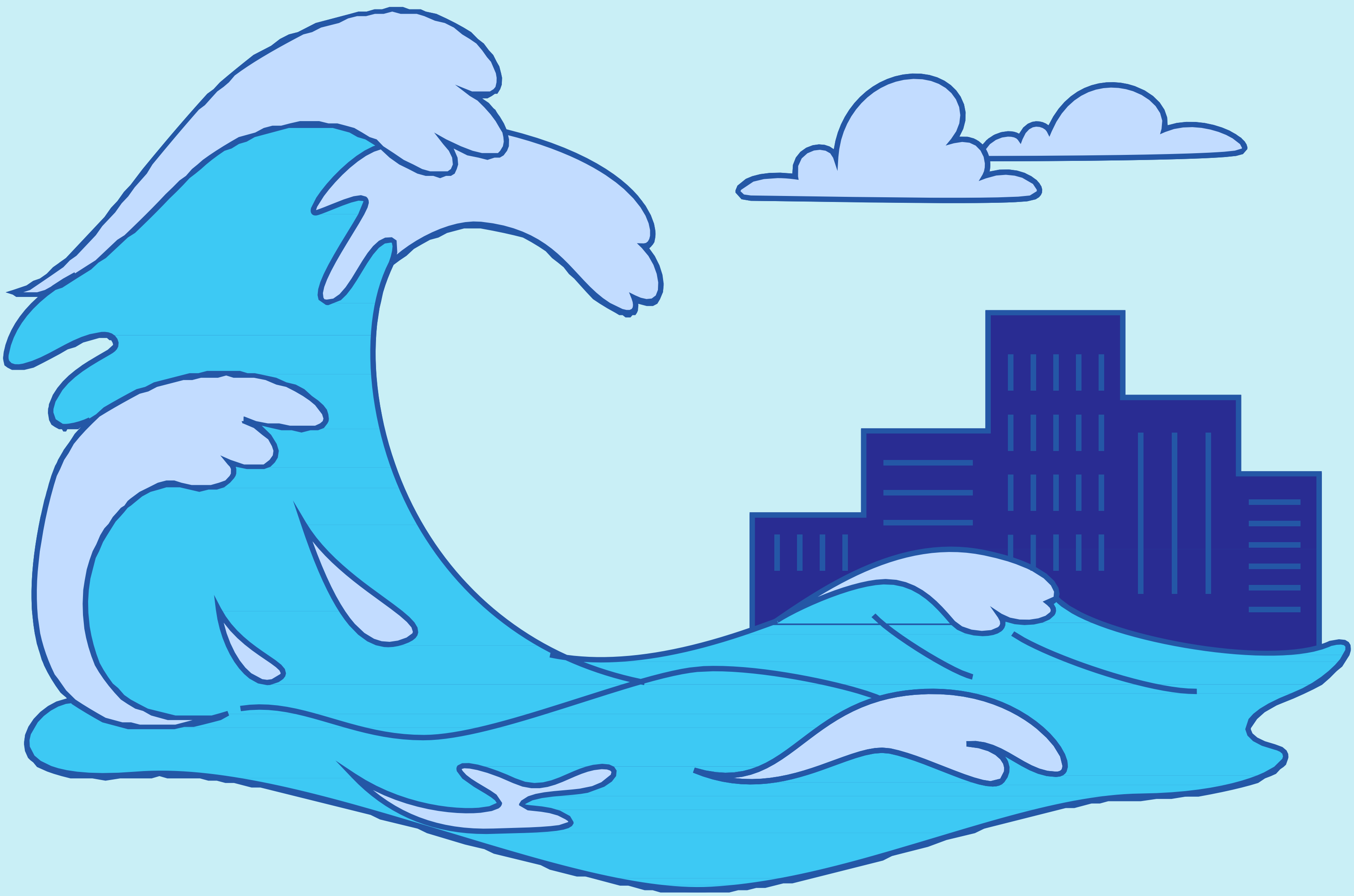
unesco
Intergovernmental Oceanographic Commission

TWC-MSC Training

Decision Support Tools
Tsunami Forecasting



1 Finding Event Source Information **2**
1.1 USGS NEIC 2
1.2 CISN Display 5
1.3 Google Earth 10
2 Calculating TTT (Tsunami Travel Time) **14**
2.1 Using TTT Software (Basic) 14
2.2 Advanced TTT Calculation 17
Instructions 17
Outputs 18
2.3 Interpreting TTT Products 19
3 Sources of Real-Time Sea Level Data **21**
3.1 Tide Tool 21
3.2 National Data Buoy Center 27
3.3 IOC Sea Level Monitoring 29
3.4 NOS Tsunami Capable Tide Stations 31
3.5 Pacific Ocean Portal 33
4 Using Sea Level Data to Confirm and Monitor Tsunamis **35**
4.1 Tide Tool 35
4.2 Other Sea Level Data Sources 36
5 Pre-Calculated Tsunami Forecast Modeling **36**
5.1 MOST Model Parameters (Used to generate multiple propagation databases) 36
5.2 NOAA Propagation Database (Used in SIFT and TsuCAT) 38
5.3 ComMIT 40
5.4 JMA 40

1 Finding Event Source Information

After an earthquake occurs, there are multiple sources that will quickly report the event source information.

1.1 USGS NEIC

The United States Geological Survey (USGS) National Earthquake Information Center (NEIC) posts real-time and regularly updated information on earthquakes. Using the following link, you can view all the latest earthquakes and apply filters to show earthquakes based on magnitude and location:

USGS NEIC

The interactive map displays the earthquakes that can be clicked on to view more information, as shown below:

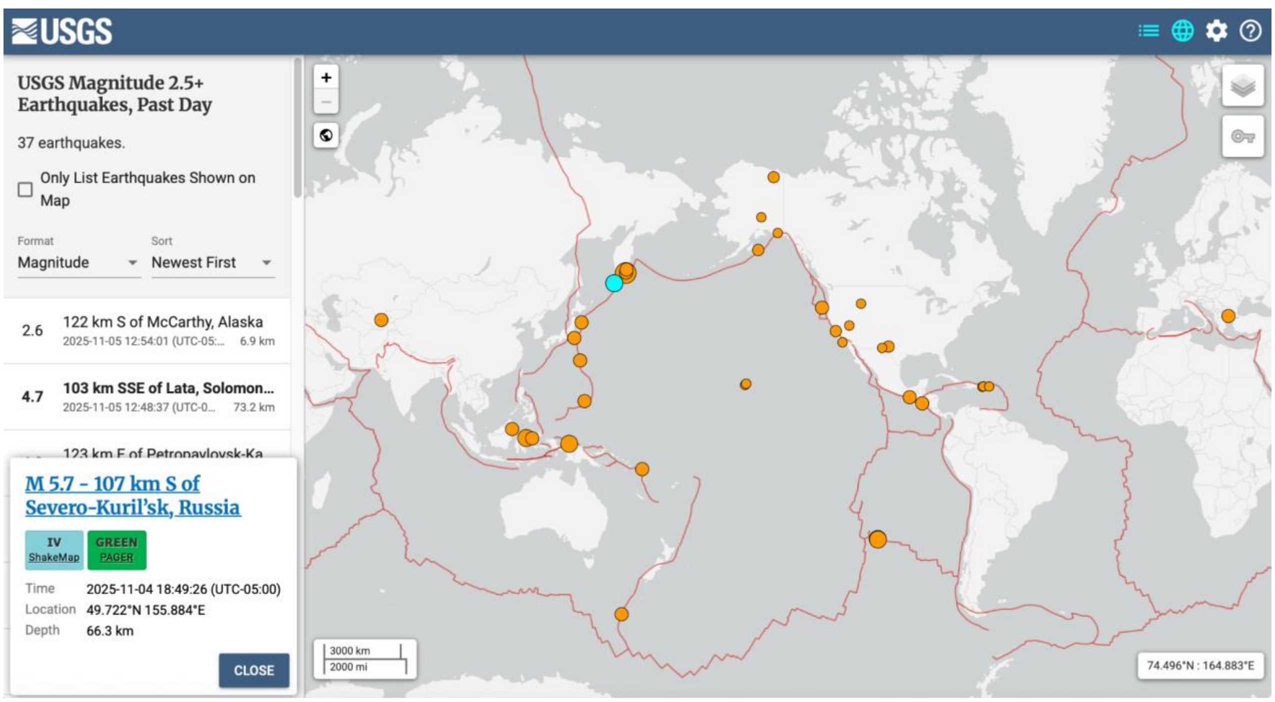


Figure 1.1.1: USGS NEIC interactive earthquake map. (Credit: USGS/NEIC, 2025)

To filter the results by magnitude, date, and location, you can click on the settings symbol in the top right corner, as shown below:

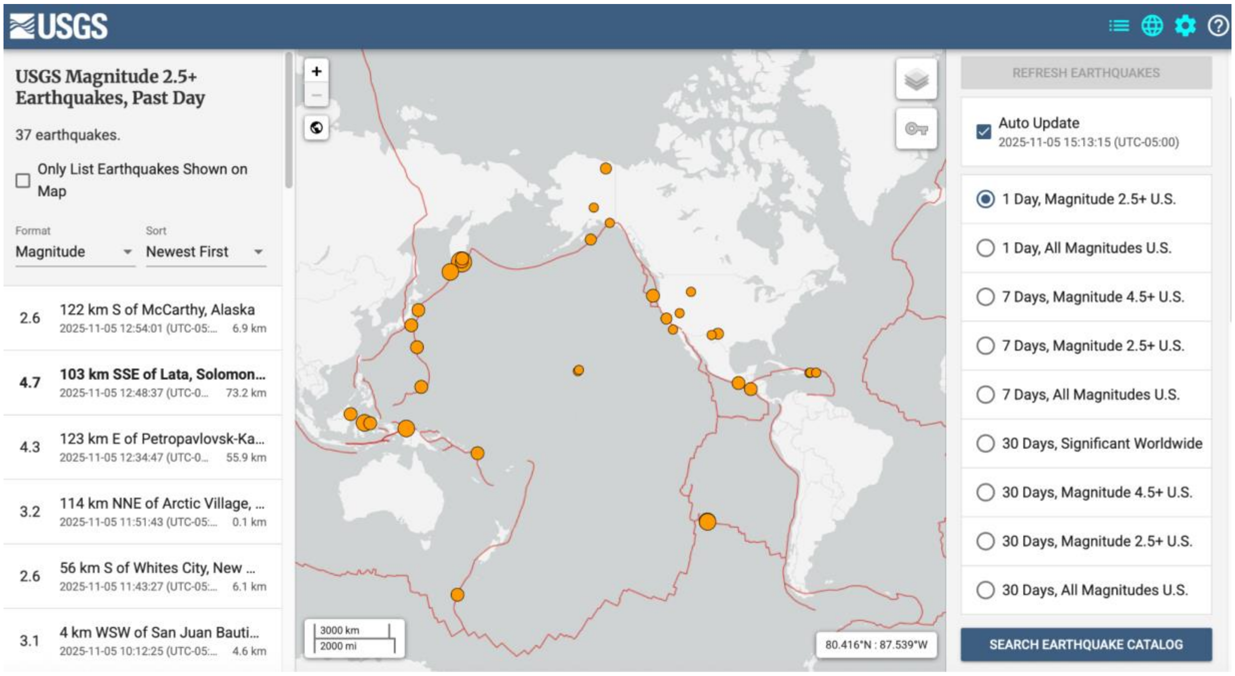


Figure 1.1.2: USGS NEIC interactive earthquake map showing filters. (Credit: USGS/NEIC, 2025)

Rather than monitor for current earthquakes, clicking the 'SEARCH EARTHQUAKE CATALOG' button (or using the following link) allows you to search the entire USGS NEIC database for historical earthquakes.

[USGS NEIC Earthquake Catalog]

As shown in the image below, there are a number of different criteria you can use to search for earthquakes. You can also choose how to download the results if you are looking to use a dataset.

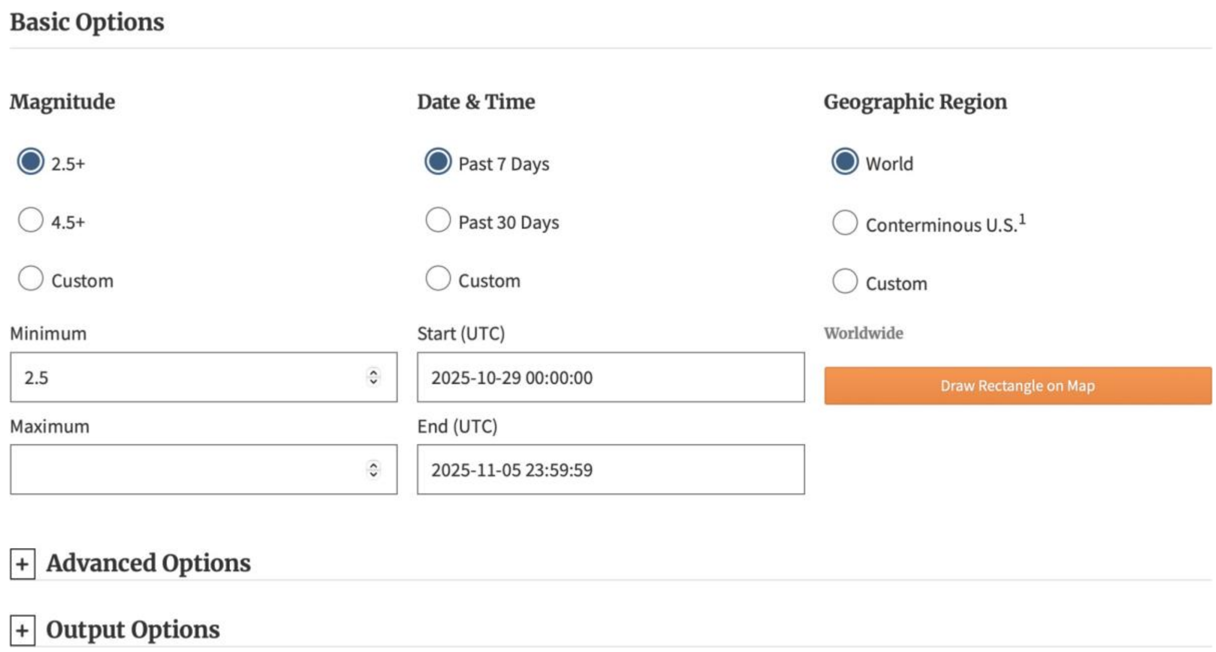


Figure 1.1.3: USGS NEIC earthquake catalog search criteria. (Credit: USGS/NEIC, 2025)

When searching for or analyzing a specific earthquake event, you can find it by searching through the earthquake catalog or by using the recent events map if the event is recent enough. You can then click on the specific earthquake that will then bring you to the event page for that earthquake with much more information than is available on the map. For example, linked below and shown in the following figure is the event page for the 2025 M8.8 Kamchatka earthquake. (Alternatively, searching in your browser for the earthquake parameters (magnitude, date/time, location, etc.) and including 'USGS' should also lead you to the event page for that earthquake).

[2025 M8.8 Kamchatka earthquake]

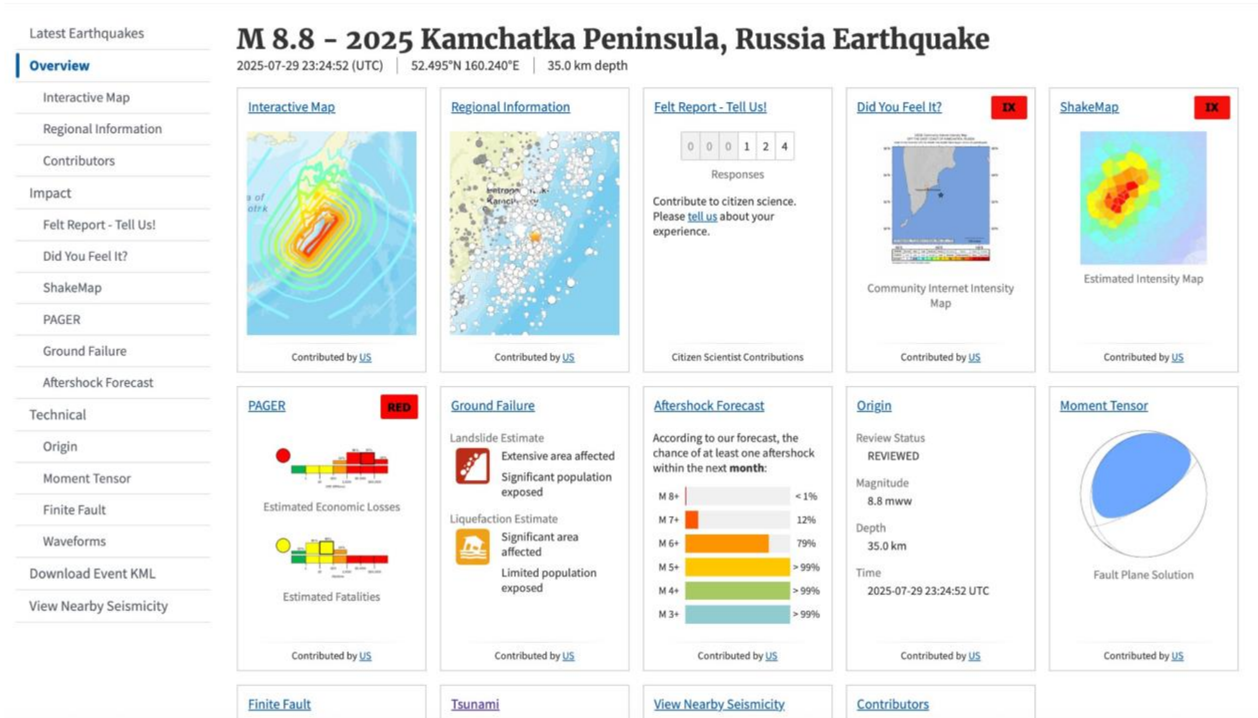


Figure 1.1.4: USGS NEIC event page for 2025 M8.8 Kamchatka earthquake. (Credit: USGS/NEIC, 2025)

For certain major earthquakes, one resource available on the event page is the finite fault solution. The finite fault solution can be imported into RIFT (a propagation model introduced in the Core Science Module) to give a more precise representation of the rupture.

1.2 CISN Display

The California Integrated Seismic Network (CISN) also releases near real-time seismic data. Like USGS, there is a webpage component that frequently refreshes (although sometimes there is a delay between earthquake origin time and the time it is posted to CISN) to show the most recent earthquakes. The webpage can be accessed with the following link:

CISN webpage

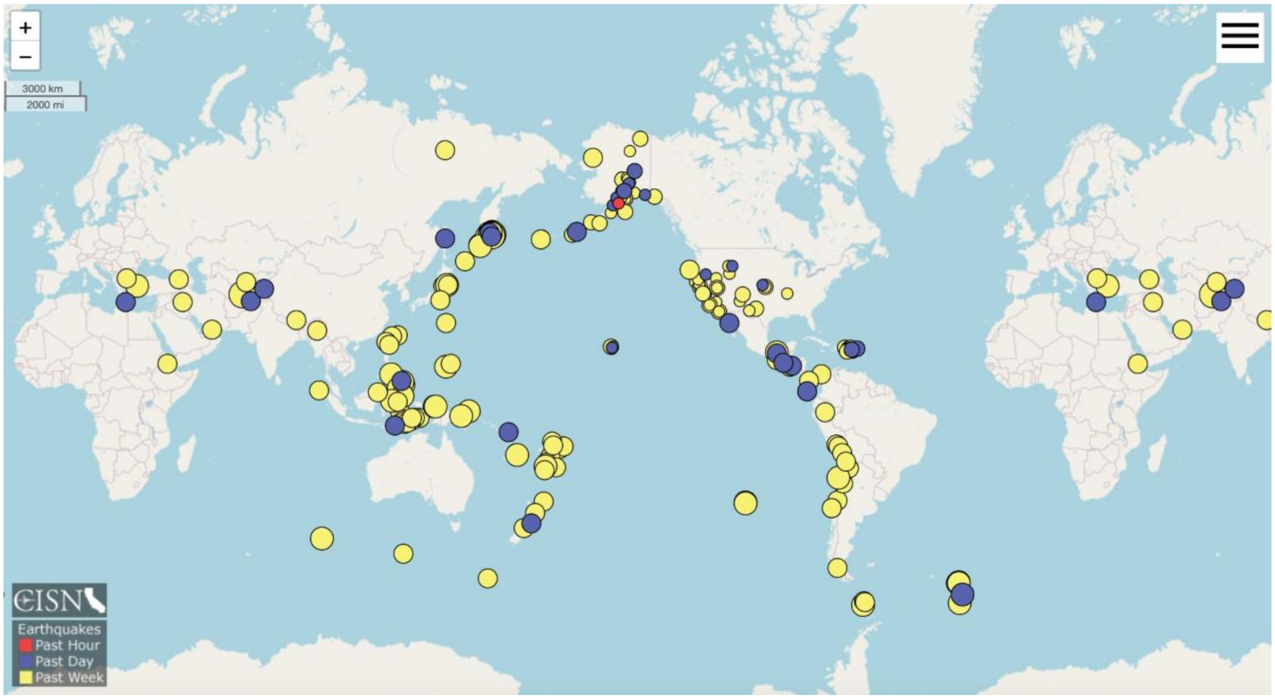


Figure 1.2.1: CISN recent earthquakes webpage with the colors denoting how recent the earthquake occurred and the size of the circle representing the earthquake's magnitude. (Credit: CISN, 2025)

CISN's map is also interactive and you can click on any one of the displayed earthquakes to learn more about it. CISN will give the magnitude, origin time, depth, and descriptive location of the earthquake. Clicking 'Earthquake Details' will open a new window that takes you to the USGS NEIC earthquake event page for the specified earthquake.

In addition to the webpage, CISN also has a desktop application that can be downloaded. When there's a new earthquake, the application can be set to give a visual and/or an audible alarm (instructions below). As shown in the figure below, the CISN application keeps a running display of the origin time and magnitude of previous earthquakes. The map displays recent earthquakes with the box's color denoting how long ago the earthquake occurred and its size corresponding to the earthquake's magnitude.

The CISN map in the application is also interactive and when you click on one of the earthquakes on the map, its information will be displayed on the banner on the bottom of the screen. The banner shows the basic earthquake parameters and also has direct links to the USGS NEIC event page, the USGS NEIC centroid moment tensor (CMT), and the USGS NEIC origin products.

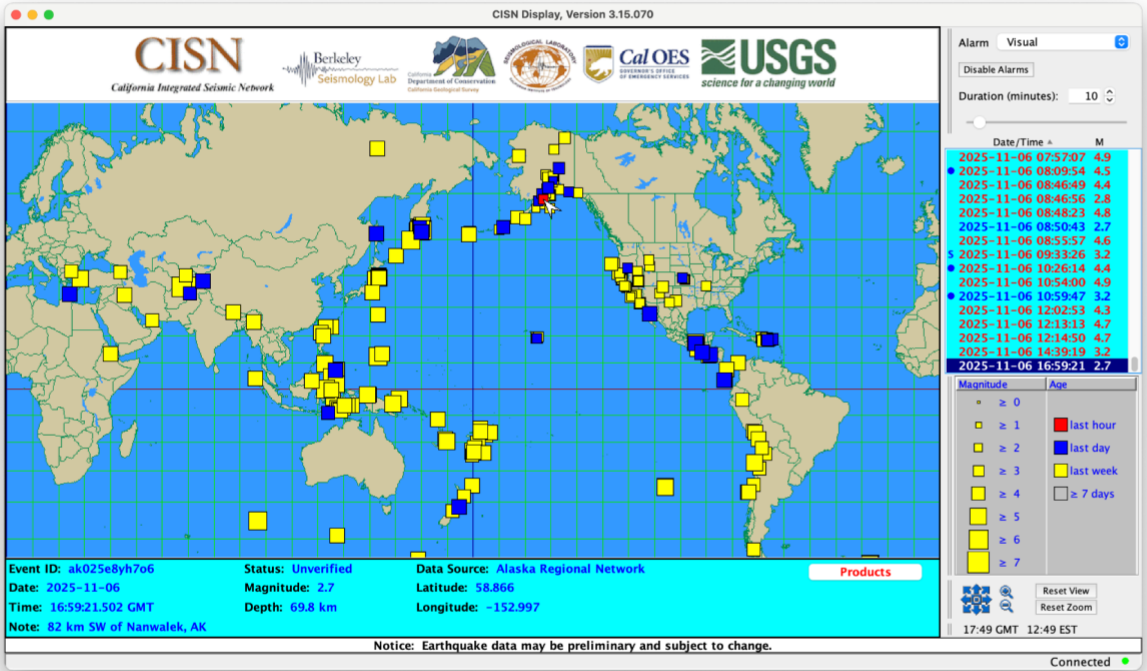


Figure 1.2.2: The CISN desktop application. (Credit: CISN, 2025)

The CISN application can be downloaded here:

[CISN application]

Within the application, there are settings that can be adjusted to your preferences. There are many different modifications you can make, but here we will mention a few of the most important ones. Once you have the CISN application downloaded, in your computer's menu bar at the top click on 'QWClient' and then choose 'Settings.' A new menu should pop-up with tabs at the top. The first tab is 'Alarm,' shown below.

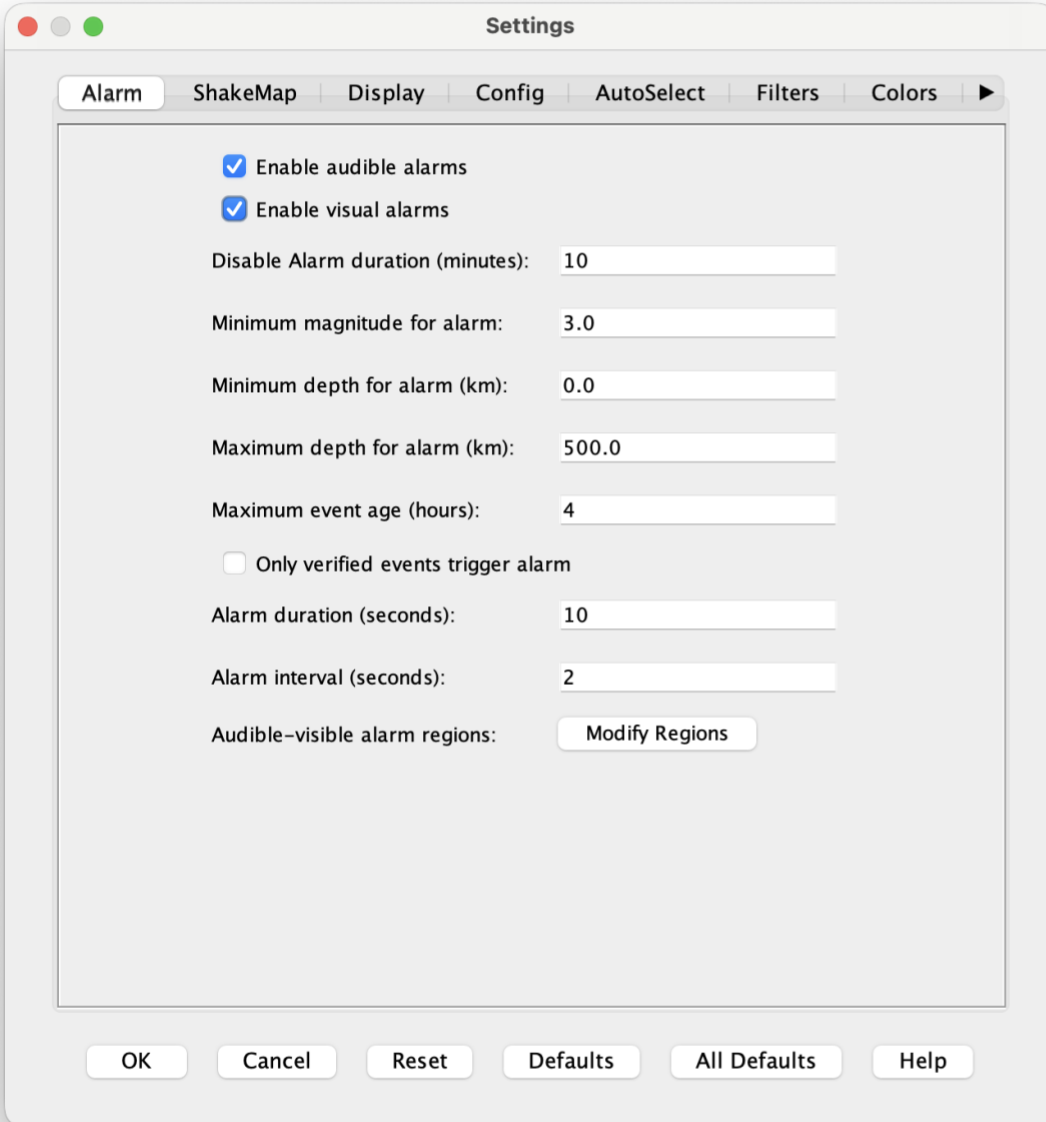


Figure 1.2.3: CISN's settings window showing the 'Alarm' tab. (Credit: CISN, 2026)

At the top of this window are two check boxes that allow you to enable audible and visual alarms. If you would like to enable these alarms, make sure the boxes are checked. The second line below the boxes allows you to choose the minimum earthquake magnitude that will trigger the alarms. Choose a magnitude that is sensible based on your center's criteria.

Under the 'Display' tab, the first option allows you to select the time zone that CISN will use. Ensure that the time zone selected is the time zone in which you wish to work (likely GMT or UTC).

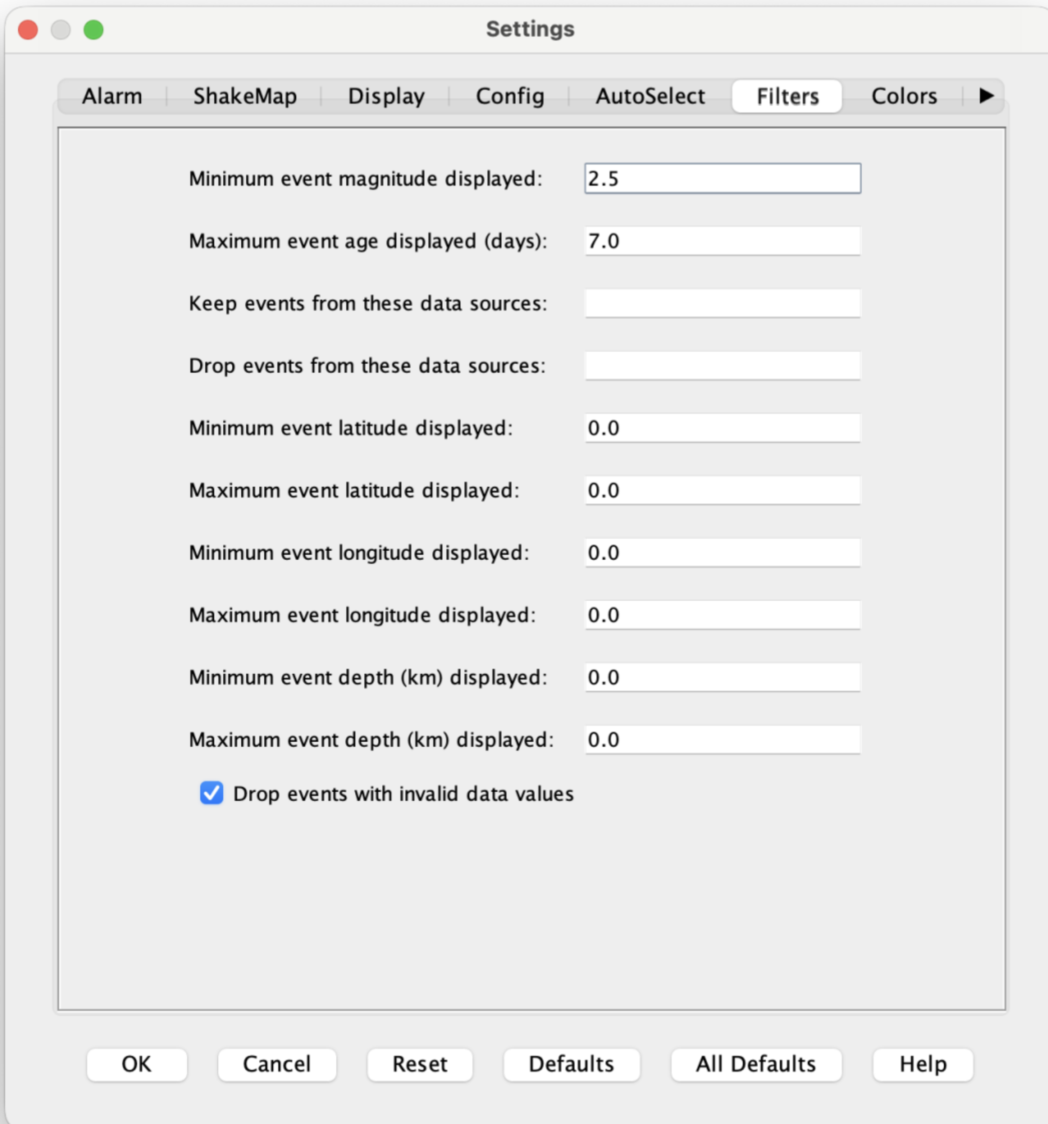


Figure 1.2.4: CISN's settings window showing the 'Filters' tab. (Credit: CISN, 2026)

Under the 'Filters' tab, the first two items should be adjusted to display the minimum magnitude and maximum age (how many days of data) that you would like to view on the map.

These parameters should be set mindfully, considering your center's use of CISN and also considering the minimum magnitude threshold you set for your alarm. You want to make sure that the minimum magnitude that will trigger your alarm is either the same or higher than the minimum magnitude that will be displayed on your map. For example, you don't want to be getting alarms for any earthquake M2.5 and above, but only have earthquakes M4.0 and above displayed on your map.

1.3 Google Earth

Google Earth can be used to visualize spatial earthquake data (and other spatial data). When downloaded, Google Earth can be used to view detailed satellite imagery of specific areas of the Earth while offline. To ensure that your area of interest will be stored in Google Earth's offline 2GB cache, you should zoom in and view a detailed image of your location while connected to the internet. Once a high-resolution image of your area of interest is saved to the 2GB cache it can later be accessed while offline.

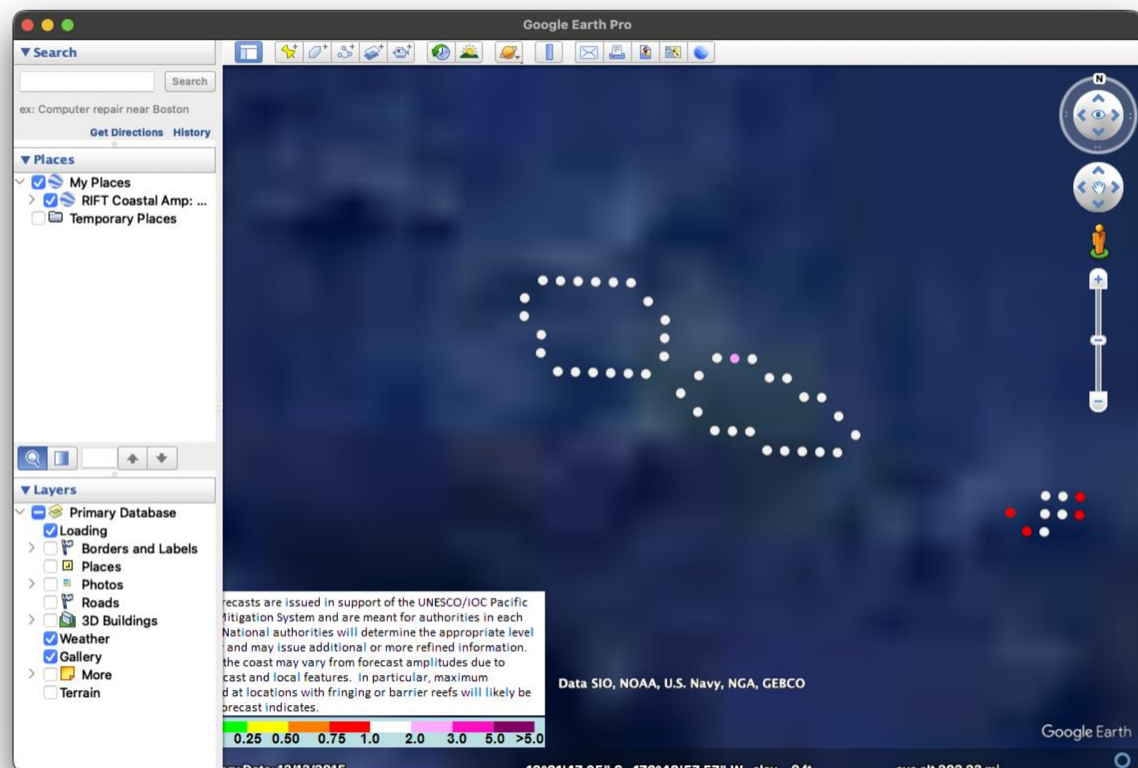


Figure 1.3.1: A Google Earth map of Samoa (with coastal forecast points from a .kmz file from PTWC) that has not been cached to Google Earth's 2GB memory and therefore appears pixelated when viewed offline. (Credit: Google Earth, PTWC, 2026)

Above, a map of Samoa (with some of PTWC's coastal forecast points) is shown. The map appears quite pixelated because a high resolution version was not accessed when the user was connected to the internet.

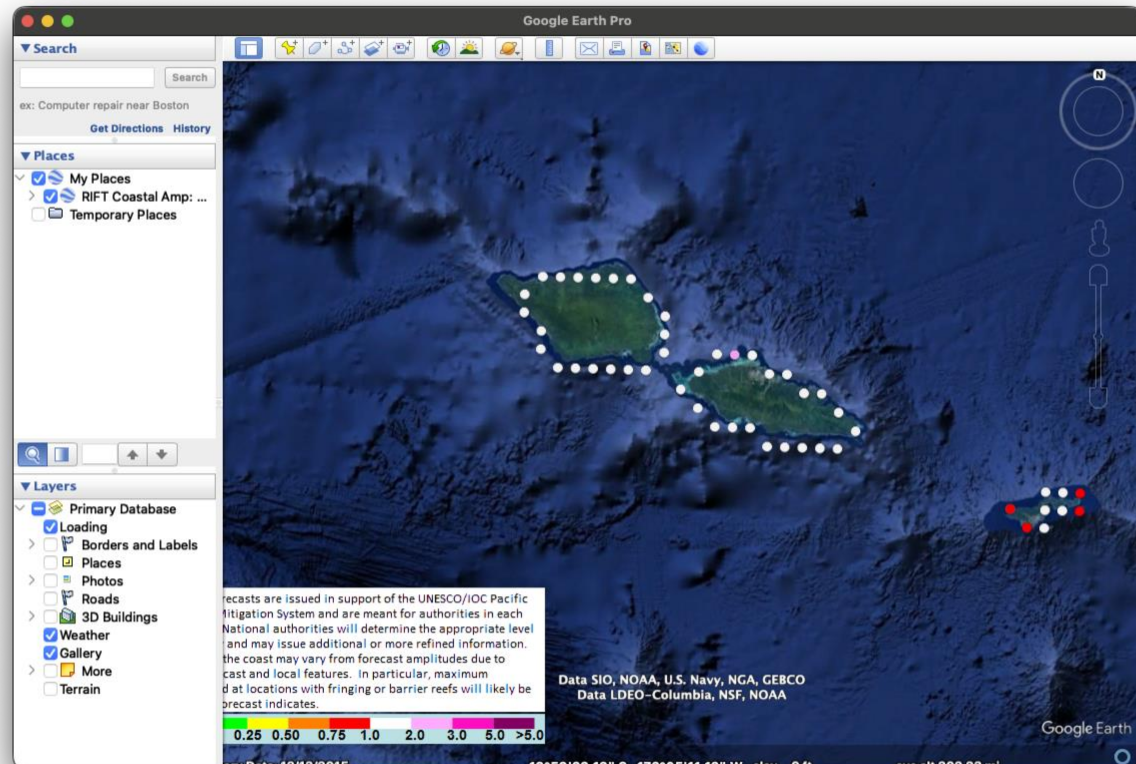


Figure 1.3.2: A Google Earth map of Samoa (with coastal forecast points from a .kmz file from PTWC) that has been cached and fully loaded so that more details are visible. (Credit: Google Earth, PTWC, 2026)

Once the high resolution images have been loaded for a specific area, the map is usable offline for that area. Shown above is a higher resolution version of the first map once it has been fully loaded.

Spatial earthquake data that can be plotted in Google Earth can be downloaded from the [USGS Earthquake Catalog](). Within the earthquake catalog you can filter for which earthquakes you would like to view based on origin time, magnitude, and geographical location. After you fill in your desired parameters, click ‘search’ (shown below).

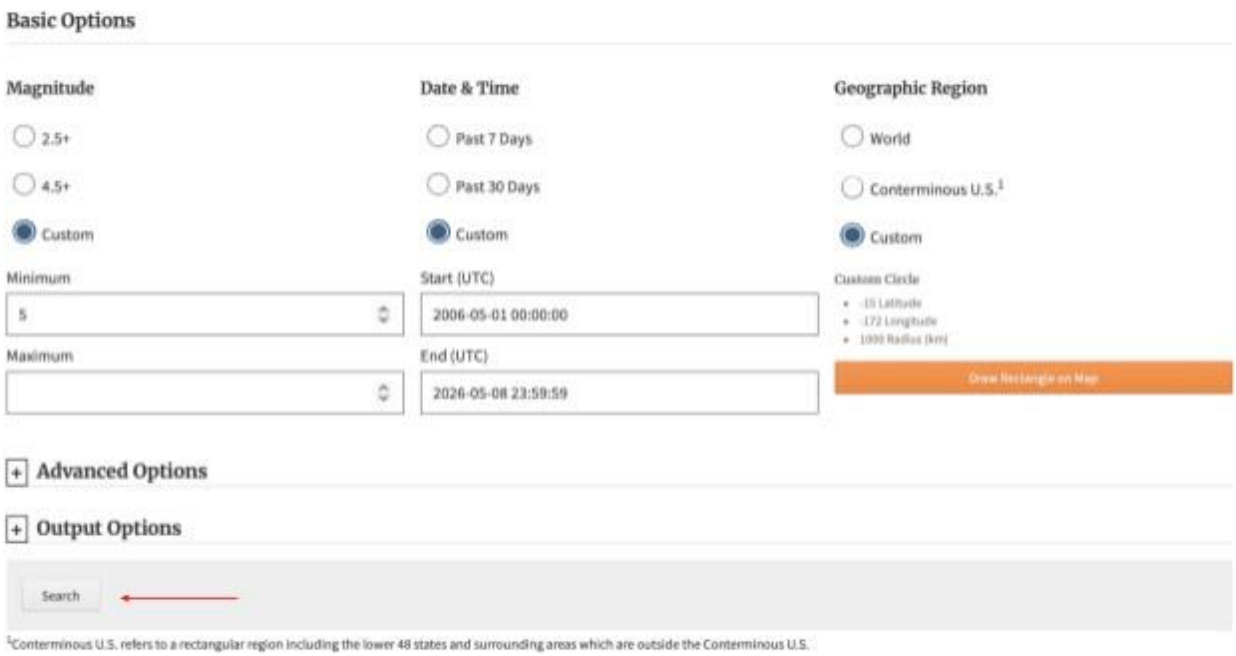


Figure 1.3.1: USGS’s Earthquake Catalog page with some parameters filled in and a red arrow pointing towards the search button. (Credit: USGS, 2026)

Once you click search you will be automatically redirected to a map displaying all of the results from your search. On the left side of the webpage if you scroll through all of the listed earthquakes all the way to the bottom there is a ‘download’ button. Clicking this button prompts a pop-up window asking you to choose in which format you would like to download your data. Choose any KML file to be able to load it into Google Earth.

After the file has been downloaded, you can click and drag it into Google Earth. The data should automatically appear.

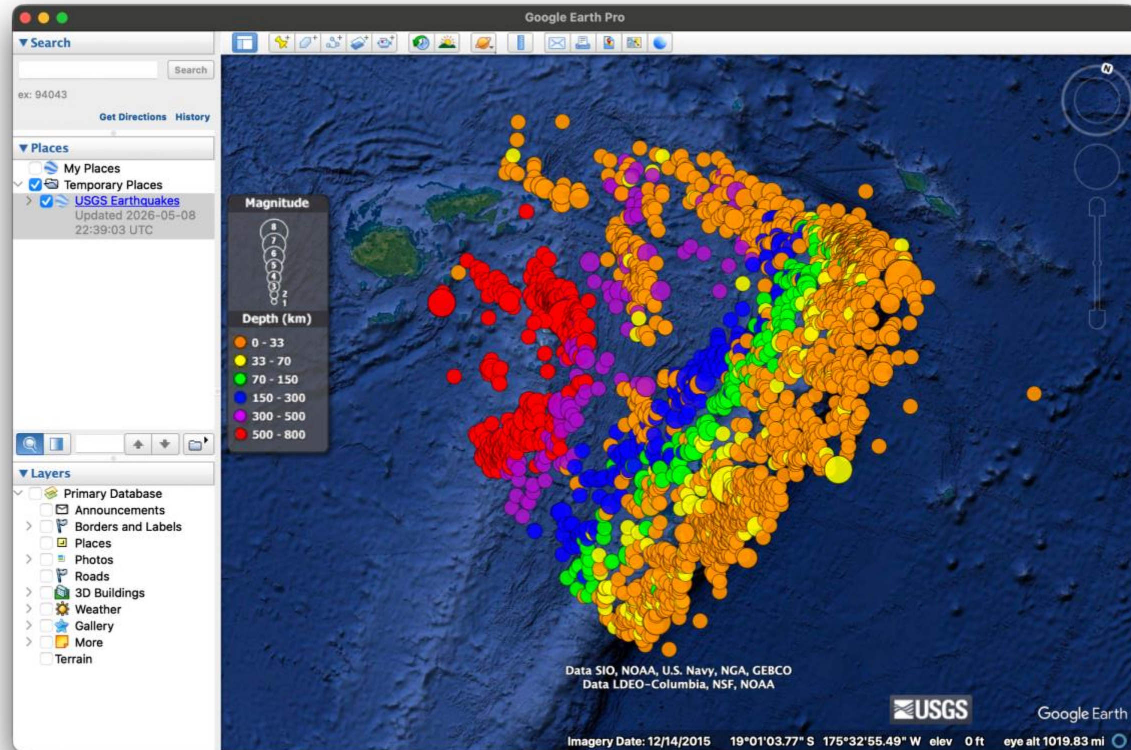


Figure 1.3.2: A Google Earth map showing historical earthquakes from May 1, 2006 to May 8, 2026 within a 1,000 km radius around -15º, -172º with a magnitude of 5 or greater. Each point is colored to represent the depth of the earthquake and sized according to its magnitude. (Credit: Google Earth, USGS, 2026)

Once the data are loaded into Google Earth you should be able to zoom in and out and mouse over each point to view its magnitude and approximate location.

Google Earth can also be used to plot coordinates on a map. To plot multiple points at once, click the 'Add Placemark' button to save the current location as a pin and then enter the coordinates of the next location (and repeat as many times as needed).

2 Calculating TTT (Tsunami Travel Time)

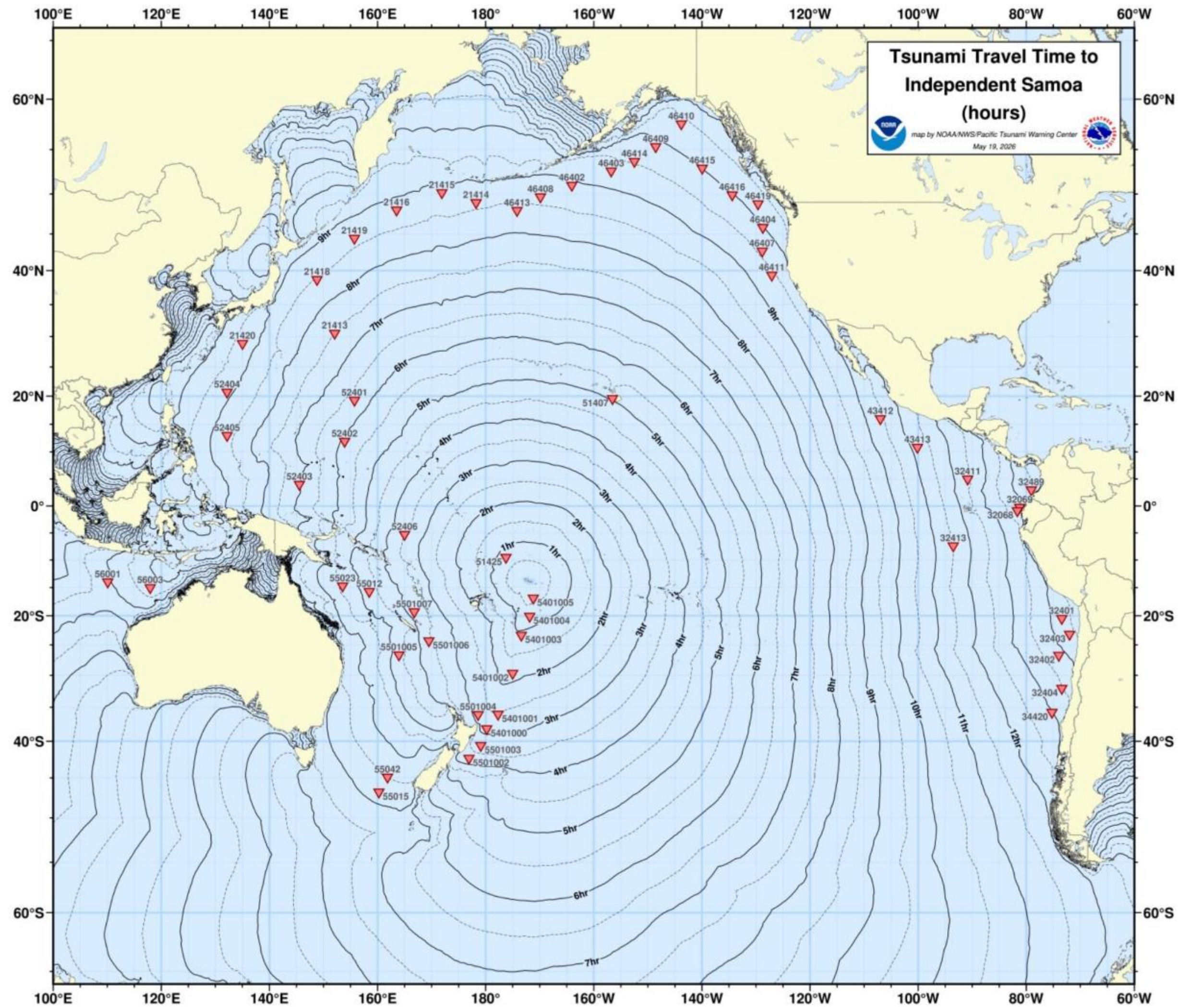


Figure 2.0.1: A Tsunami Travel Time (TTT) map showing the travel time to Samoa from around the Pacific Ocean. (Credit: NOAA/PTWC, 2026)

The above map shows a tsunami's travel time to Samoa from anywhere in the Pacific Ocean. Choosing the nearest contour line (or interpolating if possible) will give the time in hours that a tsunami generated at that location will take to reach Samoa.

2.1 Using TTT Software (Basic)

TTT can be directly downloaded from:

Download TTT

The TTT software is designed to work on Windows, but can be run on another system through a virtual machine. The download link includes detailed instructions on how to successfully install TTT.

Upon downloading and opening TTT, you are shown the following window with options for inputs:

1. **Manual Mode:** Restores baseline parameters to clean fields for manual coordination input.
2. **Get PTWC from Email (Auto Mode):** Direct integration with a configured Google Web App API. Clicking this button connects to an analytical script that scrapes the absolute latest operational threat message distributed by the Pacific Tsunami Warning Center (PTWC), automatically populating coordinates, geographic name headings, and time matrices.
3. **Custom File Mode:** Allows operators to choose a comma-delimited input data packet (.txt) exported from structural field assets to auto-populate coordinates and magnitudes instantly.

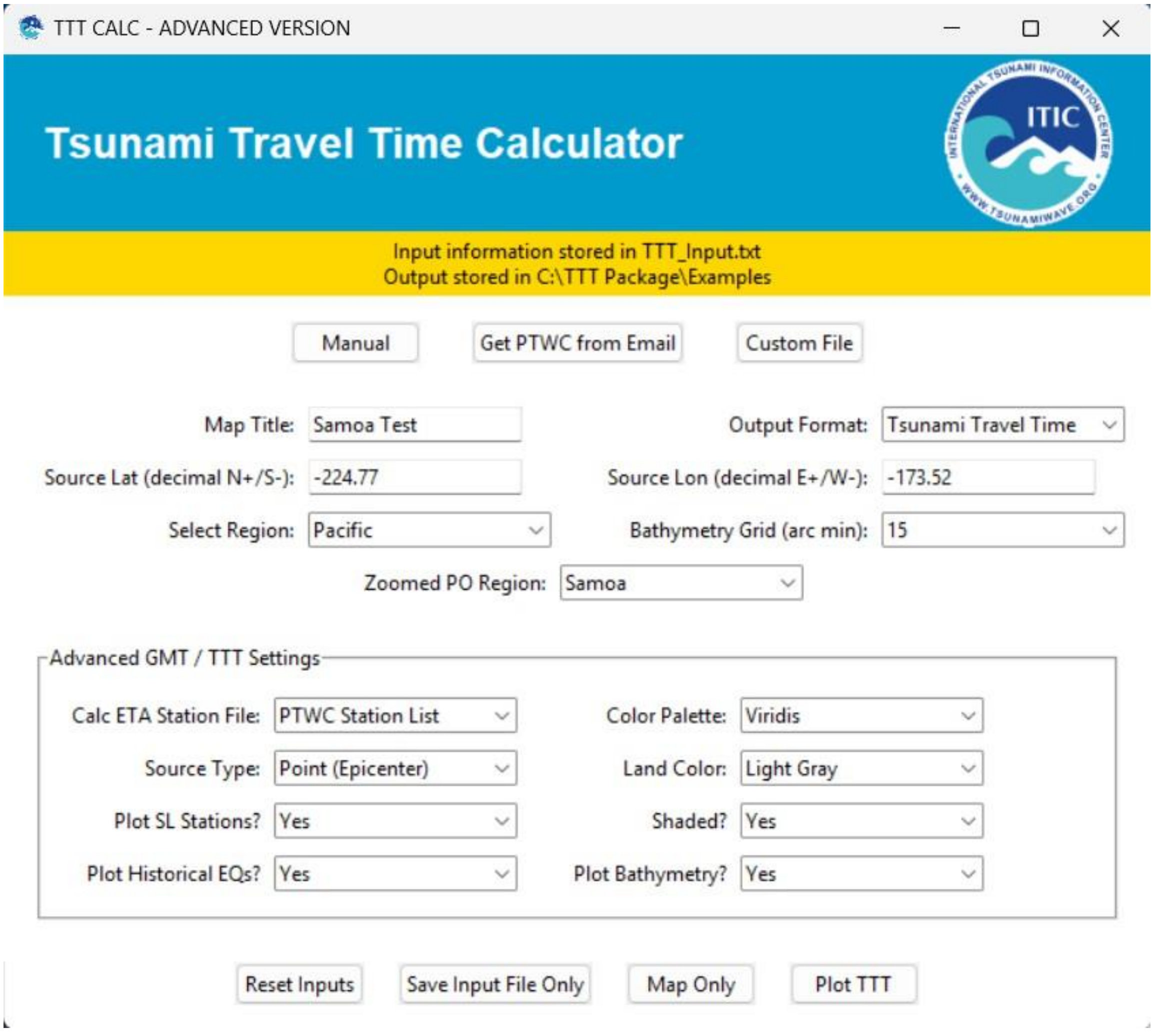


Figure 2.1.1: The TTT application GUI with all selections filled out. (Credit: ITIC, 2026)

To run a scenario in TTT, you must fill out the required primary inputs, configure any advanced visual or source settings, and choose your execution action. Before running the model, ensure the following core parameters are set:

- **Map Title:** Enter an alphanumeric identifier (under 50 characters) to name your output files.
- **Latitude & Longitude:** Enter the coordinates of the earthquake epicenter in formal decimal degrees.
- **Ocean Region:** Select the target basin (**Atlantic/Caribbean**, **Indian**, or **Pacific**). This selection automatically adjusts the regional map zoom.
- **Output Format:** Choose how you want to track the tsunami:
    - *Tsunami Travel Time:* Measures duration (hours/minutes) from the moment the event starts.

- *Tsunami Arrival Time:* Calculates the actual clock-time of arrival based on a specific event timestamp.
- **Bathymetry Grid Resolution:** Select a spacing option from the dropdown menu (ranging from 1 to 60 arc-minutes).
  - *Note:* Smaller grid spacing increases calculation accuracy but requires significantly more processing time.

Important Note on Magnitude: The basic TTT model requires the earthquake's latitude and longitude, but not its magnitude. While a higher magnitude increases the size and impact of a tsunami along the coast, it does not change the speed at which the waves travel. Because tsunami speed is determined by water depth rather than earthquake intensity, TTT relies on the epicenter coordinates to map travel times.

You can further customize your scenario and map visuals using the secondary control options:

- **Station File (Calc ETA):** Choose between the standard global verification network (stations.txt) or upload a custom user directory containing specific regional stations you want to track. This requires latitude, longitude, and station names.
- **Source Type:** Toggle how the tsunami trigger is shaped:
  - *Point Source (Epicenter):* Creates a traditional single-point origin.
  - *Line Source:* Creates a distributed configuration. You can manually enter the fault parameters or let the system dynamically scale the fault length based on the earthquake's magnitude. This is the only portion of the GUI that asks for magnitude and does not impact travel times.
- **Visual Properties:** Customize the map's appearance, including:
  - GMT color palettes (e.g., Rainbow, Jet, Hawaii, Viridis).
  - Land base colors (using Hex codes).
  - Bathymetric hillshade rendering.
  - Visibility toggles for sea-level stations and historical earthquake layers.

2.2 Advanced TTT Calculation

Instructions

1. Open ttt_calc64.exe, double click the TTT_CALC64 icon on desktop
2. Choose your ingestion protocol at the top of the interface:
   - **Manual:** Clear all inputs for manually typed values.
   - **Get PTWC from Email:** Query your operational Google Apps Script connection to automatically extract attributes from the latest warning message.

- ○ **Custom File:** Load predefined location arrays from structured external text files.

3. Verify that your Map Title contains fewer than 50 characters and check your coordinates (Latitude/Longitude) for accuracy.
4. Set your target **Bathymetry Grid**: Use **15-20 min grids** for fast calculations, or **1-2 min grids** for detailed post-event analysis.
5. Select your visualization settings in the **Advanced GMT Frame** (such as choosing your color palette, land color shading, and station visibility).
6. Execute your calculation by clicking **Plot TTT**.

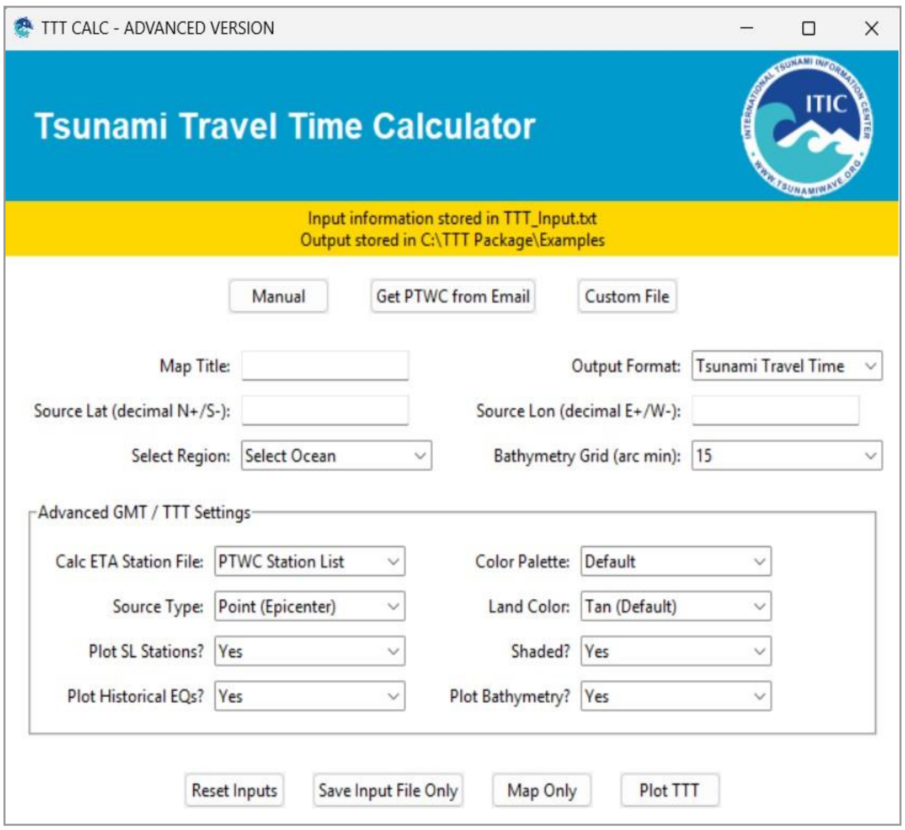


Figure 2.2.1: The TTT application GUI with the advanced settings options selected. (Credit: ITIC, 2026)

Outputs

The underlying script automatically handles file routing, generation, and formatting:

- **TTT_Input.txt:** Formatted parameters file written to C:\TTT Package\Examples\.
- **Binary Travel Grids:** Compiled calculation grids mapping wave travel velocities.
- **ETA Data Table:** Text-based output tracking specific calculated arrival times for chosen stations.

- **Proportional PNG Maps:** Up to three distinct map layouts mapping local, regional, and full-basin perspectives. These outputs are stored in your configured directory inside timestamped folders named TTT_AUTO_hrmnsec.

2.3 Interpreting TTT Products

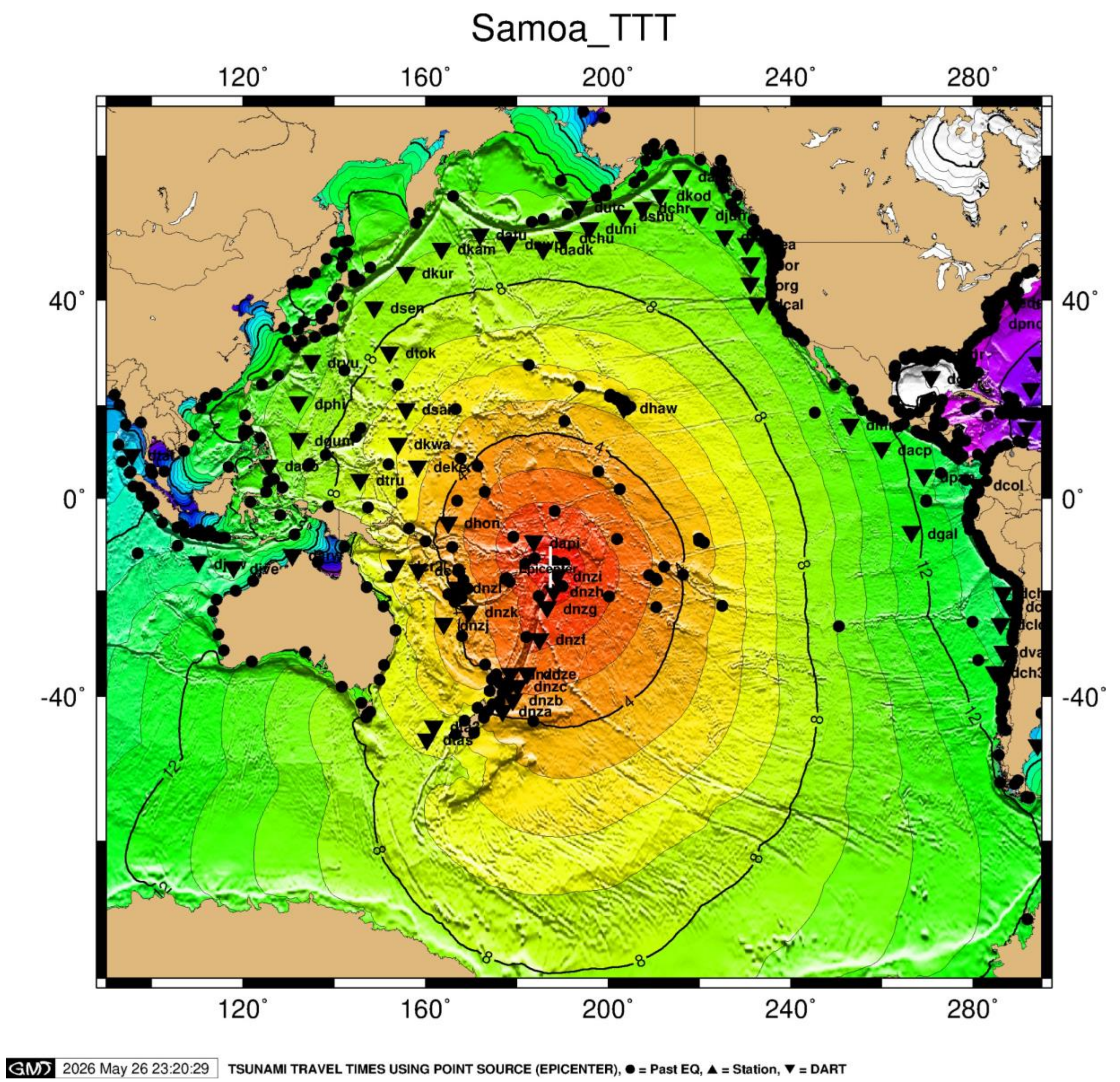


Figure 2.3.1: Pacific Ocean basin map generated by TTT for an earthquake near Samoa. Please note that the legend at the bottom of the map is incorrect and that the circles indicate sea level stations, not past earthquakes. (Credit: ITIC, 2026)

The above map is one of the maps generated by TTT. The colors on the map correspond to the contours, which show the tsunami's arrival time in hours from the origin time. The contour lines successively increase by one hour and are bolded and written out every four hours. The warmer colors indicate a sooner arrival time and the cooler colors indicate a later arrival time. As shown on the map, the darkest red area surrounding the epicenter indicates the area that will be impacted by the tsunami within one hour of the earthquake's origin time.

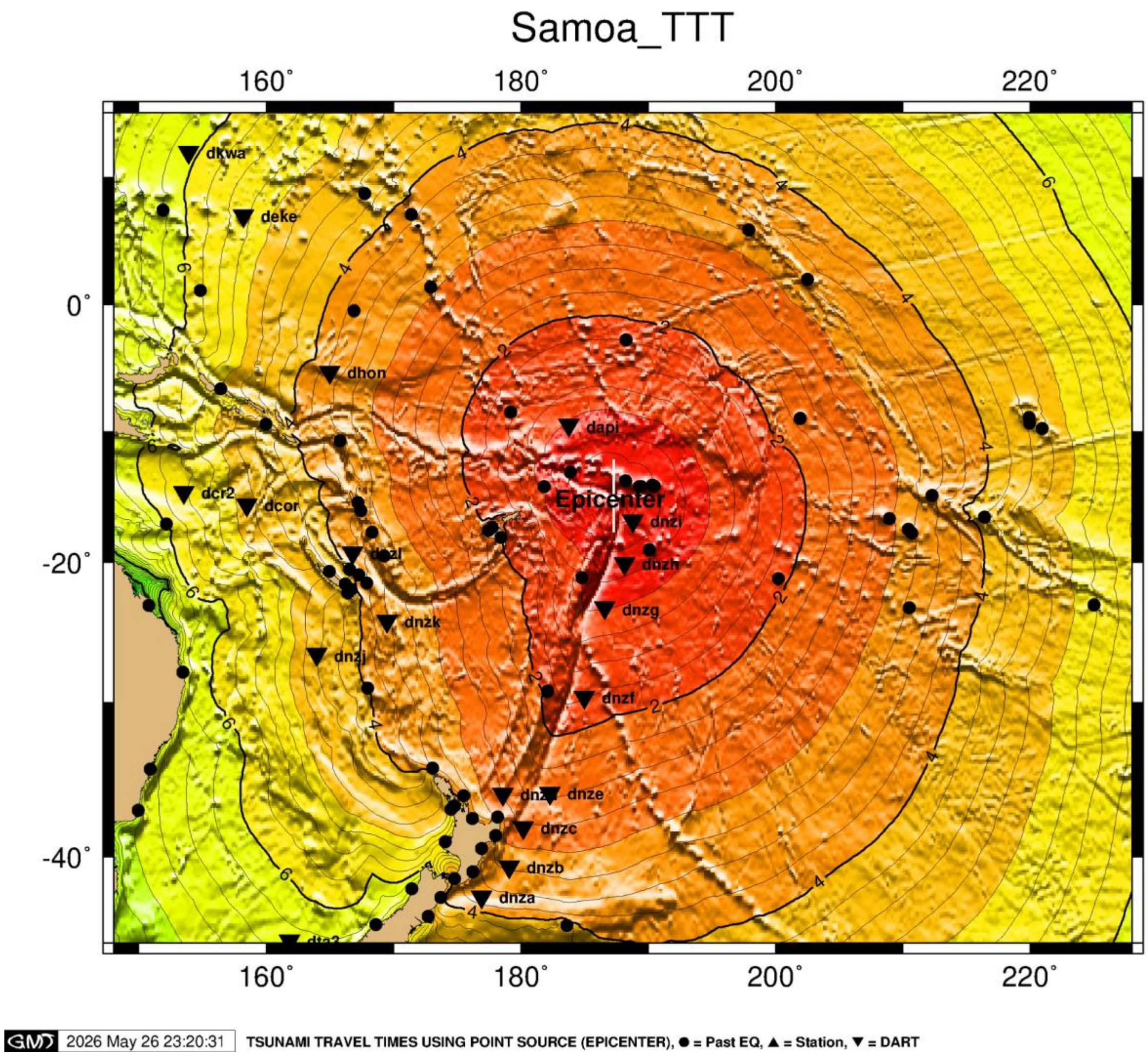


Figure 2.3.2: Southwest Pacific Ocean map generated by TTT for an earthquake near Samoa. Please note that the legend at the bottom of the map is incorrect and that the circles indicate sea level stations, not past earthquakes. (Credit: ITIC, 2026)

The above map was generated during the same run of TTT as the previous map, but this one shows a more zoomed-in view of the Southwest Pacific. This more detailed map includes thinner contour lines to indicate 15-minute intervals between the thicker hourly contour lines.

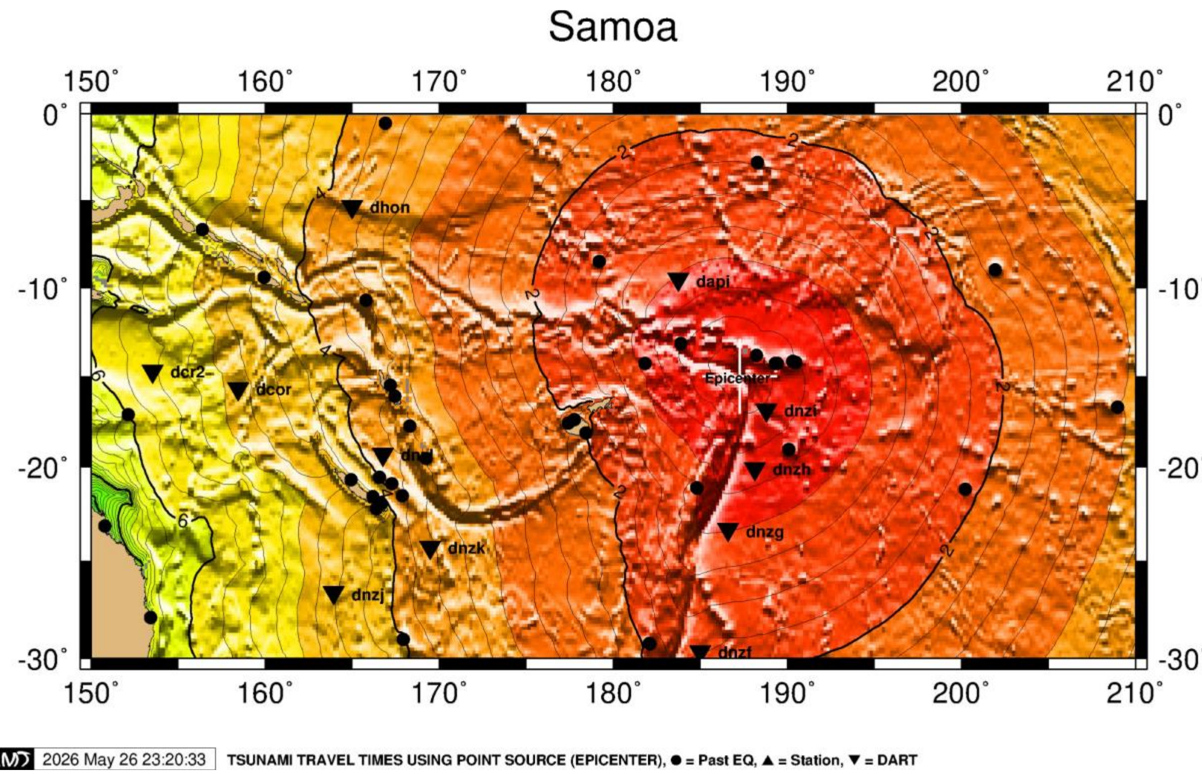


Figure 2.3.3: Southwest Pacific Ocean map generated by TTT for an earthquake near Samoa. Please note that the legend at the bottom of the map is incorrect and that the circles indicate sea level stations, not past earthquakes. (Credit: ITIC, 2026)

The third map generated for this same TTT run is shown above, which is an even more zoomed-in view of part of the Southwest Pacific. The locations of the maps produced when TTT is run will differ depending on which ocean basin and zoomed region are selected before TTT is run.

3 Sources of Real-Time Sea Level Data

3.1 Tide Tool

PTWC uses Tide Tool, an in-house-made program, to import and visualize sea level data. Sea level data is pushed directly to the Tide Tool application. PTWC monitors over 800 sea level gauges that are less expensive and easier to maintain than DARTs. Globally, there are over 1,000 sea level gauges monitored by the [IOC Sea Level Station Monitoring Facility](#).

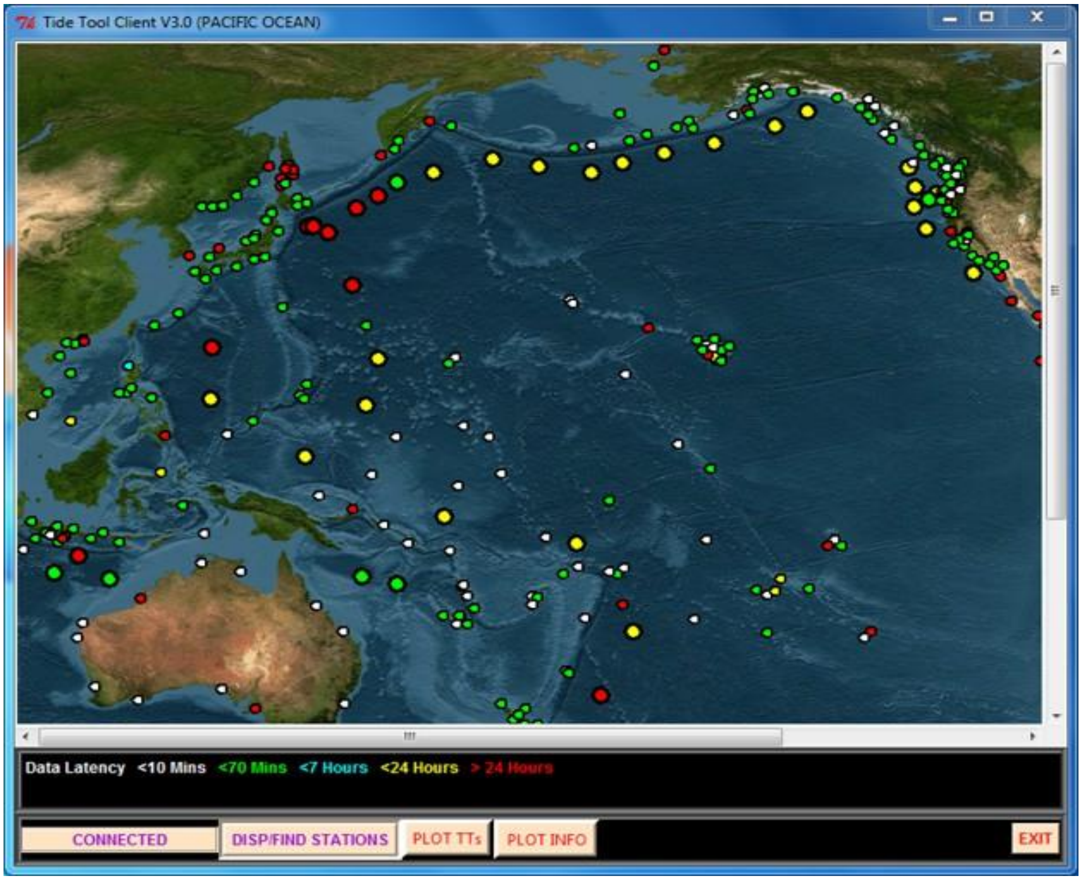


Figure 3.1.1: A map showing Tide Tool's Pacific client with the larger dots corresponding to DARTs and the smaller dots corresponding to coastal tide gauges. (Credit: NOAA/PTWC, 2024)

Tide Tool relies on the Global Telecommunications Service (GTS) to receive sea level data. The GTS consists of a network of surface and satellite telecommunications links that directly connects National Meteorological and Hydrological Services (NMHS) and is maintained by the World Meteorological Organization (WMO).

Figure 3.1.2: The Hiva Oa sea level station in French Polynesia. (Credit: NOAA/PTWC, 2024)

For Tide Tool to use data collected by coastal sea level stations, first the TWC must establish access to the GTS. If the TWC is not located within the national meteorological service, it should contact its NMHS to obtain access. Once a connection is established, the program uses a decoder to translate the sea level messages into usable data. Non-operational versions exist for data transmissions through the internet and for archived data.

Figure 3.1.3: Examples of different formats of GTS sea level data. (Credit: NOAA/PTWC, 2024)

Because Tide Tool receives the data in a number of different formats (as shown above), the decoder is essential in converting the data into a usable format. Tide Tool continuously decodes the data in real time.

Tide Tool has three main components:

1. A data retriever called get_data that acquires data from NOAA and the IOC webservice.
2. A decoder that reads log files of GTS sea level messages and a sea level station metadata base.
3. Dynamic map-based clients that allow the user to select a single station or group of stations to display and analyze.

Tide Tool has a different map-based client for each ocean or sea of interest. Upon double clicking on a buoy whose data you want to view, a drop down menu appears showing all the different sensor options available for that buoy, as shown below.

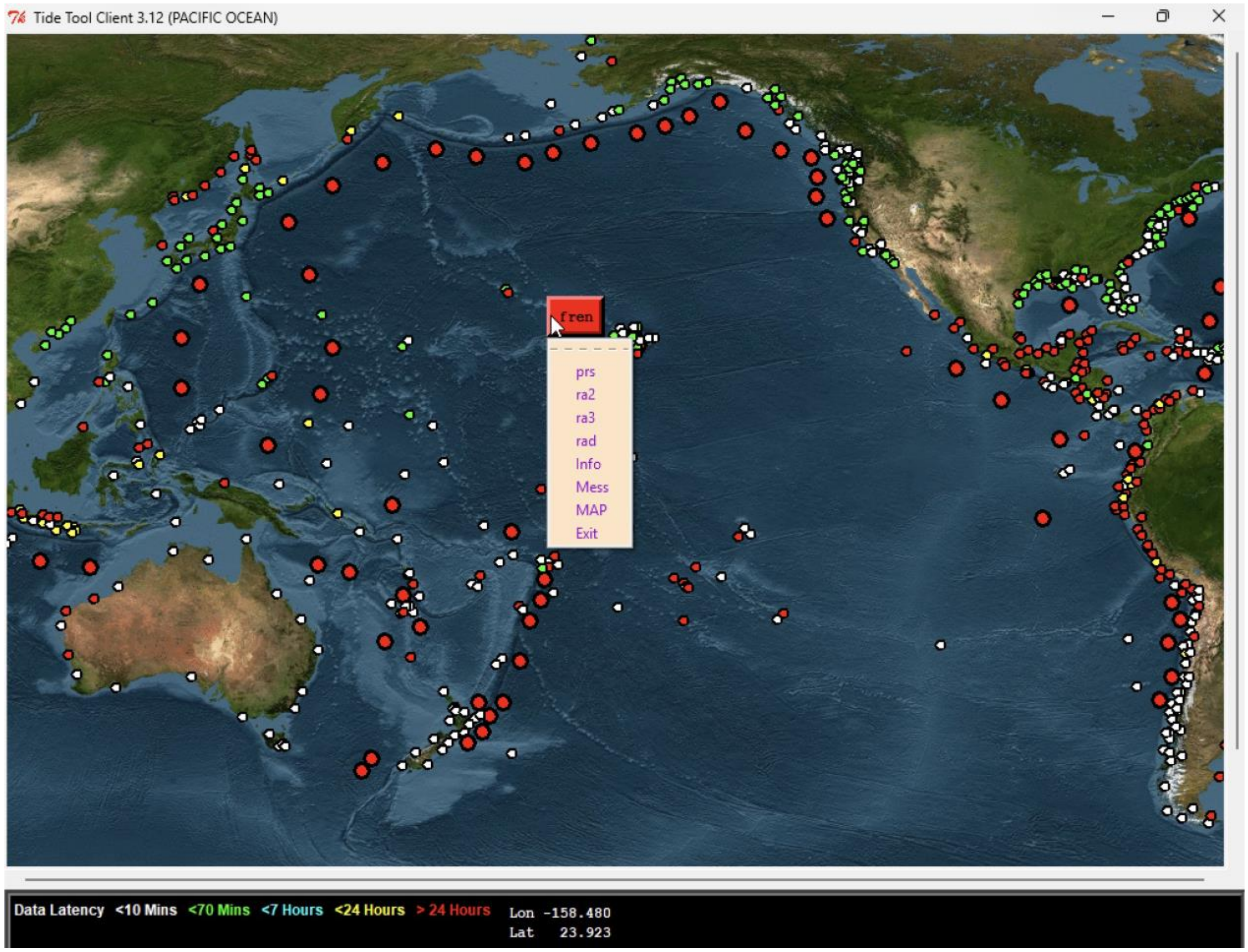


Figure 3.1.4: Tide Tool's Pacific Ocean client showing the different potential sensors for the buoy in the French Frigate Shoals. (Credit: NOAA/PTWC, 2026)

For an area of interest, the marigrams of specific stations can be individually selected and displayed or collectively selected and displayed in a strip chart. During a tsunami event, the estimated arrival time of the tsunami is shown on each marigram as a vertical magenta line as shown below. Scientists use the magenta line as an indicator of when they should expect to see the tsunami appear on the marigram.

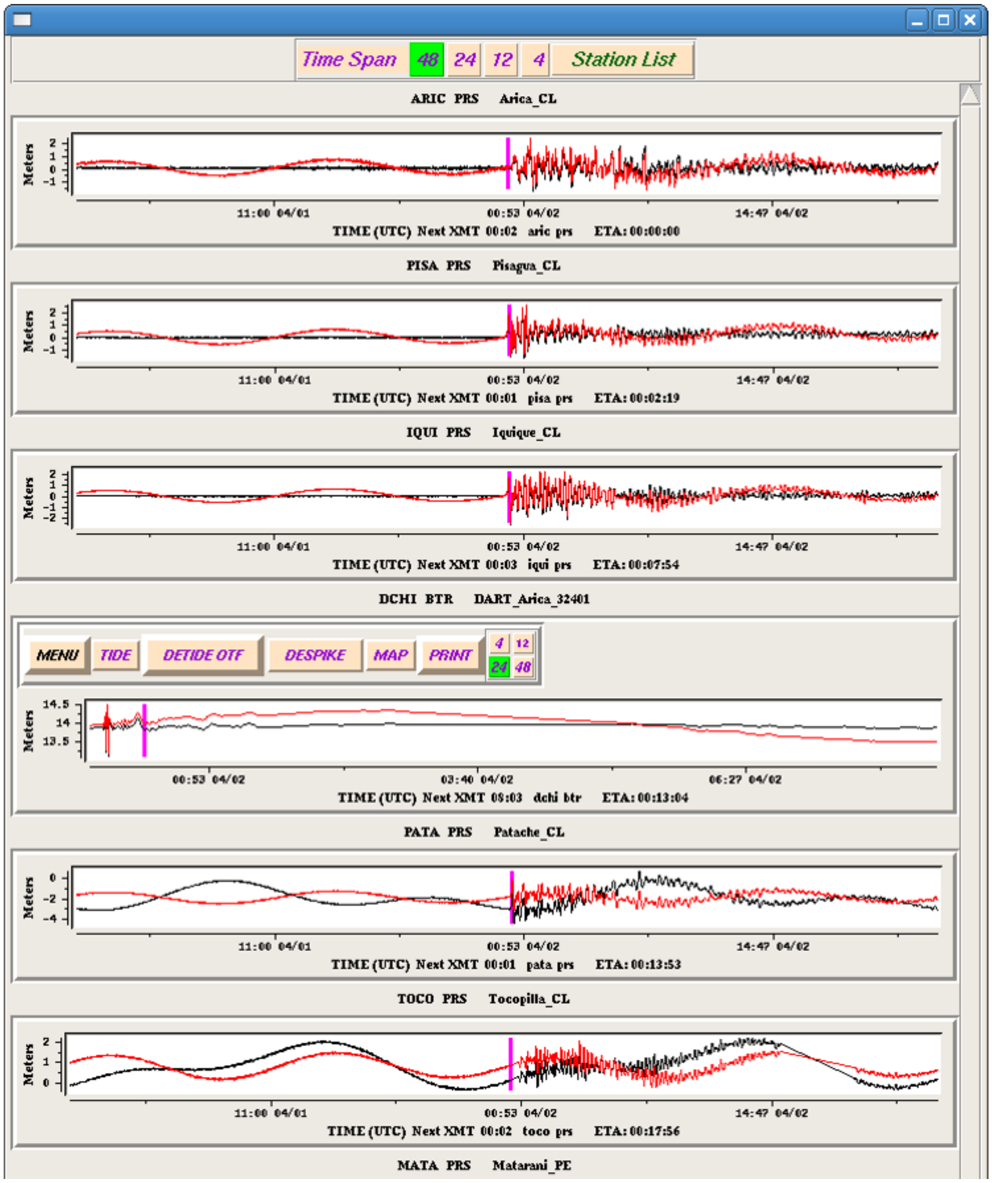


Figure 3.1.5: A strip chart from Tide Tool showing marigrams from multiple stations with the expected tsunami arrival time shown as a magenta line. (Credit: NOAA/PTWC, 2024)

Tide Tool's marigrams are updated in real time to show the most recent measurements, which makes Tide Tool a useful tool for monitoring a tsunami's progression and severity. Selecting one station, the tsunami's wave height or amplitude can be measured as shown below.

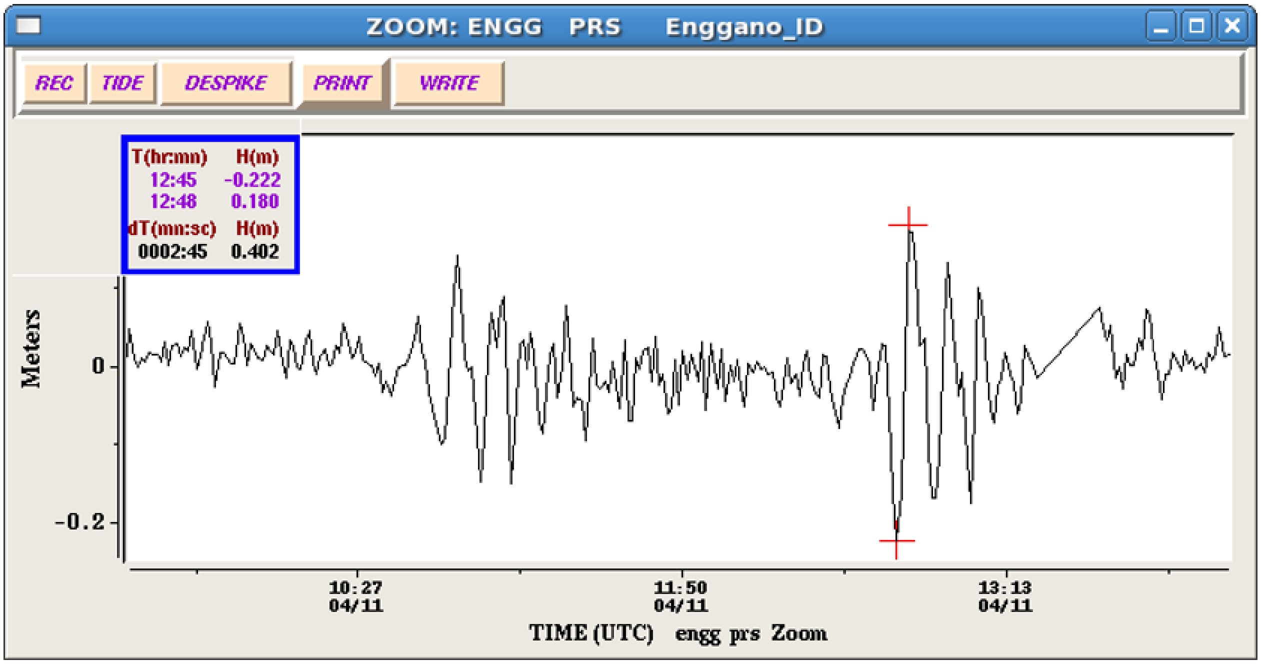


Figure 3.1.6: A marigram of a tsunami in Enggano, Indonesia showing a trough to peak measurement of one of the waves. (Credit: NOAA/PTWC, 2024)

From the figure above, we can see that the trough to peak measurement ranges from -0.222 meters to 0.180 meters, which gives an amplitude of 0.201 meters or around 20 centimeters.

3.2 National Data Buoy Center

The National Data Buoy Center (NDBC) is a website that provides real-time tidal data. The data on the NDBC website must be pulled in by the user who is accessing the website, as opposed to Tide Tool, which pushes data directly to the application.

NDBC provides buoy data that can be accessed at:

NDBC

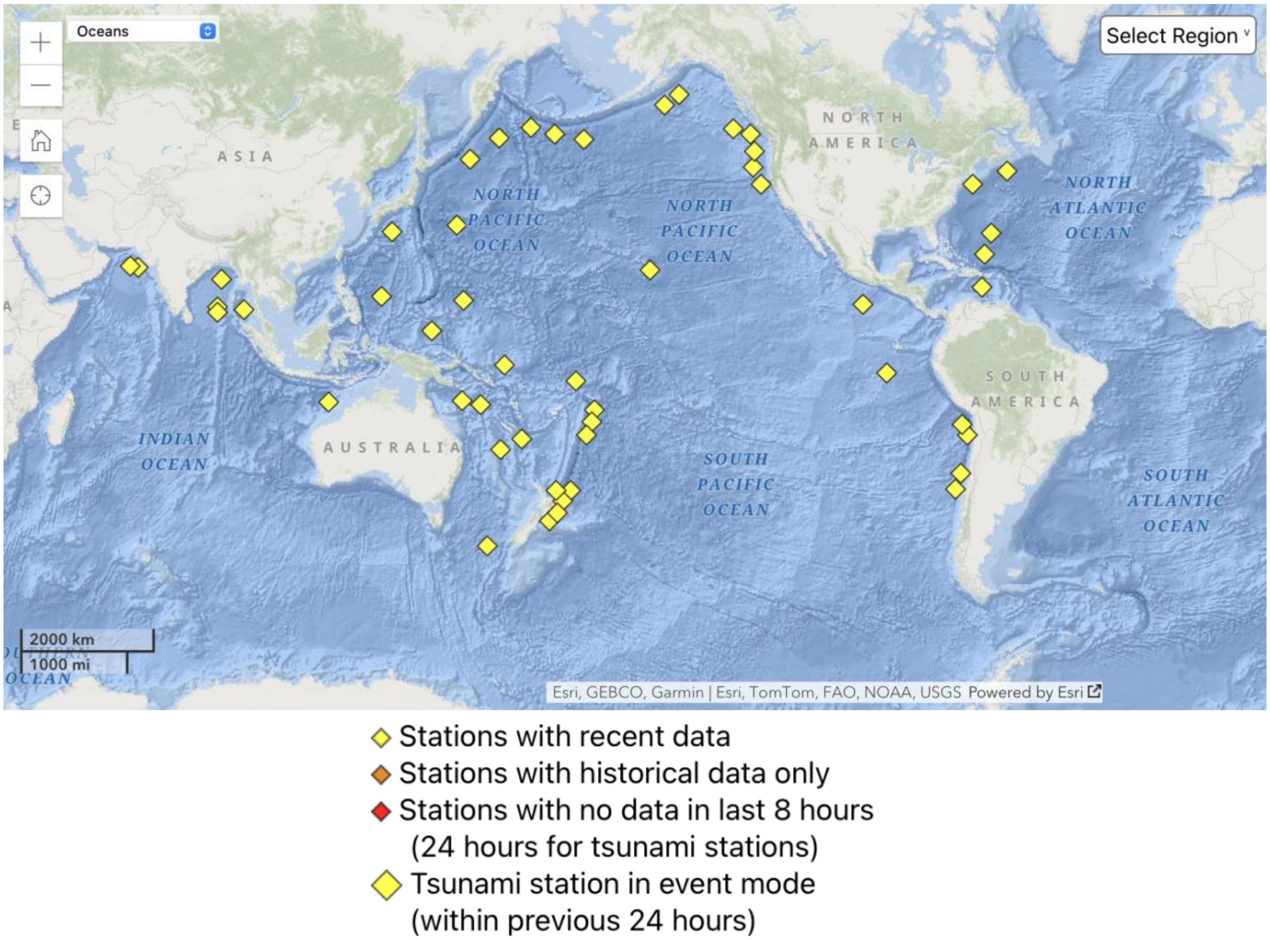


Figure 3.2.1: Interactive map showing buoys within the tsunami program filter and legend. (Credit: NOAA/NWS/NDBC, 2026)

NDBC provides an interactive map, which is shown above. Filters can be applied to the map to view buoys based on the program the buoy is a part of or which organization owns it. To view only buoys that are part of the tsunami program (as shown above), check the 'Tsunami' box on the top left from the 'Program Filter' menu. After checking this box, clicking on a specific buoy allows you to see its most recent water column height. For example, below is NDBC's water column height plot for the offshore Niue Tonga buoy.

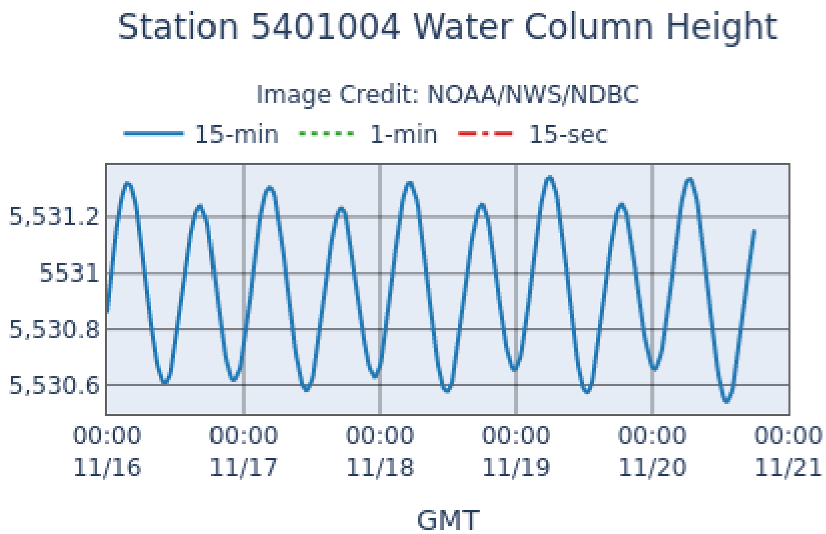


Figure 3.2.2: Water height column plot from the offshore Niue Tonga buoy. (Credit: NOAA/NWS/NDBC, 2025)

While the marigram from a NDBC buoy is updated regularly, the plot itself is static. The timescale can be adjusted by changing the date range, but the plot remains static and measurements cannot be made like they can be in Tide Tool. There is an option to toggle a switch to automatically refresh the page (and plot) every 10 minutes, but during a tsunami event updates more frequently than every 10 minutes would be more helpful.

3.3 IOC Sea Level Monitoring

Another resource to monitor real-time sea level data is through the IOC Sea Level Monitoring website, which can be accessed at:

IOC Sea Level Monitoring Facility

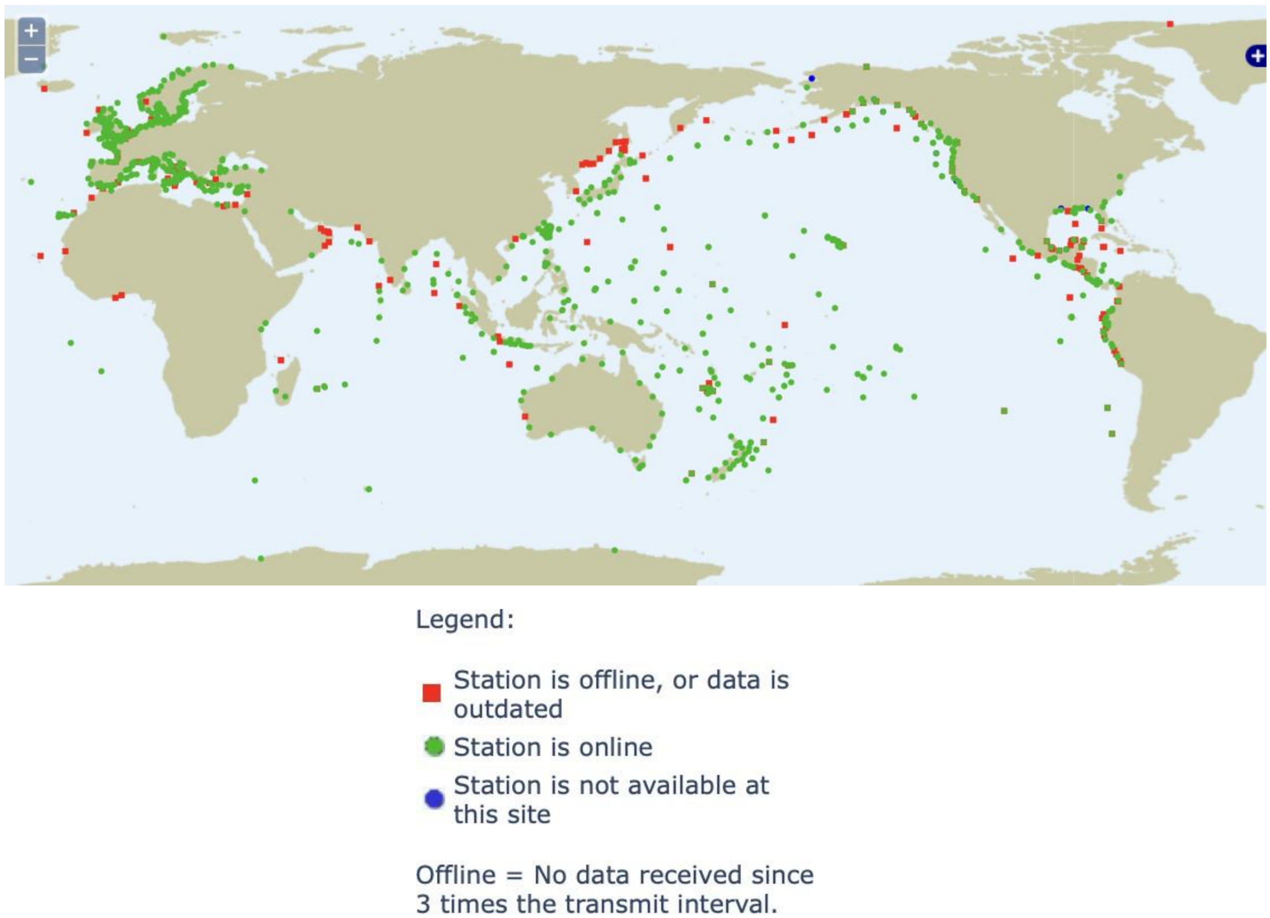


Figure 3.3.1: Interactive map and legend of IOC Sea Level Monitoring website showing status of global buoys. (Credit: IOC Sea Level Monitoring, 2025)

As shown above, the IOC Sea Level Monitoring website provides an interactive map view showing sea level stations around the world. Clicking on one station brings up its most recent data in a new window. For example, clicking on the Hale'iwa Harbor station opens a window with the following plot:

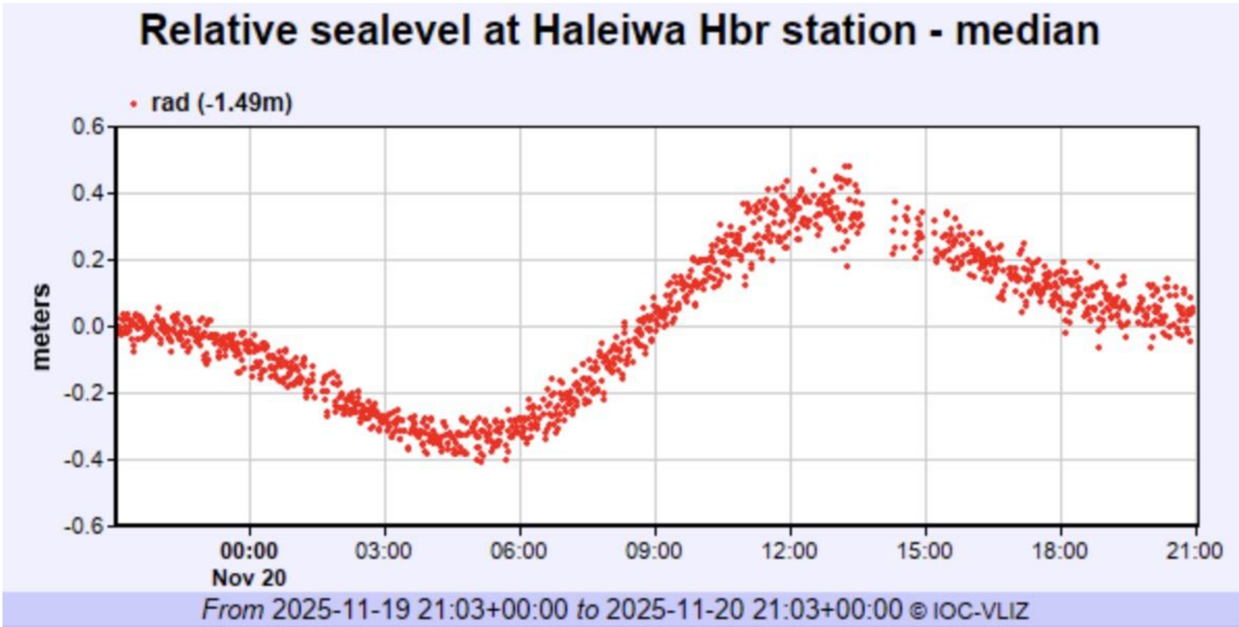


Figure 3.3.2: Relative sea level at Hale'iwa Harbor buoy shown over a 24-hour period. (Credit: IOC Sea Level Station, 2025)

The timescale can be adjusted to show the last 12 hours, 24 hours, 7 days, or 30 days. When monitoring for tsunamis, more constrained timescales (like 12 hours or even 24 hours) are more useful for identifying deviations from the expected wave height.

3.4 NOS Tsunami Capable Tide Stations

The US National Ocean Service (NOS) has a public website that shows real tidal data from their tsunami capable tide stations:

NOS Tides and Currents

The NOS website functions similarly to the NDBC and IOC websites. The interactive map and legend is shown below.

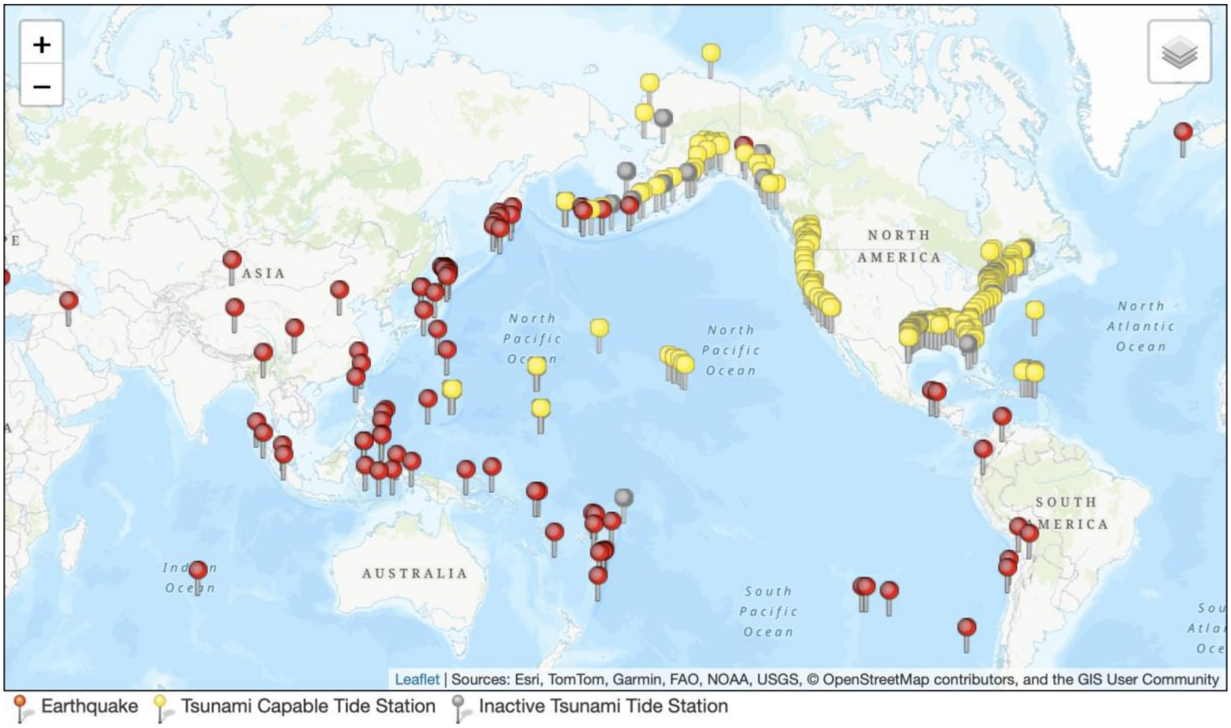


Figure 3.4.1: Interactive map showing NOS tsunami capable tide stations. (Credit: NOS, 2025)

One feature that NOS's website has that NDBC and the IOC Sea Level Monitoring websites don't is pins showing the locations of the most recent earthquakes, shown above in red. While the NOS map shows earthquakes around the globe, the functioning tide stations are only located in the US and its territories because the website is run and maintained by the US's National Ocean Service.

Similarly to NDBC and the IOC Sea Level Monitoring websites, each station can be clicked on to view the most recently collected and reported data. Clicking on Hawai'i's Hilo station prompts a pop-up window that displays Hilo's most recent tide data along with residuals and predictions, as shown below.

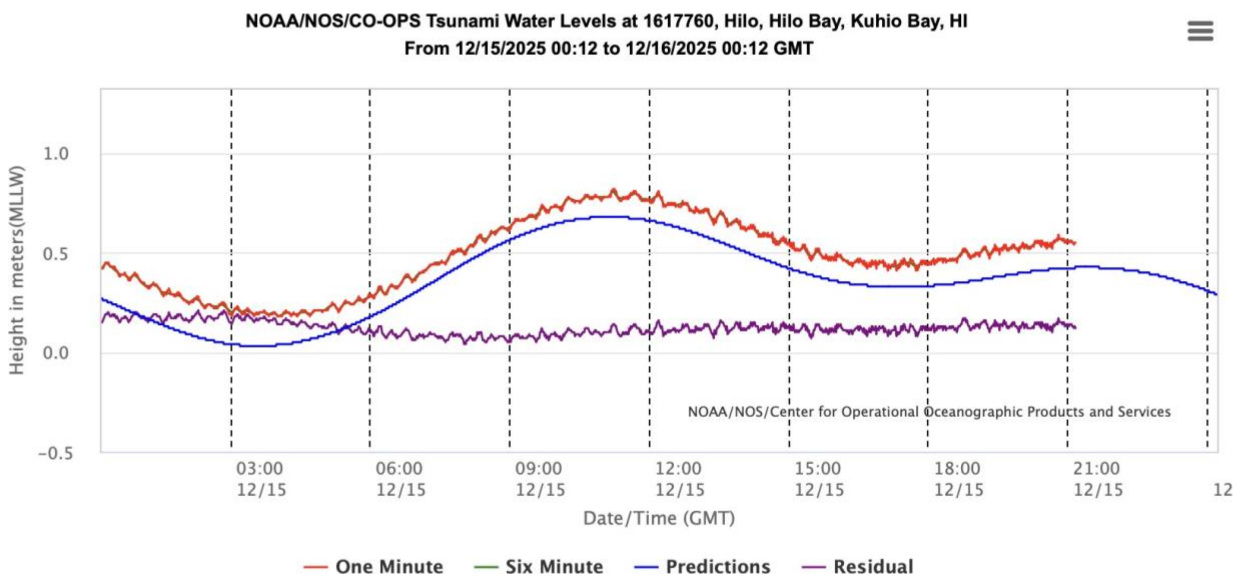


Figure 3.4.2: Most recent data, residuals, and predictions from NOS Hilo tide station. (Credit: NOS, 2025)

3.5 Pacific Ocean Portal

Another resource to check regional tidal data is the Pacific Ocean Portal, which can be used to display real time tide data near Australia, New Zealand, and around the South Pacific. The Pacific Ocean Portal can be accessed with the following link:

Pacific Ocean Portal

Similarly to the previously discussed tidal data websites, the data on the Pacific Ocean Portal website is displayed using an interactive map, shown below.

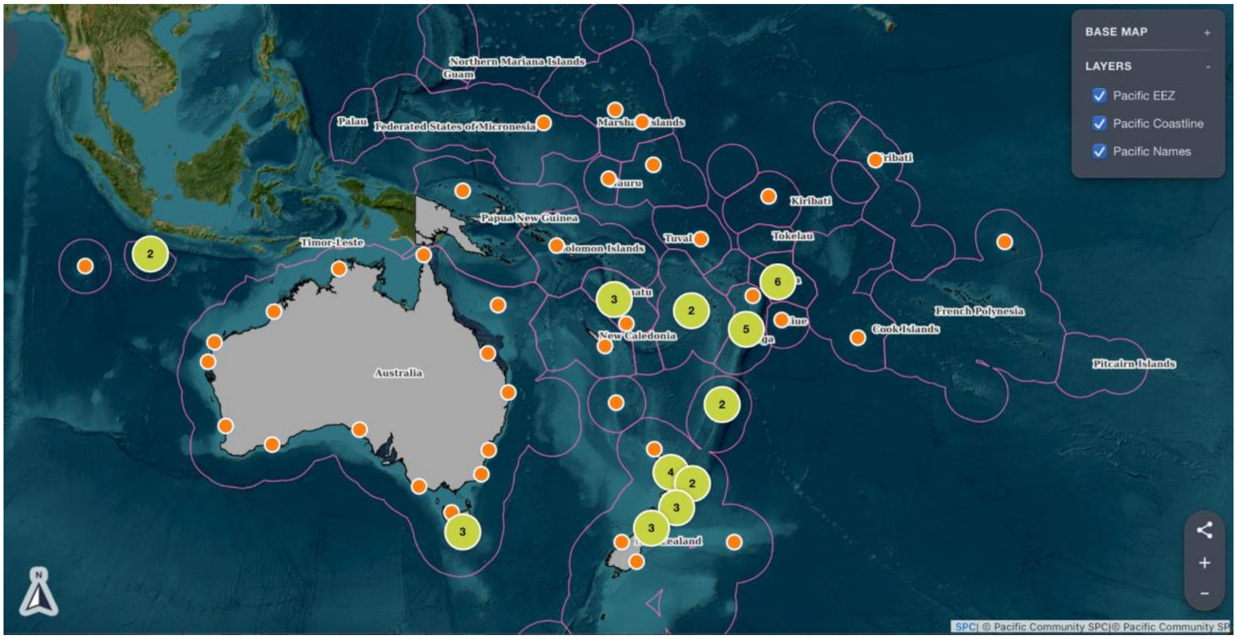


Figure 3.5.1: Interactive map from the Pacific Ocean Portal showing tide gauges, DART buoys, and wavebuoys. (Credit: Pacific Ocean Portal, 2025)

On the Pacific Ocean Portal website, the user can choose which data layers they want to add to the map. The map shown above is displaying the tide gauges, DART buoys, and wavebuoys along with the Pacific EEZs, Pacific coastlines, and names of Pacific countries (as shown in the top right corner of the map). While the current focus is tidal data, the Pacific Ocean Portal has many other types of data that can be added to the map including chlorophyll, coral bleaching, surface pH, surface phytoplankton, surface salinity, and more.

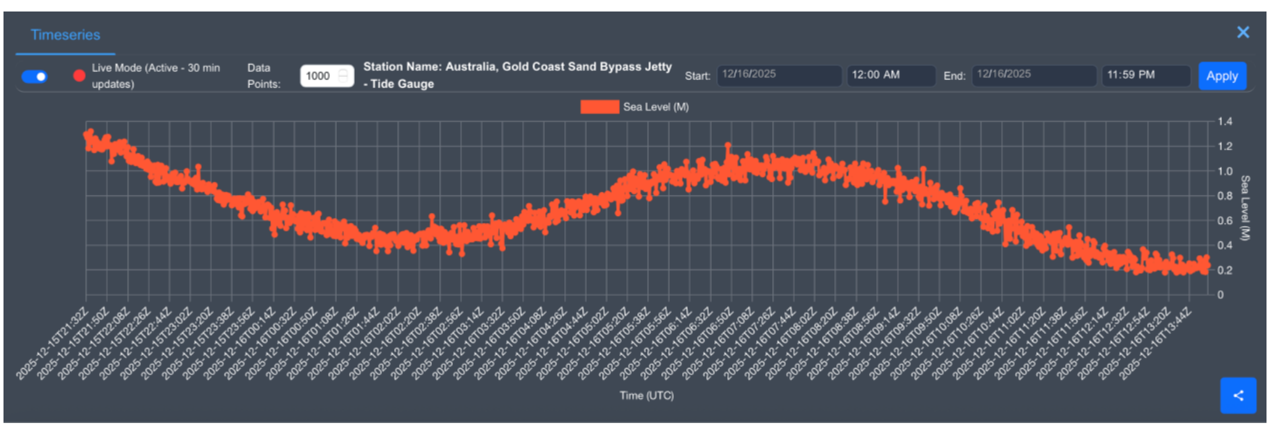


Figure 3.5.1: Tidal data from Australia's Gold Coast Sand Bypass Jetty tidal gauge. (Credit: Pacific Ocean Portal, 2025)

If one of the buoys is clicked on a pop-up showing the most recent data for that buoy will appear. Shown above is the most recent data for Australia's Gold Coast Sand Bypass Jetty tidal gauge. Each individual data point can be moused over and the sea level and date and time of data collection for that point will be shown. The top left corner of the pop-up window shows a switch that can be toggled on to activate 'Live Mode,' which will continuously automatically refresh the plot with the most recent data from that buoy. Live data updates are helpful when monitoring a tsunami in real time.

4 Using Sea Level Data to Confirm and Monitor Tsunamis

4.1 Tide Tool

The source of sea level data that is best to use for confirming the existence of a tsunami and monitoring its propagation is Tide Tool. The other sea level data sources that were mentioned in the previous section all pull data from the source, whereas sea level data is automatically pushed to the Tide Tool application. Additionally, Tide Tool can use an earthquake's location to predict the tsunami arrival time, which is helpful when looking at a marigram to confirm the existence of a tsunami. When using Tide Tool, a vertical magenta line will appear on the marigram to indicate the expected arrival time of the tsunami as shown below.

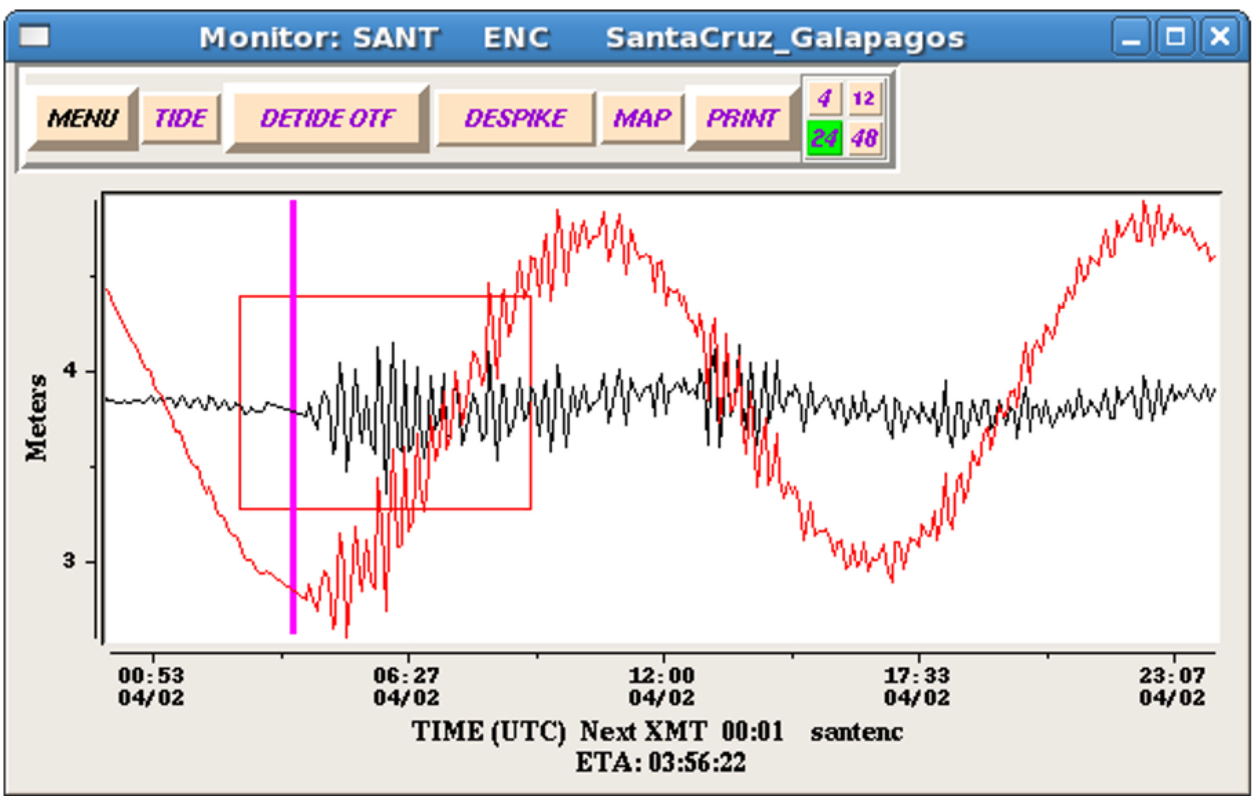


Figure 4.1.1: A marigram with raw and de-tided data as well as the tsunami arrival prediction time from Tide Tool from Santa Cruz, Galápagos. (Credit: NOAA/PTWC, 2024)

In the above plot the red line is the raw tidal data and the black line has been de-tided, which makes anomalies (like a tsunami) easier to detect. A tsunami will appear on a marigram as a sudden increase or decrease in wave height beyond the expected change in tide. As shown above, the wave height of an incoming tsunami may gradually increase and the first arriving wave may not be the largest. When monitoring tsunamis and sending out warnings, it is important to remember that the first wave may not be the largest.

4.2 Other Sea Level Data Sources

Similarly to Tide Tool, the other real-time sea level data sources also give marigrams to present their sea level data. Regardless of the data source, a tsunami's signal will appear similarly on a marigram. When using a source other than Tide Tool, there may not be an indication of the tsunami's expected arrival time. The marigram should be continuously monitored for deviations from the expected tidal variations.

When tracking a large, destructive tsunami that may cross ocean basins, its progress can be followed by viewing the data from different buoys as the tsunami moves. Tracking a tsunami as it propagates across an ocean can indicate how fast the tsunami is moving (you can confirm your expected ETAs are correct) and at what rate its energy is dissipating. The wave heights in the marigrams of buoys close to where the tsunami was generated can indicate how quickly the tsunami is losing energy.

5 Pre-Calculated Tsunami Forecast Modeling

While PTWC most heavily relies on RIFT, which performs real-time calculations, other centers use pre-calculated models to forecast tsunamis. For a given tsunami event from a seismic source the pre-calculated model and the model using real-time calculations will likely return different results. The model doing calculations in real-time needs to make some approximations to be able to do the calculations fast enough to use the model in real-time.

5.1 MOST Model Parameters (Used to generate multiple propagation databases)

The MOST (Method Of Splitting Tsunamis) model is a numerical simulation model created by PMEL (Pacific Marine Environmental Laboratory) of NOAA. The MOST model passes through three distinct stages when it is run:

1. Deformation phase: generates the initial conditions for a tsunami by simulating ocean floor changes due to a seismic event.
2. Propagation phase: propagates the generated tsunami across deep ocean using Nonlinear Shallow Water (NSW) wave equations.
3. Inundation phase: simulates the shallow ocean behavior of a tsunami by extending the NSW calculations using a multi-grid "run-up" algorithm to predict coastal flooding and inundation.

To properly run the MOST model the following input parameters are needed:

- Minimum amplitude of input offshore wave (m)
- Minimum depth of offshore (m)
- Dry land depth of inundation (m)
- Friction coefficient (n**2)
- Let A-grid and B-grid runup
- Max eta before blow-up (m)
- Total number of time steps in run
- Time steps between A-grid computations
- Time steps between B-grid computations
- Time steps between output steps
- Time steps before saving first output step
- Save output every n-th grid point

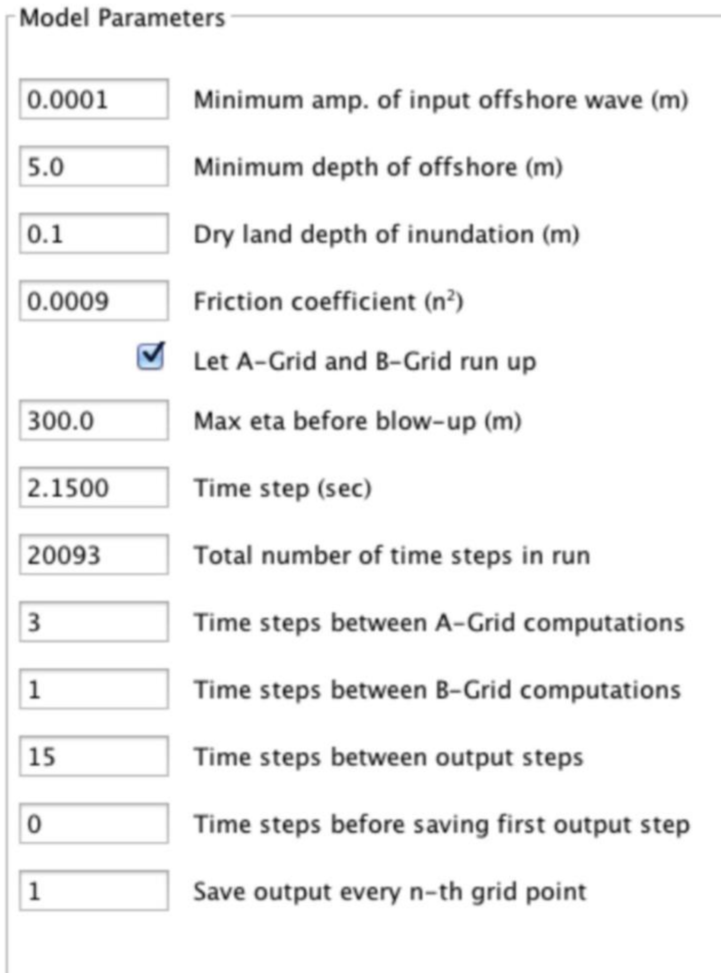


Figure 5.1.1: Interface showing the inputs for the MOST model. (Credit: NOAA)

5.2 NOAA Propagation Database (Used in SIFT and TsuCAT)

NOAA has created its own pre-computed tsunami database that is used in the SIFT (Short-term Inundation Forecasting for Tsunamis) model and in TsuCAT, an intuitive program that allows the user to rapidly model a tsunami and assess its impacts. The database consists of deep-water wave elevations and flow velocities that are pre-computed for 50 x 100 km unit sources along all known subduction zones in each ocean basin and are used to create the offshore wave amplitude database. At least two rows of unit sources are placed along the trenches, one shallower and one deeper.

The MOST model is used to generate the majority of the database. For earthquake magnitudes less than Mw 8.0 where the 50 x 100 km unit source size is too large, RIFT is used to model the offshore wave amplitudes rather than MOST. When RIFT is used, the same epicenter location that would have been used in the MOST model is used, but smaller length, width, and slip parameters are substituted to more accurately represent the earthquake. The earthquake is approximated to be a shallow thrust fault earthquake. The database sources can be linearly combined to produce synthetic boundary and initial conditions of water elevation and flow velocities to initiate tsunami forecast computations. The propagation database's accuracy has been assessed and validated by comparing its runs of 17 different tsunamis with data from the real tsunami event.

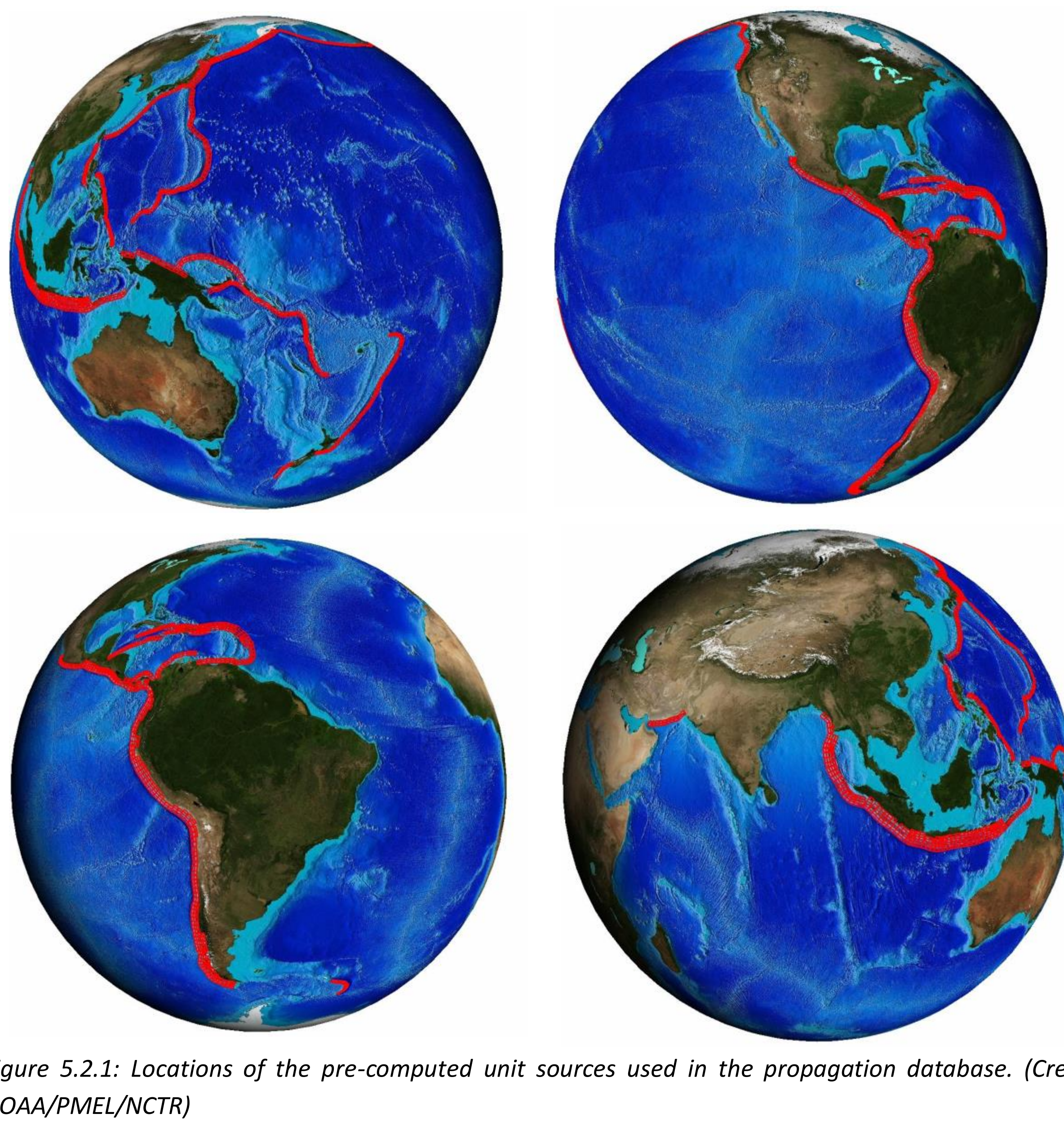


Figure 5.2.1: Locations of the pre-computed unit sources used in the propagation database. (Credit: NOAA/PMEL/NCTR)

The model is first run with preliminary earthquake parameters and later updated once the parameters are more refined. Better earthquake parameters help to create a better tsunami forecast. Once the tsunami waves reach a DART buoy, the DART inversion is performed to adjust the slip distribution of the unit sources or add more unit sources as necessary.

5.3 ComMIT

ComMIT, or Community Model Interface for Tsunamis, is an interface that uses NOAA's MOST model. It was created after a recommendation from the Intergovernmental Coordination Group (ICG) for the IOTWMS in response to the December 2004 Sumatra-Andaman earthquake and tsunami. The goal in creating this model was to provide global access to tsunami models and allow for the exchange of modeling expertise, hazard assessment, mitigation, and tsunami forecasting capabilities between Indian Ocean countries. While useful operationally, ComMIT also allows the user to develop evacuation maps beforehand, which increases preparedness.

ComMIT's initial conditions come from a precomputed propagation database. In general, the inputs that tsunami models require are: seafloor and coastal topography, initial and boundary conditions, and run-specific model information (time-step, spatial resolution, run length, etc.). ComMIT users can select the inputs for the model run and display graphical results. ComMIT is designed to have an intuitive graphical interface and be easy to use. Results of the model, including maximum or minimum wave amplitude over time and maximum wave speeds, can be easily saved and shared. An animation of the model results can also be created if desired. The model's output can be saved as ASCII, PNG, or GoogleEarth files.

While initially designed for countries in the Indian Ocean, as of 2015 ComMIT is used operationally by more than 325 scientists in 57 countries around the world.

5.4 JMA

JMA (Japan Meteorological Agency) uses three different tsunami databases to model tsunamis. One is used for domestic warnings/advisories for tsunamis occurring off the coast of Japan, the second is used for domestic warnings/advisories for distant tsunamis impacting Japan, and the last is used for NWPTAC (Northwest Pacific Tsunami Advisory Center). All three models have the same requirements for database construction.

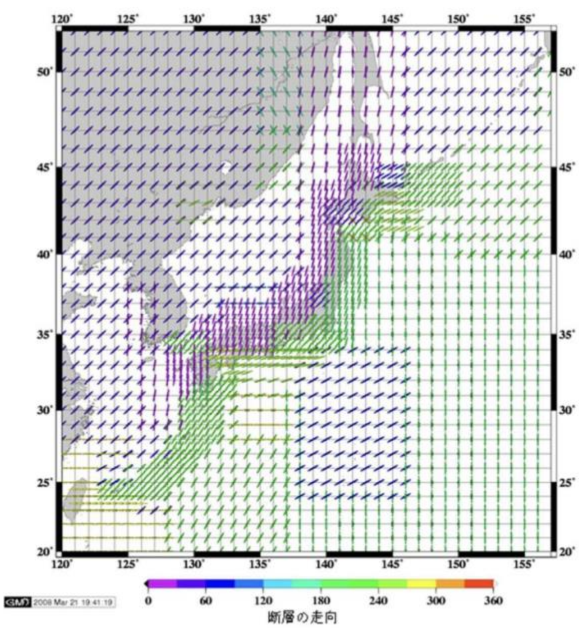
JMA's requirements for database construction are:

- Setting of assumed faults: hypocenter location, depth, magnitude
- Setting of fault parameters: strike, dip angle, slip angle
- Calculation of sea floor deformation

- Calculated using the elastic theory (Okada, 1985)
    - Tsunami source is assumed to be the same shape as the sea floor deformation
- Numerical simulation
    - Resolution of bathymetric data
    - Tsunami simulation models are based on the non-linear long wave theory (Satake 1995)
- Forecast points and estimation of tsunami height at coast
    - Position forecast points several to dozen of kilometers offshore
    - Tsunami amplitudes at forecast points are simulated
    - Tsunami amplitudes in coastal areas are estimated from forecast points using Green's Law

Like RIFT, JMA's models estimate the tsunami's wave height at offshore points and use Green's Law to calculate the wave height along the coast.

Database for domestic warnings or advisories from a nearby source:



Assumed fault locations and strike

➢ Setting of assumed faults

Hypocenter location	every 0.5 degree around Japan every 1 degree in the other
depth	0km, 20km, 40km, 80km, 100km
Magnitude	M8.0, M7.4, M6.8, M6.2

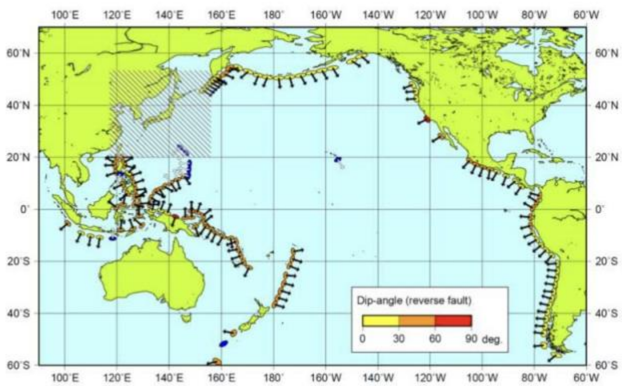
➢ Setting of the fault parameters

strike	along the trench or coast line
dip angle	45 degree
slip angle	90 degree

➢ numerical simulation

resolution	1-arc-minute

Database for domestic warnings or advisories from a distant source:



➢ Setting of assumed faults

Hypocenter location	(as shown in the figure on the left)
depth	10km
Magnitude	M8.5, M8.0, M7.5

➢ Setting of the fault parameters

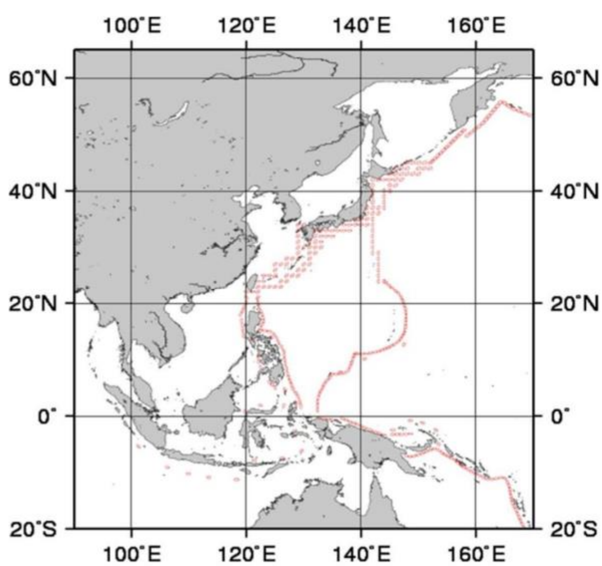
strike	a same strike of previous earthquake occurred in that area (if no previous earthquake, along the trench or coast line)
dip angle	30 degree
slip angle	90 degree

➢ numerical simulation

resolution	30-arc-second (around Japan) 1.5-arc-minute (far from Japan)

※Green's Law is not used in this database.

Database for NWPTAC:



Assumed fault locations

➢ Setting of assumed faults

Hypocenter location	(as shown in the figure on the left)
depth	0km, 20km, 40km, 60km, 80km, 100km
Magnitude	M8.5, M8.0, M7.5, M7.0

➢ Setting of the fault parameters

strike	a same strike, dip angle, slip angle of previous earthquake occurred in that area (if no previous earthquake, along the trench or coast line)
dip angle	
slip angle	

➢ numerical simulation

resolution	1-arc-minute

Activity 1:
Customize the parameters and download a dataset from USGS and load them into Google Earth. Report:

- Parameters you used: (Be smart! Don't use the whole world, all magnitudes, since 1900–that would be way too many earthquakes! Constrain by mag., date, and geographic extent)
  - Min. magnitude
  - Dates
  - Geographic extent
  - etc
- Direction of subducting slab
- Anything notable about the seismic area
- Any notable earthquakes

Activity 2:

1. Open TTT and choose any location to set your earthquake at and use any parameters that you desire.
2. Prepare some application to be able to set a timer (either on your phone or computer, wherever is easiest).
3. For the first run, choose a very low resolution to run TTT (like 60). As soon as you click run, start your timer. Keep the timer running as long as TTT is running and be prepared to stop the timer as soon as it is done running (for a low resolution this will be very quick). Note the run time and save the image outputs.
4. Re-run your same exact parameters, but this time choose a very high resolution (like 1 or 2).
5. Like last time, be prepared to time how long it takes TTT to run with these settings. This time, it will likely take much longer to run. Note the run time and save the output images.
6. Be prepared to share this information:
   a. What were the parameters you chose?
   b. What were the two run times you got?
   c. What differences did you notice in the outputs of the two runs?

Activity 3:

1. Look at the file Polygons_M9.pdf and first identify in which polygon Samoa is located. Next, look through each scenario and determine which epicenter locations for an M9 will produce waves meeting a warning criteria (> 1 m, orange) in the Samoa polygon.
    a. An M9 earthquake in which locations produces warning level waves in Samoa?
    b. Were you expecting some locations to produce a warning that didn't? Or vice versa?
2. Look at the file Coastal_M9.pdf and identify which coastal forecast points are in Samoa (a few very small dots!). Next, look through each scenario and determine which epicenter locations for an M9 will produce waves meeting a warning criteria for the coastal forecast point in Samoa.
    a. Was your answer for the coastal forecast points the same as your answer for the polygons? Why or why not?
    b. Were you expecting some locations to produce a warning that didn't? Or vice versa?
3. You've already looked at the polygons and the coastal forecast points so you know which of these epicenter locations will produce a warning in Samoa. Now look at the file Deep_Ocean_M9.pdf, which shows the deep ocean amplitude forecast.
    a. Did the beams of energy look how you thought they would look based on the polygons and coastal forecast points?
    b. What did you notice about the Tonga trench earthquakes?
4. Look at the file Polygons_Kurils.pdf. What is the threshold magnitude that will produce warning level waves in Samoa? (E.g. what is the minimum magnitude to produce a warning?)
    a. Is this the magnitude that you expected for this location?
5. Compare the file Coastal_Kurils.pdf to the polygons you just looked at. Based on how you know these two products are related, were the coastal forecast points what you were expecting to see? Why or why not?
6. Look at the file Deep_Ocean_Kurils.pdf. As you progress through the higher magnitudes, what changes? What doesn't change? Why do you think that is?
7. Lastly, look at the file RIFT_NewHebrides_depth_25-275.pdf. This file keeps the epicenter (New Hebrides) and magnitude (8.2) the same, but varies the depth.
    a. Do any of the scenarios reach the warning threshold in Samoa?
    b. What would you expect to see for an earthquake in the same location, also M8.2, at 10 km depth? What about 500 km depth?
    c. What would you expect to see for an M9 at 10 km? 100 km? 500 km?

Activity 4:

1. Look through the slides in Tonga_Kermadec_Trench.pptx.
2. Knowing that the magnitude is kept constant at 8.0 for all of these scenarios, what do you notice about slides 3-10(ish) compared to the rest of the scenarios?
3. Is there anything notable to comment on between slides 21 and 22? What about between slides 23 and 24? 25 and 26?
4. Having observed the changes in the forecast resulting from small changes in location, what is one of the benefits of being able to run a model rather than just basing alerts off of earthquake magnitude?
5. What are the advantages to running a model in real time rather than referring to a database?