UNIVERSITY of DELAWARE

# Landslide Tsunami Benchmark Workshop

# Intercomparison of Model Results

# Categorizing the Models

- Models characterized by approach to hydrodynamics:
  - ○ Hydrostatic (depth-integrated or not)
  - ☆ Weakly dispersive (Boussinesq-type)
  - ✡ Fully dispersive (non-hydrostatic or mild slope)
  - ✴ Navier-Stokes solvers
- Models characterized by approach to modeling slide motion:
  - ○ Solid slide or analytic specification of bottom as f(t).
  - ○ Depth-integrated slide, Newtonian viscous rheology
  - ○ Depth-integrated slide, granular rheology
  - ○ 3D slide, continuous density variation, variable rheology

| Model name | Model # | Hydro Type | Slide Type | Numerical | BM1 | BM2-d61 | BM2-d120 | BM3-case30 | BM3-case32 | BM4-test17 | BM5 Case 1 | BM5 Case 2 | BM6 | BM7 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| data | 0 | 0 | 0 | | y | y | y | y | y | y | y | y | y | y |
| nhwave-s | 1 | 3 | 1 | 2 | y | y | y | y | y | | | | | |
| nhwave-v | 2 | 3 | 2 | 2 | | | | | | y | | | | y |
| nhwave-g | 3 | 3 | 3 | 2 | | | | | | y | y | y | | |
| globouss-l | 4 | 2 | 1 | | | y | y | | | | | | | |
| globous-nl | 5 | 2 | 1 | | | y | y | | | | | | | |
| boussclaw-0 | 6 | 2 | 1 | | | y | y | | | | | | | |
| boussclaw-15 | 7 | 2 | 1 | | | | | | | | | | | |
| tsunami3d | 8 | 4 | 4 | | | y | y | | | y | | | | y |
| thetis-newt | 9 | 4 | 4 | | | | | y | | y | y | | | |
| nhwave-3d | 10 | 3 | 4 | 2 | | | | | | y | | | | |
| thetis-mui | 11 | 4 | 4 | | | | | | | | y | | | |
| ls3d | 12 | 2 | 1 | | | y | y | | | | | | | y |
| 2lcmflow | 13 | 1 | 3 | 2 | | | | | | y | y | | | |
| Alaska GI-L | 14 | 1 | 2 | | | y | y | | | y | | | | y |
| nhwave-s-hydrostatic | 15 | 1 | 1 | 2 | | y | y | | | | | | | |
| nhwave-g-hydrostatic | 16 | 1 | 3 | 2 | | | | | | y | | | | |
| landslide-hysea | 17 | 1 | 3 | | | y | y | | | y | | | | y |
| fbslide | 18 | 1 | 1 | | | | | | | | | | | |
| Lynett-nlsw | 19 | 1 | 1 | | | y | y | | | | | | | |
| Lynett-Bouss | 20 | 2 | 1 | | | y | y | | | | | | | |
| Lynett-MSE | 21 | 3 | 1 | | | y | | | | | | | | |
| NHWAVE+FUNWAVE | 22 | 3 | 2 | | | | | | | | | | | y |

**Hydro Types**

0 - data
1 - non-dispersive
2 - weakly dispersive, one layer
3 - nonhydrostatic
4- Navier Stokes

**Slide Types**

1 - moving boundary
2 - viscous layer
3 - granular layer
4 - 3D multiphase

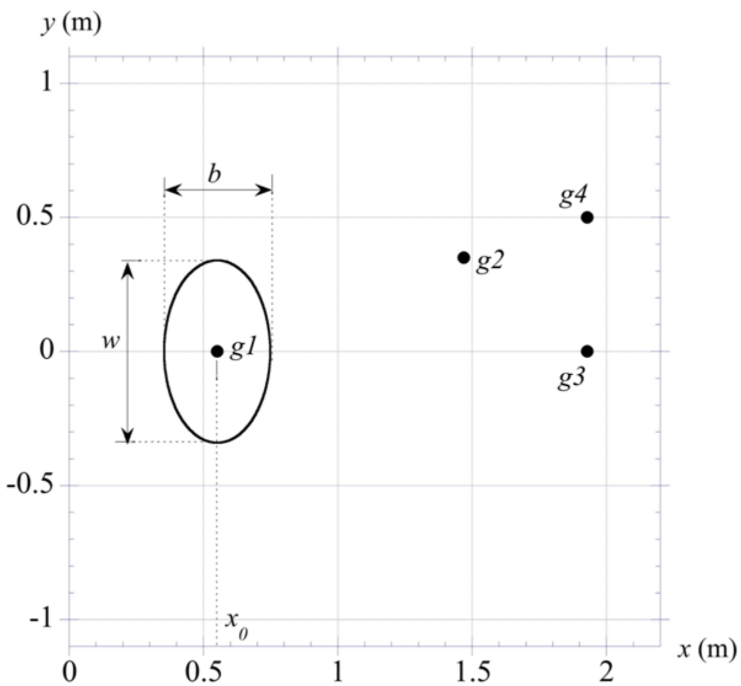
# Analyzing Results: Benchmarks 2 and 4

- RMS error measures comparing models to data
- Behavior of transient solutions in frequency and time
- Distributions of maximum and minimum elevations, maximum excursions, and variance of generated wave packets

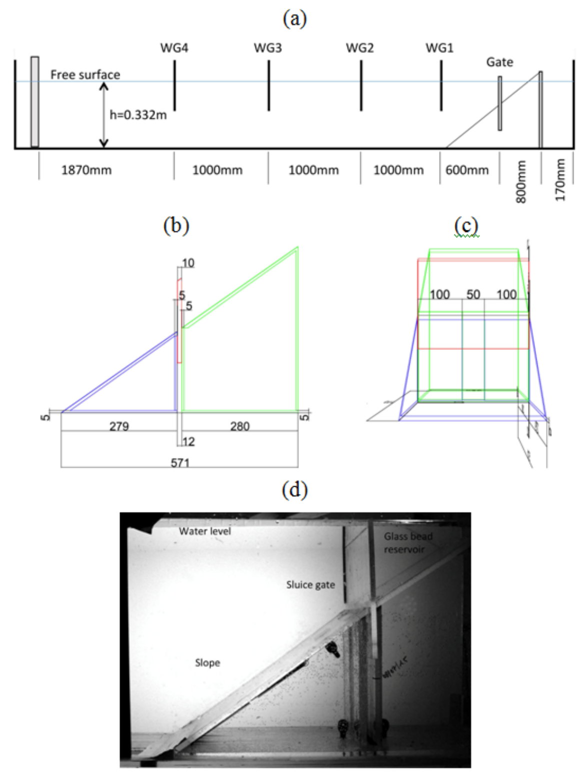
# RMS error estimates

- For both benchmarks, model and data times are synchronized by aligning the maximum crest elevation occurring at Gauge 2.
  - For benchmark 2, hydrostatic cases were synchronized at minimum elevation at Gauge 1
- Two error estimates computed, one for each gauge alone and one over the entire set of gages. Only the first option is presented here.

# Gauge positions for Benchmarks 2 and 4

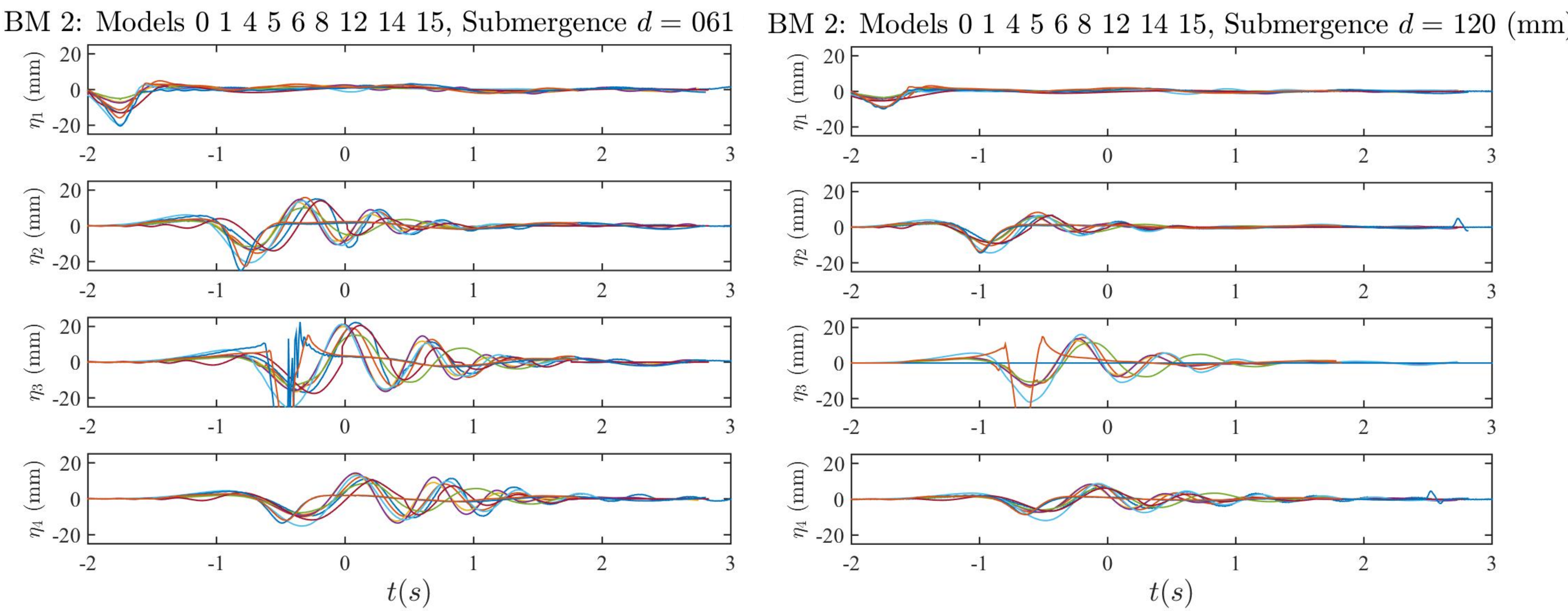



Benchmark 2

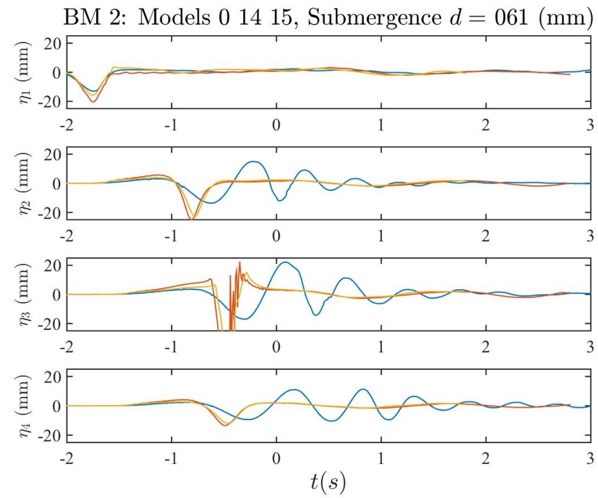


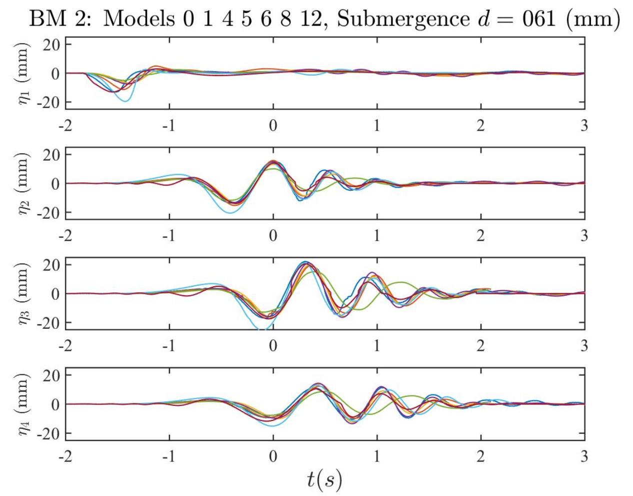

Benchmark 4

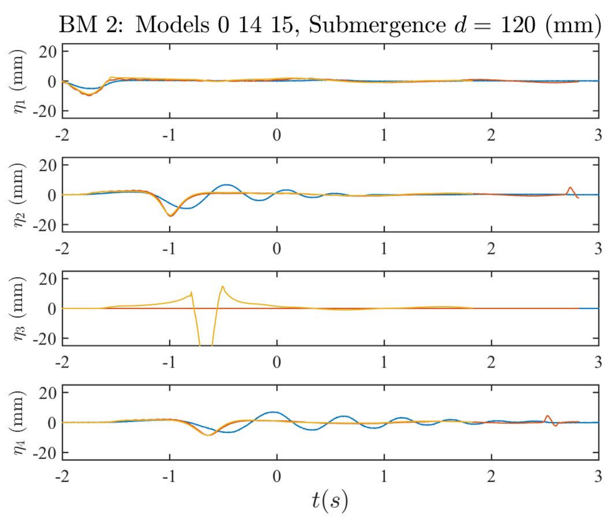
# Benchmark 2: Overall scatter in results

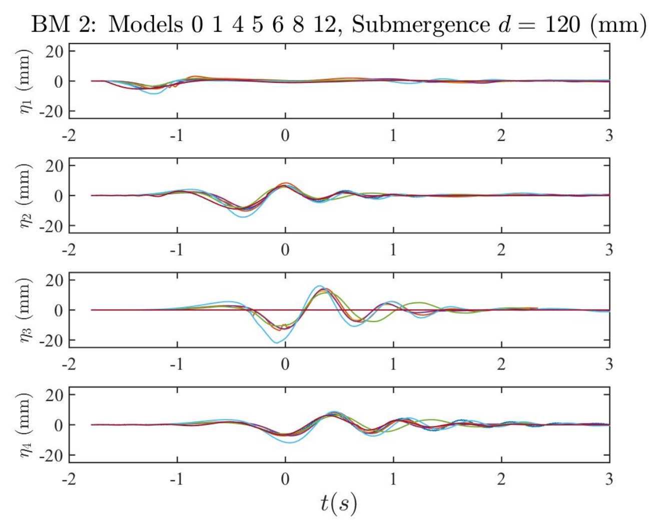


# Benchmark 2: Hydrostatic vs. nonhydrostatic cases



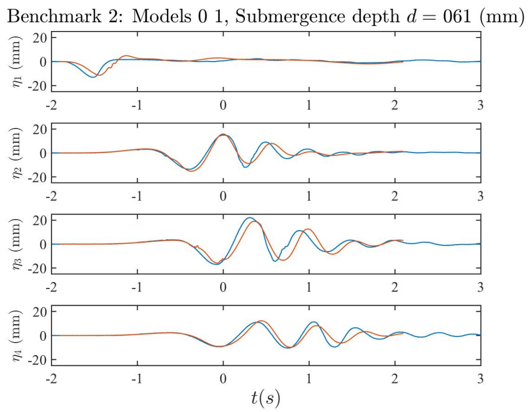



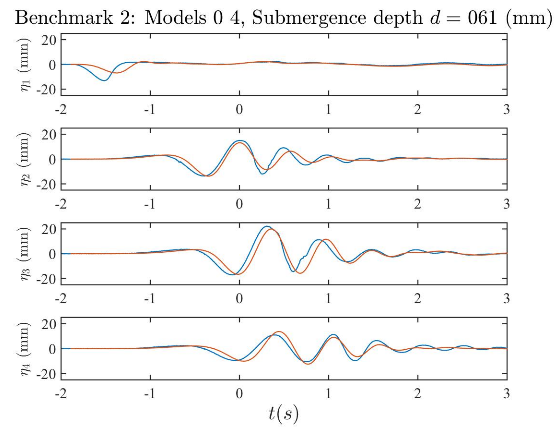



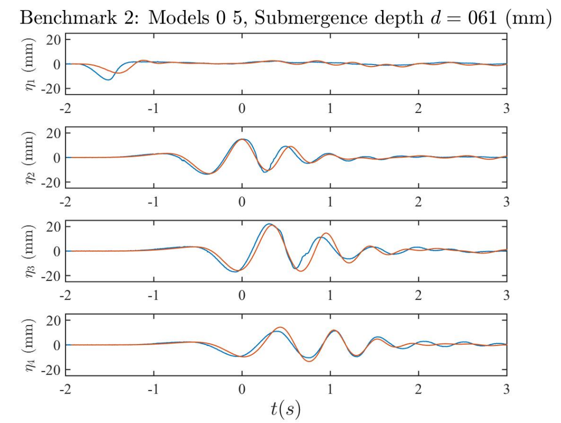

hydrostatic

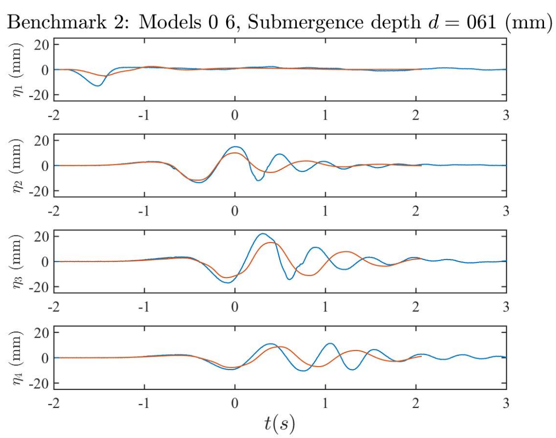
Non-hydrostatic

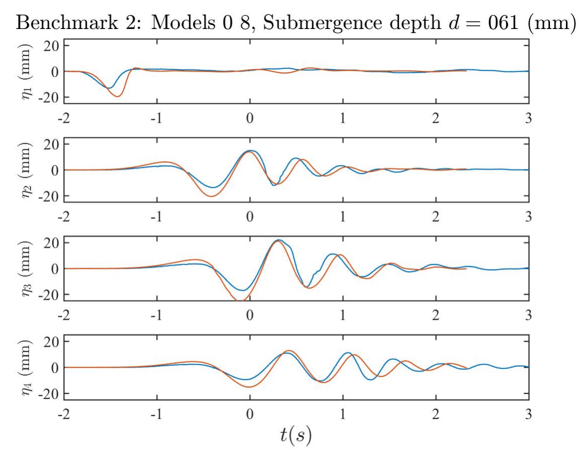
# Benchmark 2: Individual results for dispersive models

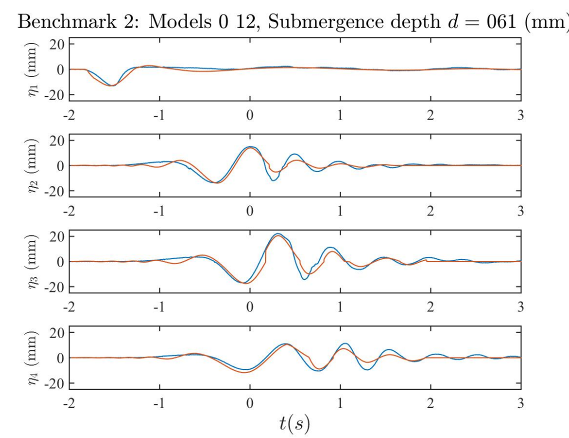


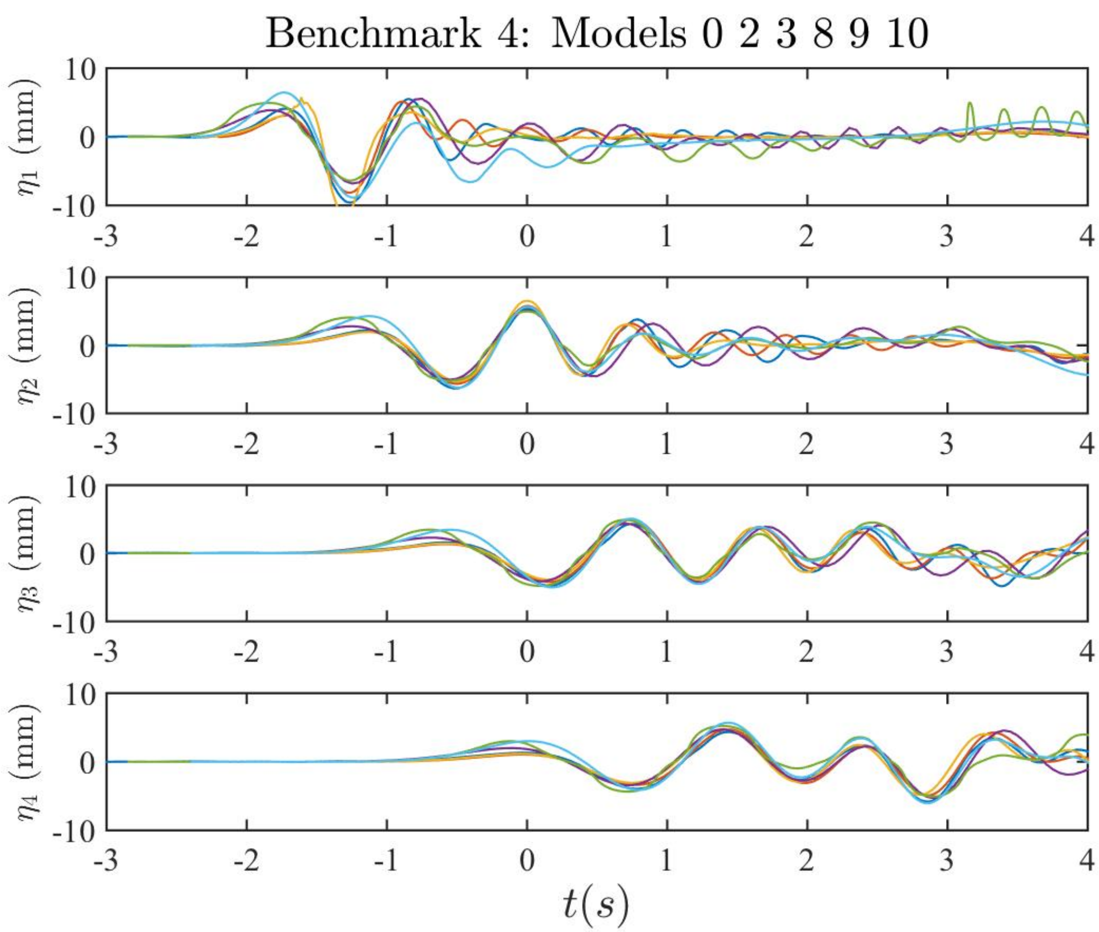



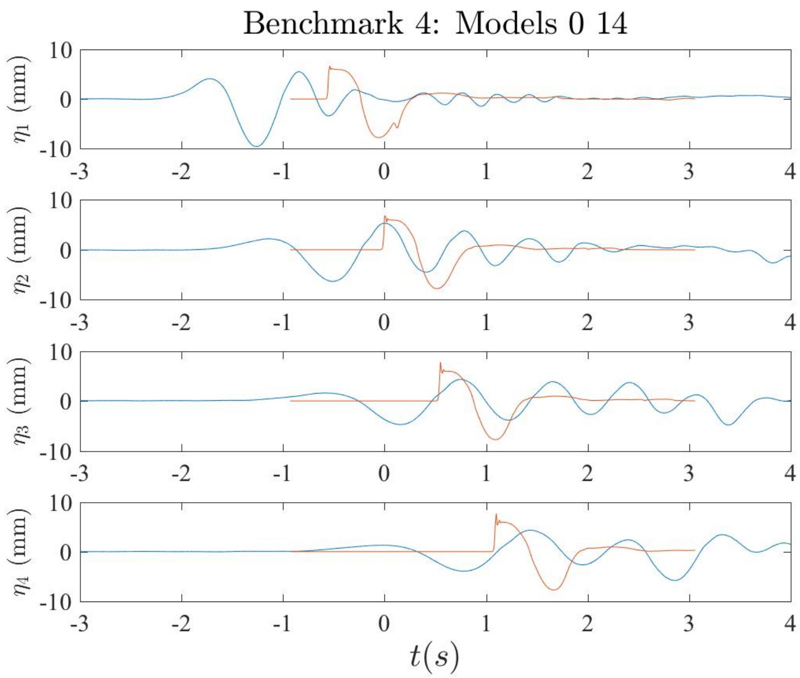



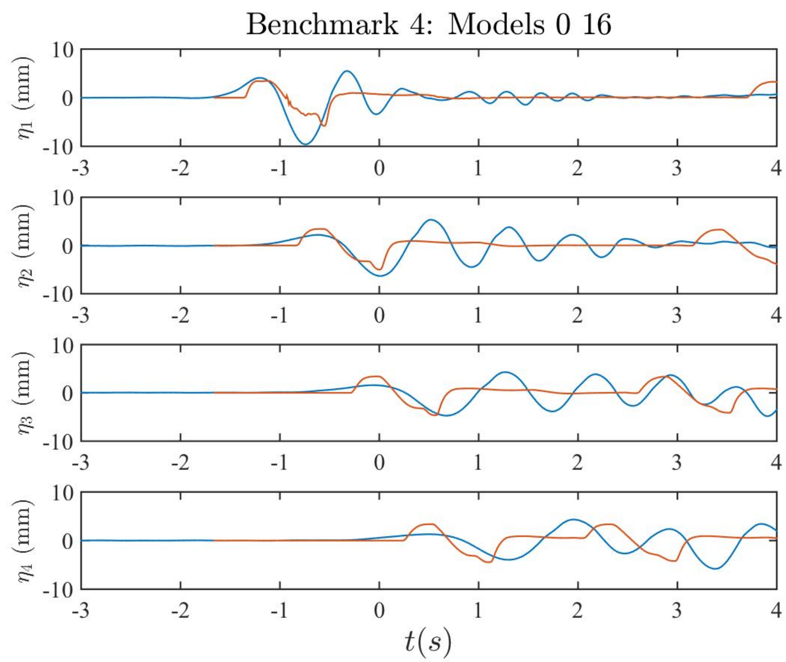



# Benchmark 4: Dispersive models

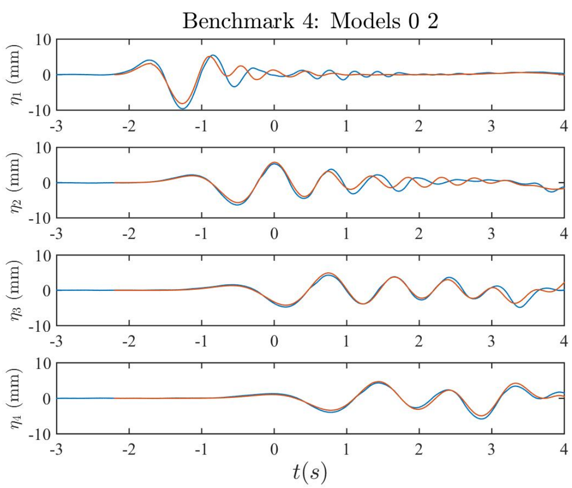


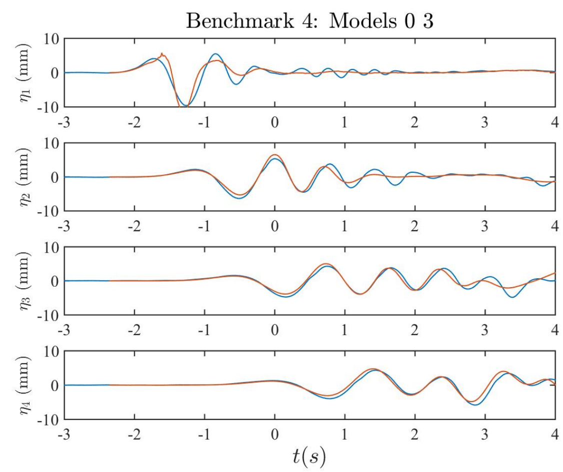
# Sample nondispersive model results

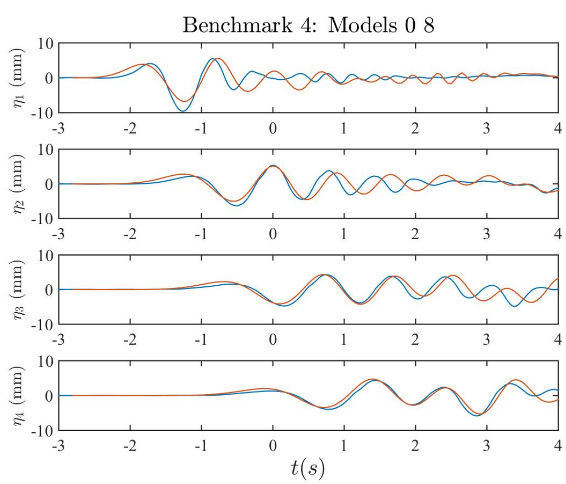


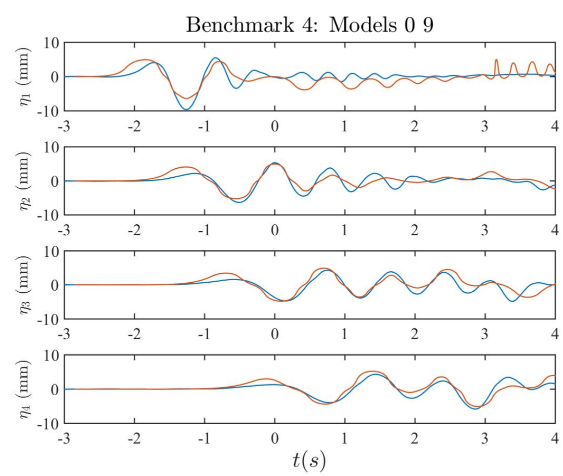



# Benchmark 4: Individual results for dispersive models



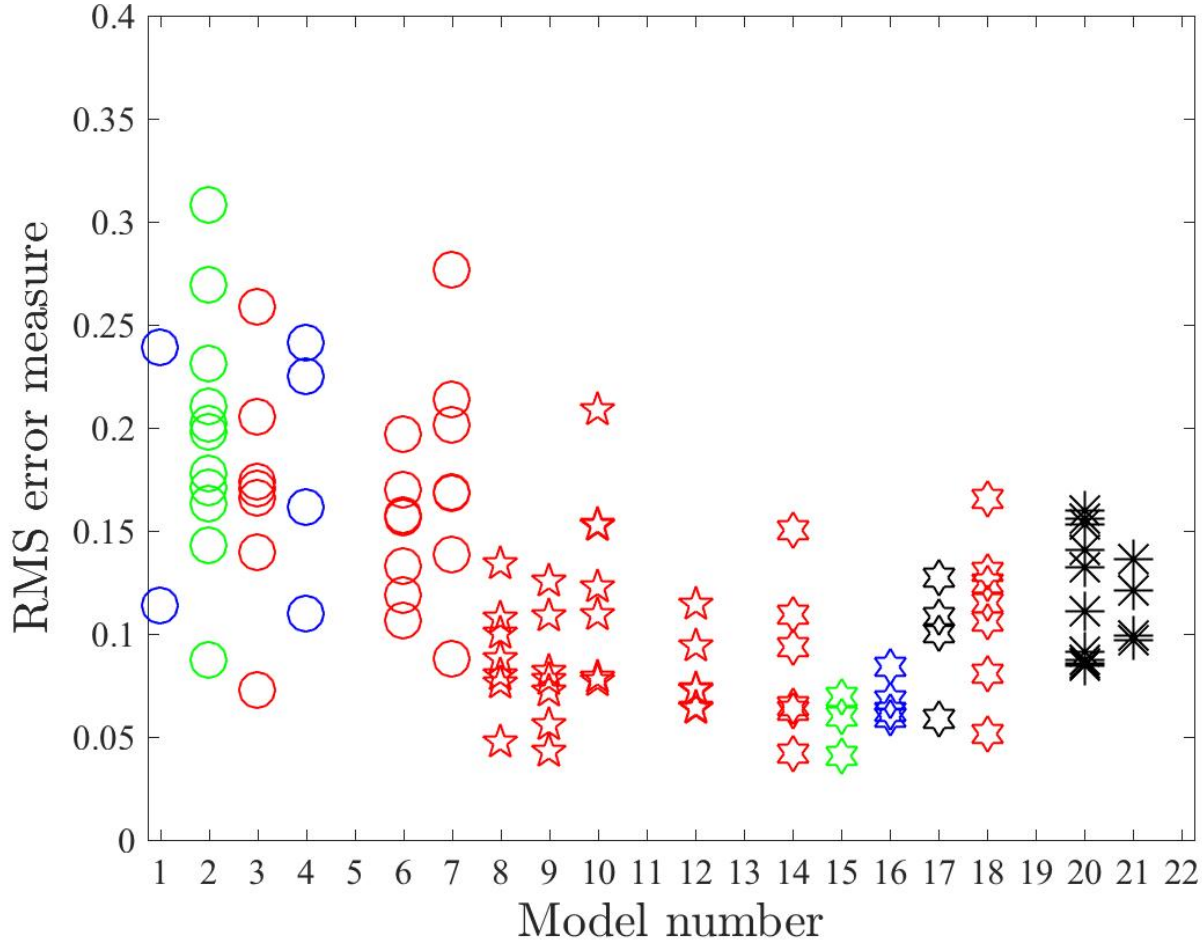



# Error estimates

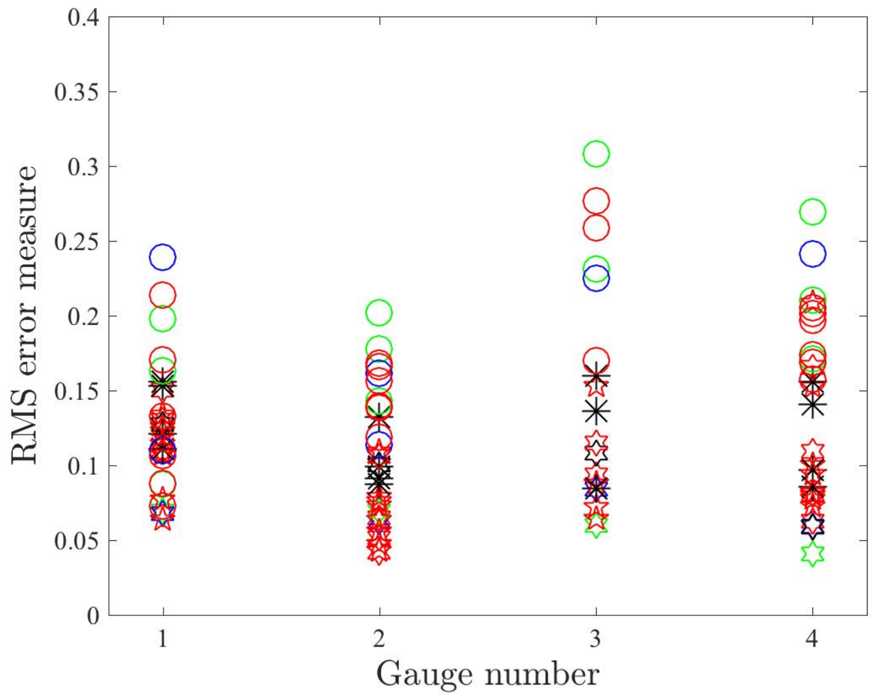
$$\epsilon_j = \frac{\sqrt{\sum_i (\eta_m(i,j) - \eta_o(i,j))^2}}{\max_i(\eta_o(i,j)) - \min_i(\eta_o(i,j))}; j = 1,4$$

Subscript *m* denotes mode, *o* denotes observation.
Sum is over time series index *i*.
Individual gauges are denoted by *j*

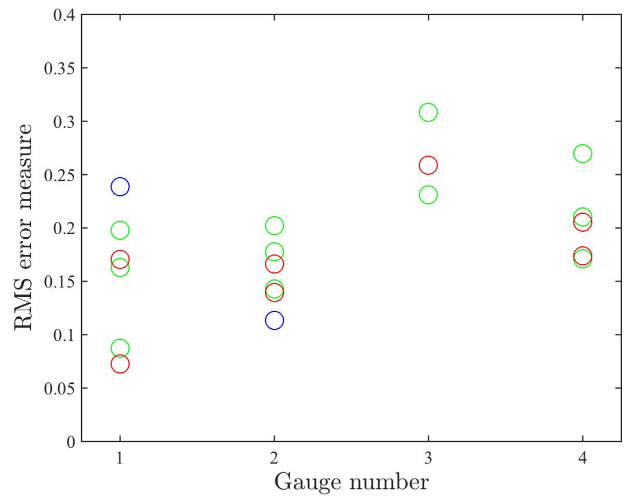
# Distribution of errors by model for all gauges

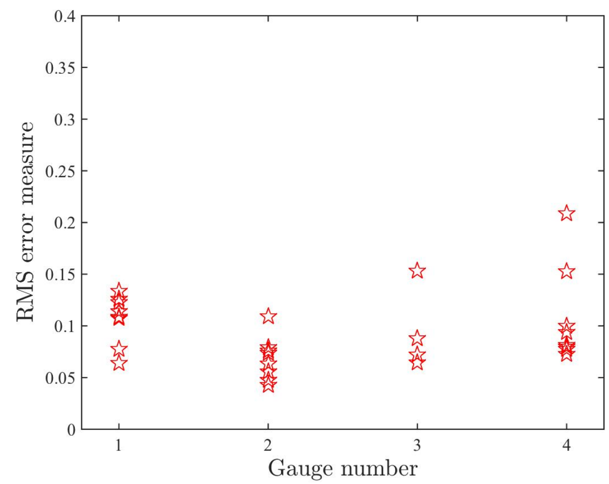


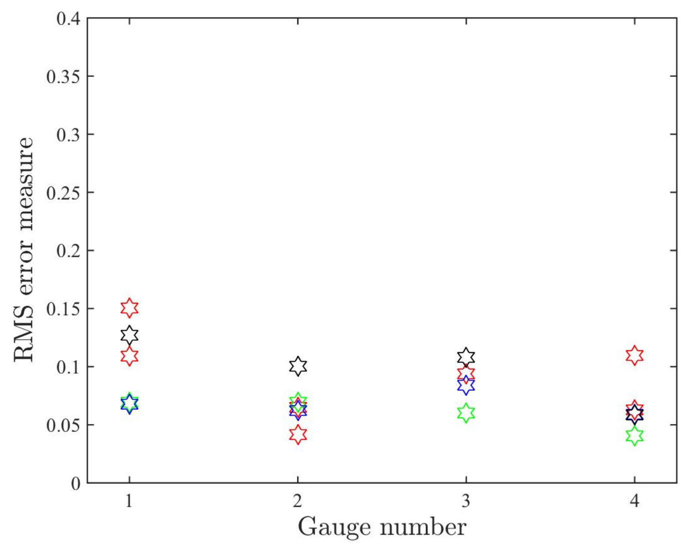
# Distribution of errors for all models by gauge

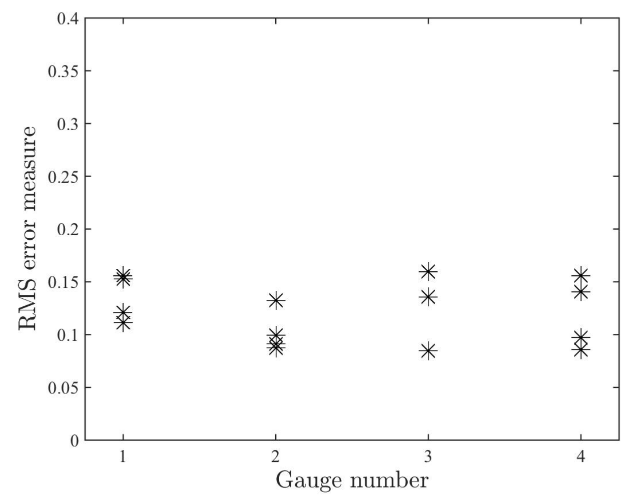


# By hydrodynamic type



# Statistics of surface displacements

- Maximum surface displacement for a single gauge, normalized by observed values

$$\epsilon_1 = \mathrm{Max}(\eta_{j,m}(t))/\mathrm{Max}(\eta_j^{obs}(t))$$

- Minimum surface displacement for a single gauge, normalized

$$\epsilon_2 = -\mathrm{Min}(\eta_{j,m}(t))/\mathrm{Min}(\eta_j^{obs}(t))$$

- Total surface excursion for each gauge, normalized

$$\epsilon_3 = [\mathrm{Max}(\eta_{j,m}(t)) - \mathrm{Min}(\eta_{j,m}(t)]/[\mathrm{Max}(\eta_j^{obs}(t)) - \mathrm{Min}(\eta_j^{obs}(t)]$$

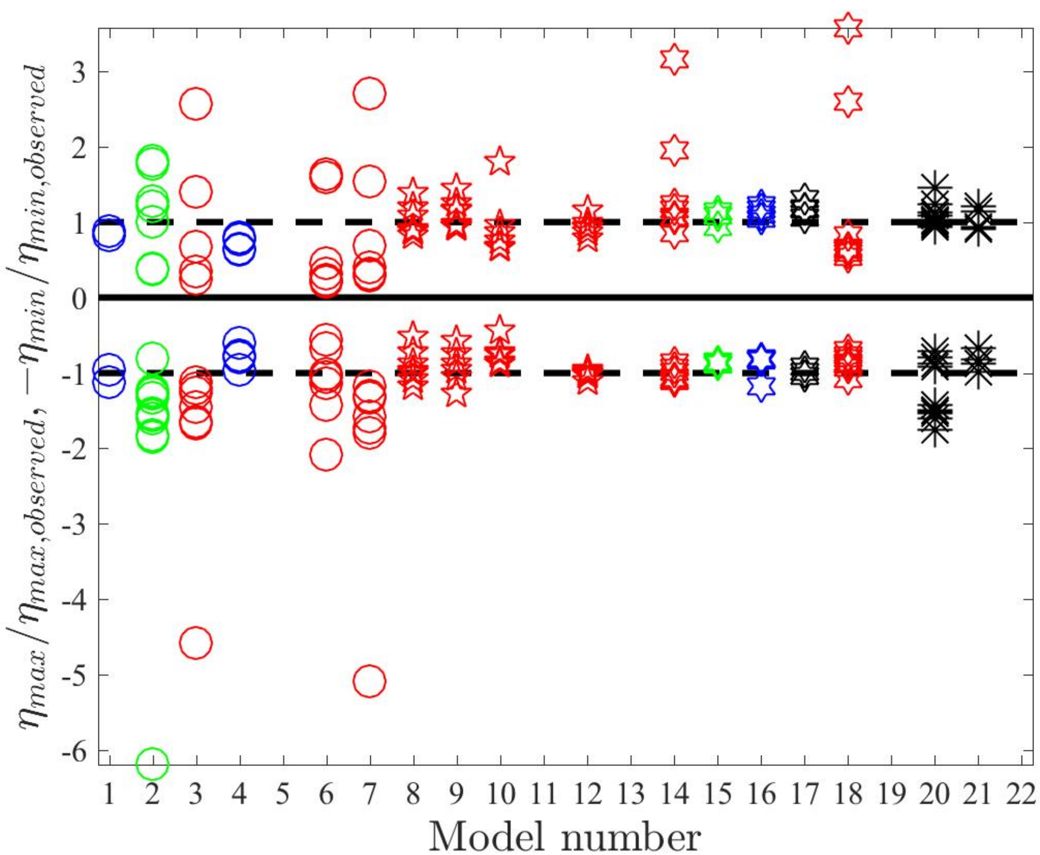
- Variance ½, normalized

$$\epsilon_4 = [\int \eta_{jm}^2 dt / \int \eta_j^{obs,2} dt]^{1/2}$$

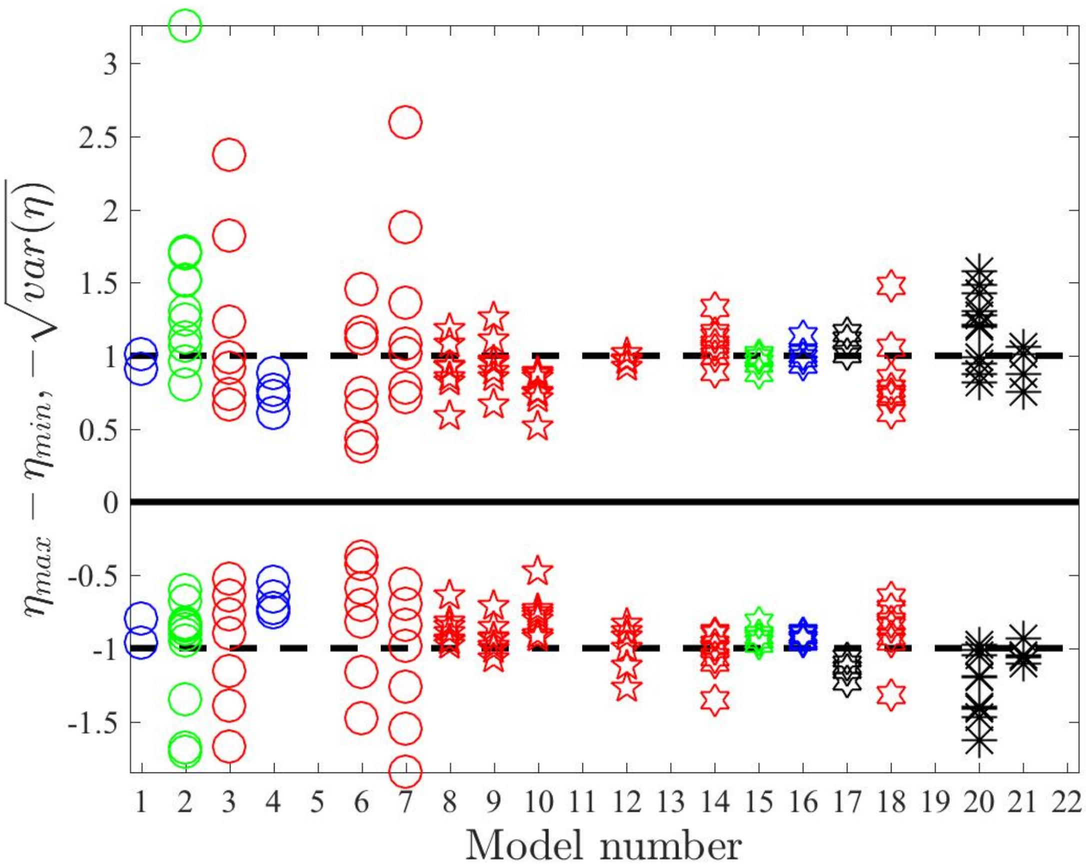
$$j = 1 - 4$$

$$m = \mathrm{model}$$

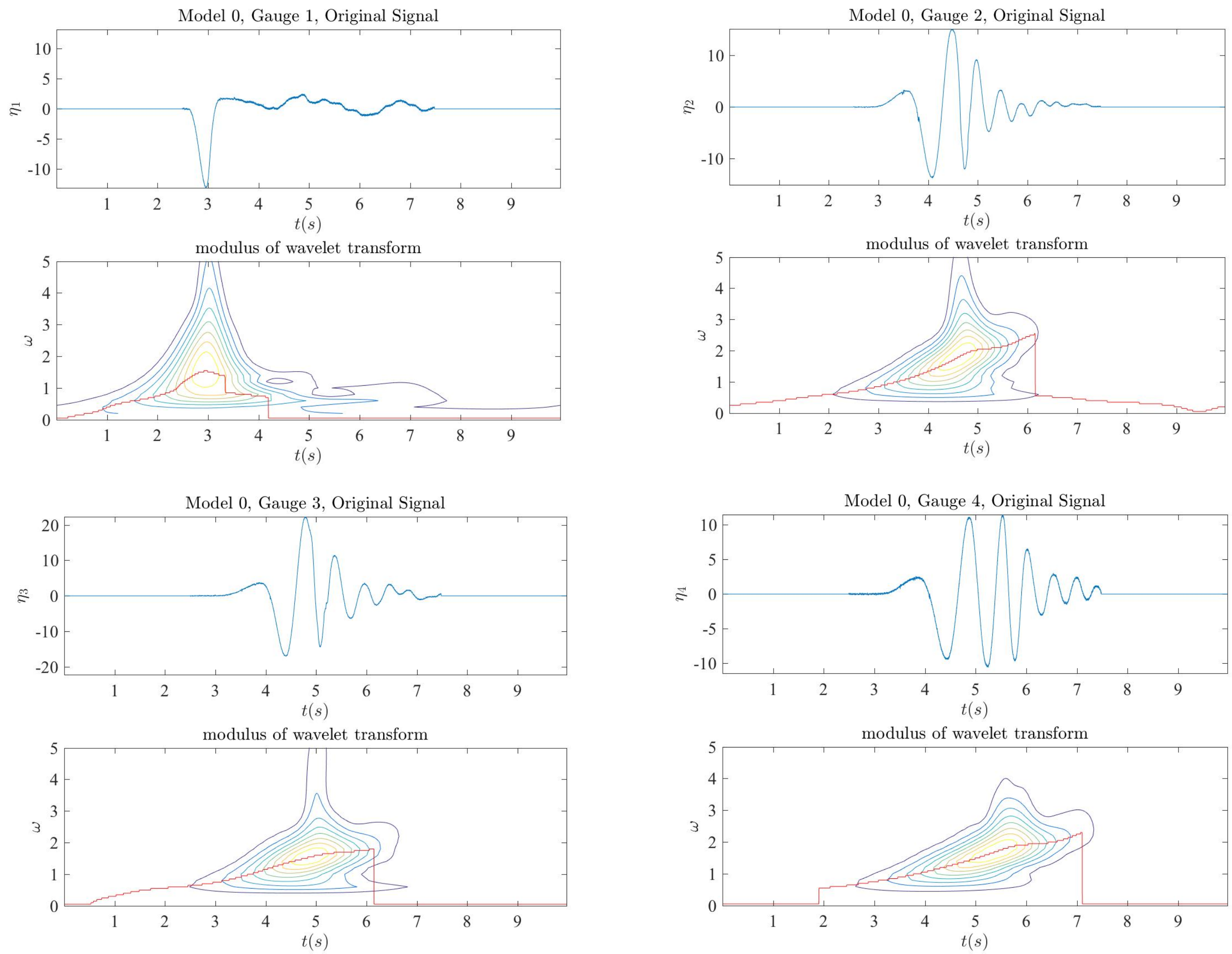
# Normalized maximum positive and negative elevations



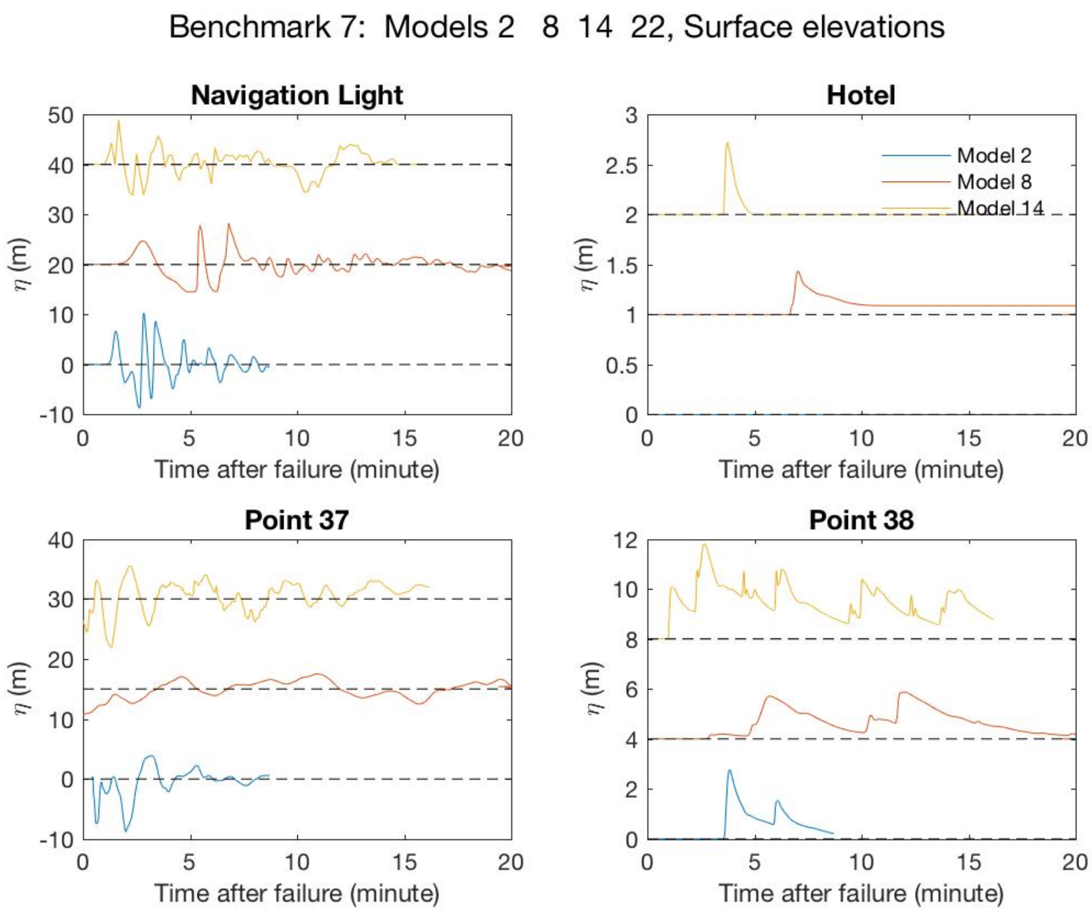
# Normalized max excursion, variance$^{1/2}$



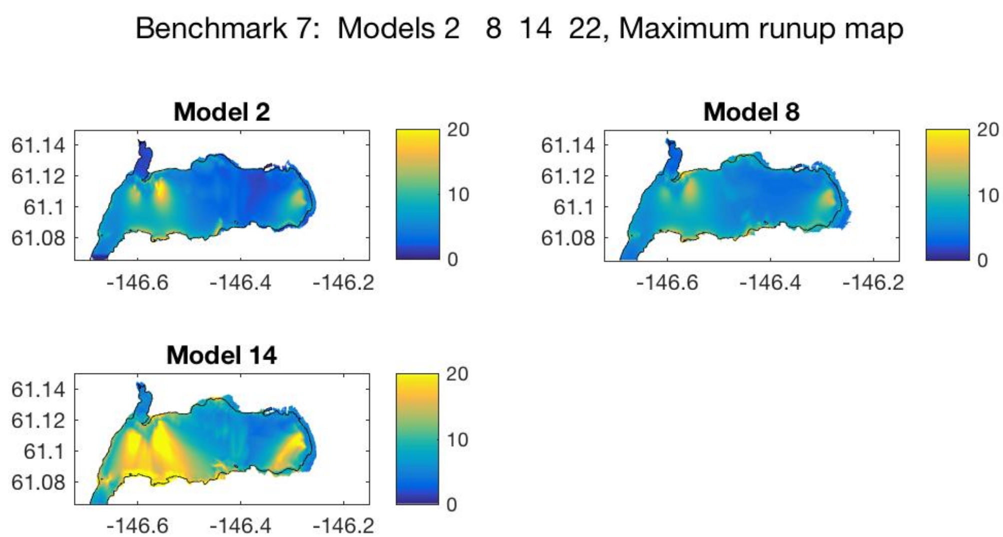
# Structure of wave packet



# Benchmark 7: Times series



# Variability of maximum surface elevations



# Variability of inundation line estimates