Nonhydrostatic Evolution of Ocean Waves

NEOWAVE for Tsunami Modeling

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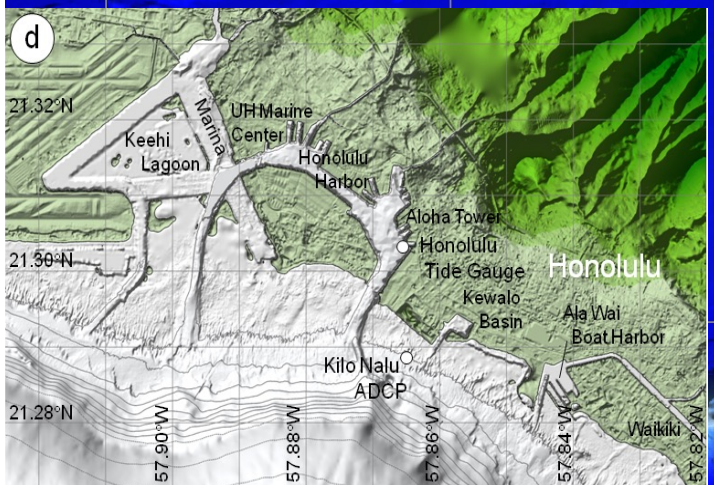


Water Wave Mechanics

Terminology

- Wavelength (L), wave period (T), celerity ($c = L/T$)
- Wave height (H) versus wave amplitude (A)
- Water depth (d) versus flow depth (D)
- Water depth parameter (d/L or $kd = 2\pi d/L$)

Shallow water: $d/L < 1/20$

- Vertical velocity ≈ 0
- Uniform wave-induced pressure or horizontal velocity to ocean bottom (hydrostatic)
- $c = (gd)^{1/2}$ [non-dispersive means $c \neq f(T)$]

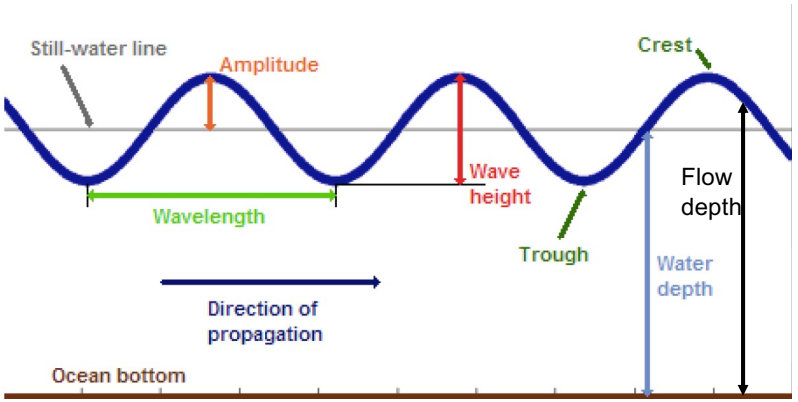
Deep water: $d/L > 1/2$

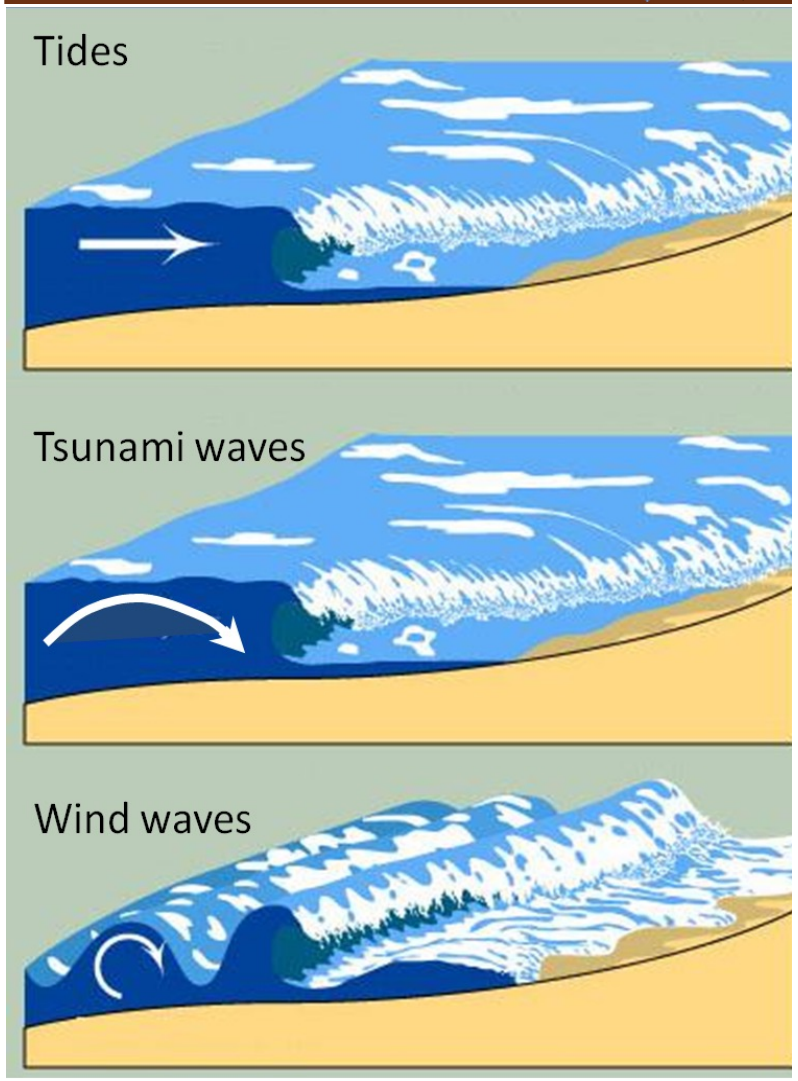
- Exponential decay of wave induced velocity and pressure to zero below $d = L/2$ (non-hydrostatic)
- $c = gT/2\pi$ [dispersive means $c = f(T)$])

Intermediate water: $1/20 < d/L < 1/2$

- Decay of wave-induced velocity and pressure to non-zero values at ocean bottom (non-hydrostatic)
- $c = (gT/2\pi)\tanh(2\pi d/L)$

Discussion: What are the implications for tsunami generation and propagation?





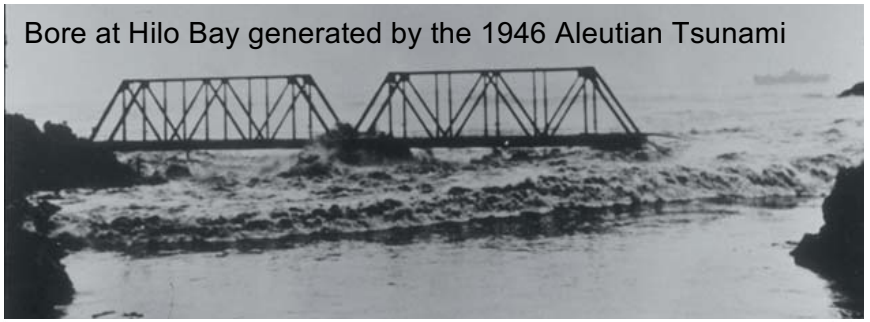
Tsunami Models

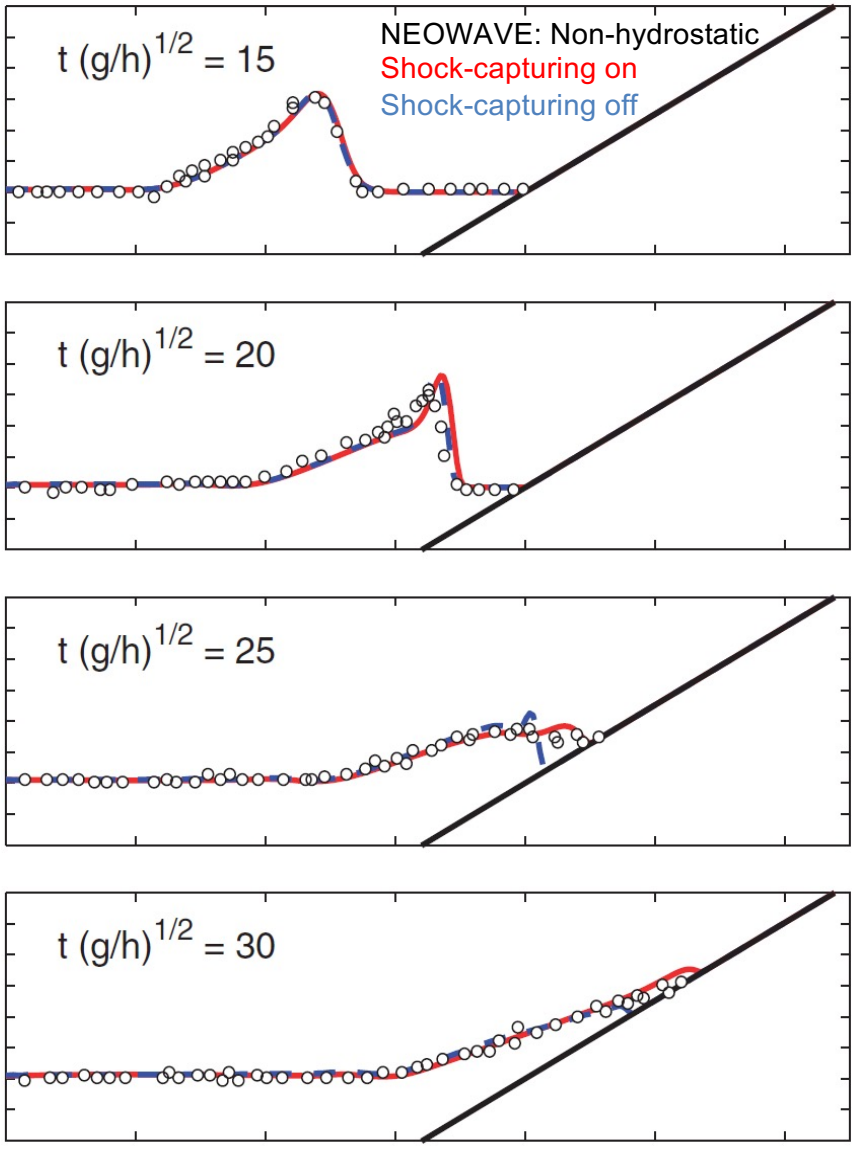
Shallow-water or hydrostatic models
- Zero vertical velocity and uniform wave-induced pressure and horizontal velocity ($d/L < 1/20$)
- TUNAMI, ALASKA, COMCOT, MOST, FVWAVE*, GeoCLAW*, …

Boussinesq-type models
- Linear velocity and quadratic non-hydrostatic pressure profiles over water column ($d/L < 1/5$ in typical tsunami range)
- Polynomial distributions ($d/L > 1/2$)
- High-order PDEs in terms of the horizontal velocity
- pCOULWAVE*, FUNWAVE-TVD*, BOSZ*, …

Non-hydrostatic models
- Linear velocity and pressure profiles over water column in NEOWAVE* ($d/L < 1/5$)
- Multi-layer formulation ($d/L > 1/2$)
- First-order PDEs including vertical velocity and non-hydrostatic pressure (tsunami generation)

*Shock-capturing scheme for bore formation

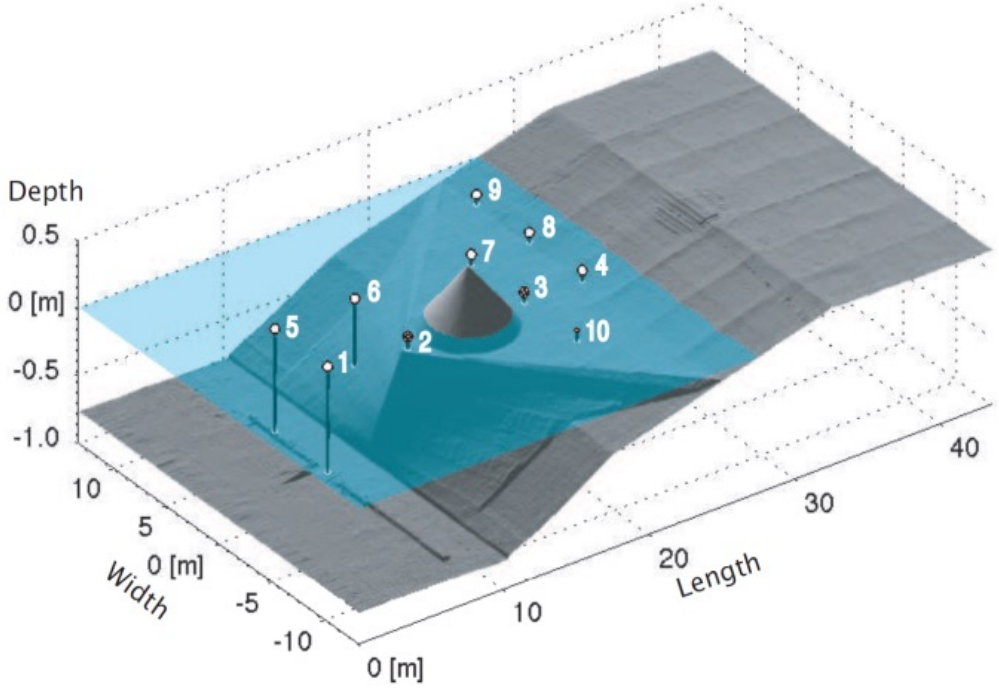


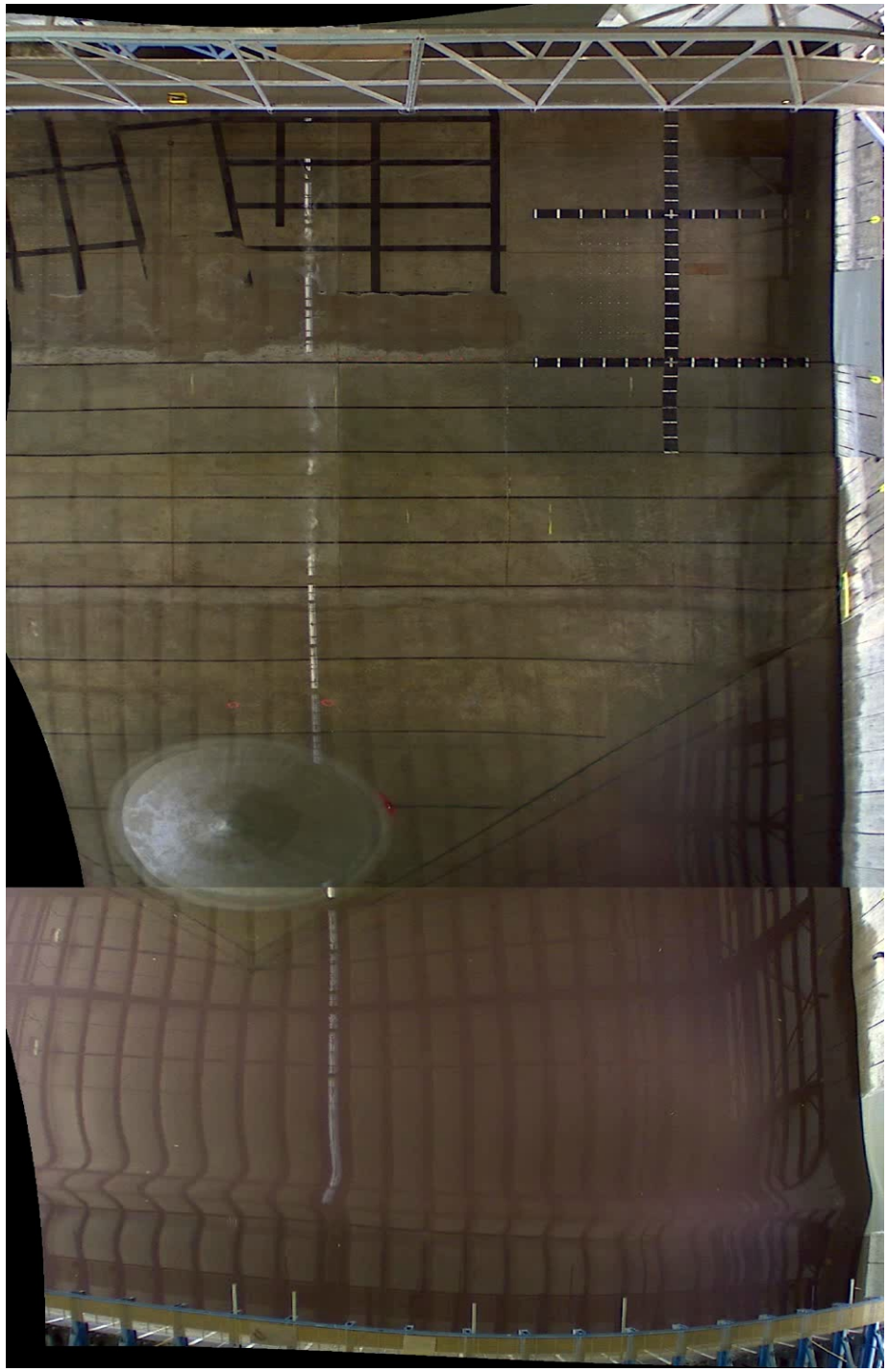


2009 Benchmark Challenge Sponsored by National Science Foundation

Basin tests at Oregon State University to evaluate validity of tsunami models

- Test configuration involving an island on a steep triangular shelf over gentle slopes
- Measurements of water surface at multiple locations
- Blinded tests for computer models with participants not knowing the measurements





Video from Pat Lynett, University of Southern California

ISEC BM NO.2

NEOWAVE2D

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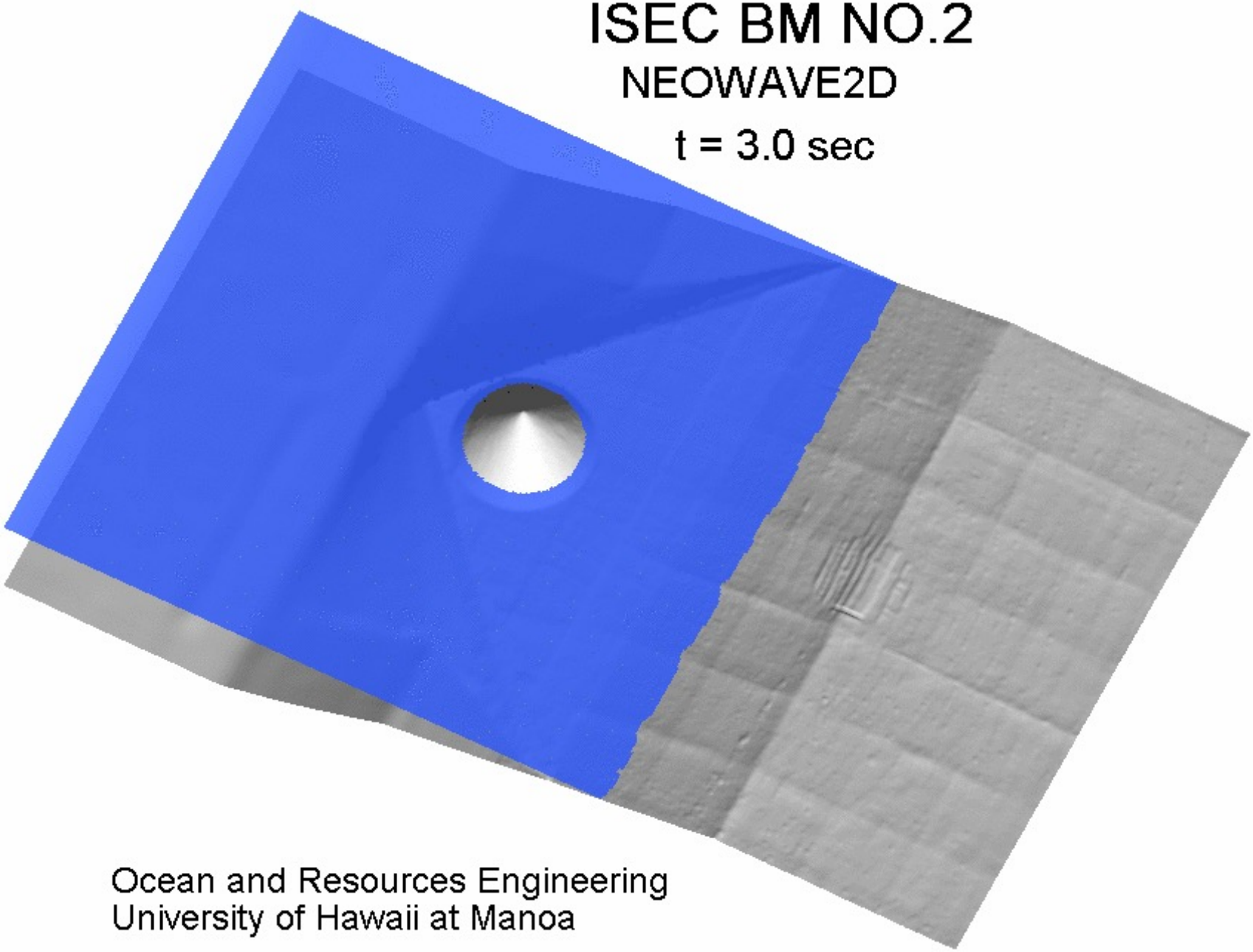

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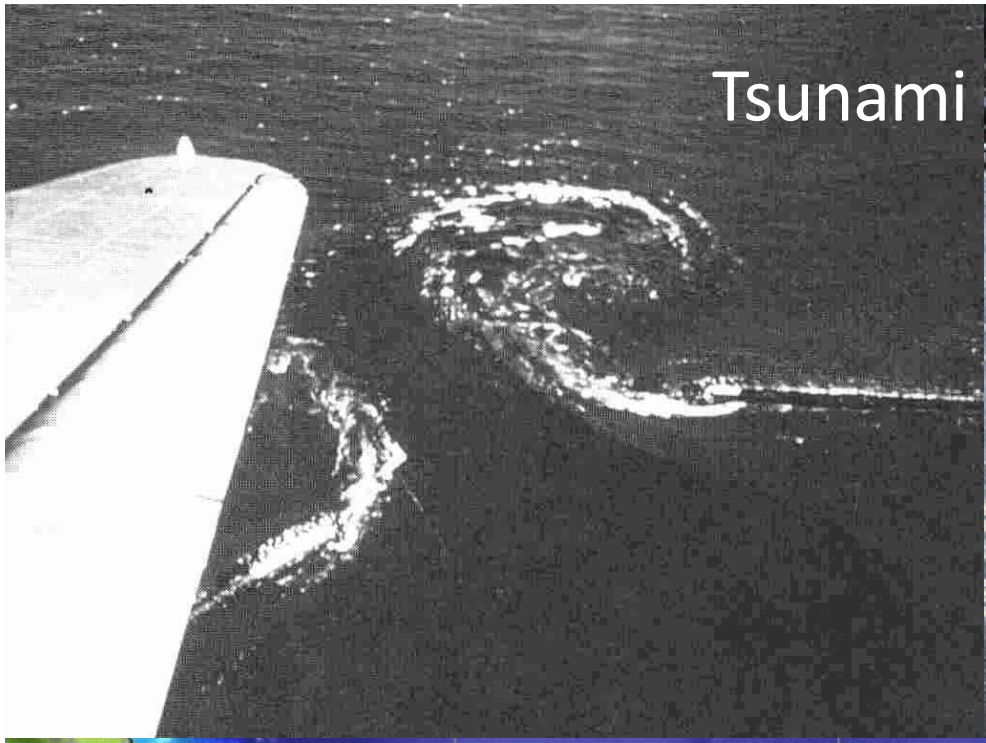
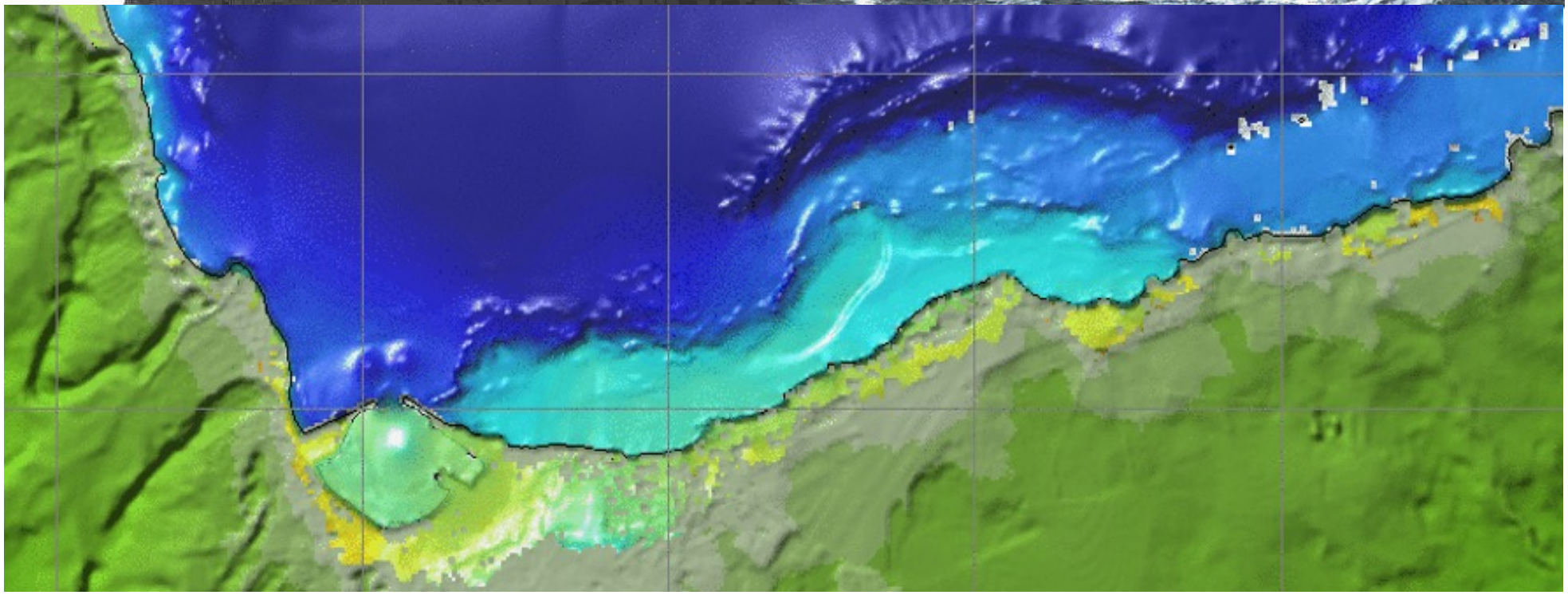
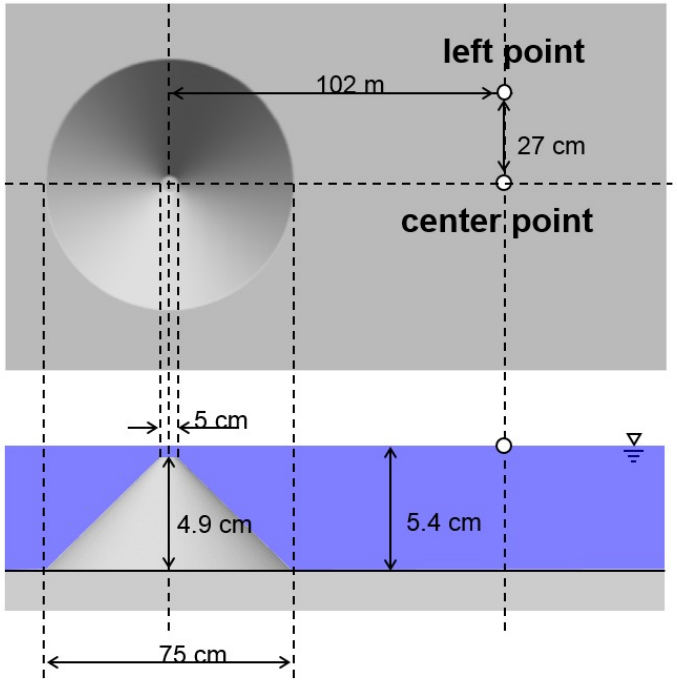
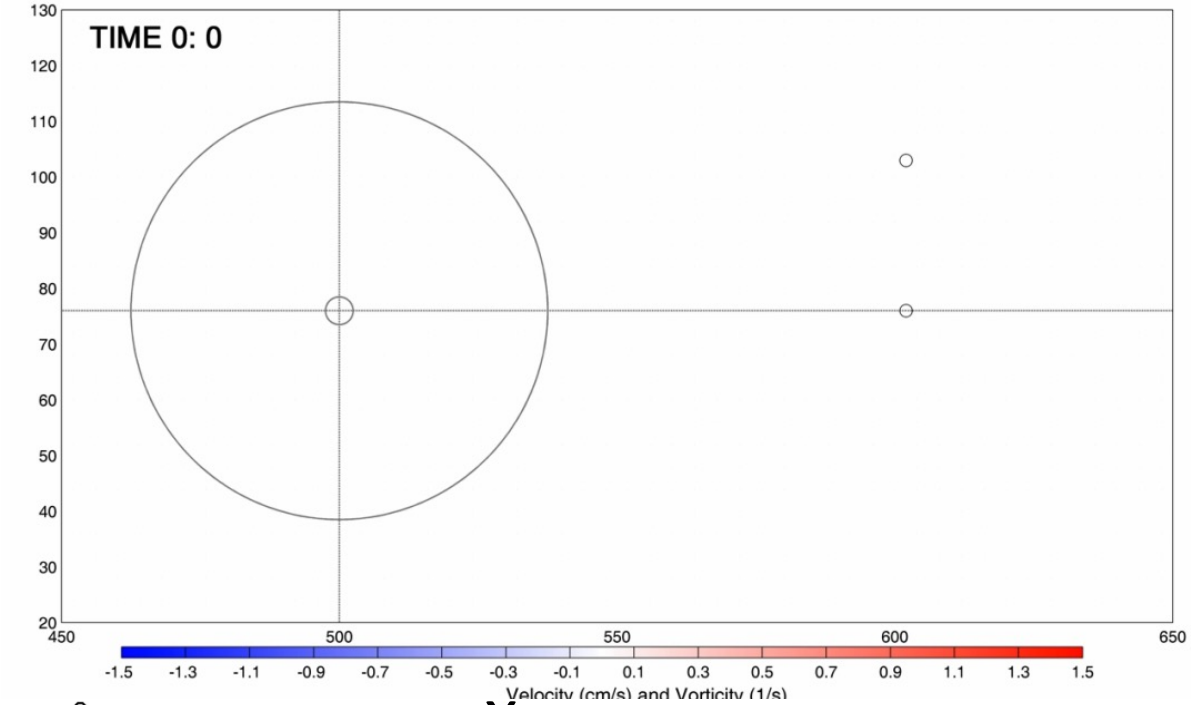
Tsunami Currents

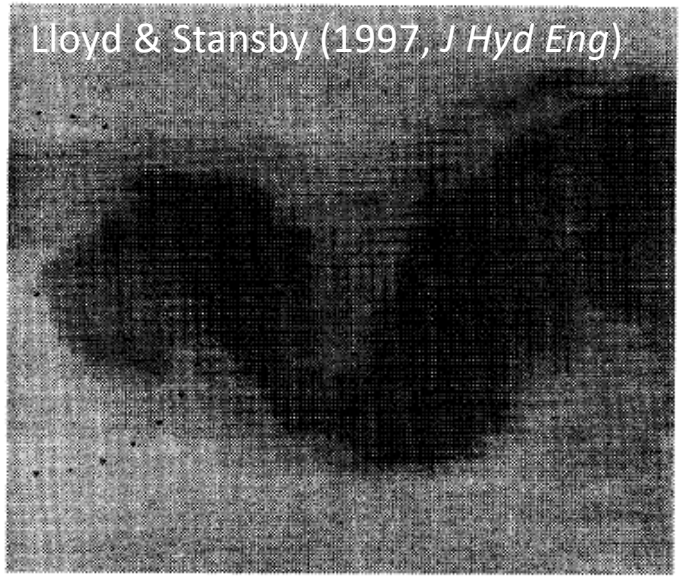


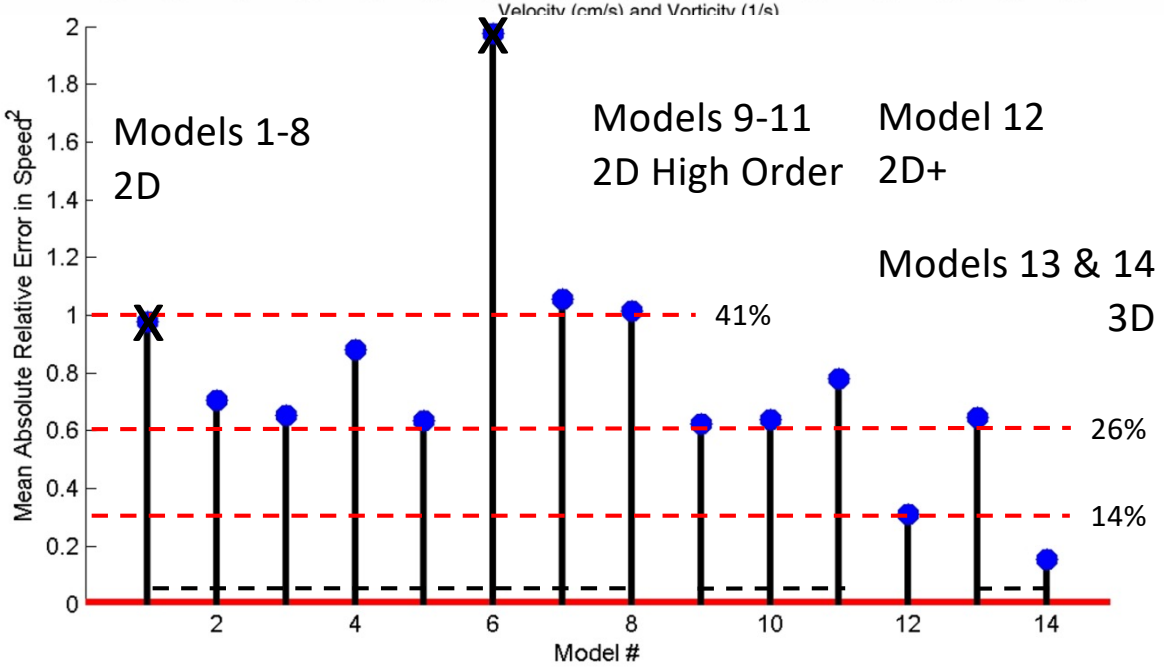


2015 NTHMP Benchmark Results





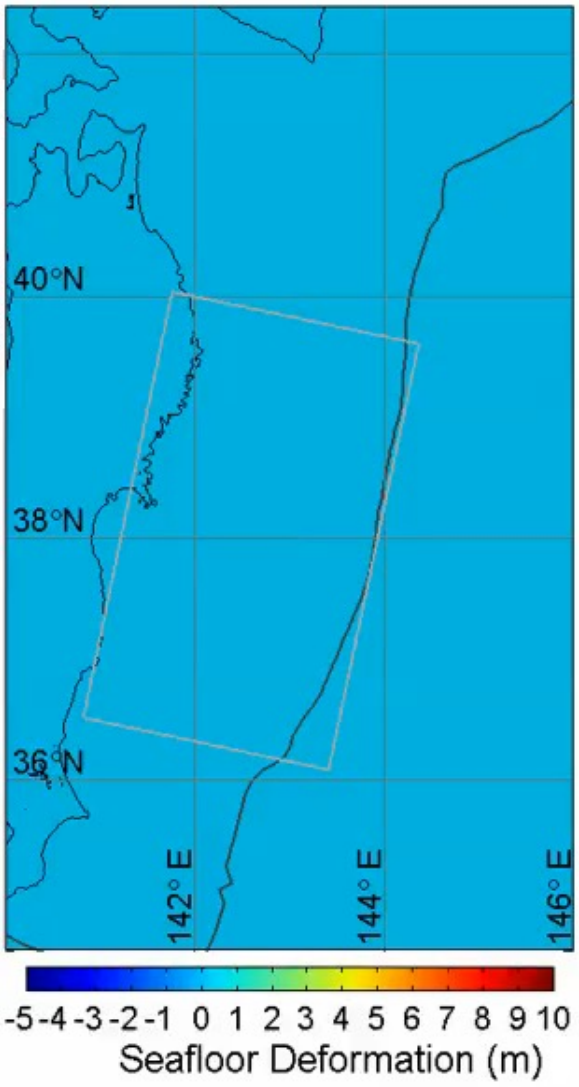


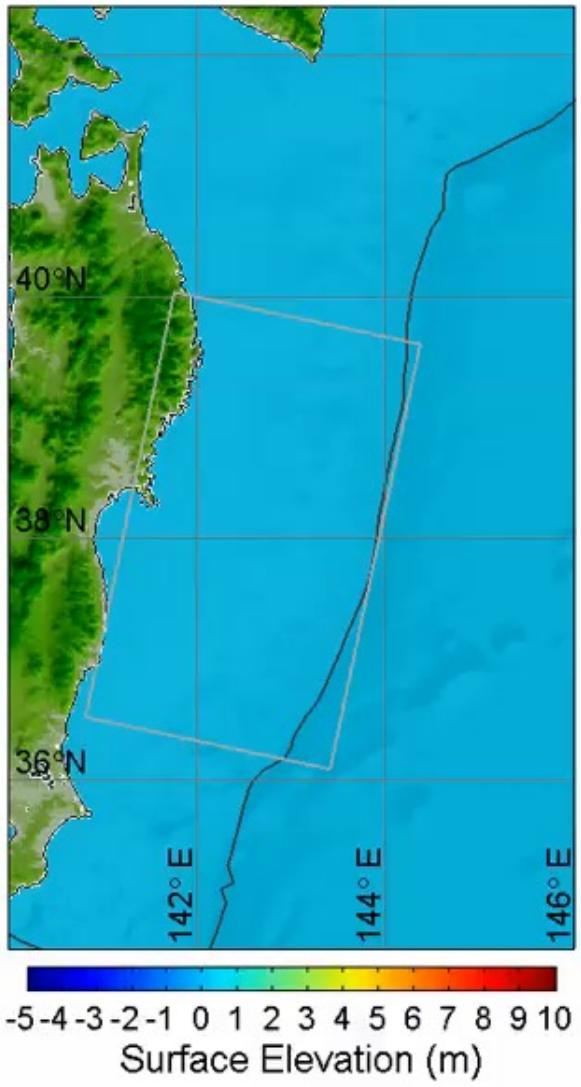


The 2011 Tohoku Earthquake and Tsunami

The 2011 Tohoku Earthquake and Tsunami Generation

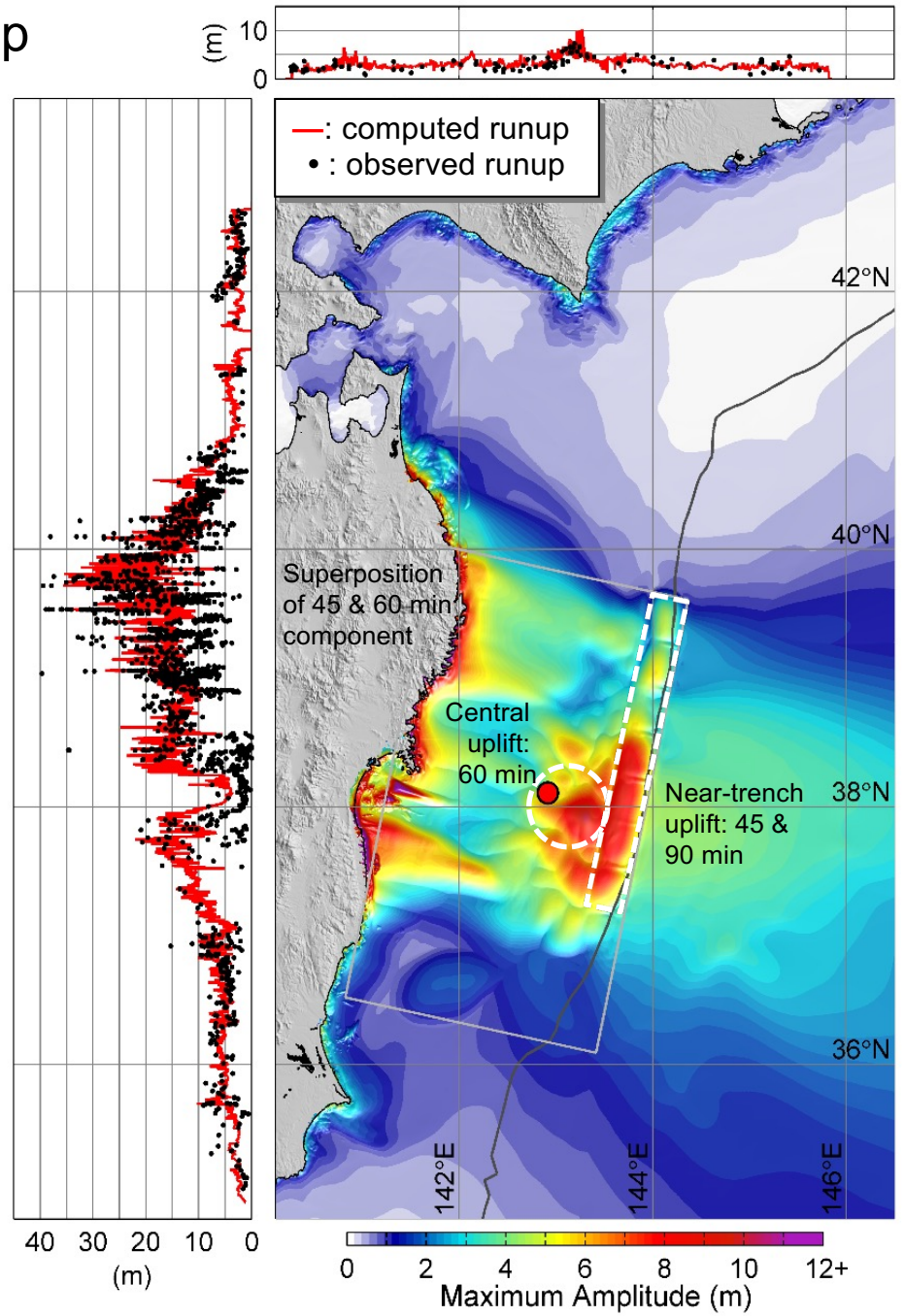
Non-hydrostatic Modeling with Boundary Conditions from Kinematic Seafloor Deformation



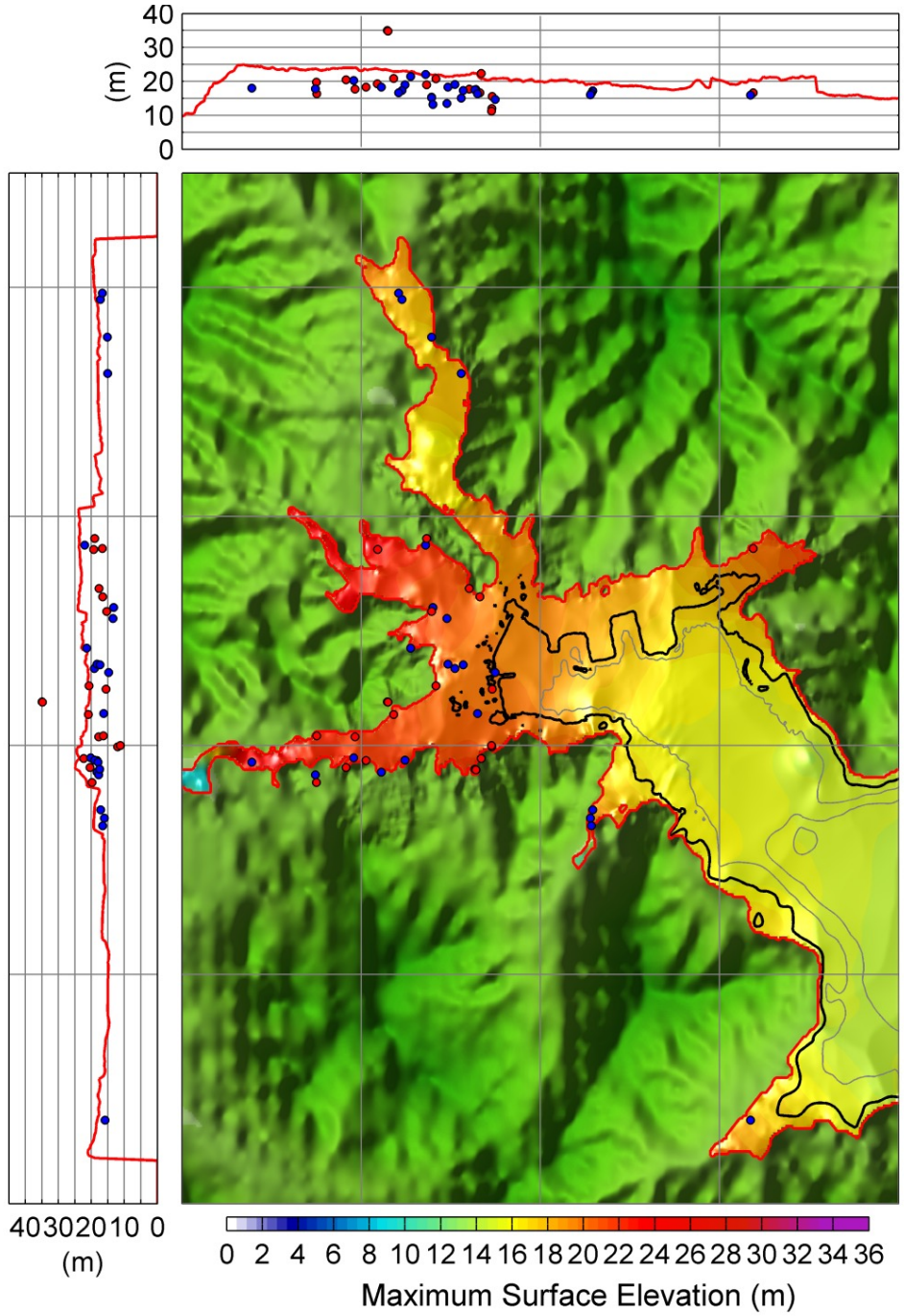


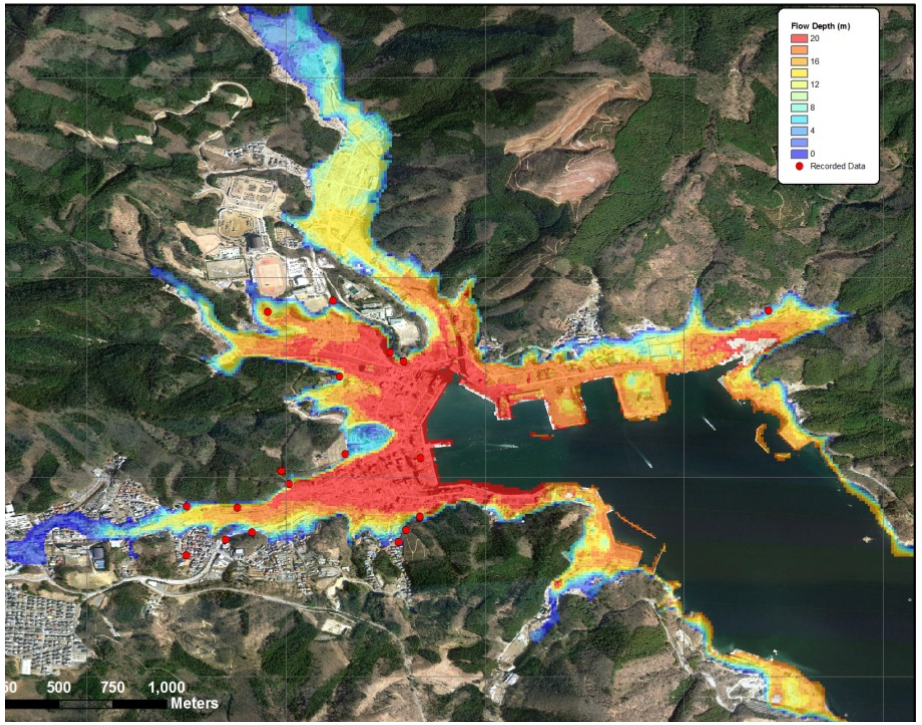
The 2011 Tohoku Tsunami

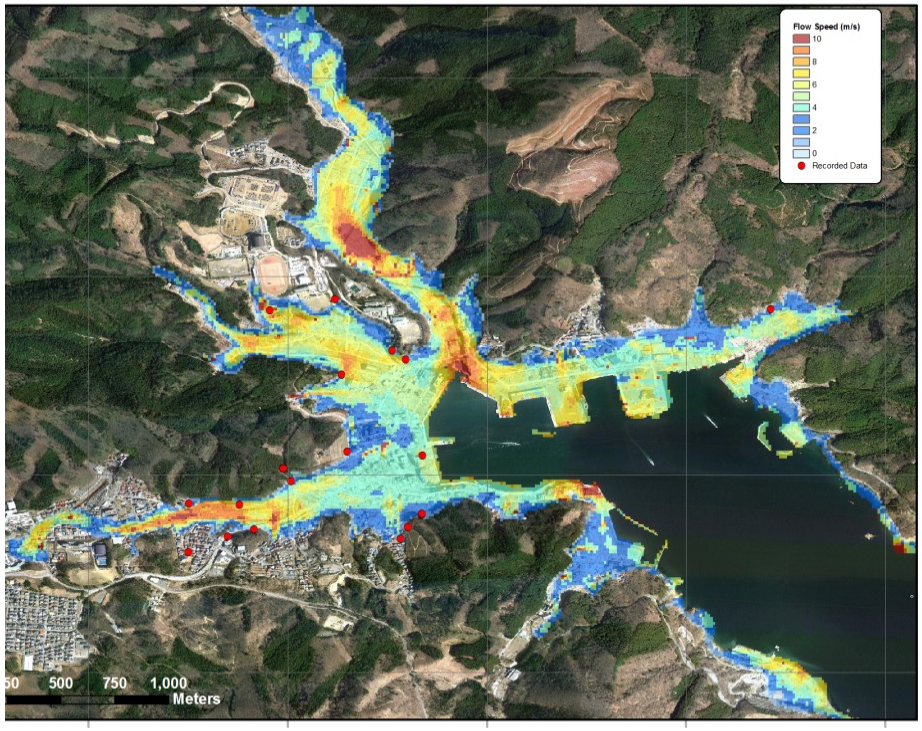
Near-field Waves and Coastal Runup



Inundation at Onagawa, Miyagi







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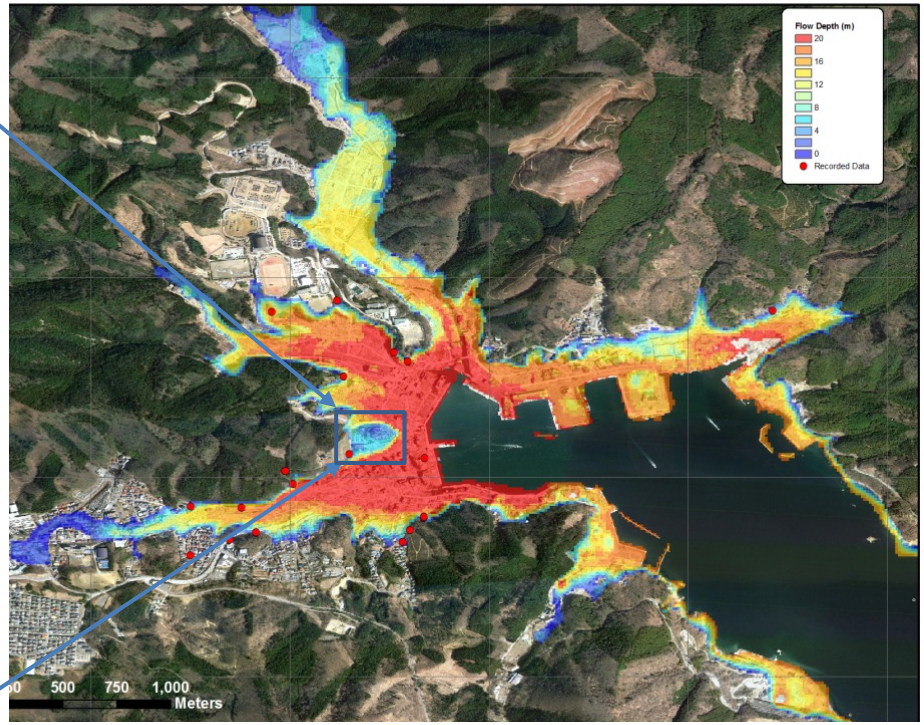
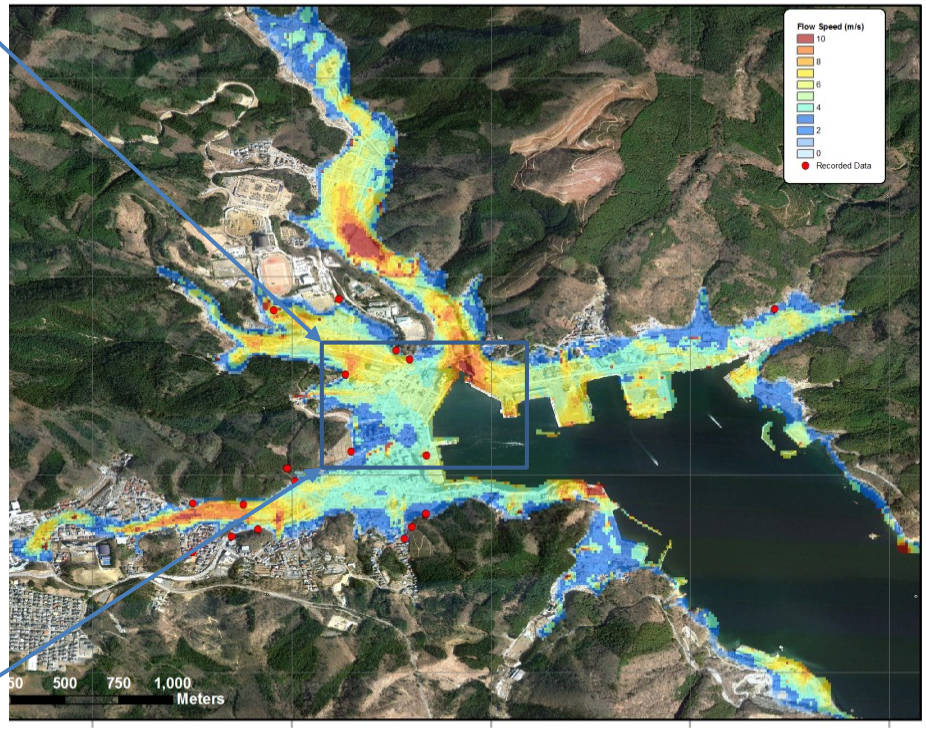
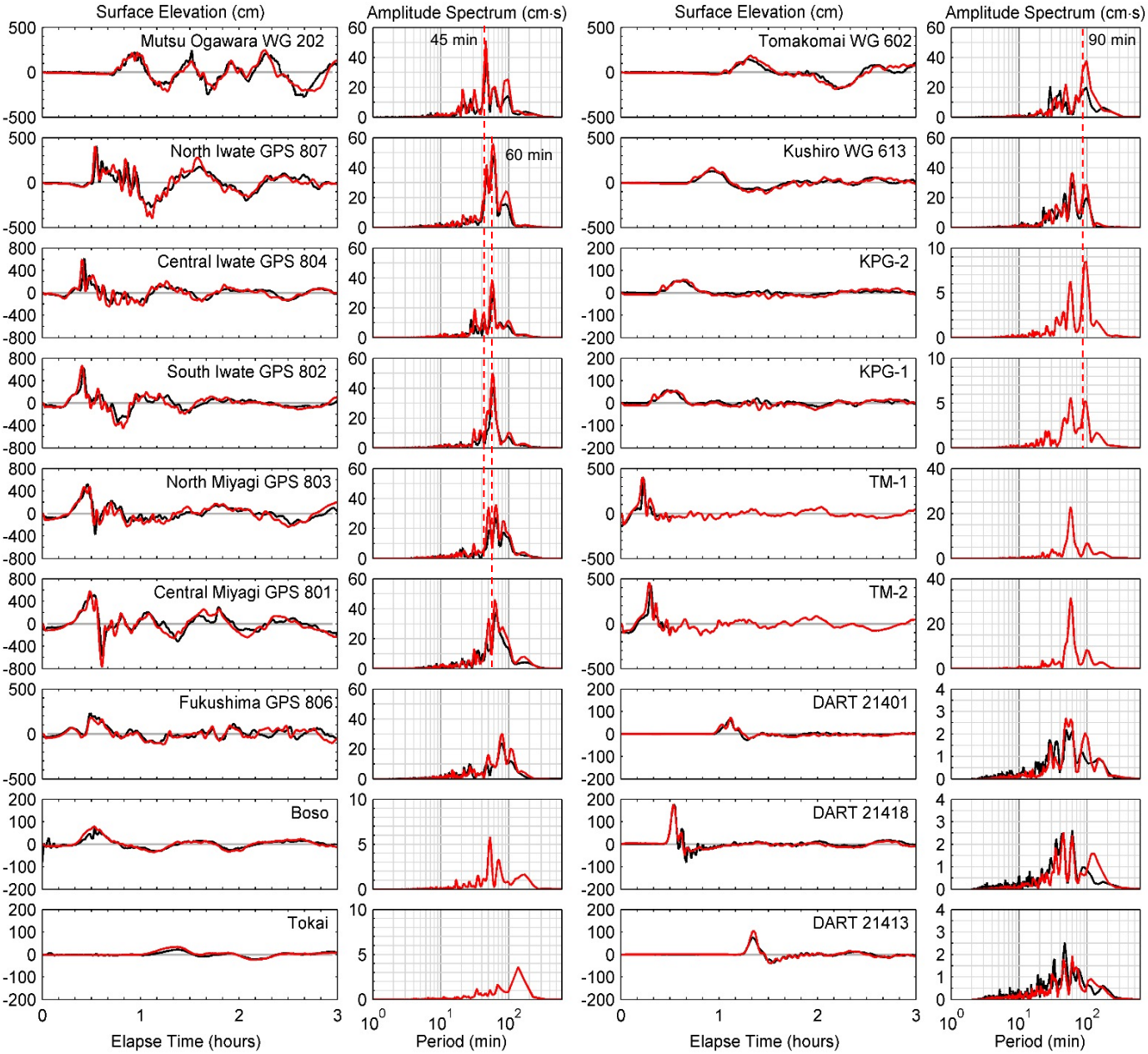
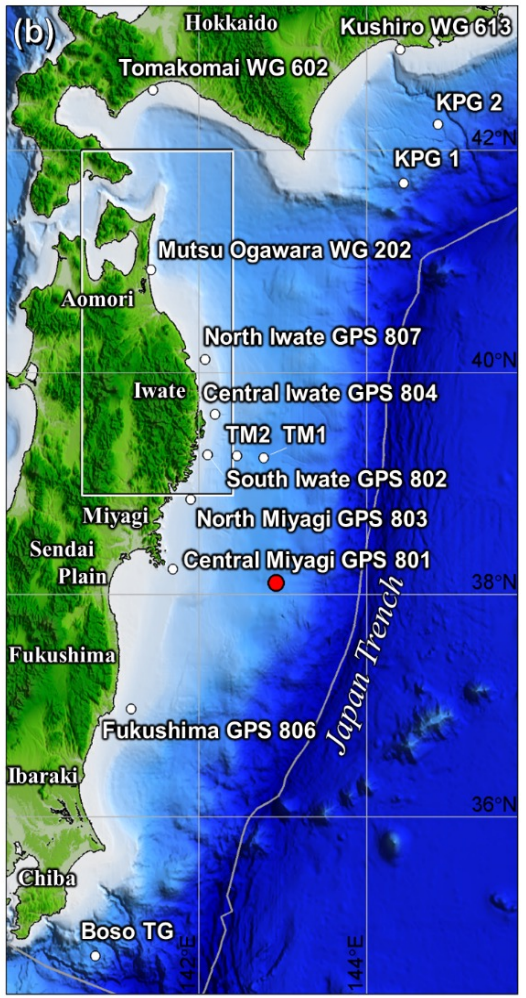




The 2011 Tohoku Tsunami

Near-field Waveforms and Spectra

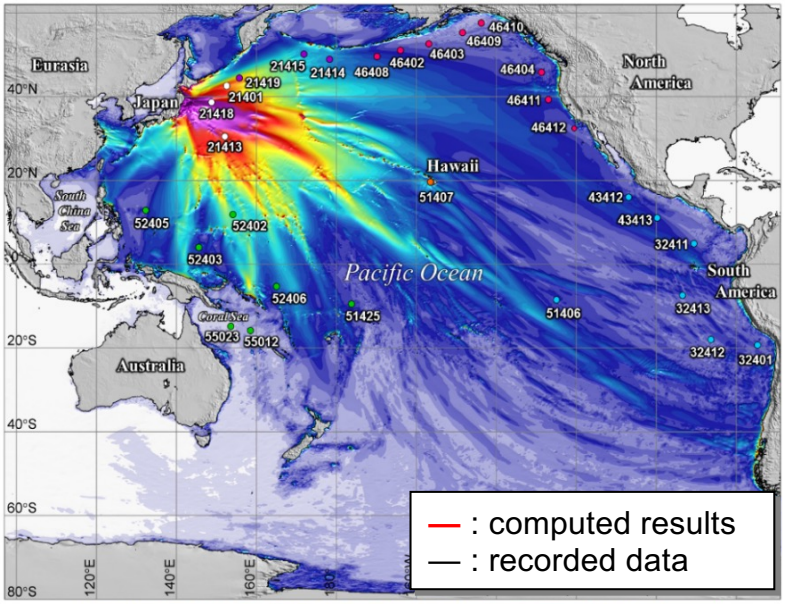


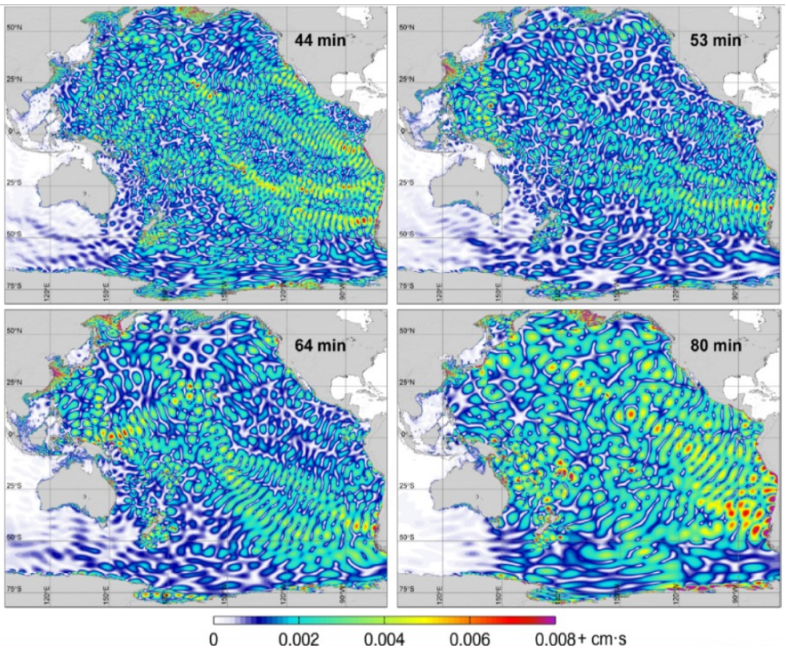


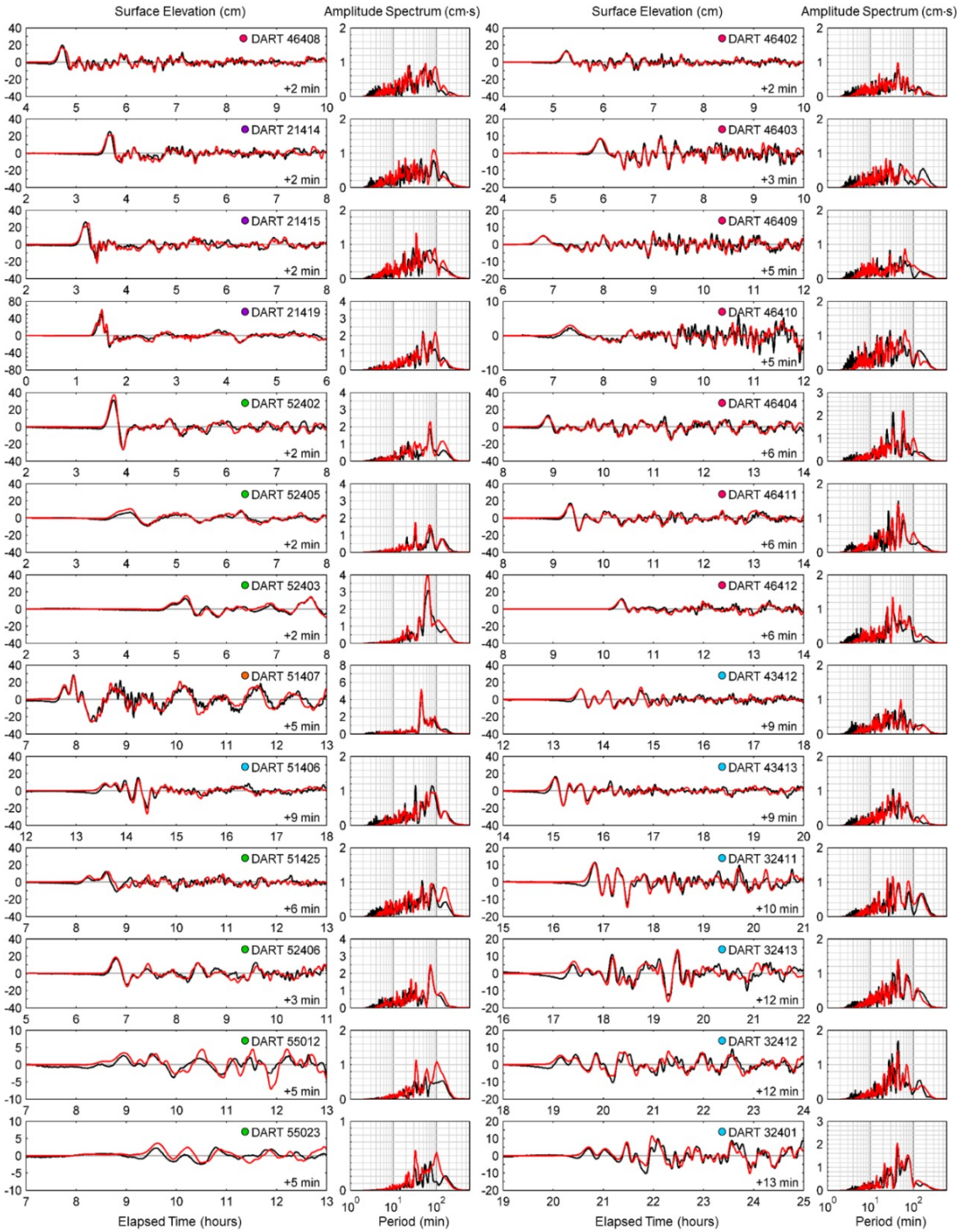
— : computed results
— : recorded data

Model Validation

Far-field Waveforms & Spectra

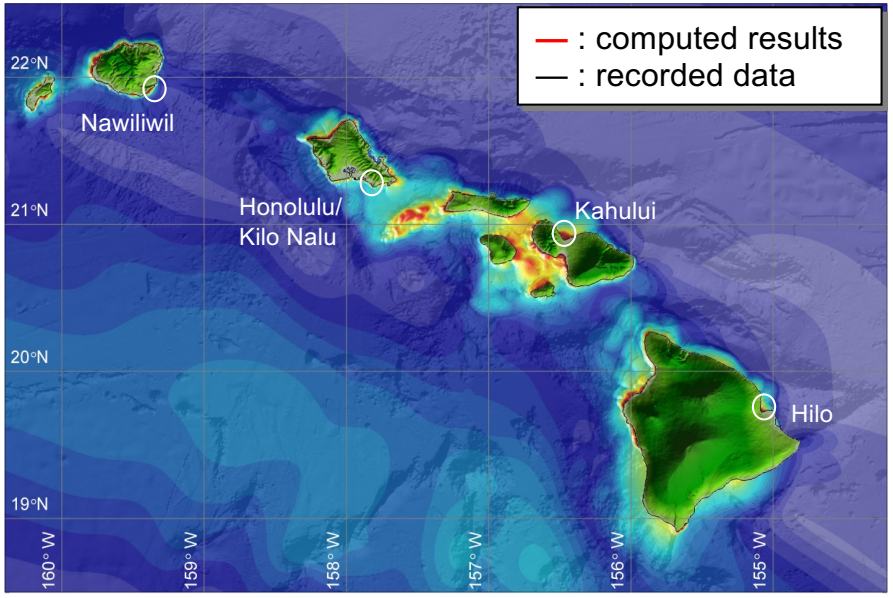


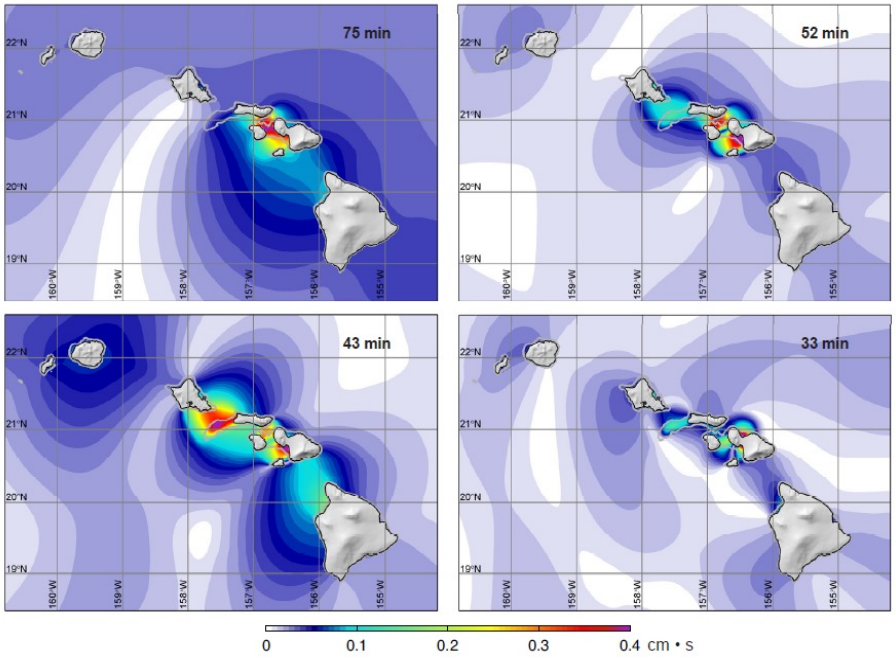


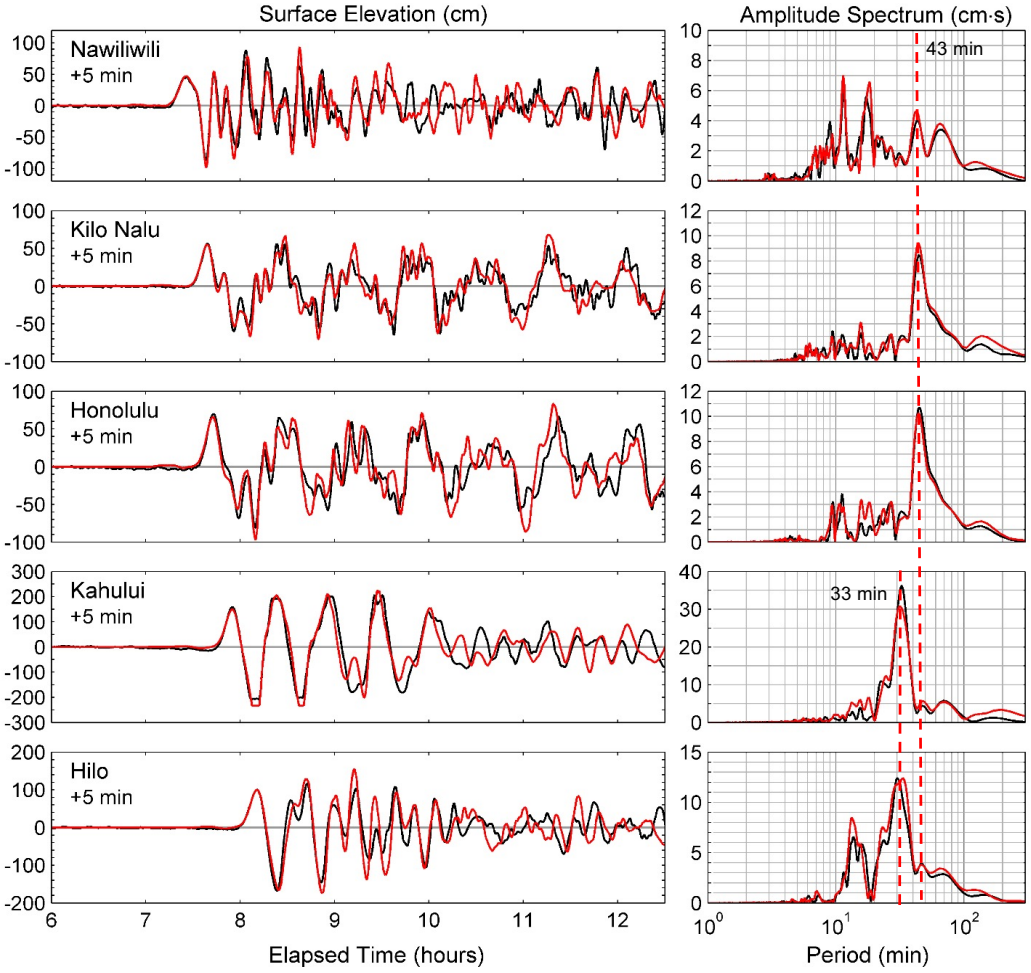


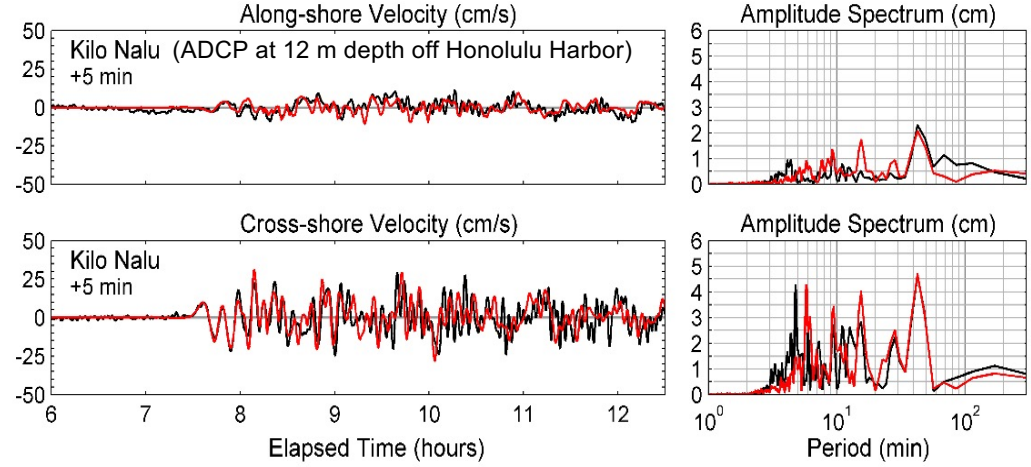
Model Validation

Hawaii Tide Gauges & ADCPs



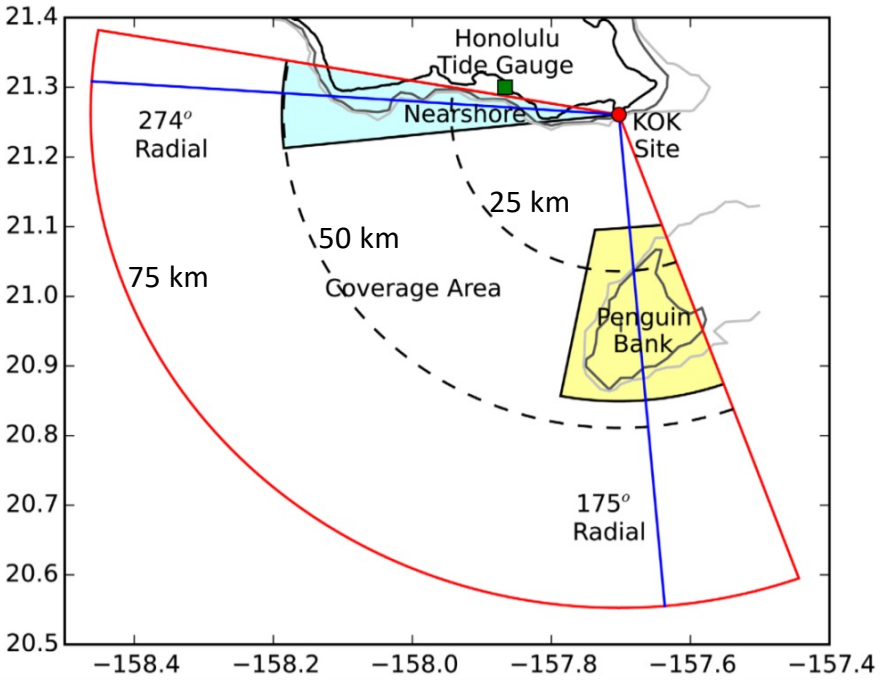




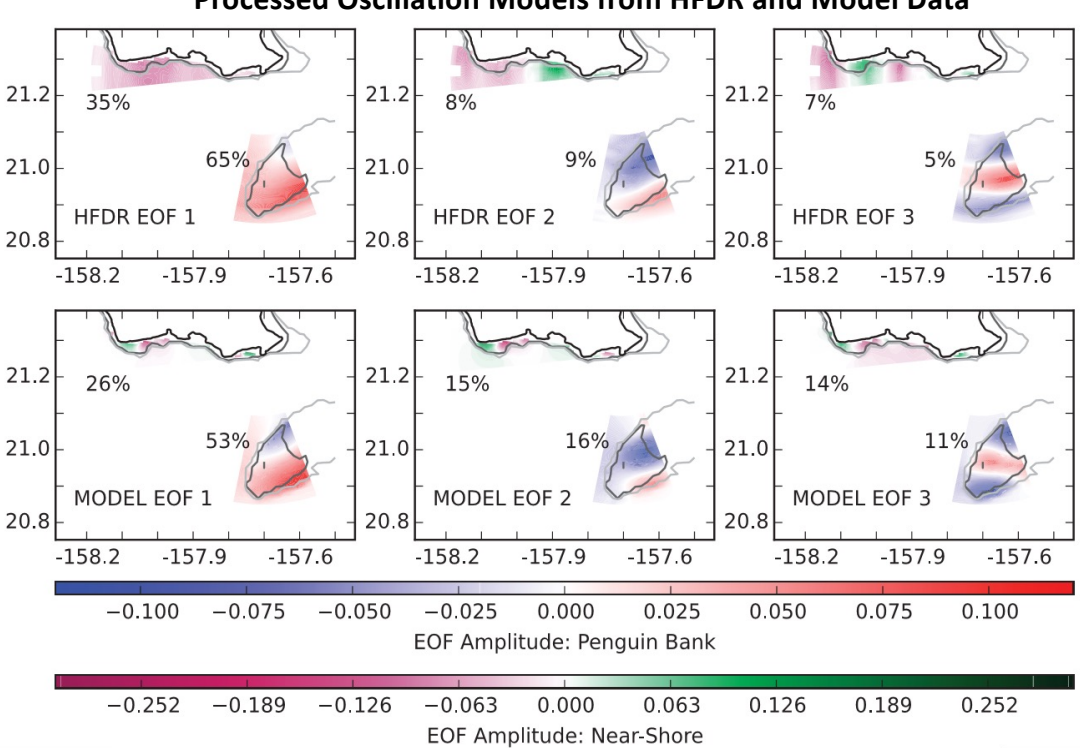


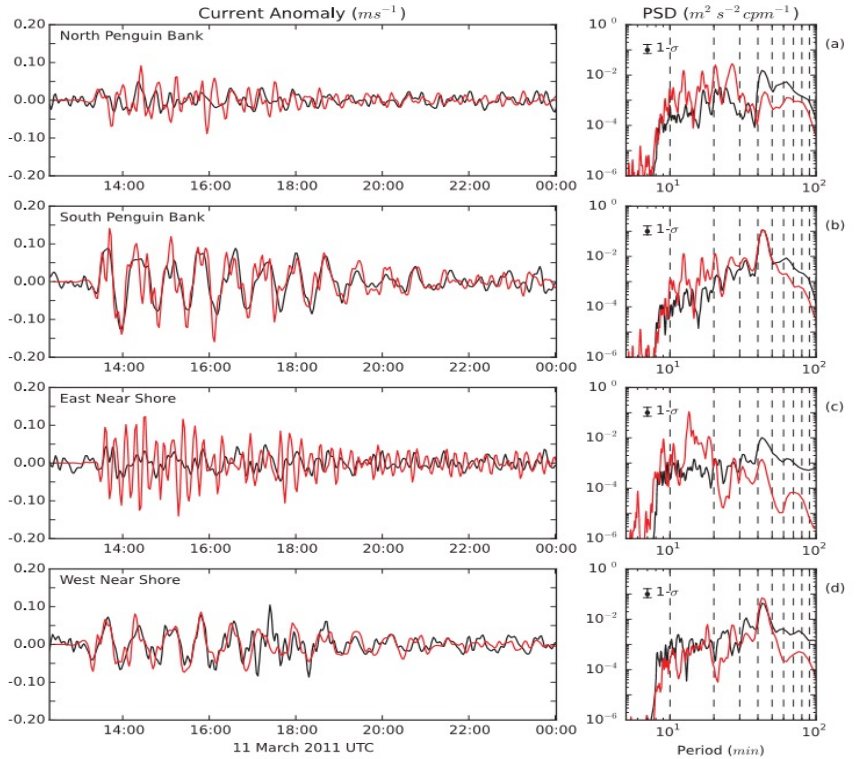
Validation with 2011 Tohoku Tsunami

- High Frequency Doppler Radar (HFDR) detection of currents south of Oahu
- Confirmation of resonance oscillations over Penguin Bank
- Discrepancies between model and recorded data due to side-lobe contamination of HFDR
- Benjamin, Flament, Cheung & Luther (2016, *Journal of Geophysical Research*)



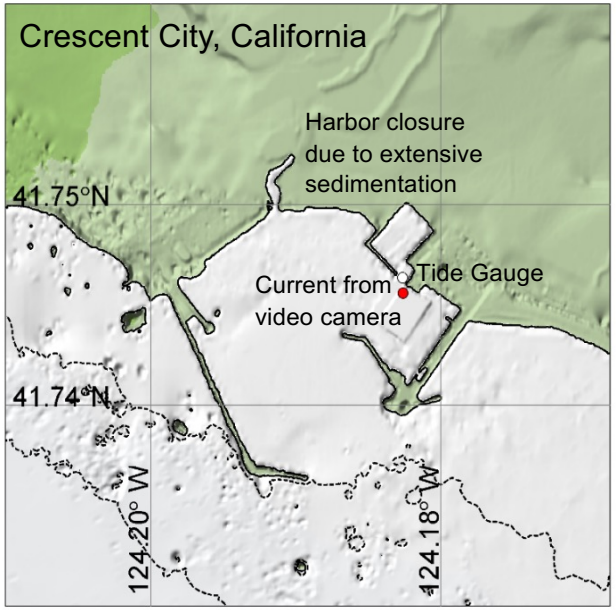
Processed Oscillation Models from HFDR and Model Data

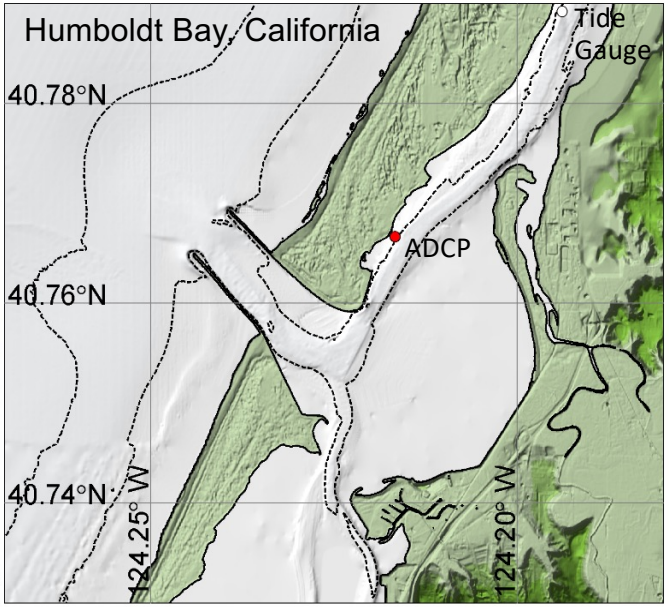


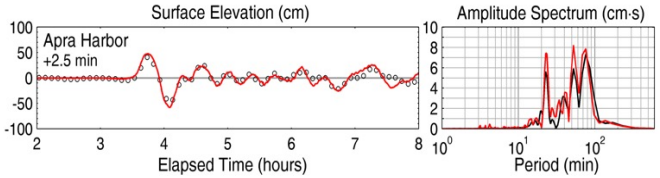


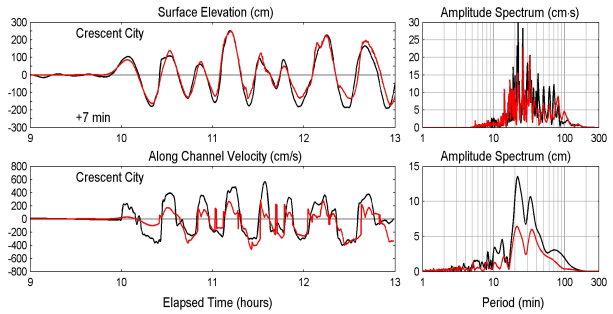
Model Validation

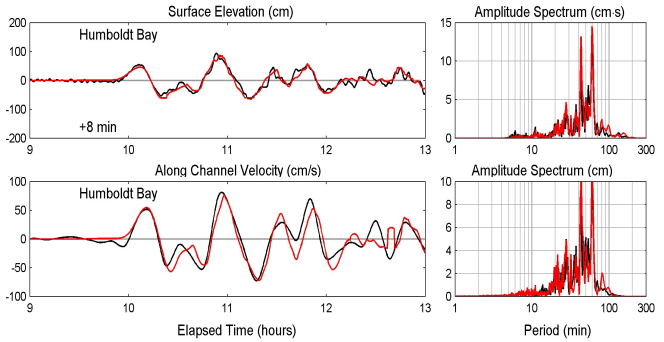
Mariana Islands and US West Coast











Concluding Remarks and Continuing Work

NEOWAVE is a proven tool for tsunami modeling and inundation mapping as evident in the validation with laboratory experiments and the 2011 Tohoku earthquake and tsunami.

Modeling of recent events in collaborating with Prof. Thorne Lay of UCSC including the 2021 Mw 8.2 Chignik, 2020 Mw 7.6 Shumagin, 2020 Mw 7.8 Simeonof, 2018 Mw 6.9 Hawaii Island, 2018 Mw 7.9 Alaska, 2017 Komandorsky Islands, 2017 Mw 8.2 Chiapas, 2016 Mw 7.8 Kaikoura, 2016 Mw 7.8 Ecuador, 2015 Mw 8.3 Illapel, 2013 Mw 8.0 Santa Cruz Islands, 2012 Mw 7.8 Haida Gwaii, 2010 Mw 7.8 Mentawai, 2009 Mw 8.1 South Pacific earthquakes and tsunamis.

Implementation of NEOWAVE for mapping of tsunami inundation and maritime hazards in support of emergency management.

Implementation of NEOWAVE for design and assessment of infrastructure, harbors, and land reclamations.