Analytic Tsunami Model for Physics-Based Impact Risk Assessment

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Contributors

- Engineering risk model development
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- Simulation results
  - Darrel Robertson
  - Marsha Berger
  - Mike Aftosmis
  - Randall LeVeque

Overview

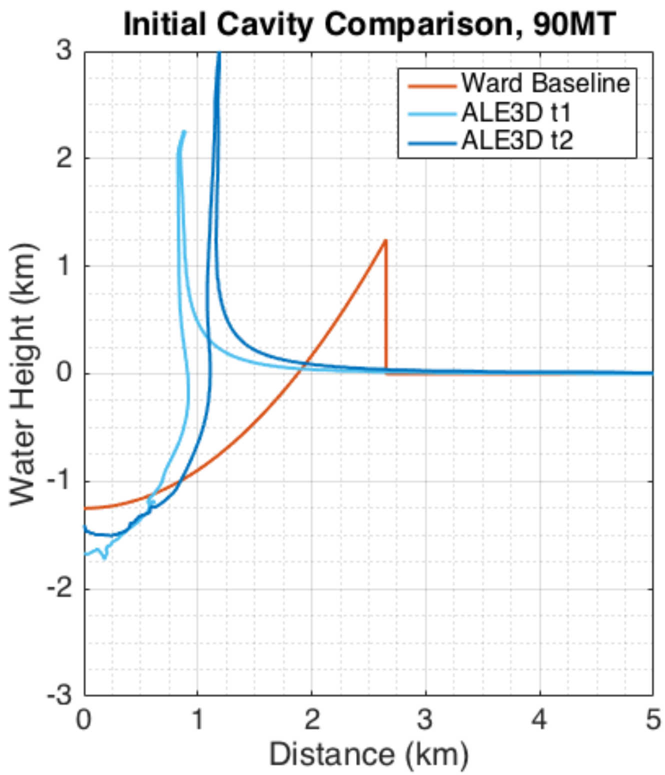
- Motivation for engineering model
- Baseline Ward-based model and our application/adaptation/ implementation
- Baseline model seemed to be overly pessimistic compared to initial simulations
- Compare components of the model predictions/assumptions with simulation results to see where adjustments/scaling may improve predictions
  - Energy coupling for splash and airburst
  - Bathymetry: shoaling amplification & shelf effects
  - Inundation

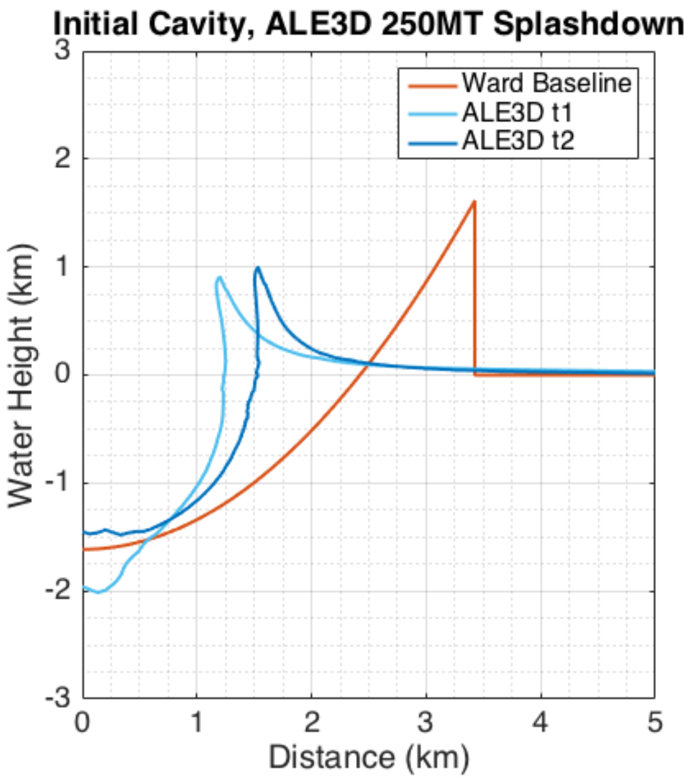
Engineering Model Overview

- Based on formulations from Chesley & Ward 2006, Ward & Asphaug 2000
- Estimates run-in distance as a function of cavity depth (D_c), cavity diameter (d_c), distance (r) from impact point, ocean depth (d_o) at impact point:
  - $X_{max} = 2.2796e\text{-}3 * (d_o^{1/10}) * (d_c^{1/2}) * (D_c^{2/5}) * (1+2r/d_c)^{-2\psi/5}$
  - $\psi = 0.5 + 0.575*\exp(-0.0175*d_c/d_o)$
- Cavity depth and diameter estimated based on impactor energy and tsunami energy fraction ε of 15% of impactor energy
  - $D_c = R_I^{3/4} [8\varepsilon\rho_I v^2/(9g\rho_{water})]^{1/4}$; $d_c = 3D_c$;
- Intermediate relations for deep-water wave height and shoaled run-up wave height, velocity, and period
- Assumes:
  - Water impact
  - Cavity diameter/depth ratio = 3
  - ~15% impact energy goes into tsunami
  - All water deposited onto cavity lip (no water ejected)

Cavity Comparison

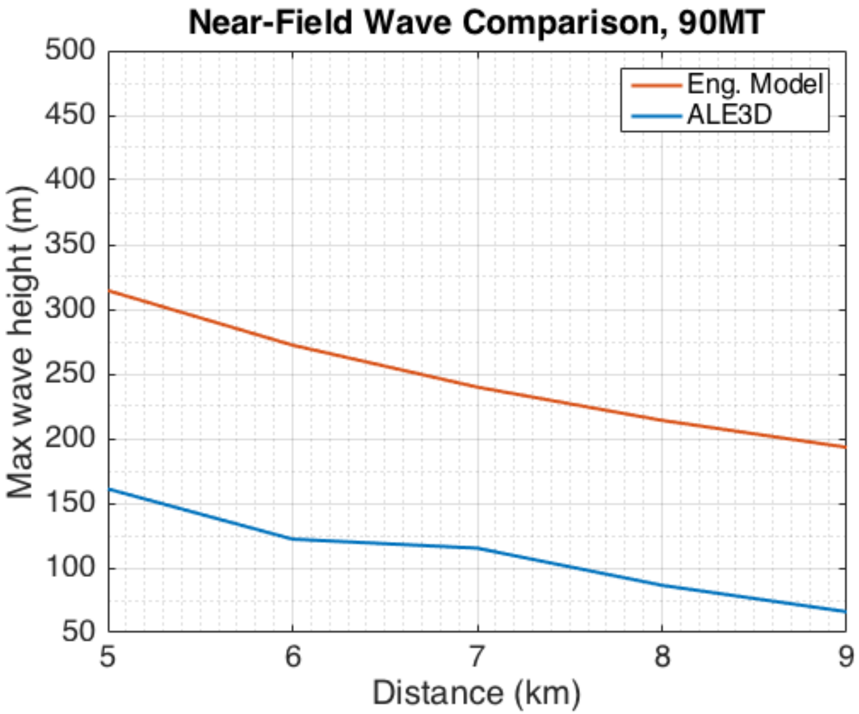
- Baseline engineering model assumes much wider initial cavities than ALE3D simulations generate
- Depth compares reasonably well
- Cavity ratio ~1.5 for 90 mt and ~2 for 250 mt case

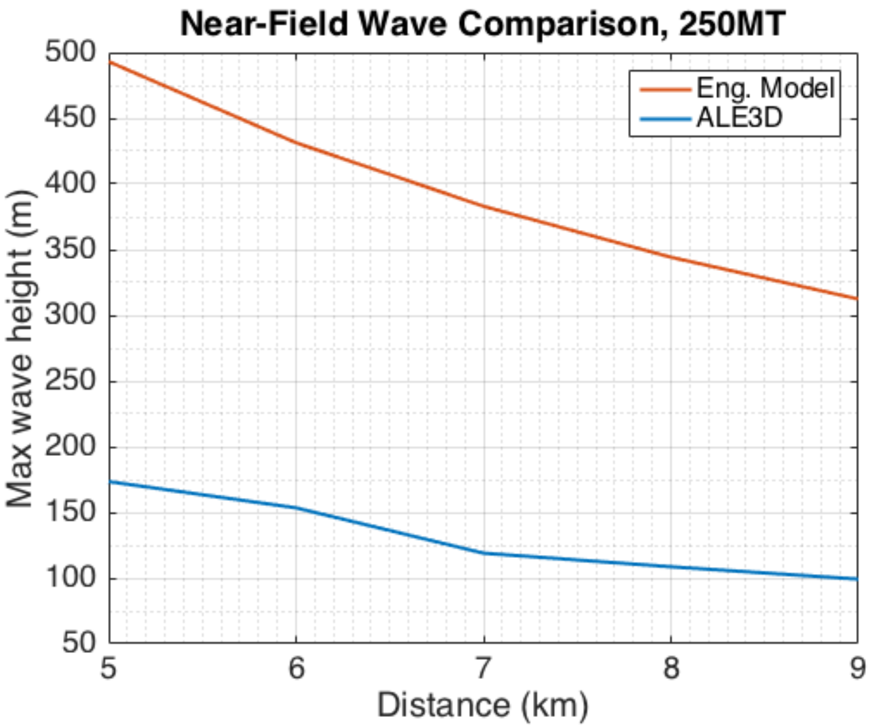




Near-field Wave Comparisons

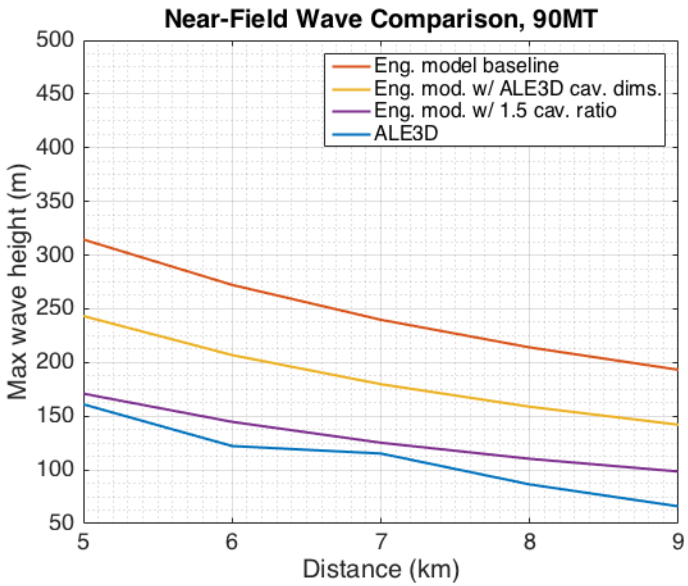
- Baseline engineering model over-predicts near-field waves by a factor of ~2-3 compared to ALE3D simulations
- Decay rates compare reasonably

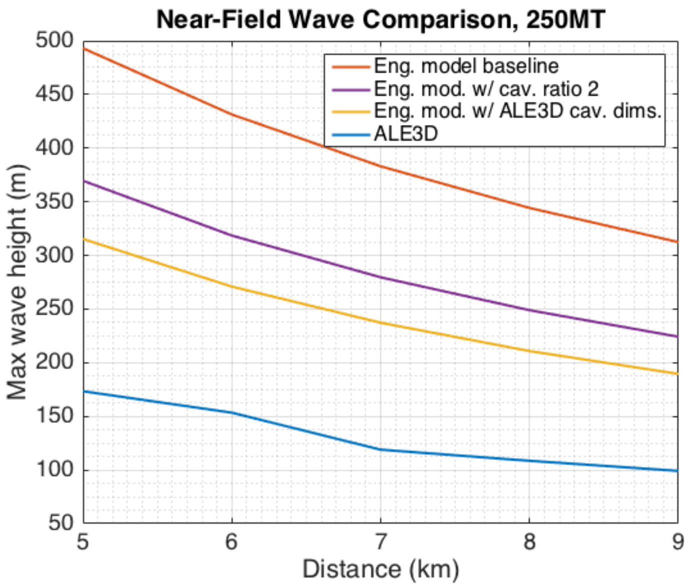




Cavity Scaling Comparisons

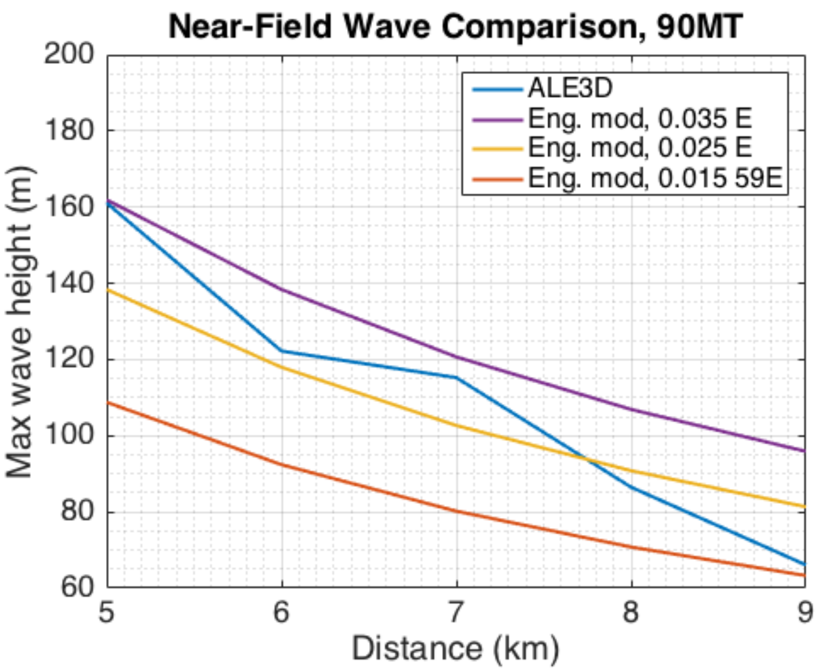
- Initiating baseline model with simulation cavity dimensions/ratio improves comparison somewhat, but still generates larger near-field waves

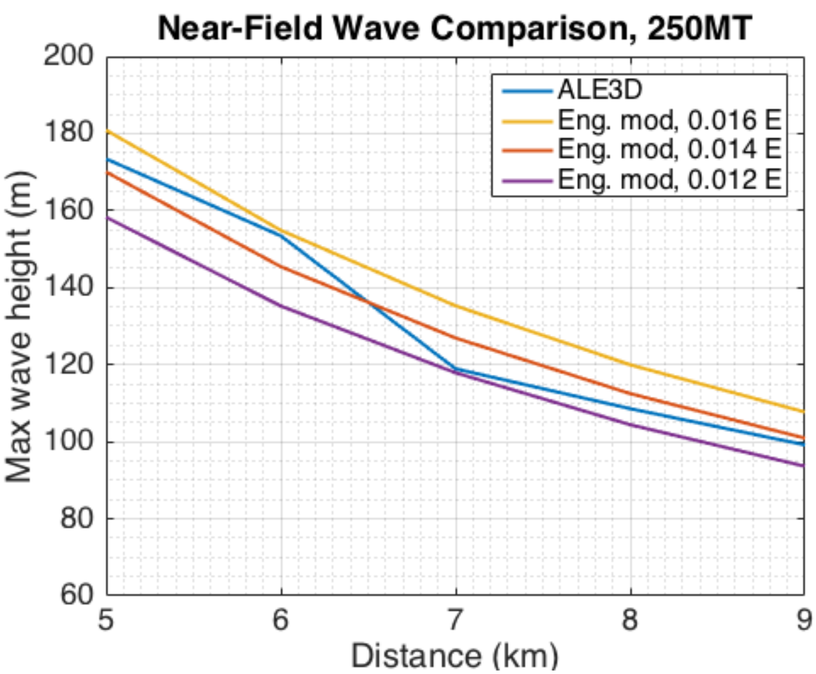




Energy Scaling Comparisons for Impact Cases

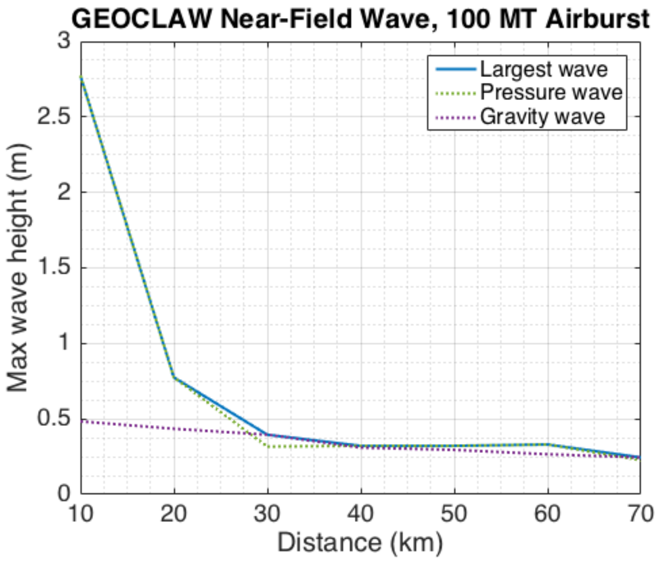
- Scaling tsunami energy fraction down from 15% to 1.5% of impact energy gives good comparisons with hydrocode waves out to ~10km
- Decay rates and wave heights reasonable

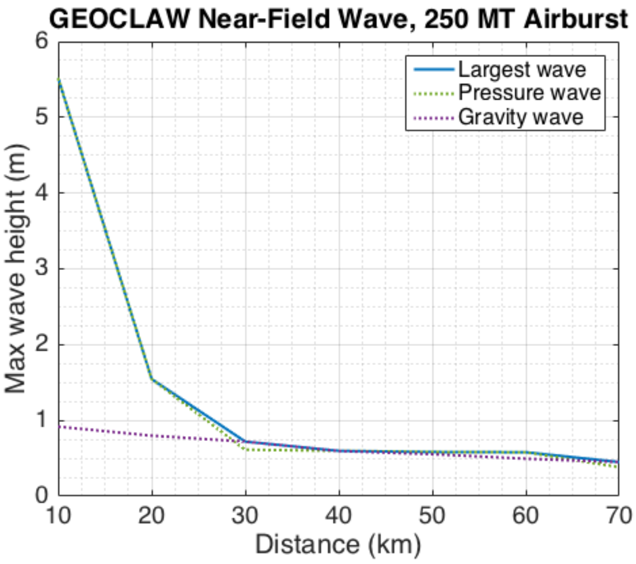




Energy Coupling for Airbursts

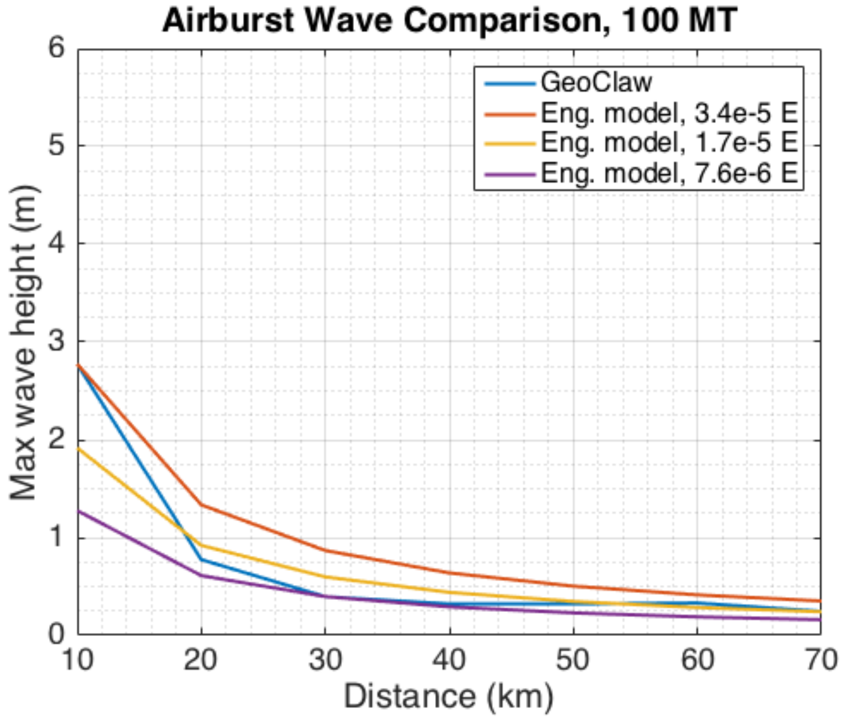
- Performed similar energy scaling comparisons using Marsha Berger's GeoClaw simulations of airburst-generated waves
  - 100 mt and 250 mt airburst at 10 km altitude
  - Initiated using Cart3D spherical burst simulations by Michael Aftosmis
  - Shallow-water 2D radially symmetric
  - 3 km deep, flat-bottom ocean
  - Ran out to ~70 km from impact

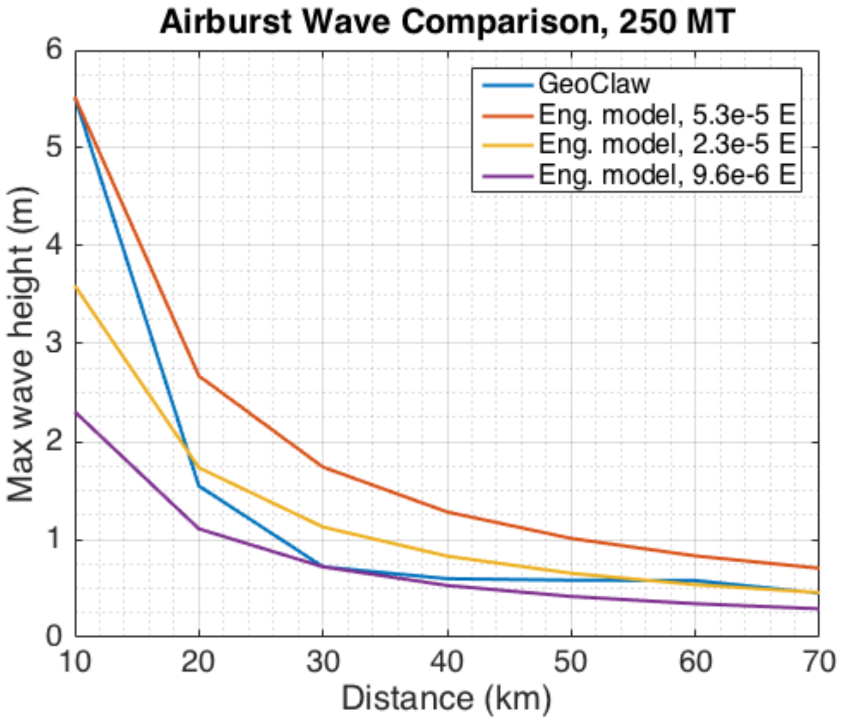




Energy Scaling Comparisons for Airburst Cases

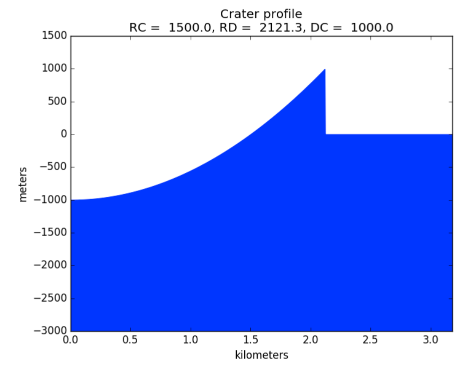
- Reducing energy coupling to on the order of 1-5e-5 gives reasonable comparisons
- Leading pressure-driven wave is initially larger and decays more rapidly over first 20km





Bathymetry & Shoaling Effects

- Baseline engineering model does not account for effects of potential variations in bathymetry between impact and shore.
- Randall LeVeque provided simulations of waves propagating over a simplified bathymetry variations for comparison
  - 1D radially symmetric model
  - Shallow-water wave equations
  - Initiated with a 3 km x 1 km cavity
- Bathymetry Variations:
  - Beach slopes: 0.02, 0.1
  - Shelf widths: 0-60 km
  - Shelf depth 100m
  - Shelf slope 20km wide
  - Ocean depth 3km



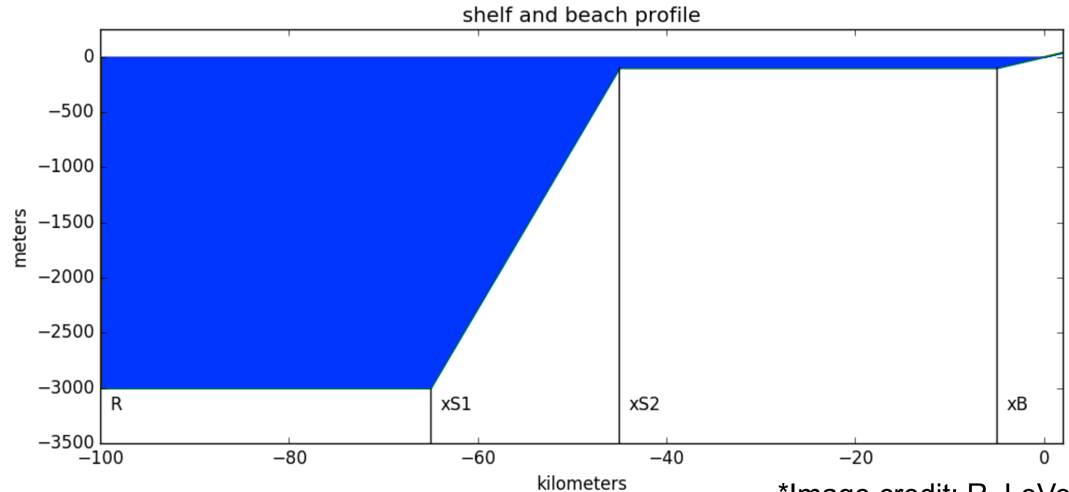
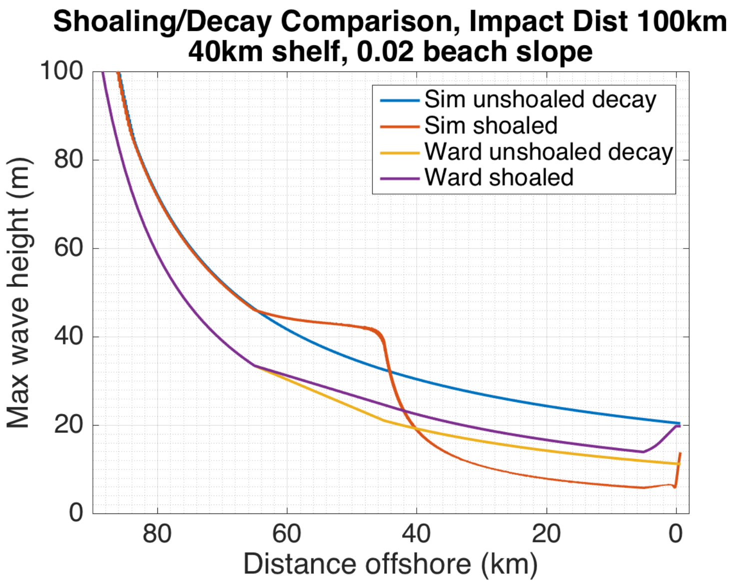
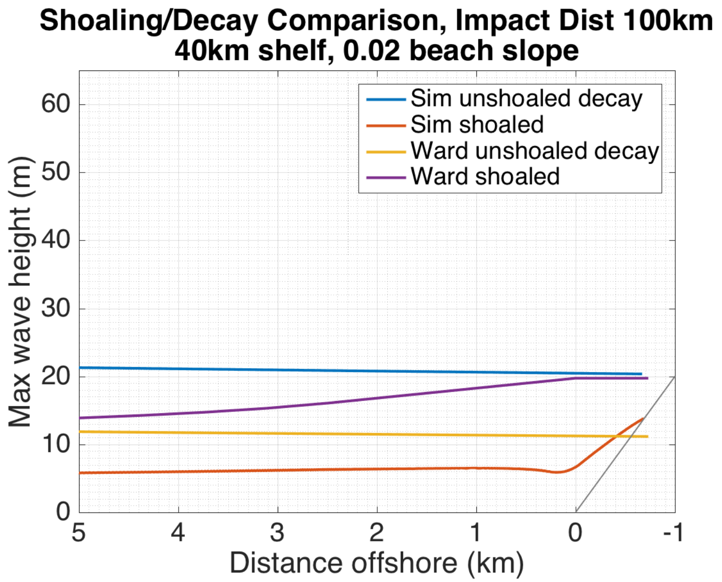


*Image credit: R. LeVeque

Shoaling Comparison

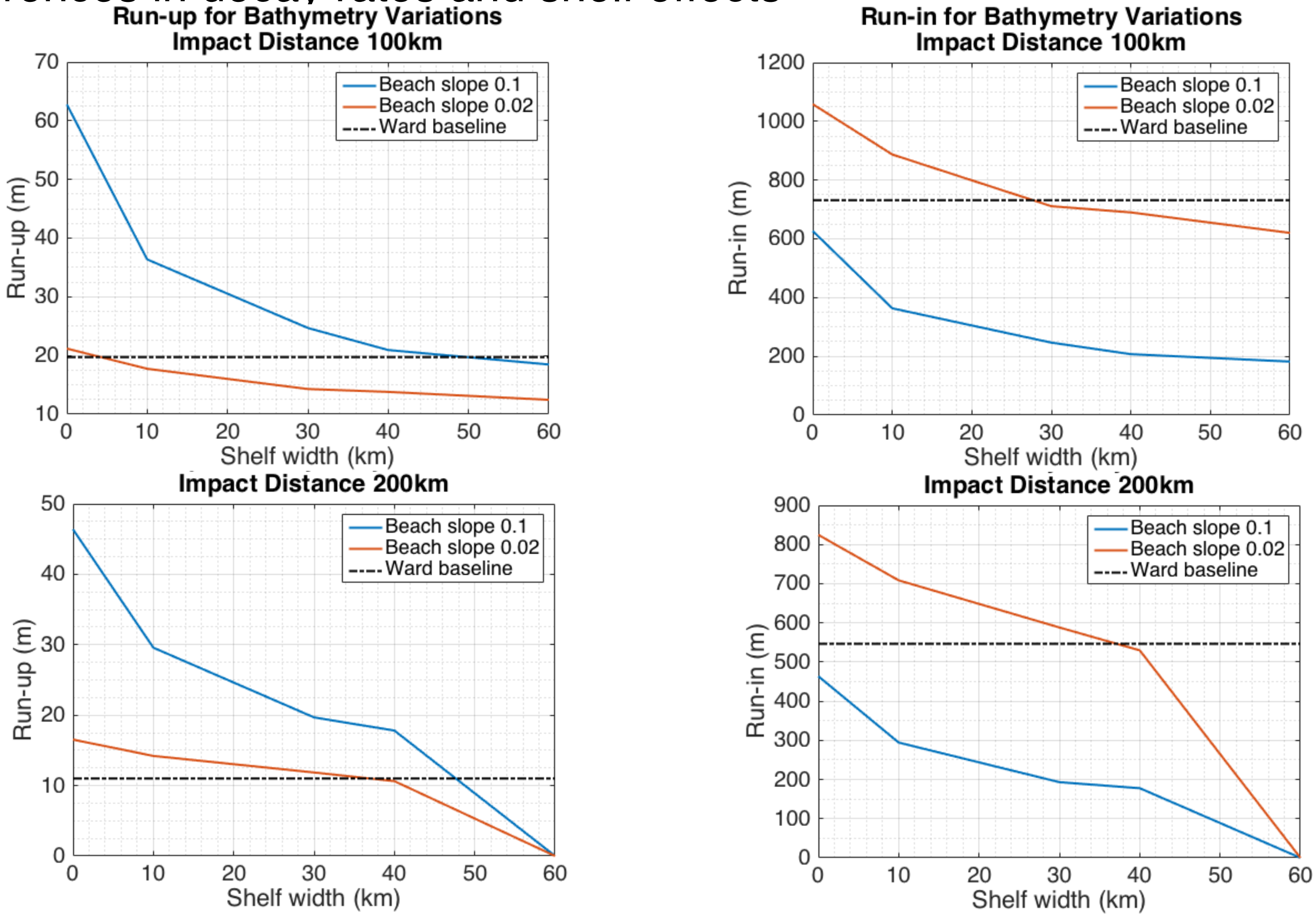




- Engineering model
  - Shoaling factor amplifies deep-water wave to obtain shoaled wave heights at a given depth
  - Final run-up taken as wave height shoaled to the point where the depth = wave height
  - Final run-up estimates are independent of intermediate bathymetry
  - Shoaling effect increases wave height/slows decay compared to unshoaled wave
  - Decays faster in deep-water than
- Simulations
  - Unshoaled wave heights taken from 200km impact distance cases over flat ocean before shelf
  - Wave decay slows going up over the shelf slope, but then wave decays much more rapidly as it propagates over the shallow shelf distance

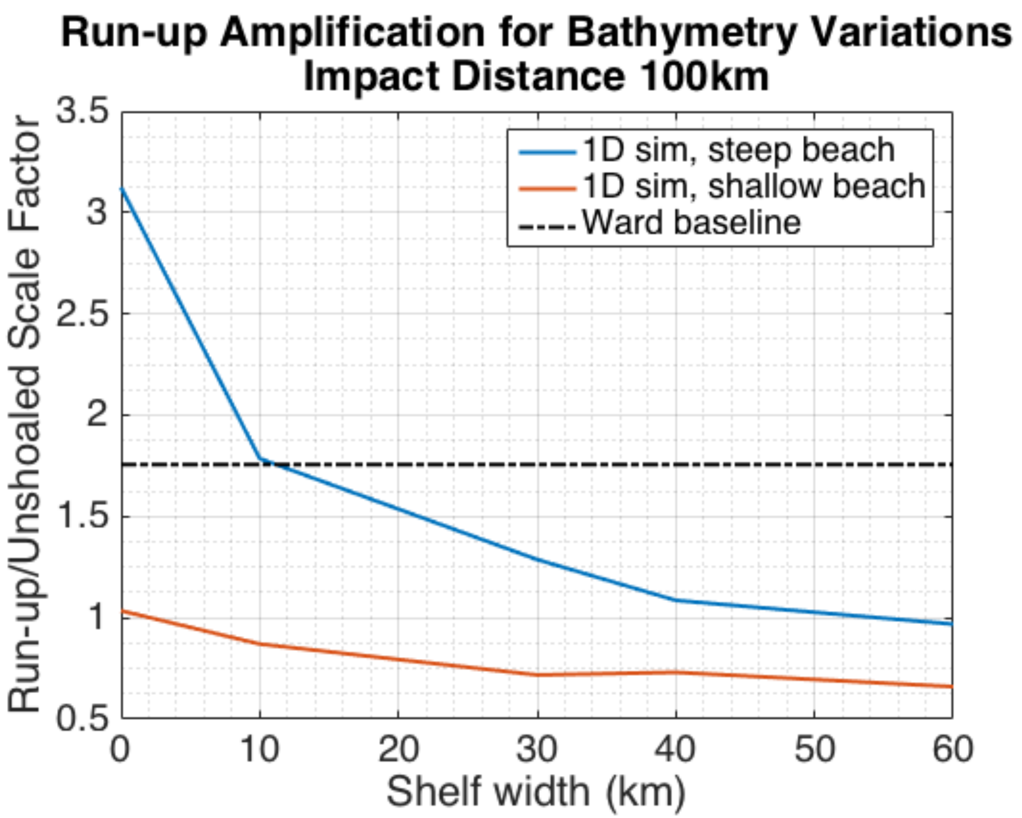
Run-up & Run-in Comparisons for Bathymetry Variations

- Baseline engineering model estimates of final run-up/run-in are within reasonable range of simulation results if you ignore the intermediate differences in decay rates and shelf effects



Shelf Protection vs Shoaling Amplification

- Eng model's run-up shoaling amplification is pessimistic compared to 1D sims over bathymetry
- For no shelf, Ward amplification is within the range for shallow/steep beach sims
- For 10km shelf is comparable to steep beach, but about twice that for shallow
- For shelves >= 30 km, Ward amp factor is ~1.5x that of steep beach sims and 2.5x that of shallow beach sims



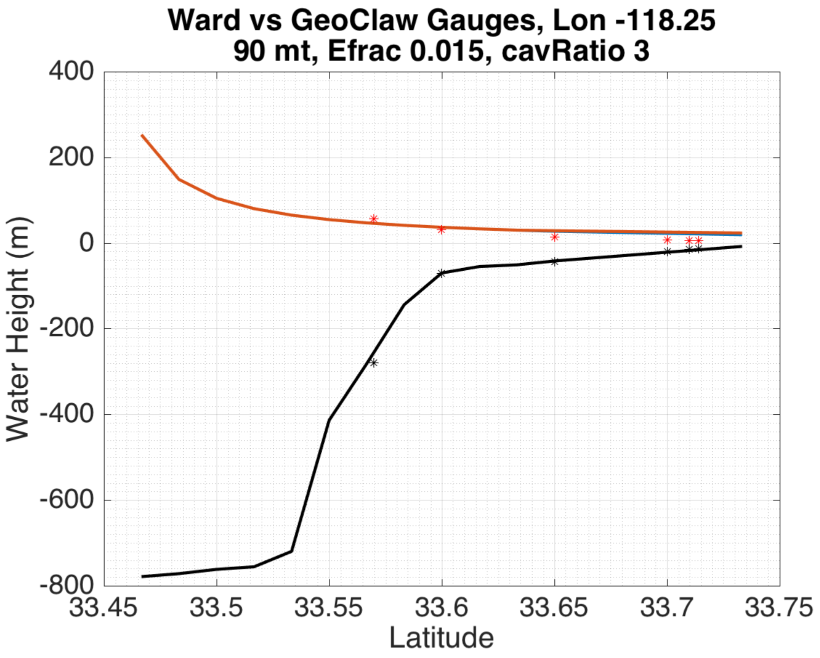
Shelf width (km)	0	10	30	40	60
Steep beach	0.6	1	1.4	1.6	1.8
Shallow beach	1.7	2	2.4	2.4	2.7

Long Beach Case

- 90 mt water impact off the coast of Long Beach
- Impact location:
  - Coordinates: 33.451, -118.25
  - Depth: 800m
  - Offshore dist: 29.4 km
  - Shelf width:
  - (kind of a peculiar case, not very deep, right on bottom of shelf)
- Compared with Marsha's GeoClaw sim
  - 3D shallow-water simulation
  - Initiated from Darrel's 90 mt splash case

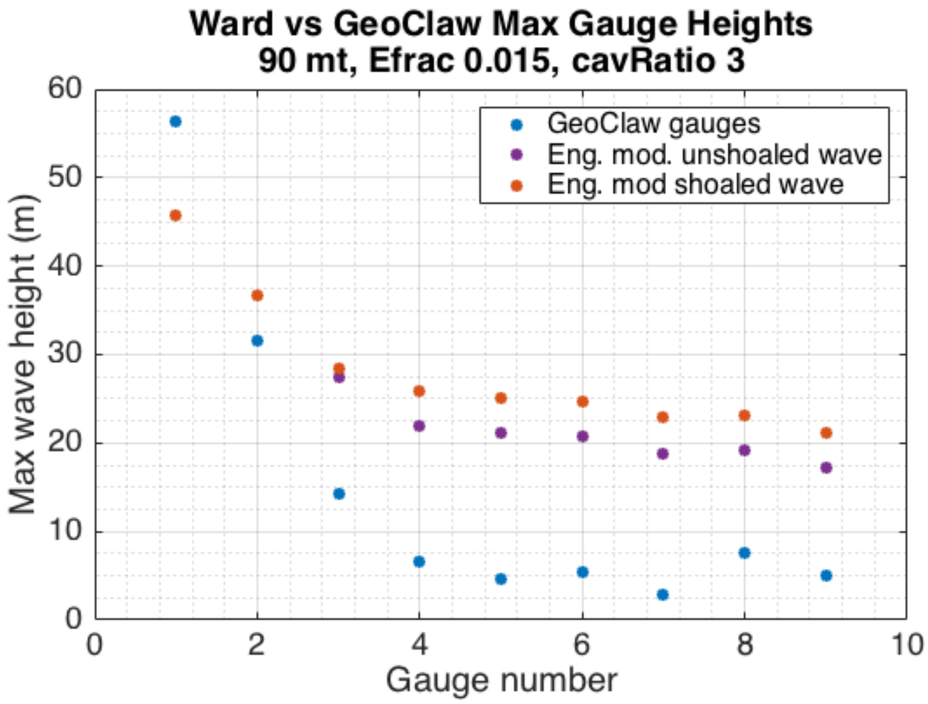
Near-Shore Wave Height Comparisons

- Compared max waveheights at simulation gauge locations with engineering model waves computed at those distances and relative depths.



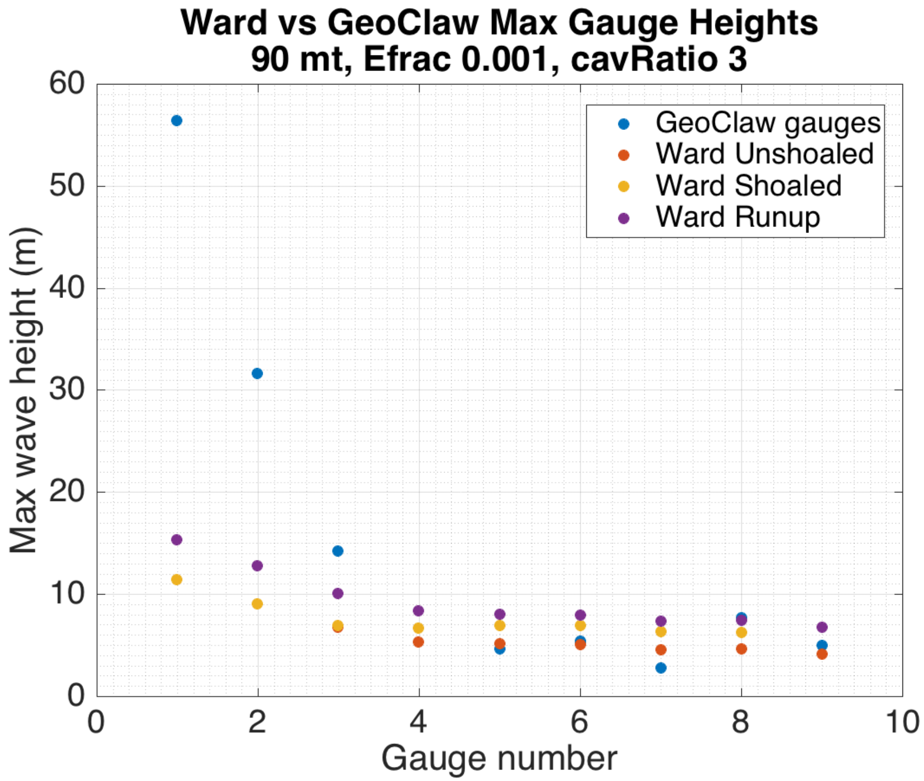
Long Beach Case

- Engineering model with energy fraction scaled to 1.5% overpredicts shoaled waves near the shore compared to simulation
  - 2-8x larger than near-shore simulation gauge heights
  - Similar to what we observed in the 1D ideal bathymetry comparisons

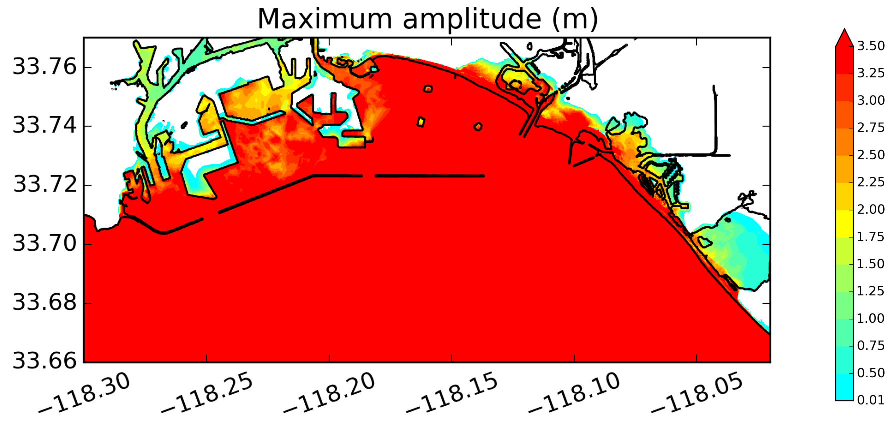


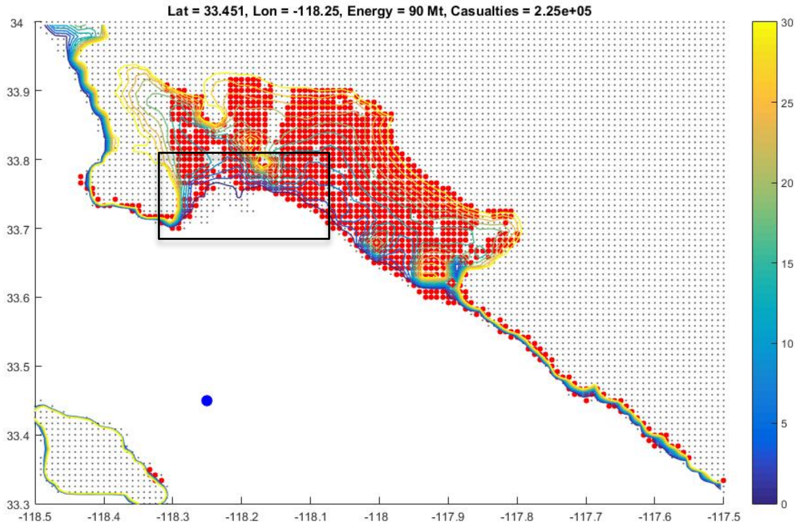
Energy Scaling to Gauge Wave Heights

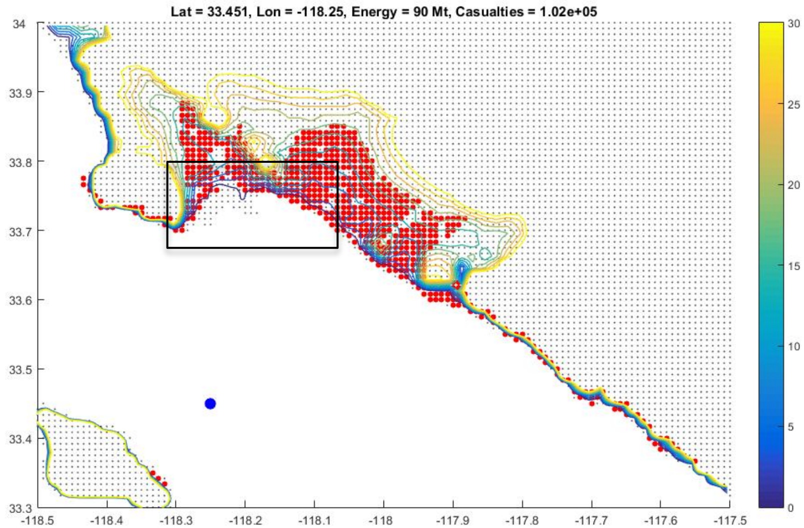
- Scaling initial energy fraction down further to 0.1% matches near-shore gauges, but under-predicts waves further offshore
  - (However this is only one, fairly unusual comparison case – would need other comparisons to determine whether a simple energy scaling could reasonably be used to account for shelf protection factors in shoaling)



Inundation Comparisons







* Image credit: Paul Register

Summary

- Reducing initial energy coupling from 15% to 1.5% for water impacts provides better wave height predictions compared to simulations
- Energy coupling fraction needs to be reduced down to Ø e-5 to represent air-burst generated waves
- Baseline model over-predicts shoaling amplification and final near-shore wave heights in cases with continental shelf protection
- Using scaled engineering model run-up estimates with local topography provides bounding, pessimistic inundation
- Forward work
  - Additional simulation comparisons for broader range of cases
  - Investigate implementation of a shelf-protection factor to better match shoaled wave heights near shore
  - Refine modeling assumptions on how far inland a given run-up wave height is able to flood