Impact Tsunami Hazard:

My Best Guess

P.D.C.   Washington, DC   3/7/07

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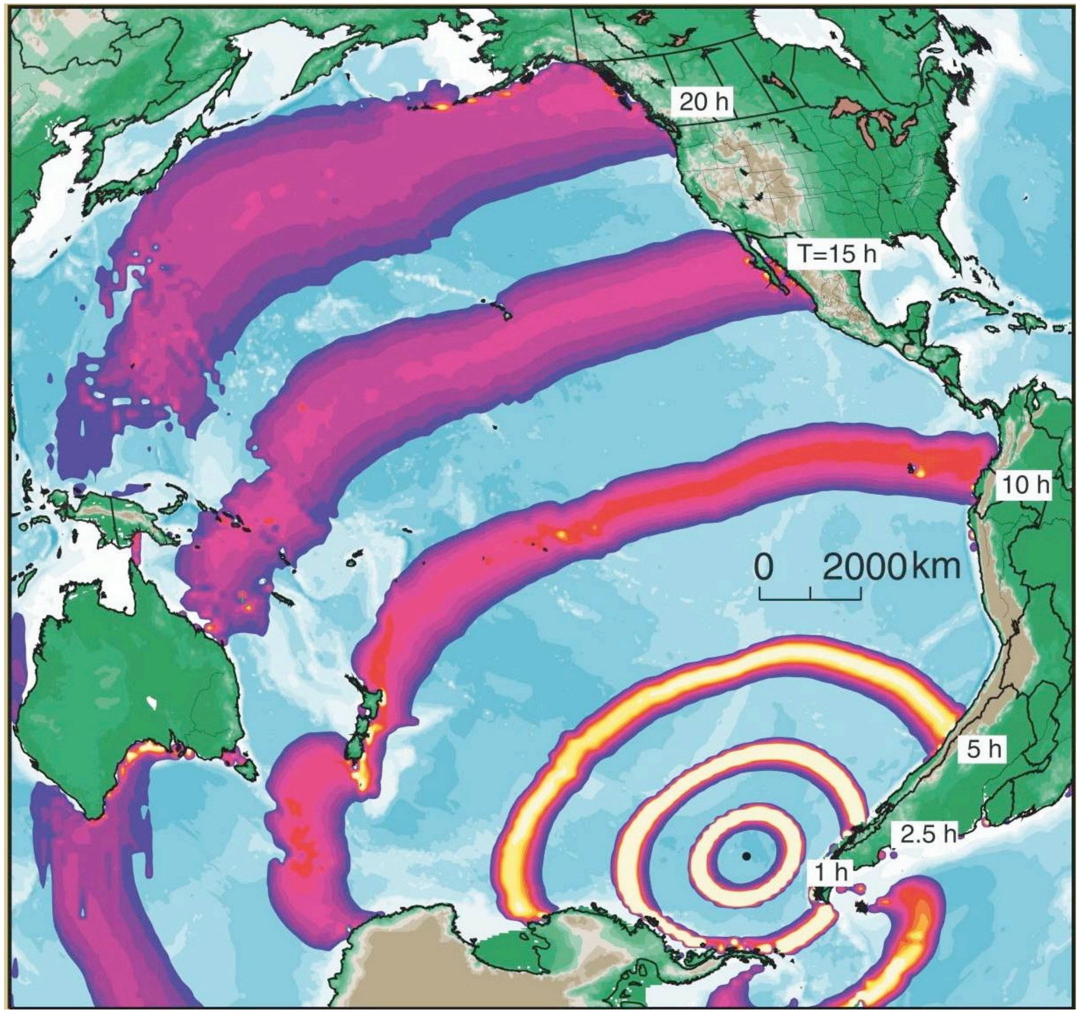

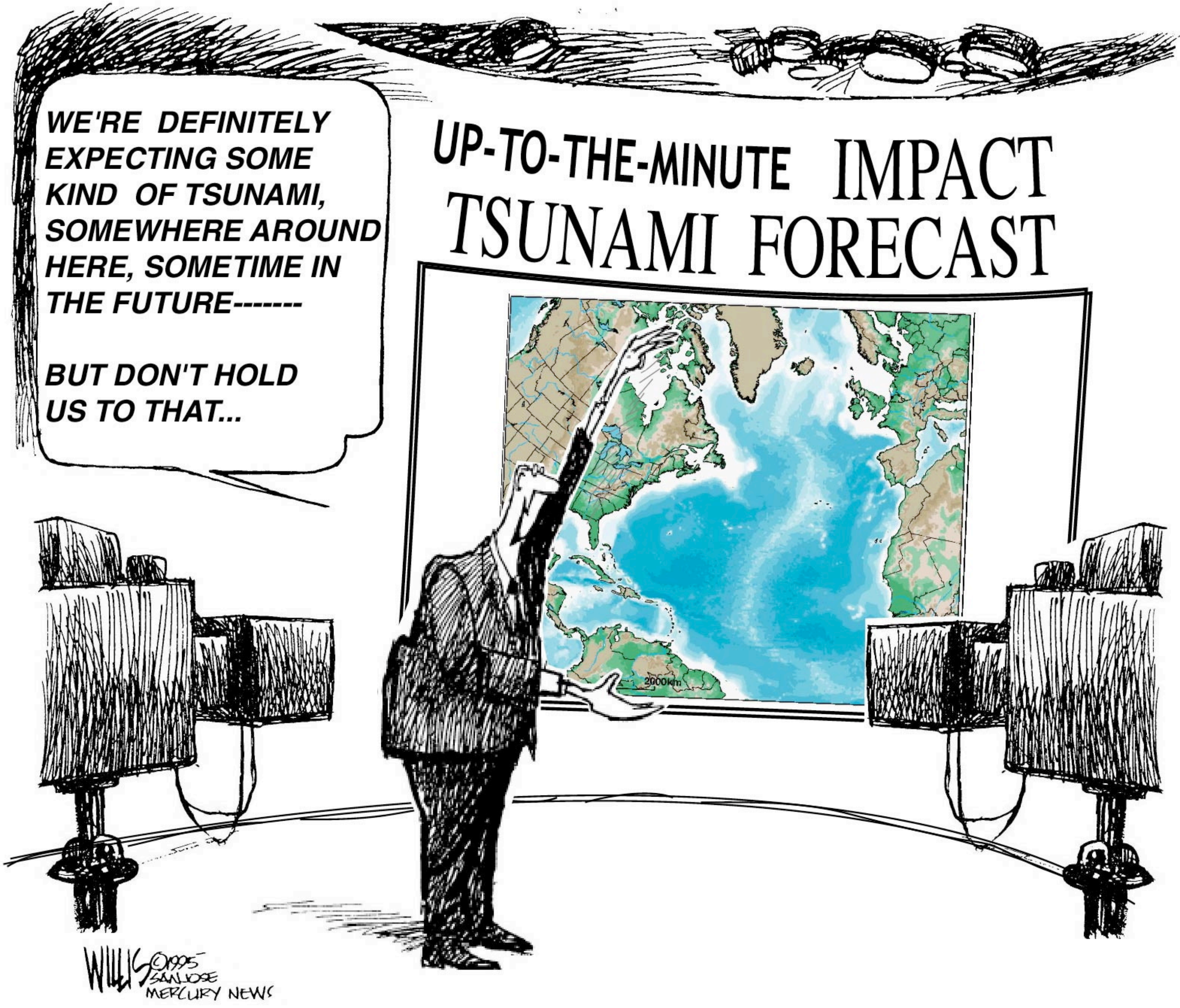
WE'RE DEFINITELY EXPECTING SOME KIND OF TSUNAMI, SOMEWHERE AROUND HERE, SOMETIME IN THE FUTURE-------
BUT DON'T HOLD US TO THAT...
UP-TO-THE-MINUTE IMPACT TSUNAMI FORECAST
2000km
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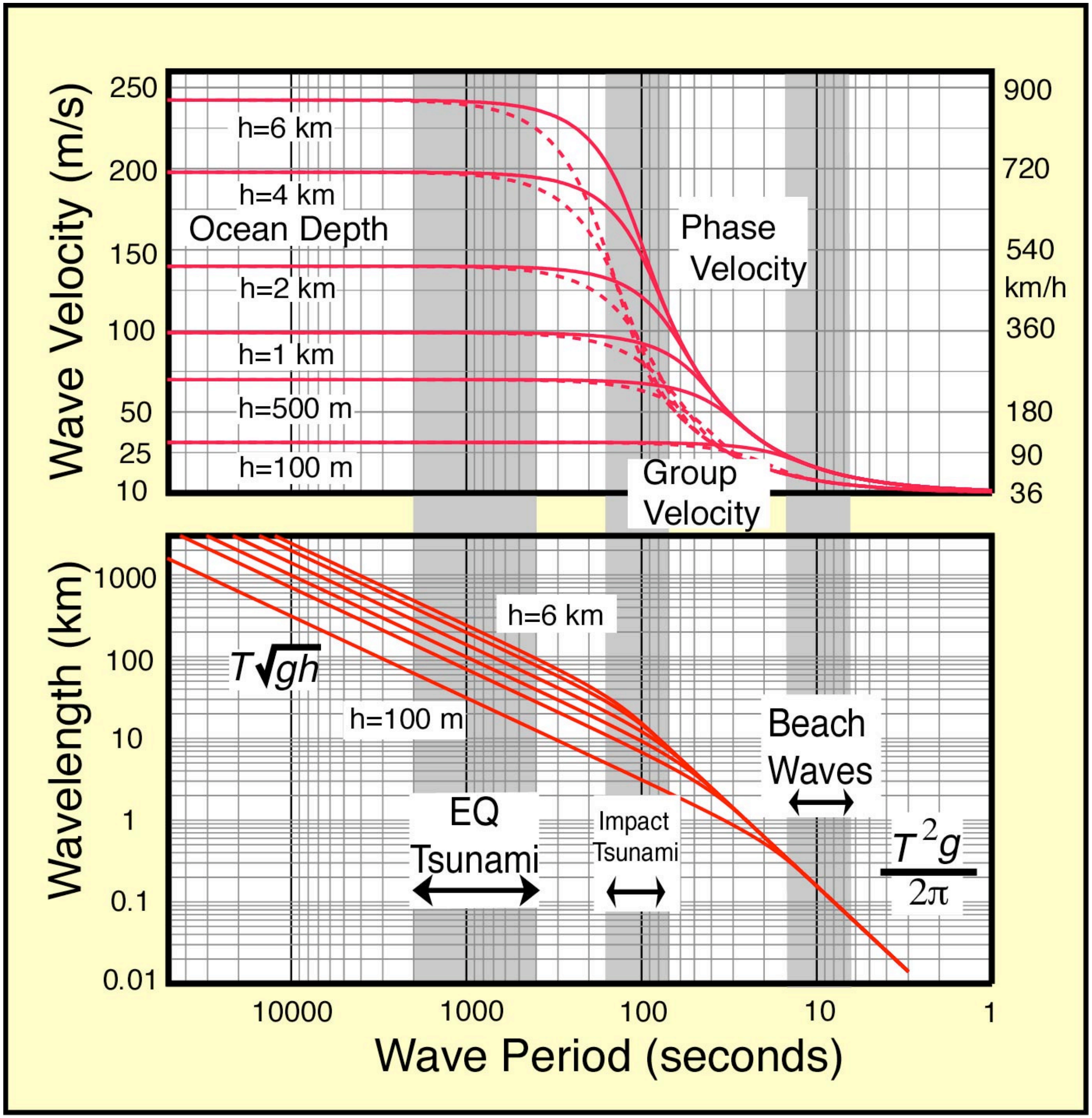
Tsunami waves have far greater period, faster speed, and longer wavelength than familiar beach waves :10-15s

EQ Tsunami: 400-2000s

Impact Tsunami: 70-150s

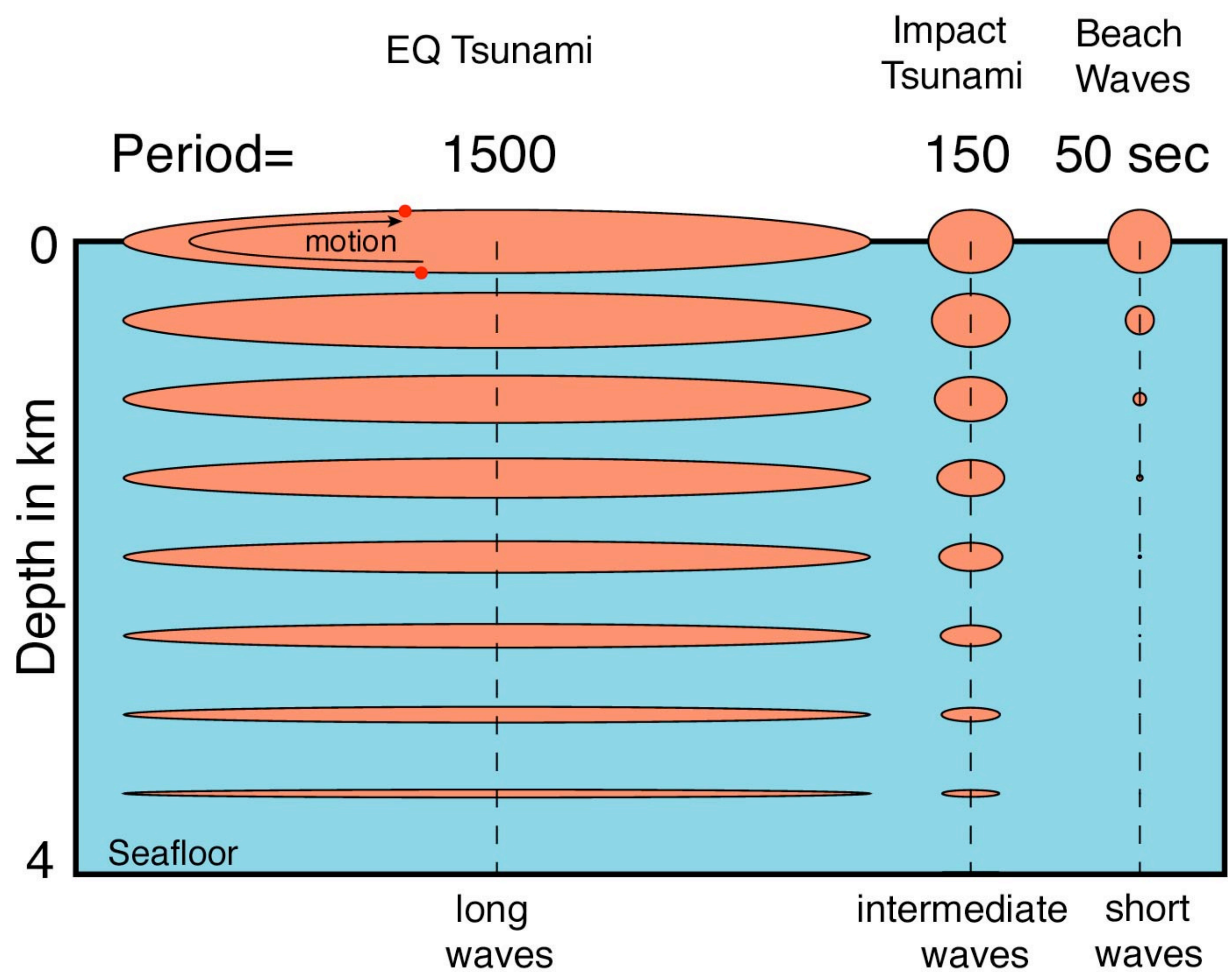


Tsunami move the ocean differently than beach waves

Unlike beach waves, tsunami reach all the way to the sea bottom.

Generate Bedforms

--You can't out dive a tsunami.



Tsunami motions versus depth in the ocean.

What are the actual rates, diameters and velocities of asteroids targeting Earth?

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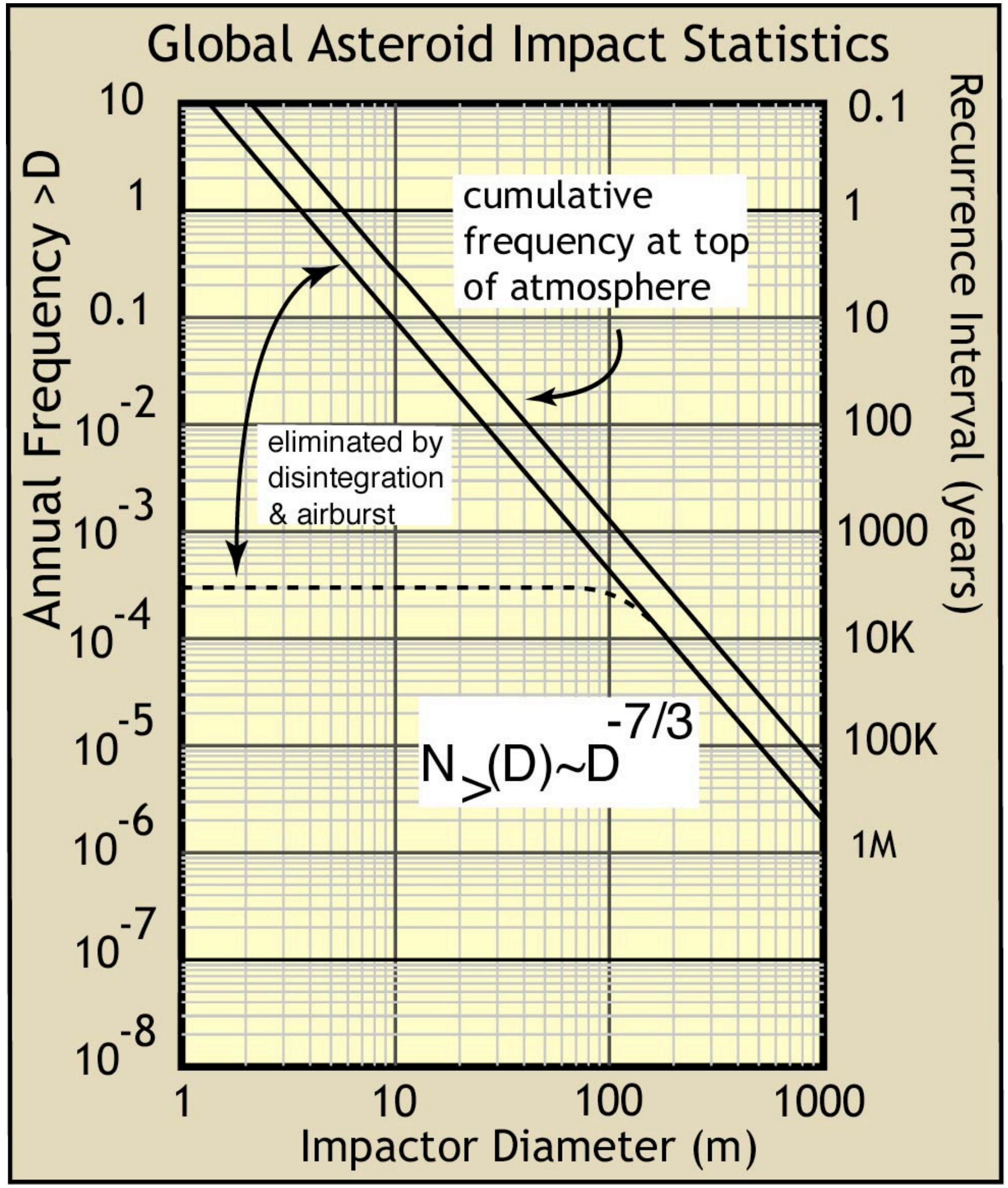
How much tsunami energy vanishes in the “last mile” as waves break on continental shelves?

How high might the water run up? How long would the flooding last? How far inland will water penetrate?

Like many things in nature, asteroids follow a power law distribution of size versus number.

*Astronomers think they know asteroid flux to a **factor of three** or so.*

*Impact velocities also spread by **factor of two** or so.*



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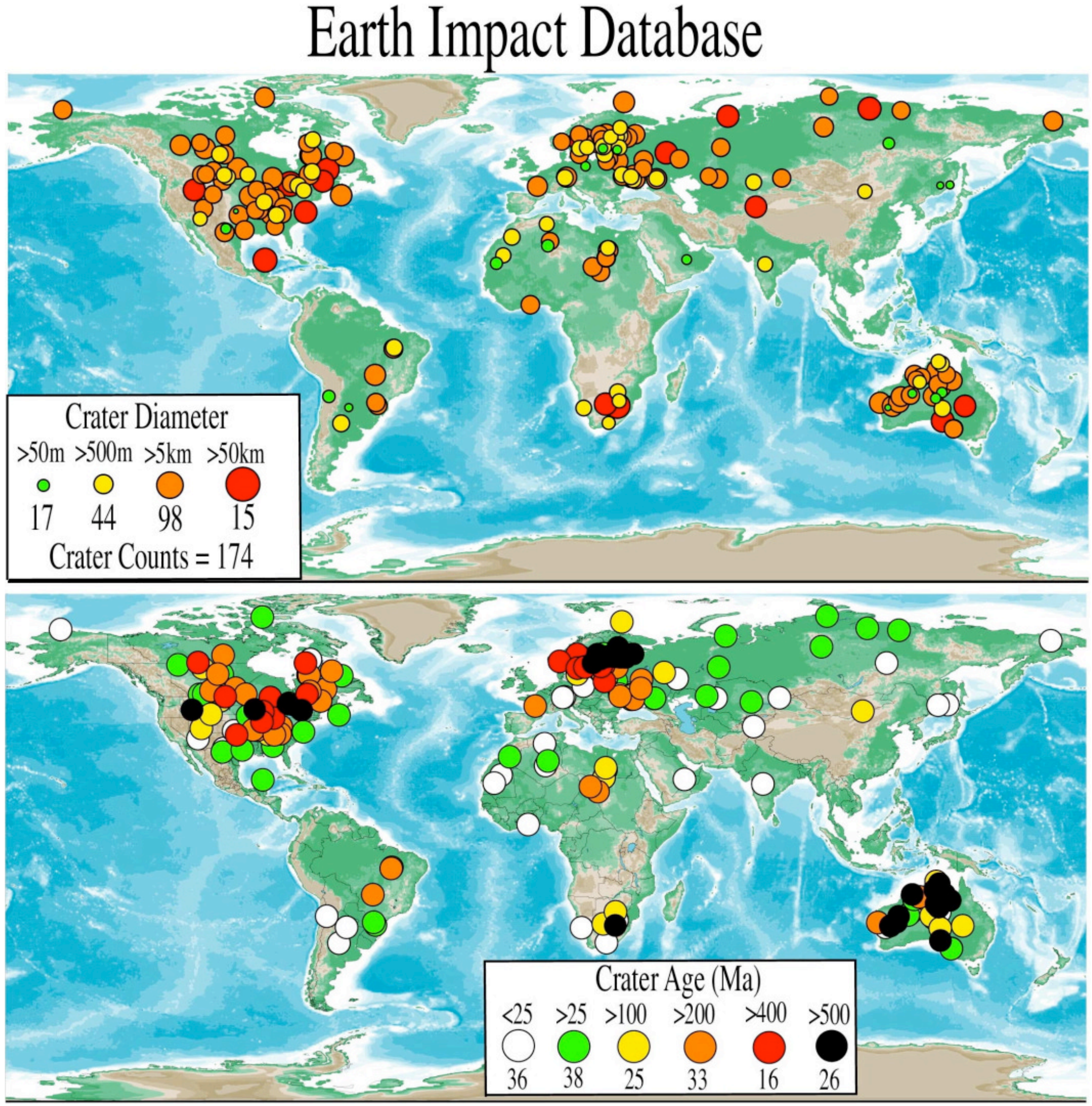
Crucial Question for Tsunami Hazard is:

How many of the those asteroids actually make it to the surface?

Let's count craters on Earth.

We know crater ages too! This really helps



Plot of Observed Crater Counts versus Crater Size (Triangles)

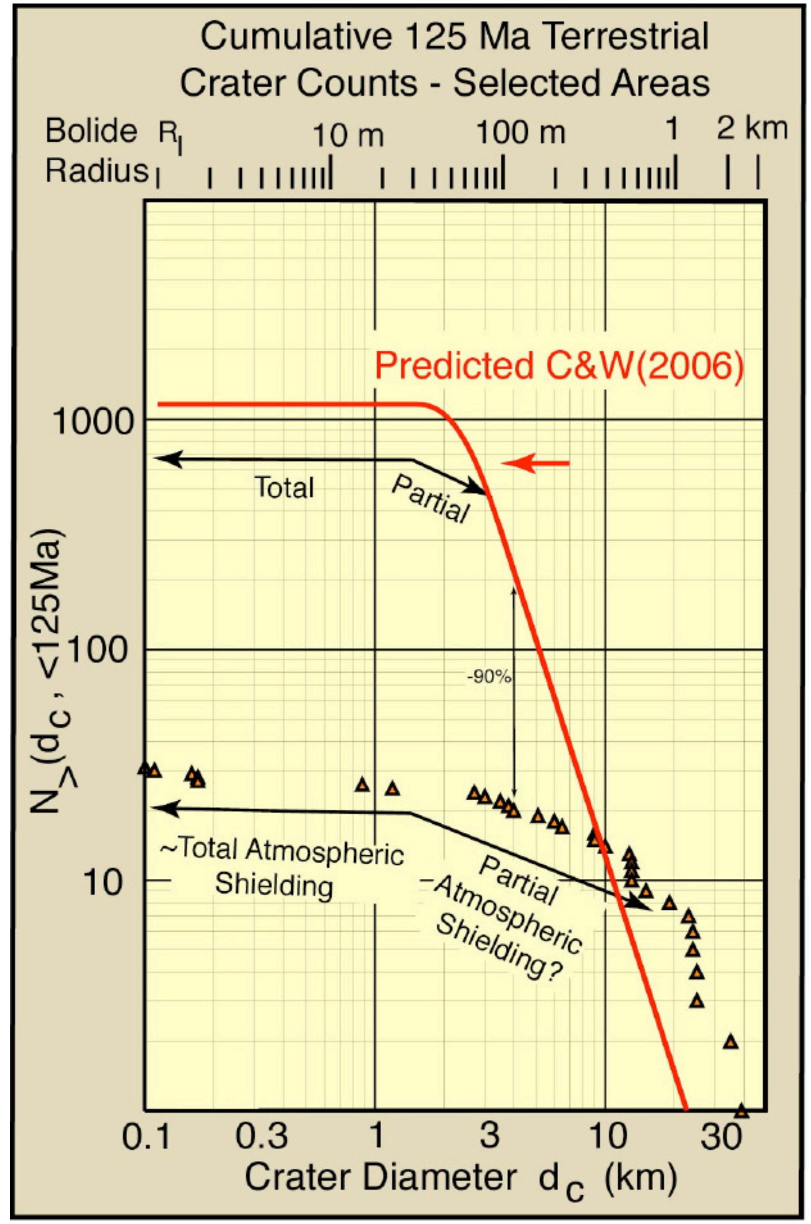
*Current astronomical estimates (red lines) are not too bad (**factor of 2-3**) for large bolides D>1000m*

But estimates are way way, too large for smaller ones (D<800m).

Lack of small craters is not due to erosion.

Atmosphere Shielding may be far stronger than supposed for R_I<300m

*Huge uncertainty in surface impact rates (**factor of 10!**) if this is true.*



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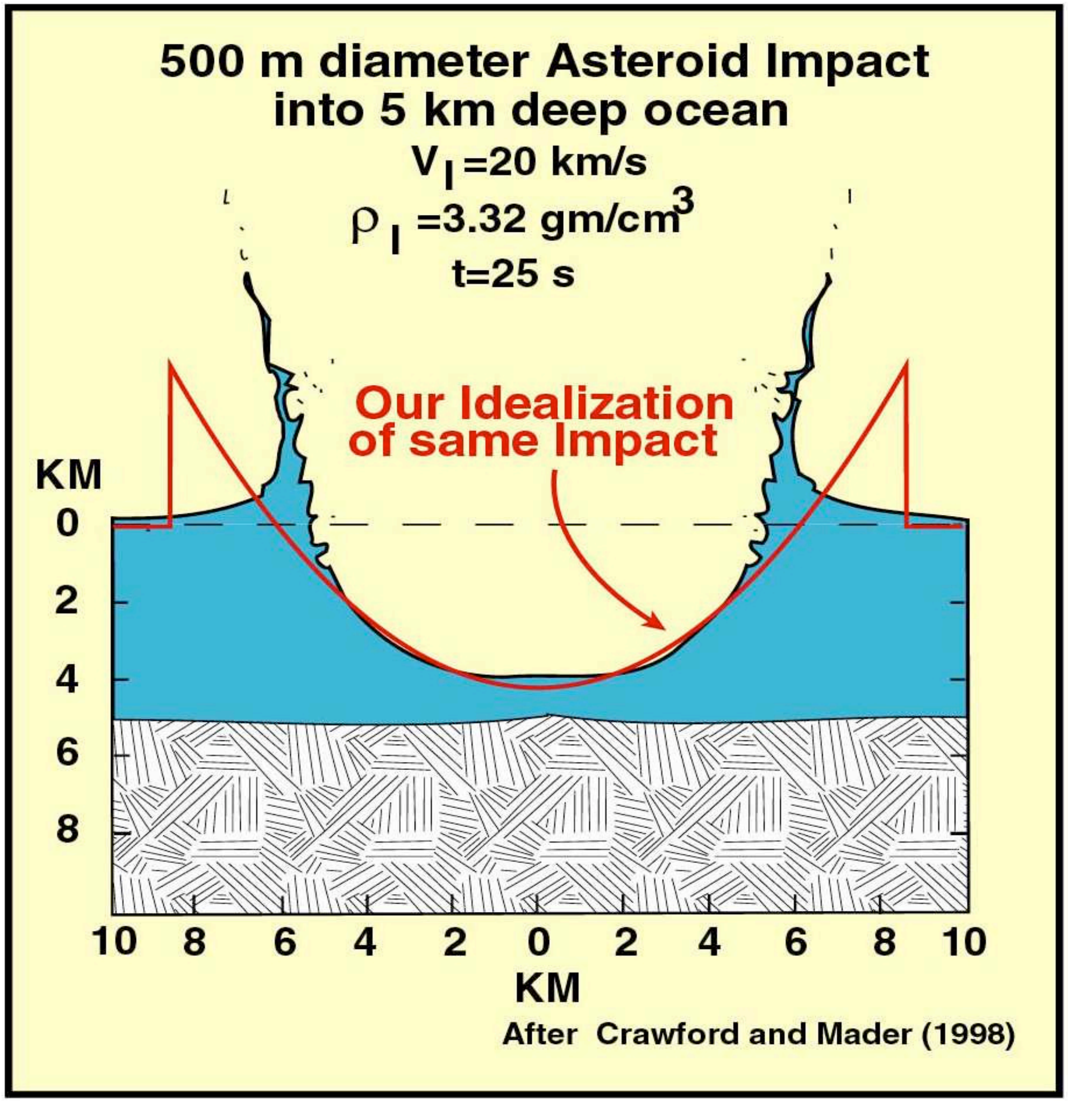
There is not too much (25%) disagreement on the size of transient cavity generated by impacts of fixed size and speed.

Simple Linear theory is not meant to represent details of impact, *rather extract the essence of what is important about the cavity in regard to tsunami properties at distance using a few parameters*



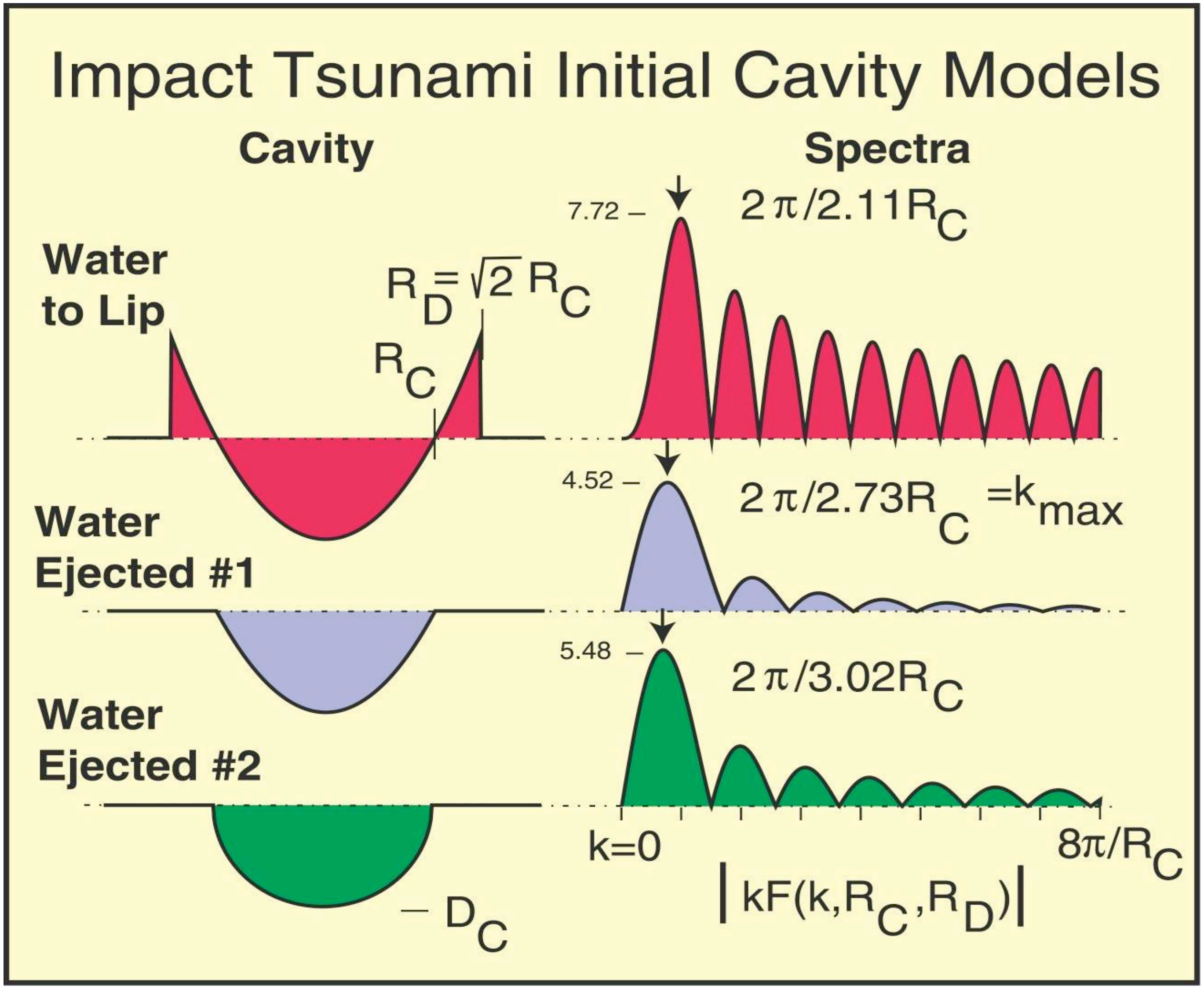
We do same thing in Seismology -

"Magnitude" "Fault Plane"

Idealized, but useful concepts of earthquakes

The most important features of impact cavities as far as tsunami are concerned are cavity depth and cavity diameter.

Other details are interesting but secondary.

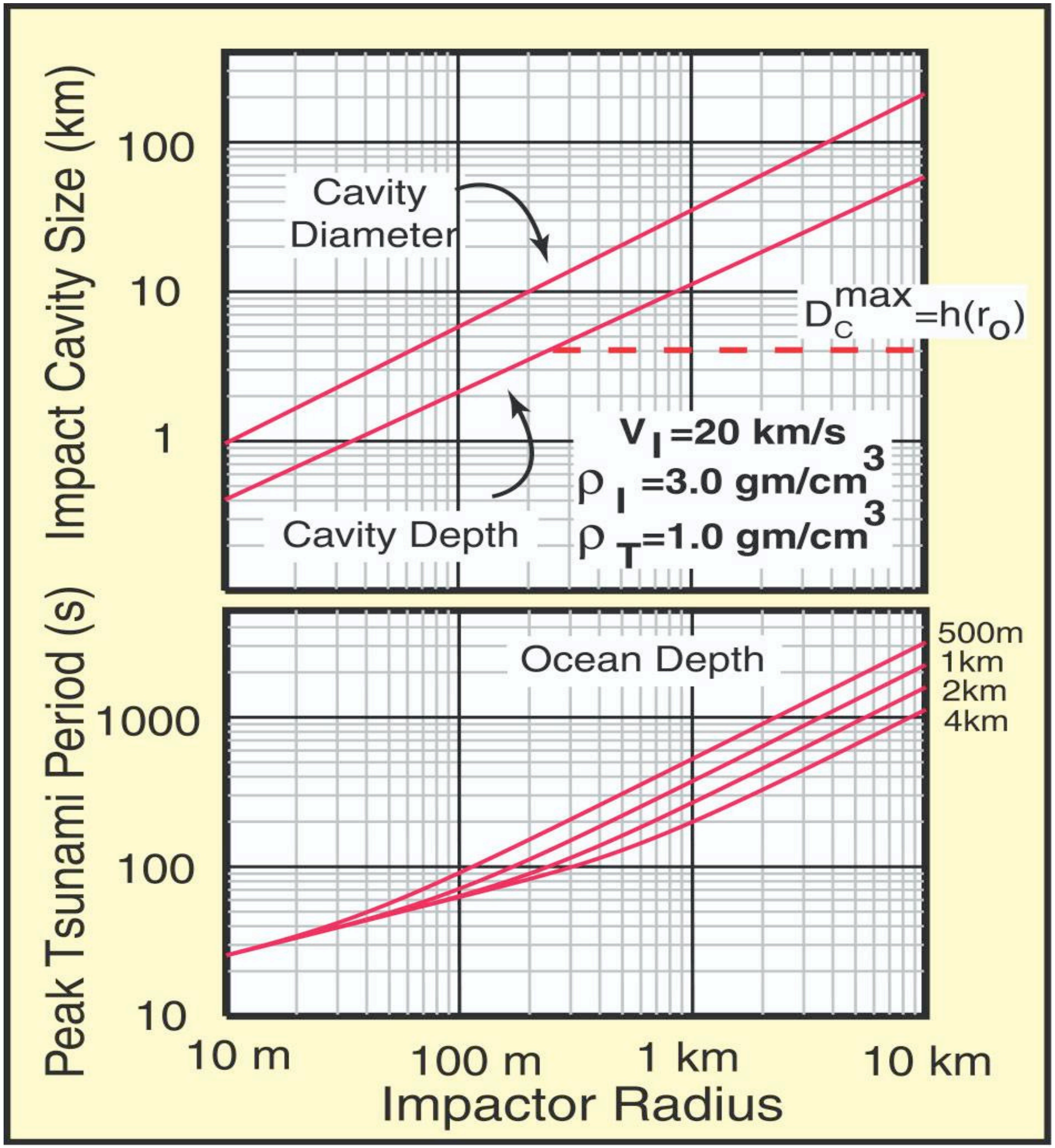


NOTE: Bigger cavities produce longer waves. Peak tsunami heights are in waves of length 2 to 3 times crater diameter.

Typical cavity diameters are 10-50 km.

Typical tsunami periods from cavities of that size are 70 -150 s

Other than landslides, nothing makes waves of this period, so it is hard to find natural analogs of impact tsunami



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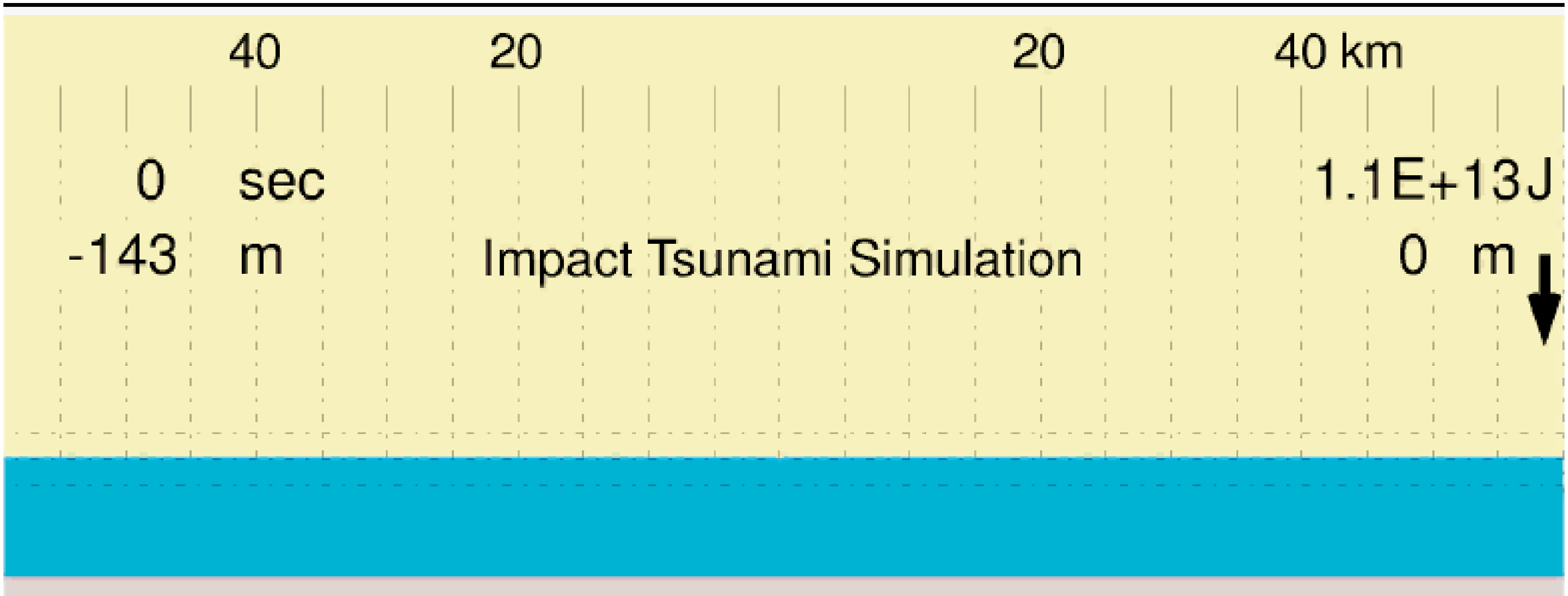
True, linear theory tells us nothing about non-linear, turbulent dissipation. Fancy hydrocodes help, but disagreements exist there too.

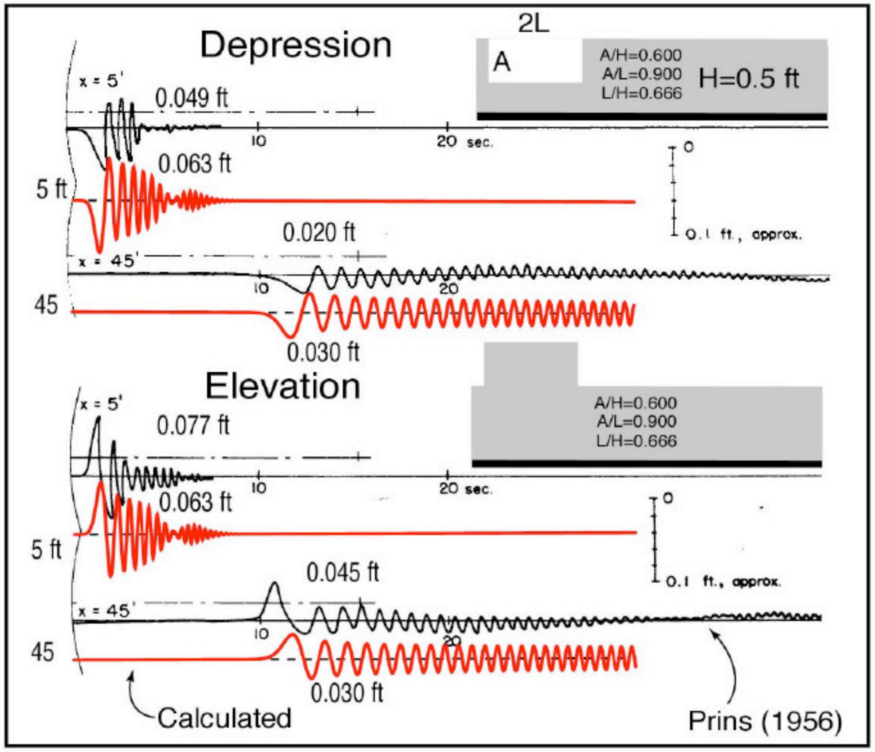
Still, as long as the theory predicts tsunami REASONABLY WELL AT SOME DISTANCE AWAY, that's OK given all the other uncertainties

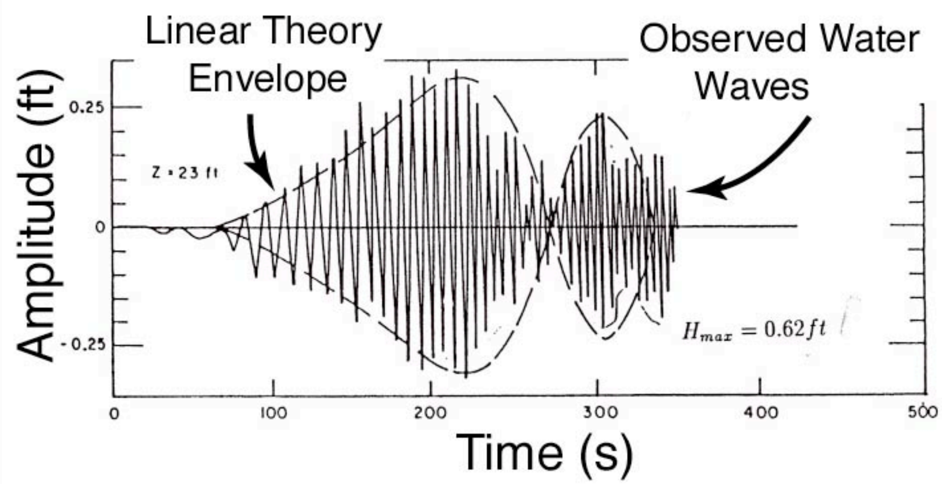


Impact of 1km diameter asteroid into 4600 m ocean. Cavity rebounds and tsunami waves are sent out. Dark line is hydrocode result by Valery Shuvalov. Simple model doesn't look half bad to me.

Can we Ground Truth Anything about impact tsunami models?
It's not easy.

Linear Theory versus Wave Tank Experiments and TNT Explosion





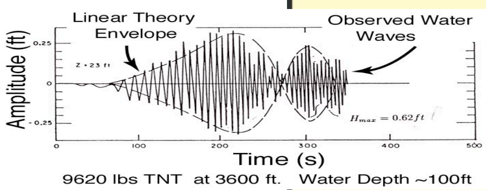
9620 lbs TNT at 3600 ft. Water Depth ~100ft

(Most) everyone agrees that simple linear theory MUST hold at some distance from impact. We know for sure that linear theory works well for earthquake and landslide tsunami.

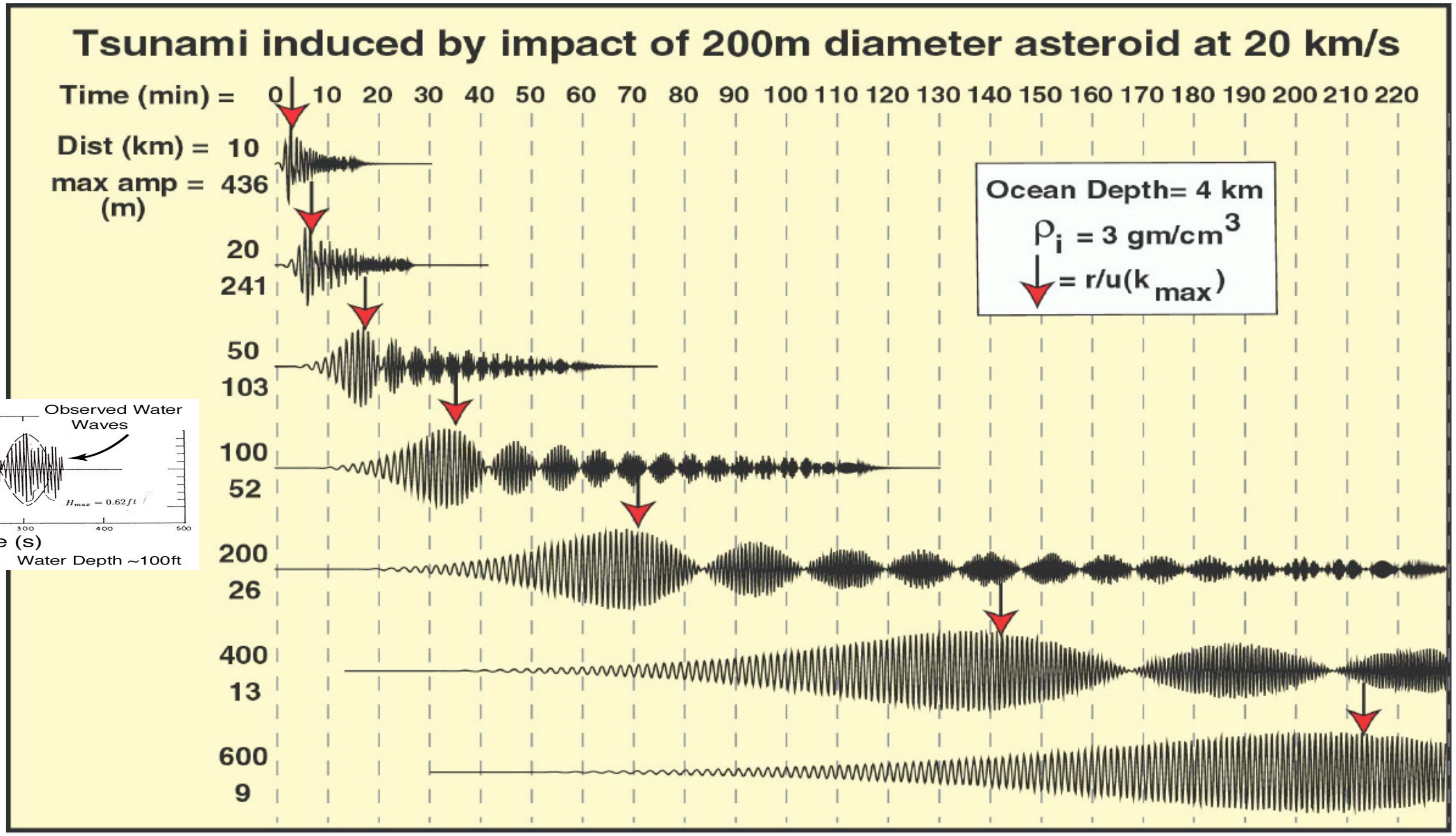
Impact tsunami waves versus time and distance

(Below.)

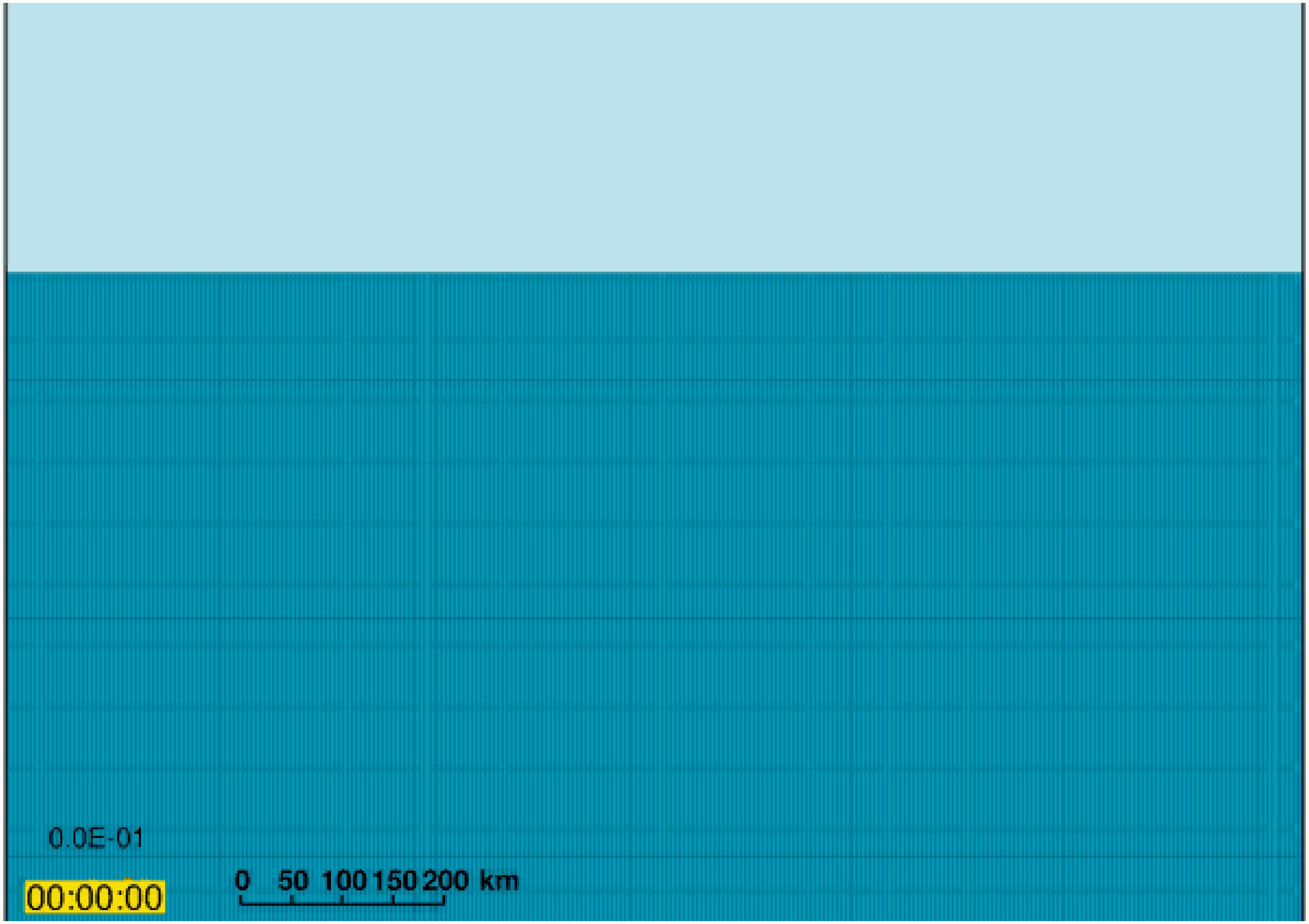
Real explosion again. Looks about the same



as simple model (Right) to me



Impact tsunami are very dispersive. Long periods travel faster than short periods. Dispersion reduces impact tsunami size with distance faster than EQ tsunami.



3d movie of an impact tsunami. See the many waves.

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Tsunami are cylindrical waves not spherical waves **Geometrical Spreading** *for tsunami follow* $R^{-1/2}$ *not* R^{-1}

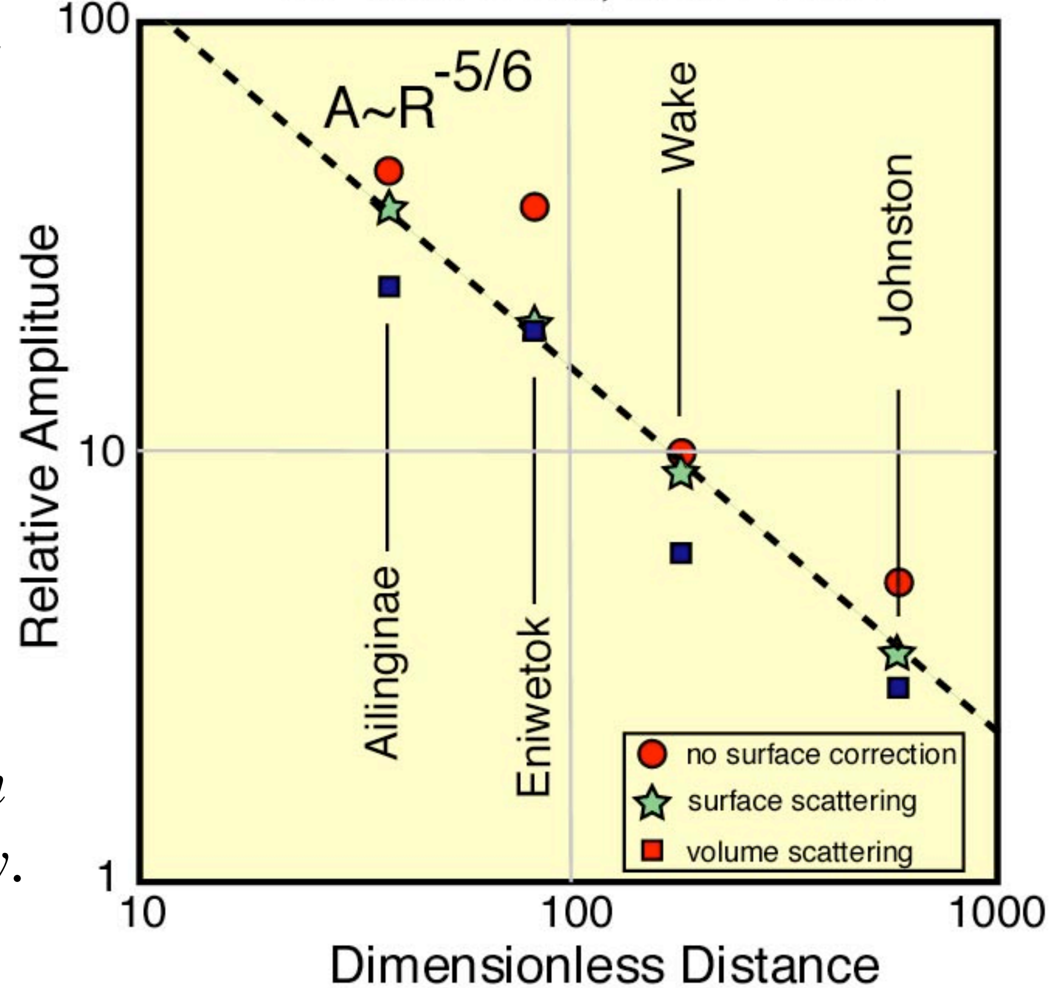
Frequency Dispersion reduces heights by an additional $R^{-1/4}$ *to* $R^{-1/2}$

In 1961 W. Van Dorn measured tsunami waves generated by nuclear tests.

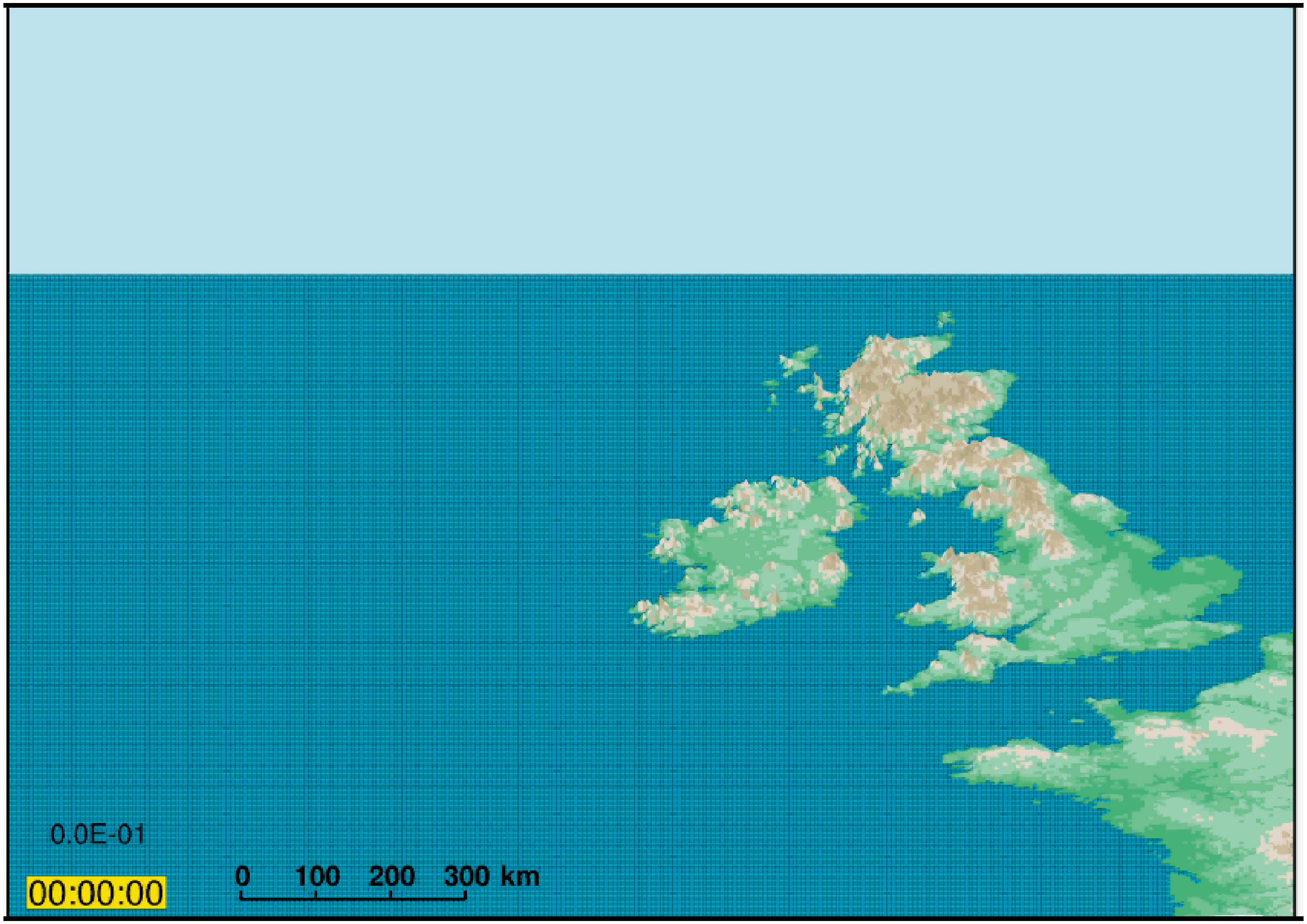
He found $R^{-5/6}$ *decay much in accord with linear theory.*

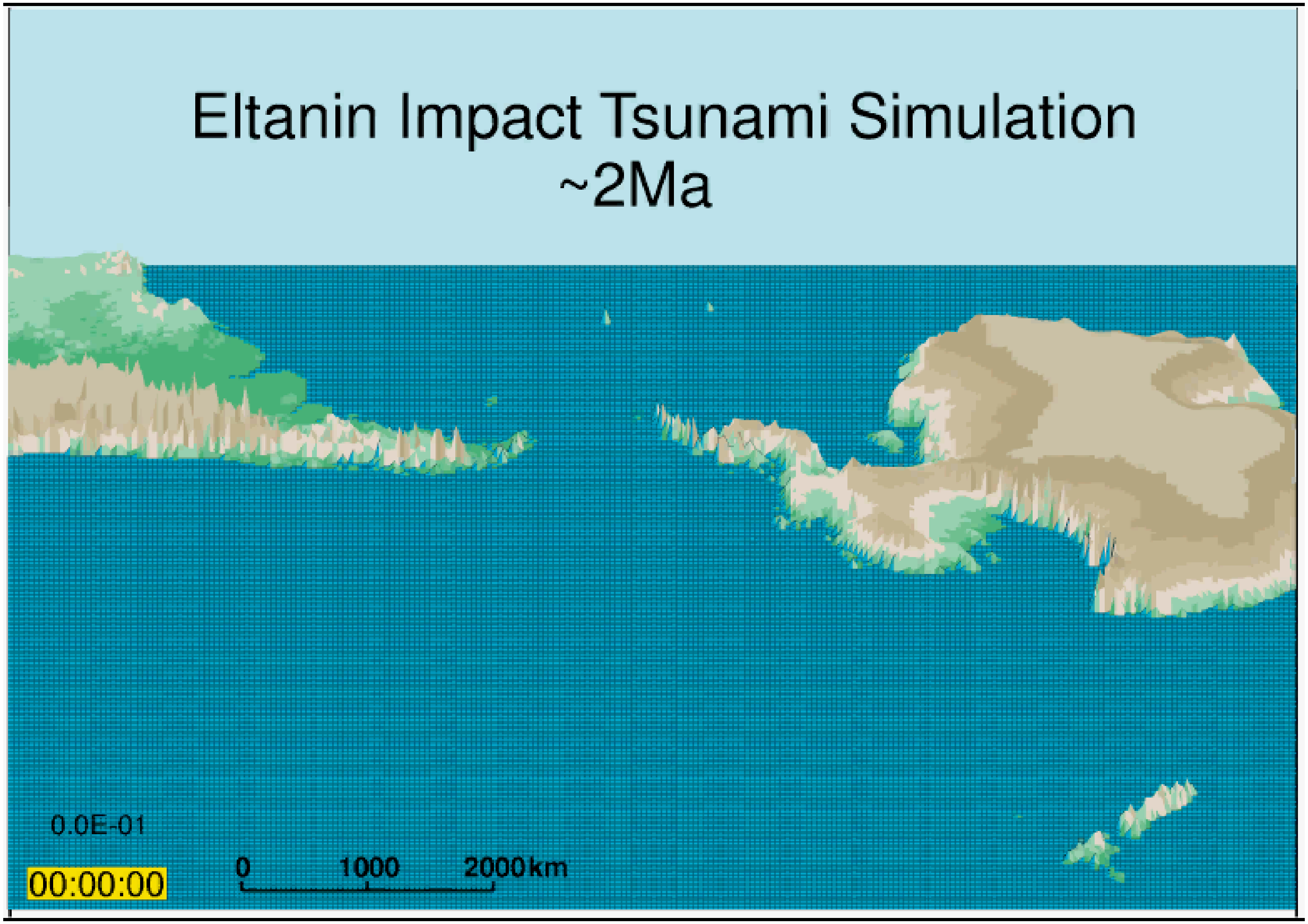
Measured Tsunami Amplitudes Versus Distance from Nuclear Explosions

W. Van Dorn, JGR 1961

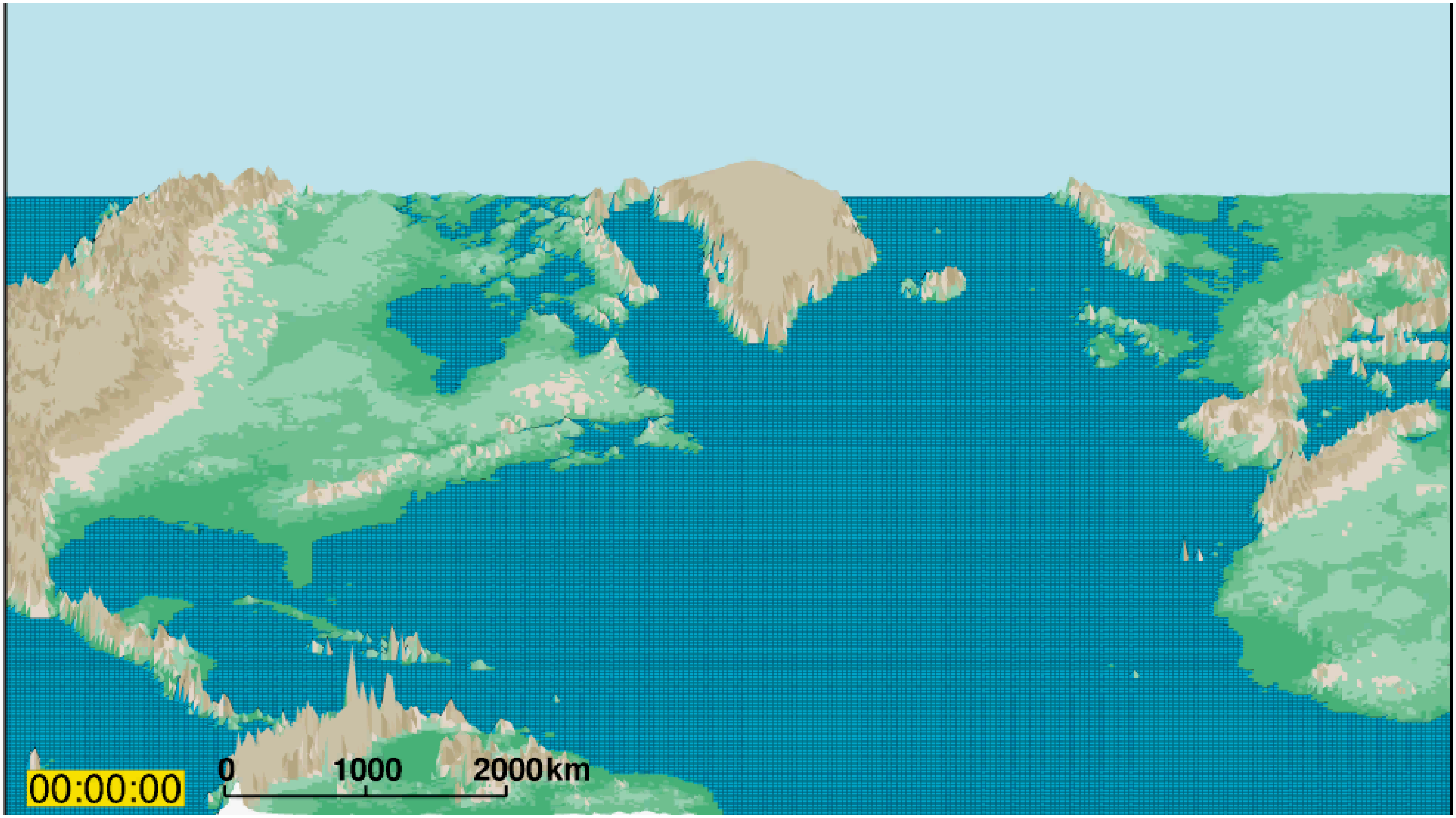


Propagation of tsunami well beyond the cavity is not widely in dispute. Tsunami waves crush together in the shallows and "bend around" obstacles. Watch out Ireland.





Tsunami envelope shown here - many wave cycles underneath the cover.
There is real geological evidence *of the tsunami from Eltanin.*



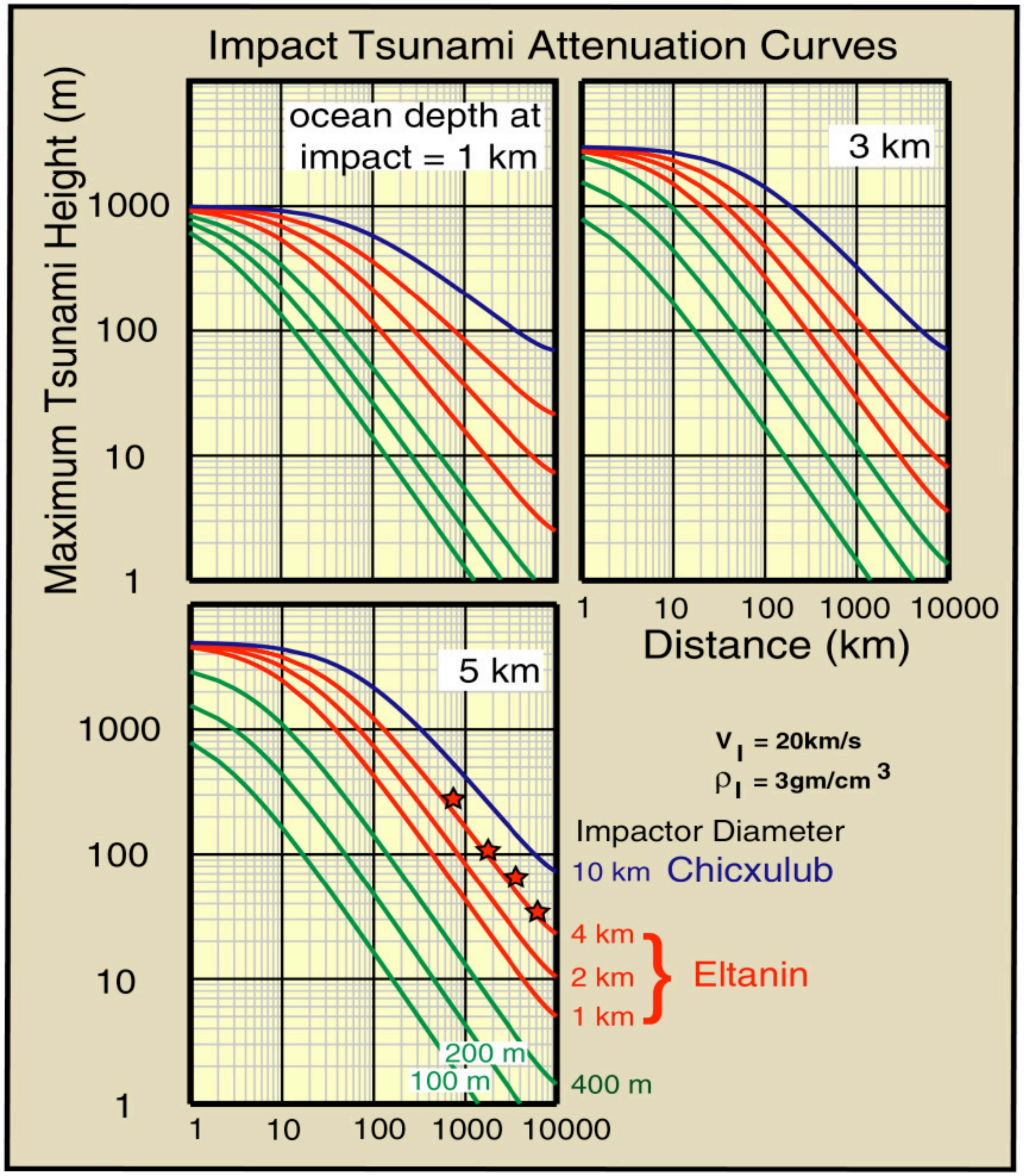
Tsunami take ~8-15 hours to cross ocean basins. Tsunami envelope plotted here again. Runups in meters shown.

Yikes, this is a big one

You can't run every case, so we approximate the results as Attenuation Curves.

Just "read off" predicted tsunami height at a given distance for a given size impactor for a given water depth at impact.

Have to correct these curves for shoaling effects near shore.



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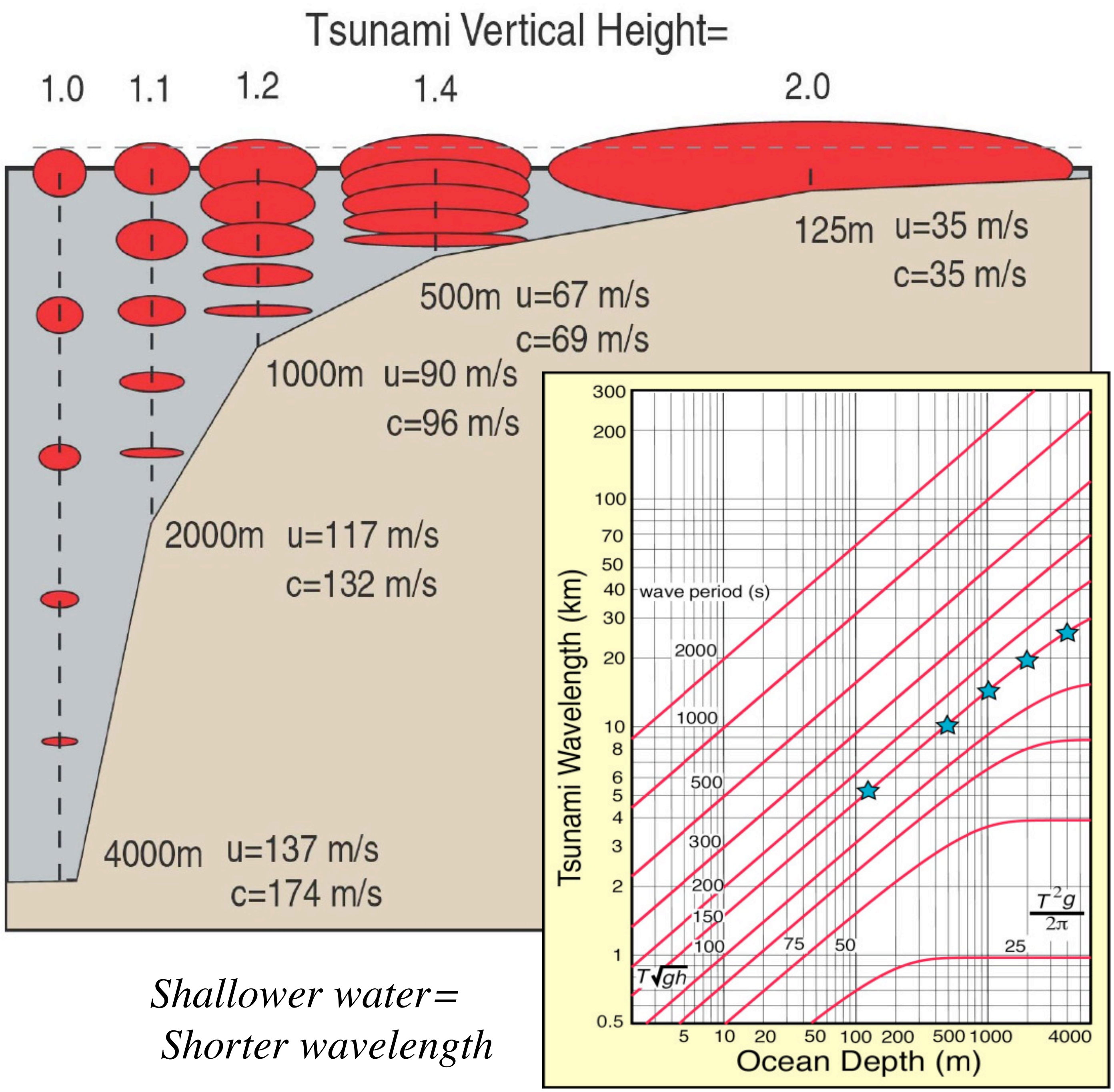
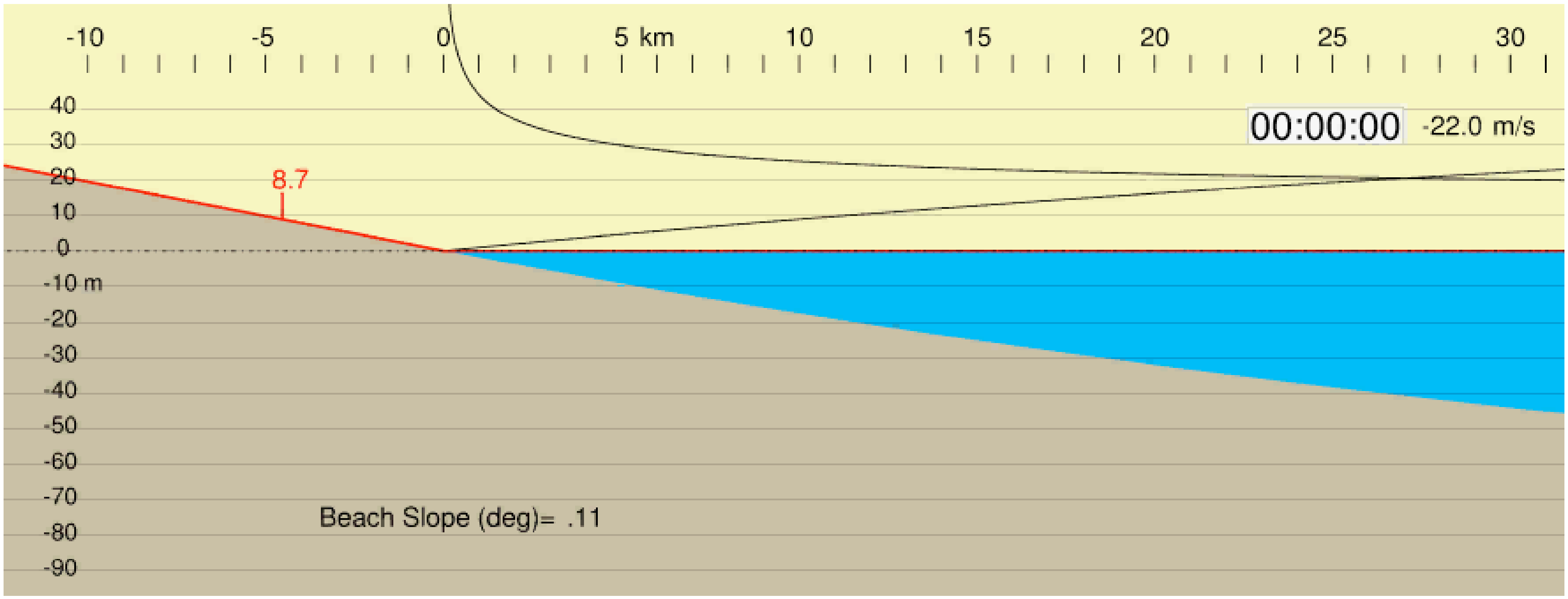
Tsunami slow from 300mph to about 30mph and grow by factors of 3-5 as they near the coast.

We know this pretty well, but the waves can not grow in size forever….



Shallower water=
Shorter wavelength

…so most all waves eventually break as they approach shore. Because of their size (maybe 20m), impact tsunami may break 10-20km off the coast.

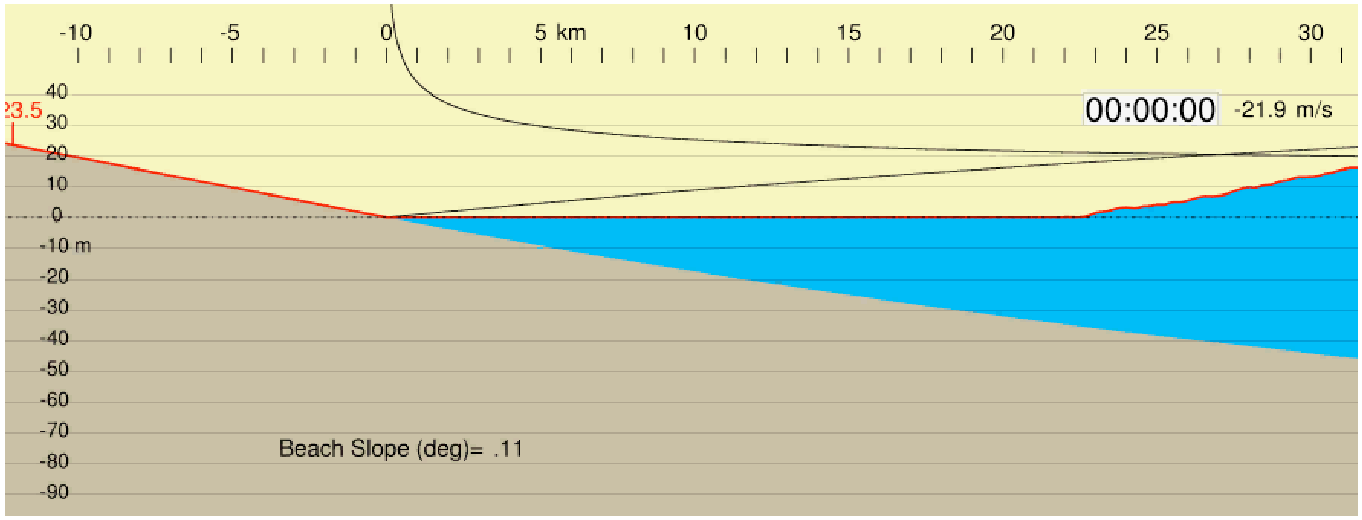


*There is moderate (**factor of 4**) uncertainty in how significant wave breaking is. One problem is that there is almost no experimental or observation data in the period/amplitude range needed.*

Extent of breaking depends partly on ocean depth offshore

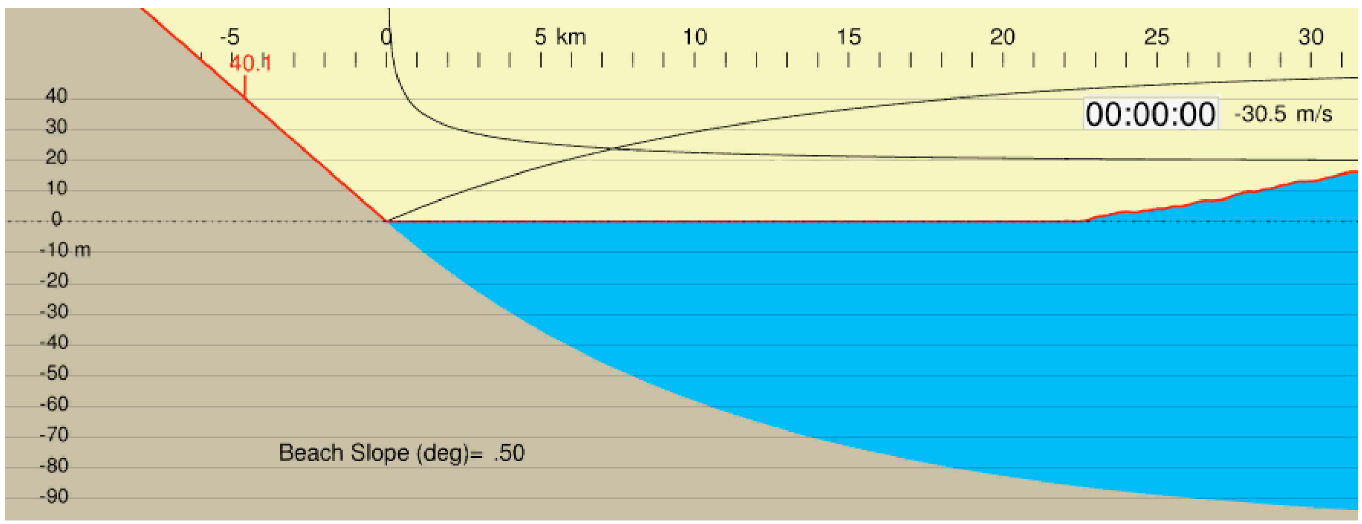
Wide Shelf:

U.S. East Coast



Narrow Shelf:

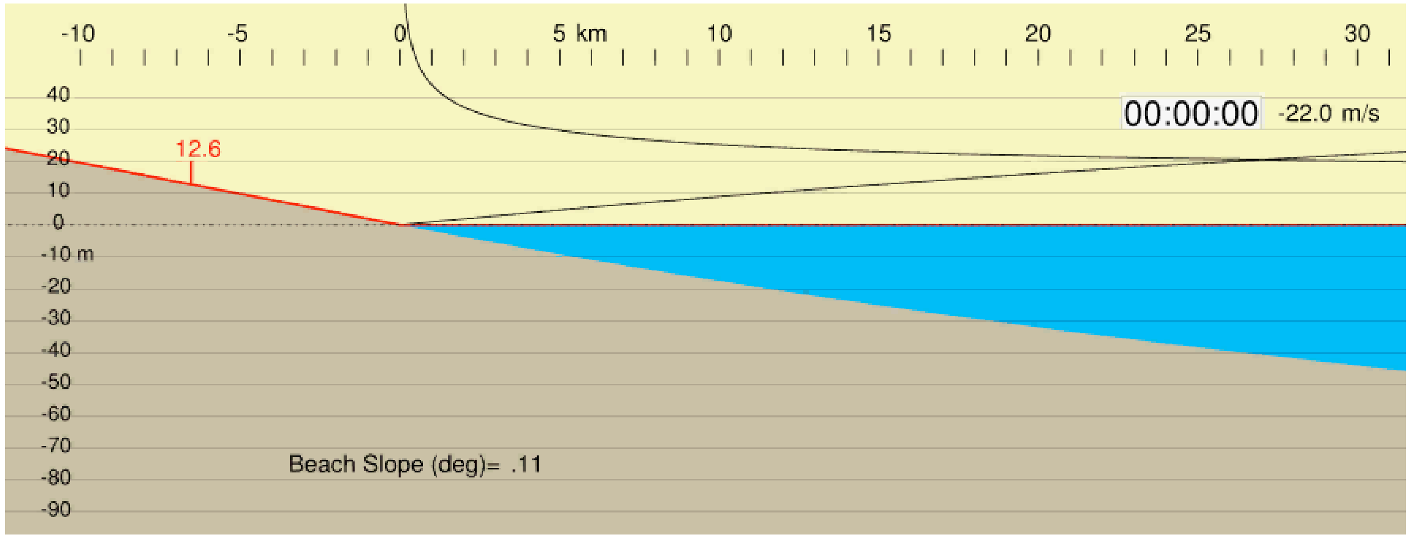
U.S. West Coast



Generally, Waves on Steeper Coasts = More Runup

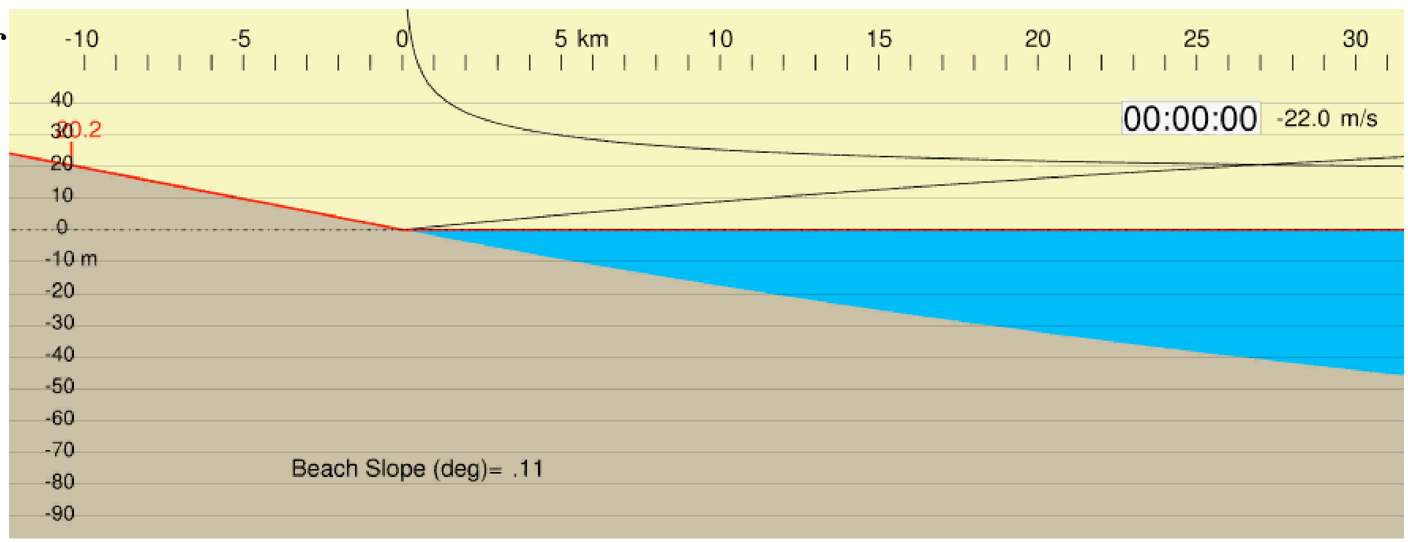
Second Problem: Impact tsunami have many waves.

Breaking might strongly affect one wave



Many Waves tend to merge together even if broken and flood the land as "set up"

Kind of like a storm surge.



...Generally, Many Waves = More Runup

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The final stage of the tsunami is runup and inundation.

"Will I get Wet?"

is what everyone wants to know, but even if you saw the tsunami coming, the answer is complicated as it depends on:

Size of the Waves

Period of the Waves

Beach Slope

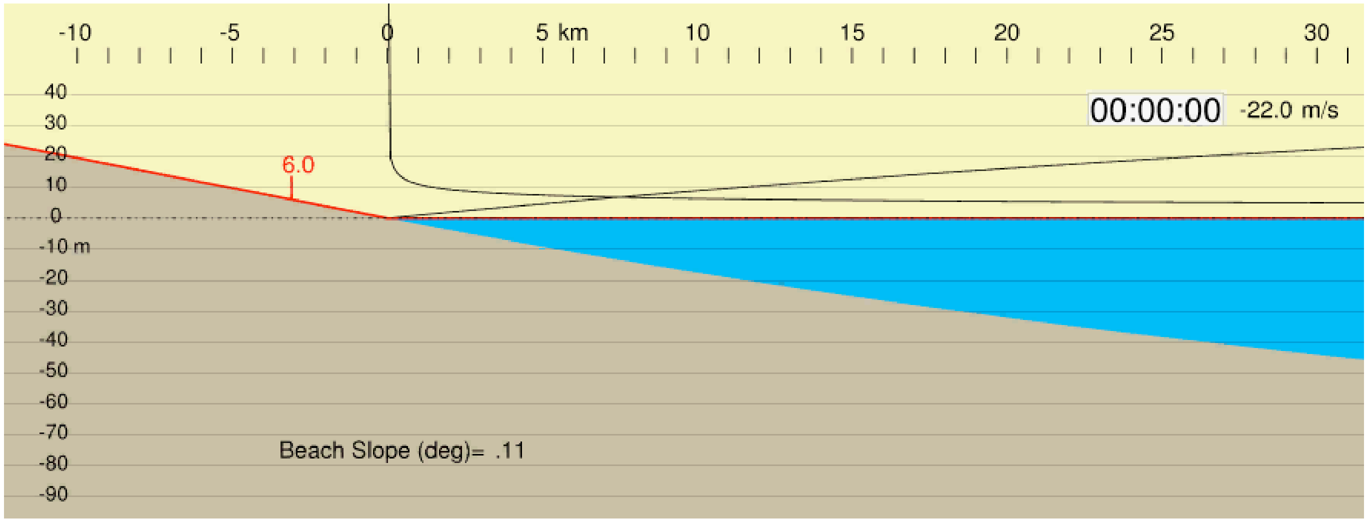
Offshore obstacles

Number of Waves

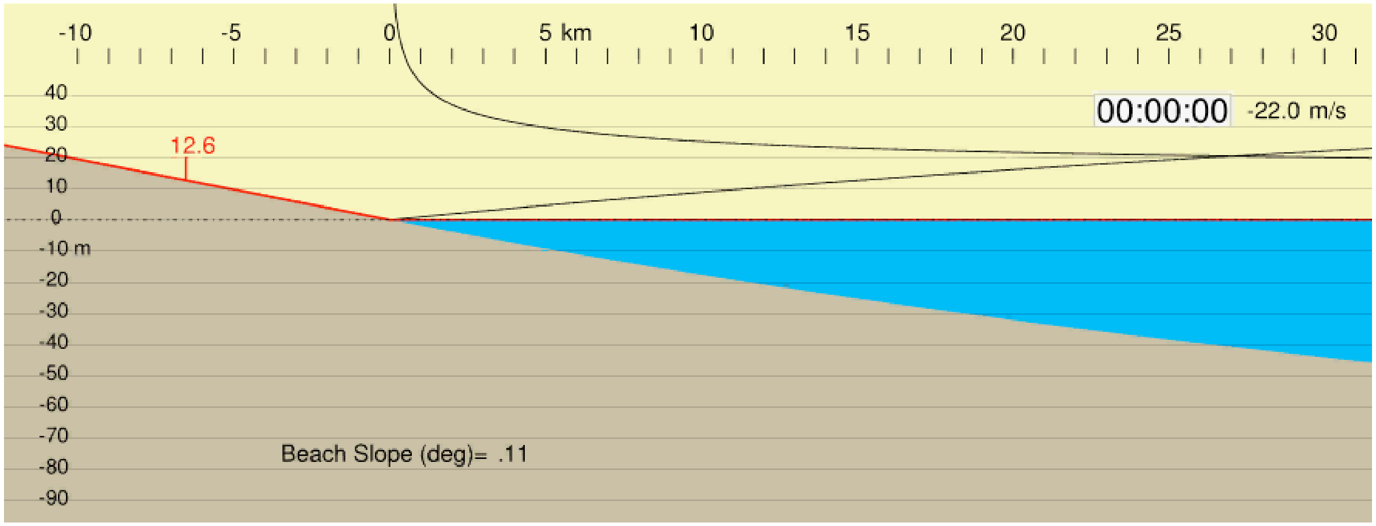
"Will I get Wet?"

Size Of Waves:

Smaller Wave



Larger Wave



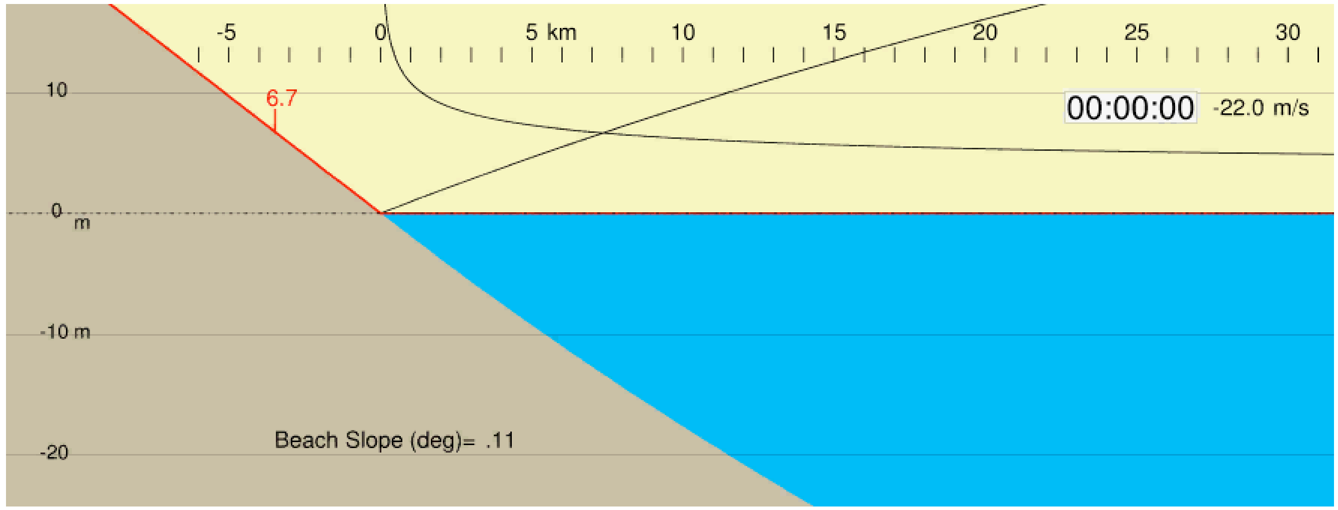
Generally, Bigger Waves = More Runup - duh

"Will I get Wet?"

Offshore Obstacles

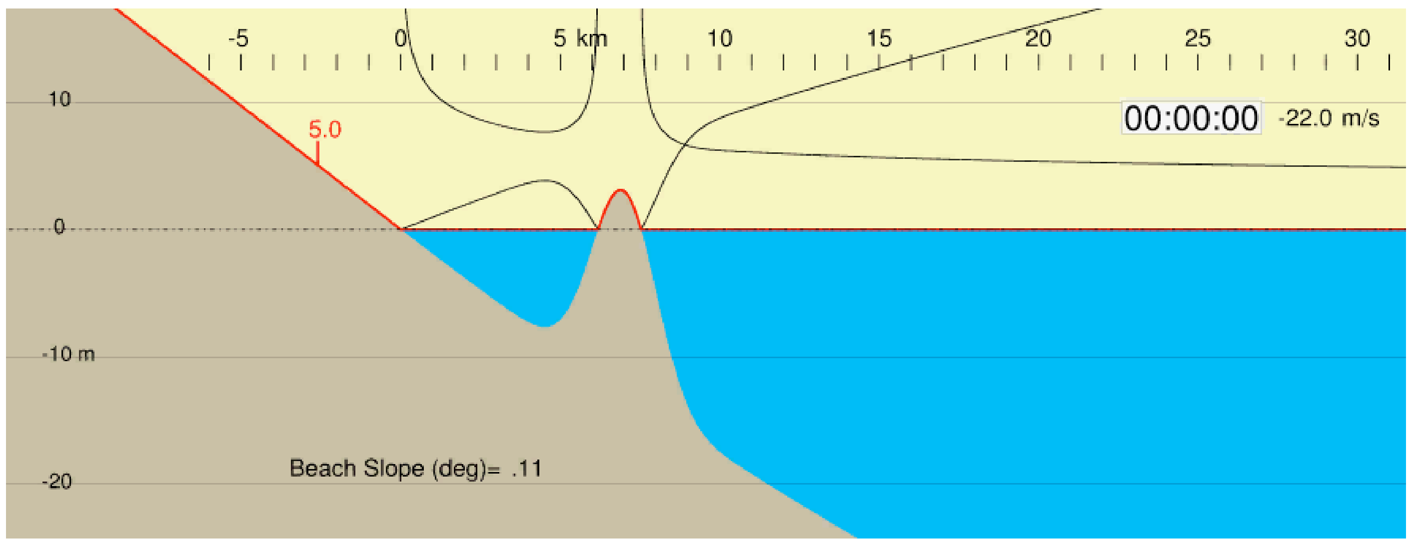
No Protection:

Maybe California



Some Protection:

Maybe Cape Cod or NYC

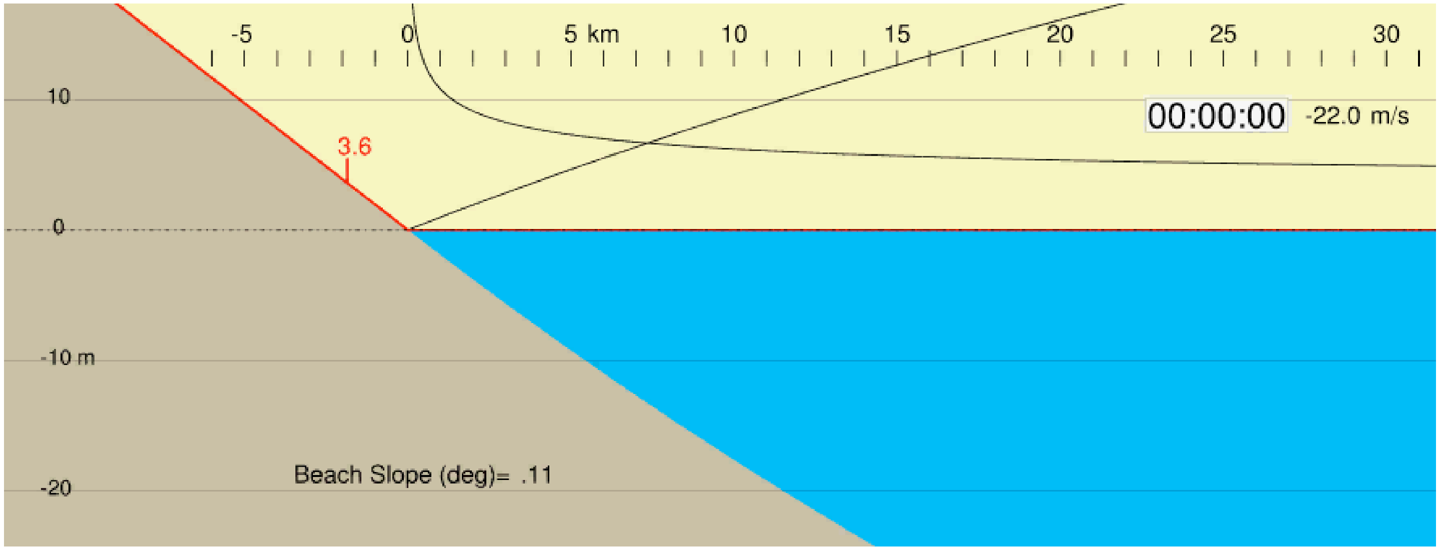


Generally, Waves on Protected Coasts =Less Runup

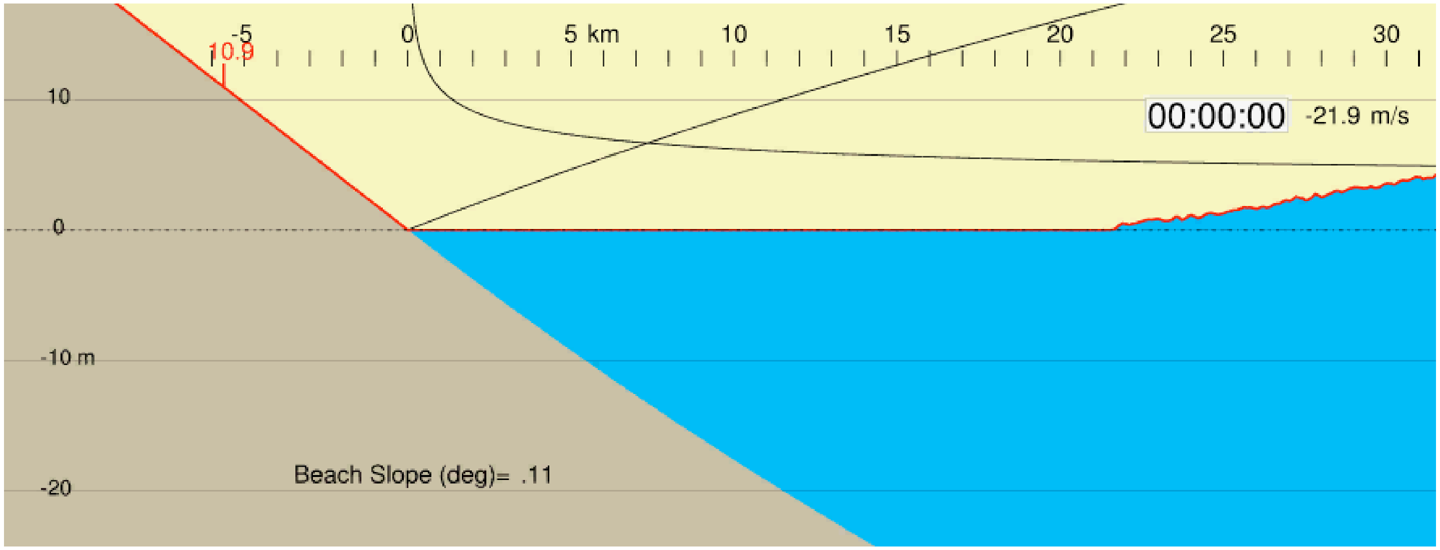
"Will I get Wet?"

Period Of Wave:

Shorter Period



Longer Period



Normal waves: 15s

EQ Tsunami: 600s-1000s

Generally, Longer Period Waves = More Runup

WELL,………

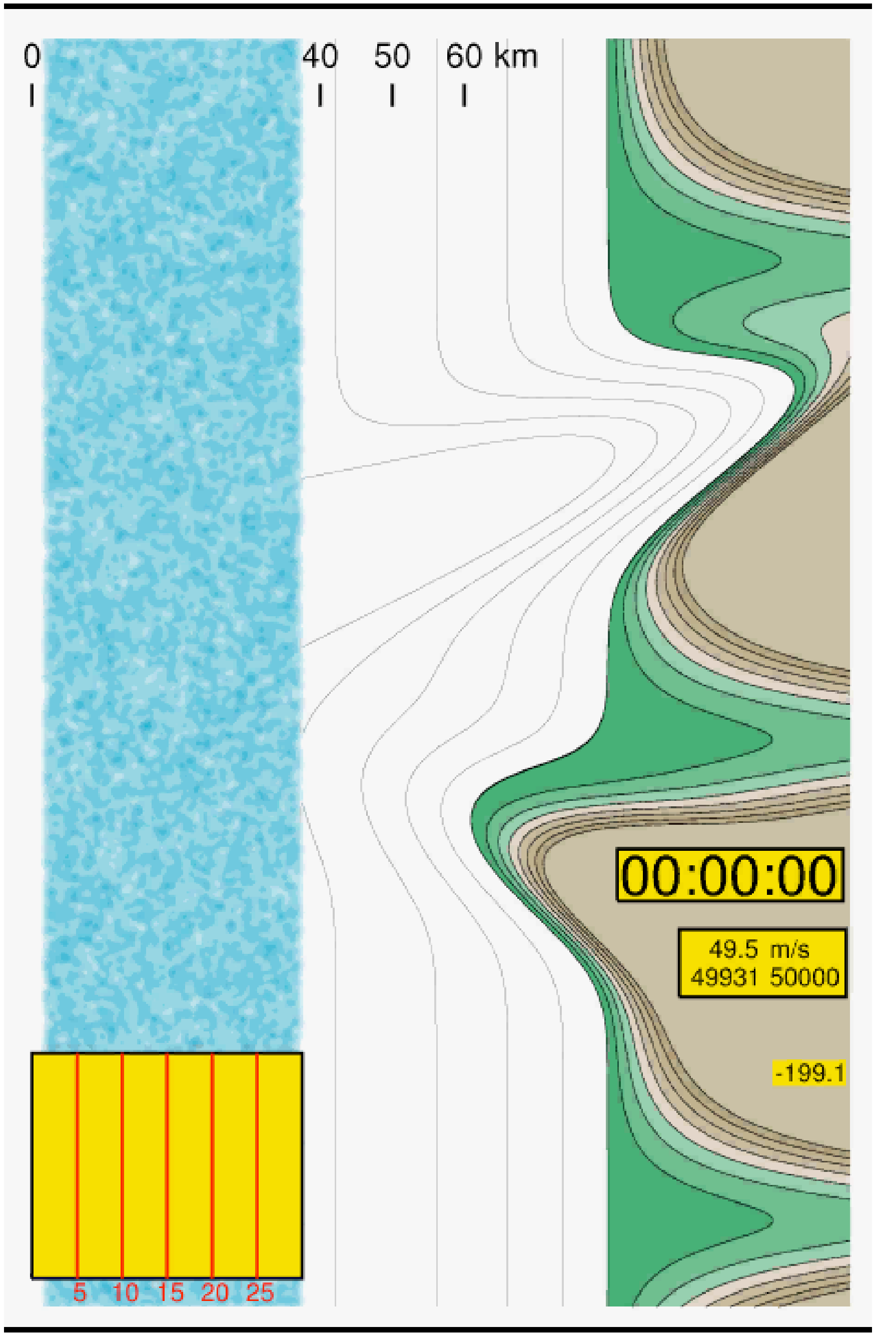
"Will I get Wet?"

True, scientists understand the general concepts of inundation, but in any given tsunami in a real 3-D world, don't expect miracles from us!

We really can only supply a "Best Guess"

or "Vegas-Style" odds

Best to consider runup a random variable.



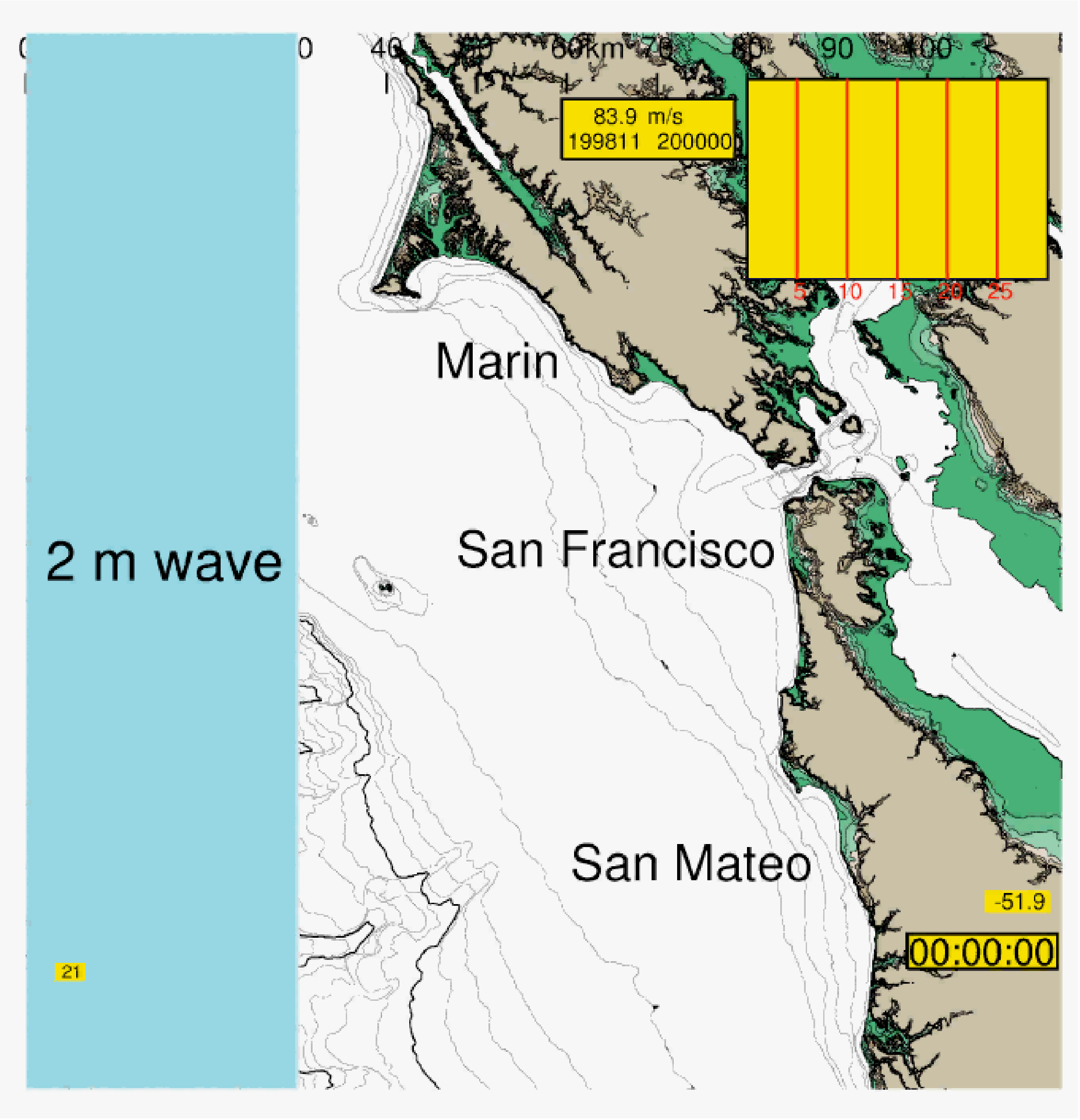
Real Case.

2m wave sent into the Marin/San Mateo Coast.

Steep Beaches at Point Reyes take it hard.

Only a bit of water can push through the Golden Gate.

Note wide variation in runup (Yellow box)



Consider poor

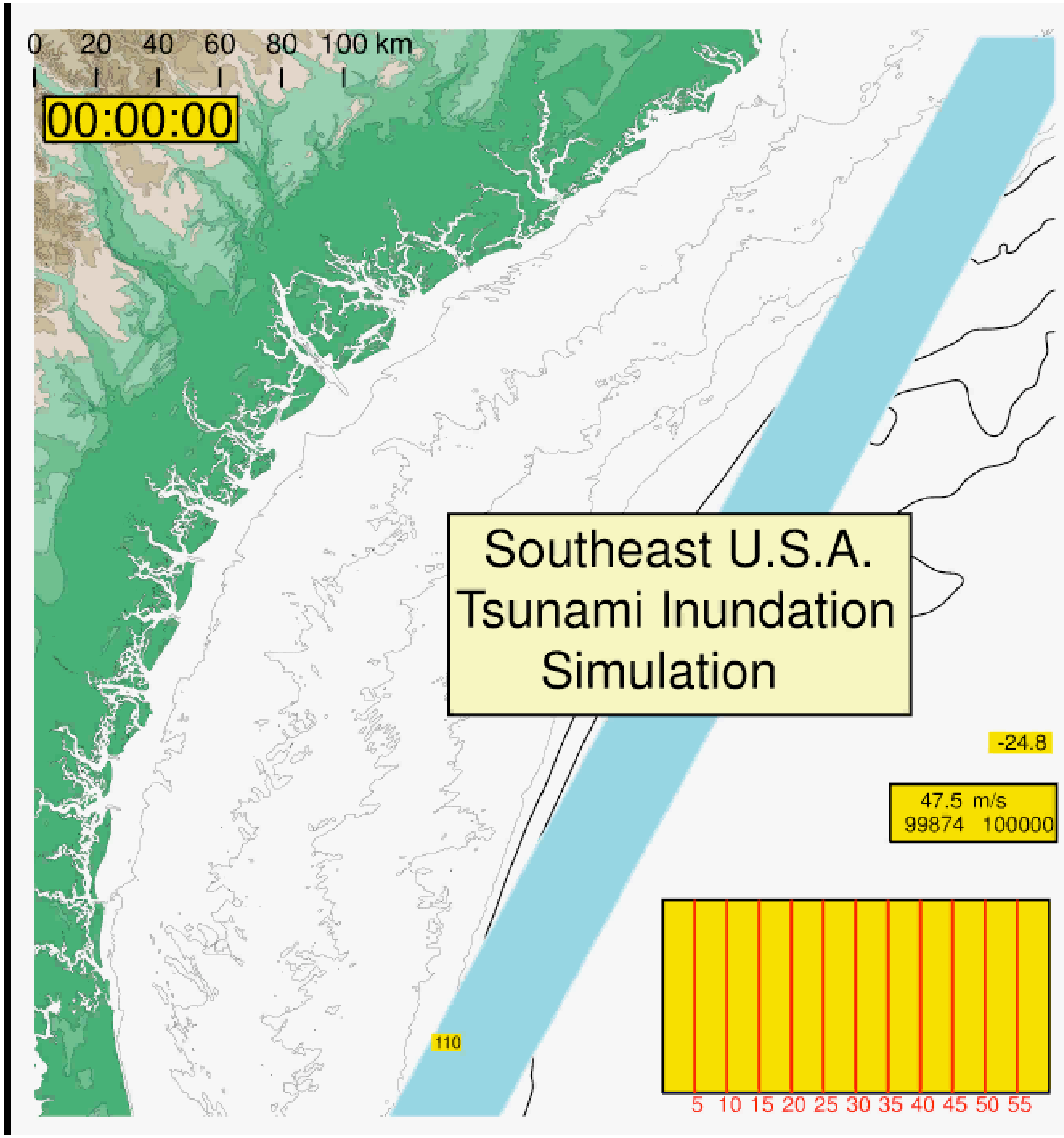
Georgia….

You have to travel

35 miles inland

to reach 10'
elevation.

A big tsunami there might flood several to 10s of miles inland.



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All this stuff gets stirred into a quantitative estimate of impact tsunami hazard, but in the end it is...

What You Have AT RISK that matters.

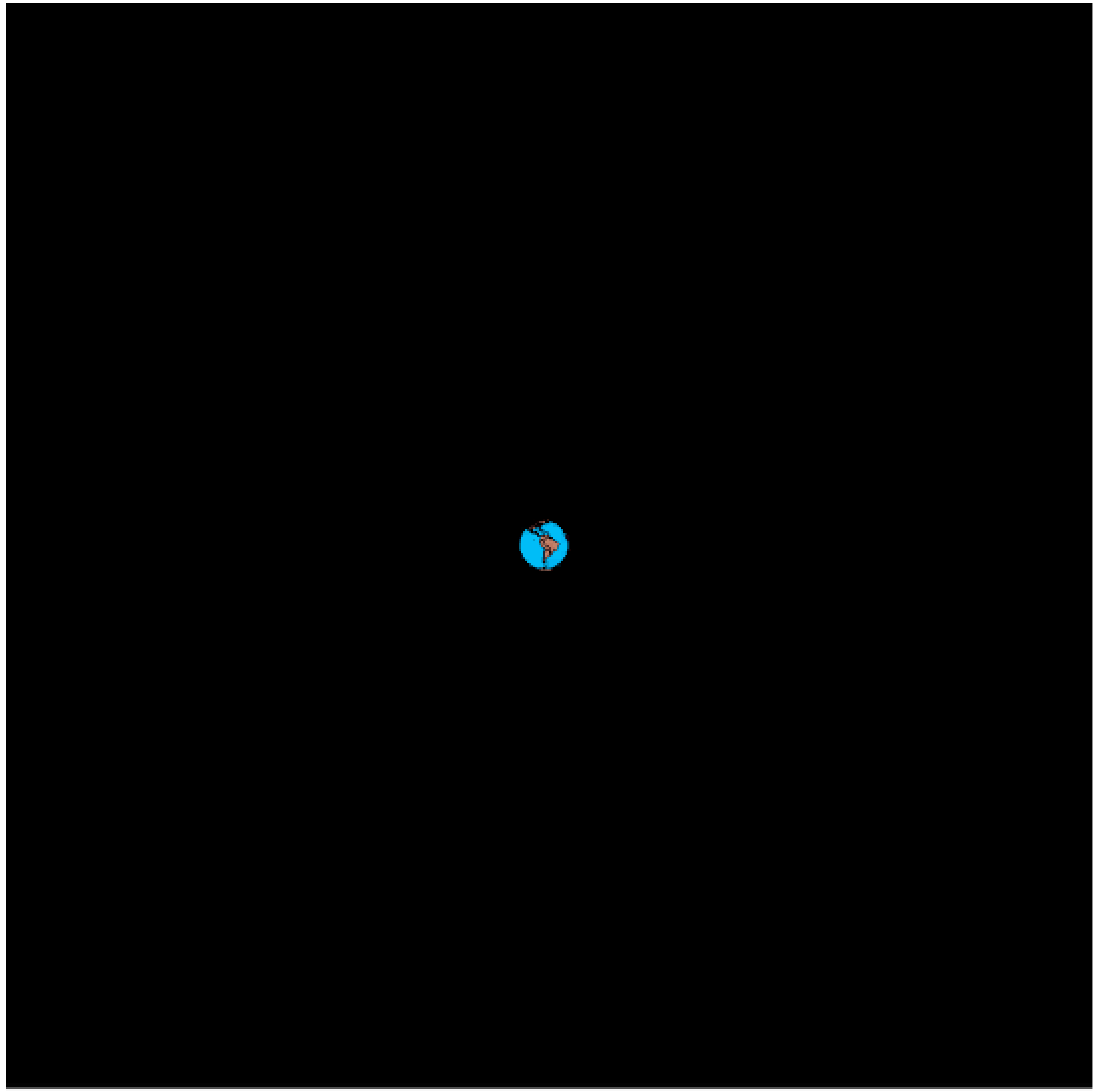
Banda Aceh - “Before”

Banda Aceh - “After”

Impact tsunami hazard assessment is messy business, but….

that's how I make my best guess.

Let's follow Apophis on final approach.



Thanks for Attending.