Primary
8-11

esa

education resource pack

THE WATER CYCLE

Teacher guide and student worksheets

climate change initiative education resource pack – THE WATER CYCLE
https://climate.esa.int/en/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 WATER CYCLE: Overview

Fast facts

Subject(s): Geography, Science, Earth Science

Age range: 8–11 years old

Type: reading and practical activities

Complexity: easy to medium

Lesson time required: 6 hours

Cost: low (5–20 euro)

Location: indoors/outdoors

Includes the use of: soil, water, various containers, measuring cylinders, food colouring, standard software, Internet

Keywords: solid, liquid, gas, state, water vapour, evaporation, condensation, satellite

Brief description

In this set of activities, students will learn about the water cycle and, in particular, how water in the soil contributes to the cycle and responds to changes in it.

The first activity uses the story of a snowflake to illustrate the water cycle.

A set of practical activities allow students to look more closely at the processes of evaporation and condensation from free water and water in the soil.

In the final activity, students use real satellite data to explore changes in soil moisture across the world over recent years.

Intended learning outcomes

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

Describe how water changes state changes in the context of the water cycle.

Apply knowledge about the water cycle to suggest how it might change as a result of global heating.

List factors affecting the rate of evaporation.

Evaluate an experimental procedure.

Record detailed observations.

Recognise that soils hold water.

Explain that plants play a role in moving this water into the atmosphere.

Carry out an experiment to determine how much water a soil can hold.

Relate the results of the experiment to the role of soils in the water cycle.

Use the Climate from Space web application to explore changes to soil moisture levels and related variables.

Select appropriate data to investigate a hypothesis.

Integrate information from a range of sources to present a concise summary of independent research.

Summary of activities

	Title	Description	Outcome	Prior learning	Time
1	The water cycle today and tomorrow	Developing a diagram of the water cycle based on a reading assignment Discussion on the importance of freshwater	Describe how water changes state changes in the context of the water cycle. Apply knowledge about the water cycle to suggest how it might change as a result of global heating.	None	1 hour
2	Investigating evaporation	Measuring rate of evaporation in different conditions	List factors affecting the rate of evaporation. Evaluate an experimental procedure.	Be able to read lengths from a ruler to the nearest mm	15 minutes set-up 10 minutes once or twice a day for several days 30 minutes plenary
3	Exploring condensation	Looking closely at condensing water	Record detailed observations.	None	15 minutes set-up 4 × 5 minutes over 1–2 hours 20 minutes plenary
4	Plants, soil and the water cycle	Demonstration that water for the water cycle can come from soils and that plants support this process	Recognise that soils hold water. Explain that plants play a role in moving this water into the atmosphere.	None Activity 3 may be helpful	15 minutes set-up 5 minutes 20–60 minutes later 20 minutes for final results and plenary 20–60 minutes later
5	Water in the soil	Measuring how much water soil can hold	Carry out an experiment to determine how much water a soil can hold. Relate the results of the experiment to the role of soils in the water cycle.	Be able to use a measuring cylinder	30 minutes for stages 1 and 2 30 minutes several hours later for stage 3 and plenary
6	Measuring water in the soil from space	Research activity using Climate from Space web application	Use the Climate from Space web application to explore changes to soil moisture levels and related variables. Select appropriate data to investigate a hypothesis. Integrate information from a range of sources to present a concise summary of independent research.	None Activity 5 will give students a feel for what the numbers mean	30–60 minutes plus research time (home learning) and feedback time

Practical notes for teachers

The **timings** shown in the summary table 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.

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 online resource. 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.

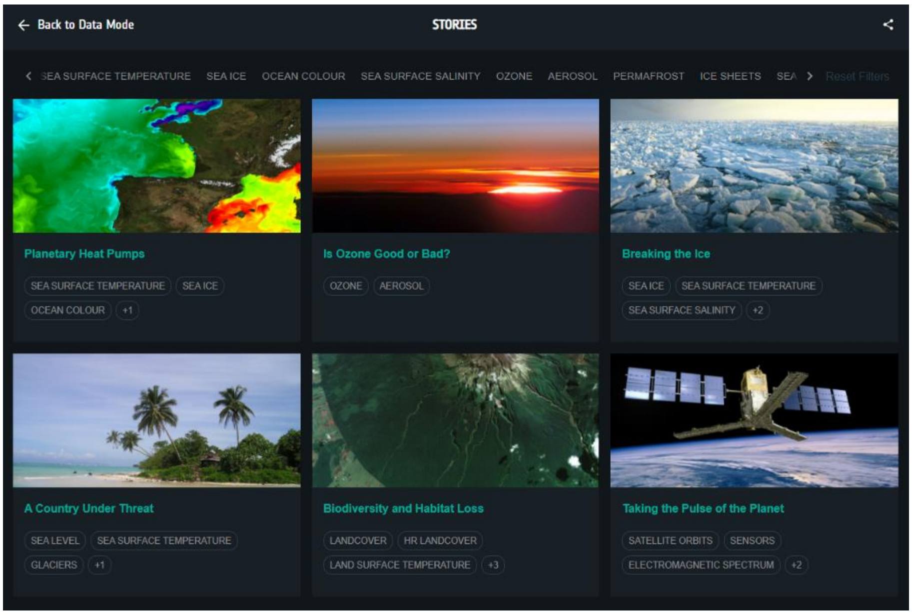

Figure 1: Stories in Climate from Space (Source: ESA CCI)

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.

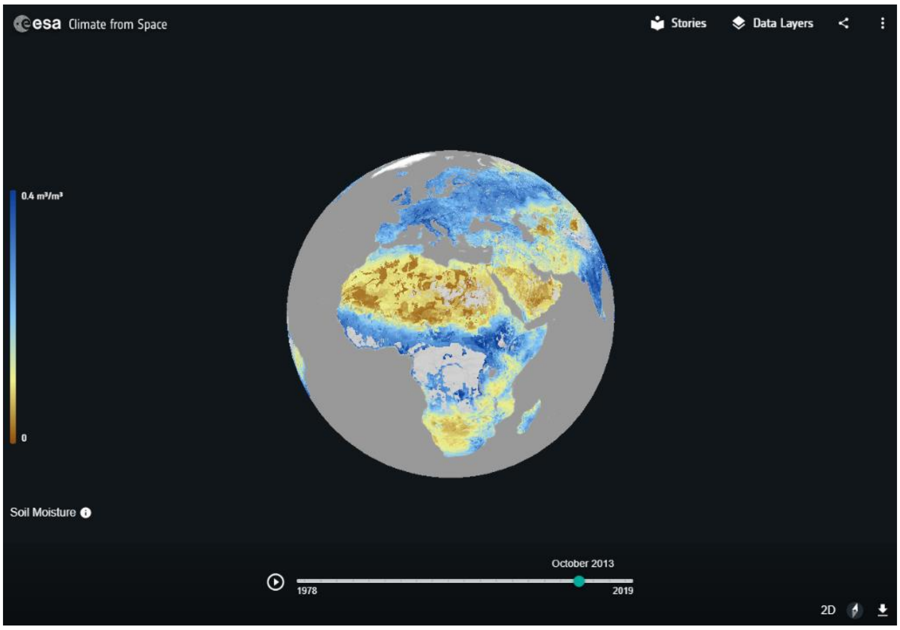

Figure 2: Exploring soil moisture in the Climate from Space web application (Source: ESA CCI)

Climate and the water cycle: background information

As the Sun heats the Earth, warm moist air rises from the surface of the land, the oceans and other bodies of water; the water vapour in the air condenses forming clouds; when the water droplets in the cloud are heavy enough, they fall back to Earth as rain or snow. Rainwater and melting snow and ice may flow back to the ocean or seep into the ground. Water that soaks into the earth may collect in underground aquifers or be taken up by the roots of plants that eventually send it back out into the air. This water cycle is crucial to sustaining life on Earth and we depend on the freshwater that cycles through it for hygiene and industry as well as for drinking and growing our food.

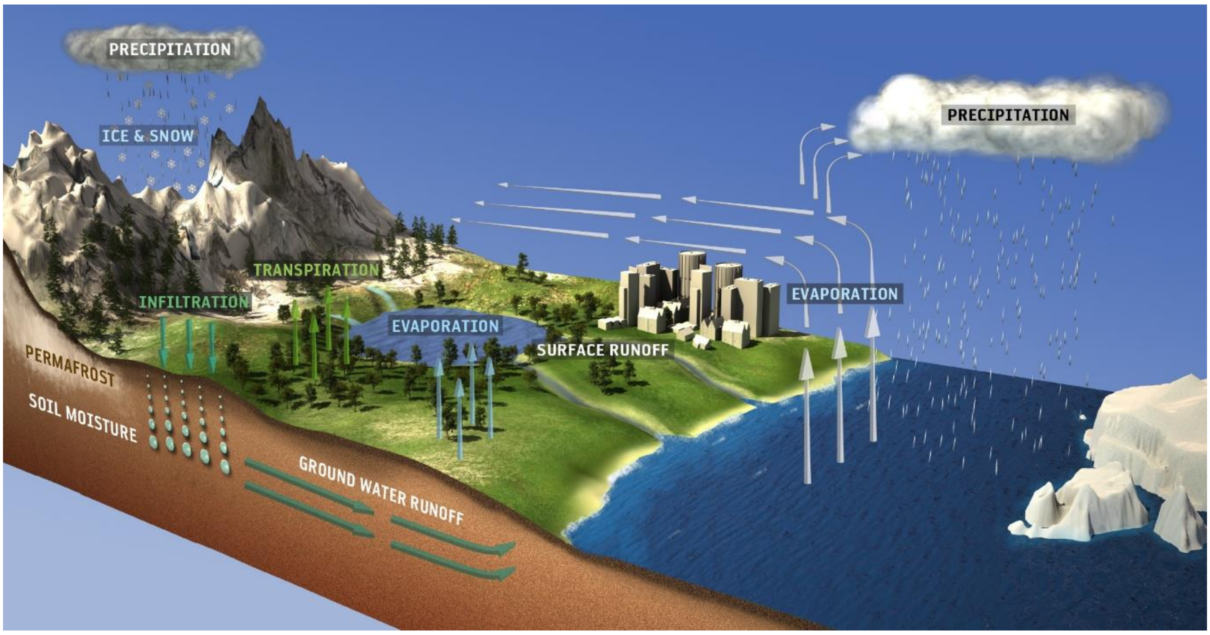

Figure 3: The water cycle (Source: ESA)

Even a straightforward description of the water cycle like the one above shows that it is closely linked to climate. The impact of increasing temperatures on it may, at first, seem obvious: as the world warms, ice will melt, evaporation will increase and more water will circulate through the cycle. But warm air can hold more moisture, so will we actually see more rain? Or will more land dry out? More water vapour in the air must mean more clouds. Will they reflect more of the Sun’s energy into space or act as a blanket because water is a greenhouse gas too? The water cycle is affected by the climate and itself affects the climate in complex ways that vary from place to place around the world.

Climate scientists trying to answer these questions use satellite measurements of many things associated with the water cycle including ice, snow, the temperature of the ocean, how we use the land, and cloud cover. The activities in this pack lead students towards taking a closer look at water in the soil.

A word about vocabulary

'Water' is one of those words that we use in slightly different ways in our everyday life and when doing science. For a scientist, water is water no matter which state of matter it is in, and so water vapour (gas) and ice (solid) are just as much water as liquid water. It is such a common substance that the same problem besets some of the words associated with it, so it is worth making sure that we use them correctly when teaching science.

We tend to talk about water boiling, becoming clouds of steam, at 100°C and think of this as the change of state from liquid to gas. But the steam that we see is actually small droplets of liquid water that have condensed in the cooler air: the gas itself – water vapour – is invisible. And liquid water does not need to boil to change into a gas. It can evaporate at any temperature*. It is the latter change that matters in the water cycle.

The word for the opposite change is also used in a more precise way in science. 'Condensation' refers to the *process* of changing from a gas to a liquid rather than to the droplets of water that form on a cold surface or in the air.

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*This happens because there are always some molecules that have enough energy to break free of the surface. The hotter the liquid, the more molecules are able to escape. When water boils, bubbles of gas form everywhere in the liquid, float up and pop. Evaporation depends on the speed of individual molecules and only happens at the surface; boiling happens when the average speed of all the molecules is high enough and takes place throughout the liquid.

Activity 1: THE WATER CYCLE TODAY AND TOMORROW

The story of Stephan the snowflake illustrates the water cycle and the associated changes of state. In this activity, students consider the importance of water for life, develop diagrams of the water cycle based on their reading of the story, and use these to explore ideas about the possible impact of climate change on the cycle. Confident readers could read the story independently in preparation for the lesson.

Equipment

- Information sheet 1 (2 pages, second page optional)
- Student worksheet 1
- Plain paper and coloured pencils, or appropriate software for creating images

Exercise

1. Start with a discussion about why water – particularly freshwater – is important. Prompt students by asking how plants, animals and humans use it. They can note ideas by answering question 1 on the worksheet before or after this discussion. You might also consider where we get freshwater from.

2. If students have not read the story of Stephan the snowflake on Information sheet 1 prior to the lesson, read it with or to the class.
   You might like to illustrate the story using an online map or application such as Google Earth to find the places mentioned.
   You can download a large version of the glacier image from
   https://www.esa.int/ESA_Multimedia/Images/2019/01/Gangotri_India

3. Use discussion to check understanding of the keywords in bold and any other unfamiliar words or ideas, including those on the second page (solid, liquid, gas, state) if you choose not to print it.

4. Ask students to give individual answers to question 2 from the worksheet.

5. Students may then work independently or in pairs or small groups to create annotated diagrams of the water cycle. This task could also be set as homework. You may wish to use the outcome for assessment, or ask students to give each other or to other groups feedback on their diagrams.

6. Ask students to discuss the final two questions on the worksheet in small groups, encouraging them to refer to their diagrams to work out what happens at one part of the cycle, and then what effect that change will have on each subsequent stage of the cycle. They should continue by considering the impact these changes will have on the land, the ocean and living things.

Worksheet answers

All questions on the worksheet are open, but answers may include some of the following ideas.

1. To drink, to produce food, to produce goods, to stay clean, *etc*.

2. The word clouds or spider diagrams should include all the keywords shown in bold in the story.
3. See Figure 3 on page 7. The vocabulary on this is more advanced than might be expected from students, but many standard textbooks and resources include appropriately labelled diagrams.
4. Increasing temperatures lead to increased evaporation. Warmer air can hold more moisture so this may lead to heavier rain and more intense storms.
   More ice is likely to melt when temperatures increase.
5. More freshwater available for use, increased flooding, changes in areas that are useful for farming (some places will now have enough water, others become waterlogged), faster river flow, *etc*.

Activity 2: INVESTIGATING EVAPORATION

This is the first of three linked practical activities that could be used, as shown here, to examine key processes in the water cycle. An alternative approach would be to complete these activities first, to introduce, rather than consolidate, the key concepts.
In this activity, students monitor the evaporation of water over a period of time and evaluate the strength of their conclusions, considering alternative explanations.

Equipment

- Three cups or small trays or bowls for each group – preferably straight-sided (wider containers will give more noticeable results)
- Three sticky labels or a marker
- Water
- Rulers – preferably ones with zero at the edge
- Towels for wet hands and to deal with any spills
- A copy of Student worksheet 2 (2 pages) for each student with spares in case of spills – you might want to copy the two sides separately rather than back-to-back
- Graph paper (optional)

Preparation

You will need to choose locations where the containers can be left safely for the several days that this experiment will take and, perhaps, have sufficient room for several students to work together. If space is at a premium, you may want to do this as a whole-class experiment with groups of students taking turns to make the measurements. They could record them on a copy of the table on flipchart paper.

Results are highly dependent on the size and shape of the container used and the surrounding conditions, so it is worth trying this out in advance to determine an appropriate time interval for your classroom.

Health and safety
Ensure there is material available to deal with spills.

Exercise

1. Ask students what they think will happen to the water cycle if the world is sunnier and explain that we are going to investigate this idea.

2. Get students working in groups to set up the equipment as described on Student worksheet 2.1. Depending on the age and ability of the group, you may wish to discuss whether or not it is important to use the same amount of water in each container or/and consider getting each person in the group to measure the height in each container and taking an average.

3. At intervals over the week – say the start or/and end of each day – ask students to measure the height of the water in each of their containers.

It may be necessary to remind students that a result that shows no change is as valid – and often as useful – as one that shows a difference.
They could plot a graph of the results but note that this will be more demanding if they take more than more measurement each day as the intervals between readings will then not be uniform.

4. When students have collected all of their results, ask them to work through the discussion questions on Student worksheet 2.2.
   You could ask them to do this by themselves – maybe as homework – if you wish to assess their individual understanding, or each group could discuss their ideas before noting agreed answers to share with the class or take to a discussion with another group.
   See Worksheet answers below for additional information you could use to support students.

Sample results

As noted above, these will vary considerably, but height differences are likely to be in mm rather than cm.

Worksheet answers

1. **Similarities:** there may have been a (small) drop in level in all containers.
   Differences: there will probably have been a greater drop in the container left in the sun.

2. Student answers to this question will depend on their prior knowledge and you may wish to remind them of relevant ideas or extend their understanding when discussing answers as a class.
   The water went into the air/it evaporated.
   Particles moving faster than the others had enough energy to escape from the surface of the liquid.

3. a. There will be more evaporation. This means there will be more water in the cycle with all the consequences listed in the answer to Activity 1 question 4.

   b. There will be less evaporation, so less water in the cycle.

4. a. Key things that might be different are temperature and draught/wind. (The light level has an effect only because the sunny area is likely to be warmer or/and the dark area to have no movement of air.)

   b. Think about good conditions for drying laundry.
   Higher temperatures increase rate of evaporation, as does a draught or wind.

   c. The answer to this open question is dependent on previous answers, but students might mention using a similar set-up before leaving the containers at cold, warm and hot places or beside a fan or open window, in the classroom and in a box.

Activity 3: EXPLORING CONDENSATION

The emphasis in this activity is on making detailed and careful observations of something that students are probably already aware of, but have not looked at in detail.

Equipment

- A transparent bottle or jar with a tight-fitting lid for each group
- Sticky label or marker
- Food colouring or ink
- A jug or beaker for each group
- A funnel for each group (not essential but reduces splashing)
- Towels for wet hands and to deal with any spills
- Student worksheet 3 – one copy per student with spares in case of spills
- Camera (e.g. smartphone) for each group
- Presentation, image- or/and word-processing software with which students are familiar (if using cameras)

Preparation

You will need to identify a warm place where students can leave the bottles for what might be several hours and, if possible, make their observations without moving the bottles again.

As in the previous activity, the results depend on the equipment and the environment so do try out the activity beforehand to determine an appropriate time interval and duration. Aim for 3–5 observations at regular intervals.

You may want to prepare jugs of coloured water rather than allowing children to colour the water themselves.

Health and safety

Instruct students not to put anything – including their fingers! – in their mouths.

Ensure there is material available to deal with spills.

Care should be taken if glass bottles or jars are used.

Exercise

1. Discuss everyday examples of water vapour from the air condensing on cool surfaces such as mirrors and drinks cans. What does it look like? Explain that an important part of science is looking at things very closely to see exactly what happens and this is what we are going to do with condensation.

2. It might be difficult to keep a surface cold, and there may not be enough water vapour in the air, so we are going to put some water in a bottle where it can evaporate but not blow away. Discuss what places might be good to use. Explain we are colouring the water to help it show up better.

3. Ask students to set up their bottles as described on Student worksheet 3.

4. Discuss how they might record their results – there are several ideas on the worksheet. If they are writing descriptions or drawing pictures, they could draw a table on the back of the worksheet or in their exercise books.

5. Periodically ask students to return to their bottle and observe what has happened. There are key questions in the box on the worksheet to help them describe what they see or add labels to their diagrams or pictures.
   Using a camera will allow students to zoom in and see more detail. It also means they are less likely to need to disturb the bottle.

6. The results can be related back to the water cycle by asking groups to create a timeline showing how water vapour turns into rain inside a cloud.
   The worksheet also asks students to make a qualitative comment on the results. The answers could be shared with the class and form the basis of a display, perhaps including creative responses if students have drawn or taken pictures.

7. If students have noticed that the drops that form are transparent, not coloured like the water at the bottom of the bottle, you could challenge them to use this observation to explain why the water in seasonal lakes becomes saltier as the lake evaporates or/and say what effect global warming might have on the saltiness of the sea. (The water evaporates and condenses, but the substances dissolved in it do not.)

Sample results

Figure 4: Sample results from a glass jar and a plastic bottle that have been left in a sunny place for about half an hour. The zoomed-in images on the bottom right show droplets of different sizes and shapes. (Source: ESA CCI)

Activity 4: PLANTS, SOIL AND THE WATER CYCLE

This activity demonstrates the role plants play in moving water from soil to the atmosphere.

Equipment

- Two identical pots or paper cups for each group, one containing a plant and one just soil
- Sticky labels or marker
- Two clear plastic bags for each group (see note below)
- Elastic bands (depending on bags used)
- Dustpan and brush to deal with spills
- Student worksheet 4 – one copy per student

Preparation

This works best with plants that have a well-established root system and a good number of leaves, so the first set of pots will need to be set up in advance. If students are observing the growth of plants from seed, you could use these once they have reached an appropriate stage of development.

The second cup or pot needs to contain roughly the same amount of soil of about the same dampness as that in the other pot. Asking students to set these up themselves can provide an opportunity to practise measuring techniques. However, it does get rather messy and quite often leads to over-watering which reduces then differences between the two pots.

The plastic bags should be reasonably thick so that they can stand clear of the soil when filled with air. Ziploc bags are easiest to use – the zip can be done up so the bag fits around the pot. Cheaper sandwich or freezer bags can be held on to the pots with elastic bands. Doing this will probably need two pairs of hands, but it does give a better seal.

Health and safety

Instruct students not to put anything – including their fingers! – in their mouths.

Ensure there is material available to deal with spills.

Students should wash their hands after handling soil.

Exercise

1. Introduce the activity by referring back to the previous activities which effectively modelled the water cycle above water. In this activity, we are going to look at the water cycle above land – both bare land and land covered in plants.

2. Ask students to follow the instructions on Student worksheet 4.
   Once again, the time required is situation dependent but if the pots are in a warm sunny place (indoors or outdoors) and the soil is fairly moist, taking observations

at 20 to 30 minute intervals should be sufficient to observe condensation and a difference between the two pots.

3. When students have collected their results, discuss the answers to the questions at the end of the worksheet.
   You can confirm students are aware the water has come from the soil by asking them to suggest what might happen if we used rocks in a third cup.
   If time allows, they could try this out or investigate it at home using the alternative method described below.

4. Challenge students to apply what they have learnt by discussing in groups what effects deforestation or/and increasing urbanisation might have on the water cycle.

Alternative method

An alternative method is to use a glass, or a cloche made from the top half of a two-litre plastic bottle, placed on the ground outdoors directly above say, grass, larger-leaved plants, bare soil and concrete.

Figure 5:.The alternative method used on a sunny day after overnight rain: set-up (left image) and results (right image) after three hours (Source: ESA CCI)

Worksheet answers

1. a. Students should see some water droplets on both bags.

   b. Water vapour in the air trapped in the bag condensed on the plastic.
   Some/most of this water was originally in the soil.

2. a. There should be more water or/and droplets should have begun to form sooner on the bag above the plant.

   b. In both pots, water from the soil evaporated into the air.
   The plant takes in water through its roots and sends it into the air through its leaves.
   This means more water moves from the soil into the air above the pot with the plant in.

Activity 5: WATER IN THE SOIL

In this activity, students carry out practical work and calculations to determine the amount of water soil can hold.

Equipment

- A pot with holes in the bottom filled with soil for each group – you could use a large needle to make holes in the base of a paper cup or use a flowerpot with some gauze to make the holes smaller, for example
- A small tray or dish for the pot to stand on – one that has corners or a lip will be easier to use than a flowerpot saucer
- Measuring cylinder or cup that can measure 25 cm^3 and 50 cm^3 for each group
- A jug or large beaker of water for each group
- A timer or stopwatch per group
- A copy of Student worksheet 5 (2 pages) for each student with spare copies in case of spills – you might want to copy the two sides separately rather than back-to-back
- Empty pots identical to those filled with soil (optional)
- Towels for wet hands and to deal with any spills

Preparation

We are suggesting you prepare the pots of soil in advance but students could do this themselves if time allows. Make sure it is reasonably well-packed but not compacted – adding water should not make it noticeably shrink down the container. Any soil will do, but it could be interesting to investigate different types if these are available.

Note the volume of soil you use in each container if you are not going to ask students to measure it (see below).

Health and safety

Instruct students not to put anything – including their fingers! – in their mouths.

Ensure there is material available to deal with spills.

Students should wash their hands after handling soil.

Exercise

1. Start by asking students about water in the soil. What have they found out from previous activities? Why is water in the soil important? Explain that they are going to measure how much water soil can hold.

2. Ask students to carry out the first stage of the activity as described on Student worksheet 5.1. You may wish to take them through the instructions before they start. Depending on the equipment they use, they may need to be reminded that 1 cm^3 = 1 ml.

3. In the gap between stage 1 and stage 2, you could do one or more of the following depending on the age and ability of the students and resources available:
    - Ask students to measure the volume of an empty pot.
    - Help them convert their tally into a volume of water.
    - In their group, through class discussion, evaluate the work they have done so far. Were any steps tricky? If things did not go quite right, will it matter?
    - Draw diagrams to show what they think they would see if they used a magnifying glass to look at (a) dry soil, (b) the soil when they had added a little water and (c) the soil once water had started coming out.

4. Ask students to carry out stage 2 and then move to different activities before making their final measurements (stage 3) and carrying out the calculations on student worksheet 5.2.

5. Compare results across the class, discussing similarities and differences. Relate this to how much soils contribute to the water cycle and how well they respond to changes to it (this will be developed in activity 6). You could also discuss how we change soils (using mulches, compost, sand and so on) so they hold more or less water to suit different plants or uses.

Sample results and worksheet answers

Soil

What type of soil?	from school grounds
How much soil is in the pot?	750 cm^3

Water in

Number of 25 cm^3 measures of water	𝍸|||
Amount of water added in stage 1	$8 \times 25\ cm^3 = 200\ cm^3$
Total amount of water added to the soil	$200\ cm^3 + 50\ cm^3 = 250\ cm^3$

Water out

Amount of water in the tray after a quarter hour	About 3 cm^3
Amount of water in the tray after several hours	72 cm^3
Total amount of water that came out of the soil	$3\ cm^3 + 72\ cm^3 = 75\ cm^3$

Water left behind in the soil: $250\ cm^3 – 75\ cm^3 = 175\ cm^3$

Centimetres cubed of water per centimetre cubed of soil: $175\ cm^3 \div 750\ cm^3 = 0.23$ (Although the soil moisture data in the next activity is given in $m^3/\ m^3$, it is effectively the same unit since both are ratios between volumes.)

Answers to the final question will vary.
If all groups have used similar soil they should get similar answers but there may be some variation. Most soils are a mixture of various components that absorb different amounts of water so, for example, one sample dug from the school might have more plant material mixed up in it than another.
If different groups have used different types of soil then the answers will vary. Sand or sandy soils (large particles) retain less water than clay-heavy soils (finer particles). You could challenge more able students to draw diagrams to explain this.

Activity 6: MEASURING WATER IN THE SOIL FROM SPACE

In this activity, students use the Climate from Space web application to explore satellite measurements of soil moisture across the globe over time and consider the causes and effects of variation in the amount of water in the soil. They use this as a springboard for carrying out research on their own, individually or in groups.

Equipment

- Internet access
- Climate from Space web application
- Student worksheet 6 (2 pages)
- Presentation software such as PowerPoint (optional)
- Materials for making a poster (optional)

Exercise

1. Discuss what problems we might face if we want to measure water in the soil across the world. Elicit the ideas that we would need to dig up a lot of soil from a lot of different places. We would also need to make measurements again and again if we want to see how it changes over time.
   Explain that special cameras on satellites going round the Earth can take images that allow us to work out how much water is in the soil without having to dig soil up. You may want to add that the scientists still make some measurements on Earth so that they can check the instruments on the satellite are working properly and work out what the readings mean.
2. Ask students to open the Climate from Space web application and navigate to the soil moisture data layer. Give students some time to explore. The web application is fairly self-explanatory, but you may wish to display the data layer they need or/and demonstrate the controls.
3. Discuss what the colours in the visualisation mean: blue indicates wet soils, brown indicates dry soils, yellows and pale blues are in between. (This is more important than knowing what the figures mean.) The units are a volume/volume ratio, so you could refer students who have carried out the previous activity back to their results.
   Explain that there are gaps in the data – where the grey underlying map shows through – for times and places where the satellite could not get a reading. In many cases, this is because there was a lot of cloud that month so the satellite could not 'see' the ground.
4. Students can then use information from Climate from Space to answer the questions on Student worksheet 5.1.
   - Students may need to refer to an online map or atlas to be able to identify/name the places with high and low moisture levels.
   - Some students may need some help locating India in order to answer question 3.
   - They will need to draw on their knowledge of the water cycle in order to answer question 4.

- Question 5 is more tricky and you may wish some students to omit it. It requires some knowledge of the location of mountainous regions, rainforests or/and ice. You could offer support by pointing students towards an appropriate location (see Worksheet answers, below), or/and discussing possible answers as a class.

5. Ask the class how much water there needs to be in the soil for plants to grow well. Guide the discussion towards the answer 'it depends on the plant' by thinking about, for example, cacti and reeds.
   Link this to the idea that sometimes knowing the amount of water in the soil is not very useful: knowing how much drier (or wetter) than usual it is can be more useful.
6. Direct students to the soil moisture anomalies data layer and check they understand how the colour scale shows if the soil is drier or wetter than usual. (Once again, they do not need to know what the figures mean, but you may wish to discuss it with older or more able students.)
7. Ask students to answer the questions on Student worksheet 5.2.
8. Show students how to compare the soil moisture anomaly data with information from another data layer, as shown in Figure 6, and discuss which datasets might be linked to soil moisture (cloud, snow, fire are available at time of writing; land surface temperature shall also become available later).
9. Ask students to use Climate from Space or/and the Internet to do further research. There are some suggestions at the end of Student worksheet 5.2. You may wish to allocate questions to individuals or groups of students, or allow more able or enthusiastic students to choose their own. They could carry out the research in class or as a homework activity.
   You might want to provide more structure for some students by, for example, asking them to investigate a particular event or providing a list of keywords.
10. Challenge students to present their findings to the rest of the class in a concise way such as a small poster, or a one-minute presentation with no more than three slides. These outcomes could be used to assess their understanding of the topic as a whole.

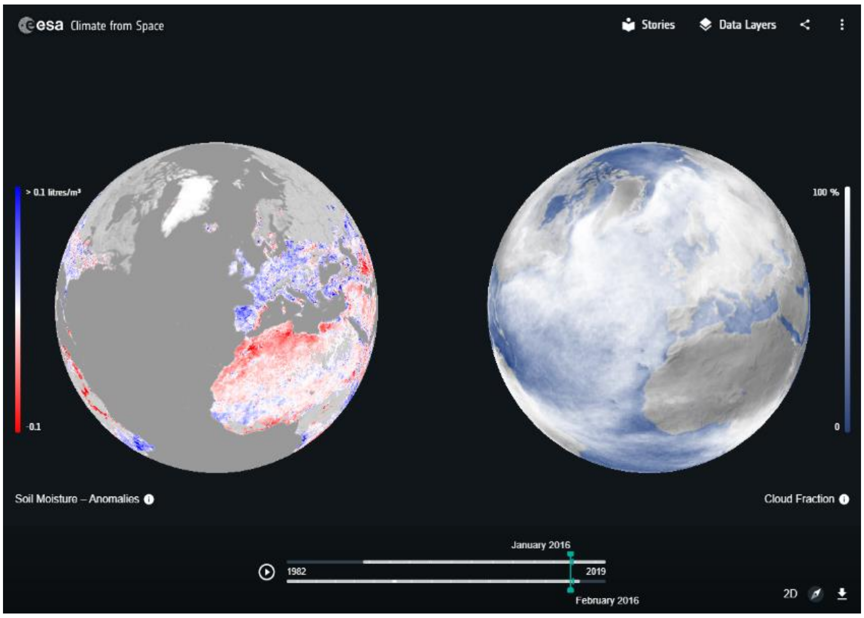

Figure 6. Comparing soil moisture anomaly and cloud in the Climate from Space web application (Source: ESA CCI)

Worksheet answers

Key points or examples are given for open questions.

How does the amount of water in the soil change around the world?

1. Places with soil moisture of around 0.4 m^3/m^3 include Brazil in July 1980, Northern Ireland in September 1994 and China in April 2006.
2. Places with soil moisture of around 0 m^3/m^3 include parts of California in December 1980, parts of the Sahara in June 2001 and central Australia in December 2019.
3. a. September–December.

   b. April–June.
4. a. Heavy rain, being near a river, melting snow/ice, *etc*.

   b. Hot weather, high wind, people using water from underground, *etc*.
5. Amazon or central African rainforests, because the sensor cannot see through the trees; polar regions, because the ground is always frozen; the Himalayas or Alps, because mountain peaks are bare rock (or covered with ice/snow).

How does the amount of water in the soil change from year to year?

1. a. The answer will depend on the student's answer to the earlier question …

   b. … and this answer will, in turn, depend on the answer to part a. If the place is wetter than usual, it may be flooded; if it is the same as usual, then it may be a rainy season/time of year; if it is drier than usual but still very wet (unlikely if students have picked a place with soil moisture of 0.4 m^3/m^3), then it is likely to be an area that is marshy or boggy most of the time.
2. a. Again, the answer will depend on the answer to the earlier question …

   b. … and this answer will follow on. If the place is wetter than usual (unlikely if students have picked a place with soil moisture of 0 m^3/m^3), it is probably desert; if it is the same as usual, then it may be a dry season/time of year; if it is drier than usual, it may be experiencing a drought.
3. a Drought conditions. Plants will not grow without irrigation, soil may blow away, wildfires more likely as plants dry out, *etc*.

   b. Waterlogged conditions or flooding. Floods disrupt transport, destroy property, *etc*. There may be landslides. Students may not be aware that waterlogged soil – even if there is no flooding – is also a problem for plants as it prevents roots from functioning and may lead to them rotting.

Find out more

Students may take the given questions in a variety of directions or develop their own questions to research. The notes below include some key points and give a place where students who are stuck with one of the suggested questions could start.

- See if you can find evidence to support your ideas from question 4 on worksheet 5.1 or one of the questions on this page.
  Students could use the compare option in the data layers list to open another relevant dataset alongside the soil moisture or soil moisture anomalies information. Depending on the idea or/and location they are investigating, they might look at clouds, land surface temperature (once this becomes available), snow, land cover or permafrost. They might also use online maps or/and a site that gives monthly average weather data by location (e.g. https://www.timeanddate.com).
- Look for news stories about droughts or floods and see what the web application shows you about that time and place.
  Wikipedia has lists of major floods and droughts that could be a good starting point for this – go from the list to the relevant article and then to the sources for the article to get an appropriate news story.
  https://en.wikipedia.org/wiki/List_of_floods#1990%E2%80%932000
  https://en.wikipedia.org/wiki/List_of_droughts
- Find out more about a satellite that measures water in the soil.
  Some relevant satellites and instruments are shown below.

Satellite	*Instrument*
MetOp-A	ASCAT
MetOp-B	ASCAT
SMOS	MIRAS
GCOM	AMSR2
Aqua	AMSR-e

Worksheet 1: THE WATER CYCLE TODAY AND TOMORROW

Why water matters

1. What do we use water for?
   Write as many things as you can think of in the box.

The water cycle

Read or listen to the story of Stephan the snowflake.

2. Draw a spider diagram or make a word cloud about the water cycle.
   Make sure you include scientific words from the story.

3. Use these notes and ideas to help you draw a large diagram of the water cycle on a new sheet of paper. Your diagram should show:
   - places where water is found
   - what state the water is in in each place
   - who uses this water, and what for
   - where and how it changes state.

Changing the water cycle

Use your water cycle diagram to help you discuss these questions with your group.

4 How might the water cycle change if the world gets hotter?

5. How would these changes affect us?

Worksheet 2: INVESTIGATING EVAPORATION

What you need

- Three cups
- Three sticky labels or a marker
- Water
- Ruler
- A clock

Health and safety

- Mop up any spills quickly.
- When you fill a cup or tray, leave some room at the top so you can carry it without spilling any water.

What to do

1. Label your three cups with the name of your group.
2. Pour some water into each one. Try to get the same amount in each.
3. Use a ruler to measure the height of water in each cup.
   Write your measurements on the table along with the date and time.
4. Leave one of your cups somewhere sunny, another somewhere shady, and the third in a dark place.
5. Now and again (your teacher will tell you how often), measure the height of the water in every cup and record it in the table.

Results

Day	Time	Time since start	Water height in cm		
			Cup in a sunny place	Cup in a shady place	Cup in a dark place
		0			

You could also make a graph to display your results.

Discussion

1. What happened to the height of the water in the three cups?
   Make sure you say what things were **the same** and what things were **different**.

2. What happened to the water that disappeared?
   If you can, use ideas about particles in your answer.

3. What do your results suggest happens in the water cycle on:

a. a sunny day

b. a cloudy day

4. The cups were in places with different light levels (at least during the day).

a. What else might have been different in the three places?

b. How might this (or these) have affected what happened to the water?
   Try to give an example to explain your idea(s).

c. How could you test your idea(s)?

Worksheet 3: EXPLORING CONDENSATION

What you need

- A bottle with a lid
- A sticky label or marker
- A funnel
- Coloured water
- A clock or timer

You might also want

- A camera

Health and safety

- Pour coloured water carefully so you don't stain your skin or anything else.
- Mop up any spills quickly.
- Do not taste anything. Keep your hands away from your mouth.

What to do

1. Label your bottle with the name of your group.
   Write the name or stick the label near the bottom.
2. Use the funnel to gently pour a little coloured water into your bottle.
   You need it to be about 1 cm deep.
   Be careful not to splash any drops further up the side of bottle.
3. Put the lid on the bottle.
4. Carefully carry the bottle to a place where the water will evaporate quite quickly.
   Remember, we do not want to splash drops up the side of the bottle.
5. Now and again (your teacher will tell you how often), look closely at the higher parts of the bottle.

Results

Each time you look at your bottle, record the time and what you see near the top of the bottle. The key questions in the box below will help you look closely.

You could make a table and write or draw what you see, or you could take pictures to put in a document or presentation.

Key questions

1. Has anything happened yet?
2. Is there mist or fog?
   Is it on the sides of the bottle, in the middle or both?
3. Are there droplets on the side of the bottle?
   - What size are they?
   - What shape?
   - What colour?
   - How many?
   - Are they moving?
   - How?

Discussion

What was the most interesting or surprising thing you noticed by looking closely?

____

____

____

____

____

____

Worksheet 4: PLANTS, SOIL AND THE WATER CYCLE

What you need

- A plant in a pot
- A pot of soil with no plant in it
- Two sticky labels or a marker
- Two clear plastic bags
- Water
- A clock or timer

Health and safety

- Clean up any spills quickly.
- Do not taste anything. Keep your hands away from your mouth.
- Wash your hands after setting up your equipment and again after and clearing up.

What to do

1. Label your pots with the name of your group.
2. Shake the plastic bags open so there is some air in them.
3. Fix one plastic bag over each pot so they stand up.
4. Put the pots in a sunny place.
5. Now and again (your teacher will tell you how often), look closely at the plastic bags. Use the table below to note what you see.

Results

Time	What we saw on the plastic bags	
	Plant and soil	Just soil

Discussion

1. a. What did you see on the plastic bag above both pots? ____________________

   b. Why did this happen? ____

   ____

2. a. How was what happened different for the two pots? ______________________

   ____

   b. Why was there a difference? ____

   ____

Worksheet 5: WATER IN THE SOIL

What you need

- Some soil in a pot with holes in the bottom
- A tray
- A measuring cylinder or cup
- Water
- A timer or stopwatch

Health and safety

- Clean up any spills quickly.
- Do not taste anything.
  Keep your hands away from your mouth.
- Wash your hands at the end of each stage.

What to do

Stage 1

1. Put the pot of soil on the tray.
2. Measure out 25 cm^3 of water.
3. Pour the water onto the soil (be careful not to splash) and start the timer.
4. Measure out another 25 cm^3 of water.
5. After a minute, look to see if any water has come through the holes in the pot and on to the tray.
6. If no water comes through into the tray, go back to step 3.
   Keep a tally of the number of times you do this.
7. If there is water in the tray, it is time to stop adding water for now.
   Work out how much water you have added in this stage.

Stage 2

Do this about 15 minutes after the end of Stage 1.

1. Measure how much water has come through into the tray.
   Remember to record your reading.
2. Put the pot of soil back into the tray.
3. Measure out 50 cm^3 of water.
4. Pour the water on to the soil. Go slowly so that you do not splash.
5. Work out the total amount of water you have added.

Stage 3

Do this a few hours after the end of Stage 2.

1. Measure how much water has come through into the tray.
2. Record your reading.
   Work out the total amount of water that came out of the soil.

Results

Remember to show your working out when you do a calculation.

Soil

What type of soil we are using	
How much soil is in the pot	

Water in

Number of times we added 25 cm^3 of water to the soil (use tally marks like these 卌)	
Amount of water we added to the soil in stage 1	
Total amount of water we added to the soil (stage 1 and stage 2)	

Water out

Amount of water in the tray after a quarter hour (stage 2)	
Amount of water in the tray after several hours (stage 3)	
Total amount of water that came out of the soil (stage 2 and stage 3)	

How much water is in the soil?

Work out how much water was left behind in the soil.

____

Now work out how many centimetres cubed of water there are in every centimetre cubed of soil.

____

Compare your value with that of another group. Are they similar? ________________

Why?____

____

____

Worksheet 6: MEASURING WATER IN THE SOIL FROM SPACE

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

Click on the Data Layers symbol (top right) then pick Soil Moisture from the list.

Check you understand the colours and how the controls on the screen help you to look more closely at particular places or times.

How does the amount of water in the soil change around the world?

The amount of water in the soil is different in different places and changes over time.

1. Move around the globe and use the slider on the timeline to see different times and places.
   Find a place and time where there was a lot of water in the soil (a high soil moisture value).

   Date ____

   Place ____

   Estimated soil moisture ______________________________ m^3/m^3

2. Now look for a place and time where the soil was not much water in the soil.

   Date ____

   Place ____

   Estimated soil moisture ______________________________ m^3/m^3

3. Zoom in on India.
   Press the ‘play’ button and watch the data change.
   Keep an eye on the timeline as well as the colours.

   a. Name a month where the soil in India is often very wet ________________

   b. Name a month where the soil in India is often very dry ________________

4. What might make the soil in a particular place:

   a. very wet? ____

   b. very dry? ____

5. The web application shows the grey map instead of a coloured square in places where the satellite could not measure how much water was in the soil that month.

   Find a place where the satellite can **never** measure the soil moisture.
   Why do you think it cannot get a measurement in this place?

   ____

   ____

How does the amount of water in the soil change from year to year?

Click the Data Layers symbol in the Climate from Space web application.

This time, pick Soil Moisture – Anomalies from the list.

This map shows how much water is in the soil compared to the usual value for the time of year. Shades of blue mean the soil is wetter than usual, shades of red mean the soil is drier than usual. The darker the colour, the bigger the difference.

1. Move the globe and the timeline to the place you found that had a lot of water in the soil (question 1 on worksheet 5.1).

a. Was the soil wetter, drier or the same as usual? ____________________________

b. What extra information or ideas does this give you (if any)? ___________________

____

____

2. Now go to the place and time you found that had very little water in the soil.

a. Was the soil wetter, drier or the same as usual? ____________________________

b. What extra information or ideas does this give you (if any)? ___________________

____

____

3. What might happen in a place if the soil is:

a. much drier than usual? ____

____

____

b. much wetter than usual? ____

____

____

Find out more

Do some research into water in the soil using the Internet and the web application. You could:

- See if you can find evidence to support your ideas from question 4 on worksheet 5.1 or one of the questions on this page.
- Look for news stories about droughts or floods and see what the web application shows you about that time and place.
- Find out more about a satellite that measures water in the soil.

Be prepared to present your findings to others in the class.

Information sheet 1: THE WATER CYCLE TODAY AND TOMORROW

Stephan the snowflake

At the top of a glacier in the Himalayas sat Stephan, a little snowflake. Being high up in the sky, he could look far into the distance and see farmers working their fields, herds of cattle and horses roaming, and rivers flowing to the sea. This made him curious. He wanted to see what was out there. Luckily, he did not have to wait long for his wish to come true.

A glacier in the Himalayas, seen from space (Source: Contains modified Copernicus Sentinel data (2018), processed by ESA)

Gravity pulled him and the rest of the glacier slowly along until he found himself halfway down the mountain. It was warmer here, and he could feel something strange happening to him. He was shrinking, and his spiky edges were getting smoother. Stephan had **melted** and turned into a water drop. He noticed that he was not the only one. Together with his friends, he rolled further down the mountain. They made a little stream and joined with other little streams. More and more streams came together until they became a mighty river – the Indus.

Some of Stephan's friends soaked into the soil beside the river. Plant roots pulled in some of the water. They used it to help them grow before sending it back into to the sky as water vapour (just like you do when you breathe out). The rest sank deeper into the soil and rock, and pooled together under the ground.

Stephan floated in the Indus for weeks. He travelled through China, India and Pakistan until he reached the Arabian Sea hundreds of kilometres away from the Himalayas. It was even hotter here. So hot that he found himself saying goodbye to his friends and floating into the sky as water vapour. He was **evaporating**!

But as he went higher and higher the air became colder and colder. He joined up with his new friends from the Arabian Sea and old friends that had passed through the plants on the ground. They **condensed** into a tiny droplet floating in the air. They travelled through the sky with lots of other droplets as a fluffy cloud.

The wind carried the cloud back to the Himalayas. As they travelled over the mountains, the water droplets became heavier and heavier until they were so big and heavy they fell back down to the land. Stephan **froze** back into a snowflake, ready to start his journey again.

Watching the water cycle

The journey of Stephan describes the water cycle. Water is essential for life on Earth. Without it, plants cannot grow, people do not have clean freshwater to drink, and farmers and factories cannot produce food and goods.

Water in all its **states** – as a **gas** in the air; as **liquid** water in clouds, rivers or the soil; and as **solid** snow or ice – affects our climate, so knowing what happens to water is an essential part of looking after the Earth.

There are special cameras that can see all forms of water (gas, liquid and solid). Scientists put these cameras on satellites so they can track water everywhere on Earth. They can use pictures of clouds to tell if it will rain or snow, watch how snow piles up to make glaciers, and see how much water soaks into the soil.

Links

ESA resources

Climate from Space online resource
https://cfs.climate.esa.int

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

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

Paxi – The water cycle (animation)
https://www.esa.int/ESA_Multimedia/Videos/2017/10/Paxi_-_The_water_cycle

ESA space projects

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

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

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

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

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

SMOS monitoring droughts
https://www.esa.int/ESA_Multimedia/Videos/2020/06/SMOS_monitoring_droughts#.X57vUIj7nvA.link

Extra information

Helping to manage water
https://www.esa.int/Applications/Observing_the_Earth/Safeguarding_our_most_precious_resource_water

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