Activity: Sendai, Japan Tsunami Animation
Teacher Guide

Science and Engineering Practices:
- Developing and Using Models

NGSS Crosscutting Concepts:
- Cause and Effect

NGSS Disciplinary Core Ideas:
- ESS3.B: Natural Hazards

Background
On March 11, 2011, a tsunami was generated by a 9.0 magnitude earthquake. The earthquake was centered 130 km off the east coast of Sendai, Japan. The 9.0 magnitude earthquake was the biggest earthquake ever measured in Japan, and many large aftershocks followed the main event. Buildings in Japan were damaged by the main earthquake and by the aftershocks. The nuclear power plant at Fukushima was also damaged.

The highest tsunami waves reached the coastline of Japan about 30 minutes after the earthquake occurred. The tsunami added to the damage caused by the earthquakes. The tsunami also had widespread impact across the Pacific ocean basin.

Additional Information
More information about tsunamis is available at these websites:
- Tsunami Facts: http://ptwc.weather.gov/faq.php

International Tsunami Information Centre (ITIC):
- http://ptwc.weather.gov/jump.php?site=www.tsunamiwave.info/

NOAA West Coast & Alaska Tsunami Warning Center FAQ:
- http://ptwc.weather.gov/jump.php?site=wcatwc.arh.noaa.gov/frequently.htm

NOAA Center for Tsunami Research FAQ:
- http://ptwc.weather.gov/jump.php?site=nctr.pmel.noaa.gov/faq.php

Pacific Tsunami Museum FAQ:
- http://ptwc.weather.gov/jump.php?site=www.tsunami.org/faq.htm

American Red Cross Tsunami FAQ:
- http://ptwc.weather.gov/jump.php?site=www.redcross.org/services/disaster/0,1082,0_592_,00.html

Materials
- Table 5.13
- A globe or map of the Pacific ocean basin
- Computer with internet access
- Graphing paper or graphing program
- Table 5.12

Activity Sheet
- **Table 5.13. Datasheet of observations from the Sendai Japan tsunami animation**

Procedure

1. Using a globe or map of the Pacific ocean basin, locate Sendai, Japan.
    a. Choose a location on the other side of the Pacific ocean basin (on the North or South American continent). Envision an imaginary line between Sendai and your location.
    b. Use google maps, a globe, or map with a scale bar to determine the distance between the two locations.

    If students type into google, "distance from Sendai Japan to a specific city," a number of free resources come up. For example, Google maps gives the distance as 8,015 km between Sendai and San Francisco, CA. Other sources (e.g. http://disween.com/) give slightly different distances = 8,030km.

    Alternatively, students can measure distances between any two points using Google Maps. Right click on any point, select "Measure distance," then left click on a second point. A linear distance on the globe surface is presented in miles and in kilometers. For example, the distance between Sendai, Japan and Valparaiso, Chile is roughly 17,022 km.

2. Assume that a typical tsunami travels at about 750 km/hr. Estimate how long it will take for the tsunami wave to reach your chosen location.

    Students should divide the distance from #1 by the speed (750 km/hr). For example, the time for the tsunami to reach San Francisco = 8,015 km / 750 km/hr = 10.7 hours. Time to reach Valparaiso, Chile = 17,022 km / 750 km/hr = 22.7 hours.

3. Predict how the energy of the earthquake will propagate across the Pacific ocean basin.

    Answers will vary. In general, energy from the initial earthquake will spread throughout the Pacific ocean basin and dissipate as the leading wave edge moves away from Sendai, Japan.

4. Tsunamis form waves in sets that radiate from their point of origin, like the ripples caused by throwing a rock into a pond. Predict what will happen to the height of the tsunami waves as they travel from Sendai to your location.

    Answers will vary. Tsunamis have small wave heights but long wave periods. There will generally be small wave heights from a tsunami for most of its journey across the Pacific ocean basin. Wave heights might be expected to increase as the tsunami approaches shore and interacts more with the bottom. In fact, surges of 2-3 meters were reported in coastal Chile after the 2011 Sendai tsunami. Note, however, that the NOAA animation does not show waves increasing in height near the shoreline; the animation shows much smaller wave heights in Chile than what was observed.

5. The National Oceanographic and Atmospheric Administration (NOAA) has posted a Wave Energy Map of the tsunami (See Fig. 5.33.1 A)
    a. Go to website https://www.coast.noaa.gov/psc/dataviewer/#view=japanEnergy to view the wave energy map.
    b. Describe the pattern of waves and their relative and height as they move across across the Pacific ocean basin.

Wave Energy Map

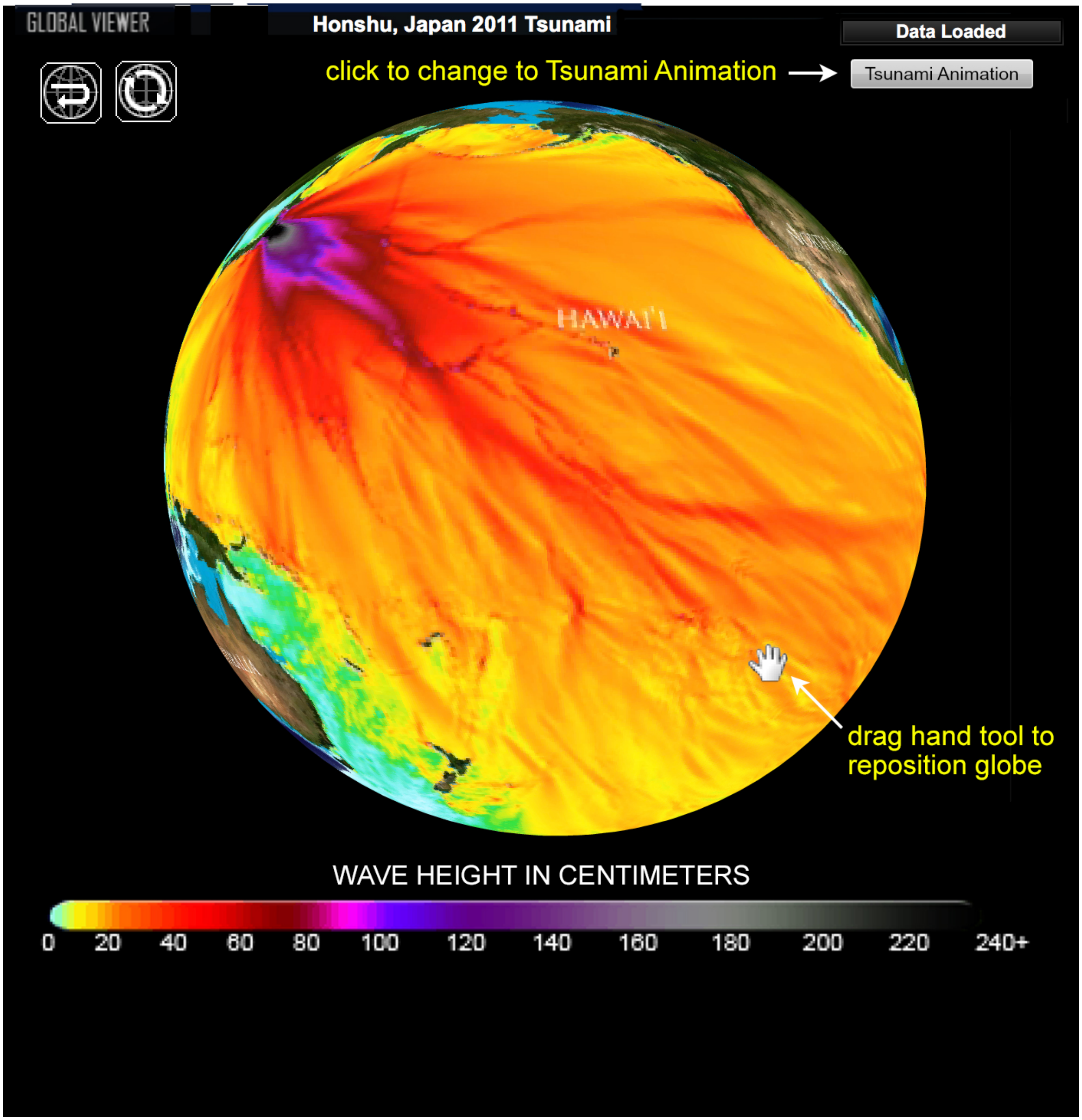


Fig. 5.33.1 A. Wave Energy Map view, showing hand tool that lets you rotate the globe

Tsunami Animation

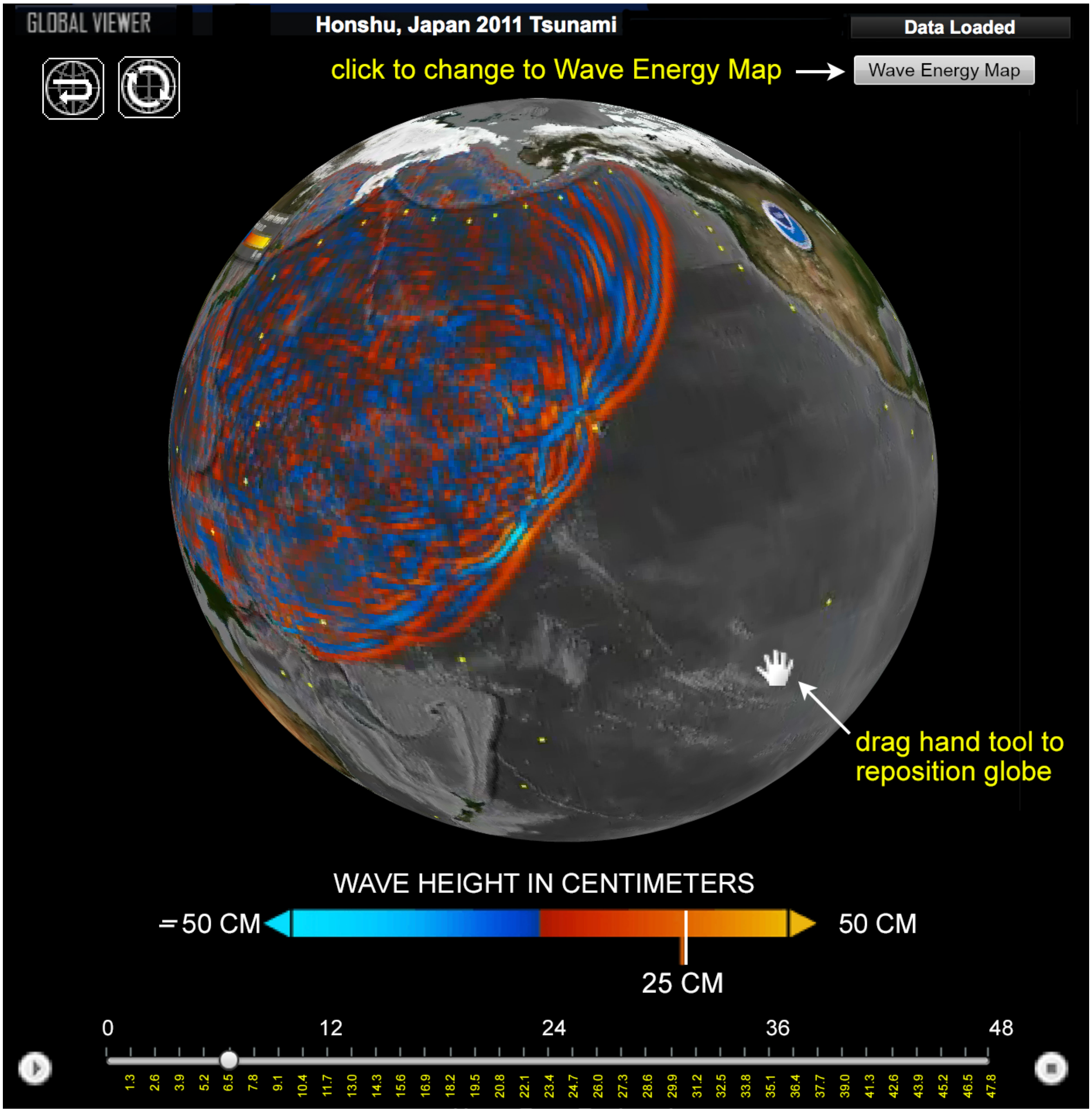


Fig. 5.33.1 B. Tsunami with start/pause button and hour timescale bar with tick marks (each mark is 1.3 hours)

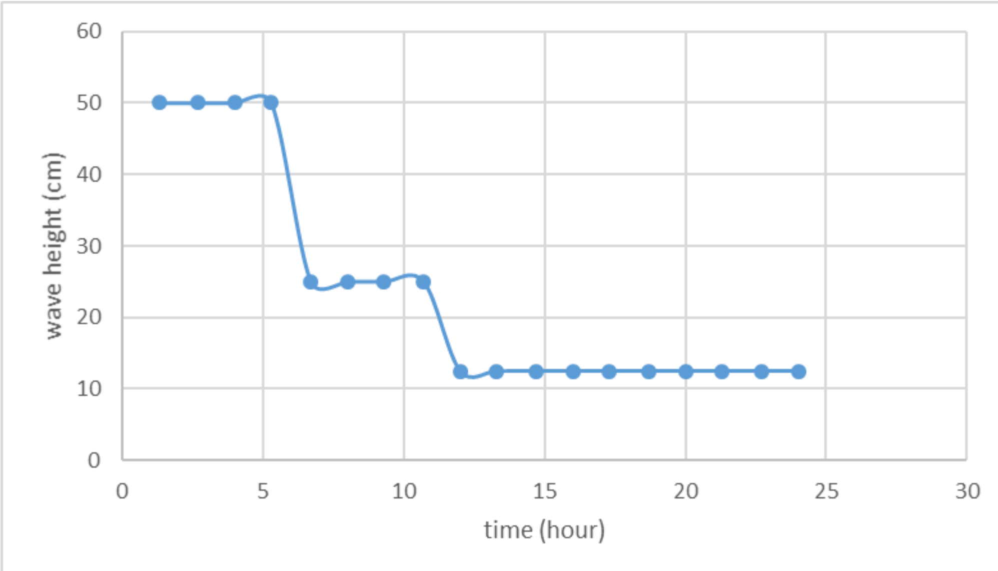
6. NOAA has also developed an animation that shows the Sendai tsunami moving across the Pacific.
   a. Go to the website: https://www.coast.noaa.gov/psc/dataviewer/#view=japan11.
      i. This is the tsunami animation view. You can switch between the Tsunami Animation and the Wave Energy Map by clicking the button in the upper right corner. However, the labels are confusing. When you are in the Wave Energy Map, the button shows Tsunami Animation (because you click the button to go to the animation). See the labels in Fig. 5.xx.
   b. Familiarize yourself with the animation controls (Fig. 5.33.1 B).
      i. Use the hand tool to rotate the globe to view different areas of the Pacific ocean basin.
      ii. Practice starting, pausing, and restarting the animation.

7. Use the animation to observe and record how a tsunami impacts the Pacific ocean basin.
   a. Run the animation to determine the time that the tsunami reaches your chosen location.
      i. Use the timescale below the animation. Each tick mark is equal to approximately 1.3 hours. (see Fig. 5.33.1 B).
      ii. Record the time the tsunami reaches your chosen location in the observation column of Table 5.13.
   b. Record the highest estimated height of the leading edge of the tsunami wave as it moves across the Pacific for 24 hours.
      i. Run the animation again, stopping every 1.3 hours (each time the timeline reaches a new tick mark).
      ii. You will need to rotate the globe using the hand tool to continue to be able to see the leading edge of the wave.
      iii. You will need to estimate the wave height based on the color scale.
         1. The crest of the leading wave is positive in height and colored yellow-orange-red. The trough between the waves is negative, because the trough of the waves is lower than the average sea level.
         2. Note that the wave height will not change dramatically over time, but it does change! Watch carefully!
         3. Your estimate will be based on the color scale bar, which does not have a lot of differentiation (see Fig. 5.33.1 B). Do your best to estimate the wave height.
   c. Observe and record any other general observations about the tsunami wave and the patterns of the waves as they move across the Pacific.
      i. Run the tsunami animation again without pausing for at least 48 hours.
      ii. Notice how the tsunami moves in the open ocean compared to how it moves near islands and continents.
      iii. Record additional observations in the observation column of Table 5.13 or in the space below the table.

It will be helpful for students to have a Pacific map open to identify place names during this part.

See attached Table 5.13 with estimated wave heights and observations. The tsunami leading edge reached San Francisco, CA around 9.3 hours after the earthquake and Valparaiso, Chile around 18.7 hours after the earthquake.

8. Using graph paper or graphing software, create a graph of wave height versus time from the data you collected in Table 5.13. Label your graph appropriately.



Activity Questions:

1. Compare your predictions about each of the following to your observations.
    a. Wave height
    Answers will vary. In general, the wave heights in the northwestern and north central Pacific ocean basin were larger than expected. This could be due to the amount of energy in the initial earthquake, and also local bathymetric features such as small islands and trenches in the northwestern Pacific.

    b. Time needed to reach destination
    Answers will vary. The 2011 tsunami reached San Francisco, CA and Valparaiso, Chile faster than expected. In general, the model suggests that the 2011 tsunami moved faster than the average tsunami.

    c. Wave energy
    Answers will vary. In general, wave energy dissipated throughout the Pacific as expected.

    If your predictions were close to your observations, explain what prior information helped your form your prediction. If your predications were different than what you observed, describe what additional information would have been useful in generating a more accurate prediction.

2. Were there any changes in wave height as the tsunami propagated, or spread, across the ocean? If so, explain how the wave height changed.
Answers will vary. In general, wave height generally decreased over time and distance from Sendai, Japan.

3. Did you observe any wave boundary behavior or interference patterns as the tsunami moved by islands and continents? If yes, explain what patterns you observed and where they occurred.
   Answers will vary. In general, larger wave interference patterns happened after the leading edge of the tsunami hit mainland North and South American. There was also smaller diffraction of the tsunami through small islands and island chains. The New Guinea-Bismarck-Solomon chain seems to have protected eastern Australia.

4. Reflect on your observations in this activity. Think about the long wavelength of a tsunami wave and the fact that tsunami wave energy often touches the ocean floor. What factors do you think affect how a tsunami propagates through an ocean basin?
   Answers will vary. In general the seafloor features/bathymetry, the distance from energy source, and the size of the original energy source all affect how a tsunami propagates.

5. As tsunami waves travel across the deep open ocean, they are usually no more than 30 cm high, which means ships cannot detect tsunamis passing beneath them. Explain why these relatively short tsunami waves can form large waves, and large walls of water, as they come to shore.
   Tsunamis have very long wavelengths (some are over 700 km), which means the energy of tsunami waves can extend thousands of meters down to the bottom floor of the ocean basins. When a tsunami approaches the shore, its speed decreases and its height increases (see Fig. 5.32). As the tsunami waves reach shallow water and are slowed by contact with the bottom, faster-moving water near the surface piles up, creating a wall of water.

6. Even though the tsunami warning system worked well, the death toll, environmental damage, and economic cost of the 2011 Japanese tsunami were extremely high. Explain why you think this might be.
   Answers will vary. In general, people in northeast Japan are extremely well prepared in terms of tsunami disaster prevention. Researchers report that the degree of damage from the tsunami was probably due to its complexity. The combination of an earthquake of M9.0, aftershocks, and a giant tsunami were unprecedented in Japan's recent history. Also, the added nuclear accident caused serious and widespread damage. The complications of these events caused massive damage despite the well-prepared population—providing evidence that we should prepare more adequately for the possibility of multiple potential hazards happening together.

   Also see this paper for more information: https://link.springer.com/article/10.1007/s11027-011-9297-7

7. The 2011 Japanese tsunami breached high breakwater walls surrounding coastal cities. What other technology or coastal engineering options might help people in low-lying coastal areas mitigate the effects of tsunami? (Refer to Table 5.12 for examples of structures human can build along shorelines.)
   Answers will vary. In addition to conventional "grey" infrastructure and coastal engineering, we can invest in "green infrastructure" or "living shorelines" such as constructed coral reefs, oyster beds, mangrove swamps, kelp reefs, tidal wetlands, and seagrass meadows.

Sample wave height estimates, observations of places the tsunami waves reach at each time point, and general observations of the tsunami propagation across the Pacific.

Table 5.13. Datasheet of observations from the Sendai Japan tsunami animation

Elapsed time since earthquake (hours)	Wave height of wave front (cm)	Observations
1.3	50	Localized to Japan
2.6	50	Almost to Taiwan and most of NW Pacific
3.9	50	Most of Philippines + western central Pacific
5.2	50	NW Hawaiian Island + Aleutian Islands
6.5	~25	New Guinea, Hawai'i, + Alaska mainland
7.8	~25	British Columbia + south Pacific
9.1	~25	**San Francisco + WA, OR, CA, Fiji
10.4	~25	Baja California
11.7	0-25	Sonora Mexico, northern New Zealand
13.0	0-25	Southern Mexico, southern New Zealand
14.3	0-25	Central America
15.6	0-25	Panama
16.9	0-25	Ecuador, Peru, Antarctica
18.2	0-25	**Valparaiso, Chile
19.5	0-25	Southern Chile
20.8	0-25	Cape Horn
22.1	0-25	larger reverberations to NW from Chile
23.4	0-25	

The tsunami waves start off bright yellow (50 cm+) near Japan, with large troughs (-50 cm+). The waves are circular and well organized. As the tsunami moves across the Pacific, the leading edge remains organized and gradually gets smaller (as does the trough). The waves behind the leading edge become more and more disorganized as reverberating waves move back toward Japan.