A Real-Time Tsunami Inundation Forecast System for Tsunami Disaster Prevention and Mitigation

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ABSTRACT

The tsunami disasters of Indonesia, Chile and Japan have occurred in the last decade, and inflicted casualties and damaged social infrastructures. Therefore, tsunami forecasting systems are urgently required worldwide for disaster prevention and mitigation. For this purpose, we have developed a real-time tsunami inundation forecast system that can complete a tsunami inundation simulation at the level of 10-meter grids within 20 minutes. A HPC system is essential to complete such a huge simulation. As the tsunami inundation simulation program is memory-intensive, we incorporate the high memory-bandwidth NEC vector supercomputer SX-ACE into the system. In this poster, we describe an overview of the system and the characteristics of SX-ACE, the performance evaluation of tsunami simulation on SX-ACE, and an emergency job management mechanism for real-time simulation on SX-ACE. The performance evaluation indicates that the performance of SX-ACE with 512 cores is equivalent to that of K computer with 9469 cores.

1. INTRODUCTION

We have developed a real-time tsunami inundation forecast system with a highly-accurate tsunami inundation simulation using NEC vector supercomputer SX-ACE. The system provides information about maximum inundation depths, tsunami arrival times, etc. with a high resolution of 10-meter grids within 20 minutes at the latest after an earthquake occurrence.

As shown in Figure 1, the system consists of a tsunami source modeling system, a simulation system, and a delivery/mapping server. SX-ACE serves as the simulation system and plays a central role in our forecast system. The processor of SX-ACE has four vector architecture cores with a high memory bandwidth, commensurate with their high computational ability. As shown in Figure 2, the processor can provide a memory bandwidth of 256 GB/s and double precision floating-point operation rate of 256 Gflop/s.

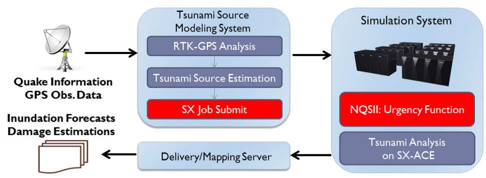


Figure 1: Diagram of the real time tsunami inundation forecast system

Assignable Data Buffer (ADB) and Miss Status Handling Register (MSHR) leverage the high memory bandwidth further by avoiding redundant memory transactions for vector load operations. The SX-ACE multi-node system is composed of up to 512 nodes connected via a custom interconnect network.

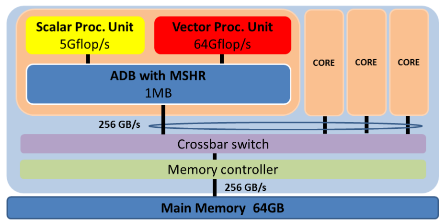
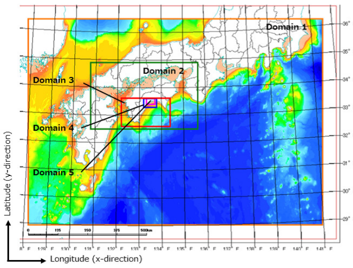


Figure 2: Diagram of SX-ACE node

As earthquakes and Tsunamis occur unpredictably, the resources of SX-ACE are required immediately for the tsunami inundation simulation after the tsunami source estimation phase to complete. Then the SX-ACE system also adopts the jobs suspending scheme to minimize the time lag of job invocation for tsunami simulation. SX-ACE has an original queuing system named NQS II. It has been enhanced to support urgent job prioritization for the real-time simulation. The urgency function executes the tsunami inundation simulation job on the SX-ACE system at the highest priority, while immediately suspending other active jobs. The suspended jobs automatically resume as soon as the tsunami inundation simulation completes. The SX-ACE has 64 GB memory per node where several GB is reserved for the OS and urgent job execution, and the remaining memory is available for normal job execution. A real-time system using a supercomputer is realized by adopting these functions.

2. PERFORMANCE EVALUATION OF TSUNAMI INUNDATION SIMULATION

The tsunami inundation simulation solves non-linear shallow water equations, and uses the staggered leap-frog 2-D finite difference method as the numerical scheme [1]. This method is adopted as the standard method for prediction of tsunami inundations by UNESCO.



Domain	Grid Size (m)	Number of Grid	
		x	y
1	810	1536	1020
2	270	1680	990
3	90	2292	1260
4	30	1782	1188
5	10	3504	2364

Figure 3: Computational domains of Kochi

As shown in Figure 3, the entire computational domain is divided into five sub-domains with different grid-sizes. In applying MPI parallelization, we choose 1-D (the y-direction) domain decomposition instead of 2-D (the x- and y-directions) domain decomposition, because the x-direction loops are used for vectorization in order to fully extract the vector performance of SX-ACE. To achieve load balance, these five sub-domains are further divided into smaller regions with the same number of grids. Each MPI process calculates the tsunami propagation and inundation in a region.

Table 1: Hardware specifications

System	SKT Perf. (Gflop/s)	No. of Cores	Core Perf. (Gflop/s)	Mem. BW (GB/s)
SX-ACE	256	4	64	256
LX406Re-2	230.4	12	19.2	59.7
K computer	128	8	16	64

Figure 4 shows the execution time of the simulation for multi-node environment on SX-ACE. For comparison, we measure the performance when using LX, an Xeon-based (E5-2695v2) cluster system. In addition, we also plot the performance on K computer reported in [2]. Table 1 shows specifications of each hardware. We think the comparison is reasonable because these systems use the same tsunami simulation program, and the total number of grid points and the time step are almost same in these systems as shown in Table 2. Figure 4 indicates that the performance of 512 cores on SX-ACE is equivalent to that of 9469 cores on K computer. This is because SX-ACE can achieve high computation efficiency of high performance cores with the high memory bandwidth.

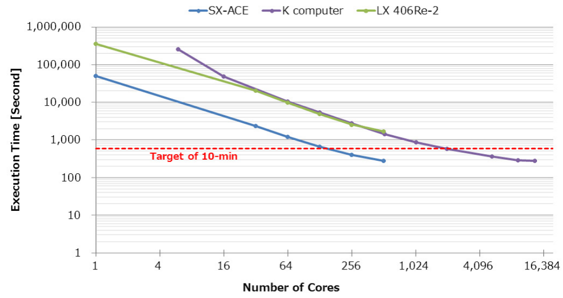


Figure 4: Multi-node performance

The process of the tsunami forecast system consists of two phases: coseismic fault estimation phase and tsunami inundation simulation phase. Using this system for the Nankai trough earthquake case in Japan with 6-hour simulation, both phases can complete in less than 8 minutes and 5 minutes, respectively. Additionally, the simulation results can be visualized and sent to local governments within 4 minutes. Thus, the system completes the tsunami inundation forecasting with 10-meter grids resolution within 20 minutes.

Table 2: Total number of grid points, time step, and simulation time

System	Total Number of Grid Points	Time Step (sec)	Simulation Time (hrs)
SX-ACE & LX406Re-2	16,533,376	0.1	6
K computer	14,831,739	0.1	2

As a result, a processor with the small number of strong performance cores and a high memory bandwidth like SX-ACE can extract high performance from memory-intensive programs like this program compared to a commercial processor with many low-performance cores.

3. SUMMARY

As quick understanding of accurate tsunami disaster situations enables prompt responses to the disaster, tsunami forecasting systems require increasing the accuracy and reducing the processing time. Therefore, we have developed a real-time tsunami inundation forecast system using SX-ACE. The experimental results suggest that the system can achieve the high-accuracy tsunami inundation forecasting in less than 20 minutes.

4. REFERENCES

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