Secondary
14-16

education resource pack

URBAN HOTSPOTS

Teacher guide and student worksheets

climate change initiative education resource pack – URBAN HOTSPOTS

https://climate.esa.int/educate/

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

The ESA Climate Office welcomes feedback and comments
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Produced by the ESA Climate office

URBAN HOTSPOTS: Overview

Fast facts

Subject(s): Geography, Science, Physics, Earth Science

Age range: 14–16 years old

Type: reading, mathematical investigation, online research

Complexity: medium to advanced

Minimum lesson time required: 4 hours

Cost: low (5–20 euro)

Location: indoors

Includes the use of: Internet, spreadsheet software

Keywords: electromagnetic energy, black body, peak radiation, emissivity, satellite observation, land surface temperature, brightness temperature, heatwave, urban heat island, urban planning

Brief description

In this set of activities, students will learn how the built environment leads to the urban heat island effect and how Earth observation can be used to monitor this effect and support attempts to reduce it.

In the first activity, students explore visual temperature data for a city and use it to identify some of the causes of urban heat islands.

The second activity introduces the principles behind the measurement of land surface temperature and applies this to calculating the effect of using different materials in cities.

In the final activity, students use the Climate from Space web application and downloaded data to compare temperatures and trends in an urban and rural environment.

Intended learning outcomes

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

Describe the urban heat island effect and list some of its consequences.

Identify aspects of the built environment that enhance and reduce the urban heat island effect.

Relate the behaviour of these aspects to the physics of heat transfer.

Carry out calculations to show how measurements of thermal radiation can be converted to temperature values.

Relate emissivity values of a range of materials used in cities to brightness temperatures.

Analyse and present data from a large data set using a spreadsheet.

Create a report to summarise and explain conclusions drawn from analysed data.

Summary of activities

	Title	Description	Outcome	Prior learning	Time
1	Urban hotspots	Reading and image analysis	Describe the urban heat island effect and list some of its consequences. Identify aspects of the built environment that enhance and reduce the urban heat island effect. Relate the behaviour of these aspects to the physics of heat transfer.	Heat transfer through conduction, convection and radiation	1½ hours
2	Radiation and temperature	Calculations based on equations for black body radiation (spreadsheet assisted)	Carry out calculations to show how measurements of thermal radiation can be converted to temperature values. Relate emissivity values of a range of materials used in cities to brightness temperatures.	Regions of the electromagnetic spectrum, calculations using standard form, SI prefixes	1 hour
3	Town and country	Analysis of numerical data using a spreadsheet	Analyse and present data from a large data set using a spreadsheet. Create a report to summarise and explain conclusions drawn from analysed data.	Activity 1	1½ hours

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

Practical notes for teachers

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

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

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

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

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

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

Health and safety

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

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

Climate from Space

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

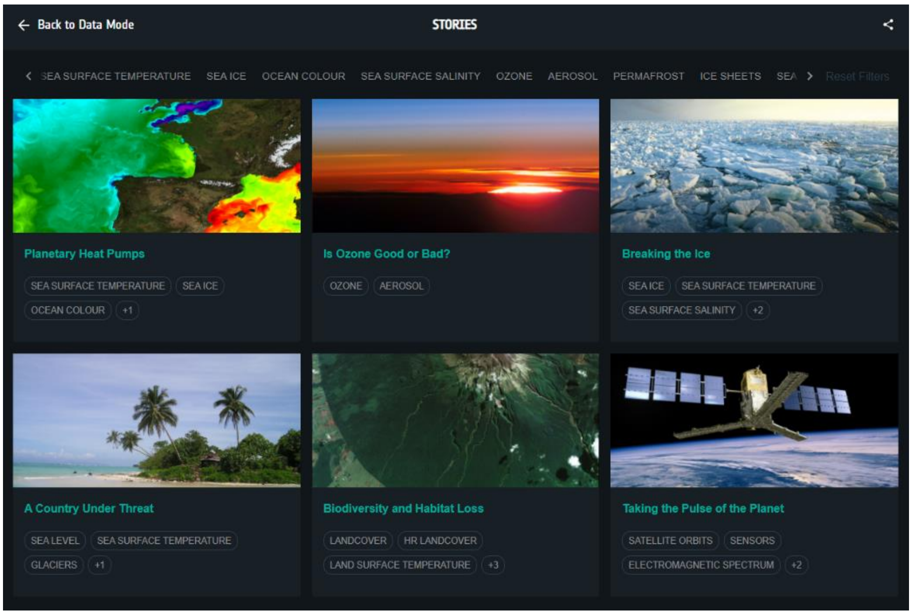


Figure 1: Stories in the Climate from Space web application (Source: ESA CCI)

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

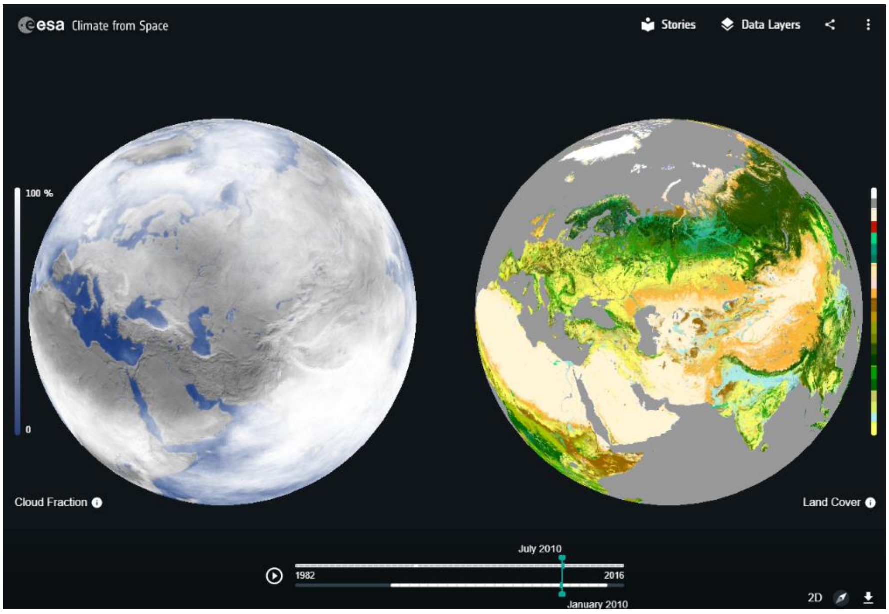


Figure 2: Comparing cloud and land cover in the Climate from Space web application (Source: ESA CCI)

Warming cities: background information

The urban heat island effect is a phenomenon that leads to temperatures in cities often being higher than those in surrounding rural areas. This effect is amplified during heatwaves, as the materials used to create the built environment have high heat capacities and this limits the amount of cooling that takes place each night.

Growing urban populations and the effects of climate change mean that more and more people will be affected by this over the coming decades.

In some cities, many people use air conditioning to reduce indoor temperatures – a solution that is not only impossible to implement outdoors but also exacerbates the problem by using energy, much of which is still generated from fossil fuels. Sustainable management of the temperature in a city relies on more passive solutions that consider the heat capacity and surface properties of materials used, architectural structures that enhance the natural circulation of cooler air, and urban planning that helps reduce emissions.

Making a city climate-resilient may involve looking for ways to reintroduce plants into the urban environment. One example of this is the green roofs being introduced in Arnhem, The Netherlands. Another approach, that has been tried in Los Angeles, is painting dark asphalt roads with a layer of paler material. This has led to a local temperature decrease of 5°C and modelling shows that, if applied at a large scale, it could reduce the temperature of the entire city by 1°C. This happens simply because dark colours will absorb radiation while light ones reflect the energy away.

Urban heat islands, and individual areas within them, stand out clearly in satellite-derived land surface temperature images. These show much more detailed temperature data than it would be possible to collect from surface measurements alone. Earth observation is, therefore, very useful for analysis and planning.

The activities in this pack focus on how such data is collected and how we evidence the heat island effect. As well as exploring data in visual and numerical forms, students learn about how thermal radiation levels are converted into temperature data that can be used to monitor urban heat and support the design of climate-resilient cities. This does require consideration of black body radiation and, while this concept is likely to be part of a more advanced curriculum, the key points needed to complete the work are described on Information sheet 2 and are not difficult to grasp. The maths required is more challenging, so students can use the companion spreadsheet to help with calculations.

Activity 1: URBAN HOTSPOTS

This activity introduces the urban heat island effect and considers the potential impact in a warming world that is becoming increasingly urbanised. Students explore a heat map of a city and apply what they have learnt to create a hypothetical heat map of a local urban environment. Some or all of this activity could be used as a homework exercise.

Equipment

- Information sheet 1 (2 pages, second page optional – see step 3)
- Student worksheet 1
- Internet access
- Outline maps of a local urban area (optional)
- Image processing software or coloured pencils
- Large sheets of paper (optional – see step 5)
- Climate from Space web application: *Urban Hotspots* story (optional)

Preparation

If students are to complete step 5 on paper, you will need to print outline maps of a local urban area. If possible, reduce the saturation before printing to remove blocks of colour and leave grey outlines.

Exercise

1. Introduce the topic by asking students to share personal experiences of heatwaves and how the surroundings affect how hot they feel – perhaps by referring to where they go on holiday, particular buildings, or certain parts of a local urban environment.
2. Ask students to read Information sheet 1.1 and share with a partner one thing they learnt from the story and one question they want to ask about it.
   If doing this in class, you could supplement the text with material from the Climate from Space web application story *Urban Heat*.
3. Ask students to work through questions 1–4 on Student worksheet 1. They could use an electronic copy of the heat map of Madrid if you wish to reduce the amount of colour copying required. The image can be downloaded from https://www.esa.int/ESA_Multimedia/Images/2008/07/AHS-observed_relative_temperatures_of_Madrid_Spain#.X9ouo5WBoXk.link
4. Discuss the answers to the questions from the worksheet as well as any of the questions students identified while reading the Information sheet that have not been answered by doing the activity.
5. Challenge students to produce a theoretical heat map of a local urban area. They could do this by adding layers or blocks of colour to a screenshot of an online map, or by colouring a paper map.
   Step 6 on the student worksheet asks students to annotate their map. They could do this using text boxes, labels or sticky notes. Putting the map in the centre of a larger piece of paper or canvas/publication, with text around the border, may make for clearer presentation.

6. Students can discuss and peer-assess their maps as a plenary exercise or, if this part of the activity is used for homework, in a subsequent lesson.

Worksheet answers

The detail students give will depend on the prior knowledge they bring to the task and so their answers may not include all the points below or/and include other valid connections.

1. Roads are made from concrete or tarmac (asphalt) which is dark so absorbs heat well and reradiates it at night. It also has a higher heat capacity than air so stores a lot of heat. Friction between the road and the tyres of vehicles travelling along it will generate additional heat that will be transferred to the road and stored by it.
2. The white roof of the stands is a poor absorber of heat. The open layout of the stadium means that hot air is not trapped inside it but can move out by convection. If there has not been a match that day, there will have been few people in the stadium – and even a resting human body emits energy at a rate of about 100 W.
3. There are various parks and playing fields in the area, but one of the most striking contrasts is the roundabout at Plaza de la Republica Argentina.
4. The buildings are arranged around a row of courtyards – an architectural feature that has been used extensively in hot climates since ancient times because of the shade they provide and the passive cooling effect they create. The roof covering is paler than the tiles used in many surrounding buildings. Students may also point out that, it being midnight when the picture was taken, air conditioners that may have been operating during the day will not be adding heat to the surroundings.

Responses to the remaining questions will vary.

Activity 2: RADIATION AND TEMPERATURE

This activity demonstrates how sensing the intensity of thermal radiation can be used to determine land surface temperatures by considering the characteristics of a black body. Students are introduced to the relevant equations and use a spreadsheet to carry out calculations using them.

Equipment

- Information sheet 2
- Student worksheet 2 (2 pages)
- Calculator
- Urban hotspots Activity 2 spreadsheet

Preparation

You may wish to download the Urban hotspots Activity 2 spreadsheet from the Urban hotspots section of the ESA Climate for Schools webpage (https://climate.esa.int/educate/climate-for-schools/) to a location where your students can access it without going online.

Students may also need access to a diagram showing regions of the electromagnetic spectrum if this work is not being carried out as part of a related topic. (See, for example, the companion education resource pack *Taking the Pulse of the Planet* (Lower Secondary) available from the web address above.)

Exercise

1. Ask students to list methods and instruments used to measure temperature, perhaps extending the discussion to include advantages and disadvantages of each.
   Continue by considering which of these could be used for remote sensing of temperature – for example, thermocouples or other electronic thermometers could be attached to a transmitter to relay data to a different location.
   Explain that we are going to find out more about how thermal cameras work and carry out some of the calculations that underly their operation.
2. You could simply ask students to read the information sheet and complete the calculations on the worksheet with the help of the spreadsheet. However, the equations are quite intimidating so it might be better to read through a section of the information sheet, carry out the related calculations and check these answers before moving on to the next section. This would allow you to check understanding and offer support as required.
3. You could ask students to combine their learning from this activity with the maps they produced at the end of Activity 1 to suggest specific changes that could be made in the area they have studied to reduce the urban heat island effect.

Worksheet answers

1. 2. Students may or may not be aware of subdivisions of the infrared portion of the spectrum used in Earth observation and remote sensing. You could introduce these if you wish. (NIR = near infrared; SWIR = short-wave infrared.)

	Temperature / K	/ °C	Peak wavelength / m		Electromagnetic spectrum region
Sun	5795	5522	5.00×10^{-7}	500 nm	visible (green)
molten glass	1700	1427	1.70×10^{-6}	1.70 μm	infrared (NIR)
lava	1500	1227	1.93×10^{-6}	1.93 μm	infrared (SWIR)
hot concrete	333	60	8.70×10^{-6}	8.70 μm	infrared (thermal)
Earth (average)	300	27	9.66×10^{-6}	9.66 μm	infrared (thermal)
cool concrete	283	10	1.02×10^{-5}	10.2 μm	infrared (thermal)
Earth (coldest ever)	184	–89	1.57×10^{-5}	15.7 μm	infrared (thermal)

3. a. 1.50×10^{7} W $sr^{-1}m^{-3}$ b. 9.65×10^{6} W $sr^{-1}m^{-3}$ c. 7.38×10^{6} W $sr^{-1}m^{-3}$

4.

Surface	**Emissivity**	**Brightness temperature / K** at 10.85 μm and 27°C
Water	0.99	23.1
Rough concrete	0.94	22.3
Tarmac (asphalt)	0.93	22.1
Oak trees	0.885	21.4

5. Trees have a lower brightness temperature meaning their surface emits less energy into the atmosphere so they do not warm up the air around them to the same extent as water, concrete or tarmac.

They also provide shade, which will prevent the ground beneath them absorbing energy from the Sun and so reduce the energy the ground emits in turn.

They send water into the atmosphere through transpiration, and the energy for evaporation at the surface of the leaves is taken from the atmosphere, lowering its temperature.

Activity 3: TOWN AND COUNTRY

In this activity, students use the Climate from Space web application to identify the land cover types associated with a pair of contrasting locations and analyse downloaded temperature data. They consolidate their learning from the topic by producing a report relating the patterns they have found to information about the radiative behaviour of different surfaces and, perhaps, other climate variables.

Equipment

- Internet access
- Climate from Space web application
- Student worksheet 3 (2 pages)
- Urban hotspots Activity 3 spreadsheet
- Spreadsheet and word processing software

Preparation

You may wish to download the Urban hotspots Activity 3 spreadsheet from the Planetary heat pumps section of the ESA Climate for Schools webpage (https://climate.esa.int/educate/climate-for-schools/) to a location where your students can access it without going online.

Exercise

1. Remind students that they have looked at how we measure land surface temperature from space and how it varies across a city but have not, so far, considered evidence for the urban heat island effect. That is what we will do in this exercise by comparing data for an urban area with that for a rural area.
2. Ask students to do this by following the instructions and answering the questions on Student worksheet 3.
   Students may require additional support in the following areas:
   - The key for land cover in Climate from Space is quite detailed. Encourage students to look for broader categories: urban areas are red, bare rock and sparse vegetation are pale colours, forests and wooded areas are shades of green, other types of vegetation are shown in yellow, and so on.
   - Some students may need help in determining an appropriate graph to plot. It could be helpful to make composite labels for the *x*-axis as in the example.
   - The quickest way to determine average temperatures for each month for question 4 is to use the SUMIF function.
3. You could ask students who work quickly to do one or more of the following:
   - Compare the temperature trend in winter and summer for each location (say January and July). Are these changing in the same way as the annual trend? If not, what differences are shown?
   - Students with a greater knowledge of statistics could also quantify the variation at each location – either over the entire period or for particular times – and consider how well the evidence supports the trends they have described.

- Students might also look at other data layers in the Climate from Space web application that they think might have an impact on the temperature in each location – soil moisture and cloud, for example.

4. The final task on Student worksheet 3.2 is to produce a report to summarise and explain these findings. This report could be used to assess student learning from the topic as a whole, and also communication and data-handling skills against local criteria.

Worksheet answers

1. Heathrow – urban; Waddington – cropland.

2. Remove data prior to 2009 from the Heathrow data set;
   calculate average temperatures for Heathrow.

3. See Figure 3.
   Similarities: maxima and minima occur at the same time each year in both locations (January and July, respectively); the range between highest and lowest temperatures in each location is similar (about 20°C).
   Differences: In general, temperatures are higher in Heathrow than in Waddington; winter temperatures in Waddington are considerably lower than those in Heathrow about one year in three; summer temperatures in Heathrow are noticeably higher than those in Waddington almost every year.

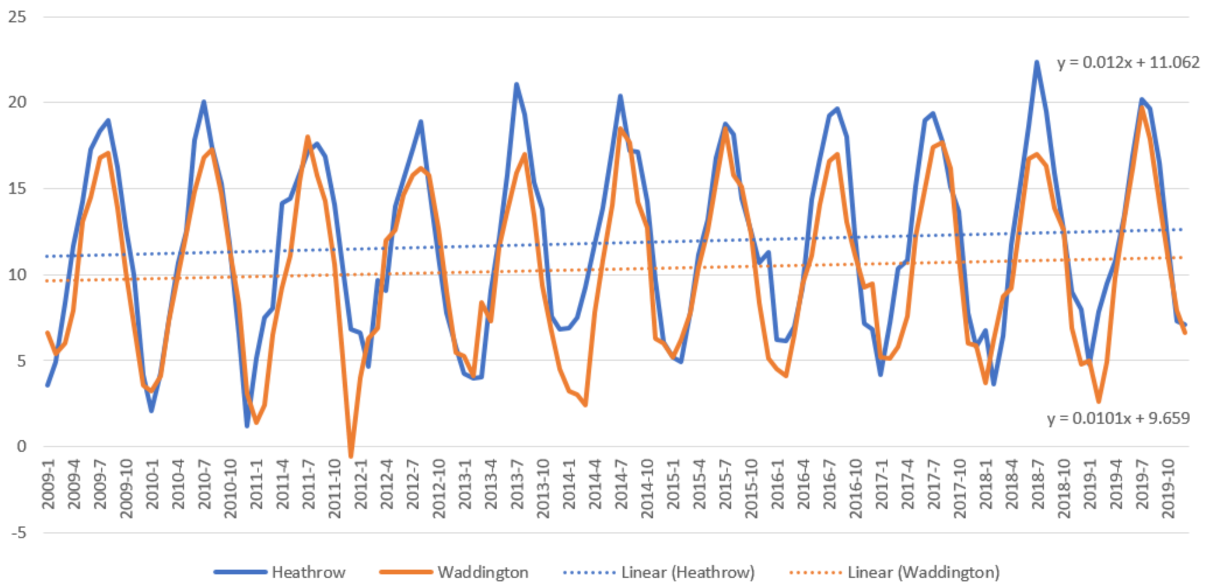


Figure 3: Average monthly temperatures for Heathrow and Waddington, UK (Source: climate-data.org)

4.

Average temperature /°C	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Heathrow	5.1	5.7	8	10.9	13.9	17	19.5	18.6	16	12.8	8.5	6.4
Waddington	4.3	4.5	6.5	9.2	12.2	14.9	17.4	16.9	14.4	11.4	7.4	4.9

5. This data reinforces the conclusion that Heathrow is generally warmer than Waddington. Comparing the monthly averages suggests this difference is usually greatest in the summer months.

6. See Figure 3.
   Temperatures in both locations are increasing,
   at a faster rate in Heathrow than Waddington.
   The rates are 0.010°C/month = 0.12°C/year in Waddington and
   0.012°C/month = 0.14°C/year in Heathrow.

Numerical data for this activity was downloaded from:
www.metoffice.gov.uk/pub/data/weather/uk/climate/stationdata/heathrowdata.txt
and
www.metoffice.gov.uk/pub/data/weather/uk/climate/stationdata/waddingtondata.txt

Worksheet 1: URBAN HOTSPOTS

Find a street plan or/and aerial photographs or true-colour satellite images of the part of Madrid shown in the night-time picture on Information sheet 1.2.

Use this to help you answer the questions below.

1. The road network shows up clearly in the picture. Why?

____

____

2. The Bernabéu stadium also shows very clearly. Why?

____

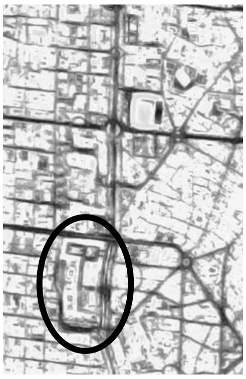
____

The text on Information sheet 1.1 mentions several measures that can help keep cities cool including reintroducing nature, improving airflow in and around buildings, and using different materials or colours.

3. Identify a place that appears to be cooler than the surroundings because it contains plants.

____

4. The row of government buildings, circled in the extract on the right, appear to be cooler than some others.
   What feature(s) of their architecture may explain this?
   Support your answer by referring to contrasting buildings.



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What would you expect a similar map of part of your city, town or nearest urban area to look like?

5. Colour a map extract to show what you think. Remember to include a key.
6. Add labels to explain your decisions for at least four features or locations.
7. Compare your map with that produced by other people.
   Do they agree?
   If not, discuss the differences, aiming to reach a consensus.

Worksheet 2: RADIATION AND TEMPERATURE

For some of these questions, you may want to use the Urban hotspots Activity 2 spreadsheet. Your teacher will tell you how to find this.
In all calculations, take care to use the correct units.

Temperature and peak wavelength

The peak intensity of radiation from the Sun is at 500 nm.

$$\lambda_{\text{peak}} = \frac{b}{T}$$

1. Use Wein's Law to estimate the temperature of the Sun.

____

Add your answer to the table below.

2. Now use Wein's Law to calculate the peak radiation wavelength of the things in the table. Give your answer in both standard form and using an appropriate prefix, and state what part of the electromagnetic spectrum the radiation is in.

	Temperature / K	/ °C	Peak wavelength / m		Electromagnetic spectrum region
Sun			5.00×10^{-7}	500 nm	visible (green)
molten glass	1700				
lava	1500				
hot concrete	333				
Earth (average)		27			
cool concrete		10			
Earth (coldest ever)		–89			

Radiance at other temperatures

The sensor on an Earth observation satellite detects infrared radiation with a wavelength of 10.85 µm.

3. Enter appropriate data in the spreadsheet to use Planck's black body radiation formula to calculate the radiance from concrete at the temperatures shown below.
Remember to change temperatures into Kelvin before using the formula.

$$L_{BB}(\lambda) = \frac{2hc^2}{\lambda^5\left(\exp\frac{hc}{\lambda k_B T} - 1\right)}$$

a. 60°C (hot) ____

b. 27°C (average) ____

c. 10°C (cool) ____

Brightness temperatures

Urban surfaces are not black bodies, so we need to take emissivity into account.

4. Enter appropriate data in the spreadsheet to calculate the brightness temperature of water, concrete, tarmac (asphalt) and oak trees at a temperature of 27°C.

$$T_b = \frac{hc}{\lambda k_B \ln\left(1+\frac{1}{\epsilon(\lambda)}\left[\exp\frac{hc}{\lambda k_B T}-1\right]\right)}$$

The emissivities are shown in the table, which you can also use to record your answers. Assume the sensor is detecting the same wavelength as that in question 3.

Surface	**Emissivity**	**Brightness temperature / K** at 10.85 μm and 27°C
Water	0.99	
Rough concrete	0.94	
Tarmac (asphalt)	0.93	
Oak trees	0.885	

5. How do your answers to question 4 support the idea that vegetation can help reduce the urban heat island effect?
Are there any other ways in which it does this?

___

___

___

___

Worksheet 3: TOWN AND COUNTRY

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

Click on the Data Layers symbol (top right) and pick Land Cover.

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

Click the ⓘ button, bottom left, to see the key. Check you can recognise the types of colour used for various categories of land use.

You are going to examine temperatures in two places in the United Kingdom.

- Heathrow, London.
- Waddington, Lincolnshire.

Find these places on an online map so you know how to locate them in the Climate from Space web application.

1. What type of land cover is there in and around each place?
   Has it changed significantly over the time covered by the data?

Heathrow ____

Waddington ____

You will need the Urban hotspots Activity 3 spreadsheet for the next steps.
Your teacher will tell you how to find this.

Harmonising the data

The spreadsheet shows monthly temperature records for each location. Before you can compare them, you need to make the data sets match.

2. What does this mean you need to do?

____

Make a copy of the sheet and harmonise the two data sets.

Examining the data

Plot both sets of data on a single graph with date on the *x*-axis and temperature on the *y*-axis.

3. Compare the annual cycle of temperature variation in each place, using figures to support your conclusions.

Similarities: ____

____

Differences: ____

____

4. Calculate the average temperature for each month in each location. You may also wish to create an appropriate plot of this data.

Average temperature /°C	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Heathrow												
Waddington												

5. Does this provide any new information, or confirm or contradict one of the conclusions you drew from the full plot? Explain your answer.

____

____

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

6. What do these lines and their equations tell us is happening to temperatures in Heathrow and Waddington? Once again, look for similarities and differences and use figures to support your descriptions.

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____

____

Reporting your conclusions

Write a short report based on this data. Your report must include:

- a description of the locations and data used
- an acknowledgement of the data source
- at least one chart
- a description of key patterns or trends
- an explanation of each pattern or trend based on what you have learnt in this topic.

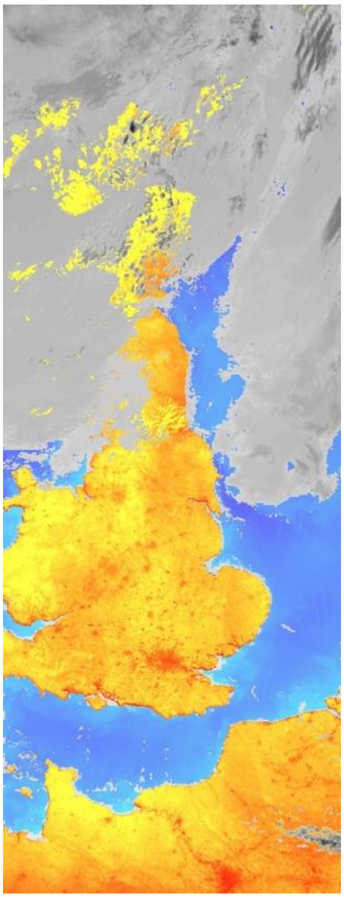
Your report may also include:

- additional charts, maps, diagrams or illustrations
- supporting data from other sources, correctly referenced
- actions that could be taken to reduce any trends that are causing problem, or may do so in the future
- suggestions for further investigation, including what data you would need and how you would use it.

Your report should be no more than 1000 words including annotations and captions but not references.

Information sheet 1: URBAN HOTSPOTS

For the 2020 New Year celebrations in Moscow, they had to make artificial snow. In the Russian capital, famous for its cold hard winters, temperatures had reached 5.4°C – the highest December temperature since records began in 1879. A snowboarding event used 'snow' scraped from the surface of a nearby ice rink. Children played football in courtyards that usually hosted ice hockey games.



A night-time heat map of of northwest Europe. The grey areas are clouds and land shown in red is warmer than land shown in yellow. (Source: ESA)

Heatwaves killed 70,000 people across Europe in 2003 and 55,000 in Russia alone in 2010. The most extreme temperatures were recorded in cities. As more and more people move into an urban area, roads and buildings replace vegetation. Since the materials used for these have a much higher heat capacity than plants and trees, the built environment stores energy and temperatures soon rise. Cities become 'urban heat islands' that can be up to 7°C warmer than the surrounding countryside. You can see how clearly built-up areas stand out in the satellite image on the left which shows the temperature of the land surface at night.

About 2% of the Earth's surface is covered by cities that are home to over 55% of the world's 7.7 billion inhabitants. By 2050, it is expected that 75% of a world population of 9.5 billion will live in cities, so many more people will feel the impact of the heat island effect.

How much an urban area is affected by this effect depends on things such as the number, type and arrangement of buildings and roads, and what they are made from. Reintroducing nature into cities, positioning buildings in a way that improves airflow, and using materials and colours that trap less heat than those we currently use could prevent city temperatures from climbing so steeply. But are such measures enough to cool our growing cities?

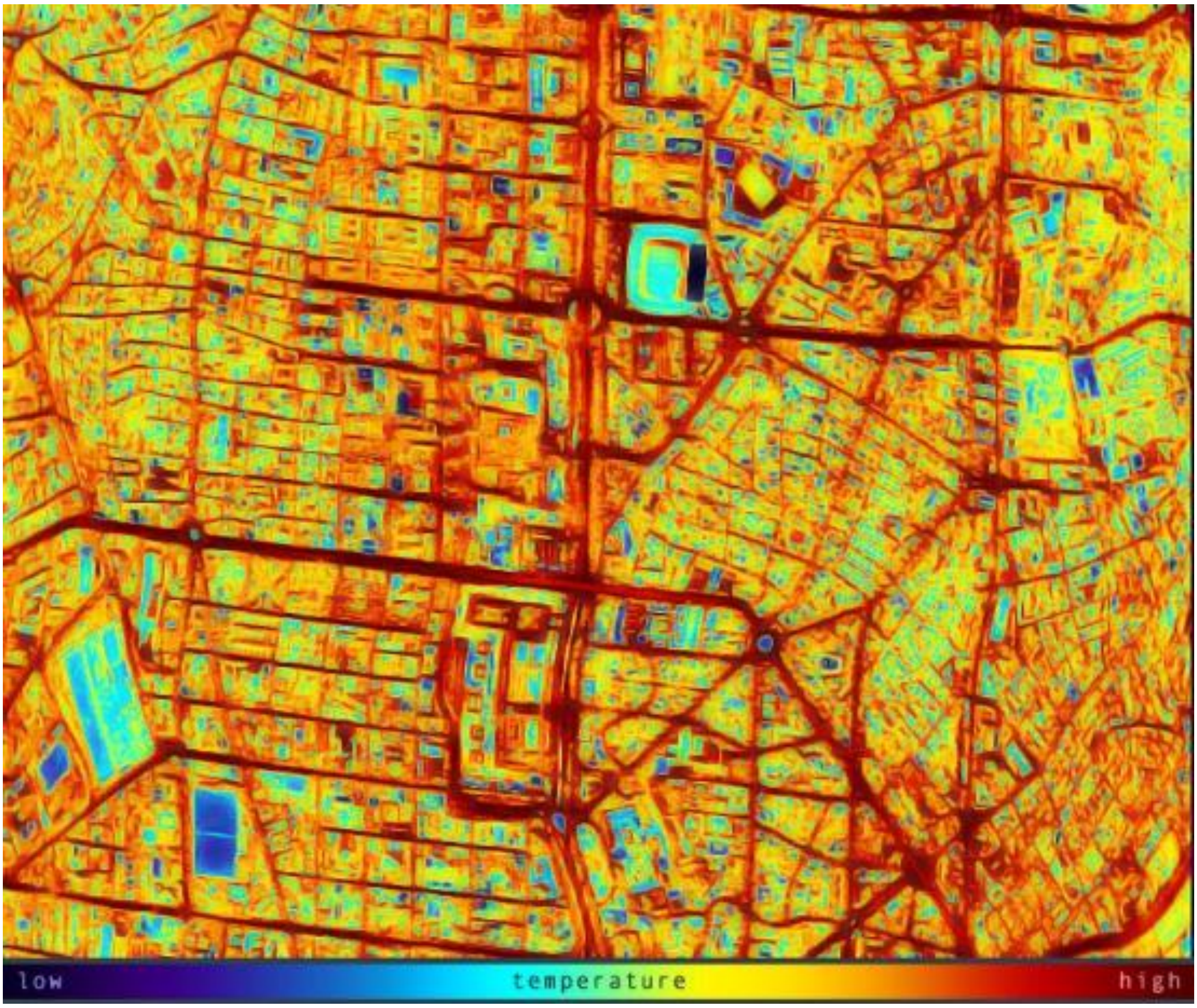
Measurements of land surface temperature (LST) from space can show how heatwaves affect temperature. Scientists funded by the European Space Agency (ESA) have made LST maps giving a snapshot of temperatures on the ground that are detailed enough to show the key features of a city like London. Comparing these with accurate long-term records allows researchers and planners to investigate the impact of heatwaves and changes to the urban environment. Information at the level of an individual city block – or even a district – can help town planners improve the design of cities by suggesting where to locate green areas, which materials to use, and how to orient buildings to maximise cooling.

Another group of ESA-funded scientists is using satellite data to produce detailed maps of land cover. We can use these alongside LST information to explore interactions between humans and nature and to examine how climate change affects these interactions. In fact, ESA teams produce data sets for a whole range of quantities known as essential climate variables (ECVs) that help to describe and explain how climate change is affecting our planet. Land cover and LST are just two of these ECVs that together help us to understand how to plan for a better future.

Identifying hotspots

This picture of Madrid was produced from data collected by an instrument flying in the air above the city at midnight on 1 July 2008.

You can download a high-resolution copy of the picture to use in Activity 1 from https://www.esa.int/ESA_Multimedia/Images/2008/07/AHS-observed_relative_temperatures_of_Madrid_Spain#.X9ouo5WBoXk.link



(Source: ESA)

Information sheet 2: RADIATION AND TEMPERATURE

Black bodies

Any object warmer than absolute zero (0 K, or –273°C) emits electromagnetic radiation. So-called black bodies are perfect radiators: they emit a continuous spectrum and the amount of radiation they emit at each wavelength depends only on their temperature, *T*, usually given in Kelvin, K.

A black body emits the greatest amount of radiation at the peak wavelength, λ_{peak}. Wein's law states that the hotter object, the shorter the peak wavelength:

$$\lambda_{\text{peak}} = \frac{b}{T}$$

T is the temperature in Kelvin and *b* is Wein's constant, which has a value of 0.00290 m.K (metre Kelvin).

Black body radiation curves

Planck's formula is used to calculate how much radiation* a black body of a certain temperature emits at a particular wavelength. This quantity is known as the radiance, L_{BB}. The formula looks complicated, but the key thing to note is that all the terms in the equation apart from temperature, *T*, and wavelength, *λ,* are constants:

$$L_{BB}(\lambda) = \frac{2hc^2}{\lambda^5\left(\exp\frac{hc}{\lambda k_B T} - 1\right)}$$

h = Planck's constant, 6.63×10^{-34} J s
c = speed of light, 3.00×10^{8} m s^{-1}
k_B = Boltzmann's constant, 1.38×10^{-34} J K^{-1}

Finding temperatures

Planck's equation can be rearranged like any other so, if we know L_{BB} for a particular wavelength, we can calculate the temperature of the black body that emitted it. This is how a thermal camera works: the sensor detects infrared radiation in the same way your camera's sensor detects visible light, and the software converts the 'brightness' of each pixel to a temperature which it displays in a particular colour.

However, most objects are not black bodies: the amount of radiation they emit at each wavelength depends on more than the temperature. Therefore, to find the temperature, we need to adapt the equation slightly as well as rearrange it.

$$T_b = \frac{hc}{\lambda k_B \ln\left(1 + \frac{1}{\epsilon(\lambda)}\left[\exp\frac{hc}{\lambda k_B T} - 1\right]\right)}$$

The extra term, emissivity, ε, has no units because it shows the ratio of the radiation the object emits at a certain wavelength to that emitted by a similar black body.

This surface temperature, T_b, is known as the brightness temperature. It may not correspond to the temperature of the object as a whole, but it does show how the object radiates heat to the surroundings and is, therefore, useful if we want to see the effect of different types of land cover on the atmosphere.

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* Strictly, the amount of energy emitted per second per metre cubed in a particular direction, so the units are W sr^{-1}m^{-3}

Links

Resources

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

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

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

Black body radiation
https://sci.esa.int/web/education/-/48986-blackbody-radiation

ESA space projects

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

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

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

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

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

Extra information

Measuring Earths' temperature using satellites
https://www.esa.int/Applications/Observing_the_Earth/Taking_Earth_s_temperature

Heat waves, urban hotspots and heat islands
https://www.esa.int/Applications/Observing_the_Earth/Satellites_predict_city_hot_spots

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