WAVES 11, KONA HAWAI`I

Modeling of the 2011 Tohoku-oki Tsunami and it's impacts to Hawaii

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Outline

1. NEOWAVE
   - Theoretical and Numerical Formulations
2. Finite-Fault Model and Tsunami Generation
   - Finite Fault Solution
   - Tsunami Generation and Near-field Tsunami Modeling
3. Tsunami Propagation and Impacts on Hawaii
   - Tsunami Propagation across Pacific
   - Tide Gauge Prediction at Honolulu, Oahu
   - Runup and Inundation Modeling at Waikoloa, Big Island
4. Conclusions
5. Future Studies and Developments

NEOWAVE

(Non-hydrostatic Evolution of Ocean WAVE)

Governing Equations

- Depth-integrated, Non-hydrostatic Equation
  - Consideration of Weakly Wave Dispersion through Non-hydrostatic Pressure. (Stelling and Zijlema, 2003; Yamazaki *et al.*, 2009 & 2011)

Numerical Schemes

- Semi-implicit, Finite Difference (FD) Model
  - Explicit Hydrostatic solution
  - Implicit Non-hydrostatic solution
- Momentum Conserved Advection (MCA) Scheme
  - Shock Capturing Scheme for FD Models (Stelling and Duinmeijer, 2003; Yamazaki *et al.*, 2009 & 2011)
- Grid Refinement Scheme
  - Two-way Grid-nesting scheme of Yamazaki *et al.* (2011) ensures propagation of dispersive waves and discontinuities across the inter-grid boundary.

NEOWAVE

Governing Equations

- Depth-integrated, Non-hydrostatic Equations in Cartesian Grid

Continuity equation

$$\frac{\partial(\zeta-\eta)}{\partial t}+\frac{\partial(UD)}{\partial x}+\frac{\partial(VD)}{\partial y}=0$$

x-momentum equation

$$\frac{\partial U}{\partial t}+U\frac{\partial U}{\partial x}+V\frac{\partial U}{\partial y}=-g\frac{\partial \zeta}{\partial x}-\underline{\frac{1}{2}\frac{\partial q}{\partial x}}-\underline{\frac{1}{2}\frac{q}{D}\frac{\partial}{\partial x}(\zeta-h+\eta)}-f\frac{U\sqrt{U^2+V^2}}{D}$$

y-momentum equation

$$\frac{\partial V}{\partial t}+U\frac{\partial V}{\partial x}+V\frac{\partial V}{\partial y}=-g\frac{\partial \zeta}{\partial y}-\underline{\frac{1}{2}\frac{\partial q}{\partial y}}-\underline{\frac{1}{2}\frac{q}{D}\frac{\partial}{\partial y}(\zeta-h+\eta)}-f\frac{V\sqrt{U^2+V^2}}{D}$$

z-momentum equation

$$\underline{\frac{\partial W}{\partial t}=\frac{q}{D}}$$

The 2011 Tohoku-oki Earthquake

- Finite Fault Model

Mw = 9.0
05:46:18, March 11, 2011 (UTC)
14:46:18, March 11, 2011 (Local time)

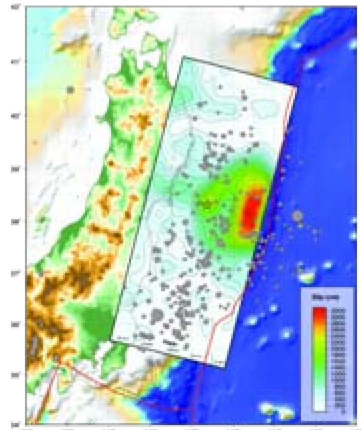
Zhao *et al*. (2011)
epicenter : 38.107° N, 142.916° E
depth : 14.5 km

JMA
epicenter : 38.103° N, 142.861° E
depth : 24.0 km

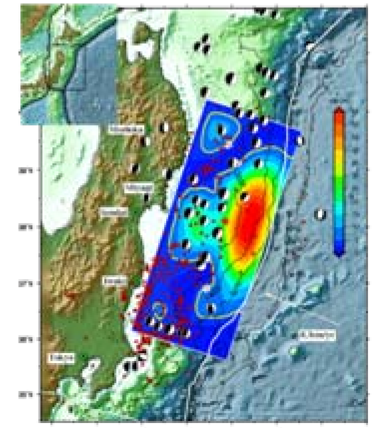
USGS
epicenter : 38.297° N, 142.372° E
depth : 30.0 km

Strike angle: 190º < ϕ < 202º
Dip angle: 10º < δ < 12º

USGS: ϕ=194.4º, δ=10º
625km x 260km

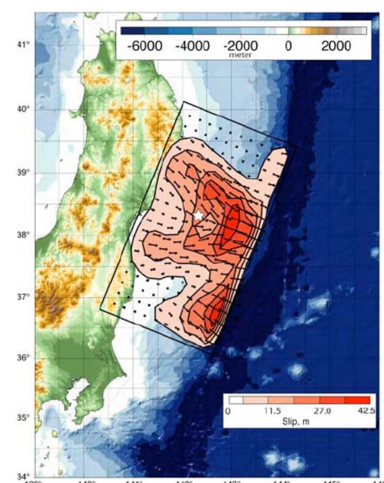


UCSB: ϕ=198º, δ=10º
475km x 200km

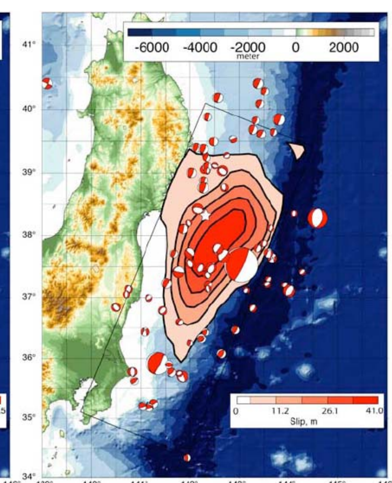


Lay et al. (2011): ϕ=202º, δ=12º

Lay model (P-MOD1)
380km x 200km



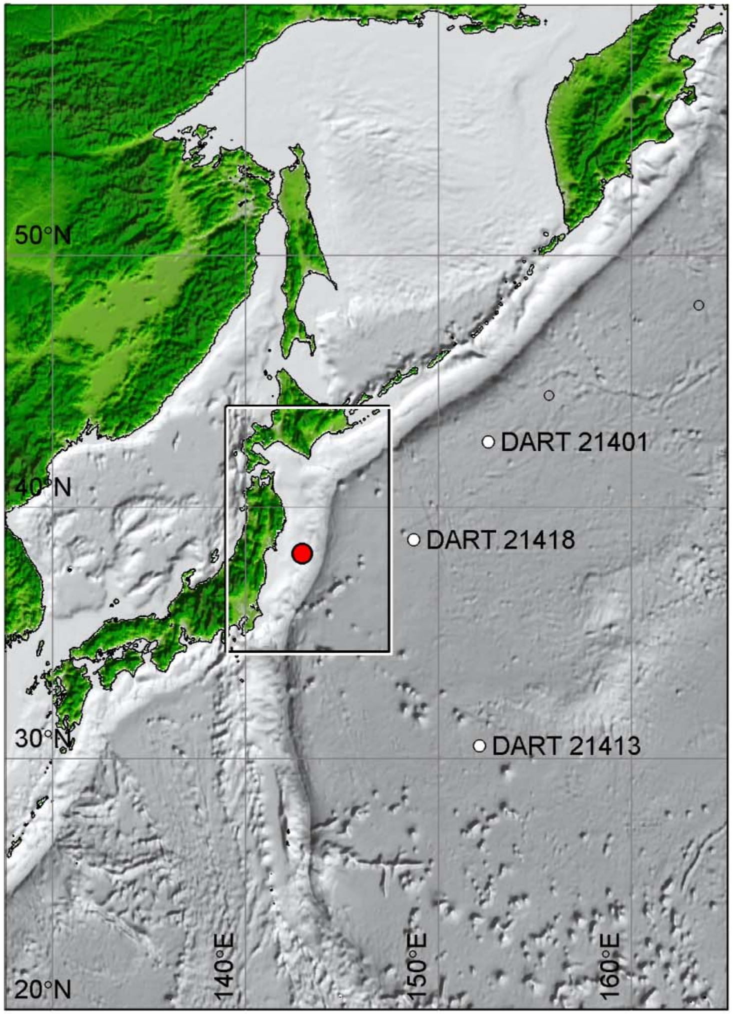
Ammon model (J-MOD)
600km x 210km



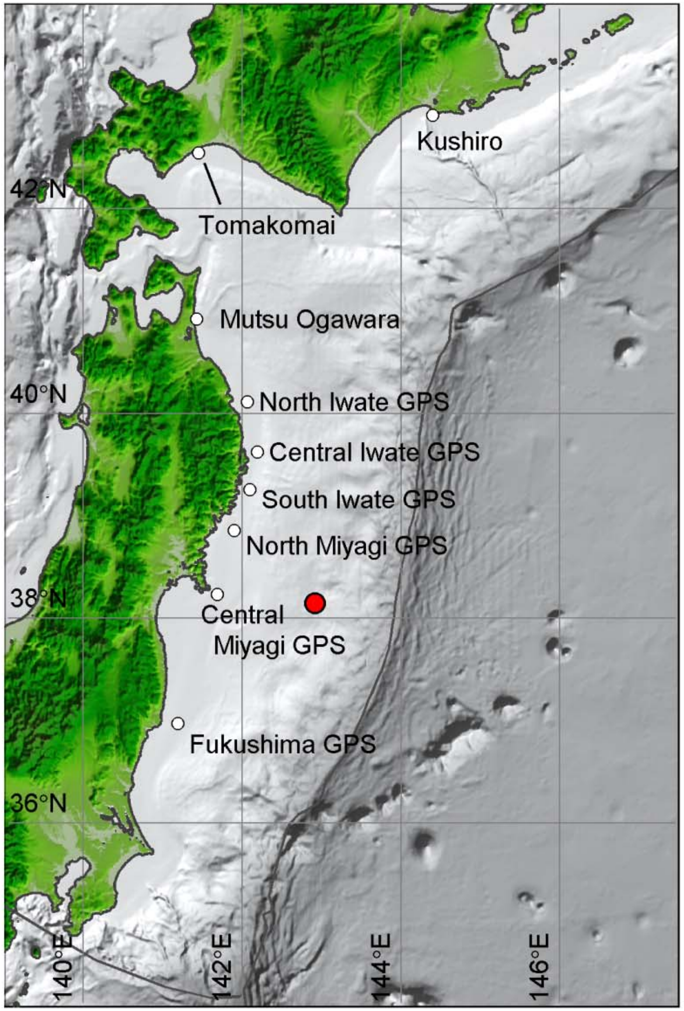
Tsunami Generation and Near-field Impact

- Model Setup: Two Levels of Nested Grids

Level-1 Grid
2 arcmin (~3700m) Northwest Pacific



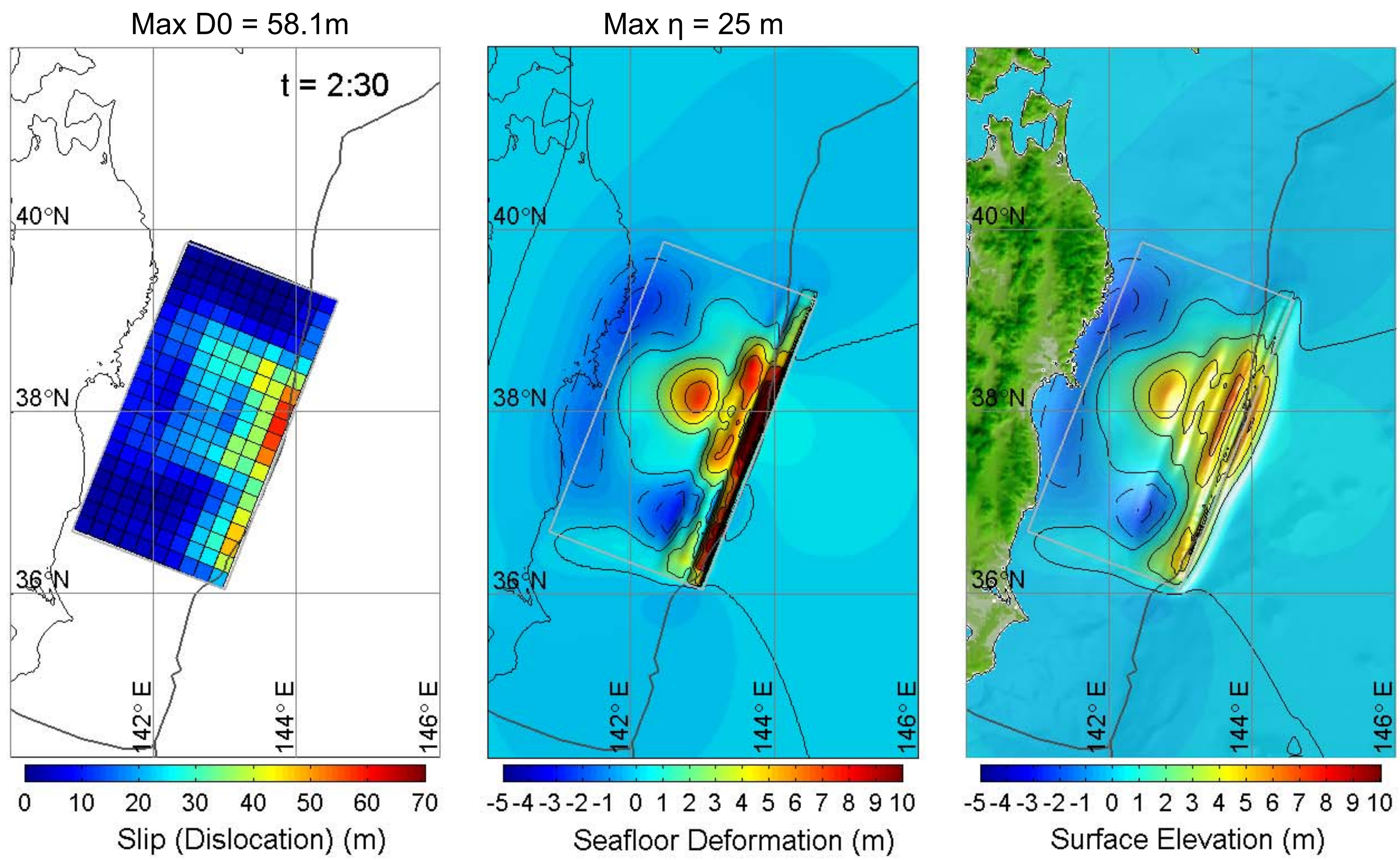
Level-2 Grid
24 arcsec (~600m) East Japan



Tsunami Generation and Near-field Impact

- Tsunami Generation with Finite Fault Solution

Rupture Duration: 148 sec (~2.5min)

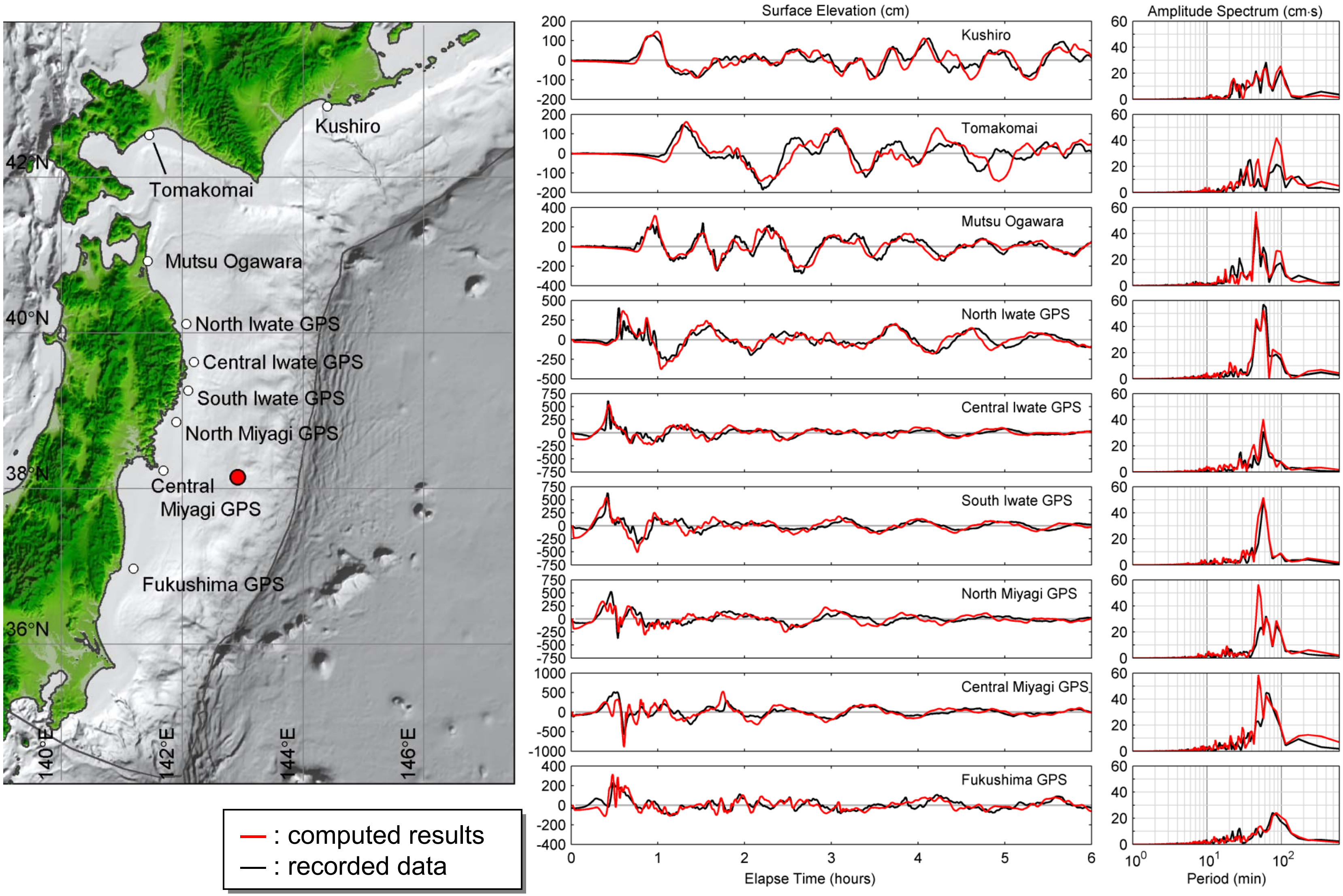


QuickTime™ and a
H.264 decompressor
are needed to see this picture.

Tsunami Generation and Near-field Impact

- GPS Buoys and Wave Gauge Comparisons

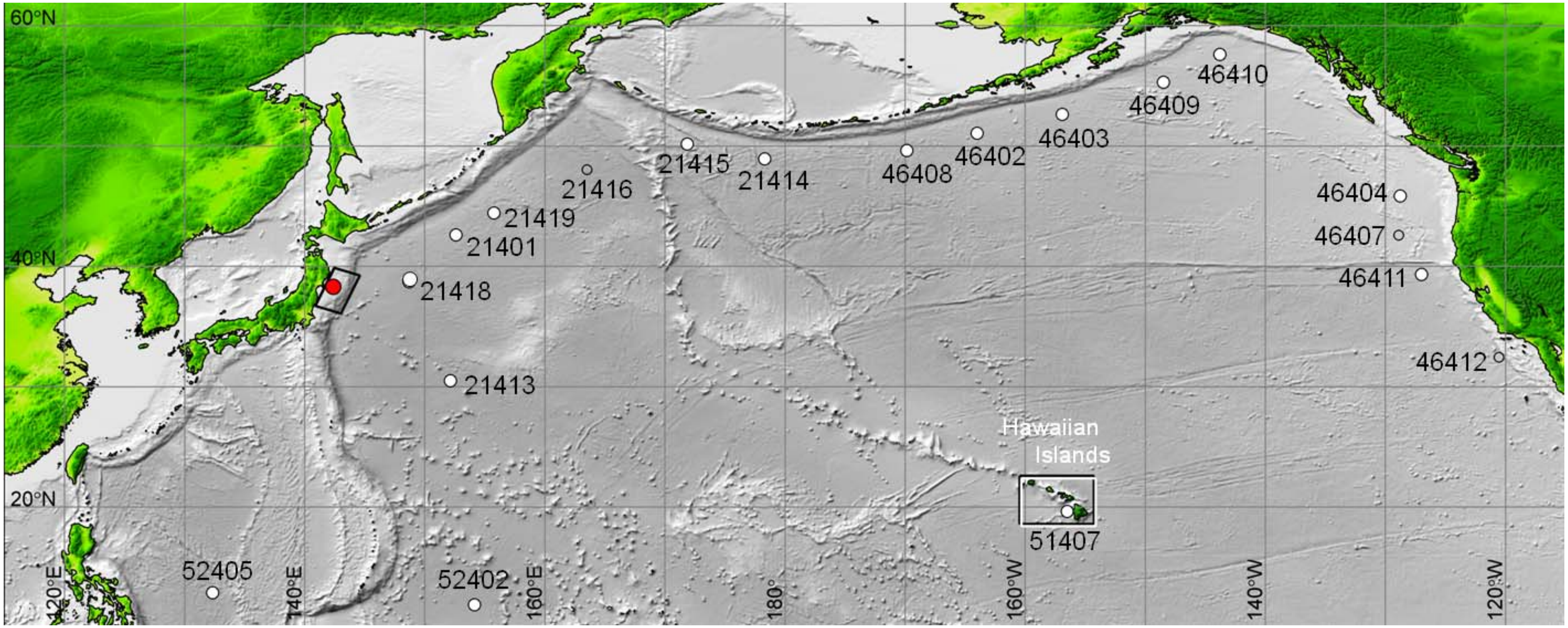
Time-series and Spectra of Surface Elevations



Distant Tsunami Evolution

- Tsunami Impact over North Pacific

DART Buoys Locations in North Pacific



Distant Tsunami Evolution

- Tsunami Impact over North Pacific

DART Buoys Locations in North Pacific

QuickTime™ and a
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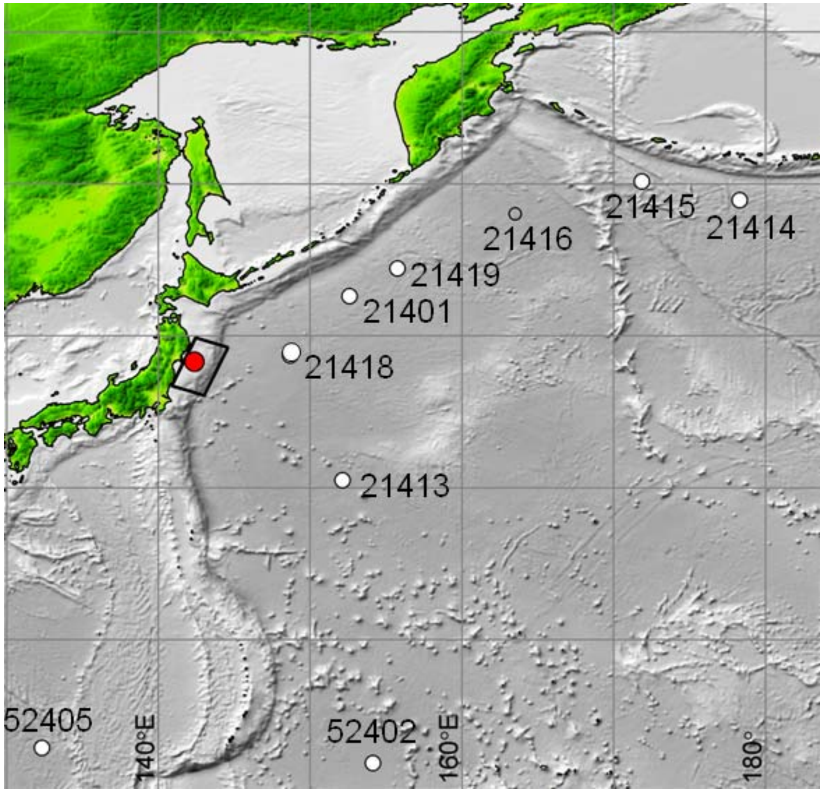
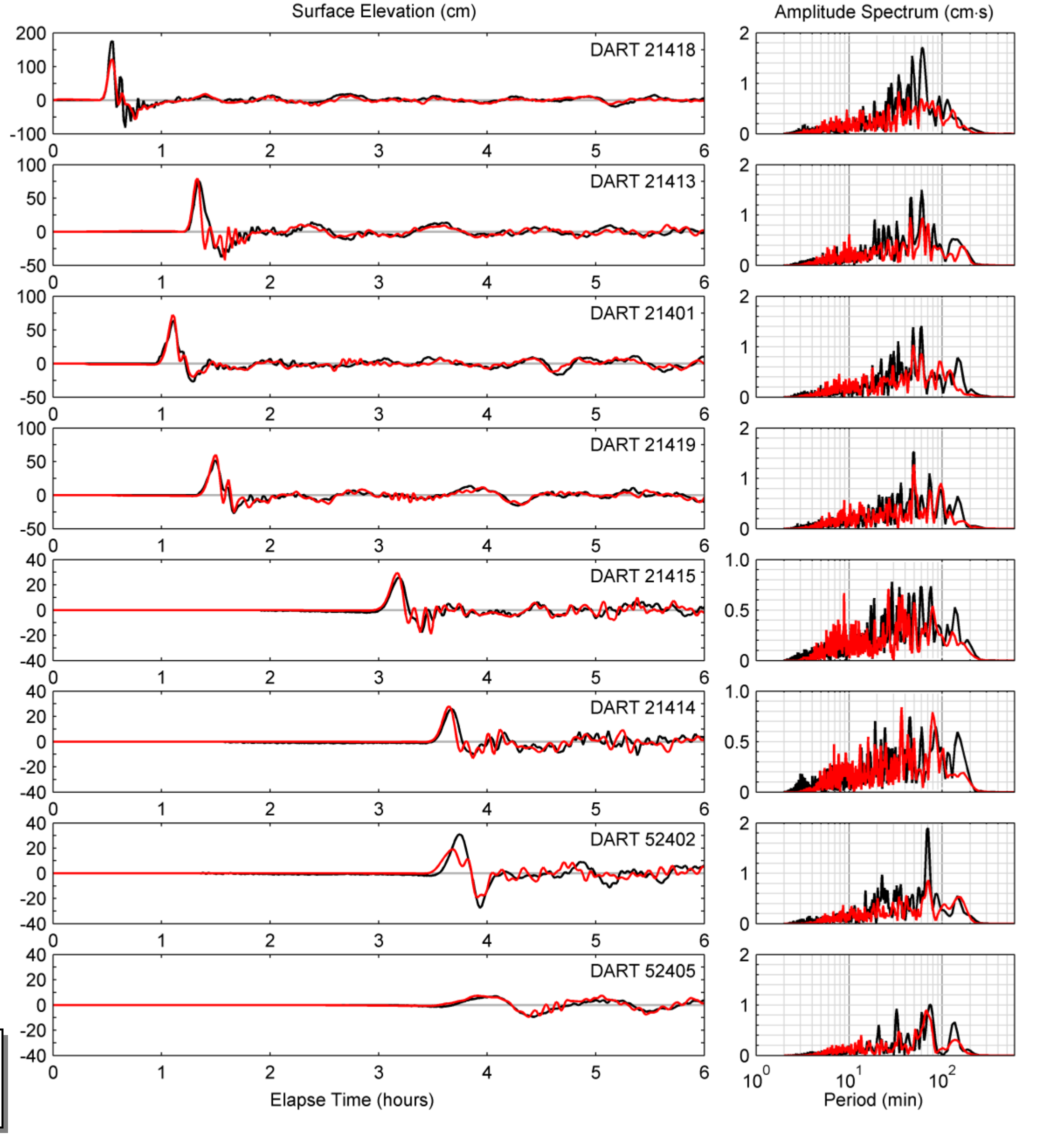
Distant Tsunami Evolution

- DART Buoy Comparisons (Northwest Pacific)



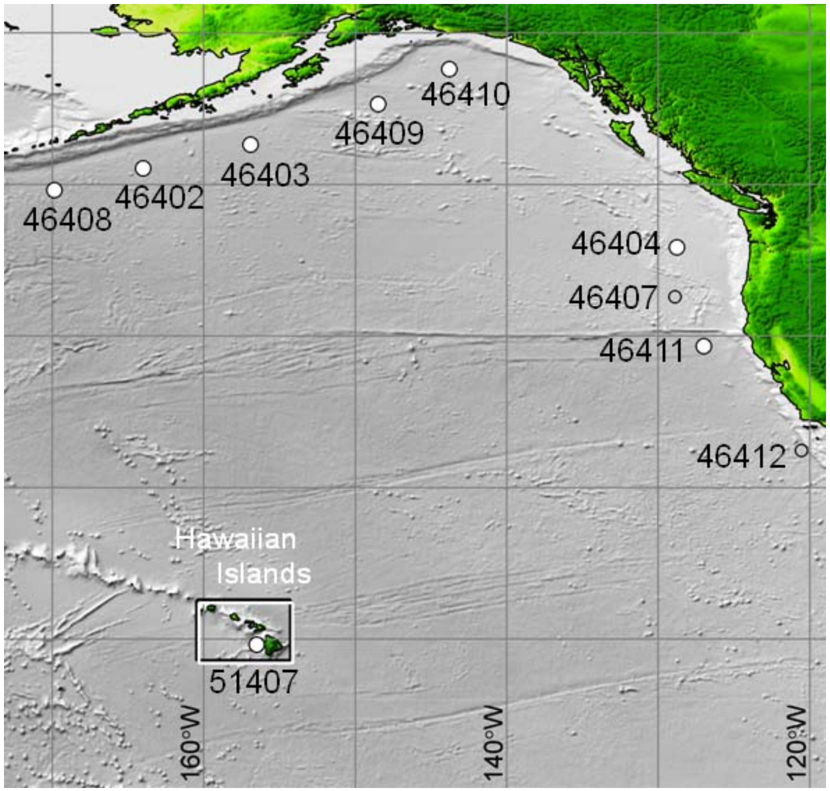
Time-series and Spectra of Surface Elevations

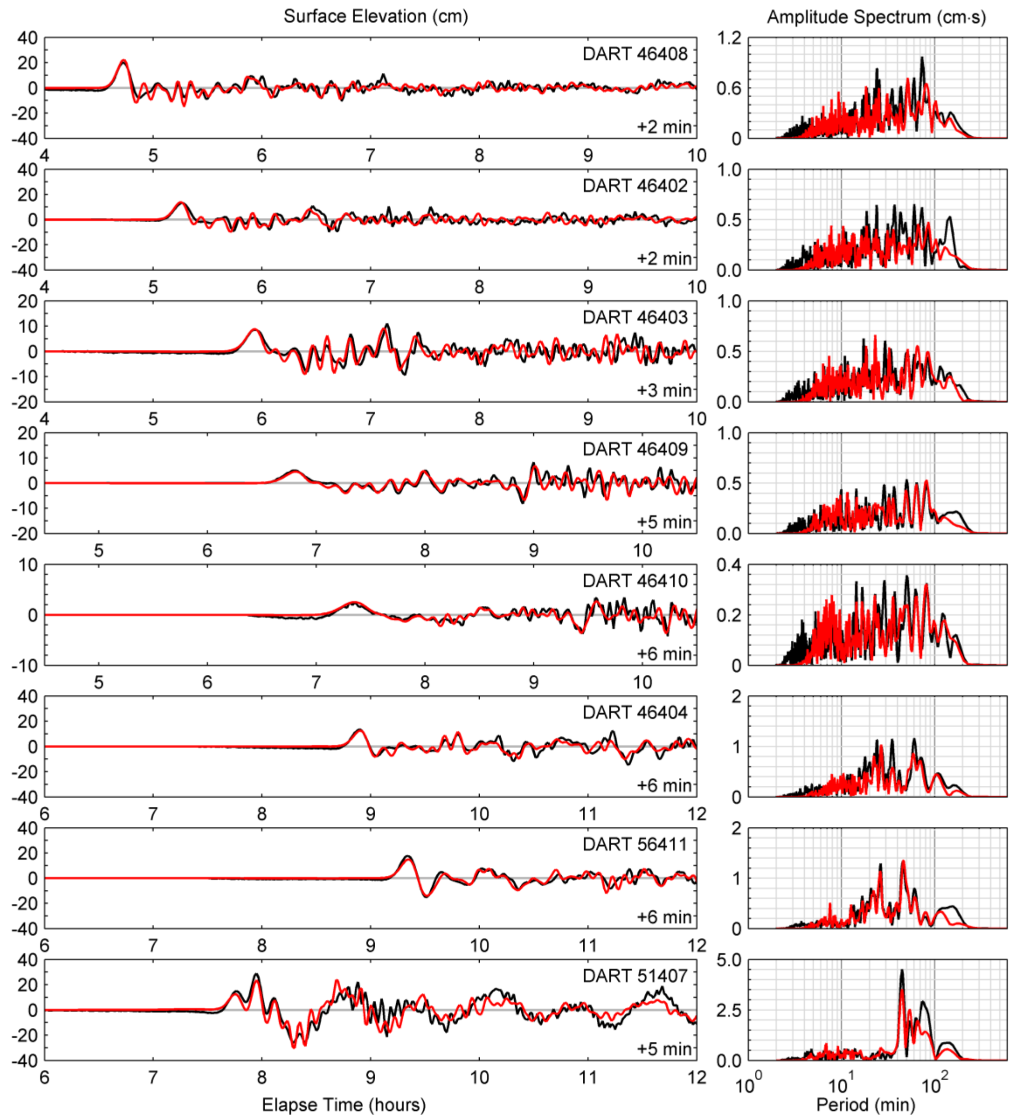


Distant Tsunami Evolution

- DART Buoy Comparisons (Northeast Pacific)

Time-series and Spectra of Surface Elevations



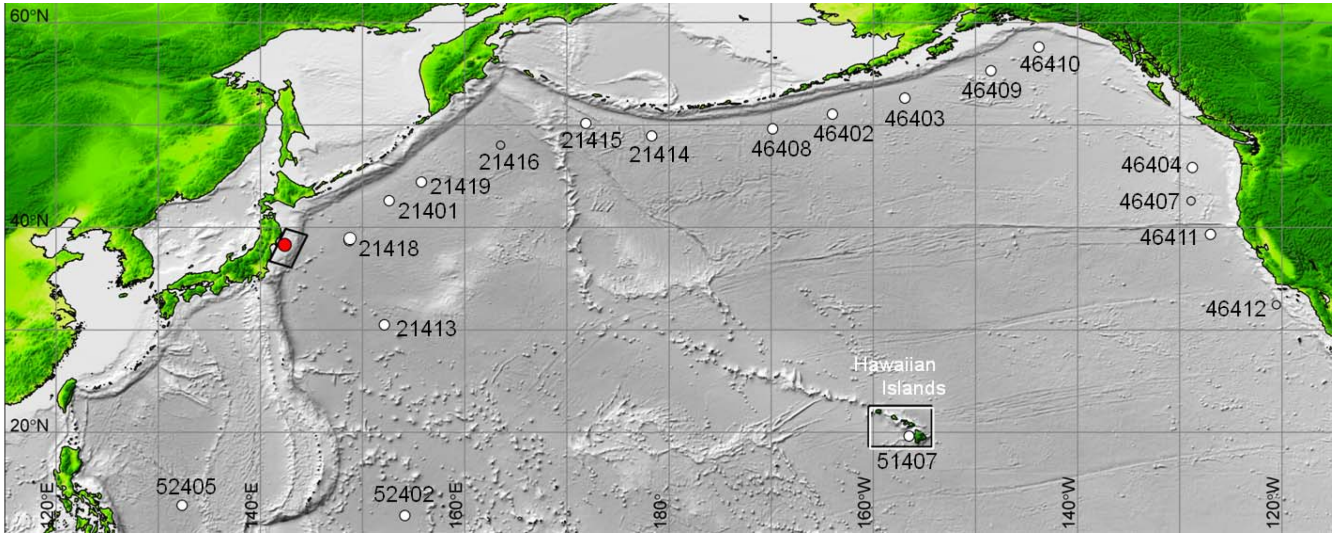


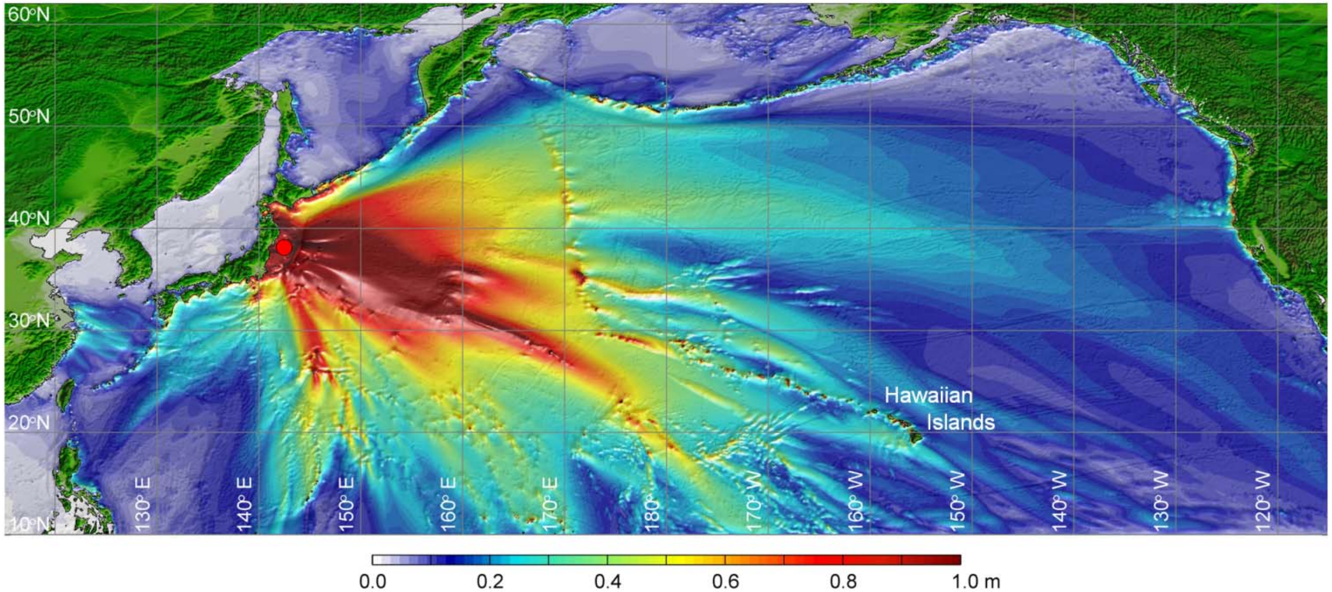
— : computed results
— : recorded data

Distant Tsunami Evolution

- Tsunami Impact over North Pacific

Maximum Wave Amplitude

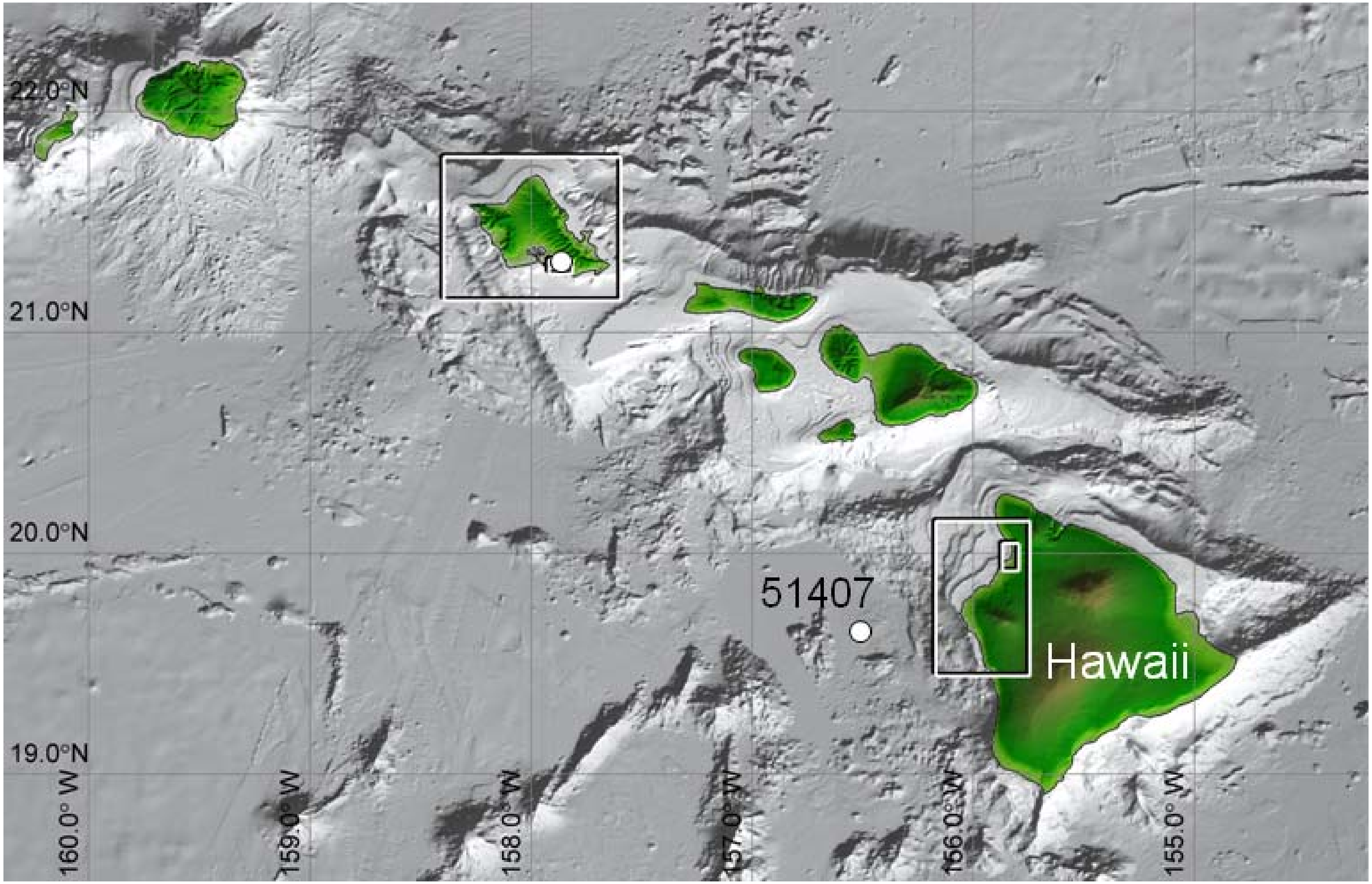




Distant Tsunami Evolution

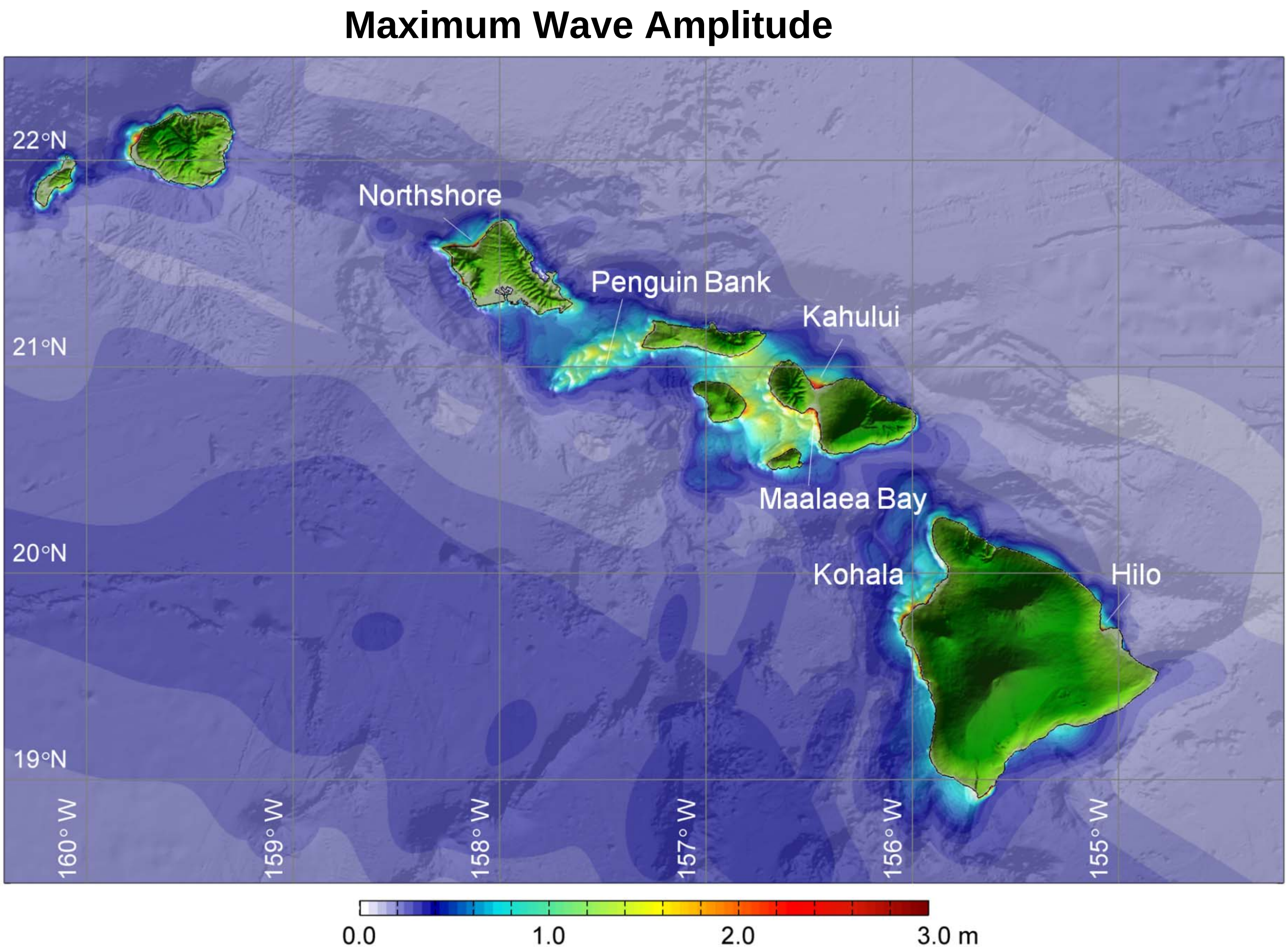
- Tsunami Impact on Hawaii

Shallow Shelf around Hawaiian Island Chain



Distant Tsunami Evolution

- Tsunami Impact on Hawaii

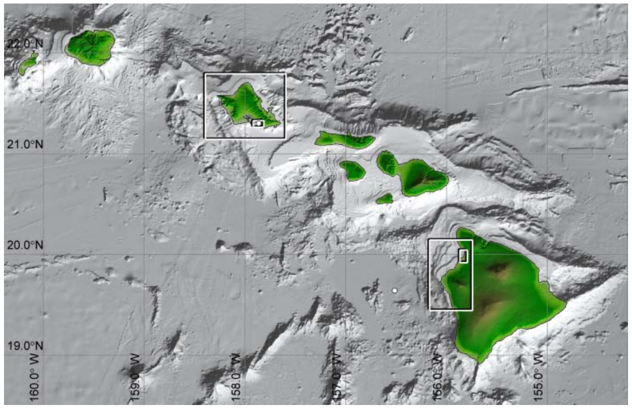


Distant Tsunami Evolution

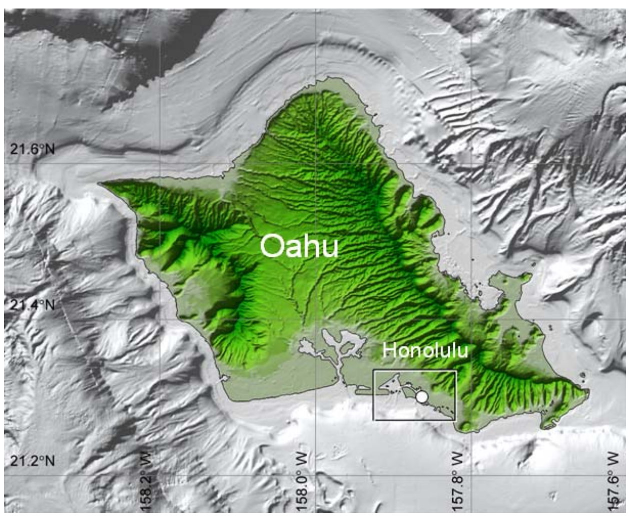
- Tide Gauge Comparison at Honolulu, Oahu

Four Level of Nested-Girds

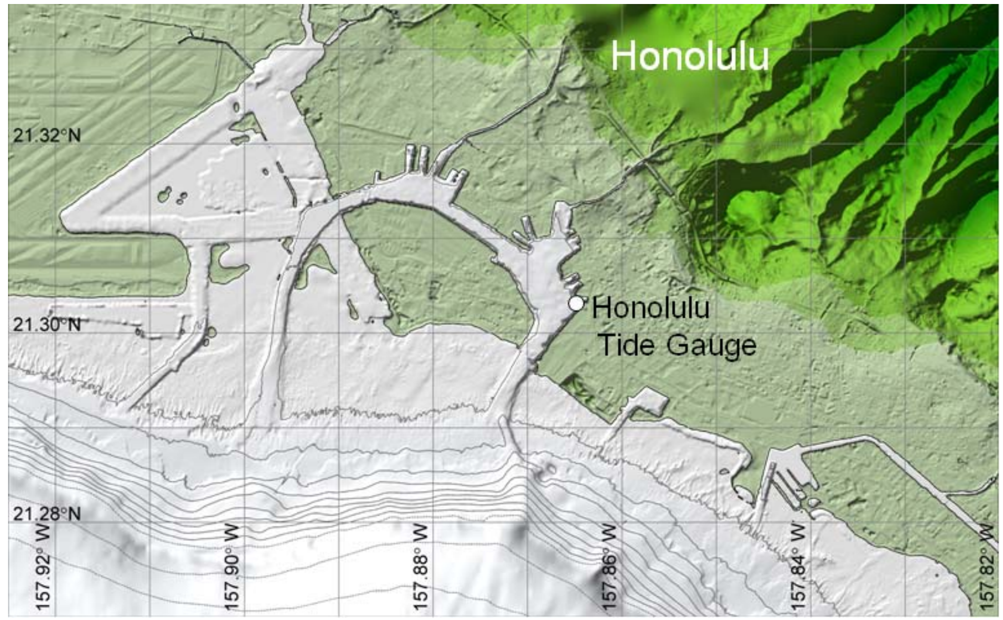
Level-2 Grid
15 arcsec (~450m) Hawaiian Islands



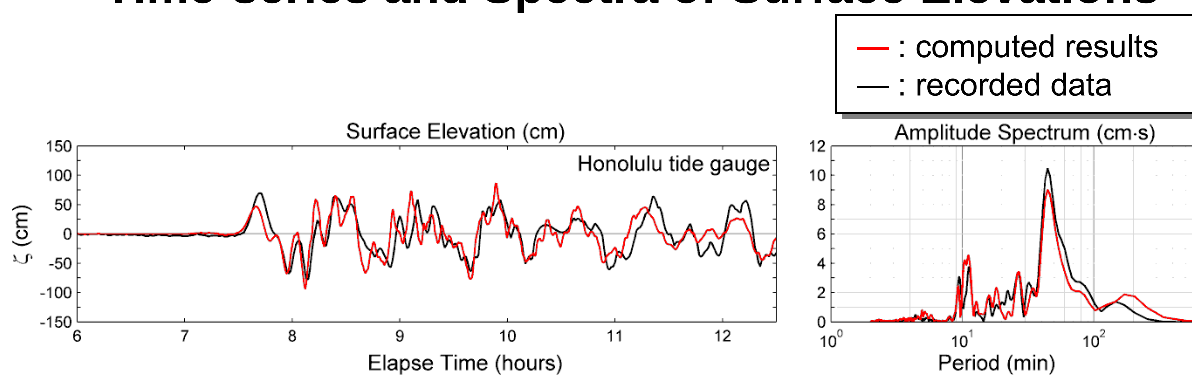
Level-3 Grid
3 arcsec (~90m) Northwest Pacific



Level-4 Grid
0.3 arcsec (~9m) Honolulu



Time-series and Spectra of Surface Elevations



Distant Tsunami Evolution

- Tsunami Impact at West Big Island

QuickTime™ and a
H.264 decompressor
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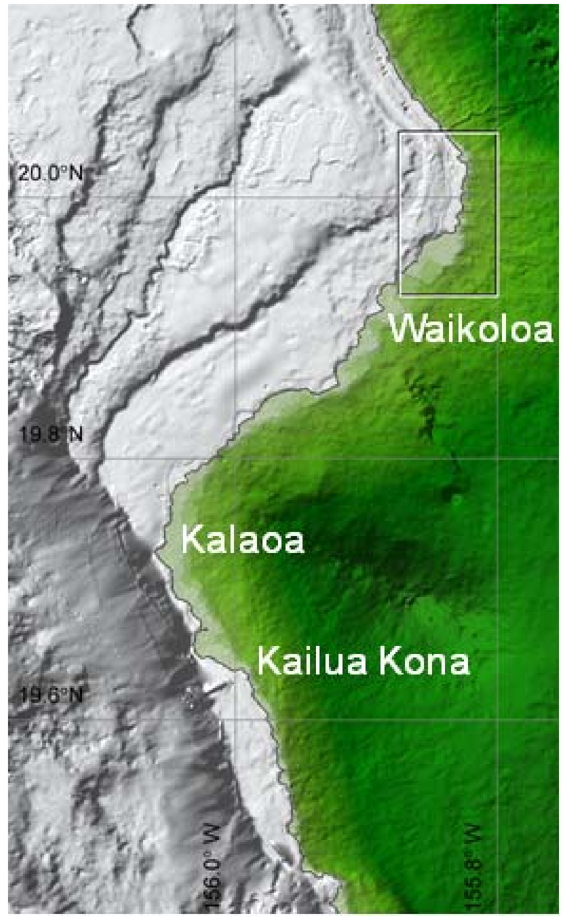
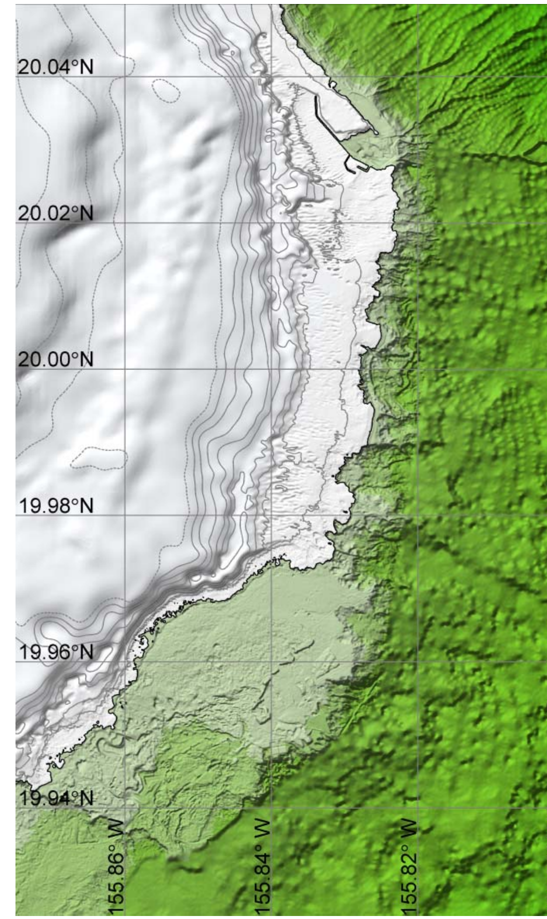
Four Level of Nested-Girds

Level-3 Grid
3 arcsec (~90m) Northwest Big Island



Level-4 Grid
0.3 arcsec (~9m) Waikoloa



Distant Tsunami Evolution

- Tsunami Impact at Waikoloa, Big Island

Wave Transformation and Resulting Runup and Inundation

QuickTime™ and a
H.264 decompressor
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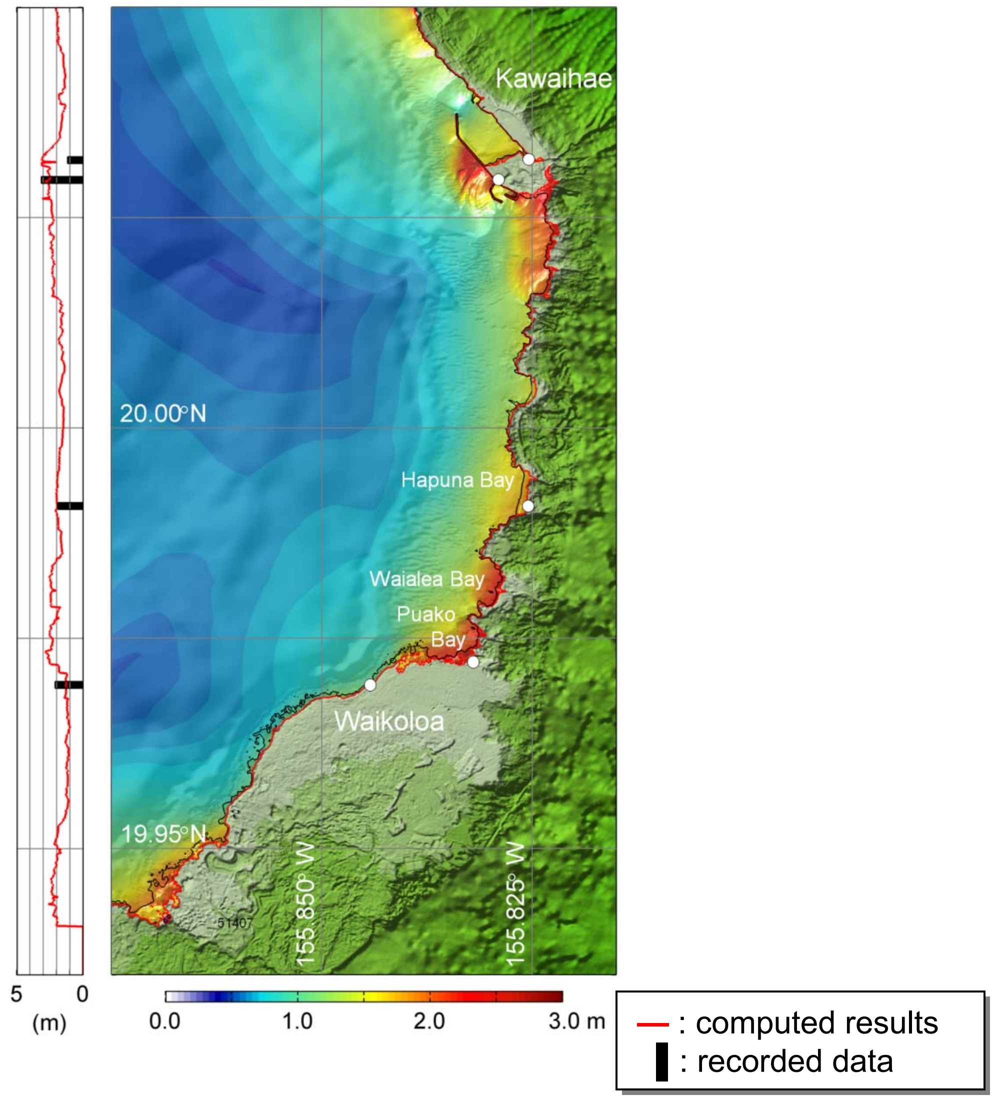

Conclusions

- 2011 Tohoku-oki earthquake tsunami provides the best extensive recorded dataset for better understanding of earthquake and tsunami physics and improvement of assessment tools.

- A Finite-Fault model provides the time sequence of rupture processes to model tsunami generation from seafloor deformation and considering land subsidence.

- NEOWAVE gives good agreement with recorded water level stations along the Japan and across the Pacific, which validates the Finite-Fault model as well as the capability of NEOWAVE for modeling both near-field and distant tsunamis.

Future Studies and Developments

- Future Studies

(1) Modeling other Hawaiian Islands' coastlines

(2) Modeling Runup/Inundation and studying Resonance Amplification for coast of Tohoku, Japan, and US West coast.

- Developments

(1) Improvement of Dispersion

(2) Parallelization of NEOWAVE

- Applications

(1) Tsunami Inundation Mapping for Hawaii, Northwest Hawaiian Islands, American Samoa, Western Samoa, US Gulf coasts, Puerto Rico, and Chile.

(2) Storm Surge and Wave Modeling for Pacific Islands and US East coasts.