

SOund Fixing And Ranging - SOFAR (So Good!)

<http://www.coexploration.org/bbsr/classroombats/html/sofar.html>

SOUND IN THE OCEAN

National Science Education Standards:

Unifying Concepts & Processes: Constancy, change, and measurements

Science As Inquiry: Abilities necessary to do scientific inquiry

Physical Science: Interaction of energy and matter

Life Science: Matter, energy, and organization in living systems

Earth and Space Science: Energy in the earth system

Science and Technology: Understandings about science and technology

Objectives:

After this activity, students should be able to:

1. Understand how changes in temperature and pressure (due to going deeper in the ocean) each affect the speed of sound.
2. Explain how, as you go deeper in the ocean, increasing pressure and decreasing temperature combine to form a sound speed minimum channel (the SOFAR channel).
3. Describe the sound transmission properties of the SOFAR channel.
4. Describe possible natural and human uses of the SOFAR channel.
5. Predict the speed of sound in ocean water given its temperature and pressure.

Materials:

Large bucket filled with water

Garden hoses

OceanExplorer interactive worksheet (*if computers are available, optional*)

Concepts:

Humpback whales migrate thousands of kilometers each year. How do they keep track of each other during these long journeys? Many scientists think that humpback whales use the SOFAR Channel to communicate across these vast distances.

What is the SOFAR Channel? It's a layer of water deep in the ocean (near Bermuda it's around 1000 m deep) where the speed of sound is at a minimum. Sound waves can get caught in this channel and travel hundreds of kilometers. Scientists think that humpback whales may dive down to this channel and "sing" to communicate with other humpback whales many kilometers away.

The SOFAR channel is formed by the interplay between changes in ocean temperature and pressure with increasing depth. Temperature and pressure are the two main factors that determine the speed of sound in the ocean. "SOFAR" stands for Sound Fixing And Ranging.

Let's take a closer look at the SOFAR channel and how it works. (The "BATS" data in this activity takes its name from the Bermuda Atlantic Time-series Study, a long-term

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program of the Bermuda Biological Station for Research (BBSR). Scientists in this program set sail every month to study the chemical, physical, and biological properties of the ocean near Bermuda, with a focus on the ocean's role in global environmental change. The data collected by BATS scientists represent the world's longest continuous time series of open-ocean measurements.)

Activities/Procedure:

1. First introduce the concept of a sound channel by performing Hands-on Activity #1 below.
2. Now have the students use OceanExplorer data to explore what parameters affect the speed of sound and to answer the following three sets of questions. *(If you have access to computers with Excel students can collect the data and generate the graphs themselves. If not, the graphs are provided for class discussion.)*

To use OceanExplorer:

<http://www.coexploration.org/bbsr/classroombats/html/oceanexplorer.html>

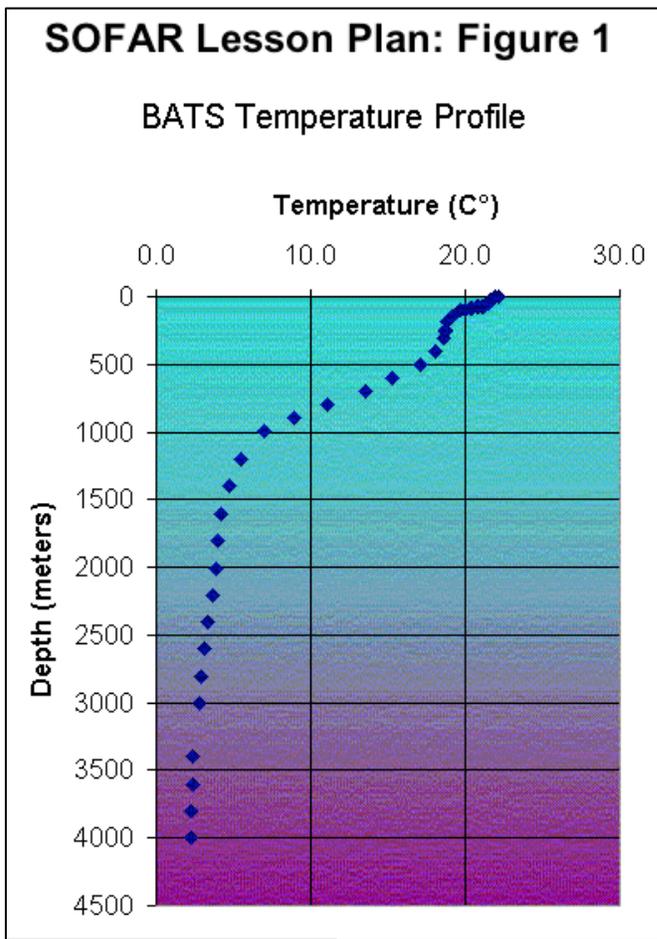
a. Open OceanExplorer and use the autofilter button to select data from a single year (e.g., 1990).

b. Then use the autofilter to select data from a single cruise (e.g., Cruise 19).

Select a cruise on which measurements were collected from a wide range of depths.

c. Extract this data (using the Extract Data button) to another sheet.

d. From the view menu, select toolbars and select the "Speed_of_Sound" toolbar so it's ready when you need it.

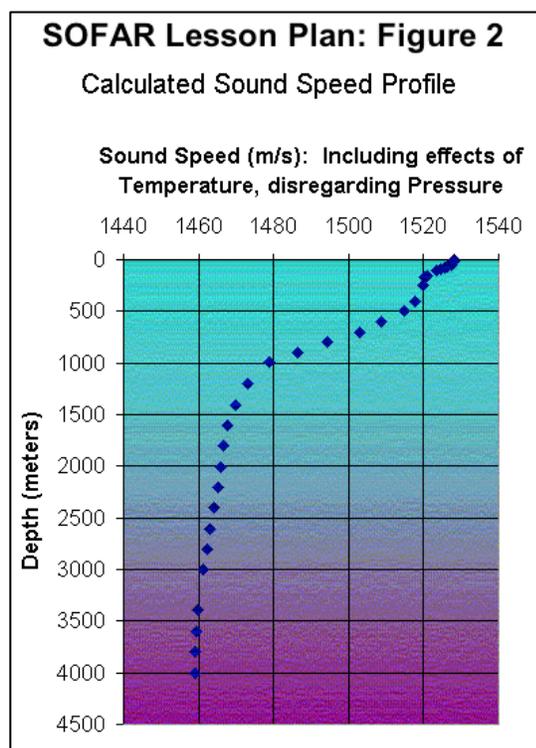


Effects of temperature on the speed of sound

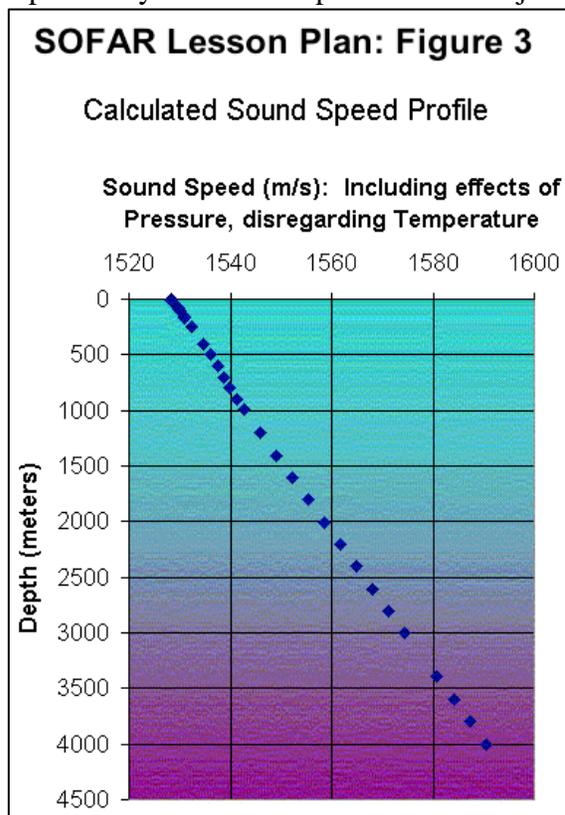
It's a fact of physics that the speed of sound in water decreases as the temperature decreases. So how does the change in temperature as you go deeper in the ocean affect the speed of sound? First, we need to look at how temperature varies with depth in the ocean. Refer to Figure 1. *(In OceanExplorer: Press the Temperature (Depth Profile) button to see how temperature varies with depth for this data set. Your students' graphs should look something like Figure 1.)*

How does temperature vary with depth?
Does it change at the same rate the whole way down? (If different students have extracted and plotted data from different years or cruises, ask them to describe and discuss the differences among their temperature profiles.)

Next, we'll look at how sound speed varies with temperature (taking pressure out of the equation). Refer to Figure 2. (In *OceanExplorer*: With the data set you acquired above, press the "Sound Speed Depth Profile" button on the "Speed_of_Sound" toolbar. Choose the second option: Including temperature, disregarding pressure. You should get a sound speed profile that resembles Figure 2.)



How similar is this profile of sound speed vs. depth (where pressure was disregarded) to the previous profile of temperature vs. depth? Do you think temperature is a major factor on the speed of sound in water?



Question Set 2.2: Effects of Pressure on the speed of sound

Now let's look at how sound speed varies with pressure (taking temperature out of the equation). Refer to Figure 3. (In *OceanExplorer*: With the same data set as above, press the "Sound Speed Depth Profile" button on the "Speed_of_Sound" toolbar. This time choose the third option: "Including Pressure, disregarding Temperature." You should get a sound speed profile that resembles Figure 3.)

What is the relationship between pressure and the speed of sound in the water?

Question Set 3.2: Effects of both Temperature & Pressure on the speed of sound

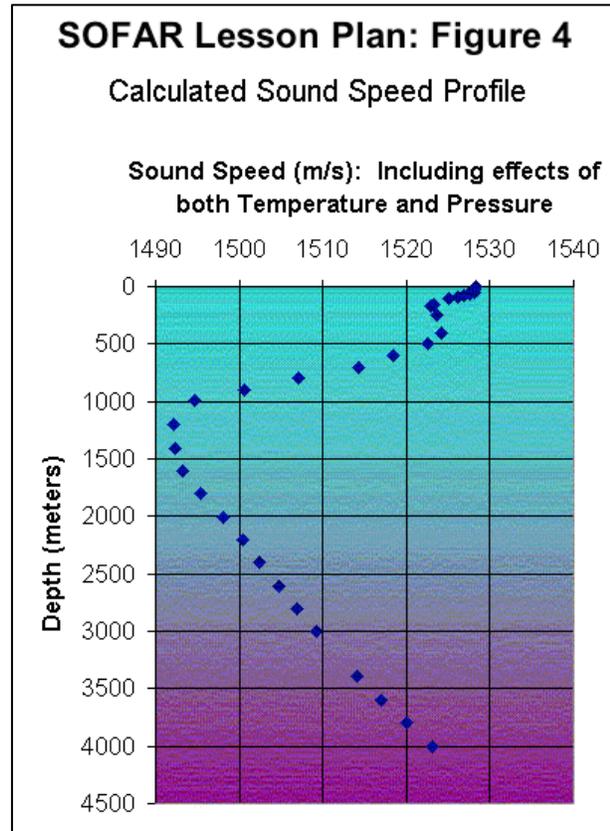
Now let's examine a sound-speed profile when both pressure and temperature are

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considered. The speed of sound in water depends on both temperature and pressure. Refer to Figure 4. (*In OceanExplorer: With the same data set as above, press the "Sound Speed Depth Profile" button on the "Speed_of_Sound" toolbar. Choose the first option: "Including both Temperature and Pressure". You should get a sound speed profile that looks like Figure 4.*)

Near the surface, where the water temperature changes quickly (Figures 1 and 2), temperature has a large effect on the speed of sound. Thus the top of the speed-of-sound profile tends to follow the temperature profile, and the speed of sound decreases as temperature decreases. At depth, the temperature becomes more constant, but pressure is still changing (Figure 3). Thus the bottom part of the speed-of-sound profile tends to follow the pressure profile. Since the speed of sound varies with pressure, the speed of sound increases as pressure increases with increasing depth. Thus there is a mid-water sound speed minimum, visible in Figure 4. At what depth is this sound speed minimum found?

So, now we've found a region where the speed of sound is at a minimum.



3. SOFAR Channel:

Sound waves bend towards a region of minimum sound velocity due to refraction. Thus a sound channel forms where the speed of sound is at a minimum in the ocean. This is the "SOFAR" channel. To demonstrate this concept, have the students perform Hands-on Activity #2 below.

4. Uses of the SOFAR Channel by Humans and Animals:

After having gone through this discussion, what ways can you think of to use an underwater sound channel? Have the students list possible ways of using the SOFAR channel. See student worksheet answer key for some examples.

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Hands-on-Activity #1: A garden hose as a sound channel

This activity introduces the concept of a sound channel. It also shows how organisms, such as humans or whales, can use a sound channel to communicate.

Bring in a few garden hoses. Assign several students to each hose and have them stretch it as far across the room as space permits. Have the student on one end put his/her ear to the hose, and have the other student whisper into the hose. Tell the students to whisper softly so the sound is not too loud. Then have the students switch who is whispering and listening and pass the message back. See how softly they can whisper before the message is inaudible. Make sure each student is able to both listen and whisper.

Now ask the students to put down the hoses and perform the same task by just whispering across the room. Ask the students which method was most likely to get their message across just by whispering. Also have them hypothesize why this is true, and how humans could use this concept in their daily lives (expanding from the garden hose example, of course).

Hands-on-Activity #2: The Speed of Sound in Water

This activity introduces the concept of how sound can get caught in medium with a lower sound speed and not be able to cross a sound-speed boundary.

Have a pair of students fill a large bucket with water (fresh water is fine). Ask for volunteers (some of whom are willing to get their heads wet). Ask one student to put his/her head (at least up to both ears) in the bucket of water. Then ask another student to say something to the first student (e.g. "You water-wallowing walrus!"). The student with his/hers head in the bucket tries to understand what is being said.

Have the students come up with ideas why the student with their head in the bucket wasn't able to hear the other student. (The speed of sound in air is slower than the speed of sound in water. Since the sound-speed difference is so large, the sound waves bounce off the boundary between the media).