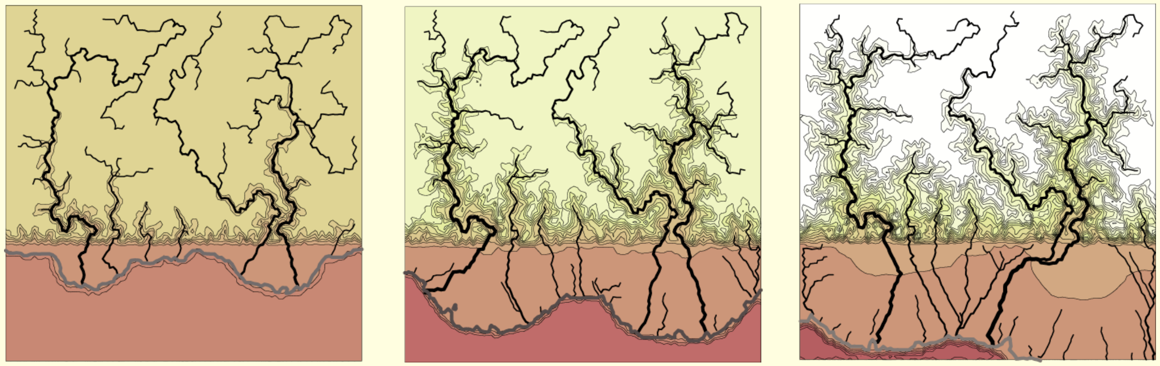


Terrestrial Surface-Dynamics Modeling: Lessons from CHILDhood

Greg Tucker

CIRES and Dept. of Geological Sciences

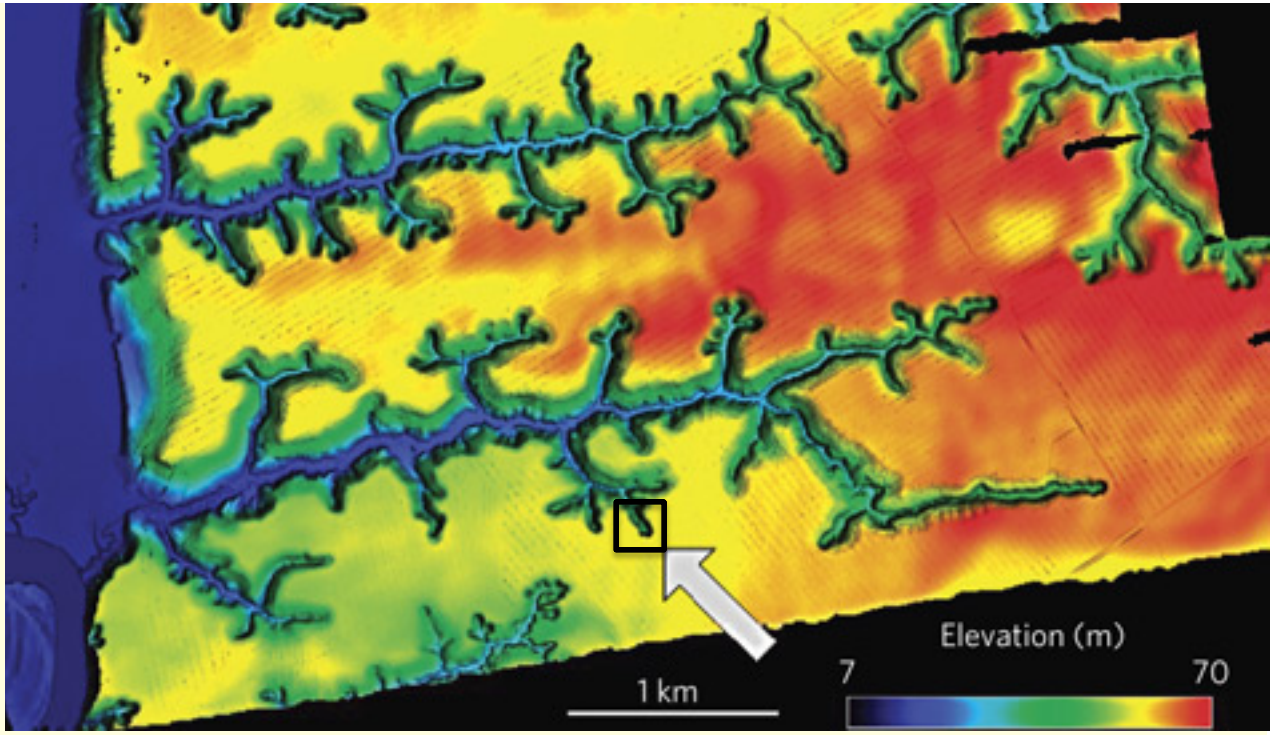
University of Colorado

On behalf of the CSDMS Terrestrial Working Group

Terrestrial Working Group

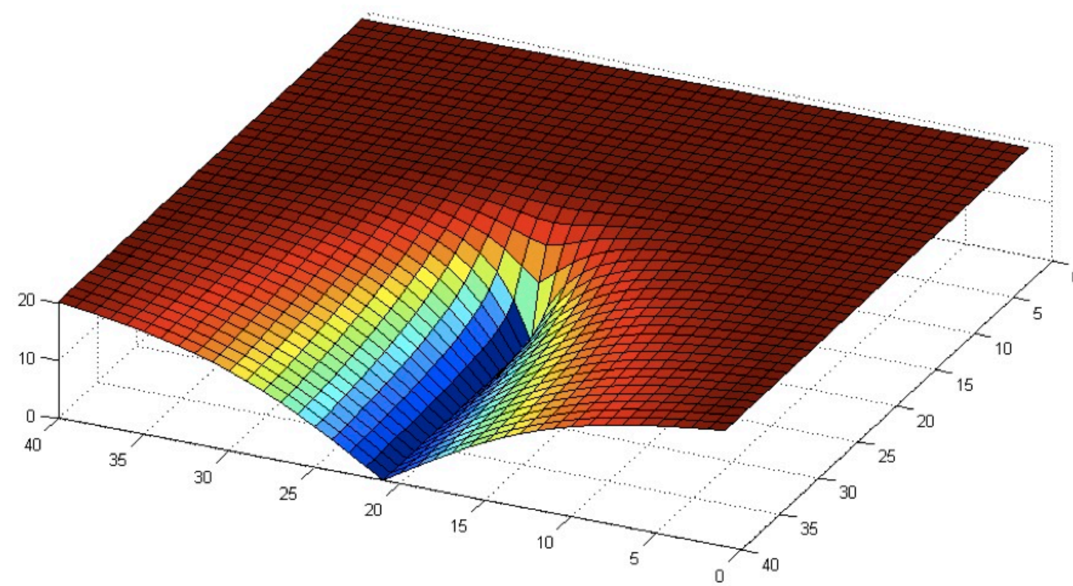
- 220 members
- 18 countries
- ~137 institutions
- 94 publically available “terrestrial models” in CSDMS library
- Plethora of activities

Hillslope response to horizontal advance of channel tips records growth rate of sapping network in unconsolidated sand
(Perron & Hamon, in prep)

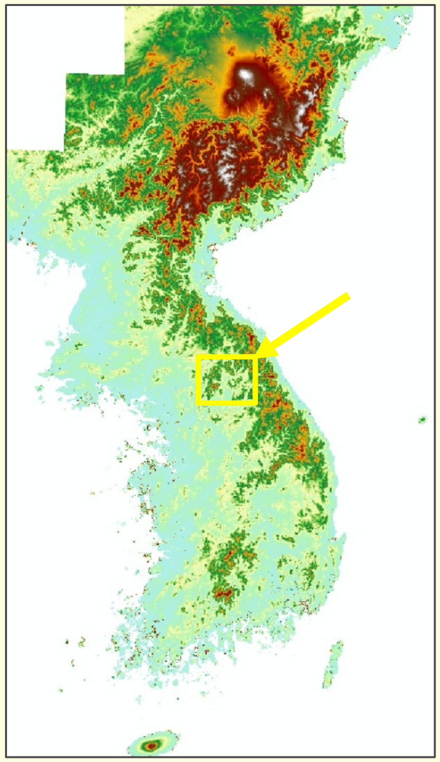


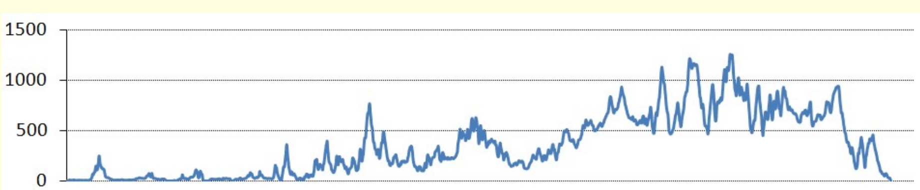
Bluffs adjacent to the Apalachicola R., Florida (Abrams et al., 2009)

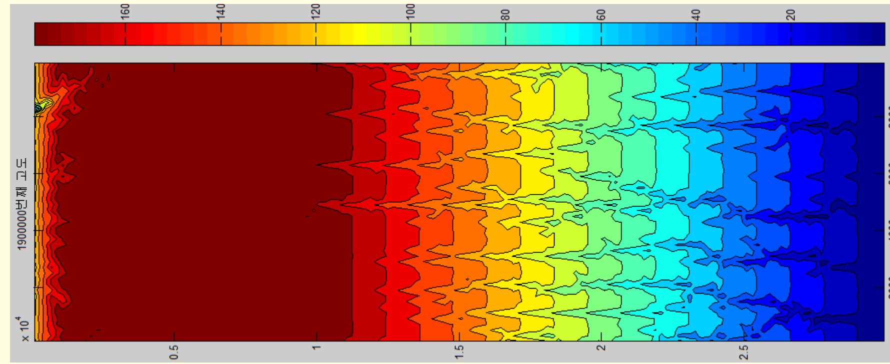
Implicit finite difference method for nonlinear hillslope transport
(Perron, submitted)
+
semi-Lagrangian advection scheme

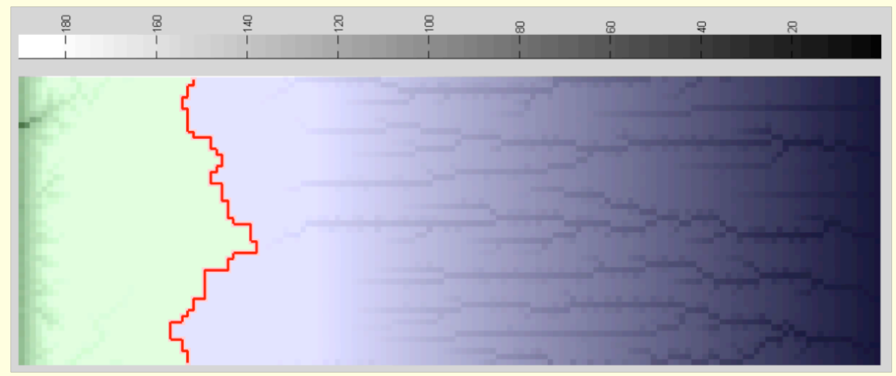


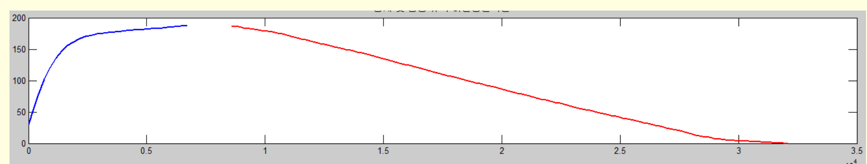
Tilted up-warping of the Korean Peninsula (Jongmin Byun, Seoul National University)





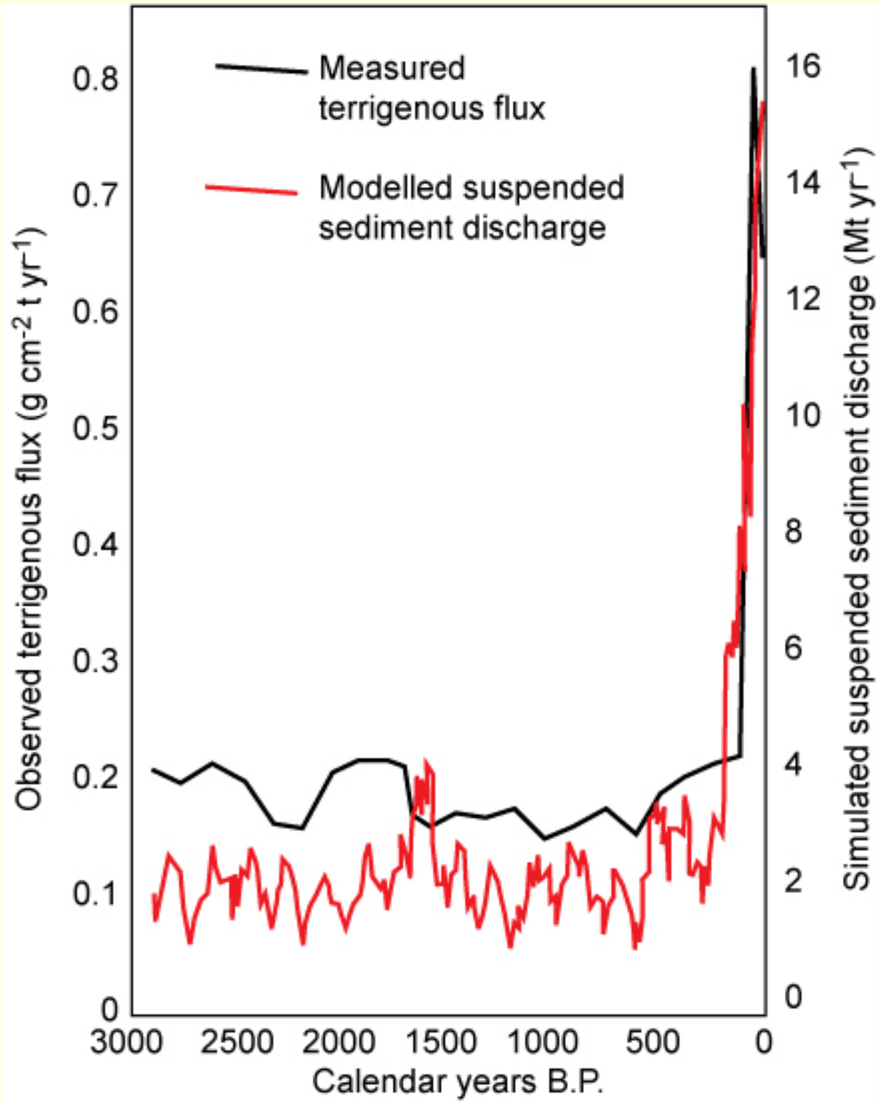


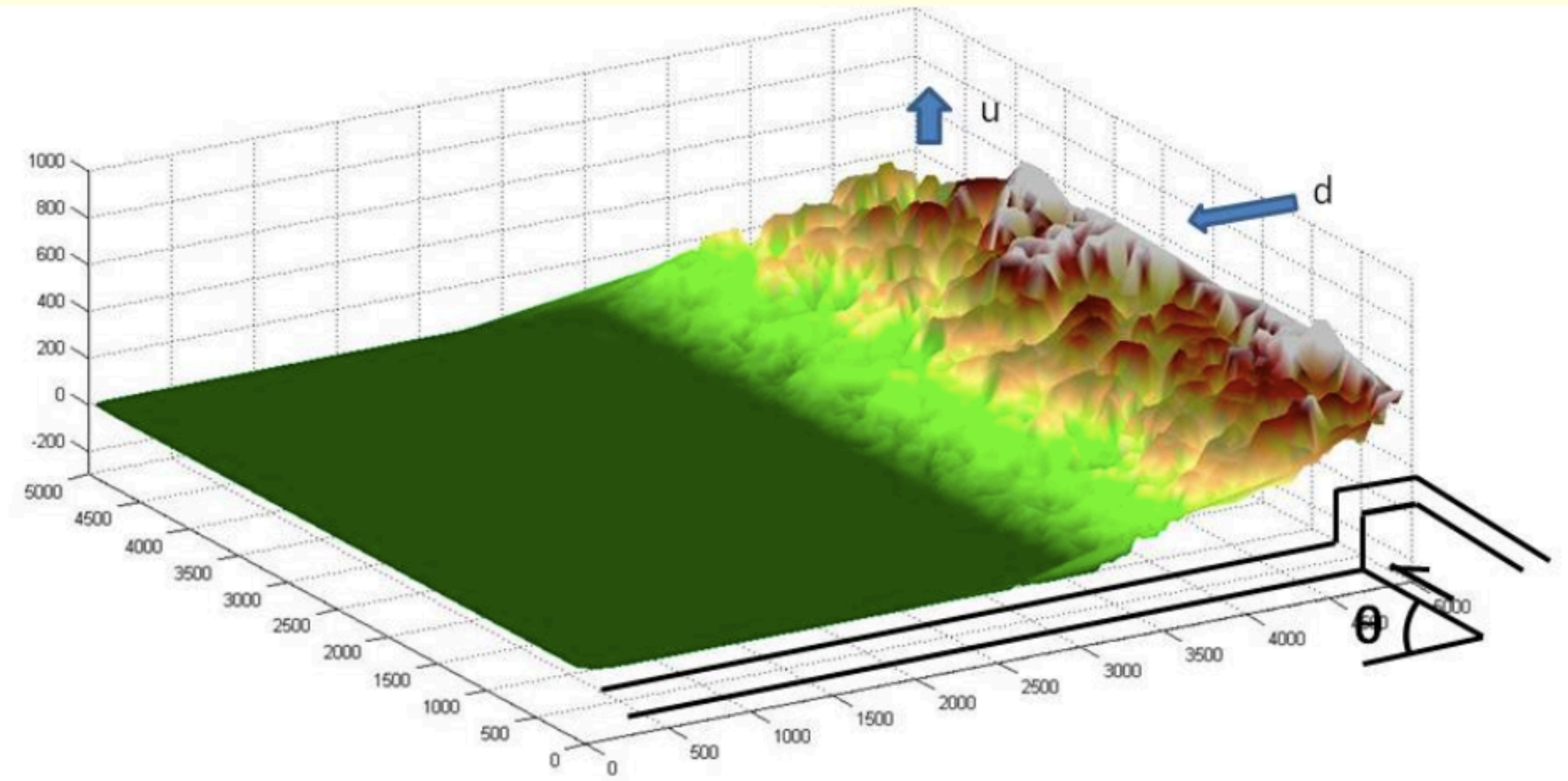




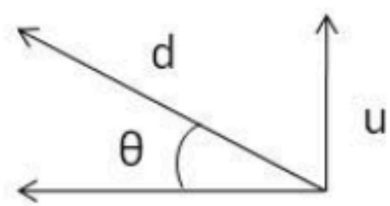
a) Elevation Contour
b) Watershed Divide
c) River Longitudinal Profile

Deforestation signal in the Waipaoa Basin, NZ (Phaedra Upton and colleagues)





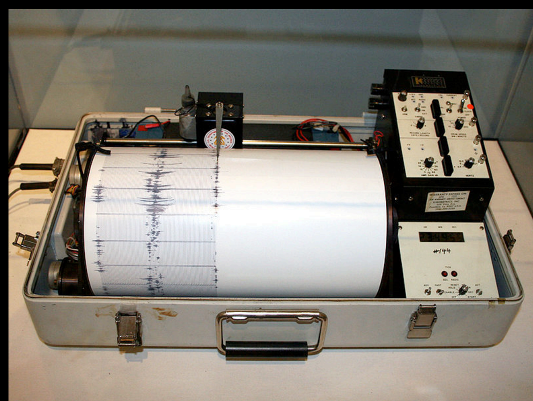
$$d \cong \frac{u}{\sin\theta}$$



Geomorphic evolution of a thrust sheet

Domenico Capolongo, Emanuele Giachetta, Alberto Refice
University of Bari, Italy

Computer models represent a unique kind of technology



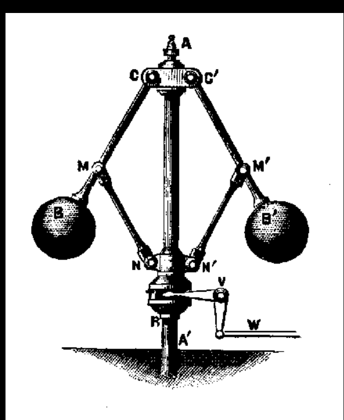
```
#----------------------------------------------------------------------
# RasterModelGrid.initialize:
#
# Sets up a num_rows by num_cols grid with cell spacing dx and
# (by default) regular boundaries (that is, all perimeter cells are
# boundaries and all interior cells are active).
#   To be consistent with unstructured grids, the raster grid is
# managed not as a 2D array but rather as a set of vectors that
# describe connectivity information between cells and faces. Each
# cell in the grid has four faces. Each face has a "fromcell" and
# a "tocell"; the convention is that these always "point" up or
# right (so a negative flux across a face is either going left or
# down).
#----------------------------------------------------------------------
def initialize( self, num_rows, num_cols, dx ):

    # Debugging output flag
    self.debug = False

    # Basic info about raster size and shape
    self.nrows = num_rows
    self.ncols = num_cols
    self.ncells = num_rows * num_cols
    self.dx = dx
    self.cellarea = dx*dx

    # We need at least one row or column of boundary cells on each
    # side, so the grid has to be at least 3x3
    assert self.ncells >= 9

    # Record number of boundary and interior cells and the number
    # of interior faces. Ultimately, this info could be overridden
    # if using an irregular geometry of "interior" cells within the
    # rectangular domain. Note that we don't include any faces
    # between boundary cells.
    self.n_boundary_cells = 2 * ( num_rows - 2 ) + 2 * ( num_cols - 2 ) + 4
    self.n_interior_cells = self.ncells - self.n_boundary_cells
    self.nfaces = ( num_rows - 1 ) * ( num_cols - 2 ) + \
                  ( num_rows - 2 ) * ( num_cols - 1 )
    if self.debug:
        print self.nfaces
```


A
C
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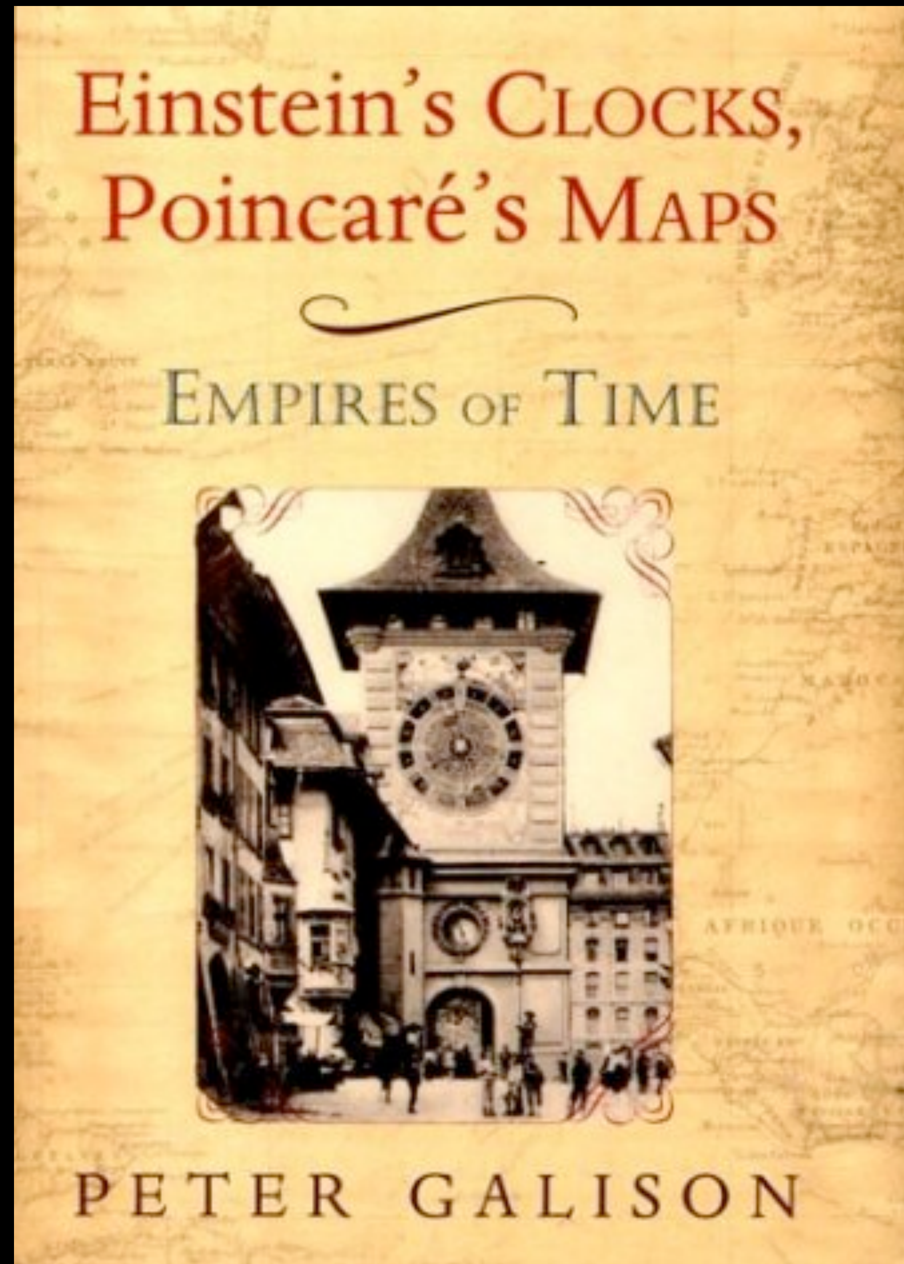

Einstein's CLOCKS,
Poincaré's MAPS
EMPIRES OF TIME
PETER GALISON

“Mind enhancing machinery”

- People are good at pattern recognition and creativity
- Computers excel at mindlessly enforcing budgets and “rules,” revealing the logical consequences of ideas and knowledge
- Computer models aren’t just “tools”: they embody knowledge and ideas in symbolic-logical form
- To be helpful, *model codes must be flexible enough to adapt as our knowledge grows, ideas change, and new questions emerge*

How to build models that evolve?

- Custom-built, "use-once" approach
  - Build new codes as the science evolves
- Modeling platform approach
  - Modify / extend / combine existing codes to address new ideas

"[Software] standardization is efficient for investment – if we pick the 'right' standards"

"Ad hoc, loose, or no coordination may lead to redundant efforts, but also gives creative, unorthodox ideas chance to demonstrate their potential"

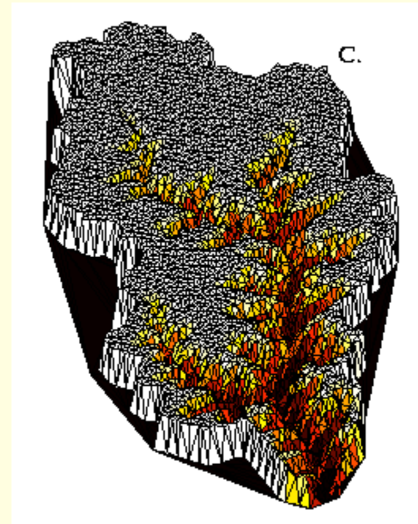
- NSF Advisory Committee on Cyberinfrastructure Software Task Force (Dec. 2009)

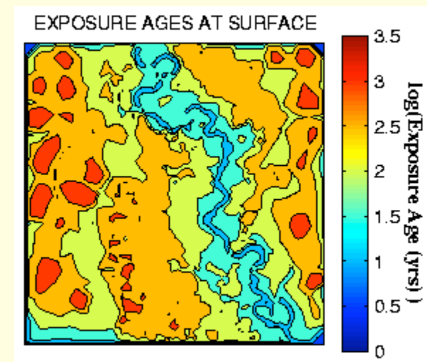
CSDMS vision

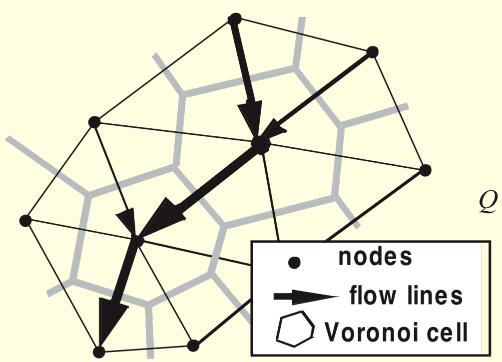
- "… community-generated, continuously evolving, open software"
- "… cyber-infrastructure to promote the quantitative modeling of earth surface processes"
- "… rapid development and application of linked dynamic models"
- "… software that demonstrably keeps pace with both hardware and scientific developments"

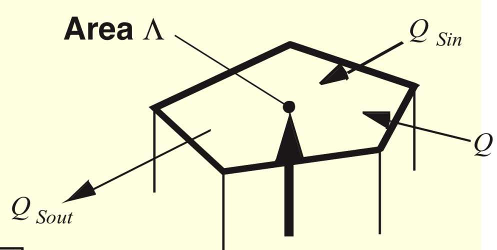
Channel-Hillslope Integrated Landscape Development (CHILD) model

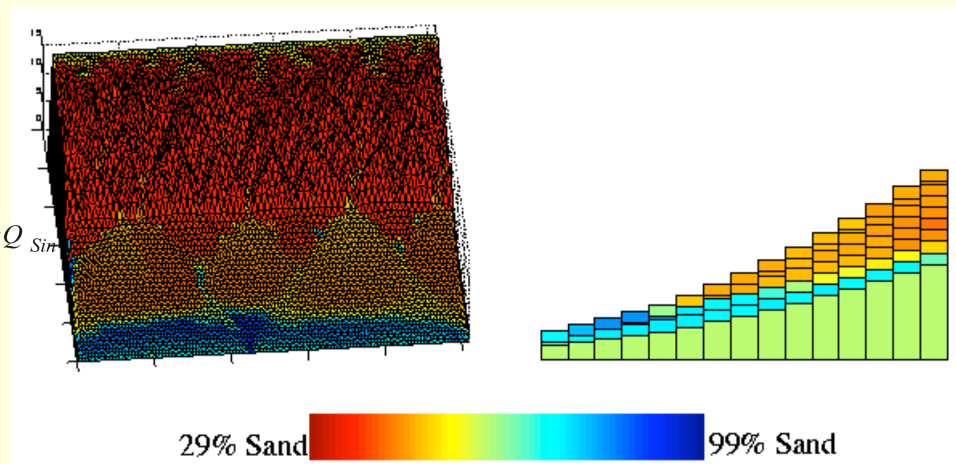
- MIT late 1990s
- Explore channel-hillslope coupling under varying climate
- Irregular mesh
- Written in C++
- Object-oriented design







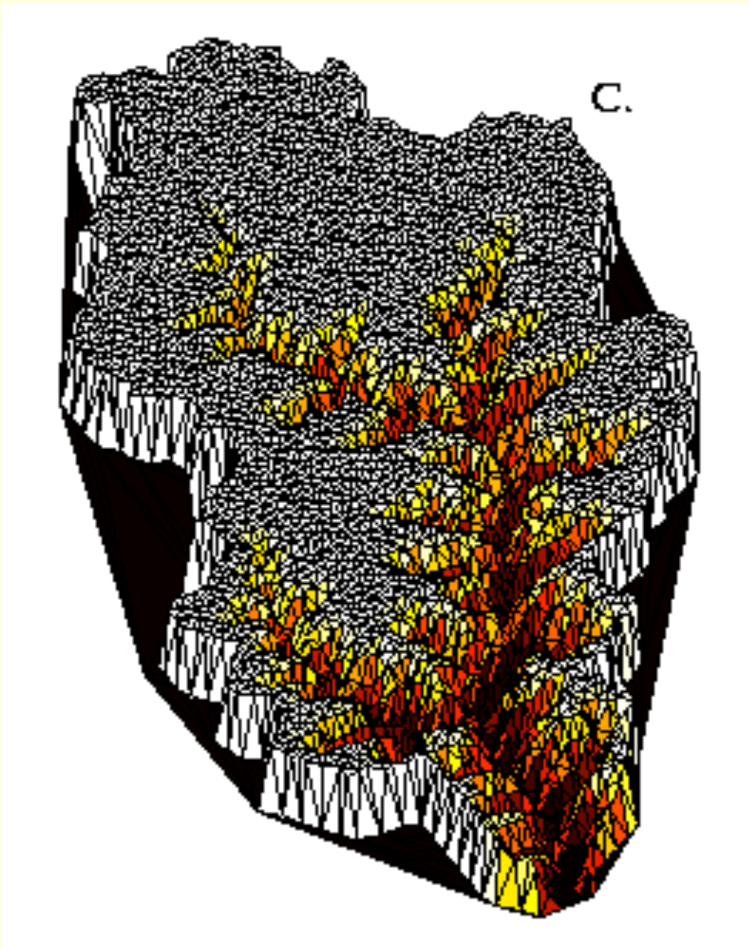


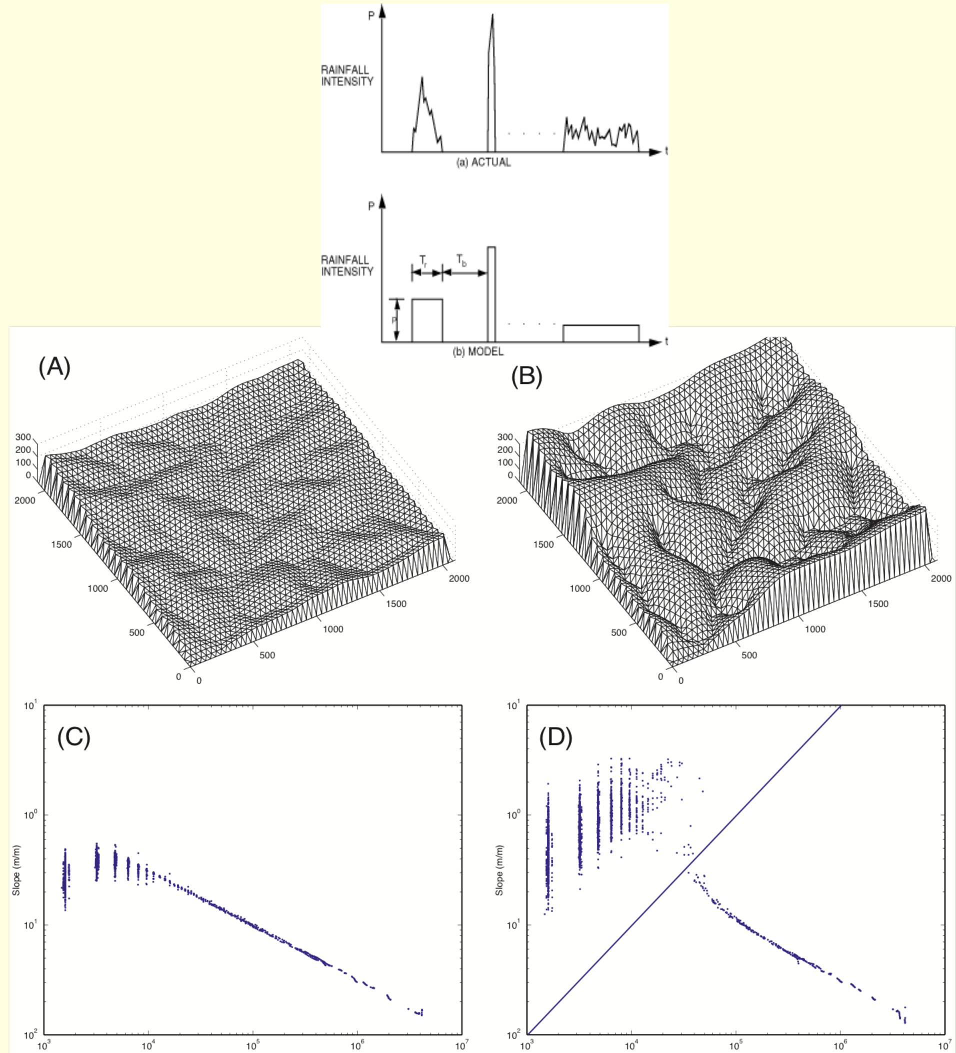


RUNOFF TRANSPORT/EROSION:

SOIL CREEP TRANSPORT/EROSION:

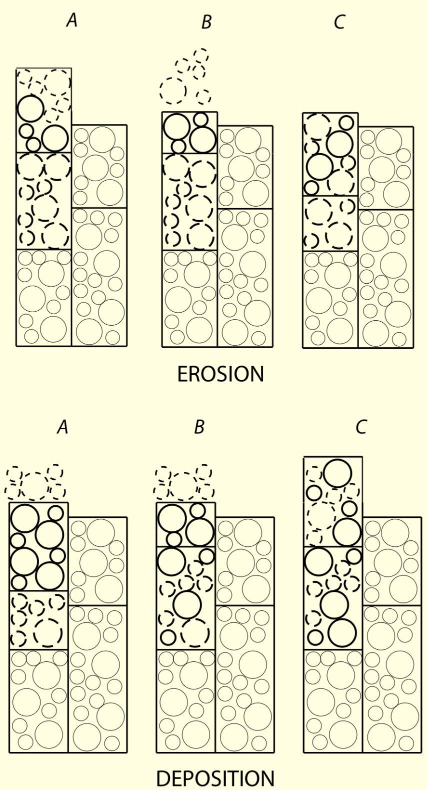
How do topography and hydrology co-evolve to shape a drainage basin?



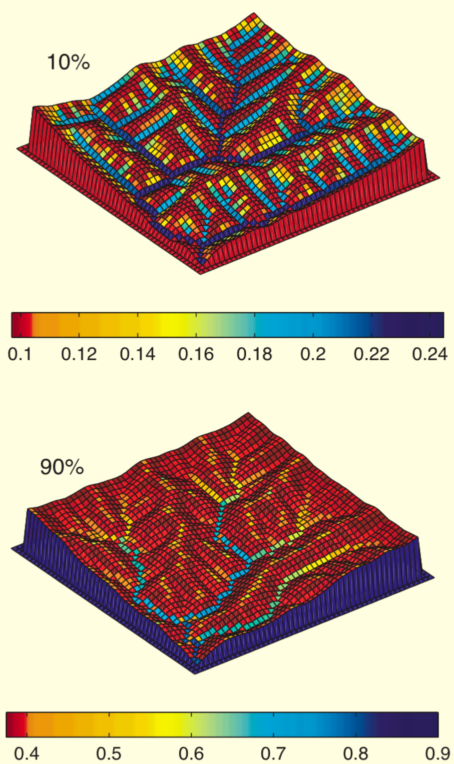


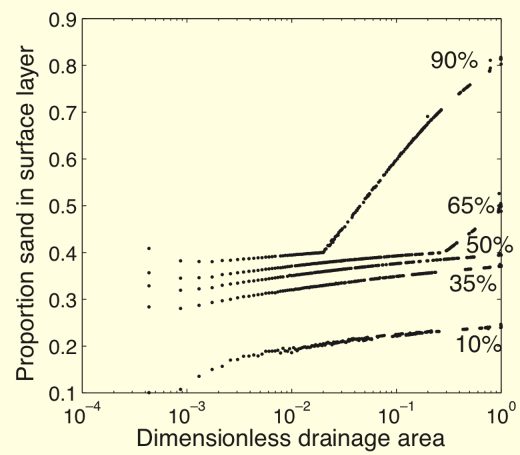
Tucker, Lancaster, Gasparini and Bras (2001)

Grain-size dynamics



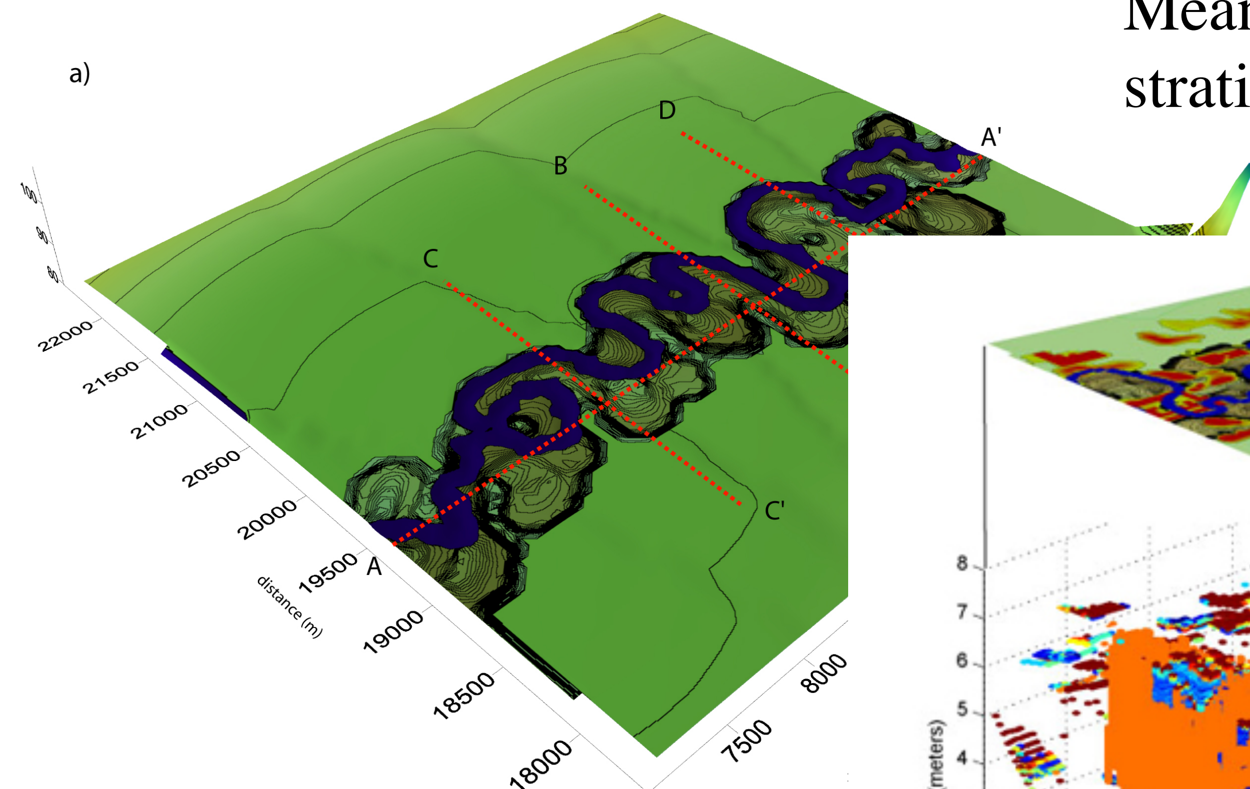
N. M. GASPARINI, G. E. TUCKER AND R. L. BRAS (2004)

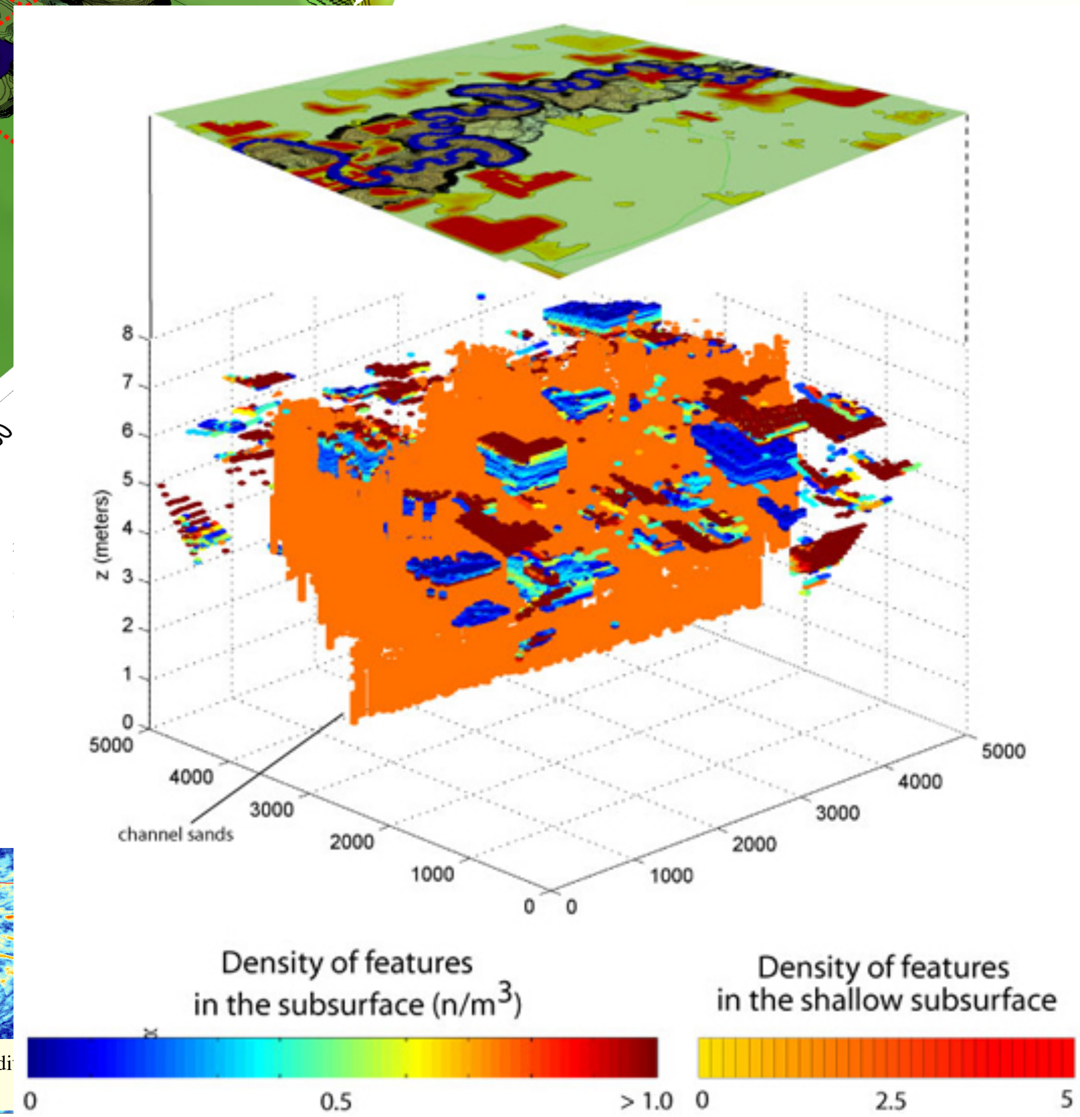




Gasparini et al., 1999, Figs 2 & 3

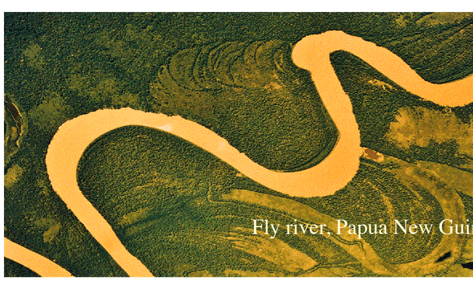
Meandering-river valley stratigraphy and archaeology

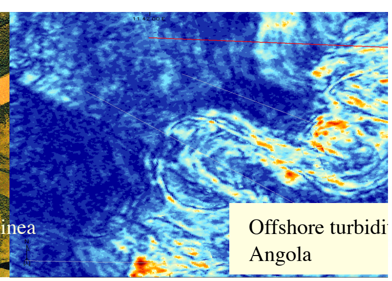




Clevis et al (2006a)
Geoarchaeology

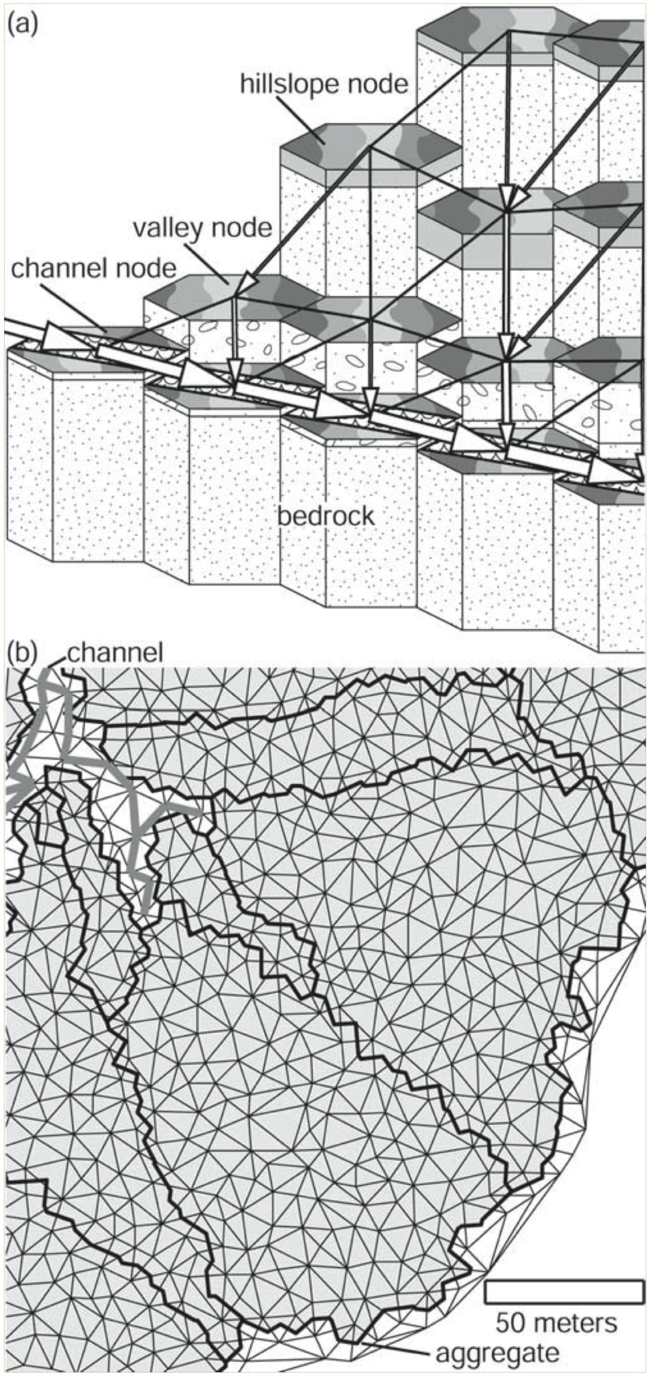
Clevis et al (2006b)
Computers & Geosciences

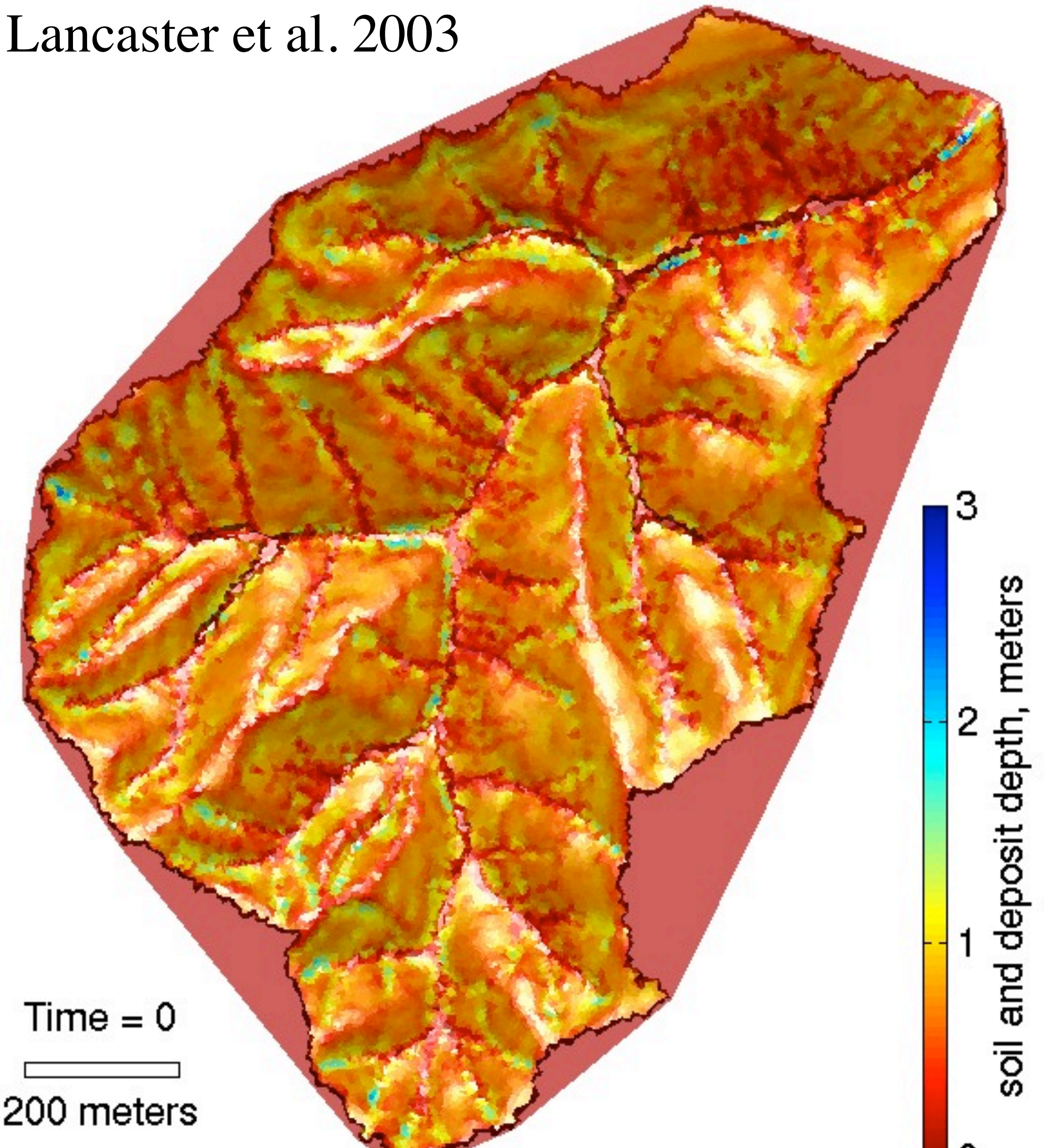




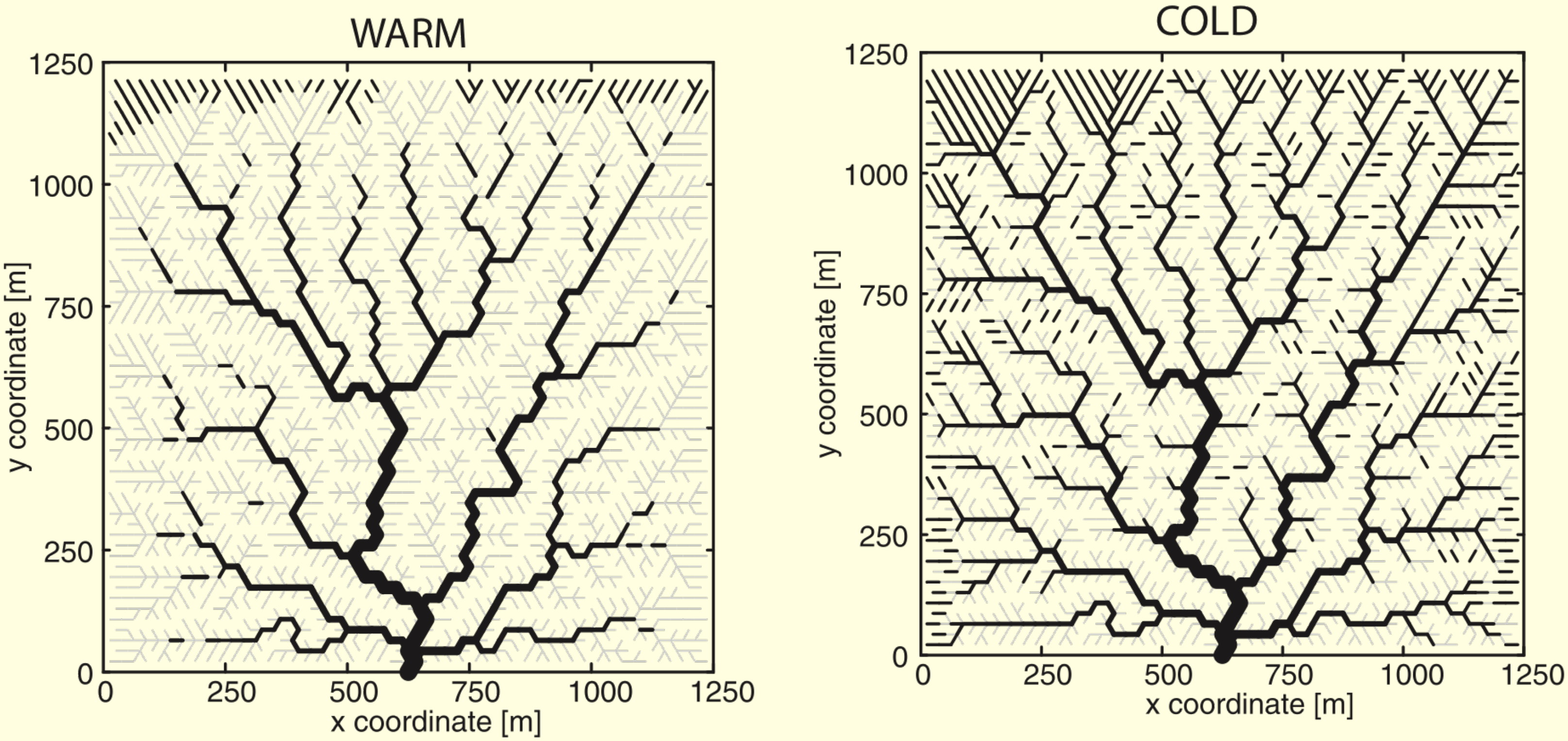
Effect of wood debris on debris-flow dynamics

Lancaster et al. 2003



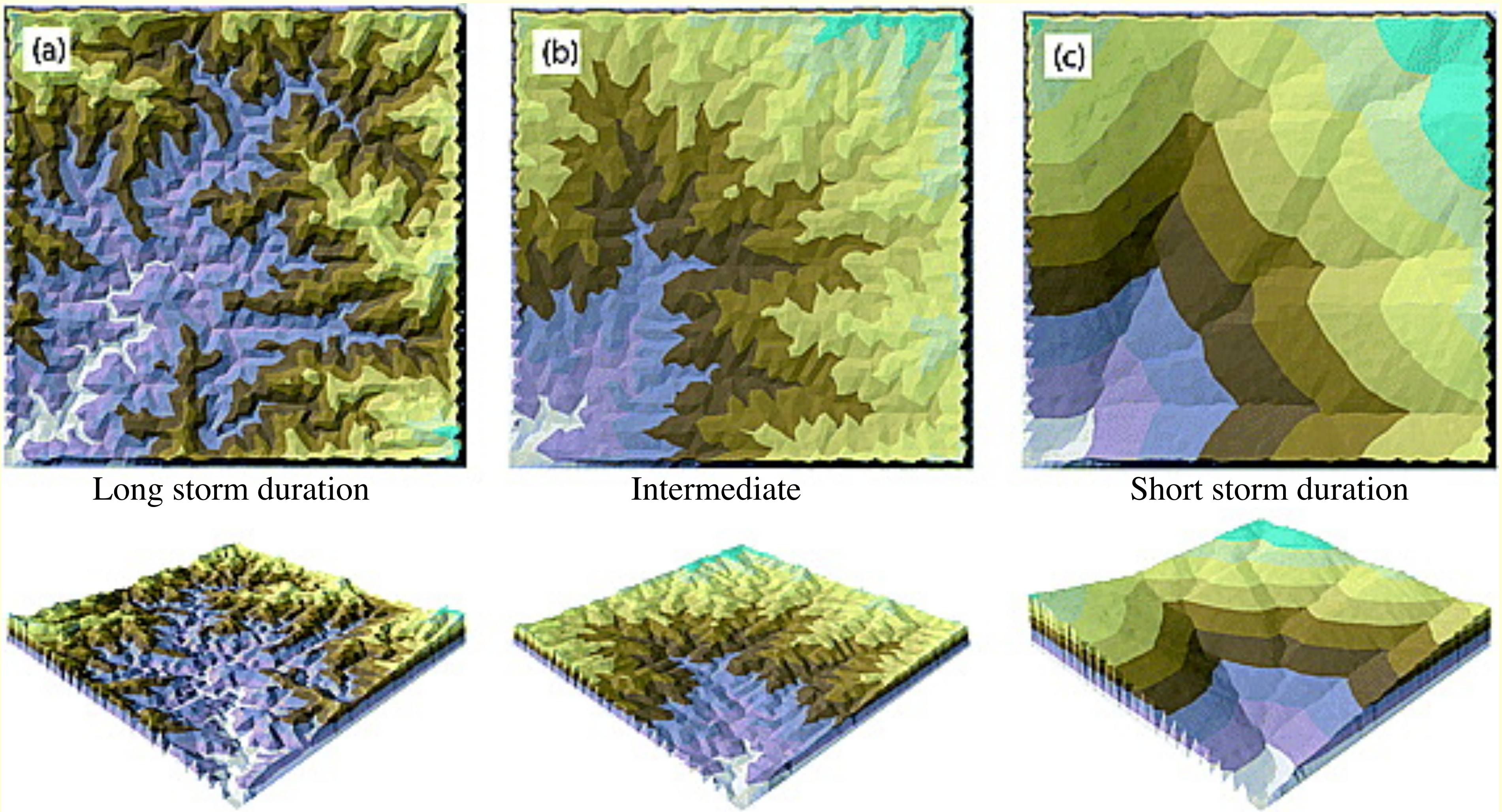


Permafrost as a control on drainage density during glacial-interglacial cycles



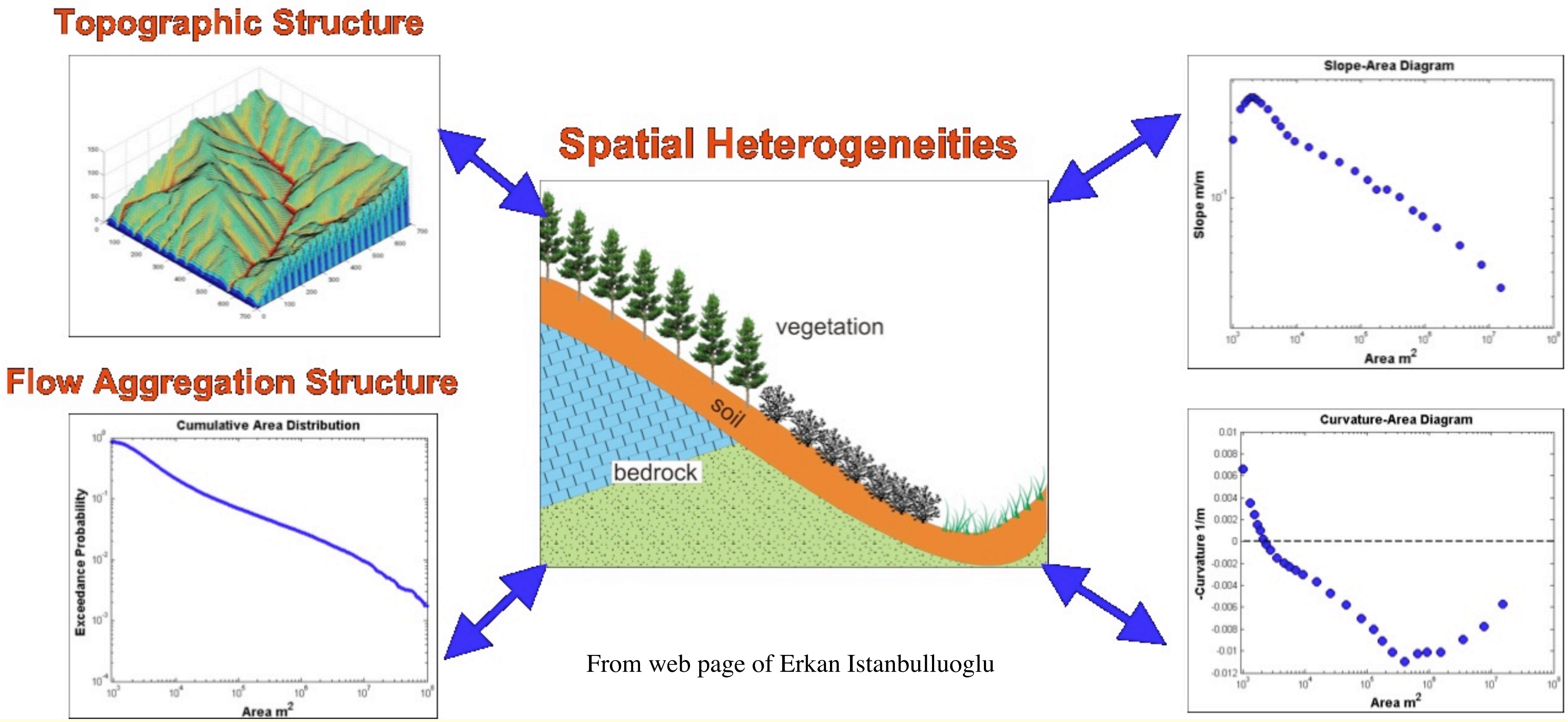
P.W. Bogaart et al. / Geomorphology 54 (2003) 257–277

Role of storm event duration in shaping catchments



(Sólyom & Tucker, 2004)

Interaction of vegetation, soil hydrology, and landscape evolution



From web page of Erkan Istanbulluoglu

Collins et al. (2004)
Istanbulluoglu and Bras (2005)

Gully dynamics

C = 5 kPa

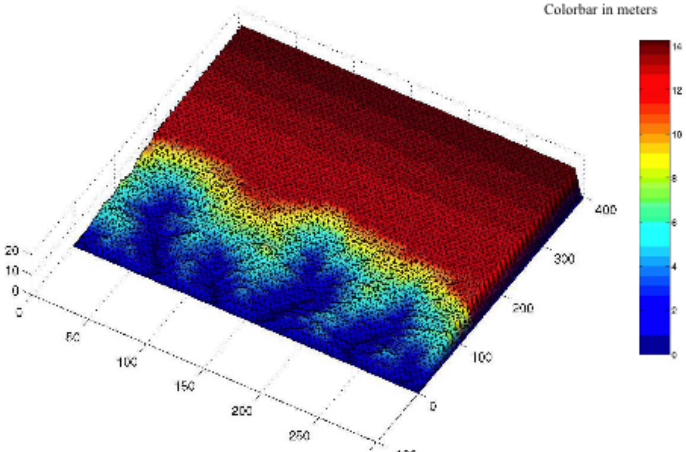


FIGURE 12 (A).

C = 10 kPa

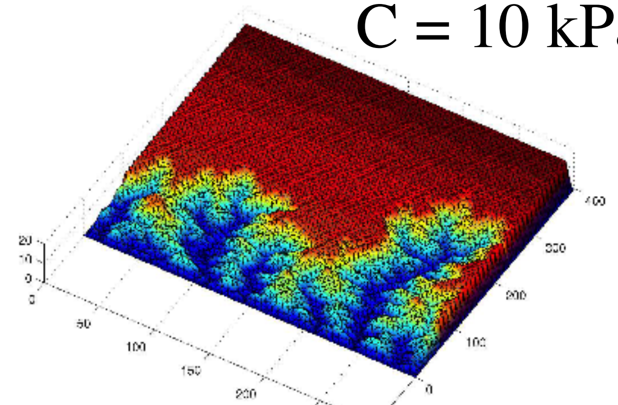


FIGURE 12 (B).

C = 20 kPa

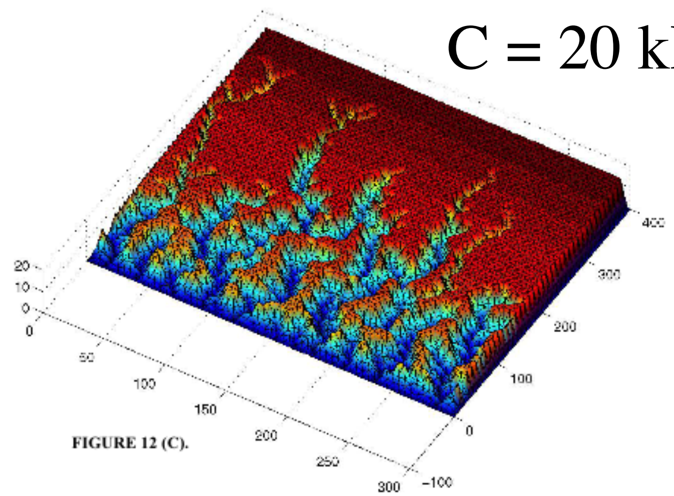


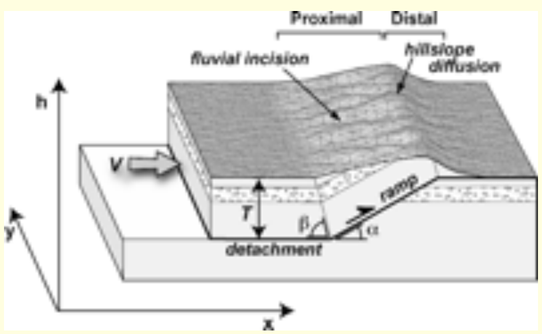
FIGURE 12 (C).

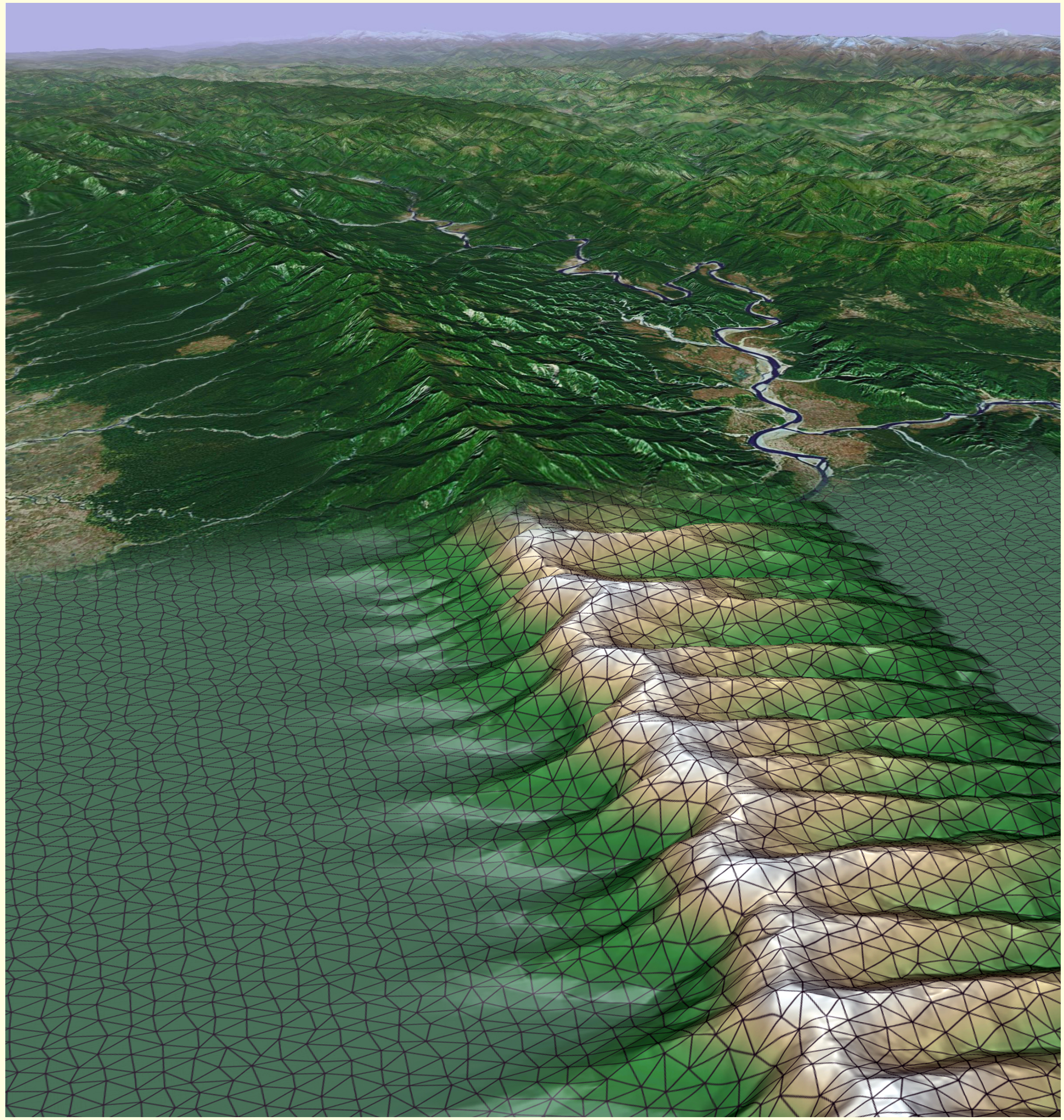
Istanbulluoglu et al., 2005

Flores-Cervantes et al., 2006

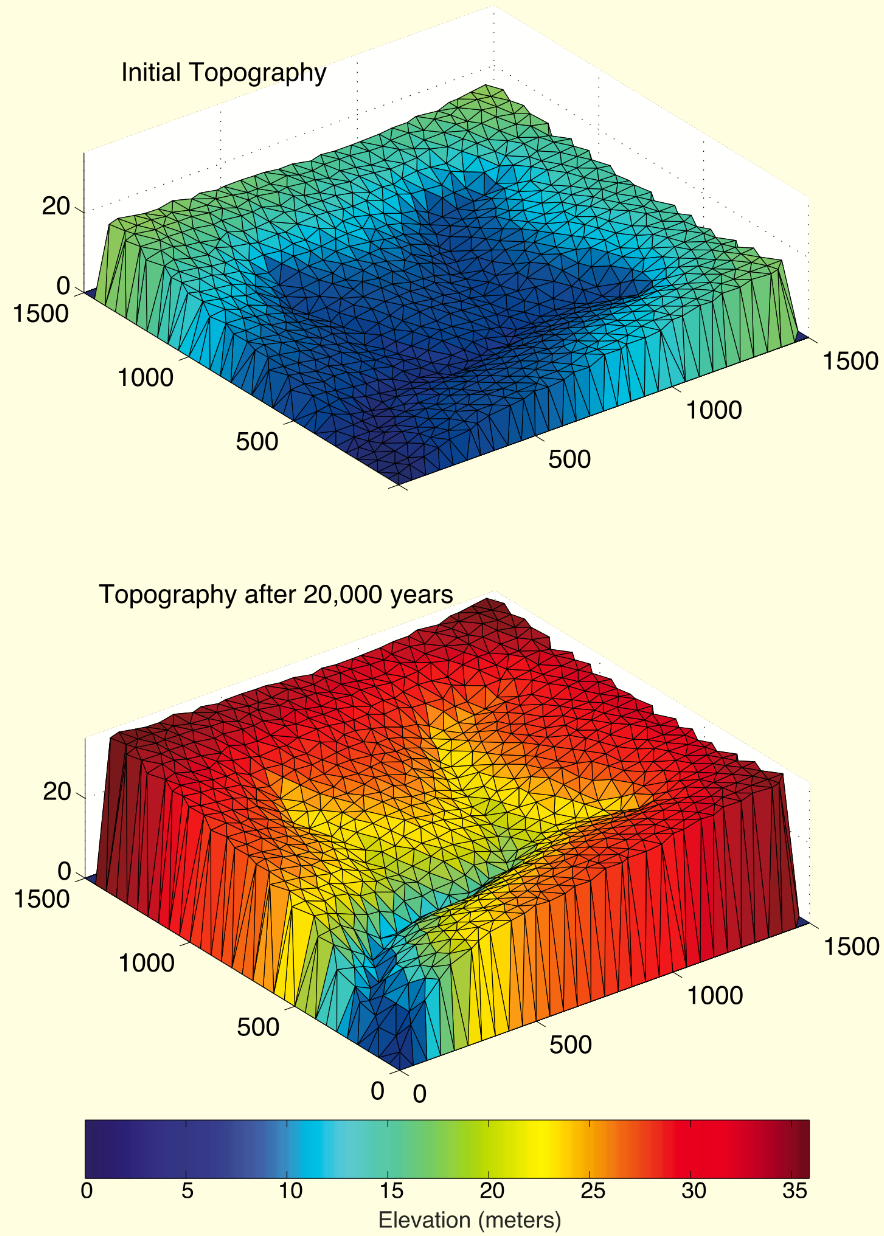
Evolution of topography over a fault-bend fold

(Miller and Slingerland, 2006, 2007)



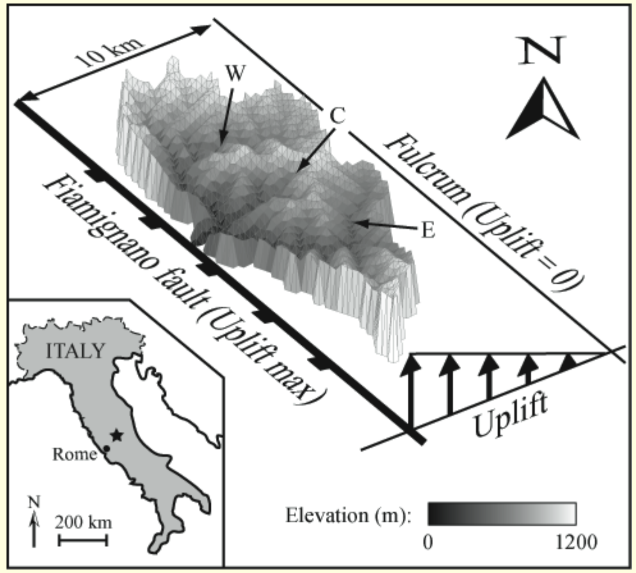


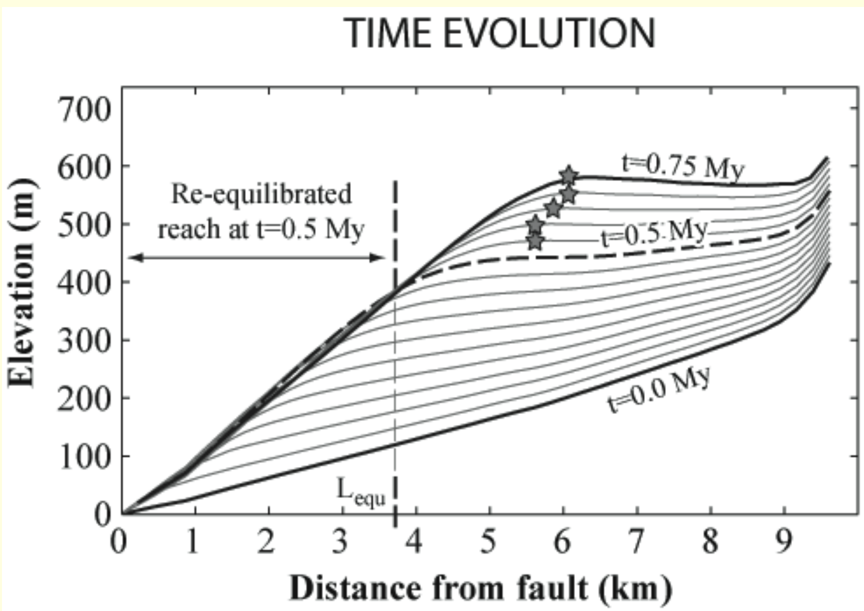
Morphological implications of alternative bedrock-erosion laws

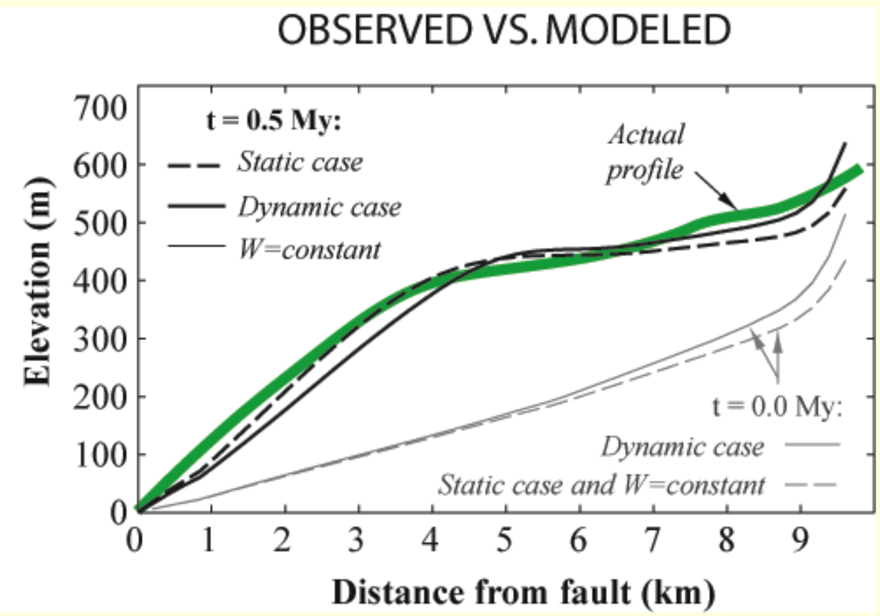


Figur e 12. Initial topography and 20,000 years after tenfold increasein uplift rate using the generalized abrasionmodel. Units on landscapeaxes are in meters. Landscapesare shadedby elevation, and scale bar on bottom applies to both landscapes. The slope and profile of the main channels are illustrated in Figures 10 and 11. Initial topography, shadedby slope, is illustrated in Figure 4.

Dynamic channel-width adjustment in response to normal-fault motion



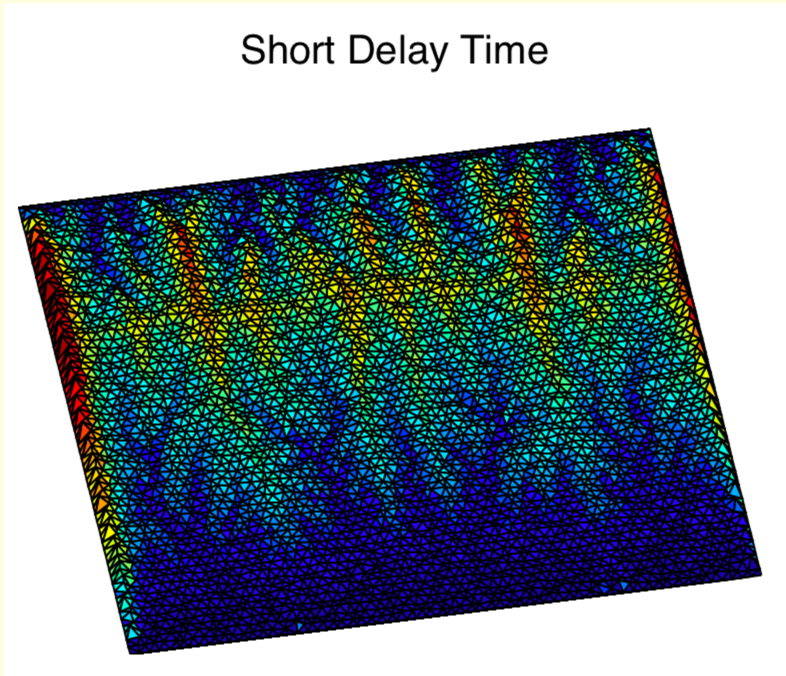


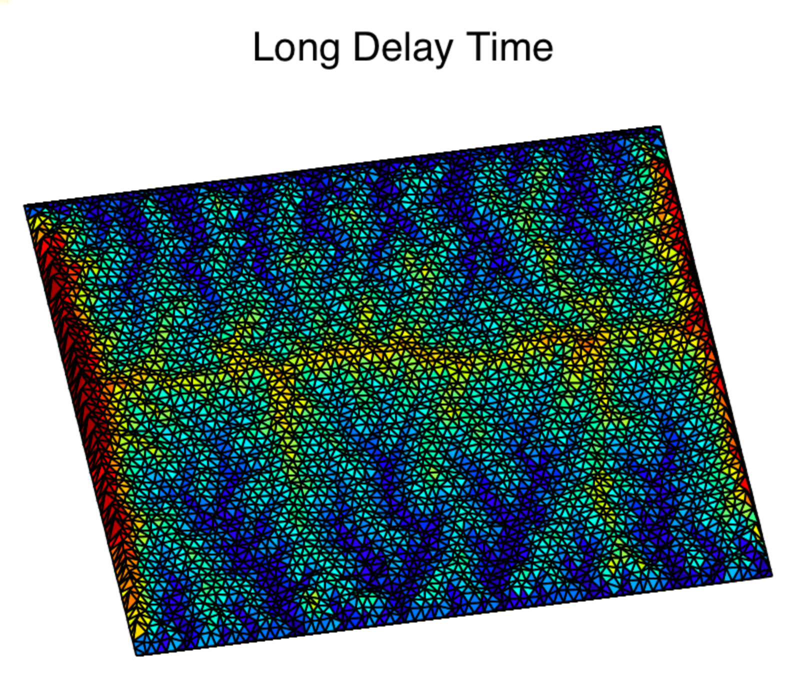


(Attal et al., 2008 JGR)

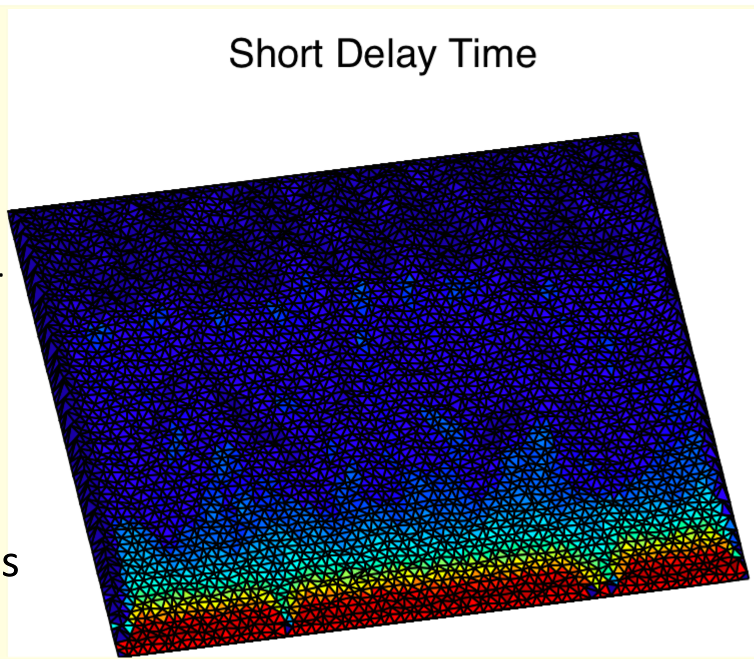
OROGRAPHIC PRECIPITATION MODELING: NICOLE GASPARINI AND JIANWEI HAN, TULANE

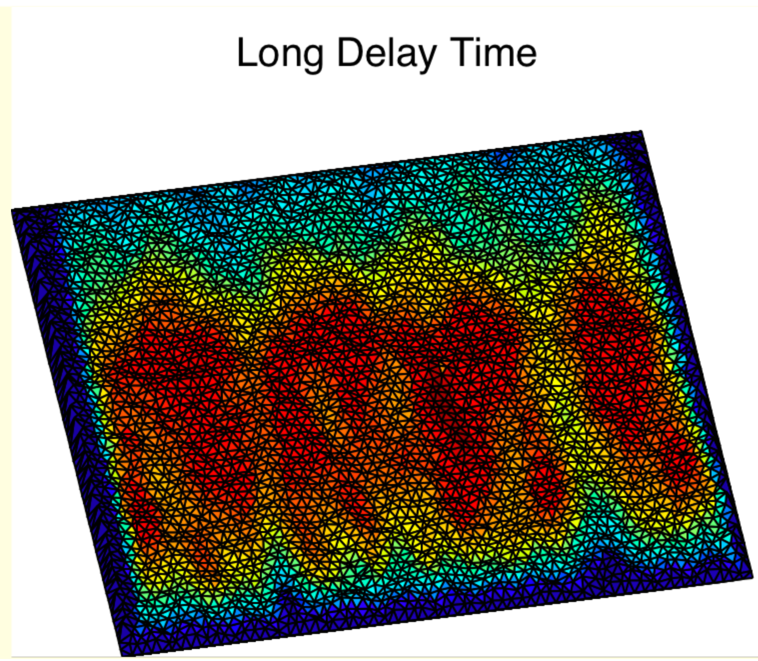
Topography shaded by elevation





Topography shaded by precipitation – note that the precipitation scale varies between the two landscapes

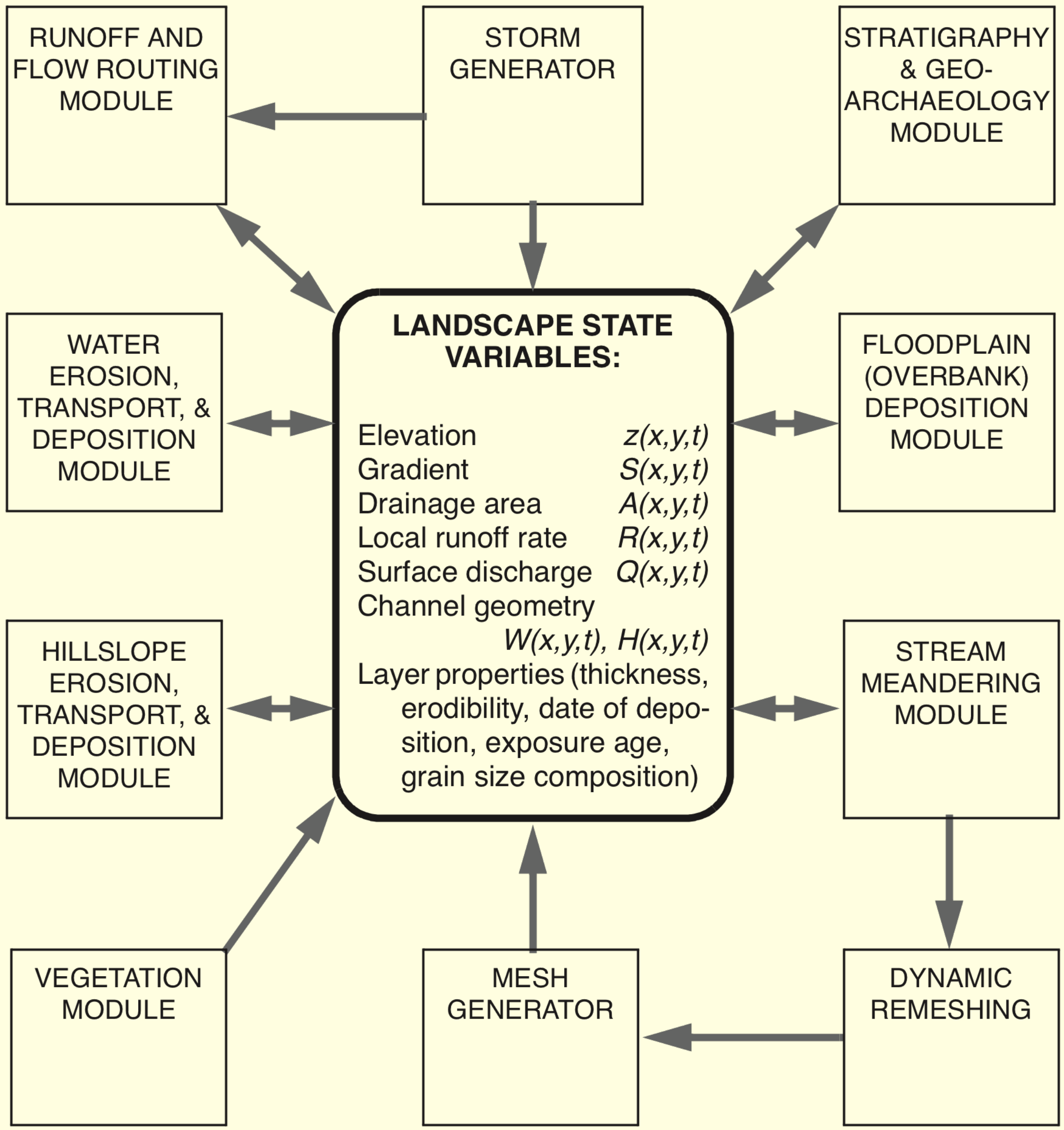




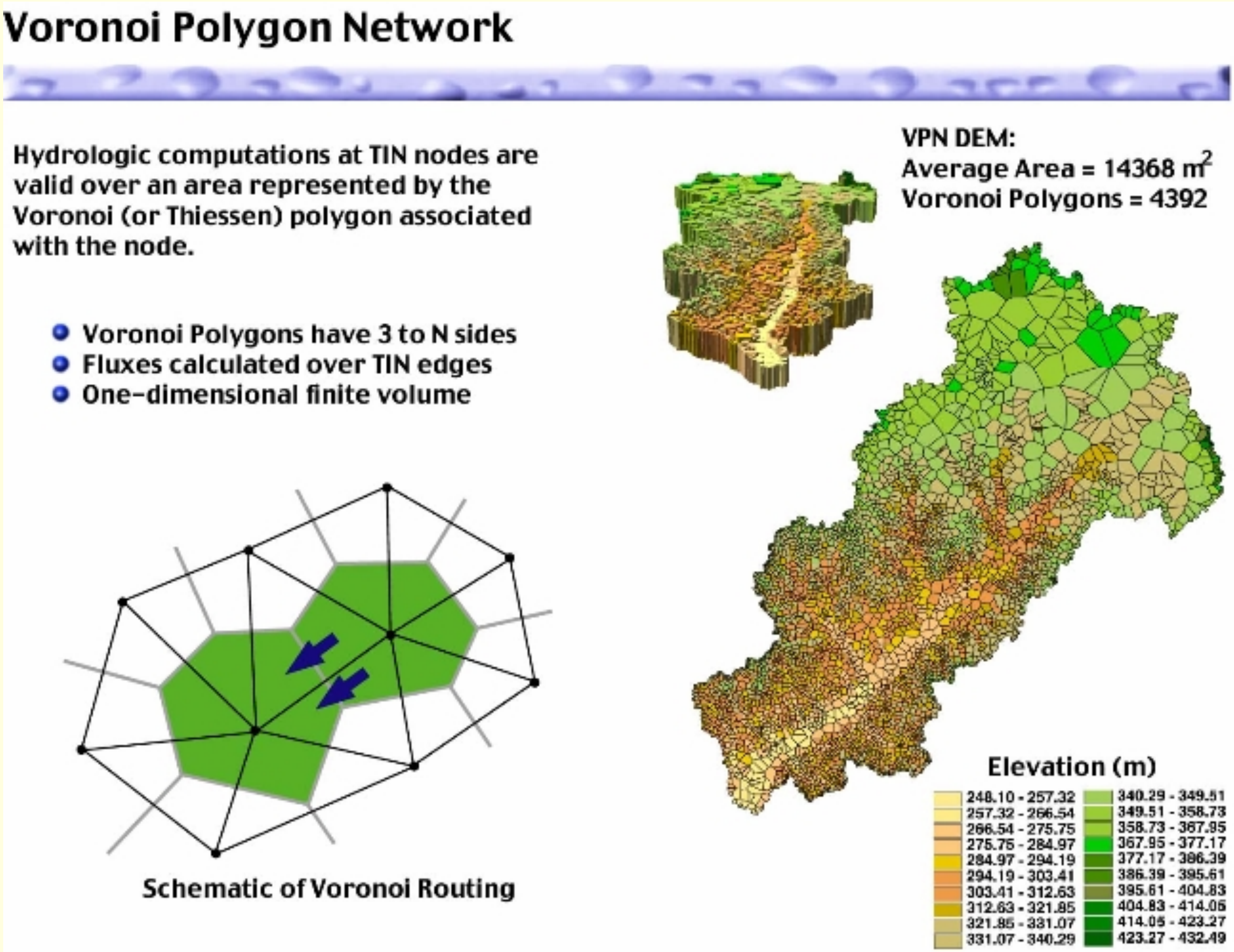
Lessons from CHILD’s history

- Software and science evolve together
- Software becomes a platform for exploring and applying new ideas
- An evolving science code can involve generations of students, postdocs, and contributors

Value of investing in careful software design



Keep gridding software separate; use for other applications



(Ivanov, Vivoni, Bras, and Entekhabi, 2001)

Maintain version-control discipline

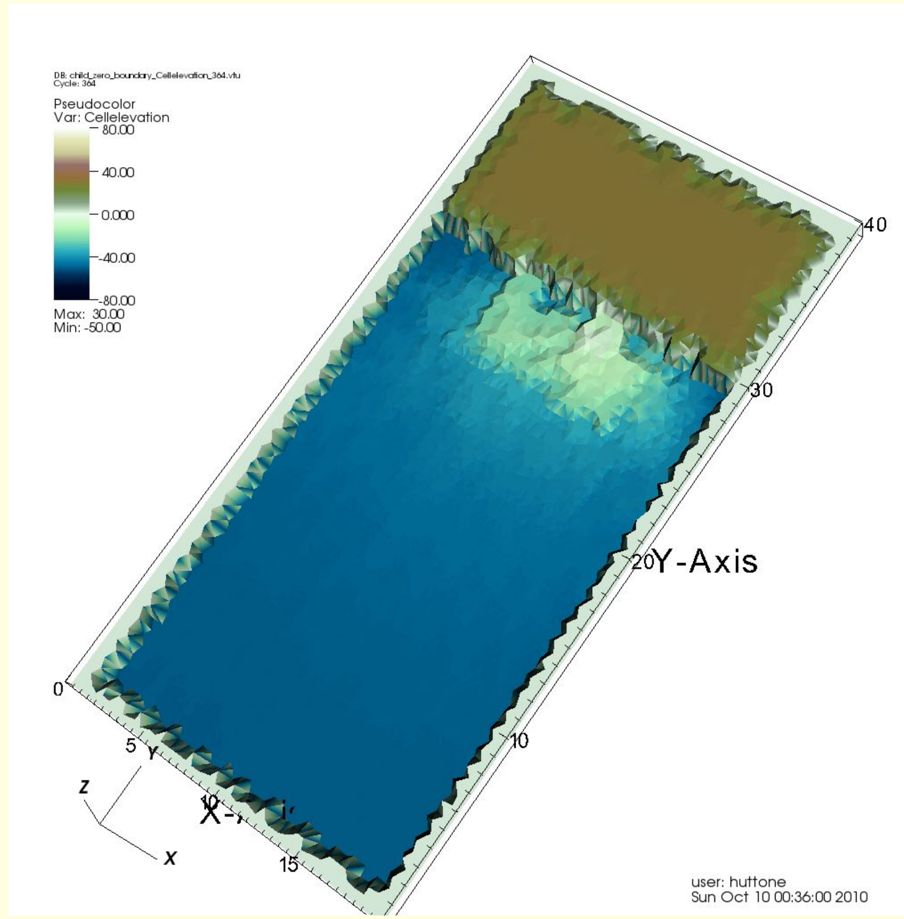
- Use networked version-control system (Subversion, CVS, etc.)
- Avoid speciation
- Use regressions (known-answer test cases) and unit tests

Add, don't replace

- Use switches to handle process choices
- Encapsulate functionality within components that can be switched on or off
- Let the user choose the level of complexity
  - Complex code can implement simple models
- Implement new or alternative process formulations as options, preserving earlier functionality

Implications for CSDMS

- *Component-based* software engineering is the logical extension of "modularity" and "switches"
- CHILD is now a CSDMS component
- ModelGrid prototype under development
- Terrestrial community has developed and contributed many *models* – now we need to turn them into *components*



Source-to-sink model combining CHILD and SedFlux components (courtesy of Eric Hutton)