Simulating Hurricane Harvey using Two Dimensional Flood Model on Titan and Summit at ORNL

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Abstract

One dimensional flood models do not represent flood wave propagation accurately, especially in urban flood-prone areas, due to inaccuracies in cross-section discretization and the inability to simulate lateral diffusion. Two-dimensional (2D) flood models provide better forecast but are computationally expensive. With effective use of modern HPC platforms, it is now possible to execute 2D high resolution hydrodynamic modeling of large-scale flood events. As a demonstration, we present a hindcast of flooding from Hurricane Harvey using a 2D flood simulation model in heterogeneous HPC environments at Oak Ridge National Laboratory (ORNL). Harvey made landfall in southern Texas and was one of the most destructive hurricanes in U.S. history. Performance improvements in the 2D flood model via hybrid distributed parallel technologies (MPI+CUDA) and modifications to support architecture-agnostic HPC environments are detailed. At 10 meter spatial resolution, the Hurricane Harvey simulation achieved eight fold speed up on Summit compared to Titan, both multi-petascale heterogeneous HPC systems at Oak Ridge National Laboratory (ORNL).

Introduction

- Hurricane Harvey Flooding has caused significant damages. ~*USD 198 Billion* (*Hicks & Burton, 2017*).
- A multi-GPU two dimensional simulation model for hurricane Harvey based on the Navier-Stokes equations by integrating the horizontal momentum and continuity equations over depth often referred to as the depth-averaged or depth-integrated shallow water equations.

Continuity equation : $$\frac{\partial h}{\partial t} + \frac{\partial uh}{\partial x} + \frac{\partial vh}{\partial y} = 0$$

Momentum in x-direction : $$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + g\frac{\partial H}{\partial x} + gS_{fx} = 0$$

Momentum in y-direction : $$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + g\frac{\partial H}{\partial y} + gS_{fy} = 0$$

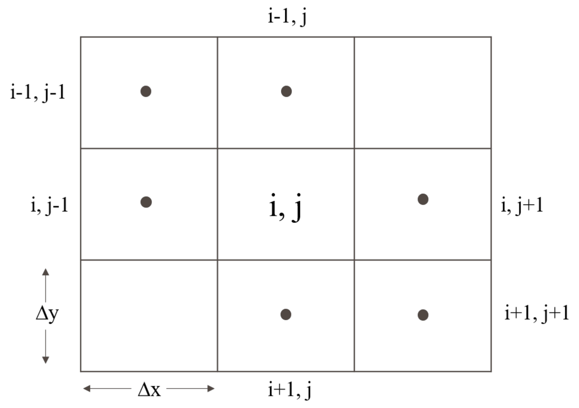


Fig. 1: Staggered grid stencil

- 6 point stencil and one dimensional data partitioning.
- Features of the implementation
  - Variable & fixed time step
  - Hot-Start from checkpoint
  - Cold-Start with initial depth and velocity
  - Multiple flow locations
  - Spatially distributed roughness
- Simulated the model for Harvey at 30 m and 10 m resolution (8.5 and 69 million cells respectively) for 10 days on Oak Ridge National Lab's Titan super computer and ported the code to Summit super computer.

Design and Implementation

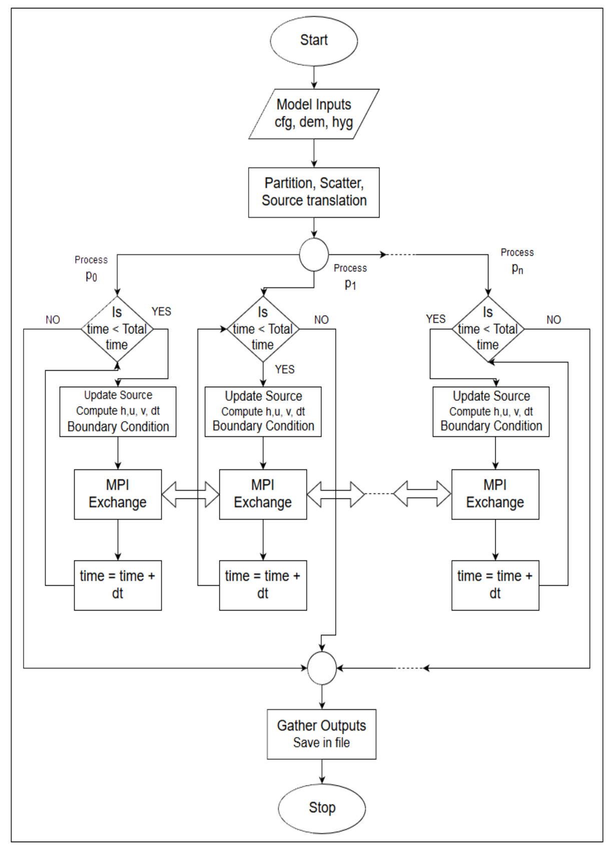


Fig. 2: Parallel Flowchart

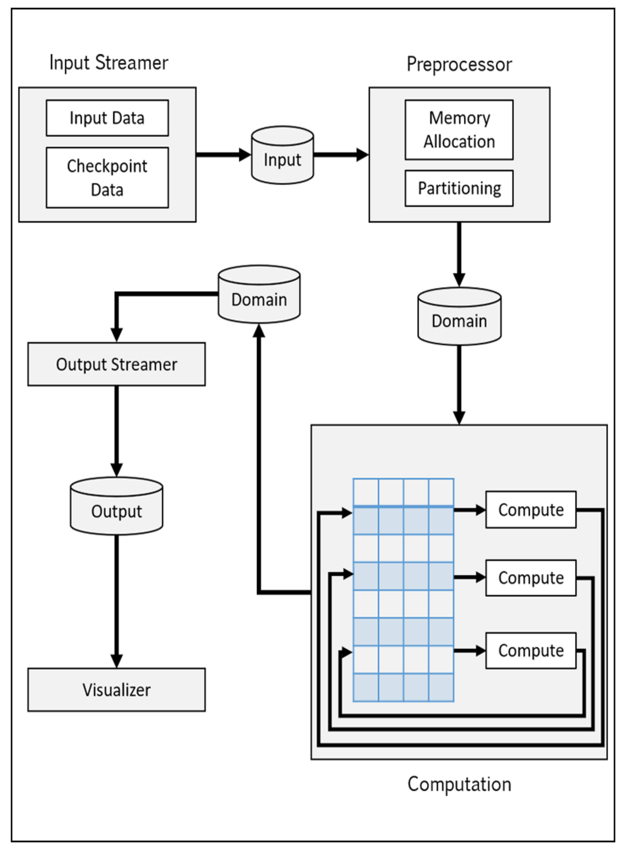
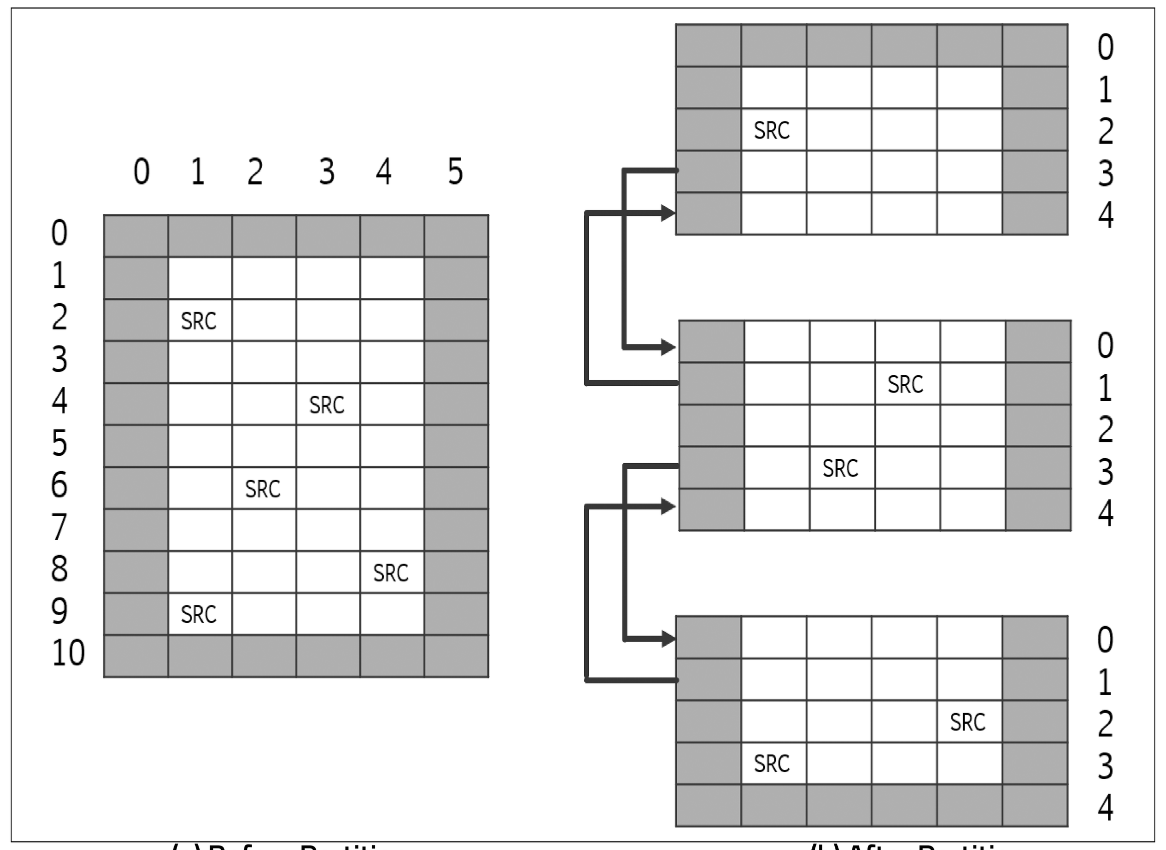


Fig. 3: Implementation Diagram



(a) Before Partition (b) After Partition

Fig. 4: Data Partition & MPI Exchange

Results

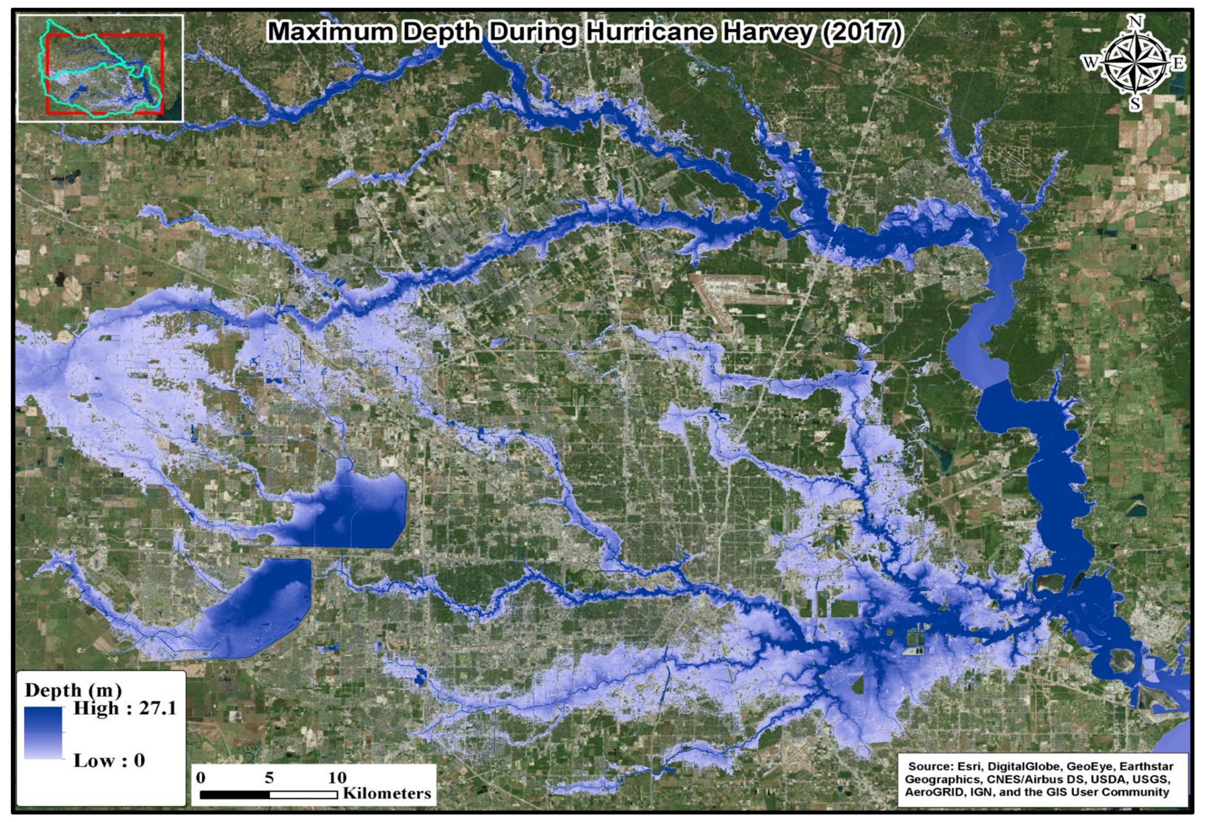


Fig. 5(a): Simulated Max. Inundation depths for Hurricane Harvey flood event

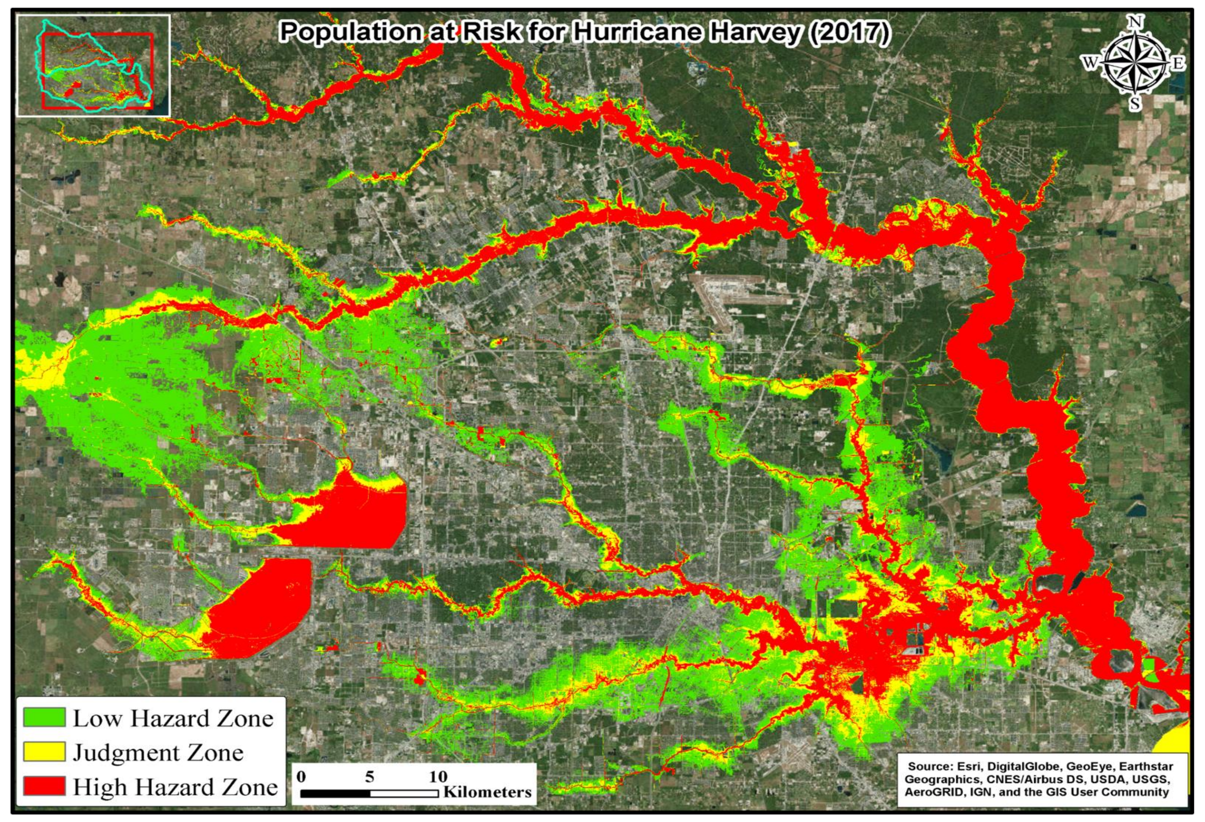


Fig. 5(b): Estimate of Population at Risk for Hurricane Harvey Flood event

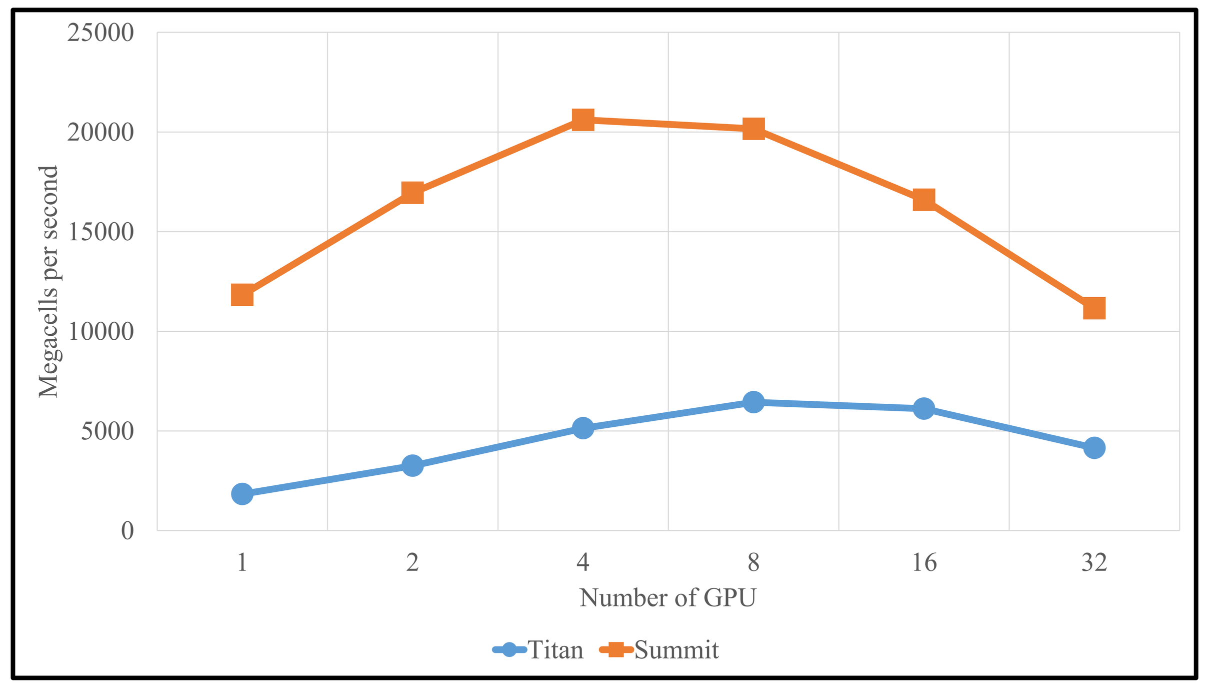


Fig. 6(a): Performance comparison of Hurricane Harvey 30m flood simulation

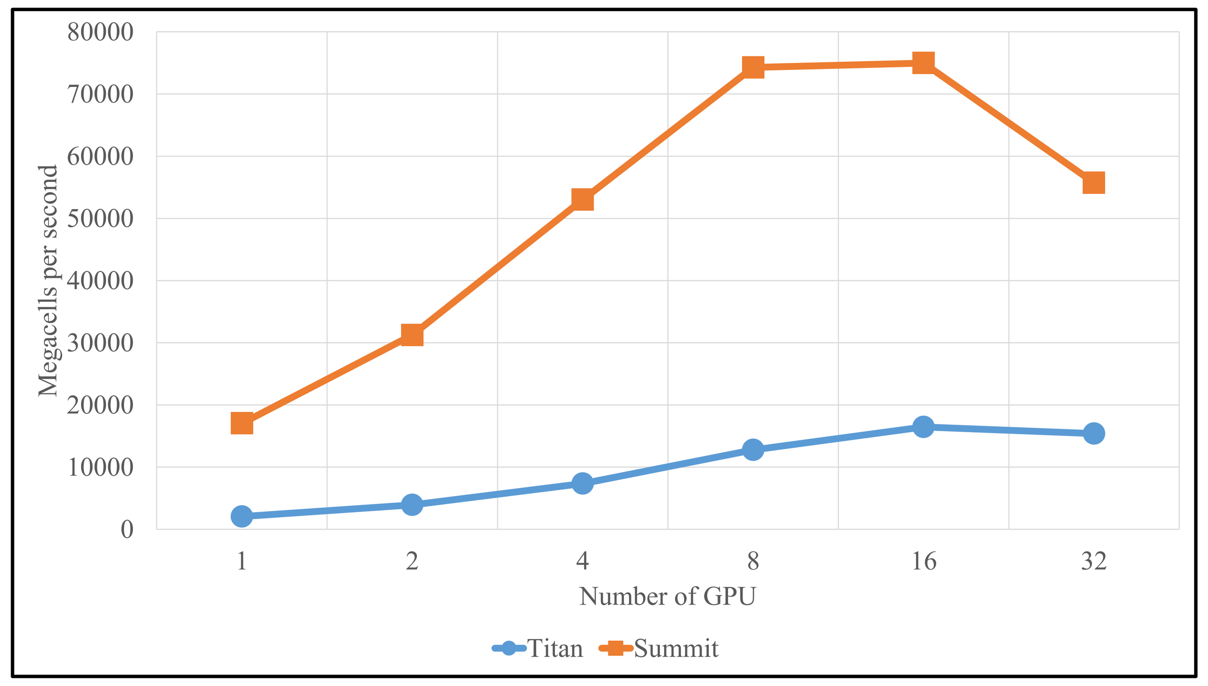


Fig. 6(b): Performance comparison of Hurricane Harvey 10m flood simulation

Result Discussion

No of MPI Process	Computation time 30m (min)		Computation time 10m (min)	
	Titan	Summit	Titan	Summit
1	475.5	73.2	8732.9	1051.9
2	266.8	51.1	4545.2	573.9
4	169.1	41.9	2430.1	338.3
8	134.9	42.9	1400.9	241.4
16	142.1	52.1	1086.2	239.2
32	209.9	77.6	1161.9	321.8

Table 1: Computation time of different test run

- Hurricane Harvey flood event was reconstructed using the integrated Meteorologic-Hydrologic-Hydraulic modeling framework (Figure 5a and 5b).
- 30m simulation scales up to 8 MPI processes (8 nodes) in Titan and 4 MPI processes (1 node) in Summit (Figure 6a).
- 10m simulation scales up to 16 MPI processes (16 nodes) in Titan and 8 MPI processes (2 nodes) in Summit (Figure 6b).
- Performance in Summit is 6.5x better than Titan for 30m (Figure 6a) when we use 1 MPI process and 1 GPU. For 10m, Summit performs 8.3x better (Figure 6b) for the same configuration.

Conclusion & Future Work

- Show a scalable and efficient 2d flood simulation model implementation.
- Show performance improvement on Summit.
- Strategy can be helpful not only flood simulation but also similar types of cellular automata applications.
- Future exploration includes the development of a set of generalized data structures supporting a number of different partitioning strategies, runtime configuration parameters.
- Build a user-friendly meta-computing API so that domain scientists can access efficient hardware without the expertise that is required today.

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