Heat Capacity: Can't Take the Heat?

A Classroom Activity for Ocean Gazing Episode #11: Penguins in the hot seat

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Grade Level: 6-12
Lesson Time: 45 min

Materials Required

Student Worksheet, Figures 1-3, Completed Graph, Ruler, Graph paper (optional)

Summary

Why does coffee take so long to cool down? Why is ocean water sometimes the warmest when the average daily air temperature starts to drop? How can buoys help us explore these questions? In this hands-on introduction to heat capacity by the Bridge and COSEE-NOW, students explore the concept and its effects on our daily lives. Students use ocean observing system data to investigate why water acts as a thermal buffer and the practical applications this has.

Objectives

- ✓ Analyze graphs of air and water temperature
- ✓ Create graphs of temperature range
- ✓ Describe the difference in the heat capacities of air and water
- ✓ Explain the practical applications of water's high heat capacity

Vocabulary

Heat capacity, Specific heat, Buffer, Thermal buffer

Introduction

Imagine it's the beginning of fall. School has been back in session for a few weeks and the temperature is beginning to cool as autumn quickly approaches. At dinner one night, your parents surprise you with a trip to the beach for the weekend. Normally, if it were summer, this would be great news—hot sun and the refreshing ocean water! Unfortunately, the beach is not located in one of those areas that stay warm year-round. So how much fun will this weekend be if you cannot swim in the ocean!?

The weekend finally arrives and you find yourself in your bathing suit standing inches from the breaking waves. The air temperature is in the mid-70s, but you're at the beach, so you must brave the coldest of water temperatures to get your money's-worth out of the trip. Finally, you take a deep breath, grit your teeth and run full speed into the water expecting it to feel like the Arctic the instant it touches your skin.

Once submerged, you come up for air and are ready to run out just as fast as you ran in, and curl up in your beach towel. But wait! You soon realize that the water is not cold at all, but instead, actually warmer than the air all around you. As you continue to splash around, riding waves and swimming, you start to ponder how this is even possible. How could the water actually be warmer than the air after it's been so cool out the past few days? The difference has everything to do with the heat capacities of the two substances.

Heat capacity is the amount of heat required to raise the temperature of a object by 1 degreeC without changing the state of matter. It is measured in Joules/degreesC and its value is proportional to the amount of material in the object; for example, a lake has a greater heat capacity than a puddle.

The specific heat is the actual quantity of heat energy required to raise 1 gram of a substance 1° C and it is typically measured in J/g degreesC. Water has a much higher heat capacity, and specific heat, than air, meaning it takes more energy to heat water than it does to heat air. Water has a specific heat of 4.186 J/g degreesC, versus air, which has a specific heat of 1.005 J/g degreesC.

In the beach scenario above, the water was actually warmer than the air, despite the recent lower air temperatures. This is because of water's much higher heat capacity than air; and because of its higher heat capacity, it takes longer for water to gain and lose heat (cool), than it does for air. In both cases, either heating or cooling, there will be a lag between the air and water temperatures. Because of this, you may also find chilly water temperatures in early summer, even though the air temperature has been in the 80s and 90s for weeks.

The heat capacity of water has tremendous effects on the climate of the surrounding area. Because the water buffers the air temperature, the range of air temperature near water bodies is often smaller than the air temperature range further from large bodies of water. On a greater scale, because the ocean occupies over 70% of the Earth's surface, it buffers the atmospheric temperature, providing a livable climate.

In addition to keeping the Earth's atmospheric temperature in check, water's high heat capacity has numerous practical applications for humans. We use water to prevent engines from overheating in automobiles, boats and power plants. This is also why water is used in fire fighting; it absorbs the heat of the material it comes in contact with, dissipates the heat as it changes from liquid to gas, and actually lowers the temperature of the fire. At the same time, the water increases the heat capacity of the material, making it harder for the fire to burn the material. The human body even benefits from water's high heat capacity when we sweat!

You often come in contact with materials that have different heat capacities. Perhaps you have walked home from the beach on a hot, sunny day without wearing shoes. The sand is scorching, so you quickly walk to the street, which you find is also hot, so you move to the sidewalk, which may be only slightly cooler, so you end up on the grass, which is the coolest. These materials each have very different heat capacities. Although they are all subject to the same sun exposure, they all store the thermal energy at different rates and thus radiate different temperatures to your bare feet.

The heat capacity of a material is very carefully considered in the construction of houses and other buildings. The ability of a material to collect and tolerate heat and then effectively dissipate it is critical to ensuring the durability and safety of a structure, and the comfort of its inhabitants.

Data Activity

Using the information learned above, you will now explore air and water temperature data from four monitoring stations in Virginia along an inland-to-offshore gradient. Two of the stations are NOAA National Climate Data Center monitoring stations. These are located in Amelia and Petersburg, VA and students will use only air temperature data from these stations. The other two stations are ocean observing system buoys; one is located in the James River, VA and is a part of the Chesapeake Bay Interpretive Buoy System, which is a part of the NOAA Chesapeake Bay Office. The second buoy is a NOAA National Data Buoy Center entity. From these two buoys, students will use both air and water temperatures.

A. General Analysis

1. Print out and distribute the Student Data Worksheet and Figures 1-3.
2. Using the scale in Figure 1 (map of the four monitoring stations) and a ruler, measure the distance between each station and Virginia Beach, VA. Enter the distance (in miles) into column 4 in Table 1. The first one has been done for you.
3. In column 5, convert the distance measured from miles to kilometers using the following conversion:

   1 mile = 1.609 kilometers

4. In column 6, indicate the direction the station is in relation to Virginia Beach, VA (N, S, E, W, etc.). The first one has been done for you.
5. In column 7, record the maximum and minimum temperatures for each parameter. The first one has been done for you.
6. In column 9, calculate the 2008 temperature range for each parameter. To calculate, subtract the minimum temperature from the maximum temperature.

B. Graphing and Graph Analysis

Using Figure 2, a blank graph, graph the temperature range data (Table 1, columns 7 and 8) by hand and then discuss trends as a class or in small groups.
*Note to teachers: If students are graphing by hand, instructions on how to create a floating stacked column graph, as seen in Figure 2a, may need to be given. If students do not need graphing practice, use the completed graph found here to discuss trends as a class or in small groups.

C. Additional Analysis

Answer the following questions after viewing Figure 3, air and water temperature from the Chesapeake Bay Interpretive Buoy System (CBIBS) buoy at Jamestown, VA from April 13-20, 2008.

- ✓ What is the range of the air temperature during this time period?
- ✓ What is the range of the water temperature?

D. Real Time Data Analysis: www.buoybay.org

Visit the CBIBS website and click on Get Data for one of the buoys. On the buoy page, click on Buoy Data to view the data.

- ✓ Which buoy was selected?
- ✓ Record the date and time of the most recent data.
- ✓ What are the air and water temperatures at this buoy?
- ✓ What else is measured by this buoy?

Now click on the air temperature data for the past seven days at this buoy ("7" in the Graphs column at far right).

- ✓ What are the dates these data were recorded?
- ✓ What is the air temperature range over the past 7 days?

Repeat for water temperature data.

- ✓ What is the water temperature range over the past 7 days?
- ✓ Are the two temperature ranges comparable or is there a large difference between them?

Discussion and Application Questions

1. From Table 1 and either the graph students created (Figure 2) or the completed graph (Figure 2a), what is the trend in air temperatures moving from west to east?
2. From Table 1, Figure 2/Figure 2a and Figure 3, what is the trend in air temperature range versus water temperature range?
3. In addition to the applications discussed in the introduction, how else can water's high heat capacity be utilized?
4. Describe advantages and disadvantages of buoy sensor technology.

Extensions

1. Using the NOAA National Data Buoy Center buoys (www.ndbc.noaa.gov), explore archived air and water temperature data from a monitoring station near you, or at your favorite vacation spot. What trends exist in the data?

2. Complete heat capacity lab activities:
   - ✓ Teach Engineering Activity: How Much Heat Will It Hold?
   - ✓ Coastal Versus Inland Temperatures
   - ✓ Forces of Nature: Temperature
3. Use various statistical measures to further explore the air and water temperature, or other data that are available to determine if the trends are significant.

Other Resources

- ✓ Bridge Ocean Observing System Depot – Observing system primer, links, and activities
- ✓ COSEE-Networked Ocean World – Observing system resources, blogs, forums and resources

Related Resources

Chemical oceanography, Technology, Ocean Observing Systems

References

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"Coastal Versus Inland Temperatures." Ocean Planet.
http://er.jsc.nasa.gov/seh/Ocean_Planet/activities/ts1ssac3.pdf

"Forces of Nature: Southern California Weather." Earthguide, Scripps Institution of Oceanography.
http://earthguide.ucsd.edu/weather/

Sources

To access an online version of this activity, you can go to the following URL:
http://www2.vims.edu/bridge/DATA.cfm?Bridge_Location=archive0909.html

The related podcast episode for this activity can be found by going to the podcast section of www.oceangazing.org