How Landlab has helped my research

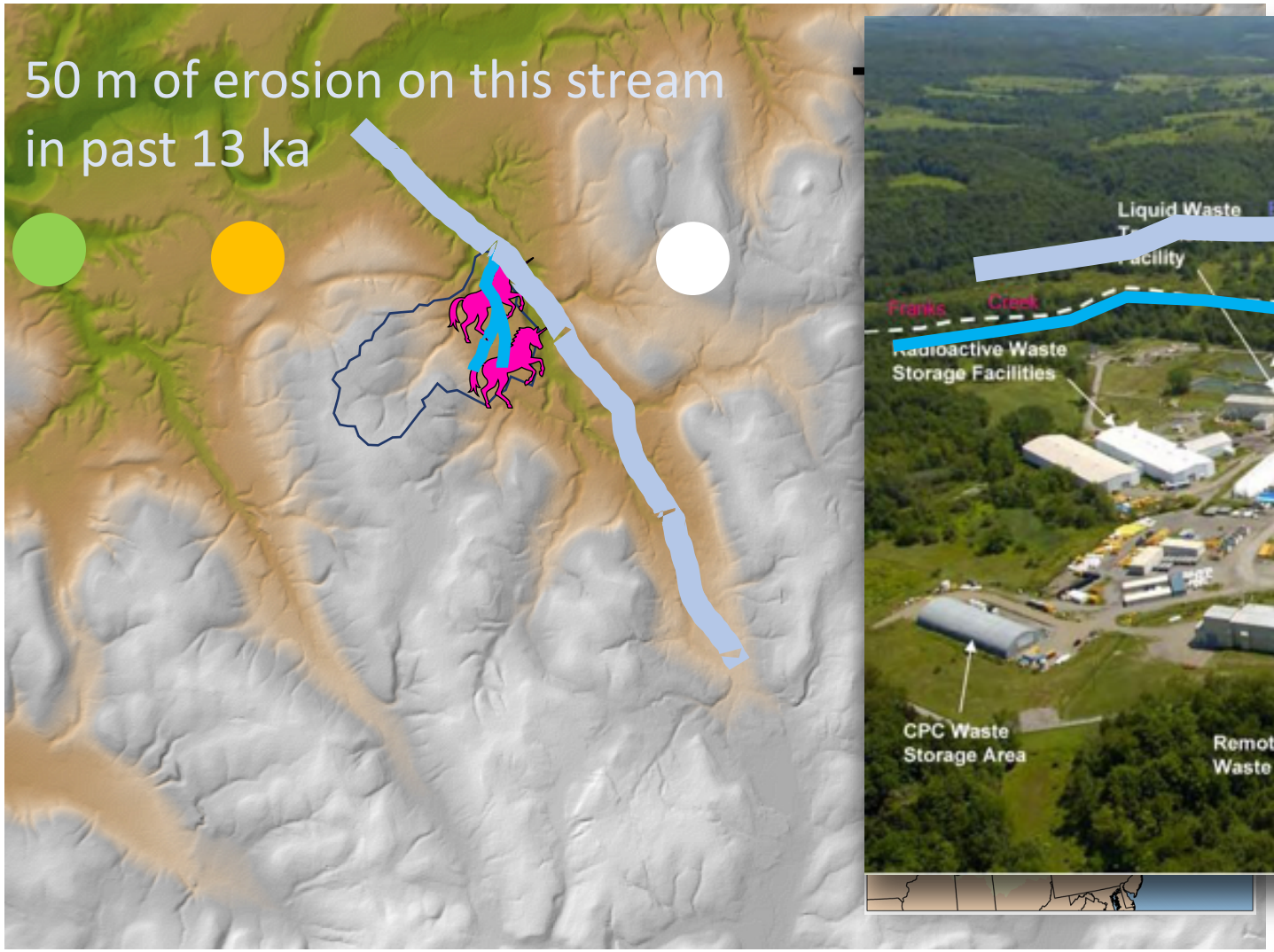
Case Study 1: Predict the erosion of a nuclear waste site on 10,000 ka timescale

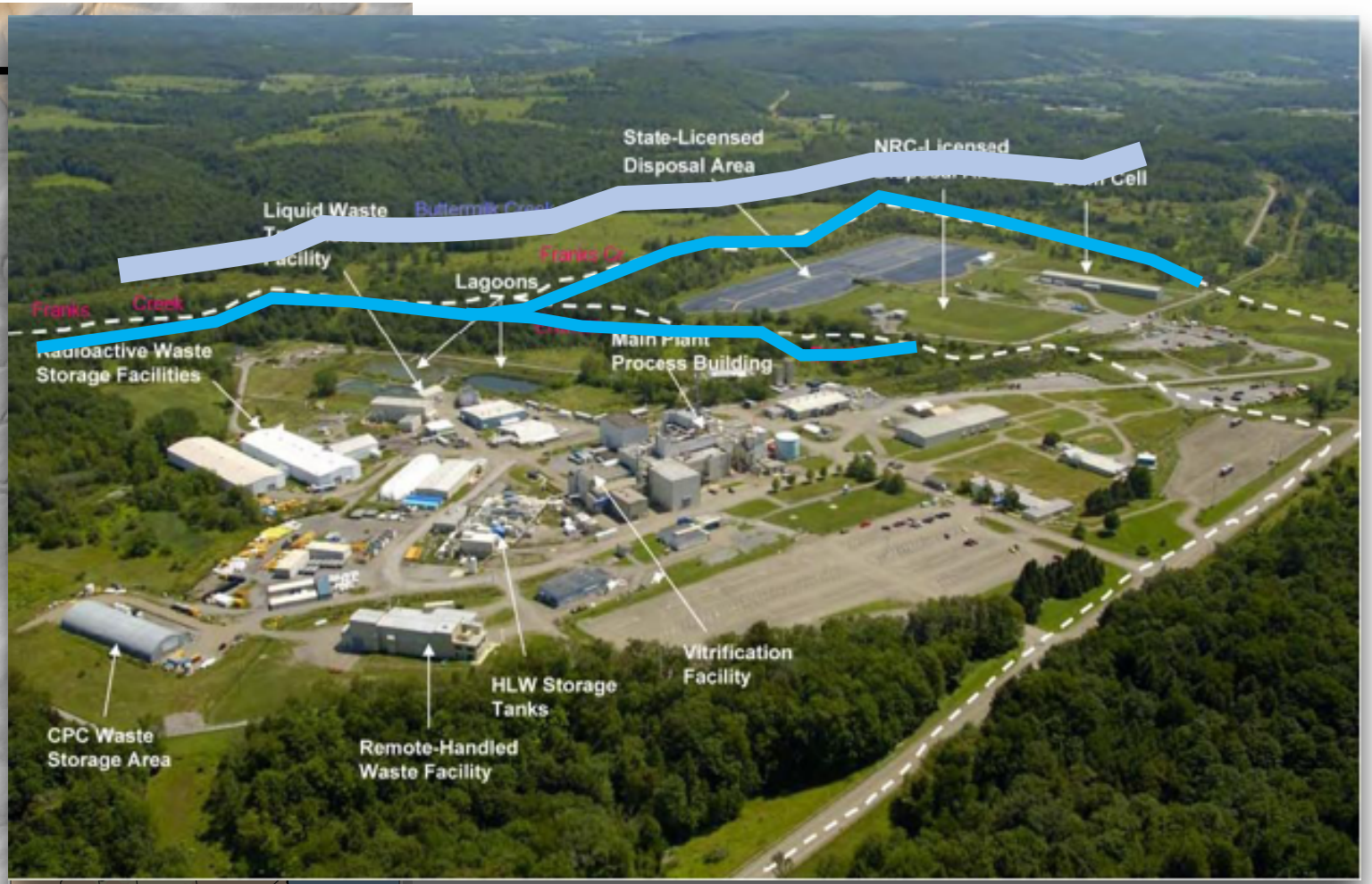
Case Study 2: Infer dynamics of debris-flow site from repeat drone-based imagery

(funded by an NSF EAR Postdoctoral Fellowship)

Katy Barnhart **CSDMS Interagency Meeting** Nov 4, 2010

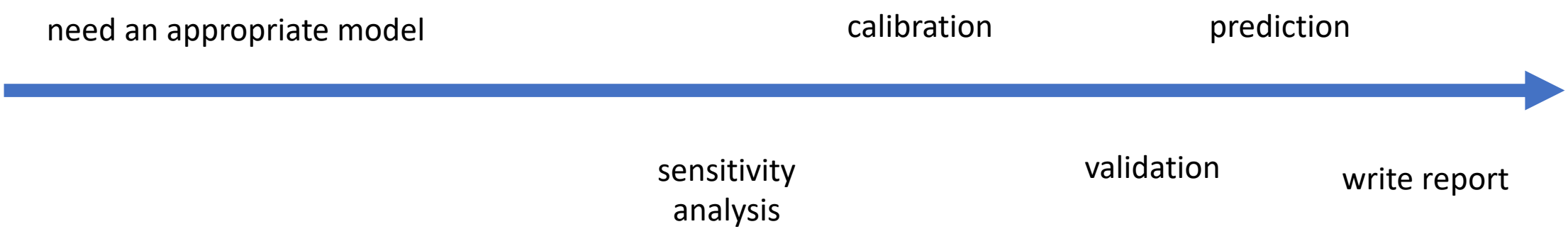
task: make predictions of erosion 10,000 years into the future



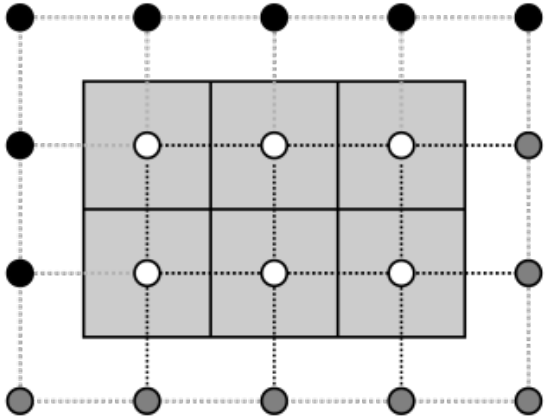


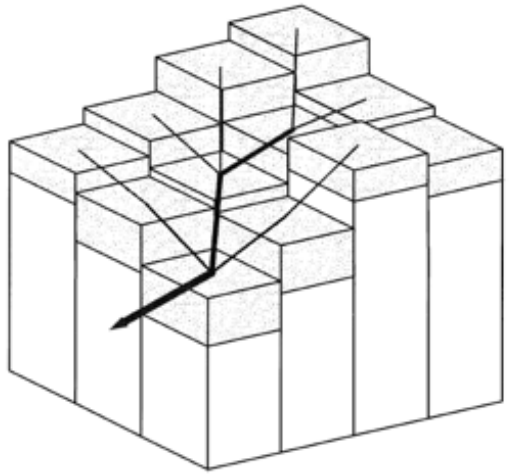
Waste disposal, 1966 - 1975

- 16-acre commercial low-level waste disposal site
- 6-acre high-activity disposal site
- 20’ deep trenches in clay-rich till



There is no standard model for this sort of system…
How then to account for uncertainty in which model to use?





Landscape Evolution Models

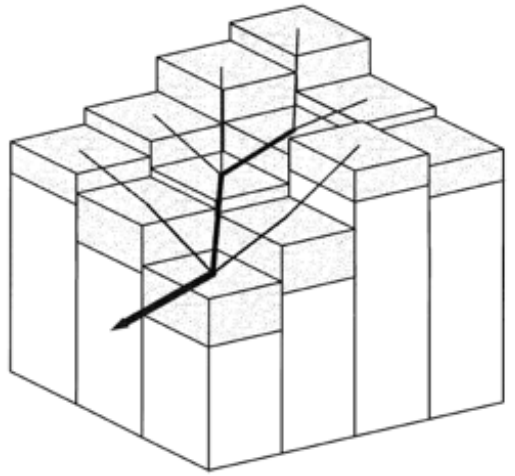
- Representation of topography (raster grid, irregular mesh)
- Method to create and route water
- Diffusion-like erosion and transport
- Channel erosion (and sometimes transport) depends on **slope** and **drainage area**
- Representations of other geomorphic processes

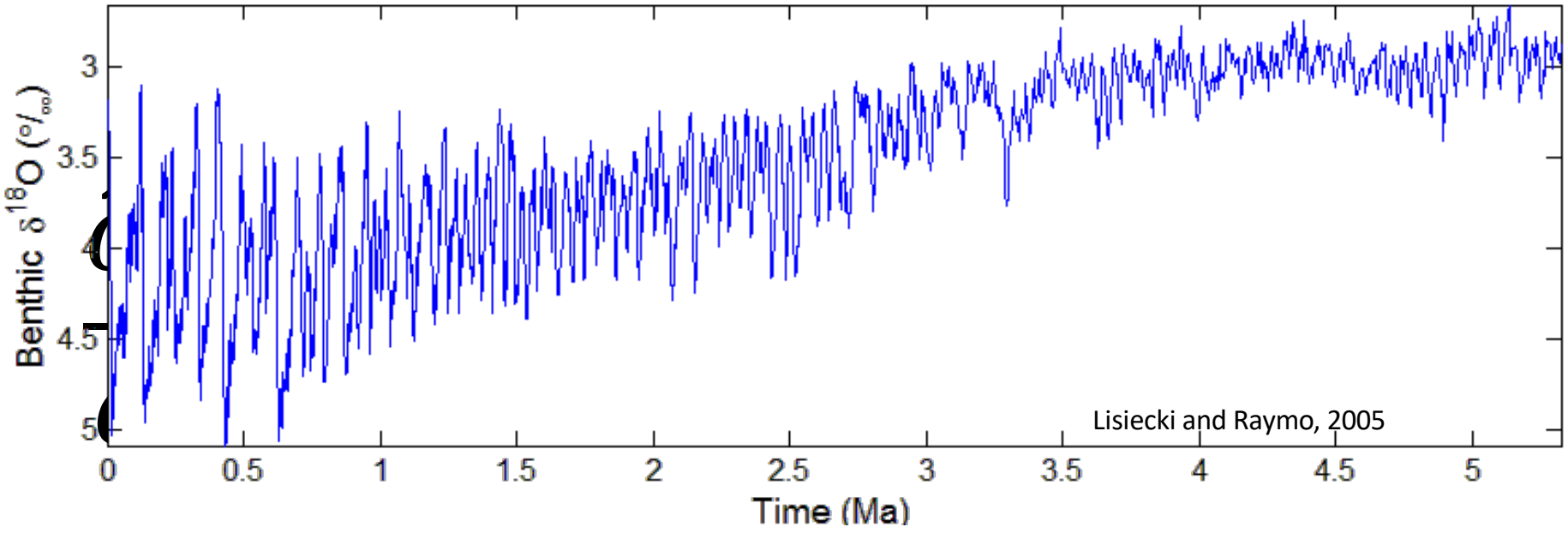
Change in surface elevation = Erosion by streams + Gravitational transport

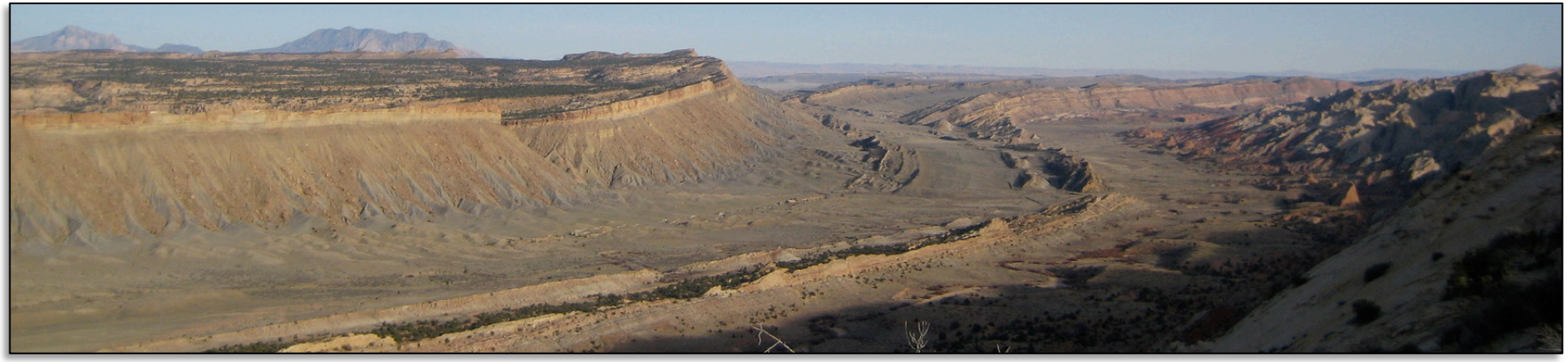
$$\frac{\partial \eta}{\partial t} = -KA^{1/2}S + D\nabla^2\eta$$

η = Land surface elevation
t = Time
A = Area, a proxy for water discharge
S = Local land surface slope

K, D model parameters




Benthic $\delta^{18}O$ (‰)
3
3.5
4
4.5
5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Time (Ma)
Lisiecki and Raymo, 2005



Set of Alternative Models

$$\frac{\partial \eta}{\partial t} = \text{water erosion} + \text{gravitational transport}$$

$$\frac{\partial \eta}{\partial t} = E_{water}(\text{hydrology}, \text{materials}) + E_{gravity}(\text{materials})$$

$E_{gravity}$

- Linear/**Nonlinear**

hydrology

- Deterministic/**Stochastic**
- Uniform runoff/**Variable Source Area**
- Time variable climate (Yes/**No**)

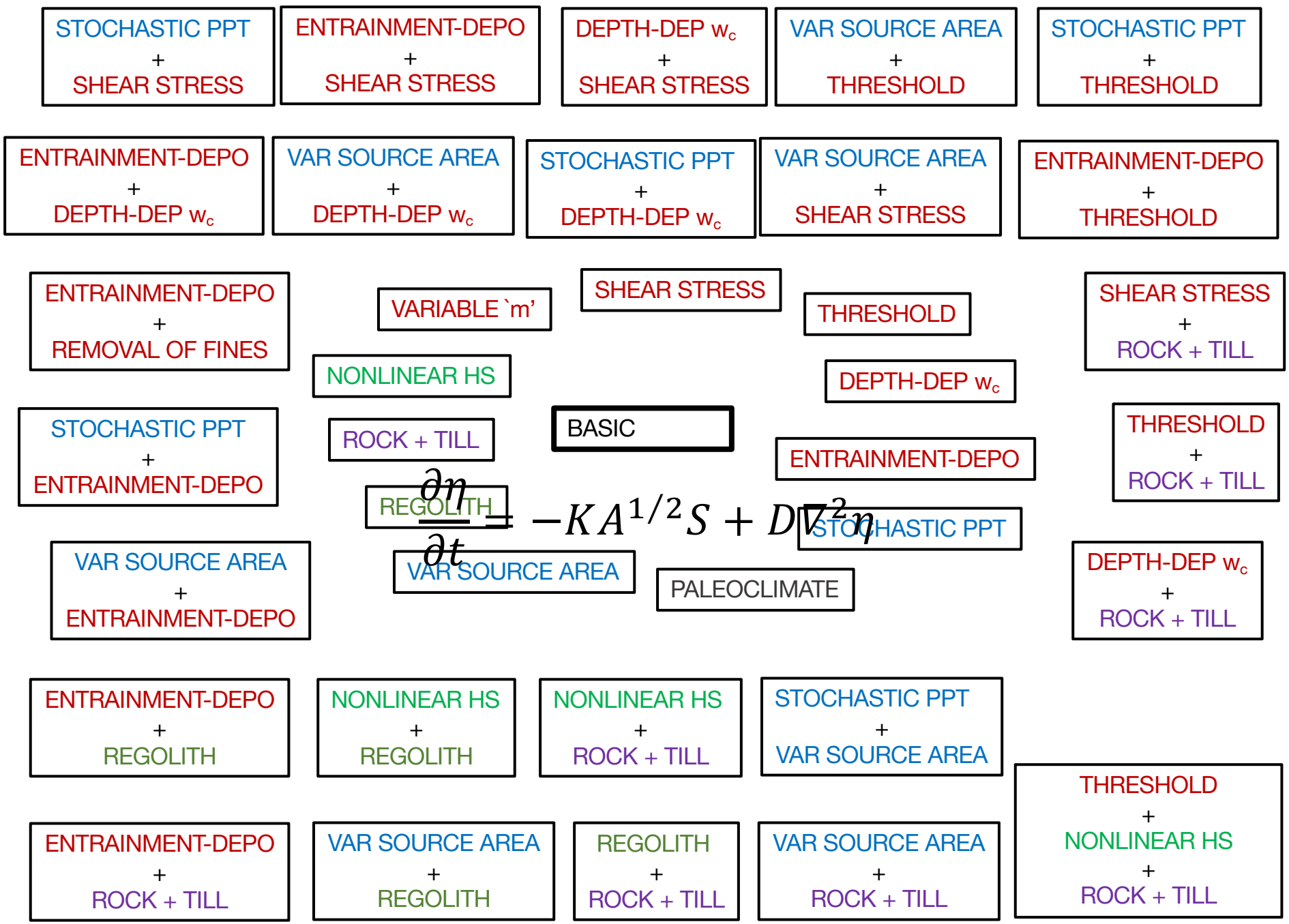
E_{water}

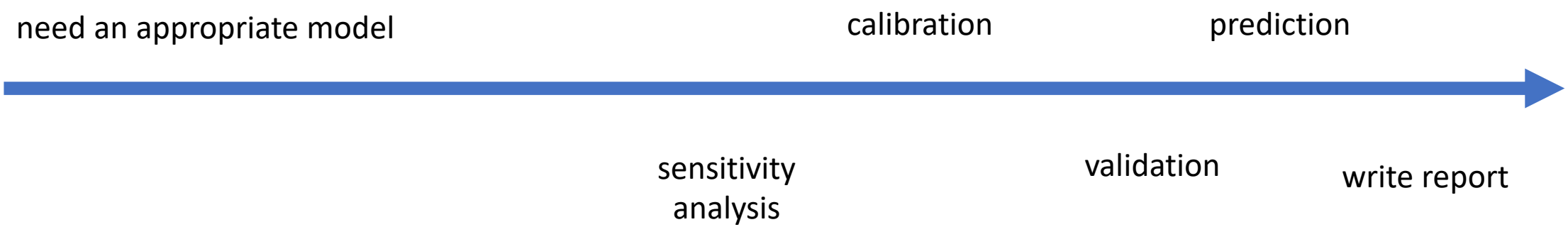
- Fixed/**Variable** area exponent
- Erosion Threshold (Yes/**No**)
- Stream power/**Shear Stress**
- Constant/**Depth dependent threshold**
- Detachment limited vs **Hybrid Transport and Detachment limited**
- Fraction of fines (Yes/**No**)

materials

- Differentiate between soil/alluvium and rock (Yes/**No**)
- Distinguish between shale bedrock and glacial till (Yes/**No**)

More complex/Simpler

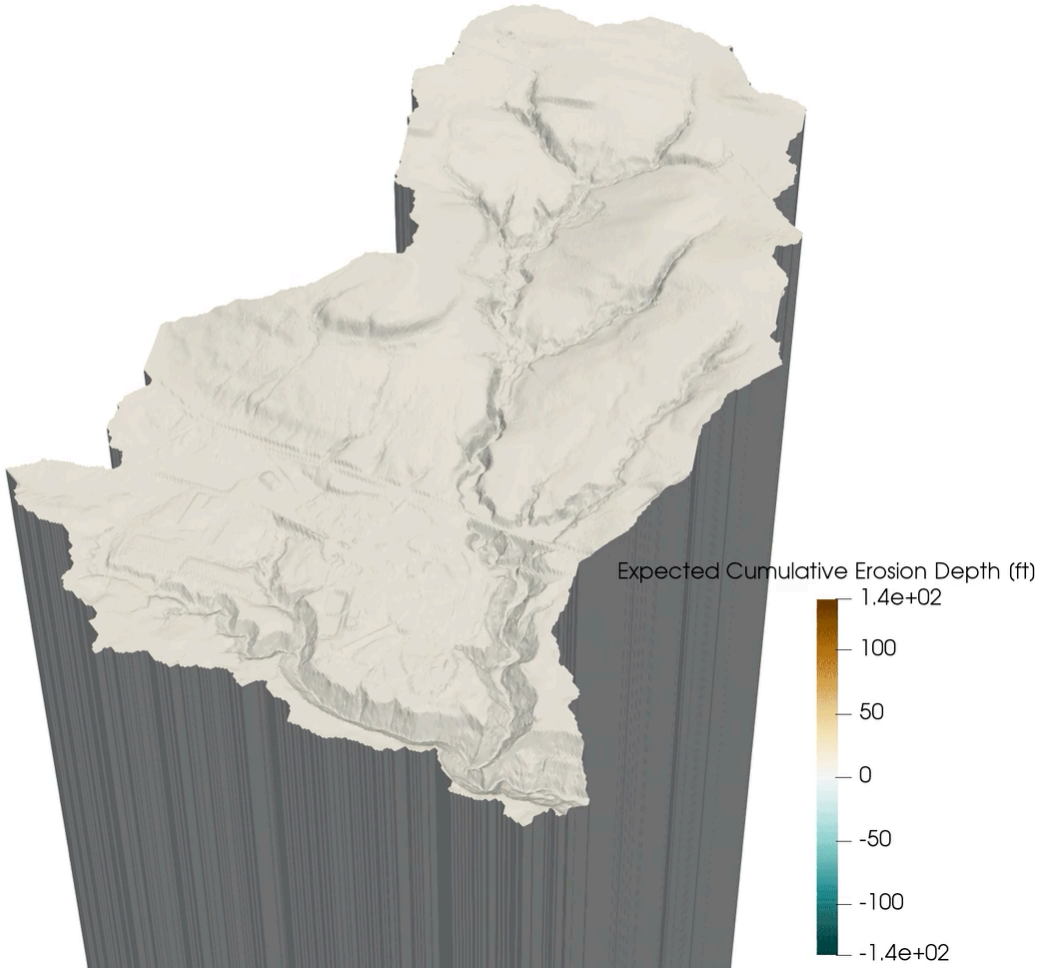

STOCHASTIC PPT + SHEAR STRESS
ENTRAINMENT-DEPO + SHEAR STRESS
DEPTH-DEP w_c + SHEAR STRESS
VAR SOURCE AREA + THRESHOLD
STOCHASTIC PPT + THRESHOLD
ENTRAINMENT-DEPO + DEPTH-DEP w_c
VAR SOURCE AREA + DEPTH-DEP w_c
STOCHASTIC PPT + DEPTH-DEP w_c
VAR SOURCE AREA + SHEAR STRESS
ENTRAINMENT-DEPO + THRESHOLD
ENTRAINMENT-DEPO + REMOVAL OF FINES
VARIABLE `m'
SHEAR STRESS
THRESHOLD
SHEAR STRESS + ROCK + TILL
NONLINEAR HS
DEPTH-DEP w_c
STOCHASTIC PPT + ENTRAINMENT-DEPO
ROCK + TILL
BASIC
THRESHOLD + ROCK + TILL
ENTRAINMENT-DEPO
REGOLITH
$\frac{\partial \eta}{\partial t} = -KA^{1/2}S + D\nabla^2\eta$
STOCHASTIC PPT
VAR SOURCE AREA + ENTRAINMENT-DEPO
VAR SOURCE AREA
PALEOCLIMATE
DEPTH-DEP w_c + ROCK + TILL
ENTRAINMENT-DEPO + REGOLITH
NONLINEAR HS + REGOLITH
NONLINEAR HS + ROCK + TILL
STOCHASTIC PPT + VAR SOURCE AREA
ENTRAINMENT-DEPO + ROCK + TILL
VAR SOURCE AREA + REGOLITH
REGOLITH + ROCK + TILL
VAR SOURCE AREA + ROCK + TILL
THRESHOLD + NONLINEAR HS + ROCK + TILL



Model analysis = hypothesis testing

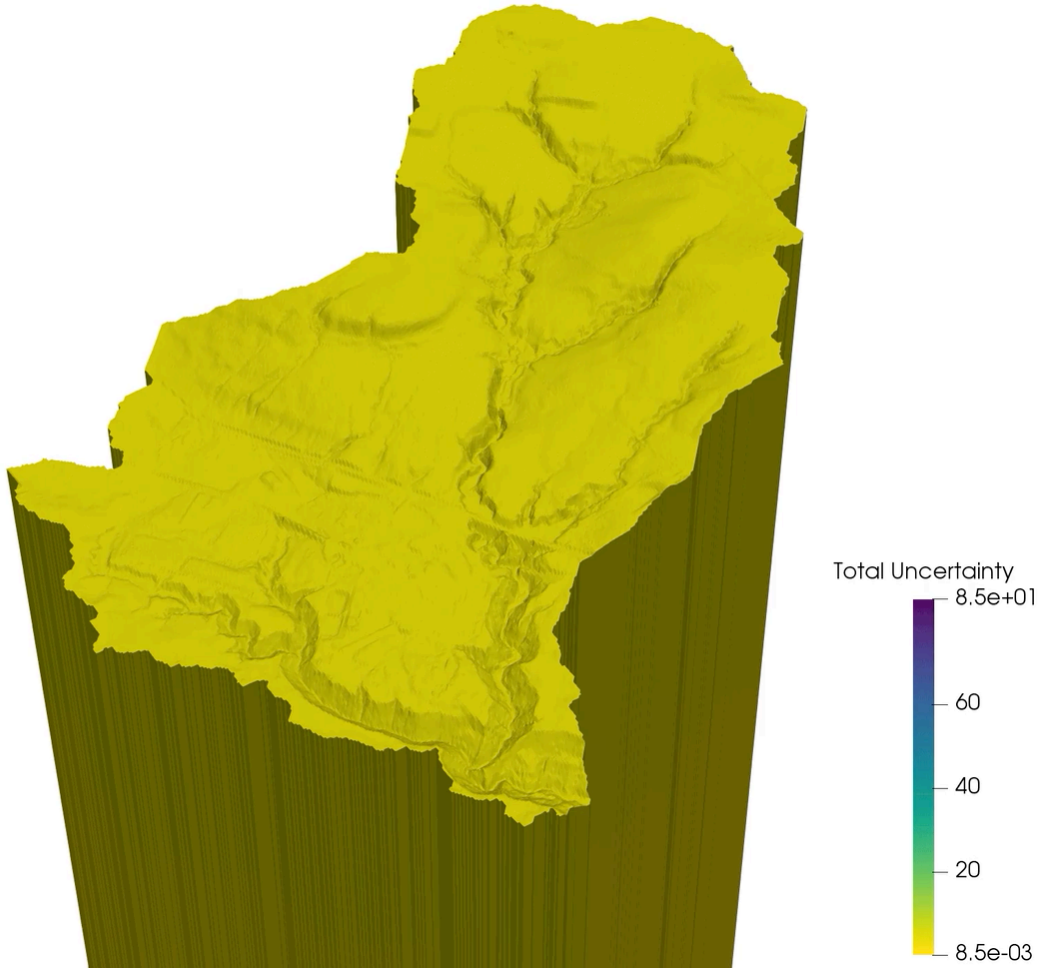
Predicted Erosion

Time: 0



Total Uncertainty in Predicted Erosion

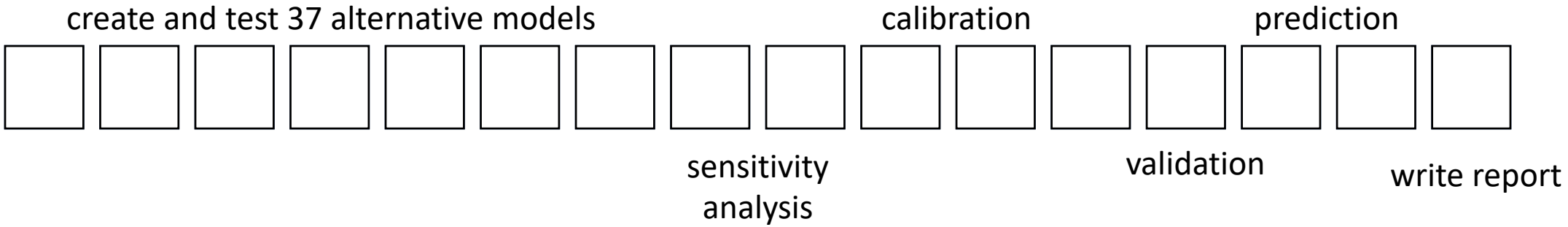
Time: 0

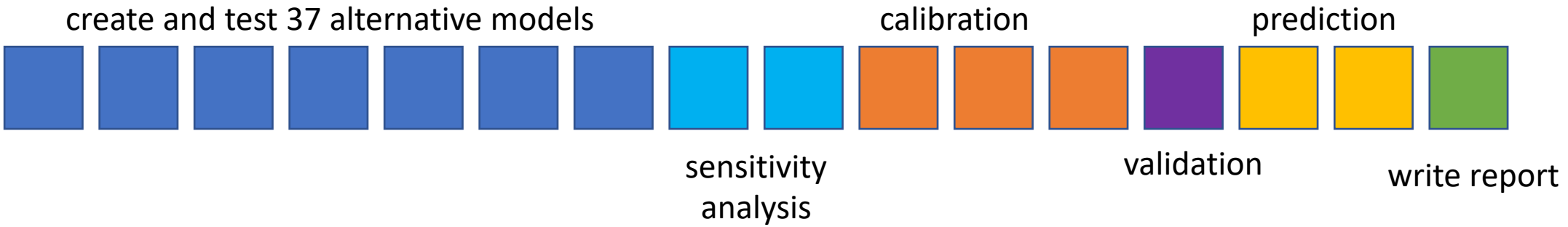


1 million SU, 5 Tb model output, fully scripted

task: make predictions of erosion 10,000 years into the future

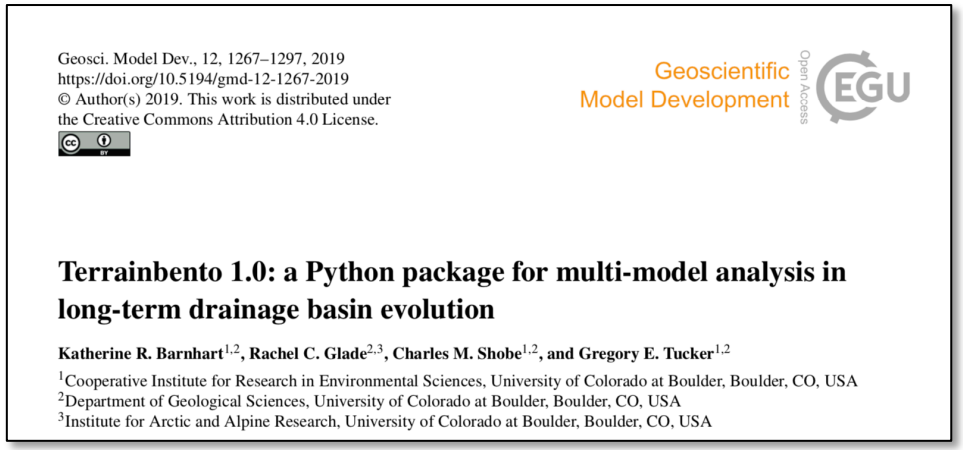
16 month timeline





Created re-usable software infrastructure

- `terrainbento`: Model package published in Geoscientific Model Development.
- `umami`: Model-data tool published in the Journal of Open Source Software.
- Both packages being used in ongoing research.
- Three publications under review at Journal of Geophysical Research-Earth Surface



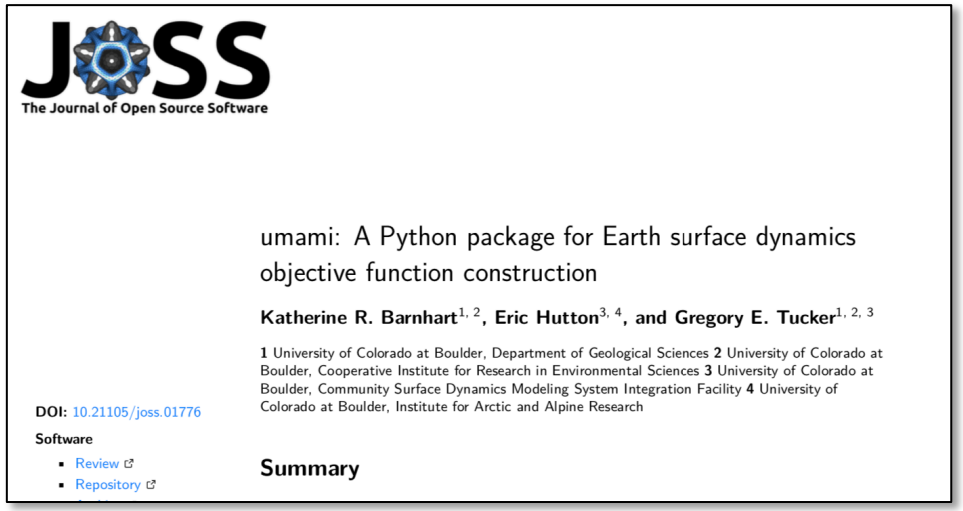
Geosci. Model Dev., 12, 1267–1297, 2019
https://doi.org/10.5194/gmd-12-1267-2019
© Author(s) 2019. This work is distributed under the Creative Commons Attribution 4.0 License.

Geoscientific Model Development

Terrainbento 1.0: a Python package for multi-model analysis in long-term drainage basin evolution

Katherine R. Barnhart[1,2], Rachel C. Glade[2,3], Charles M. Shobe[1,2], and Gregory E. Tucker[1,2]

[1]Cooperative Institute for Research in Environmental Sciences, University of Colorado at Boulder, Boulder, CO, USA
[2]Department of Geological Sciences, University of Colorado at Boulder, Boulder, CO, USA
[3]Institute for Arctic and Alpine Research, University of Colorado at Boulder, Boulder, CO, USA



The Journal of Open Source Software

umami: A Python package for Earth surface dynamics objective function construction

Katherine R. Barnhart[1, 2], Eric Hutton[3, 4], and Gregory E. Tucker[1, 2, 3]

1 University of Colorado at Boulder, Department of Geological Sciences 2 University of Colorado at Boulder, Cooperative Institute for Research in Environmental Sciences 3 University of Colorado at Boulder, Community Surface Dynamics Modeling System Integration Facility 4 University of Colorado at Boulder, Institute for Arctic and Alpine Research

DOI: 10.21105/joss.01776

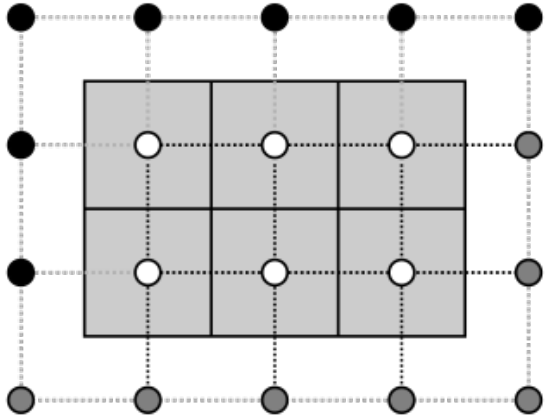
Software
- Review
- Repository

Summary

What is Landlab and how did it help?

A python software package that contains:

- Grid that represents the modeled domain
  - Know what elements are adjacent
  - Store state variables
- General methods for finite-difference numerical methods.
- Components that each handle one part of physics.
- Utilities that help with Input/Output or plotting



$$\frac{\partial \eta}{\partial t} = -K A^{1/2} S + D \nabla^2 \eta$$

Modern Software Qualities of Landlab

- Open source
- Modular
- Flexible
- Extensible
- Tested
- Documented

That made this project possible

- We used nine existing components and made five new ones.
- Testing meant we could refactor some code to make it faster without worrying that it would impact the results.
- Other people now use these components and have improved the documentation

These qualities mean that initial creation may take longer

How would I have done this in 2010?

- Pile of scripts
- Poorly documented
- No built in unit-tests
- Not designed to work at another site
- Not easily reusable
- No standard interface

I only know how to do my modeling research in a reusable, reproducible way through Landlab and CSDMS

AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Earth Surface

RESEARCH ARTICLE

10.1002/2013JF002845

Key Points:

- Coastal erosion is episodic and associated with storms that set up water
- Heat transfer governs the rate of submarine notch incision and coast retreat
- Sea level and water temperature will impact future coastal erosion the most

Modeling erosion of ice-rich permafrost bluffs along the Alaskan Beaufort Sea coast

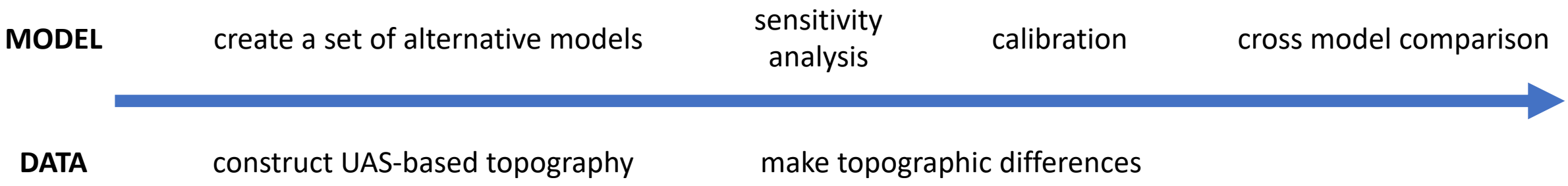
Katherine R. Barnhart[1,2], Robert S. Anderson[1,2], Irina Overeem[2], Cameron Wobus[3], Gary D. Clow[4], and Frank E. Urban[4]

[1]Department of Geological Sciences, University of Colorado Boulder, Boulder, Colorado, USA, [2]Institute of Arctic and Alpine Research, University of Colorado Boulder, Boulder, Colorado, USA, [3]Stratus Consulting, Inc., Boulder, Colorado, USA, [4]U.S. Geological Survey, Geosciences and Environmental Change Science Center, Denver, Colorado, USA

Abstract The Arctic climate is changing, inducing accelerating retreat of ice-rich permafrost coastal bluffs. Along Alaska's Beaufort Sea coast, erosion rates have increased roughly threefold from 6.8 to

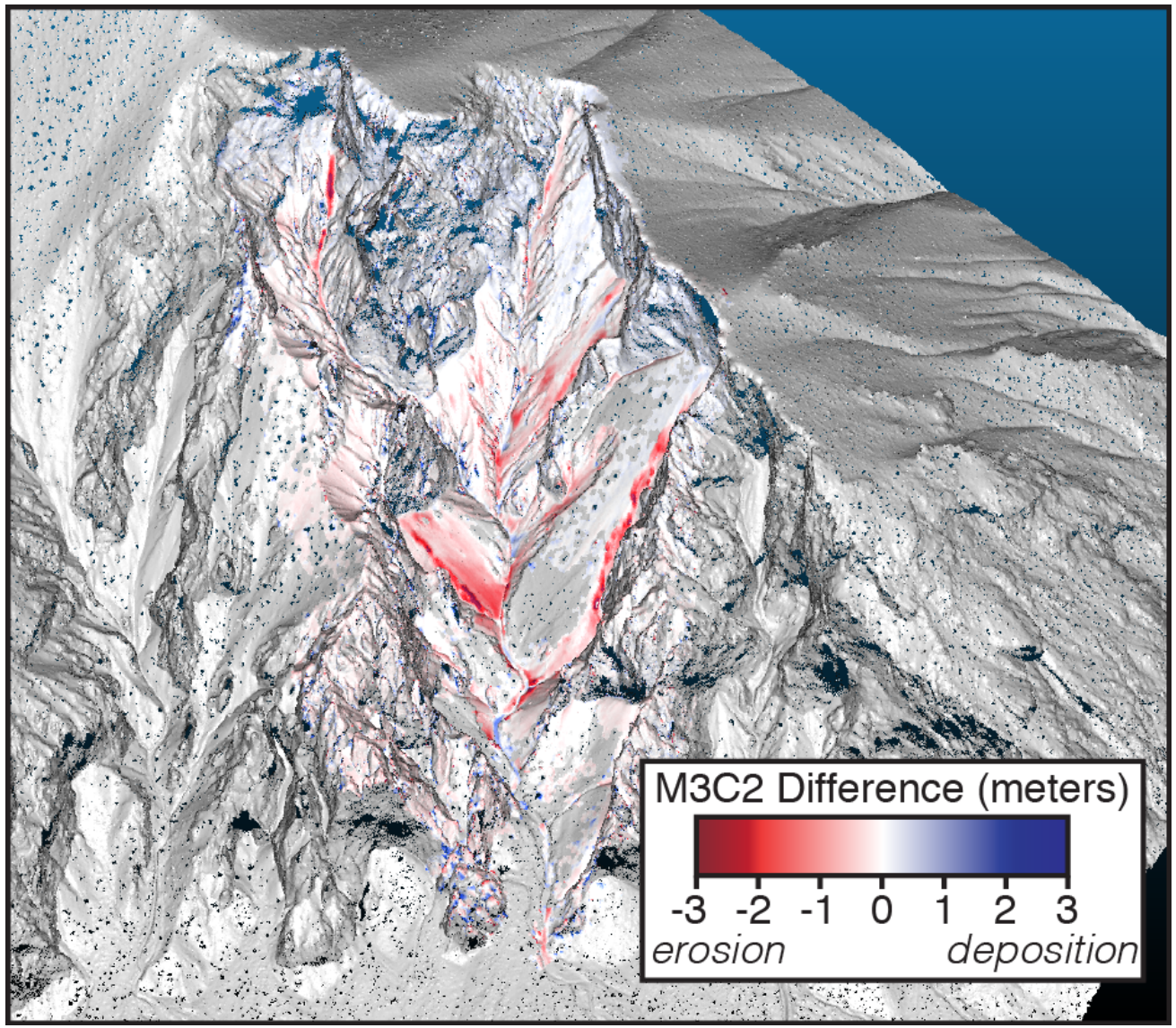
Chalk Cliffs Debris Flow Research

task: use change detection and modeling to attribute steep-slope sediment transport and debris-flow initiation mechanisms.

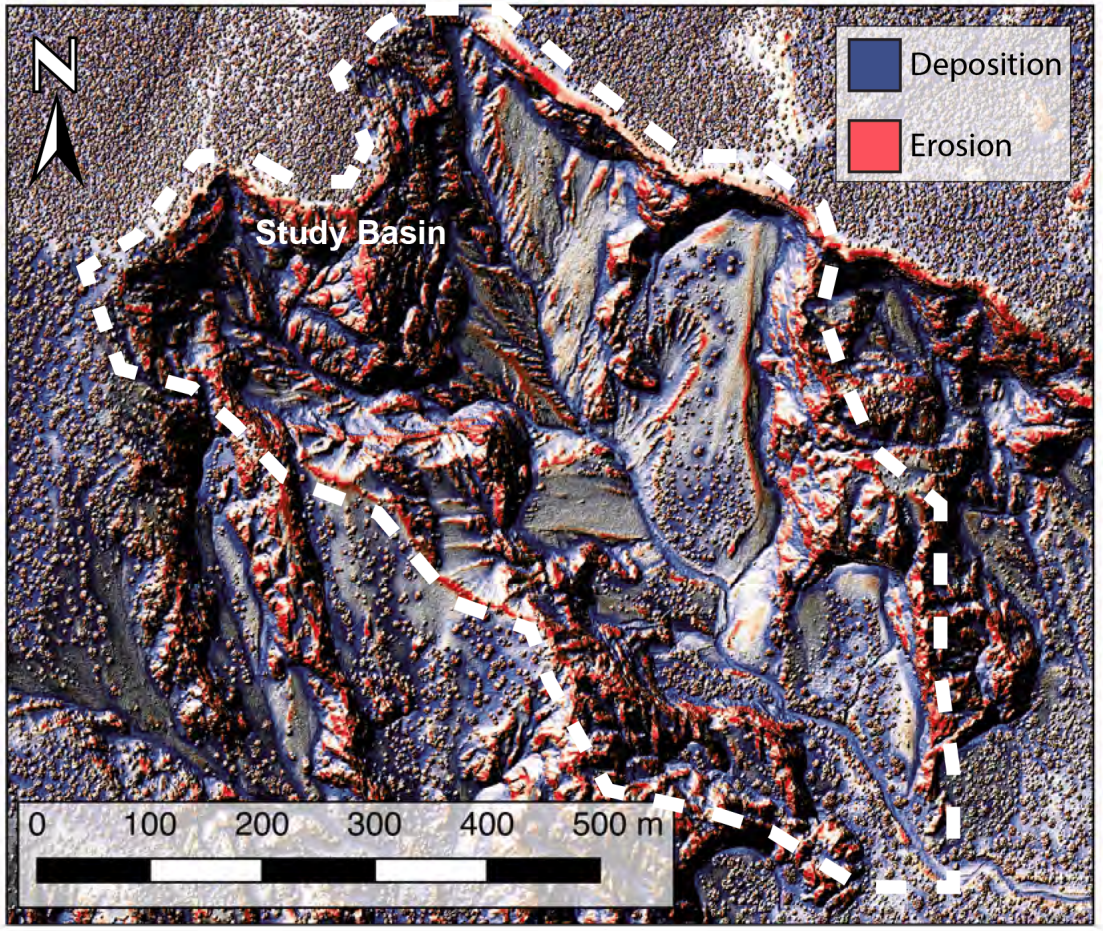


Modularity in Landlab lowers barriers to formal hypothesis testing

Observed Change (2008 LiDAR vs 2018 UAS-SfM)

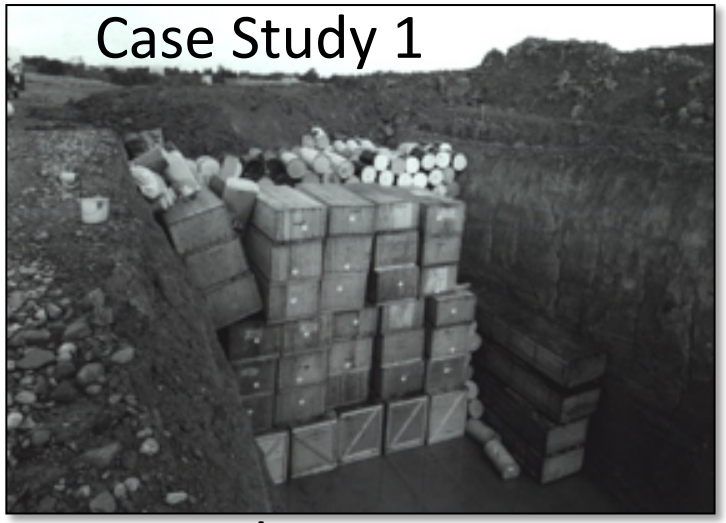


Example Model Output



Summary

- Landlab is a tool that follows modern software standards
- This made the two case studies possible.
- My work has created tools that other are now using.



Case Study 2

- This sort of software tool may take more time for one project, but integrated over multiple, it saves time.
- Basic computer science skills are necessary and CSDMS provides access to them.

katherine.barnhart@colorado.edu