# 2.5D TO 4D: INITIAL AND BOUNDARY CONDITIONS AND TESTING NUMERICAL MODELS WITH HIGH RESOLUTION TOPOGRAPHY

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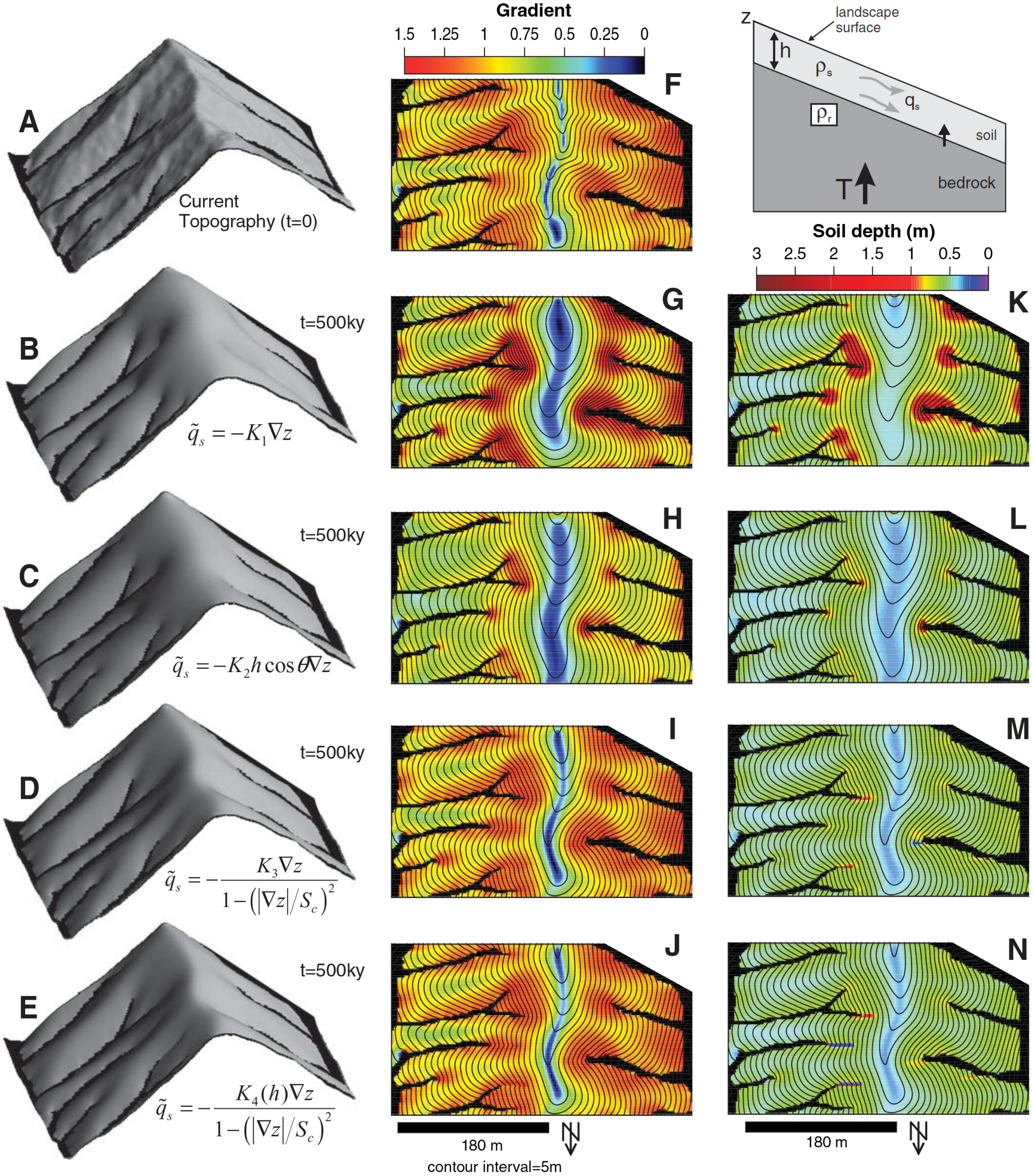
- Numerical models—some examples with HRT (CSDMS complement)
- HPC lessons from OpenTopography
- Concluding thoughts

OpenTopography is supported by the U.S. National Science Foundation under Award #s: 1226353 & 1225810



$$\frac{\partial h}{\partial t} = -\nabla\cdot\tilde{q}_s + \frac{\rho_r}{\rho_s}\varepsilon$$

Finite difference solution to mass conservation and geomorphic transport laws (GTL) run for 500kyr.

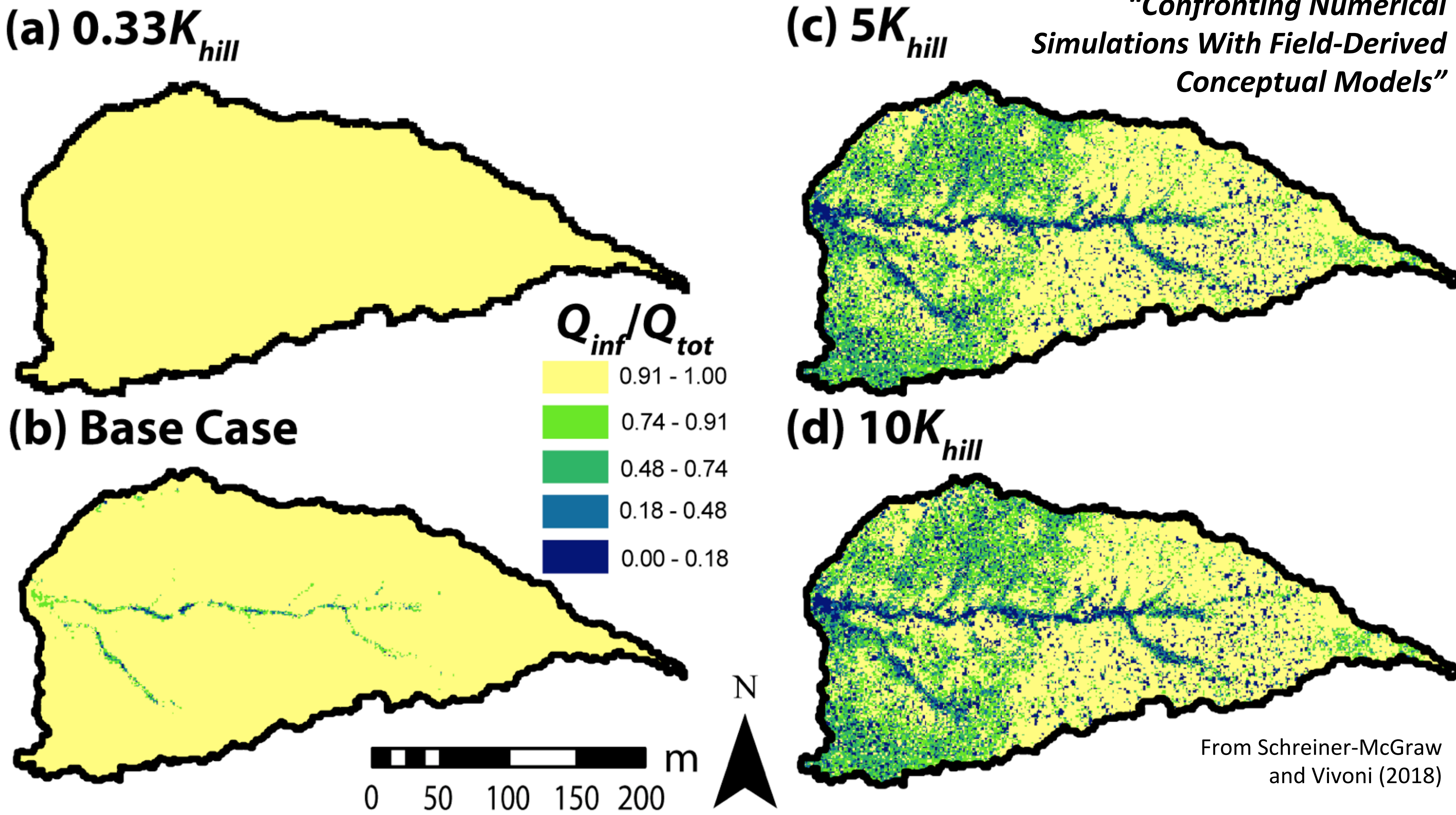
No fluvial or debris flow processes.

HRT = initial conditions and character of morphologic relationships for testing appropriate GTL.

Roering, J.J., (2008), How well can hillslope evolution models ‘explain’ topography? Simulating soil transport and production with high-resolution topographic data, Geological Society of America Bulletin, v. 120, p. 1248-1262.

**Hydrologic modeling using high-resolution terrain and vegetation maps allows unprecedented details on spatial patterns of runoff, soil moisture, ET.**

Sensitivity analysis of the simulated ratio of infiltration-excess ($Q_{inf}$) runoff to total runoff ($Q_{tot}$) for different levels of hillslope hydraulic conductivity ($K_{hill}$) show the transitions in runoff generation mechanisms of 6 year run



*"Confronting Numerical Simulations With Field-Derived Conceptual Models"*

From Schreiner-McGraw and Vivoni (2018)

# Computational fluid dynamics (Reynolds-Averaged Navier-Stokes (RANS) & Large Eddy Simulation (LES)):

Increasingly used to model flow over aeolian landscapes including 3D over natural landscapes

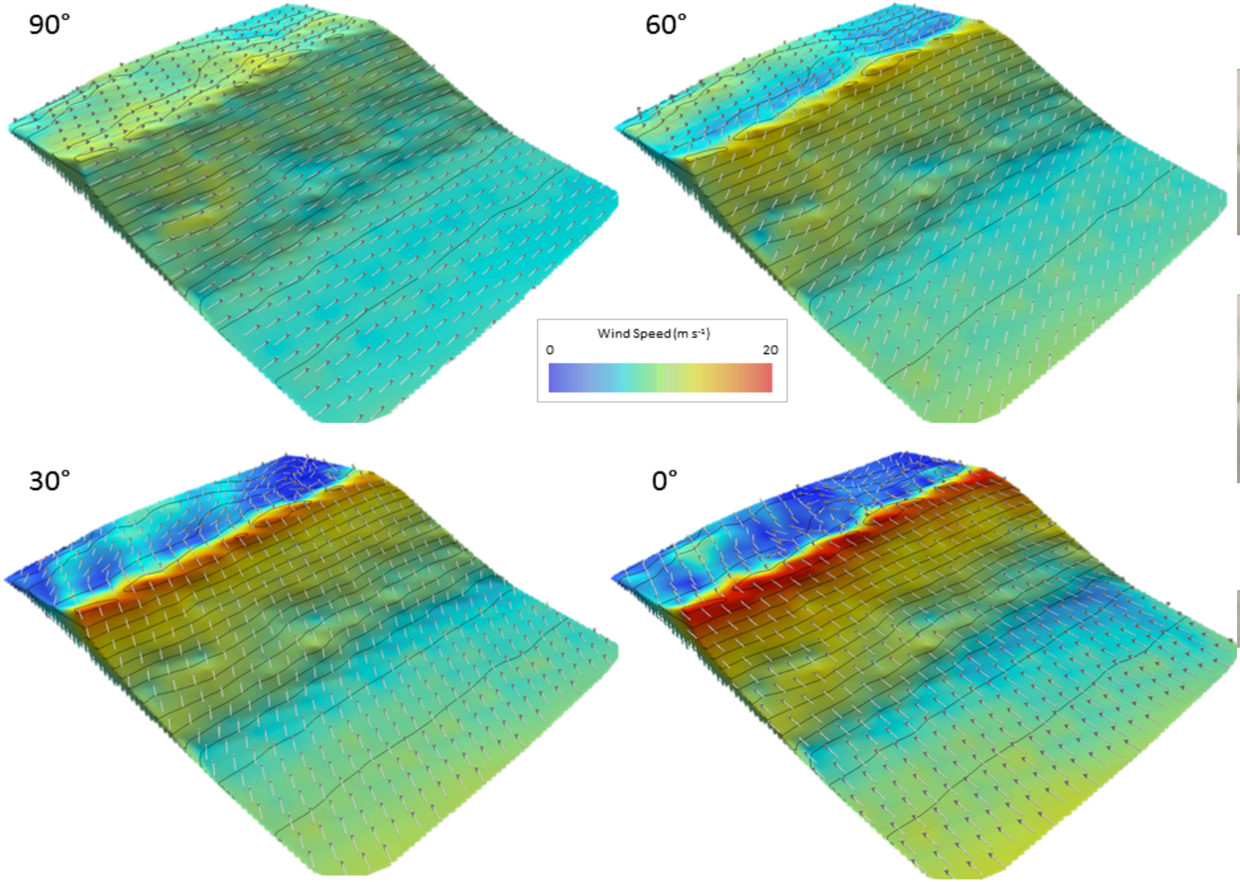
Extend empirical observations from spatially limited (often 2d) arrays

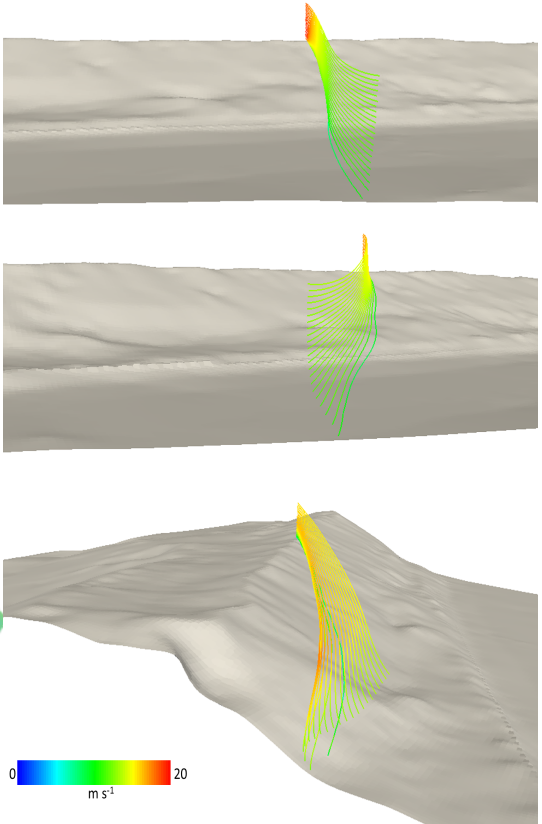
Simulate a range of incident flows; Validate with differencing

Gaps:

-roughness parameterization limits shear stress accuracy (e.g., vegetation, bedforms)

-availability of temporal resolution for events and broader freq-magnitude regime assessments

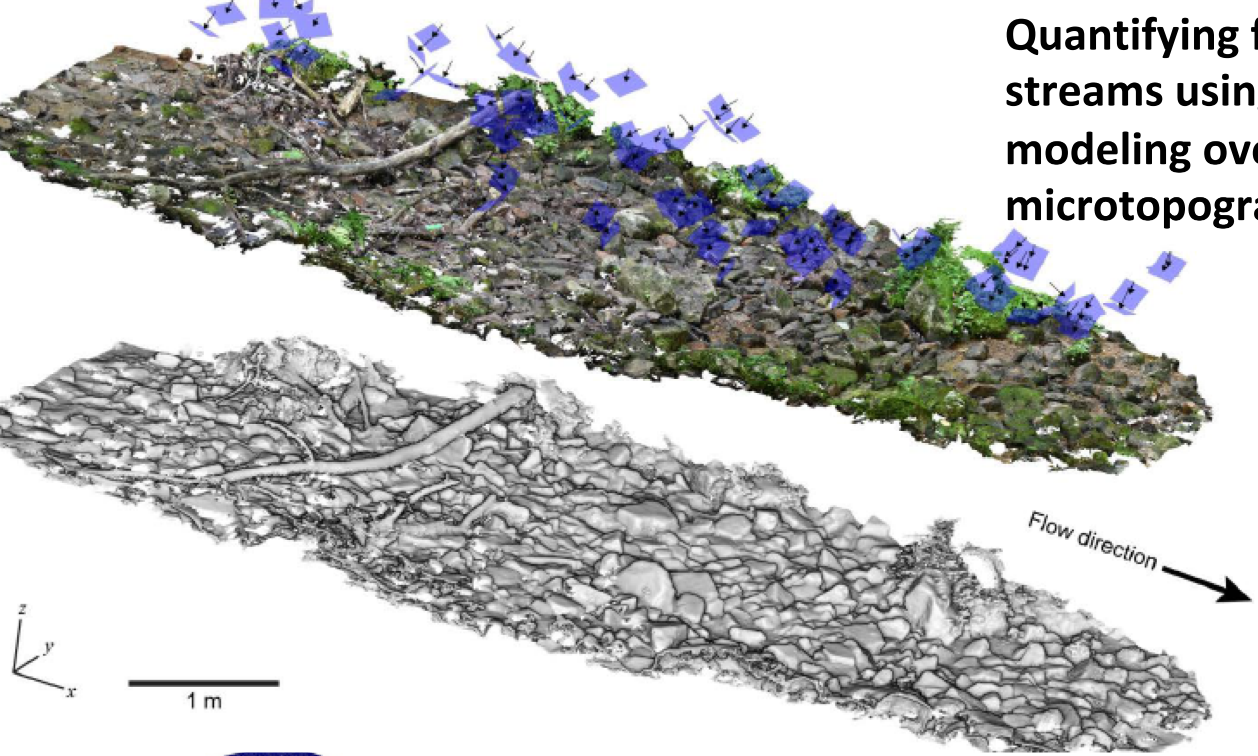




+Wascklewicz and Gares

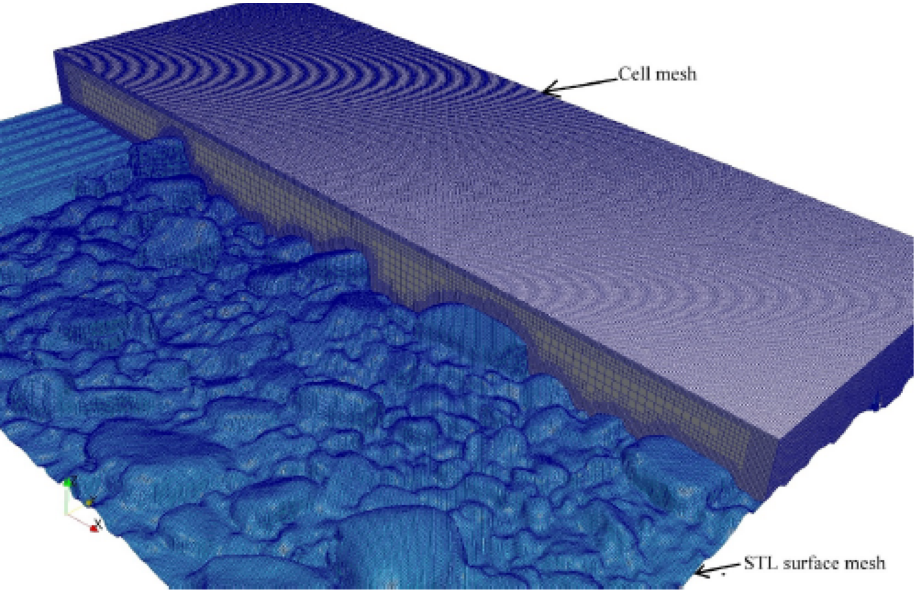
Hesp, PA, Smyth, TA, Nielsen, P, Walker, IJ, Bauer, BO (2015). Flow deflection over a foredune. *Geomorph.* 230: 64-74

# Quantifying flow resistance in mountain streams using computational fluid dynamics modeling over structure-from-motion derived microtopography

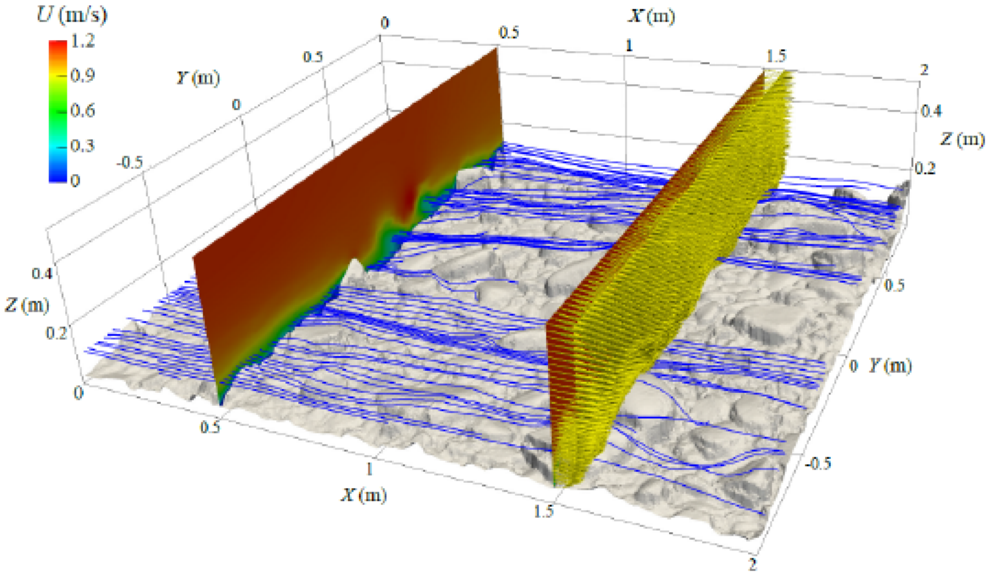


Connect scales of flow resistance with surface roughness and water depth

Chen, DiBiase, McCarroll, Liu, in review



SfM model input to OpenFoam

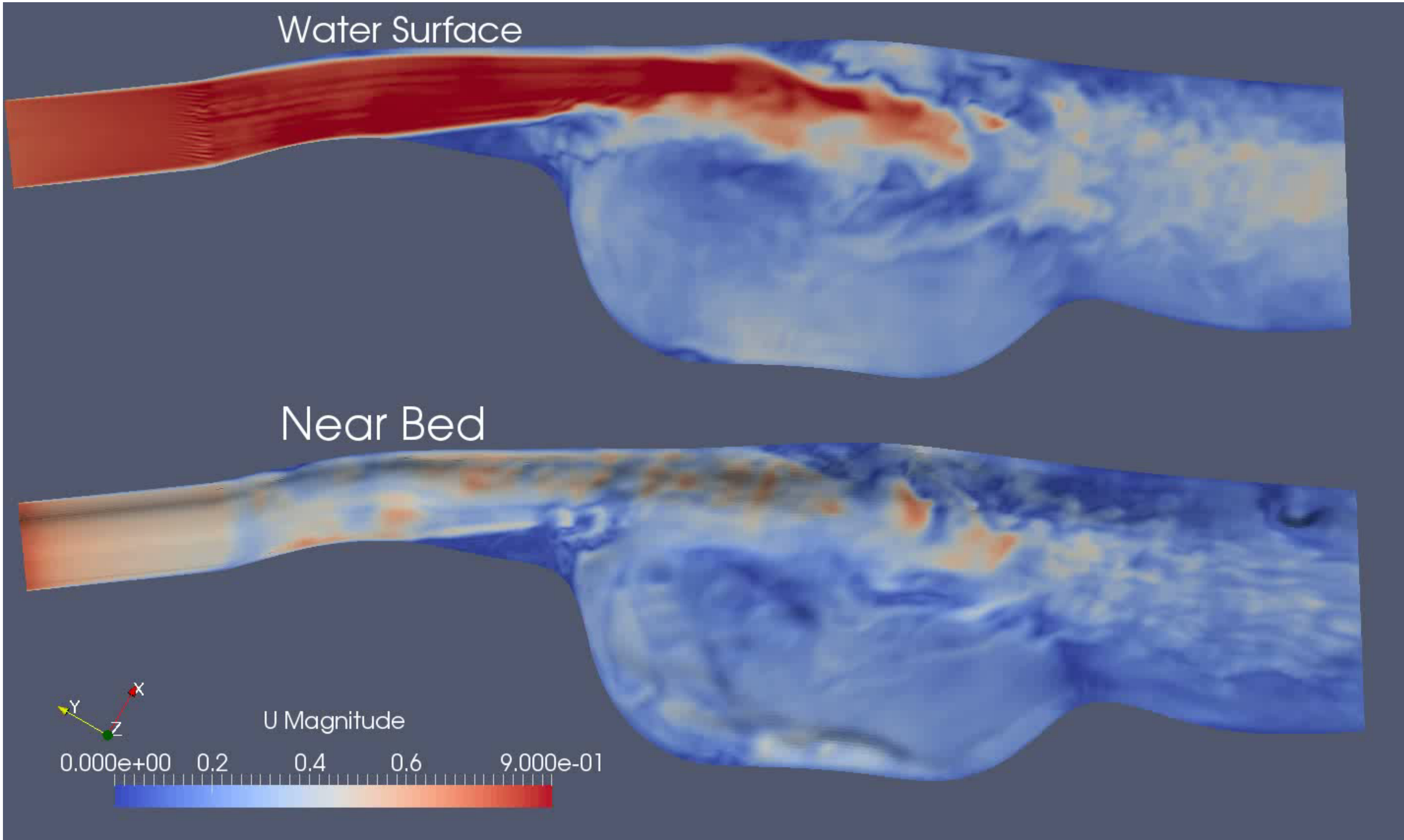


RANS simulation over Bowmans Creek microtopography
(Velocity field for H = 0.5 m)

# **Computational fluid dynamics (Detached Eddy Simulation):**

## Turbulence modeling in the Grand Canyon using LIDAR and bathymetric/total station topography: ties to field experiment (2008 controlled flood) with advanced numerical approach

Alvarez, L. V., M. W. Schmeeckle, and P. E. Grams (2017), A detached eddy simulation model for the study of lateral separation zones along a large canyon- bound river, J. Geophys. Res. Earth Surf., 122, 25–49, doi:10.1002/2016JF003895.



# Hydrodynamics to assess flood hazard in complex urban topography

Quantitative assessment of natural hazards uses predictive models to estimate the extent and dynamics

Requires computations which are forced by the surface topography (Example: Chosica, Peru)

Uses these tools for community outreach for direct engagement and preventative actions

Jeremy Phillips, University of Bristol, project funded by EPSRC in UK

*Drone photo of houses upper part of Chosica (right)*

*SfM model (below)*

https://www.globalspecies.org/images/s/Salmonidae_1.jpg

# Hydrodynamics for ecological applications

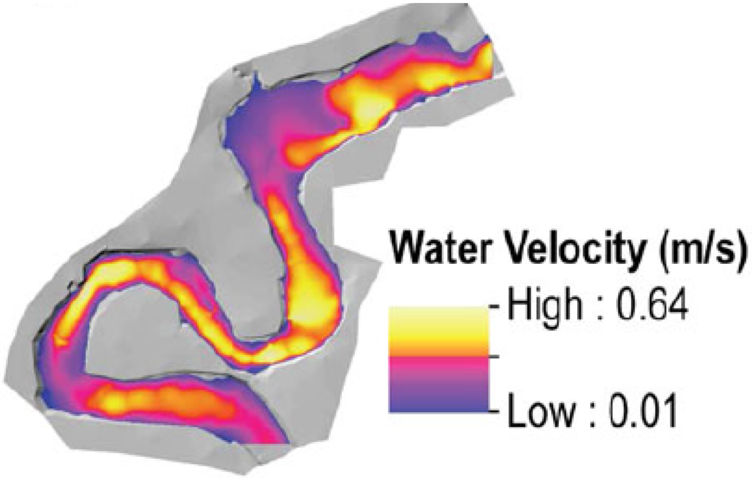
Enables exploration of relevant parameters such as *Net Rate of Energy Intake*.

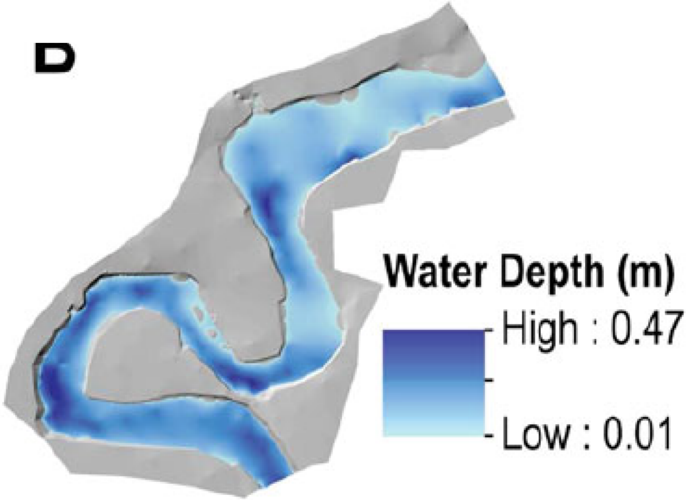
Model the net energy balance from an individual fish’s perspective if it were to maintain position within every computational node of the wetted channel (uses Delft3D)

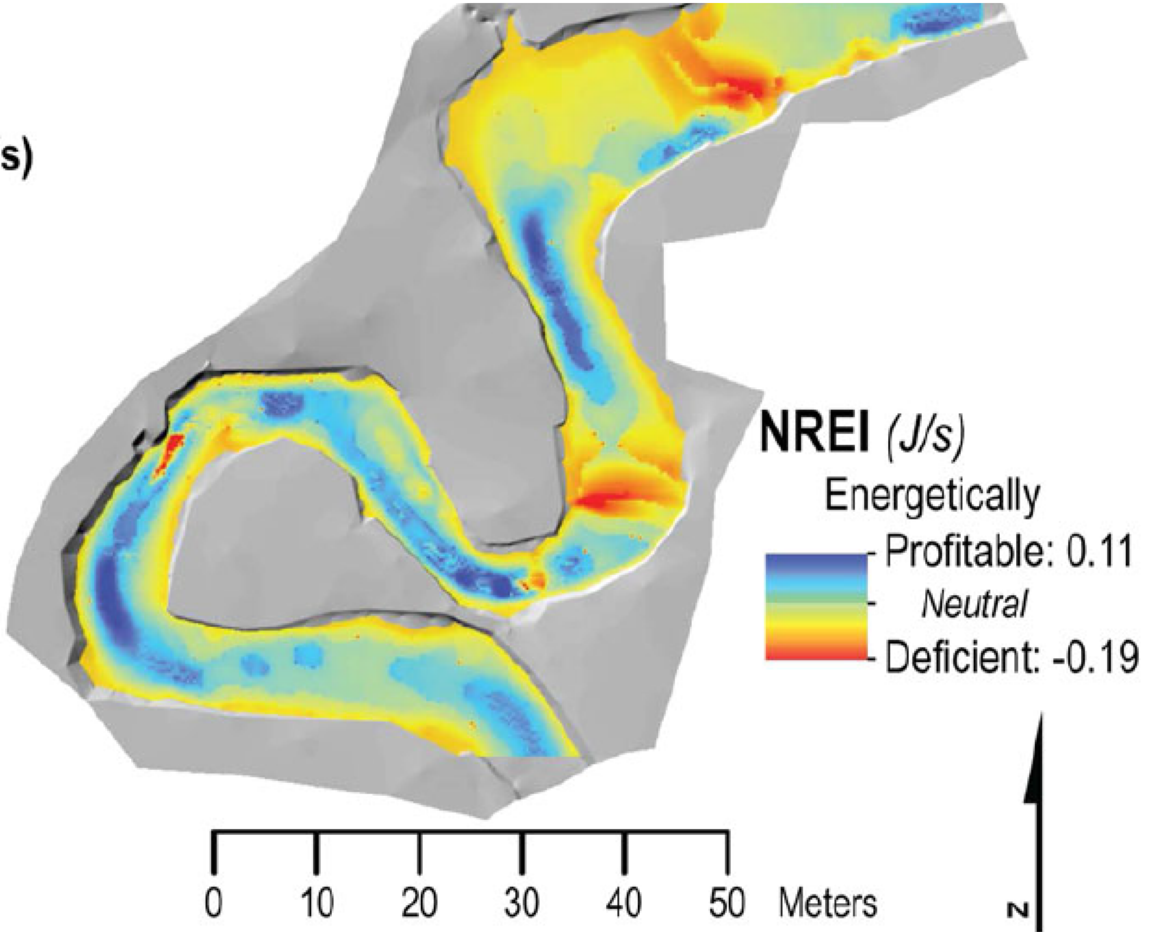
$10^4$ simulations in a fully automated a cloud computing workflow

Mesh preparation from HRT is time consuming but critical

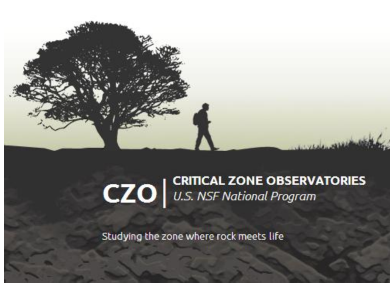
Wheaton, et al., Upscaling Site-Scale Ecohydraulic Models to Inform Salmonid Population-Level Life Cycle Modelling and Restoration Actions - Lessons from the Columbia River Basin, ESPL, 2017







OpenTopography



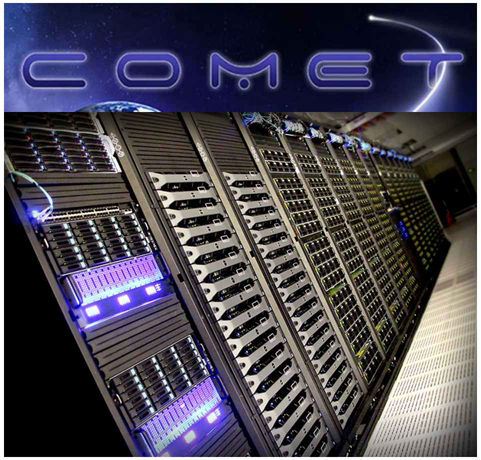
# HIGH PERFORMANCE COMPUTING

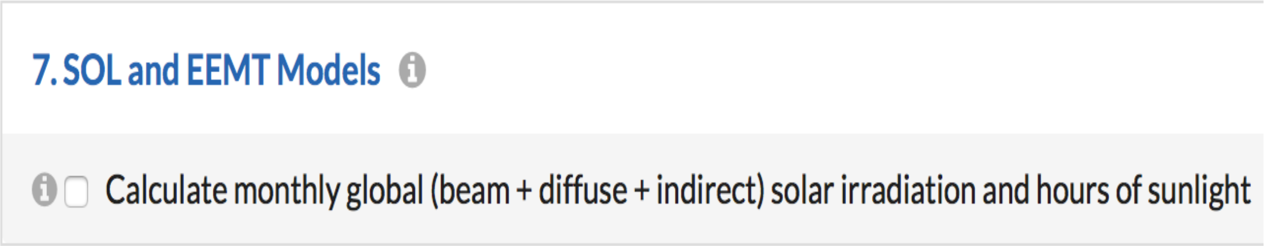
## **SOL /EEMT** (Effective Energy & Mass Transfer)

*Algorithms run on OSG and Comet*

XSEDE
Extreme Science and Engineering
Discovery Environment

Open Science Grid





7. SOL and EEMT Models

☐ Calculate monthly global (beam + diffuse + indirect) solar irradiation and hours of sunlight

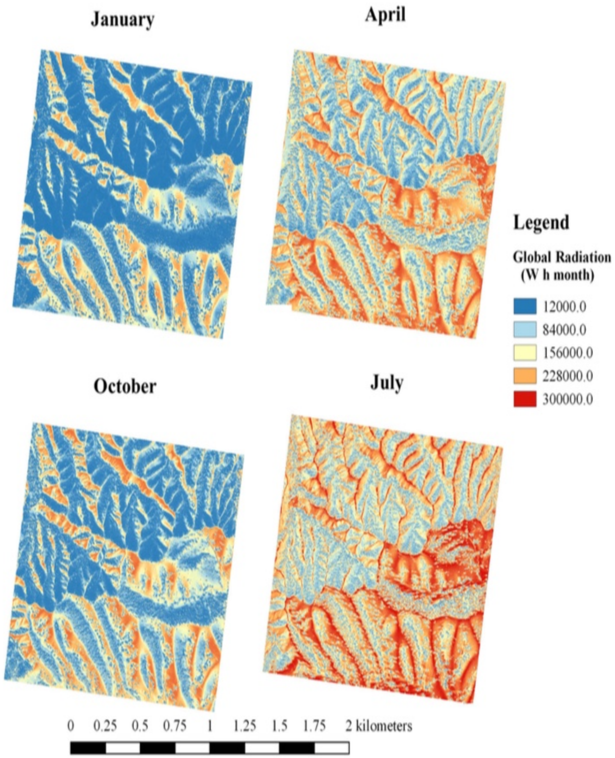


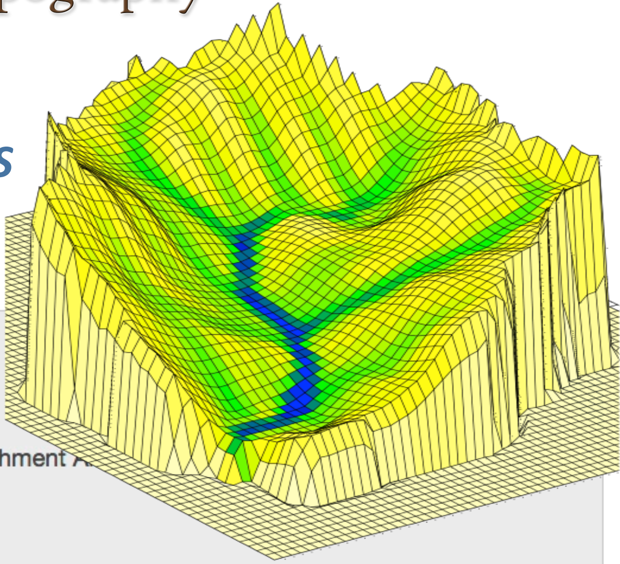
Image: Monthly solar irradiation

Swetnam, T., et. al, (2016). **Scaling GIS analysis tasks from the desktop to the cloud utilizing contemporary distributed computing and data management approaches: A case study of project-based learning and cyberinfrastructure concepts**, paper 138, XSEDE ’16

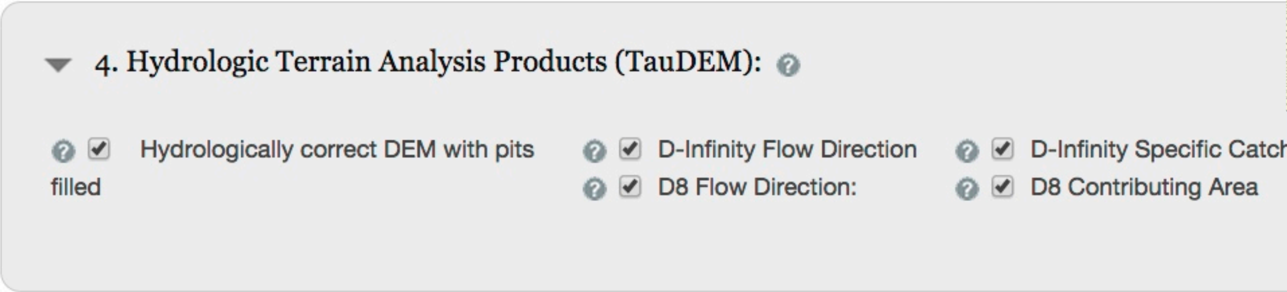
OpenTopography

# HIGH PERFORMANCE COMPUTING

## *MORE DATA & USERS, COMPLEX ANALYSIS = INCREASED COMPUTE CHALLENGES*



**TauDEM – Hydrologic analysis of terrain data (17k jobs):**



4. Hydrologic Terrain Analysis Products (TauDEM):

- ☑ Hydrologically correct DEM with pits filled
- ☑ D-Infinity Flow Direction
- ☑ D8 Flow Direction:
- ☑ D-Infinity Specific Catchment
- ☑ D8 Contributing Area

Dedicated Gordon supercomputer node:

I/O Node 48 GB Memory/4.8TB Flash memory + 16 Compute nodes, 64GB memory + InfiniBand

***Democratization* of supercomputing resources**

**NEED STAFF SUPPORT: something that works on your desktop may not easily port to this environment**

*Youn et al., 2014. Leveraging XSEDE HPC resources to address computational challenges with high-resolution topography data*

# What realism do we really need from our data and models?

Dietrich, Bellugi, Sklar, Stock, Heimsath, Roering, Geomorphic Transport Laws for Predicting Landscape Form and Dynamics, <u>Prediction</u> in Geomorphology, AGU Geophysical Monograph 135, 10.1029/135GM09, 2003

HRT?

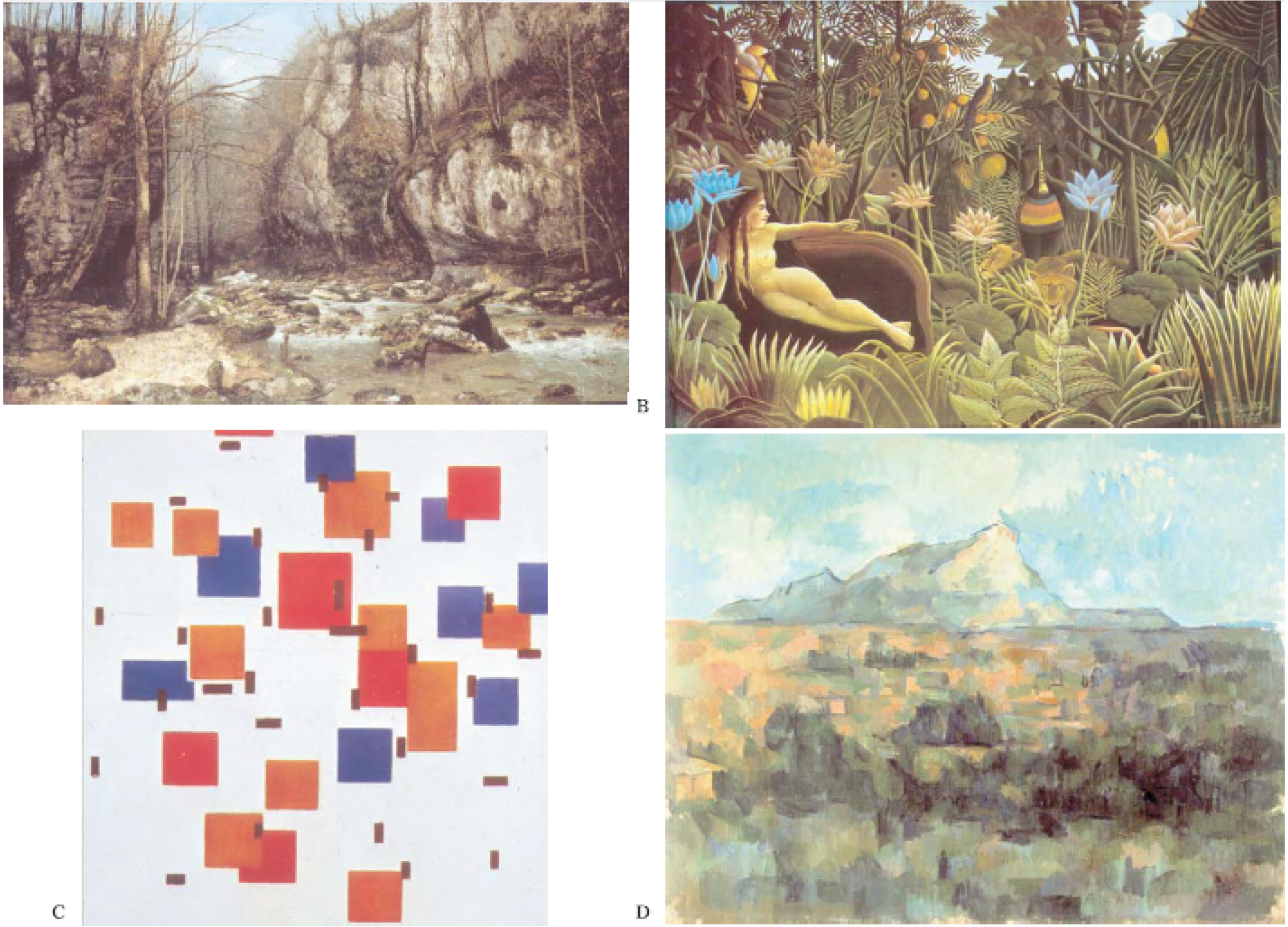


**Plate 1.** Paintings as metaphors for different approaches to landscape evolution modeling.
A) Detailed realism: G. Courbet, 1868, Streams of the Puits-Noir at Ornans (Norton Simon Museum, Pasadena).
B) Apparent realism: H. Rousseau, 1910, The Dream (The Museum of Modern Art, New York).
C) Statistical realism: Mondrian 1917, Composition in Blue B (Kroller-Muller Museum, Netherlands).
D) Essential realism: Cezanne 1904-1906, Mont Sainte-Victoire Seen from Les Lauves (Private Collection).

# Concluding thoughts

What's under the hood?

https://www.streetsideclassics.com/vehicles/0922-tpa/1969-chevrolet-chevelle

**What good are models?** (e.g., Oreskes, et al., 1994)
Build intuition upon quantitative, physical basis
Corroborate hypotheses
Elucidate discrepancies
Sensitivity analyses/parameter sweep
Explore what if questions

**High resolution issues**
Is the resolution necessary for the question?
Are we losing the power of the abstraction by adapting powerful engineering tools to complex and specific conditions?

**Needs and gaps**
Multiscale approaches
Meshing—geometric representation for initial and boundary conditions for numerical models
Address uncertainty—is it noise or is it real (roughness)
Training, tool curation, common interfaces and standards, HPC access and integration (e.g., CSDMS, OT, etc.), desktops<->cloud<->HPC
Technical staff support
Validation sites and datasets ("establishment of legitimacy")
Opportunity and challenge to go beyond steady in time and homogeneous in space (but increasing ambiguity!)