Recent Worldwide Tsunamis (2020-2023) - Comparisons Between Modeling and Measurements

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Abstract

Few high magnitude earthquakes were generated worldwide in the last three and a half years, some of which triggered tsunami waves. We took into account all the events during the interval January 2020 - June 2023. There was a total of 15 earthquakes (5 in 2020, 5 in 2021, 2 in 2022, 2 in 2023) which lead to moderate and/or small tsunami waves (above 0.1 m), having magnitudes higher than 7, but also one earthquake with magnitude below 7 (6.8) which lead to very small tsunami waves generation. Not all the high magnitude earthquakes resulted in tsunami waves, depending on the depth, focal mechanism and / or other parameters (distance to shore, local conditions, etc.). From tsunami measurements point of view, we considered the most relevant ones and studied only the events that lead to measured waves higher than 0.5 m. The most significant ones are 5 events: 23rd of June 2020 (15:29 UTC), Near Coast of Oaxaca Mexico, M7.4 (maximum waves 0.68 m); 19th of October 2020 (20:55 UTC) South of Alaska M7.4 (maximum waves 0.76 m); 10th of February 2021 (13:20 UTC) Southeast of Loyalty Island, M7.7 (maximum waves 0.78 m); 4th of March 2021 (19:28 UTC) Kermadec Island region, M8.1 (maximum waves 0.56 m) and 19th of September 2022 (18:05 UTC), Coast of Michoacan Mexico M7.6 (maximum waves 0.79 m). We compared, in this paper, the values of sea level measurements with the results of the tsunami simulations, using the parameters of each earthquake (latitude, longitude, magnitude, depth, focal mechanism). The modeling simulations were accomplished using TRIDEC Cloud software, provided by the German Research Centre for Geosciences (GFZ), Potsdam, Germany. When comparing the values between the two types of data (measured vs. computed), the results show that some simulations overestimate the measured values, others underestimate it. More studies are necessary for a better numerical assessment of sea level, in order to be more precise and closer to the real measurements. Future work might include using two or three different modeling software, for the same earthquake parameters, and comparing the results.

Keywords: worldwide tsunamis, modeling, measurements, earthquakes, sea level

Introduction

During the studied period (January 2020 - June 2023), a number of 15 high magnitude earthquakes occurred worldwide, some of which triggered significant tsunami waves. Five of the events were generated in 2020, another five earthquakes in 2021, two seismic events in 2022 and in 2023 (up to end of June) only two earthquakes, which were followed by moderate and/or small tsunami waves (above 0.1 m). Most of them had magnitudes higher than 7, but also one earthquake with magnitude 6.8 lead to very small tsunami waves generation. Not all the high magnitude earthquakes resulted in tsunami waves, depending on the depth, focal mechanism and / or other parameters (distance to shore, local conditions, and others). Generally, we know from previous studies [5] that only earthquakes generated at less than 100 km inland or closed to inland could trigger tsunamis. Moreover, depending on the type of the earthquake's focal mechanism, some of them might originate tsunamis (normal reverse fault and strike slip), some will not (reverse fault). From measurements point of view, we considered the most relevant ones and studied only the events that lead to measured waves higher than 0.5 m. The most significant ones are 5 events ([1], [2], [8], [9]) (see Table 1): 23rd of June 2020 (15:29 UTC), Near Coast of Oaxaca Mexico, M_W 7.4 (maximum waves 0.68 m); 19th of October 2020 (20:55 UTC) South of Alaska M_W 7.5(maximum waves 0.76 m); 10th of February 2021 (13:20 UTC) Southeast of Loyalty Island, Mw 7.7 (maximum waves 0.78 m); 4th of March 2021 (19:28 UTC) Kermadec Island region, M_W 8.0 (maximum waves 0.56 m) and 19th of September 2022 (18:05 UTC), Coast of Michoacán Mexico M_W 7.6 (maximum waves 0.79 m).

Tab. 1. Parameters of the selected earthquakes

Date	Time (UTC)	Location	Latitude	Longitude	Magnitude (Mw)	Depth (km)
19.09.2022	18:05	Coast of Michoacán, Mexico	18.44 N	103.01 W	7.6	20
04.03.2021	19:28	Kermadec Islands, New Zealand	29.55 S	177.27 W	8.0	24
10.02.2021	13:20	Southeast of Loyalty Islands	22.85 S	171.45 E	7.7	29
19.10.2020	20:55	South of Alaska	54.63 N	159.87 W	7.5	40
23.06.2020	15:29	Oaxaca, Mexico	16,17 N	95.73 W	7.4	10

Tsunami modeling simulations were accomplished for these events using earthquake's parameters (location, magnitude, depth) and moment tensor (MT) solutions given by German Research Centre for Geosciences (GFZ) [2] (see Table 1 and Table 2). The modeling was performed using TRIDEC Cloud software, provided by the German Research Center for Geosciences (GFZ), Potsdam, Germany [3], [4]. We compared the values of sea level measurements with the results of simulations, where it was the case, if we had sea level data available or relevant results of simulations.

Tab. 2. Moment Tensor (MT) solutions for the studied earthquakes

Date	Time (UTC)	Location	Latitude	Longitude	Magnitude (Mw)	Depth (km)
19.09.2022	18:05	Coast of Michoacán, Mexico	18.44 N	103.01 W	7.6	20
04.03.2021	19:28	Kermadec Islands, New Zealand	29.55 S	177.27 W	8.0	24
10.02.2021	13:20	Southeast of Loyalty Islands	22.85 S	171.45 E	7.7	29
19.10.2020	20:55	South of Alaska	54.63 N	159.87 W	7.5	40
23.06.2020	15:29	Oaxaca, Mexico	16,17 N	95.73 W	7.4	10

Methodology

Using earthquake's parameters (location, magnitude, depth) and moment tensor solutions for all the 5 events, tsunami modeling simulations were accomplished with TRIDEC Cloud software, provided by the German Research Centre for Geosciences (GFZ), Potsdam Germany [3], [4], [7]. The software is a useful tool in tsunami warning, modeling and maximum wave heights estimates in different coastal locations.

The TRIDEC Cloud software provides important functionality required to act in operational conditions and integrates historic and real-time sea level data and earthquake information. On-demand tsunami simulations are computed for an event either automatically or manually for immediate processing. Thus tsunami travel times, estimated times of arrival and estimated wave heights are available rapidly for visualization purposes and for further analysis and processing, including tsunami forecast points and coastal forecast zones, which is very important for issuing warning messages.

For each event, two modeling scenarios were computed (using different values of the Moment Tensor solution - see Table 2) and both will be presented, displayed and the values compared to the sea level measured data, extracted from ITIC (International Tsunami Information Centre) database [11] and / or other International sources (profile Agencies and / or websites) [6], [10]. Each case study will include a map with the location of the earthquake, a table with the measured values of the sea level from different locations and the results of the simulation in terms of maximum waves height and travel times maps.

Results

19.09.2022, Coast of Michoacan, Mexico

The earthquake from 19th of September 2022 was generated at 18:05 UTC, on the Coast of Michoacán Mexico, had an estimated magnitude M 7.6, at 20 km depth, and triggered maximum tsunami measured waves of 0.79 m in Manzanila. Lower values were recorded in Zihuatanejo MX (0.53 m), Lazaro Cardenas MX (0.32 m), and Puerto Valarta (0.21 m), according to ITIC (see Table 3). The location of the earthquake in displayed in Figure 1.

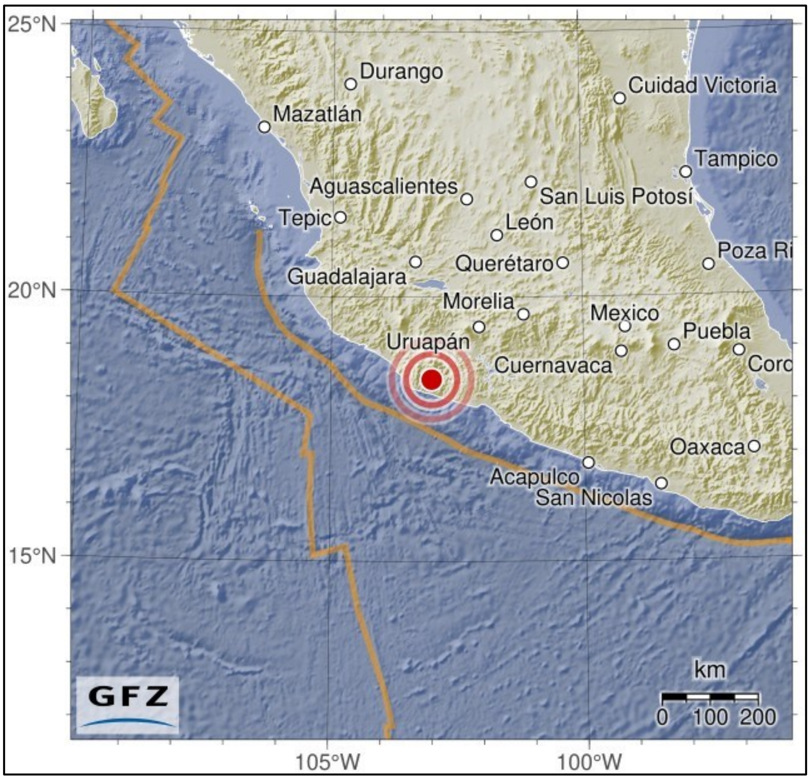

Fig. 1. Location of the earthquake from Mexico, 19.09.2022 (source GFZ)

Tab. 3. Measured sea level for the earthquake from Mexico, 19.09.2022 (source ITIC)

Location	Measured sea level (m)
Zihuatanejo MX	0.32
Zihuatanejo MX	0.46
Manzanillo MX	0.79
Puerto Vallarta MX	0.21
Lazaro Cardenas MX	0.32
Zihuatanejo MX	0.53

Unfortunately, for this earthquake scenario, no results of the simulations with TRIDEC software were available, due to the inland (or close to inland) location, according to the coordinates of the earthquake.

04.03.2021, Kermadec Islands, New Zealand

The earthquake from 4th of March 2021 was generated at 19:28 UTC, in Kermadec Islands, New Zealand, with a very high magnitude M 8.0, at 24 km depth, and triggered the highest measured waves of 0.56 m in Kingstone Norfolk IS and 0.48 m in Santa Cruz Galapagos. Other recorded waves: 0.31 m in Mahia Mansa, 0.30 m in Great Barries IS NZ and 0.29 m in in Chanaral CL. For a complete list of sea level records, see Table 4. Figure 2 evidences the location of this event.

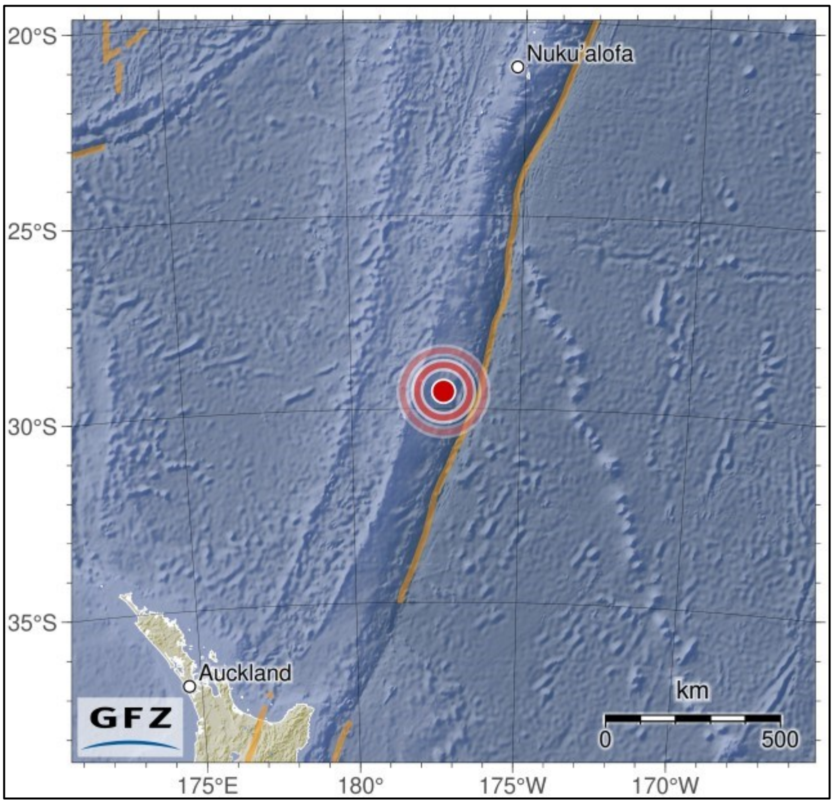

Fig. 2. Location of the earthquake from Kermadec Islands, 04.03.2021 (source GFZ)

Tab. 4. Measured sea level for the earthquake from Kermadec Islands, 04.03.2021 (source ITIC)

Location	Measured sea level (m)	Location	Measured sea level (m)
Caldera CL	0.24	Lenakel VU	0.30
Chanaral CL	0.29	Kingston Norfolk Is	0.56
Santacruz Galapagos	0.48	Great Barrier Is NZ	0.30
Bahia Mansa CL	0.31	Arica CL	0.22
Hiva Oa Marquesas	0.23	Lobos De Afuera PE	0.24
Nuku Hiva Marquesas	0.25	Callao PE	0.23

The simulations with TRIDEC software for this case displaying the maximum wave heights maps and travel times, are represented in Figure 3. In the right image (for first MT solution set), the values of the waves seem to be higher than 1 m, in comparison to the left image (for the other MT solution set), where there are lower values than 1 m estimated. The maximum measured and computed sea level for this case event show an overestimation of the simulations, double value of modeled (> 1 m) vs. measured (0.56 m).

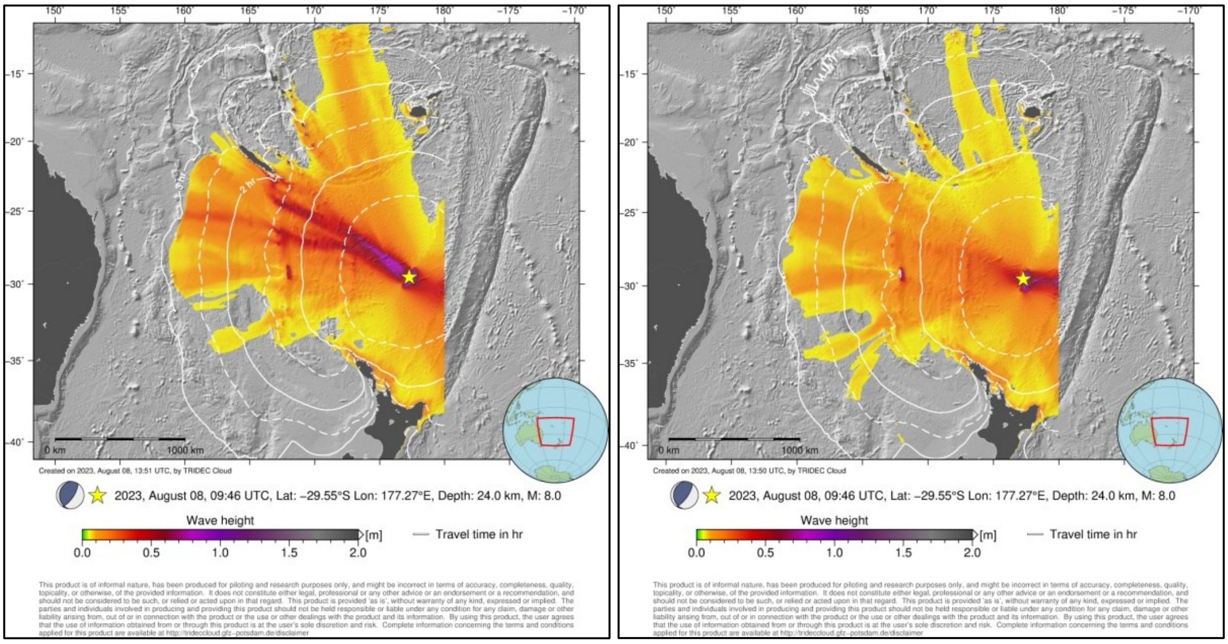

Fig. 3. Maximum wave heights and estimated travel times for the earthquake from Kermadec Islands, 04.03.2021 for different MT solutions (source TRIDEC Cloud)

10.02.2021, Southeast of Loyalty Islands

The earthquake from 10th of February 2021 was generated at 13:20 UTC, in the Southeastern part of the Loyalty Islands, with a high magnitude M 7.7, at 29 km depth, and lead to measured waves of 0.78 m in Lenakel Vanuatu. Lower sea level values were registered in Great Barrier IS NZ of 0.75 m and 0.48 m in Kinston Norfolk IS (Table 5). The location of the earthquake can be observed in Figure 4.

Tab. 5. Measured sea level for the earthquake from Loyalty Island, 10.02.2021(source ITIC)

Location	Measured sea level (m)
Lenakel Vanuatu	0.78
Ouinne New Caledonia	0.29
Great Barrier Is NZ	0.75
Kingston Norfolk Is	0.48
East Cape NZ	0.20
North Cape NZ	0.22

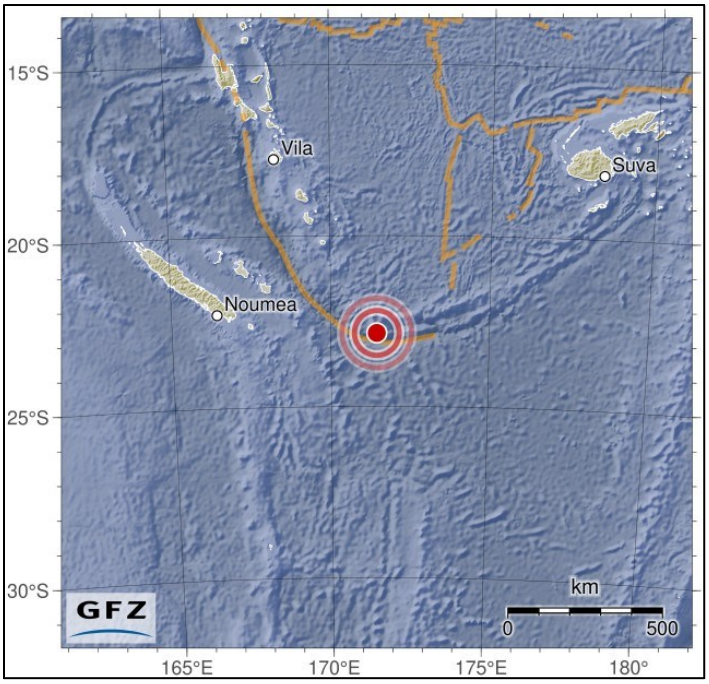

Fig. 4. Location of the earthquake from Loyalty Island, 10.02.2021 (source GFZ)

The result of the simulations with TRIDEC software are represented in Figure 5, showing the maximum wave heights maps and travel times, with different results for both MT solutions, displaying sea level values below 0.5 m heights for the first for one set of MT (left image), and around 0.7 - 0.8 m for the second (right image). In contrast to the previous case study, in this example, the computation (0.8 m) estimates quite well the measurement (max 0.78 m).

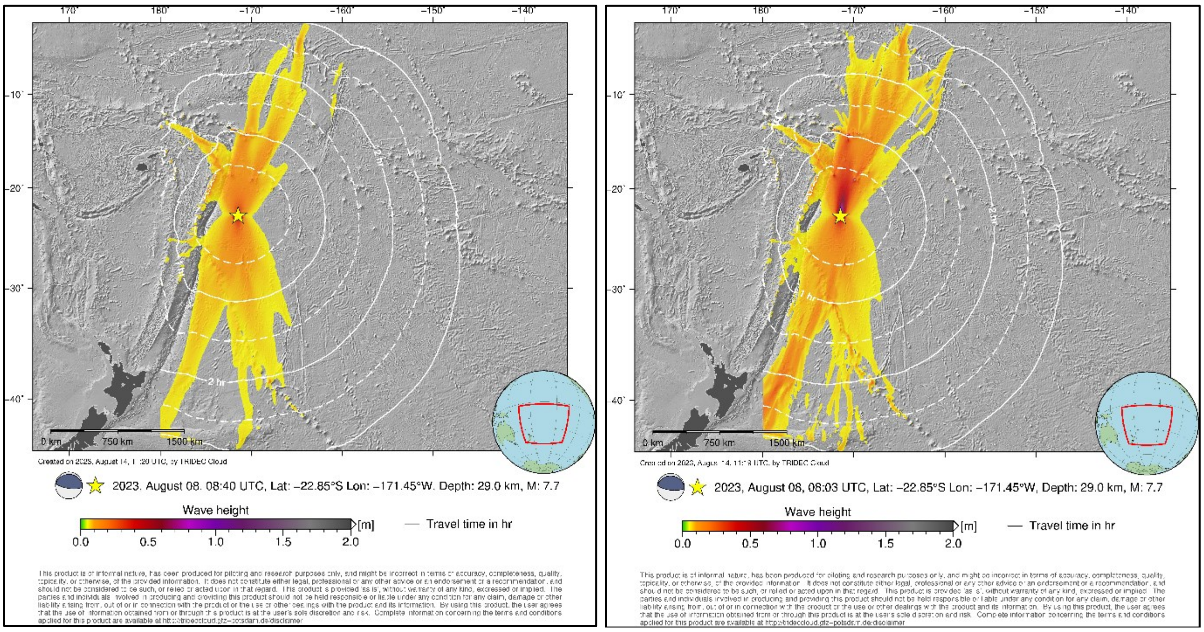

Fig. 5. Maximum wave heights and estimated travel times for the earthquake from Loyalty Island, 10.02.2021 for different MT solutions (source TRIDEC Cloud)

19.10.2020, South of Alaska

The earthquake from 19th of October 2020 was triggered at 20:54 UTC, in the Southern part of Alaska, with a magnitude M 7.5, at 40 km depth, with a maximum sea level measurement of 0.79 m in Chignik Bay Alaska. This was the only recorded value available. Figure 6 displays the location of this event.

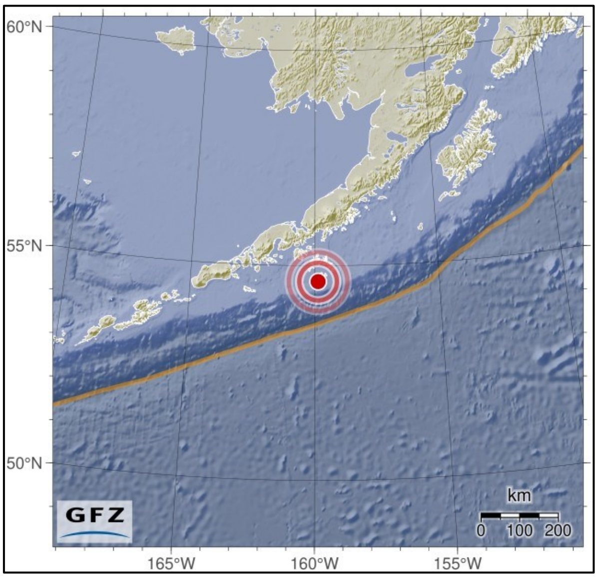

Fig. 6. Location of the earthquake from South of Alaska, 19.10.2020 (source GFZ)

The simulations with TRIDEC software can be visualized in Figure 7, with similar results for both MT solutions, displaying maximum sea level values of around 0.3 - 0.4 m. Similar to the previous case, the computation (max 0.4 m) underestimates the measurement (max 0.79 m).

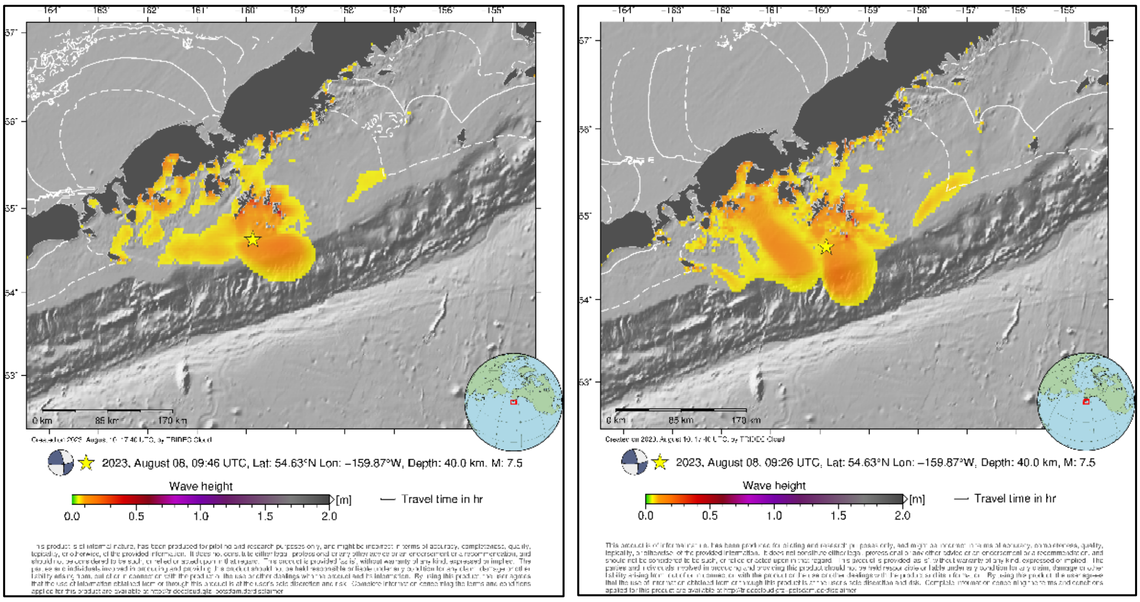

Fig. 7. Maximum wave heights and estimated travel times for the earthquake from South of Alaska, 19.10.2020, for different MT solutions (source TRIDEC Cloud)

23.06.2020, Oaxaca, Mexico

The earthquake from 23rd of June 2020 was generated at 15:29UTC, in Mexico, Oaxaca, with a magnitude M 7.4, at 10 km depth, and lead to only one record in sea level measurement of 0.68 m in Acapulco MX. This was the only recorded value available. The earthquake's location can be observed in Figure 8.

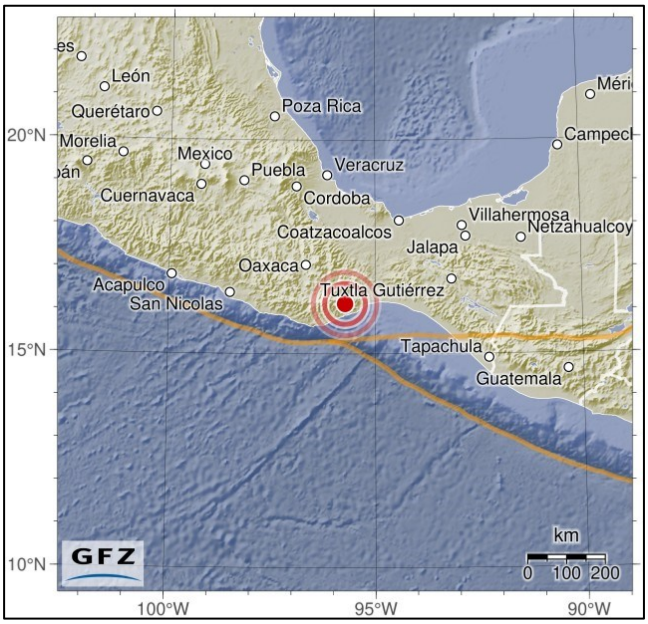

Fig. 8. Location of the earthquake from Oaxaca Mexico, 23.06.2020 (source GFZ)

Similar to the first event (also from Mexico), no results of the simulations with TRIDEC software were available, due to the inland (or close to inland) location.

When comparing the values between the modeled and measured data, a final table with all the results is structured as Table 6. The third column is a maximum general value resulted from the simulation and does not correspond to the location of the measurements.

Tab. 6. Comparison between measured vs. computed sea level (maximum value for each event)

Date / Time (UTC)	Location	Maximum computed wave height (m)	Maximum measured wave height (m)	Location of maximum measured wave
19.09.2022 / 18:05	Coast of Michoacán, Mexico	N/A	0.79	Manzanillo MX
04.03.2021 / 19:28	Kermadec Islands, New Zealand	> 1	0.56	Kingston Norfolk Is
10.02.2021 / 13:20	Southeast of Loyalty Islands	0.7 - 0.8	0.78	Lenakel Vanuatu
19.10.2020 / 20:54	South of Alaska	0.3 - 0.4	0.76	Chignik Bay Alaska
23.06.2020 / 15:29	Oaxaca, Mexico	N/A	0.68	Acapulco MX

Conclusion

Five tsunami triggered by high magnitude earthquakes were analysed, in order to compare the measured sea level to the numerical values resulted from simulations using the TRIDEC Cloud software. Only for three of the events we computed the sea level values and estimated maximum wave heights and travel times. The computations for the two earthquakes from Mexico did not provide any relevant results due to their location (inland, or close to inland). The software does not seem to be set properly for this type of locations. Future work might include using additional modeling software, for the same earthquake parameters, and comparing the results.

Furthermore, there are some differences in the results, when considering two MT given solutions. When comparing the values between different types of data (measured vs. computed), the results show that some simulations overestimate the measured values (for the case of Kermadec Island earthquake), others underestimate it (for the case South of Alaska earthquake) and for the Loyalty Island event the values are quite similar. Possible causes might be input earthquake parameters (which might differ depending on the source: GFZ, EMSC, USGS, etc) or software background specifications. These discrepancies lead to the conclusion that more studies are necessary for a better estimation of sea level computations, in order to be more precise and closer to the measurements.

Comparing the results of more software might improve the rapid estimates and be helpful as first assessments tool for tsunami waves heights, affected locations and possible casualties.

The key parameters of the tsunami modeling, in order to obtain accurate results, are the earthquake’s parameters and also a proper tool (modeling software) for tsunami waves estimations.

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