Numerical Modeling: What, Why, and How

Laura Kong, Director,
International Tsunami Information Centre

Fumihiko Imamura
Disaster Control Research Center
Tohoku University, Japan

Gaye Downes, William Powers, Roy Walters
Institute of Geological & Nuclear Sciences, New Zealand

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

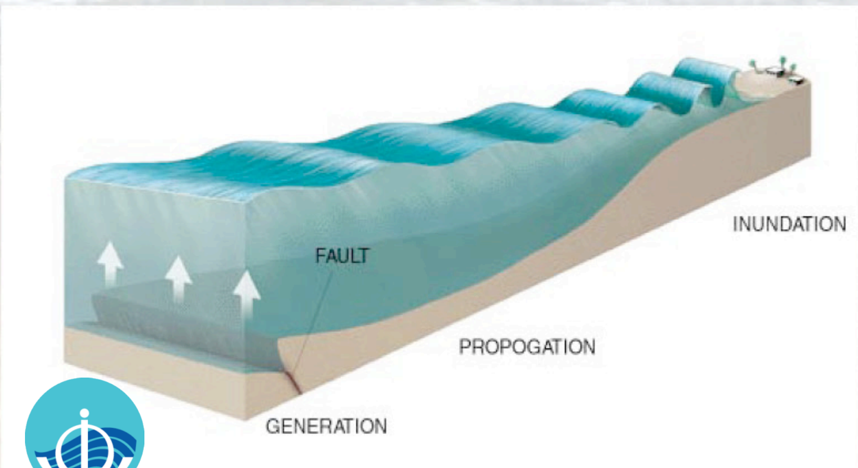
  Use of appropriate modelling technique, boundary conditions, approximations, etc critical

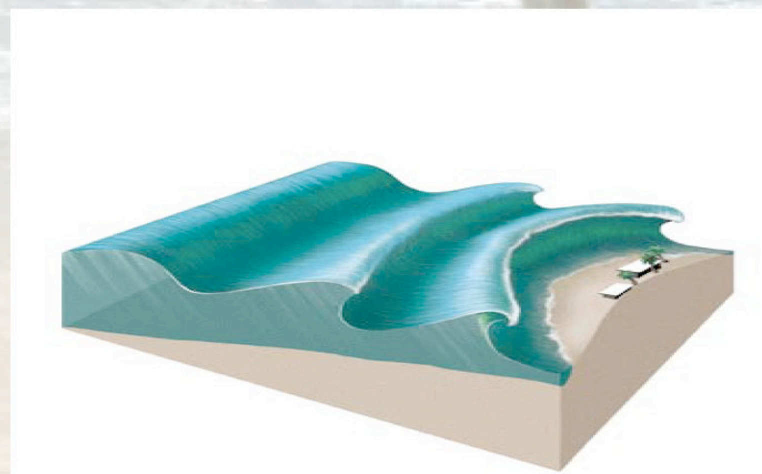
  Calibration with historical events/tide gauge records advisable

  Good bathymetry and near-shore topography essential

Tsunami Wave System

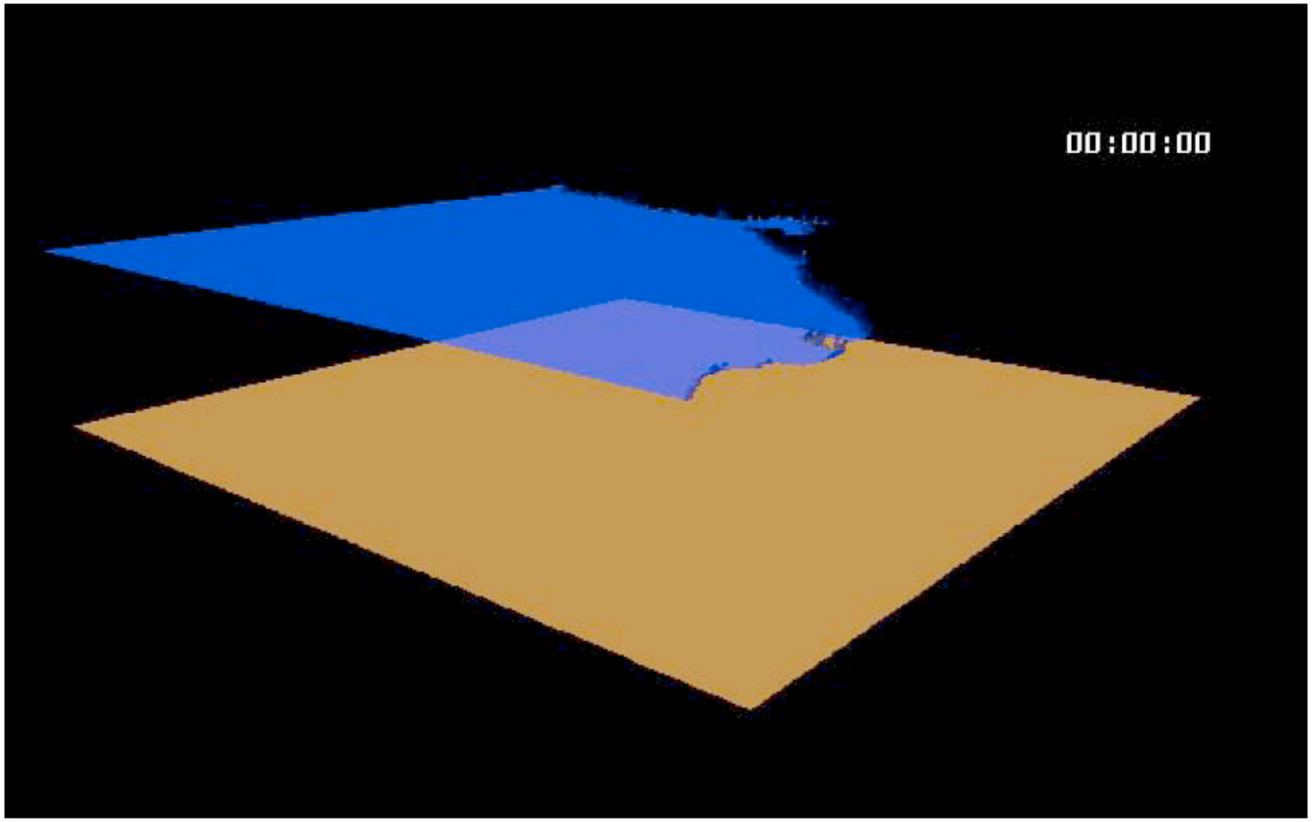
- Generation
  - A seafloor disturbance, such as motion along a fault, pushes up the overlying water.
- Propagation
  - The wave propagates across the deep ocean at jetliner speeds
  - Shoaling and refraction to amplify the wave
- Inundation
  - As the wave moves into shallower water, increased energy density increases both the wave height and the currents.
  - Runup on a land and run-down





Earthquake induced tsunamis

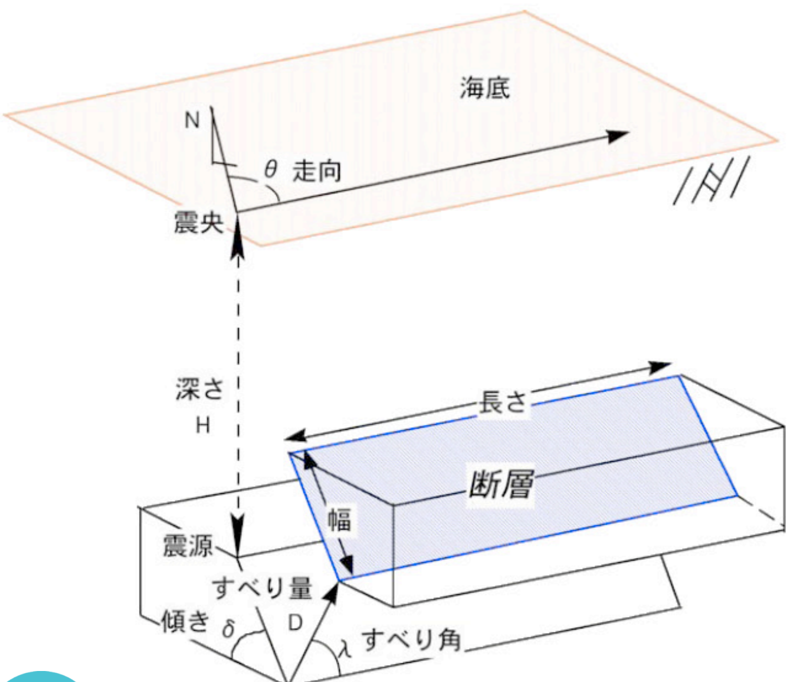
Tsunamis can be generated when the sea floor abruptly deforms and vertically displaces the overlying water.



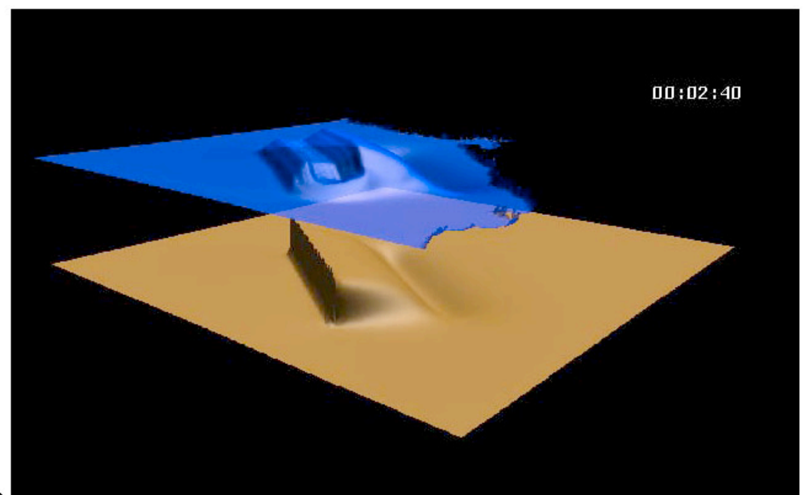
Estimation of a seabed movement (deformation)

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).

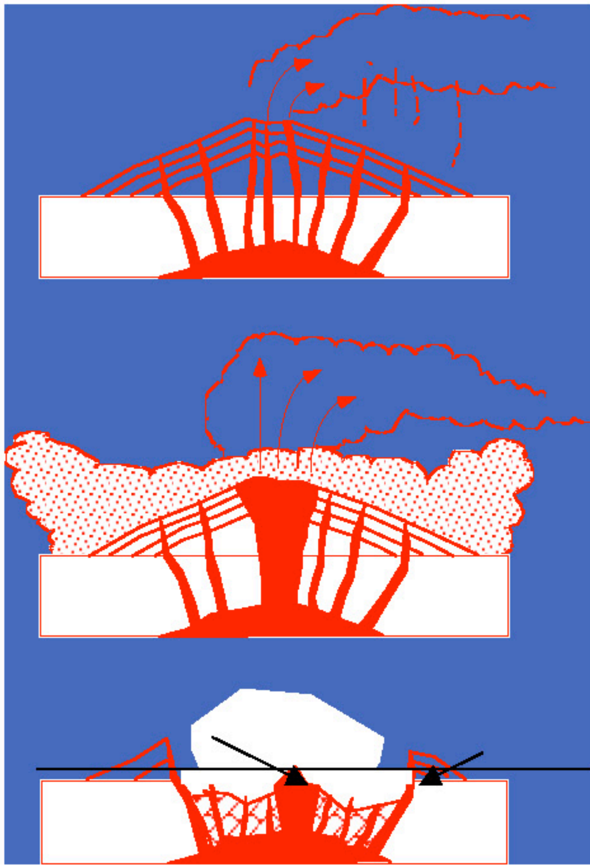


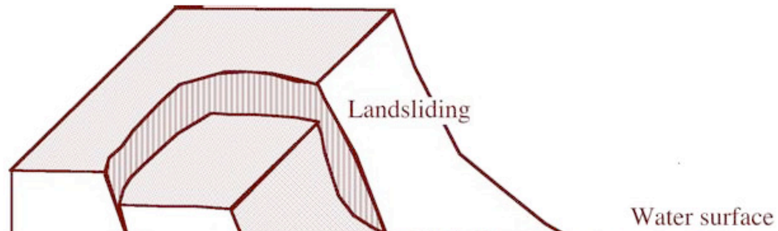
- Earthquake magnitude
- Depth of the fault
- Length and width of the fault plane
- Strike and dip angle of the fault plane
- Dislocation and slip angle

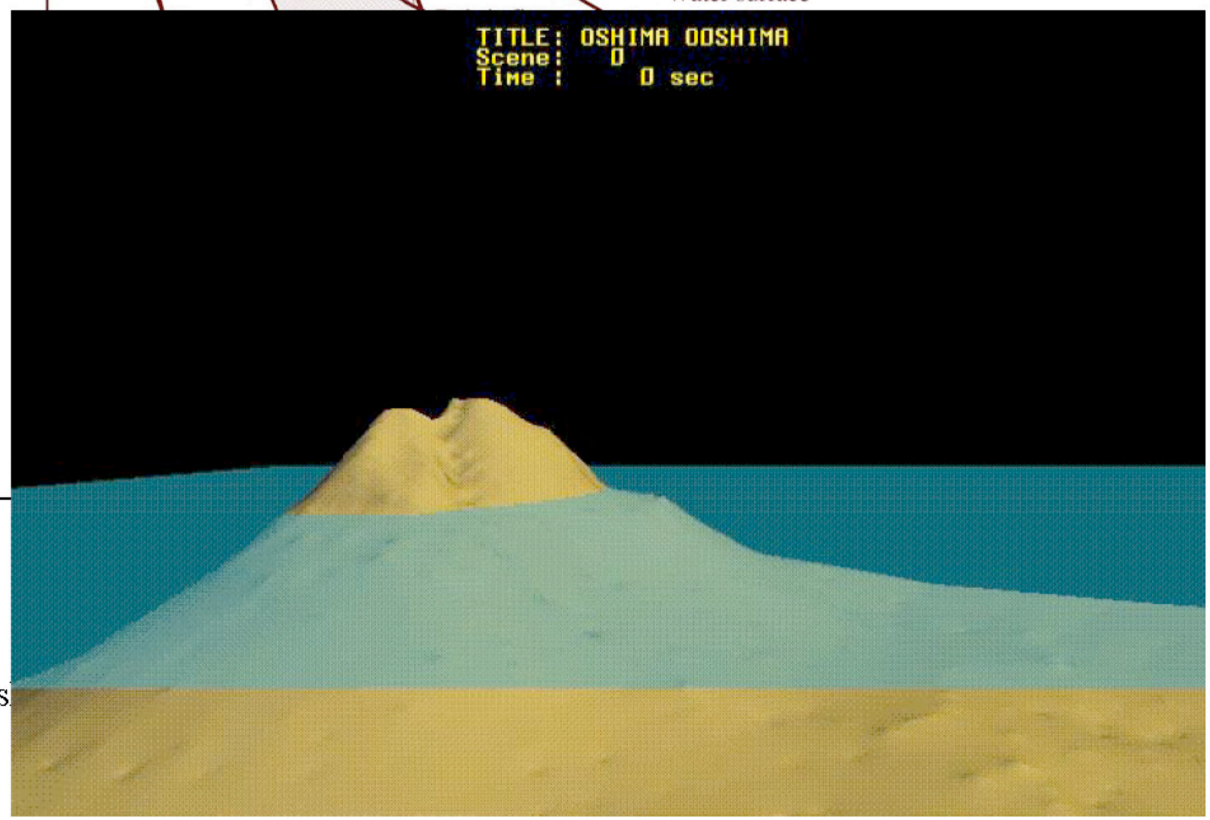


Landslide/volcano induced Tsunamis

10% of tsunamis over 100 years



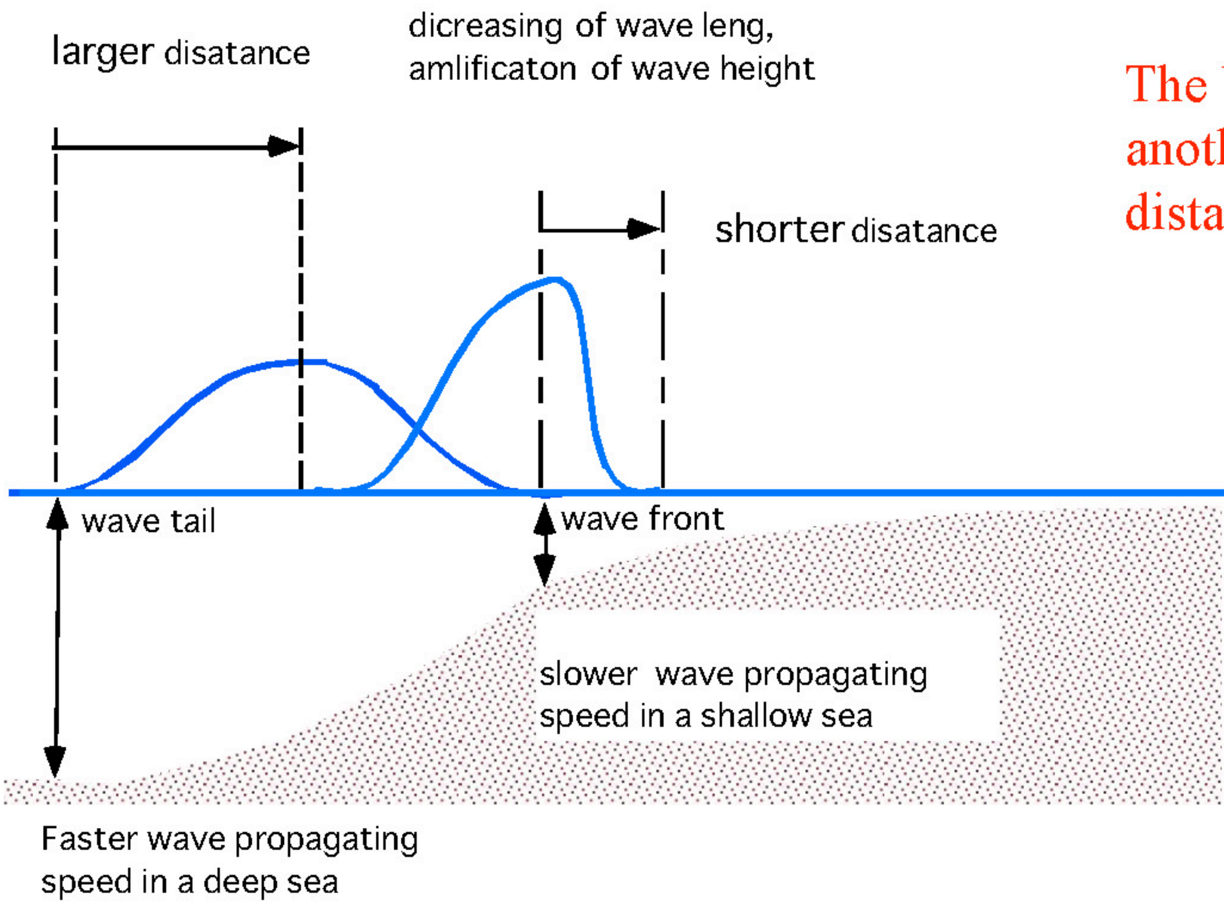




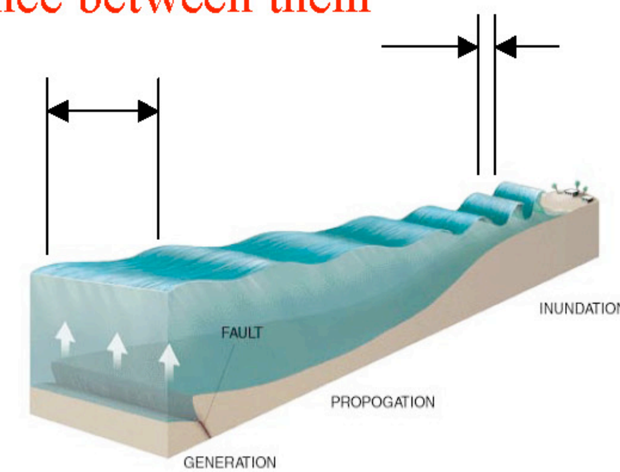
Caldera formation; surrounding water rus

Propagation : Shoaling effect

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

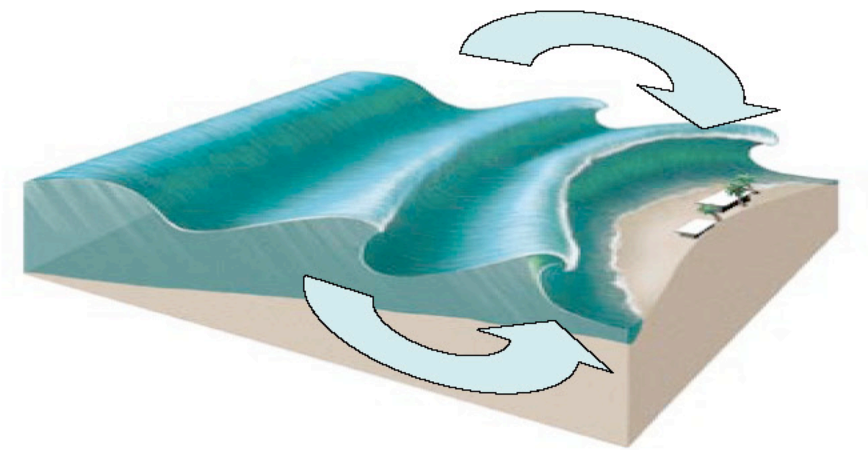


The back of wave overtake another,decreasing the distance between them

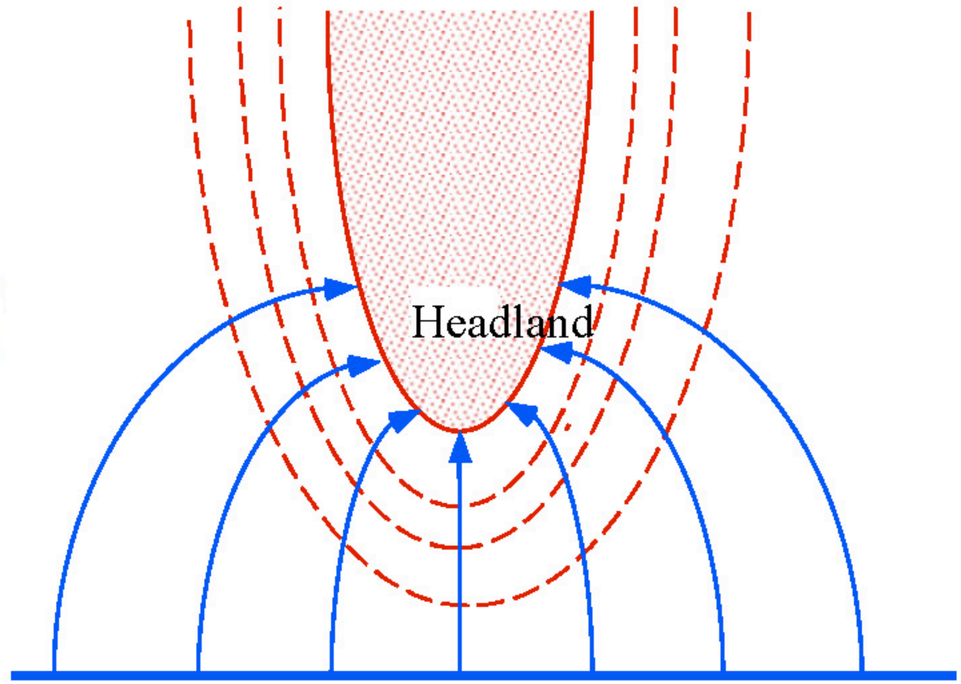


Propagation : Refraction effect

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



Energy concentration



Crest line of wave

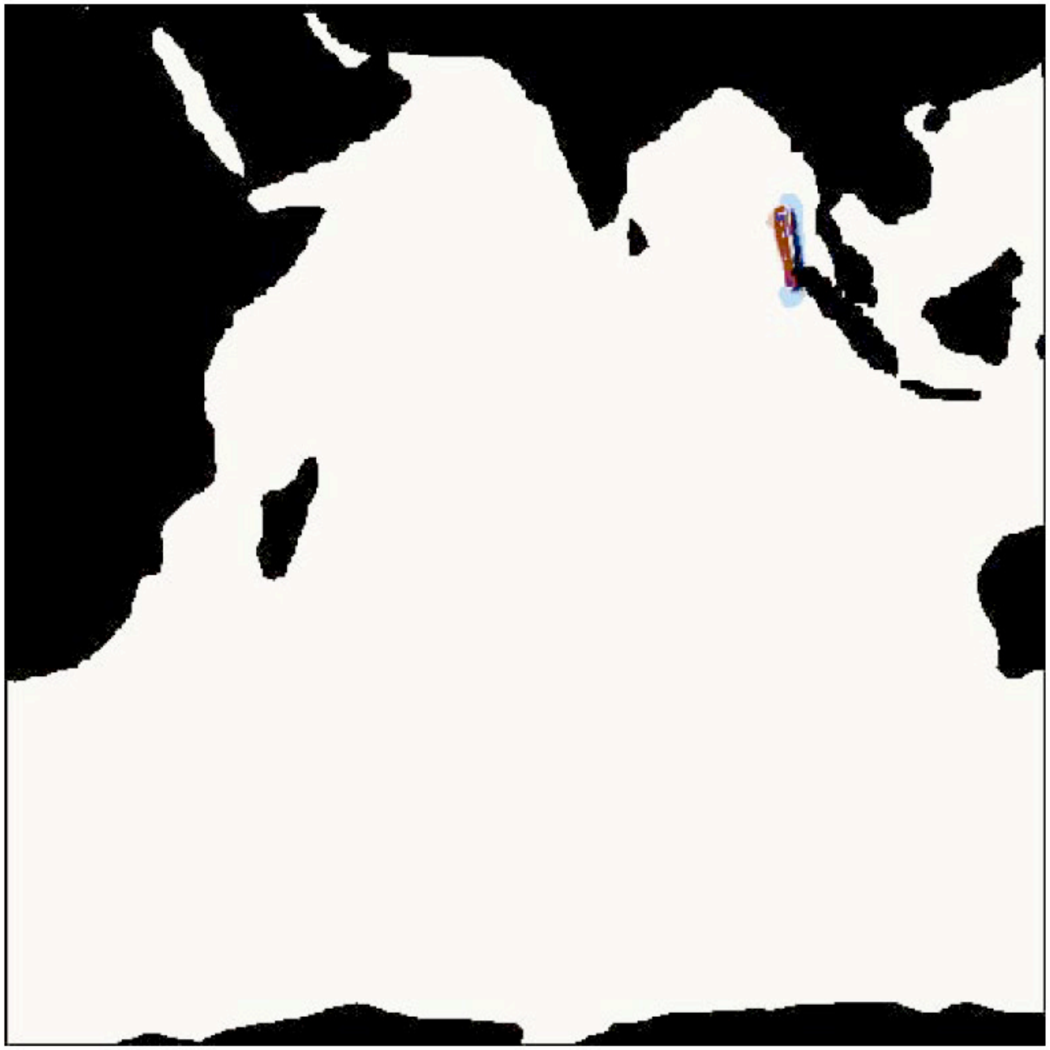
Distant Tsunamis

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

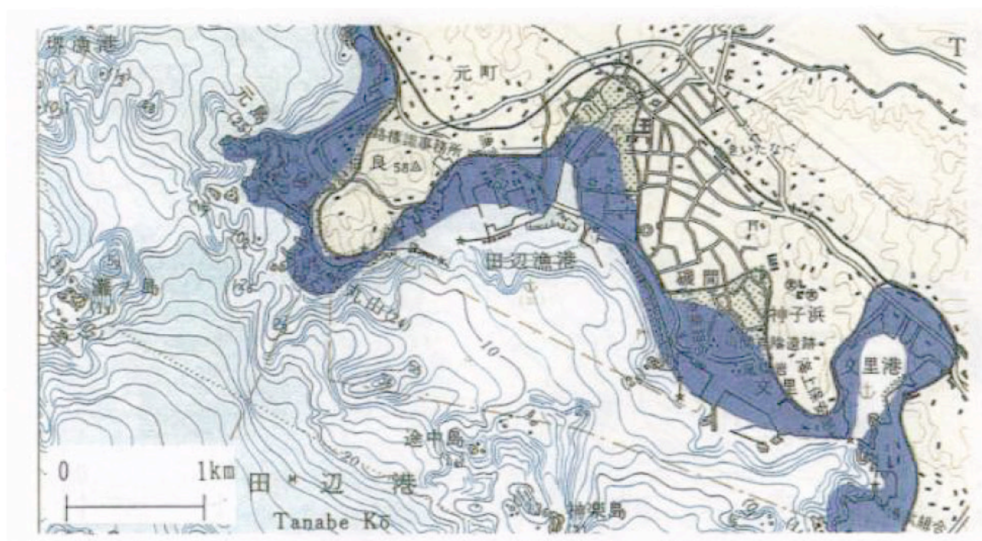
dt=2 second

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

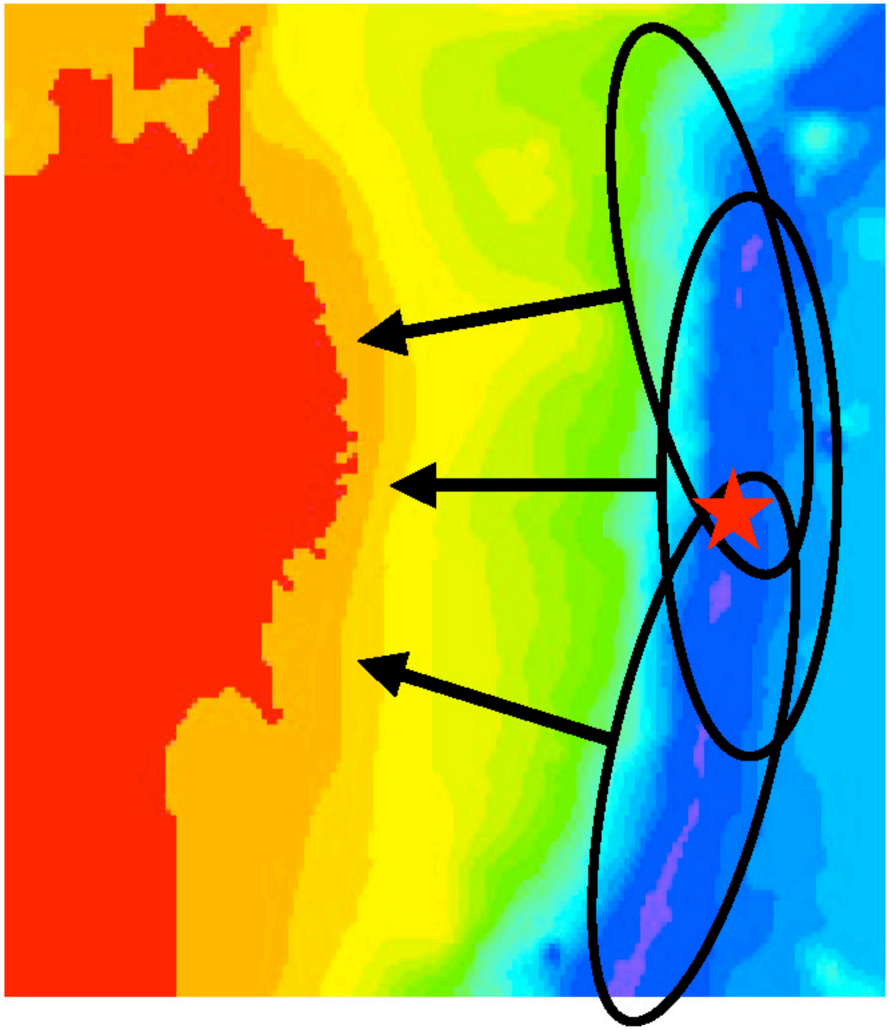
Local Propagation

- 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

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
  - <u>important near source, pt source in</u> 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

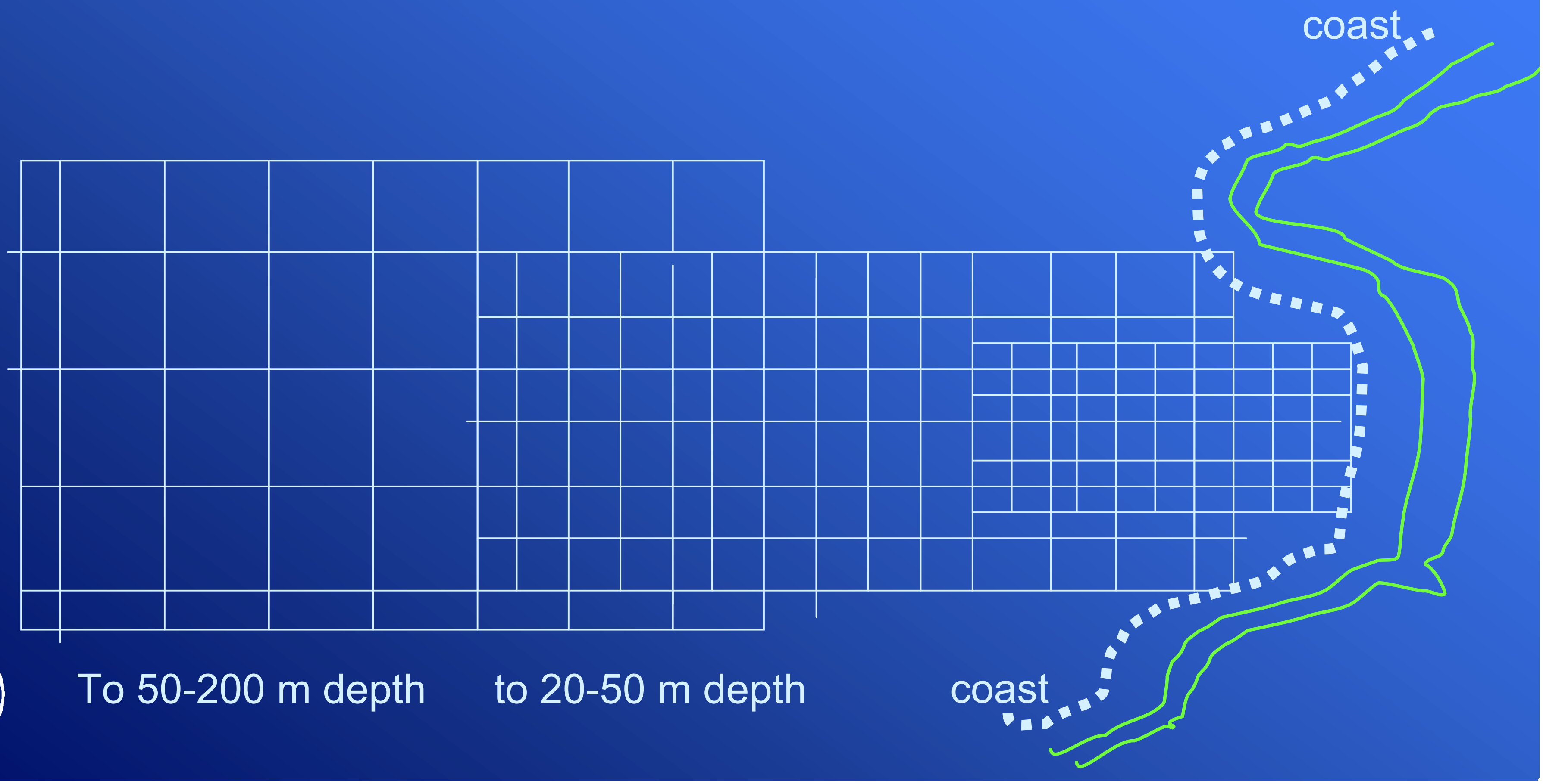
  Boundary conditions important eg set velocity to 0 at shorelines

  Computer time generally too long to run real time

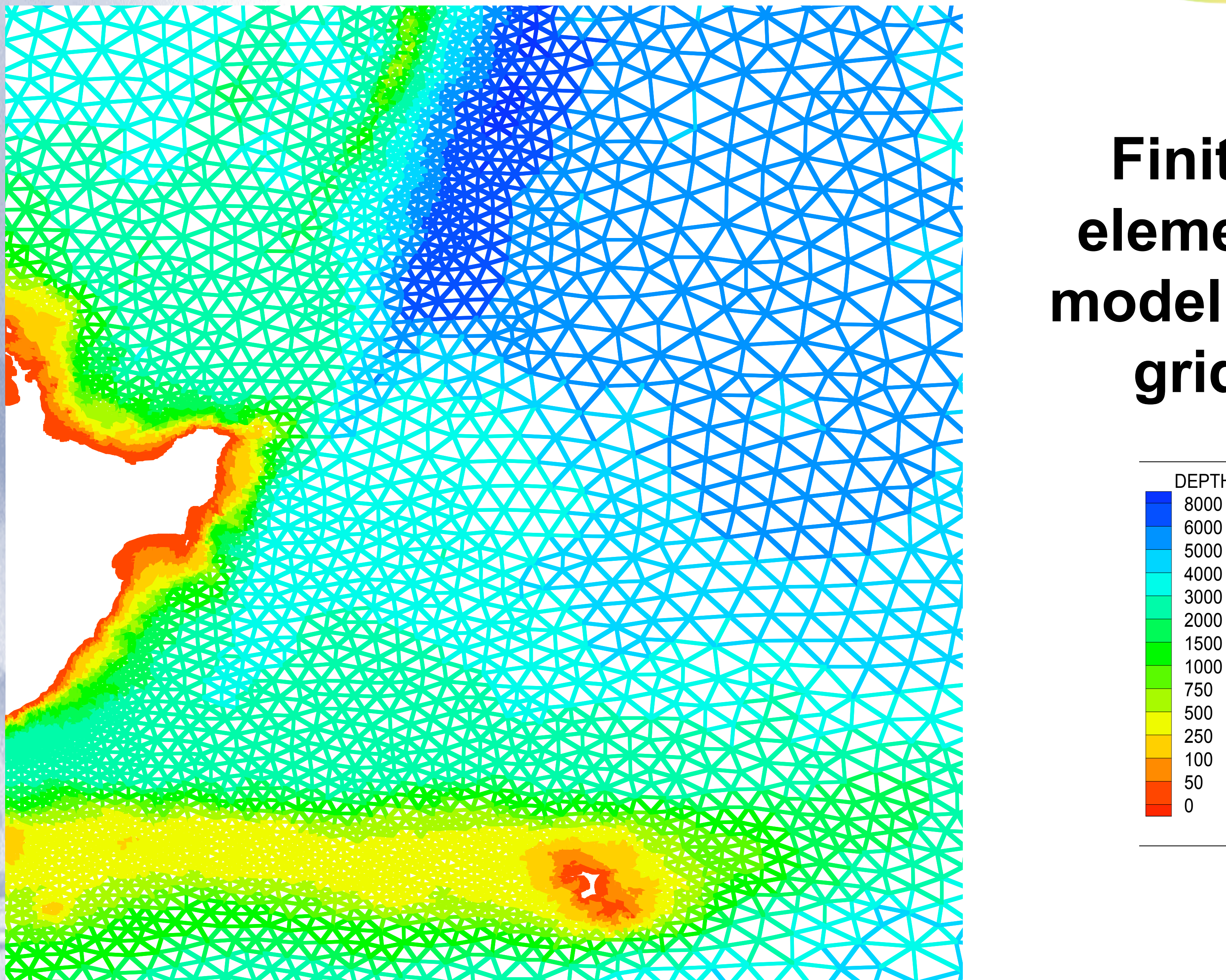
Modelling technique

Finite Difference modeling

Nested coarse to fine rectangular grids



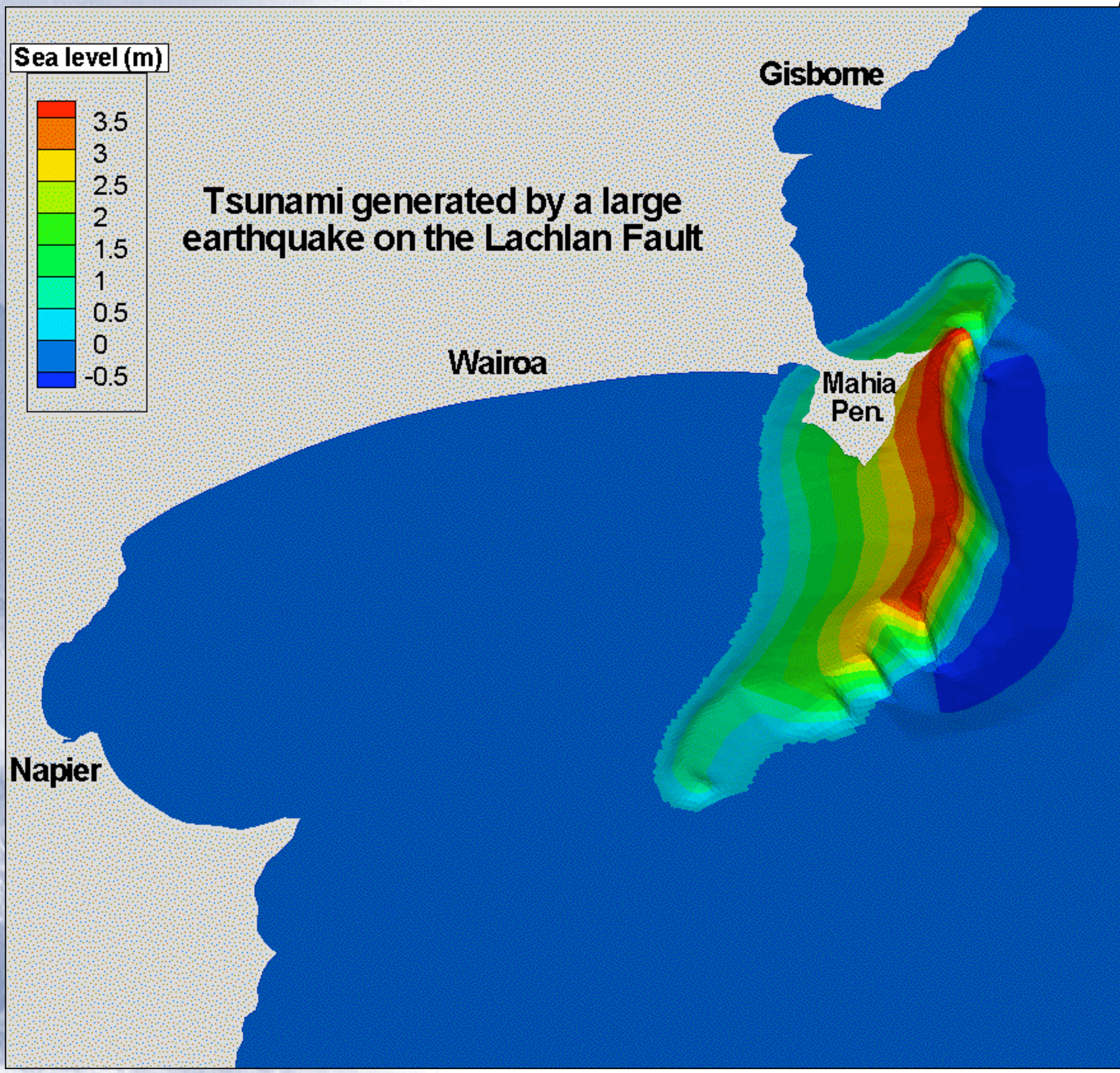
Finite element modelling grid



Modelling the inundation

- Various
  - Wave type – rapid rise & fall, bore, breaking wave
  - Roughness factors
- Require nearshore topography to at least ~1 m contour interval

Examples from US, NZ, Australian Japanese scientists

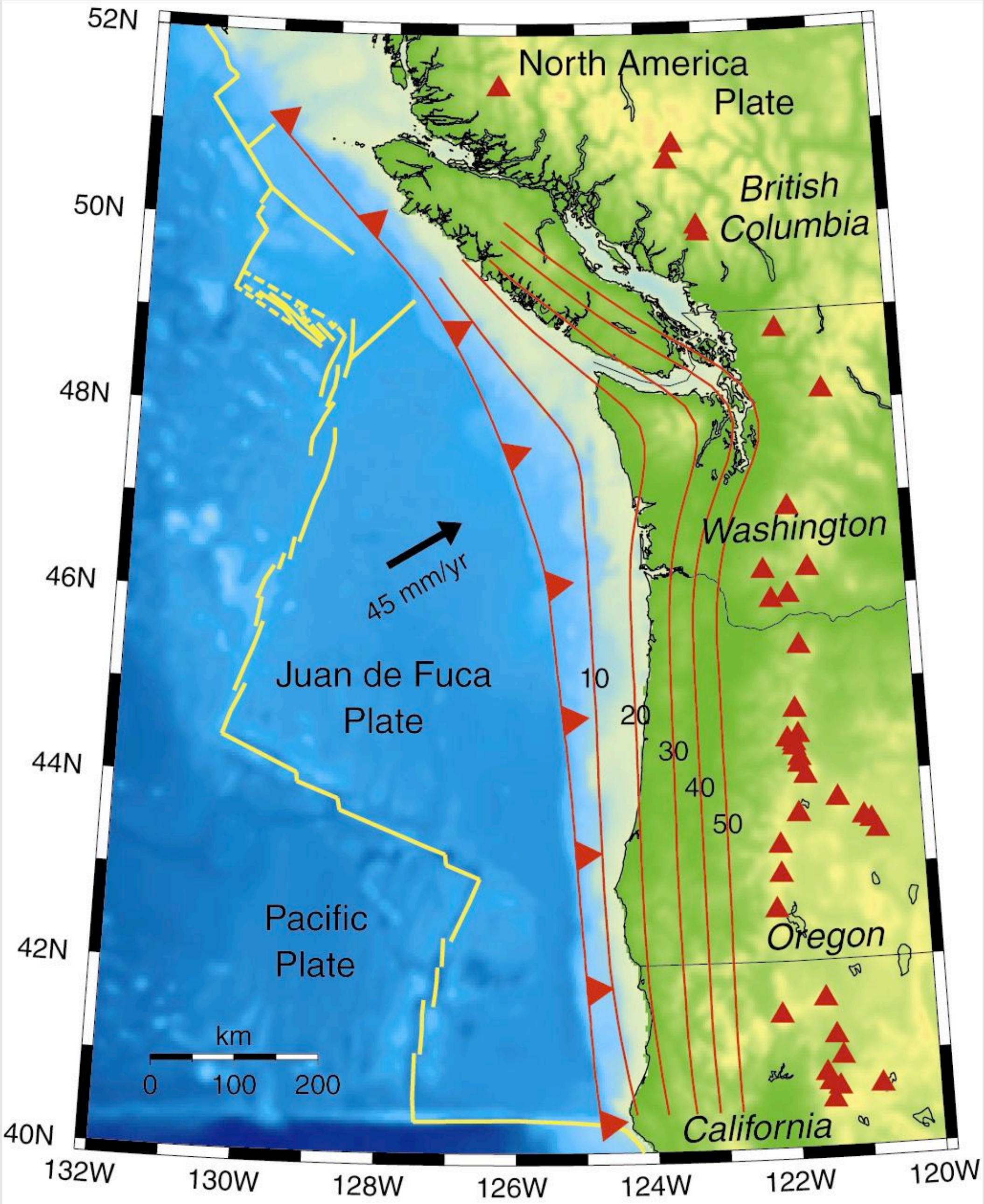


[Modelled by R. Walters, NIWA, NZ]

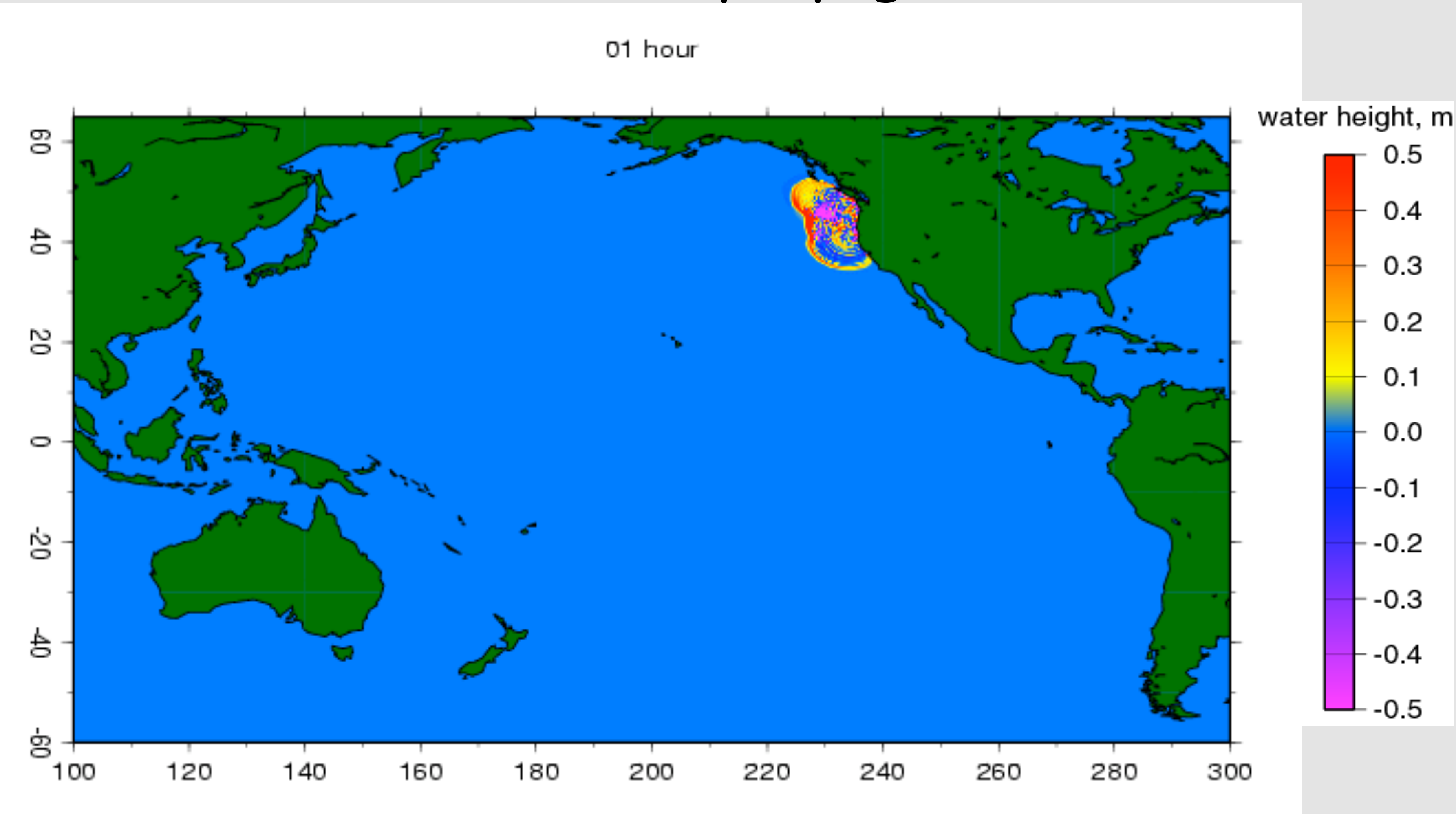
Numerical simulation of a tsunami generated by a large earthquake on the Lachlan Fault (finite difference)

It is only one of many possible scenarios of fault rupture.

Cascadia Subduction Zone

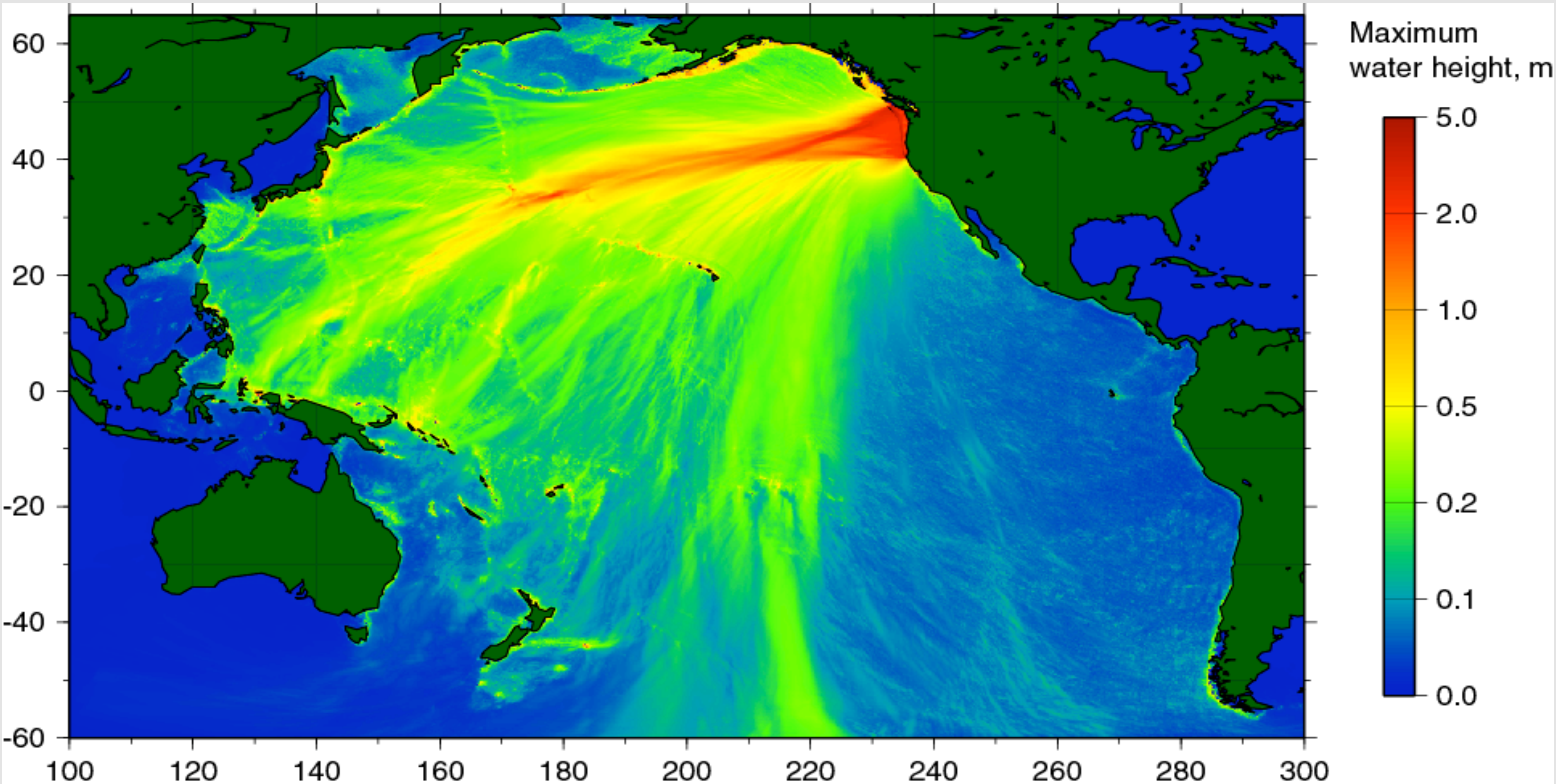


1700AD Cascadia earthquake (probable magnitude ~9) Trans-Pacific tsunami propagation – Satake et al

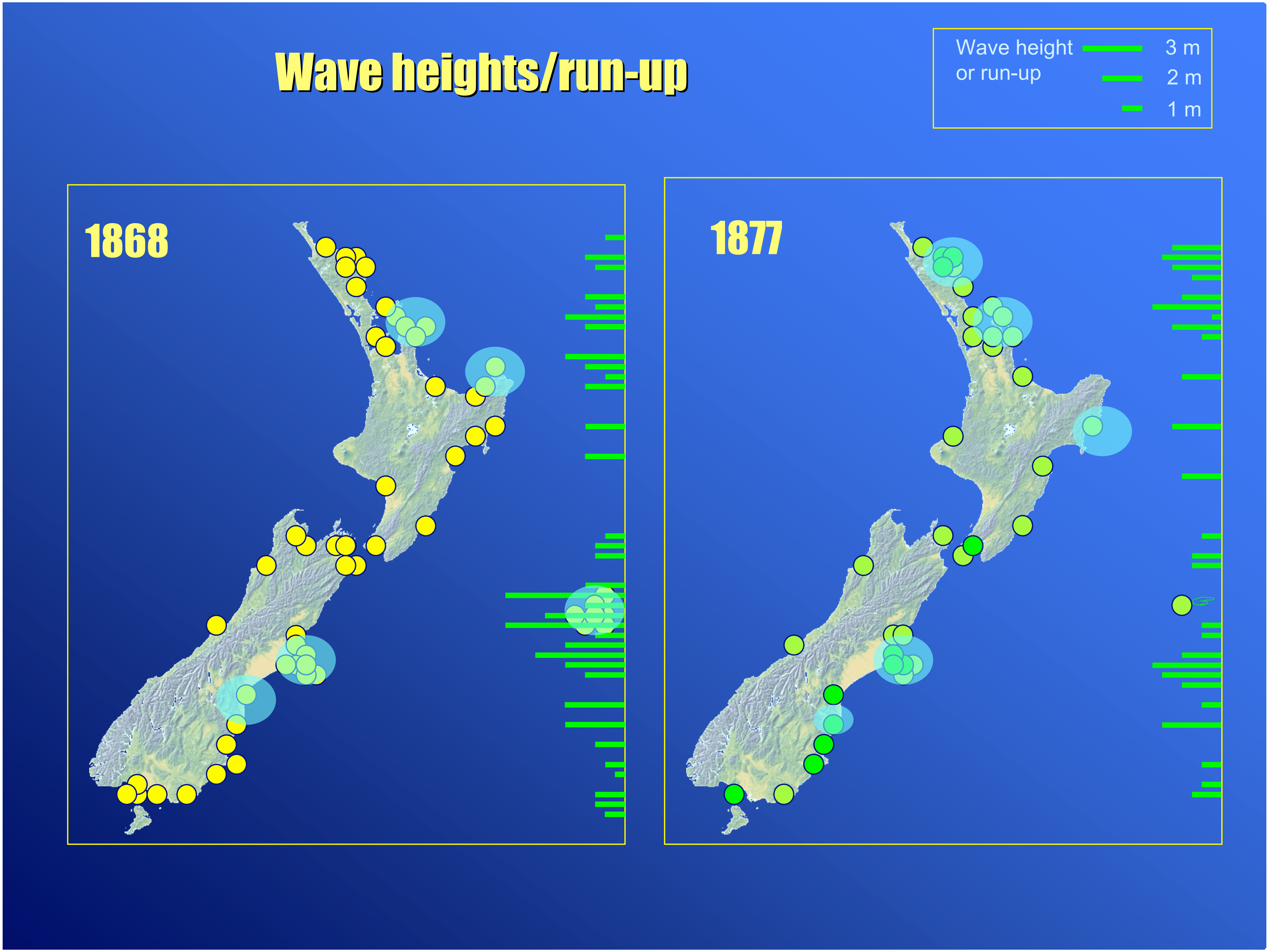


Slide from Kenji Satake's presentation, 2003 Tsunamis of the South Pacific Workshop, Wellington 2003

Maximum water height from modelled 1700AD Cascadia earthquake (probable magnitude ~9)

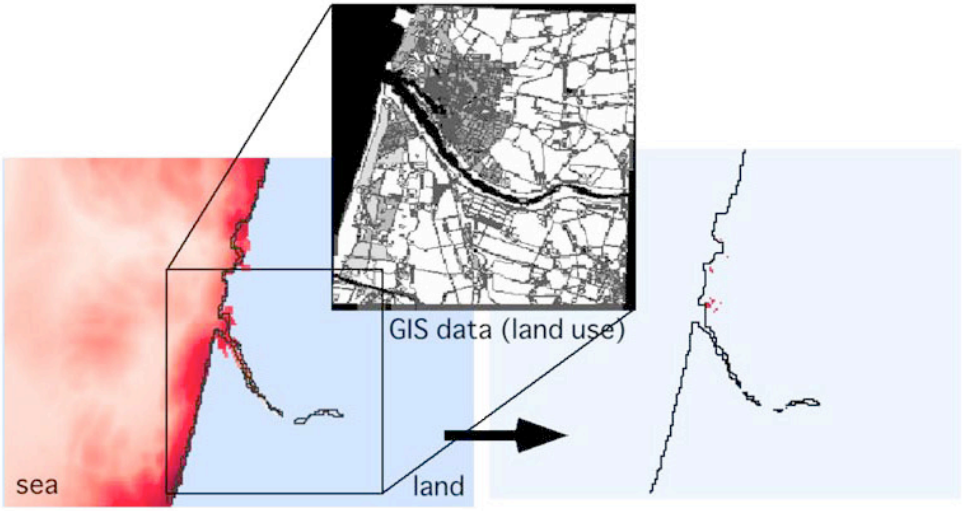


Slide from Kenji Satake's presentation, 2003 Tsunamis of the South Pacific Workshop, Wellington 2003


Wave heights/run-up
Wave height or run-up
3 m
2 m
1 m
1868
1877

Advanced information – estimating potential damage

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



Simulation of the inundation with the data of land-use

Estimation of the damaged houses by the simulation

Population	Estimated casualties	(%)
151,129	27,325	18.1
Total of houses	Damaged houses	(%)
57,344	469	0.8

Criteria to estimate damage by tsunamis

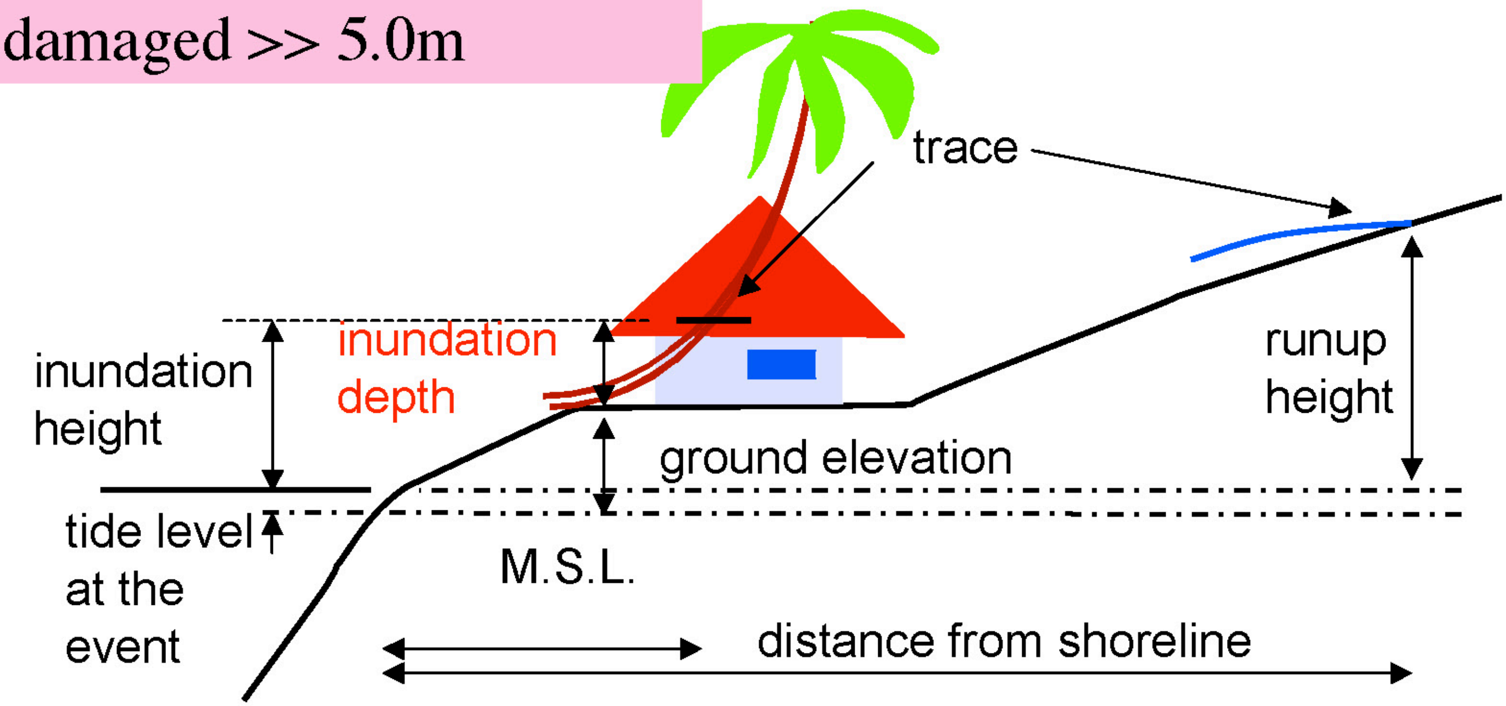
Inundation depth

Human: killed >> 50cm

House: partially damaged >> 1.0m

totally damaged >> 2-3.0m

Building: damaged >> 5.0m



津波遡上予測図１

（津波予報　８ｍ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閖上地区・下増田地区・北釜地区）の広い範囲で、ほぼ全域で0.3m以上の浸水があると、想定されます。

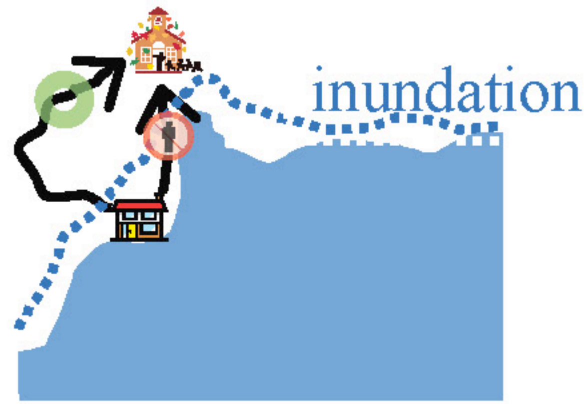
このような大津波は、予報発令から津波が来襲するまで２時間以上の時間的余裕があることが多いと考えられますので、落ち着いて内陸部（市の中央部もしくは西部地区）へ避難をしてください。

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