Measuring Ocean Depth with a Tsunami

Instructor Notes

Martin B. Farley

Department of Geology & Geography

University of North Carolina at Pembroke

Pembroke, NC 28372

martin.farley@uncp.edu

(910) 521-6478

Peter Weyl’s Oceanography[[1]](#footnote-1) was published in 1970, so the Good Friday Earthquake tsunami (1964) was quite recent and he included a fair amount of data on arrival times at various places. I decided to create a lab in which students used the average depth of the ocean to predict the arrival time at these places and then compare to the actual. I had not actually used this lab with students yet. I was reading Knauss (1997), an introductory graduate-level textbook, to solidify my knowledge of physical oceanography. In it, Knauss mentions in passing (p. 219) that “the average depth of the Pacific was inferred in 1855 by A.D. Bache by noting the arrival time of a tsunami as recorded on various tide gauges.” I immediately knew a) how Bache had done it (by using velocities to determine depth) and b) was inspired to turn my nascent lab on its head and have students calculate ocean depth from the tsunami instead of predicting arrival time with an average ocean depth.

This lab is inquiry-flavored, because students can be asked leading questions that steer them toward how they can calculate ocean depth and figure out what data they would need. The major limitation in this approach is that the tsunami can’t follow the simplest surface path (great circle) in all cases from the origin to destination because land areas get in the way.

Student Materials:

Calculator.

Access to web-based Great Circle Calculator.

<http://williams.best.vwh.net/gccalc.htm> is very handy:

1) you can use different types of latitude/longitude (degrees, decimal degrees; degrees, minutes, decimal minutes; degrees, minutes, seconds, decimal seconds) just by changing the delimiters;

2) you can choose a variety of distance units (here you want km);

3) you can choose Earth ellipsoid models if you want to; and

4) you can enter a starting point (e.g., earthquake epicenter) as lat1/lon1, calculate a distance, and enter a new lat2/lon2 without having to re-type the lat1/lon1 each time.

Globes and string--for inspecting great circle routes and noting that the great circle path between some pairs of points is not a route the tsunami could have followed. I suppose tracing great circles could be done somewhere on the web, but one of my geography colleagues, who is quite expert with Google Earth, doesn’t know how to do it simply there. My students don’t bring laptops to class, so web-based route tracing could not be conducted in class anyway. See also note below.

Instructor Materials:

Tsunami lab.xlsx—spreadsheet with the distances and arrival times that calculates ocean depths and intermediate results (i.e., the solutions). Includes the two locations that clearly require the tsunami to “go around the corner” with a corner location and distances.

Given the inquiry approach of the lab, I supply a worksheet with unlabeled columns (the activity page that prints in landscape) so students can decide what to calculate and what intermediate products would be sensible. The disadvantage of this is that if students go wrong, it can be hard to figure out why if they don’t leave a good enough trail of intermediate calculations.

Context from Course

In my Oceanography course, this activity comes about two-thirds of the time through the course and follows lectures/labs on waves, wave velocity, and seiches. The wave velocity sections re-emphasize introductory material in the course on the average and maximum depth of the ocean; these are key, of course, to recognizing that tsunamis are shallow water waves. I not only have lectures on wave celerity and equations, but a lab for shallow and deep water waves as well.

Comments on Activity

I picked locations to give a geographic spread around the Pacific Ocean with some points picked because they are locations where tsunami effects are enhanced by local conditions (e.g., Hilo, Crescent City). Although tsunami damage was substantial in Alaskan areas near the epicenter, any Alaskan site for this lab had to be far enough away that reliable timings of the tsunami are available.

I advise students verbally when they are trying out great circle routes that if a land mass intervenes, then the tsunami needs to “go around the corner.” It is reasonable (i.e., close enough) to pick a straightforward (even value lat/long) corner close to the right point rather than worrying about the exact route.

For the Alaska Good Friday earthquake, it is very convenient that (in GMT) all arrival times were on the same day. This is not necessarily true for data I have added on other tsunami (see below).

Things to look out for based on my experience:

Students can have trouble getting the delimiters right for latitude/longitude units in the web calculator.

Students carry too many significant figures through this, often beginning with the distance. Some give distances to the maximum units given by the Great Circle calculator; this seems to depend on the browser you use, but is minimally 10 cm (!) and commonly is much smaller. I have tried to get across to students that this level of precision is not justified. I have an ”Introduction to Math and Science” for the course as a beginning exercise; one part sends them to this Great Circle calculator to see how much change in distance is produced by changing locations by 1’ of latitude/longitude. The students are then to compare this difference to the precision of the calculator. This approach has not entirely worked.

I remind students that they can’t subtract times as if there are 100 minutes in an hour.

Students don’t think through whether the number that comes out of their calculator is even approximately right. I had a student in Fall 2012 who gave an average Pacific Ocean depth as 0.6 m (?!). In past years, I have commonly had students calculate depths for particular paths, especially Hilo to the epicenter, as 30 m.

I have trouble getting substantial student response to open-ended questions such as those at the end of the lab (this is true in many such cases for me). A science ed faculty member has suggested requiring a minimum number of sentences as a solution; I haven’t had a chance to try it yet.

Possible elaborations

I have acquired data for the Tohoku (Japan) 2011 tsunami and have included a set of arrival times in Tsunami lab.xlsx as its own sheet (reproducing the locations used for the Alaska tsunami as closely as possible). I have not yet used this with a class and haven’t modified the lab activity document.

I also have data for the Chile 2010 tsunami but have not yet worked it up into material suitable for this lab.

I have thought about using information on the nature of the arriving wave as a supplement. In cases where the tide gauge was not destroyed (e.g., Hilo in 1964), you can get a record of the tsunami. My idea was to get a tidal calculator estimate of expected tides and then have students subtract the actual and predicted. Two problems: 1) I had recorded a NOAA webpage URL on marigrams in 2006, but the link no longer works (this may be the replacement: http://www.ngdc.noaa.gov/hazard/tide.shtml); and 2) the tidal calculator I use doesn’t go back in time before the 1970’s.

Additional handy item:

NPR did a story about the impact of the 1964 tsunami in Crescent City CA on Nov. 18, 2005:

“Tsunami Legacy Lives with People of Crescent City”

<http://www.npr.org/templates/story/story.php?storyId=5007869>

Exam Question I have used after this exercise

Warnings need to be issued quickly after an earthquake occurs. If it took about 75 minutes for a tsunami warning to be issued in 1964, which of the towns below, if any, had already been hit by the tsunami? You can assume that the tsunami had a wavelength of 100 km, a wave height in open ocean of 1 m, and water depths averaged 3250 m. You need to show enough labeled work to make your path of reasoning clear.

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Distance from epicenter (km)

Skagway, AK 695

Juneau, AK 796

Sitka, AK 826

Wrangell, AK 1009

Prince Rupert, BC 1262

Dutch Harbor, AK 1384

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Solution:

*Tsunamis are shallow water waves, hence*

*C = sqrt (9.8\*3250) = 178.5 m/sec*

*Distance = 178.5 m/sec x 60 sec/min x 75 min*

*= 803250 m = 803.3 km*

*Thus, Sitka (barely) and farther away could be warned*

*Note that if students mistakenly use deep-water equation*

*then they get*

*C=1.25 sqrt L= 1.25 sqrt (100,000) = 395 m/sec*

*then the distance is 395 m/sec \* 60 sec/min \* 75 min = 1778 km*

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References

Most tsunami data are from National Geophysical Data Center / (NGDC/WDS) Global Historical Tsunami Database, Boulder, CO, USA. (Available at <http://www.ngdc.noaa.gov/hazard/tsu_db.shtml>)

My Warning: As of May 17, 2013, if you query the database for a tab-delimited file (suitable for importation into Excel), you will not get all the fields that are returned if you just have the data displayed on the screen. In particular, the arrival time fields will be absent.

Knauss, J.A., 1997 (repr. 2009), Introduction to physical oceanography (2nd ed.): Waveland Press, Long Grove, Ill., 309 p.

Sokolowski, Thomas, J., 20??, The Great Alaskan Earthquake and Tsunami of 1964: <http://oldwcatwc.arh.noaa.gov/web_tsus/19640328/64quake.htm> (retrieved 5/28/2013)

A report on the 1964 tsunami (note the URL “oldcatwc”, an indication that this URL may not be stable)

Weyl, P., 1970, Oceanography—an introduction to the marine environment: John Wiley, New York, 535 p.

1. This is an illustration of the advantage of serendipity. Weyl’s textbook was left to me by my predecessor in geology at UNCP; I would never heard of it otherwise. [↑](#footnote-ref-1)