Brainstorming Meeting for PEER's Role in Tsunami Research

Harry Yeh
Oregon State University

Objectives

- What can PEER contribute to tsunami research, in particular for the Washington, Oregon, and California coasts? What would be the effective research that PEER should get involved: i.e. identifying PEER's niché.
  - Identify our knowledge/engineering gap for our research needs.
  - Development of a collaborative program for scenario simulations.

FEMA: Federal role in mitigation

- Seaside, Oregon Tsunami Pilot Study – Modernization of FEMA Flood Hazard Maps (2006) Joint study with NOAA and USGS.
- FEMA p646: Guidelines for Design of Structures for Vertical Evacuation from Tsunamis. (2008)
- Development of Tsunami Methodology to be included in the HAZUS Application. (in progress)

NOAA: Tsunami warning

- Tsunami measurements by DART Buoys.
- Forecast Propagation Database and Tsunami Inundation DEM.
- Rapid Tsunami Propagation Model: MOST
- Inundation Modeling and the SIFT (Short-Term Inundation Forecasting for Tsunamis) System

USGS: Geo-Science

- Tsunami Source Estimates
- Paleo-Tsunamis: Tsunami Sediment Deposits.

NTHMP: Community-based mitigation

- Executive Office of the President
  - NOAA, FEMA, USGS (no more NSF!)
  - Alaska; California; Hawaii; Oregon; Washington; Puerto Rico; US Virgin Islands; Pacific Territories/Commonwealths; US East Coast States; US Gulf Coast States.
- Evacuation (and Inundation) Maps
- Education, Evacuation Drills
- Tsunami Evacuation Buildings
- Evacuation models
- Comprehensive Tsunami Simulator for Long Beach Peninsula.

NSF NEES

Generation:

- NEESR-SG: 3D Tsunami Evolution Using a Landslide Tsunami Generator – Fritz (Georgia Tech.), 2004
- Utilizing NEES Facilities: Landslide Generated Tsunamis and Runup – Liu (Cornell), 2004
- NEESR-CR: Tsunami Generation by Landslides – Fritz (Georgia Tech.), 2009

Propagation/Runup:

- NEESR-SG: TSUNAMOS: A Validated, Multi-Scale Tsunami Model – Lynett (Texas A&M), 2006
- EAGER: Developing and Testing Algorithms for Generating Leading Tsunami Waves – Liu (Cornell). 2009
- NEESR Payload: Dissipation by Macro-Roughness Representing Forested Areas – Irish (Texas A&M), 2009.
- NEESR Payload: Tsunamis by Interaction with Ocean Swell and Wind Waves – Kaihatsu (Texas A&M), 2009.
- NEESR-SD: Runup and Bed Shear Stress – Liu (Cornell), 2010.
- NEESR: Interaction of Tsunamis with Short Waves and Bottom Sediment -- Numerical and Physical Modeling -- Kaihatsu (Texas EES), 2012
- NEESR: Tsunami Run-up and Withdrawal Dynamics on a Sloping Beach with Discontinuous Macro-Roughness – Irish (Virginia Tech), 2012.

NSF NEES

Interaction:

- Collaborative Research on Tsunami-Structure Interactions Using NEES Tsunami Basin Facilities – Liu (Cornell), 2002
- NEESR-SG: Development of Performance Based Tsunami Engineering, PBTE – Riggs (Hawaii). 2005.
- SGER NEESR: Wave Loading on Residential Structures with Earthquake and Hurricane Applications – van de Lindt (Colorado). 2007.
- NEESR II: Mitigating the Risk through understanding Tsunami-Structure Interaction – Cox (Oregon State), 2008.
- NEESR-CR: Impact Forces from Tsunami-Driven Debris – Riggs (Hawaii), 2010.
- NEESR: Tsunami Induced Coherent Structures and their Impact on our Coastal Infrastructure – Foster (U. New Hampshire), 2012.

Deaths Caused by Tsunamis

2004	Indian Ocean Tsunami	~ 230,000
1410 BC	North Coasts Crete, Santorini	100,000
1755	Lisbon, Portugal	62,000
1782	South China Sea	40,000
1883	Indonesia, Krakatau Eruption	36,500
1498	Japan, Nankaido	31,200
1707	Japan, Tokaido-Nankaido	30,000
1896	Japan, Sanriku	26,360
1868	Chile, North Chile	25,674
2011	Japan, Sanriku	19,295
1792	Japan, SW Kyushu Island	15,030

http://www.ngdc.noaa.gov/seg/hazard/tsu.shtml

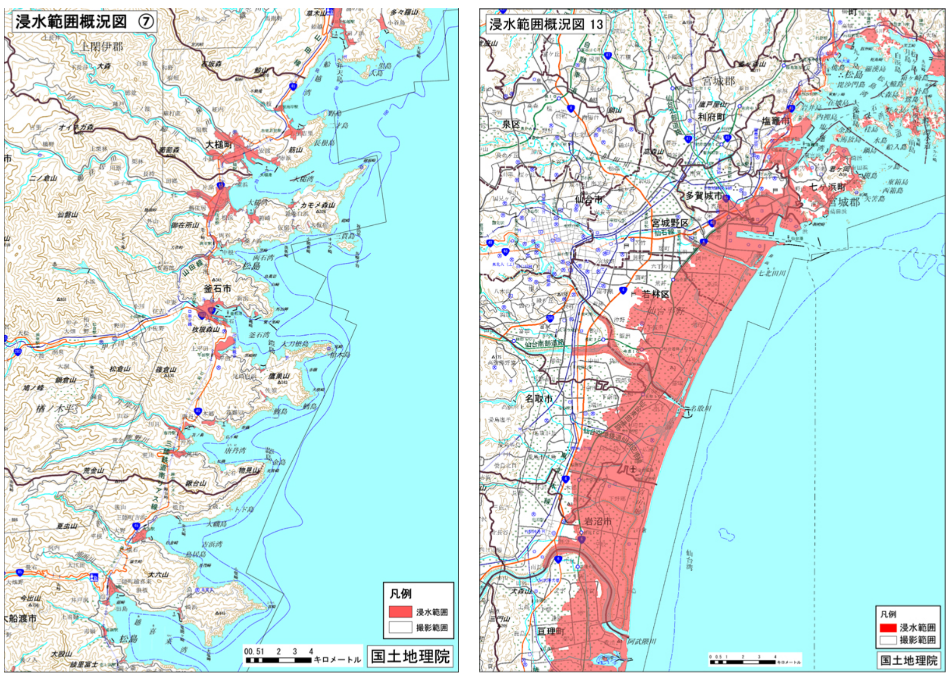
Tsunami Hazard Reduction

- Because mega tsunamis are rare and because forewarning of these events is possible (although the lead time can be very short), the primary mitigation tactic to date has been **EVACUATION** – distinct difference from earthquake hazard.

Time and loading scales of various coastal hazards

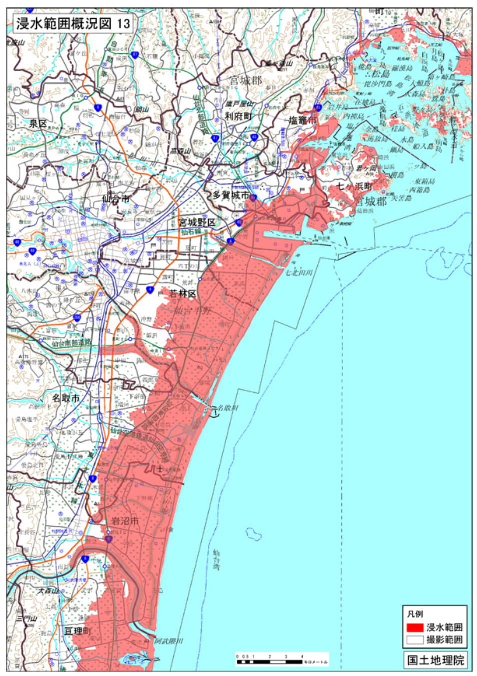
Phenomenon	Time Scale	Pressure Head	Forewarning Time
River Flood	days	< 3 meters	a few days
Hurricane/Storm Surge	hours	< 5 meters	several days
Storm-Generated Wave	seconds	< 10 meters	several days
Tsunami	minutes	< 10 meters	minutes to hours
Earthquake	seconds	N/A	none to seconds

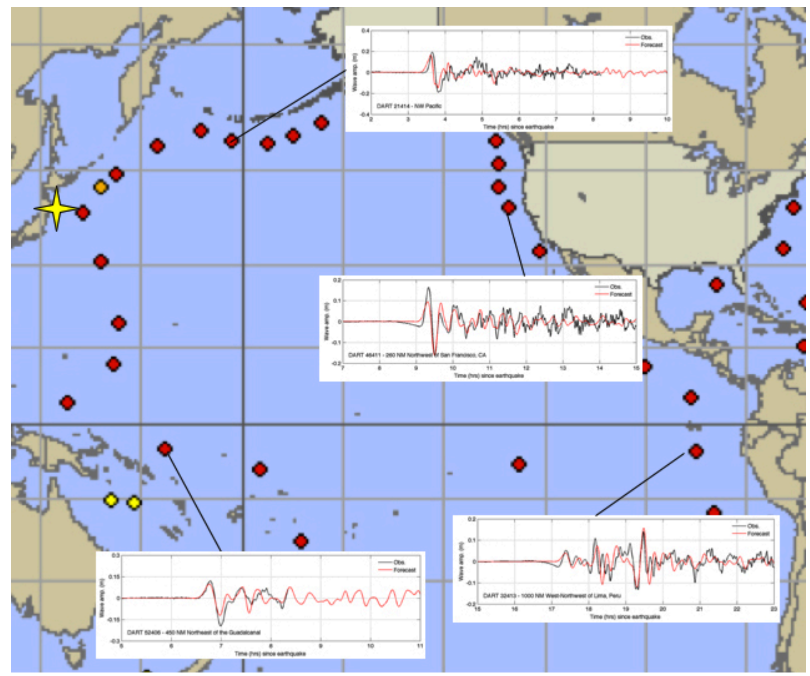
- Tsunami risk areas are limited to narrow strips along the shoreline (< a few kilometers) and pocket beaches.
- Within an inundation zone, damage and losses are heterogeneous: the nearer the beach, the higher the risk.



Inundation areas: L) Sanriku, R) Sendai

- Tsunami risk areas are limited to narrow strips along the shoreline (< a few kilometers) and pocket beaches.
- Within an inundation zone, damage and losses are heterogeneous: the nearer the beach, the higher the risk.
- On the other hand, because of the propagation, the risk spreads the entire Pacific Rim.

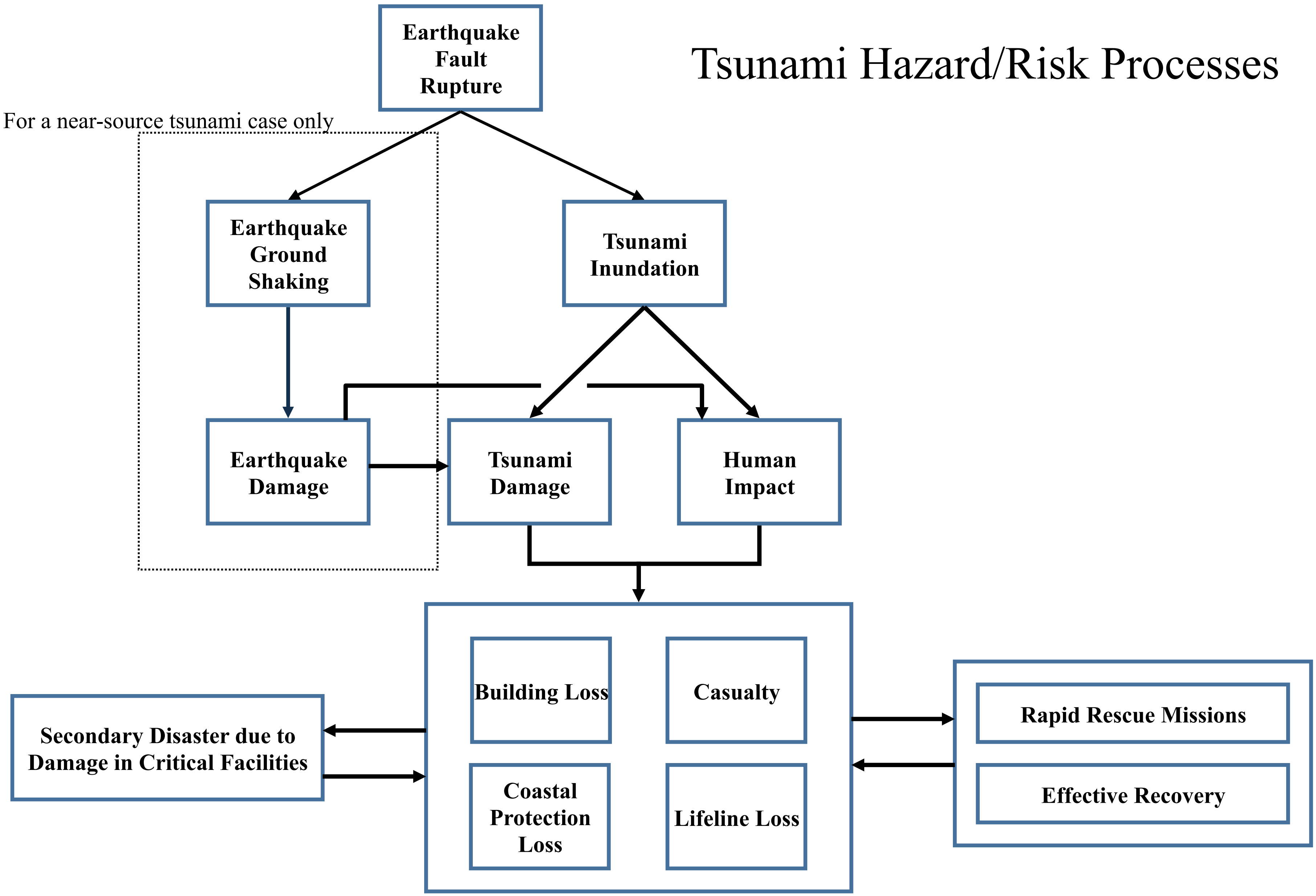


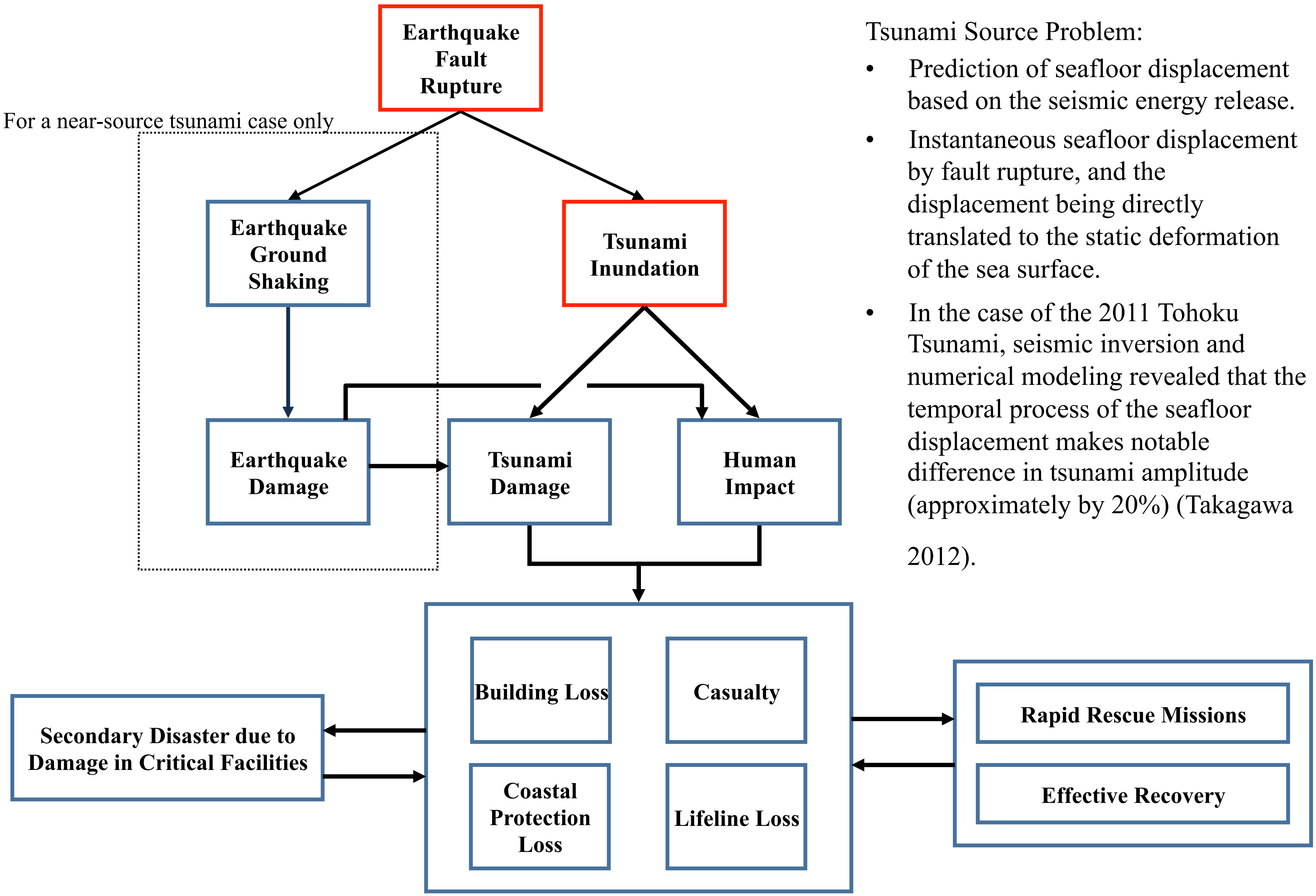


Inundation areas: L) Sanriku, R) Sendai

- The tactic for tsunami hazard reduction is distinct from that of earthquake hazard.
- Requirement for a short-time evacuation is also different from the cases of hurricane and flood hazards.

Tsunami Hazard/Risk Processes



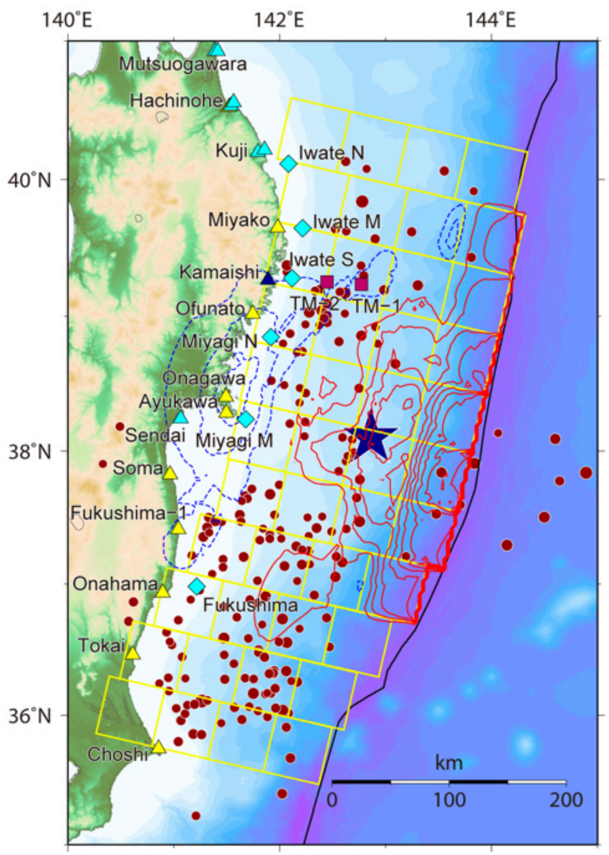


Tsunami Source Problem:

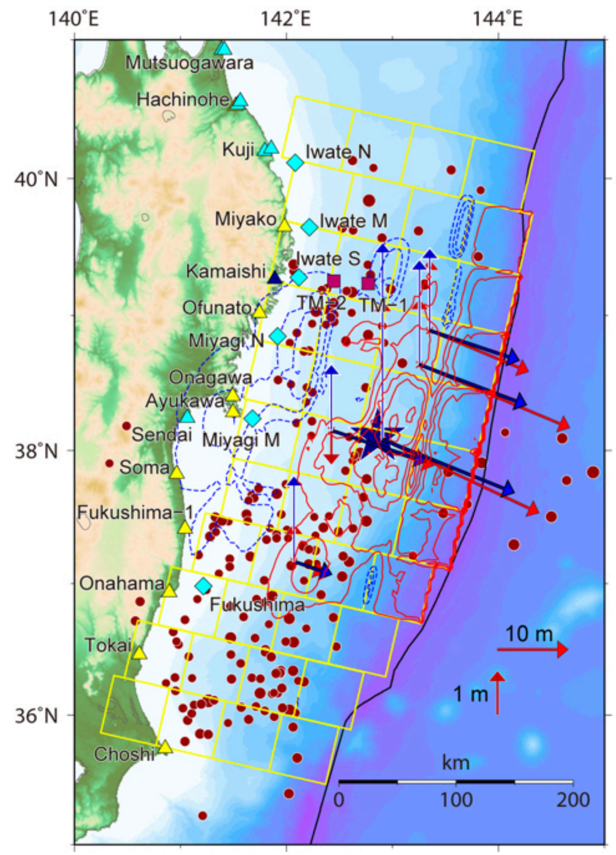
- Prediction of seafloor displacement based on the seismic energy release.
- Instantaneous seafloor displacement by fault rupture, and the displacement being directly translated to the static deformation of the sea surface.
- In the case of the 2011 Tohoku Tsunami, seismic inversion and numerical modeling revealed that the temporal process of the seafloor displacement makes notable difference in tsunami amplitude (approximately by 20%) (Takagawa 2012).

Tsunami Source Models of the 2011 Tohoku Tsunami

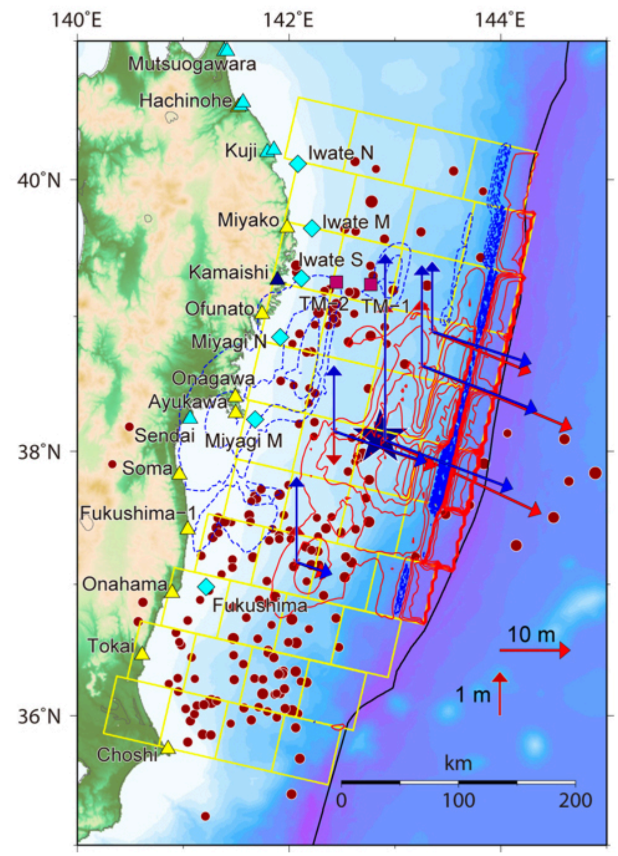
The red contours indicate uplift with the contour interval of 1.0 m, while the blue contours indicate subsidence with the contour interval of 0.5 m. The arrows were obtained from sea-floor geodetic observations



V. 6.2



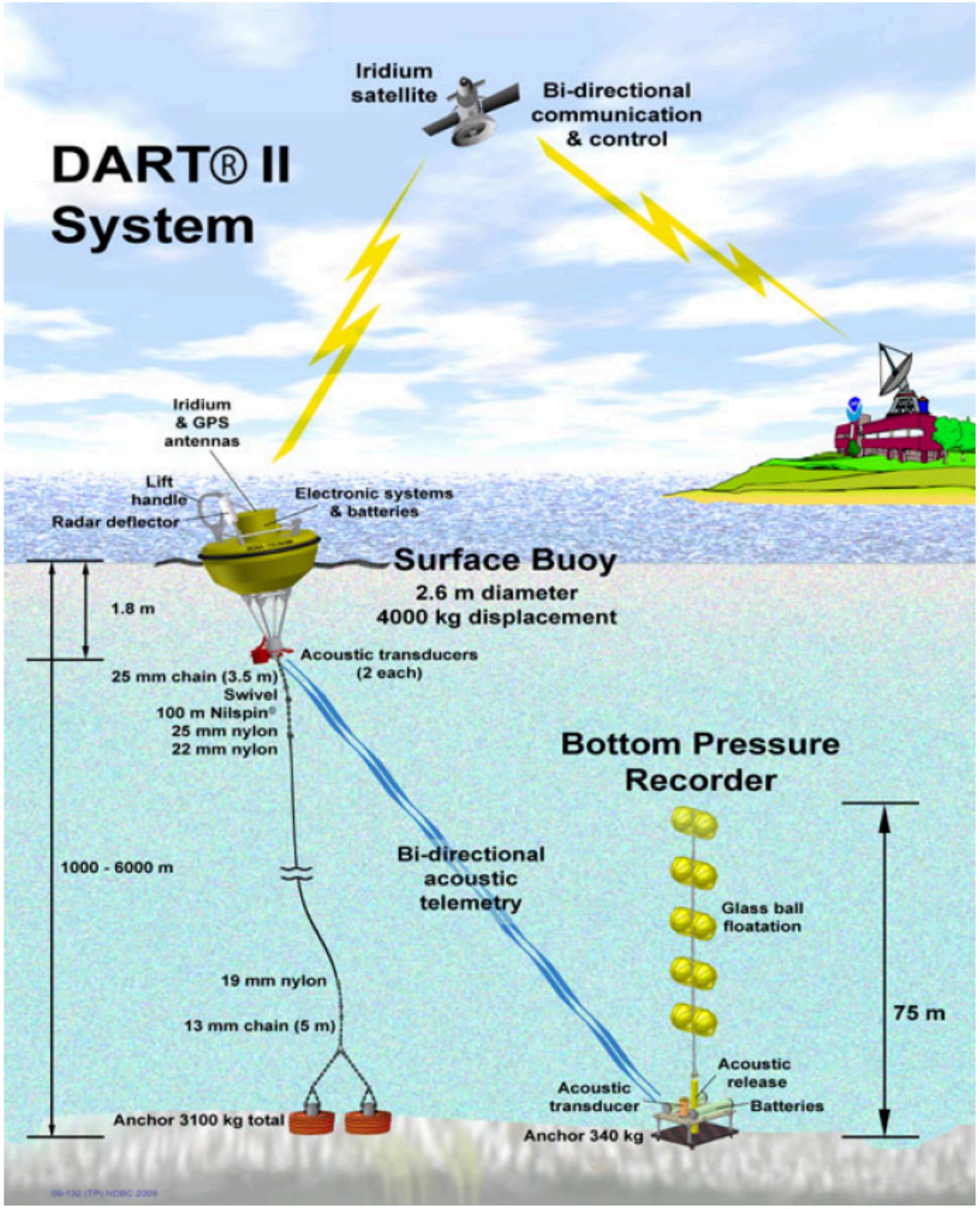
V. 7.0



V. 8.0

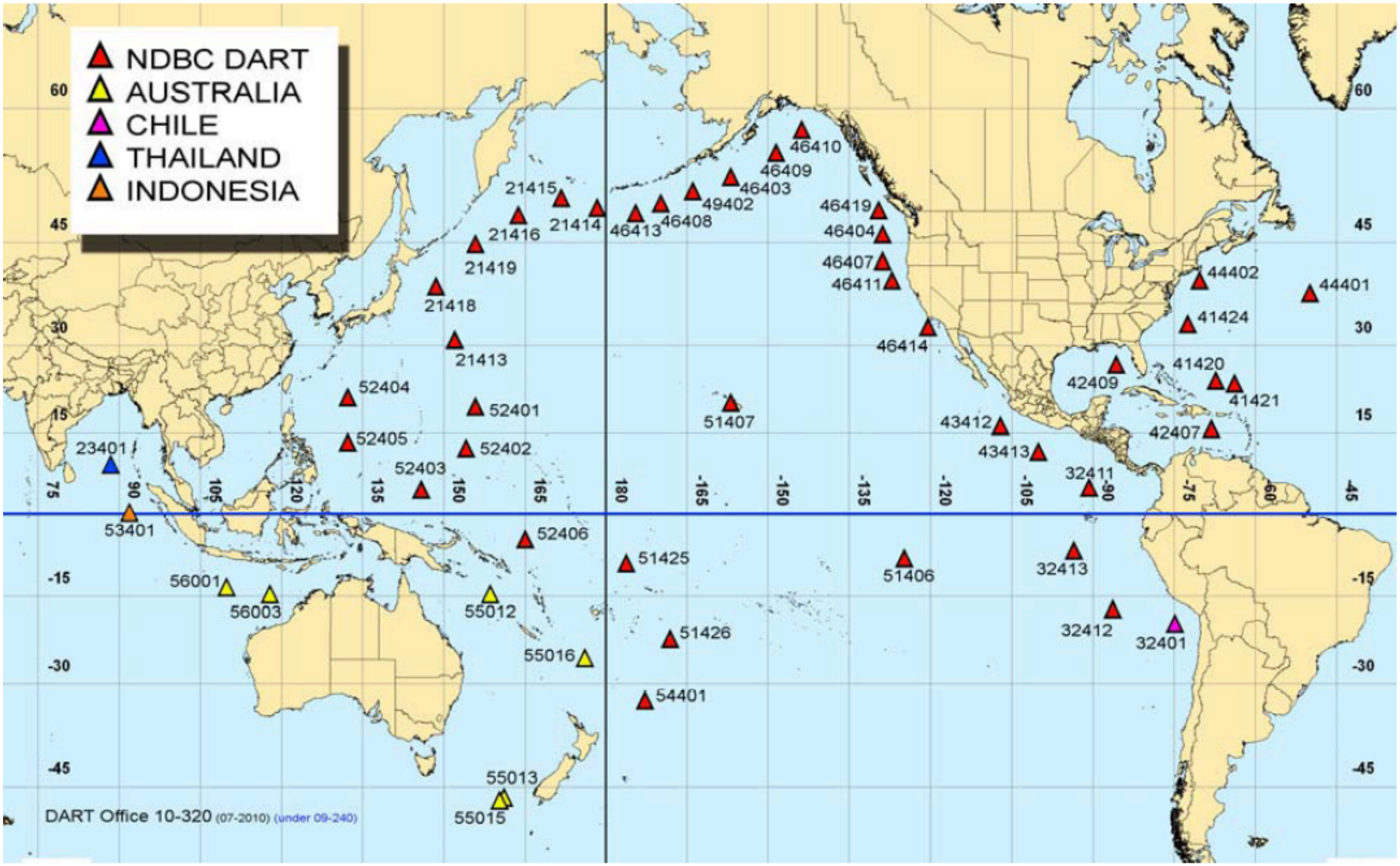
Fujii and Satake: http://iisee.kenken.go.jp/staff/fujii/OffTohokuPacific2011/tsunami_inv.html

NOAA's DART Buoy Data

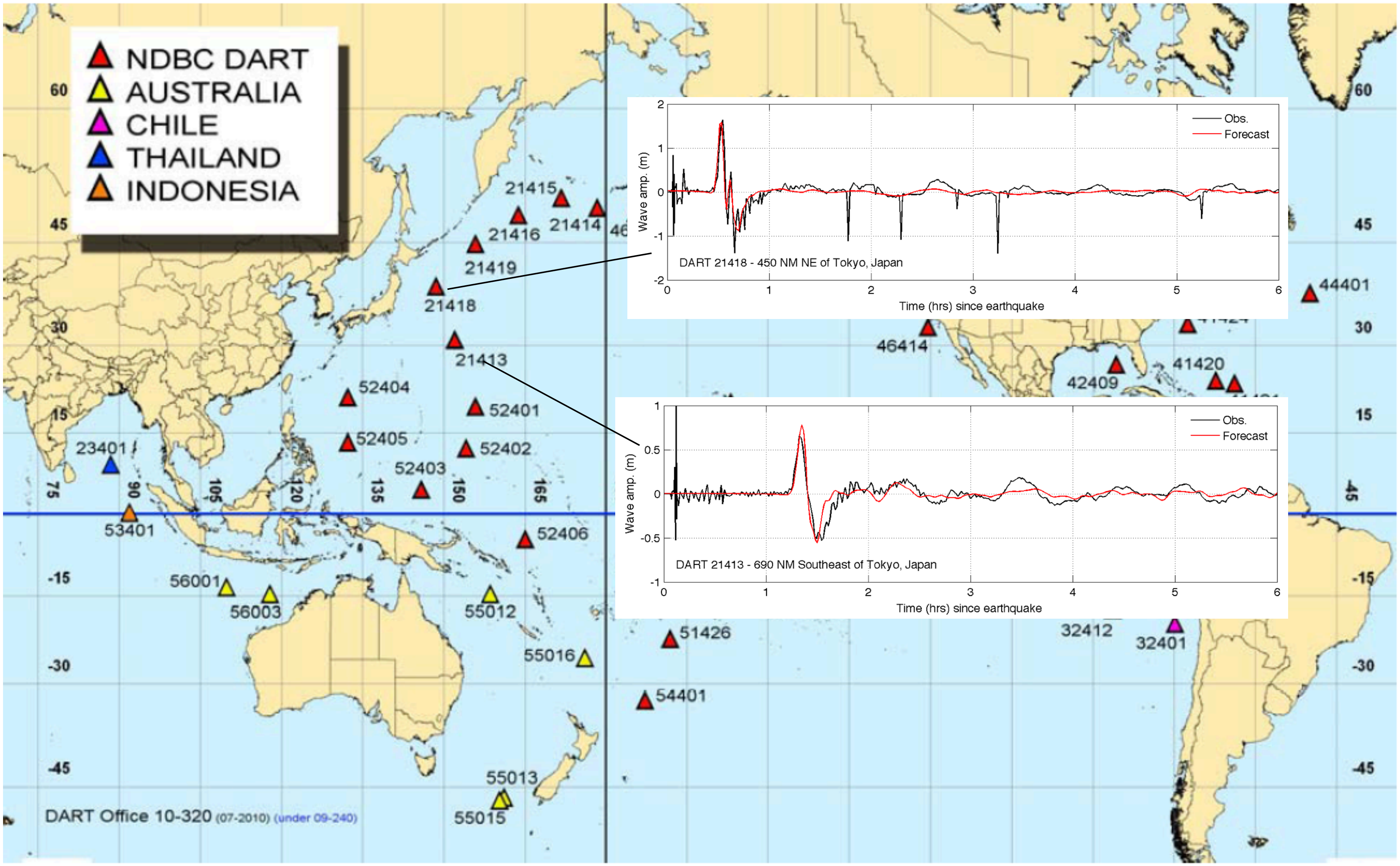


There are 39 DART stations maintained and operated by NOAA's NDBC (National Data Buoy Center): there were only 6 DART stations prior to the 2004 Indian Ocean Tsunami.

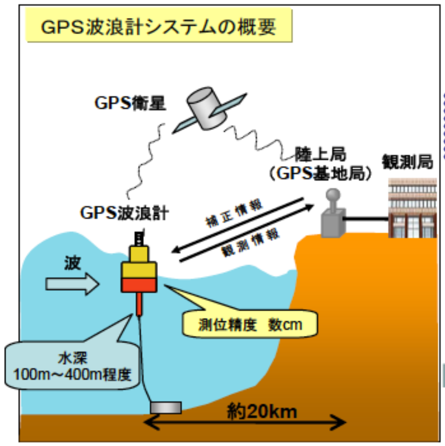
NOAA's DART Buoys and Other Buoys

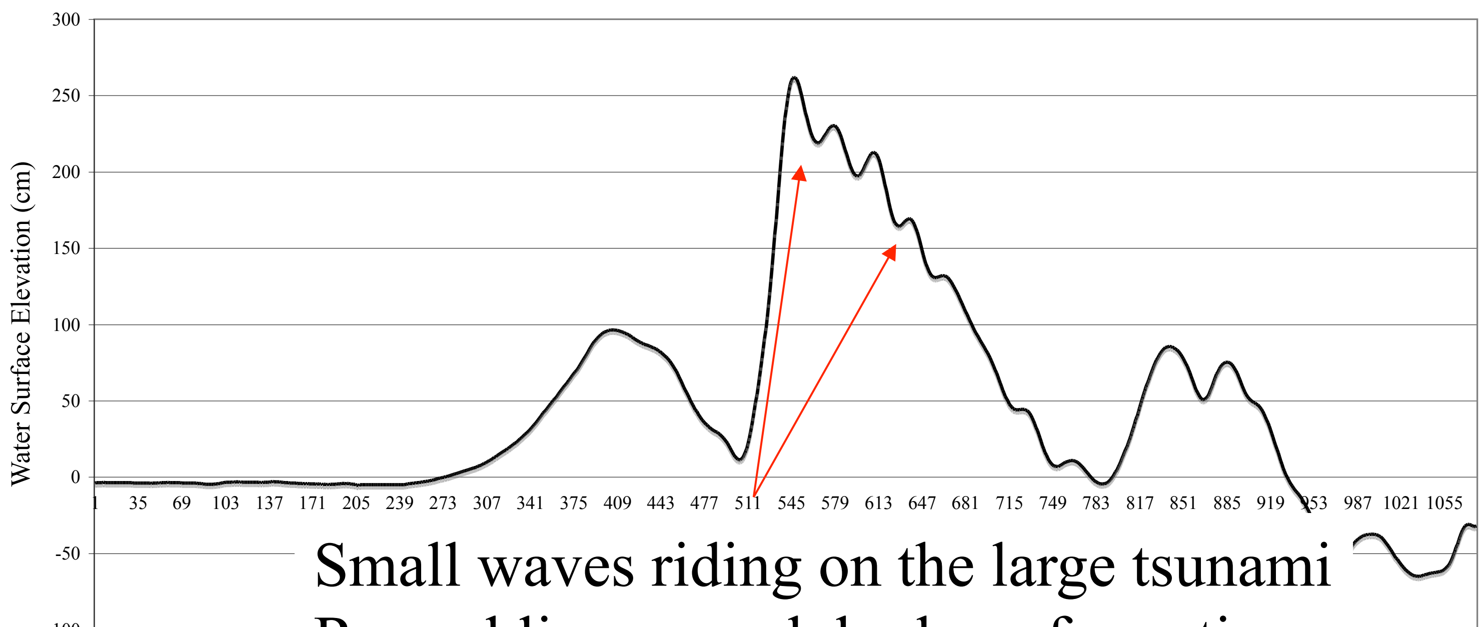


NOAA's DART Buoys and Other Buoys



GPS Wave Recorder off the Fukushima Coast

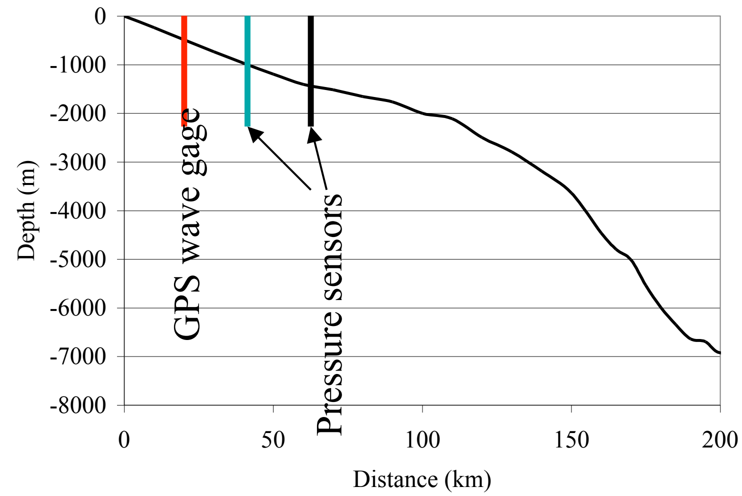


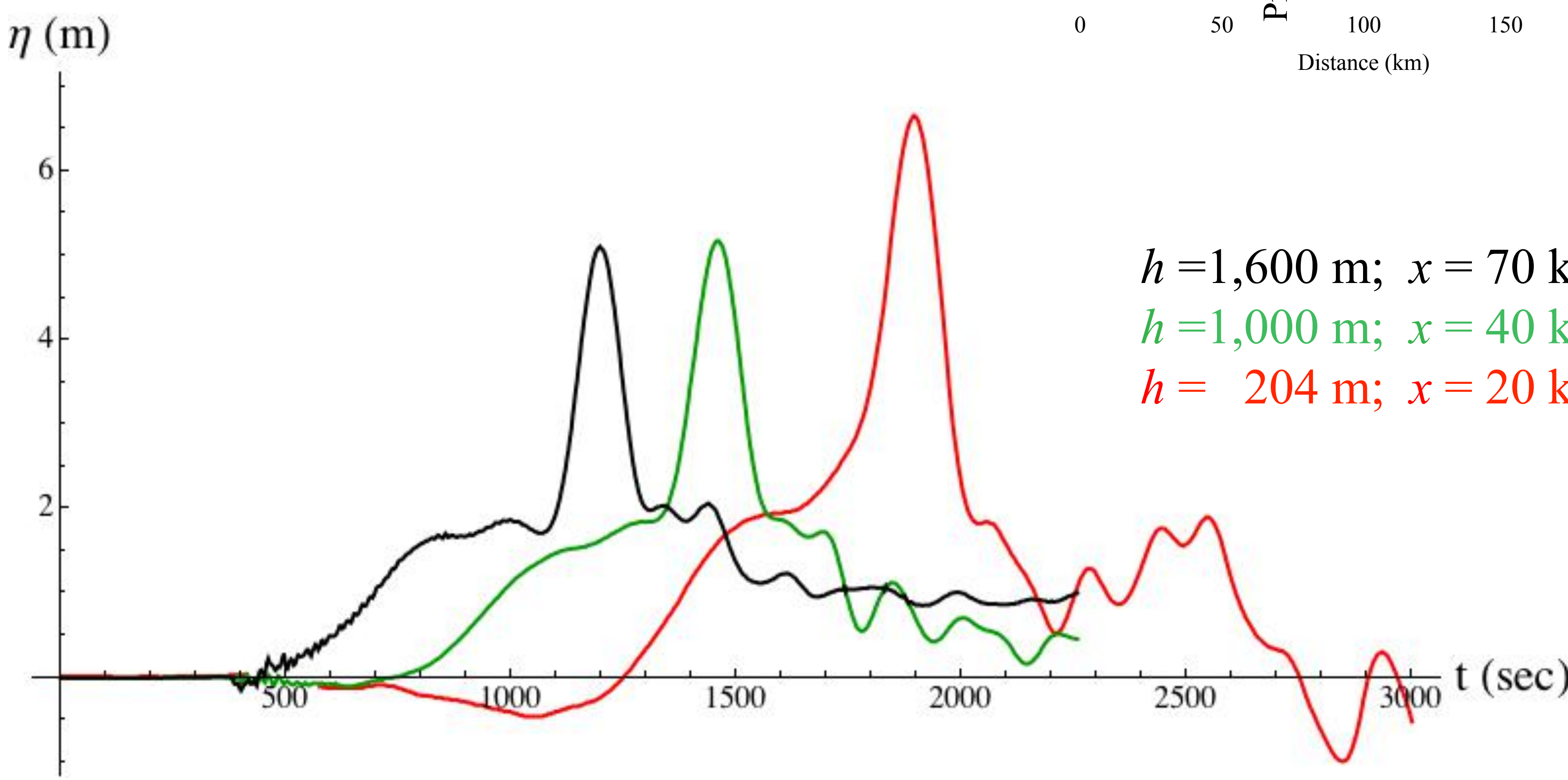


Small waves riding on the large tsunami
Resembling an undular bore formation.

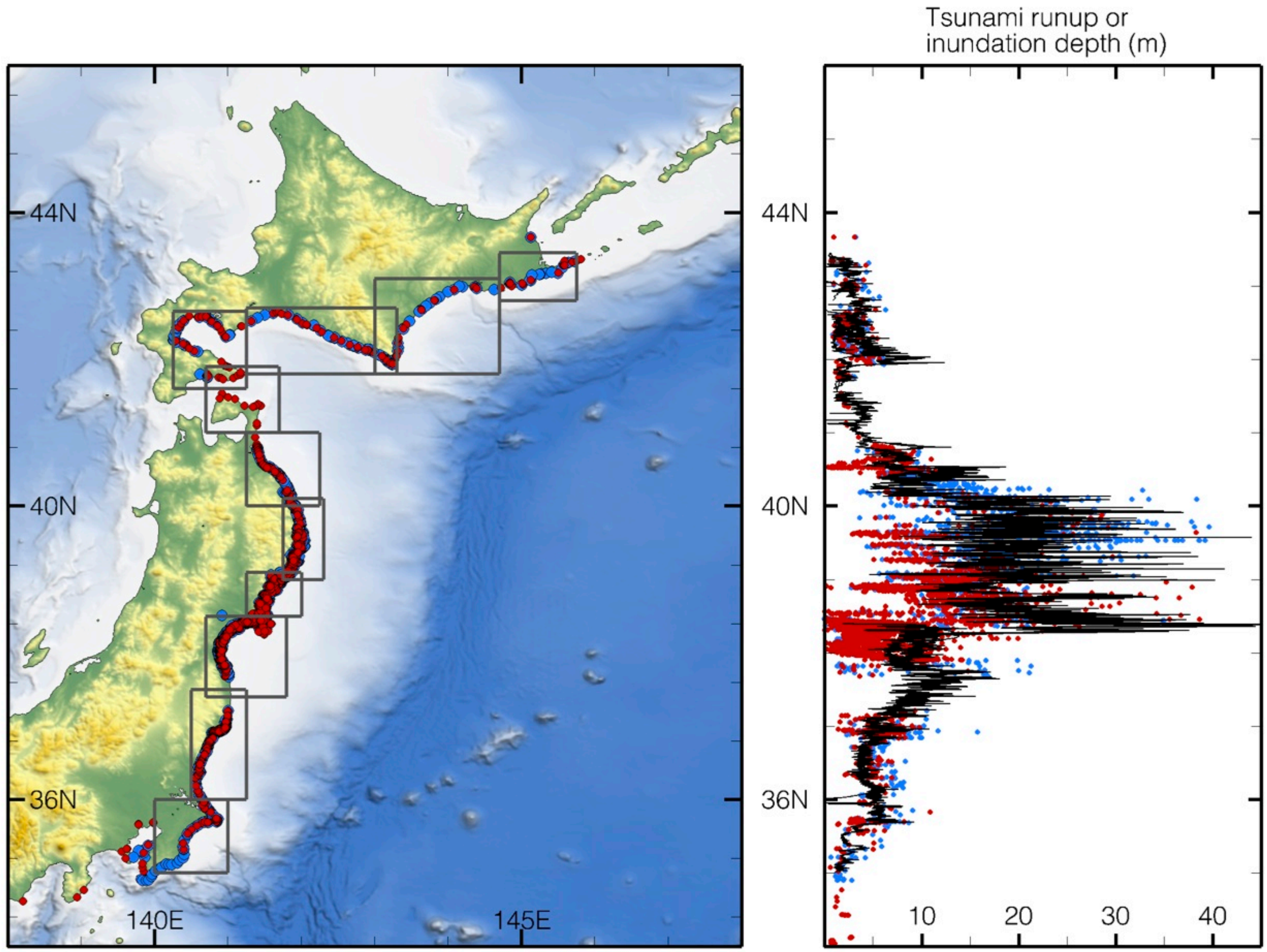
At the location of water depth 137 m (36˚58’ 17”N 141˚11’ 08”E)

Seabed Pressure Data and GPS Wave Gage Off Kamaishi



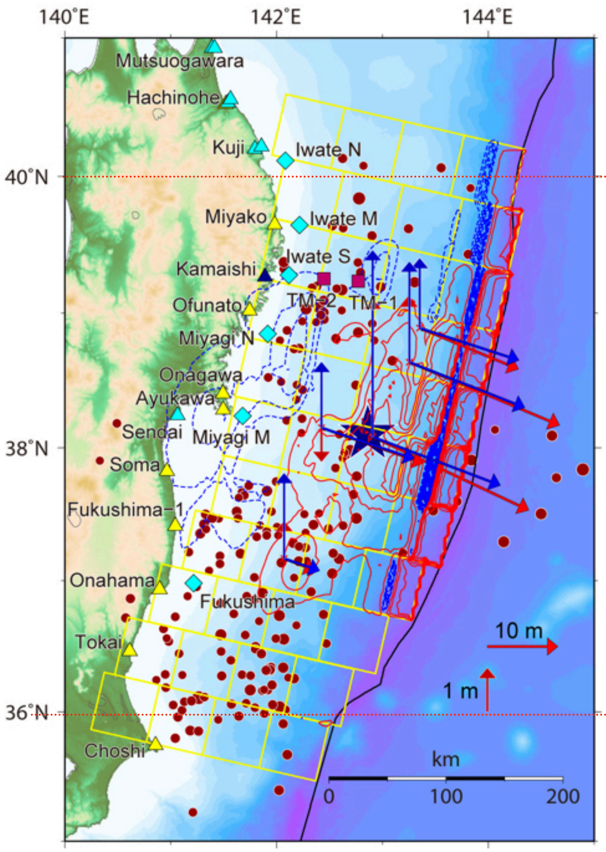


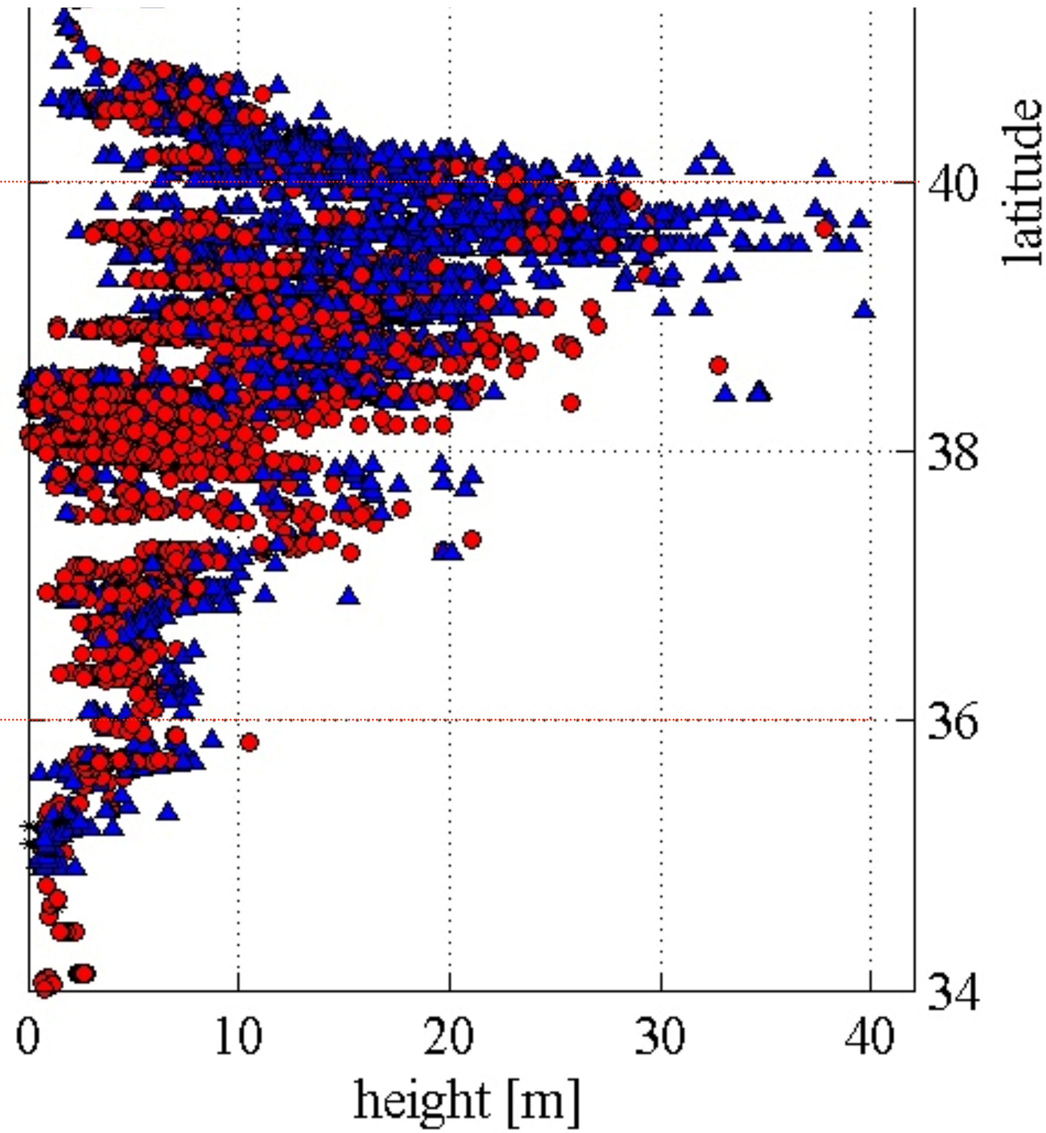
PMEL/NOAA's Work using the DART buoys' Data



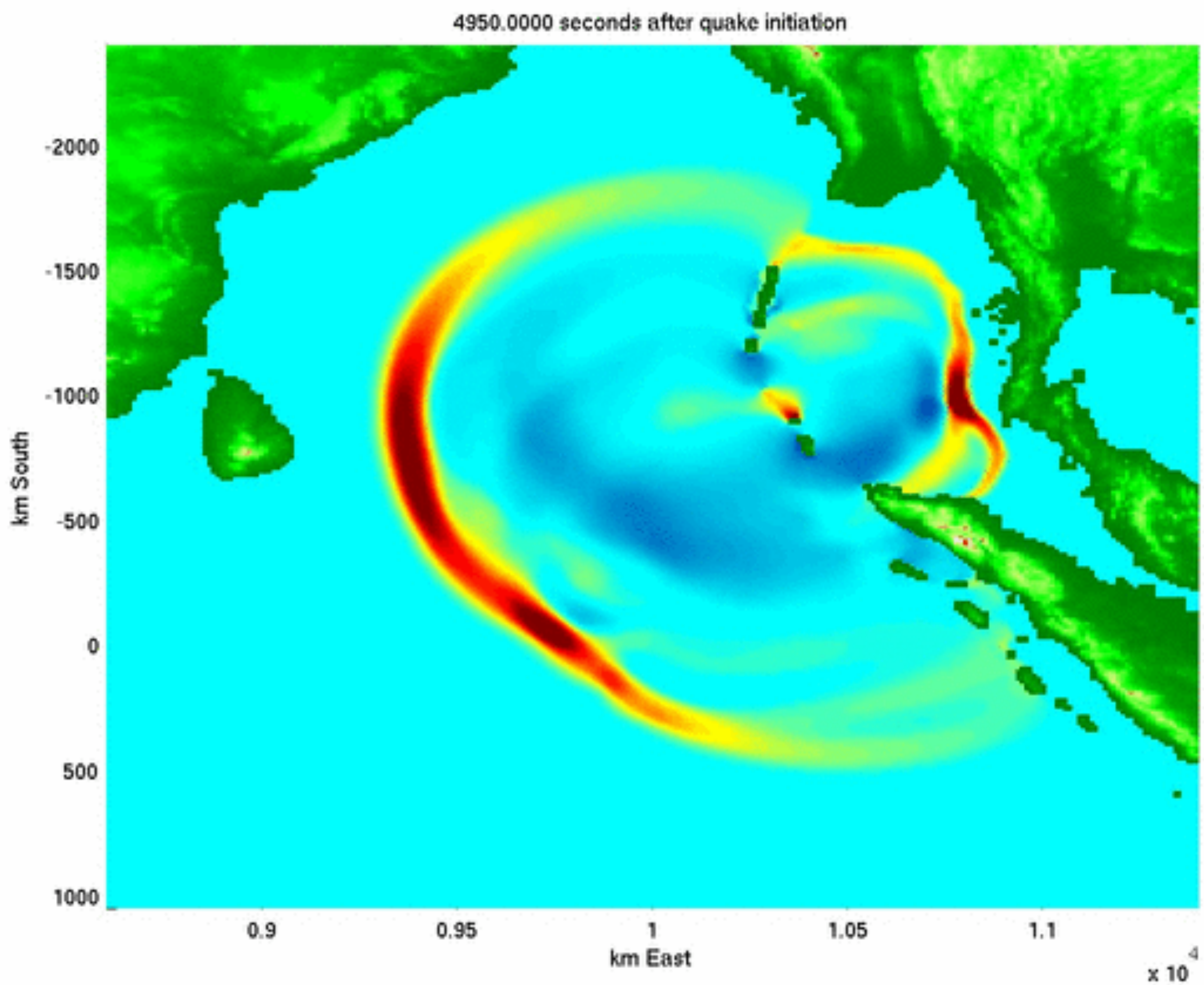
Observed tsunami runup
Observed inundation depth
MOST computed max water level
Computational domain of inundation models

Measured Runup Distribution and the Source Prediction



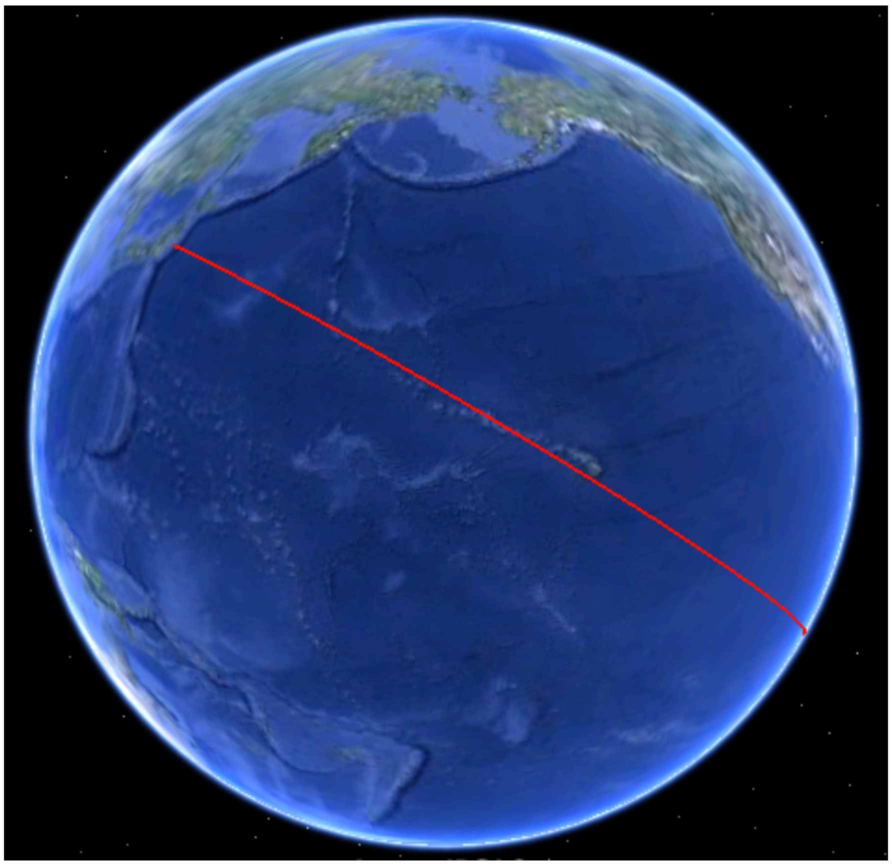


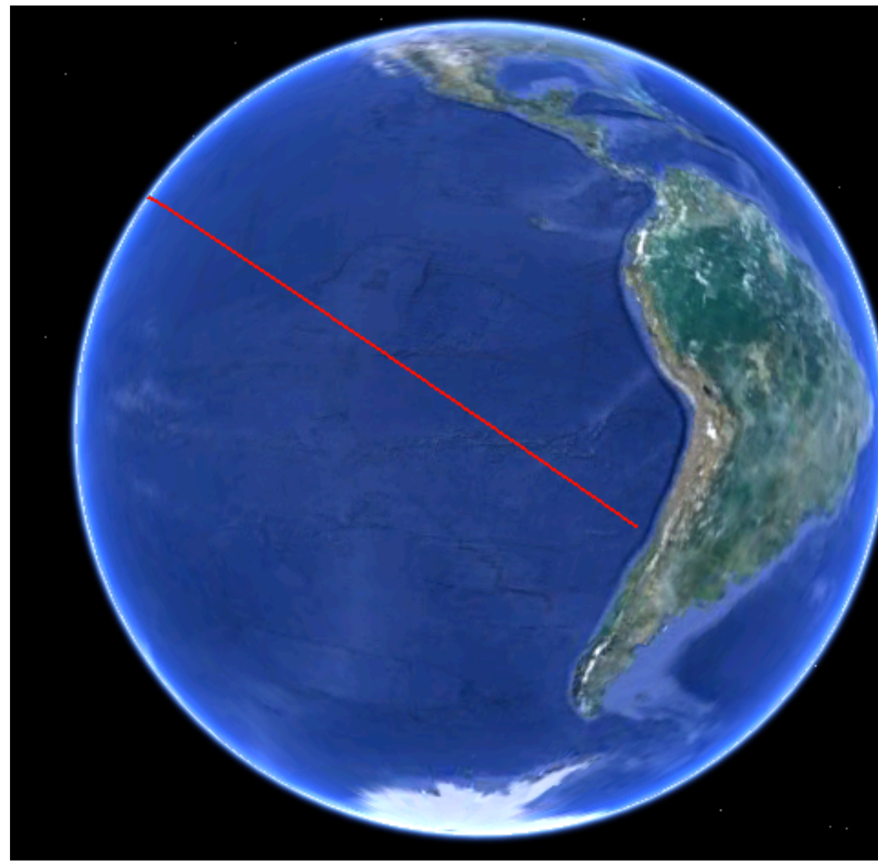
The 2004 Great Indian Ocean Tsunami



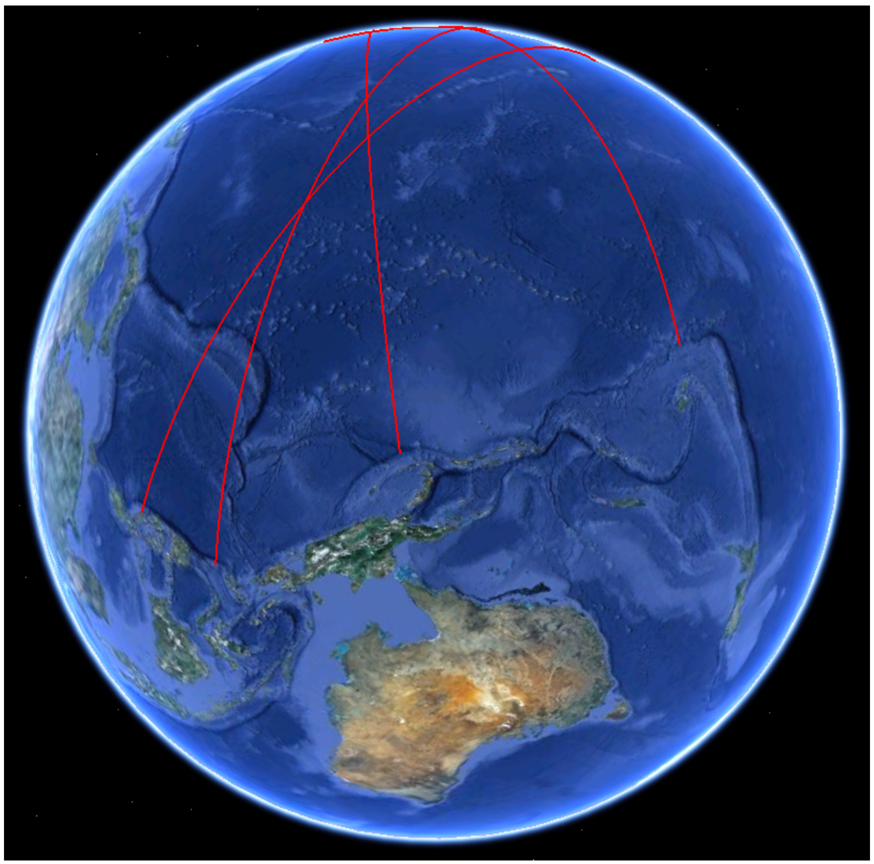
By David George & Randy LeVeque

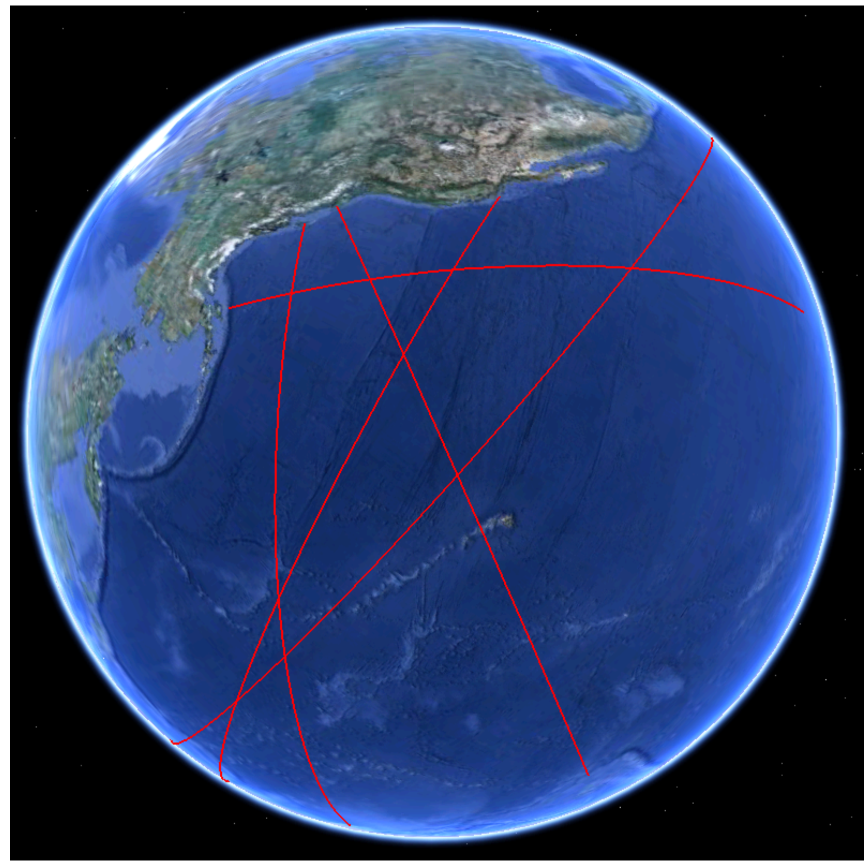
Directivity of Tsunami Energy Propagation: the 1960 Chile

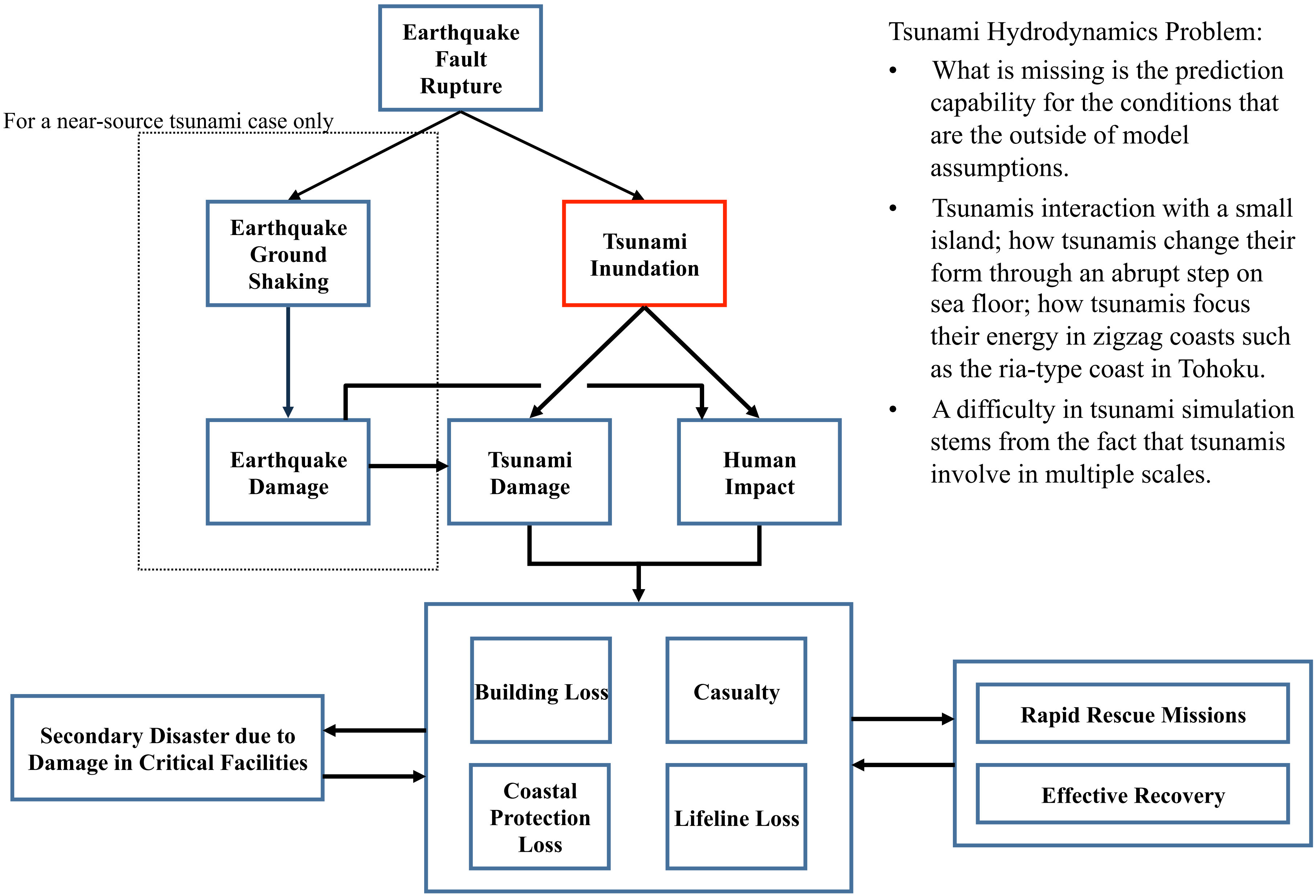




Potential Tsunami Sources that affect the US West-Coast







Tsunami Hydrodynamics Problem:

- What is missing is the prediction capability for the conditions that are the outside of model assumptions.
- Tsunamis interaction with a small island; how tsunamis change their form through an abrupt step on sea floor; how tsunamis focus their energy in zigzag coasts such as the ria-type coast in Tohoku.
- A difficulty in tsunami simulation stems from the fact that tsunamis involve in multiple scales.

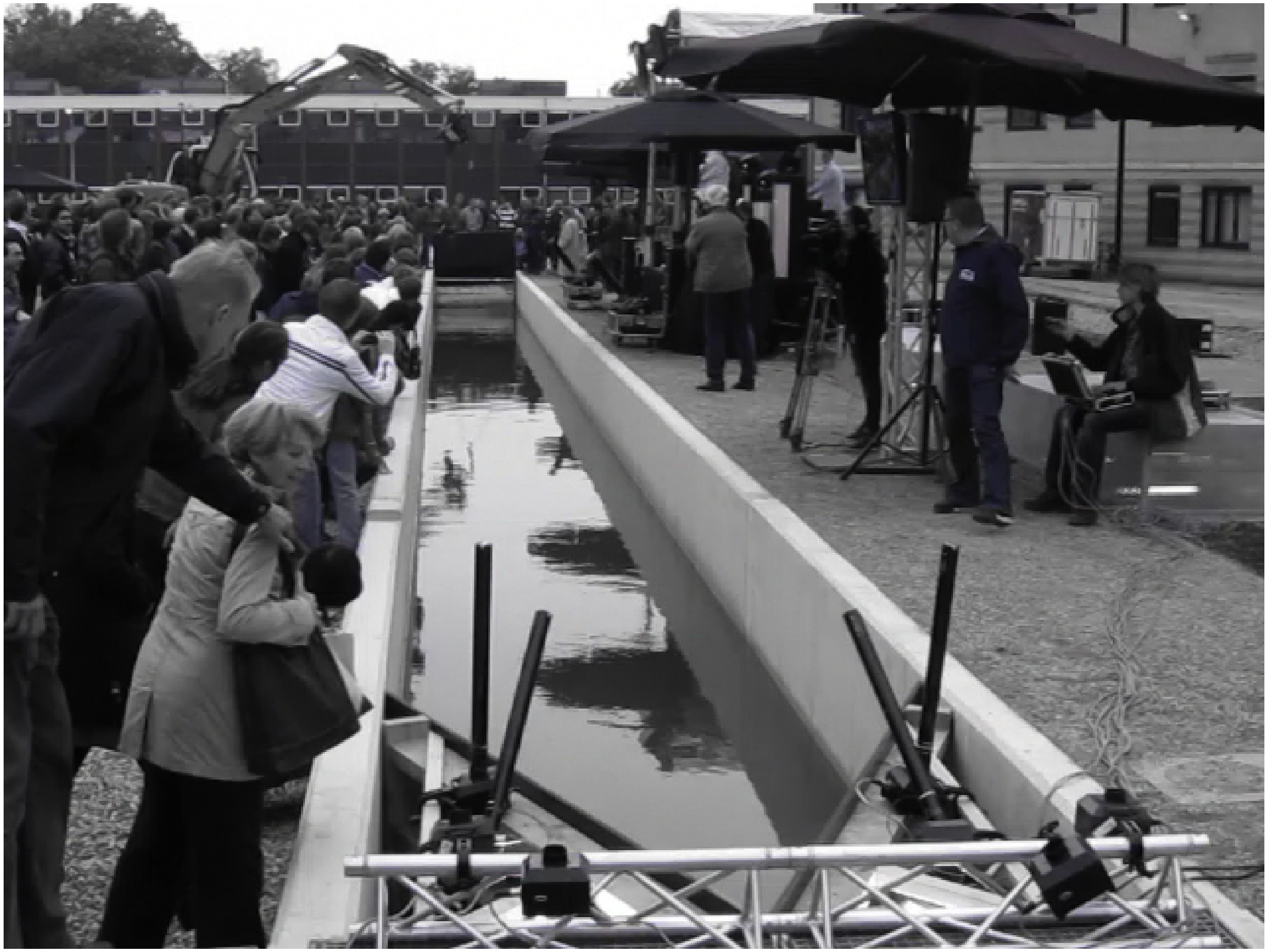
Formation of successive multiple bores riding on the incident tsunami approaching the Fukushima Dai-Ni Nuclear Power Plant.

Fukushima Prefecture Police: March 11 2011

Kido River in Fukushima

The subsequent impact appears larger than the leading impact.

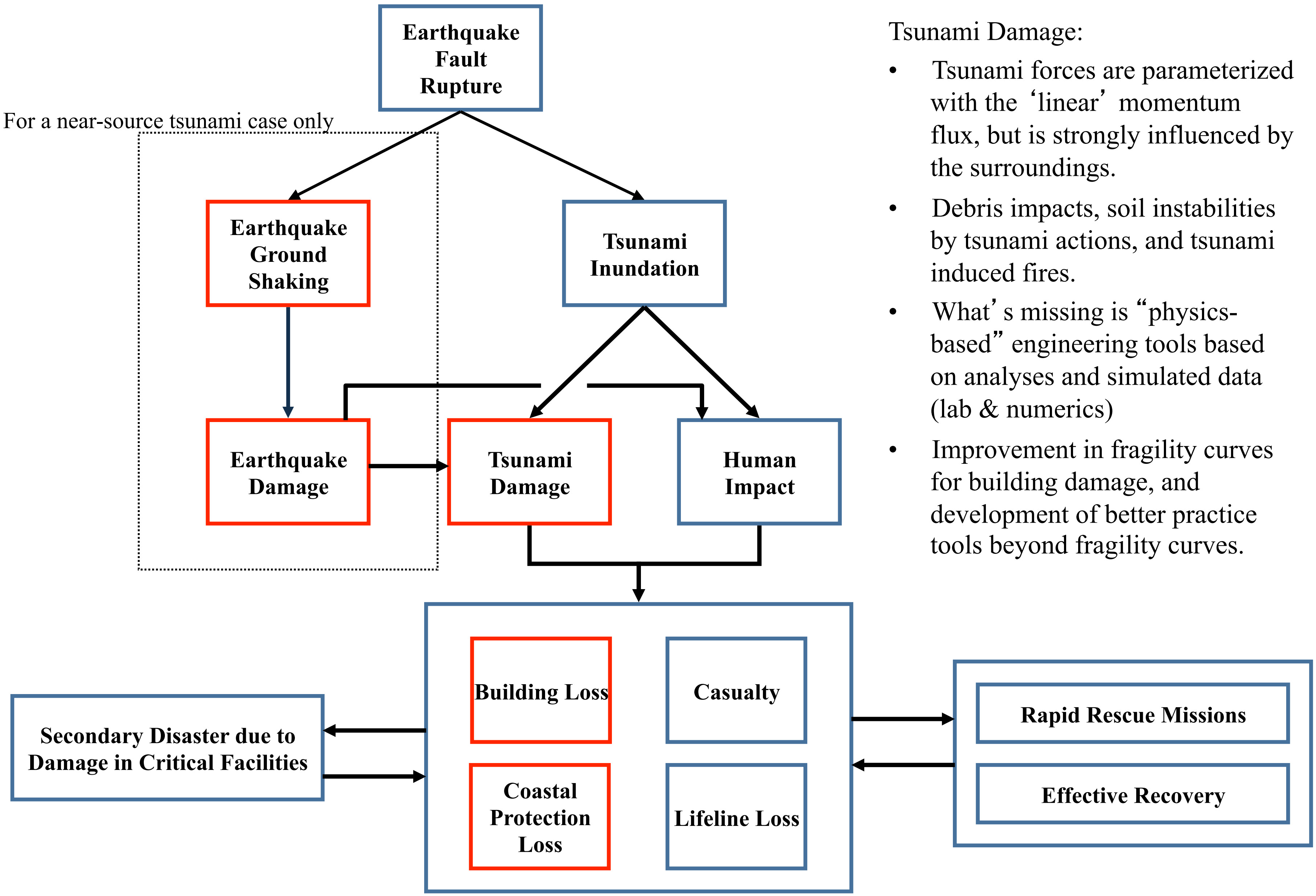
http://www.woutzweers.nl/text%202010/2010%20soliton%20splash.html



Onno Bokhove
Department of Applied Mathematics, University of Twente

Ryouri, Iwate

Standing-Wave Formations. Is it important?



Tsunami Damage:

- Tsunami forces are parameterized with the 'linear' momentum flux, but is strongly influenced by the surroundings.
- Debris impacts, soil instabilities by tsunami actions, and tsunami induced fires.
- What's missing is "physics-based" engineering tools based on analyses and simulated data (lab & numerics)
- Improvement in fragility curves for building damage, and development of better practice tools beyond fragility curves.

The March 2011 East Japan Tsunami: Onagawa

Photo by Satake: March 12, 2011

The March 2011 East Japan Tsunami: Onagawa

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The March 2011 East Japan Tsunami: Onagawa

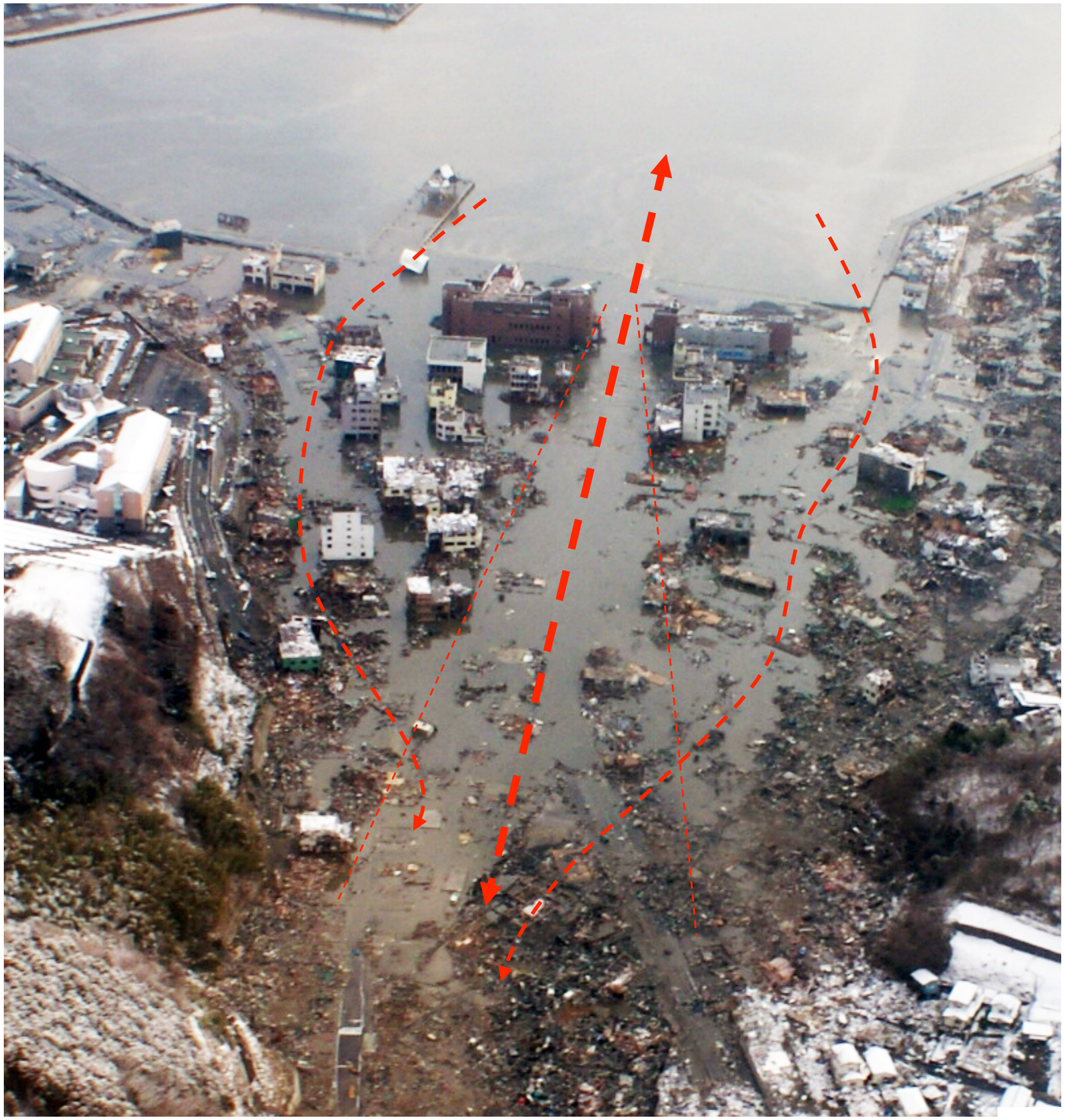


Photo by Satake: March 12, 2011

Idagawa, Fukushima

The destroyed pumping station (photos in February 2012).

Murakami Beach, Fukushima

A large and deep scour hole under the seawall. See the pile foundation.

37˚33.7773N 141˚1.5427E

Wharf Foundation Failure: in Onagawa

Substantial foundation failure of Onagawa quay.

(38˚26.50’ N 141˚26.50’ E)

Wharf Foundation Failure: in Onagawa

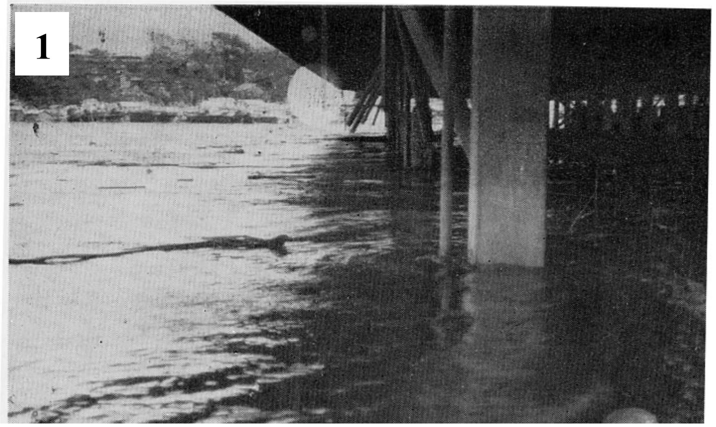
The video footage shows that there was no significant visible damage detected prior to the tsunami attack.

(38˚26.50’ N 141˚26.50’ E)

Quay-wall collapse

Konakano, Japan: the 1960 Chilean Tsunami.

1



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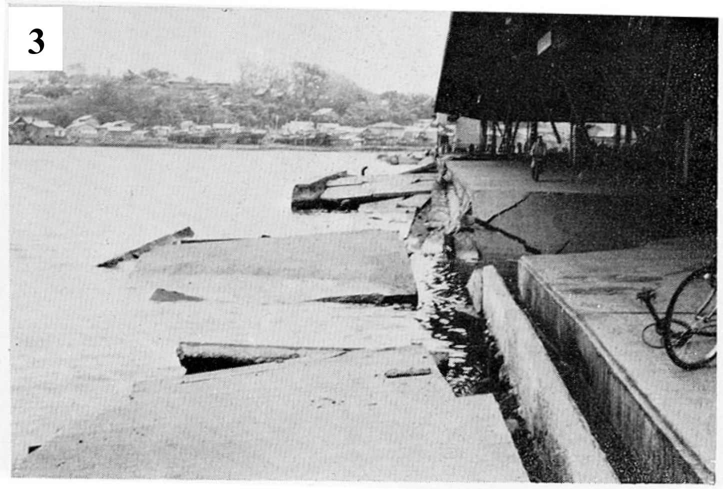

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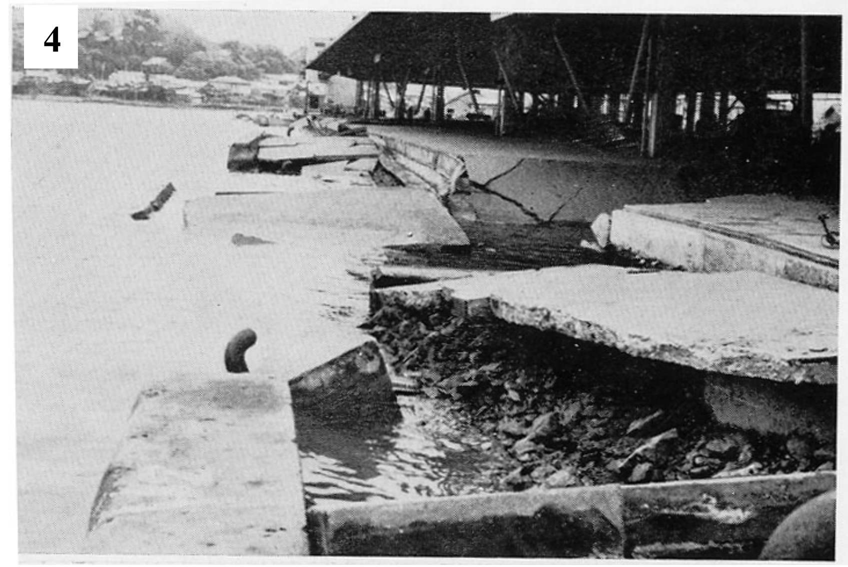
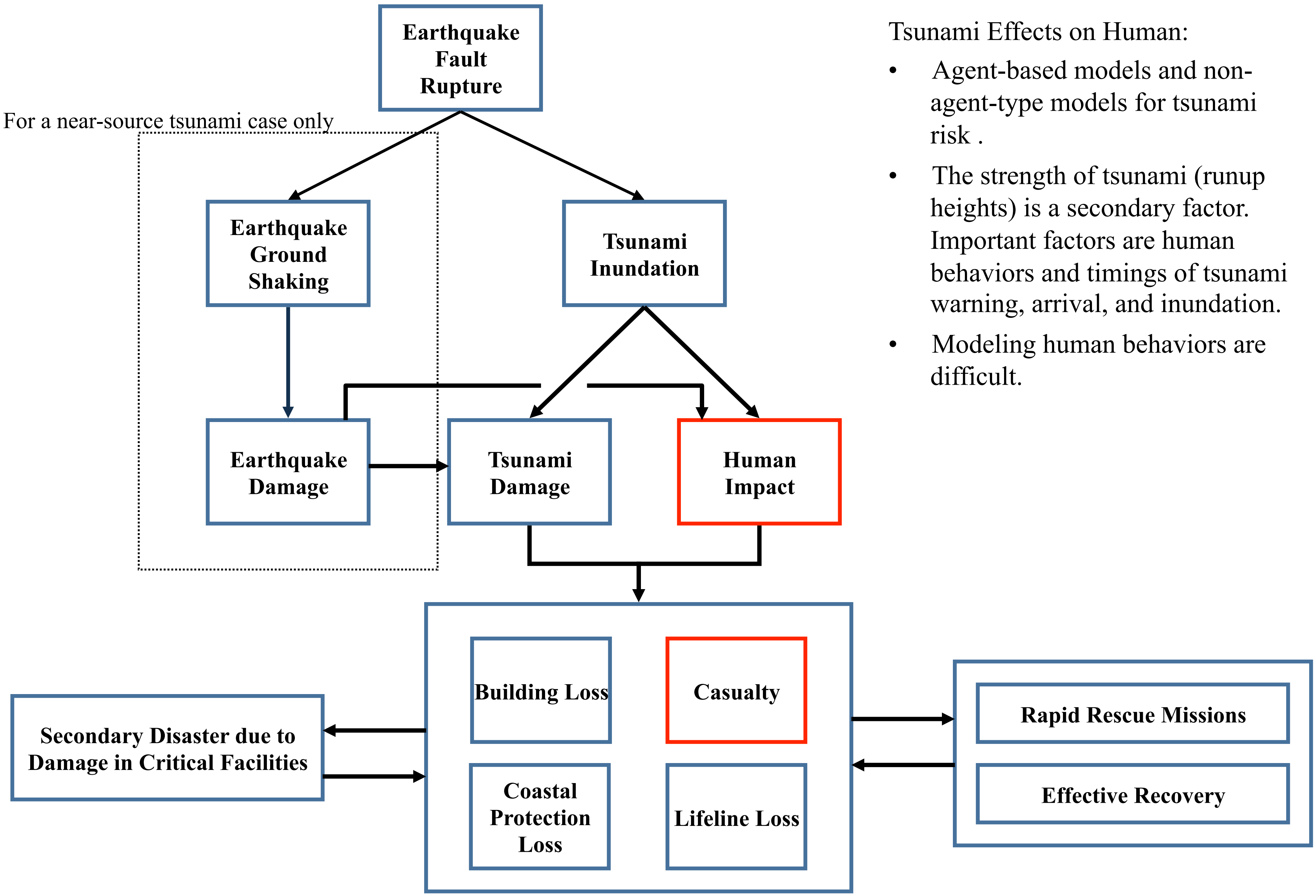


5

The Port of Soma, Fukushima

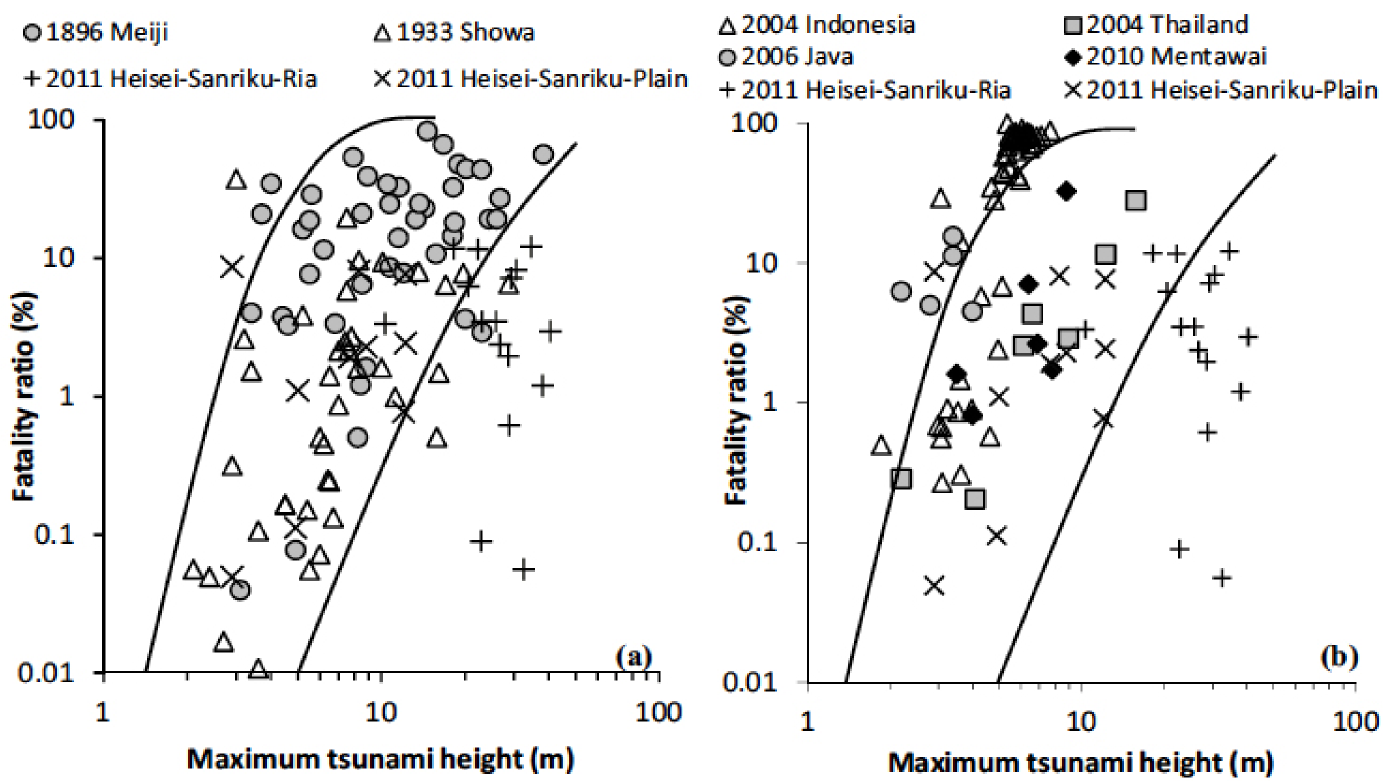


Tsunami Effects on Human:

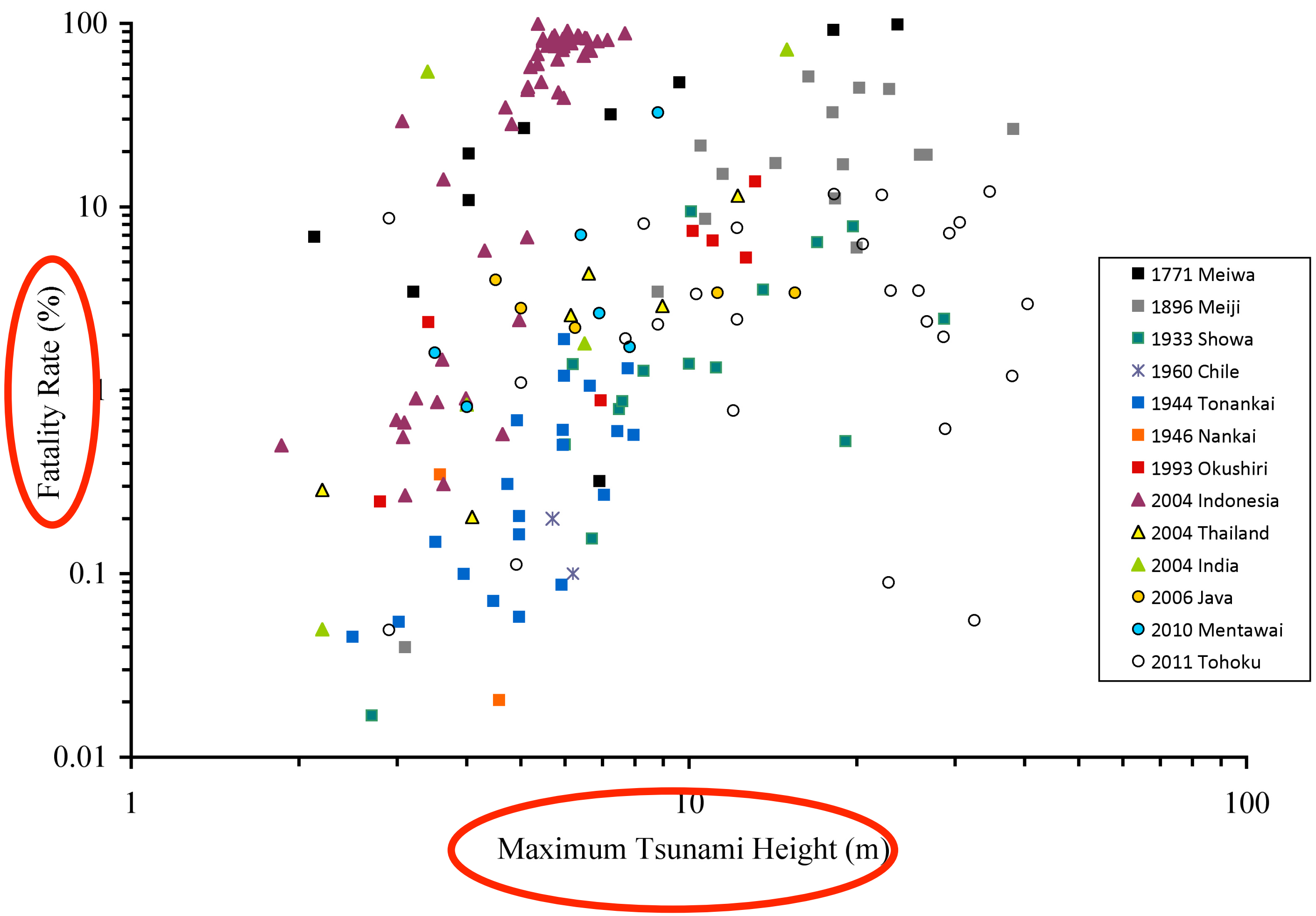
- Agent-based models and non-agent-type models for tsunami risk .
- The strength of tsunami (runup heights) is a secondary factor. Important factors are human behaviors and timings of tsunami warning, arrival, and inundation.
- Modeling human behaviors are difficult.

Indication from the Statistics

- The most comprehensive data available by Suppasri et al. (2011).
- It is evident that tsunami's flow condition is not the controlling factor.
- <u>Only</u> trend that we can detect from the figure is that tsunami fatality rate diminishes when maximum tsunami "height" is less than 1.5 m. The lower envelope curve becomes invalid because of the 2011 Tohoku event.

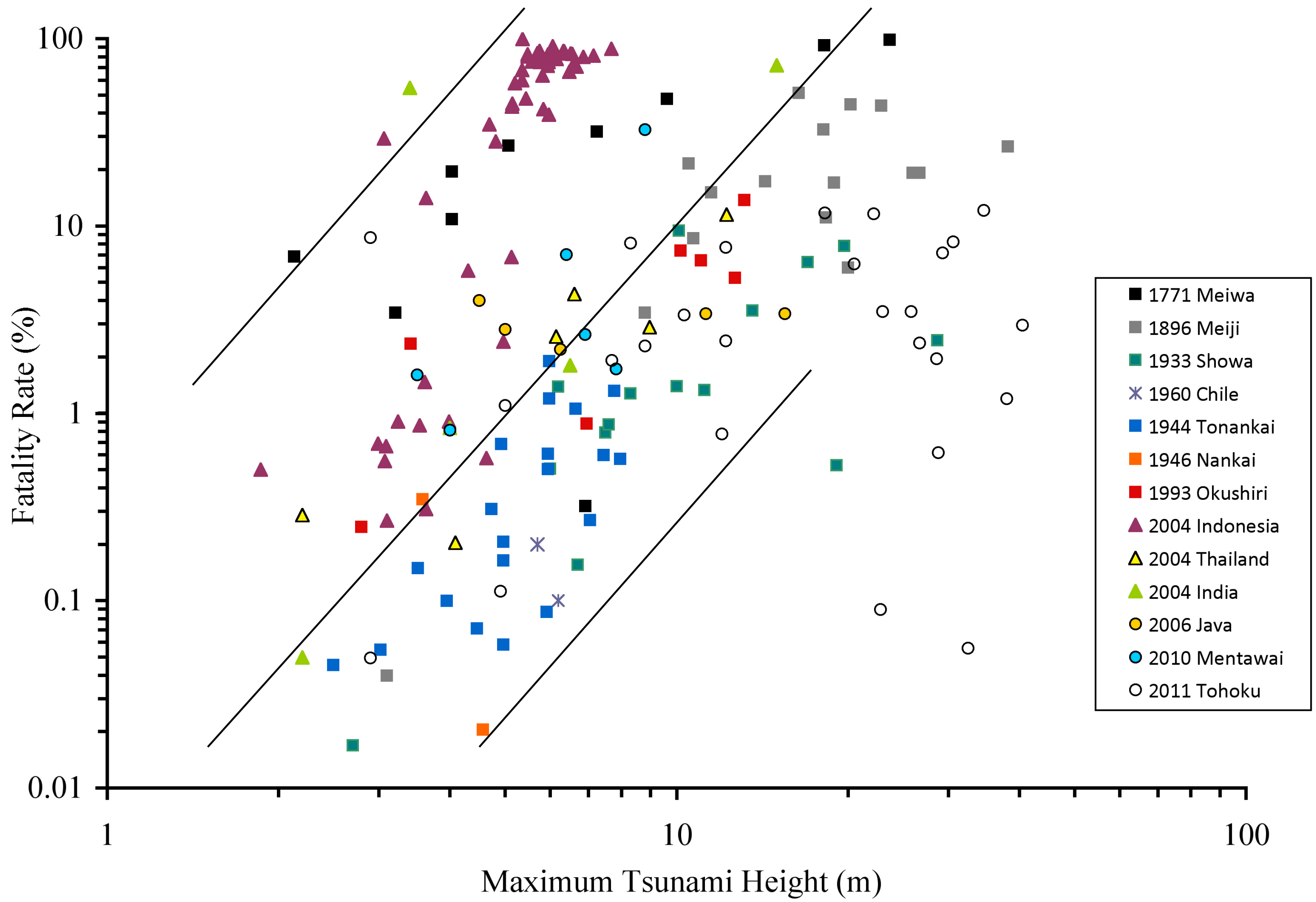


Indication from the Statistics (Suppasri et al. 2011)



Data from Koshimura of Tohoku University

Indication from the Statistics (Suppasri et al. 2011)



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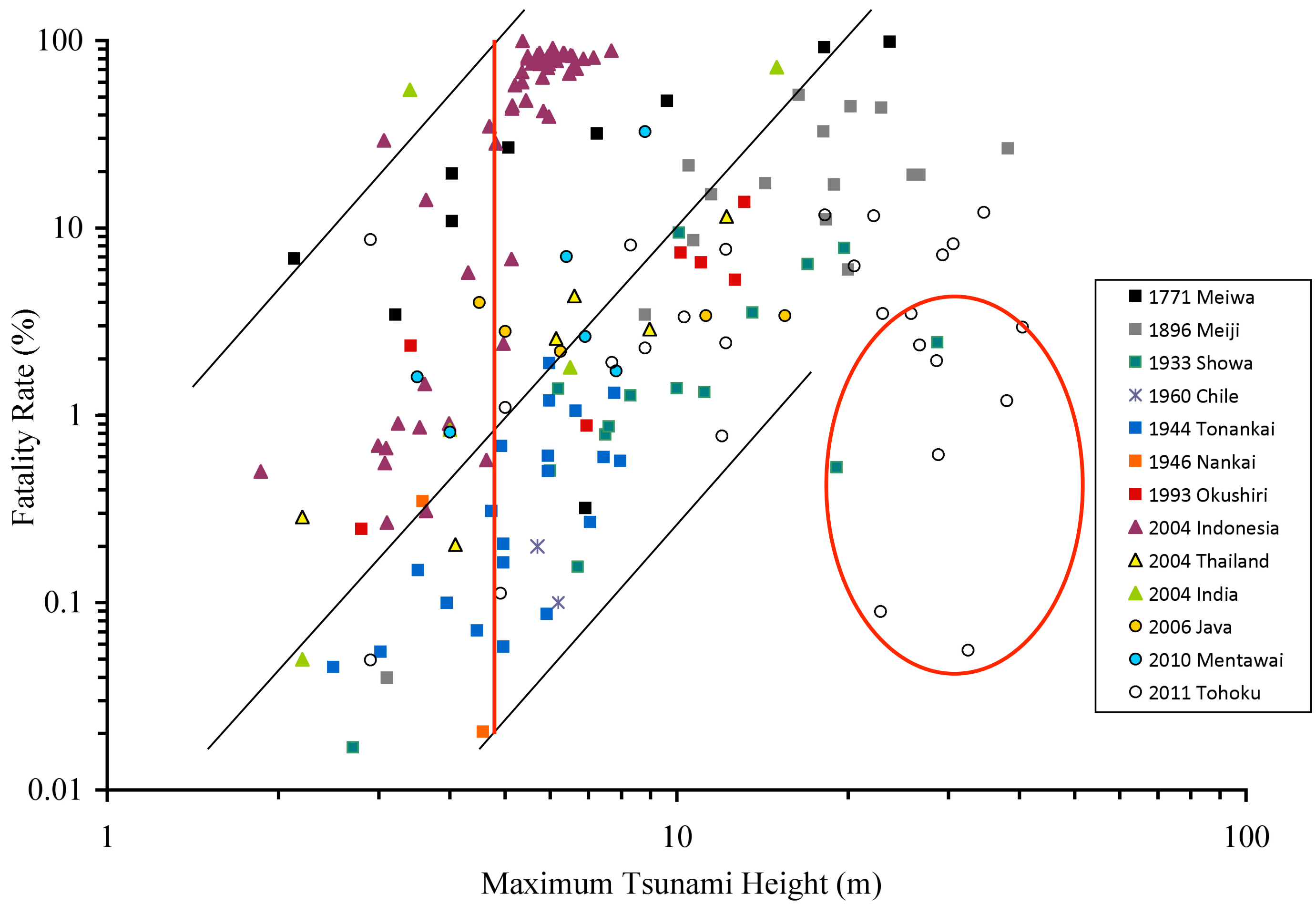

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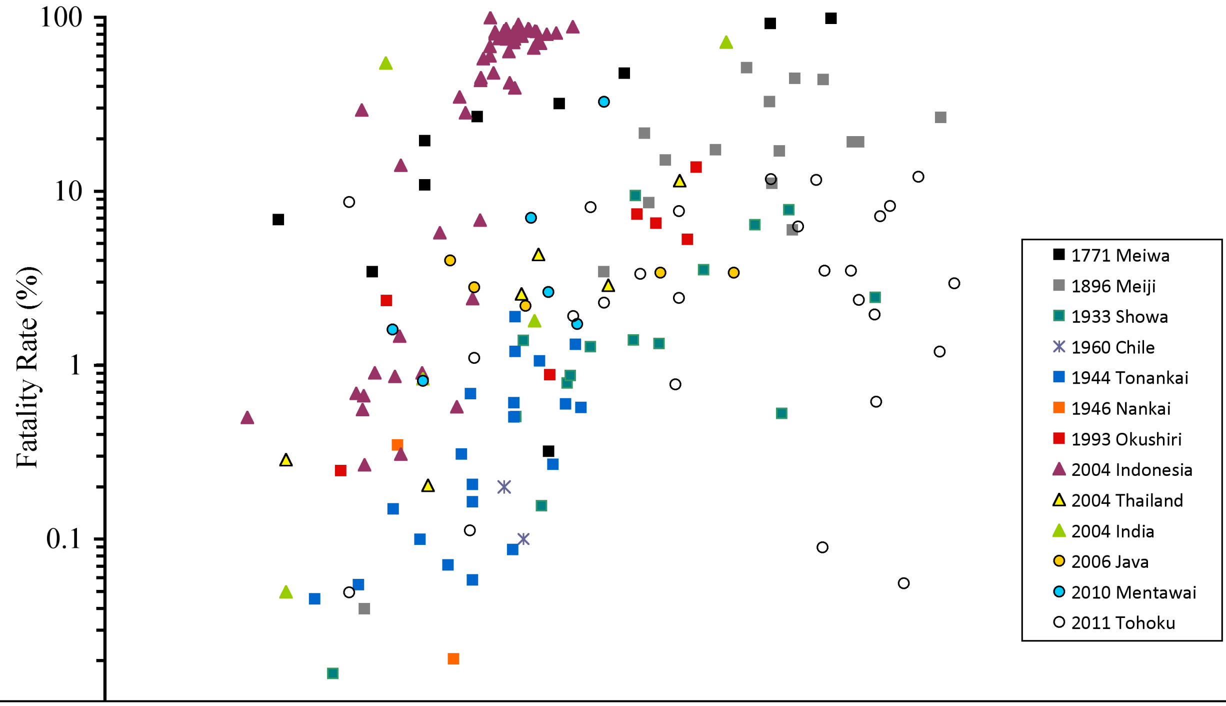
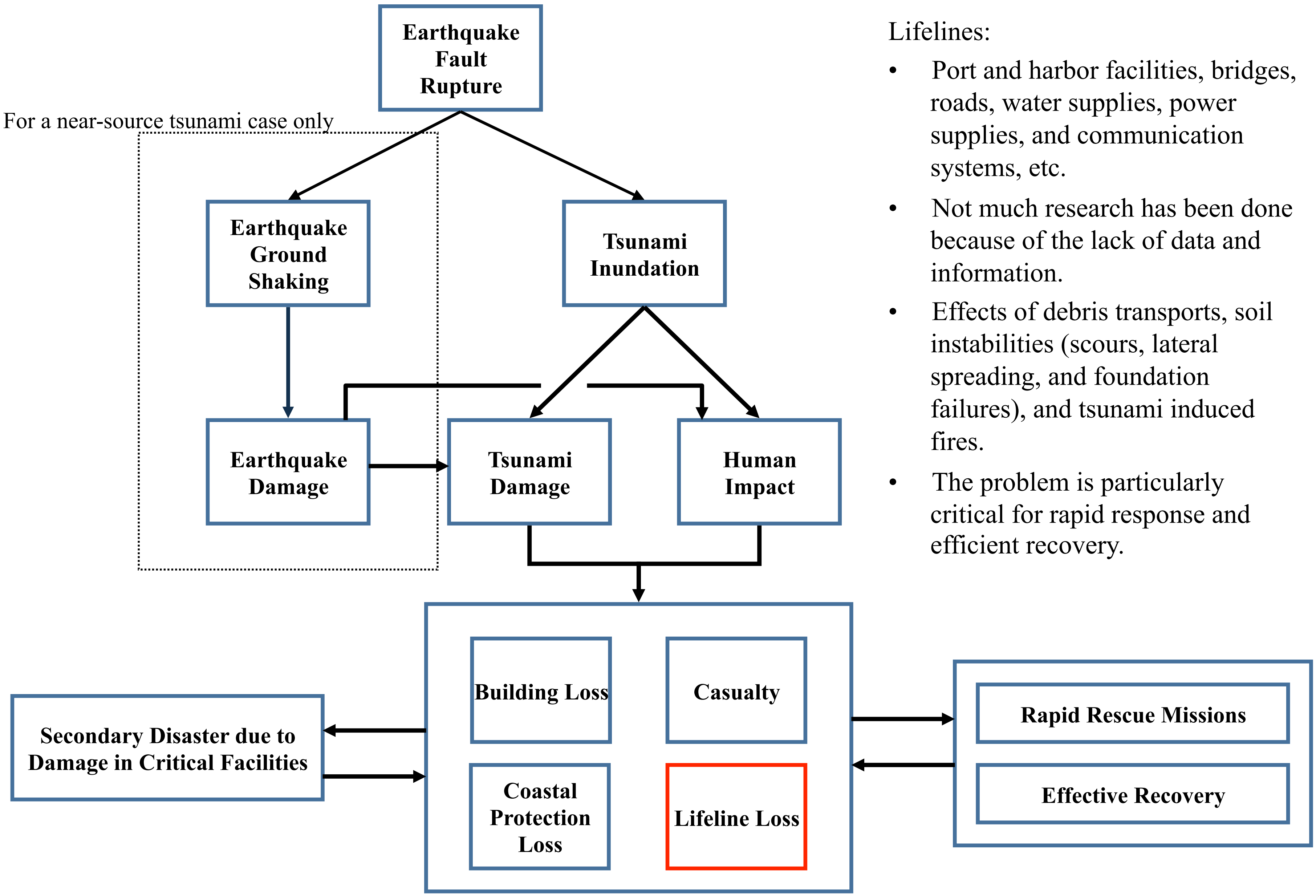
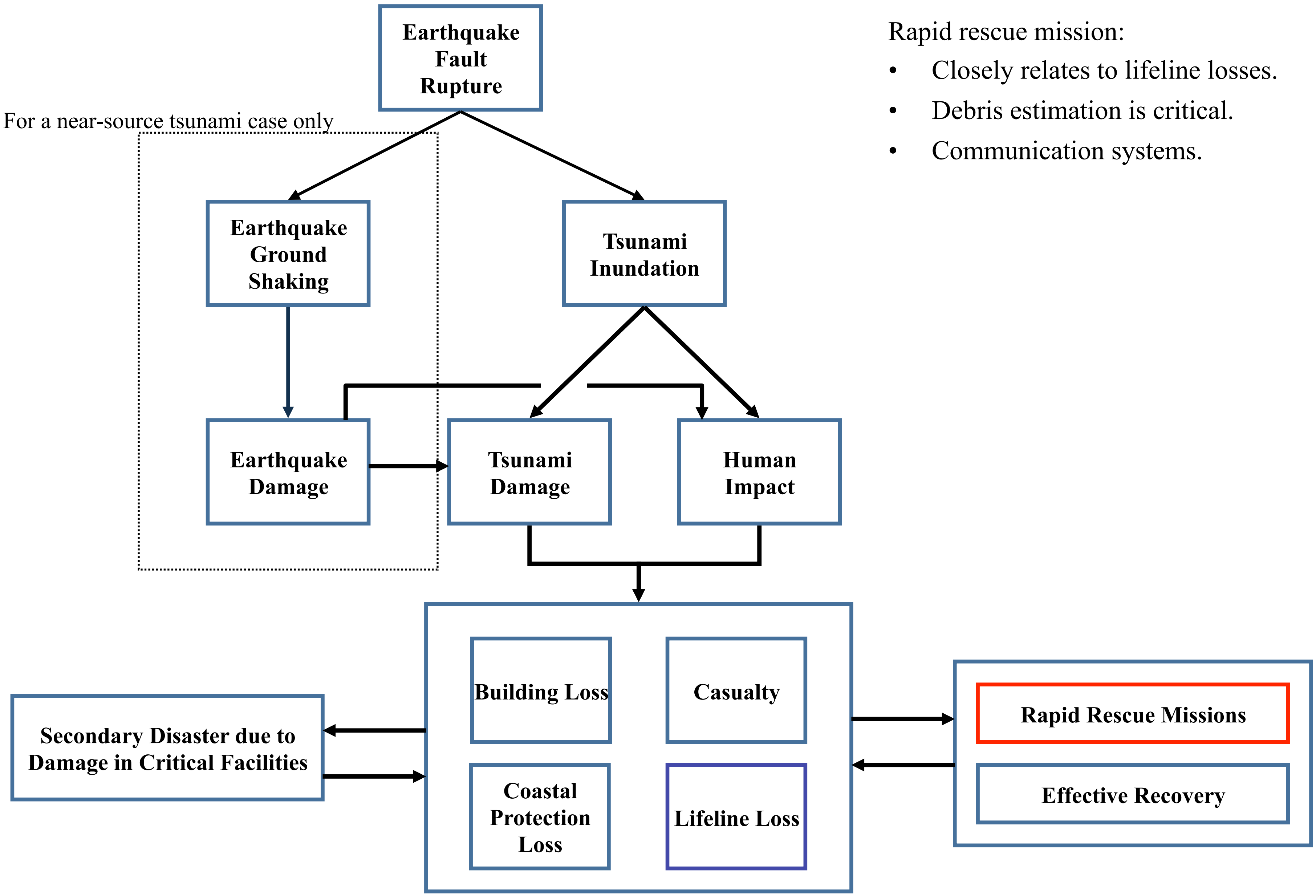


Although there is a weak trend that fatality rate increases with tsunami's runup height, the runup height is not the primary controlling factor. More likely, people's prior knowledge to tsunami hazard (i.e. education), notifications of tsunami warnings and their response made the significant difference



Lifelines:

- Port and harbor facilities, bridges, roads, water supplies, power supplies, and communication systems, etc.
- Not much research has been done because of the lack of data and information.
- Effects of debris transports, soil instabilities (scours, lateral spreading, and foundation failures), and tsunami induced fires.
- The problem is particularly critical for rapid response and efficient recovery.



Rapid rescue mission:

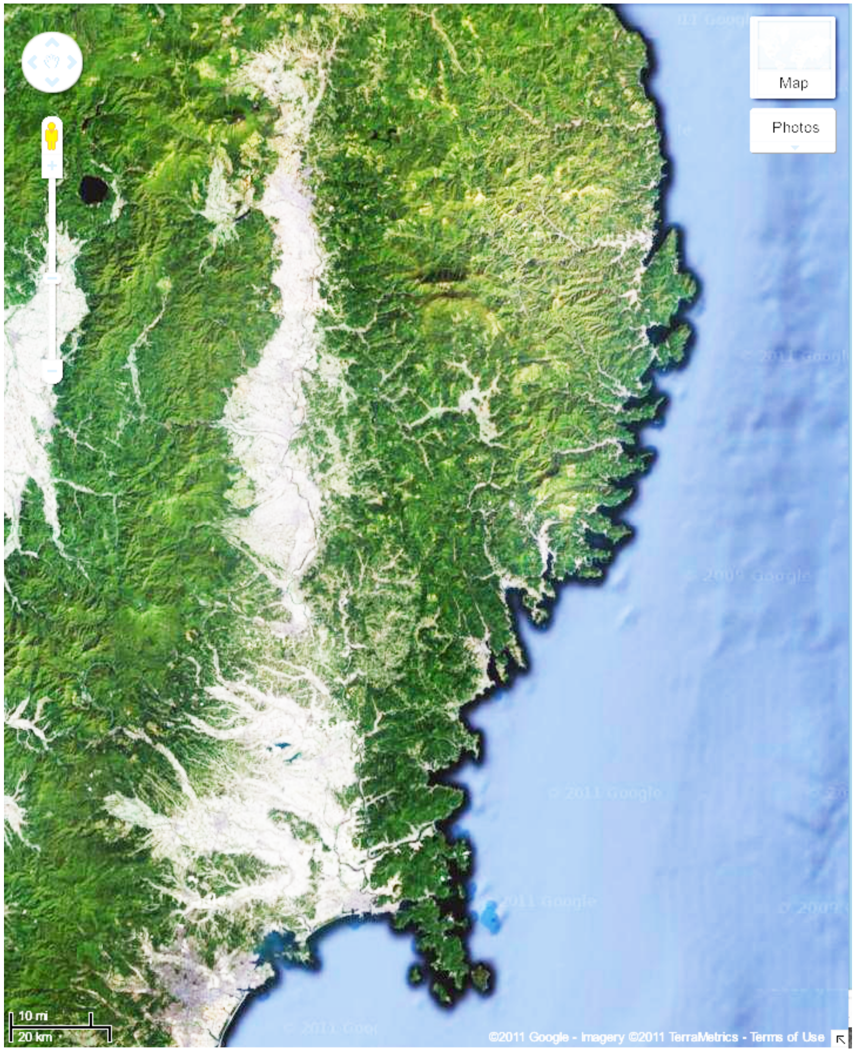
- Closely relates to lifeline losses.
- Debris estimation is critical.
- Communication systems.

Rapid Response and Relief Mission are Critical

The 2011 East Japan Tsunami

No water, no food, and no heat and blankets for more than one week!

- Rugged mountain geography.
- Lack of gasoline for automobiles.
- Lack of communication means.
- Japanese top-down system.

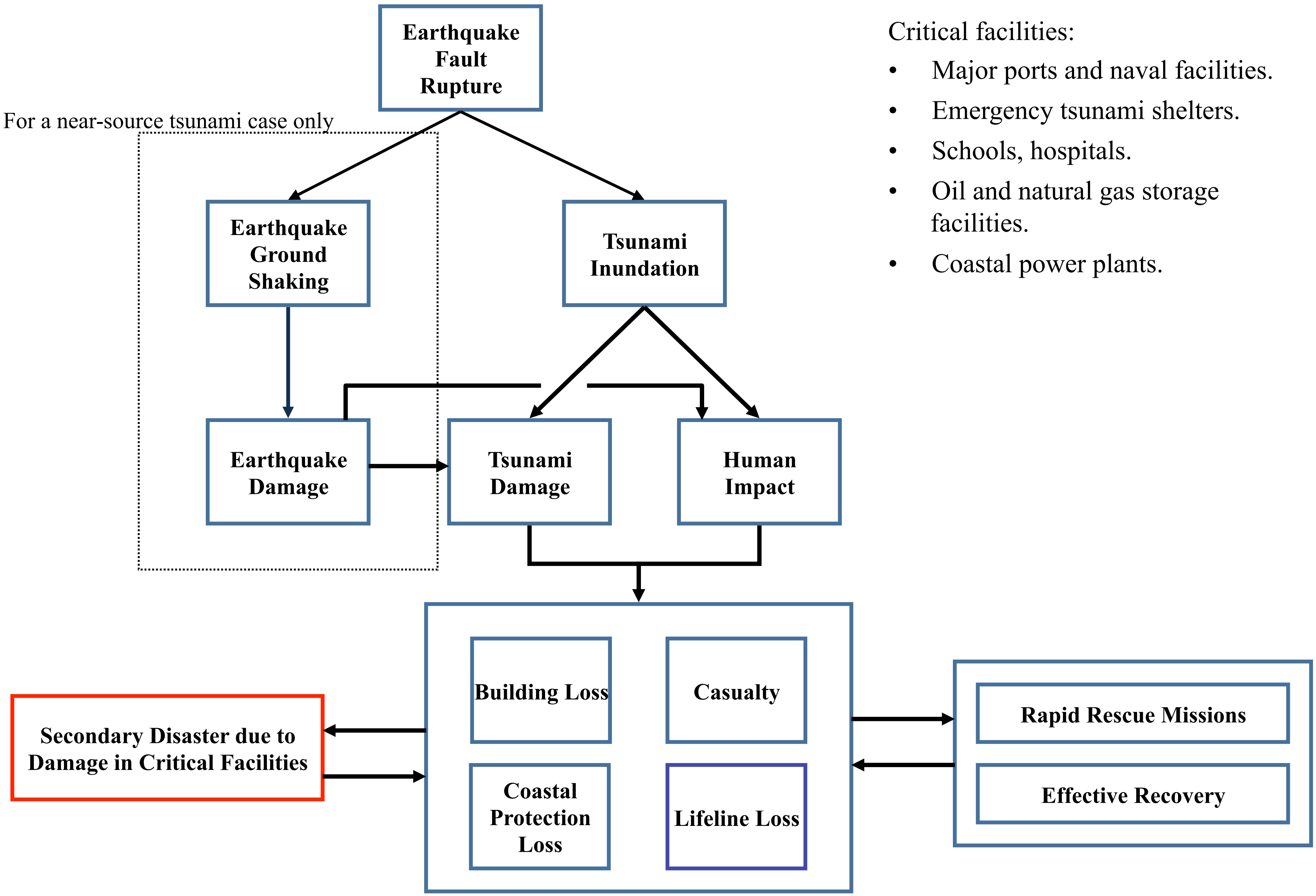


Debris Assessment for Rapid Response and Relief

Debris accumulation near the maximum penetration that can block roads, causing the delay of rapid rescue and relief missions.

Washed-away debris offshore blocking the rapid relief mission from the sea.

Scenes in the morning of March 12, 2011: Photo by Satake


Earthquake Fault Rupture
For a near-source tsunami case only
Earthquake Ground Shaking
Tsunami Inundation
Earthquake Damage
Tsunami Damage
Human Impact
Building Loss
Casualty
Coastal Protection Loss
Lifeline Loss
Secondary Disaster due to Damage in Critical Facilities
Rapid Rescue Missions
Effective Recovery
Critical facilities:
• Major ports and naval facilities.
• Emergency tsunami shelters.
• Schools, hospitals.
• Oil and natural gas storage facilities.
• Coastal power plants.

Critical Coastal Infrastructures and Facilities

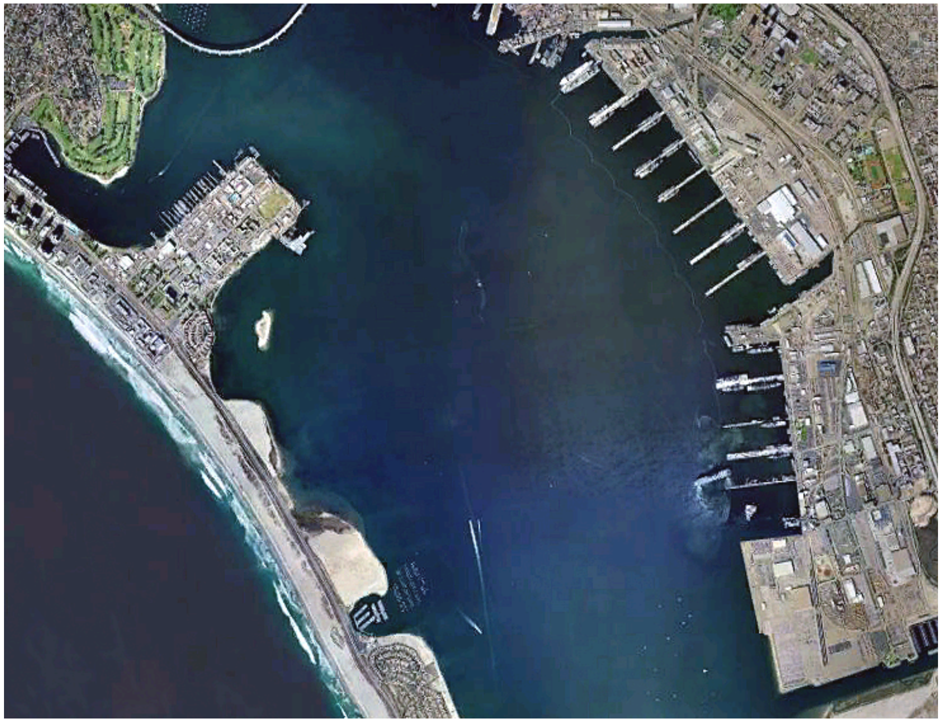
Coastal Power Plants are Critical Facilities

Diablo Canyon

San Onofre

Critical Coastal Infrastructures and Facilities

US Navy Bases are Critical Facilities

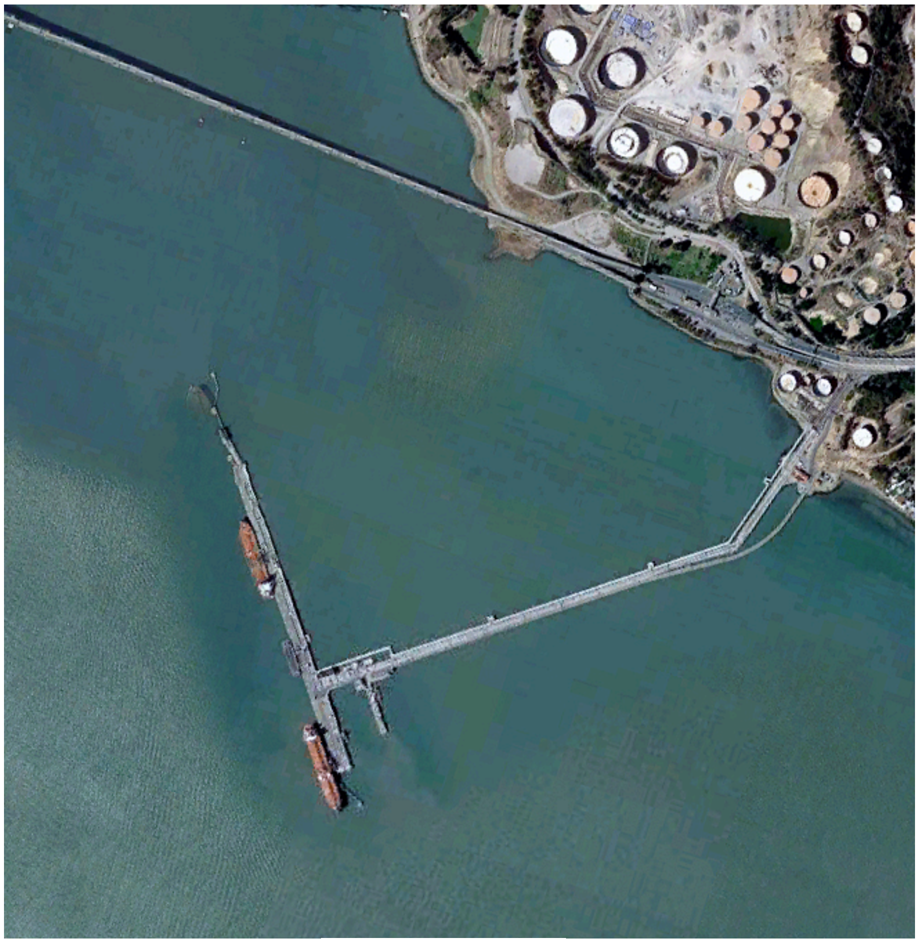


San Diego

Bangor

Critical Coastal Infrastructures and Facilities

Oil and LNG Berth and Storage are Critical Facilities



Point Richmond

Anacortes

Critical Coastal Infrastructures and Facilities

Fires

Scenes of the Japan Tsunami one day after

Kesen-numa

Ishinomaki

Photos by Satake: March 12, 2011

Critical Coastal Infrastructures and Facilities

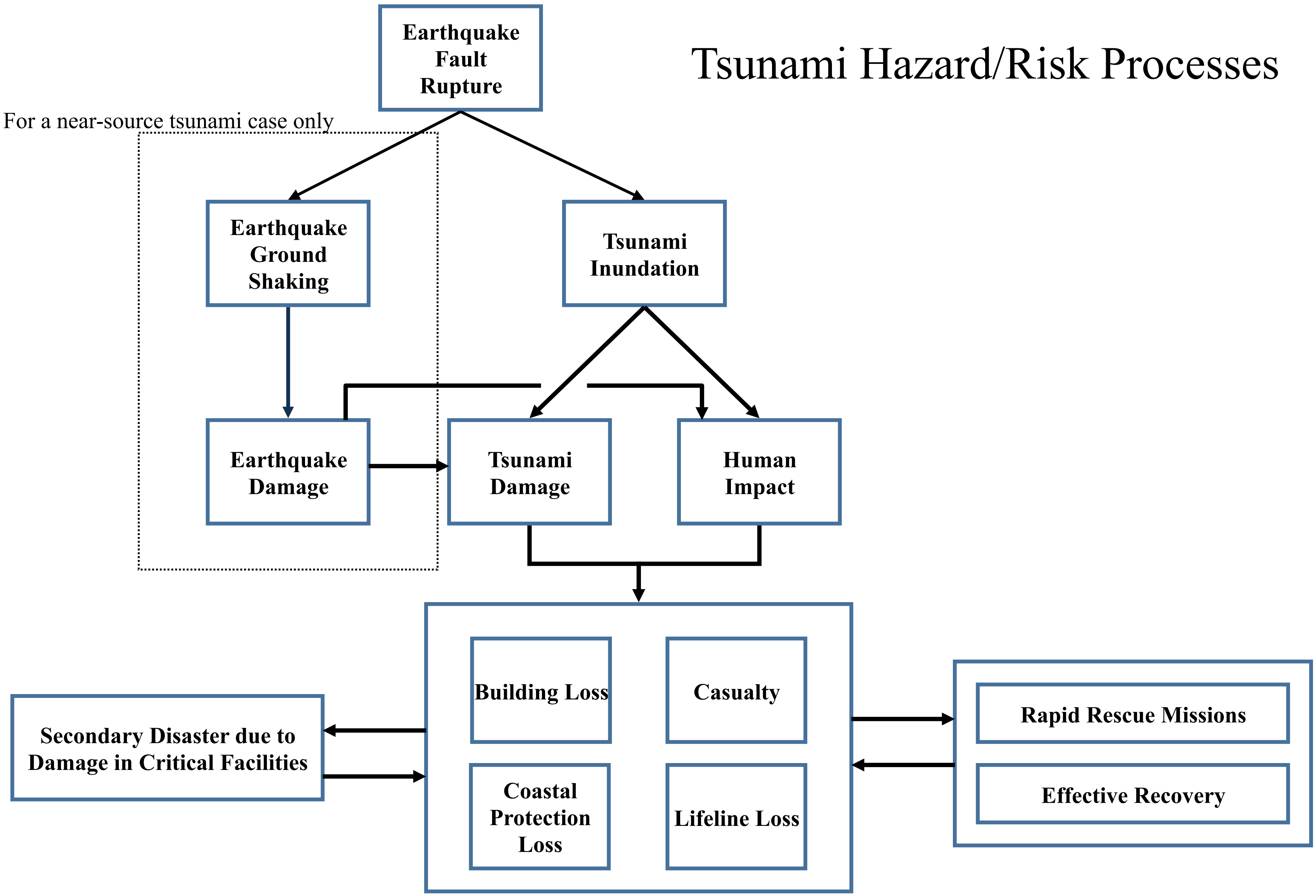
Elementary School in Okushiri, Japan

Immediate after the 1993 Tsunami

Newly constructed tsunami resilient school

Evacuation Platform

Shirahama, Japan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Earthquake Damage
Tsunami Damage
Human Impact
Building Loss
Casualty
Coastal Protection Loss
Lifeline Loss
Secondary Disaster due to Damage in Critical Facilities
Rapid Rescue Missions
Effective Recovery

Meeting Agenda

9:00 – 9:15:	Introduction
9:15 – 9:45:	Presentation of general characteristics and issues on tsunami hazard/risk (Yeh)
9:45 – 10:15:	Discussion on hydrodynamics: inundation and nearshore currents (Lynett)
10:15 – 10:30:	Coffee
10:30 – 11:00:	Discussion on structural response: buildings, bridges, other lifelines (Deierlein)
11:00 – 11:30:	Discussion on geotechnical response: quays, platforms, seawalls, breakwaters, jetties (Ashford)
11:30 – 12:00:	Discussion on human response, evacuation, casualty, and rapid rescue and recovery missions (Javanbarg)
12:00 – 12:30:	Debris and sediment transports and deposits (Petroff)
12:30 – 2:00:	Lunch
2:00 – 3:00:	Consensus seeking discussion.

NSF NEES

Generation:

- NEESR-SG: 3D Tsunami Evolution Using a Landslide Tsunami Generator – Fritz (Georgia Tech.), 2004
- Utilizing NEES Facilities: Landslide Generated Tsunamis and Runup – Liu (Cornell), 2004
- NEESR-CR: Tsunami Generation by Landslides – Fritz (Georgia Tech.), 2009

Propagation/Runup:

- NEESR-SG: TSUNAMOS: A Validated, Multi-Scale Tsunami Model – Lynett (Texas A&M), 2006
- EAGER: Developing and Testing Algorithms for Generating Leading Tsunami Waves – Liu (Cornell). 2009
- NEESR Payload: Dissipation by Macro-Roughness Representing Forested Areas – Irish (Texas A&M), 2009.
- NEESR Payload: Tsunamis by Interaction with Ocean Swell and Wind Waves – Kaihatsu (Texas A&M), 2009.
- NEESR-SD: Runup and Bed Shear Stress – Liu (Cornell), 2010.
- NEESR: Interaction of Tsunamis with Short Waves and Bottom Sediment -- Numerical and Physical Modeling -- Kaihatsu (Texas EES), 2012
- NEESR: Tsunami Run-up and Withdrawal Dynamics on a Sloping Beach with Discontinuous Macro-Roughness – Irish (Virginia Tech), 2012.

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Interaction:

- Collaborative Research on Tsunami-Structure Interactions Using NEES Tsunami Basin Facilities – Liu (Cornell), 2002
- NEESR-SG: Development of Performance Based Tsunami Engineering, PBTE – Riggs (Hawaii). 2005.
- SGER NEESR: Wave Loading on Residential Structures with Earthquake and Hurricane Applications – van de Lindt (Colorado). 2007.
- NEESR II: Mitigating the Risk through understanding Tsunami-Structure Interaction – Cox (Oregon State), 2008.
- NEESR-CR: Impact Forces from Tsunami-Driven Debris – Riggs (Hawaii), 2010.
- NEESR: Tsunami Induced Coherent Structures and their Impact on our Coastal Infrastructure – Foster (U. New Hampshire), 2012.

FEMA

- Seaside, Oregon Tsunami Pilot Study – Modernization of FEMA Flood Hazard Maps (2006) Joint study with NOAA and USGS.
- FEMA p646: Guidelines for Design of Structures for Vertical Evacuation from Tsunamis. (2008)
- Development of Tsunami Methodology to be included in the HAZUS Application. (in progress)

NOAA

- Tsunami measurements by DART Buoys.
- Forecast Propagation Database and Tsunami Inundation DEM.
- Rapid Tsunami Propagation Model: MOST
- Inundation Modeling and the SIFT (Short-Term Inundation Forecasting for Tsunamis) System

USGS

- Tsunami Source Estimates
- Paleo-Tsunamis: Tsunami Sediment Deposits.

NTHMP

- Executive Office of the President
  - NOAA, FEMA, USGS (no more NSF!)
  - Alaska; California; Hawaii; Oregon; Washington; Puerto Rico; US Virgin Islands; Pacific Territories/Commonwealths; US East Coast States; US Gulf Coast States.
- Evacuation (and Inundation) Maps
- Education, Evacuation Drills
- Tsunami Evacuation Buildings
- Evacuation models
- Comprehensive Tsunami Simulator for Long Beach Peninsula.

Interdisciplinary Research in Hazards and Disasters (Hazards SEES) NSF 12-610

The goal is to catalyze well-integrated interdisciplinary research efforts in hazards related science and engineering.

1. advance understanding of the fundamental processes associated with specific natural hazards and technological hazards linked to natural phenomena, and their interactions;
2. better understand the causes, interdependences, impacts and cumulative effects of these hazards on individuals, the natural and built environment, and society as a whole; and
3. improve capabilities for forecasting or predicting hazards, mitigating their effects, and enhancing the capacity to respond to and recover from resultant disasters.

Hazards SEES seeks research projects that will cross the boundaries of the atmospheric and geospace, earth, and ocean sciences; computer and information science; cyberinfrastructure; engineering; mathematics and statistics; and social, economic, and behavioral sciences.