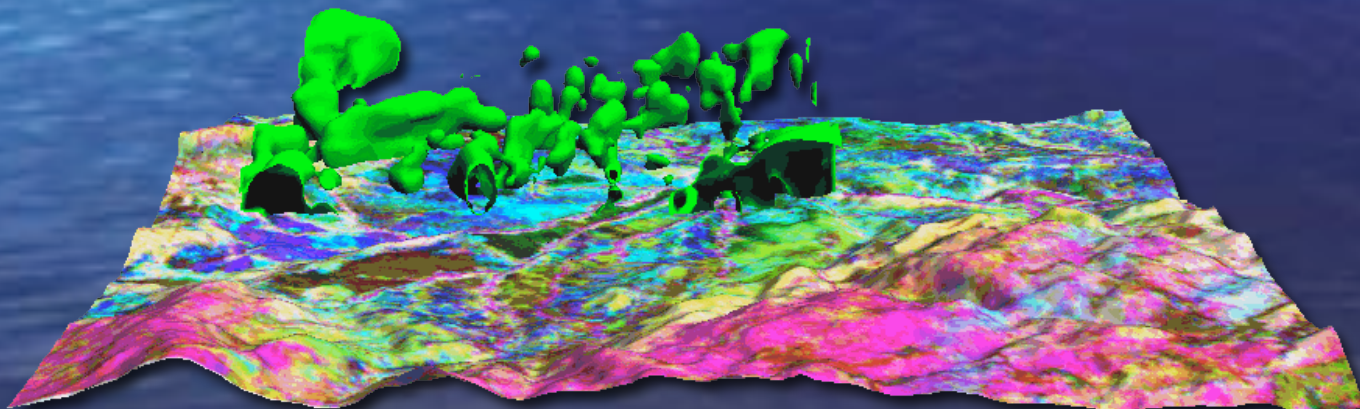


Integrating Spatial & Temporal Dynamics in Ecological Modeling: Issues & Directions

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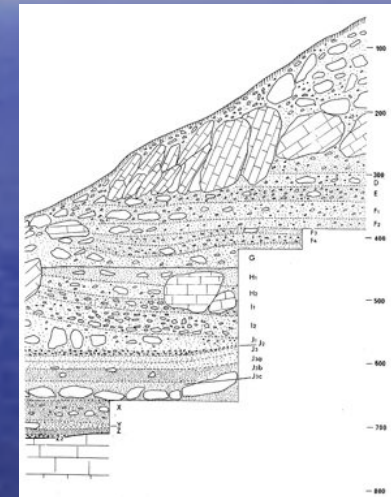


Ecosystems are dynamic

- Not just variation, but change across space and time
- Dynamic modeling, such as GARP, offers new ways to study human ecology
- Yet capturing the integrated dynamics of **both** space **and** time remains elusive

Archaeology & paleoecology

- Focus on long-term change
- Also on human-environmental interaction

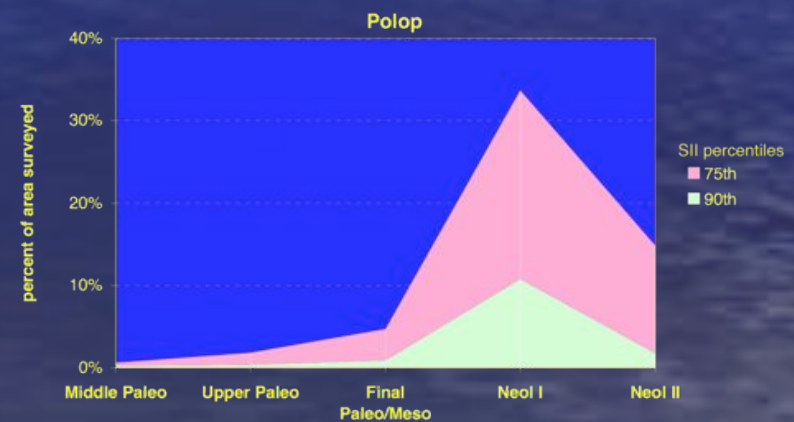
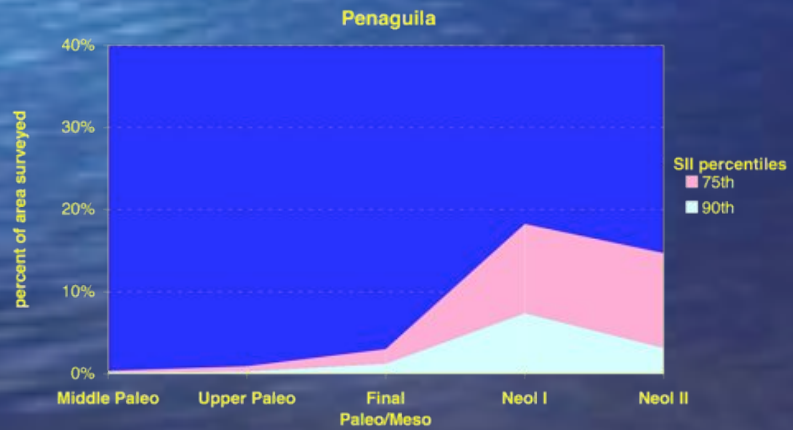
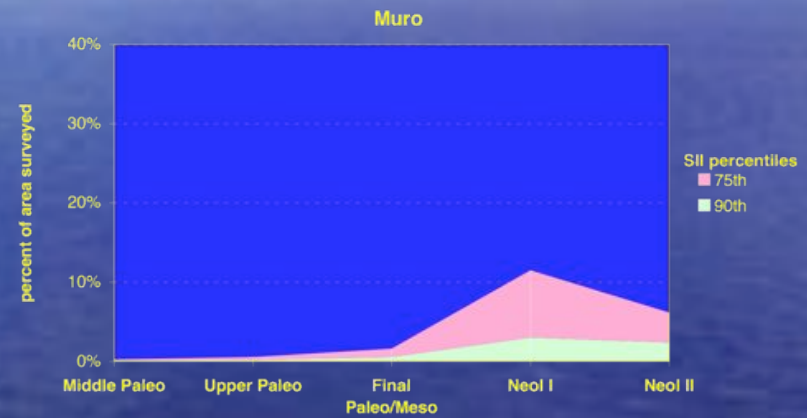
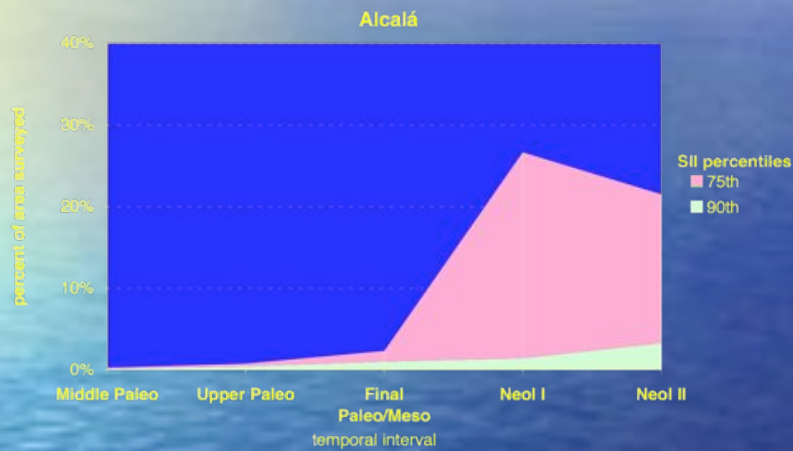


- How to integrate these in research protocols?

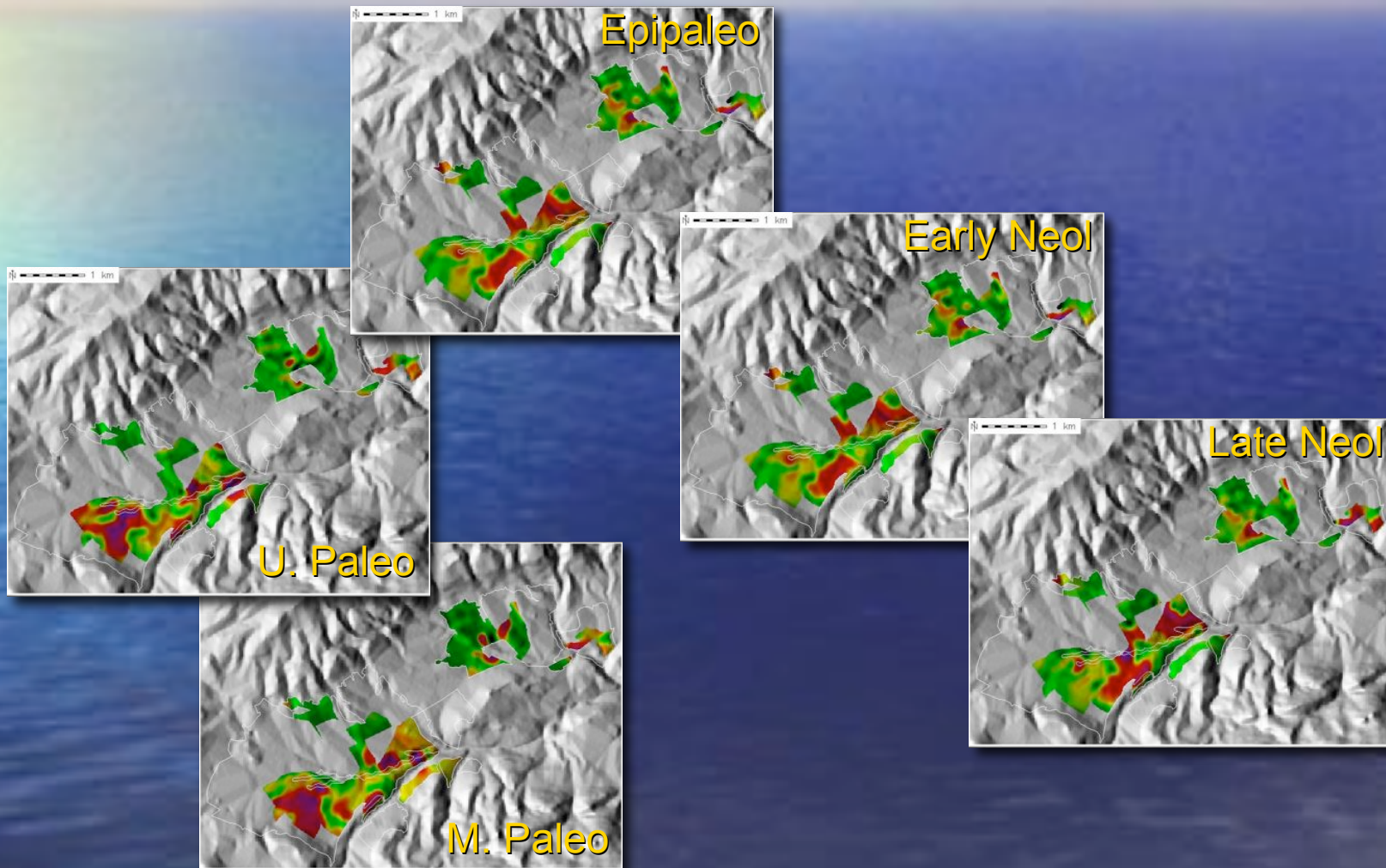
Space-time modeling: issues for current methods

- Look at change over time at several localities
- Look at change across space for several moments in time

Space-time modeling: issues for current methods



Space-time modeling: issues for current methods



Space-time modeling: issues for current methods

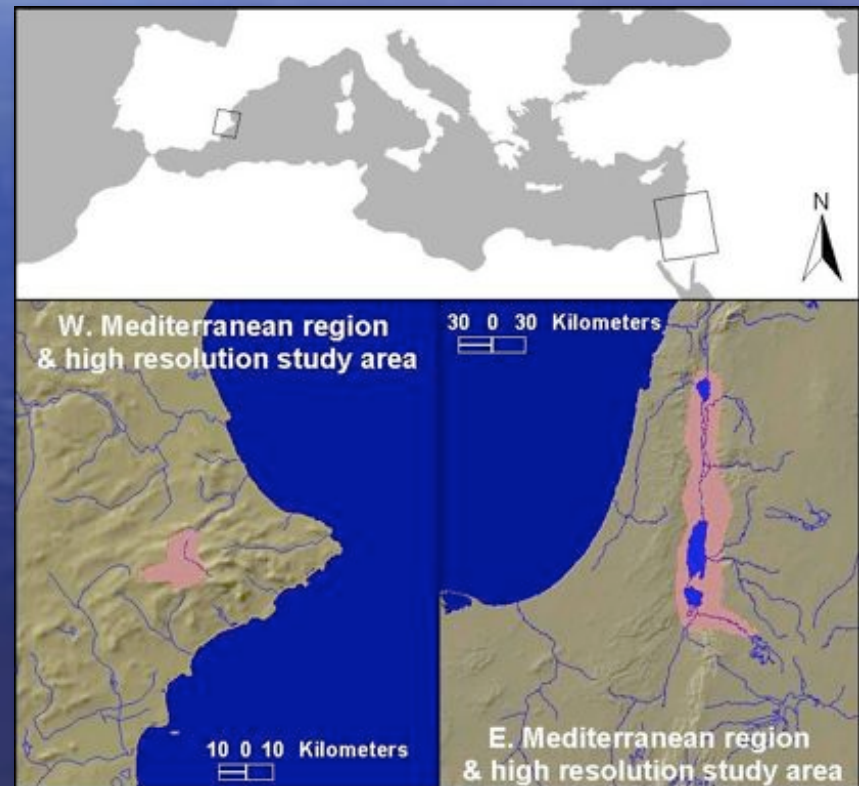
- High resolution diachronic record in one or a few sites → *unwarranted regional generalization across variable space*
- High resolution spatial record for a few time periods → *past as a sequence of snapshots with change happening invisibly between (or stepwise change)*
- Conceptualizing rich socioecological variation across space and complex dynamics through time desirable but difficult with current methods

Future directions in space-time modeling

- Goals for study of long-term dynamics of human ecology
- High resolution models
 - spatial
 - chronological
- Link dynamically so that
 - state of modeled ecosystem at any given time (t) is in part a function of ecosystem at prior time ($t-1$) and affects future state ($t+1$)
 - State of modeled ecosystem at any given locale is in part a function of state in surrounding locales
- Test against archaeo-ecological record

Future directions in space-time modeling: an example

- **Mediterranean Landscape Dynamics Project**
- Project locations at opposite ends of Mediterranean Basin
 - Encompasses wide range of ecological & social variation
 - Tracks initial spread of agriculture & replacement of foraging systems
 - Different trajectories to the appearance of social complexity and urbanism

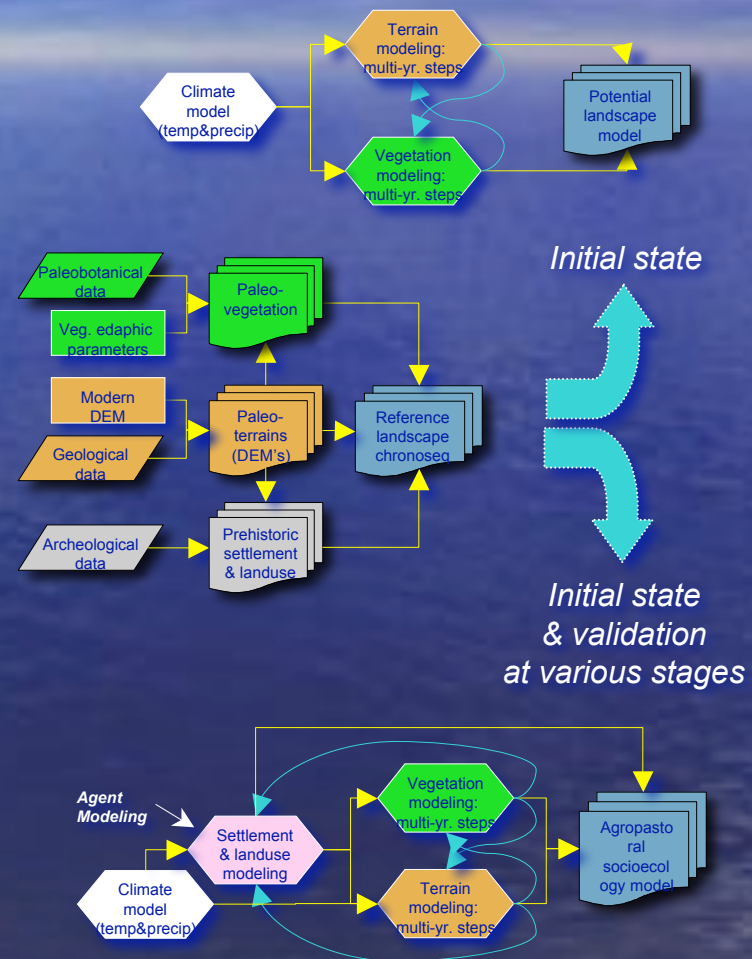


Mediterranean Landscape Dynamics Project

- Agent-based simulation of human landuse: beginning of farming to beginning of urbanism
- Surface process models of ancient landscapes and landcover
- Synoptic climate models
- All linked within a GIS framework so that change in one module can affect state variables that serve as input to another
- Test and refine against rich archaeological and paleoecological record

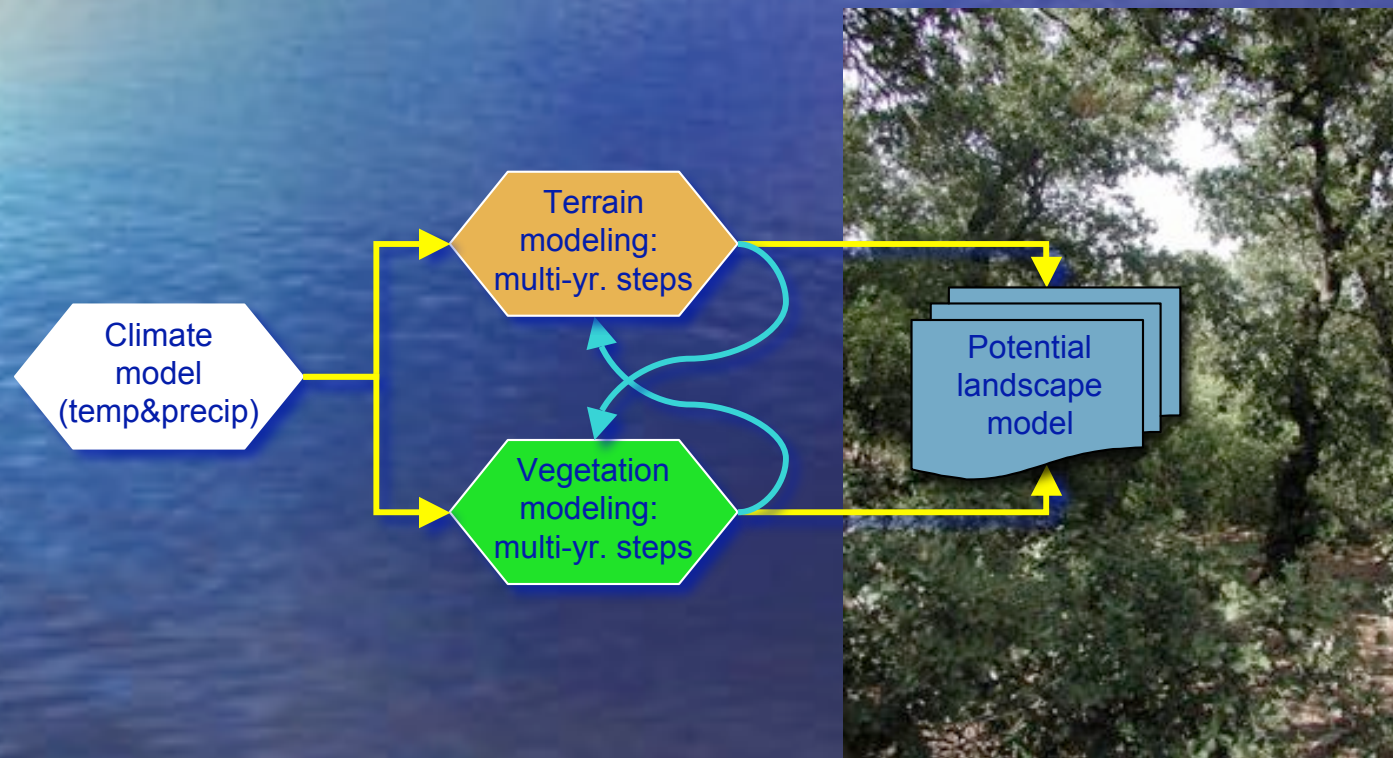
Dynamic space-time modeling

- 3 interlinked modeling environments in GIS platform
 - Potential landscape model
 - Reference landscape chronosequence
 - Agropastoral socioecology model



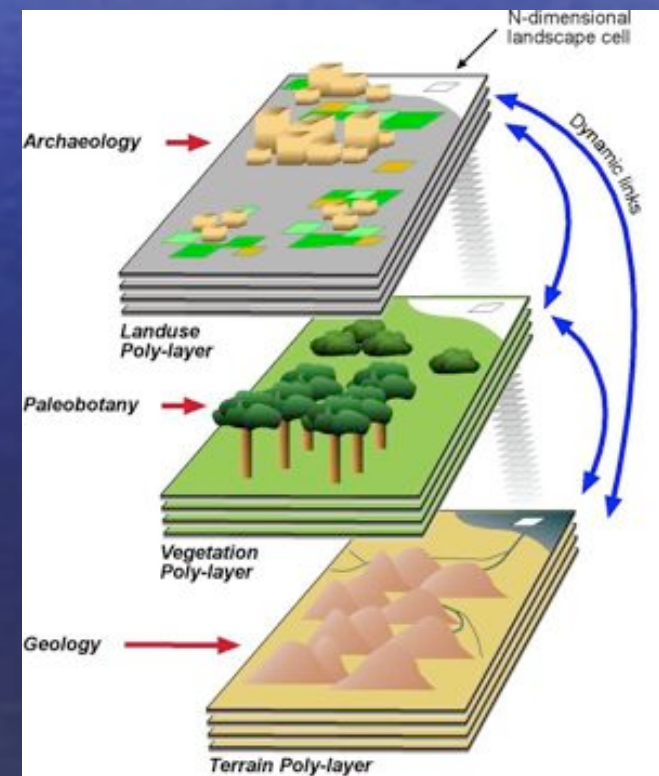
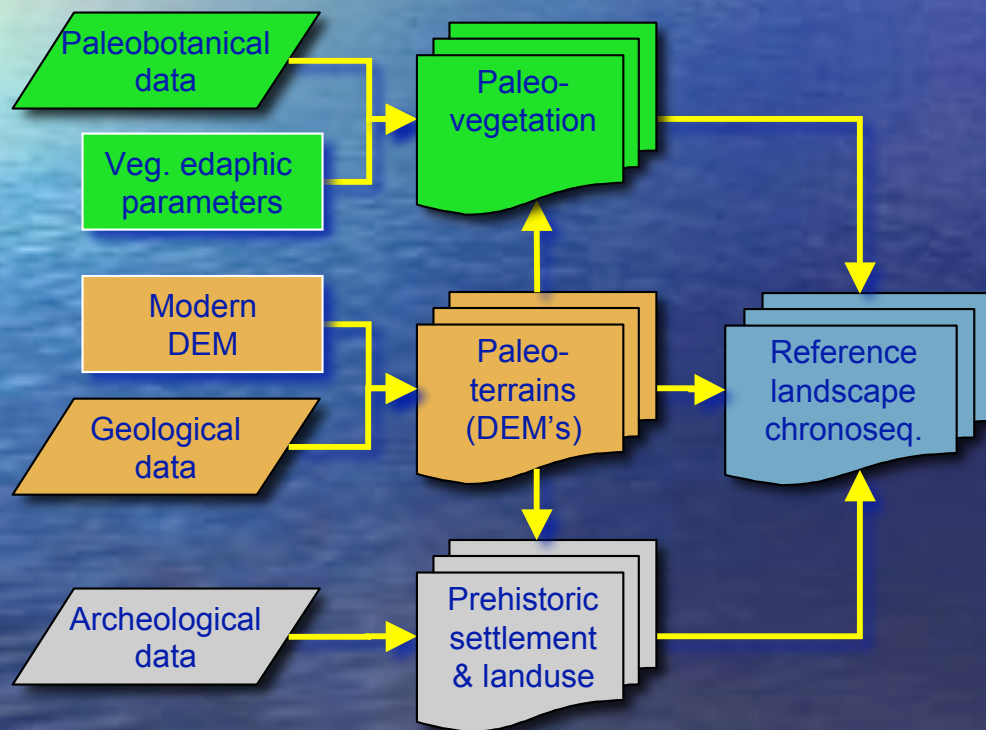
Dynamic space-time modeling

- Potential landscape model: surface processes and landcover



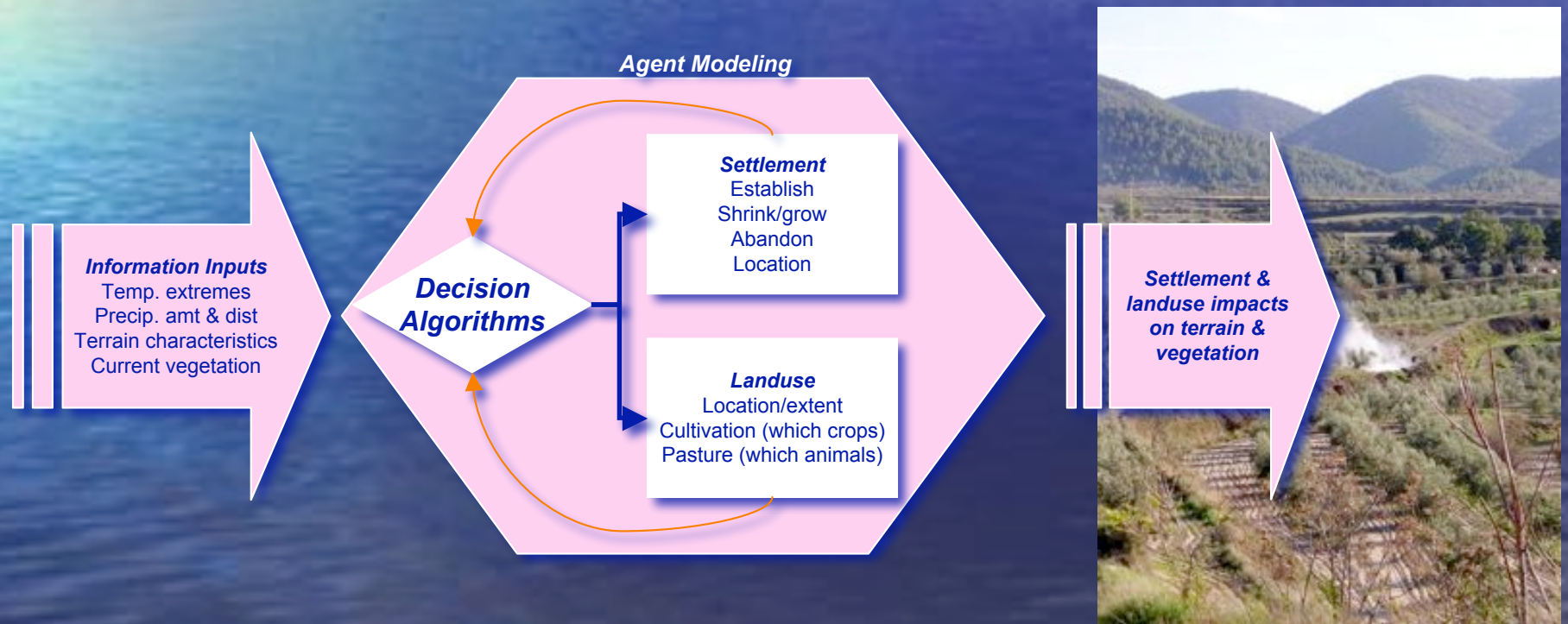
Dynamic space-time modeling

- Reference landscape chronosequence: surface processes and landcover



Dynamic space-time modeling

- Human landuse: agent simulation



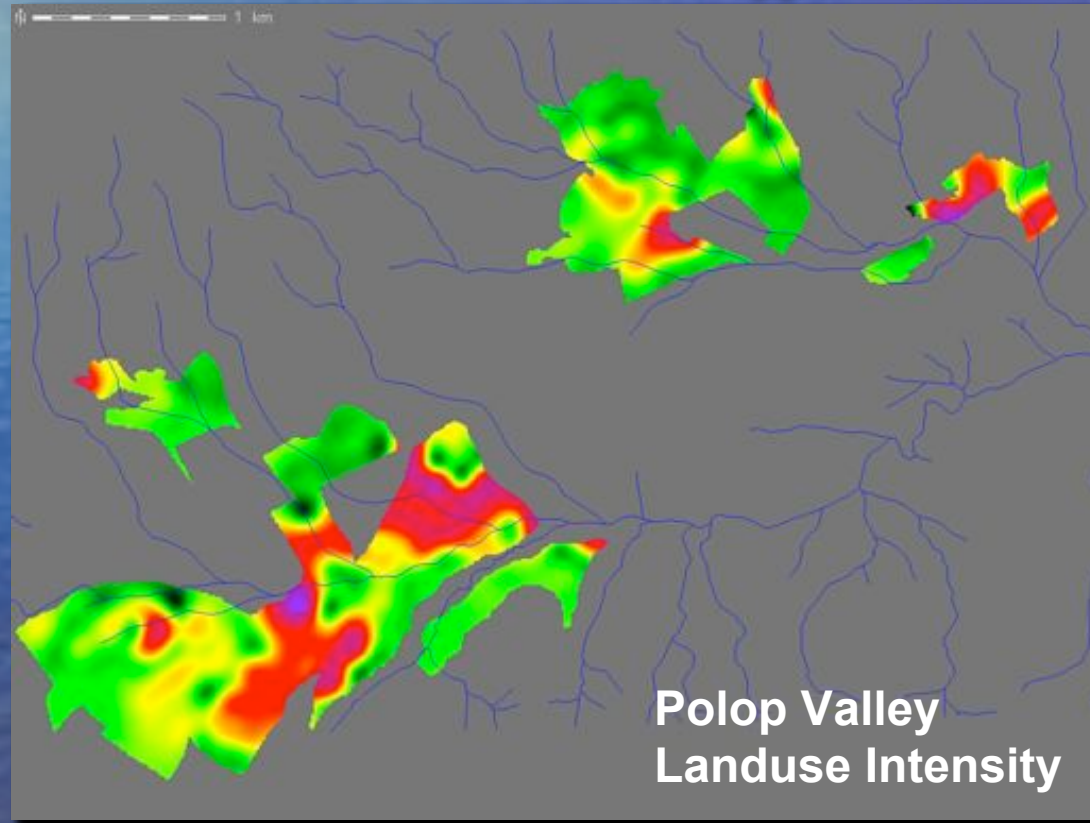
Visualization & analyzing space-time dynamics

- As we begin to approach the goal of integrating space and time in ecological modeling, *how can we visualize and analyze results?*
- How can we represent n-dimensional data in 2 dimensional media?
- How can we compare and evaluate results quantitatively?

Visualizing ecological dynamics

- Animation

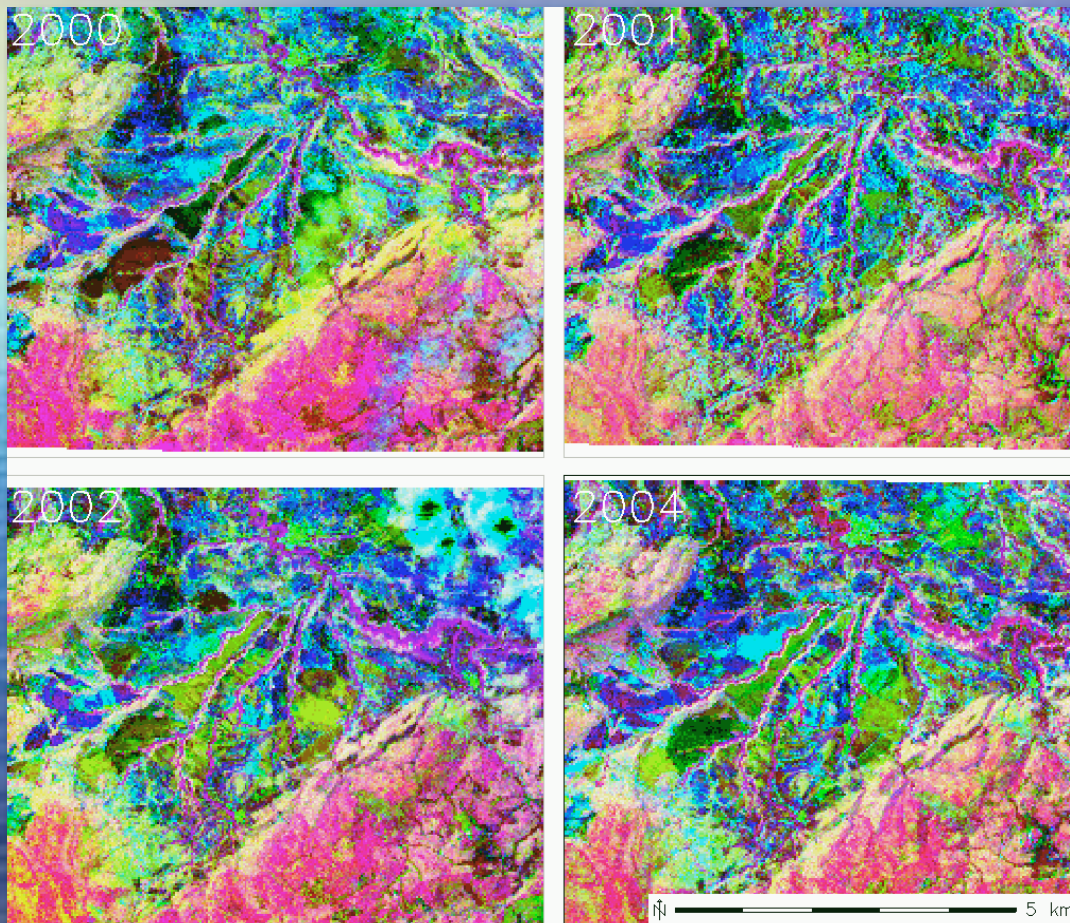
Late Upper Neolithic



Visualizing ecological dynamics

- Animation
 - Looks dynamic
 - Realistically portrays change through time
 - *Difficult to evaluate change, similarities, and differences—visually or quantitatively*
- Alternative methods of visualization and analysis to complement animation

Visualizing ecological dynamics

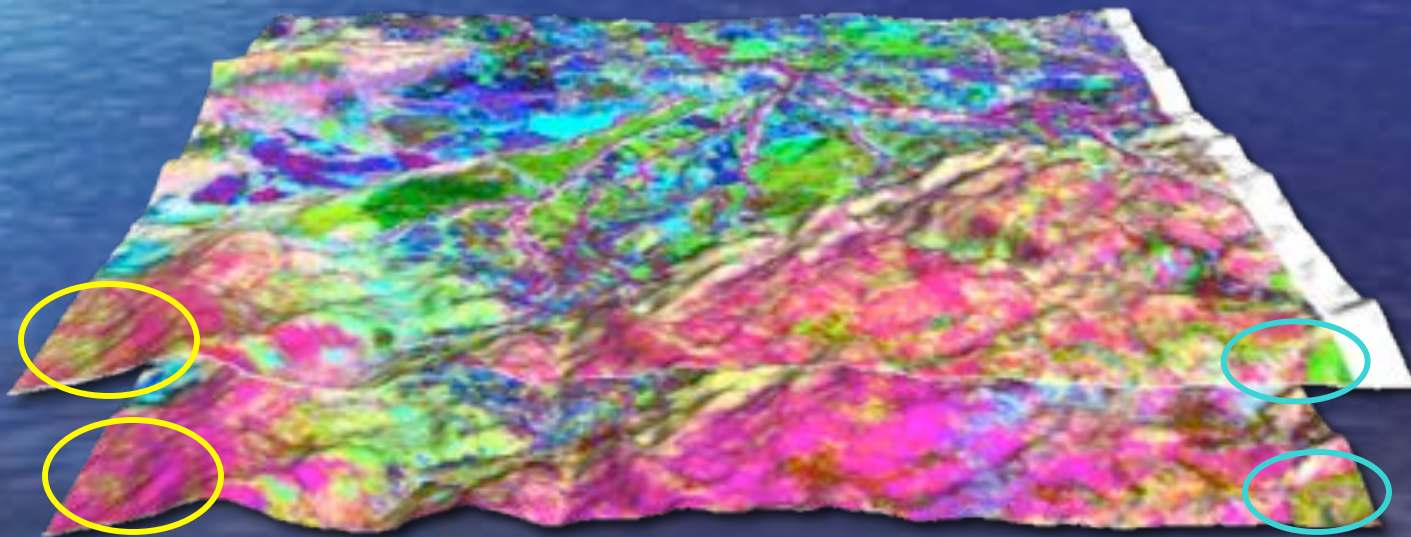


- Example from the Penaguila Valley, Spain
- Terra ASTER imagery for 2000-2004
 - Decorrelation stretch of bands 1-3
 - Landcover change
- Analysis with GRASS GIS



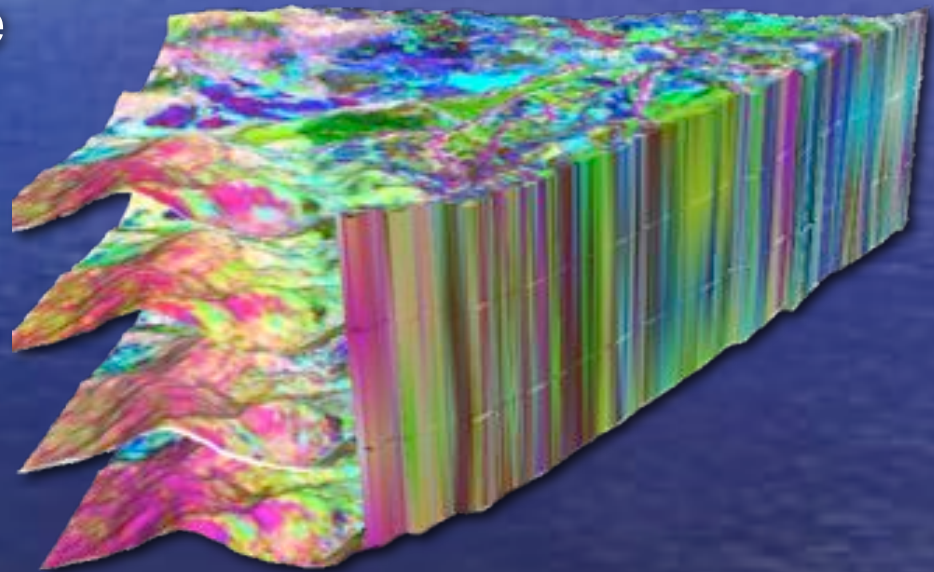
Visualizing ecological dynamics

- Stacked surfaces/landscapes
 - Can evaluate change better than with animation
 - Good for major changes
 - *Visual alignment (cell to cell) difficult for detailed evaluation*
 - *Problematic with high temporal resolution--i.e., many stacked landscapes*



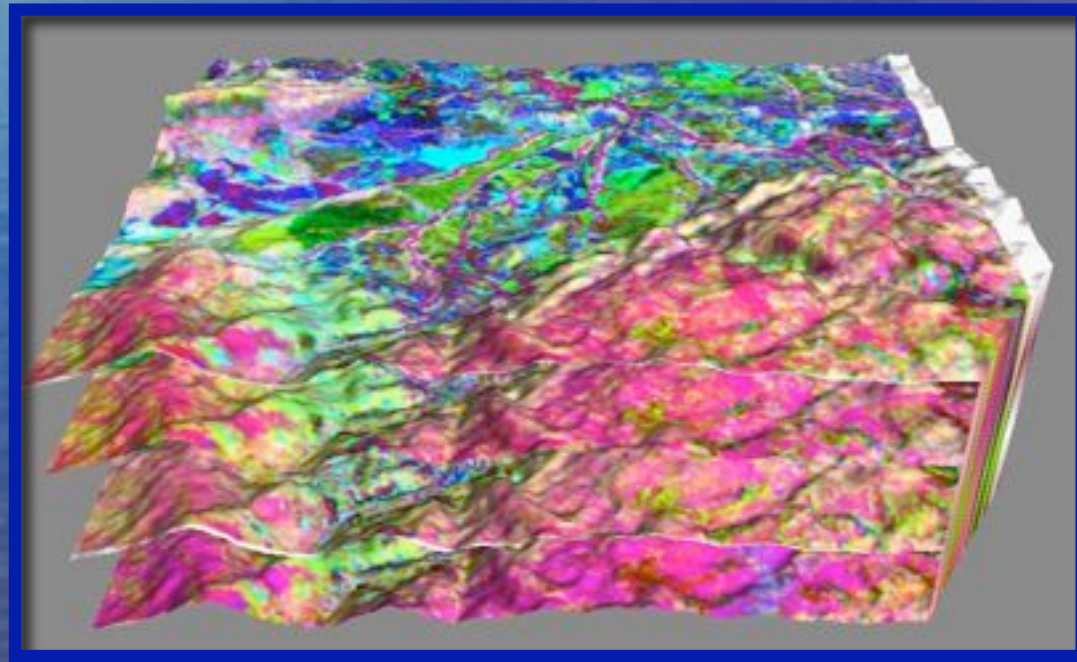
Visualizing ecological dynamics

- Stacked surfaces with a cutting plane. Color blends from each surface into next
 - Solves alignment problem
 - Allows detailed visualization of change across multiple time intervals
 - *Can only show a space-time transect (i.e., one dimensional space)*



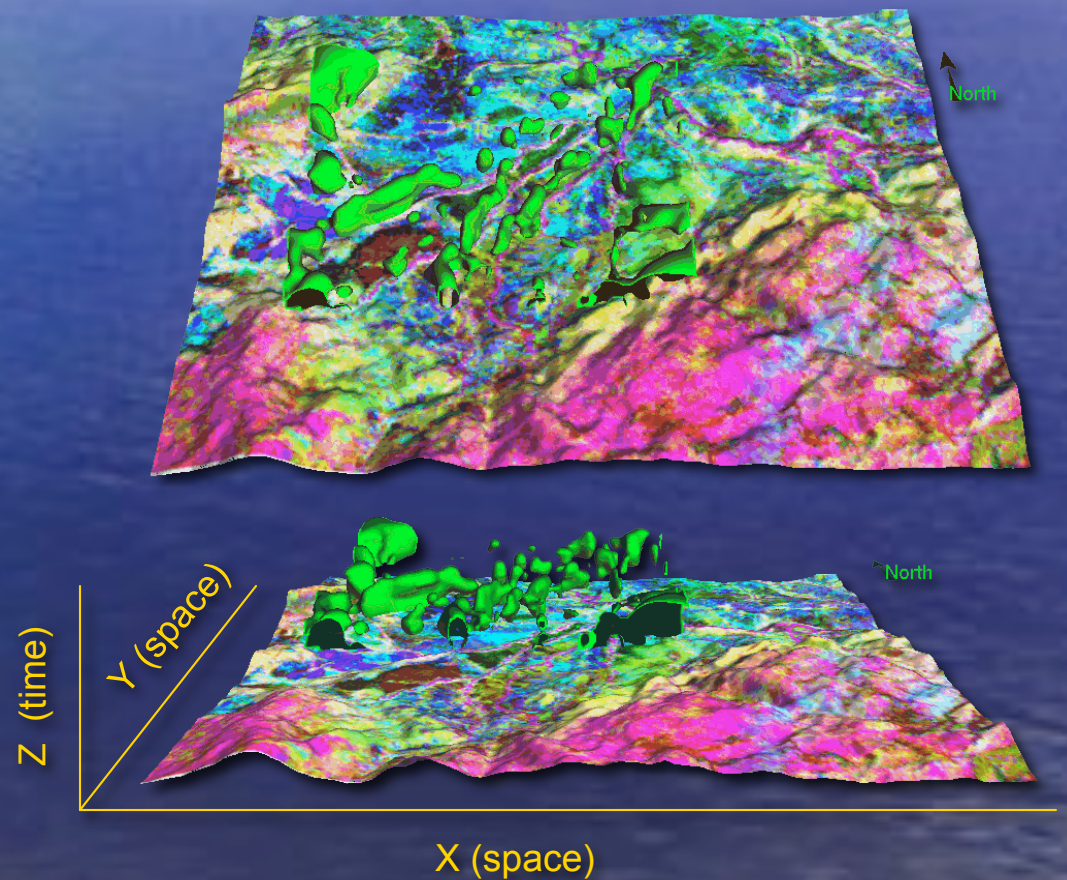
Visualizing ecological dynamics

- Stacked surfaces with movable cutting plane
- Permits interactive viewing of multiple transects



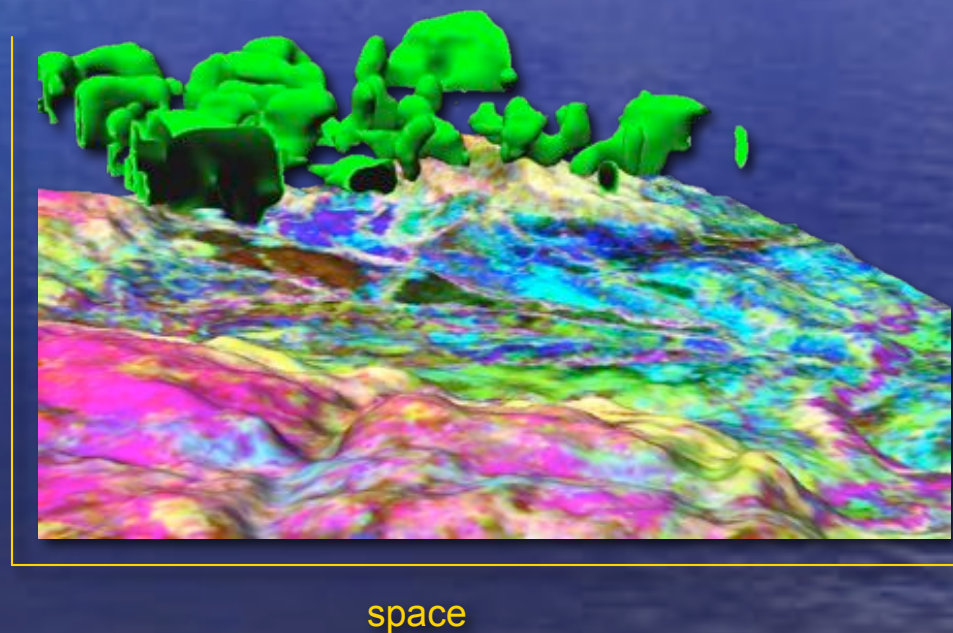
Visualizing ecological dynamics

- Space-time volumes (STVs)
- Produced through 3D interpolation
- 4D shapes that simultaneously show...
 - 2D space (x,y)
 - Time (z)
 - Socioecological variable (w)



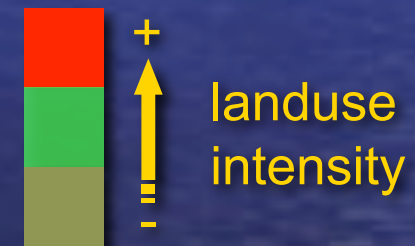
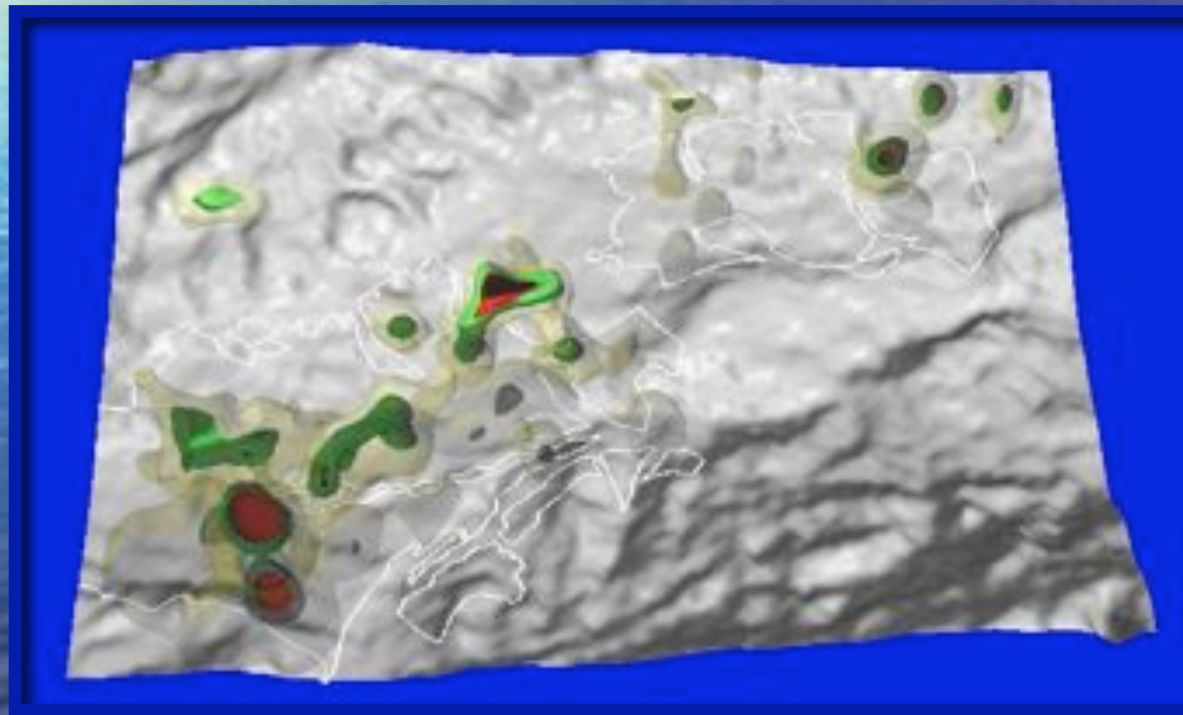
Visualizing ecological dynamics

- STVs showing dynamics in component 1 of PCA (Terra ASTER vnir bands 1-3)
- Values ≥ 200
- Proxy for *barranco* vegetation, mostly pine



Visualizing socioecological dynamics

- STVs for landuse change in the Polop Alto Valley, Spain: M. Paleolithic - Late Neolithic

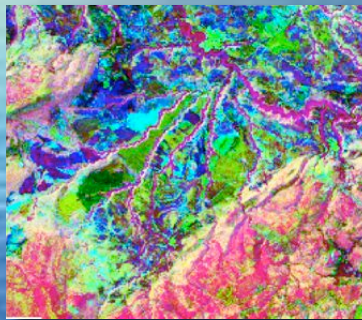


Analysis of spatial-temporal dynamics

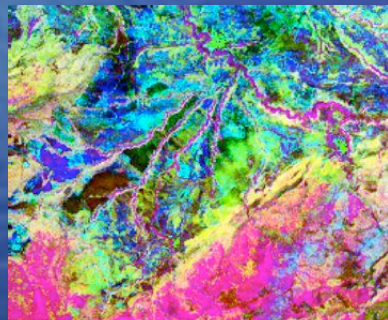
- Robust suite of methods exist for time series analysis and spatial patterns
- Comparative lack of quantitative protocols for characterizing and evaluating dynamics across space and time together
- Brief survey of potential directions

Analysis of spatial-temporal dynamics

- Basic change analysis. Normally for surface pairs

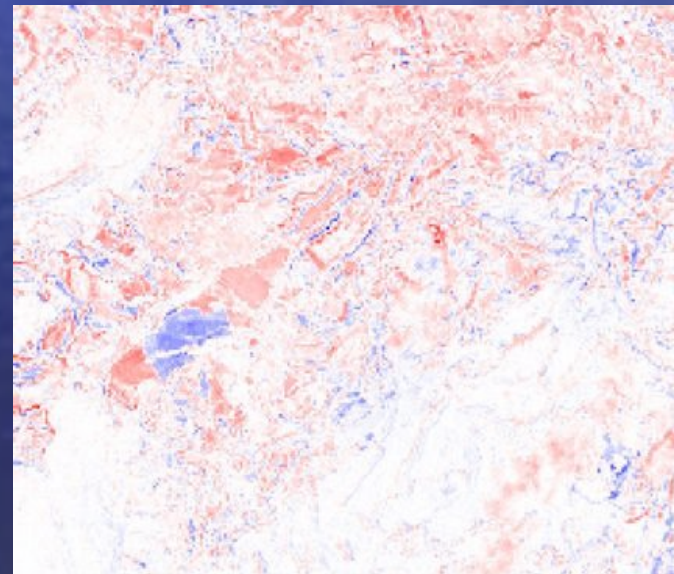


2004



2000

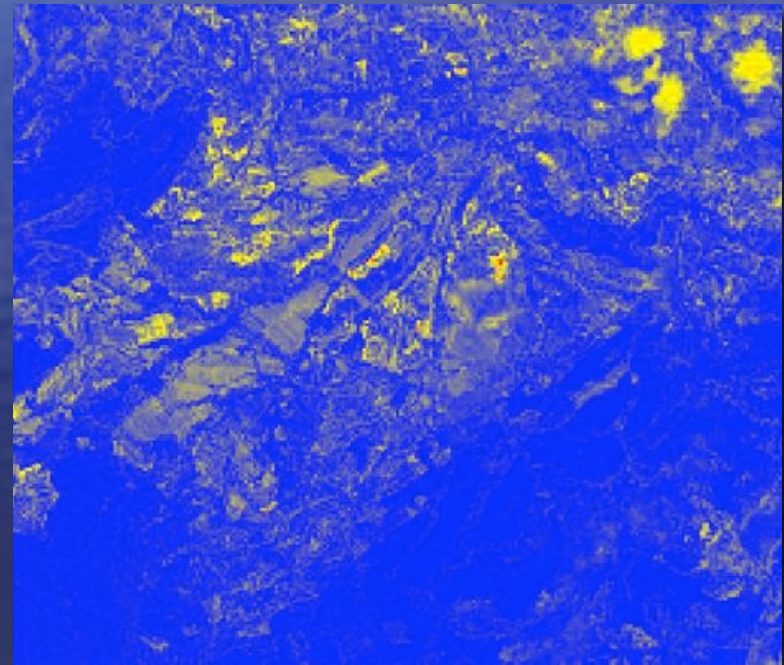
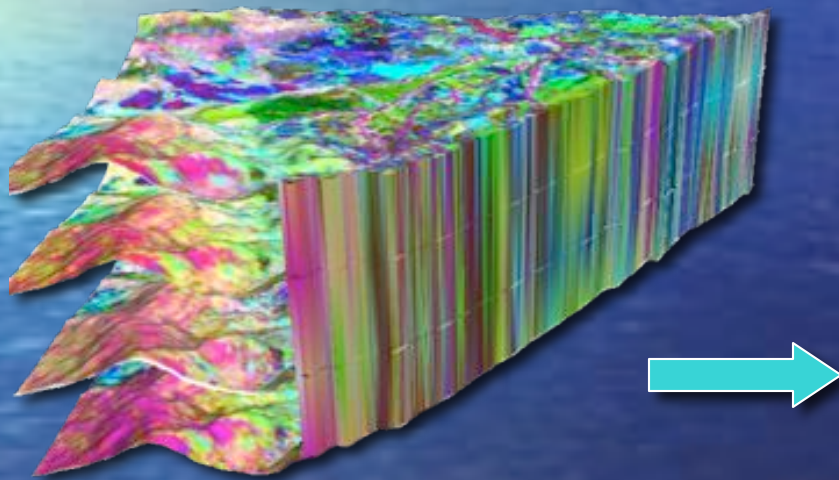
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red=positive, blue=negative

Analysis of spatial-temporal dynamics

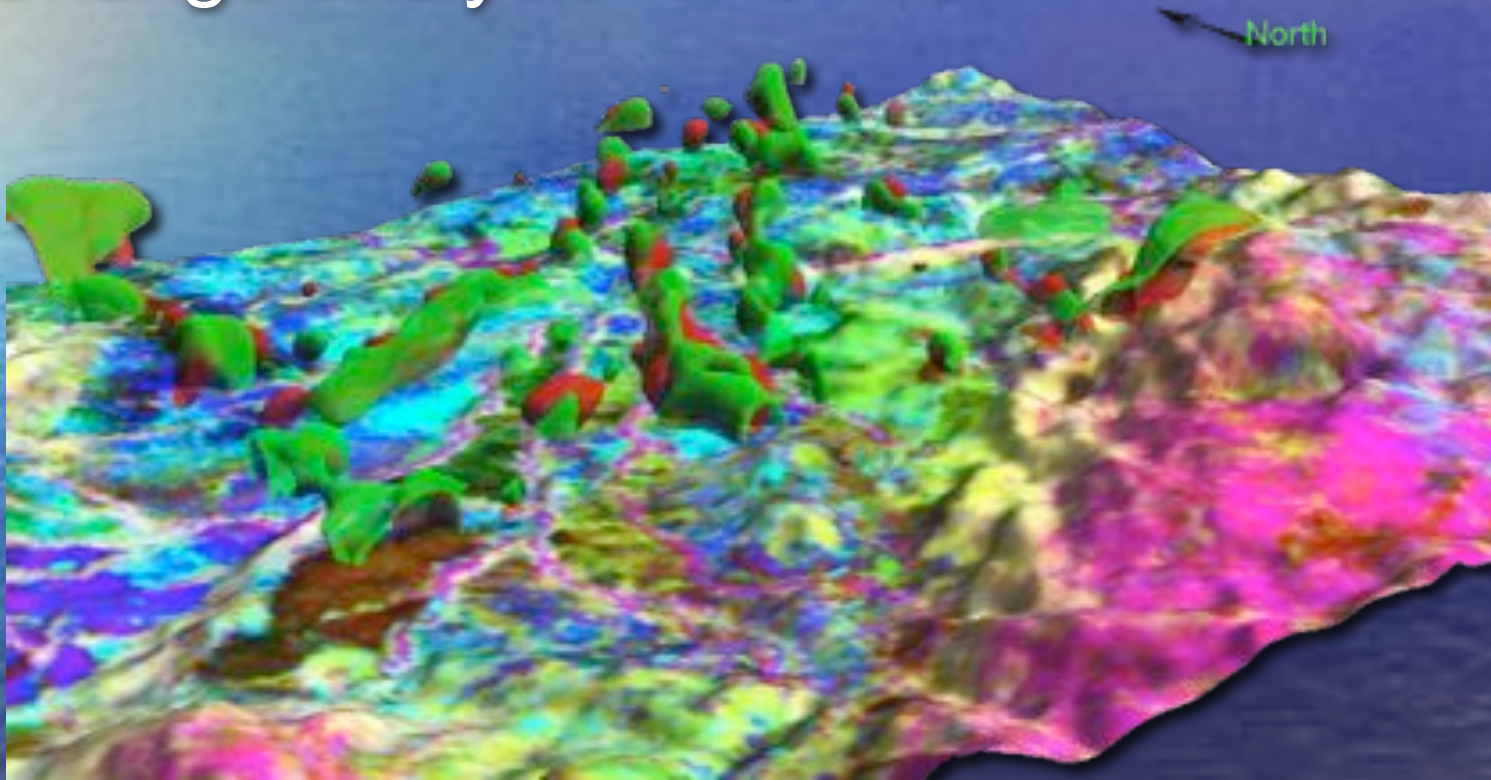
- Time series analysis for landscapes



Coefficient of variation (2000-2004). Terra
ASTER PCA component 1. Red=high, blue=low

Analysis of spatial-temporal dynamics

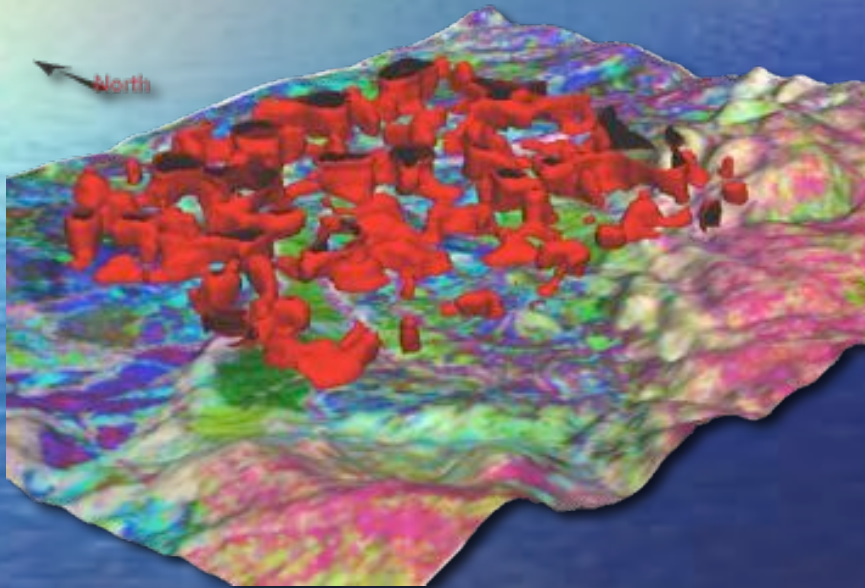
- Change analysis for STVs



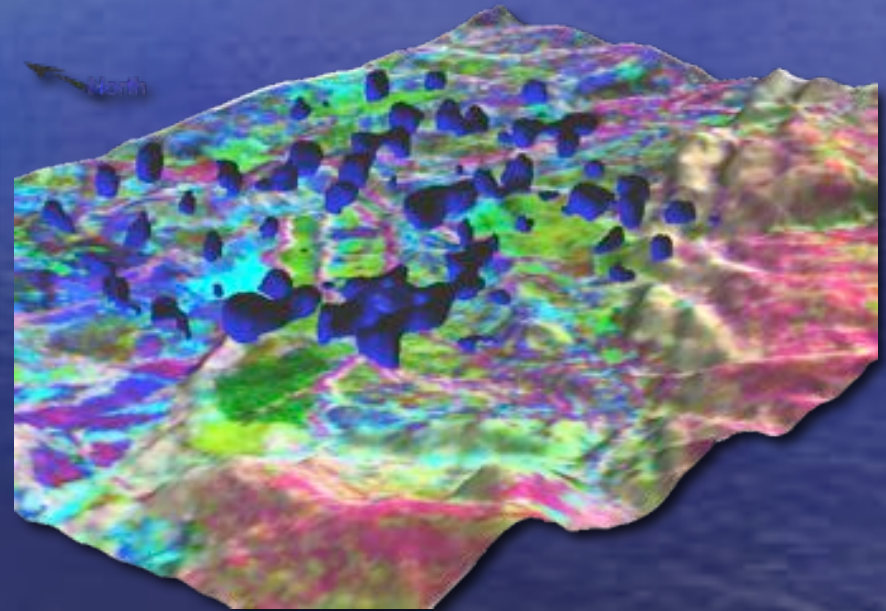
red=2000-2001, green=2002-2004

Analysis of spatial-temporal dynamics

- Change analysis for STVs (STV[2002-2004]-STV[2000-2001])



2002-2004 > 2000-2001



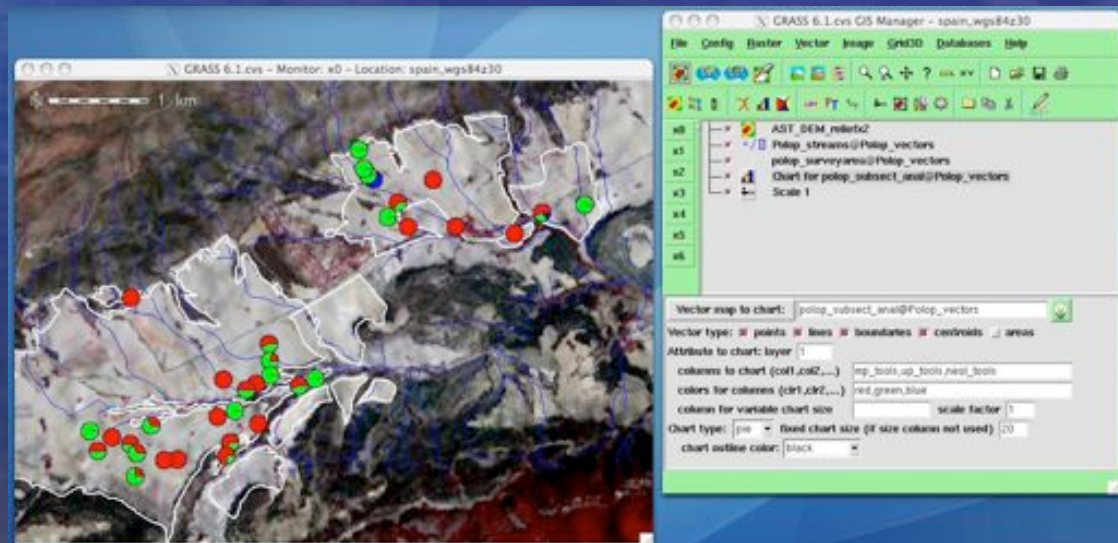
2002-2004 < 2000-2001

Analysis of spatial-temporal dynamics

- Representing space-time dynamics as volumes offers potential for new methods of analysis
 - Extension of map algebra to volumes already available
 - Regression, trend analysis, and other methods now applied to surfaces and point distributions can potentially be applied to volumes
- Example of ways to address new challenges posed by modeling human ecology across space and time

GRASS as platform for eco-cultural modeling

- Open source
 - Modifiable, scriptable
 - Multi-platform
 - GPL licensing for access and dissemination
 - Internationalization
- Rich suite of modeling tools (e.g., r.le, r.neighbors, r.mapcalc)
- 3D volumetric tools
- Visualization tools



Support & collaboration

- **NSF:** ERE Biocomplexity in the Environment Program, grant BCS-0410269
- **ASU:** School of Human Evolution and Social Change, School of Earth and Space Exploration, School of Computing and Informatics, Geographical Sciences, International Institute for 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.

