SOFAR Student Worksheet – Answer Key

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 do you think the change in temperature as you go deeper in the ocean affects the speed of sound? Use Figure 1 or BATS data for temperature at depth in the ocean.

How does temperature vary with depth? Does it change at the same rate the whole way down? *Student's graphs should show relatively fast cooling in the surface layers, tapering to a pretty constant temperature at depth. The area with rapid temperature change is called a* ***thermocline****.*

How does sound speed vary with temperature (taking pressure out of the equation)? Refer to Figure 2/BATS profile of sound speed vs. depth (where pressure was disregarded). How similar is this profile of sound speed vs. depth (where pressure was disregarded) to the previous profile of temperature vs. depth? *Speed profile based on temperature only should be similar to the first graph. Speed of sound decreases with colder temperatures.*

Do you think temperature is a major factor on the speed of sound in water? *Yes!*

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/BATS profile of sound speed vs. depth (where temperature is disregarded).

What is the relationship between pressure and the speed of sound in the water? *There is a linear relationship: speed of sound increases as pressure increases. Pressure continues to change at depth, unlike temperature that becomes relatively constant.*

Effects of Both Temperature & Pressure on the Speed of Sound
Now let's examine a sound-speed profile when both pressure and temperature are considered. The speed of sound in water depends on both temperature and pressure. Refer to Figure 4/BATS data.

Describe how changes in temperature and pressure (due to going deeper in the ocean) each affect the speed of sound. *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.*

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Find the region where the speed of sound is at a minimum. At what depth is this sound speed minimum found? *In this data (BATS – Bermuda Atlantic Time-series) it is found at about 1000m.*

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. "SOFAR" Stands for SOund Fixing And Ranging.

What ways can you think of to use an underwater sound channel? List possible ways both people and animals might use the SOFAR channel.

Examples:
Humans:

ATOC project: Acoustic Thermometry of Ocean Climate – measuring global warming using the speed of sound in the ocean. Scientists proposed playing sounds across the ocean using the SOFAR channel. As we learned above, the speed of sound in water depends heavily on temperature. So how fast the sound arrives at the other side would depend on the temperature of the ocean basin. In this way the scientists could measure the temperature of the whole ocean. For a congressional report on ATOC and related marine mammal issues, see http://www.cnie.org/nle/mar-2.html

SOSUS array: US Navy Sound Surveillance System – array of hydrophones (underwater microphones) used by the Navy for deep ocean surveillance during the cold war. The SOSUS array has since been used for seismic monitoring, marine mammal monitoring, and for the ATOC project. For more information on the SOSUS array, see http://newport.pmel.noaa.gov/geophysics/sosus_system.html#GENERAL

Tracking of vessels in distress – Before GPS (Global Positioning System) the SOFAR channel was used for locating ships and aircraft in distress as well as for tracking floats for the study of ocean currents.

Animals:

Humpback Whales:

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. 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.