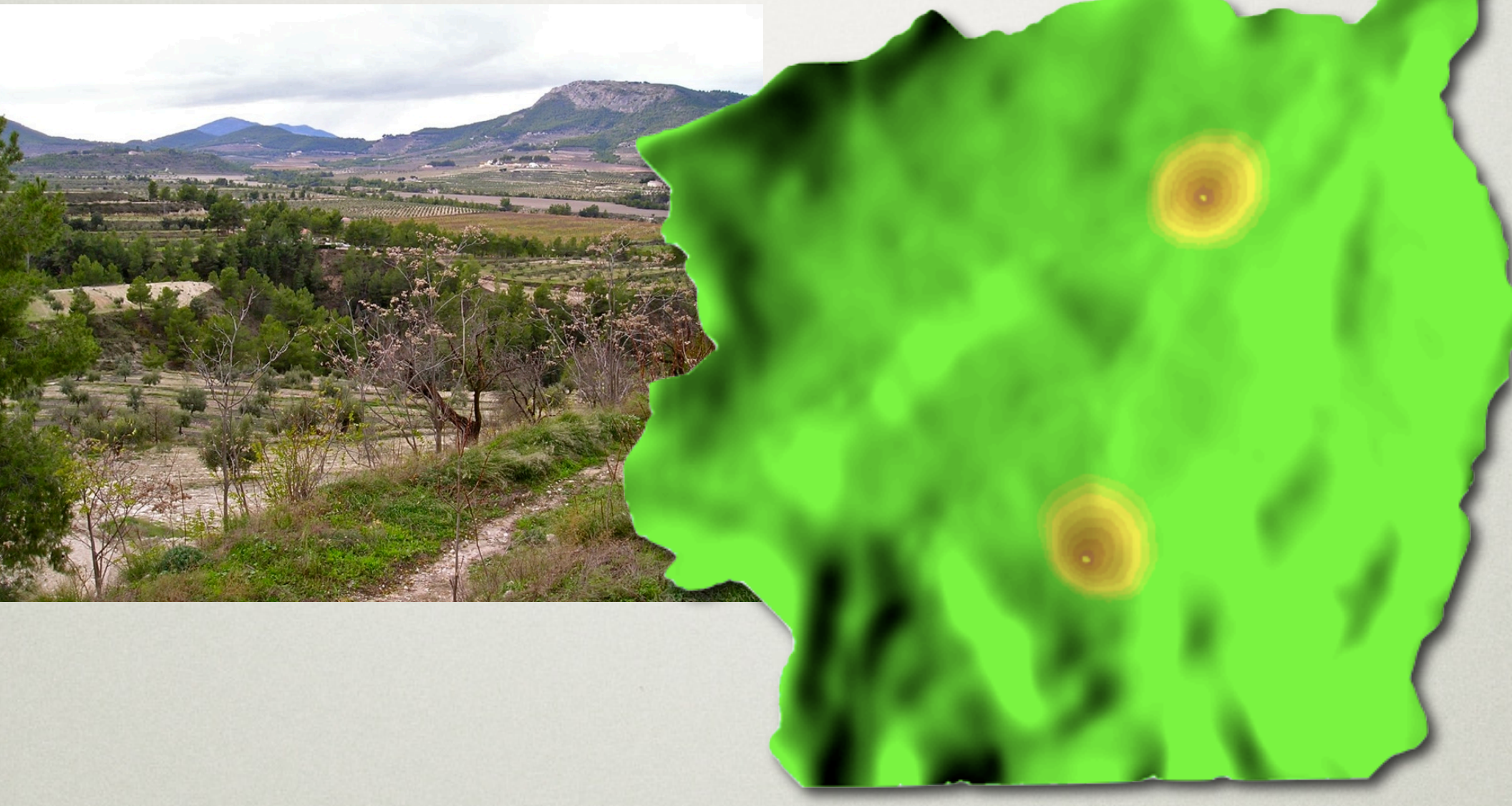


Modeling in GRASS

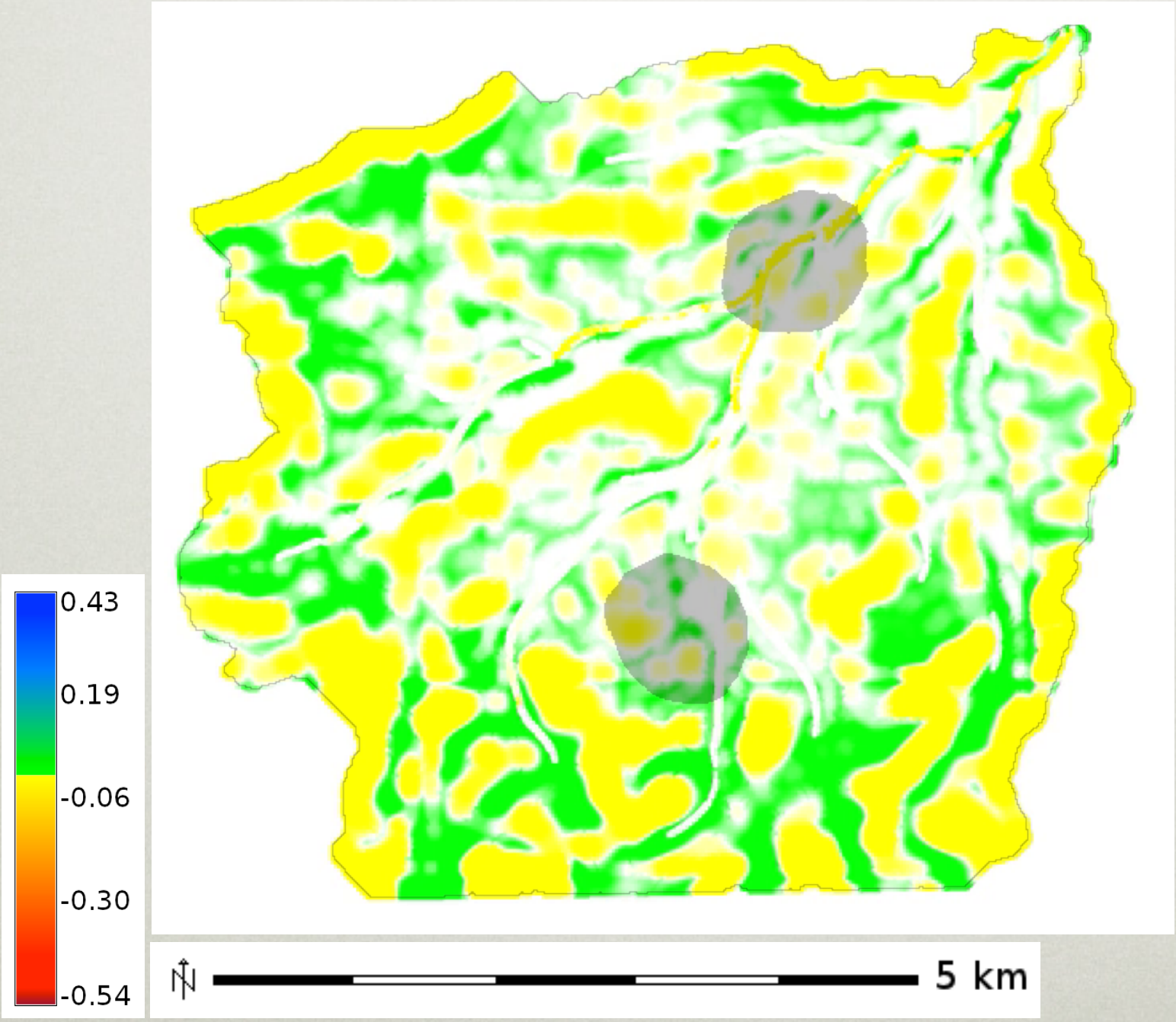
- Can complete 1 modeling cycle in under 1 minute for 1 million cells
- Tuned for annual cycles
- Could be retuned for monthly, daily, or event-based cycles



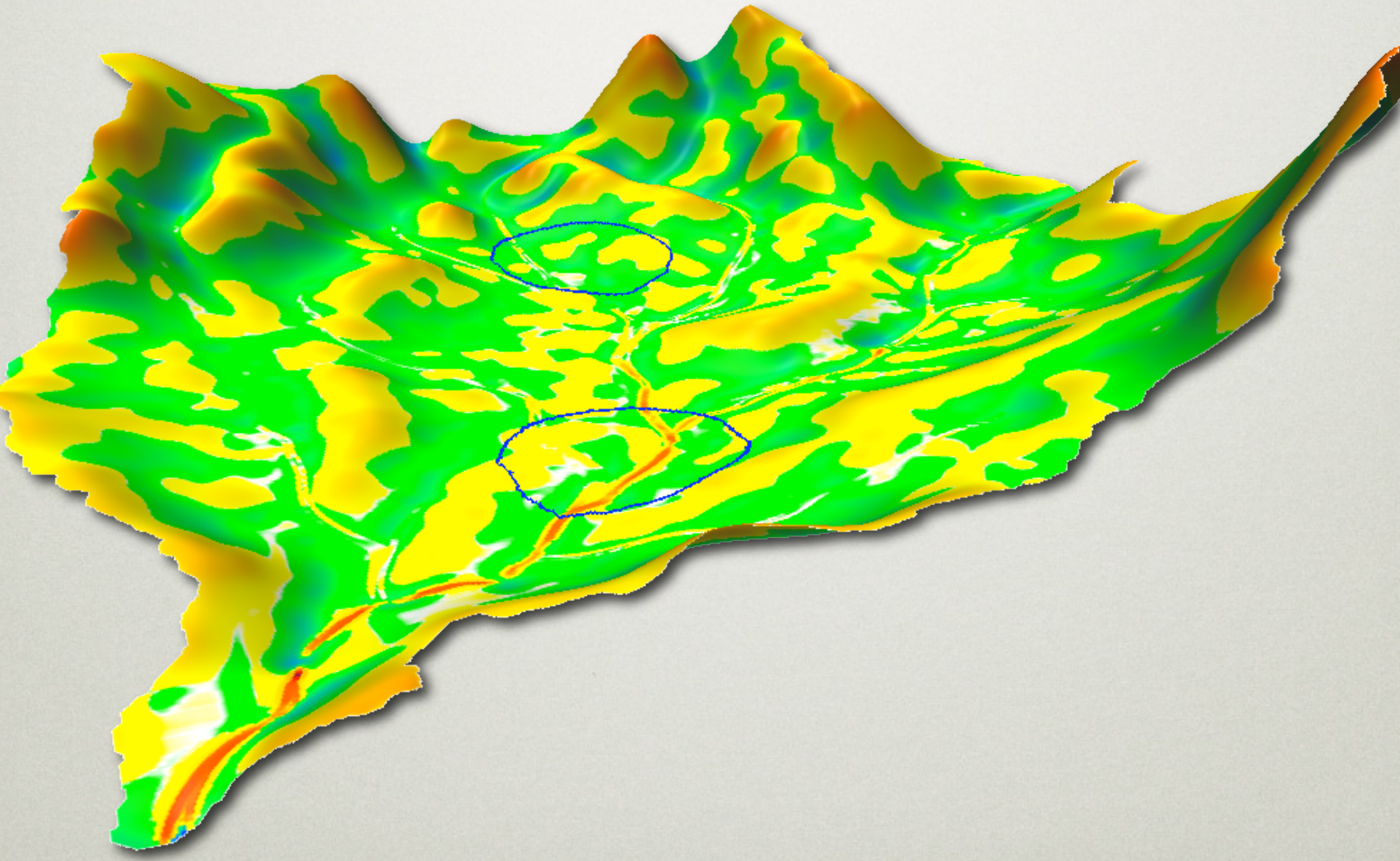
Modeling in GRASS



Modeling in GRASS



Modeling in GRASS

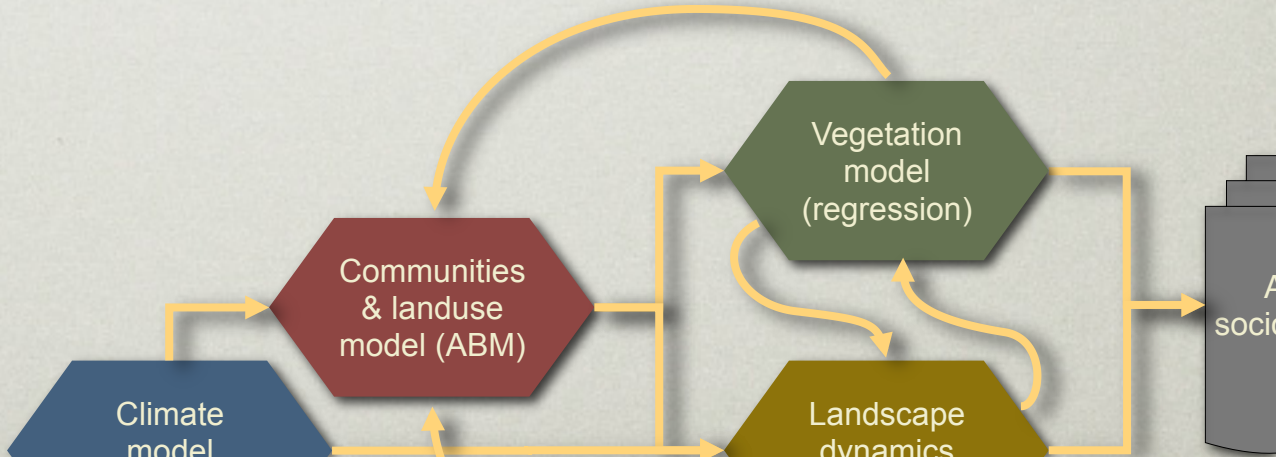


Laboratory

- 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

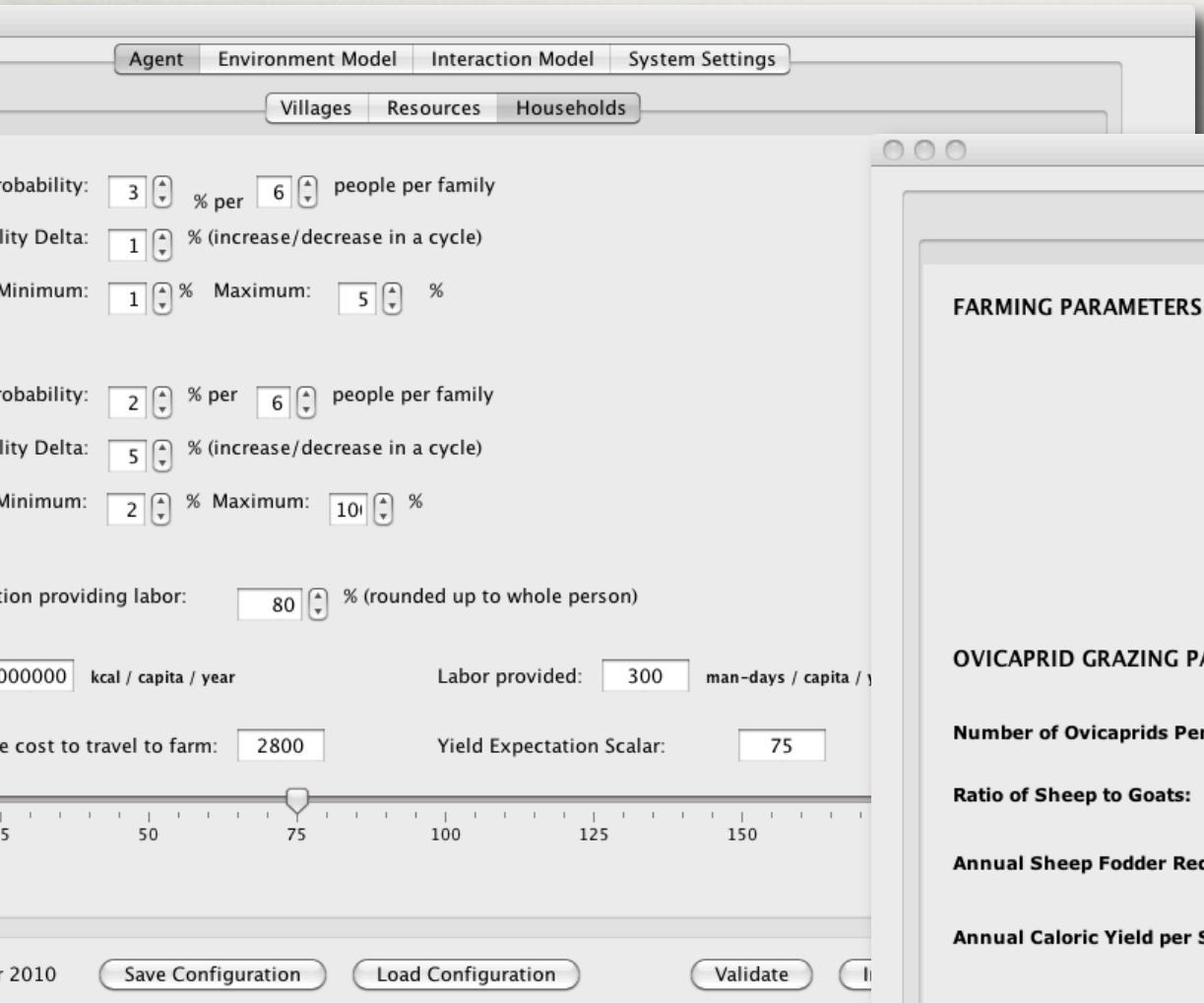
e (
acims.arizona.edu/
E/software.shtml)

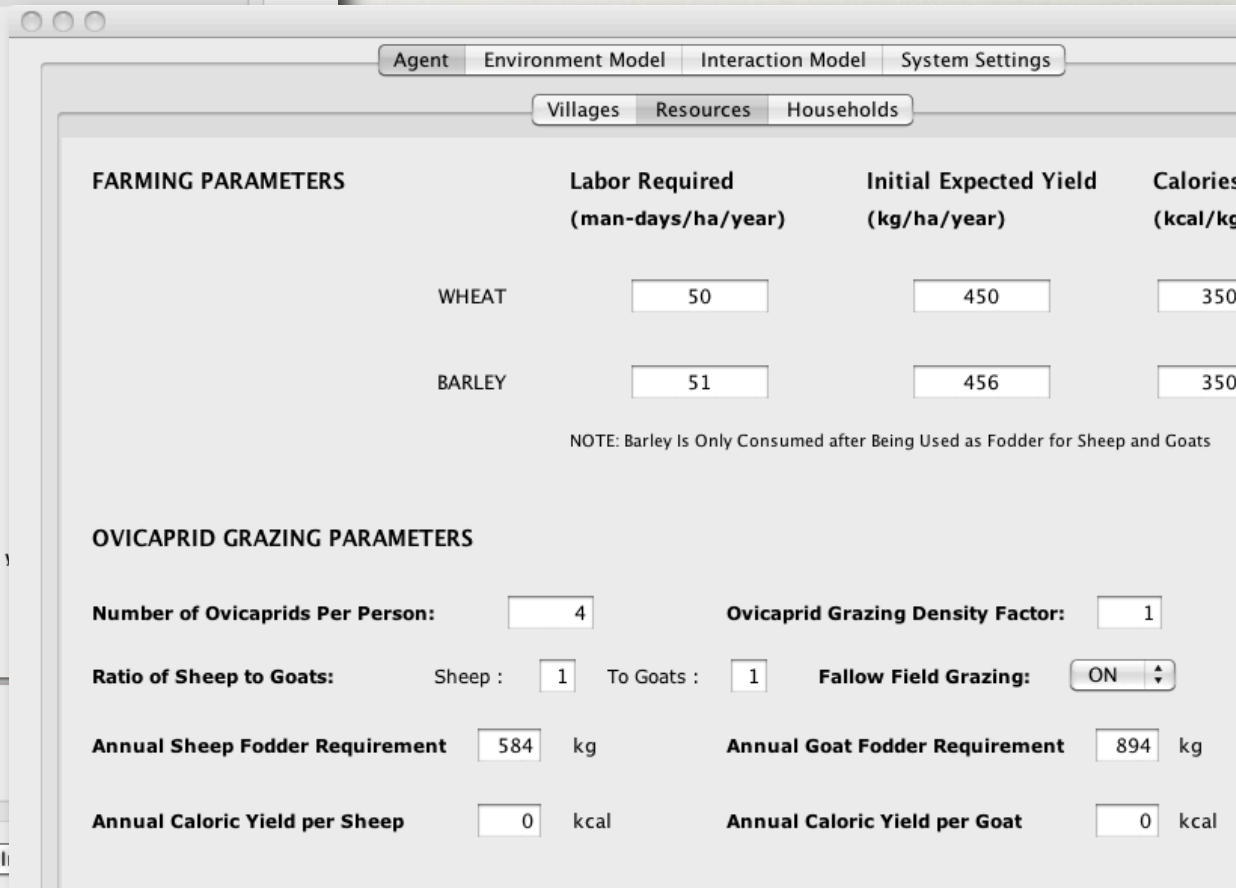
S (http://
o.org)



Laboratory

- Coupled modeling system controlled from Java ABM and interface



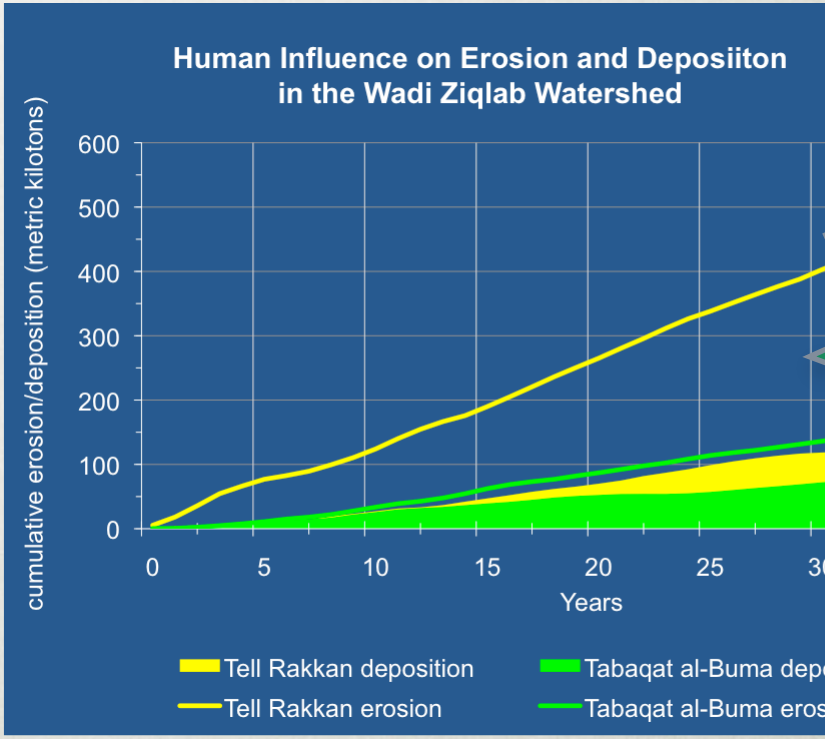


Laboratory

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

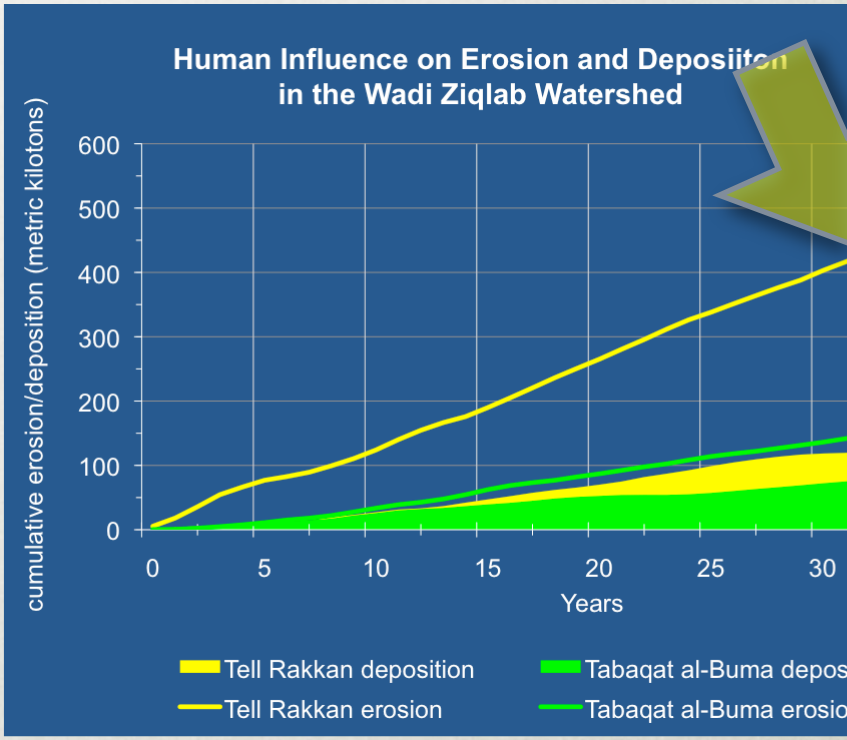
in Northern Jordan

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

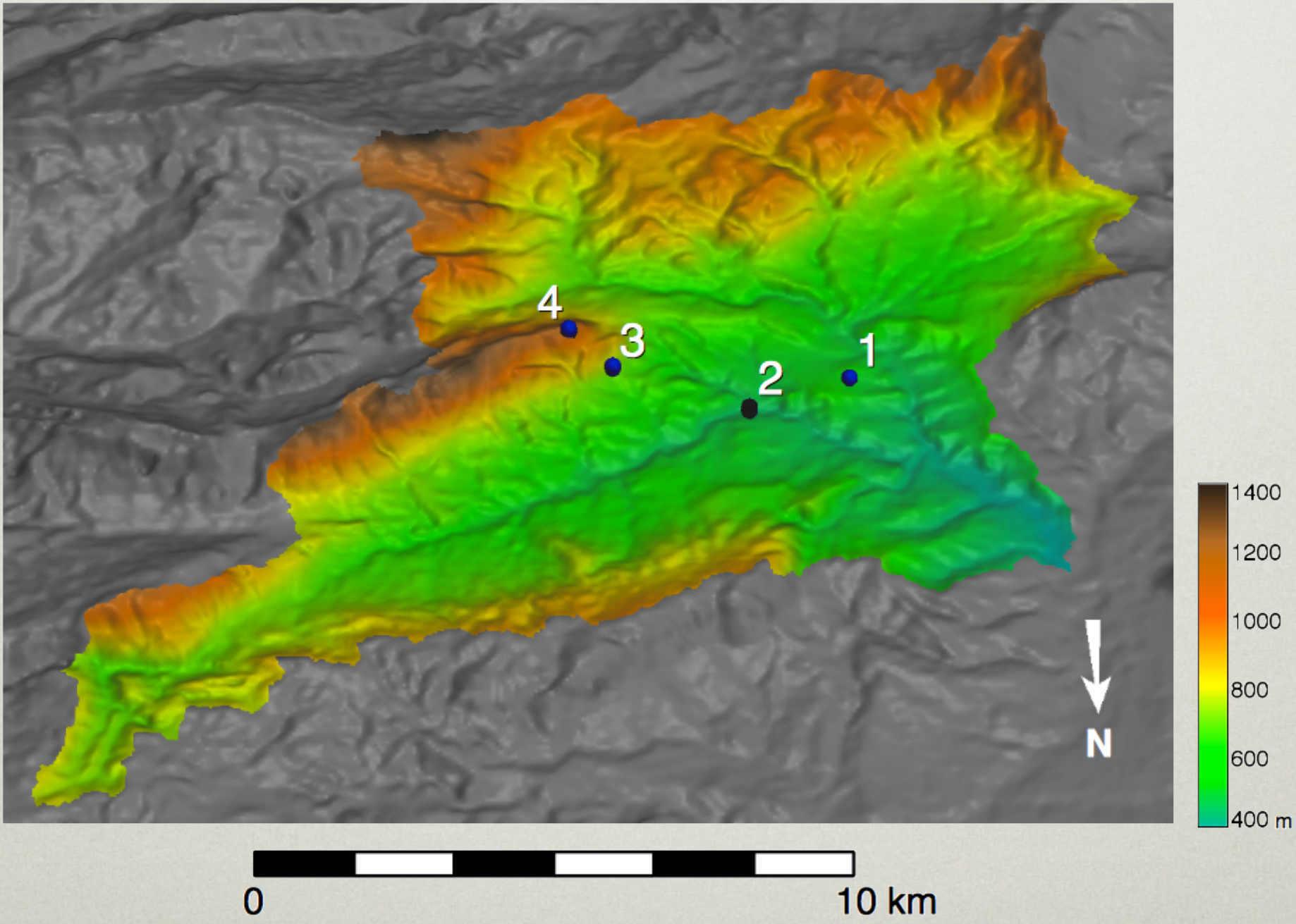


in Northern Jordan

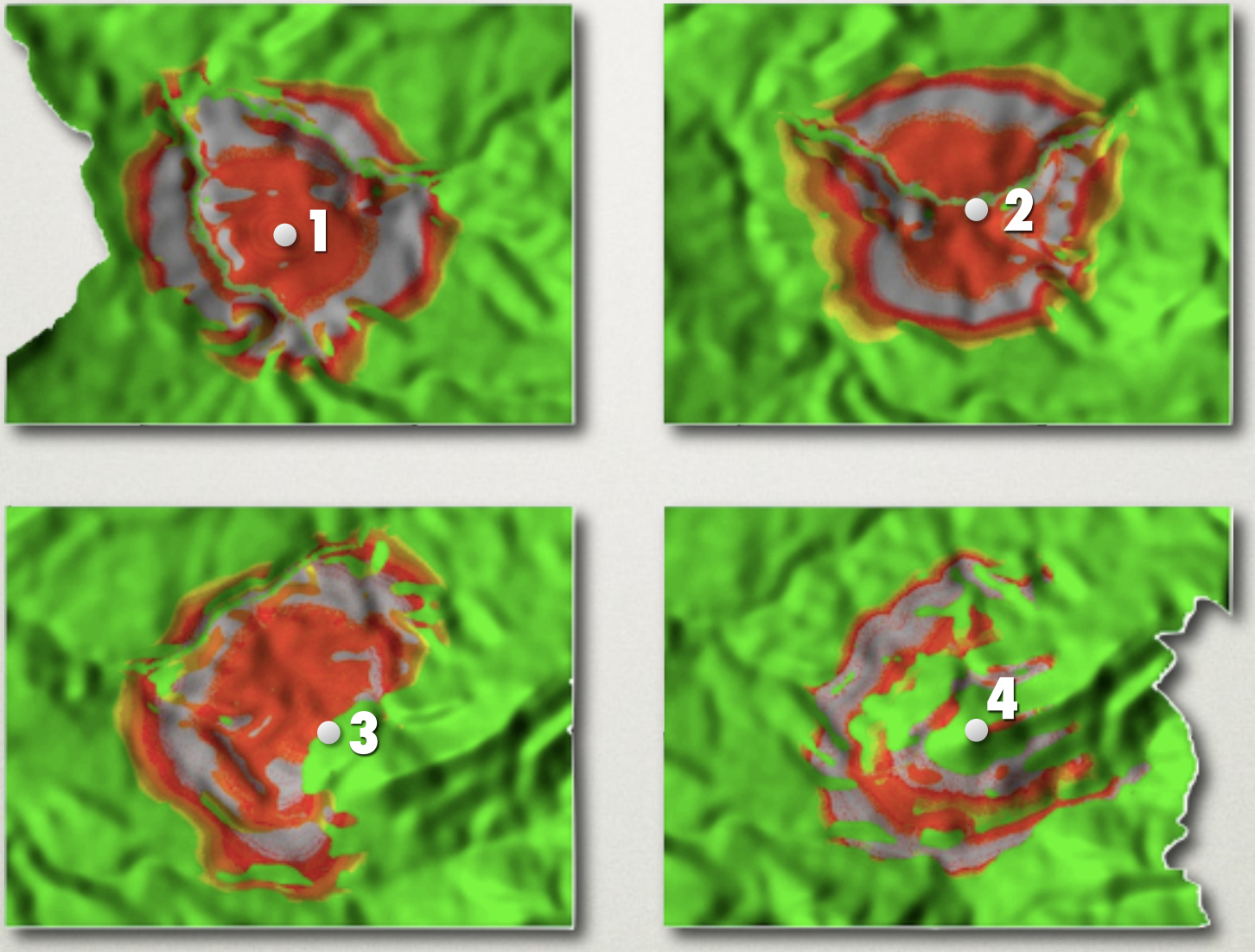
- Village
  - Cultivation in uplands; more extensive grazing
  - Cultivation causes most erosion
  - Erosion in cultivated and uncultivated zones
  - Redeposited sediment only 29% of erosion



Dynamics in Eastern Spain



Dynamics in Eastern Spain

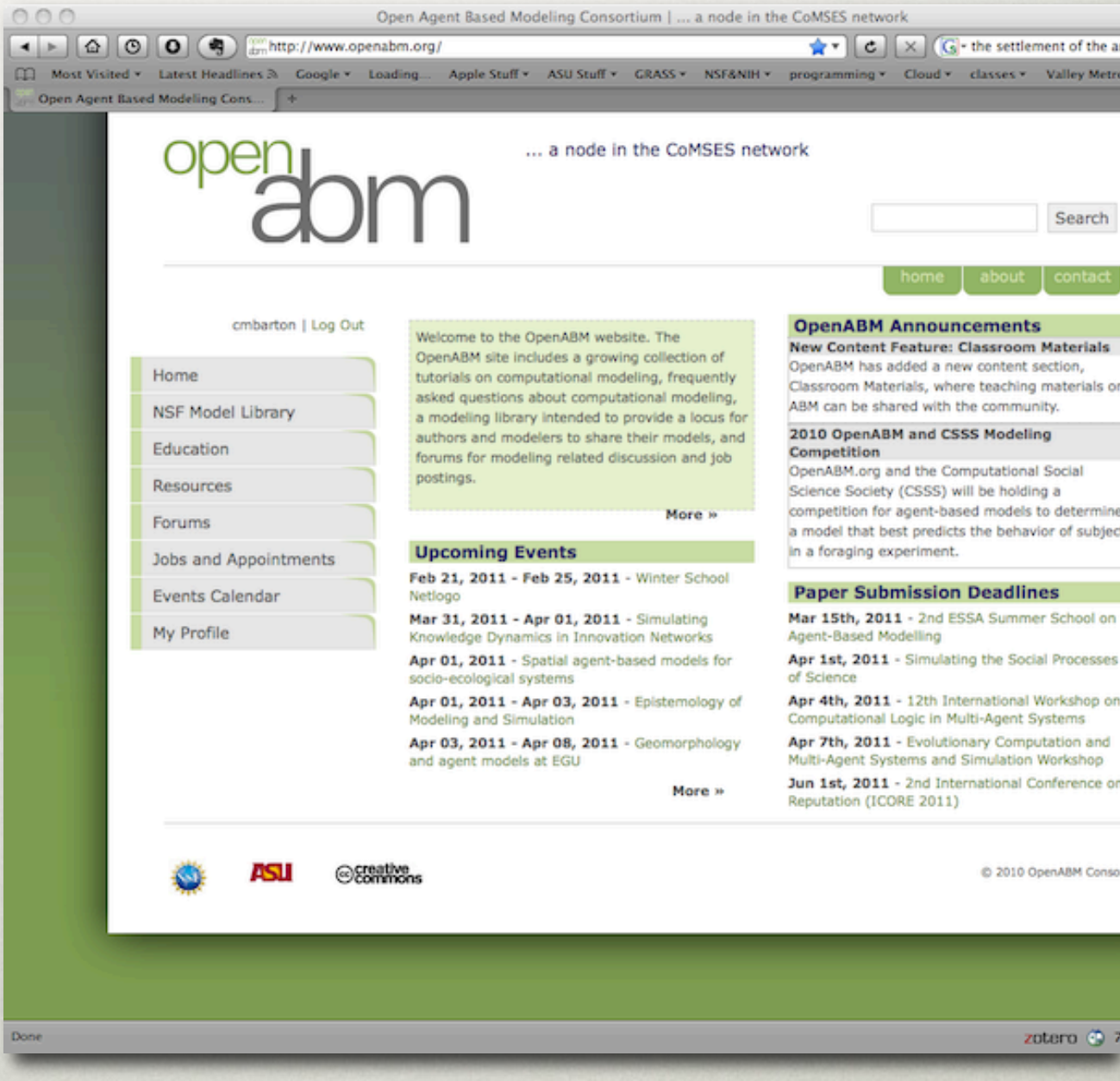


Relevant Publications

- 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 Soci 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 Modelin 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. Surfac 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.

CoMSES Network

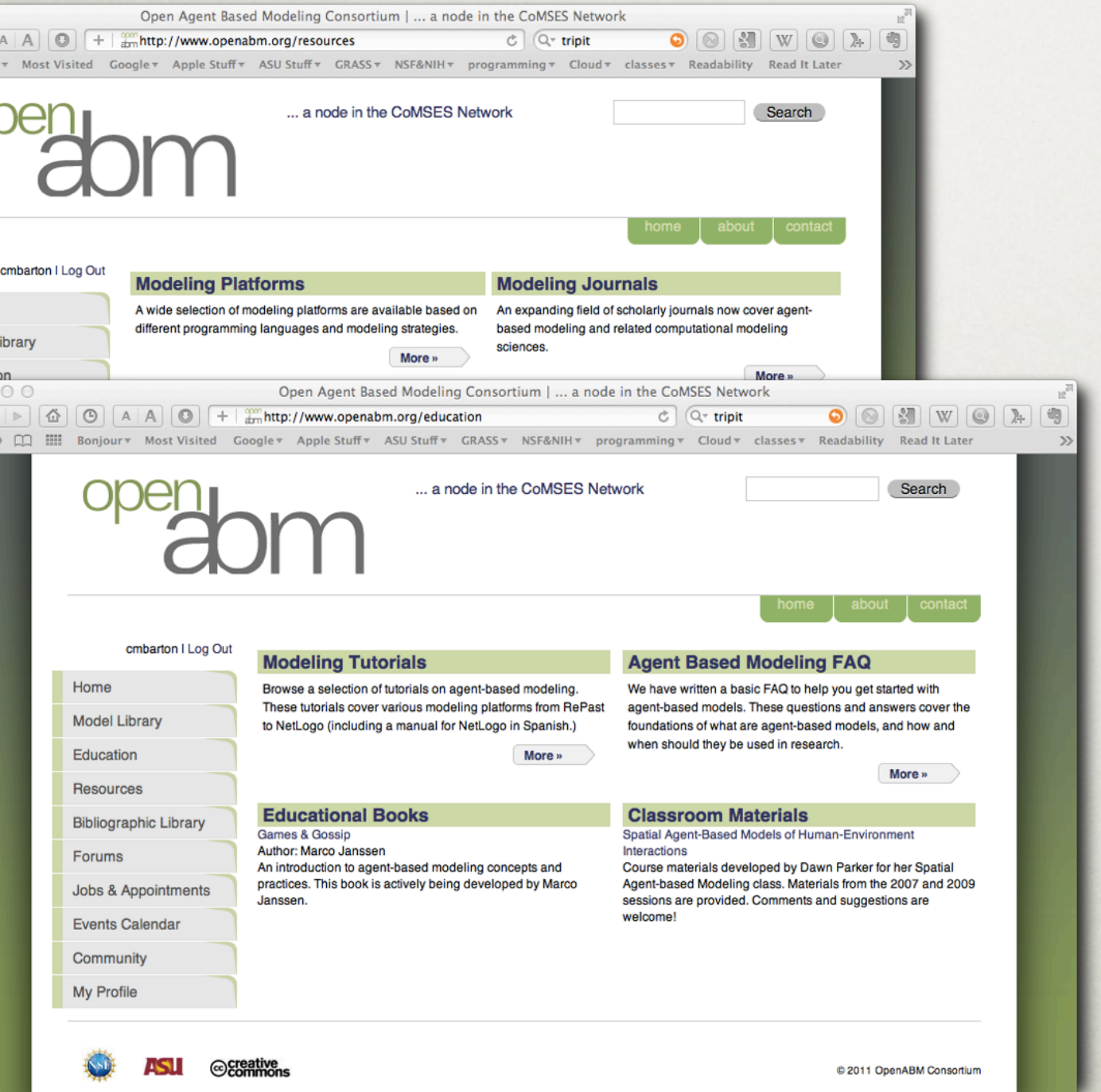
- A new community of practice
- Building capacity and promoting best practices for computational modeling



CoMSES Network

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

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

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- **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