NOVA

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PBS

Wave That Shook the World

PROGRAM OVERVIEW

NOVA explores what happened and why when the December 26, 2004, tsunami developed off the Sumatran coast.

The program:

- tracks the Indian Ocean tsunami as it progresses outward from its epicenter.
- notes how Earth's continental plates can create earthquakes when they collide.
- describes how the tsunami developed from an earthquake that occurred at a subduction zone off the Sumatran coast.
- relates how the Pacific Tsunami Warning Center in Hawaii first registered the earthquake but, due to lack of any tsunami sensor networks in that region, was unable to know if a tsunami had formed.
- recounts through descriptions and animations how the tsunami developed after the earthquake, how it traveled in the open ocean, and how it amplified as it neared the shoreline.
- interviews survivors in several locations and shows the destruction caused by the waves.
- details the influence of coastal morphology and seabed gradient on the tsunami's destruction.
- relates how Pacific Tsunami Warning Center officials were eventually able to calculate the tsunami's travel time and alert East African embassies of its impending arrival.
- recounts other Indonesian tsunamis and points out that some scientists had predicted catastrophic geological activity in that region.
- considers the impact that no tsunami warning system or little tsunami education had on the outcome of the disaster.
- reviews the four main causes of tsunamis—earthquakes, meteor impacts, volcanic or other explosive eruptions, and above-water and undersea landslides.
- states that while, by some estimates, tsunamis pose a direct threat to about one-quarter of the world's population, protection against them remains a matter of cost and politics.
- speculates what could happen if a major earthquake occurred at the Cascadia subduction zone off the Pacific Northwest coast or if the Cumbre Vieja volcano in the Canary Islands collapsed into the sea.

BEFORE WATCHING

1 Discuss with students what a tsunami is and how it can be created. Define epicenter. (See Activity Answer on page 4 for more information.) Have students use an atlas to locate some of the places in the program—the Indian Ocean, Sumatra, Thailand, Sri Lanka, and East Africa.

2 Draw a chart on the board that compares tsunamis and wind-driven waves. (See Activity Answer on page 4 for more information.) Discuss the main differences between these wave types.

3 Organize the class into four teams and assign a tsunami topic to each team: physical characteristics, awareness and safety information, occurrence worldwide, and impact on life. Have teams generate questions related to their topics. As students watch, have them take notes on their areas of focus.

AFTER WATCHING

1 Provide time for teams to research questions they wrote down that were not answered in the program. Have teams share what they learned. What findings surprised students the most?

2 Ask students to consider why tsunamis can sometimes cause such damage and devastation. What are some characteristics of the wave that factor into how much damage it could cause? (Some characteristics include size and speed.) How do coastal or shoreline features factor into the extent of damage? (Cliffs can buffer some of the energy and limit damage; open shorelines with gradual inclines can result in more substantial damage.) What role could a warning system play? (A warning system could potentially help save lives.)

CLASSROOM ACTIVITY

Objective

To calculate approximate speeds and travel times for sample tsunamis.

Materials for each team

- copy of "Tracking Tsunamis" student handout
- copy of the "Tsunami Scenarios" student handout
- copy of the "World Map" student handout
- calculator with square root function
- drawing compass
- ruler

Materials for the class

- world atlases

Procedure

1 Review subduction zones and how earthquakes occur in these zones. (See Activity Answer on page 4 for more information.) Draw a subduction zone on the board and review with students how the December 26, 2004, earthquake off of the Sumatran coast created a tsunami: A massive displacement of water from its equilibrium position caused the tsunami. Gravity worked to restore the water to its equilibrium position. The waves traveled from their place of origin in all directions and energy from the quake was transferred by the water.

2 Tsunamis, because of their long wavelengths, lose little energy as they travel. (The rate at which a wave loses energy is inversely proportional to its wavelength.) Inform students that there is a formula that can be used to estimate the speed of the wave created from this energy. The formula is used to measure the speed of ocean waves, like tsunamis, that have very long wavelengths relative to the depth of the water. Tsunamis can have wavelengths greater than 700 kilometers (the average ocean depth is 3–4 kilometers). The formula estimates the tsunami's speed while it is in deeper waters (as it approaches shallower coastal waters, the tsunami slows down, its wavelength shortens, and its height increases).

STANDARDS CONNECTION

The "Tracking Tsunamis" activity aligns with the following National Science Education Standards and Principles and Standards for School Mathematics.

GRADES 5–8

Science Standard B:

Physical Science

Transfer of energy

- Energy is a property of many substances and is associated with heat, light, electricity, mechanical motion, sound, nuclei, and the nature of a chemical. Energy is transferred in many ways.

Science Standard D:

Earth and Space Science

Structure of the Earth system

- Lithospheric plates on the scales of continents and oceans constantly move at rates of centimeters per year in response to movements in the mantle. Major geological events, such as earthquakes, volcanic eruptions, and mountain building, result from these plate motions.

Mathematics Standard:

Number and Operations

Video is not required for this activity.

Classroom Activity Author

Developed by WGBH Educational Outreach staff.

CLASSROOM ACTIVITY

3 Brainstorm with students some factors that may play a role in the speed of a tsunami. (Student responses may include the magnitude of an earthquake, the amount of displaced water, and the depth of the water.) Tell students that the formula to approximate tsunami speed considers the depth of the water and the acceleration due to gravity. The formula is:

$$\text{speed} = \sqrt{g \times d}$$

where speed (meters/second) = square root of *g* (acceleration due to gravity, which is 9.81 meters/second^2) x *d* (water depth in meters)

4 Have students work with a partner. Provide each team with a copy of the handouts and other materials. Review the handouts with them. Tell students that they will use the speed formula to calculate tsunami speed and determine the time each tsunami takes to travel to specific locations in each of the scenarios presented. Students can check their distance estimates at **www.wcrl.ars.usda.gov/cec/java/lat-long.htm**

5 Students will need to convert their answers, which will be in meters/second, to kilometers/hour. Help students think how they might move the decimal point to accomplish the last step in this conversion.

6 To conclude, hold a class discussion about the order in which the tsunami will strike each location (1st, 2nd, or 3rd). Have teams share some ways people at each location might prepare for the approaching tsunami. (Some considerations are evacuating people to high ground, alerting hospitals, deciding whether there is time for help from outside the country, or sending people away by boat.)

7 As an extension, ask students to research why and how the Pacific Tsunami Warning Center was developed and what future plans are being formulated for a worldwide tsunami warning system.

STANDARDS CONNECTION (CONT.)

GRADES 9–12
Science Standard B:
Physical Science
Motions and forces

- Gravitation is a universal force that each mass exerts on any other mass. The strength of the gravitational attractive force between two masses is proportional to the masses and inversely proportional to the square of the distance between them.

Conservation of energy and the increase in disorder

- The total energy of the universe is constant. Energy can be transferred by collisions in chemical and nuclear reactions, by light waves and other radiations, and in many other ways. However, it can never be destroyed. As these transfers occur, the matter involved becomes steadily less ordered.

Interactions of energy and matter

- Waves, including sound and seismic waves, waves on water, and light waves, have energy and can transfer energy when they interact with matter.

Mathematics Standard:
Algebra

ACTIVITY ANSWER

A tsunami is a series of waves created in a body of water by a disturbance that vertically displaces the water column. Tsunamis are not tidal waves (they are not caused by the forces that create tides). An epicenter is the point on Earth's surface straight above where an earthquake originates.

Water waves are grouped by the forces that cause or generate them (generating forces) and those that restore equilibrium (restoring forces). The generating forces are different for tsunamis and wind-driven waves, but the restoring force for both is gravity.

Most tsunamis are created by sub-marine earthquakes that occur at subduction zones. At these zones, one tectonic plate is moving or subducting beneath its neighboring plate. Many things can happen at these sites to trigger a tsunami. At Sumatra, stick-slip friction occurred. The upper plate dragged downward with the lower plate and then the upper plate became deformed, built up strain energy, and then snapped up. The magnitude of an earthquake determines how much energy is released and then transferred by the water. The earthquake's magnitude also plays a role in how high above sea level the water level rises. Magnitude does not play a large role in the tsunami's speed.

Several factors affect the height of a tsunami wave and the damage it can cause as it approaches and reaches the shore—the energy the wave carries; the tides, whether high or low; and the land formation and features.

Kind of Wave	Mode of Generation	Range of Wavelength	Wave Frequency (Period)	Wave Speed
wind-driven	local or distant winds that blow across the ocean's surface	about 100 m to 200 m	5 s to 20 s	about 40 to 90 km/h (40 km/h, the speed of a moped, is most common)
seismic-sea wave (tsunami)	sub-marine earthquakes (most tsunamis); also created by volcanic eruptions, land-slides, underwater explosions, and meteor impacts	from 100 m to >500 km; are at least three times the ocean depth at which the wave was generated	10 min to 2 h	variable, up to 1,000 km/h (the speed of a jet plane)

Scenario A
The Seward, Alaska, tsunami created at an ocean depth of 4,000 m is calculated to travel at 713 km/h. The travel times to each location are:
Kodiak, Alaska: about 32 minutes
Kauai Island, Hawaii: about 6 hours
Kwajalein, Marshall Islands: about 9 hours 26 minutes

Scenario B:
The Ka Lae, Hawaii, tsunami created at an ocean depth of 4,500 m is calculated to travel at 756 km/h. The travel times to each location are:
Dutch Harbor, Alaska: about 5 hours 6 minutes
Kwajalein, Marshall Islands: about 5 hours 30 minutes
Samoa: about 5 hours 30 minutes

Scenario C:
The Gran Canaria, Canary Islands, tsunami created at an ocean depth of 3,500 m is calculated to travel at 667 km/h. The travel times to each location are:
Terceira, Azores: about 2 hours 21 minutes
Safi, Morocco: about 1 hour 5 minutes
St. Johns, Newfoundland: about 5 hours 44 minutes

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LINKS AND BOOKS

Links

NOVA Web Site—Wave That Shook the World
www.pbs.org/nova/tsunami
In this companion Web site to the program, find out about how well officials can prepare for the next big tsunami, read an Ask the Expert feature, see how the Indonesian event unfolded, and delve into the global history of these seismic sea waves.

Calculating the Threat of Tsunami
www.science.org.au/nova/045/045key.htm
Defines the term tsunami and includes information about wave energy.

Earthquakes and Society
www.umich.edu/~gs265/society/earthquakes.htm
Includes charts and information about earthquakes at subduction zones.

The Great Sumatra Earthquake and Tsunami of December 2004
www.wilson.wnyric.org/t/drobison/regents/WellOrganized/tsunami.htm
Provides a five-part high-school level earth science lesson plan that explores the geologic processes involved with the Indonesian tsunami. Includes analysis of actual seismograms from which students plot the earthquake's epicenter.

HyperPhysics: Tsunami
hyperphysics.phy-astr.gsu.edu/hbase/waves/tsunami.html
Includes graphics of subduction zones and describes how tsunamis travel.

International Tsunami Information Center
www.prh.noaa.gov/itic/library/about_tsu/faqs.html
Answers frequently asked questions about tsunamis and lists the largest historical tsunamis.

Life of a Tsunami
walrus.wr.usgs.gov/tsunami/basics.html
Explains tsunami speed and amplification.

Oceanography: Waves
www.poemsinc.org/oceano/waves.htm
Contains a map of locations for 13 tsunamis.

Physics of Tsunamis
wcatwc.arh.noaa.gov/physics.htm
Characterizes tsunamis and considers how they travel in different water depths.

Tsunami
www.tulane.edu/~sanelson/geol204/tsunami.htm
Describes the physical characteristics of tsunamis and includes definitions of wavelength, wave height, wave amplitude, wave frequency, and wave velocity. Includes formulas for calculating velocity.

Tsunami: Frequently Asked Questions
www.pmel.noaa.gov/tsunami_faqs.htm
Answers questions about causes of tsunamis and how they differ from other waves.

Tsunami—Seismic Sea Wave
vulcan.wr.usgs.gov/Glossary/Tsunami/description_tsunami.html
Describes seismic sea waves and discusses four damaging tsunamis.

U.S. Search and Rescue Task Force: Tsunamis
www.ussartf.org/tsunamis.htm
Provides basic information about tsunamis, features 10 destructive tsunamis, and presents tsunami safety rules.

Water Waves
electron4.phys.utk.edu/141/dec8/December%208.htm
Distinguishes between deep-water waves and shallow-water waves and provides an example of a tsunami velocity calculation.

What is a Wave?
www.gmi.edu/~drussell/Demos/waves-intro/waves-intro.html
Defines a wave and illustrates examples of different waves.

WorldAtlas.com
worldatlas.com/aatlas/imageg.htm
Maps latitude and longitude for cities, towns, and villages.

Books

Ford, Brent A. and Sean P. Smith.
Physical Oceanography.
Arlington, VA: NSTA Press, 2000.
Includes background information, lessons, and activities related to water, waves, and the ocean.

Macquitty, Miranda and Frank Greenaway.
Eyewitness: Ocean.
New York, NY: DK Publishing, Inc., 1995.
Focuses on Earth's ocean environments and includes a section on waves and weather.

Van Rose, Susanna.
Eyewitness: Earth.
New York, NY: DK Publishing, Inc., 1994.
Discusses Earth and highlights modern oceanography, plate tectonics, and the formation of the ocean floor.

Tracking Tsunamis

On December 26, 2004, scientists at the Pacific Tsunami Warning Center learned of the speed of the Indonesian tsunami and tracked it as it moved across the Indian Ocean. They were able to notify East African officials of the impending disaster. In this activity, you will calculate the approximate speed of three tsunamis and create a time travel map and chart that shows their arrival at specific geographic locations.

Procedure

1. Research and label your world map with each of the geographic locations presented in the scenarios.
2. Use your drawing compass to draw the wave front at each location as it radiates out from its epicenter. Place the compass tip on the epicenter and the pencil on the landfall location, then make the largest arc possible on the map. Do this for all scenario locations.
3. Read each of the scenarios on your "Tsunami Scenarios" handout and apply the formulas to determine the approximate speed of the tsunami and the time it takes for it to reach each location.
4. For each scenario, write down the order in which the tsunami will strike each location. List some ways that people, if notified, might prepare for the approaching tsunami.

WAVE SPEED FORMULA

$$\text{speed} = \sqrt{g \times d}$$

where speed (meters/second) = square root of *g* (acceleration due to gravity, which is 9.81 meters/second^2) x *d* (water depth in meters)

Your speed calculation initially will be in meters/second. Convert meters/second to kilometers/hour using the following formulas:
1 hour = 60 minutes = 3,600 seconds
1 kilometer = 1,000 meters

To convert your units to meters/hour, multiply your initial answer by 3,600. Divide the result by 1,000 to convert from meters/hour to kilometers/hour. Round your final answer to the nearest whole number.

TRAVEL TIMES CALCULATION

Calculate travel times by dividing distance by tsunami speed. Remember to convert the decimal part of the number to minutes by multiplying the decimal part by 60. For example, one point four (1.4) hours equals 1 hour and 24 minutes.

Tsunami Scenarios

Scenario A

Seismologists have just registered an earthquake in Seward, Alaska, that is big enough to produce a tsunami. The ocean depth is 4,000 meters. Use the wave speed formula to approximate the tsunami's speed. After calculating the speed, use your atlas to estimate distances from the tsunami's epicenter to each location. Calculate the travel time to each location and write it on your map.

- Kodiak, Alaska
- Kauai Island, Hawaii
- Kwajalein, Marshall Islands

Scenario B

A tsunami has just been detected off of Ka Lae, Hawaii. The ocean depth is 4,500 meters. Use the wave speed formula to approximate the tsunami's speed. After calculating the speed, use your atlas to estimate distances from the tsunami's epicenter to each location. Calculate the travel time to each location and write it on your map.

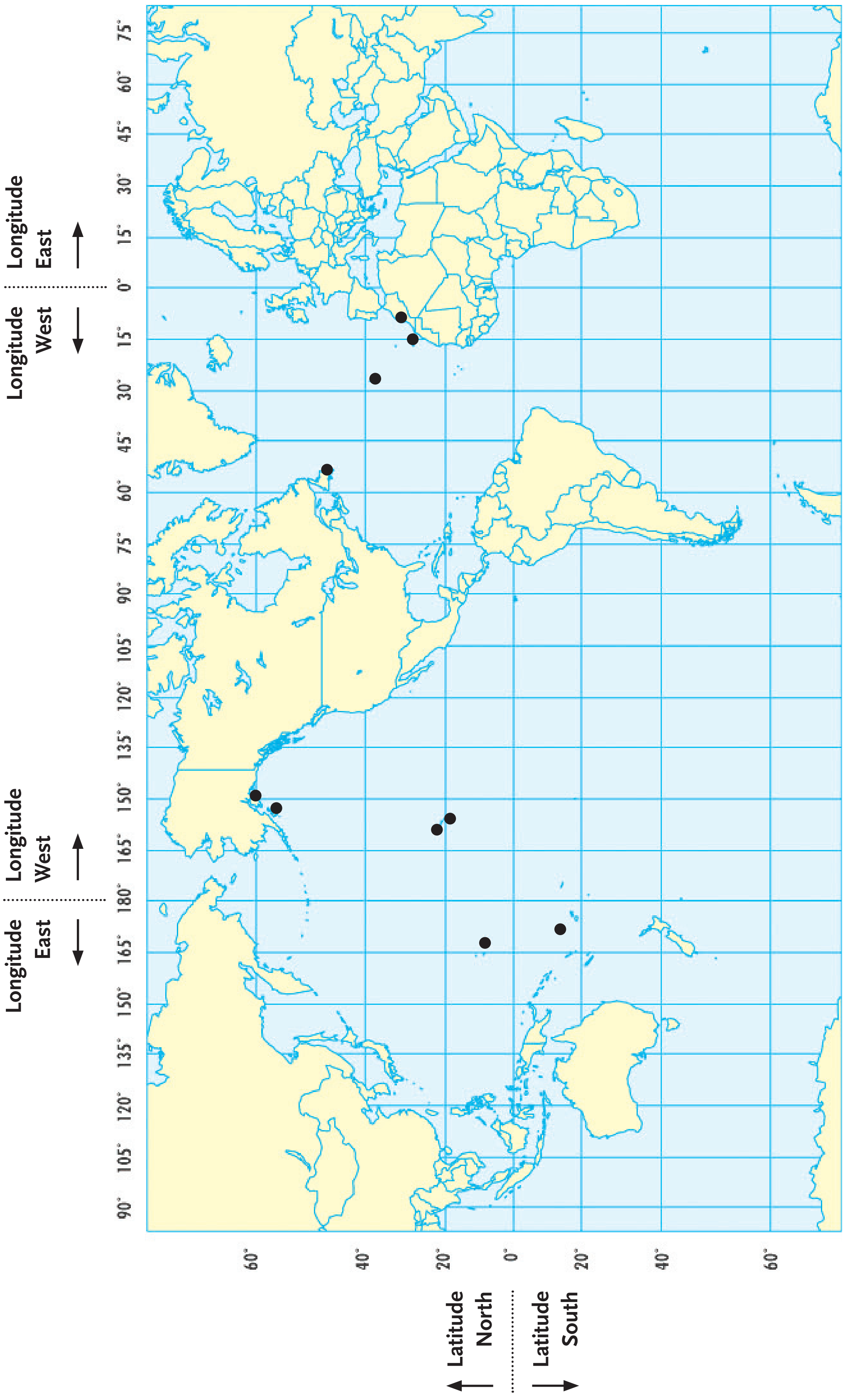
- Dutch Harbor, Alaska
- Kwajalein, Marshall Islands
- Samoa

Scenario C

A large part of a volcano in the Gran Canaria, Canary Islands, has just fallen into the ocean that is 3,500 meters deep. Use the wave speed formula to approximate the tsunami's speed. After calculating the speed, use your atlas to estimate distances from the tsunami's epicenter to each location. Calculate the travel time to each location and write it on your map.

- Terceira, Azores
- Safi, Morocco
- St. Johns, Newfoundland

World Map


Longitude East
Longitude West
Longitude West
Longitude East
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60˚ 40˚ 20˚ 0˚ 20˚ 40˚ 60˚
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