

GPU-accelerated Tsunami Run-up Simulation at Toyama-bay

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Abstract

High speed Tsunami run-up simulation is achieved by using General Purpose Graphical Processing Unit (GPGPU) at Toyama-bay coastal region. The simulation includes 5 [m] grid size geometry data and 3,341,250 (2,475 x 1,350) grid points are used. The simulation is calculated on the Graphics Processing Unit (GPU) named TESLA K20 (NVIDIA) in about 90.6 seconds and it is more than about 78 times as faster as the CPU calculation. The simulation realizes both the high resolution calculation (5 [m] intervals) and the high performance calculation.

Keywords – GPGPU, HPC, Tsunami

1 Introduction

The high speed Tsunami run-up simulation is achieved by using General Purpose Graphical Processing Unit (GPGPU) at Toyama-bay coastal region in Japan. High waves sometimes damage the human residential areas with very complex features. To include data of buildings, roads, creeks etc., several meters resolution grid points are required for the simulation. Therefore the large number of calculation grids must be included in the simulation. As a result, the simulation needs a large amount of calculation time. Reference [1] shows two hours calculation time on CPU for 5 minutes real time phenomena of Toyama-bay Tsunami run-up simulation.

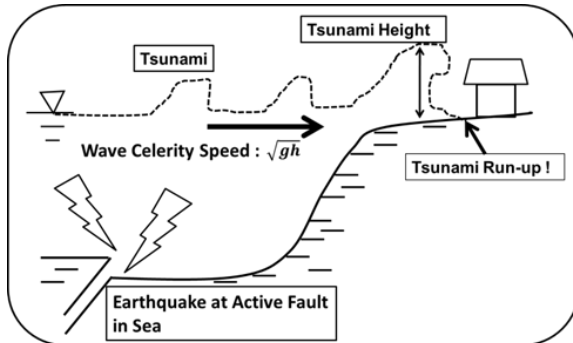


Fig. 1. Overview of Tsunami Generation and Run-up.

Fig. 1 shows overview of Tsunami generation and Tsunami run-up. When the big earthquake occurs at the bottom of sea e.g. active fault, Tsunami wave is generated at sea bottom. The wave has long-length and the speed is very high. The celerity speed is estimated by $\sqrt{gh}$, where g is gravitational acceleration and h is the depth of the sea. If the average depth at Toyama-bay is defined as 250 m, the celerity speed is about 50 m/s.

One of the main targets of the research is also included to construct Tsunami warning system. In the case of Toyama-bay the active fault is close to the land. The system must overcome the calculation time problem. In the most serious case, the Tsunami wave hits the coast and starts run-up within 10 minutes.

High Performance Calculation (HPC) is required for the high resolution calculation and the high speed calculation. Graphical Processing Unit (GPU) has high performance parallel calculation ability for the computer graphics. In recent years, the ability has been applied to the general numerical calculation which is named General Purpose Graphical Processing Unit (GPGPU). Moreover the device is very cheap and the development environment named Compute Unified Device

Architecture (CUDA) is supplied from NVIDIA. It is easy to construct the system of the high performance computation at individual desk side. In the study, the Tsunami (high wave) run-up simulation by using GPGPU is developed.

2 Methodology

2.1 Governing Equations

Tsunami wave is described by the following long-wave theorem, e.g., the continuity equation and the momentum equations.

$$\frac{\partial \eta}{\partial t} + \frac{\partial M}{\partial x} + \frac{\partial N}{\partial y} = 0$$

$$\frac{\partial M}{\partial t} + \frac{\partial}{\partial x} \left[\frac{M^2}{D} \right] + \frac{\partial}{\partial y} \left[\frac{MN}{D} \right] + gD \frac{\partial \eta}{\partial x} + \frac{gn^2}{D^{7/3}} M \sqrt{M^2 + N^2} = 0$$

$$\frac{\partial N}{\partial t} + \frac{\partial}{\partial x} \left[\frac{MN}{D} \right] + \frac{\partial}{\partial y} \left[\frac{N^2}{D} \right] + gD \frac{\partial \eta}{\partial y} + \frac{gn^2}{D^{7/3}} N \sqrt{M^2 + N^2} = 0$$

Here x and y are space coordination, h is static depth, g is gravity accelerate constant, η is elevation, D is total depth ($=h+\eta$) and n is Manning coefficient. The M and N are flux for x and y directions respectively. These equations are discretized by Leap-frog method. The first order upwind scheme is adopted for the advection terms. The method sets off the half size of the defined space mesh and the time stepping points.

2.2 GPGPU Computation

Fig. 2 shows the comparing with CPU and GPU calculation technique. In the case of CPU calculation, each computational grid is calculated sequentially. The number of calculation times is (IMAX x JMAX) when the number of x - and y -direction calculation grids is IMAX and JMAX respectively. In the case of GPGPU calculation, the calculation time is one in theory (Fig.2). If the data dependency in each computational grid is weak, the high performance parallel calculation is expected on GPU. The data dependency in the Tsunami run up simulation is weak because the simulation is realized by the explicit solver.

Table 1 shows the specifications of CPU and GPU. GPU has a large number of calculation cores and the memory bus speed is higher than CPU's one. In general higher memory bus speed leads to higher performances for the calculation because of the

simulation uses a huge number of data transfers between cores and memories.

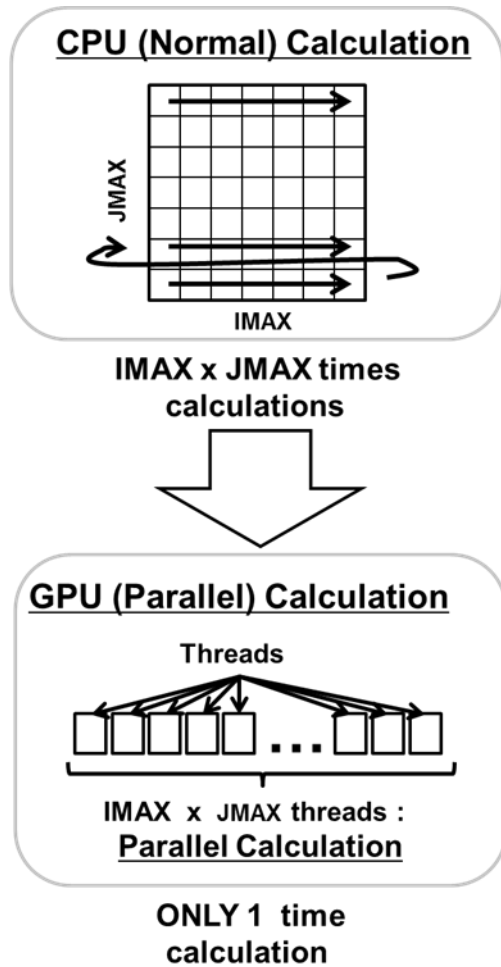


Fig. 2. CPU & GPU Calculation.

Table 1. Performance of CPU & GPU Calculation.

	CPU Intel Xeon E5-2687W	GPU NVIDIA TESLA K20
Cores	8	2,496
Frequency	3.1GHz	706MHz
FLOPS	198.4GFlops	1.17TFlops
Memory Bus Speed	51.2GB/s	208GB/s

3 Result

The tsunami run-up model is applied at the Toyama new port in Japan. At the area includes active fault at the bottom bed of the sea and it is very close to the coastal line (about 10 – 20 km). The numerical simulations under the many conditions are required and the real time tsunami run up warning system when the earthquake will occur is strongly needed. The GPGPU calculation has solutions of the high speed calculations and the high resolution calculation.

Fig. 3 shows the bird's eye result of the tsunami simulation around Toyama new port in Japan. A circular shape wave

condition is adopted for a test problem. The wave is located at 3 km far from coast and the height is set as 13 m for the initial condition. The simulation includes 5 [m] grid size geometry data, as a result, 3,341,250 (2,475 x 1,350) points are used. The grey region means water and the black region is the dry-land.

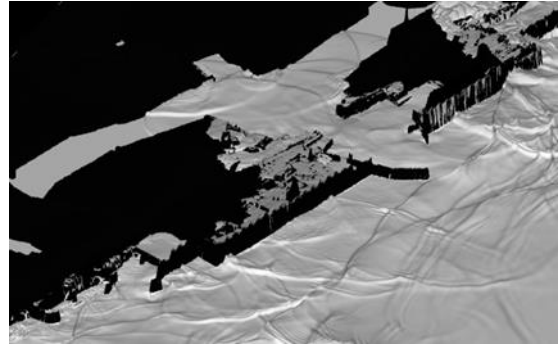


Fig. 3. Tsunami Run-up Simulation Around Toyama New Port.

The simulation is calculated on the GPU named TESLA K20 (NVIDIA) in about 90.6 seconds for the real world phenomena in 300 second. It is more than 78 times as faster as the CPU calculation (Table II).

Table 2. Calculation Performance on CPU & GPU

	CPU Intel Xeon W3565	GPU TESLA K20
Calculation Time for 300 [sec.] Real World Time Simulation	7,112.5 [sec.] ≈ 2 [hours]	90.6 [sec.]

4 Conclusion

Tsunami run-up simulation is realized at Toyama new port in Japan. The simulation needed over three million grids for the high resolution simulation (5 m calculation grid spacing). The simulation time was 1.5 minutes for 5 minutes real time phenomena on GPU device. It is over 78 times faster calculation time than CPU. The calculation time specified the time limitation for the real time Tsunami warning system. Moreover the method is also available for the high tide disasters, water level rising and river flooding simulation easily, if one includes geometry data to the simulation model. Because of the GPU is not special and not so expensive device, the technique is useful for many researchers and peoples who interested in run-up or flooding simulation. Authors open the latest information for the simulation model in [4]

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References

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