Numerical Modeling: What, Why, and How

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Intergovernmental Oceanographic Commission
Why

Warning and wave impact potential
Preparedness (inundation/runup)
Safe evacuation
Land-use zoning and coastal planning

Powerful tool for:
- Hazard assessment
- Worse case scenarios
- Understanding past events
- Forecasting the effects of potential future events
- Real-time forecasting of wave-heights from distant source events
- Developing database of potential local source events for real time local event forecasting
Numerical modelling: What

• Estimate of Wave Height and Flooding from tsunami generated by earthquake (landslide, volcano)

• Details – Need to:
  
  Selection of appropriate sources critical for local tsunamis
  
  Use of appropriate modelling technique, boundary conditions, approximations, etc critical
  
  Calibration with historical events/tide gauge records advisable
  
  Good bathymetry and near-shore topography essential
Tsunami Wave System

- **Generation**
  - A seafloor disturbance, such as motion along a fault, pushes up the overlying water.

- **Propagation**
  - The wave propagates across the deep ocean at jetliner speeds
  - Shoaling and refraction to amplify the wave

- **Inundation**
  - As the wave moves into shallower water, increased energy density increases both the wave height and the currents.
  - Runup on a land and run-down
Earthquake induced tsunamis

Tsunamis can be generated when the sea floor abruptly deforms and vertically displaces the overlying water.
Estimation of a seabed movement (deformation)

A fault movement is described by its location including its depth,
- Mechanical characteristics; (strike, dip- and slip-angles of the fault plane),
- Geometrical characteristics (length, width and dislocation of the fault plane), and
- Dynamic characteristics (rupture direction, rupture velocity and rise time of the fault movement).

• Earthquake magnitude
• Depth of the fault
• Length and width of the fault plane
• Strike and dip angle of the fault plane
• Dislocation and slip angle
Landslide/volcano induced Tsunamis

10% of tsunamis over 100 years

Caldera formation; surrounding water rush
Propagation: Shoaling effect

The deeper the water and the longer the wave, the faster the tsunami propagate.

- Larger distance: Decreasing wave length, amplification of wave height
- Shorter distance: The back of a wave overtakes another, decreasing the distance between them

Faster wave propagating speed in a deep sea

Slower wave propagating speed in a shallow sea

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Propagation: Refraction effect

Wave fronts tend to align parallel to the shoreline so that they wrap around a headland.

Energy concentration

Crest line of wave

F. Imamura, DRCR
Wave system

• The fact that the wavelength of a tsunami is much longer than the water depth leads to the system of long waves.
• The wave amplitude of a tsunami in the deep ocean is infinitesimally small compared to the water depth.
• Linearity of the water wave.
• A distant tsunami can be solved with the aid of liner equations for long waves with the Coriolis force, frequency dispersion included, described in the longitude-latitude coordinate system.
Tsunami Numerical Simulation

to be improve through the comparison with the several data

The 2004 Indian Ocean tsunami simulation by Tohoku Univ.

dx=2min.(2-4km)
in spherical coordinate
dt=2 second

Simulation of the tsunami for 8 hours needs CPU time of 1 hour using Pentium 4 computer system
Local Propagation

- Locally generated tsunami waves may propagate from their generating source to the near shore area of a nuclear power plant site;
- hence, the wave propagation phenomena become important.
- Numerical techniques, FDM, are applied to determine modification during propagation.
- The accuracy of bottom topography has a vital effect on the computed results.

TIME - project; Tsunami inundation modeling exchange
By UNESCO/IOC and IUGG  Manual 35
Accuracy of the simulation

Major causes of low accuracy induced by:

- Initial source, location and slip
- Modeling and Geometry data

For example.
The fixed epicenter and variety of locations in the fault

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Numerical Modelling

Modelling the source

Modelling the tsunami

Modelling the inundation

Examples
Modelling the Source - Earthquakes

• Assume instantaneous uplift
  Vertical movement usually most important
• Double Couple source describes EQ faulting/rupture
  e.g., strike/dip/slip/rake
• But …
  - Accurate source information/deformation not known until hours/days after event (aftershocks)
  - Source often complex. Complexity caused by
    Sediments, secondary faulting, landslides/slumps, slow “tsunami” earthquakes, variable slip along rupture
• Slip distribution
  - important near source, pt source in far-field effect

Landslides, Volcanoes: width/volume, slide depth, velocity, run-out, water-depth
Modelling the tsunami:

**Long Wave equations**
- Coriolis term - can be dropped
- Bottom friction term – important in shallow water
- Non-linear terms – important in shallow water

**Numerical modeling techniques**
- Finite Difference (rectangular grid)
- Finite Element (variable size triangular grid, size varies with depth and strong depth contrasts)
- *Grid density increases with decreasing water depth*

Initial conditions assume water matches deformation at ocean bottom

Boundary conditions important eg set velocity to 0 at shorelines

Computer time generally too long to run real time
Modelling technique

Finite Difference modeling

Nested coarse to fine rectangular grids

To 50-200 m depth
to 20-50 m depth
coast
Finite element modelling grid
Modelling the inundation

• Various
  Wave type – rapid rise & fall, bore, breaking wave
  Roughness factors
• Require nearshore topography to at least ~1 m contour interval
Numerical simulation of a tsunami generated by a large earthquake on the Lachlan Fault (finite difference)
It is only one of many possible scenarios of fault rupture.

Examples from US, NZ, Australian Japanese scientists

[Tsunami generated by a large earthquake on the Lachlan Fault]

[Modelled by R. Walters, NIWA, NZ]
1700AD Cascadia earthquake (probable magnitude ~9) Trans-Pacific tsunami propagation - Satake et al

Slide from Kenji Satake’s presentation, 2003 Tsunamis of the South Pacific Workshop, Wellington 2003
Maximum water height from modelled 1700AD Cascadia earthquake (probable magnitude ~9)

Slide from Kenji Satake’s presentation, 2003 Tsunamis of the South Pacific Workshop, Wellington 2003
Wave heights/run-up

- 1868
- 1877

Wave height or run-up:
- 3 m
- 2 m
- 1 m
Advanced information – estimating potential damage

- Scenario
- Earthquake/tsunami source
- Simulation
- Tsunami heights, velocity, wave force, inundation area
- Estimating damage on the GIS

<table>
<thead>
<tr>
<th>Population</th>
<th>Estimated casualties</th>
<th>(%)</th>
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<tbody>
<tr>
<td>151,129</td>
<td>27,325</td>
<td>18.1</td>
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</table>

<table>
<thead>
<tr>
<th>Total of houses</th>
<th>Damaged houses</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>57,344</td>
<td>469</td>
<td>0.8</td>
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</table>
Criteria to estimate damage by tsunamis

Inundation depth

Human: killed >> 50cm
House: partially damaged >> 1.0m
totally damaged >> 2-3.0m
Building: damaged >> 5.0m

F. Imamura, DRCR
津波遅上予測図1
（津波予報 8 mのとき）

「宮城県地方に、沿岸での津波の高さが8m」という津波予報が出た場合に想定される30cm以上の浸水域の予測図です。

かなり遠方で巨大な地震が発生した場合に相当すると考えられます。西暦869年（貞観11年）の地震による津波が、この程度ではなかったかと考えられています。

この場合、名取市の沿岸部（仙台東道路より東側の一帯、下増田地区・北豊地区の広い範囲）では、おもに全域で0.3m以上の浸水があると想定されます。

このような大津波は、予報発令から津波が来襲するまで2時間以上の時間的余裕があることが多いと考えられますので、落ち着いて内陸部（市の中央部もしくは西部地区）へ避難をしてください。

自治会・町内会の対応は？

Tsunami Hazard Map to provide the inundation
According to the information of JMA tsunami warning
Making the original hazard maps

- In the past, the map was provided by the local government but no use for the people
- Original information should be included
- Selecting the base map
- Collecting the information of risk
- Discussion what information be included
- Checking them by town-walking
Powerful & future tool to support the awareness; Example of Hazards map and Data base Using the image from Sattelite on GIS
How to get started

- IOC Tsunami Numerical Modeling Training
- TIME (Tsunami Inundation Modelling Exchange, Japan Tohoku Univ)
- TIME (Center for Tsunami Inundation Modelling, USA NOAA)
- CICESE (Mexico)
- Internet-available material (Community Modelling concept being developed)
- Collaborate with a modeller, a seismologist submarine landslide expert, volcanologist
- For more information, contact IOC International Tsunami Information Centre