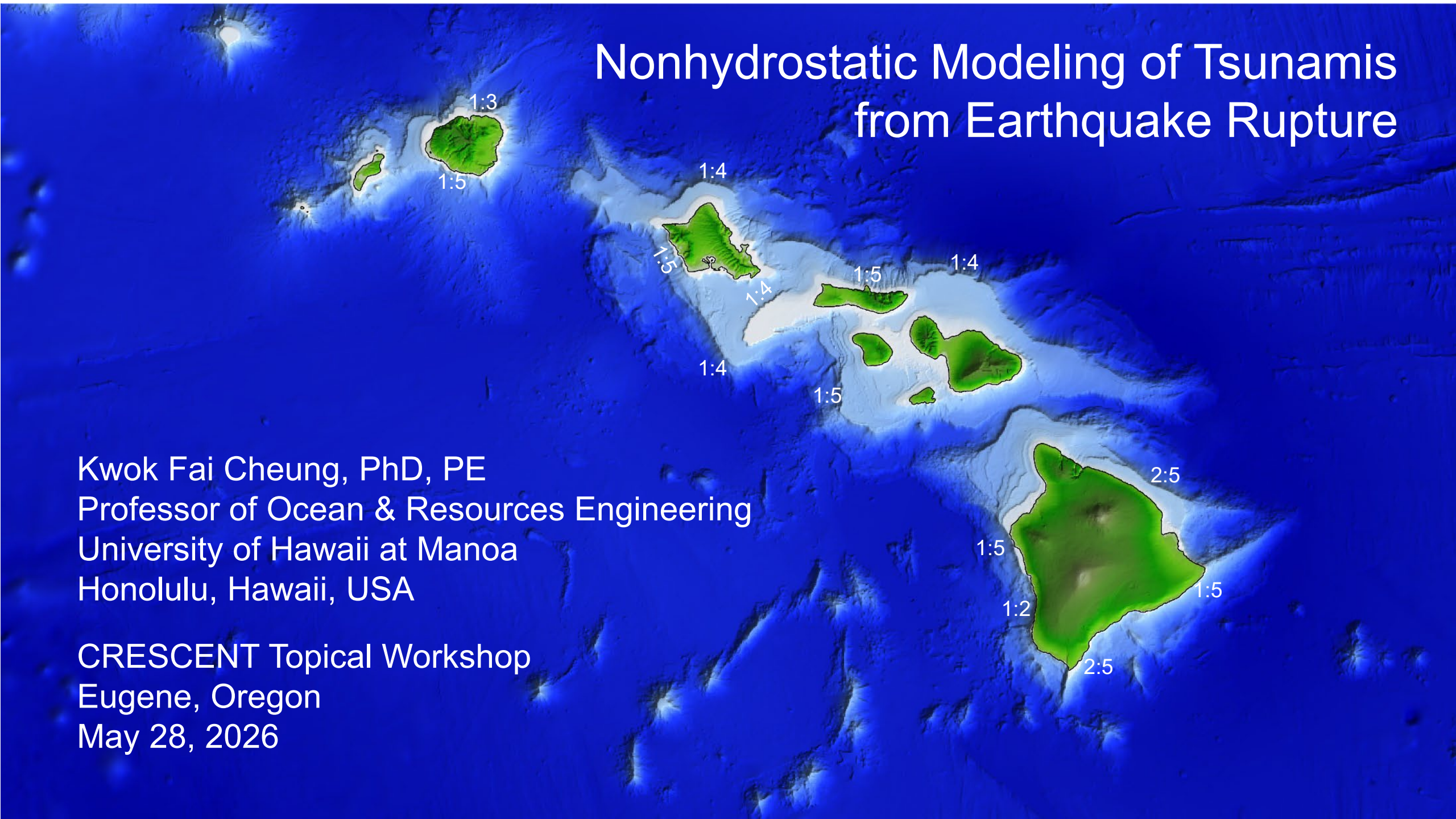


# Nonhydrostatic Modeling of Tsunamis from Earthquake Rupture

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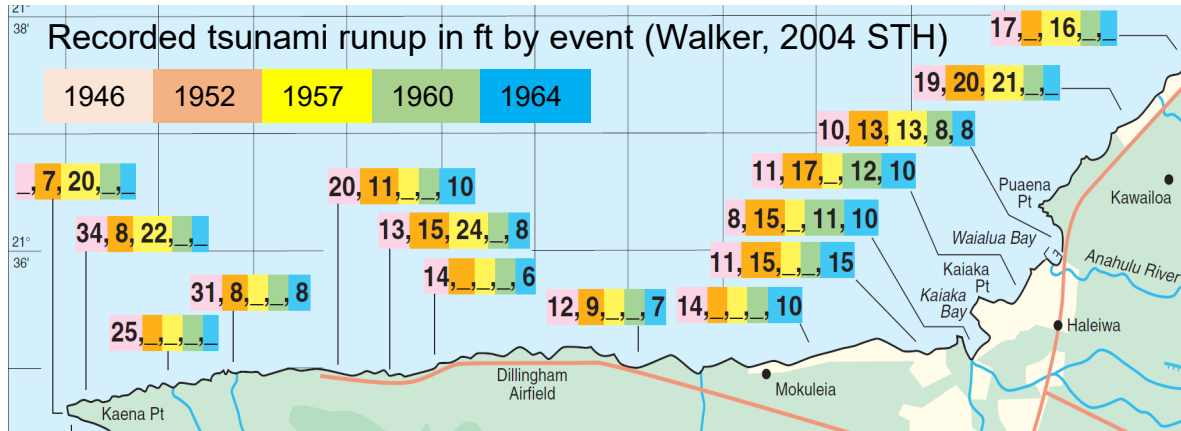
CRESCENT Topical Workshop  
Eugene, Oregon  
May 28, 2026



# Motivation for Nonhydrostatic Approach

## Hawaii's Evacuation Map Update in 2000s

- Runup records of 5 state-wide destructive tsunamis



- Hydrostatic modeling with published *uniform* slip
- 4~6x slip to match runup records

## Solution

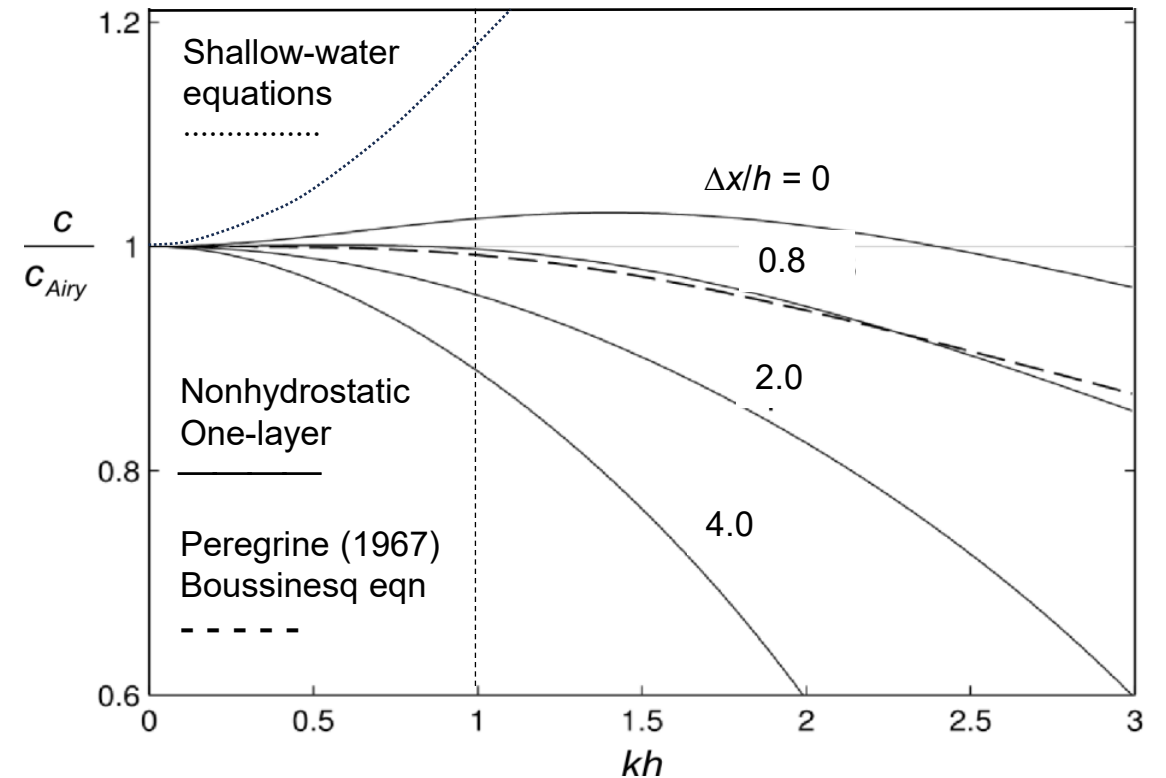
- Shock-capturing scheme → tsunami bores
- Nonhydrostatic modeling → vertical momentum
- Finite-fault tsunami source → non-uniform slip

Depth parameter  $kh = 2\pi h/L$

- $h$  = water depth and  $L$  = wavelength
- Shallow water models:  $kh \rightarrow 0$  ( $kh < \sim 0.3$  in practice)
- Tsunami range:  $0 < kh < \sim 0.6$

## Dispersion from one-layer nonhydrostatic model

- Wave celerity  $c = f(kh, \Delta x/h)$  with  $\Delta x$  denoting cell size



## Shoaling Gradient

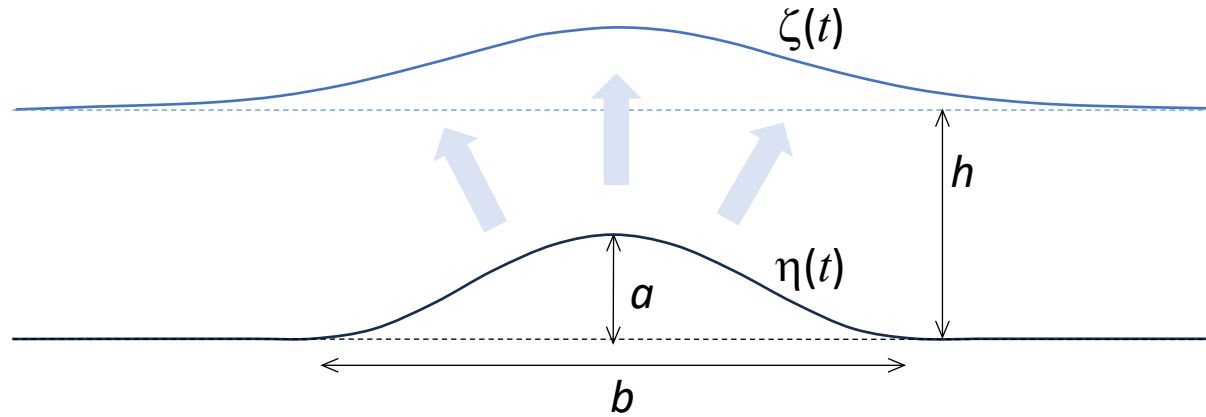
- Wave amplitude variation over slope ( $\sim \partial A/\partial h$ )

$$\gamma = \frac{1}{4} - \frac{3}{16}(kh)^2$$

- Important for shorter waves from near-trench slip

## Tsunami Generation

- Seafloor displacement  $\eta(t) \rightarrow$  boundary forcing
- Momentum transfer from vertical to horizontal



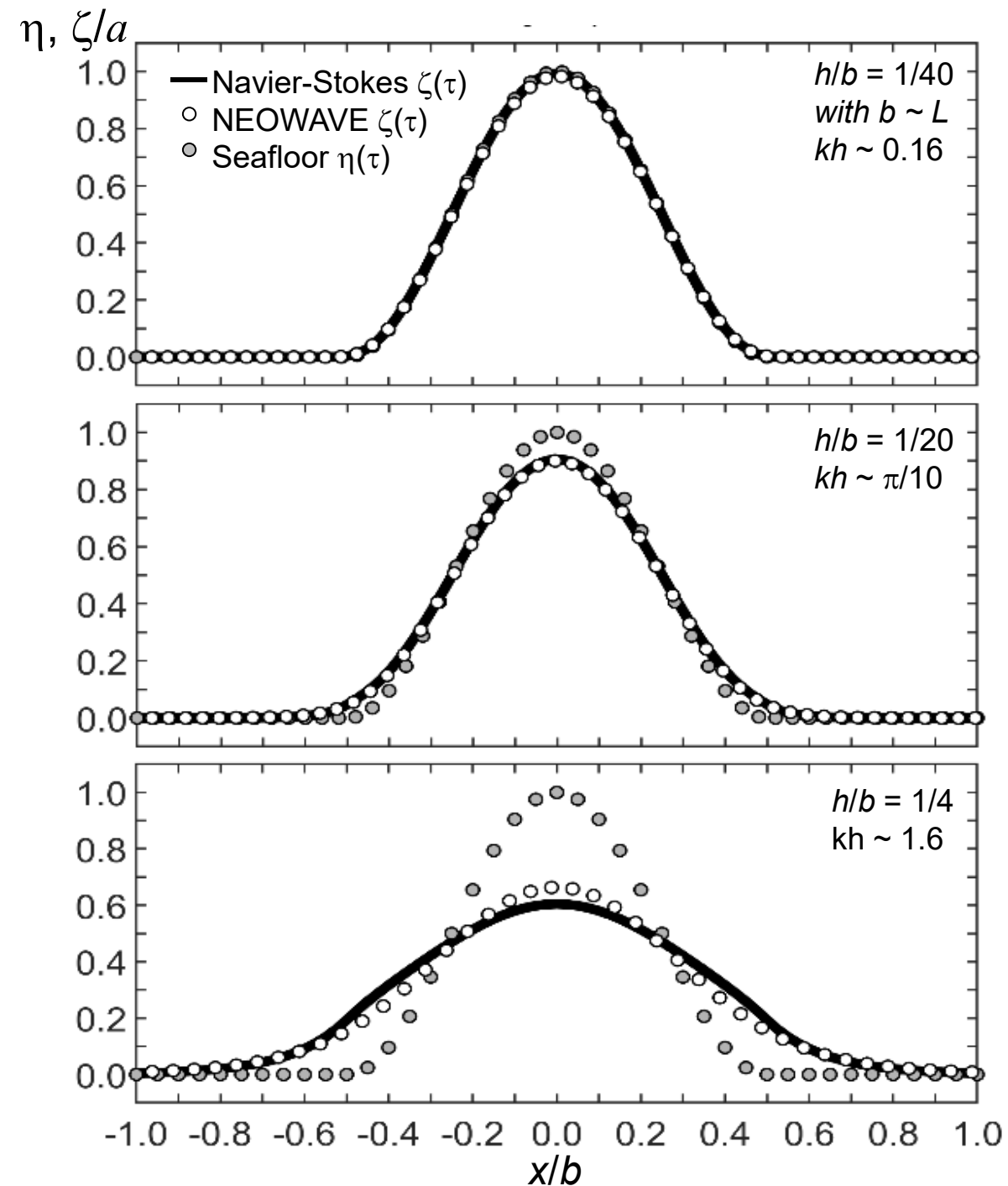
- Comparison with Navier-Stokes solver (Horrillo, 2006)  
2D hump with rise time  $\tau = 10$  s

## Nonhydrostatic Effects

- Decreasing wave amplitude and increasing wavelength & period with  $kh$

$$T = \frac{L}{\sqrt{gh \left[ 1 - \frac{1}{3} (kh)^2 + \frac{1}{16} (kh)^4 - \dots \right]}}$$

- Altering spectral content of tsunami waves with profound effects on shelf resonance and coastal impact



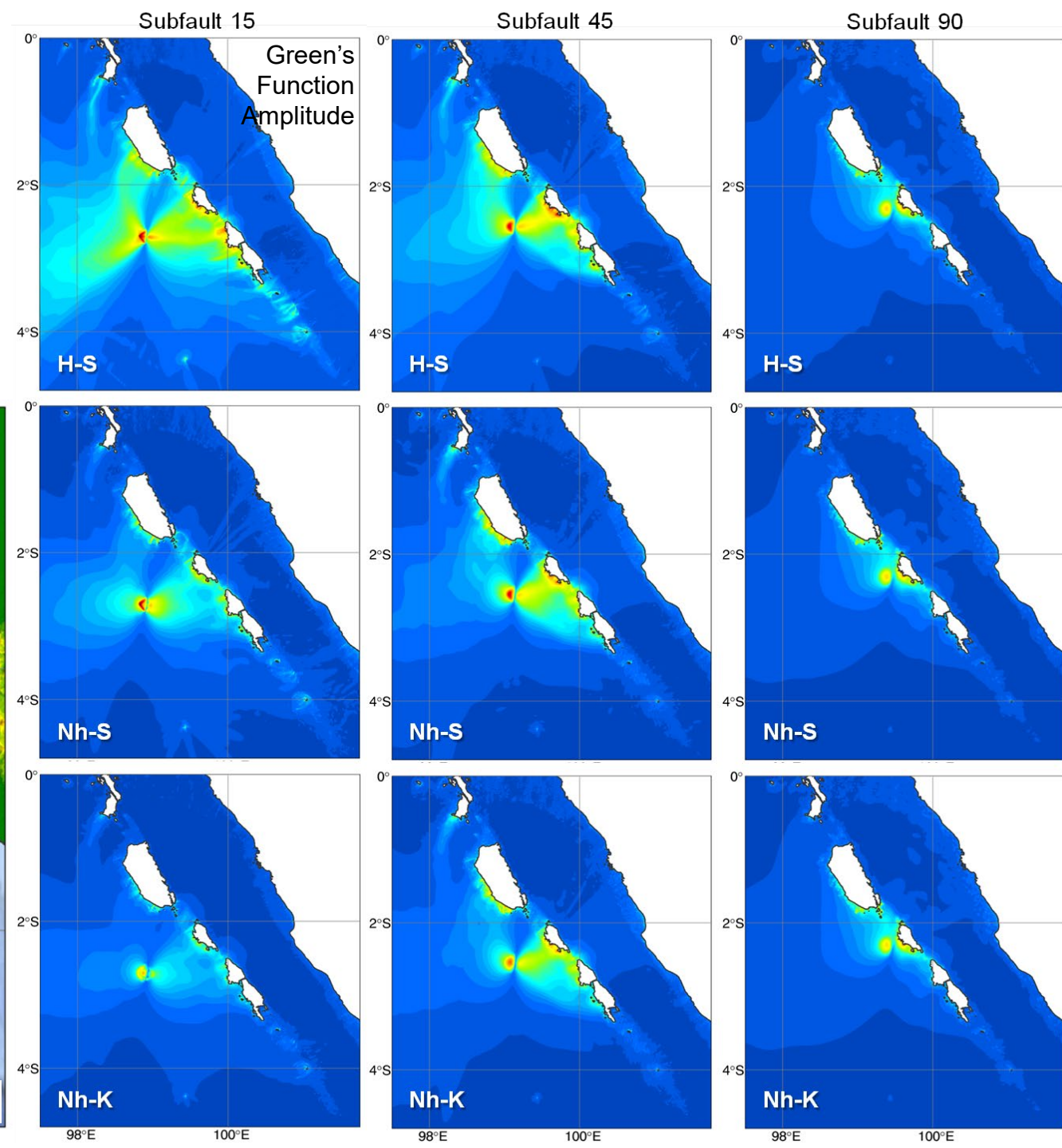
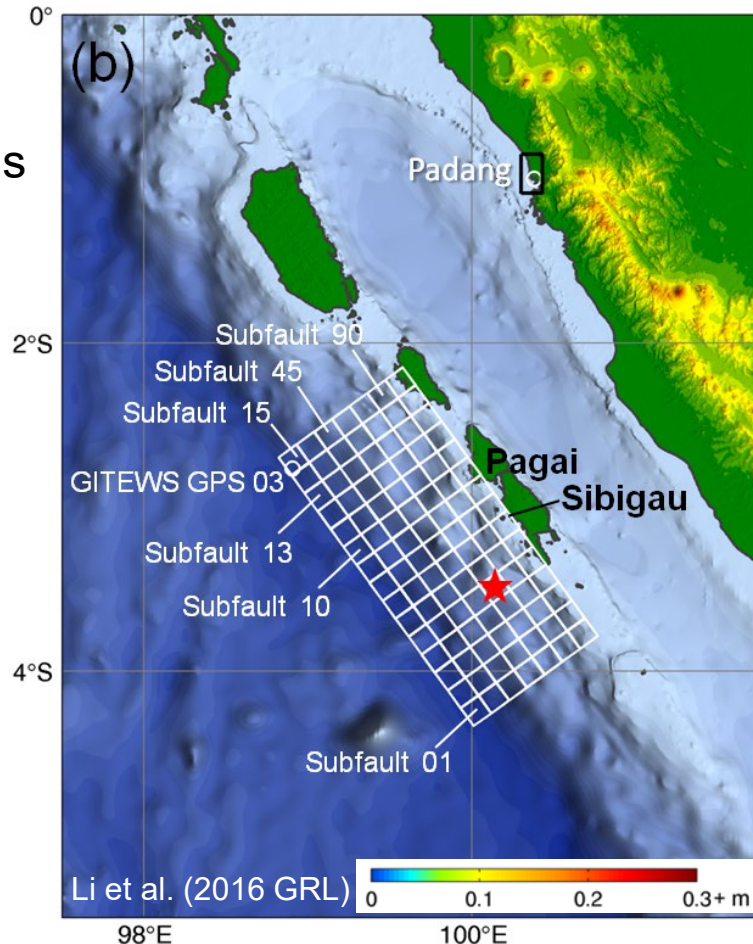
# The 2010 Mentawai Earthquake and Tsunami

## Tsunami earthquake

- Mw 7.8 with observed runup of 9 m on Pagai and 16.9 m on Sibigau
- Finite-fault models with 7 x 15 cells of 15 x 15 km each
- Tsunami waveform (2 deep-water & 2 tide stations) and joint inversion

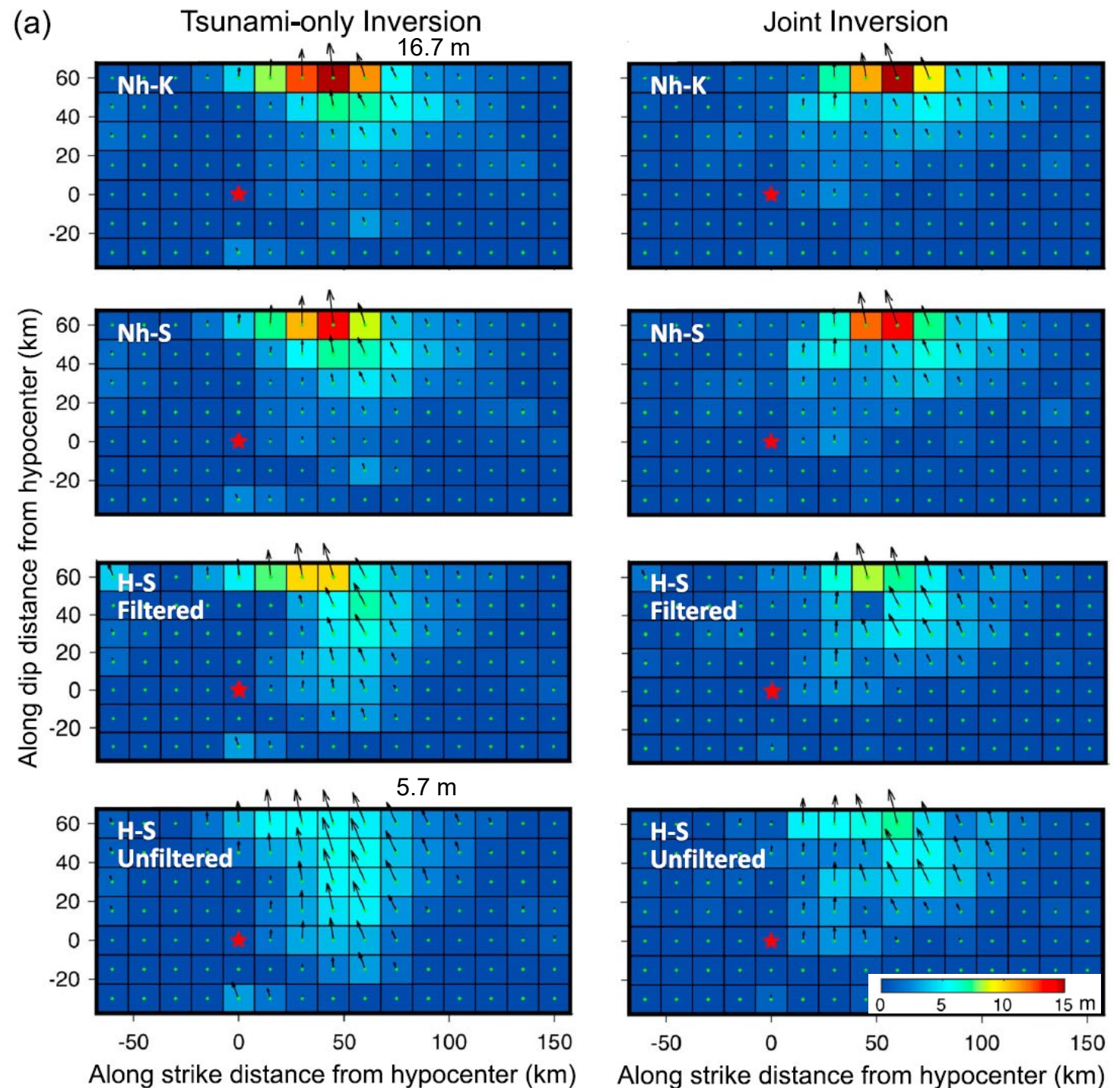
## Sensitivity Analysis with Green's functions computed from

- Hydrostatic & static initial sea surface (H-S)
- Nonhydrostatic & static initial sea surface (Nh-S)
- Nonhydrostatic & seafloor excitation (Nh-K)



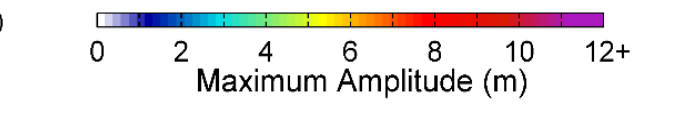
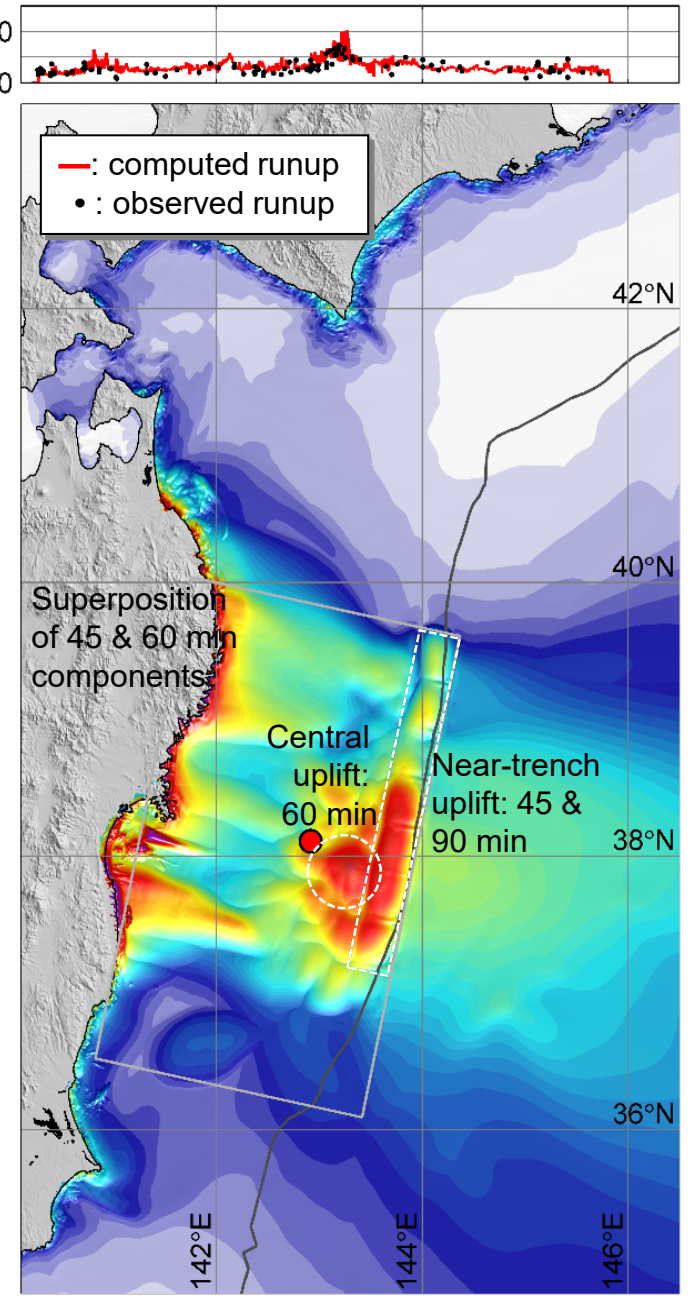
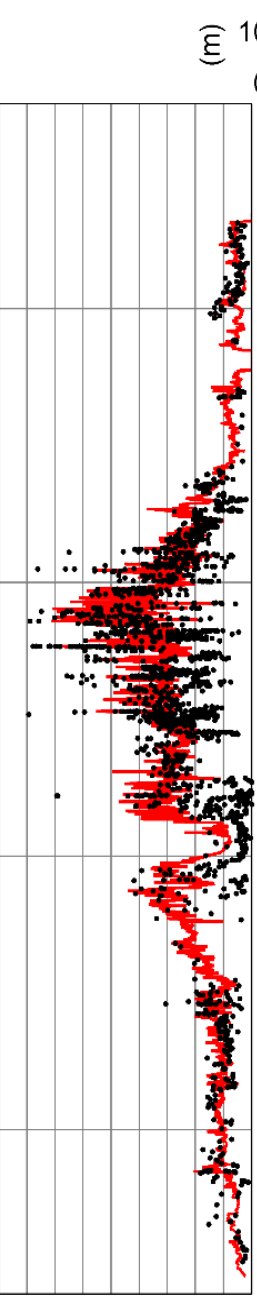
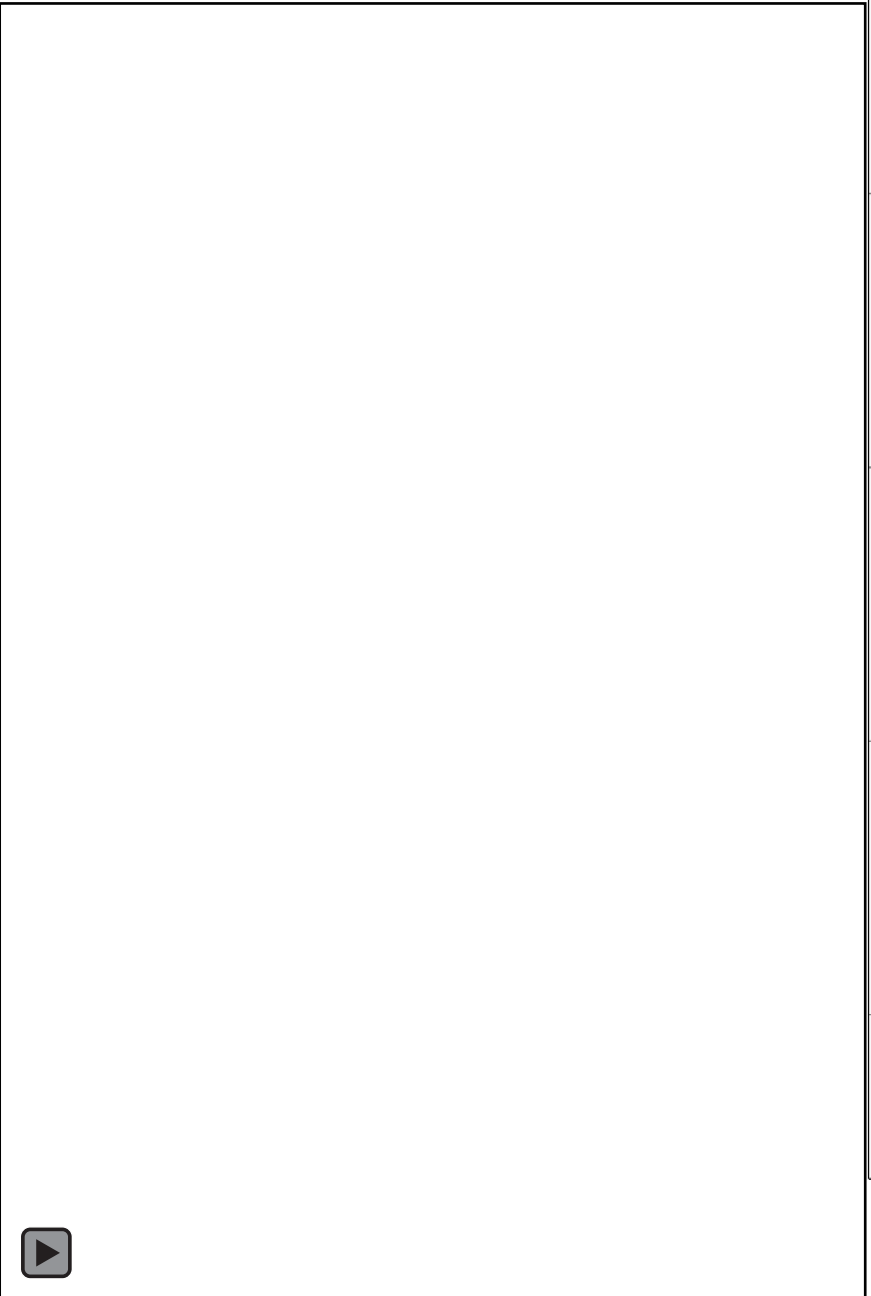
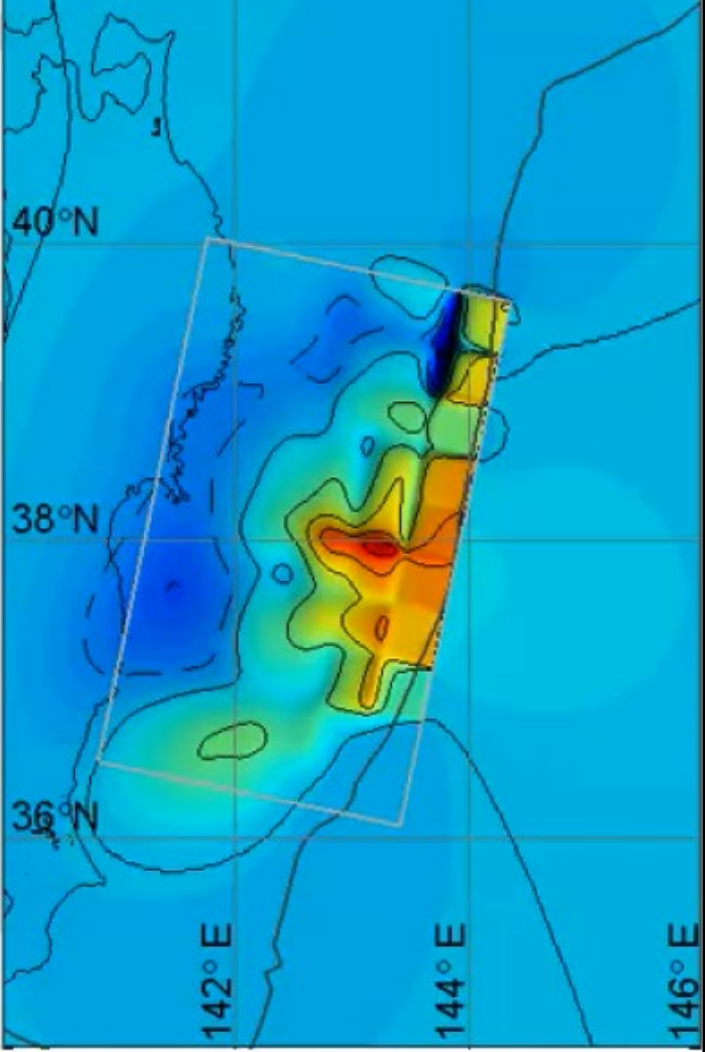
# Finite fault Inversion of 2010 Mentawai earthquake rupture

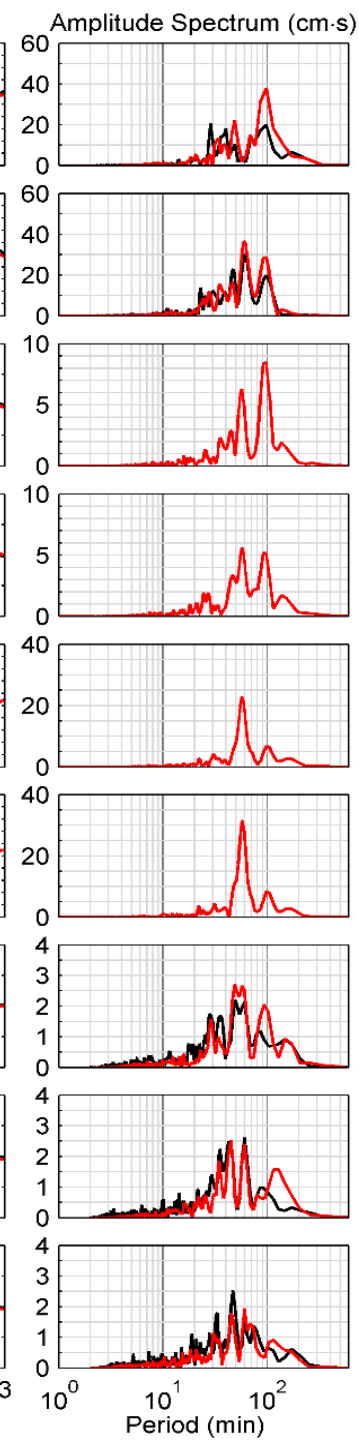
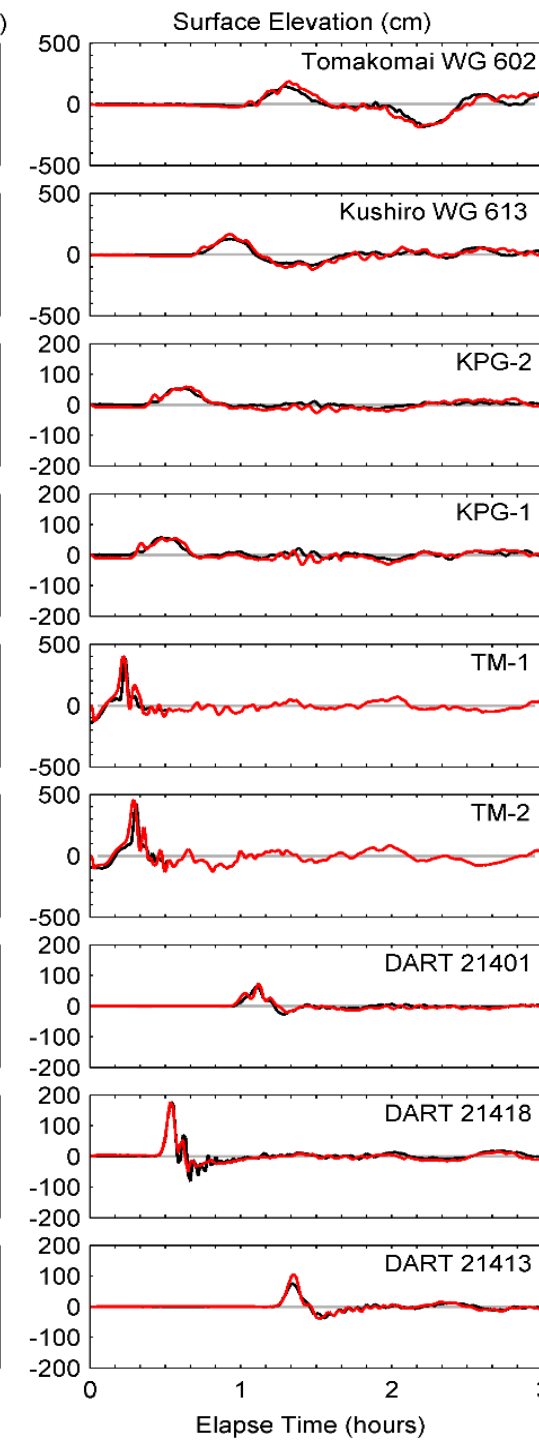
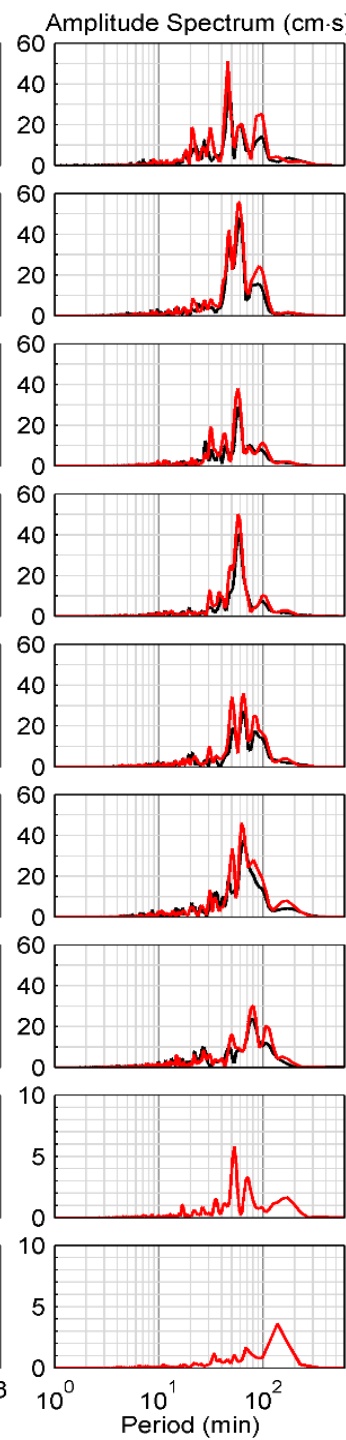
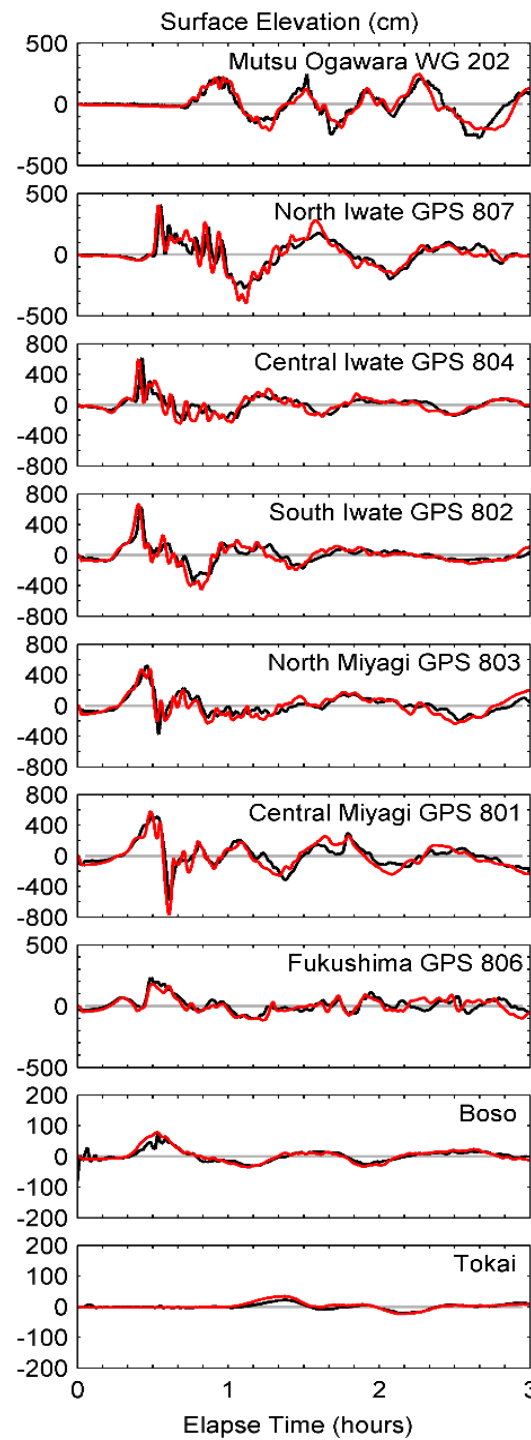
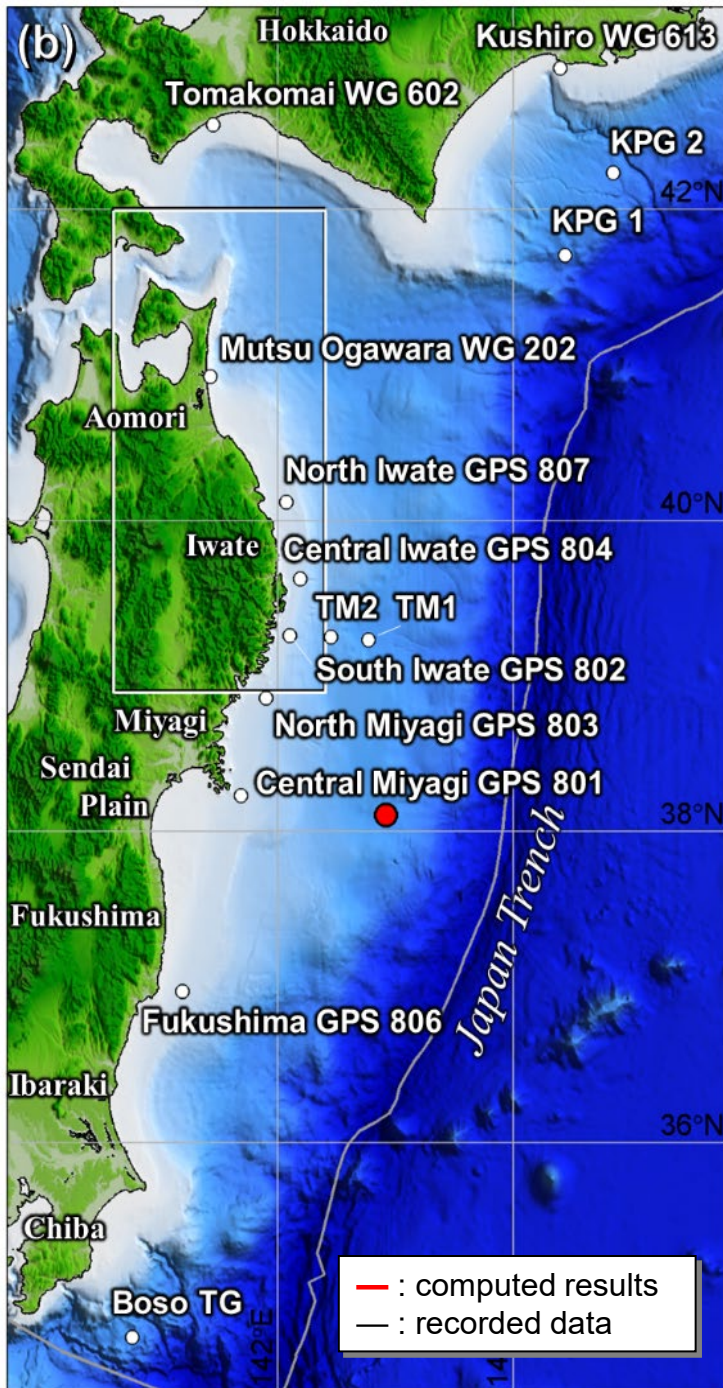
- Nonhydrostatic model is essential for resolving shallow slip
- Hydrostatic model tend to spread slip down dip to comprehensive for shifted spectral content



# The 2011 Tohoku Earthquake and Tsunami

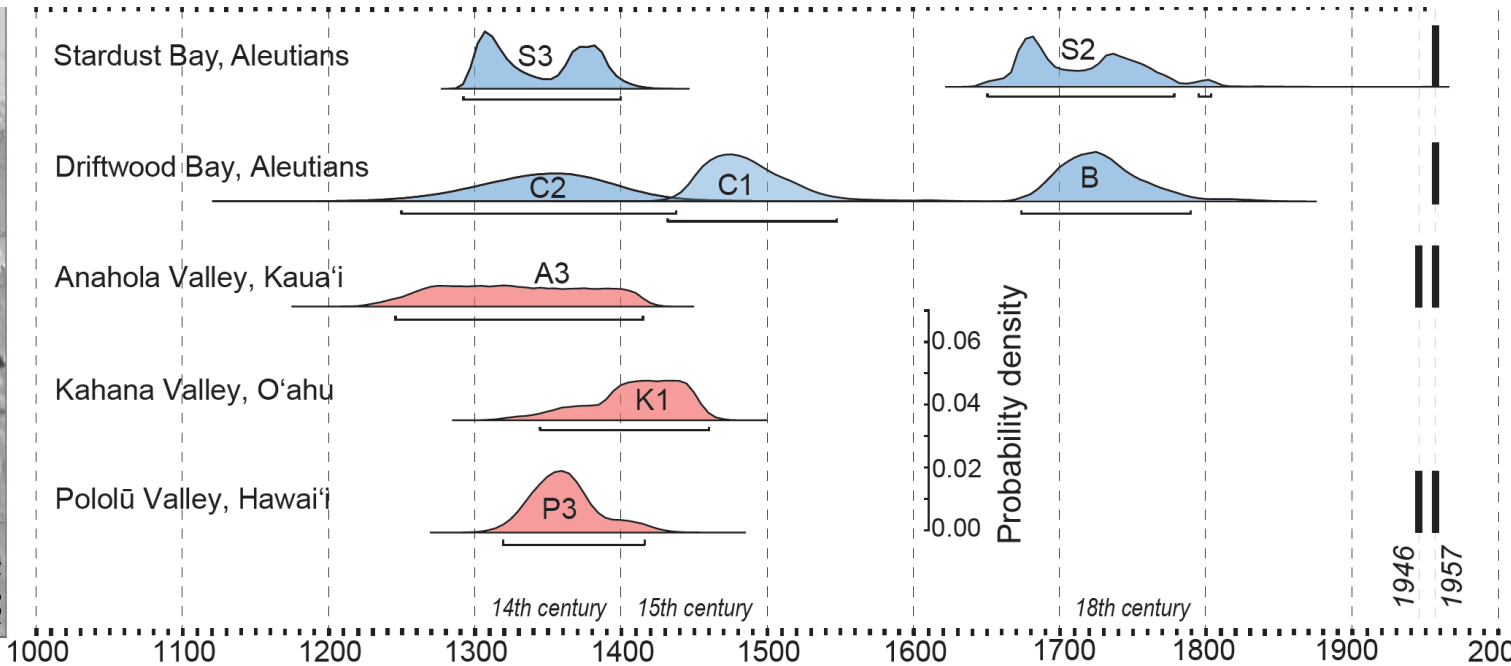
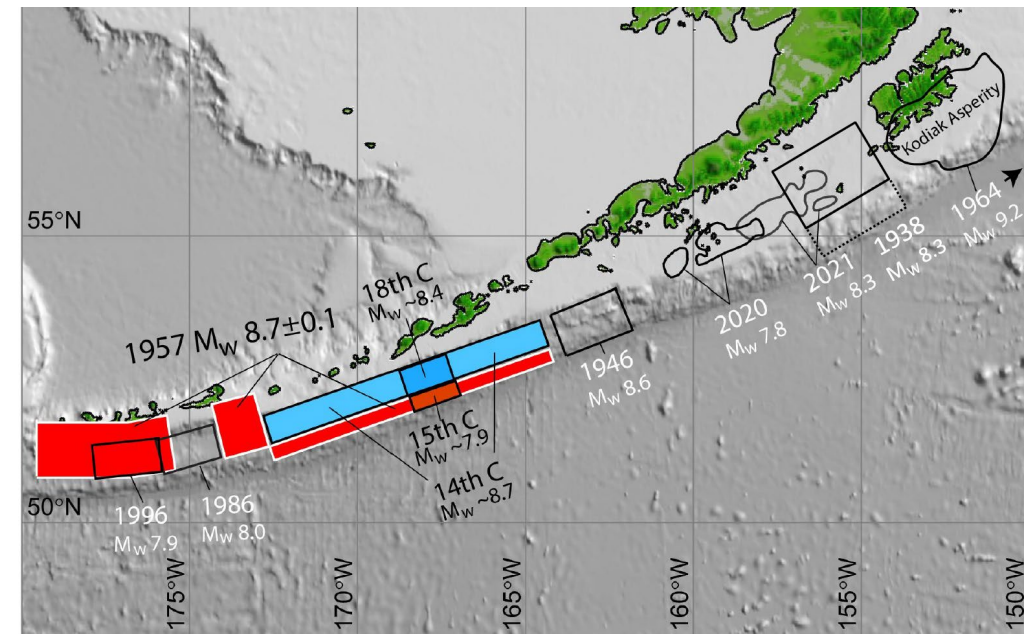
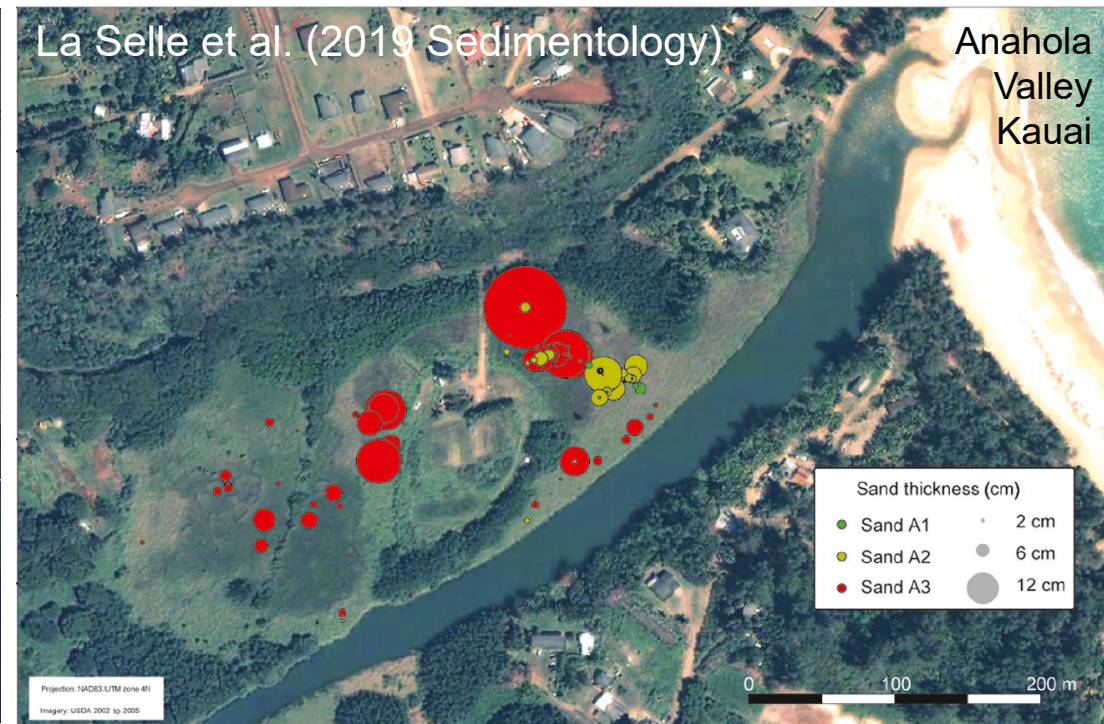
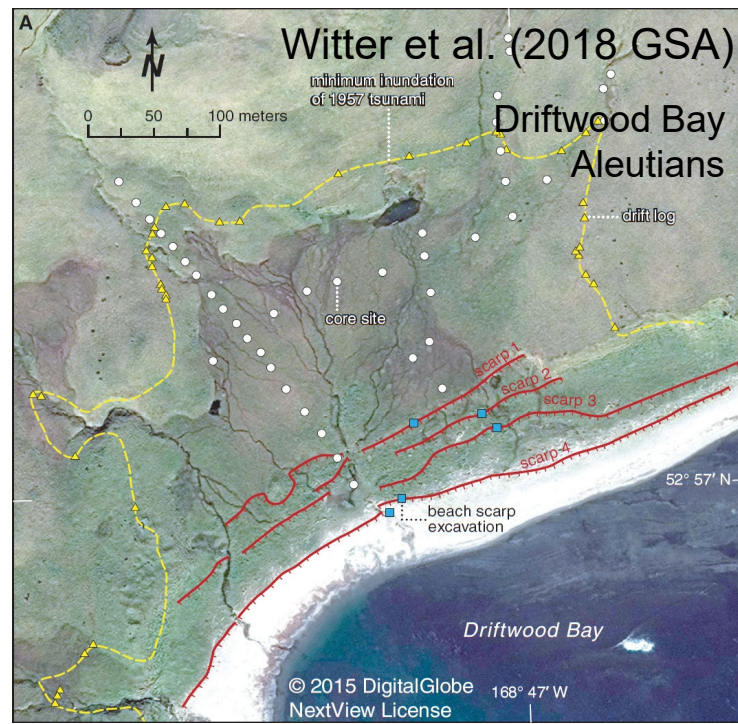
Seafloor Deformation (m) from Earthquake Rupture Model





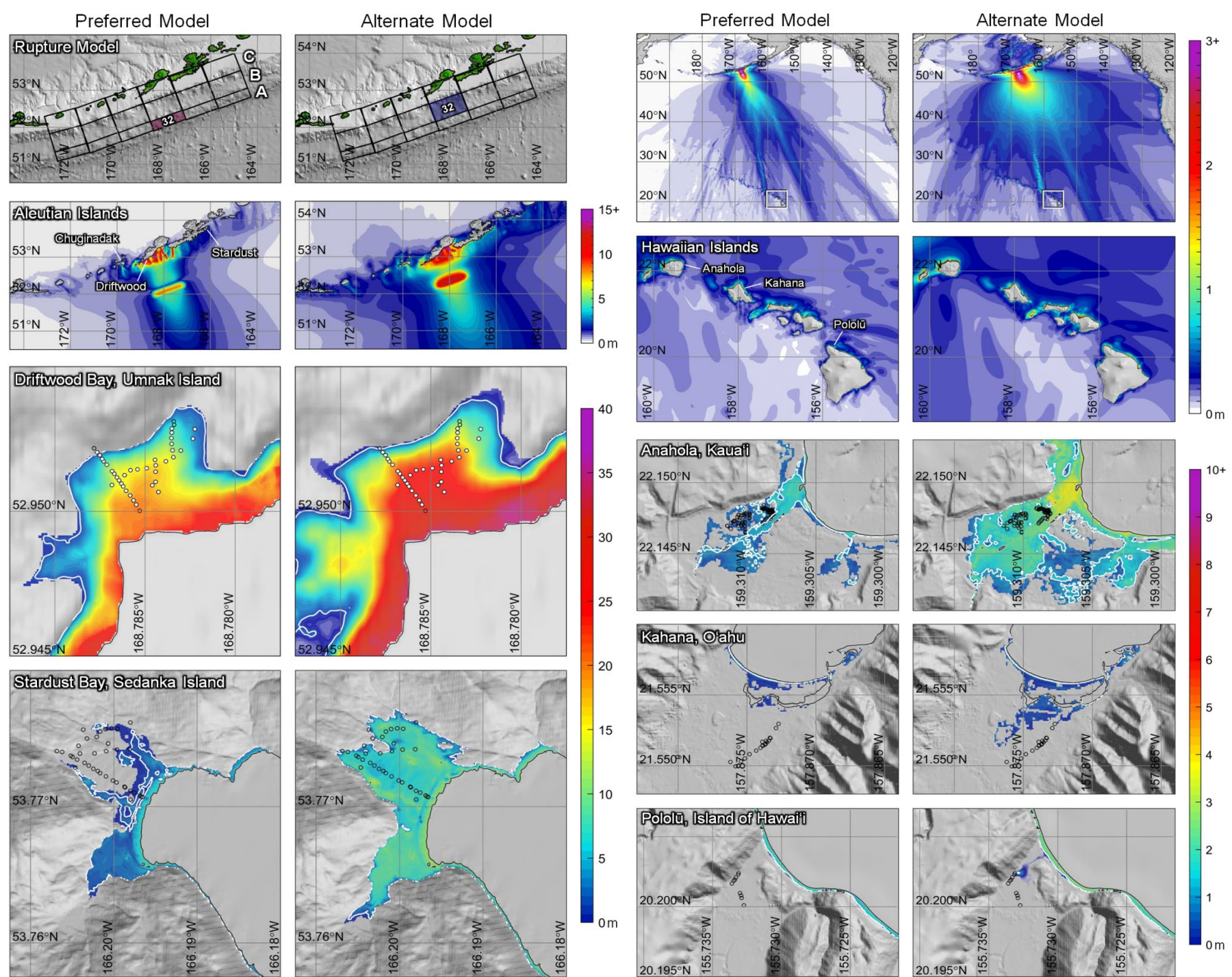
# Prehistoric Eastern Aleutian Earthquakes

- Records of marine sediment deposits in the Aleutian and Hawaii
- Modeling tsunami inundation to match inland extent of deposits
- Alternating shallow & deeper ruptures 200~300 yrs apart resolved by nonhydrostatic modeling



# Inferred 15<sup>th</sup> Century Eastern Aleutian Earthquake & Tsunami

- Two alternative solutions based on the near-field records
- Multiple sediment sites essential to constraints slip across megathrust



# Discussion and Conclusions

## Nonhydrostatic models

- Provide improved description for flow on steep slopes, shoaling, and dispersion
- Resolve period and amplitude of tsunami waves generated across the continental margin
- Realize full potential of finite-fault forward or inversion calculations.

Integration of nonhydrostatic and finite-fault modeling is a proven tool for investigation of shallow faulting and tsunamigenesis.