Secondary
14-16

education resource pack

PLANETARY HEAT PUMPS

Teacher guide and student worksheets

climate change initiative education resource pack – PLANETARY HEAT PUMPS
https://climate.esa.int/educate/

Activity concepts developed by University of Twente (NL) and
National Centre for Earth Observation (UK)

The ESA Climate Office welcomes feedback and comments
https://climate.esa.int/helpdesk/

Produced by the ESA Climate office

PLANETARY HEAT PUMPS: Overview

Fast facts

Subject(s): Geography, Science, Earth Science

Age range: 14–16 years old

Type: reading, mathematical investigation, online research

Complexity: medium to advanced

Minimum lesson time required: 4 hours

Cost: low (5–20 euro)

Location: indoors

Includes the use of: Internet, calculator, spreadsheet software, ice and coloured water

Keywords: heat capacity, density, thermohaline circulation, salinity, sea surface temperature, satellite, Earth observation, stratification, Gulf Stream

Brief description

In this set of activities, students will learn how ocean circulation has an impact on climate.

In the introductory activity, they carry out calculations to compare the relative impact of global warming on the atmosphere and oceans.

A practical activity using readily available equipment allows students to see how water of different temperatures can form layers in the ocean and to consider how they might use this to explore the effect of changes in salinity.

In the final activity, students use the Climate from Space web application to find out more about the Gulf Stream.

Intended learning outcomes

Having worked through these activities, students will be able to:

Carry out calculations to compare the role of the oceans and atmosphere in regulating the climate.

Explain how the global thermohaline circulation arises.

Describe how ocean currents transport water and energy around the Earth.

Use a model to examine the movement of water of different temperatures and explain stratification in the ocean.

Design practical methods of investigating a question about how water moves in the oceans.

Describe the behaviour of the Gulf Stream using information from climate data.

Synthesise data from records of at least two essential climate variables to explain an observed correlation or trend.

Summary of activities

	Title	Description	Outcome	Prior learning	Time
1	Planetary heat pumps	Reading and calculations	Carry out calculations to compare the role of the oceans and atmosphere in regulating the climate. Explain how the global thermohaline circulation arises. Describe how ocean currents transport water and energy around the Earth.	Calculations using standard form; surface area of a sphere; rearranging equations	1 hour
2	Rising and falling water	Practical activity	Use a model to examine the movement of water of different temperatures and explain stratification in the ocean. Design practical methods of investigating a question about how water moves in the oceans.	None	1½ hours
3	The Gulf Stream	Research task	Describe the behaviour of the Gulf Stream using information from climate data. Synthesise data from records of at least two essential climate variables to explain an observed correlation or trend.	Reading part of Activity 1	1½ hours

Times given are for the main exercises, assuming full IT access or/and distribution of repetitive calculations and plots around the class. They include time for sharing results but not the presentation of outcomes as this will vary depending on the size of the class and groups. Alternative approaches may take longer.

Practical notes for teachers

The **material required** for each activity is listed at the start of the relevant section, together with notes about any preparation that may be required beyond copying worksheets and information sheets.

Worksheets are designed for single use and can be copied in black and white.

Information sheets may contain larger images for you to insert into your classroom presentations, additional information for students, or data for them to work with. These resources are best printed or copied in colour but may be reused.

Any **additional spreadsheets, datasets or documents** required for the activity may be downloaded by following the links to this pack from https://climate.esa.int/educate/climate-for-schools/

Extension ideas and suggestions for **differentiation** are included at appropriate points in the description of each activity.

Worksheet answers and sample results for practical activities are included to support **assessment**. Opportunities for you to use local criteria to assess core skills such as communication or data handling are indicated in the relevant part of the activity description.

Health and safety

In all activities, we have assumed you will continue to follow your usual procedures relating to the use of common equipment (including electrical devices such as computers), movement within the learning environment, trips and spills, first aid, and so on. Since the need for these is universal but the details of their implementation vary considerably, we have not itemised them every time. Instead, we have highlighted hazards particular to a given practical activity to inform your risk assessment.

Some of these activities use the Climate from Space web application or other interactive websites. It is possible to navigate from these to other parts of the ESA Climate Change Initiative site or that of the host organisation and thence to external websites. If you are not able – or do not wish – to limit the pages students can view, do remind them of your local Internet safety rules.

Climate from Space

ESA satellites play an important role in monitoring climate change. The Climate from Space web application (cfs.climate.esa.int) is an online resource that uses illustrated stories to summarise some of the ways in which our planet is changing and highlight the work of ESA scientists.

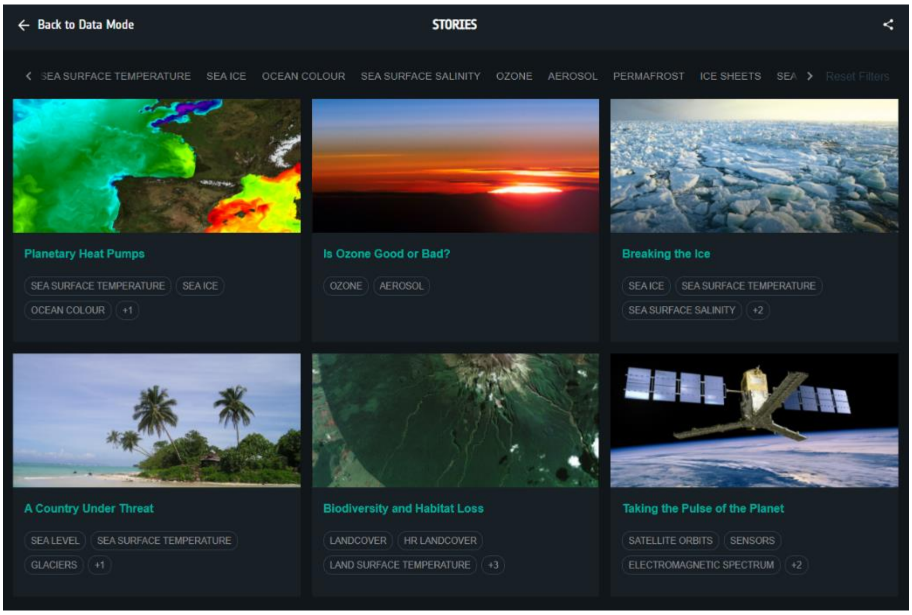

Figure 1: Stories in the Climate from Space web application (Source: ESA CCI)

ESA's Climate Change Initiative programme produces reliable global records of some key aspects of the climate known as essential climate variables (ECVs). The Climate from Space web application allows you to find out more about the impacts of climate change by exploring this data for yourself.

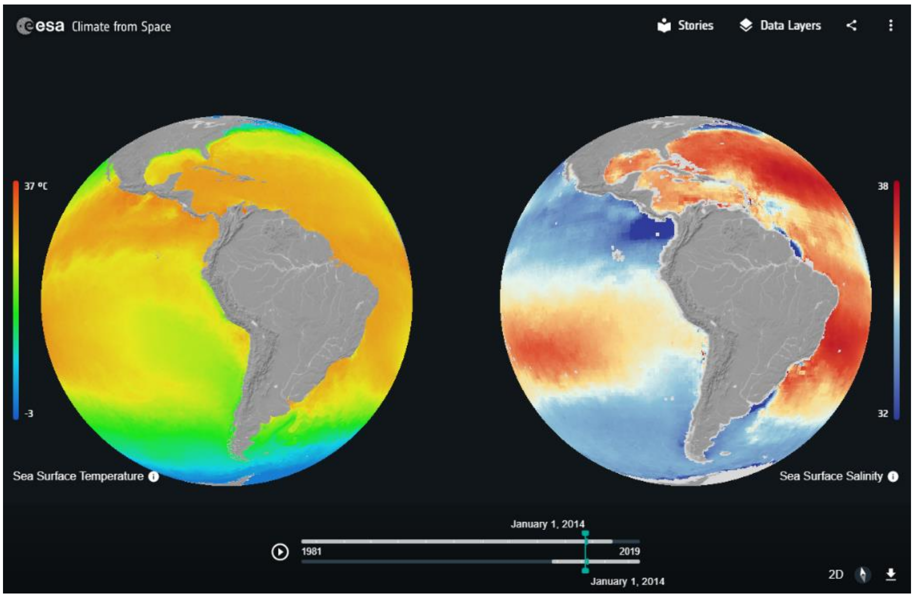

Figure 2: Comparing sea surface temperature and salinity in the Climate from Space web application (Source: ESA CCI)

Oceans and climate: background information

Oceans and climate

Weather may be complicated and difficult to predict but the redistribution of heat around the Earth is one of the main drivers: energy absorbed from sunlight moves between places with different temperatures through radiation from the surface, when water evaporates, and through the circulation of the atmosphere and oceans. Although we would expect the main direction of this movement of heat to be from the warm equator to the cold poles, the rotation of the Earth and friction between layers of the atmosphere and ocean adds an east–west component. This is only the first of many complicating factors.

Most of us spend the greater parts of our lives on the land that covers less than a third of our planet's surface. The weather that may influence our day-to-day activities is primarily affected by the movement of the atmosphere. As a result, we do not often think of the role that the oceans play in influencing weather patterns and, on a longer time scale, controlling the climate.

Areas of Earth at the same distance from the equator receive the same amount of solar radiation over the course of a year so we might expect them to have similar climates. A look at settlement patterns shows the consequences of this not being so: many European cities lie in the band between 49 and 52 degrees north, but the major cities on the east coast of North America are much further south. That the climate of places as far north as the Norwegian coast is mild compared to places at similar latitudes in the Americas or the centre of the Asian landmass is, in part, due to a major current normally referred to as the Gulf Stream. The energy this carries from tropical latitudes to the western Atlantic is transferred from the water to the air above it and carried to the land in onshore winds.

Ocean currents

The Gulf Stream system, which students can explore in Activity 3, is one of many current systems or gyres that result from surface winds dragging the upper layer of the ocean along in the same way a breeze ruffles the surface of a puddle. The subtropical gyre driven by the trade winds in the Pacific is another. Disruption of this circulation pattern leads to the El Niño or La Niña events, which are explored in the companion education resource pack *Taking the Pulse of the Planet* (Upper Secondary), available from https://climate.esa.int/educate/climate-for-schools/.

Anyone who has swum in the sea will be aware of the effects of more local circulation patterns resulting from tidal movements or the geography of the coast and seabed. A swimmer can feel changes in temperature and the direction in which the ocean pulls them, and may also need to be aware of the power of an undertow – water beneath the surface moving in a different direction. On a larger scale, water travels around the entire world in such a three-dimensional circulation pattern over the course of a thousand years or so. This so-called Great Ocean Conveyor Belt (shown in Figure 3, on the next page) is also known as the global thermohaline circulation because it is driven by differences in temperature and salinity. For example, the formation of sea ice in the Arctic leaves behind saltier water which, being more dense, sinks to the depths. Surface water is pulled towards the ice and is cooled and sinks in turn, setting up a deep cold current moving away from the ice and a warmer surface current moving towards it. Activity 2 shows – on a much smaller scale – how differences in density can lead to water moving in different directions at different depths.

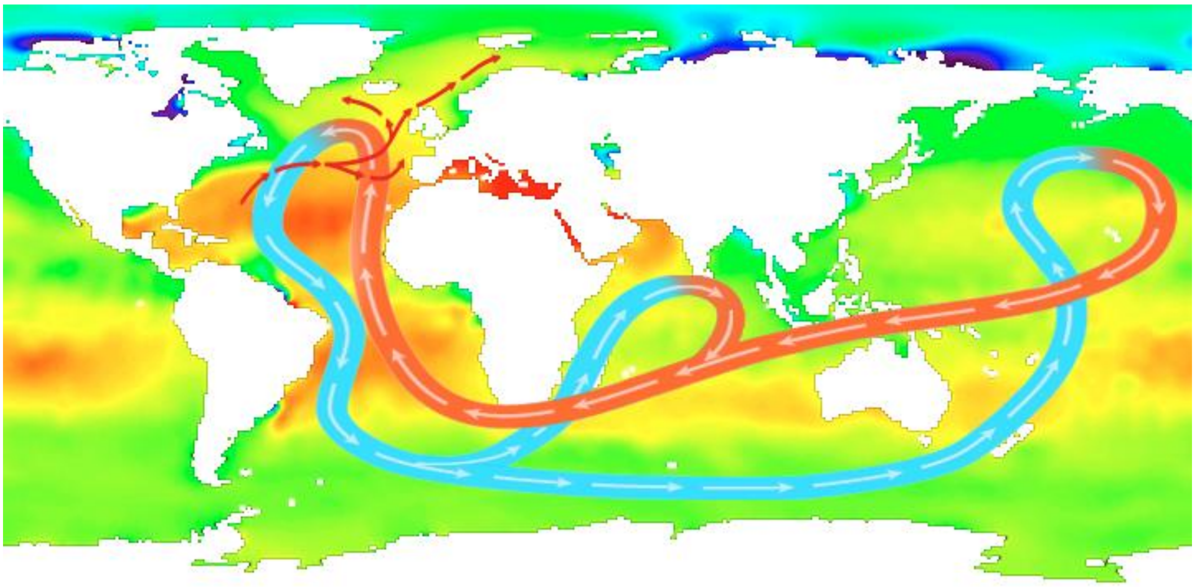

Figure 3: Average salinity (background colours: red shows high salinity, green low); the Gulf Stream (red arrows); and the global thermohaline circulation (broad band: cooler surface waters are blue, warmer surface waters red) (Source: ESA)

Satellite observations over the ocean

Before the age of satellites, the temperature of the ocean could only be measured using thermometers linked to the shore, lowered from ships, or attached to buoys or submersibles. This, of course, meant that measurements were patchy and there were continuous records for very few places.

Thermal cameras on satellites can detect the surface temperature of the ocean across the whole world at regular intervals. A satellite in geostationary orbit can view each section of the sea in a particular hemisphere once every fifteen minutes or so; one in a polar orbit, closer to the Earth, can see more detail and cover the entire planet but will only measure the temperature at a particular place every ten days or so. (The *Taking the Pulse of the Planet* pack mentioned above includes more on how satellite orbits affect the data they collect.)

Activity 1: PLANETARY HEAT PUMPS

This reading-based activity leads into calculations using specific heat capacity. The relevant equation is given so students do not need any prior knowledge of the term. Either or both parts of the activity (the reading and the calculations) could be set as homework depending on the ability of the class.

Equipment

- Information sheet 1 (2 pages)
- Student worksheet 1
- Calculator
- Climate from Space web application: *Planetary Heat Pumps* story (optional)

Exercise

1. Ask students to read Information sheet 1 and work individually or in pairs to summarise the content in a form they find helpful. This may be, for example, a list of bullet points or a concept map.
   If doing this in class, you could supplement the text with material from the Climate from Space *Planetary Heat Pumps* story as follows:
   - The gallery on slide 2 includes a map of sea surface temperatures that can spark discussion on causes of surface currents; a cross-section of the Atlantic that demonstrates the vertical distribution of water at different temperatures; and a map of the thermohaline circulation. (Use the arrow button at the very right of the screen to scroll through the different images on this slide.)
   - The globe on slide 3 shows sea surface temperatures across the world at intervals from 1981. (Step through rather than play continuously.)
   - Slide 4 includes a video giving more detail of interactions between the atmosphere and ocean, including an illustration of reduced temperatures in the wake of a hurricane (from 0:22 to 0:36) and upwelling (0:40–1:06).
   - Slide 6 gives additional information about variation in salinity and shows how it varies across the globe. The text explains the role of salinity in the globe's planetary heat pump.

2. Student worksheet 1 guides students through a calculation of theoretical temperature increases given the rate at which excess heat is being added to the Earth system. Ask students to work through the calculation, providing support as required.

3. The final question asks students to use ideas from the information sheet to explain why their calculations do not match observations.
   Widely quoted figures give a global temperature rise of about 1°C since pre-industrial times (several hundred times less than the figure calculated) and a sea surface temperature of 0.13°C per decade (about ten times more than the result of the calculation).

Discussion of these answers could lead into consideration of the way in which mathematical models used in science often start with big approximations that are gradually refined to make the situation match reality.

In this case, a second approximation for the atmosphere, based on data on the information sheet, would be to use 10% of the annual energy figure.

A second approximation for the oceans might be to find the surface area of the oceans (70% of the answer to question 1), calculate the mass of a layer say 30 m deep (the average density of sea water is 1027 kg m^{-3}), and use this value to calculate the expected temperature rise. You may wish to ask more able students to carry out this calculation.

Worksheet answers

1. Using $A = 4\pi r^2$, surface area of the Earth = 5.15×10^{14} m^2
2. Total excess energy = 0.62 W m^{-2} × 5.15×10^{14} m^2 = 3.19×10^{14} J s^{-1}
   = 3.19×10^{14} J s^{-1} × (60 × 60 × 24 × 365.25) = 1.01×10^{22} J $year^{-1}$
3. Using $\Delta T = Q \div mc$, atmospheric temperature increase
   = 1.01×10^{22} J $year^{-1}$ ÷ (5.14×10^{18} kg × 1158 J $kg^{-1}°C^{-1}$) = 1.69°C $year^{-1}$
4. Oceanic temperature increase
   = 1.01×10^{22} J $year^{-1}$ ÷ (1.4×10^{21} kg × 3850 J $kg^{-1}°C^{-1}$) = 1.87×10^{-3}°C $year^{-1}$
5. The atmosphere: because the atmosphere has a much smaller mass and air has a smaller specific heat capacity.
6. The actual figure for the atmosphere is smaller because, according to the story, 90% of the excess energy is absorbed by the oceans. Some will also be absorbed by the land, further reducing the amount available to heat the atmosphere and leading to a lower annual temperature increase.
   The calculation for the ocean used the total mass of the ocean but the energy is absorbed at the surface and most of it will remain in the upper layers: water is a poor conductor of heat and warmer water will float on colder water (at least above 4°C). It will take centuries for the thermohaline circulation to carry this energy to the depths of the ocean. The mass used in the calculation is therefore far too large, leading to an annual temperature increase that is far too small.

The headline figure for this exercise relates to the period 2000–2012 and comes from Allan, R., Liu, C., Loeb, N., Palmer, M., Roberts, M., Smith, D., & Vidale, P. (2014) 'Changes in global net radiative imbalance 1985–2012', *Geophysical Research Letters* DOI: 10.1002/2014GL060962.

Activity 2: RISING AND FALLING WATER

In this practical activity, students replicate ocean thermodynamics in a container, using coloured water to track flows and see how layers of water at different temperatures are formed and maintained. They are challenged to consider how they can use the model to demonstrate other aspects of ocean circulation.

Equipment

- Large transparent container per group – this could be a large beaker or vase, or a two-litre PET bottle with the top section cut off
- Small container per group – this should have a fairly wide base and be small enough to be submerged in the larger container; a spice jar, for example
- Plastic bags
- Rubber bands or string
- Food colouring or ink
- Ice in a bucket for cooling, or refrigerated water
- Access to hot and cold water
- Stopwatch or clock per group (optional)
- Camera or smartphone per group (optional)
- Thermometers (optional)
- Cloths or paper towels
- Student worksheet 2 (2 pages)
- Materials for creating posters, or software for creating videos or presentations (see step 3)
- Climate from Space online resource: *Planetary Heat Pumps* story (optional)

Health and safety

Use hot water between 40°C and 60°C – if hot running water is not available, mix boiling water from a kettle with cold water.

Food colouring and ink will stain, so advise students to work carefully to avoid spills and splashes.

Ensure equipment is set up on stable surfaces, away from table or bench edges.

Ensure there is material available to deal with spills.

Exercise

1. Introduce the activity with the diagram of a cross-section across the North Atlantic showing how temperature varies across the surface and with depth. This is one of the images in the gallery on slide 2 of the *Planetary Heat Pumps* story in the Climate from Space web application. It is also available on Information sheet 2. Explain that, in this lesson, students will explore how the stratification or layering shown in this diagram is created.
2. Students can then carry out the investigation by following the instructions on Student worksheet 2.1 working in pairs or groups.

If time is short, you could distribute the suggested combinations around the class, getting each pair or group to do only one or two sets of observations.
If you have more time, and thermometers are available, challenge students to investigate how the process changes with temperature difference. What is the smallest temperature difference that will drive circulation? That will result in stratification?

3. Ask students to follow the guidance on Student worksheet 2.2 to analyse and present their results in a way appropriate to the method they used to record their observations. You may wish to introduce additional requirements or constraints to enable you to assess particular skills or increase the challenge.
   Encourage students to use ideas about the variation of density with temperature to explain the observations and relate them back to what they learnt in the last activity.
4. Students could share their results with another group, looking for similarities and differences and peer-assessing the explanations offered.
5. The design tasks at the end of Student worksheet 2.2 challenge students to adapt the practical to investigate how salinity affects the movement of water and demonstrate upwelling.
   Students could discuss these in groups or do one of the tasks for homework.
   If time allows, they could implement their plans.

Sample Results

Cold water in large container, hot water in small container

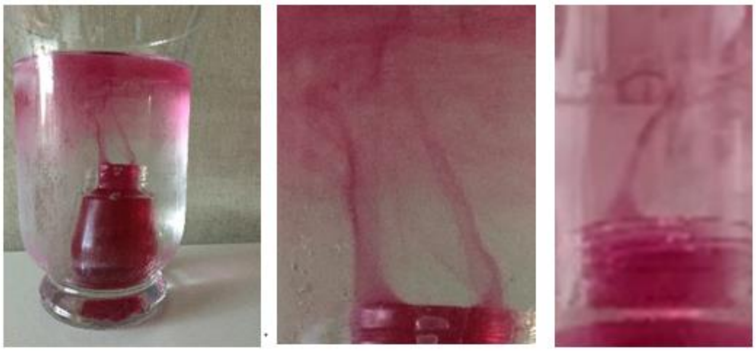

Figure 4: Results for large container of cold water, small container of hot water (Source: ESA CCI)

The less dense hotter water flows swiftly upwards forming eddies like plumes of smoke. The coloured water spreads outwards, forming a floating layer of warmer water at the surface (see Figure 4).

Hot water in large container, cold water in small container

The denser cold water stays in the container. If the large container is nudged a little, the surface water moves and some may spill out. However, it remains as a bubble, floating in the warmer water as if it were in zero gravity (see Figure 5).

Figure 5: Results for large container of hot water, small container of cold water (Source: ESA CCI)

Hot water in large container, cold water in horizontal small container

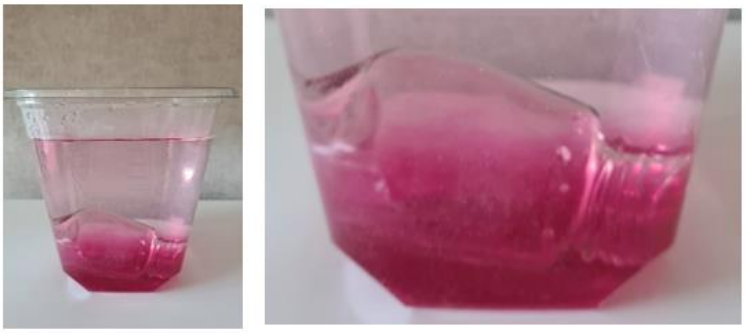

Figure 6: Results for large container of hot water, horizontal small container of cold water (Source: ESA CCI)

The water flows out of the small container and, being more dense, remains in the bottom of the big container forming a layer at the base (see Figure 6).

Hot water in large container, cold water introduced at the top

The denser cold water will sink to the bottom, creating similar eddies and flow patterns as those seen in the first experiment (see Figure 7).

Figure 7: Introducing cold water at the top of a large container of hot water

Activity 3: THE GULF STREAM

In this activity, students use the Climate from Space web application to look at sea surface temperatures along the path of the Gulf Stream and downloaded data to compare patterns and trends across the Gulf Stream with those seen elsewhere in the North Atlantic. They then research and explain links between sea surface temperature and another climate variable using understanding developed while studying the topic.

Equipment

- Internet access
- Climate from Space web application
- Student worksheet 3 (2 pages)
- Planetary heat pumps Activity 3 spreadsheet
- Spreadsheet software or graph paper (former preferred)

Preparation

You may wish to download the Planetary heat pumps Activity 3 spreadsheet from the Planetary heat pumps section of the ESA Climate for Schools webpage (https://climate.esa.int/educate/climate-for-schools/) to a location where your students can access it without going online, or print out the data it contains for students to plot by hand.

Exercise

1. Ask students to say, without using a map or atlas, which is further north: Paris or Montreal? Amsterdam or New York? Vancouver or London? Oslo or Calgary? In all cases, it is the European city. In some or all cases, many people think otherwise because the North American cities have a cooler climate.
2. Remind students that Western Europe is warmed by the Gulf Stream (as noted on Information sheet 1) and explain that they are going to find out more about this in this lesson.
3. Ask students to begin by exploring the Gulf Stream in the Climate from Space web application, following the instructions on Student worksheet 3.1. They should then use the dataset in the spreadsheet to see more detail as described in the first part of Student worksheet 3.2.
   The dataset is small enough for students to plot by hand but, if doing so, omit question 4 as it will be hard to identify a trend line.
4. The 'Making connections' section of the worksheet includes several suggestions for further investigation.
   The instructions ask students to relate what they find out to what they have learnt in the first part of the activity and the earlier part of the topic, so you may wish them to work individually and create a short report that you can use to assess their learning.
   Alternatively, you could ask pairs or groups to produce a poster, presentation or video to share what they have learnt with the rest of the class.

Worksheet answers

1. There is a clear temperature difference in the early months of the year when the warm waters of the Gulf Stream flow into colder northern waters. As the year goes on, the difference becomes less pronounced, starting at the eastern end. The stream is well defined, with sharp edges, along the first part of its journey. Where it mixes with cold water moving from the Arctic, it does so by forming circular patterns (eddies), that make the edges of the stream more fuzzy (see https://www.esa.int/ESA_Multimedia/Videos/2013/02/Sea-surface_salinity_and_currents#.X9n4wBlA-uQ.link).

2. See table.

		Estimated average temperature / °C	
	Month	**Gulf Stream**	**Gulf of Maine**
Warmest	August	26	21
Coolest	January	19	10

3. See Figure 8.

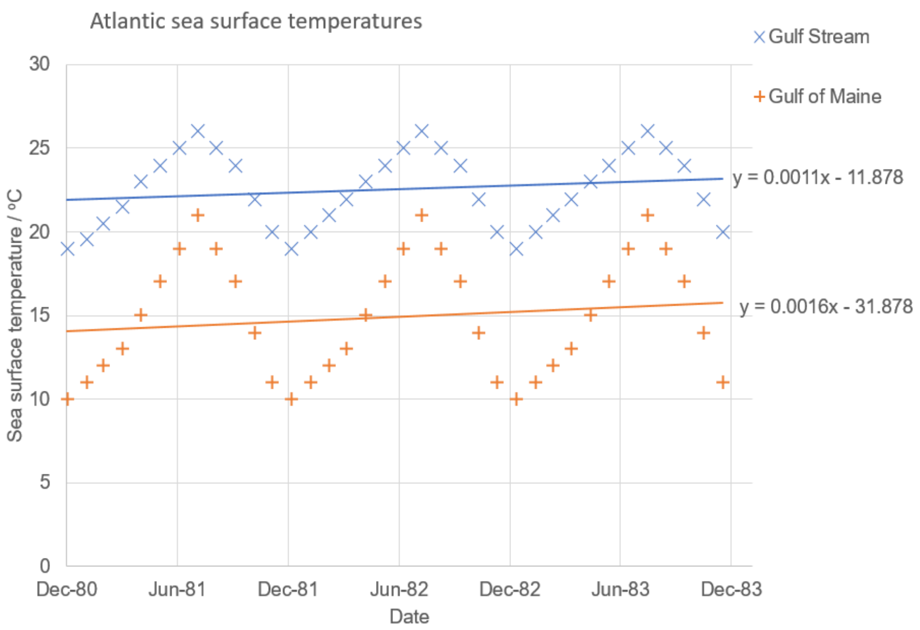

Figure 8: Plot of data from Planetary heat pumps Activity 3 spreadsheet (Source: ESA CCI)

4. The waters of the Gulf Stream are warmer and show less variation in temperature than those in the Gulf of Maine, although the same seasonal variation is visible in both places.
   Average temperatures are rising in both locations.
   The rise is slightly faster in the Gulf of Maine.
   The rates are 0.0011°C/day = 0.40°C/year in the Gulf Stream and 0.0016°C/day = 0.58°C/year in the Gulf of Maine.

Numerical data for this activity was downloaded from https://giovanni.gsfc.nasa.gov

Worksheet 1: PLANETARY HEAT PUMPS

Use your knowledge of geometry and the equations below to answer questions 1–5. Take care with units and significant figures.

Power (in W) = Energy (in J) ÷ time (in s)

Energy (in J) = mass (in kg) × specific heat capacity (in J $kg^{-1}°C^{-1}$) × temperature change (in °C)

1. The radius of the Earth is 6400 km. What is the surface area of the planet in m^2?

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2. One estimate of the extra energy trapped due to global warming is 0.62 W m^{-2}. What is the total amount of extra energy trapped across the whole world:

a. every second?____

b. every year? ____

3. If all this energy remained in the atmosphere, what would the annual temperature increase of the atmosphere be?
total mass of the atmosphere = 5.14×10^{18} kg
average specific heat capacity of air = 1158 J $kg^{-1}°C^{-1}$

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4. If, instead, all this energy went into the oceans, what would their annual temperature increase be?
total mass of oceans = 1.4×10^{21} kg
average specific heat capacity of seawater = 3850 J $kg^{-1}°C^{-1}$

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5. Which theoretical figure is larger? Why? ______________________________

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In practice, the average temperature increase of the atmosphere is much less than the figure you calculated, and measurements of ocean temperatures show a much larger increase.

6. Use ideas from the information sheet to help you explain these differences.

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Worksheet 2: RISING AND FALLING WATER

What you need

- Large transparent container
- Small container
- Plastic bag
- Rubber band
- Food colouring or ink
- Ice or refrigerated water
- Hot and cold water
- Stopwatch or clock (optional)
- Camera (optional)

Health and safety

- Work carefully to avoid spills and splashes that may lead to staining.
- Use hot water between 40°C and 60°C – if hot running water is not available, mix boiling water from a kettle with cold water.
- Take extra care if using glass containers.

Aim

You are going to look carefully at how water of one temperature behaves when it is placed in water of another temperature. Some combinations you might try are shown in the table below.

	Water in large container	Water in small container
1	Cold (from the fridge or cooled using ice)	Hot
2	Hot	Cold
3	Hot	Cold (with small container horizontal)
4	Cool (from the cold tap)	Hot

What to do

(Source: ESA CCI)

1. Put water of one temperature in the large container. Fill it about three-quarters full.
   Place it on a stable surface and allow the water to settle.
2. Put water of the other temperature in the small container.
   Colour this water with food colouring or ink. It needs to be quite dark.
   Make a lid for the small container from a piece of the plastic bag held on with a rubber band or string.
   Make some holes in the lid so the coloured water can escape but not too quickly.
3. Carefully lower the small container into the larger one, disturbing the water as little as you can.
4. Record your observations. You could use descriptions, drawings, photographs or any combination of these. You might also want to make a note of the time when you see particular things happening.
5. When the water has reached a steady state (there appears to be little change), empty out your containers and try a different combination.
   You may want to try some combinations of your own or if the containers you are using make it possible to do so safely, introduce the water from the small container at a different height.

Analysing your results

1. Summarise your observations from each combination you tried as follows:
    - Select the three observations that together best show how the situation evolved.
    - Describe each using:
        - a sentence, or
        - an annotated image, or
        - a snippet of video (no more than 5 seconds).
    - Explain what is happening at each point.
      Use ideas about temperature and density.
2. Do you notice anything interesting if you compare the observations for two different combinations (for example, combinations 2 and 3, or 1 and 4)? If so:
    - Add an extra sentence or composite image, highlighting similarities and differences.
    - Explain what has caused the similarities or differences you highlight.
3. Explain how what you have seen relates to the circulation of water and energy in the oceans. You may wish to refer back to Information sheet 1.

Your teacher will tell you what format to use to share your results with them or the rest of the class.

Investigating salinity

How could you use this equipment to investigate the effect of differences in salinity on mixing between layers of water in the ocean?

- Think about places in the ocean where bodies of water with different levels of salinity come into contact.
- Use these ideas to help you choose combinations to investigate.
- You might want to do some preliminary investigations to see how salty you can make water, or some research to find out just how salty different parts of the ocean are.

Create a plan and, if time allows, carry out your investigation.

Demonstrating upwelling

How could you use these ideas to demonstrate how offshore winds lead to upwelling of cold water from the deep ocean?

Draw a labelled diagram to show your ideas.

Worksheet 3: THE GULF STREAM

Open the Climate from Space web application (cfs.climate.esa.int).

Click on the Data Layers symbol (top right) and pick Sea Surface Temperature.

Play the animation through several times to check you understand how the controls on the screen help you to look more closely at particular places or times.

The Gulf Stream is a warm surface current that surges along the Florida coast and flows across the North Atlantic.

General patterns

Resize the globe in Climate from Space so you can see the Gulf Stream in detail and step through the animation month-by-month for a year or two.

1. How does the Gulf Stream develop and change over the course of a year? Look at things such as how far across the ocean it stretches each month, how defined the edges are, and the temperature difference between the current and the surrounding ocean.

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To find out more about the Gulf Stream, you are going to focus on two places:

- The Gulf Stream east of Norfolk, Virginia.
- The Gulf of Maine.

Use an online map to locate these two areas so that you can use the shape of the coast to identify them in the Climate from Space web application.

2. In which months do the waters of the Gulf Stream appear to be warmest and coolest? Make an estimate of the temperature in each case and compare it with that of the Gulf of Maine in the same months.

		Estimated average temperature / °C	
	Month	**Gulf Stream**	**Gulf of Maine**
Warmest			
Coolest			

Temperature changes

Open the Planetary heat pumps Activity 3 spreadsheet. (Your teacher will tell you how to access this.) The spreadsheet shows some of the data that was used to create the visualisation in the Climate from Space web application.

3. Plot both sets of data on a single graph with date on the *x*-axis and sea surface temperature on the *y*-axis.
   Use your graph to check your answers to question 2.

Add a linear trend line for each set of data, showing the equations for each line on the graph.

4. What do these lines and their equations tell us is happening to the water in the Gulf of Maine and the Gulf Stream? Look for similarities and differences and, if you can, use figures to support your descriptions.

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Making connections

Find out more about the behaviour and impact of the Gulf Stream using the Climate from Space web application and other sources.
You might investigate one of the following questions, or one of your own.

- How does the Gulf Stream affect the distribution of phytoplankton in the Atlantic Ocean? (Use the Ocean Colour data layer.)
- Is there a relationship between the Gulf Stream and patterns of salinity in the North Atlantic?
- How does the extent of sea ice affect the Gulf Stream?
- Are there differences in the roughness of the sea along the path of the Gulf Stream? (Use the Sea State data layer.)
- Are there noticeable differences in cloud cover as the temperature of the Gulf Stream varies?

Use your understanding of how energy and water move between the atmosphere and ocean to relate this new information to the sea surface temperature patterns and trends that you described above.

Information sheet 1: PLANETARY HEAT PUMPS

Go for a swim in the sea on Midsummer's day and the water may be surprisingly chilly. Indeed, one of the biggest causes of drowning, especially during the summer, is cold-water shock. Although the Sun is at its highest point in the sky and there are more hours of sunlight than on any other day of the year, the sea does not reach its maximum temperature until three months later, in the autumn. This lag shows that the sea has a high heat capacity – it takes a lot of energy to change its temperature, so it is slow to heat up and slow to cool down.

Water is incredibly good at storing heat. So good that the top three metres of the ocean alone hold as much heat as the entire atmosphere – and the atmosphere extends to a height of almost 100 kilometres. The ocean's ability to store, transport and slowly release the energy it receives from the Sun makes it one of the key regulators of climate on our planet. The upper layers of the ocean absorb about 90% of the excess heat caused by global warming.

Moving heat around the world

The equator receives much more energy from the Sun than the polar regions. However, the circulation of the ocean and atmosphere redistributes this energy around the world. Ocean currents are driven by the rotation of the Earth, surface winds, and differences in the density of the water due to differences in salinity (saltiness) and temperature. The upper layers of the ocean generally move clockwise in the northern hemisphere and anticlockwise in the southern hemisphere.

Warm surface currents, such as the Gulf Stream shown in the picture, bring heat from the equator and the tropics to higher latitudes. This poleward transport of heat is responsible for the mild climate of Western Europe. In the Pacific, the Kuroshio Current warms the eastern shore of Japan, and there is usually a cold equatorial current extending westwards from South America.

Benjamin Franklin's map of the Gulf Stream, published in 1786 (Source: Retrieved from the Library of Congress)

The so-called Great Ocean Conveyor Belt, or the thermohaline circulation, extends into the depths of the ocean and encompasses the entire globe. Water takes around 1000 years to move through it.

The oceans and the atmosphere each transport about the same amount of heat towards the poles. The circulation of the atmosphere is partly driven by the energy exchanged when ocean water evaporates and when rain falls. This makes the sea an important regulator of the climate and the temperature of its surface a key measurement for climate scientists.

The effect of warmer oceans

Higher sea surface temperatures lead to more evaporation. More water vapour in the atmosphere is likely to increase cloud cover and the amount of rain. In the western Mediterranean, warmer seas are a key factor in the development of sudden rainstorms and flash floods that afflict the coasts of France, Italy and Spain in late summer.

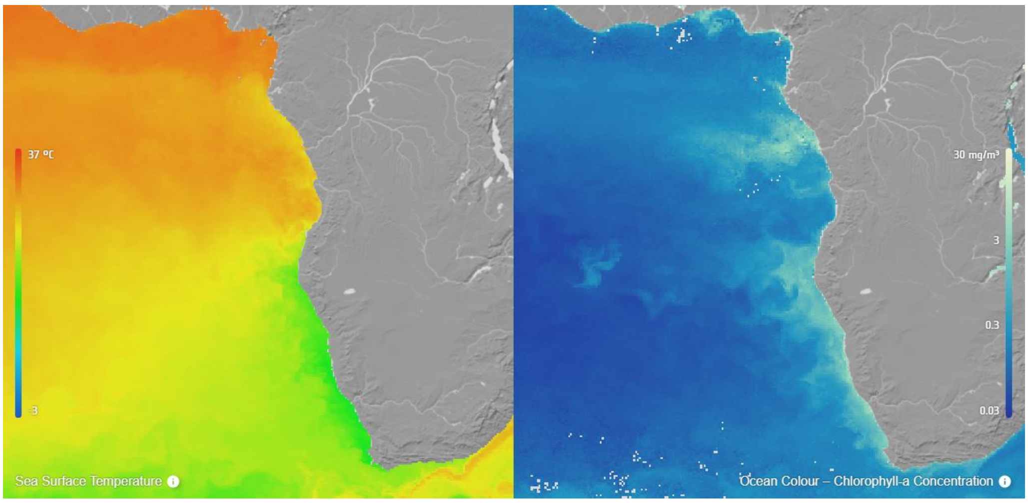
On a larger scale, high water temperatures in tropical oceans power extreme weather events such as hurricanes. So much energy is exchanged between the ocean and atmosphere during these that the surface temperature of the sea in the wake of a large hurricane can drop by a noticeable amount.

Maps of sea surface temperature show not only warm and cold currents but also where cold water is upwelling, that is, rising from the deep ocean to the surface. This happens where surface water is pushed offshore by prevailing winds.

Monitoring the ocean

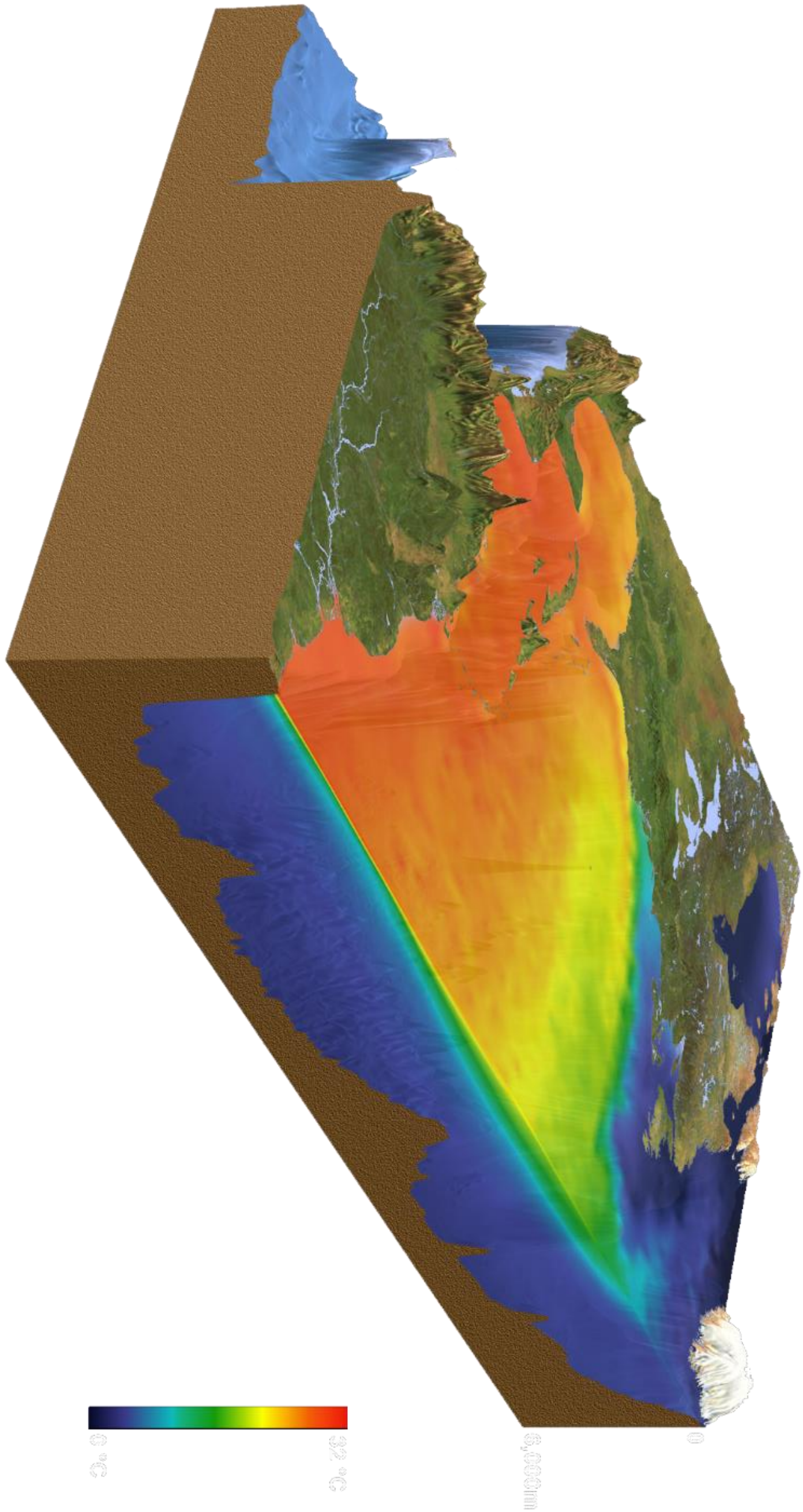
It is likely that the upper ocean has been warming since the middle of the nineteenth century. However, scientists have only been able to measure the warming of the ocean surface from space since the 1970s. Satellites carrying infrared cameras measure ocean temperatures to an accuracy of several tenths of a degree Celsius.

Some of these satellites carry sensors that provide very accurate measurements for a small area of the ocean at a specific moment in time; others sense the average temperature of a larger area and so can collect data for the whole Earth every few days. Climate scientists have combined information from sensors on a range of satellites to produce reliable high-quality data showing how the ocean has been changing in recent years. The data sets cover not only temperatures, but also variables such as salinity, sea level, wave height and levels of chlorophyll (from which we can determine the abundance of the phytoplankton at the base of the oceanic food chain).



Sea surface temperature and ocean chlorophyll along the coast of Africa The cold upwelling water carries nutrients from the sea floor on which the plankton thrive. (SOURCE: ESA CCI)

Information sheet 2: OCEAN TEMPERATURE AND DEPTH



Cross-section through the North Atlantic showing how ocean temperature varies across the surface and with depth (Source: Planetary Visions)

Links

Resources

Climate from Space web application
https://cfs.climate.esa.int

Climate for schools
https://climate.esa.int/educate/climate-for-schools/

Teach with space
http://www.esa.int/Education/Teachers_Corner/Teach_with_space3

Investigating the Gulf Stream with LEO Works
https://www.esa.int/SPECIALS/Eduspace_Weather_EN/SEM29YK1YHH_0.html

ESA space projects

ESA Climate Office
https://climate.esa.int/

Space for our climate
http://www.esa.int/Applications/Observing_the_Earth/Space_for_our_climate

ESA's Earth Observation missions
www.esa.int/Our_Activities/Observing_the_Earth/ESA_for_Earth

Earth Explorers
http://www.esa.int/Applications/Observing_the_Earth/The_Living_Planet_Programme/Earth_Explorers

Copernicus Sentinels
https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Overview4

SMOS - Soil Moisture and Ocean Salinity
http://www.esa.int/Applications/Observing_the_Earth/Space_for_our_climate/New_maps_of_salinity_reveal_the_impact_of_climate_variability_on_oceans

Extra information

Mapping salty waters
http://www.esa.int/Applications/Observing_the_Earth/Space_for_our_climate/Mapping_salty_waters

Sea surface temperature video
https://www.esa.int/ESA_Multimedia/Videos/2020/09/Sea-surface_temperature#.X9oKgkStwEY.link

More Earth from Space videos
http://www.esa.int/ESA_Multimedia/Sets/Earth_from_Space_programme

ESA Kids
https://www.esa.int/kids/en/learn/Earth/Climate_change/Climate_change