Community Sediment Models: Lessons from Landscape Evolution Modeling

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Beginnings

- F. Ahnert (1967, 1976, …)
- M. Kirkby (1971, …)

A sampling of models since 1990

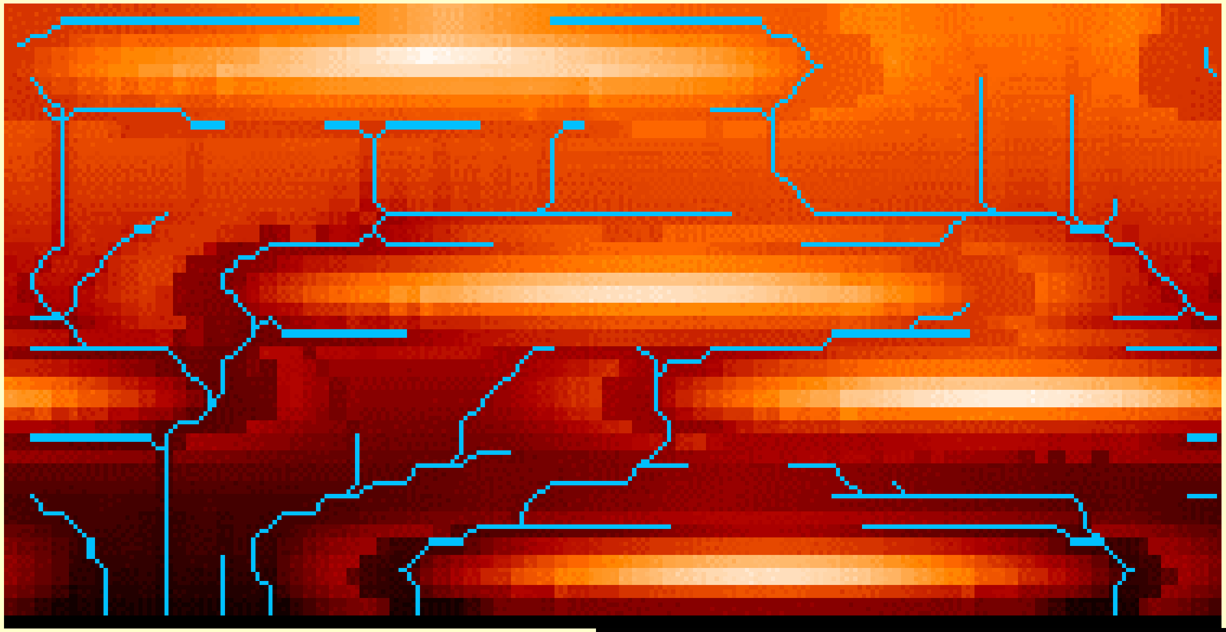
- SIBERIA (Willgoose, Bras, Rodriguez-Iturbe, 1990)
- “Precipiton” model (Chase, 1992)
- DRAINAL (Beaumont et al., 1992)
- Detachment-limited model (Howard, 1994)
- GOLEM (Tucker & Slingerland, 1994)
- CASCADE (Braun & Sambridge, 1997)
- CAESAR (Coulthard, Macklin, & Kirkby, 1997)
- ZSCAPE (Densmore, Ellis, Anderson, 1998)
- CHILD (Tucker et al., 1999)

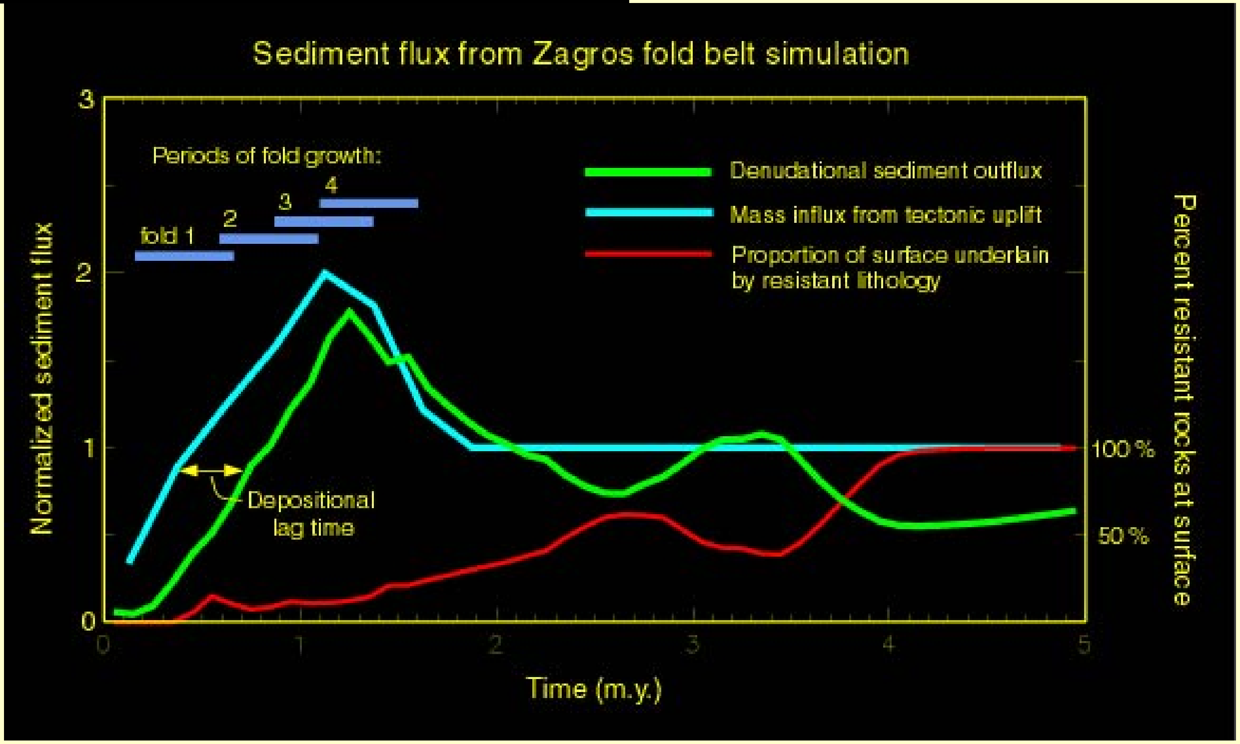
Drainage basin model beginnings

- Transport-limited
- Based on continuity equation
- Power-law transport capacity: $q_s \sim A^m S^n$
  - $\Rightarrow$ homogeneous, cohesionless fine sediment
  - $\Rightarrow$ "Geomorphically effective" runoff
- Diffusion equation for hillslope mass transport

“Orogen-scale” models

- Erosion-tectonics interaction
- Coarse resolution -> hillslopes as sub-grid-scale features
- Both detachment and transport considered simultaneously



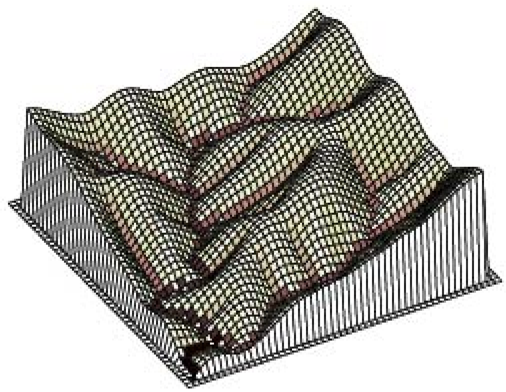


Tucker & Slingerland
Basin Research, 1996

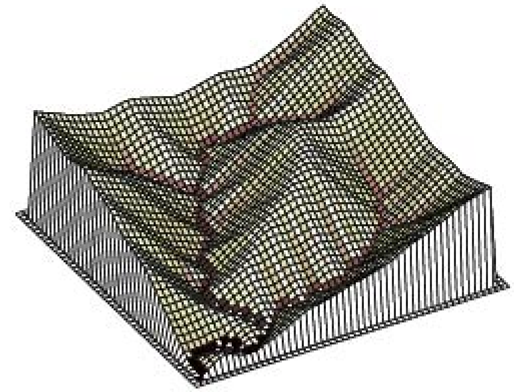
Landsliding / mass movement

- Nonlinear diffusion (Anderson & Humphrey; Howard; Roering & Dietrich)
- Threshold slope angle (Tucker & Slingerland)
- Stochastic algorithm (Densmore et al.)

SOIL CREEP

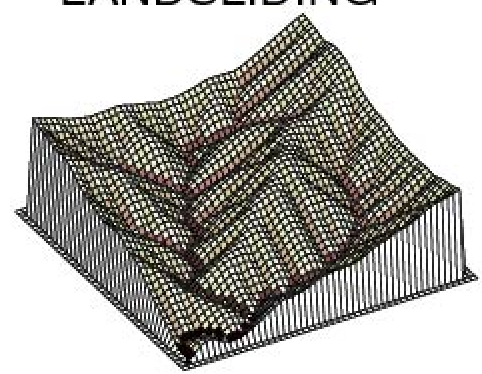


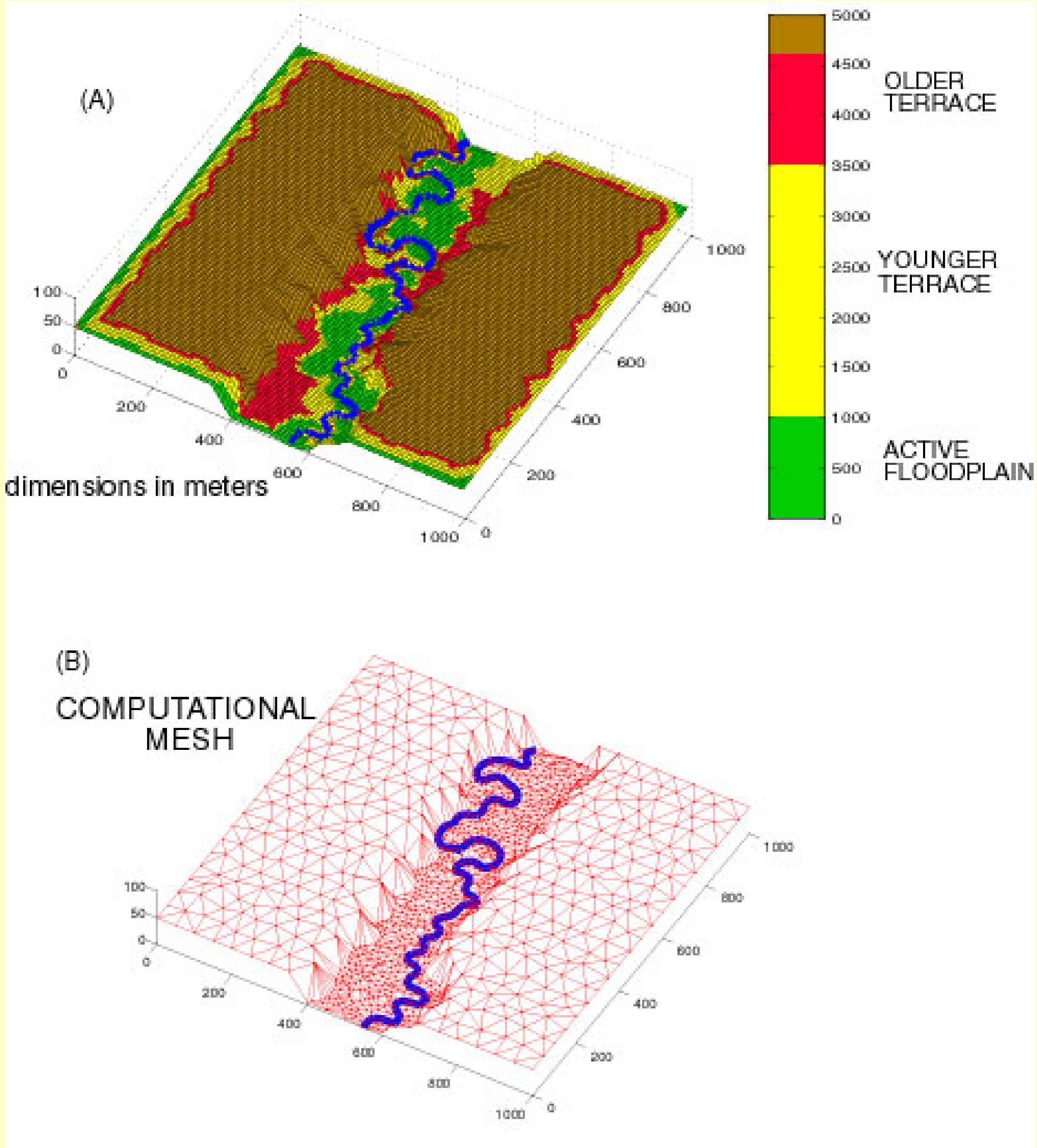
THRESHOLD LANDSLIDING

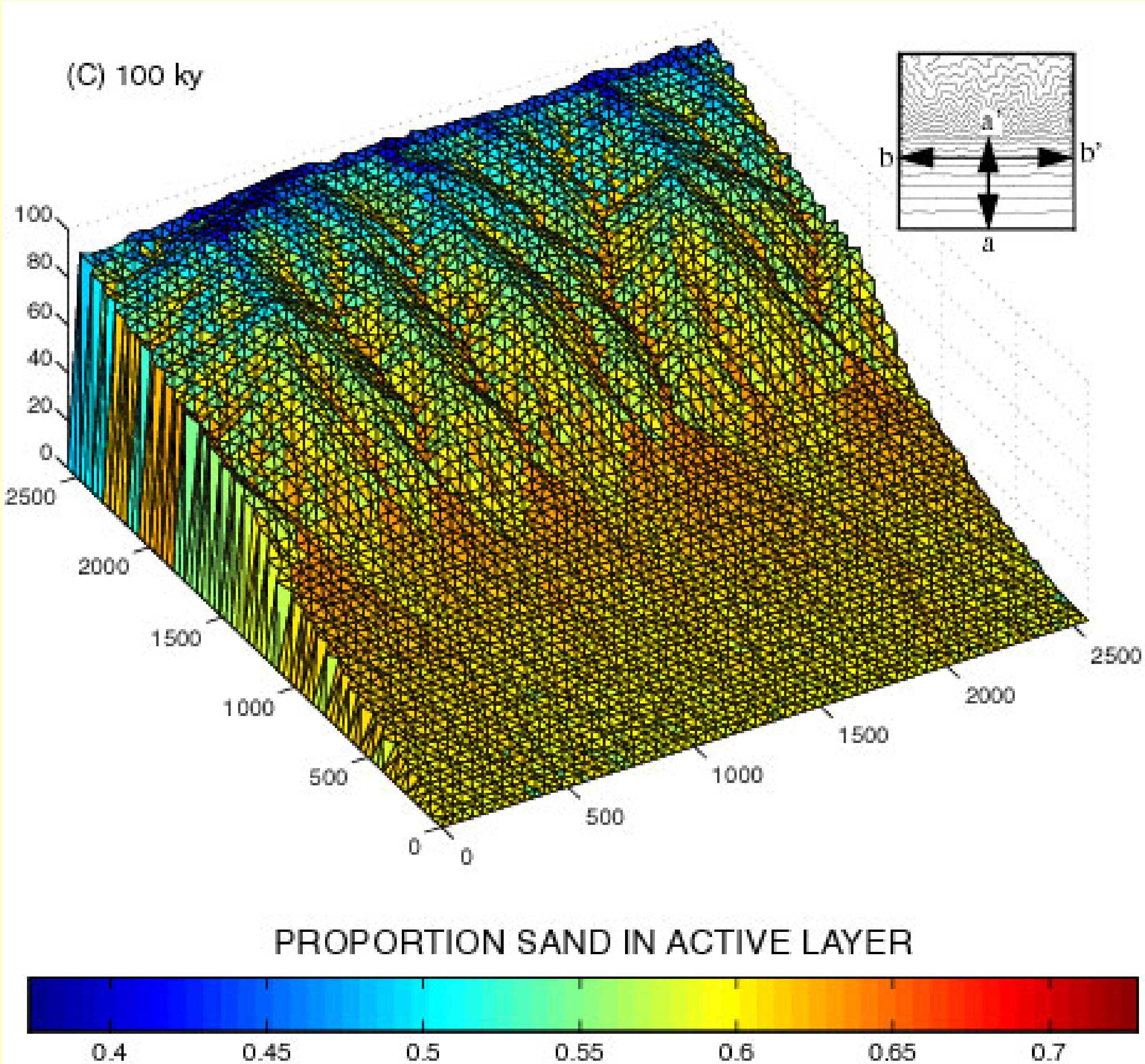


SATURATION-EXCESS RUNOFF

PORE-PRESSURE DRIVEN LANDSLIDING




(A)
dimensions in meters
OLDER
TERRACE
YOUNGER
TERRACE
ACTIVE
FLOODPLAIN
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
(B)
COMPUTATIONAL
MESH


(C) 100 ky
100
80
60
40
20
0
2500
2000
1500
1000
500
0
0
500
1000
1500
2000
2500
a'
b
b'
a
PROPORTION SAND IN ACTIVE LAYER
0.4
0.45
0.5
0.55
0.6
0.65
0.7

Fluvial erosion-transport laws

- Generally modeled as f(discharge [area], slope, sediment flux, grain size)
- Competing "laws"
- Debris flows

Frontiers

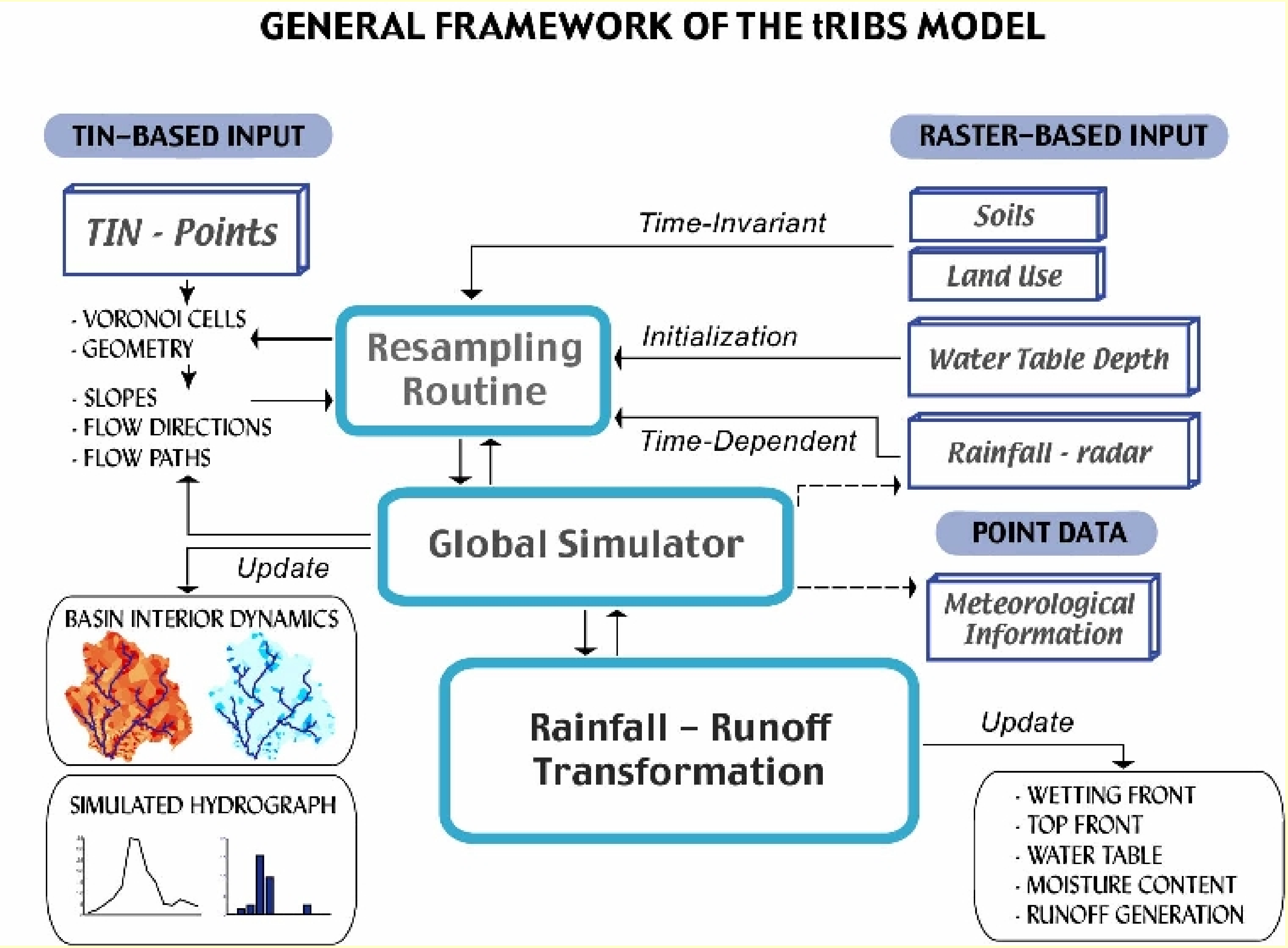
- Testing / refining fluvial erosion-transport laws
- Vegetation
- Channel adjustment
- Stochastic processes / variability
- Scaling

Summary

- Range of models -- transport/erosion laws as multiple competing hypotheses
- Similar models used across space and time scales (soil erosion to orogens)
- Capacity for yielding surprises / insights
- Models evolving rapidly

Lessons from CHILD

- Many potential applications of basic framework / technology


GENERAL FRAMEWORK OF THE tRIBS MODEL
TIN–BASED INPUT
TIN - Points
· VORONOI CELLS
· GEOMETRY
· SLOPES
· FLOW DIRECTIONS
· FLOW PATHS
RASTER–BASED INPUT
Soils
Land Use
Water Table Depth
Rainfall - radar
Time-Invariant
Initialization
Time-Dependent
Resampling Routine
Global Simulator
Update
POINT DATA
Meteorological Information
BASIN INTERIOR DYNAMICS
SIMULATED HYDROGRAPH
Rainfall – Runoff Transformation
Update
· WETTING FRONT
· TOP FRONT
· WATER TABLE
· MOISTURE CONTENT
· RUNOFF GENERATION

Lessons from CHILD

- Many potential applications of basic framework / technology
- Design for growth

Lessons from CHILD

- Many potential applications of basic framework / technology
- Design for growth
- Advantage of “toolkit” design
- Importance of version control, quality control, documentation standards

Design criteria: model(s) should …

- Foster (not constrain) scientific imagination
- Be flexible, adaptable, & extensible
  - Easy to add & change formulations
  - Choice of multiple "laws"
- Be able to operate (with suitable "switches") over a range of space & time scales

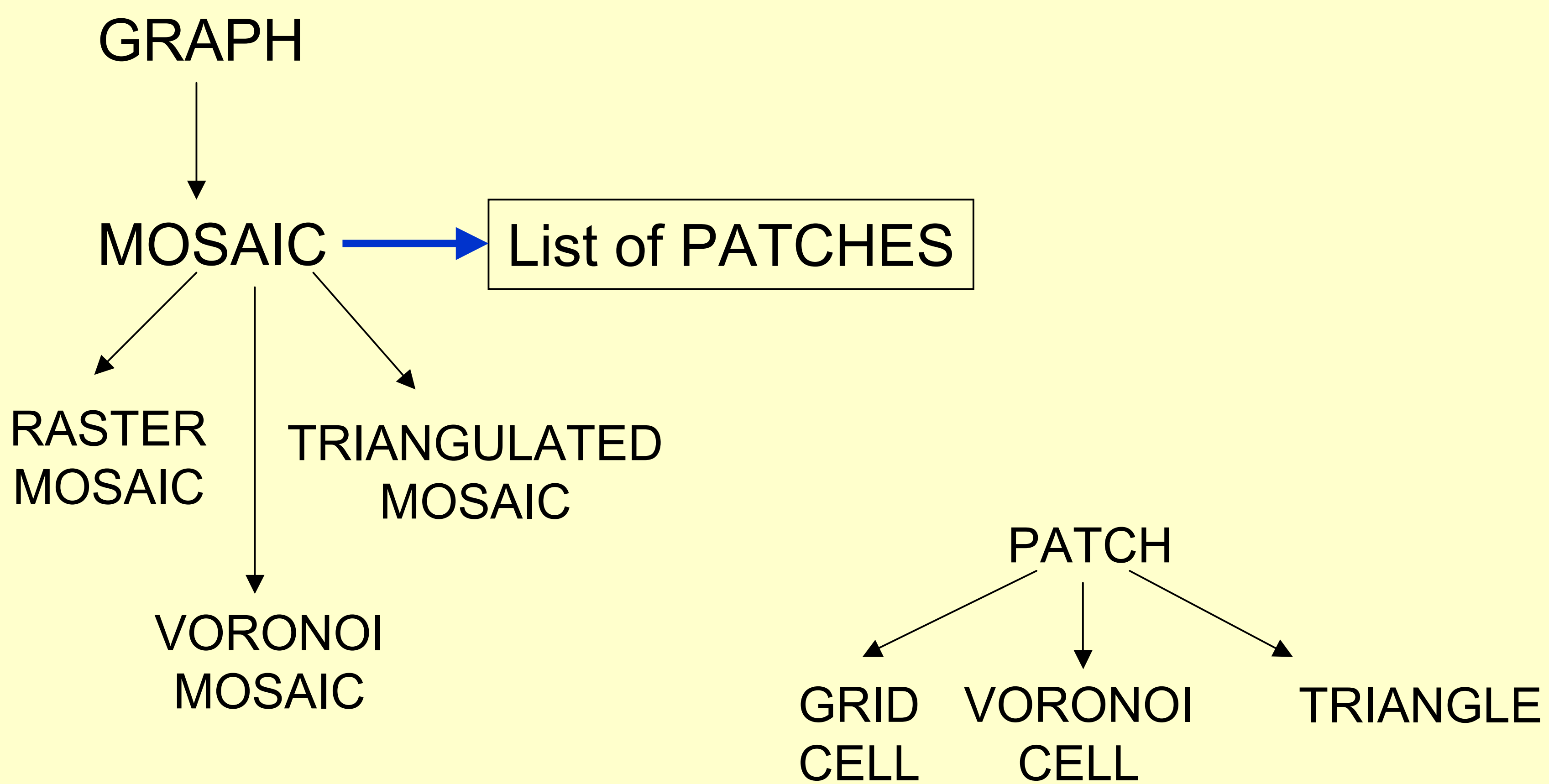
Design criteria: model(s) should …

- Be easy to understand, modify, and engineer
- Interface easily with other models
- Enable concurrent development by many researchers
- Be error-resistant
- ? Provide a range of spatial representations

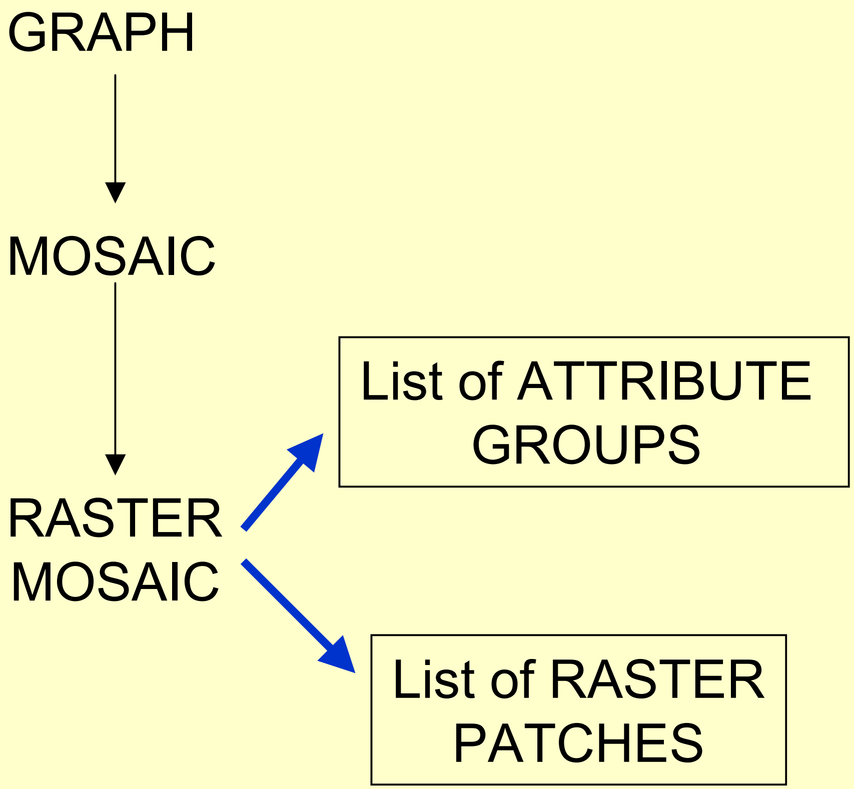
Potential design strategies

- Modularity
  - Interacting components and building blocks
  - Consistent interfaces among components
  - Grouping of related variables & processes
  - “Time” and “space” as modules
- Heirarchical design
  - Ordering of components from general to specific
  - Take advantage of graph theory & computational geometry for spatial domains

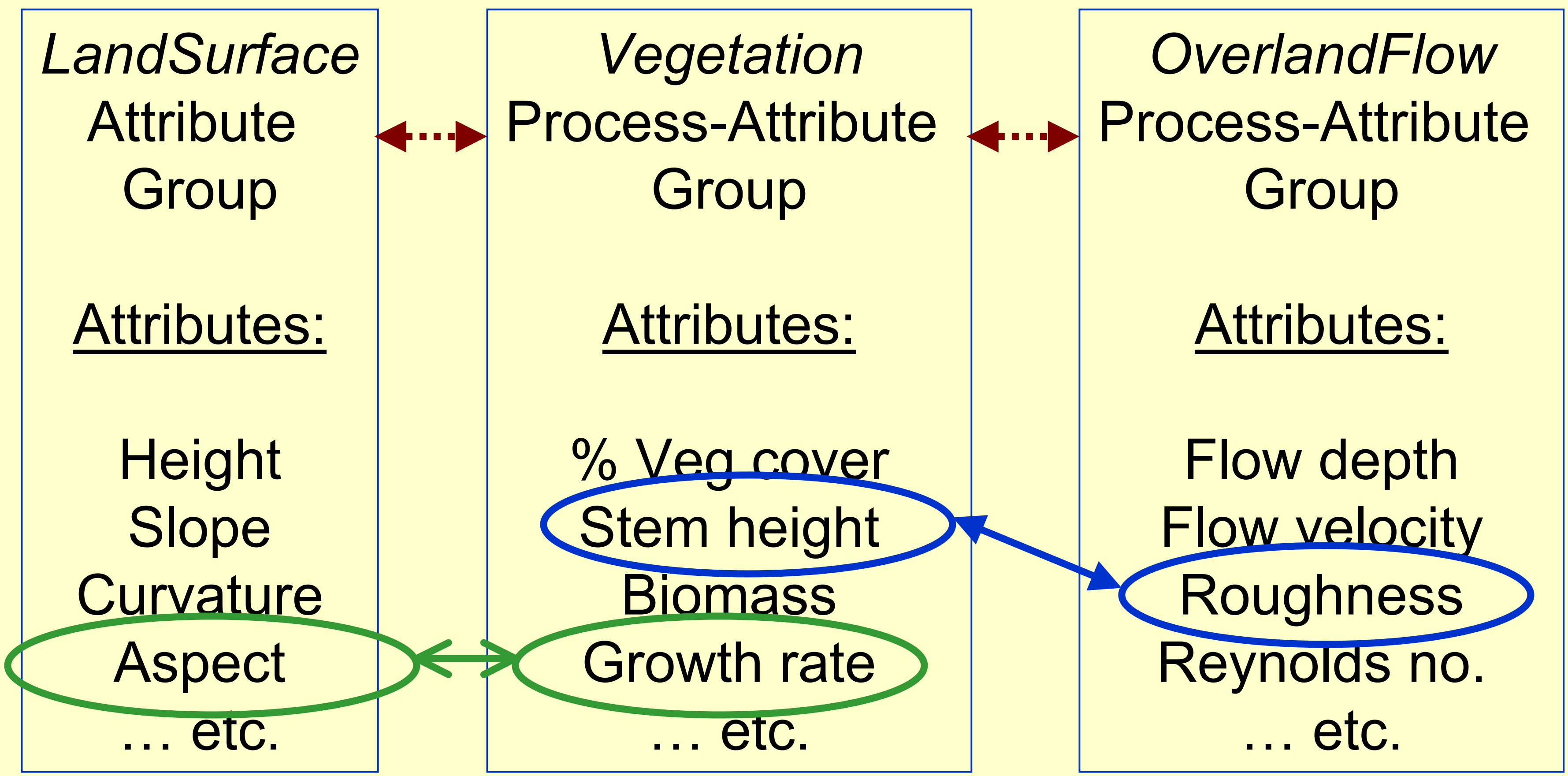
Heirarchical design example



Heirarchical design example



Attributes & Processes



Design strategies (cont'd)

- Object-oriented design
- "Data hiding" and encapsulation
- Literate programming – linking code and documentation
  - *"Models will be the storehouse of new knowledge regarding the fundamental advances in physics and theory" (CSM Proposal)*

Conclusions

"A computational study is unlikely to lead to real scientific progress unless the software environment is convenient enough to encourage one to vary parameters, modify the problem, play around."

- L.N. Trefethen (1998)