Secondary
11-14

education resource pack

TAKING THE PULSE OF THE PLANET

Teacher guide and student worksheets

climate change initiative education resource pack –
TAKING THE PULSE OF THE PLANET (Lower Secondary)
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

TAKING THE PULSE OF THE PLANET: Overview

Fast facts

Subject(s): Geography, Science, Earth Science

Age range: 11–14 years old

Type: literacy and IT activities

Complexity: medium to advanced

Lesson time required: 4 hours

Cost: low (5–20 euro)

Location: indoors

Includes the use of: Internet, standard software

Keywords: electromagnetic spectrum, radiation, wavelength, infrared, channel, band, sensor, pixel, satellite

Brief description

In this set of activities, students will learn how various types of electromagnetic radiation are used to observe how our planet is changing.

The first activity reviews the regions of the electromagnetic spectrum and outlines how they are used in Earth observation.

In the second activity, students learn about false-colour images and use data from an Earth observation satellite to create such images in order to explore a changing region.

In the final activity, students combine this technique with climate data from other satellites to produce a detailed report on a major flood or drought.

Intended learning outcomes

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

List the various parts of the electromagnetic spectrum.

Relate some of these types of radiation to the aspects of the Earth system they can be used to monitor.

Explain why it is useful to collect information about these aspects of the Earth system.

Describe how colour images are created by combining sets of data.

Evaluate the usefulness of various false-colour images.

Use satellite data to explore changes in a region.

Use the Climate from Space web application to explore changes in soil moisture and other variables.

Combine information from a range of sources to create a report on a recent natural disaster.

Summary of activities

	Title	Description	Outcome	Prior learning	Time
1	Taking the pulse of the planet	Reading about using different wavelengths of light to monitor parts of the climate system	List the various parts of the electromagnetic spectrum. Relate some of these types of radiation to the aspects of the Earth system they can be used to monitor. Explain why it is useful to collect information about these aspects of the Earth system.	If students are not familiar with the concept of wavelength, this will need to be explained	30 minutes
2	Seeing in new colours	Creating false-colour images from satellite data and using them to explore changes in a region	Describe how colour images are created by combining sets of data. Evaluate the usefulness of various false-colour images. Use satellite data to explore changes in a region.	Activity 1 If students are not familiar with colour mixing, this will need to be explained	1½hours (30–45 minutes for introductory activities)
3	Exploring climate from space	Research activity using Climate from Space web application	Use the Climate from Space web application to explore changes in soil moisture and other variables. Combine information from a range of sources to create a report on a recent natural disaster.	Activity 2	2 hours (30 minutes for introductory activities)

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

Practical notes for teachers

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

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

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

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

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

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

Health and safety

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

Some of these activities use the Climate from Space online resource or other interactive websites. It is possible to navigate from these to other parts of the ESA Climate Change Initiative website 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. 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.

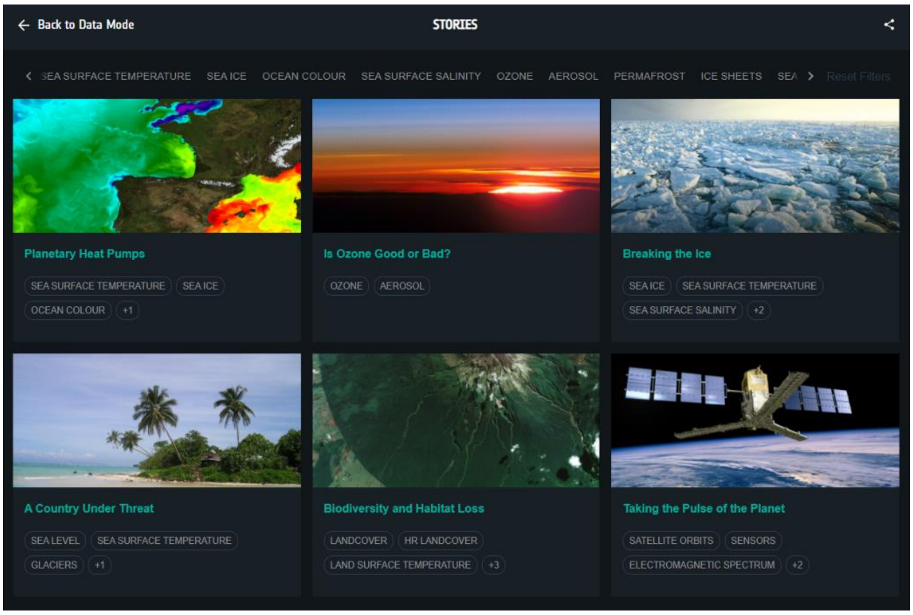


Figure 1: Stories in Climate from Space (Source: ESA CCI)

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.

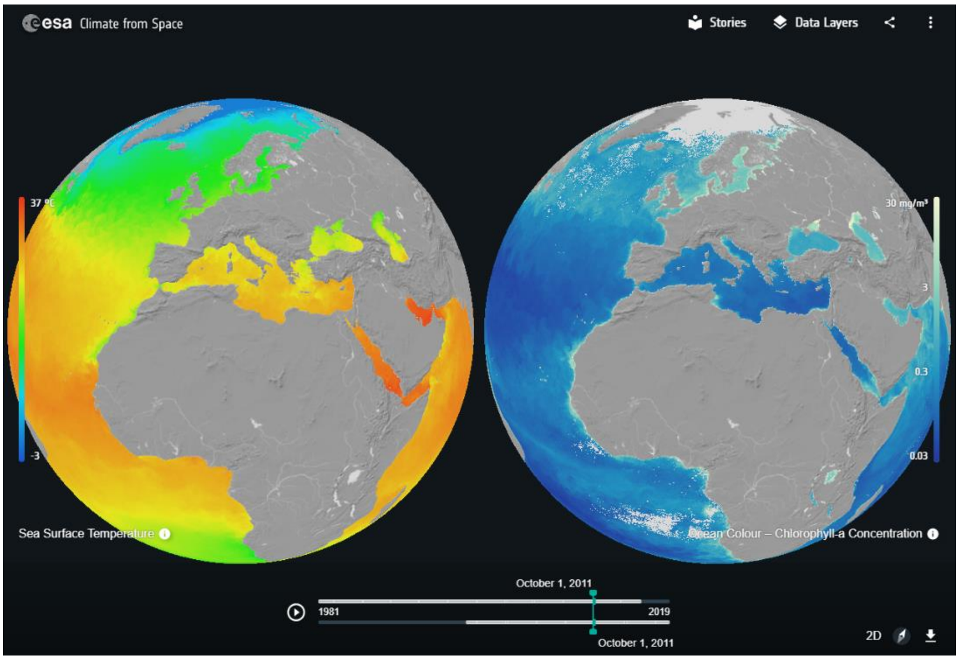


Figure 2: Comparing sea surface temperatures and ocean colour in the Climate from Space web applicationer (Source: ESA CCI)

Monitoring the Earth from space: background information

Using the spectrum

We use information gathered from a large part of the electromagnetic spectrum to monitor and measure many aspects of the Earth's climate system, but these uses are seldom listed in the tables that appear in school textbooks.

Satellites orbiting the Earth carry instruments that can detect reflected sunlight, seeing in the same way we do ourselves. However, just as a doctor monitoring the health of a patient uses a range of instruments to examine different aspects of a patient's body, scientists use various sensors to 'take the pulse' of our planet.

As well as detecting visible light, satellite instruments may be sensitive to infrared radiation. These instruments can differentiate between the short-wavelength infrared radiation reflected by vegetation, and the longer-wavelength thermal infrared radiation emitted from the surface of the land and seas that tells us about their temperature. The instruments on some satellites slice the spectrum into hundreds of pieces, taking separate readings for each narrow band of wavelengths, and this enables us to monitor the changing composition of the atmosphere.

Since different surfaces in different places reflect, absorb and emit visible and infrared light in different ways, combining information about the amount of radiation of a particular set of wavelengths reaching a satellite allows us to 'see' details that would be invisible to our eyes. These details include the amount of moisture in the soil and the health of vegetation.

This topic focuses on the operation of such 'passive' sensors, but there are also radar instruments that use microwave radiation in the same way as a ship's sonar uses sound: they send out a pulse of waves and analyse the signal that returns. These 'active' sensors allow us to 'see through' cloud and measure heights very accurately. This means they can be used for monitoring changes in sea level and ice sheets as well as producing accurate maps and examining the effect of earthquakes and volcanoes.

The satellite advantage

We could, of course, use these same instruments on Earth – and often do, not least to make sure we know what the data sent down from the satellite means and to check the instrument is still functioning properly. But satellites allow us to see a large area of the Earth at one time, including places that it would be impossible to travel to and repeat measurements regularly. Satellites in a low Earth orbit loop around the Earth from top to bottom (nearly) while the planet turns beneath them, and revisit the same place at the same time of day every few days.

Since we have been using satellites for several decades, we have reliable long-term measurements of many key indicators of the health of our planet. These are invaluable not just for scientists looking at what is happening at present but also for climate modellers trying to understand the complex system on which we all depend, and to work out how it may change in the future.

Activity 1: TAKING THE PULSE OF THE PLANET

In this comprehension activity, students explore the use of different wavelengths of radiation to monitor different components of the Earth's climate system. It could be used as an introduction to the electromagnetic spectrum, or to support later work on the uses of the various parts of the spectrum. Confident readers could carry out this activity as a standalone homework exercise.

Equipment

- Information sheet 1 (2 pages)
- Student worksheet 1
- Climate from Space online resource: *Taking the Pulse of the Planet* story (optional)
- Internet access for research (optional)

Exercise

1. Read Information sheet 1 as a class or ask students to read it in groups.
   You could supplement the text with material from the Climate from Space story *Taking the Pulse of the Planet*, particularly the following:
   - The gallery on slide 2 is a series of historical pictures of the Earth from space, including the Blue Marble image from the worksheet.
   - The slide 4 gallery shows the Earth as 'seen' at a range of different wavelengths.
   - The animation on slide 7 gives more detail about the link between measurements of ocean colour and climate.

2. Ask students to work through Student worksheet 1. The first three questions can be answered using information from the story and its illustrations, the last will require some additional research.
   The answers below show the table completed with sections of the spectrum in the order in which they appear in the story, but you could ask students to fill in the table in order of increasing or decreasing wavelength.

3. As an optional extension or homework activity, allocate individual students or groups of students a particular part of the electromagnetic spectrum and ask them to find out the names of a satellite and sensor that detects this, and an image of data produced by the instrument. The pages in the 'ESA space projects' section of the Links on page 23 are a good place to start.
   Students could share their findings with others in a poster or three-slide presentation.

Worksheet answers

1.

Type of electromagnetic radiation	Wavelengths	What we can monitor using it
visible light	380–780 nm	land cover ocean colour (phytoplankton)
X-rays gamma rays	<10 nm	(no Earth observation applications, but some students may give medical uses)
ultraviolet light	10–380 nm	ozone
near infrared	~1 μm	plant health (agricultural productivity impact of droughts)
thermal infrared	~10 μm	temperature (of land, ocean/cloud top)
microwaves	in cm	water (soil moisture, ice and snow, atmospheric water vapour)

2. Microwaves can penetrate clouds, so observations can be made in the dark and poor weather.
3. Communications (radio and TV).
4. Active sensors send out a pulse of radiation and detect when it returns and how it has changed. Passive sensors, like our eyes, depend on reflected sunlight (or thermal radiation emitted by the Earth and objects on it).

Activity 2: SEEING IN NEW COLOURS

In this exercise students learn how true and false-colour satellite images are created. They go on to explore a change to the environment and evaluate the best type of false-colour image to use in monitoring this change. The research task is open-ended and could be carried out individually at home if IT access allows, or in pairs or small groups in class.

Equipment

- Internet access
- Student worksheet 2 (2 pages)
- Student information sheet 2 (2 pages – the first side should be in colour)
- Presentation, image- or/and word-processing software with which students are familiar
- Materials for creating a poster (optional)

Exercise

1. Review student understanding of mixing primary colours of light.
   If you are using a display screen, you might reinforce this by opening a document, selecting some text and changing the font colour to a custom combination by selecting values for red, green and blue.

2. Use the ‘Building a colour image’ section of Information sheet 2.1 to explain or reinforce that pictures can be thought of as data arranged in a grid – one dataset if the picture is black and white, three datasets if it is in colour – and introduce the term ‘channel’.

3. Ask students to read, or take them through, the next section of the information sheet which describes the production of false-colour images, then answer questions 1–3 on student worksheet 2.1 to check they understand the process. You can download a high-resolution version of the image from https://www.esa.int/ESA_Multimedia/Images/2020/05/Southern_Ukraine.

4. Introduce the idea of ‘bands’ – sections of the electromagnetic spectrum that are detected by individual types of sensor in a camera or satellite instrument (see Information sheet 2.2).

5. Explain to students that they are going to explore some band combinations using Sentinelhub Playground (https://apps.sentinel-hub.com/ – see additional notes below). The worksheet describes how to access the custom combinations panel and questions 4–6 allow students to check they understand how it works before moving on to the more open-ended activity.

6. Students can work individually or in pairs to find a band combination which is helpful in showing a change and create a poster (physical or electronic) to show the change. Student worksheet 2.2 guides them through this process and will provide a record of what they have done should their filenames not include all the data they need.

You may wish to allocate particular features to students or/and suggest areas to investigate. There are some suggestions and helpful band combinations in the Worksheet answers section below.

7. Students could present their posters to the rest of the class. Did groups looking at similar features make the same decision about the best band combination to use?

Sentinelhub Playground

The site is fairly self-explanatory but you may wish to show students how it works or direct them to the animation at www.sentinel-hub.com/explore/sentinelplayground/ if they are having difficulties changing the location or date, or getting relatively cloud-free images.

The base map used is OpenStreetMap which means the 'Go to Place' search does not always find natural features. Students can use an atlas or other online source to find an area of interest and then scroll to it in Sentinelhub Playground. This will be easier if they temporarily disable the dataset layer using the dropdown menu accessed by the satellite icon in the top right.

They should stick to the default Sentinel-2 L1C dataset because the other dataset has limited coverage until 2017. (The atmospheric correction applied to the other Sentinel 2 dataset makes little difference at this level.)

Worksheet answers

Understanding false-colour images

1. Red.
2. Green algae or weed in a greenish lake.
3. Plants reflect lots of (near) infrared light.
4. The image is black and white because it only shows information from one band.
5. Red = 4   Green = 3   Blue = 2

Exploring band combinations

Possible areas to explore:

- seasonal lakes such as Lake Macleod in Western Australia
- cities in China
- rainforest at the edges of the Amazon
- temperate deciduous woodland (for seasonal change)
- local farmland (for seasonal change)
- Colombia glacier in Alaska.

Useful band combinations (R|G|B):

- 8|11|4 for comparing land and water
- 12|11|4 for urban areas
- 8|4|3, 11|8|2 or 8|11|2 for vegetation/agriculture
- 12|8|3 for snow and ice.

Activity 3: EXPLORING CLIMATE FROM SPACE

In this activity, students use the Climate from Space web application to explore satellite measurements of soil moisture and how these change over time. They use this data, along with other information from the web application, the website used in the previous activity and the Internet, to produce a report on a major drought or flood.

Equipment

- Internet access
- Climate from Space web application
- Student worksheet 3 (2 pages)
- Presentation, image- or/and word-processing software with which students are familiar
- Materials for making a poster (optional)

Exercise

1. Introduce the Climate from Space web application to students as a way of exploring reliable climate data. Show the CO_2 data layer as an example. Students will notice that the resolution is much coarser than in Sentinelhub Playground with each pixel being over 200 km on each side at the equator rather than the tens of metres available in Sentinel 2. The reasons for this difference vary depending on the quantity being looked at but include differences in the sensitivity of sensors, how often satellites revisit an area, and how much data is required in order to be sure the figure given is reliable. (In the same way that if calculating say, the average height of a class, a sample of 30 students will give a better answer than a sample of two students.)

2. Ask students, working individually or in pairs, to use the Climate from Space web application to explore soil moisture data and to peer-assess the work of another student or pair following the instructions on Student worksheet 3.
   Some students may require additional support to understand the scales (especially that on the Soil Moisture – Anomalies data layer) or/and with questions 1 and 3.
   You may wish to supplement the peer marking and feedback with a whole class discussion of these questions.

3. Discuss the problems resulting from droughts (plants will not grow without irrigation, soil may blow away, wildfires more likely as plants dry out, *etc*.) and waterlogged conditions or flooding (waterlogged prevents roots from functioning so may kill plants, landslides, floods disrupt transport, destroy property, *etc*.).

4. Ask students to research a major drought or flooding event that occurred between late 2015 and the end of 2019. (These dates reflect those for which both Sentinel-2 and soil moisture data are available at the time of writing.) Wikipedia has lists of major floods and droughts that could be a good starting point (see links on next page) – 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
This could be done as individuals, pairs or groups and some or all of the research carried out as homework if students have sufficient IT access.

4. Students should produce a report, presentation or poster to show their findings. The worksheet suggests a structure but does not constrain the nature, length or level of detail of the outcome. You may wish to get all students to feedback in the same way, focus on the same sections, or/and impose limits on the number of words, slides, diagrams or poster size depending on the time available for the task, the ability of the students and the time available for sharing the outputs.

5. The posters, presentations or reports could be shared with the rest of the class and assessed – by you or the class as a whole – against local criteria for research or communication skills, or against a list of relevant criteria drawn up in consultation with the class.

Worksheet answers

Interpreting soil moisture data

1. Ideas such as: the sensor cannot see through the trees in rainforests; ground may be permanently frozen in polar regions; mountain peaks are bare rock (or covered with ice/snow).

2. Open question to be checked by peer(s).

3. a. Soil moisture may vary from month to month in a similar way each year. Comparing with annual averages may only show this regular variation, and comparing with a different month may give no useful information. (Consider somewhere like India which is very wet September–December and much drier in April–June.)

   b. Plants (and building designs!) are adapted to the normal levels and cycles of soil moisture so dry or wet soil may not, in itself be a problem. However, if a place is wetter than usual, it may be flooded; if it is drier than usual it may be experiencing a drought.

4. Open question to be checked by peer(s).

Worksheet 1: TAKING THE PULSE OF THE PLANET

1. Use ideas from the story to fill in the table showing how different types of electromagnetic radiation are used to monitor the Earth.

Type of electromagnetic radiation	Wavelengths	What we can monitor using it

2. Why are microwaves particularly useful for monitoring the Earth?

3. Electromagnetic radiation with very long wavelengths – metres or even kilometres – is not used for monitoring the Earth. What is it used for?

Find out more

4. Most satellite instruments detect radiation in the same way as a camera detects light. They are known as passive sensors. However, many microwave satellites use active sensors. What is different about how these work?

Worksheet 2: SEEING IN NEW COLOURS

Understanding false-colour images

These questions are about the image of Southern Ukraine on Information sheet 2.1.

1. What colour would the bright green area be in real life?

____

2. What do you think the bright blue swirls near the bottom right are?

____

____

3. Vegetation shows as red in this type of image.
   What does this tell us about plants and infrared radiation?

____

____

Open Sentinelhub Playground (apps.sentinel-hub.com/sentinel-playground). In the panel on the left-hand side, select Custom You can now drag bands on to channels to create a variety of images.

4. What happens if you drag the same band on to all three channels?

____

5. Use the table of Sentinel-2 bands on Information sheet 2.2 to work out which bands need to go on to which channel to give a 'true-colour' image – one that matches what we see with our eyes.

   Red _____ Blue _____ Green _____

Try it out and see if you were right.

6. Use the 'Go to Place' search box (top right) to move to Kherson, Ukraine, keeping the true-colour combination.
   Compare what you see with the picture of Southern Ukraine on Information sheet 2.1.
   You might need to use the other controls at the top of the page to change the dates to get a relatively cloud-free image, or/and scroll around or zoom in a little to find the right area.
   Use this to check your answers to questions 1 and 2.

Exploring band combinations

You are going to try to find a band combination that makes it easy to see the changes in a particular feature of the landscape.

1. Choose a feature to investigate.
   You might look at lakes, a city, a particular type of forest, farmland or a glacier.

Feature: ____

2. Find an area which has this feature and where you think it changes over the course of a year or has changed since 2015 (the year Sentinel-2A was launched).
   You may use somewhere you know about or do some research to pick an area.

Place: ____

3. Working in true colour to start with, go to that area in Sentinelhub Playground and find the most recent image you can where there is not too much cloud cover. Download the image or take a screenshot.

Most recent date: ____

4. Now try out various band combinations and look at how well your feature shows up in them. Download images or take screenshots of the best two or three, and note the band combinations here.

   Combination 1: Red _____ Blue _____ Green _____

   Combination 2: Red _____ Blue _____ Green _____

   Combination 3: Red _____ Blue _____ Green _____

5. Step back to a month or year when you think the feature was different and find a time when the area was relatively cloud-free.
   Download or screenshot a true-colour image and note the date.

Older date: ____

6. Try out each of your top two or three combinations, taking screenshots or downloading copies of the images to compare with the more recent ones. Highlight the combination you think works the best for showing the change.

7. Make a poster showing how the area you have studied has changed.
   You should include at least four images to show the area now and at the other time in true and false-colour.
   Add notes to the images to point out how things have changed.
   You might also include:
   - more images of the same place at different times
   - images of a similar place that has not changed over the same period
   - an explanation of the false-colour combination you have used
   - information about why the change is happening or/and the effects of the change.

Worksheet 3: EXPLORING CLIMATE 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.

Explore how the controls help you to look more closely at particular places or times.

Interpreting soil moisture data

1. 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. Look for places where there is never a measurement. Why do you think the satellite can never get readings in these places? (There are several possibilities.)

____

____

2. Choose a location – somewhere local or one of the places you investigated in the last activity – and estimate the value of the soil moisture at three different dates.

Location ____

Date _______________________ Estimated soil moisture _______________ m^3/m^3

Date _______________________ Estimated soil moisture _______________ m^3/m^3

Date _______________________ Estimated soil moisture _______________ m^3/m^3

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.

3. a. Why is the phrase in bold important?
   Find evidence to support your answer.
   (HINT: You might want to go back to the soil moisture data.)

____

____

____

   b. What information might we get by looking at these differences that we could not get from soil moisture values?

____

____

4. Go back to the location you picked for question 1. For each date, say if the soil is wetter or drier than usual and estimate by how much.

Date ________________________ Wetter/drier than usual by _______________ l/m^3

Date ________________________ Wetter/drier than usual by _______________ l/m^3

Date ________________________ Wetter/drier than usual by _______________ l/m^3

Swap with a partner to check and comment on each other's answers.

Research activity: droughts and floods

Both too little and too much water in the soil cause problems. Droughts and floods over wide areas often make the news and have a considerable impact on people and the environment that often lasts after the reporters have gone home.

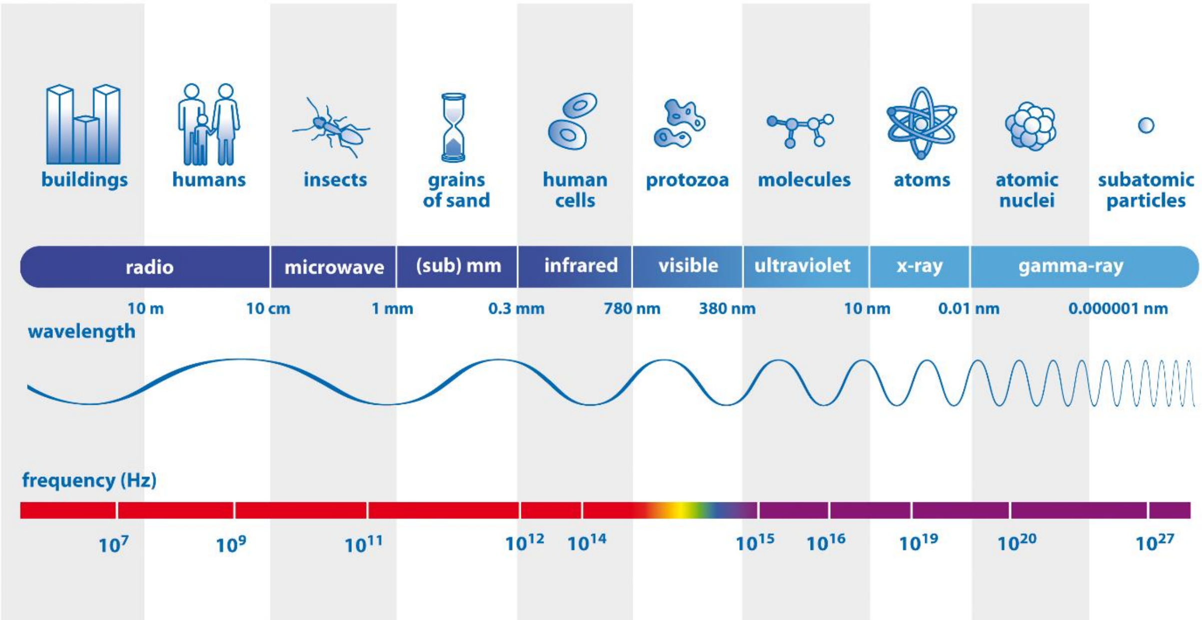
1. Pick a major flood or drought from the last five years or so. Use the Climate from Space web application to find soil moisture levels around the time of the event and how they differed from their usual values.
2. Find out more about the event, its causes and impacts using:
    - Other information in the Climate from Space web application that might be relevant. (Cloud? Land cover? Fire? Snow? Permafrost?)
    - Other satellite data from Sentinelhub Playground (apps.sentinel-hub.com/sentinel-playground). Think about which band combinations might be most useful to show how the area was different before, during and after the event.
    - Other information from the Internet such as annual climate data, economic data or/and news reports. Remember to assess the reliability of your sources when deciding whether or not to include information from them.
3. Create a report, presentation or poster to tell others about the event.
   Include at least three of the sections listed below as well as images created from satellite data.
    - Details of the event: what? when? where?
    - Can we say anything about what caused the event?
    - What impact did the event have on the area?
      (You might include before and after images to illustrate this.)
    - How did the event affect people? How many? Over what time scales? What was done to help them?
    - Is it likely to happen again? If so, what is being done to reduce the impact the next time?

Information sheet 1: TAKING THE PULSE OF THE PLANET

The famous 'Blue Marble' image of the Earth (Source: NASA)

'The Blue Marble' is the name given to a picture of Planet Earth taken by the crew of Apollo 17. It is one of the most widely reproduced photos of all time. The blue water of the seas and oceans dominate the image but when we take a closer look, we can distinguish many more colours: the yellow Sahara sand, the dark green tropical rainforests, the white of clouds over the oceans and ice and snow covering Antarctica. Pictures like this, taken with ordinary cameras, contain a vast amount of information. Similar images from space are now part of our daily life: for example, they appear on many TV weather forecasts.

The Blue Marble image shows the Earth as we see it with the naked eye. By detecting red, green and blue light, human eyes can see all the colours of the rainbow. Most of the radiation from the Sun is such visible light. But there are many more 'colours' of radiation we cannot see. Together, they make up the electromagnetic spectrum. Different types of electromagnetic radiation have different wavelengths.



The parts of the electromagnetic spectrum by wavelength.
The top row shows objects that are about the same size as one wavelength of the radiation.
The bottom row shows the frequency, that is, the number of vibrations of the wave each second.
(Source: ESA/AOES Medialab – adapted ESA CCI)

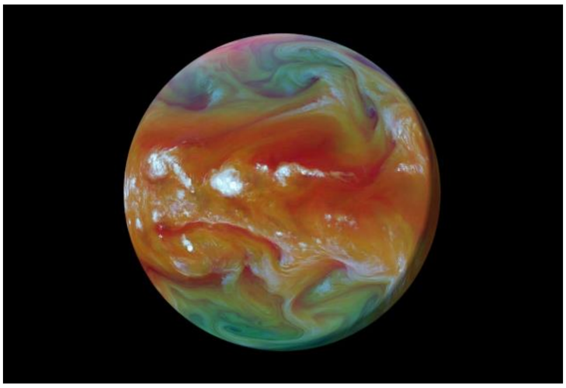
Observing the Earth at different wavelengths

Visible light has wavelengths from 380 nanometres (violet) to 780 nanometres (red). A nanometre (nm) is a billionth of a metre, a millionth of a millimetre. It is excellent for identifying land cover – when clouds do not get in the way! Monitoring the colour of the ocean tells us a lot about phytoplankton, tiny marine plants that help lock away carbon from the atmosphere and produce 50% of the oxygen we breathe.

X-rays and gamma rays used in medicine have much shorter wavelengths than visible light (less than 10 nm) and satellites observing the Earth do not use these types of radiation. However, there are satellite sensors that detect ultraviolet light (10–380 nm). Some of these played an important part in the discovery of the hole in the atmosphere's ozone layer above Antarctica. They are still used to monitor how the ozone hole is changing.

Electromagnetic radiation with wavelengths longer than we can see with our eyes is classified as near infrared if the wavelength is around 1 micrometre (a micrometre (μm) is a millionth of a metre, a thousandth of a millimetre), thermal infrared if the wavelength is around 10 μm, and microwave if the wavelength is measured in centimetres.

Sensors that detect near infrared wavelengths are sensitive to the health of plants. We can use them to track agricultural productivity and the impacts of droughts.



Thermal infrared cameras show the heat radiated by the Earth and tell us about energy exchanges in the atmosphere
(Source: Planetary Visions/ESA)

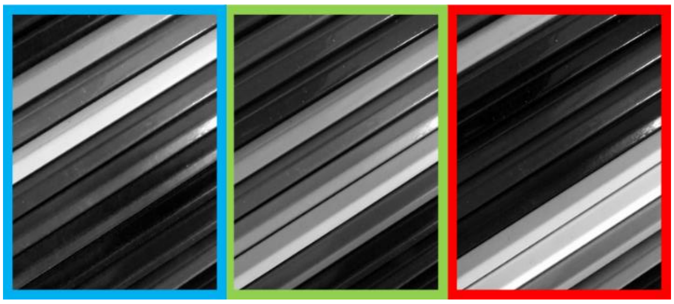
Thermal infrared sensors can measure the temperature of the Earth. They work in the same way as the cameras used at airports to detect people infected with Covid19. Using satellite sensors to measure the temperatures of the land surface, sea surface and cloud tops helps us to quantify the effects of global warming on the oceans and the atmosphere. Doing this also allows us to explore temperature changes on a smaller scale in cities and in inaccessible regions including the Arctic and Antarctic.

Microwaves are suitable for measuring water in all its forms: as liquid in the soil, frozen as snow and ice, and as vapour and water droplets in the atmosphere. Microwaves can penetrate clouds, so these sensors are able to provide data in almost any weather and in the prolonged darkness of the polar winter.

Measurements of ozone, ocean colour, land cover, land and sea surface temperature, soil moisture, snow, sea ice, ice sheets and glaciers are essential pieces in understanding the complex puzzle that is the climate of the Earth. Satellite sensors focused on specific portions of the electromagnetic spectrum, therefore, help us monitor how the climate is changing; they allow us to take the pulse of our planet.

Information sheet 2: SEEING IN NEW COLOURS

Building a colour image



Every pixel in each of these boxes can be described by a single number.
White pixels have a value of 255, black pixels have a value of 0.
Each picture is no more than a set of data arranged in a grid.

(Source: Catherine Fitzsimons/NCEO)

The colour image needs three numbers for each pixel and is made by combining the three sets of data:

- The numbers from the first box set the blue value.
- The numbers from the second box set the green value.
- The numbers from the last box set the red value.

We say that each set of data goes into a different **channel**: red, green or blue.

Seeing invisible light

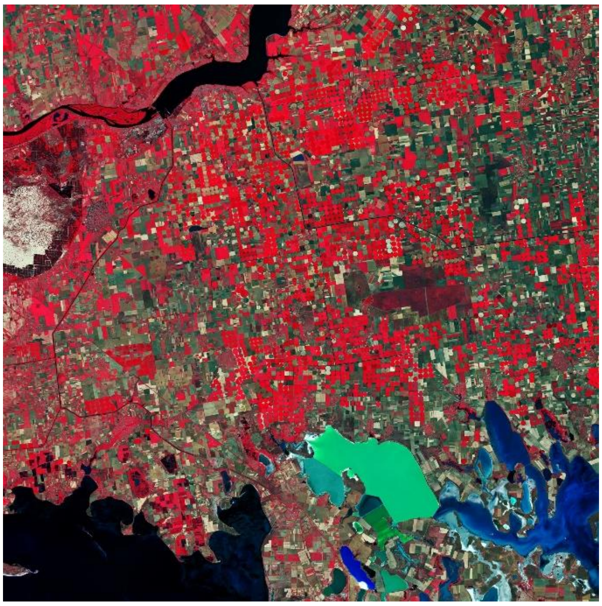
In the example above, the data we used in each channel came from camera sensors that detected light of the same colour as the channel.

But can use different data to set the colours in each channel.

In this image:

- Data from an infrared sensor sets the values in the red channel.
- Data about red light sets the values in the green channel.
- Data about green light sets the values in the blue channel.

So we are effectively 'seeing' the infrared by making it show up as red in our picture.



A false colour image of Southern Ukraine (Source: Contains modified Copernicus Sentinel data (2019), processed by ESA)

Images like this are called **false-colour images**.

Earth observation scientists often use them to explore or display data from parts of the electromagnetic spectrum we cannot see with our eyes.

Splitting the spectrum

The camera in a smartphone has three types of sensors – one for red light, one for green light and one for blue light. We call the section of the spectrum detected by each sensor a **band**, so a camera has three bands.

A satellite instrument may have a whole range of sensors to detect different parts of the electromagnetic spectrum. There might be hundreds, each sensitive to a very small range of wavelengths.

We can assign the data from any band to any channel to produce a variety of false-colour images, but some of these are more useful than others!

The table below shows the bands in the instruments on the two Sentinel-2 satellites. The main job of these satellites is to track changes in the way we use land and to monitor plant health.

Band number	Band name	Resolution / m	Minimum wavelength / nm	Maximum wavelength / nm
B1	Aerosol	60	443.9	442.3
B2	Blue	10	496.6	492.1
B3	Green	10	560	559
B4	Red	10	664.5	665
B5	Red Edge 1	20	703.9	703.8
B6	Red Edge 2	20	740.2	739.1
B7	Red Edge 3	20	782.5	779.7
B8	NIR	10	835.1	833
B8A	Red Edge 4	20	864.8	864
B9	Water vapour	60	945	943.2
B11	SWIR 1	20	1613.7	1610.4
B12	SWIR 2	20	2202.4	2185.7

The resolution gives the length of each side of a single pixel.
1 nm = 10^{-9} m

A computer-generated image of Sentinel-2 in orbit (Source: ESA /ATG medialab)

Links

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

Infrared camera hack
https://www.esa.int/Education/Teachers_Corner/Infrared_Webcam_Hack_-_Using_infrared_light_to_observe_the_world_in_a_new_way

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

Earth from Space: Southern Ukraine
https://www.esa.int/ESA_Multimedia/Videos/2020/04/Earth_from_Space_Southern_Ukraine

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