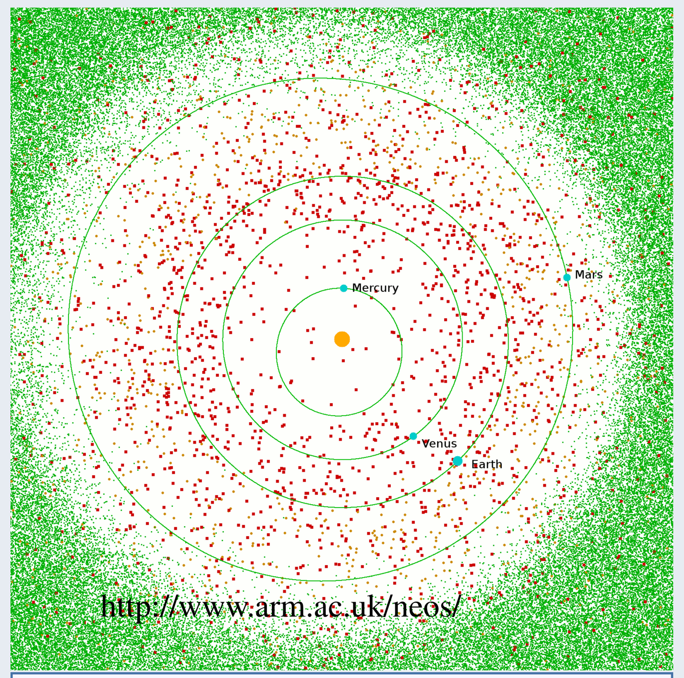
Simulations of asteroid-generated tsunamis using GeoClaw

Marsha J Berger and Randall J. LeVeque

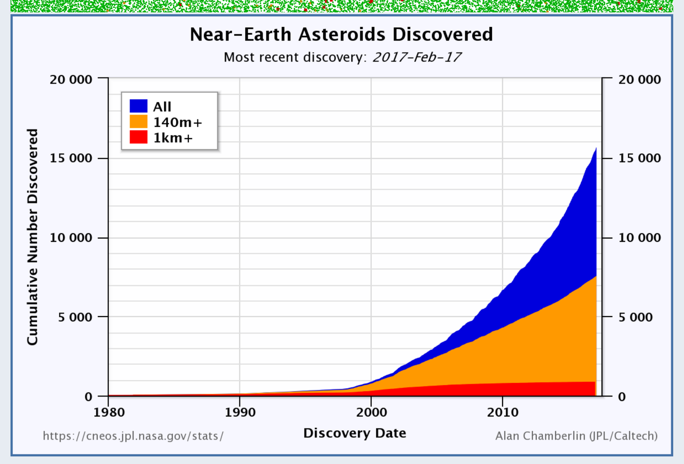
New York University / University of Washington

NASA Asteroid Threat Assessment

NASA's Planetary Defense Coordinating Office (PDCO) recently chartered a new study to determine the lower size limit of Near Earth Objects (NEOs) that should be cataloged as potentially dangerous if they strike earth, to potentially update a 2003 study that concluded the lower limit is 140 meters.

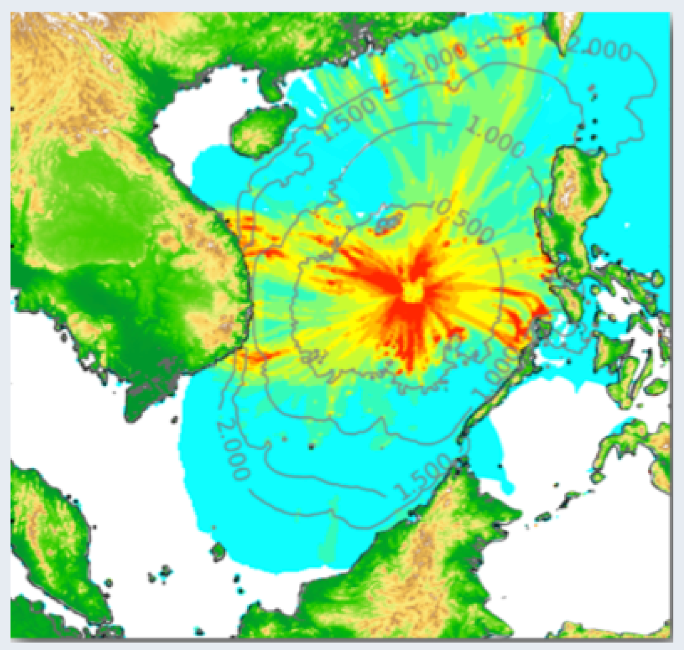


Since two-thirds of the Earth's surface is water, the size of NEOs that can create devastation from tsunamis is an important consideration. Of particular interest is the devastation that could be created by coastal inundation and run-up, and how does such a risk compare to that which the same sized object poses for a land impact.

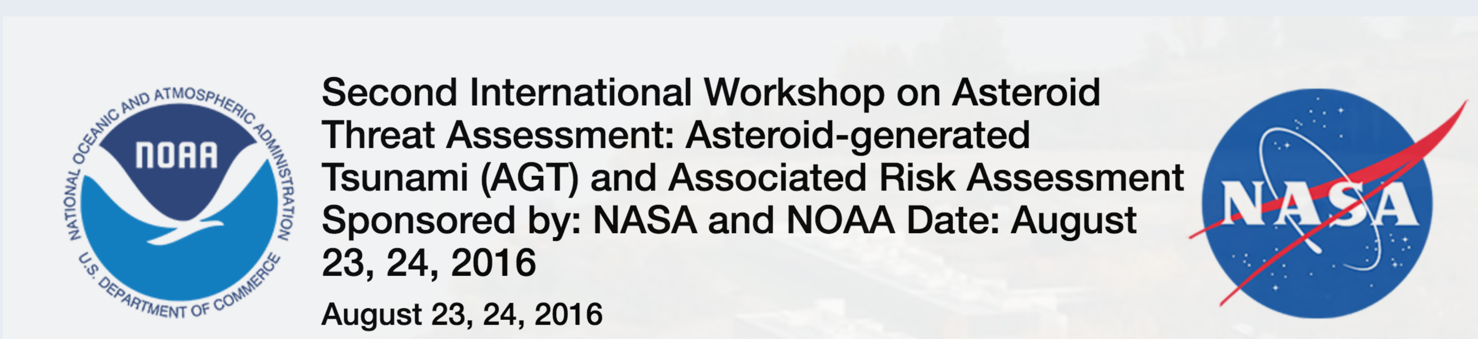


The potential effect of asteroid-generated tsunamis must also be included in updated probabilistic hazard assessments.

GeoClaw simulation — South China Sea



An interdisciplinary team of researchers from NASA Ames Research Center and several national laboratories and universities is now studying these questions using a variety of computational models. This poster shows some results presented at the 2016 workshop.



Talks from the workshop are available online:
https://tsunami-workshop.arc.nasa.gov/workshop2016/

Acknowledgements

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Airburst asteroids

Smaller asteroids explode in the atmosphere without direct impact.

Tunguska event of 1908:

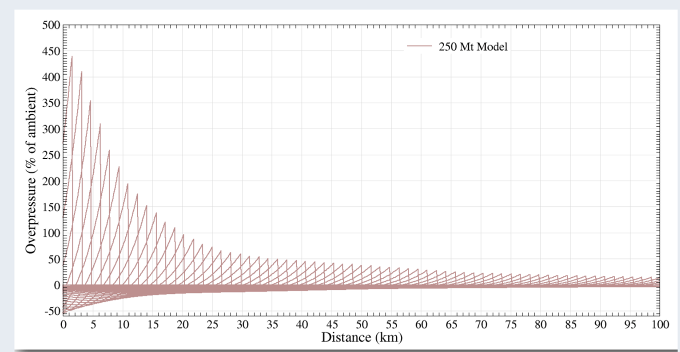
- 40–80 meter diameter,
- 5–15 megatons TNT equivalent,
- Flattened 2000 km^2 of Siberian forest

Chelyabinsk event of 2013:

- 20 meter, 20 km/sec,
- 500 kiloton,
- 1500 injured,
- 7200 buildings damaged

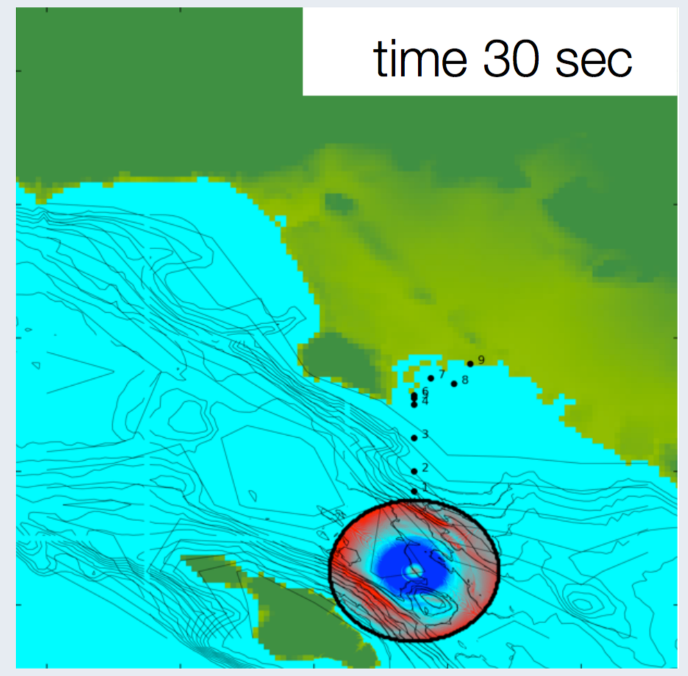
250 Mt airburst, ≈ 200m diameter:

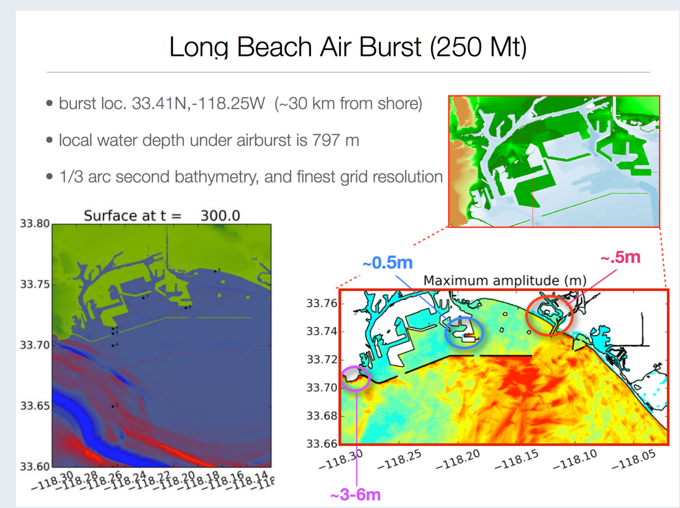
Radially symmetric pressure pulse:



What happens if this travels over the ocean?

Long Beach Case Study





One-dimensional model problem

Shallow Water Equations with atmospheric pressure forcing:

$$h_t + (hu)_x = 0$$

$$(hu)_t + \left(hu^2 + \frac{1}{2}gh^2\right)_x = -hp_x/\rho$$

where h = depth, u = velocity, p = atmospheric pressure, ρ = density of water

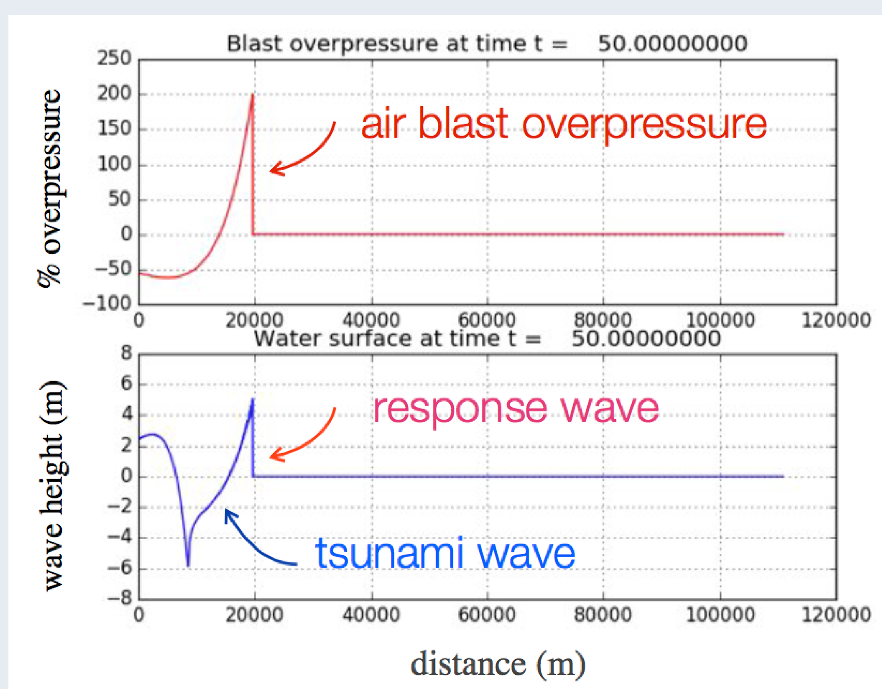
Linearized response:

$$\Delta h = \left(\frac{h_0}{(s^2 - c^2)\rho}\right)\Delta p$$

where $c = \sqrt{gh}$ = gravity wave (tsunami) speed, s = speed of sound in air.

$s > c$ so surface forced upward by increased pressure!

Stronger effect in deeper water.

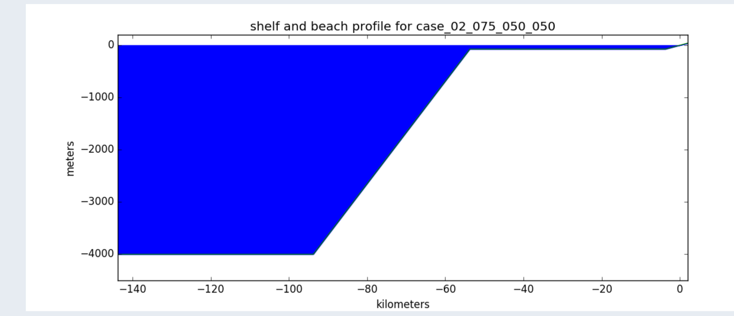


Parameter study for run-up

For global scale hazard assessment, need simple model of how much run-up can be expected for airburst of a fixed amplitude.

Full tsunami simulation cannot be performed for millions of possible impact locations and thousands of coastal locations of interest.

Can we improve on simple model of Ward and Asphaug that has been used in the past?

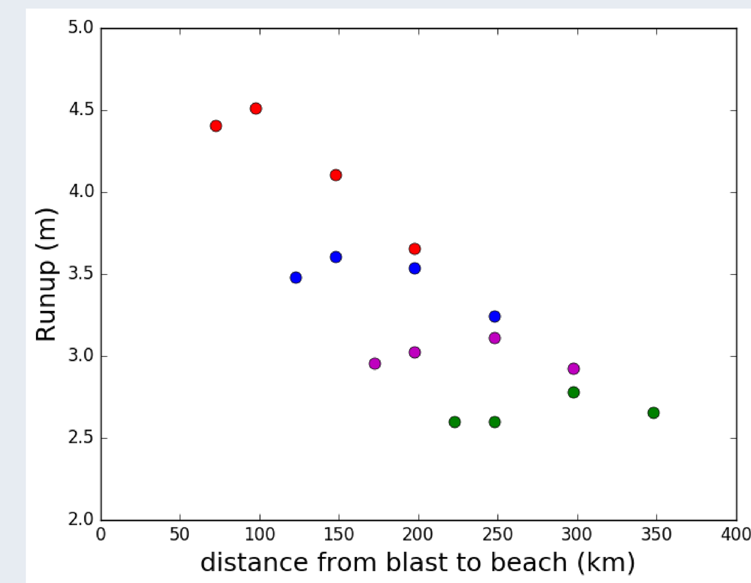


One-dimensional radially symmetric:
250 Megaton airburst, 10 km above surface.

In plot to right we show the maximum runup on shore (max elevation above sea level) for blasts at various distances from shore.

We have varied the continental shelf width
Red = 0km,
Blue = 50km,
Magenta = 100km,
Green = 150km.

In other tests we have also varied shelf depth, beach slope.

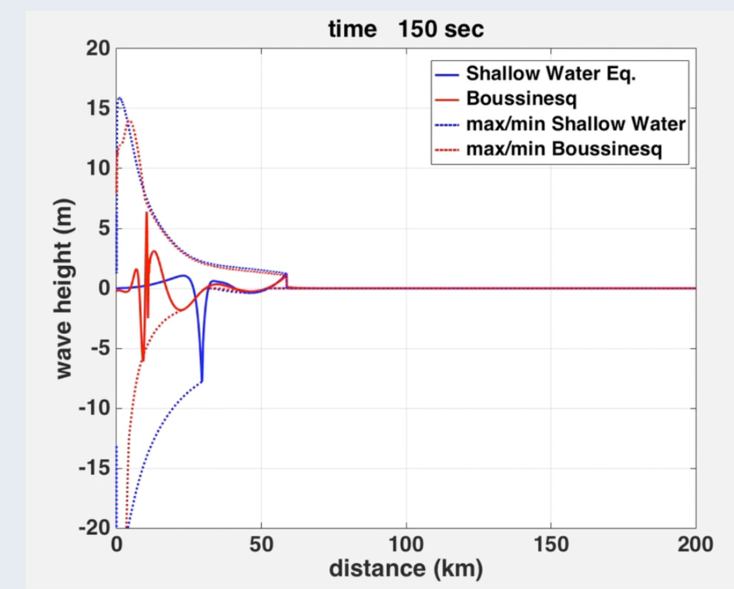


Shallow water equations vs. Boussinesq

Tests have revealed that short-wavelength asteroid-generated tsunamis might not be accurately modeled by shallow water equations.

In joint work with Robert Weiss (Virginia Tech) we are comparing shallow water results with results from Serre-Green-Naghdi dispersive equations.

We are also working with BoussClaw, a Boussinesq equation variant of GeoClaw developed by Jihwan Kim, working with Finn Løvholt and Geir Pedersen (NGI, Oslo).



References

- M. J. Berger and J. B. Goodman, Air-burst Generated Tsunamis, in preparation.
- J. Kim, G. K. Pedersen, F. Løvholt, and R. J. LeVeque (2017), A Boussinesq type extension of the GeoClaw model - a study of wave breaking phenomena applying dispersive long wave models, Coastal Engineering, 122, 75–86.
- R. J. LeVeque, D. L. George, and M. J. Berger (2011), Tsunami modeling with adaptively refined finite volume methods, Acta Numerica, 211–289.
- D. Morrison and E. Venkatapathy (2017), Asteroid Generated Tsunami: Summary of NASA/NOAA WorkshopNASA/Technical Memorandum (NASA/TM–219463).
- S. N. Ward and E. Asphaug (2000), Asteroid impact tsunami: a probabilistic hazard assessment, Icarus, 145(1), 64–78.
- Clawpack Development Team, Clawpack and GeoClaw software, www.clawpack.org