Using Corals to Determine Past Sea Temperatures

Purpose

This lesson asks students to apply an understanding of the relationship between temperature and the kinetic energy of particles and heat transfer. It also introduces students to the effects of climate change on corals.

Audience

This lesson was designed to be used in an introductory high school physics course.

Lesson Objectives

Upon completion of this lesson, students will be able to:

- describe how thermal energy affects the kinetic energy of water molecules in the oceans.
- explain how heat is transferred through radiative forcing.

Key Words

El Niño, radiative forcing

Big Question

This lesson addresses the Big Question *"What does it mean to observe?"*

Standard Alignments

- **Science and Engineering Practices**

  SP 4. Analyzing and interpreting data

- **MA Science and Technology/Engineering Standards (2016)**

  - **HS-PS3-1.** Use algebraic expressions and the principle of energy conservation to calculate the change in energy of one component of a system when the change in energy of the other component(s) of the system, as well as the total energy of the system including any energy entering or leaving the system, is known. Identify any transformations from one form of energy to another, including thermal, kinetic, gravitational, magnetic, or electrical energy, in the system.
  - **HS-PS3-2.** Develop and use a model to illustrate that energy at the macroscopic scale can be accounted for as either motions of particles and objects or energy stored in fields.

- **NGSS Standards (2013)**

  - **HS-PS3-2.** Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motion of particles (objects) and energy associated with the relative positions of particles (objects).

- **HS-PS3-4.** Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics).

- **Common Core Math/Language Arts Standards**

  - **CCSS.ELA-LITERACY.RST.9-10.7.** Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words.

Misconception Addressed

- This lesson addresses a common misconception about heat transfer, specifically that it is friction between light and molecules on Earth that lead to heat transfer from the sun (Question 8).

- Further information about student misconceptions on this topic can be found here.

Primary Sources

- **Bite** "Corals Can't Talk, but They Can Tell Us a Lot" based on:

  Jimenez, Gloria, Julia E. Cole, Diane M. Thompson, and Alexander W. Tudhope. "Northern Galápagos Corals Reveal Twentieth Century Warming in the Eastern Tropical Pacific." *Geophysical Research Letters* 45, no. 4 (2018): 1981-988. doi:10.1002/2017gl075323.

  "First Evidence of Ocean Warming Around Galapagos Corals." University of Arizona Stem Learning Center. Accessed August 14, 2019.

- **Misconceptions**

  Pathare, S R, and H C Pradhan. 2010. "Students' Misconceptions about Heat Transfer Mechanisms and Elementary Kinetic Theory." *Physics Education* 45 (6): 629–34.

Materials

Copies of the Student Handout and Science Bite for each student

Time

This lesson should take approximately one 50-minute class period.

Student Prior Knowledge

Students should know that temperature is a measure of the average kinetic energy of molecules. They should also be familiar with the three types of heat transfer: conduction, convection, and radiation.

Instructions and Teacher Tips

General Procedure

- Instruct students to read the Introduction on the Student handout and answer the first two analysis questions.
- Distribute the Bite and tell students to read and annotate it. One option for annotating is to have students star main ideas, underline new vocabulary, and put a question mark next to phrases they find confusing. This will help students remember key information and ask questions.
- Have students answer the remaining analysis questions.
- Discuss the answers to the questions and the research discussed in the Bite as a class.

Tips, Extensions, and Variations

- Additional information about why the Galápagos are so special may help students develop an appreciation for why it is important that we understand the impact climate change is having there. This page from the World Wildlife Fund describes some of the key reasons why this landscape is unique. Students may be especially interested to see pictures of the giant tortoises, marine iguanas, and other animals that live on the islands.
- If you have struggling readers or English language learners, consider having students read the Introduction and/or Bite aloud in small groups. Or read it aloud to them yourself.
- As an extension, there are other sets of temperature data related to climate change that you can discuss with students. NASA has interactive data available here.
- If your class is also studying specific heat, you could have students calculate the amount of heat energy needed to raise a certain amount of water by 0.17°C and the same amount of soil 0.17°C. The specific heat of dry soil is about one-fifth of that of water, so students should note that it takes much more heat energy to heat water than soil. This can lead to a discussion about how large the difference in the amount of heat hitting Earth's surface compared to the amount leaving must be in order to increase global ocean surface temperatures. You can also discuss why land surface temperature is rising faster than ocean surface temperature.
- This lesson was developed as part of a series of lesson plans developed by Knowles Teacher Initiative Fellows in their inaugural program in the Galápagos through the Knowles Experiential Learning Project.

Background Information and Research Details

- The Galápagos climate is largely influenced by ocean currents. The Humboldt current brings in cold water from the south while the Panama current brings warm water from the north. Additionally, the Cromwell current causes upwelling (the rising of deep seawater) to the west of the islands. The Cromwell current brings cold water and a great deal of nutrients to the waters surrounding the Galápagos. The combination of these currents causes the Galápagos to have a mild climate throughout the entire year.

- Climate change is having a wide variety of impacts in the Galápagos Islands. For example:
  - Changes in temperature and rainfall are making it easier for invasive species like blackberry to thrive on the islands. The increase in dense thickets of blackberries makes it more difficult for giant tortoises to migrate to and from beaches during breeding season which impacts the ability of the tortoises to reproduce.
  - Environmental temperature impacts the ratio of male to female sea turtle eggs in the Galápagos. Higher temperatures lead to more female sea turtles. With lower male counts, it is more difficult for the sea turtles to breed.
  - An increase in rainfall can lead to cacti collapsing under the stress of too much water.
  - Warming ocean temperatures have caused the Humboldt current to slow down, leading to fewer nutrients in the water offshore. This decreases the amount of algae and seaweed. Marine iguanas rely on algae and seaweed for food, so their survival is becoming more challenging. Other animals such as Galápagos penguins and blue-footed boobies are also struggling from the effects of dwindling food sources.
  - Warmer oceans are also leading to more intense storms which can damage wildlife in the Galápagos Islands. After a storm has started developing, warmer ocean water underneath it can cause it to become more intense very quickly.
- Scientists are also using coral skeletons and limestone rock to gather data about temperatures from thousands of years ago. This data helps scientists understand ancient warming trends and create better models of what will happen as our climate warms.
- There are numerous types of indirect data that scientists use to learn more about Earth's climate in the distant past. NOAA has a succinct overview here.

Big Question Discussion

This lesson should get students thinking about the Big Question "*What does it mean to observe?*" In particular, how are indirect measurements useful ways of making observations? If you choose to delve into the Big Question, consider the following ideas:

After students answer the last question on the Student Handout, you can have them discuss the Big Question using one or more of the following prompts:

- Why is it important to have historical temperature data from around the world?
- When scientists communicate ideas about indirect measurements, what do you think is important to discuss with the public about these types of measurements in order to ensure the public understands that these measurements are accurate?

Answers

1. As El Niño develops, does the average molecular kinetic energy of the surface water surrounding the Galápagos Islands tend to increase, decrease, or stay the same? Explain your answer.

The average molecular kinetic energy of the surface water surrounding the Galápagos Islands would tend to increase. Temperature is a measurement of average molecular kinetic energy. As temperature increases, so does the average molecular kinetic energy. As El Niño develops, the water becomes warmer and therefore the average molecular kinetic energy increases.

2. La Niña is another cyclical climate event that leads to colder water around the Galápagos Islands. How is the average molecular kinetic energy of the surface water impacted by La Niña? Explain your answer.

The average molecular kinetic energy of the surface water surrounding the Galápagos Islands would tend to decrease. Temperature is a measurement of average molecular kinetic energy. As temperature increases, so does the average molecular kinetic energy. As La Niña develops, the water becomes cooler and therefore the average molecular kinetic energy decreases

The corals used in this study did not grow for two years between 1940 and 2010. Scientists could not determine temperature data for these years. A summary of their findings is in **Figure 2** below.

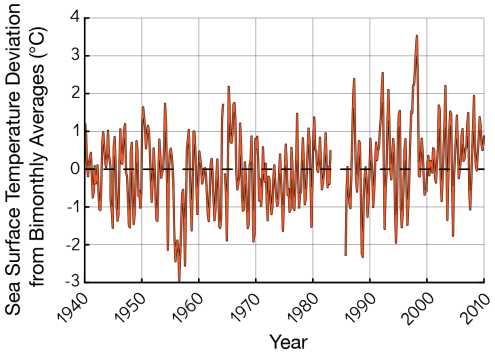

Figure 2. Sea Surface Temperature Deviation from Bimonthly Averages by Year. Scientists used coral core samples to determine how temperatures varied from the average temperature from 1940 to 2010. *Source:* Jimenez et. al., 2018.

3. Use **Figure 2** to answer the following questions.

   a. Using the graph, identify the two-year period when the corals experienced no growth. How do you know?

The corals experienced no growth from approximately 1983 to 1985. I can tell that the corals did not grow during this time, because there are no temperature records from this time period.

   b. Based on the introduction and the Bite, why do you think the corals stopped growing during that time?

The corals stopped growing during that time period, because of the immense stress they had experienced from the 1982–83 El Niño event.

c. Approximately in which year between 1940 to 2010, was the average molecular kinetic energy of the molecules in the waters around Wolf Island **greatest**? When were they the **smallest**? Explain your answers using evidence from the figure.

The average molecular kinetic energy of the molecules was greatest in approximately 1998 and lowest in approximately 1956. Temperature is a measure of average kinetic energy of molecules, so the lower the temperature, the lower the average kinetic energy of the molecules. The highest temperature recorded happened in about 1998 and the lowest happened in 1956.

In a part of the paper not covered in the Science Bite, the scientists note that their results support the conclusion that radiative forcing is the primary reason that average ocean surface temperatures around the Galápagos Islands and around the world have increased since 1940. **Radiative forcing** is the difference between the amount of energy from the sun that reaches Earth and the amount that is reflected back into space from Earth's surface.

4. Thinking about radiative forcing, explain how heat is transferred from the Sun to the ocean surface around the Galápagos Islands (and around the world).

Electromagnetic (light) waves from the Sun hit Earth. The waves are absorbed by the Earth's oceans (and land) and the light energy becomes thermal energy.

The global increase in greenhouse gasses such as carbon dioxide is preventing some light energy from being reflected into space.

5. How is the increase in greenhouse gasses impacting radiative forcing? Describe how it is changing the difference in energy hitting Earth's surface and the amount of energy reflected back into space.

As greenhouse gasses increase, more light energy is hitting Earth's surface, because instead of bouncing off the Earth's surface and going back into space, it is trapped by the greenhouse gasses and gets reflected back toward the surface.

6. Why would an imbalance in the amount of energy hitting Earth's surface and the amount reflected from Earth's surface lead to an overall increase in surface temperatures?

More energy hitting Earth's surface means that more energy can be absorbed by Earth's surface. As more light energy is absorbed, it is converted into thermal energy.

In addition to generally increasing ocean surface temperatures, these global temperature changes also make El Niño events more frequent and extreme, which poses a risk to corals and other parts of the Galápagos ecosystem.

7. Given what you read in the Bite and the data in Figure 2, what is likely to happen to corals in the Galápagos Islands as El Niño events become more extreme?

Corals will have a hard time surviving more frequent and extreme El Niño events. The El Niño events stress the corals, damage them, and cause them not to grow. If they are stressed enough, they will die and the coral reef will not be able to recover.

8. A student contends that there is friction between water molecules and photons from sunlight. He states that this friction creates thermal energy, and this is the primary cause of ocean warming and more extreme El Niño events. Identify at least two flaws in this student's reasoning.

It isn't friction between water molecules and photons from sunlight that causes thermal energy. The light energy gets absorbed and becomes thermal energy as the molecules move faster. Additionally, the cause of ocean warming is the increase in greenhouse gasses trapping more energy in Earth's atmosphere.

9. **Connect to the Big Question**. Sometimes scientists can make measurements they are interested in directly. In this study, scientists wanted to know what the temperature of the water around the Galápagos Islands had been over the last several decades, but a record of direct temperature readings was not available. Instead, they used the natural changes in coral skeletons to indirectly measure these temperatures. How do indirect measurements increase scientists' abilities to make observations? Why are indirect methods of measurement important? Can you think of any examples of how you observe temperature qualitatively in your everyday life indirectly?

Sample answer: Sometimes it is very important for scientists to have a historical record of some quantity and direct measurements of these quantities often do not exist. By using indirect measurements, scientists can create historical records of a quantity. This greatly increases their ability to see trends and make predictions. I might observe temperature qualitatively and indirectly in my everyday life by looking outside and seeing if it is snowing or if people are wearing heavy jackets, then I know it is cold out. If people are in shorts and tank tops, it is most likely warm out.

This lesson was developed in a partnership between BiteScis and KELP (Knowles Experiential Learning Project). Find more lessons and resources from KELP at www.teachkelp.com.