Meshing workflows for multiscale hydrological simulations: Wavelet-based approach improves model accuracy

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November 26, 2022

Abstract

The high computational cost of large-scale, process-based hydrological simulations can be approached using variable resolution meshes, where only the region around significant topographic features is refined. However, generating quality variable resolution meshes from digital elevation data is non-trivial. In literature, usually a slope or curvature-based criterion is defined to detect regions of refinement. These techniques often involve a number of free parameters that control the finest and coarsest resolutions, and the transition between fine resolution to coarse resolution. The influence of these parameters on the resulting mesh is usually not well-understood. In order to overcome the large number of free parameters involved, we propose to carry out the Mallat decomposition of the digital elevation data using the Haar wavelet. This gives a nested multilevel representation of the elevation data, split into average coefficients and detail coefficients. Applying hard-thresholding to these detail coefficients assigns a required level of refinement to each data point. This reduces the number of free parameters to exactly one: the acceptable error threshold. In this presentation, we focus on identifying which geomorphometric parameter(s) should be used to steer mesh refinement. We compare zero-inertia model simulation runs on meshes generated by decomposing elevation and slope. We hypothesize that because of the form of the Haar wavelet, the first mesh refinement essentially is using the gradient information, while the latter is using the curvature as refinement criterion. Our results suggest that in high-elevation catchments the curvature of the topography is a far better indicator for refinement than the slope. Using the Mallat decomposition on the tensor of the first derivative of the bed elevation (i.e., bed slope) for mesh refinement yields better agreement in the hydrograph compared to the decomposition of the bed elevation. We present surface runoff results for the Lower Triangle catchment, CO, USA, to illustrate the performance of the wavelet-based local mesh refinement.

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Mesh design for multiscale hydrological simulations: Wavelet-based approach improves model accuracy

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Watershed Scientific Focus Area Function

U.S. DEPARTMENT OF ENERGY

INTRODUCTION

The high computational cost of process-based distributed hydrological simulations at the catchment scale can be approached by *adaptive mesh refinement* (AMR).
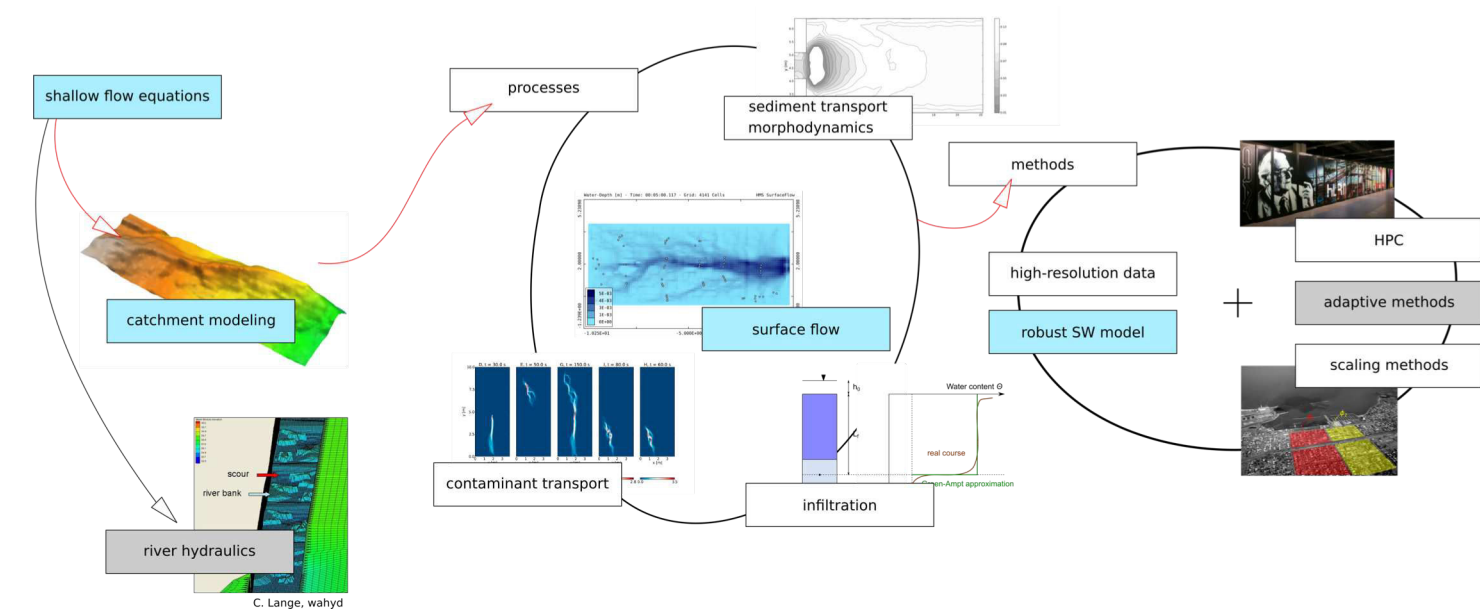

The aim is to approximate the high-resolution uniform mesh using a simplified mesh with fewer elements. This contribution presents a fixed AMR approach that is based on wavelet analysis (Kesserwani *et al.*, 2019) that produces a multiresolution triangular mesh from quad-based DEM input data.

DEM → input → tinerator → output → mesh
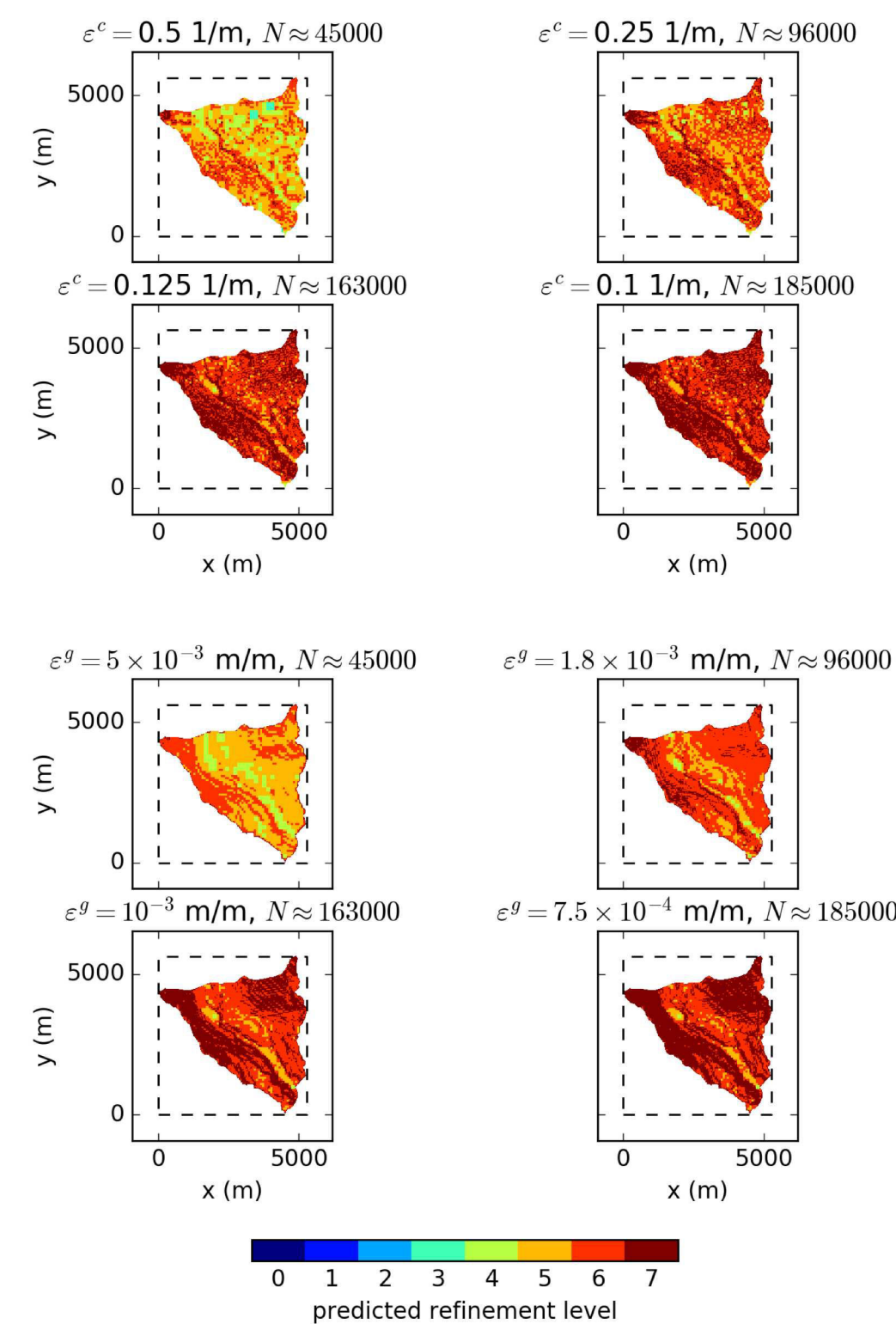mesh generator
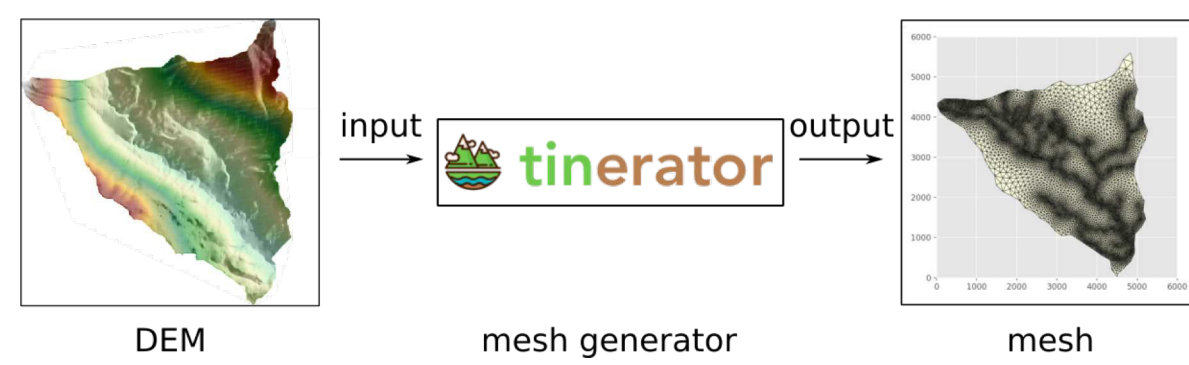
LOWER TRIANGLE, COLORADO

Lower Triangle is a subcatchment of the East River Watershed in Colorado, USA. The catchment is mountainous, and features steep slopes and high elevations. The elevation data is available as a quad-based DEM with 10 m resolution.
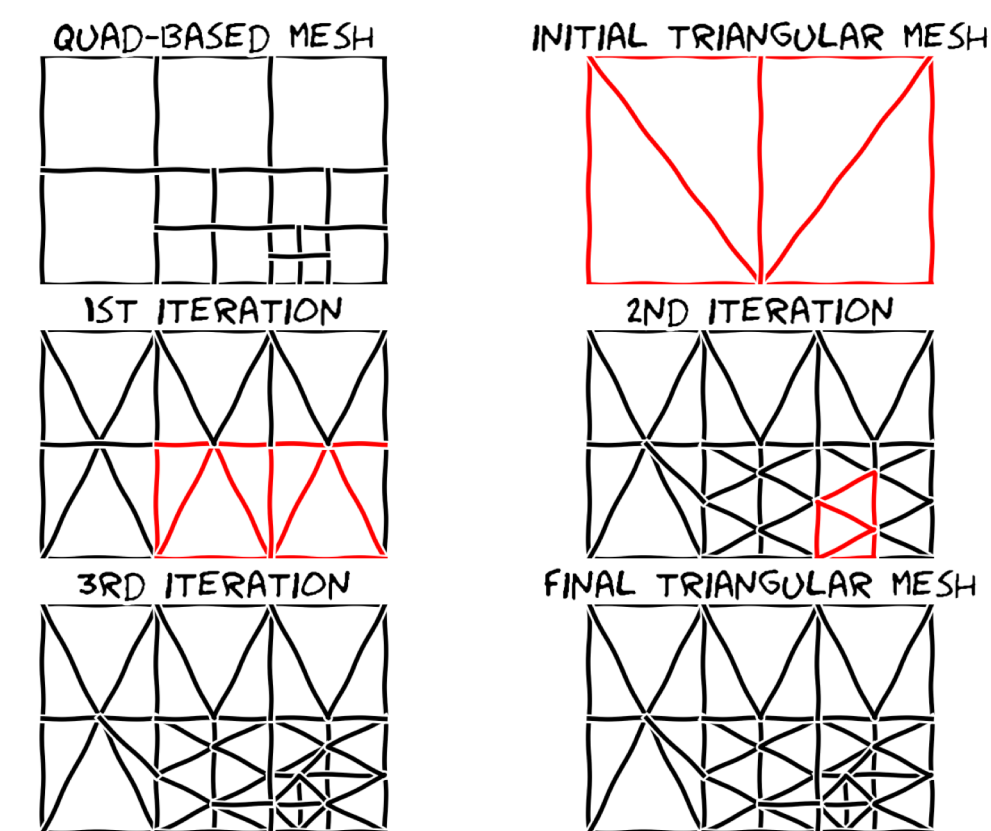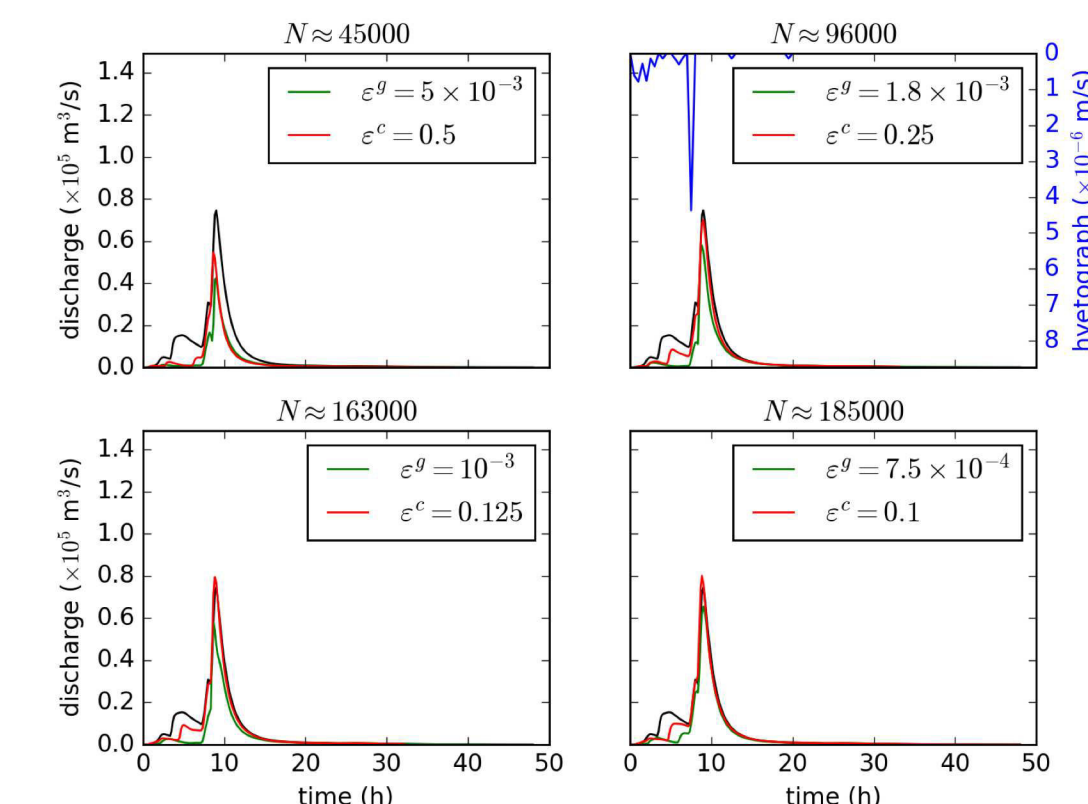

contour plot of DEM, Lower Triangle catchment, CO, USA
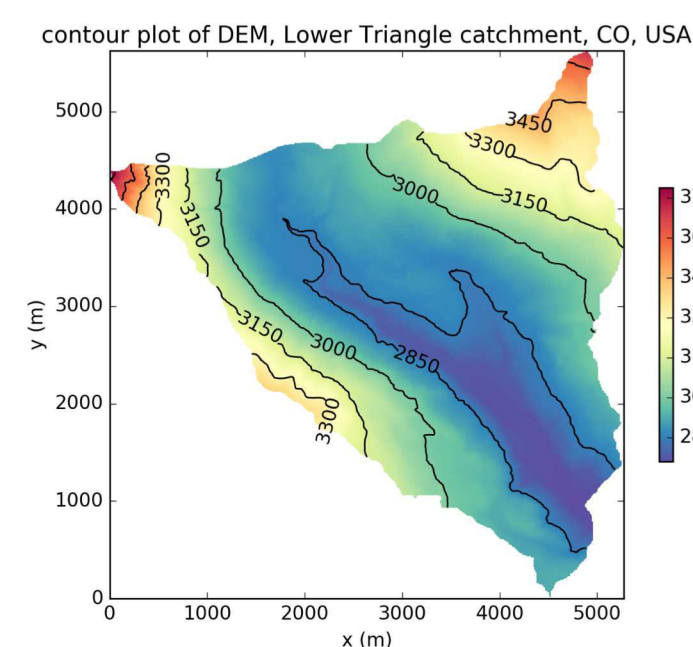
MESHING WORKFLOW

Step 1: Multiresolution analysis of DEM data

$\varepsilon^c = 0.5$ 1/m, $N \approx 45000$
$\varepsilon^c = 0.25$ 1/m, $N \approx 96000$
$\varepsilon^c = 0.125$ 1/m, $N \approx 163000$
$\varepsilon^c = 0.1$ 1/m, $N \approx 185000$

$\varepsilon^g = 5 \times 10^{-3}$ m/m, $N \approx 45000$
$\varepsilon^g = 1.8 \times 10^{-3}$ m/m, $N \approx 96000$
$\varepsilon^g = 10^{-3}$ m/m, $N \approx 163000$
$\varepsilon^g = 7.5 \times 10^{-4}$ m/m, $N \approx 185000$

predicted refinement level 0 1 2 3 4 5 6 7

Step 2: Triangular mesh generation

QUAD-BASED MESH — INITIAL TRIANGULAR MESH
1ST ITERATION — 2ND ITERATION
3RD ITERATION — FINAL TRIANGULAR MESH

RESULTS

Hydrographs at the outlet

$N \approx 45000$ ($\varepsilon^g = 5 \times 10^{-3}$, $\varepsilon^c = 0.5$)
$N \approx 96000$ ($\varepsilon^g = 1.8 \times 10^{-3}$, $\varepsilon^c = 0.25$)
$N \approx 163000$ ($\varepsilon^c = 10^{-3}$, $\varepsilon^c = 0.125$)
$N \approx 185000$ ($\varepsilon^c = 7.5 \times 10^{-4}$, $\varepsilon^c = 0.1$)
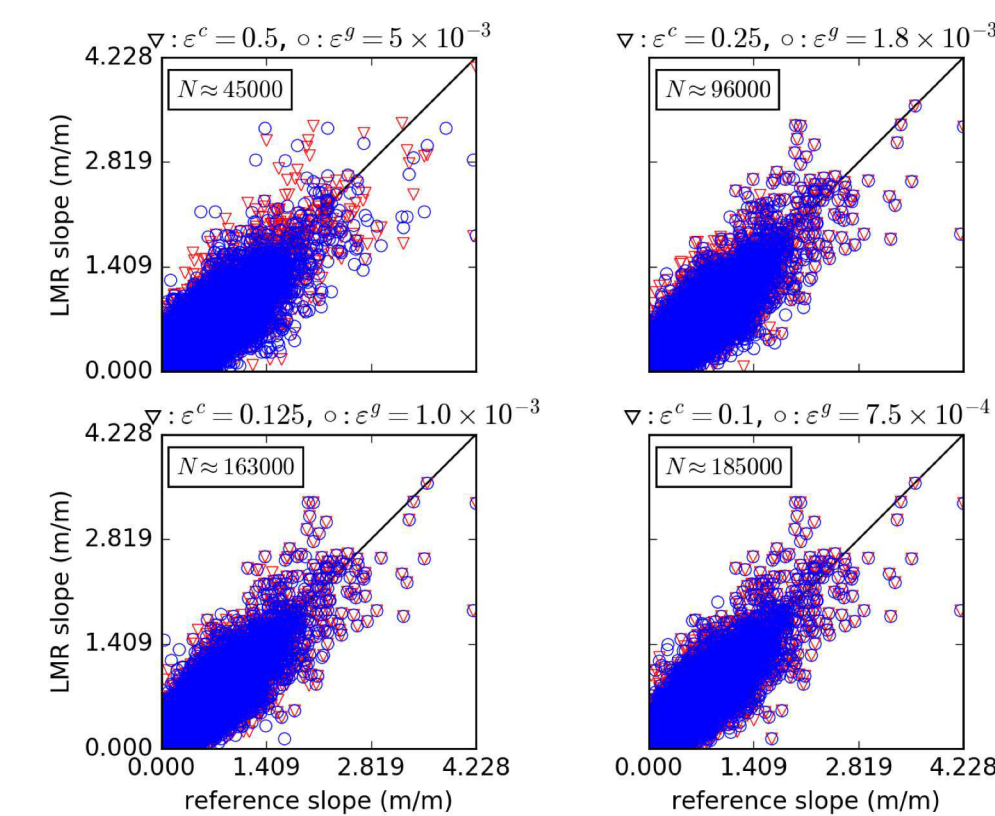
Magnitude of bed slopes

Flow velocities

$t = 10$ h in simulation time
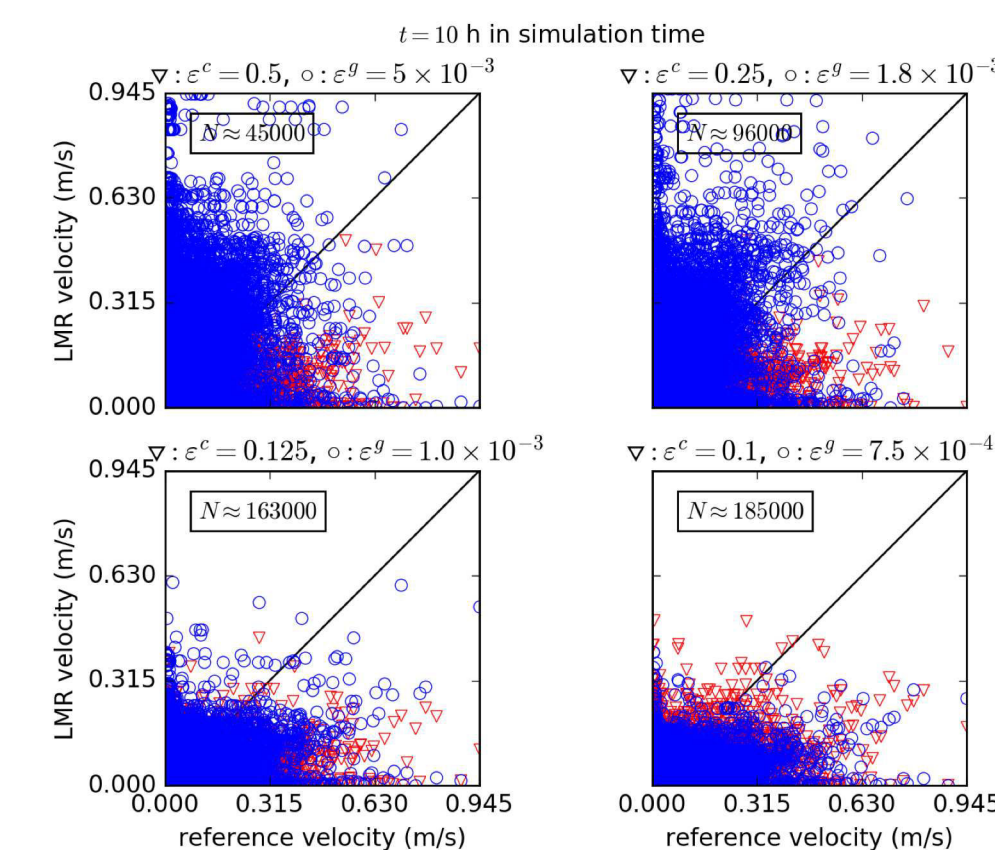
SUMMARY

1. The wavelet-based AMR is a robust method that requires only one user-specified parameter.
2. Either slope or curvature can be used to predict local refinement. For the presented case, a curvature-based refinement has been found to be more advantageous.
3. While the integral discharge at the outlet is accurately predicted by the AMR approach, ponding water depths and flow velocities inside the catchment deviate from high-resolution reference simulation results.
4. Using the proposed AMR approach reduced the computational cost by a factor of 2 up to 3, depending on the number of elements in the reduced mesh.

FORTHCOMING ATTRACTIONS

- An article that provides more details is currently under review.
- We plan to incorporate the presented AMR approach into the mesh generator TINerator:
  https://raw.githack.com/lanl/LaGriT/tinerator/html/index.html
- Applications to integrated hydrological simulations are in progress.

IDEAS Watersheds tinerator
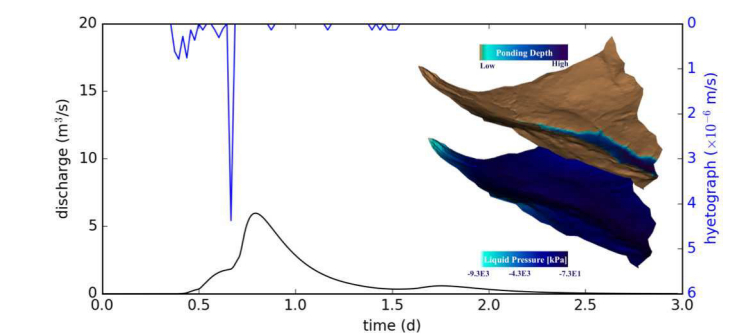
REFERENCES

Caviedes-Voullième, D., García-Navarro, P., Murillo, J., Influence of mesh structure on 2D full shallow water equations and SCS curve number simulation of rainfall/runoff events. *Journal of Hydrology*, 448-449:39-59, 2012.

Dwivedi, D., Steefel, C. I., Arora, B., Newcomer, M., Moulton, J. D., Dafflon, B., Faybishenko, B., Fox, P., Nico, P., Spycher, N., Caroll, R., Williams, K. H., Geochemical exports to river from the intrameander hyporheic zone under transient hydrologic conditions: East River Mountainous Watershed, Colorado. *Water Resources Research*, 54:8456-8477.

Kesserwani, G., Shaw, J., Sharifian, M. K., Bau, D., Keylock, C. J., Bates, P. D., Ryan, J. K., (Multi)wavelets increase both accuracy and efficiency of standard Godunov-type hydrodynamic models. *Advances in Water Resources*, 129:31—5, 2019.

ACKNOWLEDGMENTS