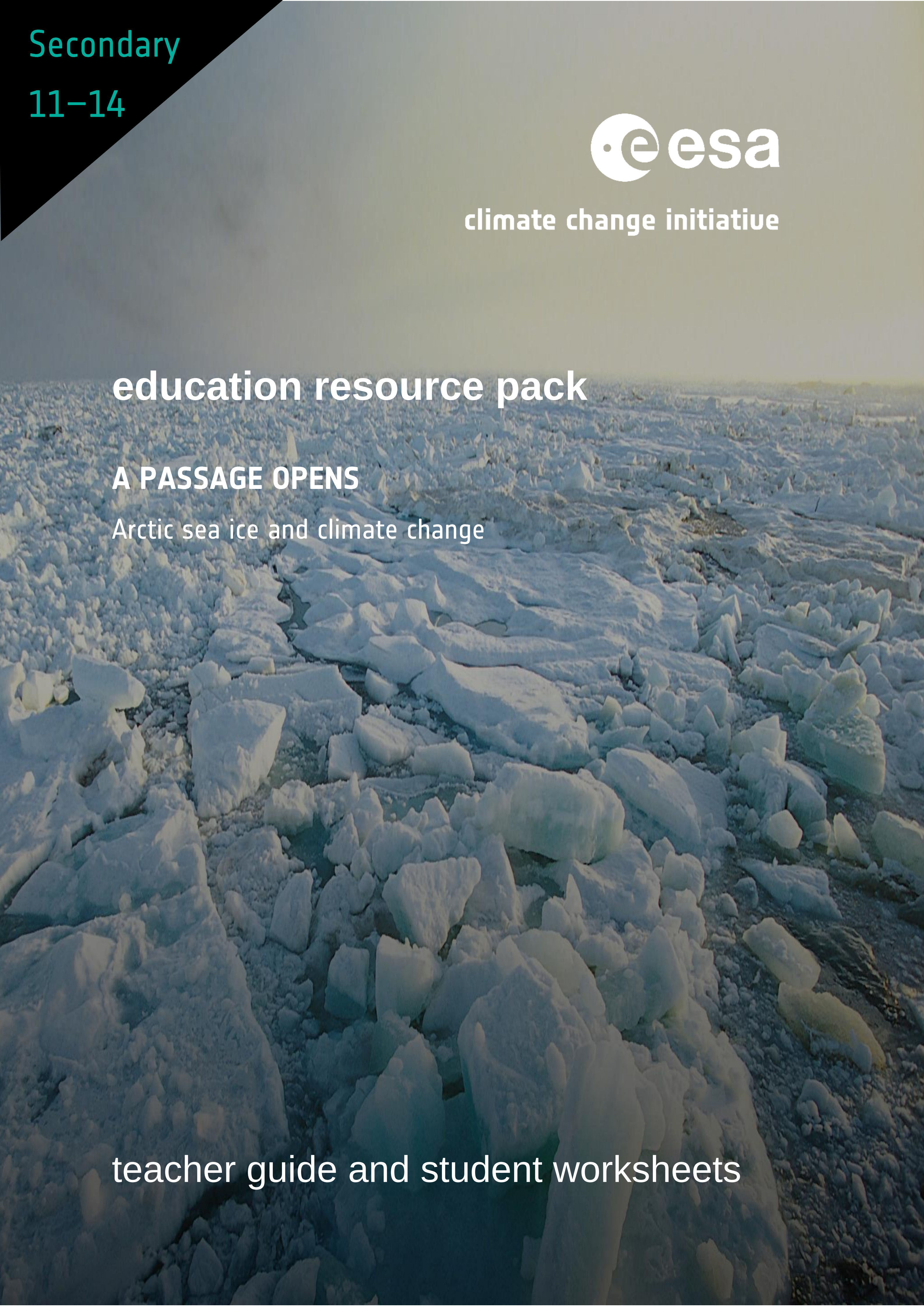

Secondary

11–14

climate change initiative

education resource pack

A PASSAGE OPENS

Arctic sea ice and climate change

teacher guide and student worksheets

climate change initiative education resource pack – A PASSAGE OPENS
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

A PASSAGE OPENS: Overview

Arctic sea ice and climate change

Fast facts

Subjects: Geography, Earth Science, Physics, Chemistry

Age range: 11–14 years old

Type: reading, mathematical modelling, data analysis; discussion

Complexity: medium to high

Lesson time required: 4 hours

Cost: low (0–20 euros)

Location: indoors

Includes the use of: Internet, spreadsheet software

Keywords: sea ice, climate change, Arctic amplification, latent heat, albedo, satellite

Brief description

In this set of activities, students will discover the important role Arctic sea ice plays in the Earth's climate system. The activities are set in the context of the Northwest Passage.

The first activity is a mathematical investigation into sea ice melt rate to illustrate what is meant by Arctic amplification.

A practical investigation provides an opportunity to discuss how models are used in science and consider the difficulties of measuring and predicting the effects of climate change.

Students then use the Climate from Space web application to explore seasonal and long-term trends in sea ice extent and sea surface temperatures.

Intended learning outcomes

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

Explain how the differing albedo of ice and ocean leads to Arctic amplification and the impact of this on climate change.

Use a mathematical model to investigate the effect of different conditions on the melting of sea ice.

Relate an experimental model to the real world and evaluate the model.

Analyse images to obtain data on the melting of ice.

Discuss the challenges of collecting data to describe and predict the effects of climate change.

Use the Climate from Space web application to explore changes in the Arctic region.

Relate changes in the seasonal pattern of sea ice extent to changes in sea surface temperatures.

Suggest reasons for changes over various timescales.

Summary of activities

	Title	Description	Outcome	Prior learning	Time
1	How quickly does sea ice melt?	Introductory scene-setting story followed by a mathematical investigation of melt rates	Explain how the differing albedo of ice and ocean leads to Arctic amplification and the impact of this on climate change. Use a mathematical model to investigate the effect of different conditions on the melting of sea ice.	Students need to be familiar with the principle of conservation of energy	1 hour
2	Ocean temperature and ice melt rate	Practical activity using a smartphone to model using a satellite to monitor the extent of sea ice	Relate an experimental model to the real world and evaluate the model. Analyse images to obtain data on the melting of ice. Discuss the challenges of collecting data to describe and predict the effects of climate change.	None	2 hours
3	The Northwest Passage	Examination of long-term sea ice and sea surface temperature data in the Arctic	Use the Climate from Space web application to explore changes in the Arctic region. Relate changes in the seasonal pattern of sea ice extent to changes in sea surface temperatures. Suggest reasons for changes over various timescales.	None	1 hour

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 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/en/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. It is possible to navigate from here to other parts of the ESA Climate Change Initiative website 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. Climate from Space (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.

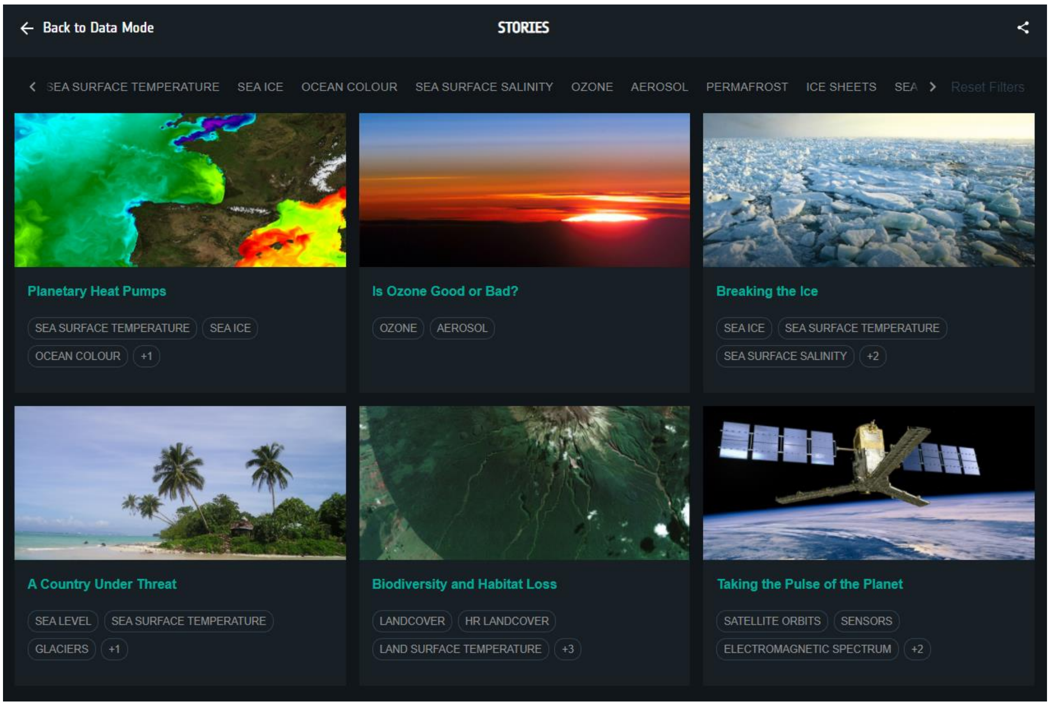

Figure 1: Stories in Climate from Space (Source: ESA CCI)

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.

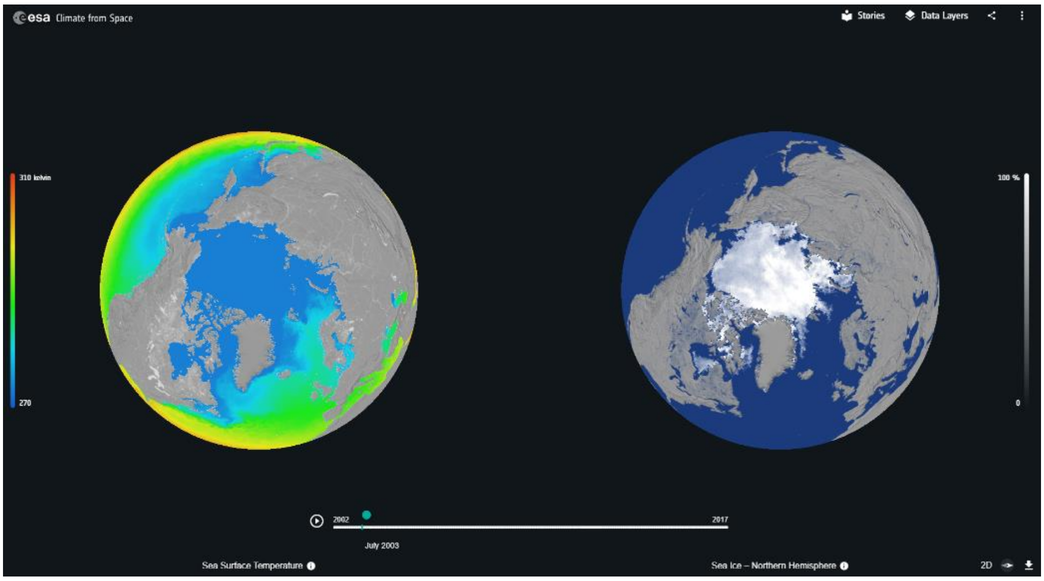

Figure 2: Exploring sea surface temperatures and sea-ice extent in the Climate from Space web application (Source: ESA CCI)

Sea ice and climate: background information

The cryosphere in the climate system

The term cryosphere is used to refer to all those regions of the Earth where water is frozen – at the ocean surface or on or beneath the land. The cryosphere is one of the five components of the climate system (Figure 3): its state is one of the things which determines the global climate.

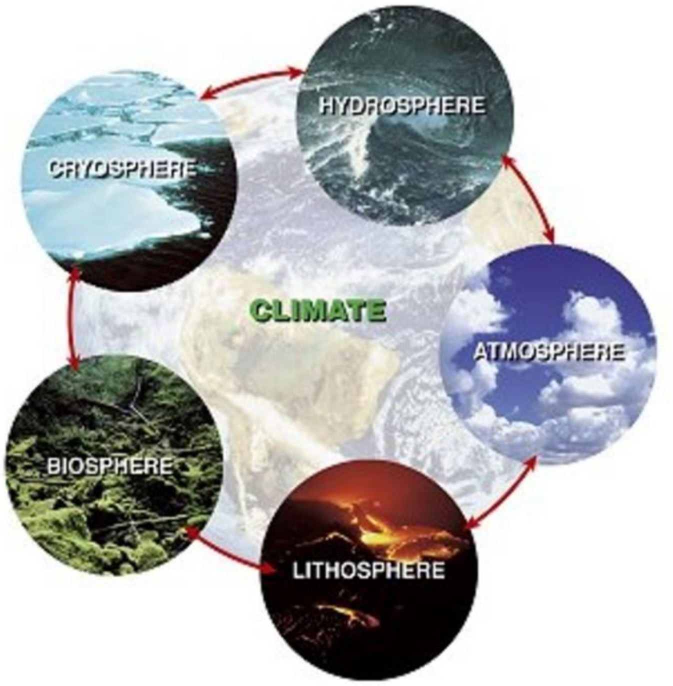

Figure 3: Components of the climate system (Source: ESA)

Water plays a central role in the cryosphere and it affects the climate in several ways when it changes from liquid (water) to solid (ice) or vice versa. Freezing releases heat to the surroundings and thawing absorbs heat from them. Sea ice growth slows the cooling of the Arctic each winter, and the melting of sea ice is responsible for a gradual rise in temperature as summer progresses. Sea ice is, therefore, a climate regulator.

Arctic amplification

Figure 4: Colour contrast between sea ice and open ocean (Source: ESA)

The colour of sea ice contrasts sharply with that of the open ocean, as shown by the photograph (Figure 4) and this also has an impact on climate. Ice and snow have a high albedo (reflectivity) – sea ice can reflect up to 90% of incoming sunlight – so only a small proportion of the energy from the Sun that reaches the Earth is available to warm surfaces covered in white ice or snow. The disappearance of sea ice means the Earth absorbs more energy from the Sun, accelerating global warming and causing even more sea ice to melt. This positive feedback mechanism is referred to as Arctic amplification. Sea ice also traps pockets of air, making it a good insulator. Like a swimming-pool cover or a blanket, it keeps the sea beneath cooler than exposed water and this is another way in which it reduces the warming of the Arctic Ocean.

Oceanic thermohaline circulation

Another, more complex, role of sea ice in the climate system comes from the part it plays in the movement of water around the globe – the oceanic thermohaline circulation. Figure 5 shows this circulation in the Atlantic Ocean. Salty seawater is denser than freshwater. When seawater freezes, the salt remains in the unfrozen water, increasing the density further. This saltier water sinks to the ocean floor and drives the large-scale circulation of cool Arctic water towards the tropics and warm water from the tropics towards the Arctic.

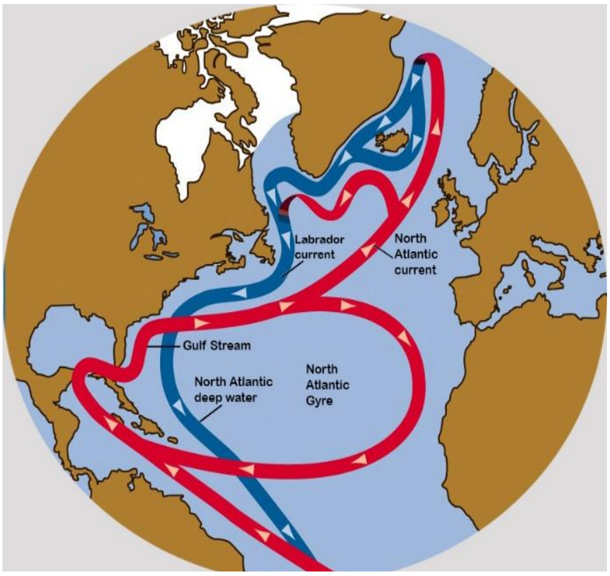

Figure 5: Oceanic thermohaline circulation in the Atlantic Ocean. Red lines indicate warm water, blue lines represent cold water and the arrowheads show the direction of the currents. (Source: ESA)

Essential climate variables

When describing climate change, most people talk about the level of global warming and are aware that many countries are working to keep it below 1.5°C and well below 2.0°C. But the picture is not as straightforward as these apparently low figures suggest.

Firstly, the average hides considerable regional differences in the level of warming. The Arctic is likely to see above-average temperature increases.

Secondly, a focus on the temperature ignores related changes. The World Meteorological Organisation (WMO) lists 54 variables that depend on and describe the Earth's climate. These physical, chemical or biological variables (or groups of linked variables) that scientists can measure reliably are known as essential climate variables (ECVs). Sea ice is one of these because of the many processes through which it affects the climate system.

The Northwest Passage

The Northwest Passage is a shipping route passing between mainland Canada and its Arctic islands that connects the Atlantic and Pacific Oceans. It is shorter than the ice-free southern passages but has seldom been navigable. The decrease of Arctic sea ice as a result of global warming may enable shipping to use this route more regularly but the freeing of the Passage is a worrying signal of changes that affect not only the Arctic region but the climate system of the entire Earth.

Activity 1: HOW QUICKLY DOES SEA ICE MELT?

This activity is introduced using a brief history of the Northwest Passage to provide a context for exploring the role of sea ice in the climate system. Students are then guided through a calculation using the conservation of energy, the concept of albedo, and latent heat of fusion (with the latter two explained) to develop a mathematical model they can use to explore Arctic amplification.

Equipment

- Information sheet 1 (2 pages)
- Student worksheet 1 (2 pages)
- Climate from Space web application: *Breaking the Ice* story (optional)
- Calculator or/and access to spreadsheet software
- Graph paper

Exercise

1. Read Information sheet 1 as a class or ask students to read it in groups. Confident readers could read it in preparation for the lesson, noting three things they found out from it and at least one question they would like to ask.
   If reading or reviewing in class, you could supplement the text with material from the Climate from Space story *Breaking the Ice*. Most pages have galleries of stunning images of the region that you can click through using the arrow at the very right of the screen. More focused pictures you may want to use include:
   - Slide 2 – an engraving of an early expedition
   - Slide 3 – potential polar shipping routes and ships travelling through sea ice
   - Slide 6 – Nuuk, the capital of Greenland
   - Slide 7 – the third image in the gallery is an artist's impression of CryoSat 2, ESA's ice satellite mission.
2. Ask students to work through Student worksheet 1.1. This demonstrates how to find the rate of sea ice melt from basic principles by guiding students through the calculation for two different scenarios. The calculation is summarised in this equation:

$$m_i = \frac{3600P_{in}}{L_f}(1 - C\alpha_i + (1 - C)\alpha_w)$$

Quantity	Symbol	Value	Units
sea ice melt rate	m_i	to be found	kg m^{-2} hr^{-1}
sea ice concentration	C	variable	%
albedo of sea ice	α_i	0.85	–
albedo of open water	α_w	0.07	–
latent heat of fusion of sea ice	L_f	3.3 x 10^5	J kg^{-1}
incoming solar radiation	P_{in}	variable	W m^{-2}

3. Ask students to use this method to investigate the effect of different levels of incoming solar radiation or/and sea ice concentration on the melt rate. They

could work in groups to decide appropriate values or use those suggested in the table on Student worksheet 1.2. Since the investigation involves repetitive calculations, students could distribute the calculations around the group or set up a spreadsheet to carry out the calculations.

4. The questions on Student worksheet 1.2 provide a structure for discussion of the investigation results.
   Note: The calculation considers only the energy provided by sunlight and assumes that all energy absorbed by the water will be transferred to the ice. You may wish to discuss how valid these assumptions are or/and explore what effect changing them will have on the results.

Worksheet answers and sample results

Student worksheet 1.1

1. 1 080 000 J (1.08 MJ)
2. 918 000 J
3. 162 000 J
4. 0.491 kg
5. a. (i) 0.7 or $\frac{7}{10}$ (ii) 0.3 or $\frac{3}{10}$
   b. (i) 643 000 J (ii) 22 700 J
   c. 415 000 J
   d. 1.26 kg m^{-2} $hour^{-1}$

Student worksheet 1.2

Results using the suggested figures are shown in the table below and in Figure 6.

Solar radiation reaching surface / W m^{-2}	Melt rate / kg m^{-2} $hour^{-1}$			
	Sea ice concentration			
	100 %	70 %	40 %	10 %
300	0.491	1.26	2.02	2.79
200	0.327	0.838	1.35	1.86
100	0.164	0.419	0.674	0.929
10	0.0164	0.0419	0.0674	0.0929

1. June
2. Melt rate increases as concentration decreases.
3. See Information sheet 1. Answers could include a reference to reduced reflectivity or Arctic amplification or/and feedback loop; increased energy transfer between ocean and atmosphere; changing oceanic circulation, etc.

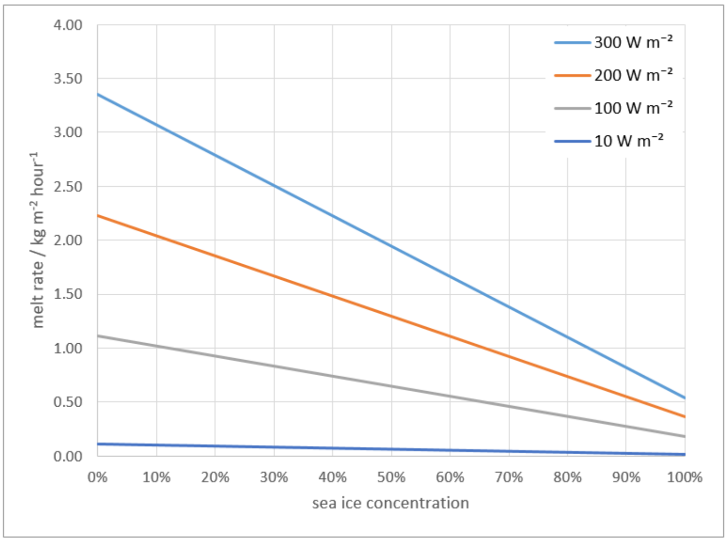

Figure 6: Melt rate against sea ice concentration for different solar radiation levels (Source: ESA CCI)

Activity 2: OCEAN TEMPERATURE AND ICE MELT RATE

In this activity, students explore the effect of changing ocean temperatures on the melting of ice using a smartphone or tablet to model a satellite monitoring sea ice. The later parts of the activity are open, providing opportunities for you to assess core scientific and mathematical skills and stretch more able students as they discuss what their investigation reveals about the difficulties of collecting reliable climate data to model change.

Equipment

Each group will need:

- A beaker, small tray or bowl
- Three or four beads or buttons of different colours
- Play dough to fix the markers in place
- At least three ice cubes or blocks of a similar size made from coloured water
- Beaker or jug
- Hot and cold water
- A thermometer
- Smartphone or tablet with a camera
- A stack of books or block of wood to support the phone/tablet
- A clock or timer (the classroom clock will suffice)
- Towels for wet hands and to deal with any spills

Students will also need:

- A copy of Student worksheet 2 (2 pages) for each student
- Access to image-processing software with which they are familiar
- Printer (optional)
- Acetate sheets printed with a grid (optional)
- Squared paper (optional)
- Tracing paper (optional)

Note: If multiple devices are not available, the practical parts of this activity could be done as a demonstration. The phone output could be displayed on a screen in real time or images displayed or printed for later analysis. (See also Sample results.)

Preparation

It is a good idea to try this practical out beforehand to find the best height and position for a phone or/and how long it takes the ice you plan to use to melt to a noticeable extent in your classroom using water of various temperatures. Using standard ice cubes in beakers of water gives rapid results but the small areas may be difficult to measure. See Sample results, below, for some indication of likely times.

Health and safety
Make sure all equipment is stable and not overhanging the edge of tables.
Ensure there is material available to deal with spills.

Exercise

1. The story used to introduce the previous activity mentioned the use of satellites to monitor sea ice extent. Ask students to identify how the set-up described on Student worksheet 2 models this activity.
   The bowl of water is the ocean, the ice represents sea ice, the beads are GPS reference points (or things that stay in one place and can easily be seen from space such as cities or headlands), the camera is the sensor on the satellite. Note that the measurements are made by Earth observation satellites in a low Earth orbit. The satellites pass over an area at regular intervals, so taking still photographs from time to time is a better model than recording video. (Still images are also easier to analyse!)

2. The previous activity explored the effect of different amounts of sunlight on melt rates. But what happens if the temperature of the ocean changes? Students will no doubt hypothesise that warmer water will increase the melt rate, but how large an effect does it have? They are going to use this model to explore some of the difficulties scientists face when trying to answer this question.

3. Get students to collect data following the instructions on the worksheet.
   They do not need to use exactly equal intervals or record the times as they can get this data from the image file.
   If time is short, you can ask each group to make a single set of measurements allocating different broad temperatures to different groups.
   The method asks students to take only initial and final measurements of the temperature of the water and use these to calculate an average. There are several assumptions hidden in this that you may wish to discuss with more able students and that could lead to further investigations using a temperature sensor connected to a data logger. Conversely, with less able students, you may wish to simply describe the water temperature or/and focus on the time it takes the block to melt in each case.

4. The second page of the worksheet asks students to discuss how to measure the area of ice. Since the aim is to make comparisons, it does not matter what units are used as long as they are the same in each case.
   You may wish to show less able students equipment (or even techniques) they might use, or challenge the more able to find the area in cm^2 by making more precise measurements and scaling their images. (If you plan to do this, it would be good for students to include a ruler in at least one photograph.)

   Possible methods include, but are not limited to:
   - Printing images and tracing the ice block outline onto squared paper (or cutting out the image of the ice block and drawing round the cut-out).
   - Using an acetate sheet printed with a grid as an overlay on printed images.
   - Creating a transparent grid layer in image-processing software (e.g. by scanning squared paper then deleting the background) and superimposing this on the photograph.

- Using an appropriate selection tool to outline the block in image-processing software and noting the dimensions of the enclosing shape to calculate the area (alternatively, the software may display the number of square pixels in an enclosed area).

5. The worksheet asks students to record the areas in a suitable table, display them on a suitable graph and describe the pattern shown. This provides an opportunity for you to assess data-handling skills against appropriate local criteria and again provide a level of support that is appropriate to the ability of each group.
   Students who have difficulty collecting results or creating equally sized photographs could analyse the sample results on Information sheets 2.1 to 2.3.

6. Discussion questions at the end of the worksheet ask students to relate their experience to the real-life scenario that their model represents, consider how the model simplifies the real-life scenario and suggest additional factors affecting melt rate. They might also think about how to adapt the investigation to get accurate numerical results. The discussion may lead students to suggest their own extension activities.

Sample results

Six sample results for water at three different temperatures are shown on Information sheets 2.1 to 2.3, and additional results are given in the table.

The discs of ice used were made by freezing coloured water in a muffin tray and were about 1 cm thick and 5–6 cm in diameter.

The temperature of the surroundings was about 18°C.

The bowl held approximately 300 cm^3 of water and had a diameter of 21 cm, meaning the scale of the photographs on the information sheets is approximately 1:3.

	Area of ice / cm^2			
Time / minutes	**Hot (37.5°C)**	**Warm (24°C)**	**Cool (14°C)**	**Cold (6°C)**
0	20	24	25	26
1	18	21		
2	12	16		
3	7	13		
4	2	9		
5		7	17	
6		4		25
7		2		
10			13	
13				24
17			6	
20				20
24			3	
26				17
28			1	
30				14
37				11
41				9

Worksheet answers

As previously stated, the questions on the worksheet are very open.

The notes below provide some indication of ideas students may come up with and information you may wish to use to direct discussion.

Analysing results

The most obvious conclusion is that the ice melts more quickly at warmer temperatures. Encourage students to look more closely at their results. Does the rate change over time? Can they calculate the rate using the gradient of the graph?

Discussion

1. Likely difficulties fall into two main categories: determining the edge of the ice block from the photograph (especially if it is easy to see different edges above and below the waterline) and resolution of the method used to determine the area (grid size, what fraction of a square could be estimated, ability to enclose the correct area, approximations made of shape to calculate the area).

2. This answer is dependent on the previous one. Students may refer to colour differences – dirty ice and grey oceans might be hard to distinguish – or note that it would be difficult to accurately ‘outline’ a large area.

3. Students might think about cloud cover, the size of the area involved, the fragmentation of the ice and so on.

4. Most of the ice is beneath the surface of the water where the temperature may be different. This means we need good models of how sea temperature changes with depth. If students have been careful not to nudge their equipment, they may be able to see that cold water from the melting ice sits beneath the warm water (see later images on Information sheet 2.1).

5. Students may suggest cloud cover, air temperature, wind, the fragmentation of the ice, how rough the sea is and so on.

6. Answers will depend on suggested factors.

Activity 3: THE NORTHWEST PASSAGE

In this activity, students use the Climate from Space web application to explore satellite data on sea ice extent and sea surface temperature and examine annual and long-term trends in the Northwest Passage and across the wider Arctic region. It could be used to reinforce their understanding of key climate processes in the Arctic. Alternatively, you may wish to use it at the start of a topic on climate change or the Arctic as a way of getting students to share their existing knowledge and suggest questions to investigate.

Equipment

- Internet access
- Climate from Space web application
- Student worksheet 3 (2 pages)
- Information sheet 3 (optional)
- Coloured pens or pencils

Exercise

1. Show a map of the Northwest Passage. You could print Information sheet 3 for students to use or extract the image to use in presentation software. Discuss why people have repeatedly tried to find or/and navigate it, and other polar routes, over the centuries.

2. Ask students to use the Climate from Space web application to complete questions 1 and 2 on Student worksheet 3.1. The web application is fairly self-explanatory but you may wish to display the sea ice data layer or/and demonstrate the controls.

3. Discuss the results with the class, asking why question 2 does not ask if the data *proves* the Earth is warming. (If students did not complete Activity 1, it is worth pointing out the difference between long-term climate trends and natural variability.)
   This could lead to students carrying out independent research into other phenomena that provide evidence for changing climate – from the lived experience of grandparents to frequency and severity of, for example, storms, droughts and heatwaves.

4. Give students some time to explore the sea ice concentration data layer and compare it to sea surface temperature data in the Climate from Space web application.
   Note that, although the animation does not tell us the exact area covered by sea ice at a particular time, we can see how it changes during a year and from one year to the next.

5. Ask students to use the visualisation to answer questions 3 to 7 on Student worksheets 3.1 and 3.2. They could work individually or in pairs or small groups depending on IT access and the ability of the class.

6. If students have been working individually or in pairs, arrange them in small groups to discuss the questions at the end of Student worksheet 3.2. This is a very open activity, allowing you to ask students to structure the discussion in a particular way or/and report back in using a method appropriate to the class and where this falls in your teaching sequence. For example:
   - If students are only beginning to study climate change, each group could list their ideas indicating how certain they are about each statement they make. They could also add questions arising from the data to investigate in future sessions.
   - If you are using this near the end of a unit, groups or individuals could be asked to relate these trends to their existing knowledge of climate change in a paper/poster that could be used to assess their learning.

Worksheet answers

Ice-free years

1.

Year	Ice-free?	Year	Ice-free?
2002	No	2009	No
2003	No	2010	Yes
2004	No	2011	Yes
2005	No	2012	Yes
2006	No	2013	No
2007	Yes	2014	No
2008	Almost	2015	Almost

2. Three of the four years in which the Northwest Passage was open have been in the last decade. This data, therefore, supports the idea that the climate of the Earth is changing. However, there is still natural variability so the data does not, by itself, prove that the world is warming.

Arctic sea ice trends

3. a. March/April b. September/October
4. Increased sea surface temperature means less ice.

5. 6. See Figure 7 on the next page.

7. **Sea ice – similarities:** maxima and minima occur in the same months each year – there is an annual cycle. **Sea ice – differences:** maximum extent on average is less; there is a smaller area that is always frozen.
   Sea surface temperatures – similarities: maxima and minima occur at the same times each year (but this annual cycle is the opposite to that of sea ice).
   Sea surface temperatures – differences: the maximum and minimum temperatures are both higher.
   Students may give reference to specific areas in their answers depending on their geographical knowledge.

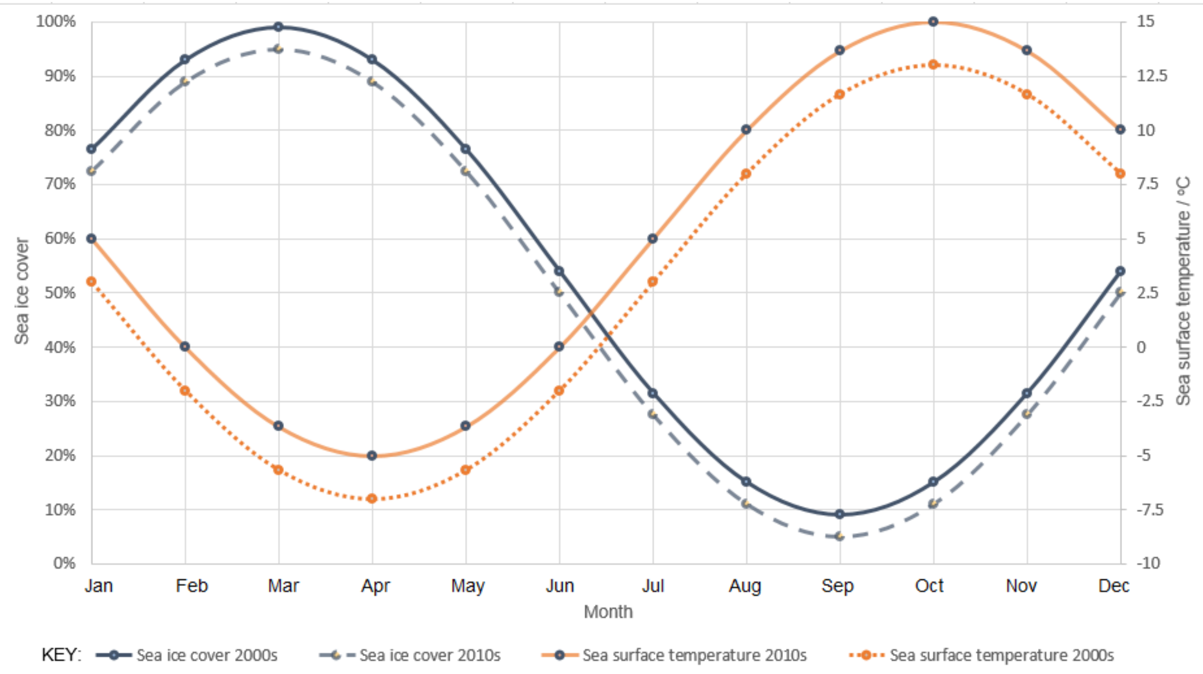

Figure 7: Seasonal cycles of sea ice extent and sea surface temperature (Source: ESA CCI)

To discuss

Student responses to these questions will vary depending on when this activity is used, how the discussion is structured, and the expected outcomes. The notes below deal with a couple of matters that commonly arise in the discussion.

8 a. Over a year, the maximum and minimum extent of sea ice are seen when the temperature is starting to increase and decrease respectively: the Arctic needs to warm up for ice to start melting, and cool down for ice to start to form. You could explain this as a short-term example of the ice holding a ‘memory’ of past weather – an attribute that is made use of (through cores) in longer-term studies.

b. Over the last three decades, climate change has affected the average temperature of the atmosphere but much of the excess energy has been absorbed by the oceans. The Arctic region is primarily ocean covered in sea ice – unlike the Antarctic where most of the ice is in ice sheets or glaciers on land and it only comes into contact with the ocean at the edges of the continent. This is one of the reasons change has been more rapid in the Arctic.

9. Scientists expect the rate at which sea ice disappears to accelerate thanks to Arctic amplification (see page 8).

Worksheet 1: HOW QUICKLY DOES SEA ICE MELT?

The **specific latent heat of fusion** is the amount of energy it takes to melt 1 kg of a solid (without changing the temperature). For sea ice, it is 330 000 J kg^{-1}. We can use this together with ideas from the information sheet *A Passage Opens* to explore factors affecting how quickly sea ice melts.

Calculating melt rates

1. About 300 W of solar radiation reaches each square metre of the Earth's surface in the Arctic on a clear June day. How much energy is this per hour? (HINT: remember, 1 W = 1 J s^{-1}.)

___

2. About 85% of the radiation falling on sea ice is reflected away from the Earth's surface: we say it has an **albedo** of 0.85. On a clear June day, how much energy does a square metre of sea ice reflect in an hour?

___

3. How much energy is left for the ice to absorb?

___

4. What mass of ice can this amount of energy melt? (HINT: use the information about latent heat of fusion at the top of the page.)

___

This is the melt rate in kg m^{-2} $hour^{-1}$ on a clear June day when the sea ice concentration is 100% (the whole surface is covered by ice).

5. If the sea ice concentration is 70%:

a. What fraction of a square metre is (i) ice? __________ (ii) open ocean? __________

b. How much of the solar energy falling on each square metre in an hour will now be reflected by:

(i) the ice in that square metre?
(HINT: your answer should be smaller than your answer to Q2.)

___

(ii) the ocean in that square metre, given that the albedo of the ocean is 0.07?

___

c. How much energy does the ocean absorb when the sea ice concentration is 70%?

___

d. If all this energy is transferred to the ice, what is the new melt rate?

___

Exploring melt rates

Investigate how melt rate changes:

- if the amount of radiation reaching the surface changes (due to cloud cover or a different time of year)
- as the sea ice concentration changes.

You could display your results on a graph or/and summarise them in a table like this.

Solar radiation reaching surface / W m^{-2}	Melt rate / kg m^{-2} $hour^{-1}$			
	Sea ice concentration			
	100 %	70 %	40 %	10 %
300	Answer to Q4	Answer to Q5d		
200				
100				
10				

Use your results and information from *A Passage Opens* to answer these questions:

1. 10, 100, 200 and 300 W m^{-2} are typical solar radiation levels for the Arctic region in March, April, May and June, respectively.
   In which month is sea ice melt rate largest?

____

2. Describe the relationship between sea ice melt rate and sea ice concentration.

____

____

3. Explain in your own words why sea ice plays a vital role in the climate system.

____

____

____

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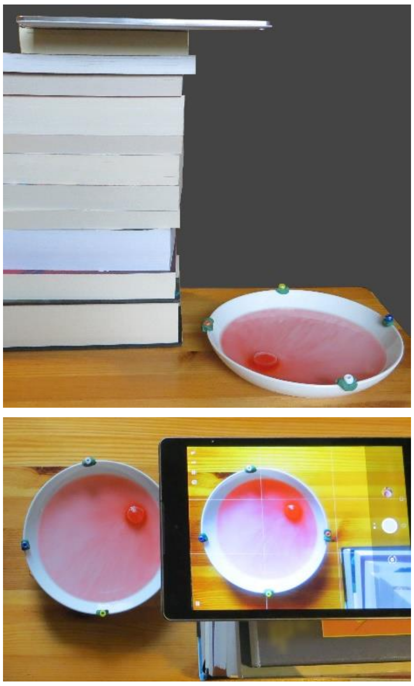
Worksheet 2: OCEAN TEMPERATURE AND ICE MELT RATE



Using a tablet to monitor melting ice. The top picture is a side view, and the bottom picture is a bird's-eye view. (Source: ESA CCI)

Health and safety

- Make sure your equipment does not stick out over the edge of the table.
- Mop up any spills quickly.
- Do not taste anything.
  Keep your hands away from your mouth.

What you need

- Bowl
- Three or four beads (different colours)
- Some play dough
- A pile of books
- A smartphone or tablet
- A beaker or jug
- At least three ice cubes or blocks (keep in the freezer until needed)
- A thermometer
- A clock or timer

Collecting data

1. Use the play dough to stick the beads evenly around the edge of the bowl. These will act as reference points if you need to resize your pictures.
2. Place the phone or tablet on top of a pile of books so the camera can view the whole bowl (see pictures).
3. Pour some water into the bowl and measure the temperature of the water.
4. Put your block of ice in the water, check the time and take a photograph.
5. Take another photograph every so often (your teacher may give you some advice on this). Try not to move the camera or bowl between shots.
6. Note the temperature of the water when you have taken your final picture.
7. Repeat steps 3 to 6 at least twice; use water at a different temperature each time.

Run number				
Initial water temperature / °C				
Final water temperature / °C				
Average water temperature / °C				

Analysing results

1. Work out the average temperature of the water for each run of the experiment.
2. Check that all the photographs are to the same scale by using image-processing software to check the distance between your reference points or the size of a square drawn around your bowl.
   If any photographs are too big or too small, resize them to match the others.
3. Your next task is to measure the area of the ice in each image.
   Discuss the questions below with your group to help you decide how to do this.
   - Will you make measurements from the screen or printed copies?
   - Is the area of the ice in your images the same as the actual area of the ice?
     If not, does this matter?
     If it matters, what will you do about it?
   - What units will you measure in?
   - What steps will you take to make your measurement as precise as possible?
4. Use the method you have chosen to measure the area of ice in each picture.
   Record your results in a suitable table and plot them on an appropriate graph.

Describe the pattern shown by your graph, giving as much detail as you can.

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Discussion

Discuss the questions below with your group.

1. What made it difficult to get an accurate measurement of the area in this model?
2. Would scientists using satellite data also experience these problems? Why?
3. Are there any other things that might make it more difficult to measure changes in the area of sea ice in real life?
4. Satellites that measure the temperature of the ocean from space record the surface temperature. Does this affect how easy it is to link ocean temperature to how quickly sea ice melts? Why?
5. What factors other than those you have already investigated (light intensity, area of sea ice and ocean temperature) might affect the rate at which sea ice melts?
6. What effect do you expect each factor to have? Why?

If you can, investigate one of your ideas. You might create a mathematical or physical model, or do some research online.

Worksheet 3: THE NORTHWEST PASSAGE

Open the Climate from Space web application (cfs.climate.esa.int). Click on the Data Layers symbol (top right) and pick Sea Ice – Northern Hemisphere. 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.

Ice-free years

(Source: Encyclopædia Britannica, Inc.)

Run the animation slowly, focusing on the area shown on the map.

The red line marks a potential shipping route known as the Northwest Passage.

1. Complete the table to show the years in which the Northwest Passage was free of ice, allowing ships to pass.

2. Does the information in the table provide evidence for climate change? Explain your answer.

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Year	Ice-free?	Year	Ice-free?
2002		2009	
2003		2010	
2004		2011	
2005		2012	
2006		2013	
2007		2014	
2008		2015	

Arctic sea ice trends

Go back to the Climate from Space web application. Click on the Data Layers symbol, scroll down the list to Sea Surface Temperature and click COMPARE.

3. In which month each year does Arctic sea ice:

a. cover the largest area? ____

b. cover the smallest area? ____

4. How is sea ice extent related to sea surface temperature?

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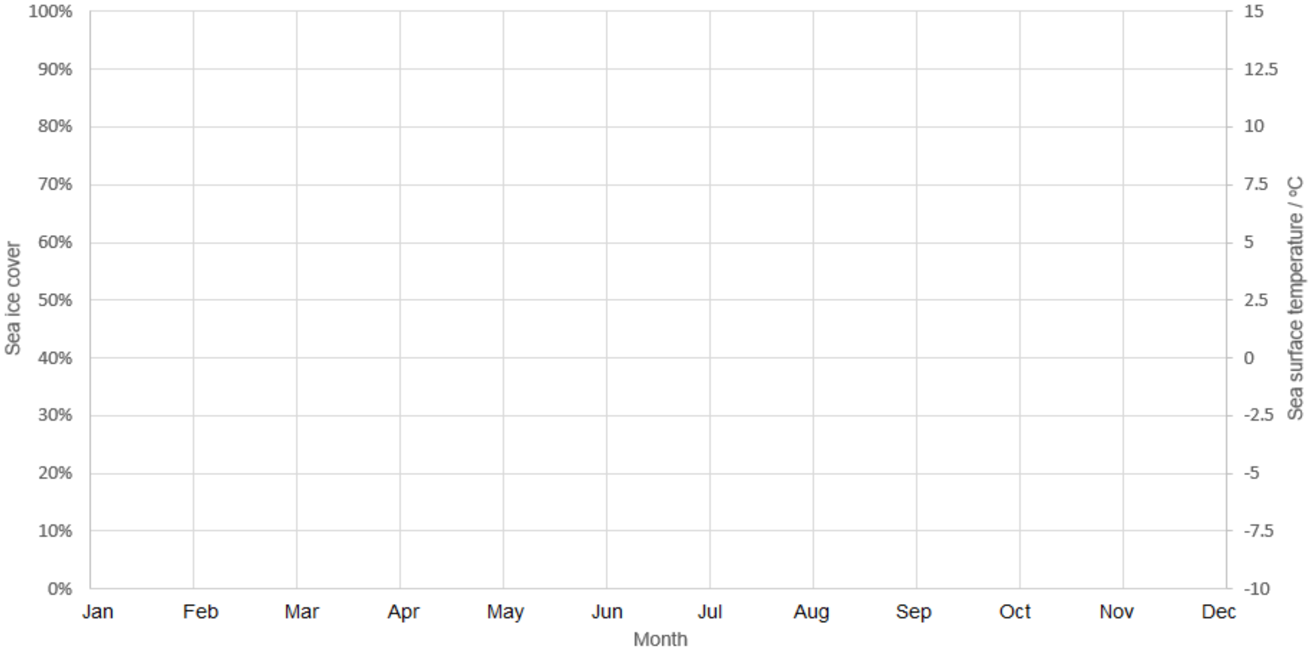
5. Play through the years 2000 to 2009 a little more slowly. On the axes below:
a. Sketch a line in blue to show how the percentage of the ocean covered by sea ice changes through a typical year in this decade.
b. Sketch a line in red to show how sea surface temperature changes through a typical year in this decade.
You do not need to find precise values, just show the general pattern.
For sea surface temperature, it may be helpful to focus on a particular area.



KEY: Sea ice cover 2000s Sea ice cover 2010s Sea surface temperature 2010s Sea surface temperature 2000s

6. Now play through the years from 2010 to the end of the visualisation.
Add lines to the graph to show how the percentage of the ocean covered by sea ice and sea surface temperature changed in these years.
Use two different colours and do not forget to add the information to the key.
The lines may overlap if the pattern is the same for all or some parts of the year.

7. Describe the similarities and differences in the pattern for each decade.

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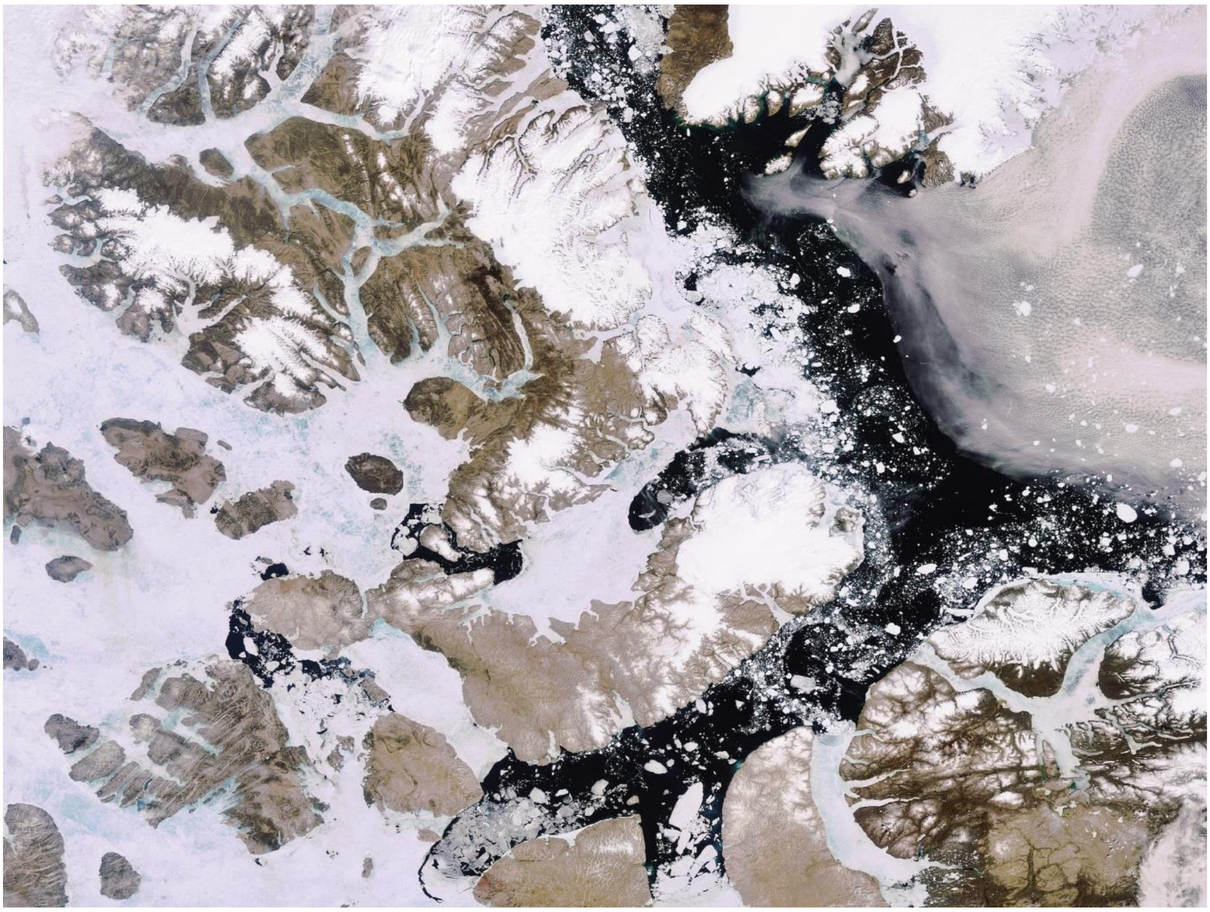
To discuss

8. What causes the area of sea ice to change:
(a) over a year? (b) from decade to decade?
9. How might the pattern change over the next decade or decades?
Explain your ideas.

Information sheet 1: A PASSAGE OPENS

For centuries, ships travelling between Europe and Asia have had to go all the way around the land and ice that separates the two. The so-called Northwest Passage between mainland Canada and its Arctic islands would be a shorter sea route but, for most of recorded history, it has proved impenetrable, locked firmly in the grip of a frozen sea. The ice has defeated many, including the British Royal Navy. Sir John Franklin's 1845 expedition was lost. Eighteen search parties sent out over the following thirty years failed to find any trace of him, his two ships, or the crew of 130 individuals. In 1906 Roald Amundsen became the first person to get through the Northwest Passage, taking three years to make the voyage in a small boat.



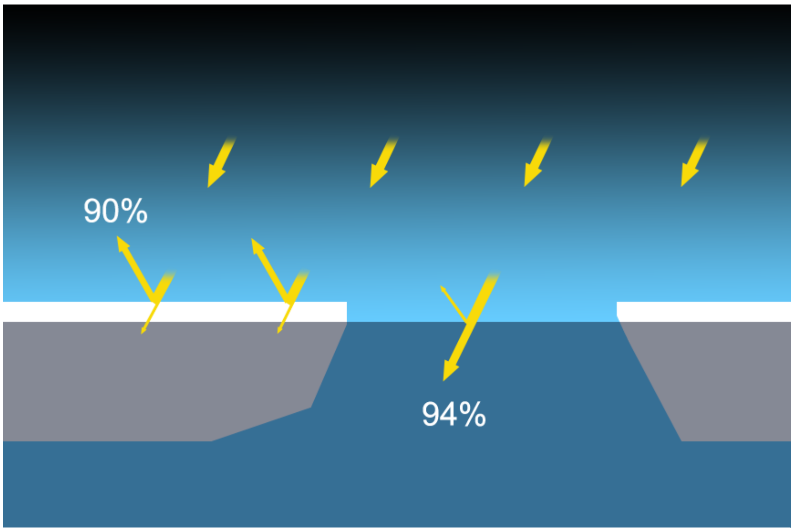
A satellite image of summer sea ice in the Arctic.
The narrow channel between mainland Canada and its Arctic islands is usually impassable.
In this picture, Lancaster Sound (lower centre) is open, but ice still blocks Parry Channel to the west.
(Source: ESA)

In the century that followed, only a few more ships made the journey – with the aid of icebreakers. But, at the same time, the Arctic sea ice started to melt. Satellite images show that the passage opened for the first time in 2007, decades before climate models had predicted it would. While the opening of the Northwest Passage can make the shipping of goods from Asia to Europe faster, it is a very worrying milestone for both the Arctic and our planet as a whole.

Arctic amplification

The route opened because the overall temperature of the Earth is rising. And temperatures in the Arctic are rising two to three times faster than the global average.

Why? White ice reflects a lot of sunlight, just like the light-coloured clothing many people prefer to wear in the summer. When sea ice melts, ocean water is exposed. The dark sea absorbs most of the sunlight hitting it so the water warms up. Warmer water melts away more of the sea ice, exposing more ocean to absorb the sunlight and so the melting gets even faster. This is known as Arctic amplification and is an example of a positive feedback loop.



Ice reflects about 90% of the incoming solar radiation, whereas open water absorbs about 94% (Source: ESA)

In recent years, warmer seas have reduced the area of the Arctic Ocean that freezes each winter. And Arctic amplification is speeding up this change.

Using the Northwest Passage as a shipping route may make the situation even worse. Ships' exhaust gases will send soot and chemical pollutants into the air over the Arctic. When soot falls on sea ice, it darkens the surface and so the ice absorbs more sunlight and melts more quickly than before.

Sea ice and the climate

Sea ice keeps the water beneath it warm in the same way that igloos provide insulation to keep the Inuit people warm. As sea ice melts, the insulating layer is removed and heat from the ocean is transferred to the atmosphere above. The melted ice is fresh water that dilutes the ocean around it and affects circulation patterns that are partly driven by differences in the density of seawater. (Salty sea water is denser than fresh water.) So, the effect of melting sea ice on the atmosphere and the ocean is complex.

Sea ice not only shows how the Earth's climate is changing, but it also plays an important part in regulating that climate. Things that do this, and that we can track reliably, are called essential climate variables (ECVs). One of the ways in which scientists monitor ECVs is by using satellites. Radar instruments on certain satellites can 'see through' cloud to measure the extent and thickness of sea ice. Data from these instruments shows that the area of ice in the Arctic has reduced by 40% over the last four decades.

Information sheet 2.1: MELTING ICE – Warm water

0 minutes

1 minute

2 minutes

3 minutes

4 minutes

5 minutes

(Source: ESA CCI)

Information sheet 2.2: MELTING ICE – Cool water

0 minutes

5 minutes

10 minutes

17 minutes

24 minutes

28 minutes

(Source: ESA CCI)

Information sheet 2.3: MELTING ICE – Cold water

0 minutes

6 minutes

13 minutes

20 minutes

26 minutes

30 minutes

(Source: ESA CCI)

Information sheet 3: THE NORTHWEST PASSAGE

(Source: Encyclopædia Britannica, Inc.)

Links

ESA 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

Sea ice from space
esa.int/Education/Teachers_Corner/Sea_ice_from_space_-_Investigating_Arctic_sea_ice_and_its_connection_to_climate_TEACH_WITH_SPACE_G04

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

Envisat
esa.int/Applications/Observing_the_Earth/Envisat

Extra information

Greenland and Antarctica losing ice six times faster than expected
esa.int/Applications/Observing_the_Earth/Space_for_our_climate/Greenland_and_Antarctica_losing_ice_six_times_faster_than_expected

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

Appendix: DID YOU KNOW?

A selection of interesting facts related to the topic that you can use in a variety of ways. You might introduce a lesson with one of them, put the ideas on cards to add to displays of student work, pick a point as a discussion starter, use the statements in a true/false quiz ...

- The Northwest Passage is about 1900 km shorter than the route via the Panama Canal.
- Freshly fallen snow can have an albedo up to 0.90. This decreases as the snow becomes older and turns into ice crystals.
- Ice floats because it is less dense than water. This is unusual because most substances are denser when they are solid than when they are liquid.
- Sea ice concentration can be measured with satellite instruments that detect microwave radiation.
- A fleet of microwave satellites capable of measuring sea ice concentration has been operational for more than four decades.
- Many Earth observation satellites are in such orbits that they cannot take measurements directly above the North or South Pole – although they can ‘see’ everywhere else on Earth.