Numerical Prediction of Water Level and Hydrodynamic Loads in Coastal Communities During a 500-year CSZ tsunami

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INTRODUCTION

The modeling of tsunami flows and tsunami-induced forces in coastal communities with the incorporation of the constructed environment is challenging for many numerical modelers because of the scale and complexity of the physical problem:

- 2D models
  - Efficient for modeling of waves offshore
  - May not be accurate enough to predict the complex flow around constructed environments on land
- 3D models
  - Much more computationally expensive
  - Can become impractical due to the size of the problem

In this study, a 2D model and a 3D model are built and compared.

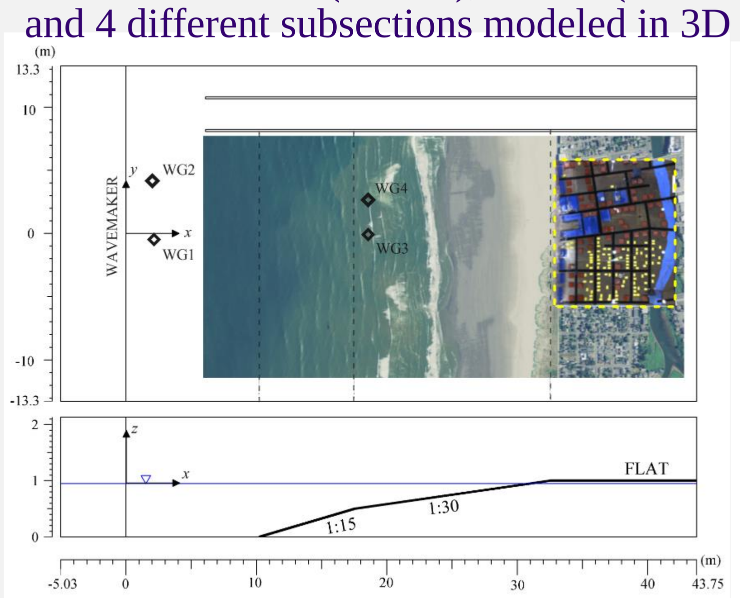
SIMULATION METHODOLOGY

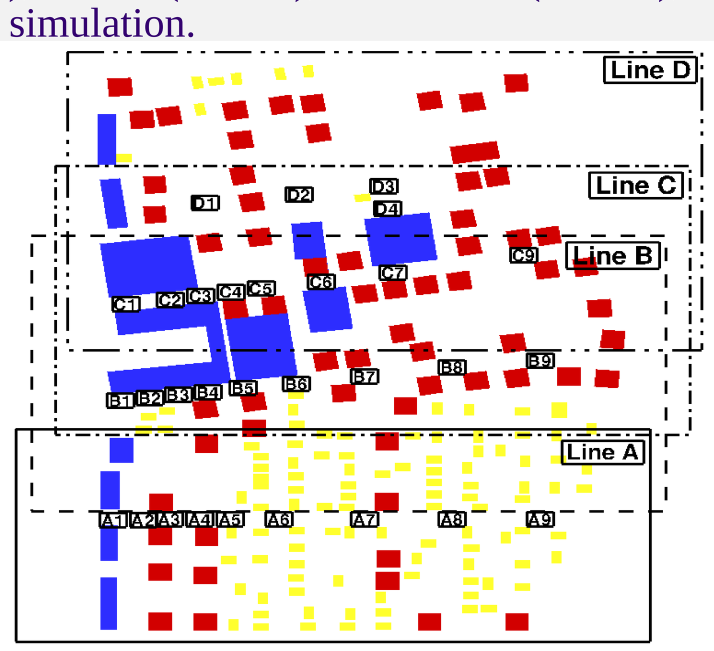
In this study, two different numerical approaches were used to model the inundation.

- **2D Simulations:**
  - Depth-averaged shallow water equations solved using open-source package **GeoClaw** with high-resolution finite volume methods and Adaptive Mesh Refinement (AMR) techniques.
  - Typical computation time: 5-6 hours with 1 computer core
- **3D Simulations:**
  - CFD models developed using open-source CFD package **OpenFOAM**
  - Typical computation time: 8-10 days with 128 computer cores in parallel
  - Domain subdivided into four sections to improve computational efficient
  - Allows for direct computation of forces and moments on structures

Setup of Models

A 1:50 scale model of part of the town of Seaside, Oregon, located on the U.S. Pacific Northwest coastline and adjacent to the Cascadia Subduction Zone (CSZ), was built and a series of experiments were conducted to measure flow velocities and water levels during a tsunami inundation (Park et al., 2013). The figure below on the left shows top view and side view of the basin superimposed with the experimental setup and an image of the town of Seaside. In the front of the town, there was seawall with a height of 0.04 m (model scale). The figure below on the right shows the locations of the 31 gauges where **water level and flow velocity were measured** in the experiment, numbered A1-A9 (Line A), B1-B9 (Line B), C1-C9 (Line C), and D1-D4 (Line D), and 4 different subsections modeled in 3D simulation.

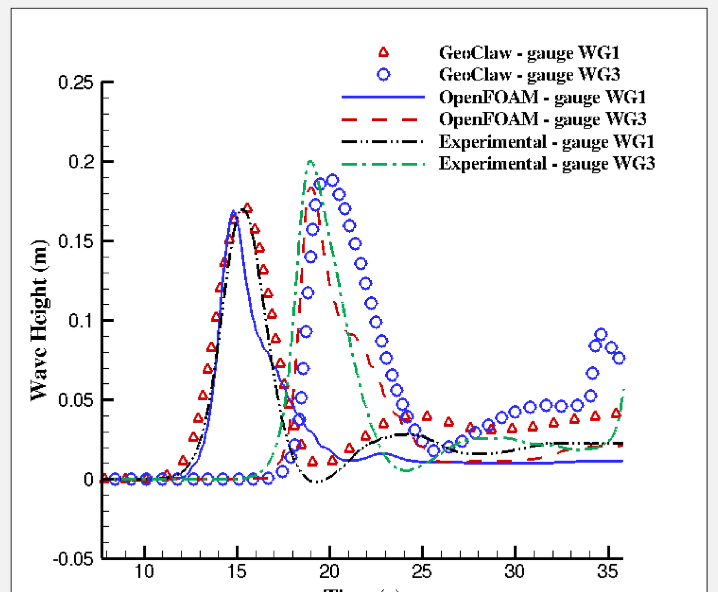




Figures adapted and modified from Park et al. ,2013

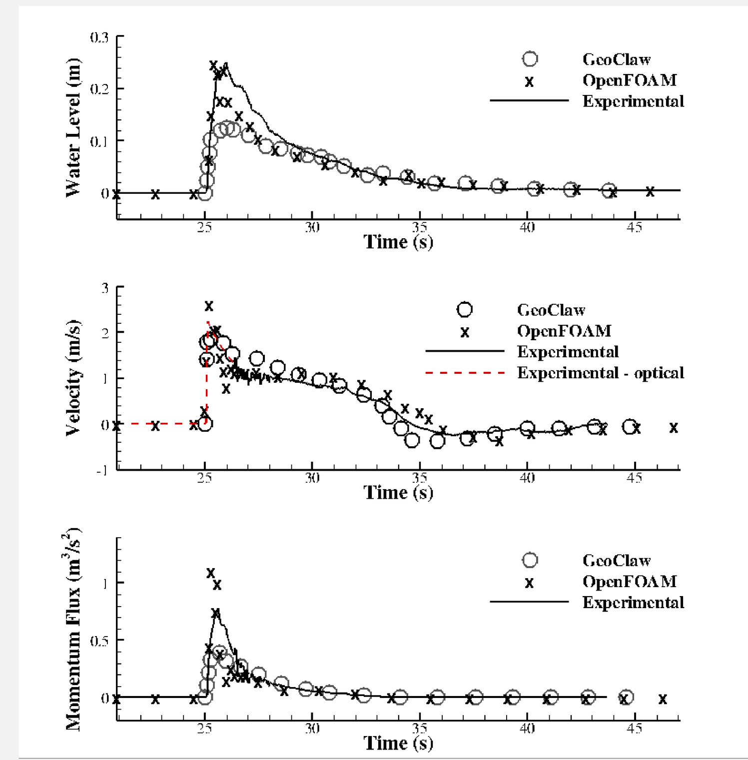
OFFSHORE FLOW PARAMETERS

- The figure at right shows time history of wave height at two wave gauges offshore.
- Good correlation between the measured and predicted results
- The tsunami waves generated in the numerical model were slightly underestimated and had slightly slower propagating speed.

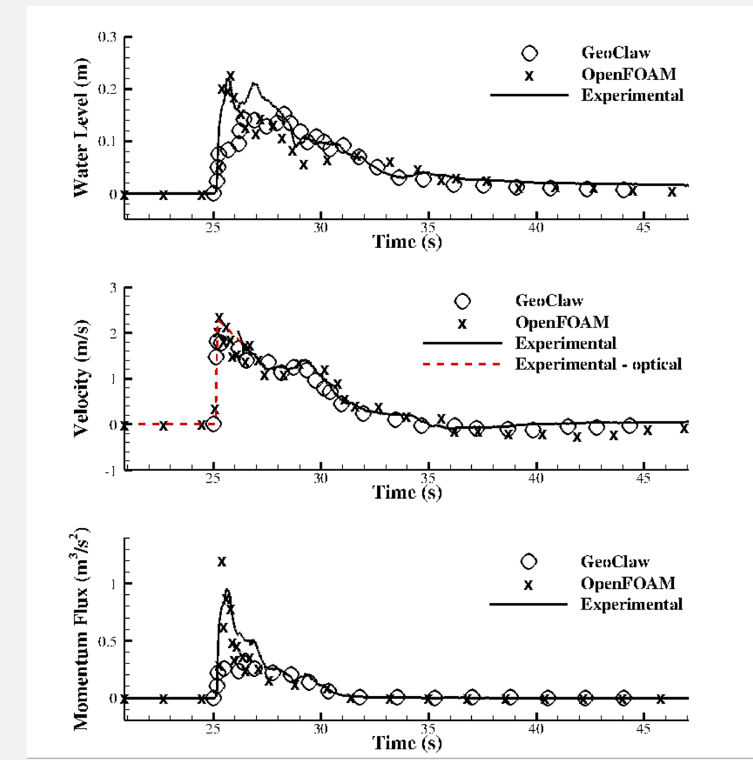


ONSHORE FLOW PARAMETERS

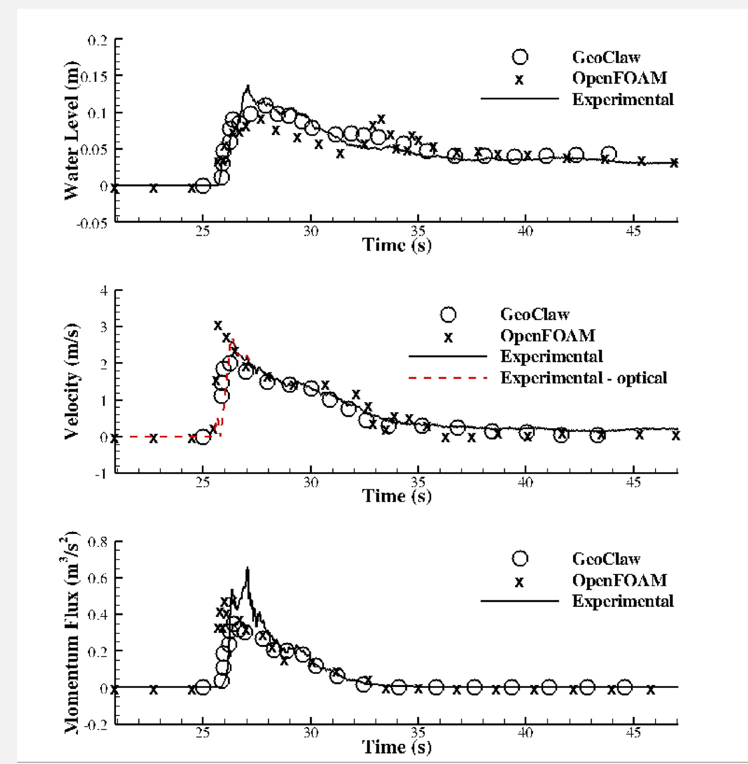
Free surface elevation, h, cross-shore component of velocity, u, and momentum flux, hu^2, at selected gauges onshore are shown below. For velocity subfigures, the solid line is obtained by Acoustic Doppler Velocimeter. The dashed line is obtained by analyzing the trajectory of bore front in recorded video.



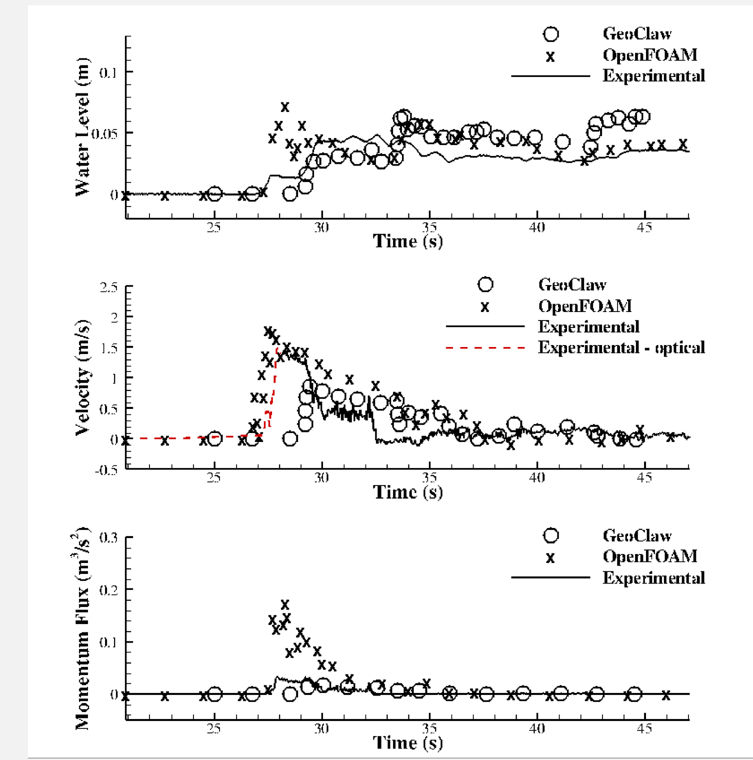
Gauge A1



Gauge B1



Gauge C3



Gauge D3

- Discrepancy in peak velocity

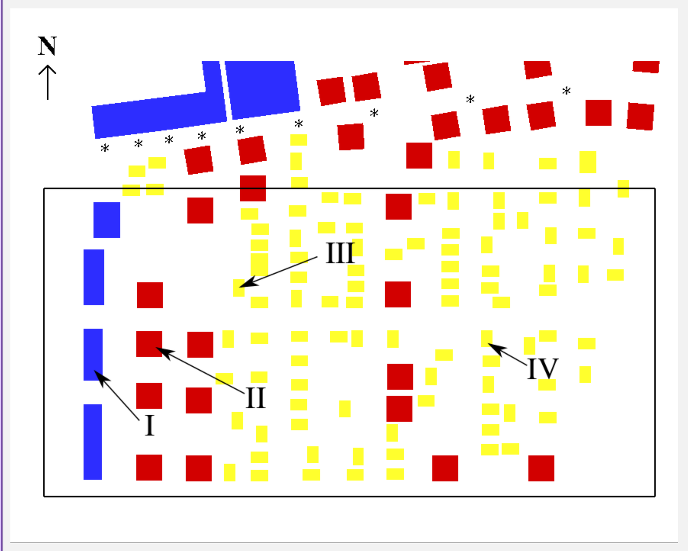
  The difference in measuring methods for velocity turns out to cause the discrepancy in velocity near initial impact. The is because the moving speed of the bore front is not necessary equal to peak velocity. Analyzing the video of numerical results from the 3D model reduce the discrepancy in velocity near initial impact.
- Water level

  Water levels predicted by the 3D model agree fairly well with measurements at many of the gauges in groups A, B and C, but the 2D model underestimates the amplitude at many gauges. These differences reflect the challenge of modeling a turbulent and rapidly varying bore front, with large variation in vertical direction.
- Flow parameters at gauge D

  Gauges in groups A, B and C are placed along straight lines while gauges in group D are set behind buildings => flow around group D gauges is more complex and challenging to model
- Conclusion

  The fluid dynamics in the bore front are transient and turbulent. Thus near the initial impact, prediction of flow parameters is challenging. The 3D RANS model solves this challenge better than the two-dimensional NSWE model but needs much more computational resources

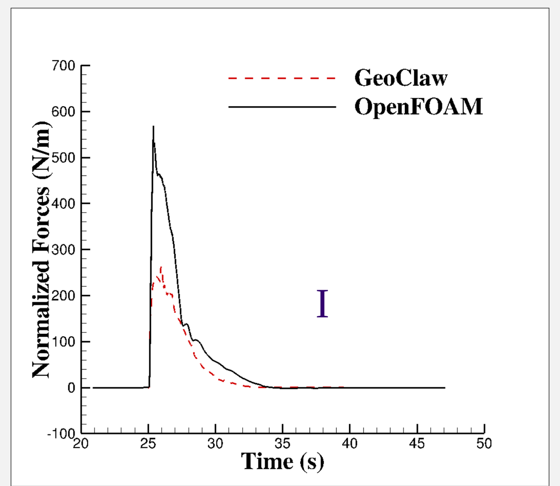
SAMPLE FORCES ON BUILDINGS

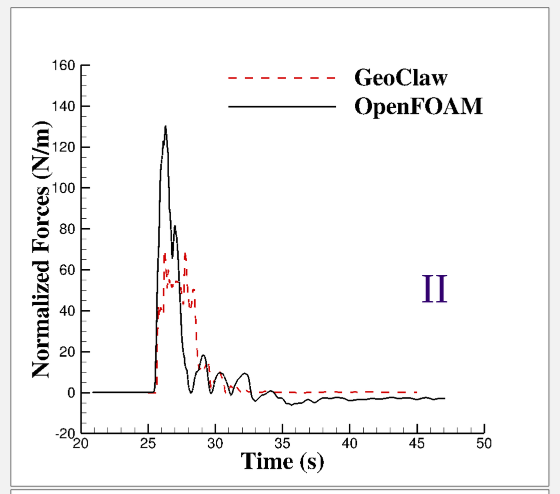


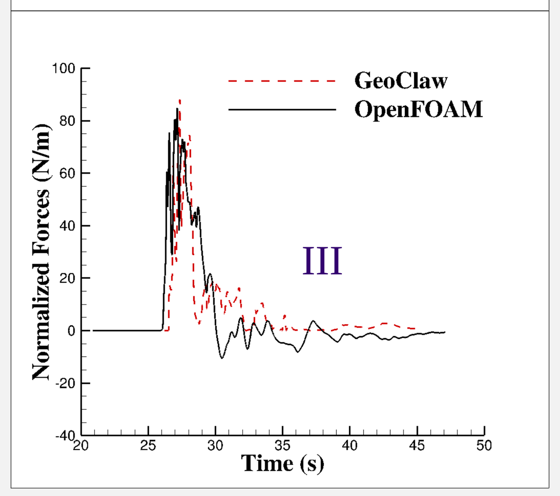
The 4 figures below show predicted forces in the cross-shore direction from the two models on 4 selected buildings (numbered in the figure on the left).

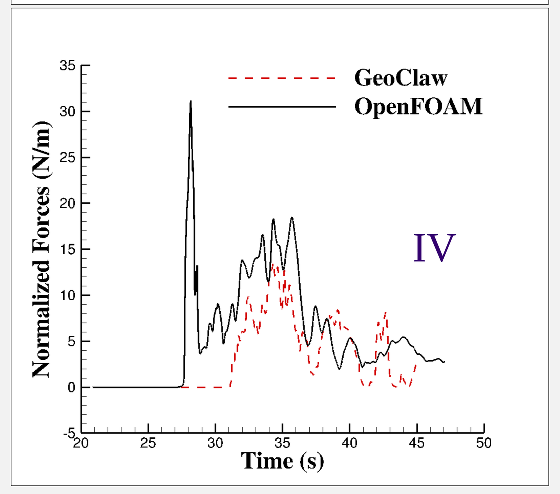
Forces from the 3D model are computed by integrating pressure on object surfaces. Forces from the 2D model are computed with the definition of drag coefficient (with C_D chosen as 2.0).

The comparison indicates that using a drag coefficient to predict fluid forces on structures from the 2D model in the simple case works well but becomes less reliable with complex constructed environment. Simply choosing a drag coefficient of 2.0 can underestimate fluid forces by up to a half.

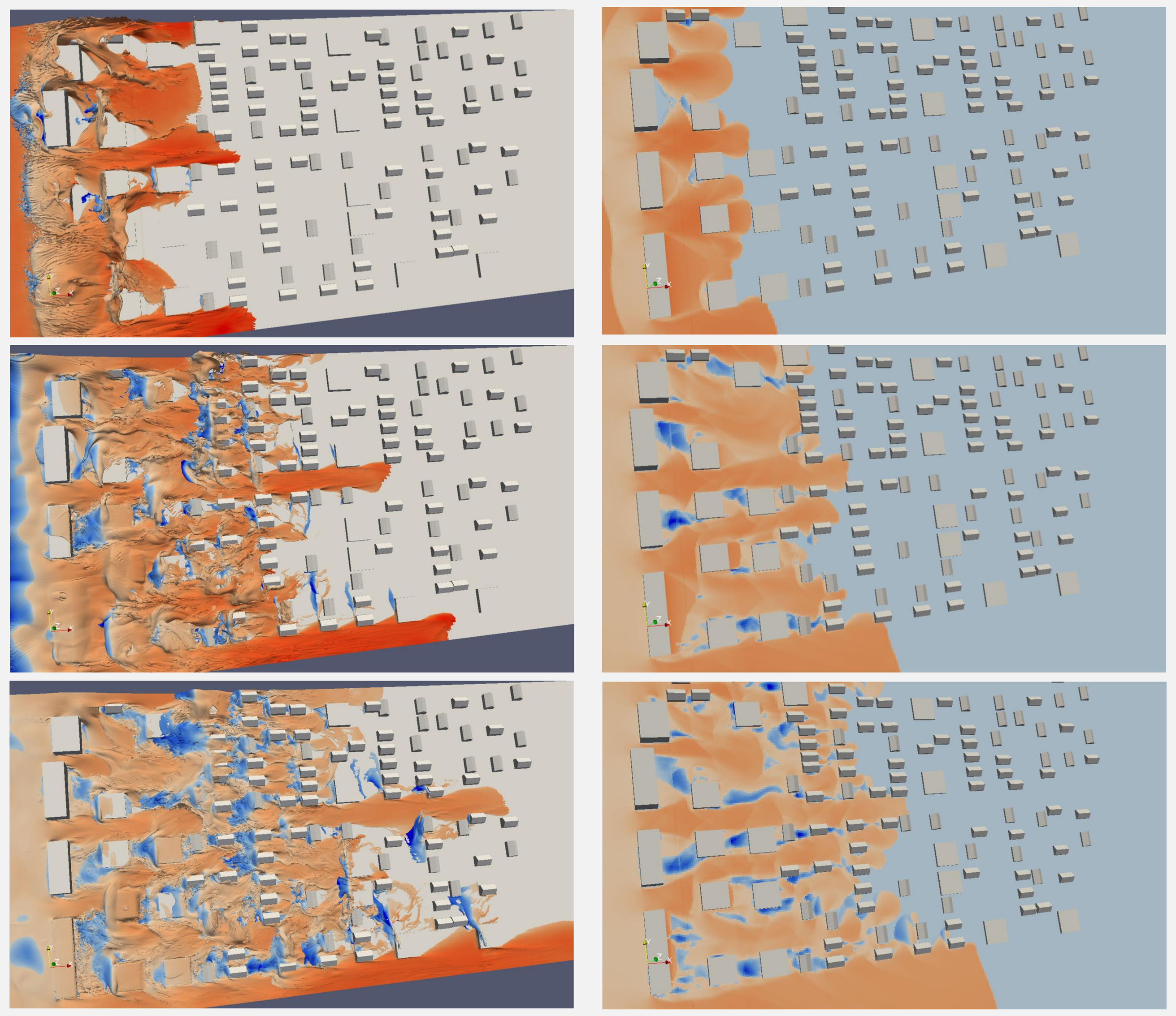








SNAPSHOTS OF THE SIMULATION



Snapshots of the simulation near line A, colored by cross-shore velocity, at 3 different times (from top to bottom): t = 25:9 s, t = 27 s, t=28:1 s. Left: Geoclaw; Right: OpenFOAM

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