Tsunami Inundation and Damage Forecasting with HPCI

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The 2011 Tohoku Tsunami
NHK Video

Inundation of 561 km², highest run-up of 40 m
18,549 fatalities (3% in the inundation zone)
120,000 buildings destroyed
23 mil. tons of debris, 10-20 times of annual waste amount
25 trillion JPY, ¼ of annual budget (250 billion $)
Critical problems

- How extensive the tsunami penetrates? (Where is the safe place?)
- How many people are exposed?
- How many structures/infrastructures are damaged?
- How extensive disaster relief activities should be deployed?
- How much losses are?
Goal

Establishing a new procedure of tsunami inundation forecasting, damage estimation and mapping, by fusion of real-time simulation, sensing, and geo-informatics.
Why we DO forward simulation?

Tsunami inundation forecasting result

= f (source, model, grid size, coastal structure, land use, ...)

Elapsed Time = 01:00:00
Challenges towards real-time tsunami inundation forecasting and damage mapping for near-field tsunami events

1. Rapid determination of tsunami source model (Rapid estimation of coseismic fault model).

2. Acceleration of tsunami inundation simulation with high-performance computing infrastructure (HPCI).

3. Establishing quantitative damage estimation and mapping methods to provide responders with mapping products.
10-10-10 Challenge

Complete tsunami source estimation in 10 minutes

Complete inundation simulation with 10 m grids in 10 minutes
Real-time Fault Estimation using GNSS RAPiD, Ohta et al. (2012)
Nankai Megathrust
About 1200 slip distribution data obtained from GEONET (GSI)
1707 Hoei rupture
2. Acceleration of tsunami inundation simulation with high-performance computing infrastructure
### TUNAMI-Code

**Tohoku University’s Numerical Analysis Model for Investigating Tsunami**

**Computational Conditions**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Governing Equations</td>
<td>Non-linear Shallow Water Equations with bottom friction terms</td>
</tr>
<tr>
<td>Numerical Scheme</td>
<td>Staggered Leap-frog Finite Difference Method</td>
</tr>
<tr>
<td>dx</td>
<td>Nested Grid system, 810m, 270m, 90m, 30m, 10m, 20,000,000 grids</td>
</tr>
<tr>
<td>dt</td>
<td>0.2 sec. (Satisfying stability condition)</td>
</tr>
<tr>
<td>Tide level</td>
<td>HWL</td>
</tr>
</tbody>
</table>

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

\[
\frac{\partial M}{\partial t} + \frac{\partial}{\partial x} \left( \frac{M^2}{D} \right) + \frac{\partial}{\partial y} \left( \frac{MN}{D} \right) = -gD \frac{\partial \eta}{\partial x} - \frac{\tau_{bx}}{\rho}
\]

\[
\frac{\partial N}{\partial t} + \frac{\partial}{\partial x} \left( \frac{MN}{D} \right) + \frac{\partial}{\partial y} \left( \frac{N^2}{D} \right) = -gD \frac{\partial \eta}{\partial y} - \frac{\tau_{by}}{\rho}
\]

\[
M = \int_{-h}^{\eta} u dz = \bar{u}(\eta + h)
\]

\[
N = \int_{-h}^{\eta} v dz = \bar{v}(\eta + h)
\]

\[
\frac{\tau_{bx}}{\rho} = \frac{gn^2}{D^{7/3}} M \sqrt{M^2 + N^2}
\]

\[
\frac{\tau_{by}}{\rho} = \frac{gn^2}{D^{7/3}} N \sqrt{M^2 + N^2}
\]
Disaster mode
Immediately suspending other active jobs to execute tsunami inundation simulation.

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**Computing Platform**
Vector Supercomputer SX-ACE (NEC) in Tohoku Univ.

**SX-ACE Specification**

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<table>
<thead>
<tr>
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<tbody>
<tr>
<td><strong>System Performance</strong></td>
<td>707 Tflops (2,560 nodes)</td>
</tr>
<tr>
<td><strong>Node Performance</strong></td>
<td>276 Gflops (4 cores)</td>
</tr>
<tr>
<td><strong>Single Core Performance</strong></td>
<td>69 Gflops</td>
</tr>
<tr>
<td><strong>Memory Through-put</strong></td>
<td>256 GB/sec./node</td>
</tr>
<tr>
<td><strong>Memory Capacity</strong></td>
<td>64 GB/node</td>
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</tbody>
</table>
Tsunami Simulation Performance on SX-ACE (3 hour forecasting)
Target Forecasting Areas

- 30 forecasting sub-grids of 30 m resolution (6000 km long coast line).
- Using 518 nodes of super computer.
3. Establishing **quantitative damage estimation and mapping** methods to provide responders with mapping products
Tsunami Fragility Curve
Koshimura et al. (2014)

Damage Probability

Wooden houses
Others (Steel, RC)

Inundation Depth (m)

(c) Geospatial Information Authority of Japan (GSI)

Damage inspection
- Surviving
- Washed-away
Test Bed
Kochi Prefecture
Mapping products
Tsunami flow depth
Mapping products
Exposed population
Mapping products
House damage
Hazards and Response
Mobile Phone Data and Evacuation Simulation

Kashiyama et al. (2018), Journal of Disaster Research
Real-time tsunami inundation forecasting with use of advanced GNSS data and HPCI.

- 7 minutes for tsunami source estimation
- 3 minutes to complete inundation simulation and mapping (3-hour forecasting)
- With 10 m grid resolution

Just started operation as a function of the response system of central government (Cabinet Office) in Nov. 2017 (but not for warning purposes).
Timeline of Disaster Response
Central Government

Acquisition of disaster information
Mapping products
Tsunami arrival time

![Map showing tsunami arrival times and locations](image-url)
Tsunami forecasting

- Offshore Monitoring and Database-driven Approach (pre-computed scenarios)
  e.g. JMA tsunami warning (no inundation forecasting), DONET (JAMSTEC), S-net (NIED)

- Forward (Real-time) Modeling Approach