EVALUATING REALISTIC TSUNAMI SIMULATIONS WITH SWE MODEL

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Abstract: We evaluate the ability of SWE shallow water numerical model to perform efficient and realistic tsunami simulations. SWE model was used to reproduce 2004 Great Sumatra–Andaman and 2011 Tōhoku tsunami. In order to enhance the performance of the simulations, GPU-enabled clusters Tesla-CMC and Todi Cray XK-7 were used. The clusters were benchmarked using different number of processes and GPUs to obtain the most efficient and the fastest SWE configurations.

Keywords: SWE, tsunami, GPU acceleration

1 INTRODUCTION

Tsunamis belong to the most devastating ocean disasters in the world. When they reach the dense-populated coastline areas unexpectedly, fatal destructions and lot of deads are claimed. In order to prevent such scenarios, it is required to have a tool that would provide fast and detailed simulation of tsunami. One of the models that could be used for tsunami simulation is SWE model [1].

Shallow water equations [3] model the behavior of a fluid, in particular water, in a two-dimensional domain. Shallow water equations describe the change of water depth and horizontal velocities over time, depending on some initial conditions, in this case – ocean floor displacement during the earthquake. The respective changes of water depth in time can be described by a system of partial differential equations.

High-resolution tsunami simulations result into large problems, that could often be solved in reasonable time only by using parallel computations. This study is aimed to find the most efficient configuration and evaluate performance of emerging massively-parallel graphics processing units (GPUs).

2 SIMULATION METHODOLOGY

In the SWE model, tsunami is identified by the number of input data fields. First of all, we need the model of the Earth's surface including the mainland as well as the ocean floor. ETOPO1 [2] Global Relief Model is a 1 arc-minute (~1.8 km) model of Earth's surface that integrates land topography and ocean bathymetry. The global 30 arc-second grid (~0.9 km) ocean floor relief (bathymetry) is provided by General Bathymetric Chart of the Ocenans (GEBCO).

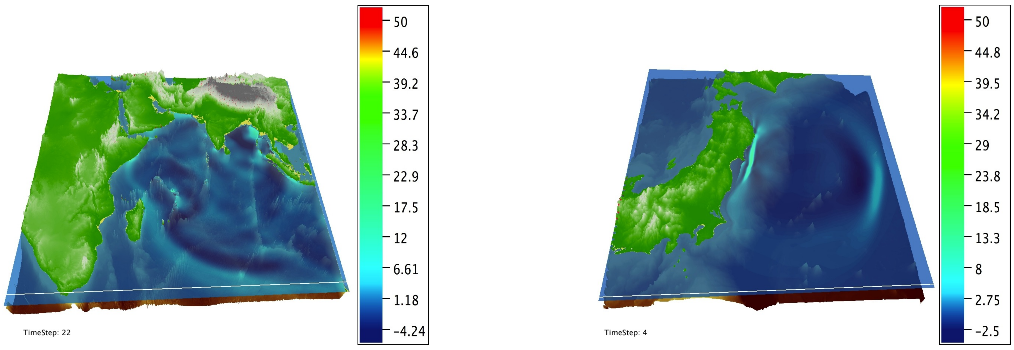
The relief data cannot be used by the SWE in a raw form. The basic data structure of the SWE is a rectangular plain grid. The bathymetry and topography data need to be projected on the grid including the whole region of interest. For this purpose Generic Mapping Tools are used. GMT merge topography and bathymetry data and generate the rectangular grid of region defined by latitude and longitude coordinates.

We also need a model of the seismic event that triggered the tsunami. The tsunami is initiated when the sea floor displacement occurs. We need to know several aspects of the event including the exact area of the sea floor that was displaced, how much it was displaced and the time and direction of the movement. The movement of the sea floor is estimated using various sensor measurements in the area affected by the earthquake. These measurements are usually maintained by U.S. Geological Survey, which also provides the data in several formats. The SWE is configured for the subfault format. The resulting wave propagation is computed with SWE model.

3 EXPERIMENTAL RESULTS

In case of great Sumatra–Andaman earthquake and tsunami the rupture process was estimated using tsunami waveforms observed at tide gauges and the coseismic vertical deformation observed along the coast [4]. The tsunami waveform inversion was used to estimate the slip distribution of the earthquake. The fault area of the earthquake is divided into several smaller subfaults and the slip amount on each subfault is estimated from the observed tsunami waveforms.

Simulation of the tsunami wave propagation can begin after the initial sea floor displacement and initial waveform have been computed. Propagation model and the behavior of the wave is defined in the SWE model. Wave propagation is simulated for specified time range and on specific area of interest defined relative to the epicenter. SWE is able to adapt time step for numerical stability conditions. Visualization of wave propagation can be seen in Figure 1.



(a) Sumatra 2004 (b) Tōhoku 2011

Figure 1: Visualization of tsunami waves

SWE can be configured to run in parallel or to use GPU accelerators in order to speed up the simulation. Detailed description of used configurations and the resulting speed up and efficiency is discussed in the section 4.

3.1 CREDIBILITY OF PERFORMED TSUNAMI SIMULATIONS

Credibility of the performed tsunami simulations has been verified by comparison to numerous reports containing the list of mainland areas hit by tsunami, observations of the tsunami wave and ocean level sensors measurements. The visualizations in video form are available at `http://goo.gl/atbkz6` and `http://goo.gl/pLmZow`.

4 BENCHMARKING

The SWE has been run with different configurations to find out the most efficient settings. SWE was used in parallel mode with 1 to 8 MPI processes and also with GPUs included. The simulations were run on two different clusters: Tesla-CMC, equipped with NVIDIA Tesla C2075 GPUs and Todi Cray XK-7, equipped with NVIDIA K20 GPUs. The summarization of the speedups can be found in the Table 1.

It was observed, that when higher degree of parallelism is used the speedup increased. However in such high degree parallelism the efficiency is decreasing because of the inter-process communication. When the GPU is used the speedup increases dramatically. When multiple GPUs are used, speedup continues to increase, while the efficiency only slightly decreases.

Config \ Process	0	1	2	3	···	16	32	48	64
MPI-16	1.00	1.00	1.00	1.00	···	1.00	-	-	-
MPI-32	1.94	1.94	1.94	1.94	···	1.94	1.94	-	-
MPI-48	2.90	2.90	2.90	2.90	···	2.90	2.90	2.89	-
MPI-64	3.88	3.88	3.88	3.88	···	3.88	3.88	3.88	3.88
MPI-GPU-1	14.43	-	-	-	···	-	-	-	-
MPI-GPU-2	29.22	29.08	-	-	···	-	-	-	-
MPI-GPU-4	61.35	60.99	61.06	60.64	-	-	-	-	-
MPI-GPU-8	116.16	111.05	109.83	113.49	···	-	-	-	-
MPI-GPU-16	103.03	82.23	103.12	97.98	···	104.14	-	-	-
MPI-GPU-32	260.99	225.87	237.98	248.89	···	235.67	251.78	-	-

Table 1: Performance of Tohoku tsunami simulation on *Todi Cray XK-7*, speedups relative to process 0 time with usage of one full node (6,027.5 sec)

5 CONCLUSION

In this paper we presented the realistic tsunami simulations with an emphasis on how fast and detailed solution could be achieved on emerging parallel architectures. Such simulations are important for analysis and prediction of catastrophical scenarios in dense-populated areas reachable by tsunamis.

The SWE model has been run with different configurations to benchmark the performance of the GPU-enabled clusters Tesla-CMC and Todi Cray XK-7. SWE model has been run in parallel mode with multiple CPU processes with and without using GPUs. The performance of the massively-parallel graphics processing units (GPUs) have shown impressive results. Using all available GPUs, we observed the maximum speedup of 158x in comparison to single-core CPU version. The most efficient configuration was the one with a single GPU, achieving speedup of 58x.

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