**PART 1: Cool data from the 2004 Sumatra-Andaman tsunami**

*For questions 1.1 - 1.17, you will need to look at the tide gauge records on the course website*

**Questions for Record 1:**

**1.1** The latitude and longitude of this station are given in degrees and minutes. (i.e. 15-56 N means 15° 56' North latitude and 54-00 E means 54° 00' East longitude). Each degree contains 60 minutes. For later calculations, we will want to use decimal degrees instead of minutes. Convert the latitude and longitude of this station to decimal degrees. HINT for getting started: If the latitude were 12-13 N, meaning 12° 13' N, this would equal 12.22° because 13/60 = 0.22.

**1.2** Let’s look at the axes and data now. The X axis is showing time and the Y axis is showing water height. The X axis ranges from 26 to 31. These are days of December 2004. The Y axis ranges from -200 to +200 cm. Now let's look at what is being plotted here. The black line connects data measurements shown by small black dots. The red line is a prediction of the tidal signature at this station. Okay, what are the obvious things to see here? You should be able to discern the approximate arrival time of the tsunami. When is it? Where on this record is the prediction of wave height doing a good job and where is it failing? Why does the prediction fail where it does? For about how long does the tsunami have a significant impact on the wave height at this station?

**1.3** Look at the background tidal signature. Describe the tidal cycle for one 24-hour period.

**1.4** What is the normal tidal amplitude? Compare this with the amplitude of the tsunami. Keep in mind that the tsunami amplitude is superimposed on top of the tidal signature.

**Questions for Record 2:**

**1.5** The time scale on the X axis is given up in the right hand corner of the record. It says "Time scale: 1 line = 10 minutes (1 sheet = 1 day)". Okay, so take a look at the grid. What do the numbers on the X axis refer to? How many days are shown in this record?

**1.6** The vertical scale is given. (It's floating in the middle of the record.) What is the normal tidal amplitude at this station?

**1.7** Comment on the differences you note between the tidal cycle at this station and at the Salalah station. Comment on the differences you note between the normal tidal amplitude here and at Salalah and the differences between the tsunami amplitude at this station compared to the Salalah station. Why are there differences?

**1.8** Notice that because of the fact that more than one day is shown on this record, you can see that the tidal peaks and troughs are offset slightly as the days go by. Tides do not have a period that fits exactly into one day. That is, the peak-to-peak time is not exactly 12 hours. Approximately what is the period? (If you live near the coast, or have spent any time near the ocean, you already knew that the time of the high and low tides change predictably as the days go by. Isn't it reassuring when recorded data confirms what an observant person already knows! Science works!)

**1.9** When does the tsunami arrive at Ranong? What is the amplitude of the tsunami compared to the background tidal amplitude? For about how long does the tsunami affect sea level height at Ranong? Compare these answers with your observations of the records from Salalah station.

**Questions for Record 3:**

**1.10** The coordinates of this station are given in degrees, minutes, and seconds. There are 60 minutes in each degree and 60 seconds in each minute. Convert the station coordinates to decimal degrees.

**1.11** The local time at this station is "UTC +3". This means that this station is three hours ahead of "Universal time", which is set for historical reasons at Greenwich, England, where the longitude is zero. Find out the difference between UTC and the time in your hometown. (Your computer probably knows. Otherwise, a quick web search should accomplish this task.) Remember to cite the place where you found the answer.

**1.12** What are the units of the X and Y axis on this record?

**1.13** When does the tsunami arrive?

**1.14** What is the tsunami amplitude compared to the normal tidal amplitude? Compare this to your observations at the previous stations.

**Questions for Record 4:**

**1.15** The latitude and longitude are given for this station in degrees and minutes. Convert to decimal degrees.

**1.16** The X axis is given in "Julian days" of 2004. Julian days are numbered consecutively from 1 to 365 (or 366 in leap years). So January 1 is Julian day 001, February 1 is Julian day 032. What is the Julian day of your birthday? Convert the values of the X axis from Julian days to normal dates. (To get this answer, you have to recall whether 2004 was a leap year or not.)

**1.17** Read the text given by the spelling-challenged station operator as part of this record section. Now look at the data records. When does the tsunami arrive? What happens to the data at this point? Why does the red line continue uninterrupted?

**PART 2:**

**Analysis of DART data from the 2011 Tohoku-Oki tsunami**

**Using the station records provided online, complete the table below.**

*If you are new to Google Maps, see my short tutorial on the course website to accomplish problem 2.0.*

**2.0** Using Google Maps, mark the location of the Sumatra-Andaman earthquake and each of the four stations from Part 1 on a map. Now add the location of the Tohoku-Oki earthquake and each of the DART stations in Part 2 to the map. When you are done with your map, save it, make a link to it and paste the link here. Or you can take a screenshot and paste that here.

*For 2.1 - 2.5 I have done the first problem for you and explained on the course website how to make each measurement or calculation.*

**2.1** You already worked with Julian days in Part 1. Now we are going to work with time as expressed in fractions of a day. The earthquake happened on 2011/3/11 at 5:46:23. What is the Julian day of this time, exactly, as expressed in decimal form?

**2.2** Look at each station record and pick the arrival time of the tsunami. I have done the first one for you. Make sure you pick the arrival time of the tsunami and not the arrival time of the seismic waves. Fill in your answers in the table.

**2.3** Calculate the tsunami travel time to each station by subtracting the origin time from the arrival time. (Now aren’t you glad you converted the origin time to decimals!!). I’ve done the first one for you. Your answers will be in fractions of a day, so convert them to hours. Fill in your answers in the table.

**2.4** Calculate the epicenter-to-station distance. Use the great circle path formula for calculating distance on the surface of a sphere. Here is the formula for great circle distance: cos(d) = sin(a)sin(b) + cos(a)cos(b)cos|c| in which d is the distance in degrees, a and b are the latitudes of the two points and c is the difference between the longitudes of the two points. Multiply the answer by 111.32 to get from degrees to kilometers. I’ve done the first one for you. Fill in your answers in the table.

**2.5** Calculate the tsunami speed for each station. To get the speed, you use the formula speed = distance/time. I’ve done the first one for you. Fill in your answers in the table.

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| --- | --- | --- | --- | --- | --- | --- |
| **STATION NAME** | **STATION LATITUDE (°N)** | **STATION LONGITUDE (°E)** | **TSUNAMI ARRIVAL TIME (Jday)** | **TSUNAMI TRAVEL TIME (hr)** | **EPICENTER TO STATION DISTANCE (km)** | **TSUNAMI SPEED (km/hr)** |
| **21418** | 38.7110  | 148.6940 | 70.26 | 0.468 | 551.9 | 1179 |
| **21413** | 30.5150 | 152.1170 |  |  |  |  |
| **21415** | 50.1762 | 171.8486 |  |  |  |  |
| **52402** | 11.8830 | 154.1100 |  |  |  |  |
| **46402** | 51.0683 | -164.0053 |  |  |  |  |
| **51407** | 19.6169 | -156.5106 |  |  |  |  |
| **51425** | -9.5044 | -176.2297 |  |  |  |  |
| **46411** | 39.3238 | -126.9910 |  |  |  |  |
| **51426** | -22.9911 | -168.1031 |  |  |  |  |
| **51406** | -8.4800 | -125.0270 |  |  |  |  |
| **43413** | 10.8372 | -100.0842 |  |  |  |  |
| **32413** | 7.4003 | -93.4989 |  |  |  |  |
| **32412** | -17.9865 | -86.3887 |  |  |  |  |

**2.6** I want you to think about the uncertainties in the calculations you performed in determining tsunami velocity. One obvious source of uncertainty is measurement precision at each tide gauge station. For example, let’s say that you are working with a DART station that takes a measurement every 15 minutes. This means that picking the arrival time of the tsunami can't be more precise than this. Go back and change the arrival time pick for Station 21418 and for Station 32412 each by 15 minutes. Now recalculate the speed of the tsunami for each of those two stations. How much has your answer changed for each one? Which one is affected more by the uncertainty in arrival time and why?

**2.7** What are other sources of uncertainty in these calculations?

**2.8** Calculate the mean speed for the tsunami. Are you surprised by this speed? How does this speed compare to a jet airplane? an Indy car? a bullet fired from a gun? an earthquake P wave? a major league fastball? Pick several items that interest you (they don't have to be any of the examples above if you don't like those) and compare them to the speed of the tsunami.

**2.9** Tsunami speed is controlled by water depth. In fact tsunami speed equals the square root of the product of water depth and g, the gravitational constant (9.8 m/s2). Calculate mean water depth of the Pacific Ocean. To do this, use the mean speed of the tsunami that you calculated in **2.8**, convert it from km/hr to m/s, then plug into the equation speed=sqrt(depth\*g).

**2.10** I want you to think about approaching the question of tsunami speed from a different perspective. What if you wanted to determine how fast a hypothetical tsunami could get from point A to point B? List what would you need to know to make this calculation.

**2.11** Now try it!  Let's say a large earthquake happens in the Pacific northwest, approximately at the location of Seattle, generating a tsunami. Determine how long it would take the tsunami to arrive in Hilo, Hawaii.

**2.12** What are the sources of uncertainty in the calculation you just did in the previous question?

**2.13** There are definitely tide gauge stations on the west coast of Japan and they recorded the tsunami as well. However, we did not use any data from those stations to calculate the speed of the tsunami or to calculate the mean water depth between the earthquake and those stations. Why not? (In order to answer this question you will need to look at the map you made and think about what assumptions we made to do our calculations)