Modeling Strategies

Developing A Community Sediment Model
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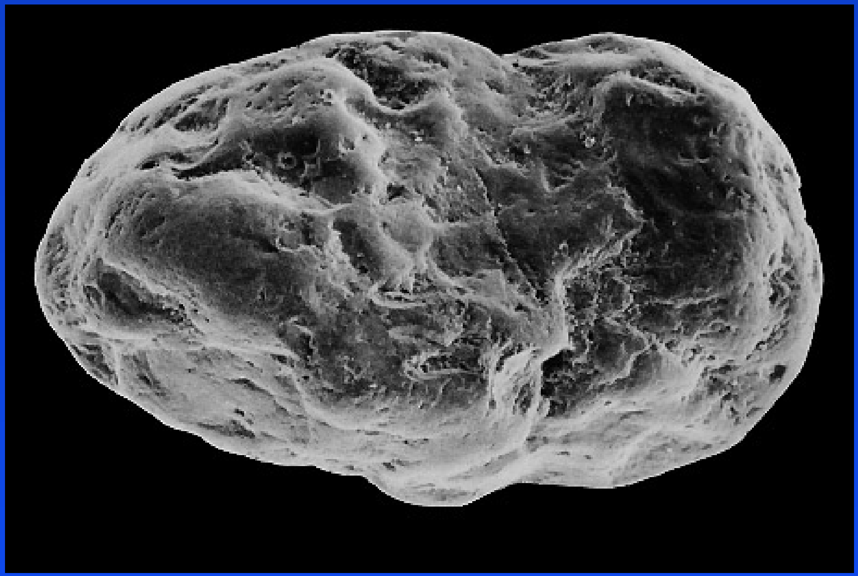
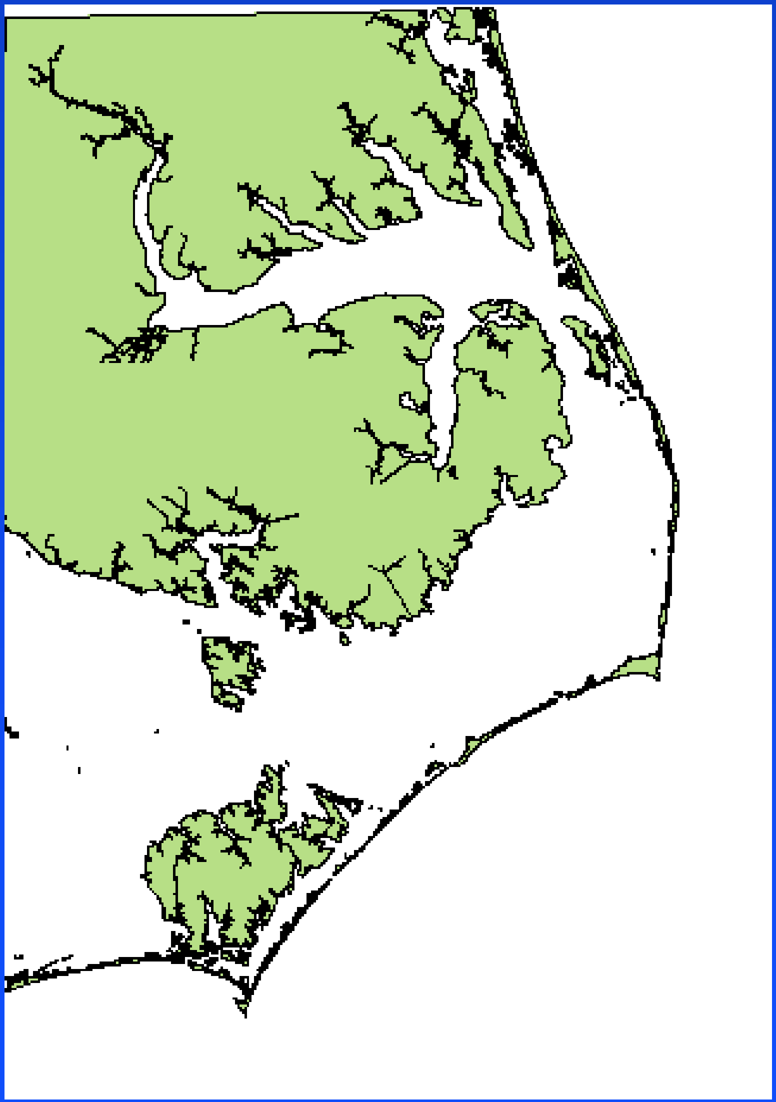
The Problem of Scales





Sand and the Evolution of the Outer Banks

(with digression: hi-resolution topographic/bathymetric data)

Some purposes of modeling

- Analysis of observations
- Hypothesis testing
- Prediction of geomorphic behavior under a variety of conditions, including “unrealistic” ones
- New discoveries of geomorphic or sediment transport phenomena
- Suggestions for research directions

Elements, scope, and coupling

- Geology
- Atmosphere
- Hydrology
- Geomorphology
- Biology
  - Animal
  - Vegetable
  - Human
- Interactions between model elements

Approaches using computers

- Differential eqns (discretize and conquer)
  - Finite difference (not covered in this talk)
  - Finite element (not covered in this talk)
  - Path-sampling
- Rule-based
- Cellular
- Hybrid (e.g. finite difference + path + cellular)
- Stochastic models (overlap with all above)
  - Incorporate essential random components of processes
  - Estimate probability distributions

Choosing one or more approaches

- Model elements described by well known physics: discretization and solution of PDEs
  - Atmosphere -- e.g., various GCM and other models for smaller length and time scales
  - Oceans -- e.g., POM (finite difference), ADCIRC (finite element)
- Particle-based
  - Discrete particles, e.g. sediment transport
  - Path-sampling methods
- Rule-based -- e.g. biological interactions
- Cellular -- local interactions: e.g. braided streams, eolian dunes
- Hybrid (e.g. finite difference + path + cellular)
- Stochastic models (overlap with all above)
  - Incorporate essential random components of processes
  - Estimate probability distributions

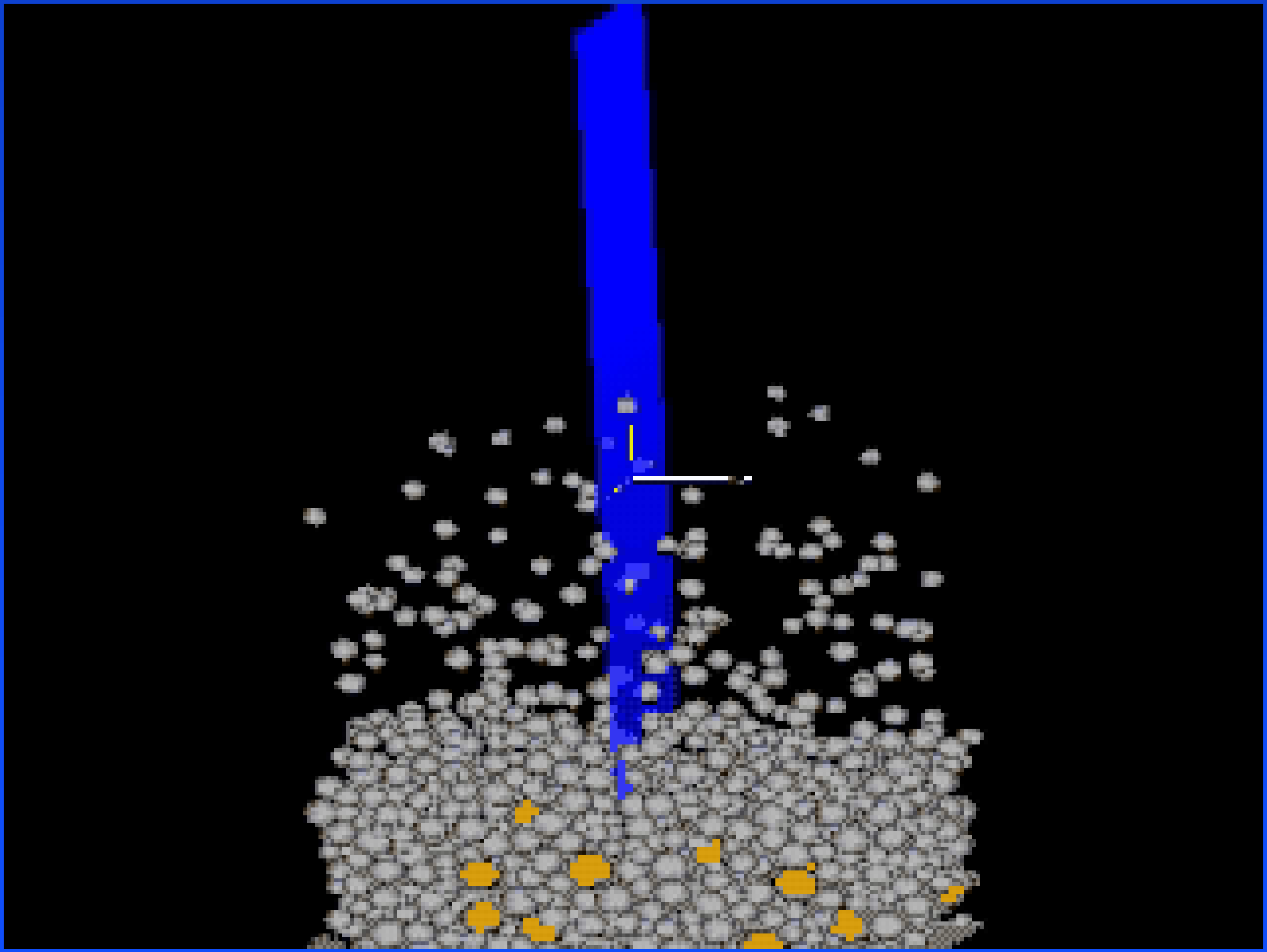
Focus on particle,cellular, and path sampling models

- Address discrete nature of sediments
- Problems (i.e. “opportunities”) that arise at the boundaries between models
- Physics poorly known
- F = ma not the relevant physical law (e.g., vegetation growth and interaction with landscape evolution)
- Linking mesh-free models to those requiring meshes

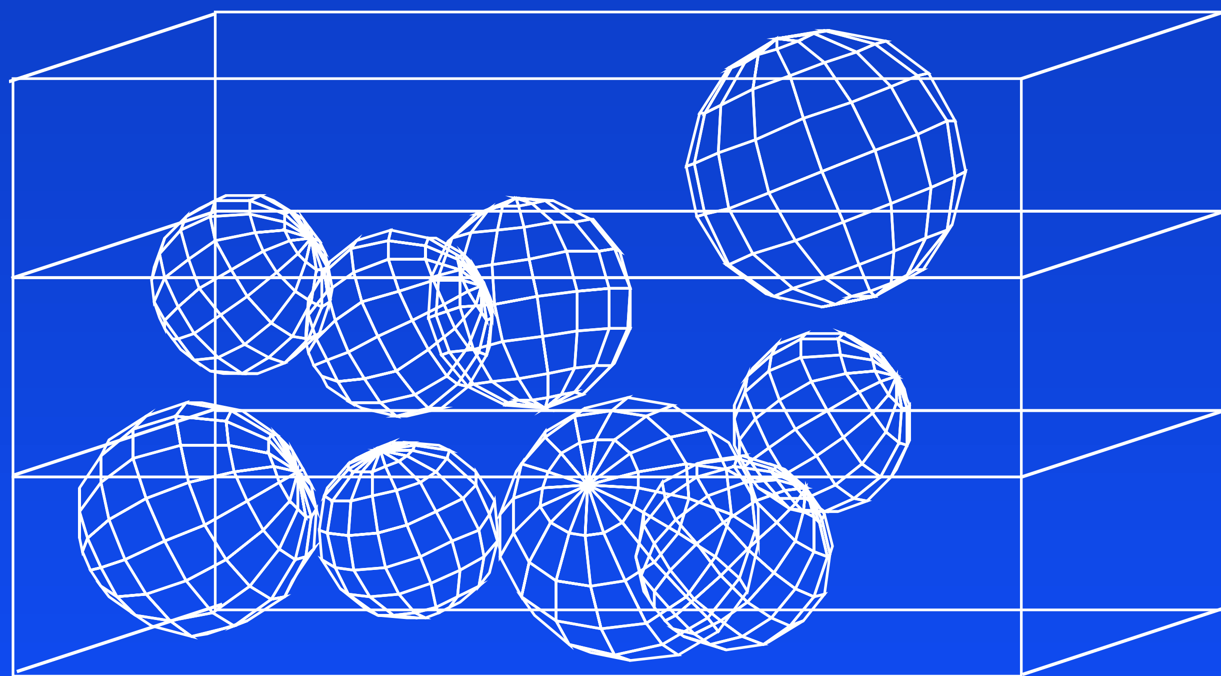
Examples from coastal sediment transport studies in North Carolina

- Grain-scale transport processes O (mm, s)
  - Transport rates of different grain sizes
  - Grain sorting and generation of stratigraphy
- Bedform genesis and evolution O (m, h)
- Meso-scale features O (tens of m, weeks)?
- Influence of underlying geology O (km,years)
  - Structural and lithologic control of morphology
  - Implications of insufficient sand supply?

Sheet flow transport in the surf zone in real time



Simulations



Interactions:

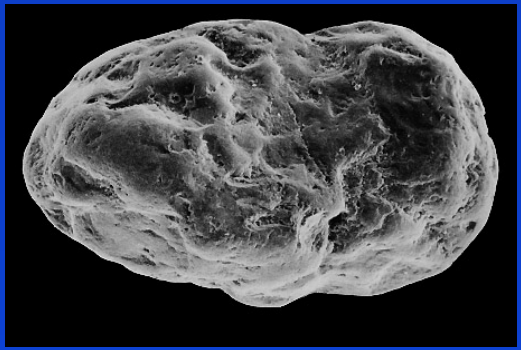
Grain-grain: elastic-plastic theory & experiment
Grain-fluid: buoyancy,drag, virtual mass
Fluid-fluid: eddy viscosity model

Fixing the Bagnold/Bailard/Bowen model for bedload transport

$$\langle q \rangle = \frac{\rho_s}{g(\rho_s - \rho)} \rho c_f \frac{\varepsilon_b}{\tan\phi} \langle u(t)^3 \rangle$$

For cross-shore flow with no steady currents

Grain-scale summary



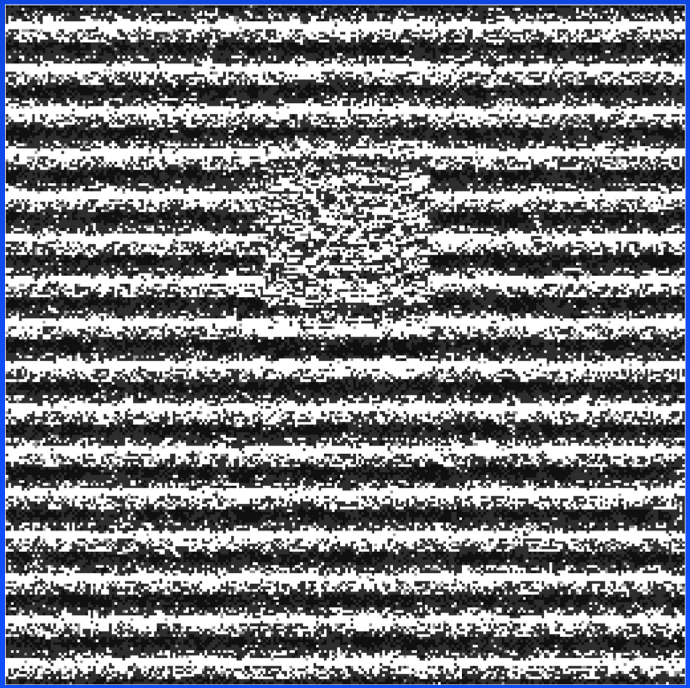
- Discrete-particle models can provide parameterizations for larger scales
  - Bulk and size-dependent transport laws, rheologies of debris flows
- Generate sedimentary structures on a grain-by-grain basis

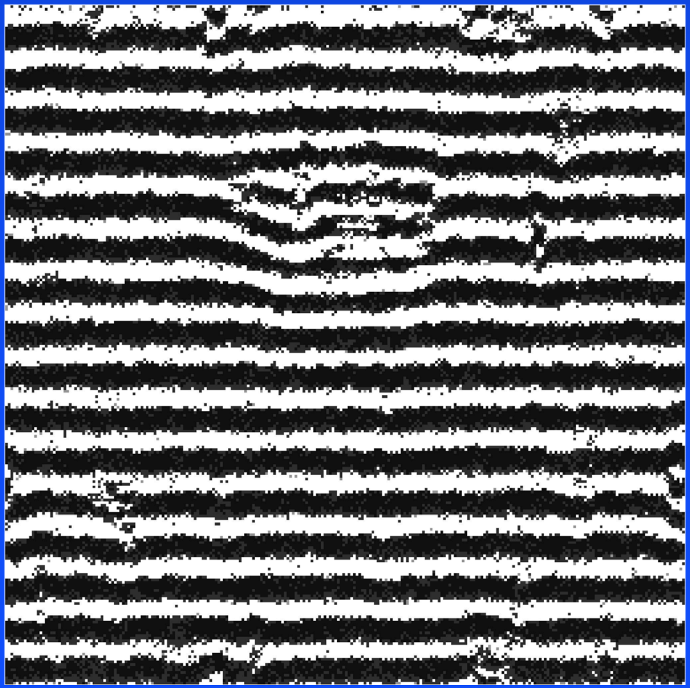
Sediment transport length scales

- Grain-scale transport processes O (mm)
  - Sorting and generation of stratigraphy
- Bedform genesis and evolution O (m)
  - Patterns and domains
- Meso-scale features O (tens of m)?
- Influence of underlying geology O (km)
  - Structural and lithologic control of morphology
  - Effect of insufficient sand supply?

Cellular Modeling Approach

- Example: Lab studies of bedform evolution
  - Patterns generated by local interaction
- Attractive for determining minimal physics responsible for pattern formation
- Theoretical models (Werner and coworkers)

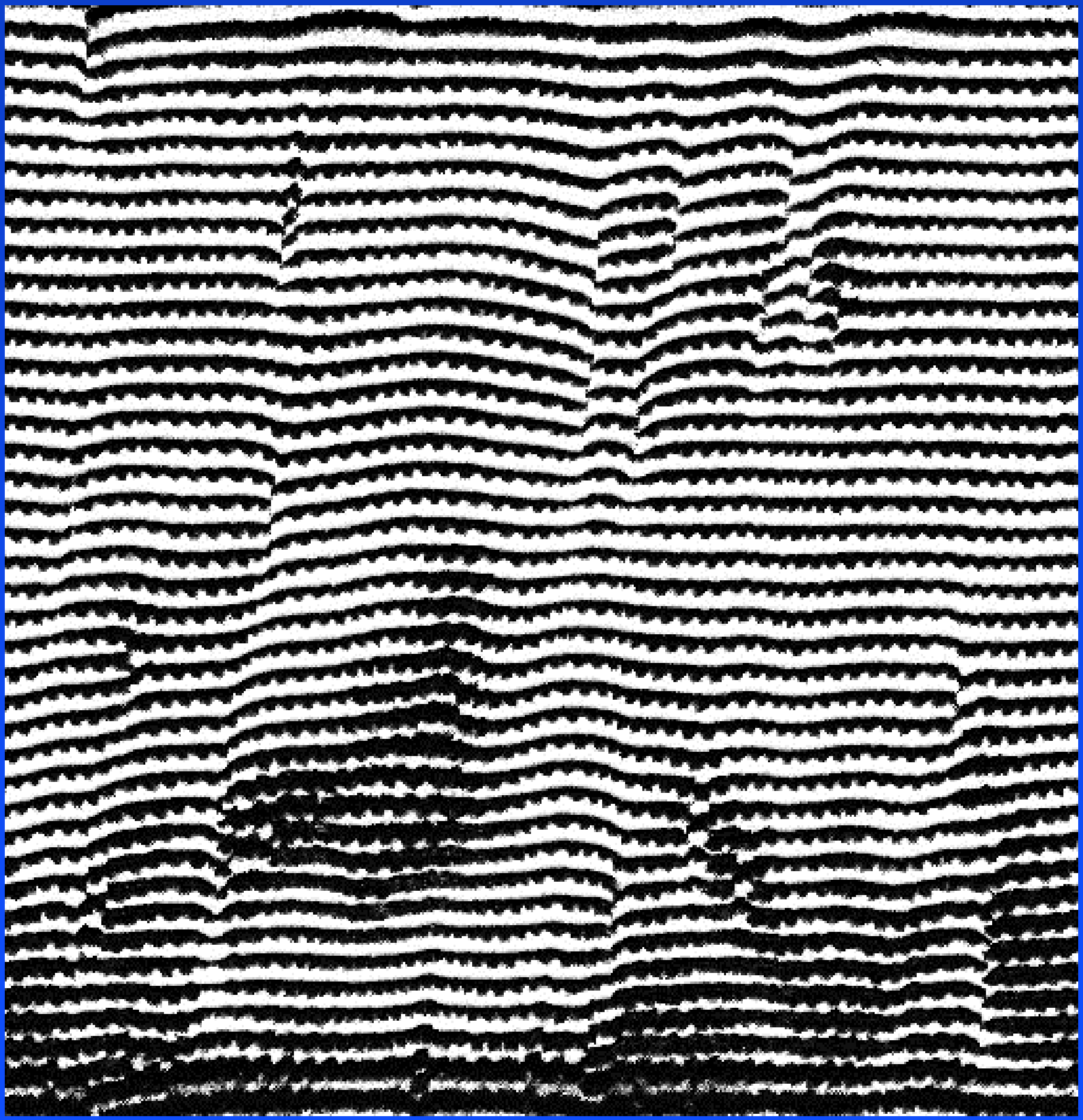




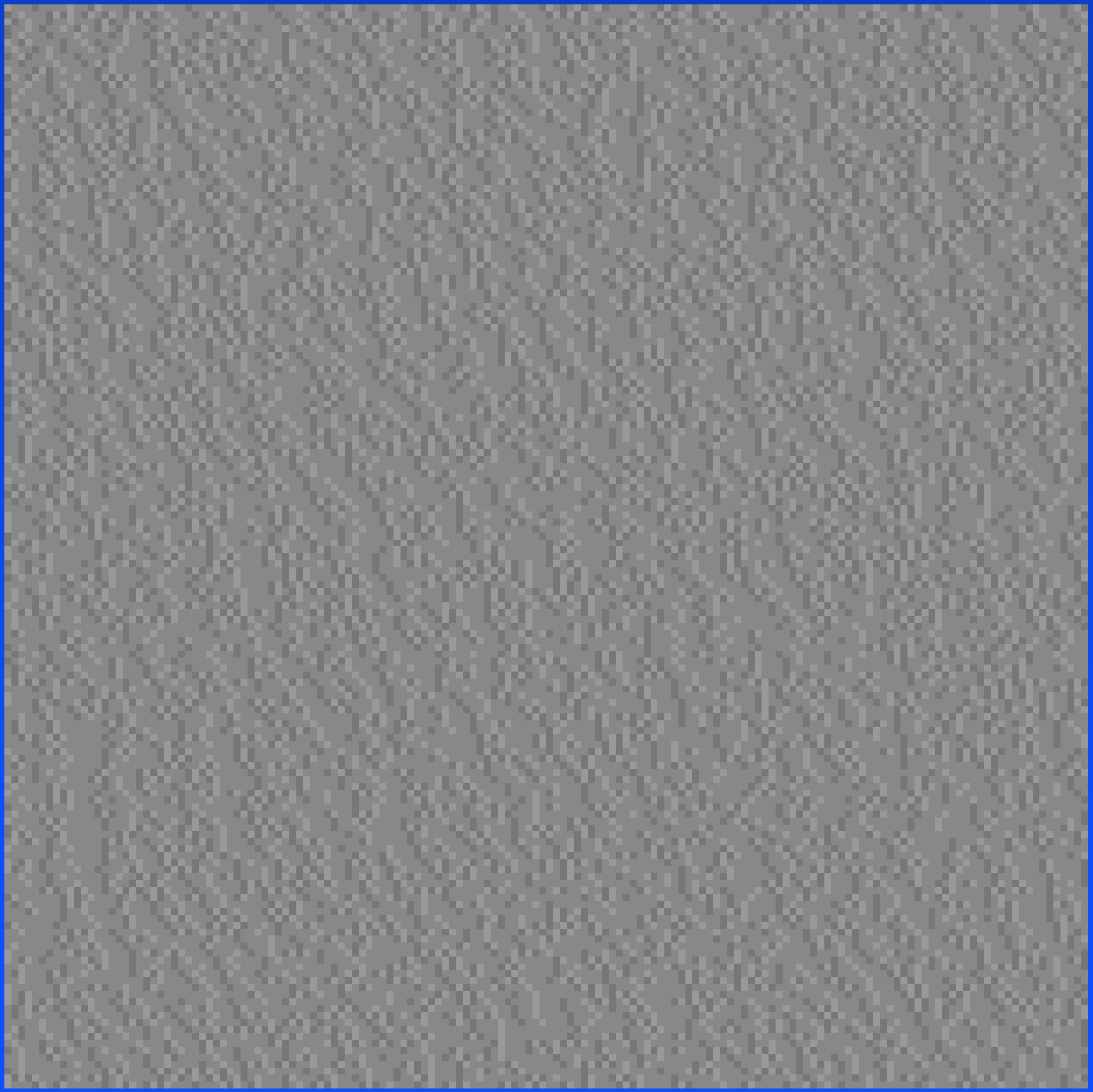
Coarse-grained cellular bedform simulations

- Sand slabs 1 cm square and 1 mm thick
  - Quasi-particles consisting of thousands of grains
- Slabs move on lattice of square cells
- Erode and deposit according to rules derived from
  - simulations of individual grains
  - physical experiments
  - analytical theory
  - or commonly, some combination of all three approaches.

Domains bounded by ripple imperfections



Megaripple simulation



Simulation Results

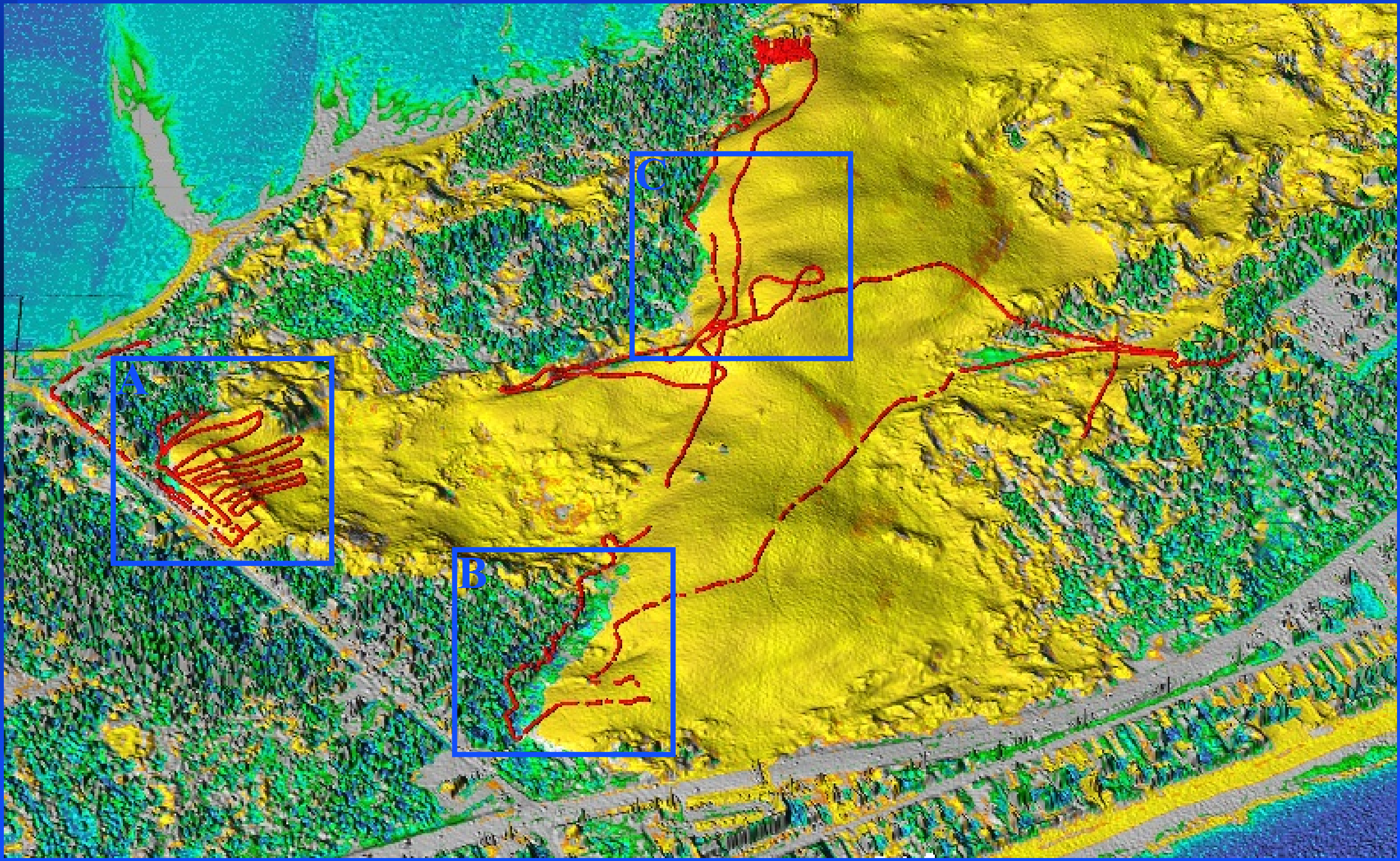
- Imperfections migrate in direction of waves at 3 to 4 times rate of bedform migration
- Areal density of imperfections decreases exponentially with time

Questions:

- Physical mechanisms by which defects migrate?
- Degree of coupling with flow?
  - One-way flow to bed interaction seems sufficient, at least in this case

Jockey's Ridge, NC: data integration

IR-DOQQ, LIDAR (USGS) and RTK GPS to assess and model dune evolution for park management (courtesy of H. Mitasova)



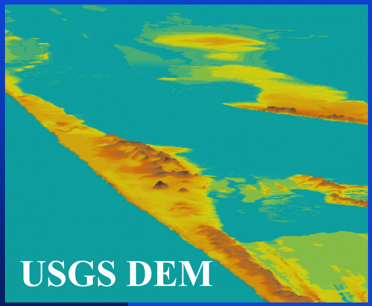
Jockey's Ridge 2000 - 2002

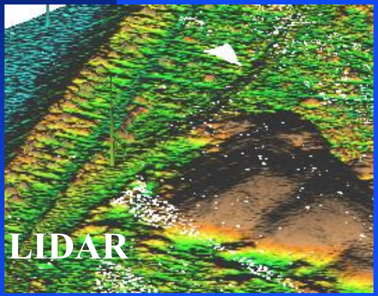
2000

2002

Rapid exhumation of putt-putt golf castle

Digital nearshore data and GIS





USGS DEM, digital photogrammetry, RTK GPS, LIDAR, nearshore bathymetry from multibeam surveys; and conventional sonar

Challenges:

- **massive data sets, oversampling**
- **noisy data and complex surfaces**
- **anisotropy and heterogeneous coverage**
- **almost all data are spatio-temporal**

Fast, accurate and consistent transformation between the measured data and GIS data models is necessary: grid, contours (vector), sites

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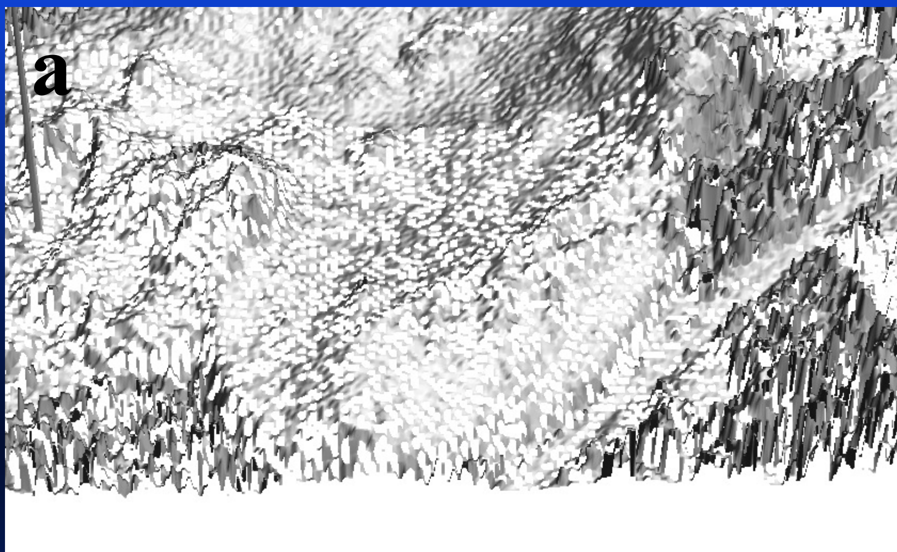
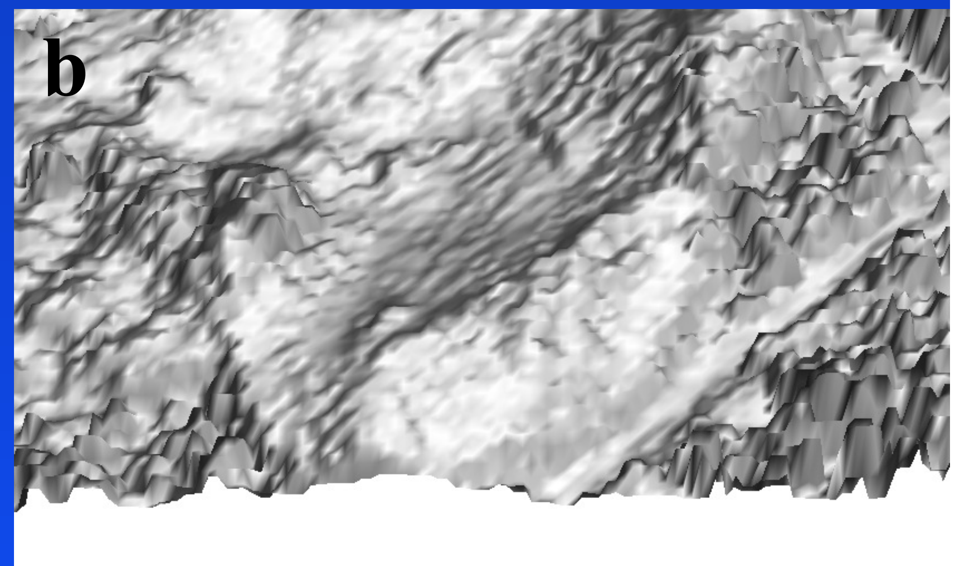
Jockey's Ridge LIDAR data

Enhancing information content through interpolation





points assigned directly to a grid:
a) 1 m and b) 3 m resolution

c) RST interpolation:

1-m resolution grid

all points with distance > 0.5m are preserved

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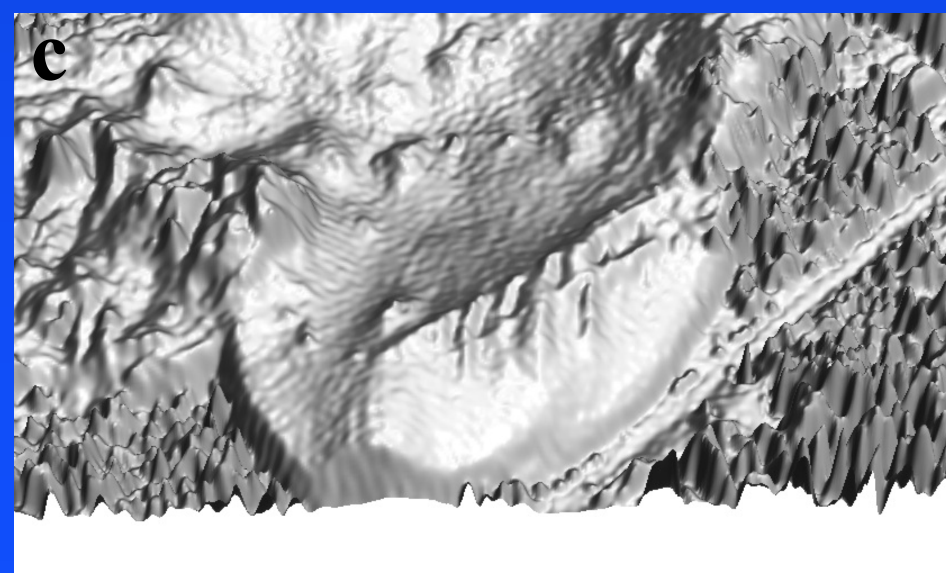
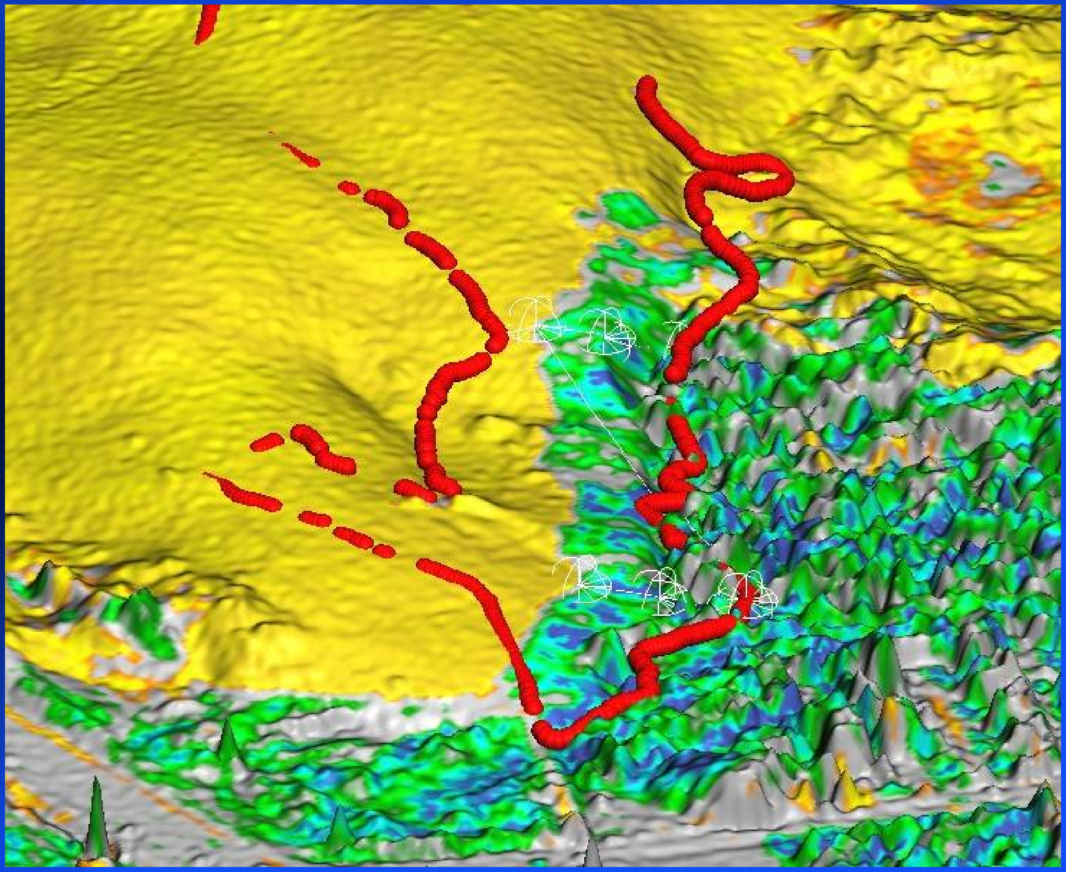


Dune movement based on
1998 (IR-DOQQ) - 1999 (LIDAR) - 2002 (RTK-GPS)



Approaches:

- Cellular model
- Crest migration (e.g., A. Valance)
- Data smoothing
- Data integration (crests and vegetation from georeferenced air photos)
- Note: only wind data from 20 km north at Duck Field Research Facility

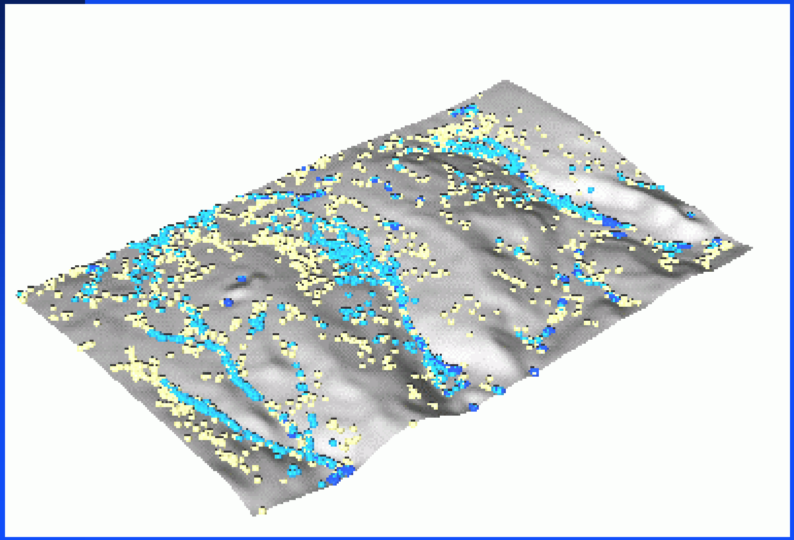
H. Mitasova

Path-sampling approaches:
(Mitasova and Mitas)

uses duality between particle and field representation to solve the governing equations

Transformation between these representations:

- **particles -----> particle density function --> field *f* (r)**
- **field *f* (r) -----> sampling with density *f*(r) --> particles**
- **Process can be modeled as evolution of particles or fields**



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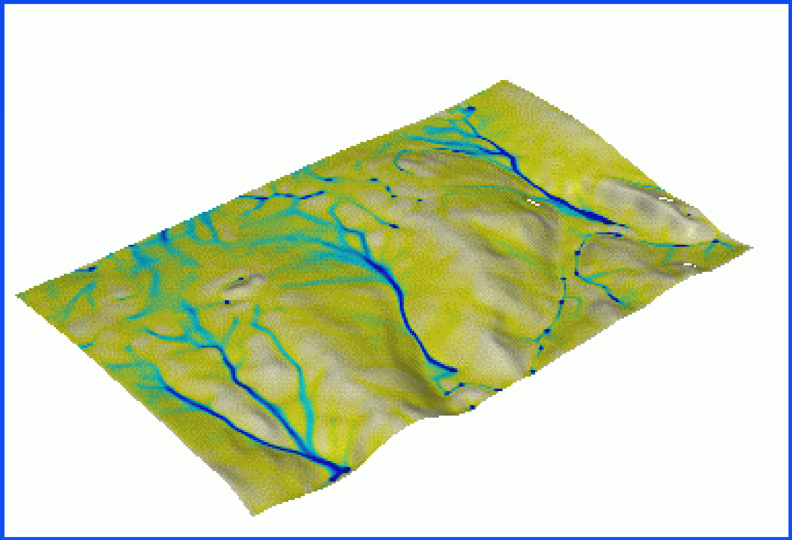


Path-sampling:

Method for solving linear partial differential equations developed in physics, used also in chemistry, finance, and other disciplines.

Governing equation: $L(c) = S$ (Mitasova and Mitas)

S is sources-sinks

c is the modeled quantity

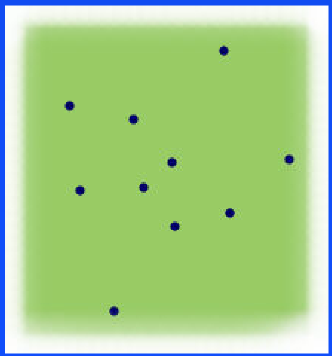
L is the operator

e.g.,diffusion+ flow/drift + proliferation/decay

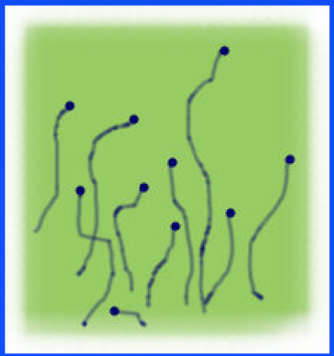
Solution: $c = L^{-1}(S)$

L^{-1} is the inverse operator

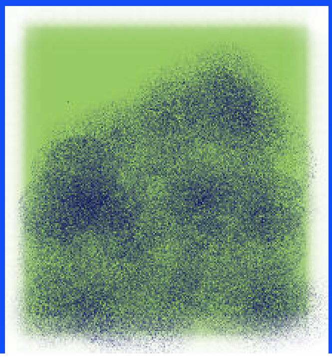
sample the source term field



simulate action of L^{-1} on S

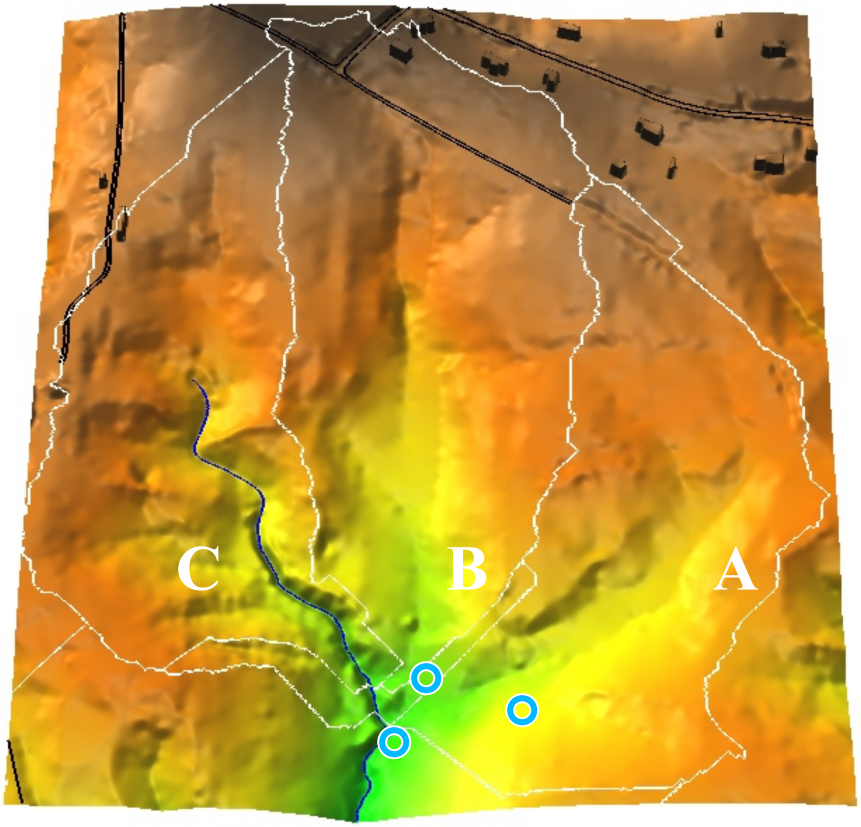


estimate c from density

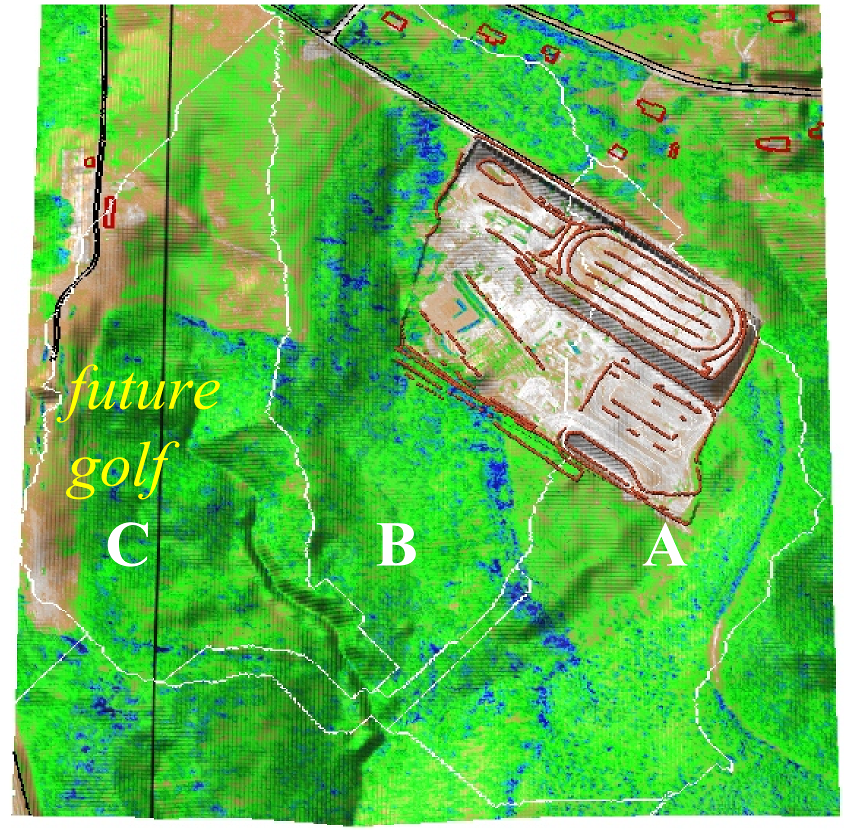


Impact of development on water and sediment flow: Centennial Campus

1993 (pre-school)



2002 (after construction)

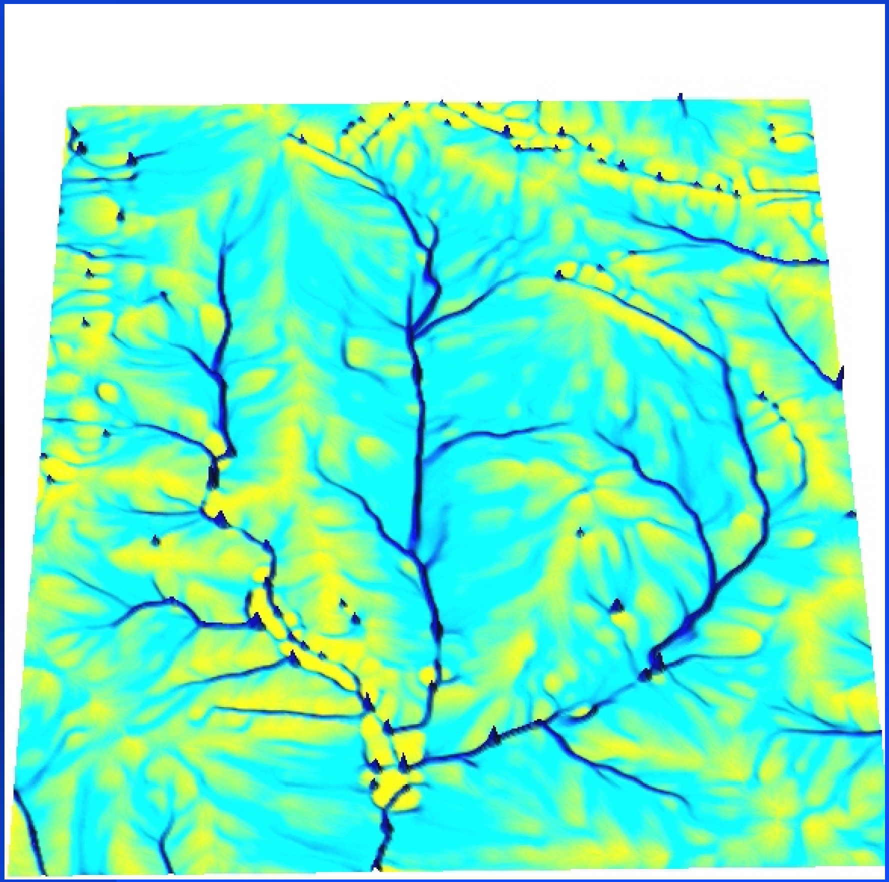


6 ft resolution DEM interpolated from 2 ft contours by RST (Austin, Mitasova)

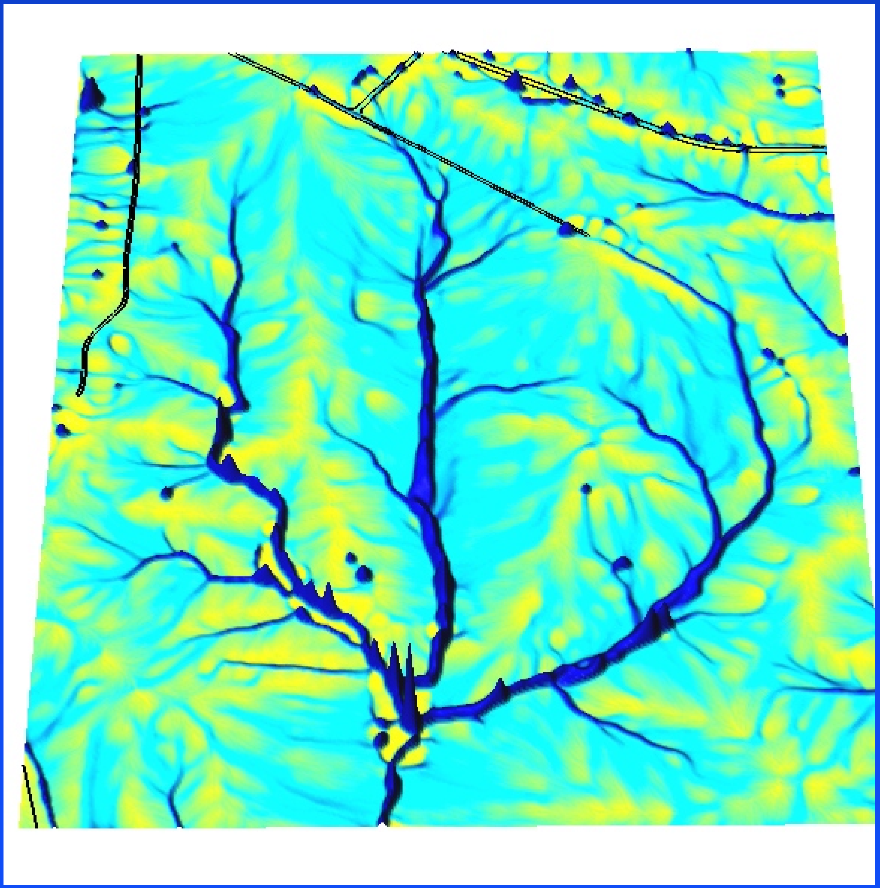
1998, 2001: IR-DOQQ, change in elevation from RTK GPS

Overland flow 1993 topography

10 min since start of runoff



60 min since start of runoff



SIMWE test run: uniform soil, cover, rainfall
2D approximation to the diffusive wave solution crucial for realistic description of water detention areas (blue dots) -- confirmed in the field

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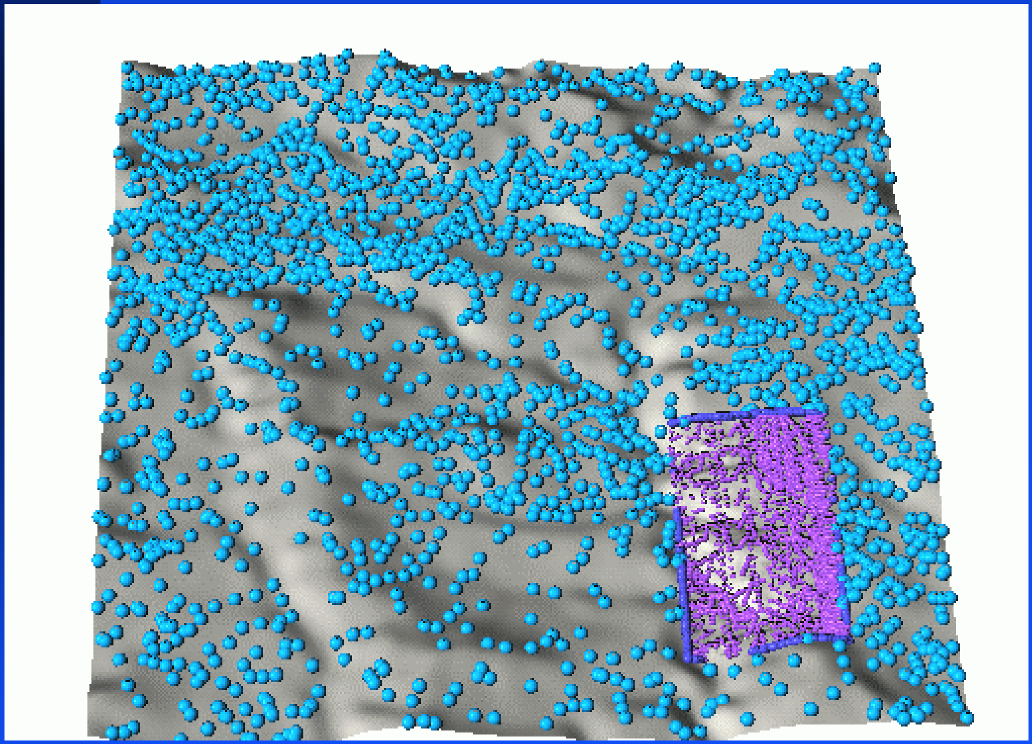
Multiscale simulations

Multiscale simulation of overland water flow:

density of walkers is adjusted to resolution



Entire area:

10 m resolution

~400x400 grid,

Inset:

2m resolution

600x400 grid

Potential for modeling critical areas such as:
beach erosion hot spots and effects of best management practices

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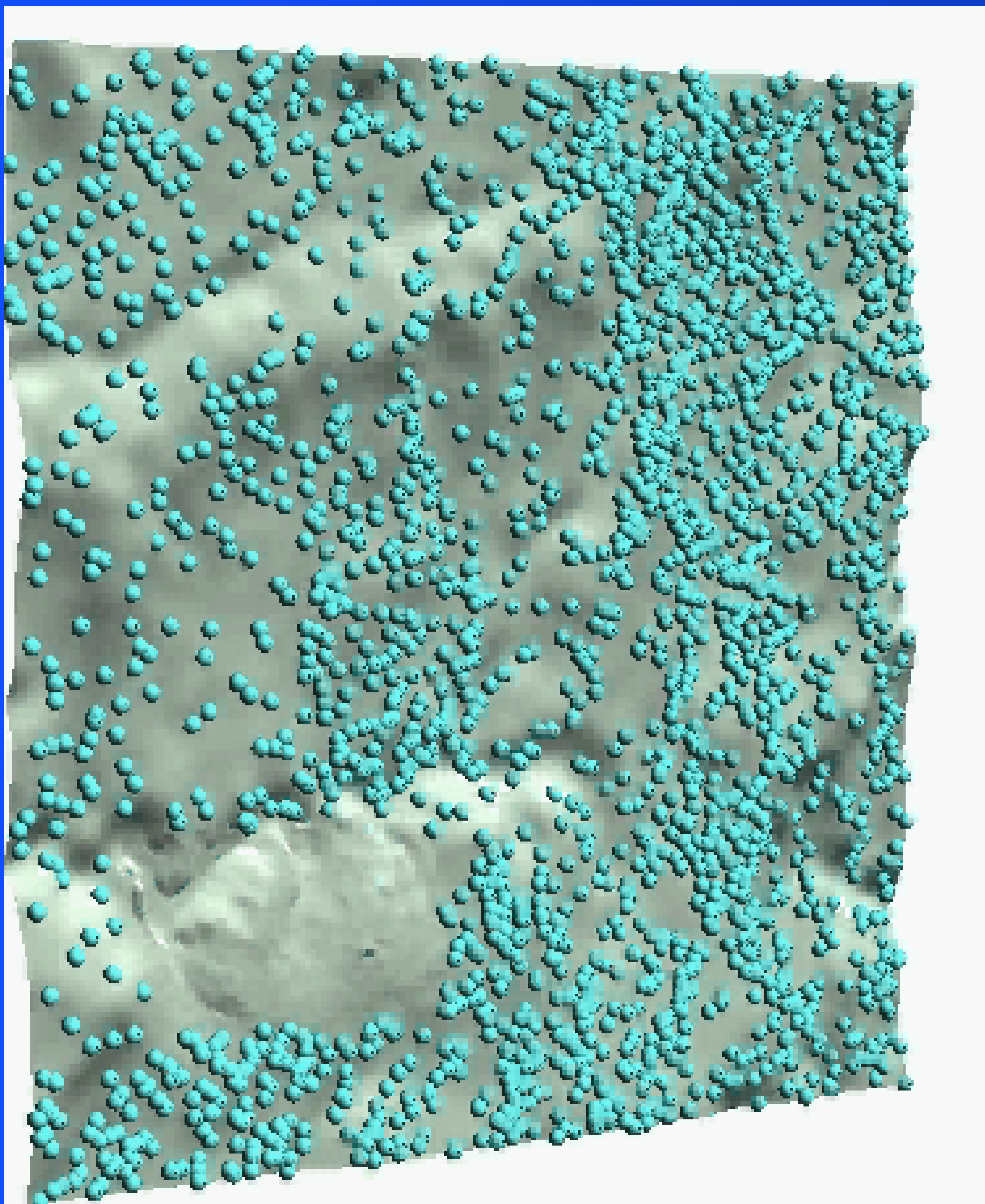


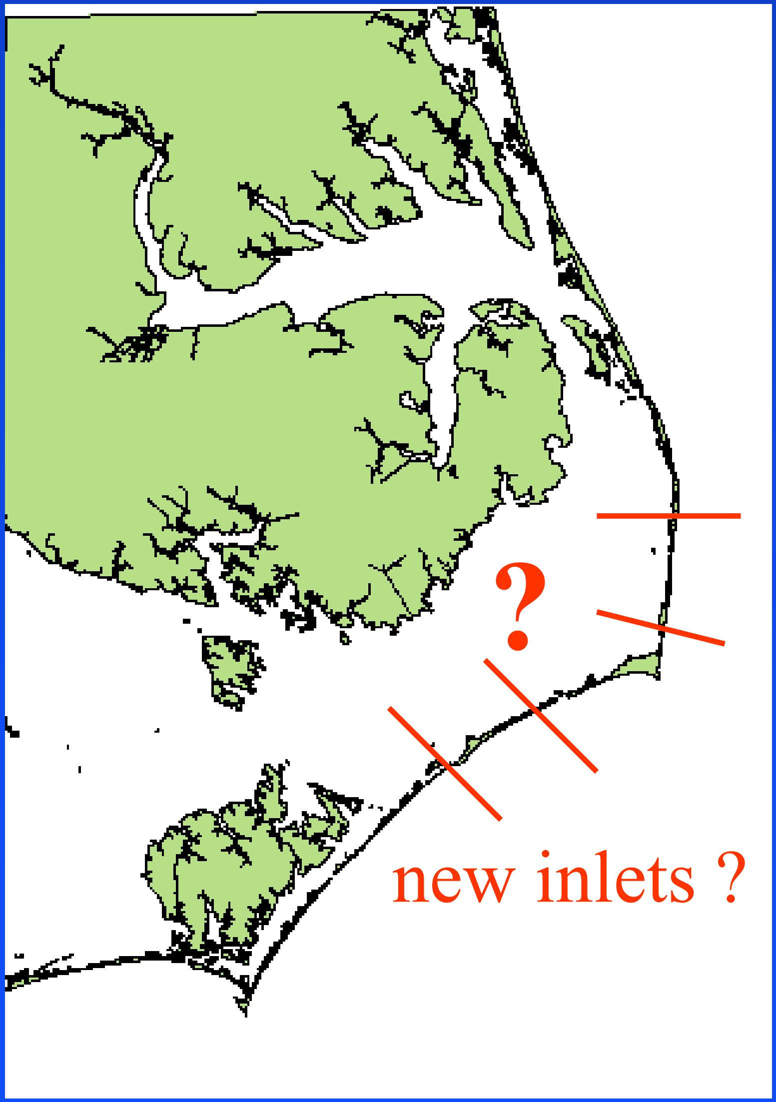
Stitching computational approaches together

- Example: Jump out of a cellular braided stream calculation to estimate size-sorting via discrete particle simulation
- Example: Use a lookup table for sedimentary deposits like cross bedding (instead of trying to do the physics); or for existence/absence of bedforms in the surf zone in a circulation model
- Example: Use a mesh-free path-sampling technique to route barrier island overwash from a finite-difference model for coastal circulation

Sediment transport length scales

- Grain-scale transport processes O (mm)
  - Sorting and generation of stratigraphy
- Bedform genesis and evolution O (m)
  - Patterns and domains
- Meso-scale bed features O (tens of m)
- Influence of underlying geology O (km)
  - Structural and lithologic control of morphology
  - Effect of insufficient sand supply?

NC Outer Banks



Example:
Path-sampling to locate potential sites for new inlets generated by overwash coupled to a nearshore mesh-based circulation model.

Circulation model can predict nearshore wave heights, then use empirical swash runup relations to initialize path sampling "walkers." Such techniques can address details of coastal DEMS, unlike the mesh-based circulation model.

Summary

- Grain-scale models
  - Address a distribution of sizes -- a critical consideration for generating sedimentary deposits
  - Generate parameterizations for computational approaches at other time and length scales
- Cellular models
  - Rule-based description of pattern evolution
  - Generate statistical description of systems governed by local laws, e.g. dune fields, braided streams
- Path-sampling models
  - Exploit the duality between particles and fields; mesh-free

References

- Tom Drake's WWW page

  http://www.meas.ncsu.edu/faculty/drake/drake.html

- Helena Mitasova's WWW page

  http://www2.gis.uiuc.edu:2280/modviz/helena/helena.html

- GRASS GIS

  http://www3.baylor.edu/grass/