Sumatra, Indonesia Earthquake And Tsunami

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1 Introduction

In this report, we will study the seismic event which occurred on the 26th December 2004, along the northern coast of Sumatra. This event triggered a tsunami, observed globally, which resulted in extensive damage and a high death toll. This earthquake is catalogued as the third largest earthquake in the world since 1900.

Situated within the geological framework of the Sumatra subduction zone, this earthquake is part of one of the most active plate tectonic margins globally[2]. The subduction process, characterised by the oblique convergence between the Eurasian and Indian/Australian plates[3], induces lateral motion. This leads to the occurrence of significant earthquakes with disastrous aftermaths.

2 The Earthquake

2.1 Seismic history

The Sumatra is a geographic location prone to big seismic events. Throughout history, big earthquakes like the ones in 1797(M 8.4), 1833(M 9) and 1861(M 8.5) have taken place along the boundaries of the plates located there. It has also been affected by various earthquakes of smaller magnitude, making it a hotspot for seismic events.[4]

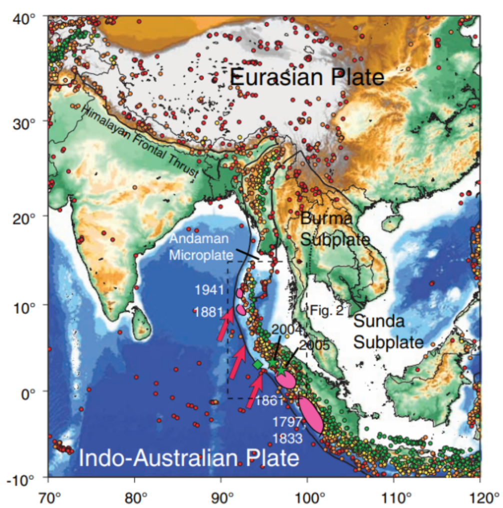

Figure 1: Regional Map exhibiting Earthquakes with magnitudes >5.0 from 1965 to 25 December 2004 from the Earthquake Catalog of the National Earthquake Information Center (NEIC)[4]

2.2 Plate Geometry and setting

The Sumatra Earthquake affected the boundary between the Indo-Australian plate, which moves northward at 40 to 50 mm/year while the southeastern part of the Eurasian pate is segmented into the Burma and Sunda subplates. The following figure illustrates the tectonic setting of the Sumatran subduction zones and the location of the earthquake.

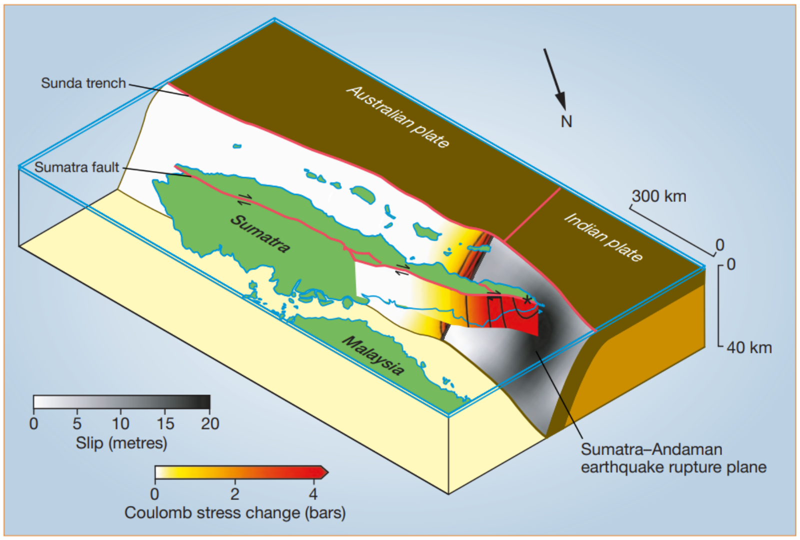

Figure 2: Tectonic plates[5]

2.3 Sumatra Earthquake and Tsunami

From seismic records, the 26th December 2004 earthquake had a significant amplitude of around 9.2 Mw. This led to the rupture of the Sumatra and Sunda subduction zones over a length of 1300 km.[6]. This consequently led to one of the deadliest tsunamis in history, giving rise to one of the highest death tolls in tsunami history with 227 898 dead. The economic repercussions were also very significant, totalling to around $10 billions in material losses and $2 billion in insured losses in the Indian Ocean region.[7]
Figure 3 shows the wave propagation over time in the Indian ocean, illustrating the Tsunami that ensued after the earthquake.

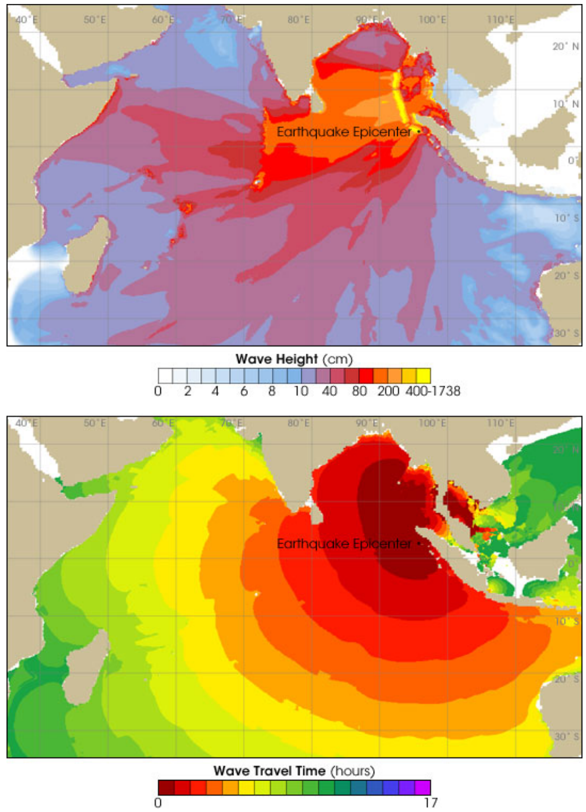

Figure 3: Maps from NOAA Pacific Marine Environmental laboratory Tsunami Research program

The tsunami arrived on the Indian east coast around 03 30 UTC, 20 minutes after the earthquake. [8] The runup [1]heights of the seismic event on the northwestern coast of Sumatra ranged between 20 to 40 meters, illustrating the immense force of the waves while runup heights ranging from 5 to 20 m were detected on the coasts of Thailand and 4 to 12 m in Sri Lanka and India, illustrating the extensive damage ensuing the seismic event.[7]

Figure 4 shows how the effects of the seismic events persist even hours after the arrival time.
For more information: https://www.ngdc.noaa.gov/hazard/26dec2004.html

[1]The runup is the difference between the elevation of the maximum tsunami penetration and the sea level during the tsunami's occurrence

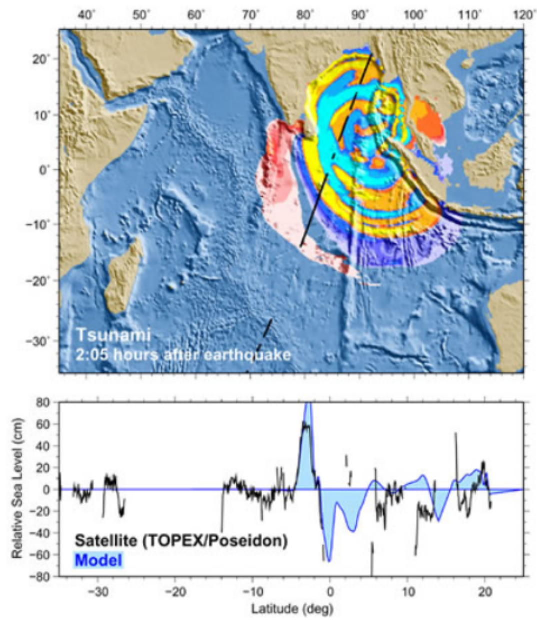

Figure 4: Tsunami wave height measured by satellites two hours and five minutes after the event

3 Data analysis from data center IRIS

3.1 Event

Given the geographic location of the seismic event chosen, we use the IRIS data center for the retrieval of data as it is a well-established network which ensures global coverage.

Other networks having regional or national focus or not operating at the time of the earthquake may not provide appropriate information on the seismic event or may not have any record of the latter. For example, using RESIF, would not give us any data about the seismic event as RESIF is primarily designed to monitor seismic activities in Europe.

Data from the IRIS data center produces coherent data which aligns with the figures referenced in the introduction, from scientific papers and sources.

Retrieving information about our earthquake with an arrival time of 2004-12-26T00:58:52.050000Z:

Table 1: Seismic Event Information

Magnitude	**Latitude**	**Longitude**
9.0	3.4125	95.9012

3.2 Choice of Stations

3.2.1 Network[1]

The network G is appropriate for the acquisition of data on the Sumatra earthquake as it is a teleseismic event[2]. This allows for the access of data from seismic stations all over the world rather than stations localised in only specific areas.

3.2.2 Channel

We used LHZ because this channel represents a long period seismometer and has a large broadband. Since LHZ refers to the use of high-gain seismometers, this type of instrument is appropriate for the detection of a broad range of ground movements. We can hence detect seismic events with a large array of magnitude and hence consistently have information about our seismic event, even when its magnitude varies. As seen in Figure 4, it is significant to have information about the event even hours after the arrival time. The use of such high-gain equipment is possible as this event occurs after the deployment of digital broadband, high-dynamic seismometers, which have high sensitivity to even small ground motions.[4]

3.3 Stations Used

Restricting our search criteria to global stations with high gain instruments, the stations used to collect the seismic data of the Sumatra Earthquake are stored in Table 2.
From the information about the location of the event and stations, we can localise both the event and the stations on a map.
The event is denoted by a purple cone while the stations are denoted in red.

[2]Earthquake occurring far from recording stations

Table 2: Seismic Station Information[1]

Station	Latitude	Longitude
AIS	-37.7963	77.5692
CRZF	-46.4310	51.8553
DRV	-66.6649	140.0021
ECH	48.2163	7.1590
FDF	14.7350	-61.1463
KIP	21.4200	-158.0112
MBO	14.3920	-16.9555
MPG	5.1101	-52.6445
PAF	-49.3510	70.2107
RER	-21.1712	55.7399
SSB	45.2790	4.5420
TRIS	-37.0681	-12.3152
WUS	41.2007	79.2165

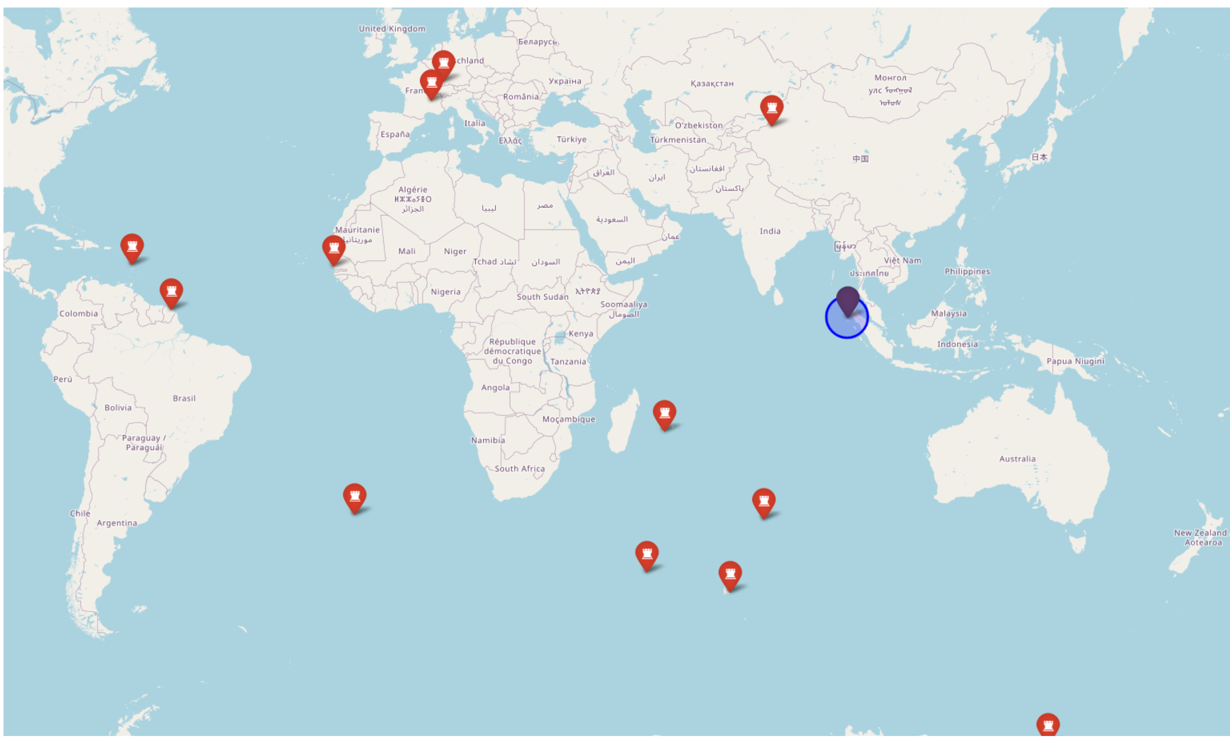

Figure 5: Map with Earthquake and Stations

4 Graphic interpretations

The following figure represents the normalised data streams of all the stations from the network G as per the criteria specified in the search query.

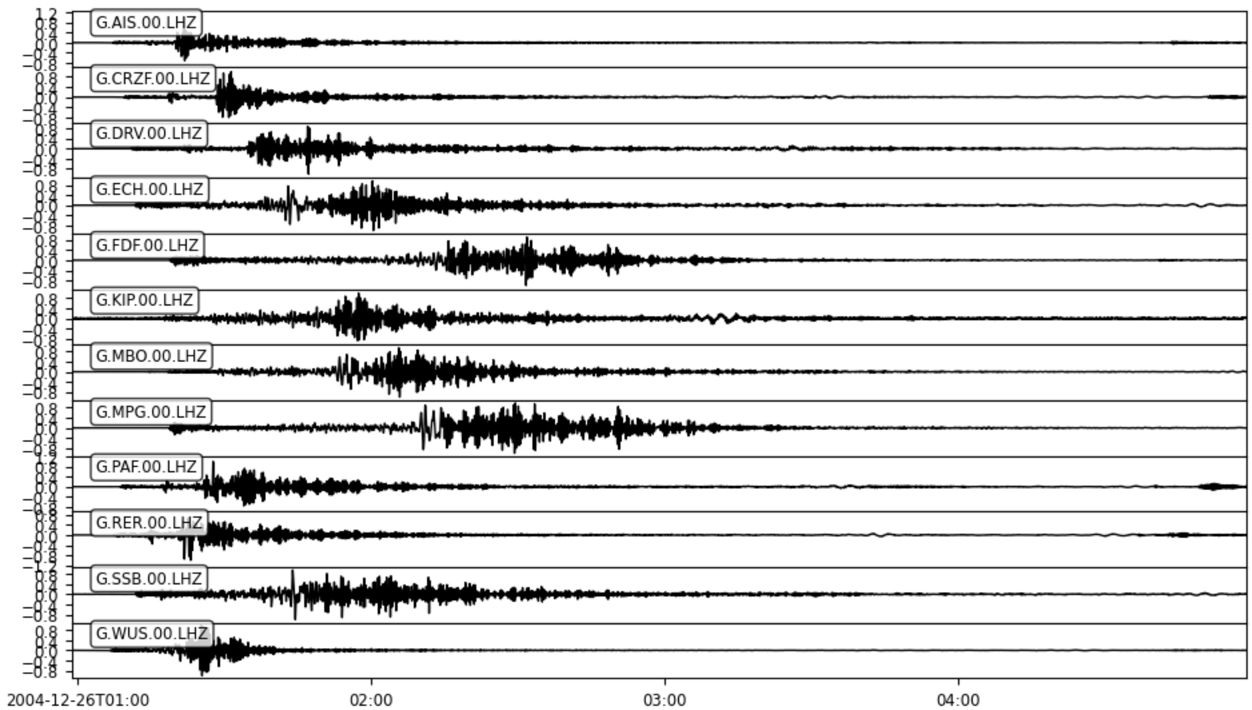

Figure 6: Unfiltered data Stream

4.1 Filters applied on KIP station data stream

For the sake of explanation of the different filters used, we focus on the data stream from the Station KIP(Latitude: 21.4200, Longitude: -158.0112)

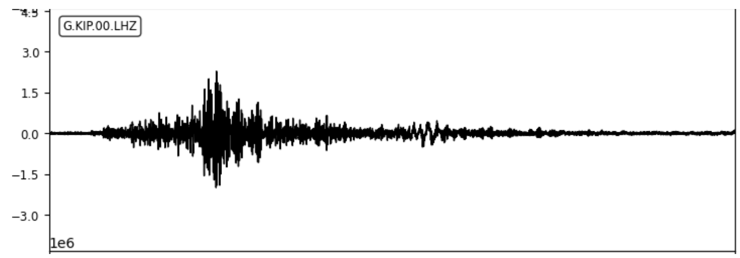

Figure 7: Unfiltered data Stream

In Figure 7, it is observed that the data is relatively noisy and it might be tricky to accurately pick the arrival of the P and S waves. Therefore, there is the need to filter the data to improve the quality of the data stream. We first filter out the mean of the data stream.

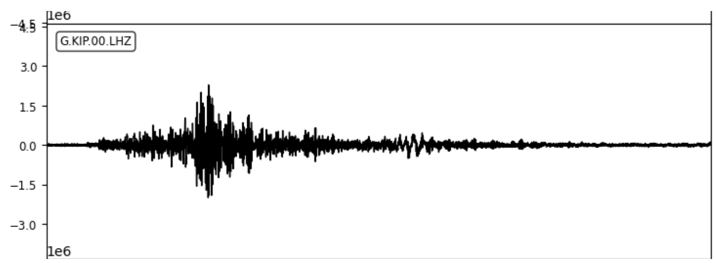

Figure 8: Data Stream After filtering out its mean

However, given that there is not a significant improvement in the result, we apply a filter to remove instrument response. This is done so as to remove the noise introduced by the instruments. Removing the instrument response gets us closer to the data of the real ground motion . In this process, we use a signal processing method known as convolution such that we can remove any redundant data from the data stream by comparing it with the instrument's transfer function and keeping only the differences, hence resulting in only the seismic data. This is shown in Figure 9 below.
Then using a bandpass filter, the data quality is improved by attenuating unnecessary frequencies, for example unwanted noise (Figure 10)

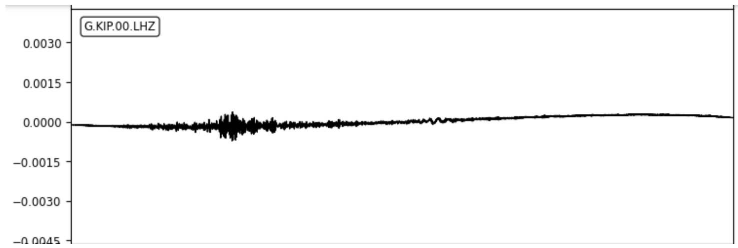

Figure 9: Data Stream After filtering out its mean

Figure 10: Data Stream After filtering out its mean

5 Power spectral density

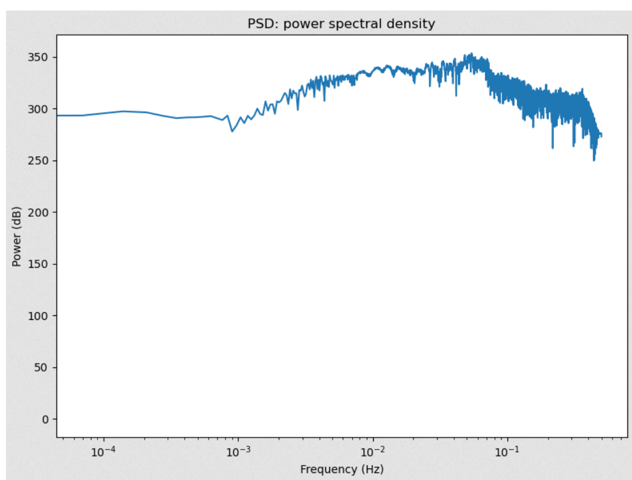

Figure 11: Unfiltered Power Spectral

Figure 11 represents the power of the signal spread across a range of frequencies. This provides useful data for researchers to analyse the principal frequencies of the Earthquake. Figure 12 shows the power spectral of the filtered data. This particular earthquake contributes significantly to seismic record due

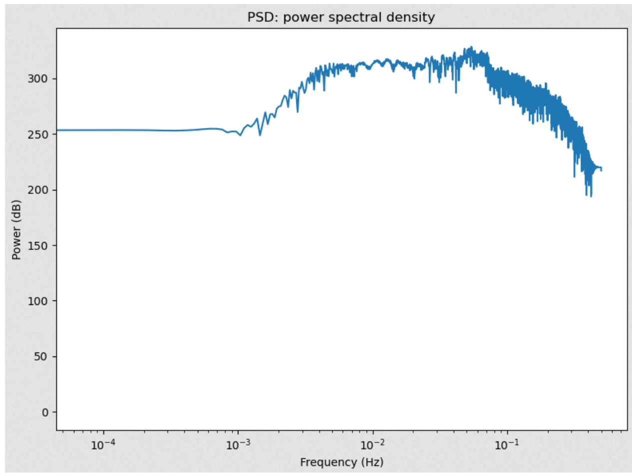

Figure 12: Filtered Power Spectral

to its elevated magnitude, as can be seen on the power spectral. Even over a range of frequencies, the earthquake has a significant power. This is a high-energy earthquake. The filtered data is de-noised to a certain level such that the power of redundant noises or other sources are discarded, explaining the differences between the Figure 11 and Figure 12

6 Conclusion

The Sumatra earthquake, as observed by data from the IRIS data center and network G is a significant seismic event, with a largely observable magnitude. Due to its high magnitude and geographic location, it is one of the most prominent earthquakes in history of seismology. The quality of the data observed is relatively high, as it occurred during a favourable time. By 2004, we already had sensitive enough instruments and stations located worldwide able to collect the data observed in the previous sections. To make data more observable, a compromise needs to be established such that while we do use filters for noise reduction or to remove redundant data, a middle-ground should be met such that there is not significant loss of data about the event signal itself.

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