ASTROEDU
Peer-reviewed Astronomy Education Activities

The Climate in Numbers and Graphs

What is climate?

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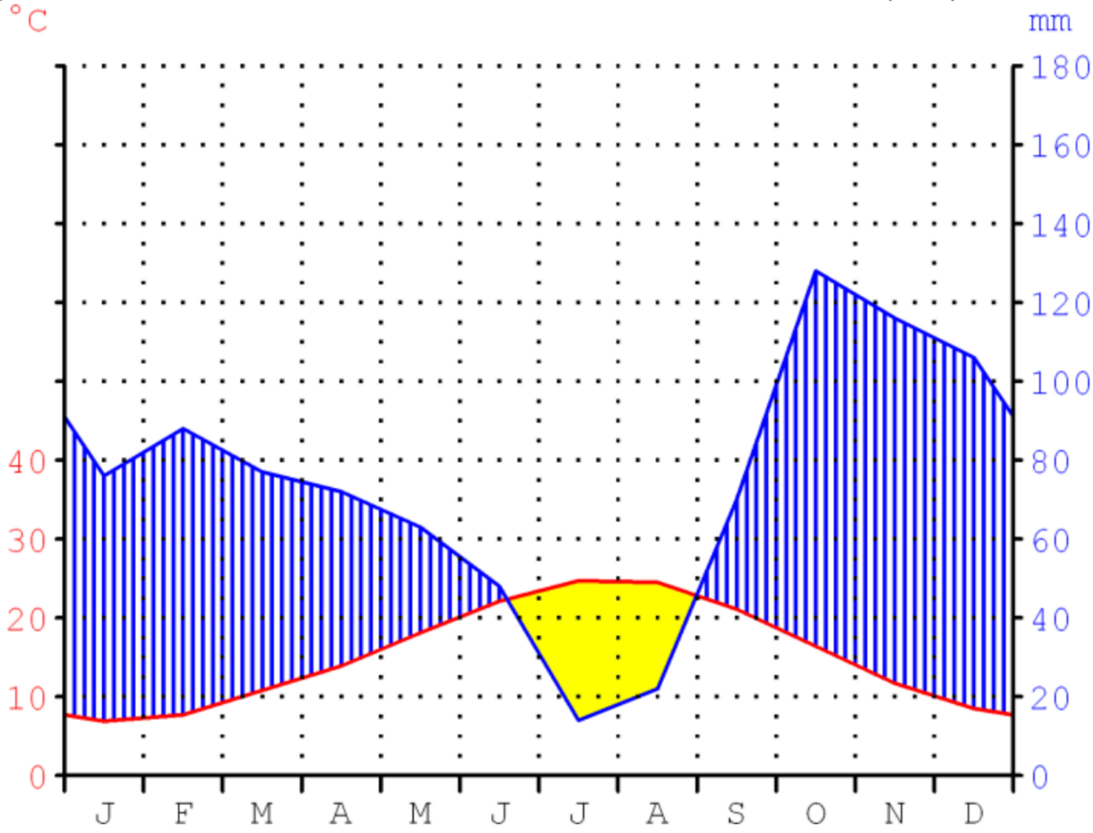
Rome (Italy)

Altitude: 46 m
Latitude: 41°54’ N
Longitude: 12°29’ E

annual mean temperature: 15.5 °C
annual summarised precipitation: 880 mm



AGE

14 - 19

LEVEL

Secondary

TIME

2h

GROUP

Group

SUPERVISED

No

COST PER STUDENT

Low Cost

LOCATION

Small Indoor Setting (e.g. classroom)

CONTENT AREA FOCUS

Earth Science

EARTH SCIENCE KEYWORDS

Atmospheric Sciences, Geography, Oceanography

CORE SKILLS

Asking questions, Developing and using models, Analysing and interpreting data, Using mathematics and computational thinking, Constructing explanations, Engaging in argument from evidence, Communicating information

TYPE(S) OF LEARNING ACTIVITY

Structured-inquiry learning

KEYWORDS

Climate, Climate zone, Weather, Average, Climate chart

GOALS

Students will understand that climate is the long-term average of weather activity. They will understand that climate zones are defined depending on average conditions. They will learn to apply and interpret climate charts according to Walter and Lieth.

LEARNING OBJECTIVES

Students will
- use the statistical tool of averages to calculate the average temperature in a month.
- use statistical tabulated data to produce scientific climate charts.
- become familiar with using spreadsheet software (e.g. Excel) to sum and find the mean.
- retrieve real scientific data from weather databases for their local area and use it to produce a climate chart.
- interpret climate charts and compare it to their expectations.

EVALUATION

The accuracy of the students' calculations can be judged by comparing their answers and climate charts for Jena to those mentioned in the activity description. Check that students have plotted their data points correctly, used an accurate scale, labelled their axes and included the title, locational information, annual mean temperature and annual mean precipitation.

Students' understanding can be determined from the replies to the questions that they are asked during the activity. These are part of the activity description.

MATERIALS

Per student:
- Worksheet
- Millimetre paper
- Pencils (black, blue, red and yellow)
- Ruler
- Computers with spreadsheet software (MS Excel), if available
- Excel file: astroedu1620-The Climate in Numbers and Graphs-Tables.xlsx (if computers are used)
- Internet access needed for activity 3 (for advanced students)
- Pocket calculators (assumed to be private or school property)

BACKGROUND INFORMATION

Climate

Climate is defined as the long-term average of weather or atmospheric phenomena, often modified by seasonal variations. In order to make a statement about the climate, weather data have to be recorded over a long period, typically 20 or 30 years. This avoids confusion with short-term variations as shown in Figure 1.

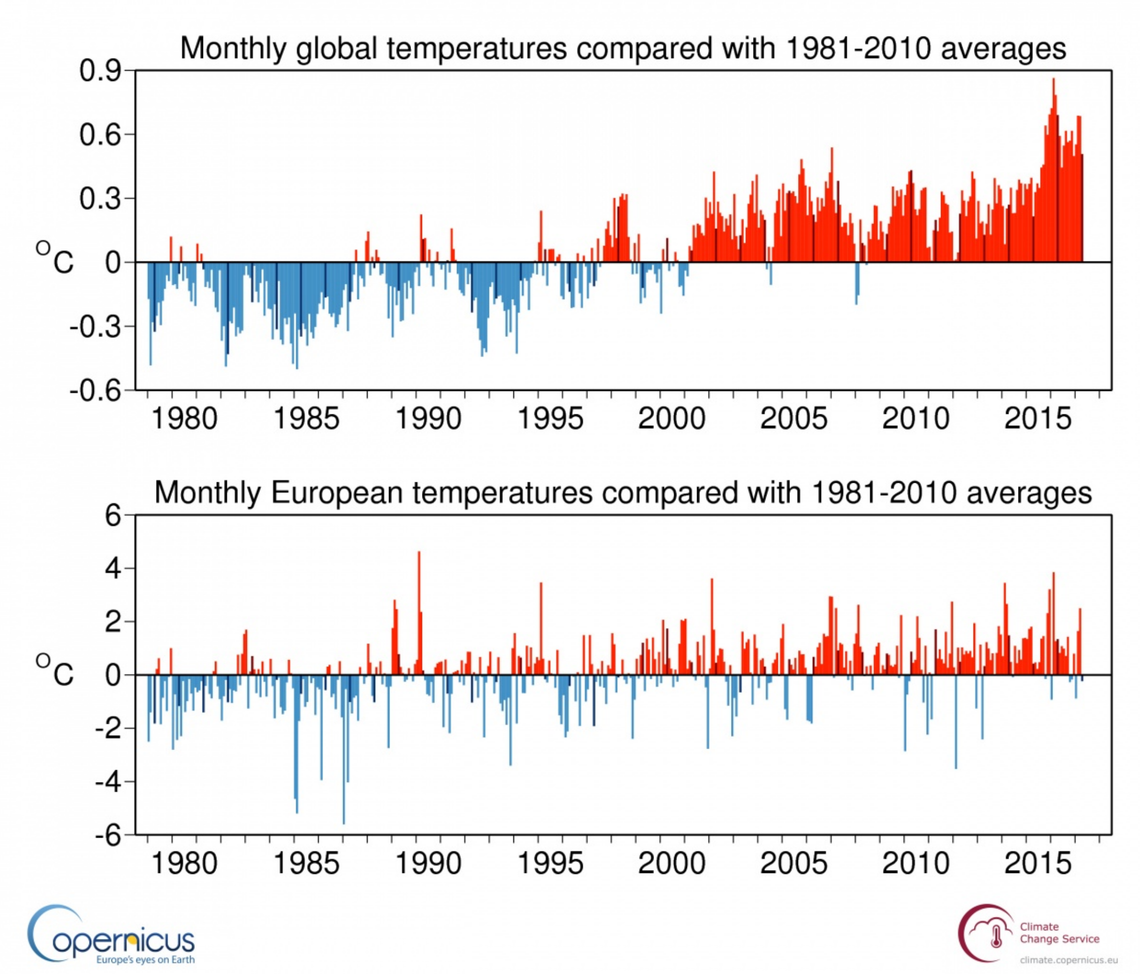


Figure 1: Monthly global mean and European mean surface air temperature anomalies relative to 1981–2010, from January 1979 to April 2017. The darker coloured bars denote the April values. Source: ERA-Interim. (Credit: ECMWF, Copernicus Climate Change Service, https://climate.copernicus.eu/resources/data-analysis/average-surface-air-temperature-analysis/monthly-maps/april-2017)

The temperature changes throughout a day (Figure 2). In many regions on Earth, these changes can be rather large. In order to have a representative temperature value for a single day, the mean value or the average of the recorded values is calculated. The daily mean temperature changes from day to day, because of seasonal influences.

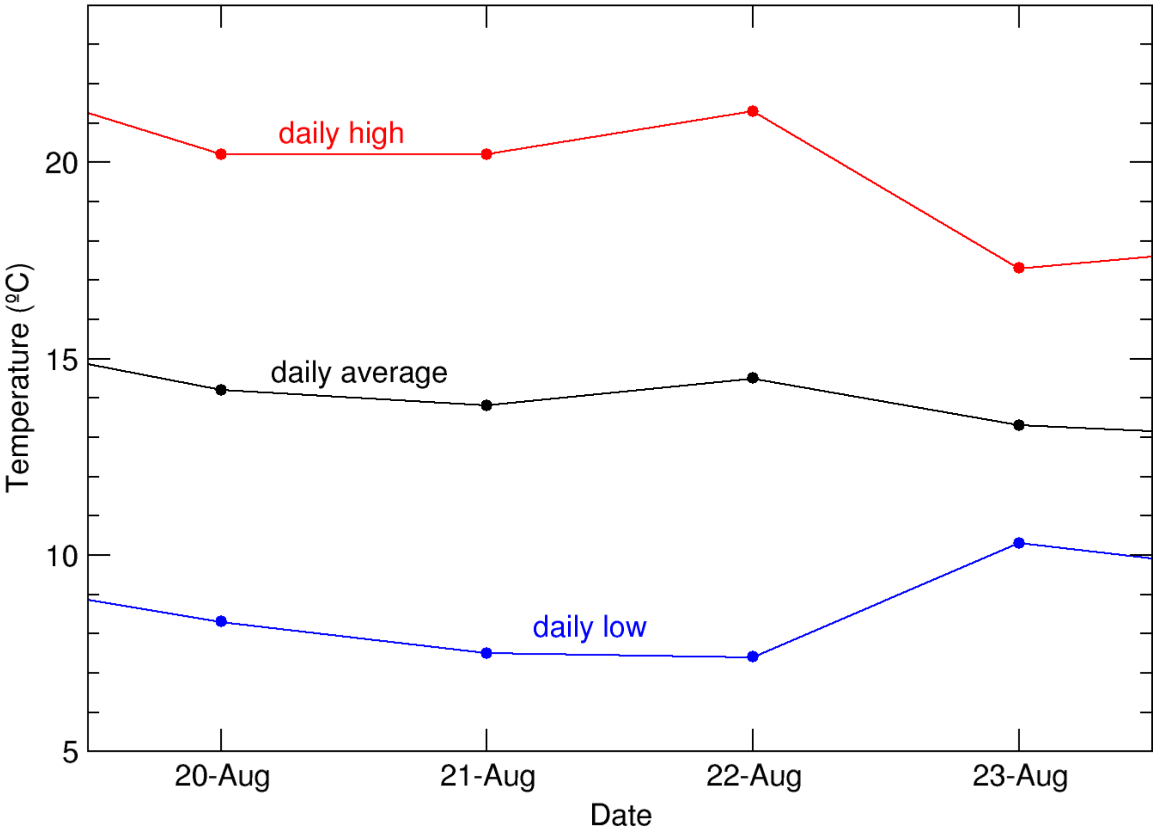


Figure 2: Temperature variations in the daily high, daily average and daily low temperatures (own work, based on data provided with this activity).

In addition, the Earth can be divided into climate zones, which have different ranges of temperatures and precipitation. These zones are produced by large-scale atmospheric interactions or geological features. Besides the previously mentioned temporal average, climate zones are defined via regional averages, which are coarsely aligned with the latitudes, mainly because of the variation of the incident angle of solar irradiation depending on latitude. Various schemes explain climate zones, but in general, there are four or five distinct zones:

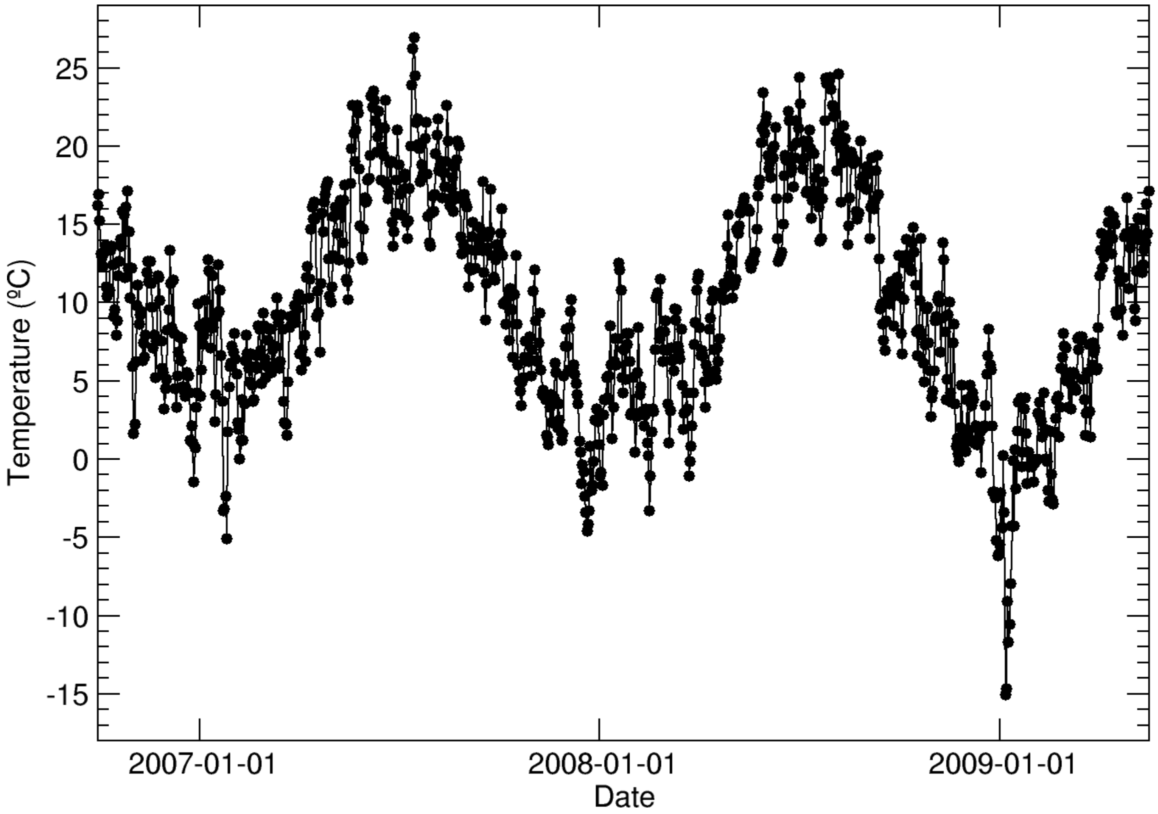


Figure 3: Seasonal variation in the daily mean temperature (own work, based on data provided with this activity).

Tropical zone (between latitudes 0° and 23.5°)
- little seasonal variation in insolation
- very warm throughout the year
- humid, high precipitation

Subtropics (between latitudes 23.5° and 40°)
- most intense insolation during the summer
- generally rather dry, little precipitation
- strong variation in temperatures between day and night (little protective cloud cover)
- rather cool and moist winters

Temperate zone (between latitudes 40° and 60°)
- low incident angle of insolation
- lower mean temperatures than those in the subtropics
- seasons and length of day differ through the year
- precipitation evenly distributed through the year, no or rare arid periods

Cold zone (between latitudes 60° and 90°)
- very low incident angle of insolation
- strong seasonal differences, little diurnal variation
- low temperatures
- amount of precipitation depends on geographical conditions

!\[\](http://astroedu.iau.org/media/activities/attach/4e92b666-a99b-4bf0-b310-8aec2f0f9925/Koppen_World_Map_(retouched_versi_qHXCTfT.png)
Figure 4: Detailed climatic zone map of the Earth showing five major climate zones (World_Koppen_Map.png: Peel, M. C., Finlayson, B. L., and McMahon, T. A. (University of Melbourne) derivative work: Br-Sc-94 (https://commons.wikimedia.org/wiki/File:Koppen_World_Map_(retouched_version).png),

‘Koppen World Map (re-touched version)’, https://creativecommons.org/licenses/by-sa/3.0/legalcode)

Climate charts

A frequently applied tool to determine the basic climatic features of a given location is a climate chart, developed by Walter and Lieth. A climate chart is a graphical representation of the two main observables that characterise weather and climate: temperature and precipitation. The chart shows one representative value for either of the two quantities for each month. The temperature is the mean temperature in a given month, while the sum for the month is displayed for the precipitation.

Calculating the mean or average of a list of values is the simplest method to determine a representative number. While the individual numbers vary, the mean value tells us what number we can expect on average, provided the boundary conditions that govern its manifestation stay the same.

The example for Rome, Italy, is given below. The chart is based on the following list of values, which represent the long-term average of temperature and precipitation for each month.

Table 1: Long-term values of climatic data for Rome.

Month	Temperature (°C)	Precipitation (mm)
January	6.9	76
February	7.7	88
March	10.8	77
April	13.9	72
May	18.1	63
June	22.1	48
July	24.7	14
August	24.5	22
September	21.1	70
October	16.4	128
November	11.7	116
December	8.5	106

The resulting climate chart according to Walter and Lieth is given as follows:

The header of the chart for Rome lists some basic information about the location. Very often, it mentions the annual mean temperature and the summed precipitation amount throughout the year. The chart itself has two scales: the red one to the left displays the temperature in degrees Celsius and the blue one to the right provides the precipitation (rainfall) in millimetres. For very high values of precipitation, the scale above 100 mm is condensed to steps of 100 mm (not in this example). The horizontal scale at the bottom lists the months through the year, abbreviated with the first letter of its name.

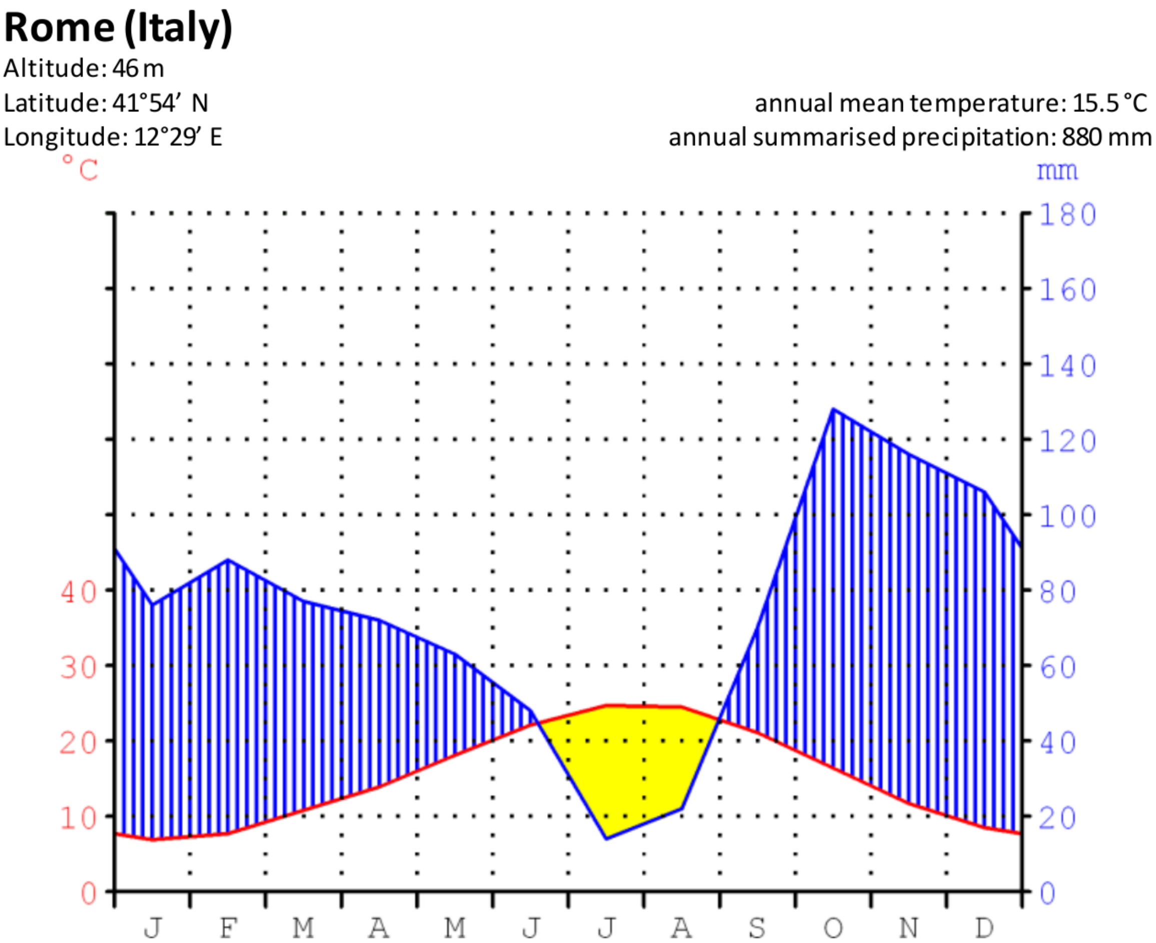


Figure 5: Climate chart for Rome, Italy. It illustrates the monthly mean temperatures and the corresponding monthly total precipitation throughout the year (own work based on Geoklima 2.1, https://creativecommons.org/licenses/by-sa/3.0/legalcode)

The red curve depicts the evolution of temperature, averaged for a given month, as listed in the table above. The blue curve shows the evolution of precipitation as the sum calculated for a given month. The values are also listed in the table. The red scale belongs to the red curve and the blue scale, to the blue curve.

In order to be able to derive climatic information from such a chart, the two scales must be adjusted so that 10°C corresponds to 20 mm of precipitation, both aligned to zero. With this strategy, humid periods are those where the curve of precipitation is above the temperature curve. In contrast, arid periods are whenever the temperature curve is above the one representing precipitation. Usually, these periods are indicated by colouring the areas between the two curves. Blue upright lines depict humid periods, while a dotted pattern or a filled yellow area represents arid periods. If the scale for precipitation above 100 mm is compacted, the area above this value is generally indicated by a filled blue area (not in this example).

Averaging, simple mean

An average value is defined as a number that is the minimum of the sum of differences between the average and the individual values. In an ideal world, this sum of differences is zero.

If T stands for a given value of a temperature measurement, we can indicate a series of measurements by adding an index, e.g. T1, T2 and T3, which corresponds to the first, second and third values, respectively. In order to calculate the average of a series of measurements, one has to calculate the sum of the individual values and divide it by the number of measurements. With three temperature measurements, the average would be calculated as follows:

$$\bar{T} = \frac{T_1 + T_2 + T_3}{3}$$

Or in general

$$\bar{T} = \frac{T_1 + T_2 + T_3 + \cdots + T_n}{n} = \frac{1}{n}\sum_{i=1}^{n} T_i$$

T̄ is the symbol for the temperature average, and n is any given positive integer that corresponds to the number of measurements.

FULL ACTIVITY DESCRIPTION

PREPARATIONS

If you choose to let the students work on computers, make sure that spreadsheet software compatible with MS Excel is installed and that the Excel file supplied with this activity is provided to them. Distribute the worksheets. They contain background information about how to construct and to interpret a climate chart.

INTRODUCTION: DISCUSSION

Start a discussion about the different components of weather that we can measure. Students may come to the conclusion that temperature, wind and rainfall are the main contributors.

An additional discussion can be conducted on the following questions and topics.

Q: If you knew the current temperature and amount of rainfall, would you be able to determine the season of the year? If the students need help, remind them of the seasons.

A: The summer is warmer than the winter in many places on Earth, but there are also cool days during summer and rather warm days during spring. Additionally, the amount of rainfall can change considerably between consecutive days.

Q: What does it mean when we say that generally, summer is warmer than winter?

A: Correct answers would be ‘most of the time’, ‘on typical days’ or ‘on average’.

Q: With this in mind, how would you characterise seasons in terms of weather phenomena?

A: Seasons characterise periods during the year that on average are associated with a certain kind of weather.

Q: Can you describe different types of climate? What are the climatic differences between … and … (select any two regions with very different climates, e.g. southern Spain and London)?

A: London is rather rainy and mild, while southern Spain tends to be dry and warm.

Q: If London is characterised as being ‘rainy’, does it mean that it rains every day?

A: No.

ACTIVITY 1: THE AVERAGE WEATHER

The students will now characterise the climatic conditions of a specific location, the Observatory of Jena (Jena is pronounced: [`je:na] or in English: yena) in Germany. In the end, they need a list of representative temperatures and precipitations for each month of the year. These values will be 30-year averages of individual weather data obtained for each day.

Table 2 provides daily mean temperatures and accumulated precipitation (rain) for June 2010. Ask the students the following question:

Q: What would be the typical temperature of that month in 2010? How would you calculate it?

A: The mean temperature is the average of all temperature measurements.

Task 1:

Let the students calculate the mean temperature and the total amount of precipitation from this. This table is also available as the ‘Task 1’ sheet in the Excel spreadsheet file provided. Choose whether the students should calculate the values manually using a pocket calculator or by means of the spreadsheet functions AVERAGE() and SUM(). The result will be added to the corresponding empty cells in Table 3 and the Excel sheet ‘Task 2’ for the year 2010. More information is given in the worksheet.

Table 2: Weather data obtained at the Jena Observatory from June 2010, including daily mean temperatures and accu-mulated precipitation.

Day	Temperature (°C)	Precipitation (mm)
1	11.2	5.2

2 | 12.3 | 1.9
3 | 17.3 | 0
4 | 16.3 | 0
5 | 19.1 | 0
6 | 22.1 | 0.3
7 | 19.5 | 0.3
8 | 20.2 | 0
9 | 23.7 | 0.1
10 | 24.1 | 0
11 | 22.6 | 1.2
12 | 17.7 | 1.2
13 | 15.5 | 0
14 | 15.3 | 0
15 | 16.2 | 0
16 | 15.4 | 0
17 | 17.4 | 0
18 | 17.5 | 0
19 | 13.3 | 0.1
20 | 13.5 | 0
21 | 13.0 | 0
22 | 14.6 | 0
23 | 16.8 | 0
24 | 19.7 | 0
25 | 20.1 | 0
26 | 19.5 | 0
27 | 19.6 | 0
28 | 21.4 | 0
29 | 22.9 | 0
30 | 23.2 | 0

Expected results:
The mean temperature is 18°C and the total amount of precipitation is 10 mm.

After completing this step, the students will now have to calculate the representative average weather data for June any years between 1981 and 2010. Table 3 lists the monthly average of the temperature and the monthly precipitation for the month of June between 1981 and 2010. Ask the students the following questions:

Q: How can you judge whether the result from the previous task is representative of any June?

A: Compare it with the values of other years.

Q: What are the highest and lowest values of the temperature and precipitation?

A: Lowest: 14.9°C, 10 mm; highest: 20.4°C, 118 mm

Q: What would be the typical temperature in June in any given year? How would you calculate it?

A: The long-term mean temperature, i.e. the average of temperature measurements over many years, e.g. 30 years.

Task 2:

Let the students calculate the mean temperature and precipitation from Table 3. This table is also available as the ’Task 2’ sheet in the Excel spreadsheet provided. Choose whether the students should calculate the values manually using a pocket calculator or software. The result will be added to the corresponding empty cells in Table 4 and the Excel sheet ‘Task 3’ for the month of June.

Table 3: Averaged weather data for the month of June obtained at the Jena Observatory from 1981 until 2010, including monthly mean values of temperature and monthly precipitation.

Year	Temperature (°C)	Precipitation (mm)
1981	17.2	62
1982	17.9	48
1983	17.4	66
1984	15.3	89
1985	14.9	60
1986	16.6	62
1987	15.4	104
1988	16.4	57
1989	16.6	57
1990	16.8	118
1991	15.3	80
1992	18.4	39
1993	16.9	87
1994	17.7	73
1995	15.4	75
1996	16.6	34
1997	16.9	50
1998	18.0	62
1999	16.3	67
2000	18.4	37
2001	15.5	61
2002	18.4	45
2003	20.4	55
2004	16.5	46
2005	17.1	39
2006	17.7	39
2007	19.0	73
2008	18.3	43
2009	15.6	56
2010		

Expected results: The mean temperature is 17°C and the mean precipitation is 60 mm.

Table 4: Climate data based on weather data obtained at the Jena Observatory and averaged over 30 years.

Month	Temperature (°C)	Precipitation (mm)
January	2.1	35
February	2.2	34
March	5.5	46
April	9.4	45
May	14.2	60
June		
July	19.2	77
August	18.5	65
September	14.3	48
October	10.0	38

November | 5.3 | 53
December | 2.4 | 46

Task 3:

From Table 4, let the students calculate the annual mean temperature and annual total precipita-tion. This table is also available as the ‘Task 3’ sheet in the Excel spreadsheet provided. Choose whether the students should calculate the values manually using a pocket calculator or the spread-sheet functions average and sum. The results are typically mentioned in the header of the climate chart to be produced during the next activity.

Expected results:

The annual mean temperature is 10°C and the annual total precipitation is 607 mm.

ACTIVITY 2: CLIMATE CHARTS

Climate charts are a useful tool to quickly grasp the basic climatic conditions for any given location. Introduce the principles of producing such a chart using the background information. The details are also available in the worksheet. The example of Rome (Table 1) is used to evaluate the student’s basic understanding of the concept. In addition, show Figure 5, which is the climate chart for Rome.

Task 1:

Let the students discuss the main features of the climate chart. This should be conducted along the following questions:
- What do the blue and red curves represent?
- Which are the months with the lowest and highest temperatures?
- What are the seasons connected with those temperatures?
- On which hemisphere do we experience summer/winter during these months?
- Which are the months with the lowest/highest precipitation?
- When does the blue curve (precipitation) fall below the red curve (temperature)?
- What does this mean for the climatic conditions? When throughout the year is it humid or dry in Rome?

Expected results:

The red and blue curves represent the long-term average annual evolutions of temperature and precipitation, respectively. The lowest and highest temperatures are achieved in January and July, respectively. This means that January represents winter, while July is in the summer. From this, one can deduce that Rome is in the northern hemisphere. The highest and lowest precipitation can be expected in October and July, respectively. Since precipitation is the lowest during the hottest month, and the blue curve is below the red one from June until August, we can expect dry summers. With the wet autumn and winter months, Rome has a climate that is between the moderate climate of central Europe and the dry climate one experiences in Northern Africa. This is typical of a Mediterranean climate.

Task 2:

Based on the results from the previous activity summarised in Table 4, let the students create a climate chart for the Jena Observatory. The instructions from the worksheet are as follows:
- Take the millimetre paper and draw the coordinate system for the climate chart. Use the one for Rome as a template. Make sure to leave some room for the

header.
- Make sure the scales reflect the values.
- The scale for the precipitation must show values that are twice the numbers in the temperature scale in the opposite axis.
- Add a header that lists the following items: name of the city and country, altitude, latitude, longitude, annual mean temperature and annual total precipitation
- Begin with the temperature: add a red dot for each temperature value in the twelve months.
- Connect the dots with a smooth red line.
- Do the same for the precipitation but use blue. Here, the dots should be connected with straight lines.
- If the blue line is above the red line, fill the area in between with blue vertical lines.
- If the blue line is below the red line, colour this area yellow.

Details of the weather station:

Name: Jena Observatory (Germany)

Latitude: 50.9251° N

Longitude: 11.583° E

Altitude: 155 m

Expected results:

Discuss the results like you did for the Rome example. Ask the students how the climate of Jena compares to Rome.

From this chart, we can conclude that
1. Jena is in the Northern hemisphere as it is warmest in July, and this is similar to Rome.
2. Jena has a temperate climate. The precipitation roughly follows the temperature evolution. This is the opposite of the climate in Rome, where it is driest and hottest in the summer.

ACTIVITY 3: DERIVE YOUR LOCAL CLIMATE CHART (for advanced students only)

Weather data are available for almost any location and area around the world. Use the links below to find the suitable weather station from which you can derive the climate data that are needed to construct your local climate chart.

USA:

https://www.ncdc.noaa.gov/cdo-web/datatools/normals

This tool permits easy access to 30-year averages between 1981 and 2010 for 9,800 weather stations in the USA. On this page, select ‘Monthly Normals’ and choose from the menu of federal states below. From the newly generates list, select the station that is nearest to your location. This produces a graph and a table. Remember that you need both temperature and precipitation data, which are not always available for all the stations.

Clicking on ‘View Station Details’ provides information needed for the header of the climate chart.

From the table, note the values for precipitation and average temperature. They have to be con-verted from inches into millimetres and from °F into °C. This can, for example, be done at
https://www.metric-conversions.org

UK:

http://www.metoffice.gov.uk/public/weather/climate-historic/#?tab=climateHistoric

This page provides access to historic and current weather data for about 35 weather stations across the UK. It also provides instructions on how to load the data into MS Excel for subsequent statistical analysis.

Select the red dot that is nearest to your location. A window appears with the name of the station and its geographical coordinates. Click on ‘Historic station data’ to access the weather data. The linked file is a simple text file that has details on the weather station and lists the weather data averaged for every month of a given year. Among them is ‘rain’ in millimetres and the mean of the daily minimum and maximum temperatures. To get the mean temperature, just calculate the average of the two values. Then proceed as in Activity 2.

Germany:

ftp://ftp-cdc.dwd.de/pub/CDC/

For details, please refer to the Readme file provided in the FTP folder.

The suitable data are located at

ftp://ftp-cdc.dwd.de/pub/CDC/observations_germany/climate/monthly/kl/historical/

The file ‘KL_Monatswerte_Beschreibung_Stationen.txt’ lists the station id (needed to identify the data file), the duration of weather observations, altitude in metres, geographical coordinates, the station name and the federal state of each of the weather stations. The data are stored in the files labelled
monatswerte_XXXXX_YYYYYYYY_ZZZZZZZZ_hist.zip.

Here, XXXXX is the station id, while YYYYYYYY and ZZZZZZZZ denote the temporal range of the data. Select the station with sufficient temporal coverage nearest to your location. The content of these files is explained in DESCRIPTION_...pdf at the top of the file list.

From the ZIP file, extract the file ‘produkt_monat_Monatswerte...txt’. From this file, you need the columns

MESS_DATUM_BEGINN: begin of measurement
MESS_DATUM_ENDE: end of measurement
LUFTTEMPERATUR: mean air temperature in °C
NIEDERSCHLAGSHOEHE: precipitation in mm

Then proceed as in Activity 2.

Task:

Compare the results with your own experience. Do the temperature and precipitation meet your expectations? How do they compare to the other locations, Rome and Jena? Why do you think this might be? Please discuss your conclusions!

CURRICULUM

This activity is part of the Space Awareness category ‘Our fragile planet’ and related to the curricula topics:
- Atmosphere
- Composition and structure
- Climate change

Country | Level| Subject | Exam Board |Section
— | — | — | —
UK | KS2 | Maths | - | **Statistics:**
- interpret and construct pie charts and line graphs and use these to solve problems
- calculate and interpret the mean as an average.
UK | KS2 | Geography | - | **Physical geography:** describe and understand key aspects of climate zones, etc.
UK | KS3 | Geography | - | **Physical geography:** through the use of detailed place-based exemplars at a variety of scales, understand the key processes in: weather and climate, including the change in climate from the Ice Age to the present.

ADDITIONAL INFORMATION

CONCLUSION

The students learn to analyse and interpret scientific weather data and how these data can be used to characterise the local climate. They apply the statistical tool of averaging to calculate average temperatures and learn to construct and use climate charts.

ATTACHMENTS

- Excel sheet

CITATION

Nielbock, M., 2018, *The Climate in Numbers and Graphs*, astroEDU, , doi: 10.14586/astroedu/1620

ACKNOWLEDGEMENT

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