Fast numerical solution to nonlinear shallow water system

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Abstract. The paper presents a fast numerical solution to nonlinear shallow water system with the use of an ordinary personal computer. It should help with the timely evaluation of tsunami wave potential threats at a particular part of the coast. High performance is achieved by using hardware acceleration which is a specialized Calculator, based on the Field Programmable Gates Array (FPGA) microchip. Precision of the obtained numerical solutions was proved by comparing it to the available existing solutions. The achieved performance makes it possible to calculate the wave parameters along the coast within a minute, provided that the initial sea surface displacement at tsunami source is given. In case of a strong seismic event offshore Japan, it takes nearly 20 minutes for tsunami wave to reach the nearest cost. The proposed approach can provide tsunami warning centres with the decision support information about evacuation measure before the wave reaches the coast.

Introduction

After the Great Tohoku Earthquake of March 11, 2011 offshore Japan, it became clear that tsunami warning systems could be significantly improved. For the local tsunami, it takes nearly 20 min to propagate from the source to the nearest coast. Modern software packages, such as: MOST (Method of Splitting Tsunamis, NOAA Pacific Marine Environmental Laboratory, Seattle, WA USA) [1] and TUNAMI-N1/TUNAMI-N2 (Tohoku University, Japan) [2], provide high accuracy simulation of the tsunami wave generation, propagation, and inundation. However, they cannot deliver the needed analysis in a few minutes even when relying on the supercomputer processing. It should be also noted that disaster events, such as the one of March 11, 2011, may lead to power shutdowns. At the same time, in order to evaluate possible negative tsunami wave implications (including infrastructure destruction and loss of human life), one does not need to know the exact wave amplitude at a particular populated coastal area or industrial site.

So, the desired tsunami warning system must: (1) work very fast (within several minutes), (2) be independent of power supply (in case of emergency) and (3) provide a realistic approximation of tsunami wave height (10% accuracy or slightly higher would be acceptable). All these requirements could be achieved by using an ordinary modern personal computer with the specialized co-processor – the FPGA based Calculator, proposed and tested in [3].

Results and Discussion

A parallel version of the McCormack finite-difference scheme (which has the second order approximation) was implemented on the FPGA platform. It takes only 38.4 sec to simulate 1-hour (7,200 time steps) wave propagation for the digital bathymetry grid of 2401x2401 nodes. Geographically small changes in tsunami source position (given in Fig. 1, left) result in valuable changes in the wave maximal heights distribution.

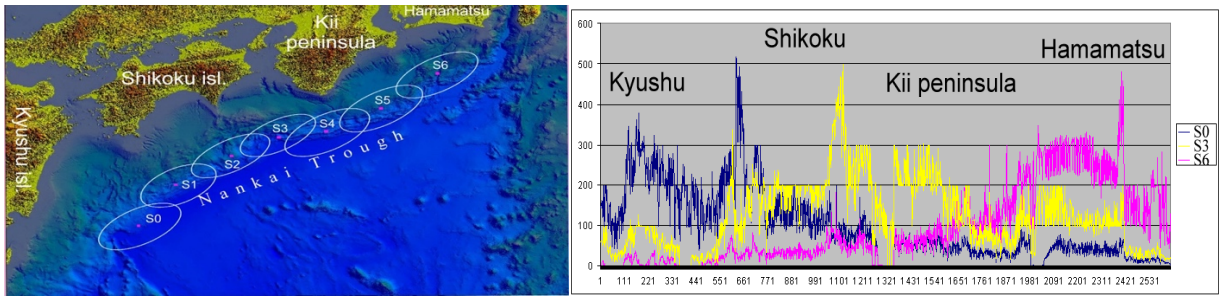

Figure 1. Digital bathymetry, water area southwest of Japan. Ellipses S0-S6 show positions of model tsunami sources (left). Distribution of tsunami wave maximal heights along the coast. Blue line = S0 model source, yellow line = S3 source, pink line = S6 source (right).

Using the hardware acceleration (FPGA-based Calculator), it is possible to determine "safe" and "dangerous" locations along the coast within a few minutes calculating wave propagation over the several hundred kilometers wide water area. It is expected that in a few years tsunami warning systems will be able to save human lives and reduce economic loss even in cases of strong offshore earthquakes.

References

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