



Steamship *Portland*

Fetch Me a Wave

FOCUS

Ocean waves and the influence of extreme storms on wave formation

GRADE LEVEL

9-12 (Earth Science)

FOCUS QUESTION

How do ocean waves form, and what is the effect of extreme storms on wave formation?

LEARNING OBJECTIVES

Students will be able to define waves and explain how they are formed.

Students will be able to explain the factors that influence the size of ocean waves.

Students will be able to draw plausible inferences about the effect of extreme storm conditions on wave formation.

MATERIALS

- Internet access for student research

AUDIO/VISUAL MATERIALS

- Overhead projector

TEACHING TIME

One 45-minute class period, plus time for student research

SEATING ARRANGEMENT

Classroom style

MAXIMUM NUMBER OF STUDENTS

30

KEY WORDS

Portland Gale of 1898
Halloween Nor'easter of 1991
Perfect storm
Hybrid storm
Nor'easter
Wave
Tsunami

BACKGROUND INFORMATION

On Thanksgiving Saturday, November 26, 1898, the passenger steamship *Portland* left Boston Harbor with 192 passengers and crew bound for Portland, Maine. During the night, New England was hit by a monster storm moving up the Atlantic coast with northeasterly winds gusting to 90 mph, dense snow, and temperatures well below freezing. At 5:45 a.m. on the morning of November 27, four short blasts on a ship's steam whistle told the keeper of the Race Point Life-Saving Station that a vessel was in trouble. Seventeen hours later, life jackets, debris, and human bodies washed ashore near the the Race Point station, confirming that the *Portland* and everyone aboard had been lost in one of New England's worst maritime disasters.

For 90 years, the location of the *Portland* wreck was unknown, despite intense and continuing public interest. Then in April 1989, members of the Historical Maritime Group of New England found wreckage more than 300 feet deep that they were certain had been the *Portland*. Because of

the depth, however, the discoverers were unable to obtain photographs or other evidence that could confirm their find. Thirteen years later, on August 29, 2002, the U.S. Commerce Department's National Oceanic and Atmospheric Administration (NOAA) confirmed that the wreck of the *Portland* had been found within NOAA's Stellwagen Bank National Marine Sanctuary. Using side-scan sonar and a remotely operated vehicle (ROV), scientists obtained high-quality video and side-scan images in a joint research mission of the Stellwagen Bank National Marine Sanctuary and the National Undersea Research Center at the University of Connecticut.

Storms can usually be classified into one of two types: extratropical cyclones and tropical cyclones. Extra-tropical cyclones are "ordinary" storms formed by the intersection of warm and cold air masses, and can form over land and water in mid-latitudes at all times of the year. The temperature difference or gradient between the air masses is the major source of energy for these storms. Tropical cyclones include hurricanes and typhoons, and are formed mainly during summer and fall over warm tropical oceans. Warm humid air in these regions is loaded with water vapor that condenses as it rises into cooler air in the atmosphere. Condensation releases latent heat of vaporization, and this heat is the primary source of energy for tropical cyclones.

Occasionally, an extratropical cyclone will develop some of the characteristics of a tropical cyclone. This hybrid storm forms when thunderstorms begin to generate near the storm's center. When this happens, the central core of the storm is warmed as latent heat is released by water vapor condensing in the thunderstorms. Pressure in the core of the storm drops—sometimes very rapidly—and creates gale-force or hurricane force winds. The rapid drop in pressure is called "explosive deepening;" if the pressure steadily falls one millibar per hour for 24 hours or more, the storm is called a "bomb cyclone." At the same time, a tight temperature

gradient is maintained on the northern side of the storm (in the northern hemisphere).

Typical weather patterns in New England states during late October and November are conducive to the formation of massive storms. At this time of the year, large cold air masses from Canada cross the midwestern states on a regular basis. At the same time, the Atlantic Ocean retains its summer heat and these warm waters sometimes spawn hurricanes. When the east-moving cold air masses encounter the warm, humid oceanic air, the result is what New Englanders call "Nor'easters:" storms that are often severe, and are often the cause of maritime disasters.

The Gale of 1989 (sometimes called the "Portland Gale") began as three air masses: an area of high pressure over the Ohio valley, a weak low-pressure area near Minnesota, and another low over the western Gulf of Mexico. By the evening of November 24, the high pressure area and Great Lakes low had both moved eastward. With the counterclockwise (cyclonic) circulation typical of air masses in the northern hemisphere, the Great Lakes low drew in Arctic air from central Canada, lowering temperatures dramatically across the northern plains. To the south, the Gulf of Mexico low was spreading rain across the southern states from Louisiana to Georgia.

By the morning of November 26, the high pressure area was off the New England coast, the Great Lakes low was centered over Detroit, and the southern low was just off the coast of South Carolina. At this point, the two low-pressure air masses were connected by an elongated area of low pressure known as a trough, which facilitated energy exchange between the air masses. As the Great Lakes low continued its eastward advance, the southern low began to move up the east coast, gradually gaining strength and speed. By three o'clock, the southern low had almost completely absorbed the Great Lakes system and was spinning off Norfolk. As the weather system continued

to grow, large amounts of moisture absorbed from the Gulf Stream became a massive snowfall that extended from Washington, DC to New York City.

As the storm moved north, a steep pressure gradient developed between the low pressure storm system and the area of high pressure to the northeast, as well as between the storm system and the Arctic high to the northwest of the storm. The result was unusually strong gales that battered central and southern New England for the entire day on November 27. By Monday, November 28, the storm had moved off to the northeast, leaving below-freezing temperatures, a devastated coastline, and shocked communities that only gradually learned of the *Portland's* fate.

In this lesson, students will research the formation of waves, and will predict and explain the effects of extreme storms on their formation.

LEARNING PROCEDURE

1. You may want to download a copy of "The Portland Gale" from <http://www.hazegray.org> for more information on the *Portland* and the monster storm of 1898. Visit <http://oceanexplorer.noaa.gov> for up-to-date information on the 2003 Steamship *Portland* expedition.
2. Briefly review the story of the *Portland* and the gale of 1898.
3. Tell students that their assignment is to prepare a written report on waves, including a prediction and explanation of the effect of extreme storms on their formation. Reports should include answers to the following questions:
 - What are waves?
 - What causes tsunamis?
 - How do waves form?
 - What factors determine the size of waves and tides?
 - What are: still-water line, crest, trough, wave height, wavelength, wave period, wave frequency, amplitude, capillary waves, wind

wave, fully developed sea, seiche, disturbing force, undulation, wave trains?

- What does the shape of a wave tell about its origin?
- What is the difference between sea and swell?
- At what depth does wave motion become negligible?
- What was the fetch of winds developed in the Halloween Nor'easter of 1991?
- What were the maximum winds measured in the Halloween Nor'easter of 1991?
- What inferences can you draw concerning the waves that were associated with the Halloween Nor'easter of 1991?

The following websites have useful information for completing this assignment:

- <http://pao.cnmc.navy.mil/educate.neptune/quest/wavetide/waves.htm> – Naval Meteorology and Oceanography Command website with information on waves and tides
- <http://www.ncdc.noaa.gov/oa/satellite/satelliteseye/cyclones> – National Climatic Data Center with information on extratropical cyclones
- <http://www.nhc.noaa.gov> – National Hurricane Center, with historical information on hurricanes
- http://www.ndbc.noaa.gov/Maps/northeast_hist.html – National Data Buoy Center website with real-time as well as historical data for data buoys in the northeast

4. Lead a discussion of students' research results. Written reports should include most of the following points:
 - Waves are an up-and-down motion of water caused by a flow of energy. Water particles move vertically in a circular pattern; there is no net horizontal movement (even though it looks like there is!).
 - Tsunamis are caused by earthquakes or volcanic eruptions that provide a disturbing force which causes large waves to form. They are sometimes called tidal waves, but are not caused by tides.
 - Waves are formed when a disturbing force

transfers energy to water particles, causing the particles to move up and down.

- The size of waves is determined by wind speed, wind duration, and fetch (the distance over which wind blows without changing direction).
- The still-water line is the level of the ocean surface if it were flat without any waves.
- The crest of a wave is the highest part of a wave above the still-water line.
- The trough of a wave is the lowest part of a wave below the still-water line.
- Wave height is the vertical distance between the crest and trough of a wave.
- Wavelength is the horizontal distance between two consecutive crests or two consecutive troughs.
- Wave period is the time required for two consecutive waves to pass the same point.
- Wave frequency is the number of waves that pass a particular point in a given period of time.
- Amplitude is the distance from either the crest or trough of a wave to the still-water line, also equal to one-half the wave height.
- Capillary waves are small ripples caused by wind blowing over a smooth water surface.
- Wind waves are waves whose wavelength exceeds 0.68 inch.
- A fully developed sea is the largest wave size theoretically possible for a specific wind speed, wind duration, and fetch.
- A seiche is a wave formed by rocking of water in an enclosed area, such as a harbor or lake.
- A disturbing force is a source of energy that causes waves, such as wind blowing across a water surface, landslides, earthquakes, or volcanic eruptions.
- Undulation is a smooth, regular rising and falling movement.
- Wave trains are progressing groups of swell with the same origin and wavelength.
- A steep, choppy wave is fairly young and was probably formed nearby. A slow, steady wave with high crests near shore is an older wave, probably formed far away.

- Seas are waves with irregular patterns in the same area as the wind that produced the waves. When waves move past the winds that generated them, they are called swell.
- Wave motion becomes negligible when the water depth exceeds one-half the wavelength.
- The fetch of winds developed in the Halloween Nor'easter of 1991 was 700+ miles.
- During the Halloween Nor'easter of 1991, NOAA buoy 44011 at 41.1°N, 66.6°W, reported maximum sustained winds of 49 kt with gusts to 65 kt; NOAA buoy 44011 at 41.1°N, 66.6°W, reported maximum sustained winds of 49 kt with gusts to 65 kt; NOAA buoy 44008 at 40.5°N, 69.5°W, reported maximum sustained winds of 53 kt with gusts to 63 kt; Canadian buoy 44137 at 42.26°N, 62.0°W, reported sustained winds of 80 kt.
- The maximum wave height in feet is usually one-half or less the wind speed in miles per hour, so the maximum expected wave height during the Halloween Nor'easter of 1991 would be around 45 ft. Canadian buoy 44137, though, reported wave heights of more than 100 ft. This might be due to instrument error, or to the interplay of weather factors that are not fully understood. It is also possible that wind speed, wind duration, and fetch interact in unusual ways at high values of these factors.

THE BRIDGE CONNECTION

<http://www.vims.edu/bridge/archive1200.html/>

<http://www.vims.edu/bridge/climate.html>

THE "ME" CONNECTION

Have students write a short essay describing a personal encounter with waves.

CONNECTIONS TO OTHER SUBJECTS

English/Language Arts, Physics, Mathematics

EVALUATION

Written reports prepared in Step 3 provide an opportunity for assessment.

EXTENSIONS

Log on to <http://oceanexplorer.noaa.gov> to keep up to date with the latest Steamship *Portland* discoveries.

RESOURCES

Bachelor, P. D. and M. P. Smith. 2003. Four Short Blasts. The Gale of 1898 and the Loss of the Steamer *Portland*. The Provincial Press. Portland, ME.

<http://www.hazegray.org/> – Website with information on naval ships, photos, etc., and a page about the *Portland* Gale of 1898

http://www.ndbc.noaa.gov/Maps/northeast_hist.shtml – National Data Buoy Center website with real-time as well as historical data for data buoys in the northeast

<http://www.ncdc.noaa.gov/oa/satellite/satelliteseye/cyclones> – National Climatic Data Center website with information on extratropical cyclones

<http://www.nhc.noaa.gov> – National Hurricane Center website, with historical information on hurricanes

<http://pao.cnmoc.navy.mil/educate.neptune/quest/wavetide/waves.htm> – Naval Meteorology and Oceanography Command website with information on waves and tides

<http://school.discovery.com/lessonplans/programs/tidalwave/index.html> – Discovery Channel School lesson plans on tsunamis (tidal waves)

NATIONAL SCIENCE EDUCATION STANDARDS

Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard B: Physical Science

- Motions and forces
- Interactions of energy and matter

Content Standard D: Earth and Space Science

- Energy in the Earth system

Content Standard E: Science and Technology

- Abilities of technological design

Content Standard F: Science in Personal and Social Perspectives

- Natural and human-induced hazards

FOR MORE INFORMATION

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