Secondary
11-14

esa

education resource pack

THE CARBON CYCLE

Teacher guide and student worksheets

climate change initiative education resource pack – THE CARBON CYCLE
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

THE CARBON CYCLE: Overview

Fast facts

Subject(s): Science, Chemistry, Biology, Earth Science

Age range: 11–14 years old

Type: reading, practical activity, online research

Complexity: medium to advanced

Minimum lesson time required: 4 hours

Cost: low (5–20 euro)

Location: indoors

Includes the use of: Internet, presentation and image software, household acids

Keywords: carbon dioxide, methane, carbon footprint, carbon cycle, emission, source, sink, greenhouse gas, satellite, Earth observation, phytoplankton, biomass, permafrost

Brief description

In this set of activities, students will learn about the carbon cycle and use it to identify actions at the individual and community level to reduce the amount of carbon being emitted to the atmosphere.

A practical activity using household materials considers the impact of ocean acidification, allowing students to design a more precise experiment to carry out in a laboratory setting.

In the final activity, students use real climate data in the Climate from Space web application to investigate a question about one part of the carbon cycle.

Intended learning outcomes

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

Create a diagram showing the carbon cycle, including fast and slow components.

Use the carbon cycle to identify actions to reduce human-induced climate change.

Structure a scientific explanation of why such an action is likely to have an impact.

Empathise with the viewpoints of others.

Describe the effect of increased ocean acidity on marine organisms.

Evaluate experimental techniques and estimates, extending existing methods to find additional information.

Use the Climate from Space web application to investigate a question related to the carbon cycle.

Select key information to inform others.

Summary of activities

	Title	Description	Outcome	Prior learning	Time
1	The carbon cycle	Reading assignment and optional assessment activity (game)	Create a diagram showing the carbon cycle, including fast and slow components. Use the carbon cycle to identify actions that may help reduce human-induced climate change. Structure a scientific explanation of why such an action is likely to have an impact. Empathise with the viewpoints of others.	Outline understanding of food chains, photosynthesis, the greenhouse effect, and the rock cycle are desirable but not essential	1 hour + ½ hour for optional assessment activity
2	Acid oceans	Practical activity	Describe the effect of increased ocean acidity on marine organisms. Evaluate experimental techniques and estimates, extending existing methods to find additional information.	None	Set-up ½ hour; 5 minutes after about an hour and once a day for next 2 or 3 days; plenary ½ hour
3	Tracking carbon from space	Research task	Use the Climate from Space web application to investigate a question related to the carbon cycle. Select key information to inform others.	The carbon cycle – e.g. 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.

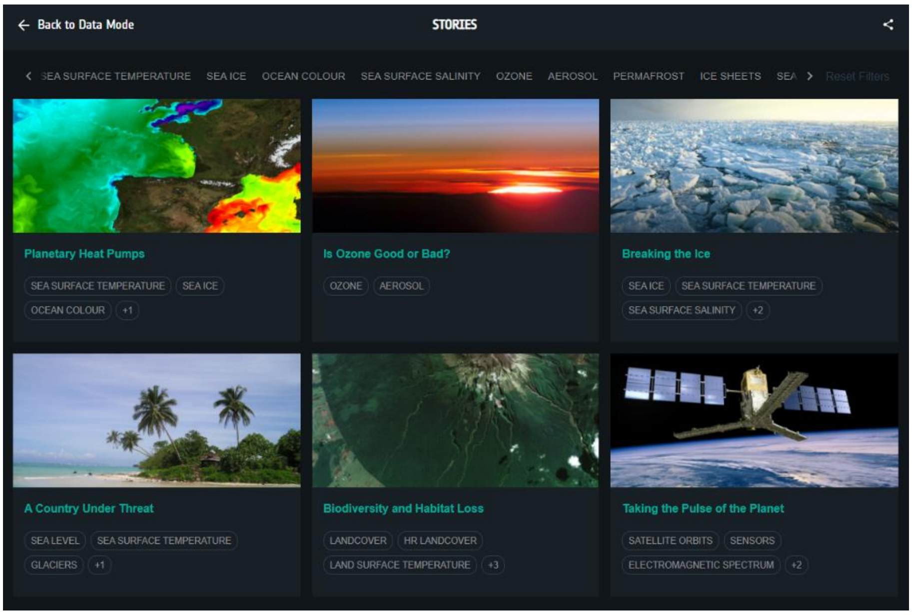

Figure 1: Stories in the Climate from Space web application (Source: ESA CCI)

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.

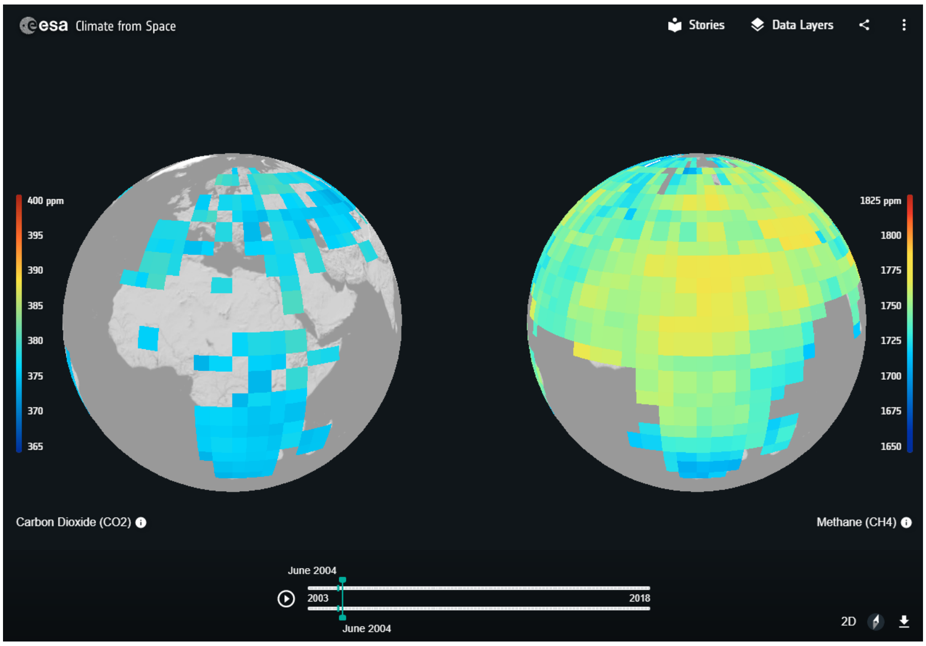

Figure 2: Comparing carbon dioxide and methane data in the Climate from Space web application (Source: ESA CCI)

Carbon and climate: background information

The carbon cycle

The relative abundance of carbon in the Earth's atmosphere and crust is surprisingly low – less than 0.5% in both cases. Yet carbon compounds are essential to life, forming the tissues of all living things. All organic carbon, and nearly all that stored in the oceans and the ground beneath our feet, was first fixed from the atmosphere by photosynthesis. Individual atoms become part of different molecules, held in different stores (sinks), and may take seconds or aeons to return to the atmosphere.

How carbon moves through the carbon cycle is well known and is described on Information sheet 1 (see also Figure 3). However, as human activities disrupt the cycle – releasing carbon compounds to the atmosphere faster than they are absorbed – the need to find out how much carbon is stored in various sinks or reservoirs, and how much transferred by each process, becomes ever more important. This is particularly true in situations where a warming planet may lead to positive feedback. For example, methane released from thawing permafrost contributes to further warming.

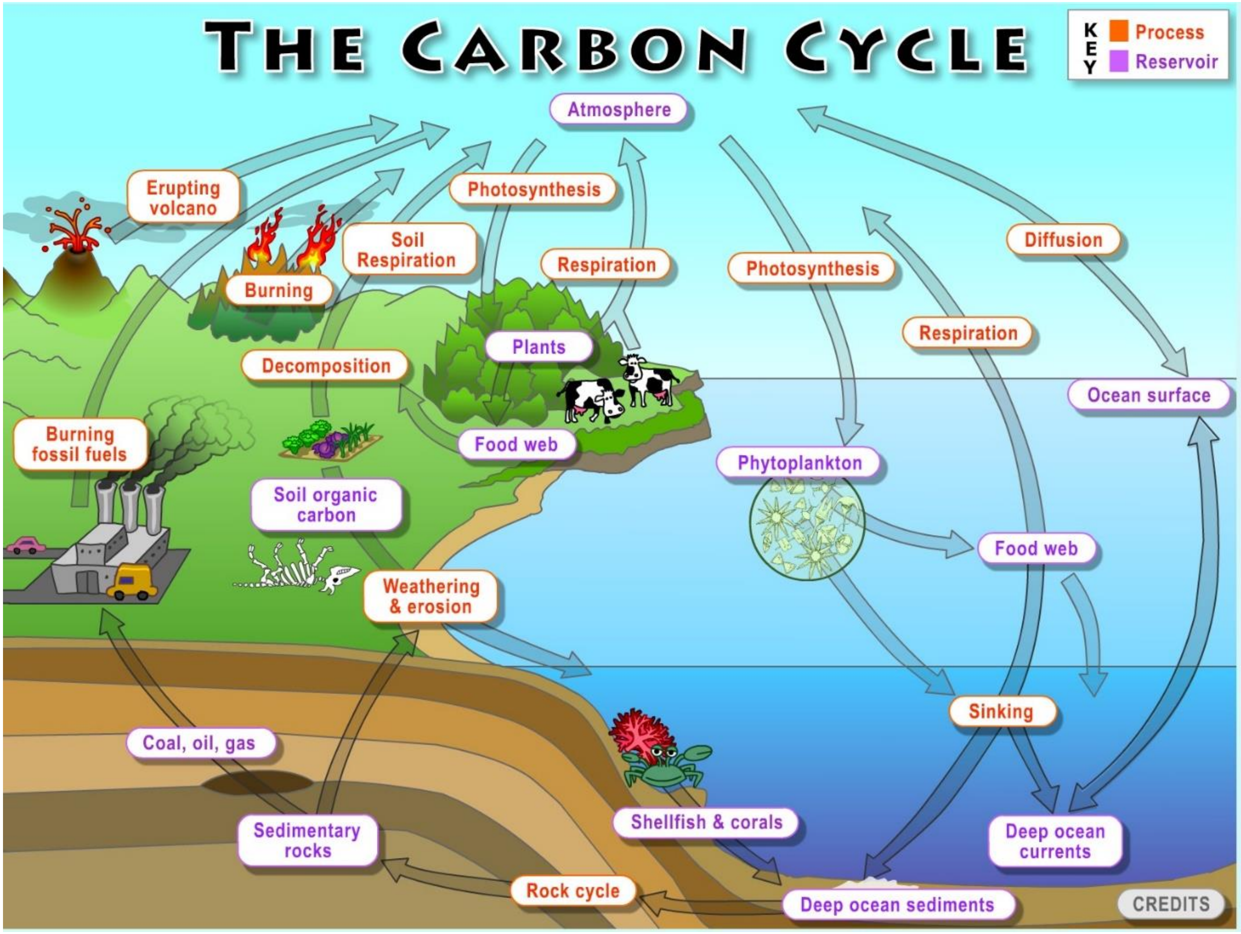

Figure 3: The carbon cycle (Source: Jeff Lockwood, used under CC BY-NC-SA 3.0)

Climate change and the carbon cycle

The key to controlling climate change is managing the carbon cycle – increasing the amount of carbon stored in sinks and cutting down emissions. Figure 4 shows the size of some of these stores and transfers (fluxes). Activity 1 allows students to relate individual and communal actions to these processes.

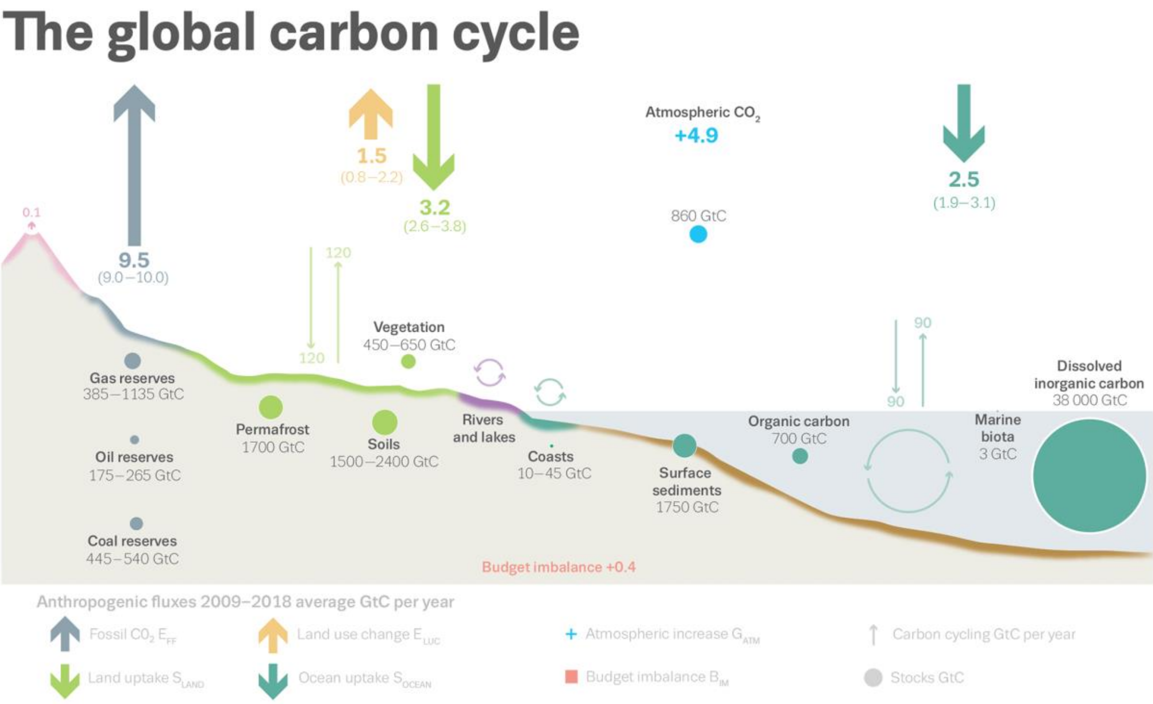

Figure 4: Human impacts on the global carbon cycle
(Source: Pierre Friedlingstein, Matthew W. Jones, Michael O'Sullivan et al.; used under CC BY-SA 4.0)

Collecting carbon data

As Figures 3 and 4 show, we need information about a huge number of things if we are to understand the carbon cycle and its impact on climate. Collecting data about, say, the proportion of the ground that remains frozen throughout the year across the entire Arctic would not be possible if we could only make measurements on the ground itself. Some satellites in orbit around the Earth 'look at' everywhere in one hemisphere every fifteen minutes. Others travel over each part of the planet once every ten days or so. A single satellite image can contain more information than an army of people could collect on the ground.

Sensors on satellites can not only take pictures to show the appearance of the Earth – which can, for example, help us monitor how we use land – but also allow us to measure many variables related to the parts of the carbon cycle that we cannot see, including the concentration of gases in the atmosphere, the temperature of the land and sea surface, and the amount of carbon stored as biomass. Activity 3 gives students a chance to interact with some of this data. They can find more about how it is collected in the *Taking the Pulse of the Planet* education resource packs available from https://climate.esa.int/educate/climate-for-schools/.

Activity 1: THE CARBON CYCLE

This activity allows students to develop an understanding of the carbon cycle, how human activities are disrupting it, and how consideration of it can help us identify actions to mitigate climate change. The tasks support students in the literacy skills of reading for understanding and writing to inform and persuade, as well as encouraging them to think critically about their knowledge and use empathy to consider another point of view. Some or all of the tasks on the worksheet may be assigned as homework: the description below suggests a way of using it in the classroom, supplemented by an additional activity.

Equipment

- Information sheet 1 (2 pages)
- Student worksheet 1
- Climate from Space web application: *Carbon Cycle* story (optional)
- Internet access
- Materials for making posters or image creation/processing software with which students are familiar (optional)
- A tennis ball or volleyball for each group of 4–6 students (optional)

Exercise

1. Read Information sheet 1 as a class or ask students to read it individually or in groups, in the way described in steps 1 and 2 on Student worksheet 1.
   If students are working in pairs or groups, encourage them to share their understanding of the terms in bold and only refer to previous work, textbooks, or the Internet if neither of them/no one is familiar with the concept.
   If you are working as a whole class, you may wish to illustrate the second reading of the information sheet with images from the *Carbon Cycle* story in the Climate from Space web application, in particular the video on slide 4.
2. Ask the students to create diagrams of the carbon cycle. Students could work individually, in pairs, or groups. They could use A4 paper, a full page in their exercise books, or image creation/processing software; and, perhaps, other media depending on the time and resources available.
   Encourage them not to make the diagram too tight to ensure they have room to add more information at worksheet step 5.
3. Once students have added information about the role of methane in the carbon cycle to their diagram (worksheet steps 4 and 5), you could use the 'Circulating carbon' activity described below to assess their understanding of the cycle.
   The responses to worksheet steps 6 and 7 can also be used in this way.
4. The next section of the activity is focused on action to reduce emissions. Start with a general discussion on climate change. Do students think they are affected by it? What individual actions are they taking?
5. Steps 8–10 on the student worksheet relate to lobbying for an action to mitigate climate change on a societal level. You may wish to specify the size of area or/and locality to be considered and the type of person who would therefore be addressed. (For example, in the UK, students might consider speaking to town

councillors about an action that the town could take, or MPs if suggesting a national policy.)

The worksheet instructions ask students to set out a logical argument for adopting their mitigation plan, consider potential weaknesses in it, and identify ways in which they can address these.

Some of the additional information required to make a good case (see the ideas in Worksheet answers, below) may be quite technical or difficult to get hold of. Even so, you may wish students to carry out the additional research required and write to the appropriate representative(s) with a proposal, particularly if working at a community level. If a visit can be arranged, students could present their proposals. In this case, it would be a good idea for students to work in groups.

Circulating carbon (optional assessment activity)

This activity needs to be carried out outdoors or in a hall or gym.

The idea is to work as a group to make up stories showing how a single atom of carbon, represented by a ball, moves through the carbon cycle. Students represent places where the atom is stored for some time.

As students pass the ball between them, they will state what they represent, in what form or/and where they 'hold' the carbon atom, and by what process they are passing it on. Students may get the ball more than once and change roles as the 'atom' moves through the cycle and back to the starting point. For example:

> STUDENT 1: I am phytoplankton and this carbon is in compounds in my cell. I am eaten by a fish. (STUDENT 1 throws the ball to STUDENT 2.)
>
> STUDENT 2: I am a fish. I digest the phytoplankton, and the carbon becomes part of a molecule of fat in my tissues. I get eaten by a bird. (STUDENT 2 throws the ball to STUDENT 3.)
>
> STUDENT 3: I am a bird. I digest the fish and use the energy stored in its fat for respiration. I exhale the carbon atom to the atmosphere as carbon dioxide. (STUDENT 3 throws the ball to STUDENT 4.)
>
> STUDENT 4: I am the atmosphere. This molecule of carbon dioxide is absorbed by a raindrop. (STUDENT 1 throws the ball to STUDENT 1.)
>
> STUDENT 1: I am a raindrop containing carbonic acid …

The raindrop can fall to the ocean and be absorbed by phytoplankton, closing the loop, or take a more circuitous path.

1. Ask students to form groups of 4–8. Each group will need a ball and should stand in a circle.
2. Demonstrate the idea by supporting one group to get started while the others watch.

3. Give groups ten to twenty minutes to come up with the longest chain they can.
4. Ask each group in turn to show their longest chain. Other groups could simply enjoy the story or be asked to assess the understanding of their peers and provide feedback.

Chains might include sections such as:

carbon in a prehistoric bird → died in cave → cave collapses → body compressed with those of many others → carbon atom now in oil → oil extracted and burnt in a car engine → carbon emitted to the atmosphere as CO_2

carbon in a leaf → leaf falls to forest floor → leaf decomposed by a fungus → fungus eaten by termite …

Worksheet answers

1. Definitions here are not complete but illustrate the level of understanding the term requires in this context.
    - **greenhouse effect:** sunlight that passes through the atmosphere warms the Earth; CO_2 and other gases in the atmosphere prevent this heat from being re-radiated into space
    - **photosynthesis:** the creation of simple sugars from CO_2 and water in the presence of light
    - **respiration:** the breaking down of simple sugars into CO_2 and water to supply energy for living things
    - **decomposition:** the breaking down of organic material over time; this may involve digestion by other organisms as well as chemical processes
    - **sedimentary rock:** rock formed when material such as sand or the remains of organisms is compressed
    - **metamorphic rock:** sedimentary rock that has been transformed by pressure or/and heat
    - **fossil fuels:** fuels formed when the remains of prehistoric organisms have been subjected to heat and pressure; coal, oil, and gas
    - **Industrial Revolution:** the rapid growth of manufacturing based on steam power that took place from around 1750.
2. Individual responses.
3. See Figure 3 on page 7.
4. Wetlands, livestock, landfills, wildfires, extraction of fossil fuels.
5. See Figure 3 on page 7.
6. How much carbon or CO_2 an individual or community releases into the atmosphere – not including what they breathe out!
7. Students might consider things such as replanting or rewilding of particular areas; financial incentives or infrastructure development for low- or zero-emission transport or reducing travel; heating or cooling of public buildings, or/and support to make that of privately-owned buildings more efficient; electricity generation and energy efficiency; waste handling, and so on.
8. Individual responses.

9. Additional data needed to assess the feasibility of a plan will vary but might include set-up costs and ongoing costs (equipment, land, time); additional benefits that may mitigate costs; how much difference to emissions the change will make; buy-in from the community, especially if people will have to make changes to how they live; the number of people affected by the plan (in both positive and negative ways); effect on employment, and so on.
10. Possible sources for this additional data will also vary. Students might suggest public databases for population data and infrastructure information; technology companies for details of particular devices; scientific literature for impact in terms of emissions; opinion polls and surveys to assess demand and likely response, and so on.

Activity 2: ACID OCEANS

These practical activities allow students to see the effects of ocean acidification, relate this to the chemical reaction that occurs, and consider how they could find out more using the same simple equipment. The use of everyday materials makes the activities appropriate for home or remote learning.

Equipment

- Student worksheet 2 (3 pages)
- 3 jars or beakers per group
- 2 bottles or smaller jars per group
- Distilled vinegar – enough to half-fill the larger jar or beaker and fill both bottles or smaller jars
- Lemon or lime juice – to half-fill one jar
- 4 eggshells per group
- 2 balloons per group
- Eye protection
- Cloths or paper towels
- Tweezers or forceps

Preparation and notes on equipment

Ask students to collect – and clean! – eggshells in advance.

The first part of the activity needs jars or beakers with an opening wide enough to allow an egg to fit through it.

The jar or bottle for the second part should have a neck narrow enough to fit a balloon onto it, but wide enough for the balloon to fit tightly. If necessary, tape, string or a rubber band can be used to improve the seal.
Note: Thin PET drinks bottles may themselves expand, so are not suitable for this activity.

Using bottled lemon or lime juice (the sort sold for cooking) will save quite a bit of time and mess. If you are using fresh fruit, strain the juice to remove any pulp.

Seashells from craft suppliers are a more realistic alternative to eggshells but are likely to take longer to show an effect. If you do use these, please check they are from a sustainable source.

Health and safety

Eye protection should be worn.

This activity uses foodstuffs, so students should be told not to taste anything.

Ensure there is material available to deal with spills.

Exercise

1. Explain that warmer oceans can absorb more CO_2 from the atmosphere and this in turn makes the oceans more acidic.
   Note: While this is the case at the moment, research suggests that continued warming may reduce the ability of the oceans to absorb CO_2.
2. We are going to explore the effect of ocean acidification using a model in which:
   - shellfish and coral are represented by eggshells (which are made of the same material)
   - sticks of chalk represent cliffs or coasts formed from sedimentary rock
   - weak acids that we can find in our kitchen represent an acidified ocean.
3. Ask students to set up their equipment following the instructions on Student worksheet 2.1 and record their initial observations. They could note some key points on Student worksheet 2.2, take pictures, or/and record more detailed descriptions in their exercise books.
   Note: It is important to pre-stretch the balloons to relax the rubber because the carbon dioxide produced does not create as much excess pressure as the students' lungs.
4. The intervals between observations do not need to be exact, so those after one hour could be made at the end of the lesson. If you are doing this, the gap could be used for discussion of questions 3, 4, and 5 from Student worksheet 2.3.
5. When students have collected their results, ask them to complete the questions on Student worksheet 2.3.
   This could be used for assessment or discussed as a class. You may wish to set some or all questions as a homework activity.
   You could support younger or less able students to answer questions 4 and 5 by suggesting additional equipment they might use (see Worksheet answers, below).
   If discussing in class it would be worth talking about the positive feedback loop resulting from this process.
6. You could ask students to carry out further research into the impact of ocean acidification on marine life.

Sample results

Bubbles will appear almost immediately around the eggshells in vinegar and lemon juice. There may be a few bubbles around the eggshells in water, but these are likely to be of trapped air and disperse over the hour or days (see Figure 5 on the next page).

Most blackboard chalk is gypsum, containing only small amounts of calcium carbonate. Bubbles coming off the chalk are likely to be smaller (see Figure 6 on the next page), although there will probably be more of them, at least at first.

After an hour, the eggshells in the acids may have begun to soften or show some pitting – particularly around the edges, which may have become smoother. The reaction with the chalks may have completely stopped if all the accessible calcium carbonate has reacted.

Figure5: Eggshells in vinegar, lemon juice and water after an hour or so (Source: ESA CCI)

The shell in vinegar will have completely dissolved after two or three days, and the shell in the lemon juice will be well on its way (see Figure 7).

Figure 6: Smaller bubbles from chalks in vinegar.Compare with those from eggshells in Figure 5. (Source: ESA CCI)

Figure 7: Eggshells after a day in vinegar (left) and lemon juice (right) (Source: ESA CCI)

The balloon above the jar containing the chalks is unlikely to expand much but that above the jar containing the eggshell is likely to collect a reasonable amount of gas, although it may not make a visible difference in the first hour or so (see Figure 8).

As the reaction between the vinegar and eggshell slows, the volume of the balloon may remain constant, or even decrease if gas diffuses through the balloon more quickly than additional gas is being evolved.

Figure 8: Balloons for part 2 of the activity after several hours: eggshell and vinegar (left), chalks and vinegar (right) (Source: ESA CCI)

Worksheet answers

1. Feed it through lime water, which will go cloudy if the gas is CO_2.
2. a. The shells of molluscs will be bleached and become thinner, making them vulnerable.
   The skeletons of corals – the part we think of as coral – will dissolve.
   b. Chemical weathering of the rock will speed up.
   c. This will increase.
3. $CaCO_3 + 2CH_3COOH \rightarrow Ca(CH_3COO)_2 + H_2O + CO_2$
4. a. The simplest approach is to use a piece of string to measure the circumference of the balloon.
   Assuming it has a circular cross-section allows us to calculate radius and assuming it is a sphere allows us to calculate the volume from the radius. Depending on the balloon used, students may also approximate the balloon as a cylinder, or a combination of a sphere and a cylinder, and suggest taking measurements accordingly.
   b. This depends on the shape of the balloon and assumptions made (see above).
   As an example: for those shown in Figure 8, the horizontal cross-section is elliptical rather than circular so the radius is likely to be smaller than that calculated from the circumference, leading to an overestimate.
   However, the inflated region would stick out above and below the sphere it is imagined to fill, so the actual volume may be larger than that calculated.
   There is a possibility the two errors may cancel.
5. Points that might be included in student answers:
   - Use vinegar/acid of different dilutions.
   - Measure the time for a given volume of CO_2 to be released, or balloon to reach a certain circumference (the latter is more risky as it is possible to miss the key time).
   - Measure the balloon’s circumference at intervals and compare or plot.
   - Use a line marked around the balloon to ensure the circumference is always measured at the same point.
   - Measure the volume of acid and mass of eggshells used each time.
   - More mathematically able students may suggest calculating rate by dividing volume by time or using the gradient of a graph. They may also be aware that even if they do not calculate volumes, they should use the cube of any linear measurement to ensure they are considering something proportional to the volume.
   - Those aware of factors affecting the rate of a reaction may note the need for constant temperature and to have the solid in similarly sized pieces each time.

Note: Since vinegar is a dilute solution of a weak acid, the volumes of carbon dioxide evolved are too small, even in theory, to make an investigation such as this practical. However, students could use the method they devise as the basis for laboratory work using hydrochloric acid and marble chips.

Activity 3: TRACKING CARBON FROM SPACE

In this activity, students use the Climate from Space web application to investigate a question about part of the carbon cycle and prepare a presentation to explain their findings to others. It may be carried out by individuals or pairs or small groups. If students are working together or/and are unfamiliar with the web application, it would be useful to do at least the first part of the exercise in class, although the activity is suitable for independent learning.

Equipment

- Internet access
- Climate from Space web application
- Student worksheet 3 (2 pages, second page optional)
- Presentation software such as PowerPoint

Exercise

1. Give students some time to familiarise themselves with the Climate from Space web application, or demonstrate its use, following the instructions in the box at the top of Student worksheet 3.1.
   The base map (dark grey oceans and pale grey land) shows through in places where it has not been possible to reliably work out how much carbon dioxide is in the air. This may be because cloud cover prevented the satellite sensor collecting enough data to be sure of the measurement.
   When students explore other variables, they may also notice the pixels are different sizes for different quantities. There are various reasons for this, including that more raw data is needed to calculate some variables than others, and that different instruments may have different resolutions. There is more information on this in the *Taking the Pulse of the Planet* packs, available from https://climate.esa.int/educate/climate-for-schools/
2. Ask students to research one of the suggested questions and produce a short presentation as described on Student Worksheet 3.1.
   You may wish to allocate questions to particular students or groups. While the task is open, allowing differentiation by outcome, earlier questions may be easier than later questions, depending on the prior knowledge of the class.
   Student worksheet 3.2 provides support by suggesting areas on which to focus (students may need to use a mapping application to locate these areas) and, in some cases, a few more detailed questions.
3. If students are to present their findings to each other, you may want to add a time constraint to the list of instructions for the presentation, or/and discuss appropriate criteria for peer assessment.

Worksheet answers

In this activity, the key thing is that students provide evidence to support their answers, rather than merely stating the obvious connection with little supporting detail.

However, in outline:

- Seasonality in levels of CO_2 is discussed on Information sheet 1 and the long-term trend of increasing levels shows clearly in the change in the predominant colour for the data.
- Rice-growing regions, or areas prone to fire have clear seasonal changes in methane levels. This data, too, shows a clear annual increase.
- The area covered by permafrost is decreasing – shown in the data by paler colours as well as the extent – and this correlates with the increased levels of greenhouse gases. Nudge students to think about whether or not this correlation shows causation and, if so, in which direction.
- On the whole, an increased area of burnt land is linked to increased levels of atmospheric carbon and reduced biomass, and it is often associated with changes in land cover from forest to agriculture. Students may or may not be able to evidence this based on the areas they choose to study.

	Dec–Feb	Mar–May	Jun–Aug	Sept–Nov
Columbia	*High*	*Medium*	*Low*	*Low*
Brazil	*Low*	*Low*	*High*	*Medium*
Cameroon	*High*	*Medium*	*Low*	*Low*
Zambia	*Low*	*Low*	*High*	*Medium*
Northern Australia	*Low*	*High*	*High*	*Medium*

- Upwelling of cooler water may increase nutrient supply and so lead to increased growth of plankton – which may not be what students are expecting to see.

The activity could be used to assess research skills, and the presentation to assess communication skills, against local criteria.

Worksheet 1: THE CARBON CYCLE

1. Skim-read Information sheet 1.
   If you are not sure what any of the words or phrases in **bold type** mean, find out before going on to the next step.

You are going to draw a diagram showing the complete carbon cycle. Your diagram will show *sources* and *sinks* of carbon and label the processes that move it through the fast and slow cycles.

2. Read the information sheet more closely, this time looking for details that you will need to include in your diagram.
   You might highlight key points or create a rough sketch as you read.
3. Create your diagram.
   You could use different colours or lettering styles to show the difference between sources and sinks or/and processes that are part of the slow and fast cycles.

The information sheet says that *methane,* CH_4, is another important greenhouse gas. As you can see from its chemical formula, methane also contains carbon. Soil absorbs a small amount of methane from the atmosphere, but most remains in the air until it undergoes a chemical reaction that changes it to carbon dioxide and water.

4. Carry out some research to find sources of methane.
5. Add information about methane to your diagram.

The Information sheet gives some actions that individuals can take to reduce their *carbon footprint*.

6. Use what you have learnt from the sheet to write your own definition of this term. Aim to use no more than twenty words.
7. Choose an action that would reduce the carbon footprint of your entire community, town, region or even country.
   Use your diagram of the carbon cycle to identify why this will have an impact. Think about what sources, sinks and processes are involved.

Imagine you have the opportunity to speak to a group of decision-makers who could implement this action.

8. Set out the points you would make as a list of bullet points.

Think about questions the decision-makers might ask or objections they might raise.

9. What extra information would you need to answer their questions or address their concerns?
10. How could you find this information?

If you think any of this information should be added to your key points, rewrite your list to show where you would include it.

Worksheet 2: ACID OCEANS

What you need

- 3 jars or beakers
- 2 bottles or smaller jars
- Vinegar
- Lemon or lime juice
- 4 clean eggshells
- 2 sticks of chalk
- 2 balloons

Health and safety

- Work carefully to avoid spills and splashes.
- Wear eye protection.
- If anything gets into your eye, wash it out immediately with plenty of cold clean water.
- Do not taste anything or touch your face.

What to do: Part 1

(Source: ESA CCI)

1. Half-fill one jar or beaker with distilled vinegar, another with lemon juice and the third with water.
2. Put two half eggshells into each jar.
3. What happens in each jar?
   You could note some keywords in the table on Student worksheet 2.2.
   You may wish to take pictures to support your observations.
4. After at least an hour, carefully remove a piece of eggshell from each jar. What do the shells look and feel like?
5. Return the eggshells to the correct jar.
6. Repeat your observations daily until you see no further change. If you are using the table on Student worksheet 2.2, you may need to add extra rows.

What to do: Part 2

Set this up at the same time as Part 1. Split tasks between your group so you can move quickly between steps 3 and 4.

(Source: ESA CCI)

1. Inflate and deflate the balloon several times until it blows up easily.
2. Fill the bottles or smaller jars almost to the top with vinegar.
3. Put an eggshell in the vinegar in one jar and two sticks of chalk in the other.
   If they are too big, break them up into pieces roughly the same size as each other and add all the pieces to the vinegar at the same time.
4. Fix the balloon to the neck of each bottle. You might need to use tape, string or a rubber band to make a good seal.
5. Record what happens to the balloons after about an hour and then at daily intervals. Again, you may wish to take pictures to support your observations.

Results

	Open container, eggshell			Balloon seal, vinegar	
	Water	Lemon juice	Vinegar	Eggshell	Chalks
Initial observations					
After 1 hour					
After 1 day					
After 2 days					

Exploring your results

1. How could you show that the gas emitted in this reaction is carbon dioxide?

____

____

2. If oceans become more acidic, what do your results suggest will happen to:

a. marine molluscs and coral reefs? ____

____

b. coastlines formed from limestones and similar rocks? ________________________

____

c. the rate at which carbon dioxide is added to the atmosphere? _________________

____

The acid in vinegar is ethanoic (acetic) acid, CH_3COOH, and the compound in shells that reacts with the acid is calcium carbonate. The reaction produces calcium ethanoate (acetate), water and carbon dioxide.

3. Complete the equation for the reaction by adding:
   a. the formulas for calcium carbonate, carbon dioxide and water to the boxes
   b. numbers, where needed, to balance the equation.

$$\boxed{} + CH_3COOH \rightarrow Ca(CH_3COO)_2 + \boxed{} + \boxed{}$$

4. Think about how you could you use the balloon to estimate the amount of carbon dioxide given off by the eggshell.

a. Explain what you would measure, how, and any calculations you would carry out.

____

____

____

b. What assumptions have you made in this calculation?
   For each one, say if it means your answer is likely to be too big or too small.

____

____

5. How could use the ideas in this activity to investigate how the rate at which carbon dioxide is given off varies with the concentration of acid?
   Discuss your ideas with a partner or your group.
   When you have a plan, write a list of the equipment and chemicals required, and step-by-step instructions, showing how you will make sure you carry out a fair test.

Worksheet 3: TRACKING CARBON FROM SPACE

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

Click on the Data Layers symbol (top right) and pick Carbon Dioxide (CO2).

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.

Click on the Data Layers symbol again, scroll down to Methane and this time click COMPARE.

Check you understand how to use the controls in the bottom right of the screen to switch between map and globe views and download what is on the screen.

1. Now you know how to use the Climate from Space web application, use it to investigate one or more of the questions about the carbon cycle listed below. You may investigate a different question of your choice related to the carbon cycle with the approval of your teacher.
2. Use what you have learnt in this topic, and information from other online resources, to help you explain the patterns, trends and relationships you have identified in the data shown in Climate from Space.
3. Produce a short presentation of no more than four slides to summarise what you have found out and how. Your slides must:
   - include at least three relevant images from Climate from Space to provide evidence for your answer to the question
   - have no more than four images on each slide
   - have no more than 100 words on each slide – this includes labels on diagrams.

The questions

1. What patterns and trends are apparent in measurements of carbon dioxide?
2. What patterns and trends are apparent in measurements of methane?
3. What relationship, if any, is there between permafrost concentration and levels of carbon dioxide or/and methane?
4. How are levels of carbon dioxide and methane in the atmosphere related to fires?
5. What effect do fires have on land cover over short and long timescales?
6. What effect do fires have on biomass levels over short and long timescales?
7. How does phytoplankton respond to changes in sea surface temperature?

Some suggestions to get you started

Questions 1 and 2

You could compare two places, one in each hemisphere (such as Paris and Johannesburg).

Look for seasonal cycles by stepping slowly through a few years.

When do levels of each gas peak in each place?

What is the trend over the period covered by the data?

If you are investigating question 2, you might also look back at what you found out about sources of methane in Activity 1.

Question 3

Permafrost is ground that remains frozen throughout the year.

You could focus on an area such as the Yamal Peninsula where, in recent years, huge holes have been opening up in previously frozen ground.

Look for seasonal cycles.

Questions 4–6

You could start by completing a table like this to show levels of fire activity in a range of places at different times of the year.

	Dec–Feb	Mar–May	Jun–Aug	Sept–Nov
Columbia	*High*			
Brazil				
Cameroon				
Zambia				
Northern Australia				*Medium*

You could use a similar table to help you investigate the other variable in which you are interested, and then compare the two tables.

Question 7

The ocean colour dataset shows chlorophyll concentration so gives an idea of phytoplankton numbers.

The Pacific coast of America is a good place to start: look at places on either side of the equator.

Are effects immediate or is there a time lag?

Information sheet 1: THE CARBON CYCLE

In recent years, news organisations have been reporting record-breaking temperatures more and more frequently. Hotter summers and warmer winters are becoming common in many countries across Europe and, in 2020, the UK Met Office told the BBC that by 2040 most people in England would not see snow in winter.

We already know that human activities are contributing to global warming by increasing the amount of carbon dioxide (CO_2) in the atmosphere and adding to the **greenhouse effect**. Scientists warn that there will be many negative consequences for humans, economies and the natural world, if this continues. Many people have, therefore, started making changes to reduce their *carbon footprint*. They may be avoiding flying, using the car less, thinking about the impact of the food they eat or avoiding products that are produced by destroying rainforests.

But what have these things to do with CO_2 in the atmosphere?

The movement of carbon – in CO_2 and other compounds – between atmosphere, land and water is in a delicate balance. The carbon cycle describes how it moves between *sinks* (places that lock carbon away, preventing or delaying its release to the atmosphere) and *sources* (that generate or release carbon-containing gases to the air).

The fast carbon cycle

Plants take CO_2 from the air during **photosynthesis**, store it in their tissues as they grow, and return some of it to the air through **respiration** and when they die. Deciduous trees absorb a lot more CO_2 when they grow new leaves each spring. But in the autumn, photosynthesis stops and the **decomposition** of fallen leaves returns CO_2 to the atmosphere. Of course, while it's spring in the northern hemisphere it's autumn in the southern hemisphere, so surely these seasonal changes cancel out if we consider the Earth as a whole? Sadly not. Not only is there more land in the northern hemisphere, but large parts of it – mainly in Siberia and Canada – are covered in forest. As a result, global CO_2 levels peak in May.

Of course, plants may also be eaten by animals. In this case, the carbon stored in the plant tissues is released when the animal respires or when it, in turn, dies and its body decays. It may be a little longer before the CO_2 returns to the atmosphere, but the whole process occurs over months or years and is usually referred to as the fast carbon cycle.

Parts of the rainforest in Borneo are being cleared to grow oil palms, reducing tree cover and releasing stored carbon. Palm oil is used in products from soap to biscuits. (Source: contains modified Copernicus Sentinel data (2019), processed by ESA.)

The slow carbon cycle

By contrast, an atom of carbon may take hundreds of thousands – even millions – of years to travel around the slow carbon cycle.

The surface of the ocean absorbs CO_2 and, although some is quickly released back to the atmosphere, some is mixed into deep waters where it stays dissolved for centuries. Carbon also reaches the ocean through the water cycle: rainwater absorbs CO_2, making it slightly acidic. This weak acid reacts with rocks and soils, breaking them down and forming new compounds that may eventually be washed into the sea.

Oceanic organisms, including phytoplankton and corals, absorb carbon as they grow. When they die, their bodies fall to the sea floor and the carbon in their shells or skeletons is locked up in **sedimentary rock**, Earth's largest carbon store. This carbon is only returned to the atmosphere as the material of the ocean floor moves through the rock cycle: some of the processes that lead to the production of **metamorphic rock**, seafloor spreading, and volcanoes all release CO_2.

Carbon is removed from the fast cycle and becomes part of the slow cycle when the remains of plants and animals cannot fully decay but instead build up and are transformed over time into peat, shales and **fossil fuels**.

Burning fossil fuels releases CO_2 into the atmosphere, effectively bypassing part of the slow carbon cycle. Deforestation reduces the Earth's capacity to take up and store carbon – and if the plant material is burnt or left to decay, the carbon it stores is returned to the fast cycle sooner than it would be otherwise. Although some of the excess CO_2 has been absorbed by the land and the oceans, the rest has accumulated in the atmosphere leading to an increase of 30% in the past 150 years.

Creating a balance

The individual actions discussed in the first paragraph can contribute to reducing the rate at which we add carbon to the atmosphere. Many communities are aiming for *net zero* – ensuring that they add no more carbon to the atmosphere than they remove. However, the gas persists in the atmosphere for a long time so additional actions will be needed if levels are to return to those that existed before the **Industrial Revolution**.

Data collected by satellites allows us to track carbon through the cycle across the globe. Satellite sensors measure the concentration of CO_2 (and *methane*, CH_4, another important greenhouse gas) in the atmosphere; monitoring land cover and estimating biomass from space allows us to determine the amount of carbon stored in vegetation on land; and studying the colour of the ocean can give an idea of how much carbon is being taken up by phytoplankton.

Climate scientists use such information to create numerical models that explain how the climate has changed in the past and can be used to predict what might happen in the future. Decision-makers can then use these models to work out how we can manage our activities as a society to restore balance in the carbon cycle.

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

Carbon cycle animation
http://www.esa.int/ESA_Multimedia/Videos/2018/02/Carbon_Cycle

Carbon and the oceans animation
https://www.esa.int/ESA_Multimedia/Videos/2017/12/Carbon_dioxide_ocean_atmosphere_exchange/(lang)

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

Other Sources

Space for climate video
https://www.esa.int/Applications/Observing_the_Earth/Space_for_our_climate

Climate and permafrost
https://climate.esa.int/projects/permafrost/news/picturing-permafrost-arctic/

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