Large-scale TSUNAMI simulation on New Earth Simulator

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TSUNAMI Simulation code: JAGURS

- ✓ Nonlinear long-wave equations [1), 2)]
  - The equations of motion

$$\frac{\partial u}{\partial t}+\frac{u}{R\sin\vartheta}\frac{\partial u}{\partial\varphi}+\frac{v}{R}\frac{\partial u}{\partial\vartheta}=-\frac{g}{R\sin\vartheta}\frac{\partial h}{\partial\varphi}-C_f\frac{u\sqrt{u^2+v^2}}{d+h}$$

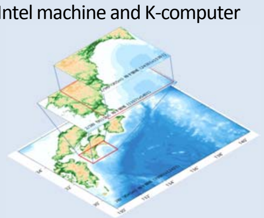
$$\frac{\partial v}{\partial t}+\frac{u}{R\sin\vartheta}\frac{\partial v}{\partial\varphi}+\frac{v}{R}\frac{\partial v}{\partial\vartheta}=-\frac{g}{R}\frac{\partial h}{\partial\vartheta}-C_f\frac{v\sqrt{u^2+v^2}}{d+h}$$

  - The equation of continuity

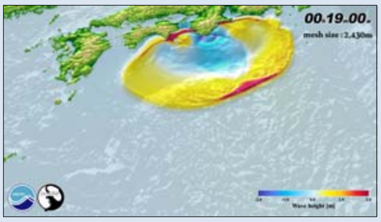
$$\frac{\partial(d+h)}{\partial t}=-\frac{1}{R\sin\vartheta}\left[\frac{\partial\{u(d+h)\}}{\partial\varphi}+\frac{\partial\{v\sin\vartheta(d+h)\}}{\partial\vartheta}\right]$$

Symbol	Meaning
t	Time
R	Earth's radius
φ	Longitude
ϑ	Colatitude
u	Depth-averaged velocity (Longitude)
v	Depth-averaged velocity (Latitude)
d	Water depth
h	Height of water
g	Gravitational constant
C_f	Nondimensional frictional coefficient

- ✓ Finite-difference method using spherical coordinates
- ✓ Staggered leapfrog method
- ✓ Variable nested-grid method
- ✓ FlatMPI and Hybrid (MPI+OpenMP) parallel program
- ✓ Multi-Case execution
- ✓ Platform: Intel machine and K-computer



Variable nested-grid method



An example of tsunami simulation (JAGURS code)

New Earth Simulator Outline

New Earth Simulator

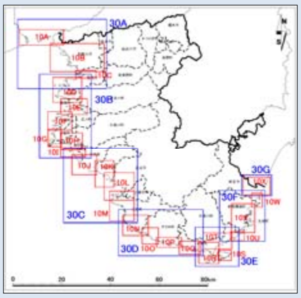
Comparison of ES2 (SX-9) with New ES (SX-ACE)

		ES2 (SX-9)	New ES (SX-ACE)
Core	ADB size	256 KB	1 MB
	Peak performance	102.4 GFLOPS	64 GFLOPS
CPU	The number of Cores	1	4
	Peak performance	102.4 GFLOPS	256 GFLOPS
	Memory band width	256 GB/s	256 GB/s
Node	The number of CPUs	8	1
	Memory size	128 GB	64 GB
System	The number of Nodes	160	5,120
	The number of CPUs(Cores)	1,280 (1,280)	5,120 (20,480)
	Peak performance	131 TFLOPS	1.3 PFLOPS
	Network speed	8 x 8GB x 2	4 GB x 2

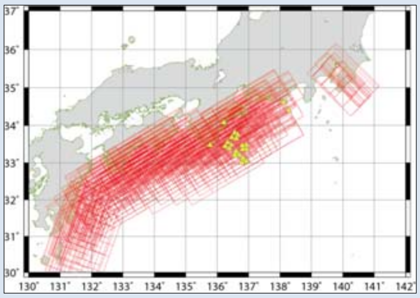
"Simulation Database for Real-time Prediction of TSUNAMI Inundation"

The purpose of this study is to do more than 40,000 cases of high-resolution TSUNAMI simulation for the whole Wakayama prefecture and make a TSUNAMI inundation map. This study is one of Earth Simulator Strategic Project with special Support in FY2015. "Strategic Project with Special Support" aims epoch-making achievements by taking maximum advantage of Earth Simulator. [3)]

An example of 10L region (One of target region shown in the right figure)	
The number of nested-grids	7 (2,430m → 810m → 270m → 90m → 30m → 10m → 3.3m grids)
The number of grids (Total)	about 15,000,000
Integral time	6 hour
Time step	0.05 sec



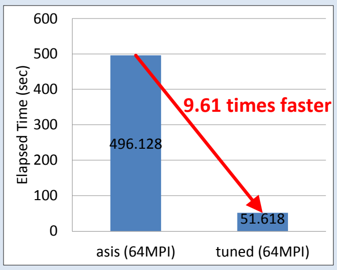
Target region of this study (red colored 24 domains)



the fault along the Nankai Trough (about 2,000 cases)

Optimization

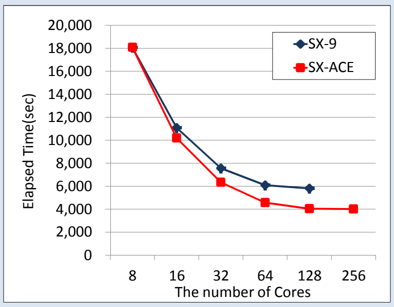
- ✓ Vectorization of non-linear flux compute routine with loop division
  - Elapsed Time: 410 sec → 13 sec (**31.5 times faster**)
  - Vector Operation Rate: 48.10% → **99.44%**
- ✓ Change of the MPI communication between the nested-grids (MPI_Alltoallv → MPI_Allreduce)
- ✓ etc.



asis vs. tuned (SX-9)

Benchmark

Compared with the same number of cores, **the computational time in the SX-ACE(64 GFLOPS) is shorter than the SX-9(102.4 GFLOPS)**.



Strong scaling benchmark (FlatMPI)

Multi-jobs control

Considering the benchmark results, computing resources amount and efficiency for Job scheduling, we decided the execution conditions.

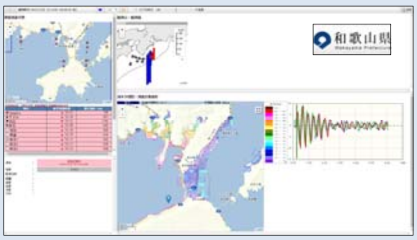
Execution Conditions	
Parallel method	FlatMPI
The number of cases / Job	2
The number of cores(nodes) / case	64 (16)

In addition, the system limits(the number of job executions, etc.) were adjusted for quickly executing many jobs.

But there will be room for the examination in future whether this was a really efficient method.

Results and Summary

- ✓ We tuned a tsunami simulation code (JAGURS) for new Earth Simulator, and speeded up 9.61 times.
- ✓ More than 40,000 cases of tsunami simulation was completed in only 3 months by using a new earth simulator.
- ✓ Using the simulation database which this study provided, Wakayama prefecture applies an inundation prediction system originally.
- ✓ It is necessary to examine a really efficient method in future. (File Handling, PrePost, Node Occupation and Parametric Execution)



inundation prediction system

References

1) Satake, K., Linear and non-linear computations of the 1992 Nicaragua earthquake tsunami. Pure and Applied Geophysics(also a book "Tsunamis: 1992-94"), 144, 455-470, 1995.
2) Baba, T., K. Ando, D. Matsuoka, M. Hyodo, T. Hori, N. Takahashi, R. Obayashi, Y. Imato, D. Kitamura, H. Uehara, T. Kato, R. Saka, "Large-scale, high-speed tsunami prediction for the great Nankai trough earthquake on the K computer", Inter. Jour. of High Per. Comp. App., doi:10.1177/1094342015584090, 2015.
3) https://www.jamstec.go.jp/es/jp/project/jamstec_prj.html