Calculating tidal delay and amplitude of tsunami waves post-earthquake events

Signal Processing

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# Key Points-

* Differences and difficulties in sampling frequencies as tsunami signal caught in tide gauges.
* Interference of waves both amplify and destroy wave amplitudes across the ocean, as well as ocean depth at the buoy position.
* The Tsunami signal has large components of both low and high frequency content.

# Abstract-

Co-seismic tsunamis are a prominent hazard in many parts of the world. First an earthquake strikes, then with little time to recollect and recover, a tsunami often ensues and may often lead to more damage than the earthquake itself. We want to understand more about tsunamis, what do they look like in tidal data and how does it vary geographically, what are their frequency content. This may be useful for future research in oceanographic study of tsunami propagation, which countries are at high risk of tsunami damages may be a useful study. The data is noisy, likely because of wave reflections off coast, water columns depth, sampling rate is inaccurate, not picking up on all the waves that pass, but general water height data. The Buoys we looked at spread southeast throughout the Pacific Ocean, following an earthquake in Japan with a magnitude of 9.1M. The tsunami can be found within the buoy data, with huge oscillations in water column height and wave propagation speeds that show the wave traveling at around 700km/Hr in open waters. Due to ocean floor topography, the wave speed may change and the wave height may change, all of which are likely to affect the tsunami wave, however has not been considered for this paper.

# Intro-

Tsunami events may often occur after an earthquake. It must be a very special kind of earthquake, one place that experiences these events often is Japan. Nearly every year, Japan has earthquake of magnitudes of 6.0M and greater. One such, very notable event, occurred in Japan in 2011, on March 11. An earthquake of magnitude 9.0M shook the island of Japan, with reported shaking intensity of at least 6.0M from the west side of the island, and only increasing in intensity towards the east coast. The tsunami wave not only had a huge impact on the island of Japan itself but many smaller islands throughout the pacific coast. It is important to understand any connections between earthquakes at underwater subduction zones as they often cause millions in damage. It then becomes important to understand tsunami waves, how they travel the oceans, wavelengths, frequencies and more.

# Methods

NOAA tide gauge data was downloaded as csv sheets in excel. Here we can see the dates of the recording, as well as the sample water column heights, and sampling rate. Here we need to clean the data from any extraneous values such as “9999” values when the system does not make accurate records. In this, we also find that the sampling rate changes, during normal tides, the sampling interval is 15 minutes, then when abnormal tides occur, 1-minute intervals, and at particularly abnormal tides, sampling intervals are 15 seconds. For each of the buoys we looked at, the sampling intervals were at 15 seconds, until around the time the tsunami hit, then the sampling rate would vary between 1 minute and 15 seconds. In this case, we need to resample, so the data is all at the same sampling rate. In python, we were able to resample the data, so that everything followed a 15 second sample interval, and interpolate any of the data that was at 15-minute intervals, since there was nothing interesting going on during these times, it doesn’t matter how accurate it was.

A graph of a sample

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Description automatically generated with medium confidenceNow that the tide data is all resampled to 15s sampling rate, we can find the amplitude spectrum and psd of the tides to get an idea of the frequencies present. Then we can filter out the tidal data using high-pass filter at appropriate cutoff frequencies. Here we can get an idea of the high and low frequency tidal oscillations brought with the tidal wave. After, we can find out when the frequencies occur on a scalogram by using a continuous wavelet transform.

A graph of a diagram

Description automatically generated with medium confidenceFigures 1. (1,2,3) – Amplitude frequency plots of unfiltered tidal signals. From closest to furthest: Iturup , Guadal Canal, Apia. The low frequencies around 0.0006 vary and decay with distance while the 0.0015 frequencies do not correlate to distance from the epicenter.

A graph showing a line graph

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A graph showing a green and blue line

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A graph showing a wave of data

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A screenshot of a computer generated image

Description automatically generated If a Butterworth is a low pass at 0.0001 hz, only the daily tidal signal comes through, without any of the signal of the tsunami wave, if we make it a high pass at the same frequency, then we cut out only the daily tides.

A screenshot of a computer generated image

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Figures 3.(1,2,3) – Scalograms of the filtered data, using the continuous wavelet transform with a morlet wavelet. Before the tsunami arrives, little to no frequencies should be present, when it doesn’t. We can see an array of frequencies at their times.

# Results-

The tsunami introduced many high and low frequencies, of which, the signature from the tsunami wave is much less clean as the buoy is further from the epicenter. The amplitude of the low frequency content seems correlated with the distance from the event, closer locations experience a larger amount of low frequency content below 10-3, while the daily tides seem to be present much lower, however each buoy presents a similar spike at the same frequency, ~ 2\*10-3 while the power of which doesn’t seem to correlate to distance from the epicenter.

The arrival times of the tidal waves coincide well with historic arrival time data, compared with an earthquake in 1968, Honshu Japan, an 8.4M earthquake with a tsunami arrival time map (National Oceanic and Atmospheric administration, n.d.). The earthquake event of 2011 is at a higher magnitude, which would then make sense to see faster travel times.

# Conclusion-

There is correlation between tsunami magnitude and the frequencies in which the tidal signal contains, as well as a likely correlation between earthquake size, wave speed and wave height. There are many variables that go beyond the extent of this project, such physical variables rely heavily on oceanography knowledge, such as how physical wave propagation decays and interferes with other tides, changes with depth, and variation along the ocean floor. More analysis may show how the tsunami wave dampens as it travels through the ocean and loses energy as well.

# References-

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