ASTROEDU
Peer-reviewed Astronomy Education Activities

Oceans As A Heat Reservoir

Why is it getting so hot?

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AGE
12 - 19

LEVEL
Middle School, Secondary

TIME
1h30

GROUP
Group

SUPERVISED
No

COST PER STUDENT
Medium Cost

LOCATION
Small Indoor Setting (e.g. classroom)

CONTENT AREA FOCUS
Earth Science

ASTRONOMY CATEGORIES
Astronomical databases

EARTH SCIENCE KEYWORDS
Glaciology, Oceanography

SPACE SCIENCE KEYWORDS
Remote sensing

CORE SKILLS
Developing and using models, Planning and carrying out investigations, Analysing and interpreting data, Constructing explanations, Engaging in argument from evidence

TYPE(S) OF LEARNING ACTIVITY
Structured-inquiry learning, Modelling, Traditional Science Experiment

KEYWORDS
Thermal radiation, Oceans, Earth, Heat capacity, Heat storage, Temperature

GOALS

With this activity the students will:
- learn how different materials respond to heat.
- learn that water can store large amounts of heat very effectively.
- understand that oceans play an important role in capturing and storing heat that cannot contribute to the global atmospheric warming.
- learn how to measure and record data for subsequent graphical presentation and analysis.

LEARNING OBJECTIVES

During this activity, the students will be able to:
- describe that the Sun is the main heat source of the Earth.
- demonstrate that each substance responds to heat with a different temperature change.
- carry out an experiment that monitors temperature.
- analyse and interpret the data obtained during the experiment.
- demonstrate the relevance of the results to the Earth's climate.

EVALUATION

- After introducing the Sun-Earth system, ask the students what the main energy source of the Earth is.
- Discuss with the students their own experiences of heating different substances (air, water, etc.).
- Watch and supervise the students while they carry out the experiment described in this activity.
- Let the students discuss and visualise the results after translating the data into graphs.
- Let the students discuss the composition of the Earth's surface and external solar heating. With the results of the experiment in mind, let them discuss the role of the oceans.

MATERIALS

Items needed for one experimental set-up (a group of at least two):
- Strong lamp
- Water
- Dirt, soil or sand
- 2 bowls or trays (e.g. petri dishes)
- Stopwatch
- Pen and paper
- Colour pencils

- Ruler
- Thermometer
- Calculator
- Anything that helps maintain the thermometer in an upright position (e.g. pin, paper clip)

Items per student:
- Worksheet
- Supplement

BACKGROUND INFORMATION

Oceans as a heat sink

Global warming caused by the increasing greenhouse effect is one of the biggest challenges for human beings today. Different from other planets in the Solar System, the Earth is covered by large oceans that make up for 2/3 of the total surface area. Therefore, they are an important player in the process of heating and cooling. Oceans act as a heat sink, as they react slower and with a less temperature change than land masses do. As a result, the oceans store more than 90% of the total global heat (Figure 1).

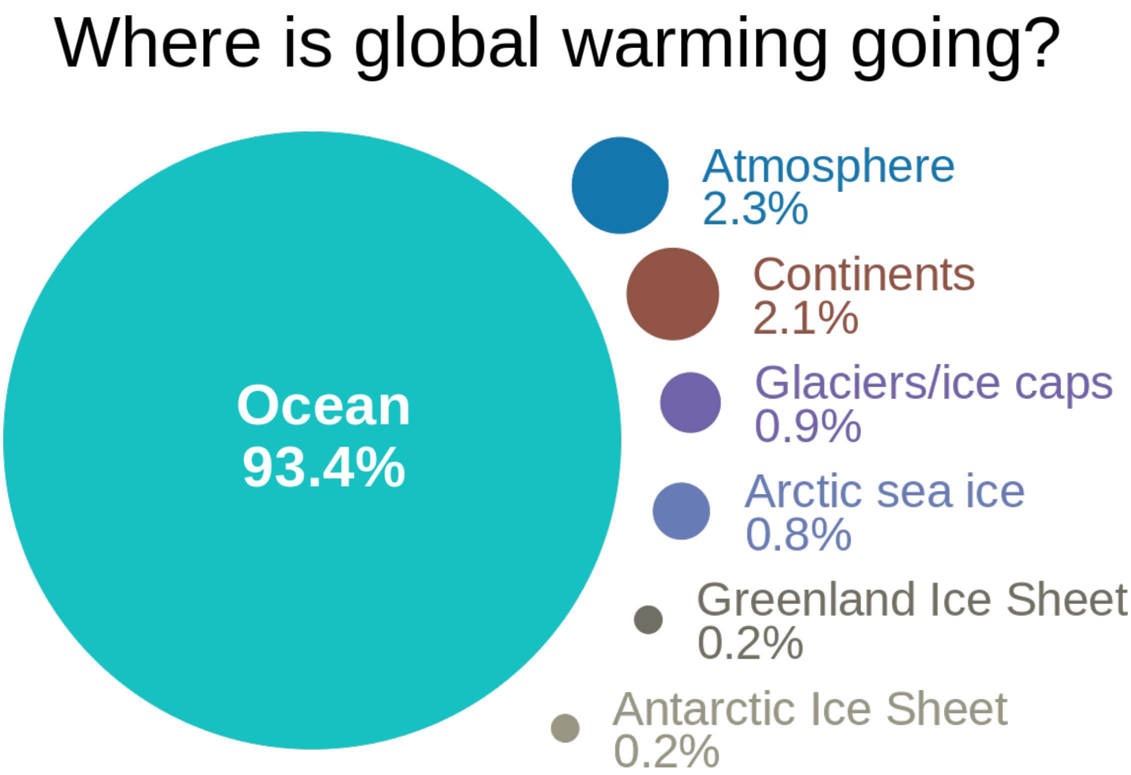


Figure 1: Amounts of energy added to the various parts of the climate system because of global warming, according to the 2007 IPCC AR(4) WG1 Sec 5.2.2.3 (http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch5s5-2-2-3.html), (Skeptical Science, vectorised by User:Dcoetzee (https://commons.wikimedia.org/wiki/File:WhereIsTheHeatOfGlobalWarming.svg), 'WhereIsTheHeatOfGlobalWarming', https://creativecommons.org/licenses/by/3.0/legalcode).

The temperature distribution of the waters on Earth is efficiently monitored from space by remote sensing Earth observation satellites. Monitoring the sea is one of the key objectives of Europe's Copernicus Earth observing programme.

Figure 2: Map of averaged global land surface temperature for March 2016 obtained with the MODIS spectrograph on board NASA's Aqua satellite, which is part of the EOS programme. The colour code indicates temperatures between -2°C and +35°C (NASA Near Earth Observations, http://neo.sci.gsfc.nasa.gov/view.php?datasetId=MYD28M).

The relevance to climate change

These monitoring programmes have shown that just like the atmosphere, the oceans are continuously warming up.

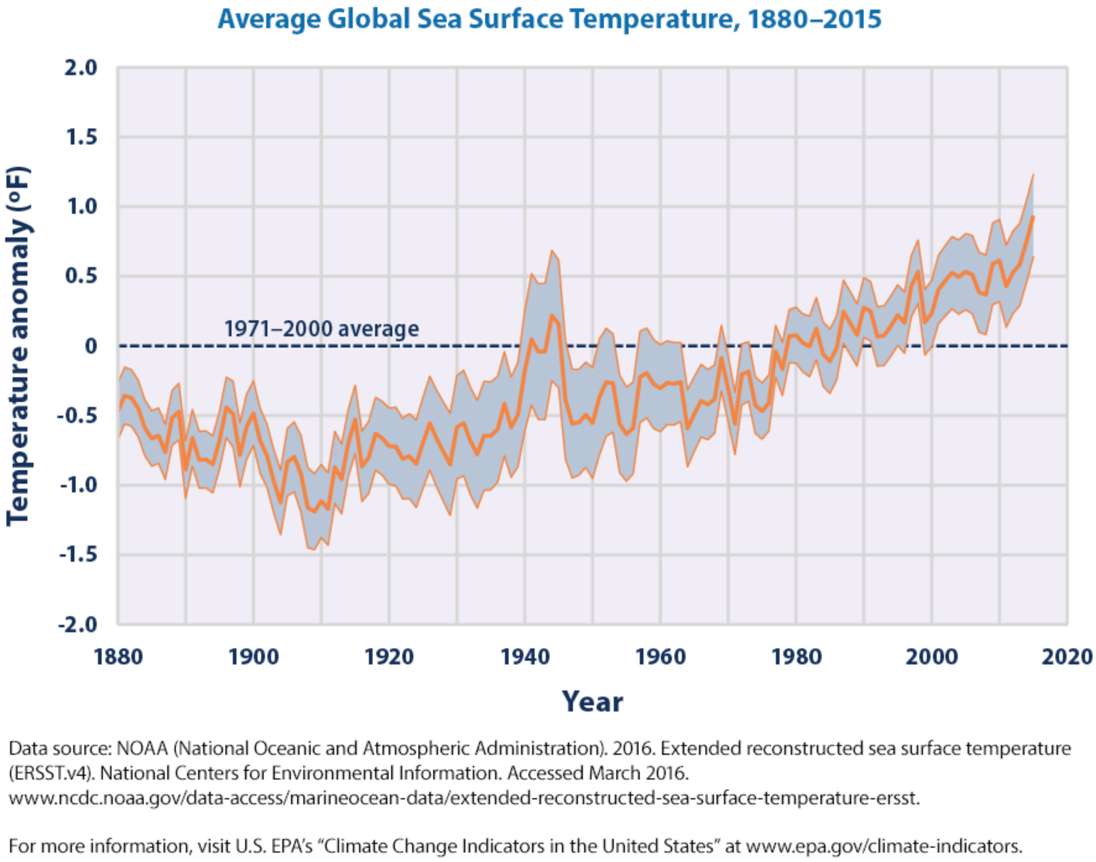
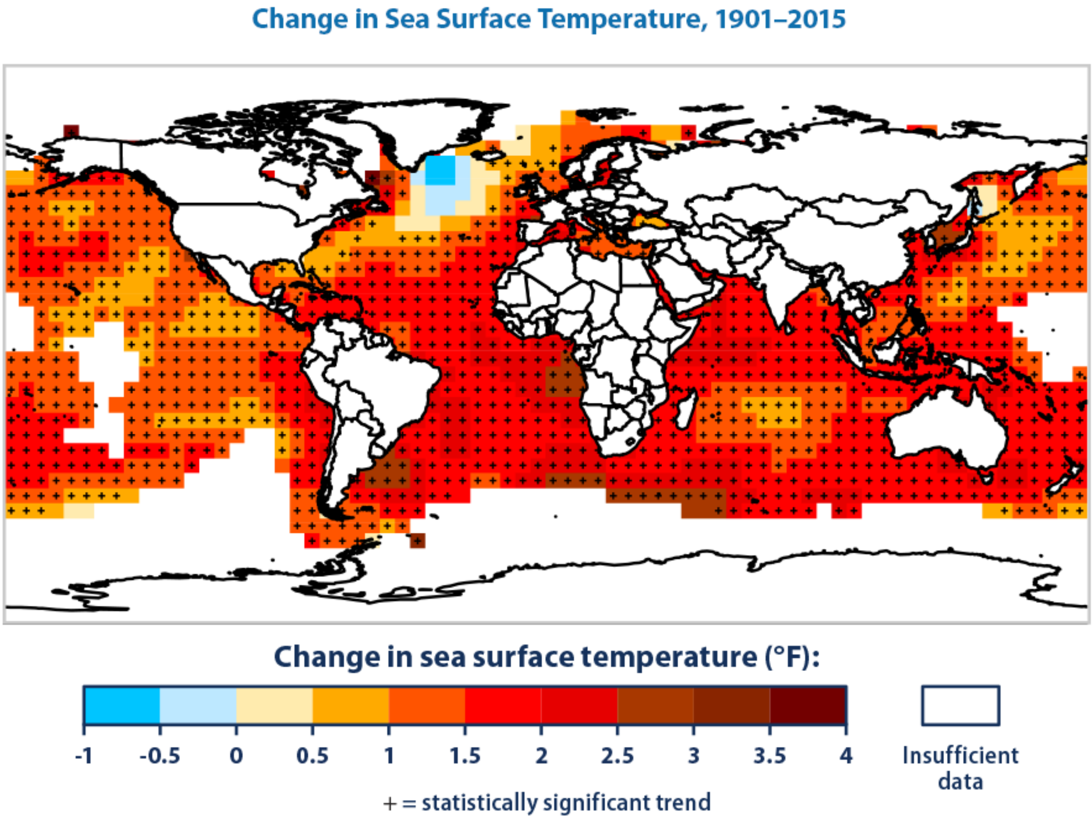


Figure 3: This graph shows how the average surface temperature of the world's oceans has changed since 1880. It uses the 1971 to 2000 average as a baseline for depicting change. Choosing a different baseline period would not change the shape of the data over time. The shaded band shows the range of uncertainty in the data, based on the number of measurements collected and the precision of the methods used (Credit: NOAA (National Oceanic and Atmospheric Administration). 2016. Extended reconstructed sea surface temperature (ERSST.v4). National Centers for Environmental Information. Accessed March 2016. www.ncdc.noaa.gov/data-access/marineocean-data/extended-reconstructed-sea-surface-temperature-ersst, https://www.epa.gov/climate-indicators/climate-change-indicators-sea-surface-temperature).

Suitable remote sensing campaigns can even analyse the spatial distribution of the warm-up process. Since the insolation (solar luminosity variations, orbital variations) does not change with the rates measured, natural causes can be excluded.



Data sources:

- IPCC (Intergovernmental Panel on Climate Change). 2013. Climate change 2013: The physical science basis. Working Group I contribution to the IPCC Fifth Assessment Report. Cambridge, United Kingdom: Cambridge University Press. www.ipcc.ch/report/ar5/wg1.
- NOAA (National Oceanic and Atmospheric Administration). 2016. NOAA Merged Land Ocean Global Surface Temperature Analysis (NOAAGlobalTemp): Global gridded 5° x 5° data. National Centers for Environmental Information. Accessed June 2016. www.ncdc.noaa.gov/data-access/marineocean-data/noaa-global-surface-temperature-noaaglobaltemp.

For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climate-indicators.

Figure 4: This map shows how average sea surface temperature around the world changed between 1901 and 2015. It is based on a combination of direct measurements and satellite measurements. A black ‚+' symbol in a square indicates that the trend shown is statistically significant. White areas indicate lack of data to calculate reliable long-term trends (Credits: IPCC (Intergovernmental Panel on Climate Change). 2013. Climate change 2013: The physical science basis. Working Group I contribution to the IPCC Fifth Assessment Report. Cambridge, United Kingdom: Cambridge University Press. www.ipcc.ch/report/ar5/wg1, NOAA (National Oceanic and Atmospheric Administration). 2016. NOAA Merged Land Ocean Global Surface Temperature Analysis (NOAAGlobalTemp): Global gridded 5° x 5° data. National Centers for Environmental Information. Accessed June 2016. www.ncdc.noaa.gov/data-access/marineocean-data/noaa-global-surface-temperature-noaaglobaltemp, https://www.epa.gov/climate-indicators/climate-change-indicators-sea-surface-temperature).

FULL ACTIVITY DESCRIPTION

PREPARATIONS

Edit the background information in the worksheet document to match the knowledge of the students. Younger students might not need the detailed thermodynamic equations.

INTRODUCTION

Introduce the role of the Sun as the main heat source of the Earth, along the following discussion and questions.

Q: We experience day and night and the different seasons. What causes the different temperatures when the seasons change?

A: The Sun’s heating.

Q: How much of the Earth’s surface is covered by water and how much by land (approximately)?

A: About 71% is covered by water.

Q: So, between land and oceans, what is the heated the most by insolation?

A: The oceans.

Q: In the deserts, the temperature changes between day and night are very strong. Can you imagine why?

A: The solid surface absorbs heat and gets warm quickly. If something heats up very rapidly, it also cools down at a very high rate. In addition, deserts usually lack the ‘blanket’ of clouds that blocks the heat from warming the Earth.

Q: In comparison, how rapidly does water respond to heating? Imagine a pot of water on a stove.

A: This is a rather slow process.

EXPERIMENTAL SET-UP 1

It would be best if the students worked in groups of two to share responsibilities. They will measure the temperature changes of water and soil heated by a lamp over time. To ensure similar conditions for both substances, the experiment is carried out in two steps.

1. Fill one tray with water and the other with soil or sand. The quantities should be the same.
2. Place the tray filled with water below the lamp.
3. Immerse the tip of the thermometer in the water. Its orientation should be as parallel as possible to the angle of irradiation. This grazing angle helps to reduce the direct heating of the thermometer.
4. Let the substances assume room temperature.
5. In the meantime, prepare a data table for filling in the measurements. It should allow for 21 lines of data and four columns (see Table 1).
6. The first column lists numbers from 0 to 20 (minutes).

Table 1: First lines of the data table, including the header.

Time t (min)	Water ϑ (°C)	Soil ϑ (°C)	Difference $\Delta\vartheta$ (°C)
0			

1 | | |
⋮ | | |

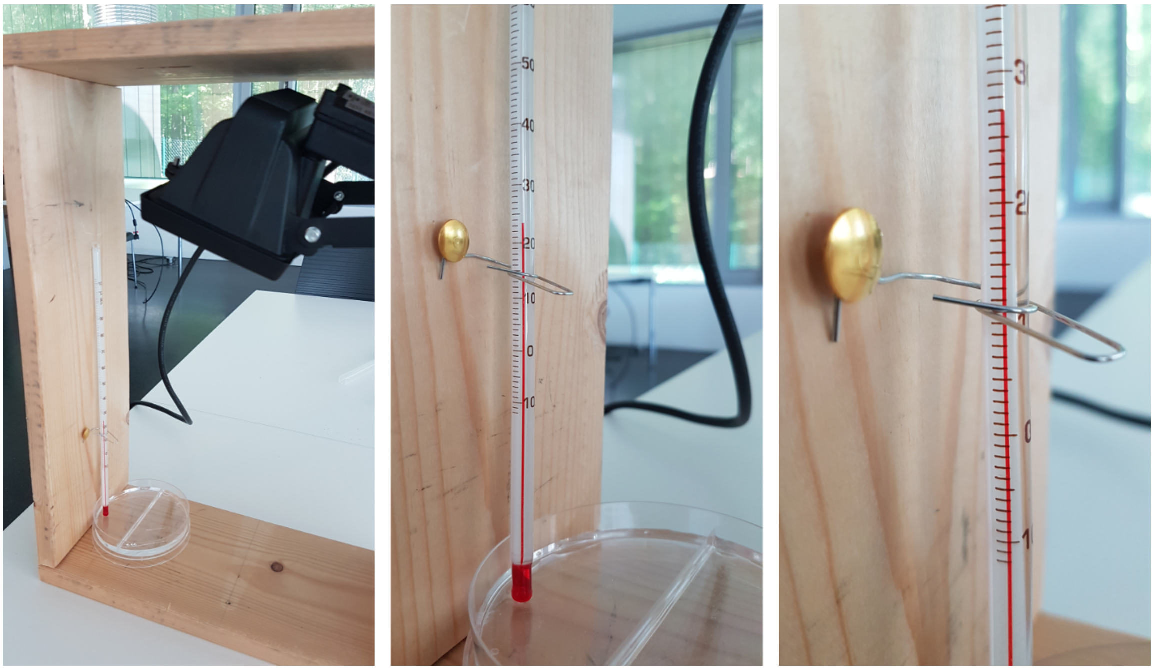


Figure 5: Experimental set-up for the temperature measurement of water. A petri dish is filled with water, and a thermometer is ready to measure the temperature. In order to maintain the thermometer in an upright position, it is attached to the frame with a pin and a paper clip. The lamp is set to illuminate the dish (own work).

Q: What do you think: how do the temperatures change after switching on the lamp?

A: The temperature rises as long as the lamp is on. When it is switched off, the water will cool down again.

Q: After examining the water, you will use soil. Do you expect a different temperature response?

A: The rates of heating and cooling will be different.

Figure 6: While illuminating the water, the temperature is read from the thermometer every minute (own work).

Experimental procedure 1

The procedure is the same for both experiments. Begin with water.

1. Take the first temperature measurement before switching on the lamp.
2. Start the stop watch and switch on the lamp (Figure 6).
3. For 10 minutes, take a measurement every minute and note down the value in the corresponding row in the table.
4. After 10 minutes, switch off the lamp and continue measuring the temperature as before.
5. Stop measuring after 20 minutes. You should have 10 temperature readings with the light switched on and 10 with the light switched off.
6. Replace the water tray with the one filled with soil.

Analysis 1

The data are analysed by producing a diagram that shows the time elapsed during the experiment vs. the temperatures measured.

While one of the students of any working group continues to fill the data into diagram (Figure 7), the other prepares the second experiment with the soil.

1. Prepare a diagram (e.g. Figure 7, upper panel) with two axes. The horizontal axis lists the time elapsed during the experiment, while the vertical axis lists the temperatures. Be prepared for a temperature range between 20 and 35°C.
2. While the thermometer assumes room temperature again, enter the data into the diagram. For each measurement, add a small cross at the coordinate that matches the time and the temperature.
3. Connect the data points of the diagram.

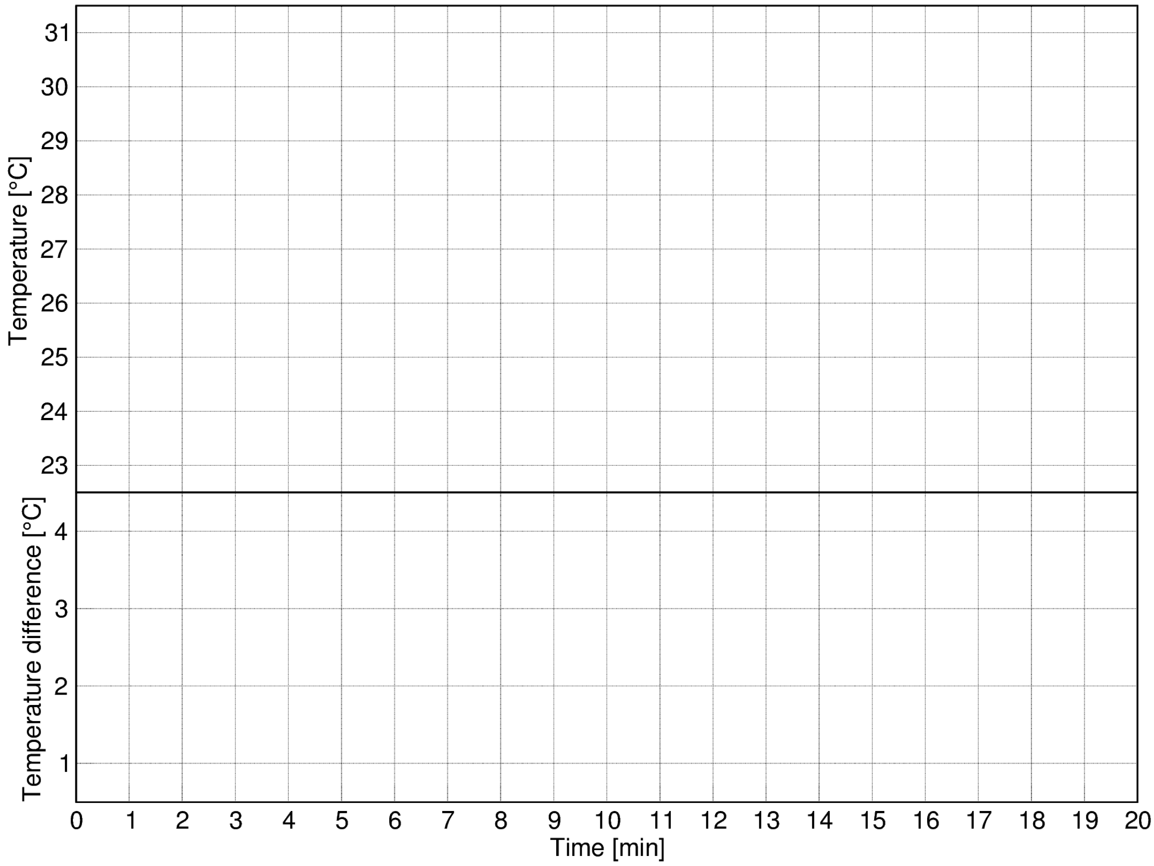


Figure 7: Template for the diagram to record the temperature measurements. The upper panel will contain the temporal changes in temperature. The lower panel is reserved for plotting the difference between the soil and water temperatures. Use different colours to represent the data (own work).

EXPERIMENTAL SET-UP 2

Let the students prepare the second experiment in the same way as the first (Figure 8). Instead of water, the students will examine the soil (dirt, sand).

Experimental procedure 2

The procedure is the same as before.
1. Take the first temperature measurement before switching on the lamp.
2. Start the stop watch and switch on the lamp.
3. For 10 minutes, take a measurement every minute and note down the value in

corresponding row in the table.
4. After 10 minutes, switch off the lamp and continue measuring the temperature as before.
5. Stop measuring after 20 minutes. You should have 10 temperatures with the light switched on and 10 with the light switched off.

Figure 8: The set-up of the second experiment is the same as for the one with water, but this time the petri dish is filled with dirt, sand, or soil (own work).

Analysis 2
1. As before, add the new data to the diagram.
2. Connect the data points.
3. In the diagram, indicate the ranges, when the lamp was switched on and when it was switched off.
4. For each time step, calculate the temperature difference and add it to the table.
5. Prepare a second diagram that shows the temporal evolution of that difference.
6. Fill that diagram with the corresponding data.

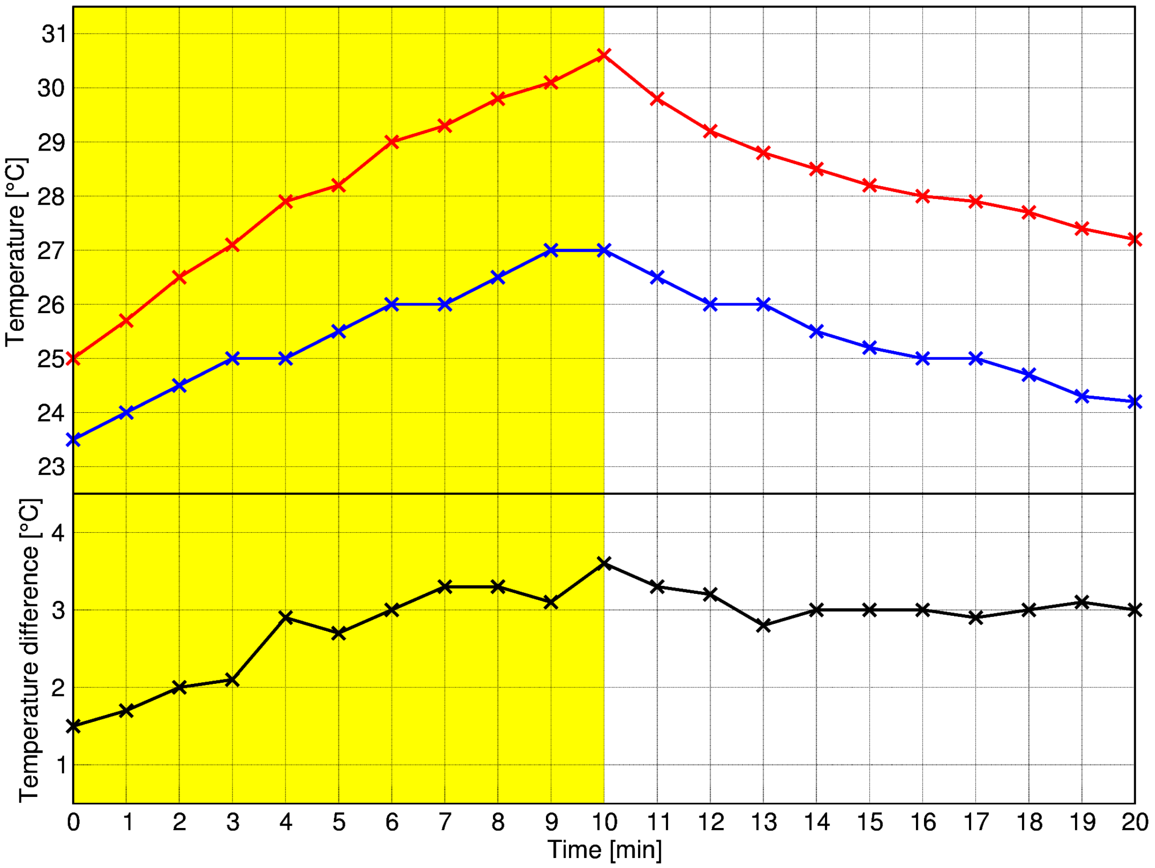


Figure 9: Sample changes in the temperatures of water (blue) and soil (red). The black curve below depicts the difference between the two temperatures (not revealed to the students in the worksheet, own work).

HINTS FOR MODIFYING THE ACTIVITY

Instead of freshwater, one may use saltwater to investigate differences between them.

If you use a petri dish that provides two reservoirs (as shown in the images), you may be able to set up the experiment such that both measurements can be recorded simultaneously. However, It may be difficult to position the lamp such that it irradiates both samples equally. This set-up was not tested. So, it is recommended to try it first before modifying the activity.

CONCLUSION

Describe and discuss the results with your group members or classmates.

Q: How did the temperatures change while the lamp was switched on and off?

A: The temperature rises while the substances were illuminated, and they cooled down as soon as the lamp was off.

Q: Do you recognise a difference between the two substances?

A: The water heats up less and more slowly.

Remark: It should also cool down more slowly. However, the particular conditions of the experimental set-up may influence the cooling process, e.g. high room temperature.

Q: The temperatures rose differently. What is causing this? What changed between the experiments?

A: Everything stayed the same, except the substance to be probed. The observed difference must be caused by the properties of the substances.

Q: Imagine now the Earth with its oceans and continents. Describe how these components react to solar irradiation.

A: During daytime, the half of the Earth facing the Sun is irradiated, and its land masses and water are heated. During the night, the heat is released. Further, oceans warm up and cool down more slowly than continents.

Q: Can you determine the role the oceans have in the global climatic system? Think of what would happen to global temperatures without oceans.

A: The oceans have a dampening effect on the global warming, as they can store heat that otherwise would lead to higher global temperatures.

Q: What happens to the oceans, if the heating rate rises, while the cooling rate stays the same?

A: The temperature rises.

CURRICULUM

Germany

Country/ Fed. State | School | Level | Subject | Section
— | — | — | —
D/BW | Sek I, Gym, OS Gem | All | NWT | 2.1 Erkenntnisgewinnung und Forschen
3. Informationen systematisieren, zusammenfassen und darstellen
4. Experimente (entwickeln), planen, durchführen, auswerten und bewerten
5. Messdaten mathematisch auswerten, beschreiben und interpretieren
8. Modelle zur Beschreibung und Erklärung von Sachverhalten nutzen
D/BW | Sek I, Gym, OS Gem | All | NWT | 2.3 Kommunikation und Organisation
1. Fachbegriffe der Naturwissenschaften und der Technik verstehen und nutzen sowie
Alltagsbegriffe in Fachsprache übertragen
3. Sachverhalte auf das Wesentliche reduziert darstellen
4. zeichnerische, symbolische und normorientierte Darstellungen analysieren, nutzen
9. beim Arbeiten im Team Verantwortung übernehmen
D/BW | Sek I, Gym, OS Gem | Klassen 8/9/10/11 | NWT | 3.2.2 Energie und Mobilität
3.2.2.1 Energie in Natur und Technik
(1) die Bedeutung der Sonne für das Leben auf der Erde beschreiben
D/BW | Sek I, Gym, OS Gem | Klassen 8/9/10/11 | NWT | 3.2.3 Stoffe und Produkte
3.2.3.1 Eigenschaften von Stoffen
(1) Eigenschaften von Stoffen
Bestimmen
D/BW | Sek I, Gym, OS Gem | Klassen 8/9/10/11 | NWT | 3.2.4 Informationsaufnahme und -verarbeitung
3.2.4.2 Gewinnung und Auswertung von Daten

(1/2) an einem ausgewählten Beispiel direkte und indirekte Messverfahren vergleichen
3.3.4 Informationsaufnahme und –verarbeitung
(1) zuverlässige Messungen durchführen
D/BW | Sek I, Gym | All | BNT | 2.1 Erkenntnisgewinnung
1. Phänomene beobachten und beschreiben
2. subjektive Wahrnehmungen beschreiben und von objektiven Messungen unterscheiden
3. einfache Messungen durchführen
4. zunehmend Beobachtungen von Erklärungen unterscheiden
5. zu naturwissenschaftlichen Phänomenen und technischen Sachverhalten Fragen formulieren, Vermutungen aufstellen und experimentell überprüfen
6. Experimente unter Anleitung planen, durchführen, auswerten
7. ein Sachmodell kritisch einsetzen
9. einfache Bestimmungshilfen sachgerecht anwenden
D/BW | Sek I, Gym | All | BNT | 2.2 Kommunikation
1. beim aturwissenschaftlichen und technischen Arbeiten im Team Verantwortung für Arbeitsprozesse übernehmen, ausdauernd zusammenarbeiten und dabei Ziele sowie Aufgaben sachbezogen diskutieren
2. ihr Vorgehen, ihre Beobachtungen und die Ergebnisse ihrer Arbeit dokumentieren
3. zur Veranschaulichung von Ergebnissen und Daten geeignete Tabellen und Diagramme anlegen
4. Zusammenhänge zwischen Alltagssituationen und naturwissenschaftlichen und technischen
Sachverhalten herstellen
D/ BW | Sek I, Gym | Klassen 5/6 | BNT | 3.1.1 Denk- und Arbeitsweisen der Naturwissenschaften und der Technik
(1) wichtige Arbeitsgeräte sicher nutzen und deren bestimmungsgemäßen Einsatz erläutern
(2) an Naturphänomenen Beobachtungen sammeln, zielgerichtet zuordnen und auswerten sowie an geeigneten Beispielen beschreiben, wie man dabei vorgeht
(4) an Beispielen die naturwissenschaftliche Arbeitsweise durchführen und erläutern
(5) Experimente planen und durchführen, Messwerte erfassen und Ergebnisse protokollieren sowie beschreiben, wie man dabei vorgeht (Tabellen, Diagramme und Skizzen)
D/BW | Sek I, Gym | Klassen 5/6 | BNT | 3.1.3 Wasser - ein lebenswichtiger Stoff
(1) Phänomene beim Erwärmen und Abkühlen von Wasser beschreiben
(2) den Temperaturverlauf beim Erhitzen von Wasser dokumentieren
D/BW | Sek I, Gym, OS Gem | All | Geo | 2.1 Orientierungskompetenz
2. geographische Sachverhalte raum-zeitlich einordnen
3. geographische Sachverhalte in das Mensch-Umwelt-System einordnen
D/BW | Sek I, GYm, OS Gem | All |Geo | 2.2 Analysekompetenz
1. geographische Strukturen und Prozesse herausarbeiten, analysieren und charakterisieren
2. systemische Zusammenhänge darstellen und daraus resultierende zukünftige Entwicklungen Erörtern
D/BW | Sek I, Gym, OS Gem | All | Geo | 2.5 Methodenkompetenz
3. mithilfe von Versuchen geographische Sachverhalte überprüfen
D/BW | Sek I, Gym | Klassen 7/8/9 | Geo | 3.2.2 Teilsystem Wetter und Klima
3.2.2.3 Phänomene des Klimawandels
(1) den natürlichen und den anthropogen verstärkten Trei hauseffekt in Grundzügen beschreiben
(3) globale Auswirkungen des Klimawandels im Überblick beschreiben (Meeresspiegelanstieg, Temperaturanstieg, …)
D/BW | OS Gem | Klassen 11/12/13 | Geo | 3.4.2/3.5.3 Globale Herausforderungen

3.4.2.273.5.3.2 Globale Herausforderung: Klimawandel

(1) Ursachen und Dimensionen des Klimawandels auf der Grundlage aktueller wissenschaftlicher
Erkenntnisse erläutern
D/BW | Sek I, Gym | All | Physik | 2.1 Erkenntnisgewinnung
1. Phänomene und Experimente zielgerichtet beobachten und ihre Beobachtungen beschreiben
4. Experimente durchführen und auswerten, dazu gegebenenfalls Messwerte erfassen
11./12. Sachtexte mit physikalischem Bezug sinnentnehmend lesen
D/BW | Sek I, Gym | All | Physik | 2.2 Kommunikation
2. funktionale Zusammenhänge zwischen physikalischen Größen verbal beschreiben
3. sich über physikalische Erkenntnisse und deren
Anwendungen unter Verwendung der
Fachsprache und fachtypischer Darstellungen austauschen
4. physikalische Vorgänge und technische Geräte beschreiben
5. physikalische Experimente, Ergebnisse und dokumentieren
6. Sachinformationen und Messdaten aus einer Darstellungsform entnehmen und in andere
Darstellungsformen überführen
D/BW | Sek I, Gym | All | Physik | 2.3 Bewertung
3. Hypothesen anhand der Ergebnisse von Experimenten beurteilen
D/BW | Sek I, GYm | Klassen 7/8/9 | Physik | 3.2.1 Denk- und Arbeitsweisen der Physik
(1) Kriterien für die Unterschei dung zwischen
Beobachtung und Erklärung nennen (Beobachtung durch Sinneseindrücke und Messungen, Erklärung durch Gesetze und Modelle)
3.2.3 Energie
(3) Beispiele für die Speicherung von Energie in verschiedenen Energieformen in Alltag und Technik nennen und beschreiben
(10) das scheinbare Verschwinden von Energie mit der Umwandlung in thermische Energie erklären
D/BW | Sek I, Gym | Klassen 10 | Physik | 3.3.1 Denk- und Arbeitsweisen der Physik
(1) Kriterien für die Unterscheidung zwischen
Beobachtung und Erklärung nennen (Beobachtung durch Sinneseindrücke und Messungen, Erklärung durch Gesetze und Modelle)
3.3.3 Wärmelehre
(2) beschreiben, dass sich feste, flüssige und gasförmige Stoffe bei Temperaturerhöhung in der Regel ausdehnen
(6) beschreiben, dass bei realen
Energieumwandlungen einTeil der Energie in thermischeEnergie umgewandelt wird
(7) ihre physikalischen Kenntnisse zur Beschreibung des natürlichen und anthropogenen
Treibhauseffektes anwenden
D/BW | OS Gem | Klassen 11 | Physik | 3.3.1 Denk- und Arbeitsweisen der Physik
(1) Kriterien für die Unterscheidung zwischen
Beobachtung und Erklärung nennen (Beobachtung durch Sinneseindrücke und Messungen, Erklärung durch Gesetze und Modelle)
3.3.3 Wärmelehre
(2) beschreiben, dass sich feste, flüssige und gasförmige Stoffe bei Temperaturerhöhung in der Regel ausdehnen
(7) ihre physikalischen Kenntnisse zur
Beschreibung des natürlichen und anthropogenen
Treibhauseffektes anwenden

ADDITIONAL INFORMATION

CONCLUSION

With this activity, students learn how and why oceans on Earth can store heat more effectively than land: because of their high heat capacity. Therefore, the oceans can mitigate part of the global warming caused by the greenhouse effect. The activity simulates Earth's behaviour with two samples of soil and water that are illuminated by a strong lamp. The recorded temperature change is generally slower for water than for soil.

ATTACHMENTS

- Worksheet editable
- Worksheet PDF
- Supplement editable
- Supplement PDF

ALL ATTACHMENTS

All attachments

CITATION

Marco Türk, 2018, *Oceans As A Heat Reservoir*, astroEDU, , doi:10.14586/astroedu/1630

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