Developing a sustainable scientific software for simulations and hazard assessment of geophysical mass flows

Ali Akhavan Safaei[†]

[†]Mechanical and Aerospace Engineering Department
State University of New York at Buffalo

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Geophysical Flows




- Huge domain
- Multi-scale
- Multi-phase
- Complex topography

Governing Equations and Simulation Challenges

$$\frac{\partial}{\partial t}\begin{Bmatrix} h \\ hv_x \\ hv_y \end{Bmatrix} + \frac{\partial}{\partial x}\begin{Bmatrix} hv_x \\ hv_x^2 + 0.5k_{ap}g_z h^2 \\ hv_x hv_y \end{Bmatrix} + \frac{\partial}{\partial y}\begin{Bmatrix} hv_y \\ hv_x v_y \\ hv_y^2 + 0.5k_{ap}g_z h^2 \end{Bmatrix} = \begin{Bmatrix} 0 \\ S_x \\ S_y \end{Bmatrix},$$

Assuming Mohr-Coulomb rheology model:

$$S_x = g_x h - \frac{V_x}{\sqrt{V_x^2+V_y^2}}\left(g_z h + \frac{hV_x^2}{r_x}\right)\tan(\phi_{bed}) - hk_{ap}\operatorname{sgn}\left(\frac{\partial V_x}{\partial y}\right)\frac{\partial(g_z h)}{\partial y}\sin(\phi_{int})$$

$$S_y = g_y h - \frac{V_y}{\sqrt{V_x^2+V_y^2}}\left(g_z h + \frac{hV_y^2}{r_y}\right)\tan(\phi_{bed}) - hk_{ap}\operatorname{sgn}\left(\frac{\partial V_y}{\partial x}\right)\frac{\partial(g_z h)}{\partial x}\sin(\phi_{int})$$

$$k_{ap} = 2\,\frac{1 \pm [1 - cos^2\phi_{int}(1 + tan^2\phi_{bed})]^{\frac{1}{2}}}{cos^2\phi_{int}} - 1$$

- Flow interface tracking
- Lack of a comprehensive model
- Hyperbolic eqns.
- Highly nonlinear
- Shallow water type (3D→2D)
- k_{ap} Effect of compressibility

TITAN2D Simulation

1

Topography

⇓

Digital Elevation Model

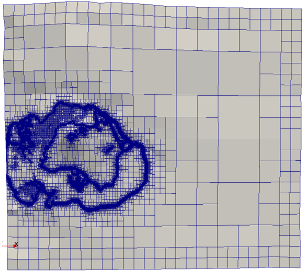
⇓

Flow Initiation

⇓

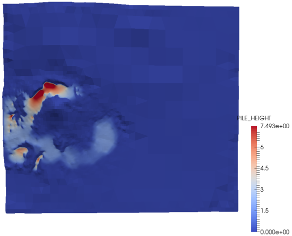
Flow Rheology

2



- **Structured**
- **Adaptive**
- **Hilbert SFC**
- **Dynamic Load Balancing.**

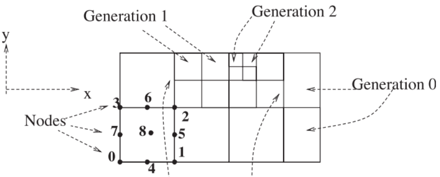
3



- **Finite Volume**
- **Parallel**
- **HLL**
- **Second order**

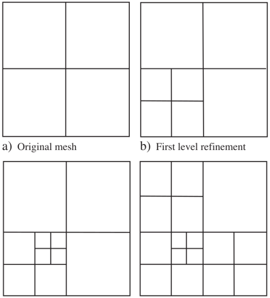
Data Structure and Grid Properties in TITAN2D

- **Hash Tables:** key and values
- **SFC** makes a **one-to-one** map between each location and its key (an unsigned integer) that was recently vectorized with a considerable impact on computational performance!
- **1-irregularity rule** in AMR



Case a) Generation 0 has Generation 1 neighbor

Case b) Generation 1 has Generation 0 neighbor

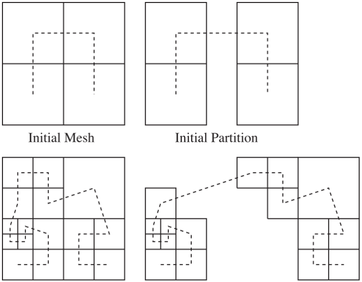


a) Original mesh

b) First level refinement

c) Second level refinement 1-irr rule is broken

d) Bigger elements get refined to enforce 1-irr rule



Initial Mesh

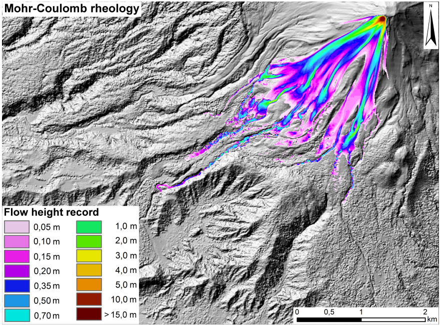
Initial Partition

Refined Mesh

Refined Partition

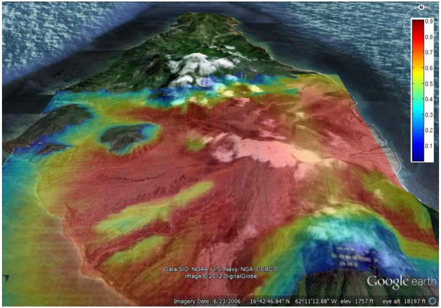
The Hazard Map Analysis

1



Max. Pile Height Record

2



Hazard Map:
Probability Distribution of inundation exceeding a threshold

The End!