1960 Valdivia Tsunami: How One Tsunami Event Can Vary by Location

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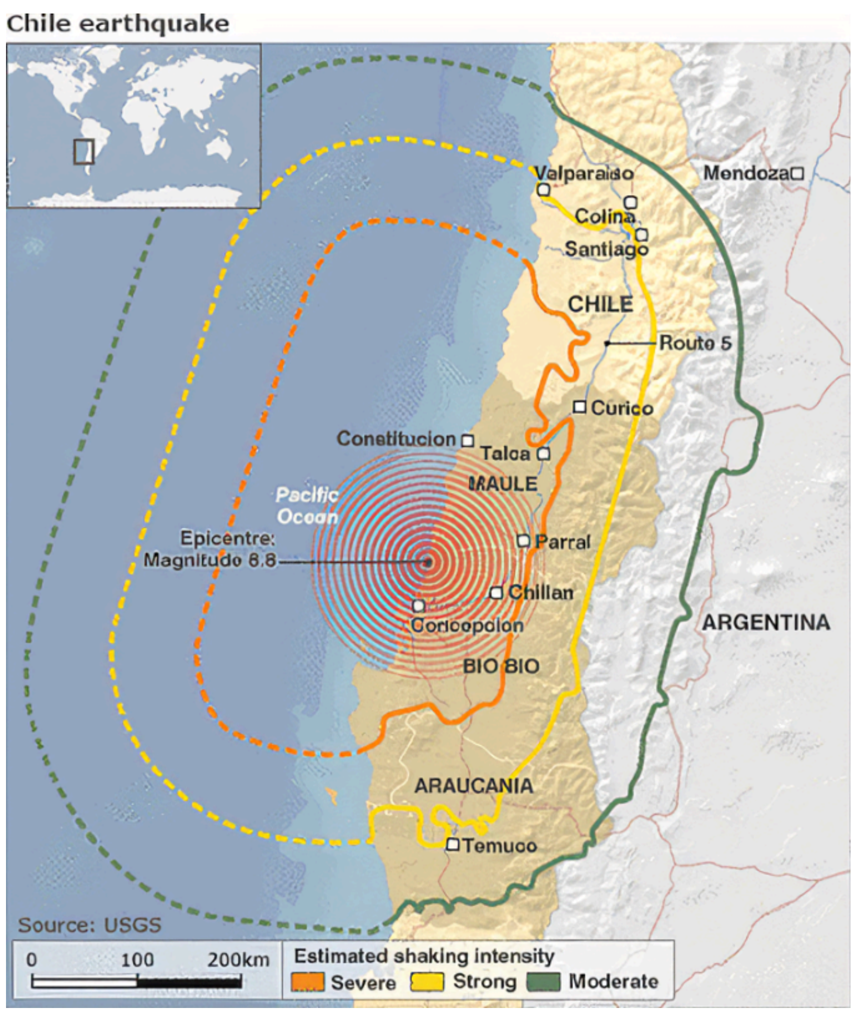
Background:

The 1960 Valdivia Earthquake, also known as the Great Chilean Earthquake, is the largest recorded megathrust earthquake, with a moment magnitude of 9.5 [1]. This earthquake was preceded by four large foreshocks, all of which had moment magnitudes greater than 7.0, and its rupture zone is estimated to have been about 1,000 km long [2]. A map showing the epicenter of this earthquake can be seen below in Figure 1.

Figure 1: Valdivia Earthquake Epicenter [3]



Although the earthquake was record-breaking in its size, it alone caused relatively minor damages compared to the resulting tsunamis. Megathrust earthquakes, caused by a large release of energy in a subduction zone, are known for causing devastating tsunamis. Many infamous tsunamis, such as the Tohoku Tsunami in 2011, were caused by this type of tectonic activity. The tsunami waves that resulted from the Valdivia Earthquake extended across continents, with impacts being felt throughout South America, North America, and Asia.

With one event causing tsunamis in so many different places, the Valdivia Earthquake provides an interesting opportunity to analyze how the impact of a tsunami can differ depending on location.

Motivation:

The goal of this analysis is to determine how the distance from the source of a tsunami changes the impact of the tsunami, as well as to determine other factors that can make a tsunami more or less devastating, by analyzing the tsunamis in Chile, Hawaii, Alaska, and Japan that were caused by the Valdivia Earthquake.

Methods:

The location selection was the first step in completing this analysis. I selected Chile, Alaska, Hawaii, and Japan to compare because they varied greatly in distance from the initial earthquake, and the path from the earthquake to reach each of these locations also varied. Having this variety is important because it provides a more comprehensive view of geographic factors' impact on tsunami impact.

Once the locations were selected, the next step was to find data to make the comparison. The National Oceanic and Atmospheric Administration (NOAA) has records of many tsunamis, and by filtering the source event to the Valdivia Earthquake of 1960, a wide variety of data about the impact of the resulting tsunami event is available [4]. The data shows the maximum wave heights at different locations, the coordinates of the measurements, the distance from the source event, the time the tsunami took to reach each location, and the death count, cost of damages, and number of houses destroyed at each location.

Using Python, and downloading the packages matplotlib, pandas, numpy, seaborn, and cartopy, visual graphs can be made to illustrate the maximum wave heights of each analyzed region, a map of the tsunami impact, a relation between maximum wave height and distance, and a graph showing the economic, life, and infrastructure loss. To more thoroughly see how the data was processed and graphs were made, see Appendix A for a link to the Git Repository for this analysis.

Finally, once the data has been processed, more qualitative information can be used to explain the results and correct any potential errors.

Results:

Figure 2 shows the range and median maximum wave heights in each region being analyzed. Chile has the highest mean and median maximum wave heights, followed by Hawaii, then Japan, and lastly Alaska. Chile, while having the highest averages, also shows the most variability, with the highest IQR, as is made evident in Figure 2. Its maximum wave heights range from 0m all the way to 25m, although this is considered an outlier in the data. Figure 3 shows a map with relative wave heights in the different analyzed locations, and the highest maximum wave height, 25m, is shown to be right at the epicenter of the Valdivia Earthquake, with much smaller maximum wave heights reaching the coast north of the epicenter.

Figure 2: Maximum Wave Height Range in Each Region [4]

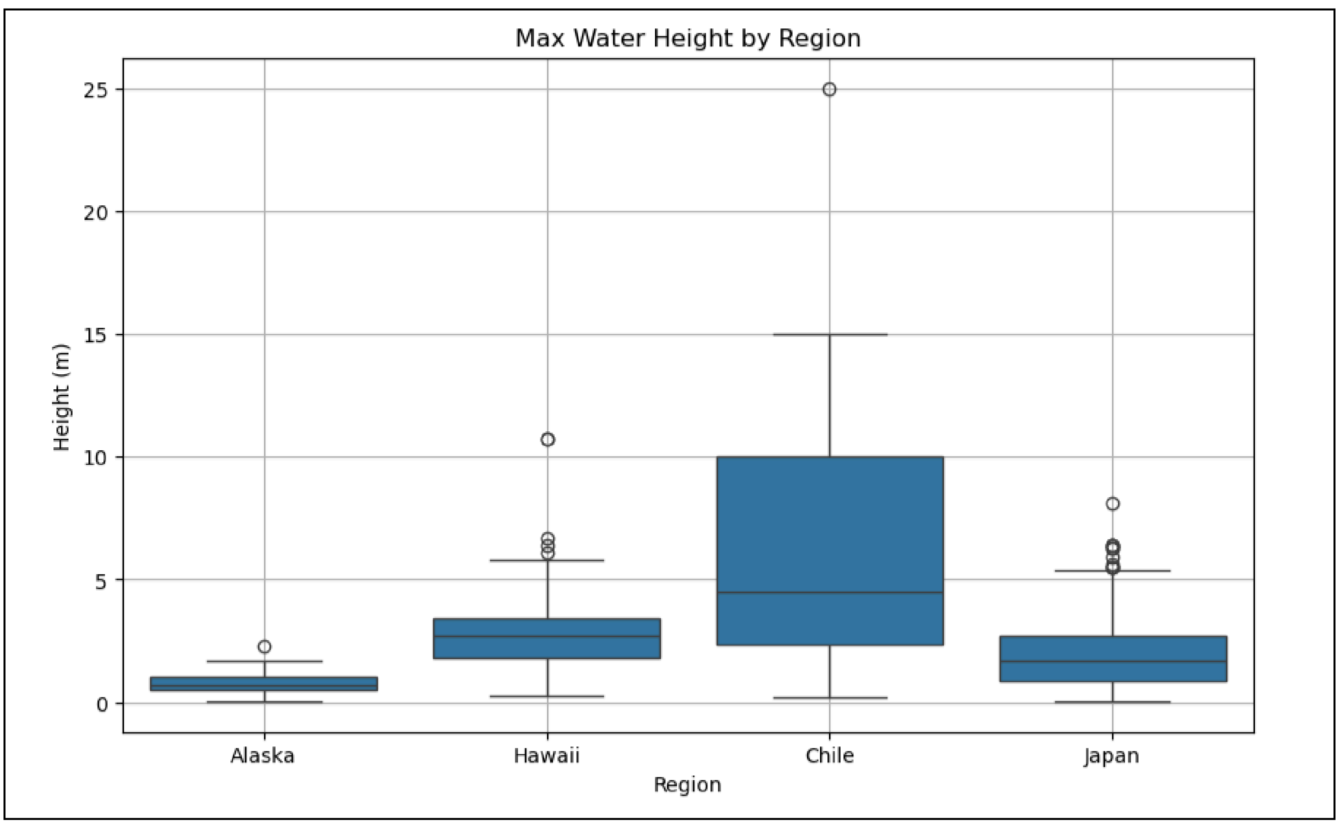


Figure 3: Maximum Wave Height Map (Larger Circles Indicate Larger Maximum Wave Heights) [4]

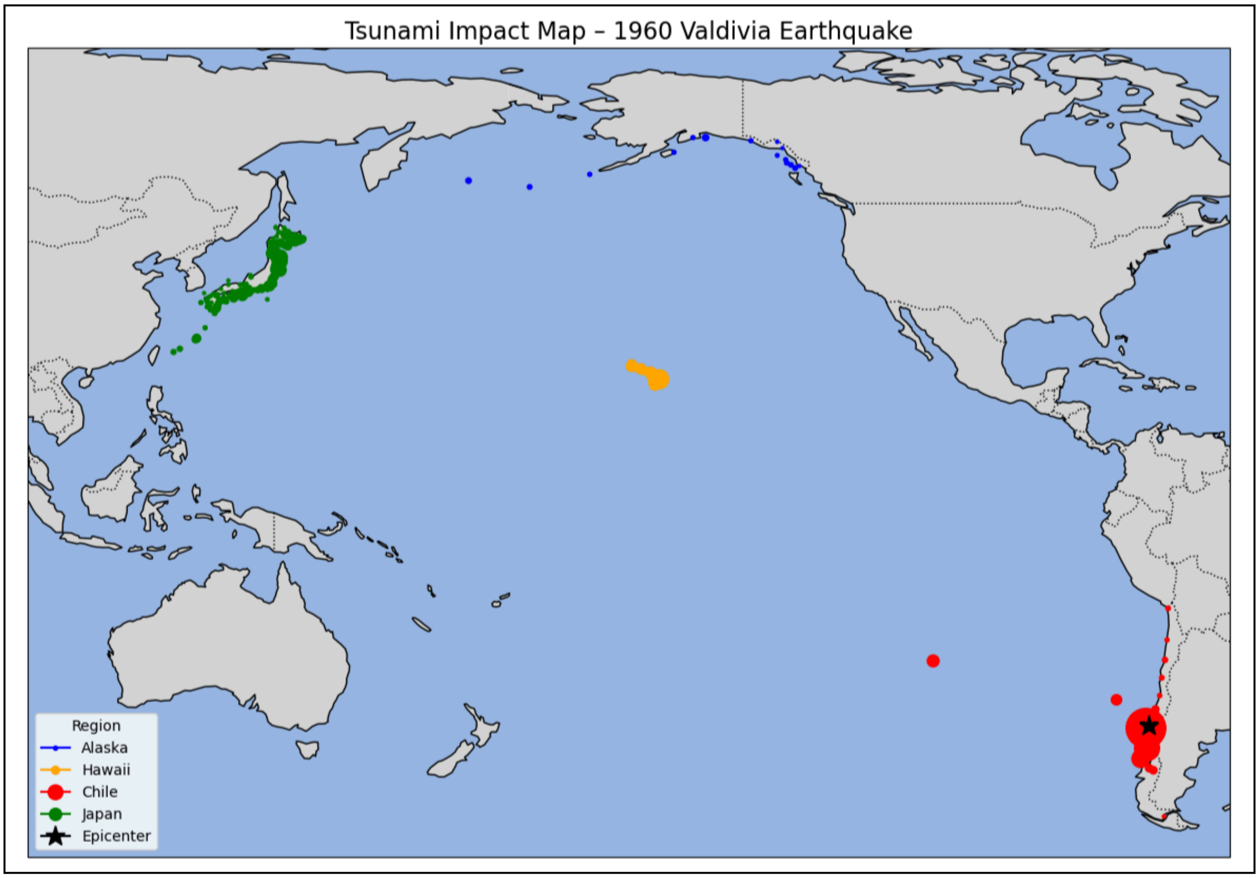


Figure 4 shows the maximum wave heights in relation to the distance from the Valdivia Earthquake's epicenter, and the data points are colored to indicate the region they came from, showing a general trend that the further away the region was from the epicenter, the smaller the maximum wave heights were. To better show this downward trend, Figure 5 shows the trend line across all the data being analyzed.

Figure 4: Maximum Wave Heights versus Distance from Source, Grouped by Region [4]

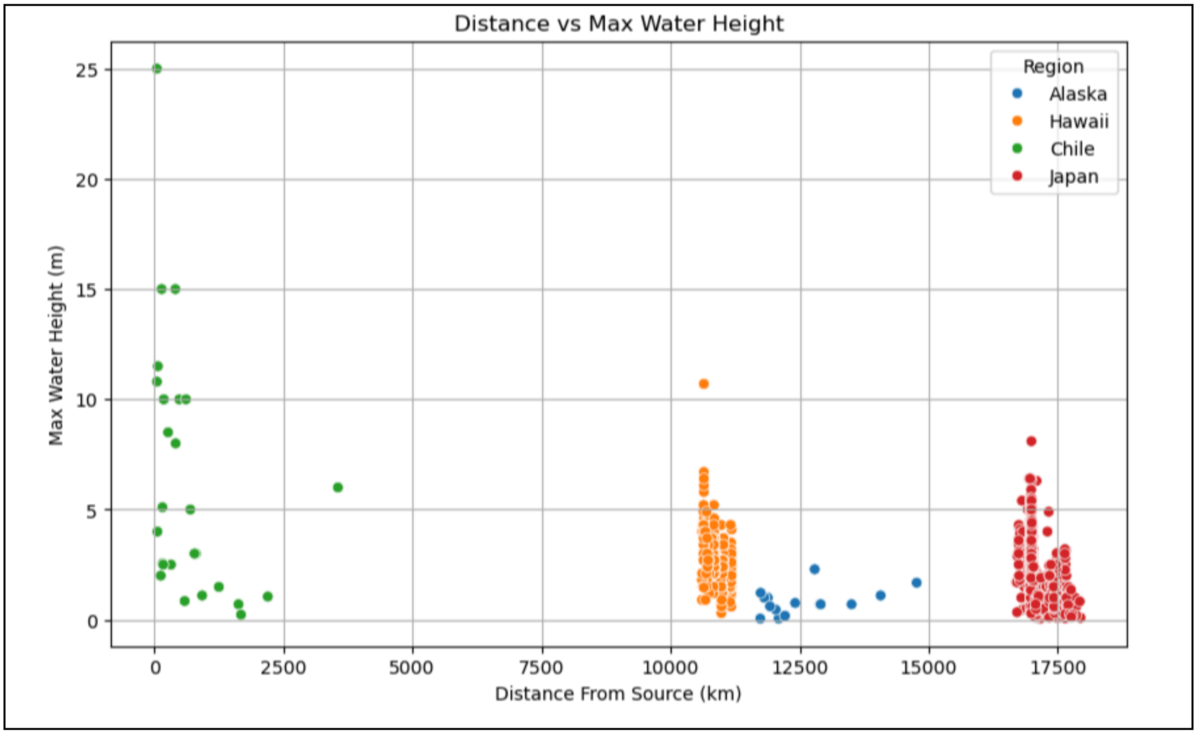
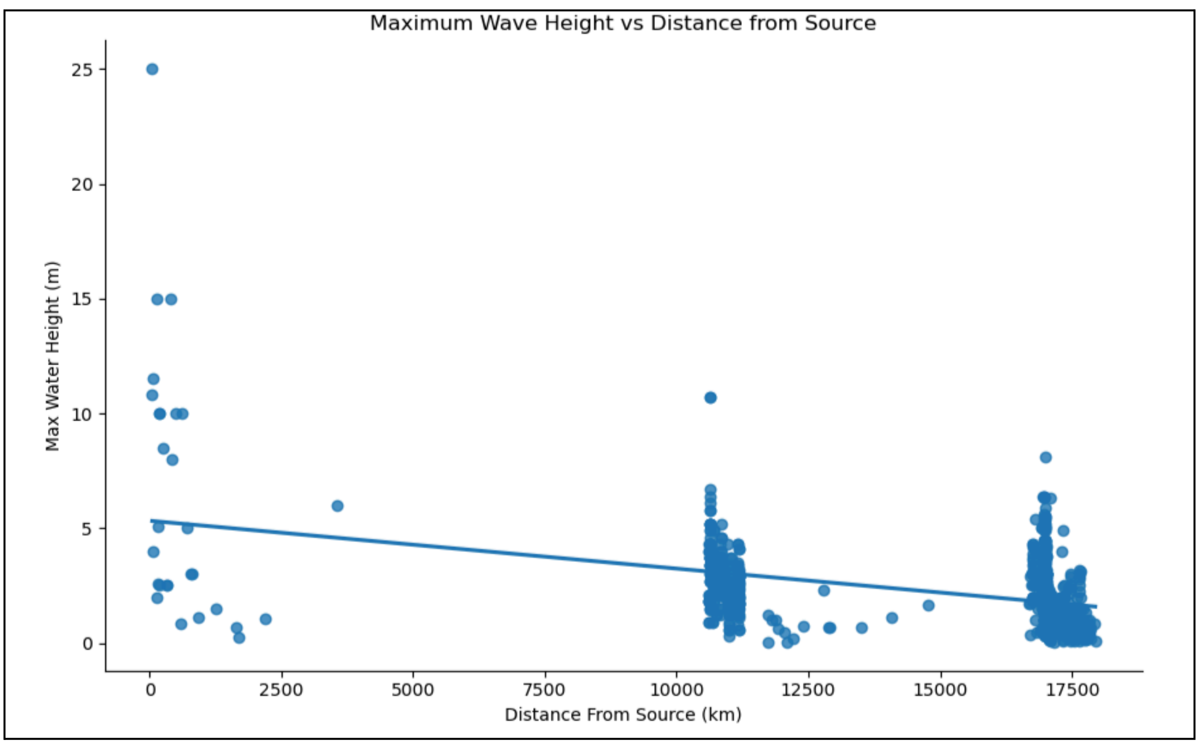


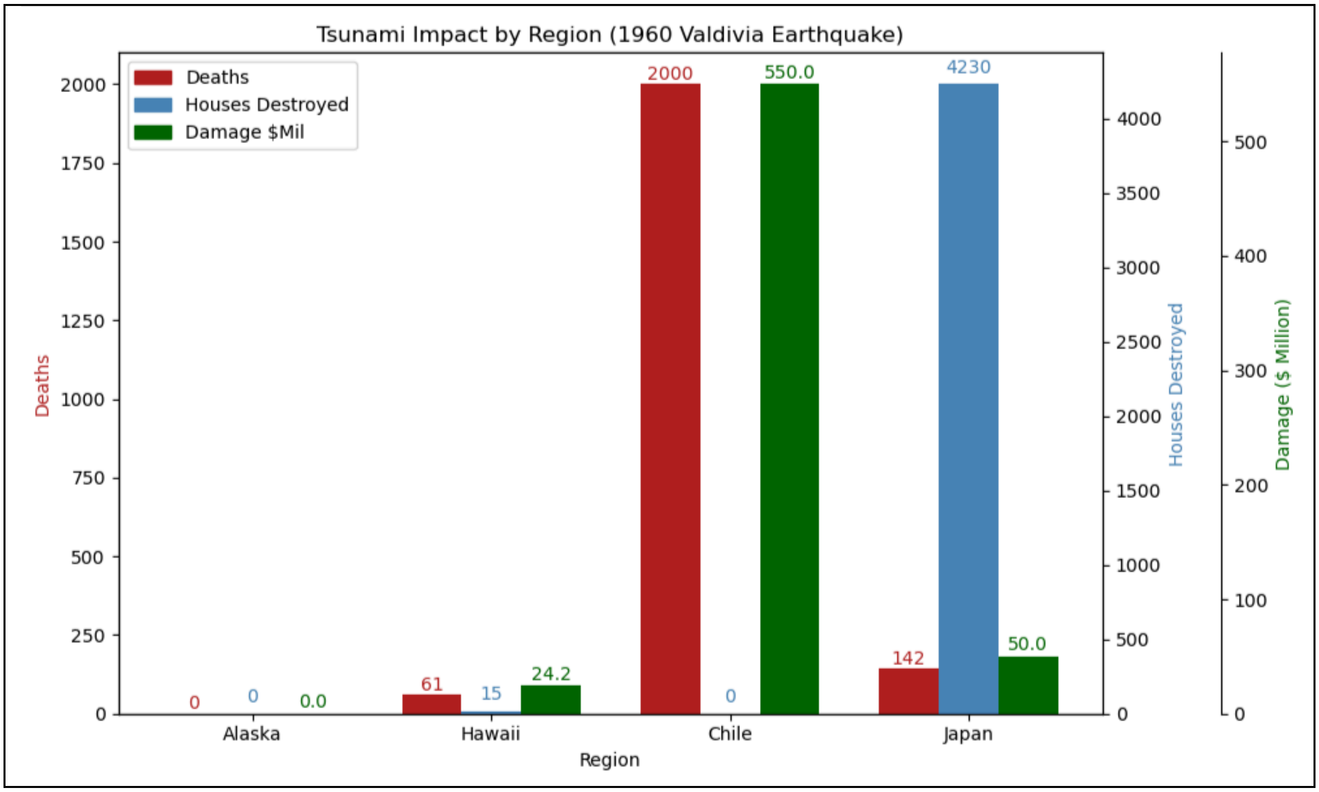
Figure 5: Maximum Wave Heights versus Distance from Source, With Trend Line [4]



Although the trend shows that the maximum wave height decreases with distance from the epicenter, it is clear from Figures 2, 3, and 4 that Japan's maximum wave height is greater than Alaska's, despite being further away by a few thousand kilometers.

As for the damages done by the tsunami event, the impact of the tsunami can be categorized in three ways– deaths, homes destroyed, and the cost of damages. Figure 6 shows these metrics for the four regions being analyzed. Chile has the most deaths, at 2,000 lives lost, and Chile also has the greatest cost of damages, with $550 million in damages. Japan, however, has the greatest number of homes destroyed, with 4,230 houses being destroyed from the tsunami. Alaska appears to have made it unscathed, with no deaths, no houses destroyed, and insignificant cost of damages. Hawaii has experienced, in relatively smaller numbers, deaths, homes destroyed, and over $24 million in damages.

Figure 6: Tsunami Impacts by Region [4]



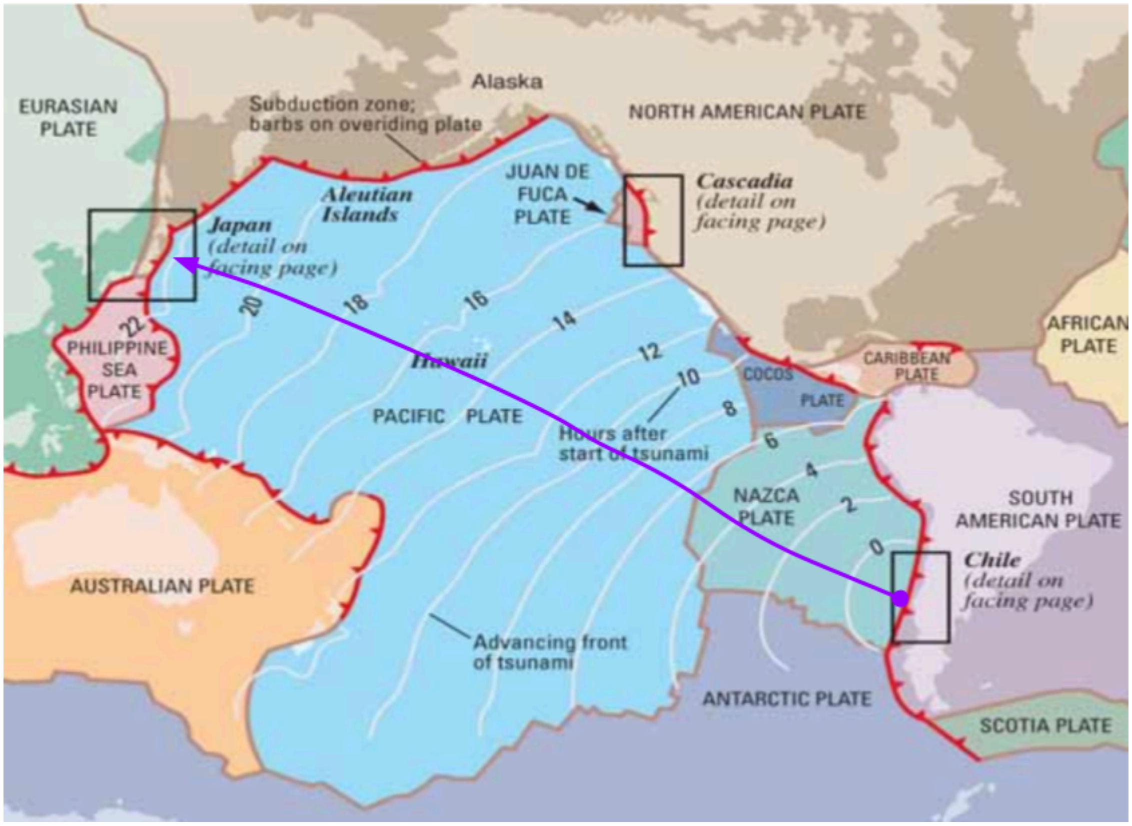
Interpretation:

It did not come as a surprise that Chile experienced the highest maximum wave heights, highest death toll, and the highest cost of damages, as Chile is where the source event occured. It can be assumed that the cost of damages includes the damages caused by the earthquake itself, not just the damage caused by the subsequent tsunami. It is odd, however, that the data showed no destroyed homes in Chile. More likely than not, this is a data reporting error, not the actual result. According to National Geographic, the Valdivia earthquake itself left approximately 2 million people homeless [5].

What was initially surprising about the data was the devastating impact the tsunami event had on Japan. Japan was over 17,000 km away from the source event, the furthest of the four regions analyzed, and yet, they were the second most devastated region. The tsunami left Japan with over a hundred lives lost, $50 million in damages, and thousands of destroyed homes, not to mention that the maximum wave heights were greater than those in Alaska, which was considerably closer to the source event. This leaves the question of why this happened.

One reason Japan may have been more affected than other regions closer to the source event is because of the path of the tsunami. The waves propagated from the source event on a direct path to hit Hawaii and Japan straight on, as is illustrated below in Figure 7. This is contrasted by Alaska, and even the northern part of Chile's coastline, which were not directly in the tsunami's path, and thus experienced smaller wave heights. See Figure 3 for this visual difference in wave height. The larger wave heights caused by the more direct hit from the tsunami was likely the biggest reason Japan experienced so much damage.

Figure 7: Tsunami Trajectory [1]



Although there is less official data on this, it is also possible that there was little communication on warning Japan about the incoming tsunami. The travel time for the tsunami to reach Japan was about 20 hours, which would have given plenty of time for evacuation and preparation. Not heeding tsunami warnings was a known issue in Hilo, Hawaii during this event, with many people not heeding the warnings, or returning to low ground too soon after the initial wave [6]. From the limited source material, it does not appear that most people in Japan were aware of the incoming tsunami, which may have contributed to the death toll.

Conclusions:

Based on this data analysis, a few conclusions can be made. Generally speaking, being located closer to the source event of a tsunami, like being in Valdivia during the 1960 Valdivia earthquake, makes a location more at risk for higher waves, more damage, and more deaths. Another risk factor is being in the direct path of a tsunami, regardless of the distance away– a difficult lesson learned by Japan.

I believe this analysis also further emphasizes the importance of tsunami warnings, modeling, and international communication. With significant advancements in these areas between 1960 and now, the international impact if the same tsunami occurred today would likely have been far less. Warnings in Hawaii would likely be more urgent and evacuations more thorough, and Japan would have had a whole 20 hours of preparation to adequately evacuate low-ground areas.

Appendix:

A: Git Repository Link: https://github.com/rrdickinson/raquel-geohazards-final-project/tree/main

Work Cited:

[1] “The most destructive Tsunamis | Chile, 1960,” Sms-tsunami-warning.com, 2011. https://www.sms-tsunami-warning.com/pages/tsunami-chile-1960 (accessed May 05, 2025).

[2] USGS, “M 9.5 - 1960 Great Chilean Earthquake (Valdivia Earthquake),” Usgs.gov, 2020. https://earthquake.usgs.gov/earthquakes/eventpage/official19600522191120_30/impact (accessed May 05, 2025).

[3]“1960 Valdivia Earthquake, Chile,” earthquakes and volcanoes (Medc’s & LEDC’s). https://astichris.weebly.com/1960-valdivia-earthquake-chile.html (accessed May 05, 2025).

[4] “NCEI Global Historical Hazard Database,” Noaa.gov, 2025. https://www.ngdc.noaa.gov/hazel/view/hazards/tsunami/related-runups/1902 (accessed May 05, 2025).

[5] M. Crooks, “May 22, 1960 CE: Valdivia Earthquake Strikes Chile | National Geographic Society,” education.nationalgeographic.org, Mar. 03, 2023. https://education.nationalgeographic.org/resource/valdivia-earthquake-strikes-chile/ (accessed May 05, 2025).

[6] “Surviving A Tsunami: Lessons from Chile, Hawaii, and Japan,” Usgs.gov, 2020. https://pubs.usgs.gov/circ/c1187/ (accessed May 05, 2025).