Boussinesq-Modeling of Tsunami Propagation in Columbia River

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Effects of Frequency Dispersion on Tsunami Propagation and Runup

• Seismically-generated tsunamis
- 2004 Indian Ocean Tsunami (Glimsdal et al., 2006; Grilli et al., 2007; Ioualalen, et al., 2007)
- 2009 Samoa Tsunami (Zhou et al., in preparation)

• Landslide-generated tsunamis (e.g., Lynett and Liu, 2002; Løvholt et al., 2008; Fuhrman and Madsen, 2009; Zhou and Teng, 2010)

• Madsen and Mei (1969, *JFM*):
While a long wave propagates over uneven seafloor, it may become disintegrated into shorter waves.

• Runup of a long wave on plane slope may also experience dispersive effects

Boussinesq-type approach in nested grids

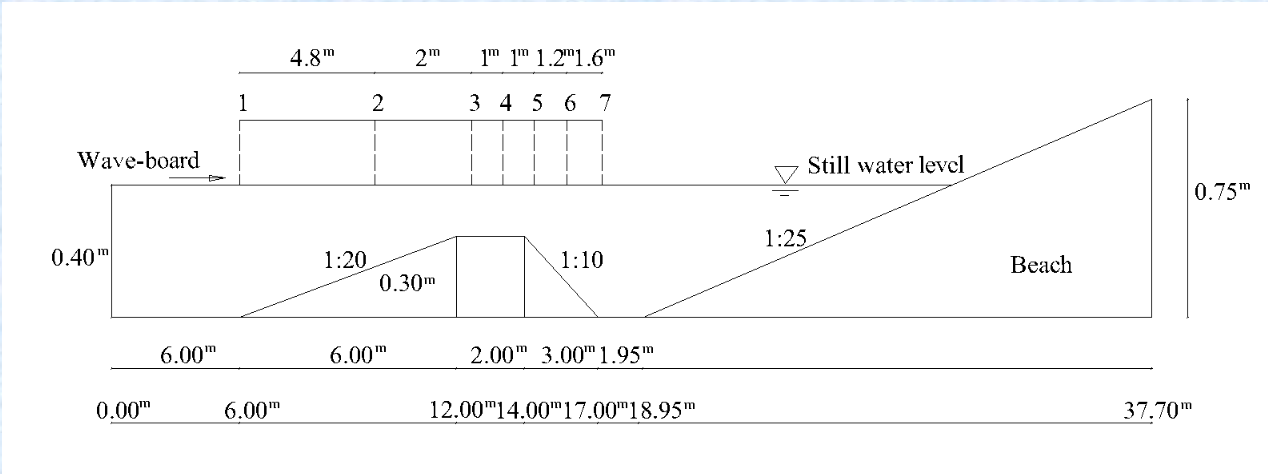
Background:

- Entire tsunami lifespan involves processes of different features at different spatial and temporal scales.
- Most tsunami simulating packages employ nested grids (MOST, COMCOT, etc.)

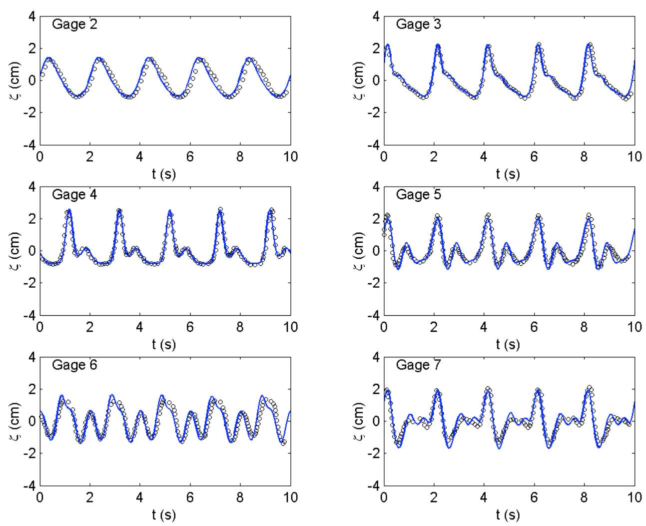
Structure:

- Nwogu's (1993) Boussinesq model converted into geographical coordinates (GB)
- Wei et al.'s (1995) fully nonlinear Boussinesq-type model (FB)
- Computed results interpolated and input into a nested grid as boundary conditions (one-way nesting)

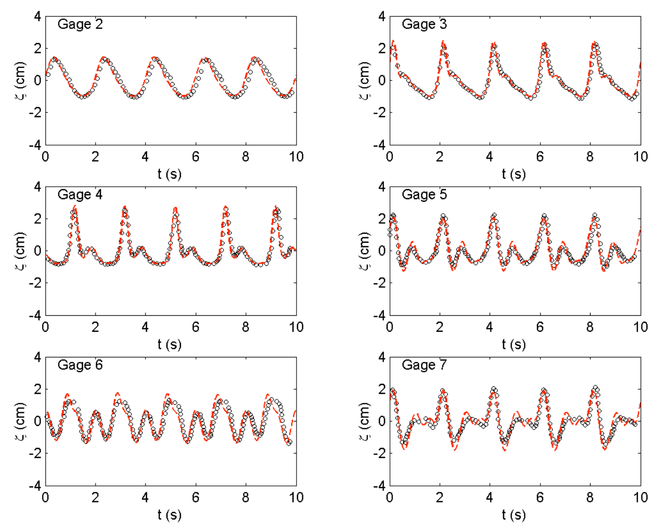
Validations— regular waves propagating over a submerged sill (Beji & Battjies, 1993, 1994)



Wave period: 2.0 s
Wave height: 0.02 m
Resolution: 0.05 m

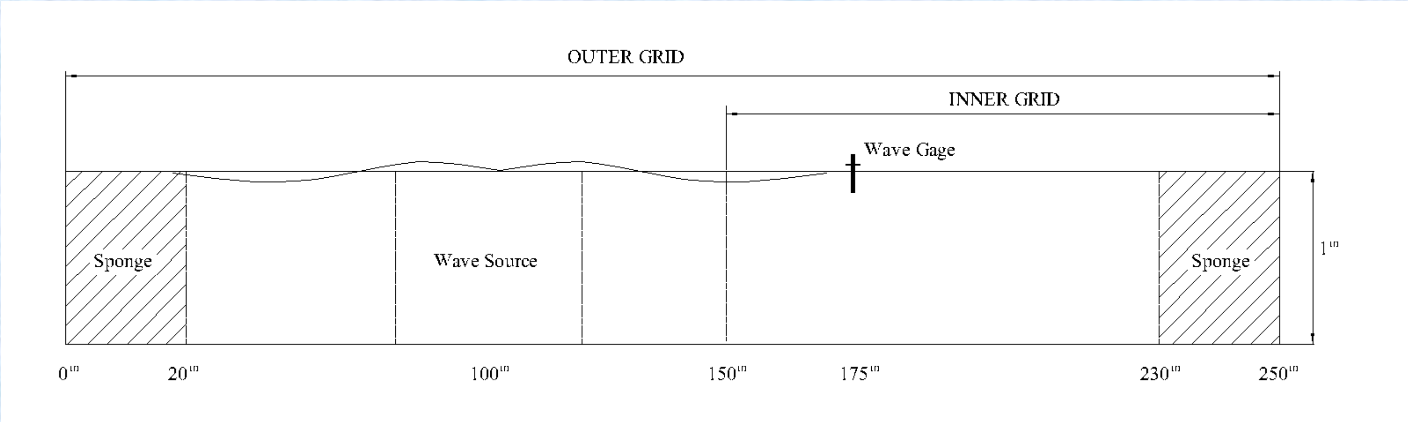


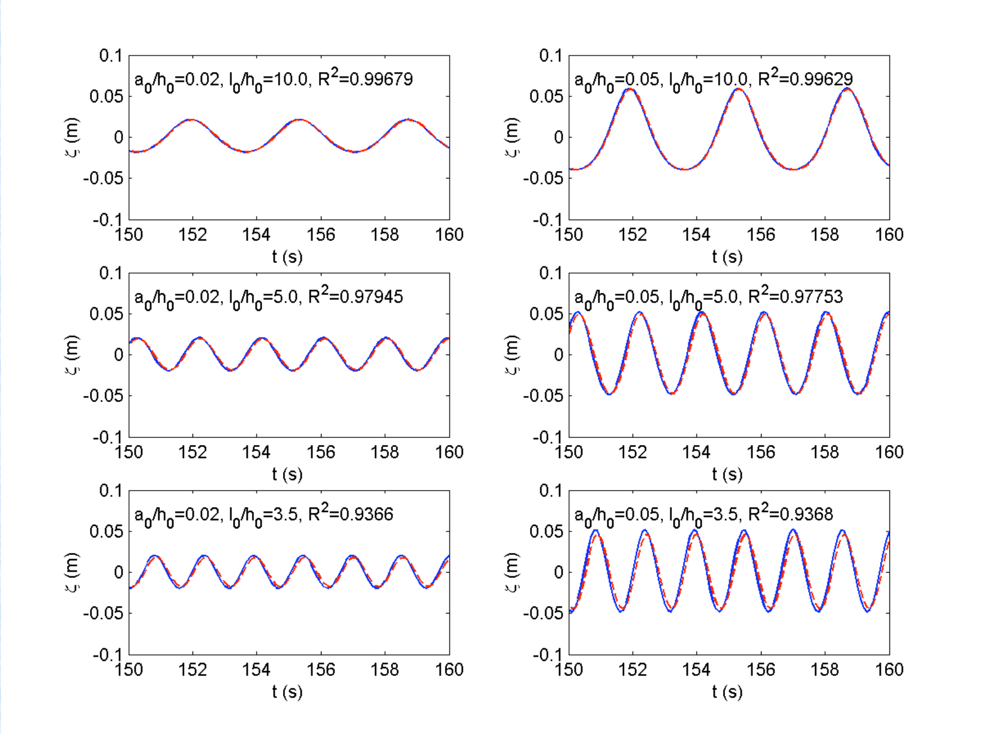
FB: solid; measurements: circle



GB: dash; measurements: circle

Validations—test of nesting scheme

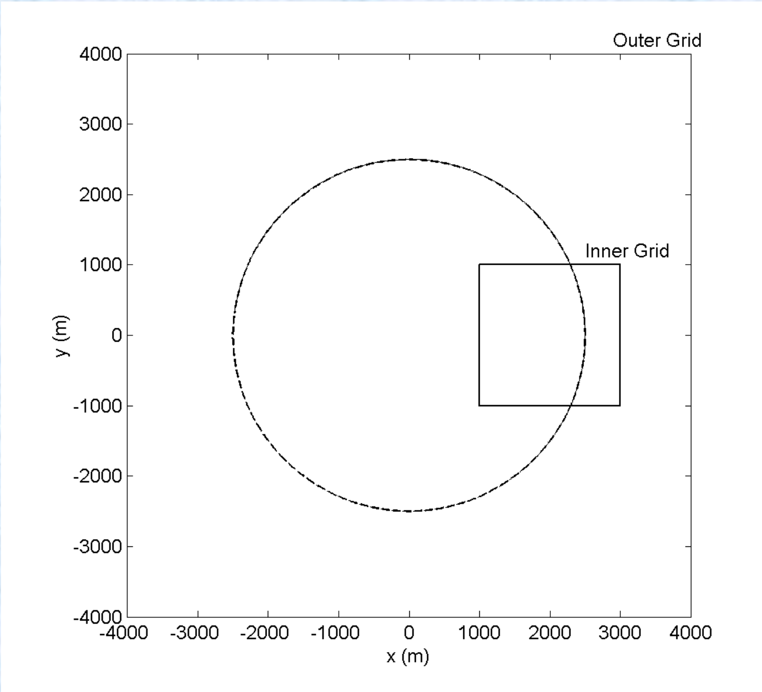




- Sinusoidal waves
- Resolutions: 0.1m (outer)
  0.02 m (inner)

Outer grid: solid; inner grid: dash

Validations— long wave oscillation in a parabolic basin (Thacker, 1981)



Outer grid: GB, resolution of 25 m;
Inner grid: FB, resolution of 5 m.

Bathymetry: $h(r) = h_0(1 - r^2/a^2)$

Profile: $\zeta(r,t) = h_o\left\{\frac{\sqrt{1-A^2}}{1-A\cos\omega t} - 1 - \frac{r^2}{a^2}\left[\frac{1-A^2}{(1-A\cos\omega t)^2} - 1\right]\right\}$

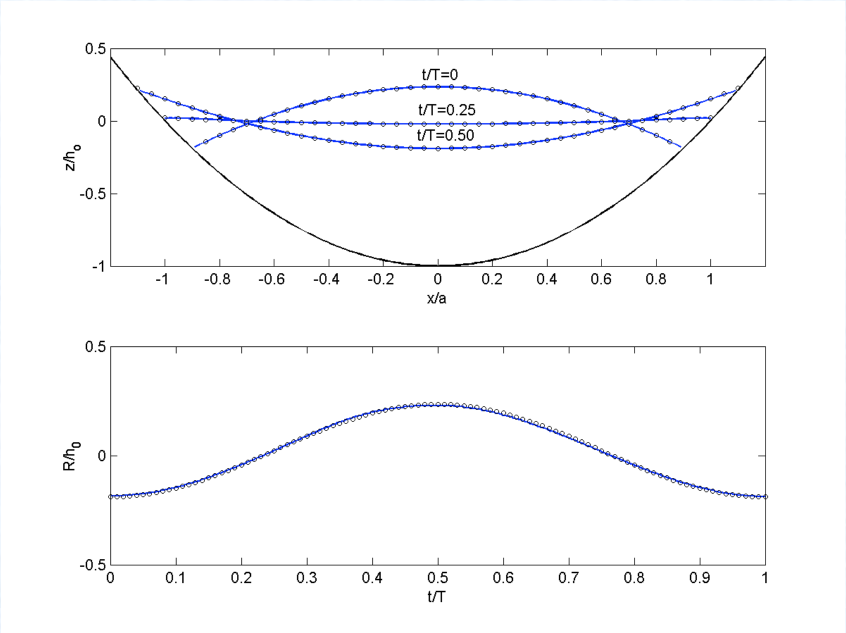
Runup: $R = -h_o\left(1 - \frac{1-A\cos\omega t}{\sqrt{1-A^2}}\right)$

$A = (a^4 - r_o^4)/(a^4 + r_o^4)$

$r_o/a = 0.9$

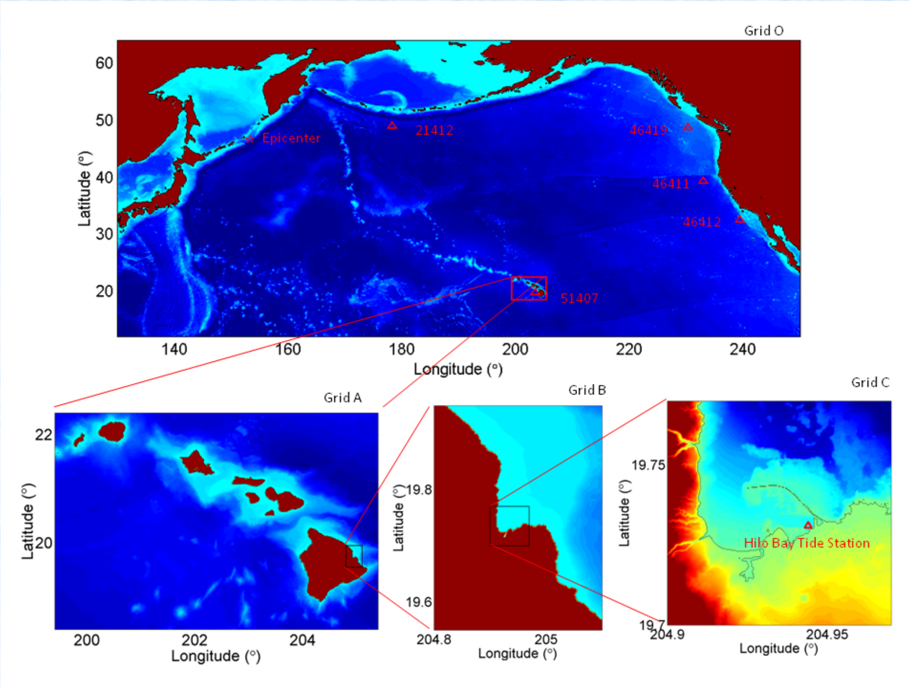
$a = 2500\ \text{m}$

$h_o = 1.0\ \text{m}$



Model: solid; analytical solution: circle

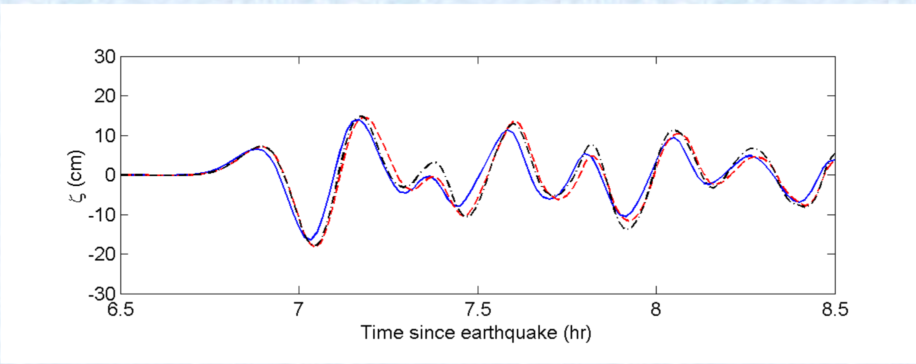
Validations— the 2006 Kuril Islands Tsunami



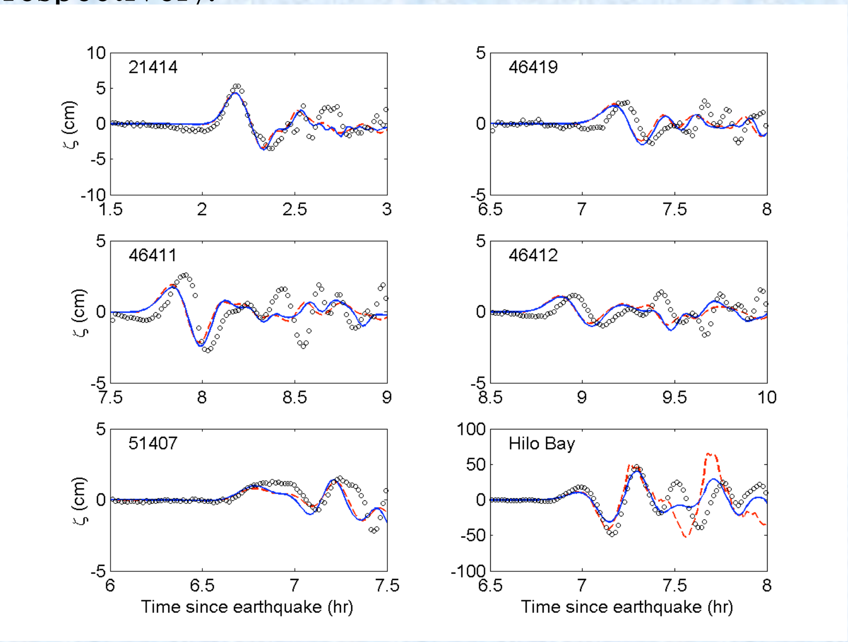
Time: 11:14:16 UTC, 11/15/2006
Earthquake: 8.3 Mw
Epicenter: (46.683° N, 153.226° E)

Resolutions: 4 min, 30 sec, 6 sec, 1 sec.

Simulations conducted in same grids with the Boussinesq-type models and MOST, respectively.



Checking point at (19.75° N, 155.07° W)
Grid A: solid; Grid B: dash; Grid C: dash-dot



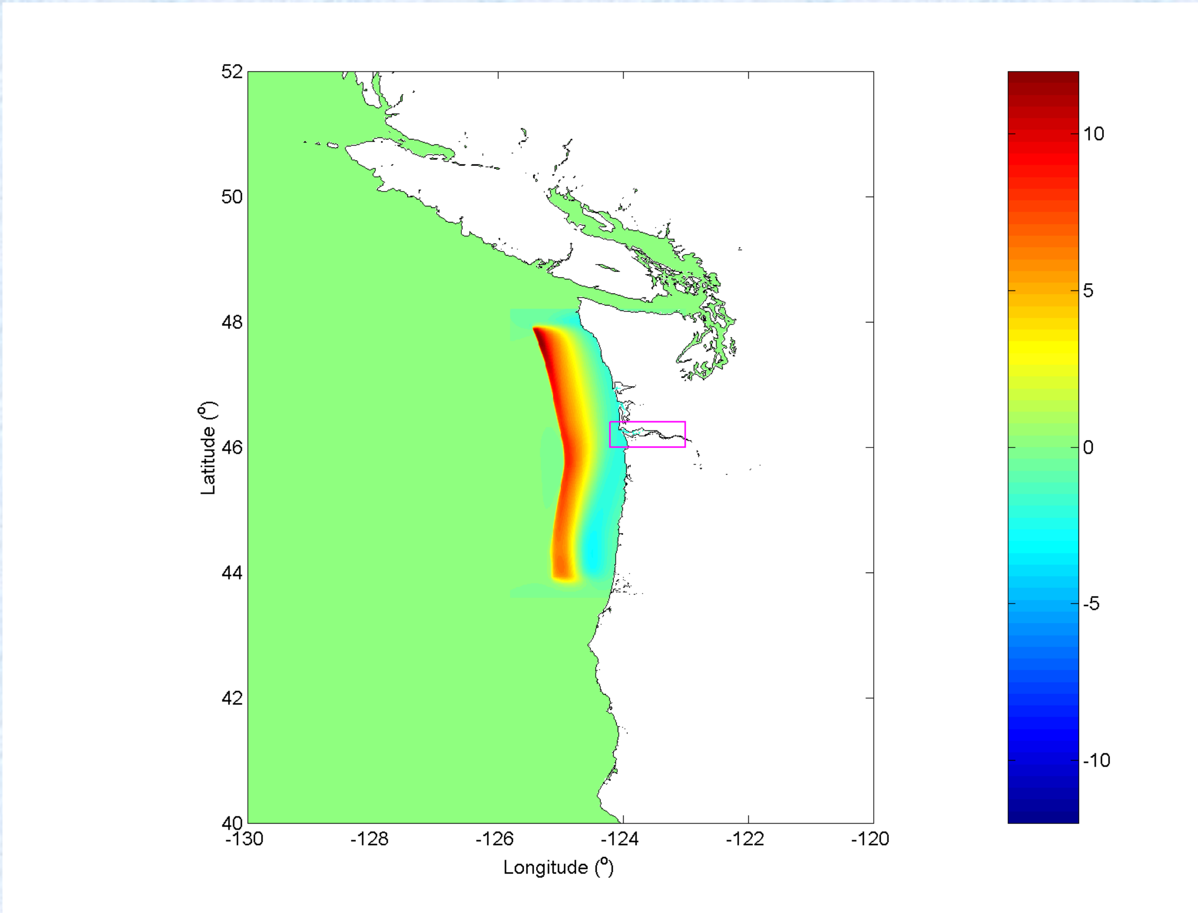
Boussinesq: solid; MOST: dash; measurements: circle

Question:

Is dispersion involved in tsunami propagation in Columbia River?

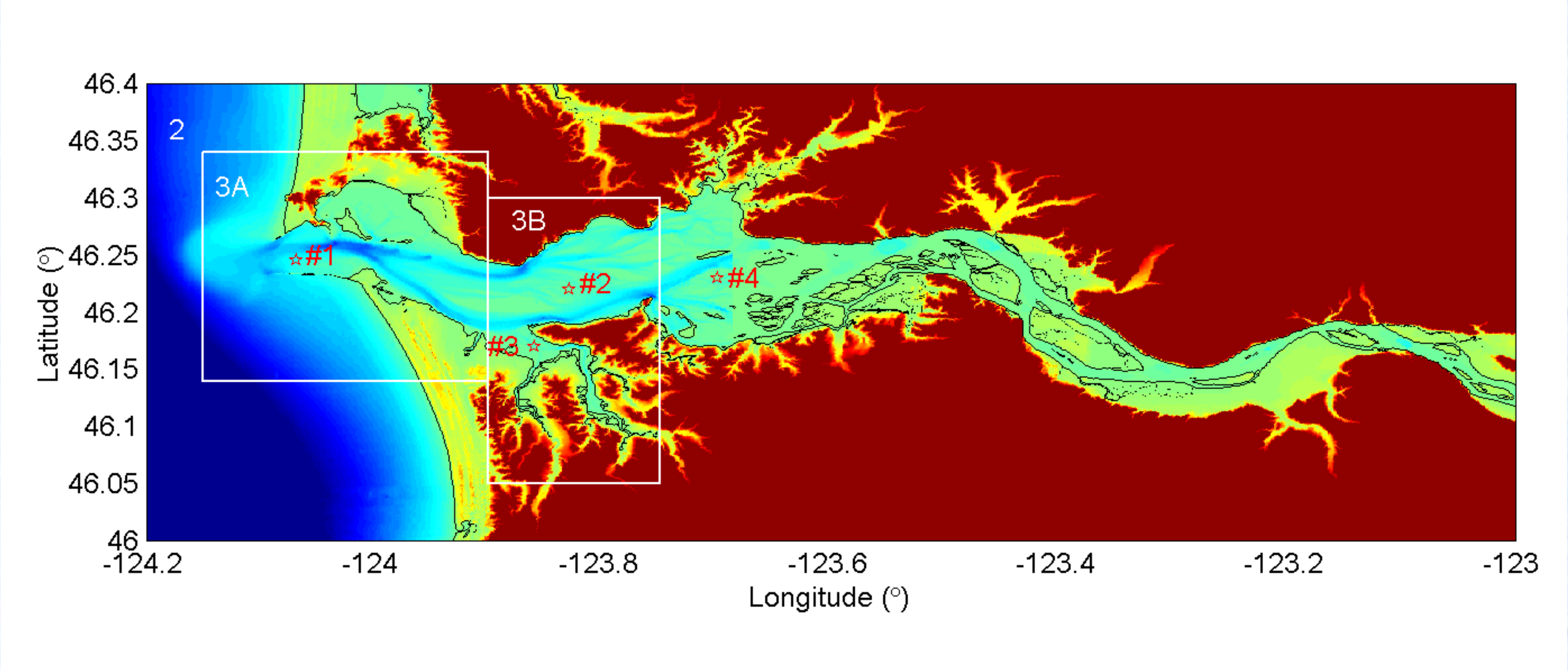
We simulate the process through models w/ and w/o dispersion.

Tsunami Propagation in the Columbia River



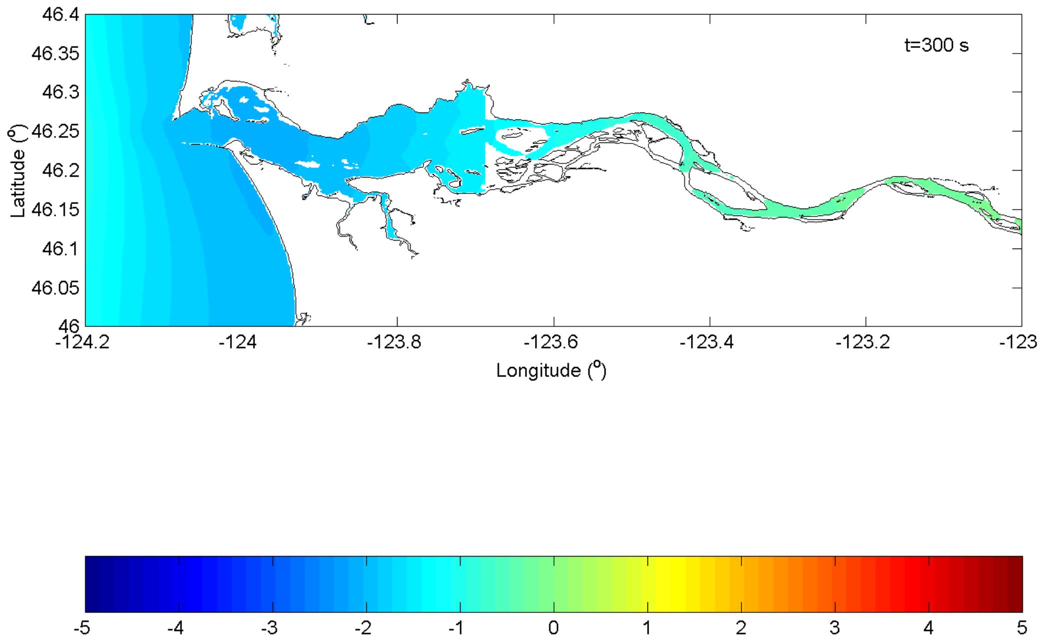
Wave height ~15.0 m, max. water surface elevation ~12.0 m.
Simulated w/ dispersion and w/o dispersion.
No tide or river flow considered.
Resolution: 40 arc sec. (Long.) by 30 arc sec. (Lat.)

Tsunami Propagation in the Columbia River



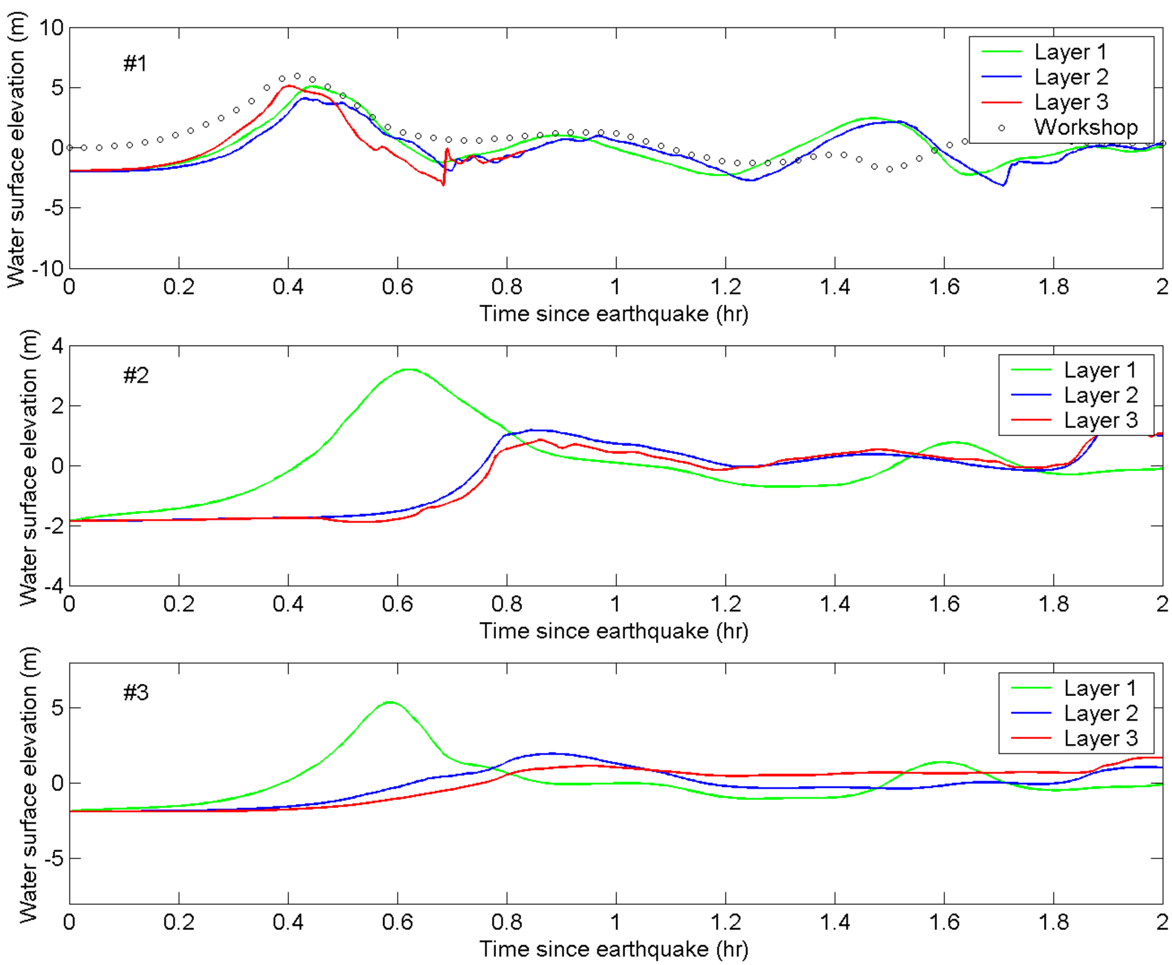
Simulated w/ and w/o dispersion.
Layer 2 resolution: 4.5 arc sec. (Long.) by 3.0 arc sec. (Lat.)
Layer 3 resolution: 1.5 arc sec. (Long.) by 1.0 arc sec. (Lat.)

Tsunami Propagation in the Columbia River



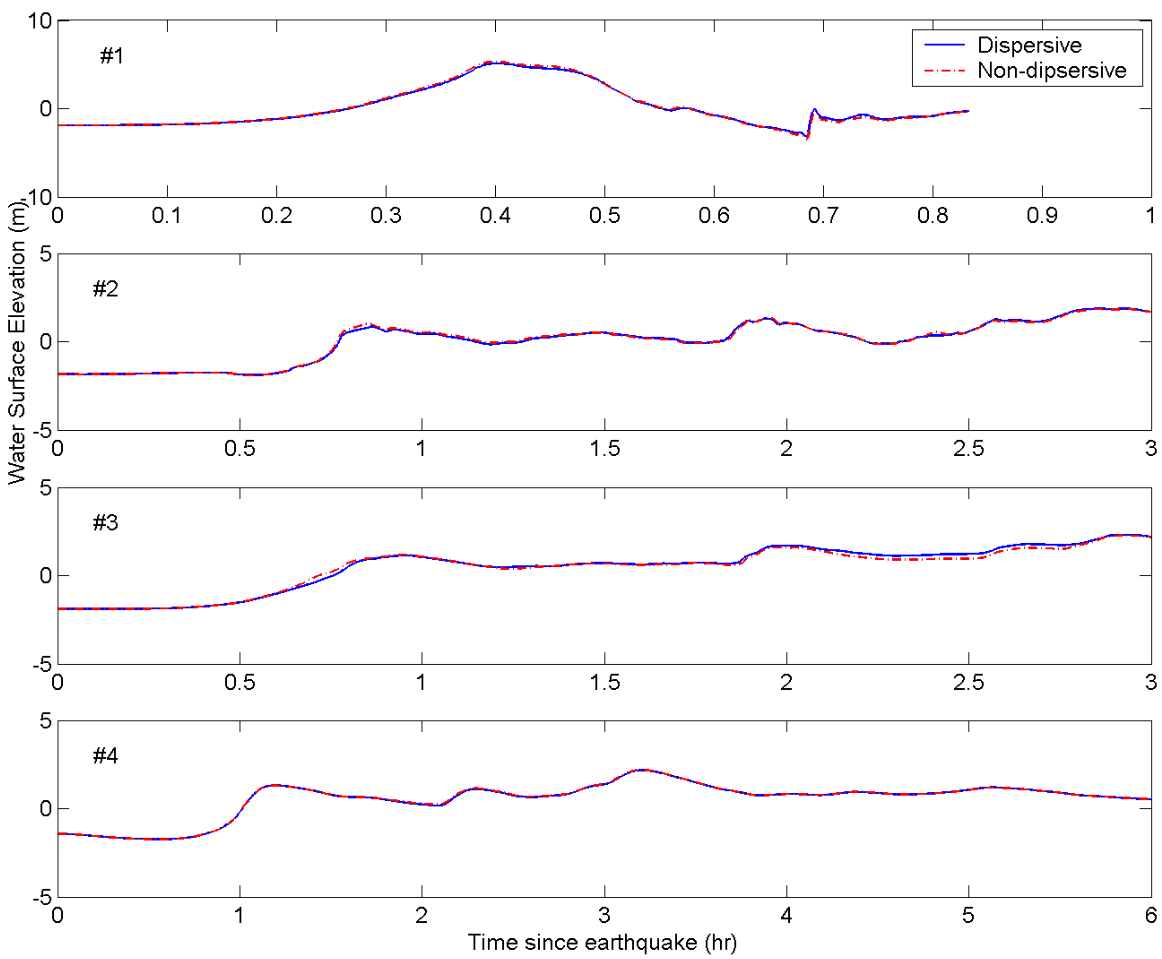
Tsunami Propagation in the Columbia River

Test of numerical convergence



Tsunami Propagation in the Columbia River

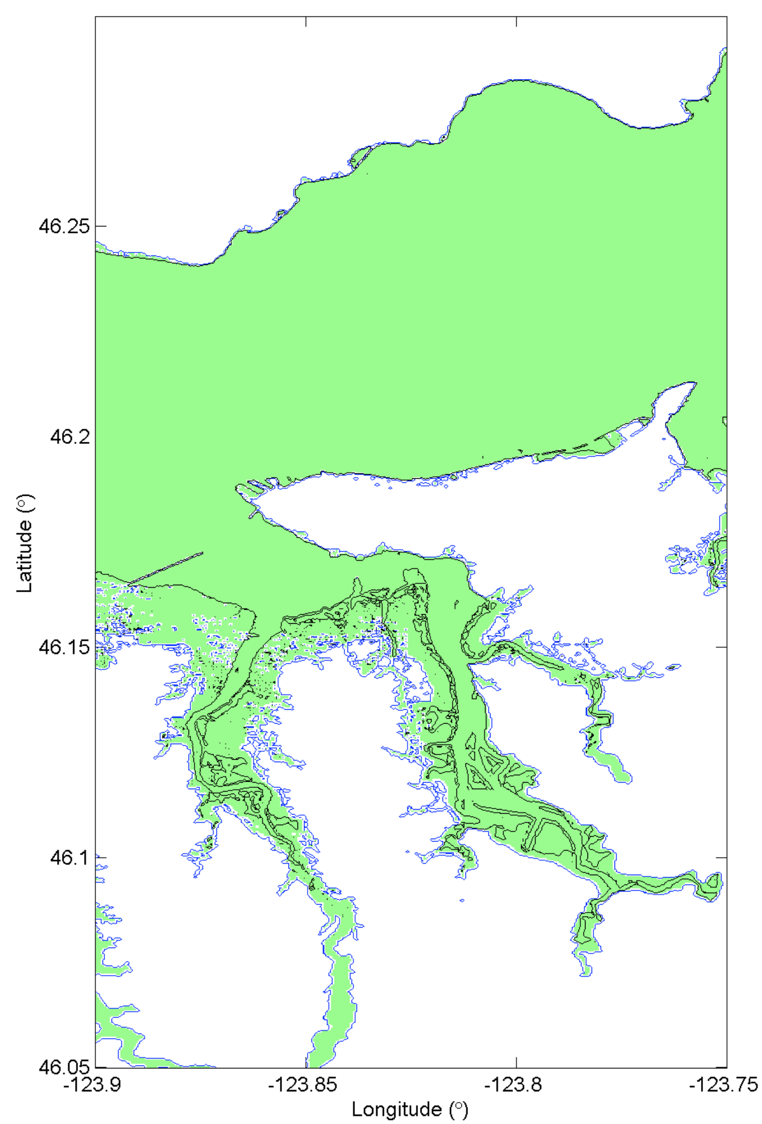
Time-series at numerical wave gages: perfect agreement between results w/ and w/o dispersion.



Tsunami Propagation in the Columbia River

Inundation in Grid 3B:
Dispersion (blue line);
Non-dispersion (green color).

Perfect agreement again!



Answer:

There may not be dispersion present in the process we investigate.