MetLink
Royal Meteorological Society

Weather and Climate:
A Teachers' Guide

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Introduction

In this teachers' guide and the **accompanying online teaching resources** found on metlink.org, we aim to give UK geography teachers all that they need to deliver relevant, engaging and thorough weather and climate lessons to 11–14+ year old students. They are not linked to any specific curriculum but should be easily adaptable to all. The book is accompanied by high quality online **background information/professional development resources** for teachers.

The Society believes that:

- all students should leave school with basic **weather literacy** that allows them to understand the weather that affects them, their leisure activities and the careers they choose to follow
- every student should leave school with basic **climate literacy** that would enable them to engage with the messages put forward by the media or politicians and to make informed decisions about their own opportunities and responsibilities.

To this end, we have embedded a **climate change thread** throughout the online resources, showing its relevance to both weather and climate. An understanding of weather and climate is fundamental to an understanding of climate change.

There is a **progression** of knowledge through the topics, supported by review and assessment activities. The resources also progressively develop key geographical skills such as data, mapwork, GIS, fieldwork and critical thinking.

In this guide, we include common **misconceptions** which should be challenged in the classroom.

There are 20 topics or chapters. Across these, there are **three threads or paths** which can be taken through the online resources, depending on the teaching time available:

Basic weather: Weather in our lives, weather measurements, weather and climate, global atmospheric circulation, global climate zones, air masses, pressure and wind and water in the atmosphere

Climate: Weather and climate, global atmospheric circulation, global climate zones, past climate change, polar climate, hot deserts, changing global climate, UK climate, changing UK climate, the climate crisis

Extending weather: Anticyclones, depressions, microclimates, urban weather, tropical cyclones.

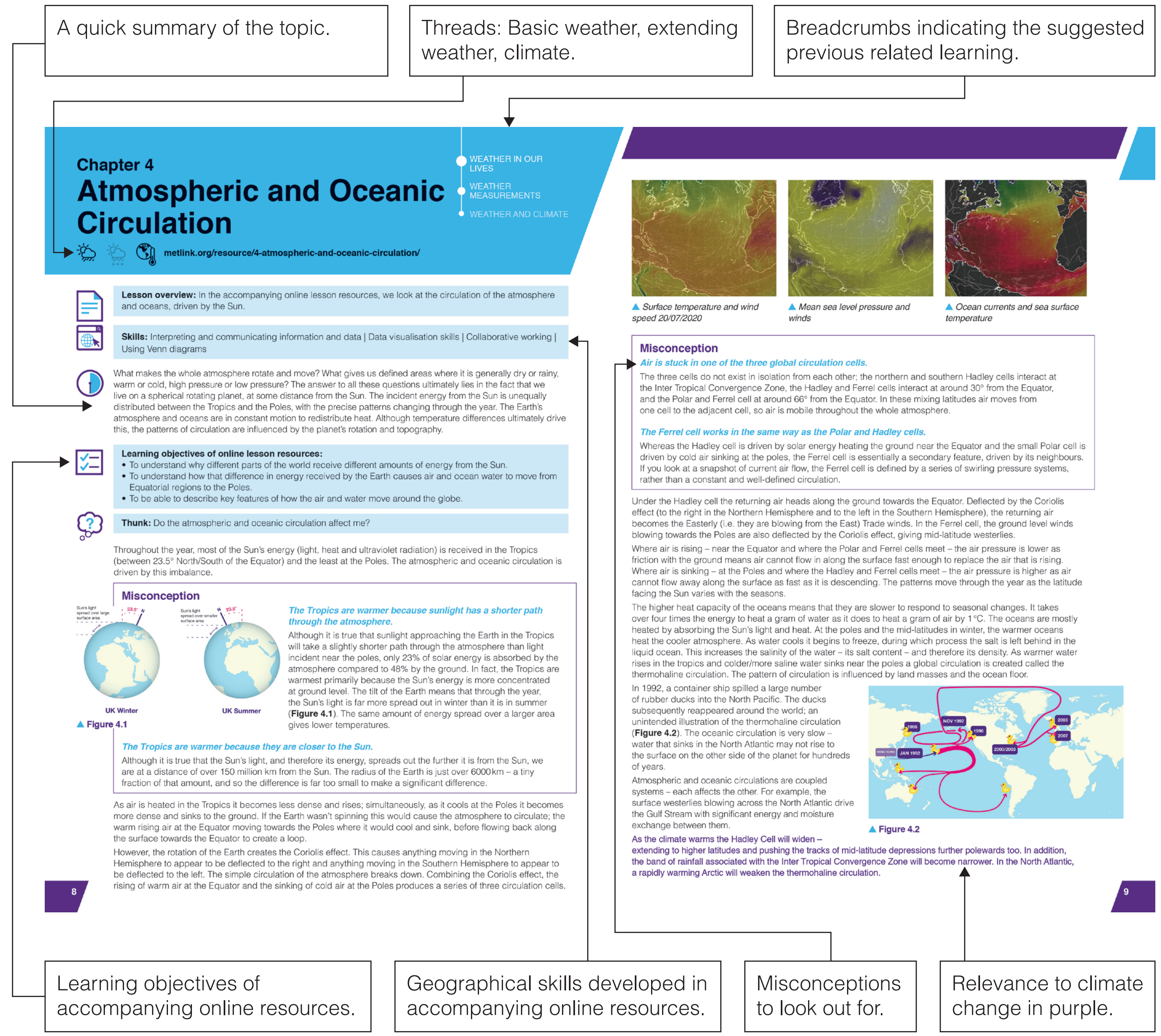
Many of the online teaching resources are available with **standard or easier versions**, as well as extension or alternative activities.

All the online resources will be updated and revised regularly.

Sylvia Knight

Royal Meteorological Society, January 2021

How to use this teachers' guide



Find the scheme of work, teaching resources, background information for teachers, as well as this guide (further copies of which may be printed on request), at metlink.org

This book has been made possible because of a generous legacy from Colin McKerrow, a member of the Royal Meteorological Society until 2019.

The Royal Meteorological Society is the UK's Professional and Learned Society for weather and climate.
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Contents

Chapter 1

Weather in Our Lives

metlink.org/resource/1-weather-in-our-lives/

Lesson overview: In the accompanying online lesson resources, we investigate what weather is and how it has an impact on our daily lives – our clothes, food, travel, work and leisure activities.

Skills: Fieldwork skills | Data skills | Observation skills | Satellite images | Mind mapping

Weather describes the atmospheric conditions in your location right now and it is impossible to ignore or escape its effects on our everyday lives. Weather affects our lives both directly, for example by determining whether we get sunburnt, and indirectly, for example by affecting the price of our food. It strongly influences our physical environments, both rural and urban. Weather data is provided by the Met Office and various other organisations in the UK and used across society to help us accommodate weather in our lives. As our climate changes so does our weather – particularly our extreme weather.

Learning objectives of online lesson resources:

- To be able to define what the weather is.
- To explain how the weather can have a direct impact upon our lives.
- To evaluate how the weather can vary from place to place and time to time.

Thunk: Do tall people experience the weather differently to short people?

▲ *Some of the many activities affected by the weather*

The weather starts affecting your day as soon as the clock ticks over to midnight. Will rain delay today's delivery? Will the school buses be late because of fog? Have winds brought down a tree on the trainline? Has the heating come on because the house grew too cold? Does an ice cream or a warming stew seem more appealing? We experience weather every day as we live our lives – it is impossible to ignore it or escape its influence.

Weather describes the atmospheric conditions at your location right now. As such it can change rapidly over the course of a day as well as vary between different places you visit, to a greater or lesser extent. Understanding the causes of certain types of weather helps us to anticipate these changes and prepare for them.

Weather has both direct and indirect effects on us. Directly it makes us wet, cold, hot and sweaty; indirectly it affects how we move around, how much our food costs, the activities we do/watch in our leisure time and the structure of our built and natural environment.

Misconception

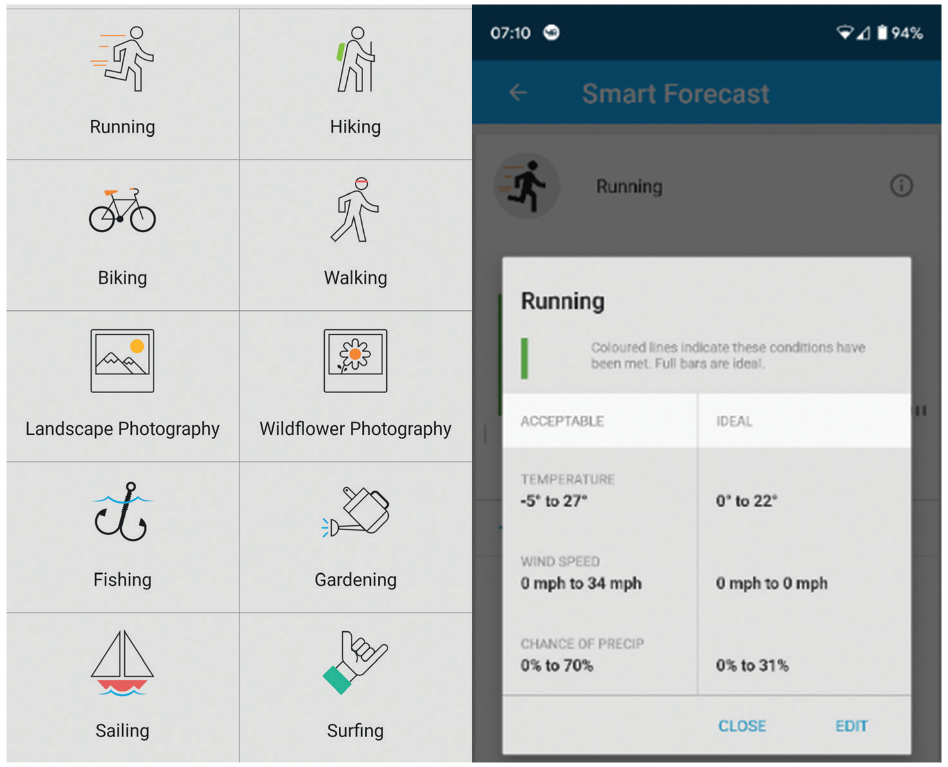
The weather does not affect me.

Even if you are not physically affected by the weather, almost every aspect of your life is. For instance, your house will need heating if it is cold, some foods will get more expensive if drought spoils the harvest or your commute will be slower if there is ice. It is impossible to live on Earth and completely insulate yourself from the effects of the weather. The atmospheric conditions we experience – both indoors and outdoors, have a significant impact on the way we feel – lethargic in hot, dull or humid conditions, more energetic when the weather is bright. There are also clear links between the weather and chronic pain.

The extent to which weather influences our lives depends to some extent on the value of our activities – if an activity has significant economic, social or personal value it normally happens come rain or shine!

Similarly, almost every industry is affected by the weather – by road or other transport conditions, extreme weather events, the impact on the cost of raw materials or the impact of the weather on consumers.

Weather data services are worth over a billion pounds each year. In the UK, the Met Office is the public service weather provider. Together with various private companies it provides weather data to users including the government, organisations and individuals through a variety of channels that include TV, radio, internet and apps (**Figure 1.1**), as well as specialised products to industries including farming and aviation. Most sports are strongly affected by the weather – if only through its impact on transport networks.



▲ **Figure 1.1**

As humans continue to change the surface of the Earth and emit greenhouse gases like carbon dioxide and methane, more and more energy is stored in the atmosphere. This changes the atmospheric processes that underpin our weather – both 'normal' and extreme weather. Changes in extreme weather have the most significant impact on our lives.

Chapter 2

Weather Measurements

metlink.org/resource/2-weather-measurements/

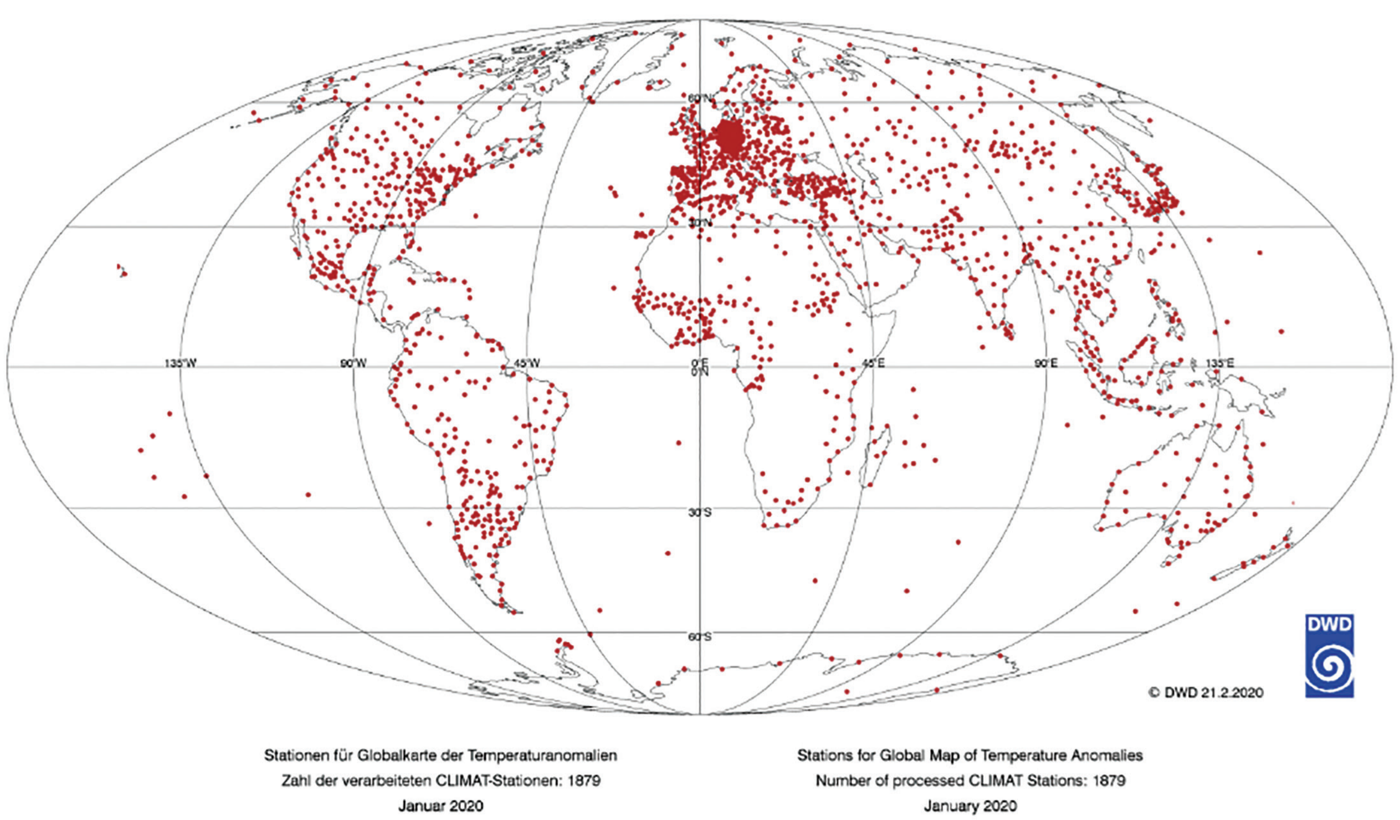
Lesson overview: In the accompanying online lesson resources, we look at the specialist instruments used to measure the weather and how data collected at different locations can be used to create weather maps.

Skills: Map interpretation | Data analysis | Fieldwork | Drawing isolines

We measure the weather to be able to understand and anticipate its effects on our lives. Gathering large amounts of data across the surface of the Earth using specialist meteorological instruments allows us to monitor atmospheric conditions around the world on a continuous basis. These data allow complex climate system models to create forecasts for many different types of user, from governments, to industry and the general public. There are agreed standards for weather instruments across the world to ensure data are accurate and comparable. With remote logging and transmission of data now possible anywhere on Earth, the quantity of weather data available has never been greater. Satellites play an increasingly important role in measuring weather as they obtain information from throughout the depth of the atmosphere. Simpler instruments can also be used to make observations and generate usable data in schools.

Learning objectives of online lesson resources:
- To be able to describe the weather instruments and units of measurement for various weather variables (e.g. temperature, wind speed, rainfall).
- To evaluate a range of sites for the suitability to host a weather station.
- To understand what we do with weather measurements once we have them.

Thunk: Where in the world is there most weather?



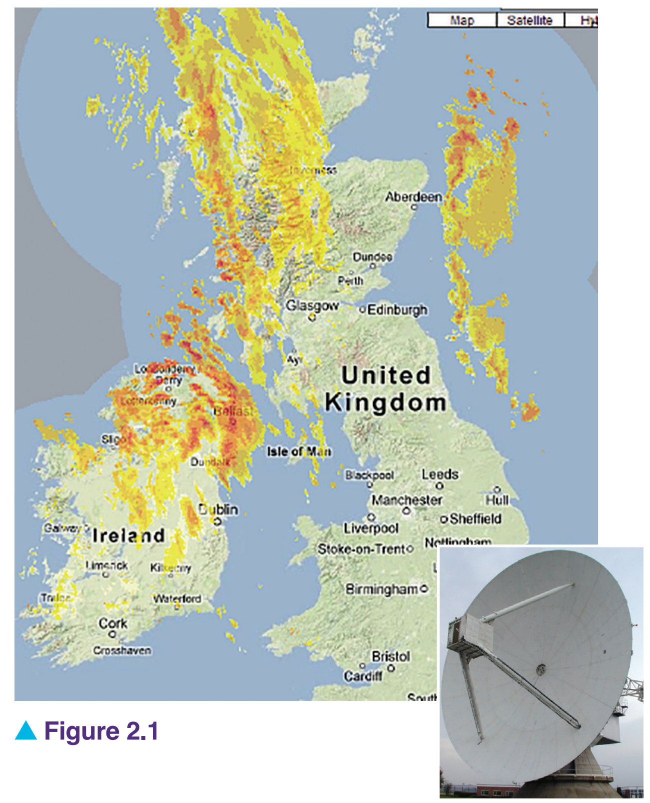
▲ *Most countries have networks of weather stations, although there is significant variation in the network density. Some countries maintain stations in remote areas such as Antarctica.*

Humans have always sought to understand weather to better anticipate its influence on our lives. Over the last few hundred years, both our understanding of the atmospheric processes that underlie the weather and our ability to accurately record the environment have improved significantly. Today we can measure a wide range of weather variables continuously across the planet and throughout the depth of the atmosphere.

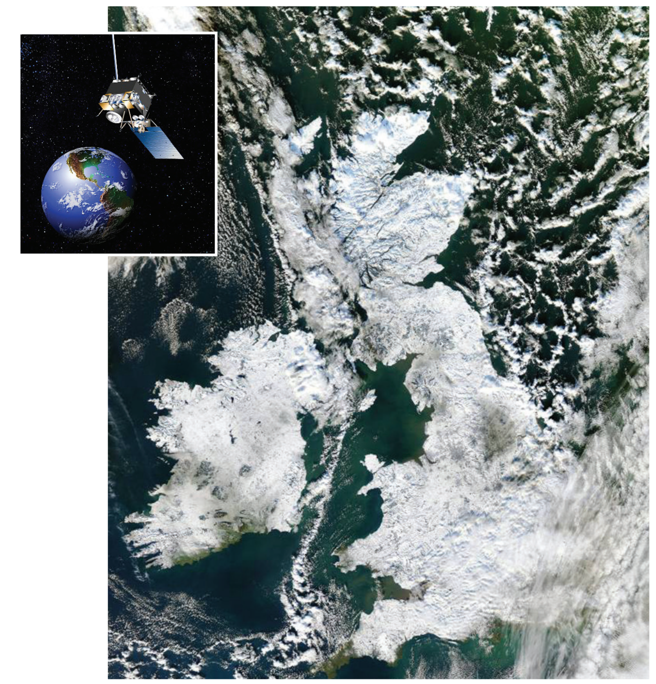
There are a number of specialist weather instruments used by meteorologists. In recent times, digital instruments, doppler radar (**Figure 2.1**) and satellite mounted remote sensing devices (**Figure 2.2**) have replaced traditional instruments such as Campbell-Stokes sunshine recorders and copper rain gauges.

Weather instruments are also mounted on ships, aeroplanes, buoys and weather balloons. Satellites provide coverage of the whole planet and can give information about the state of the atmosphere at various heights. Radar is used to observe precipitation, and ground-based lightning detectors report lightning strikes in real time.

Official instruments at all sites are calibrated to ensure data are comparable across the world. The global exchange of weather data, products and services is facilitated by the World Meteorological Organisation (WMO) – a specialised agency of the United Nations.



▲ **Figure 2.1**



▲ **Figure 2.2**

Misconception

Weather forecasts are made by looking for patterns in the weather.

There is a popular misconception that forecasts are made by looking for a similar weather pattern in the past, and then using what happened next on that occasion as the basis for the current forecast. However, no two weather patterns are ever likely to be identical. In practice, all the weather observations are assimilated into complex computer models, running on some of the biggest supercomputers in the world. These solve thousands of equations representing hundreds of physical processes – such as convection, condensation, evaporation, etc. to predict how the weather will evolve. The complexity of the models and speed of the supercomputers are improving all the time, allowing more accurate weather predictions. The forecast you are presented with is an interpretation of the information produced by the computer models, created by a human forecaster. The model output gives the forecaster an overview of what weather conditions are most likely, as well as what might be possible. This allows weather apps, for example, to tell you what the probability of rainfall is for a given time and place.

These predictions are valuable data and are packaged as services and sold to different users that include governments, industry and the media, as well as used for academic research to improve our understanding of the climate system.

We have a wide range of weather instruments available to tell us about the weather conditions now and in the recent past. However, to understand the changing climate, we need weather data from long before instrumental records began. For this purpose, 'proxy' data are used – the information we can get about temperature and rainfall conditions from the air trapped in ice, pollen preserved in sediments, tree rings and many other sources.

Chapter 3
Weather and Climate

metlink.org/resource/3-weather-and-climate/

Lesson overview: In the accompanying online lesson resources, we look at the difference between weather and climate and introduce climate graphs.

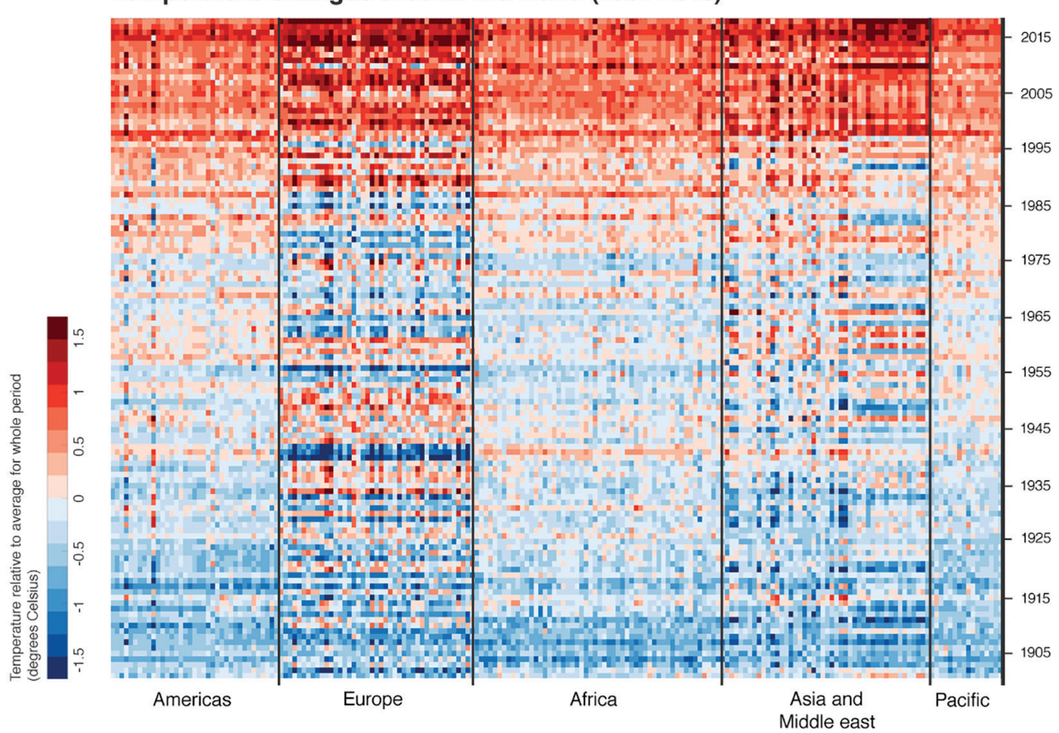
Skills: Data interpretation and analysis | Plotting climate graphs | Basic number skills | Reading and interpreting cloropleth maps

Climate is what you expect, weather is what you get. The weather, or the current atmospheric conditions in a given place, can change rapidly and from place to place. The climate is the average weather. Climate information tells you what weather is most likely (the weather you 'expect') as well as what extreme weather might occur. The climate changes on timescales which are much longer than the timescales over which the weather changes.

Learning objectives of online lesson resources:
- To be able to distinguish between weather and climate.
- To understand and be able to plot a climate graph.
- To be able to interpret climate graphs for different places and make comparisons.

Thunk: Do you talk more about weather or climate?

Temperature changes around the world (1901-2018)



Source: Ed Hawkins/Reading University BBC

▲ *This image both shows the variability of weather from year to year and the change in climate over time. Both the variability and change are different from country to country.*

Weather describes the atmospheric conditions wherever you are, right now. We normally talk about weather in relation to its qualities that affect us, for example the temperature, the chance of rain, the strength of wind or the humidity and how it might change during the course of the day. Knowing today's weather helps us make choices that allow us to prepare for its impact on our lives.

When we discuss the climate, we are essentially considering the average weather over a long time period (typically 30 years) for a particular area which could be local or global. Conventionally, the current climate reference period is the previous complete three decades (i.e. 1991–2020) however, for some purposes a running mean is more appropriate. For example, in a graph of climate against time, the point at 2019 would be the average of the 30 years up to 2019.

Weather and climate are not random. Both obey the laws of physics and these allow us to predict the climate with ever-increasing accuracy as our computer models and the quality and quantity of our weather data improve.

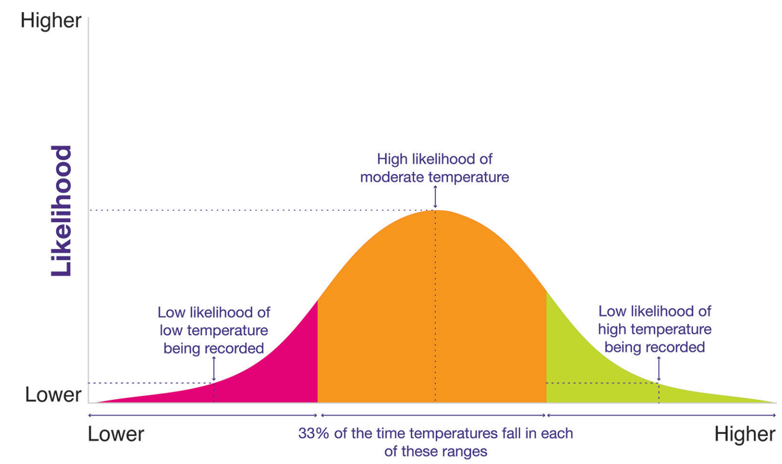
Weather, however, is chaotic. Mathematician and meteorologist Edward Lorenz determined that the interrelationships within the atmosphere and between the atmosphere, land and ocean are so complex that a small change in any one of them creates a chain of interactions that can completely change the weather you experience days later, even hundreds of miles away. This was popularised in 1972 when he wrote a paper called *Predictability: Does the Flap of a Butterfly's Wings in Brazil set off a Tornado in Texas?* which gave rise to the term 'The Butterfly Effect'.

The climate varies over time due to large scale influences such as changes in our orbit around the Sun over tens of thousands of years and processes in the atmosphere, the oceans, and between atmosphere, oceans and land. Unlike the weather, the climate is not chaotic. This means that, with an understanding of the large scale influences, it is possible to project how the climate will change for many decades into the future.

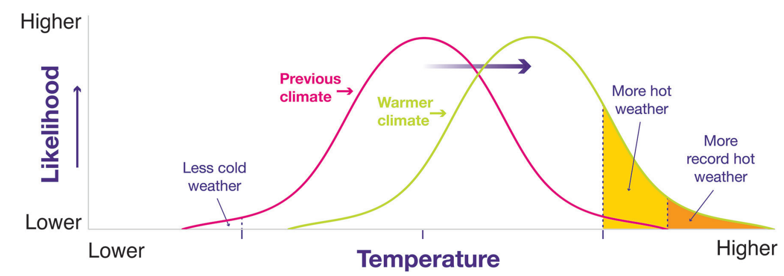
Misconception

It's really cold today so global warming isn't happening.

The climate of a particular place for a particular time of year is most fully described as a probability curve (**Figure 3.1**) showing the temperatures (or rainfall or any other climate variable) which are most likely as well as those more extreme temperatures which may occur. As the climate changes, this whole distribution changes. For example, in a warming climate (**Figure 3.2**), you would expect fewer extremely cold temperatures, and more extremely warm ones. However, extremely cold weather events can still happen, just less frequently.



▲ **Figure 3.1**

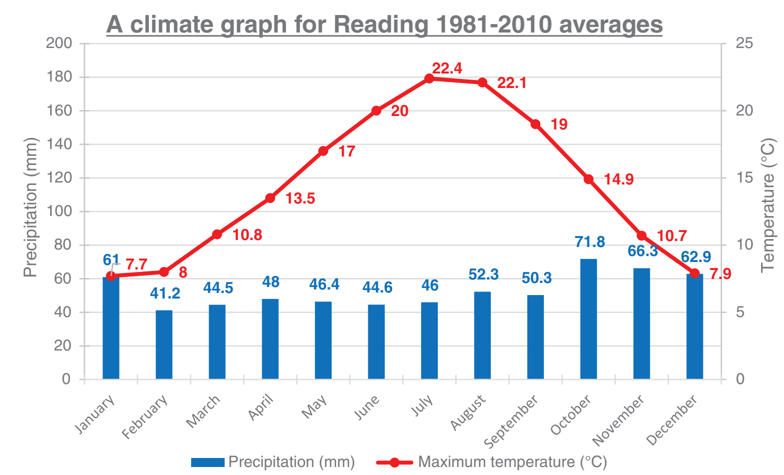


▲ **Figure 3.2**

Both weather and climate can be represented visually:
- as climate graphs (**Figure 3.3**) that show rainfall and temperature
- as choropleth maps that use colour to represent weather variables
- in more complex ways that are able to indicate our uncertainty in past measurements and future projections.

Visual representations make it easier to see patterns and trends and to quickly compare different places and time periods. A graph from Brazil, for instance, is quite different to one from Canada. Other types of graph can be used to represent a much wider range of climate data and often incorporate indication of uncertainty and changes in time.

The ability to communicate weather and climate information clearly, and to be able to understand and interpret the information, allow people/organisations to act on the information – the farmer to harvest his crops, the supermarket to order more ice cream, the authority to improve flood defences.



▲ **Figure 3.3**

Chapter 4

Atmospheric and Oceanic Circulation

- WEATHER IN OUR LIVES
- WEATHER MEASUREMENTS
- WEATHER AND CLIMATE

metlink.org/resource/4-atmospheric-and-oceanic-circulation/

Lesson overview: In the accompanying online lesson resources, we look at the circulation of the atmosphere and oceans, driven by the Sun.

Skills: Interpreting and communicating information and data | Data visualisation skills | Collaborative working | Using Venn diagrams

What makes the whole atmosphere rotate and move? What gives us defined areas where it is generally dry or rainy, warm or cold, high pressure or low pressure? The answer to all these questions ultimately lies in the fact that we live on a spherical rotating planet, at some distance from the Sun. The incident energy from the Sun is unequally distributed between the Tropics and the Poles, with the precise patterns changing through the year. The Earth's atmosphere and oceans are in constant motion to redistribute heat. Although temperature differences ultimately drive this, the patterns of circulation are influenced by the planet's rotation and topography.

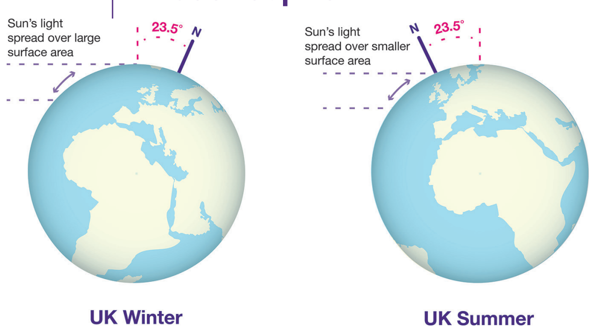
Learning objectives of online lesson resources:

- To understand why different parts of the world receive different amounts of energy from the Sun.
- To understand how that difference in energy received by the Earth causes air and ocean water to move from Equatorial regions to the Poles.
- To be able to describe key features of how the air and water move around the globe.

Thunk: Do the atmospheric and oceanic circulation affect me?

Throughout the year, most of the Sun's energy (light, heat and ultraviolet radiation) is received in the Tropics (between 23.5° North/South of the Equator) and the least at the Poles. The atmospheric and oceanic circulation is driven by this imbalance.

Misconception



▲ Figure 4.1

The Tropics are warmer because sunlight has a shorter path through the atmosphere.

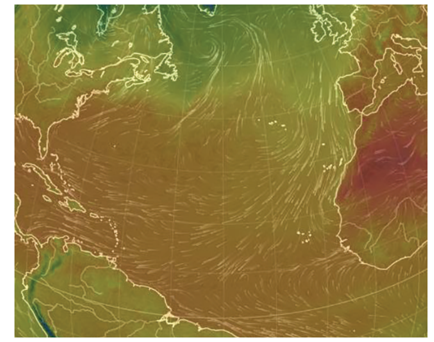
Although it is true that sunlight approaching the Earth in the Tropics will take a slightly shorter path through the atmosphere than light incident near the poles, only 23% of solar energy is absorbed by the atmosphere compared to 48% by the ground. In fact, the Tropics are warmest primarily because the Sun's energy is more concentrated at ground level. The tilt of the Earth means that through the year, the Sun's light is far more spread out in winter than it is in summer (**Figure 4.1**). The same amount of energy spread over a larger area gives lower temperatures.

The Tropics are warmer because they are closer to the Sun.

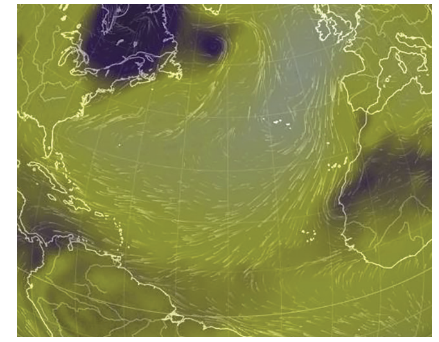
Although it is true that the Sun's light, and therefore its energy, spreads out the further it is from the Sun, we are at a distance of over 150 million km from the Sun. The radius of the Earth is just over 6000 km – a tiny fraction of that amount, and so the difference is far too small to make a significant difference.

As air is heated in the Tropics it becomes less dense and rises; simultaneously, as it cools at the Poles it becomes more dense and sinks to the ground. If the Earth wasn't spinning this would cause the atmosphere to circulate; the warm rising air at the Equator moving towards the Poles where it would cool and sink, before flowing back along the surface towards the Equator to create a loop.

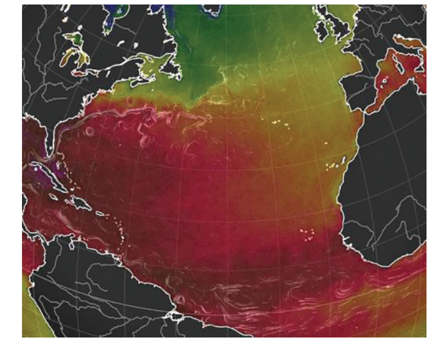
However, the rotation of the Earth creates the Coriolis effect. This causes anything moving in the Northern Hemisphere to appear to be deflected to the right and anything moving in the Southern Hemisphere to appear to be deflected to the left. The simple circulation of the atmosphere breaks down. Combining the Coriolis effect, the rising of warm air at the Equator and the sinking of cold air at the Poles produces a series of three circulation cells.



▲ *Surface temperature and wind speed 20/07/2020*



▲ *Mean sea level pressure and winds*



▲ *Ocean currents and sea surface temperature*

Misconception

Air is stuck in one of the three global circulation cells.

The three cells do not exist in isolation from each other; the northern and southern Hadley cells interact at the Inter Tropical Convergence Zone, the Hadley and Ferrel cells interact at around 30° from the Equator, and the Polar and Ferrel cell at around 66° from the Equator. In these mixing latitudes air moves from one cell to the adjacent cell, so air is mobile throughout the whole atmosphere.

The Ferrel cell works in the same way as the Polar and Hadley cells.

Whereas the Hadley cell is driven by solar energy heating the ground near the Equator and the small Polar cell is driven by cold air sinking at the poles, the Ferrel cell is essentially a secondary feature, driven by its neighbours. If you look at a snapshot of current air flow, the Ferrel cell is defined by a series of swirling pressure systems, rather than a constant and well-defined circulation.

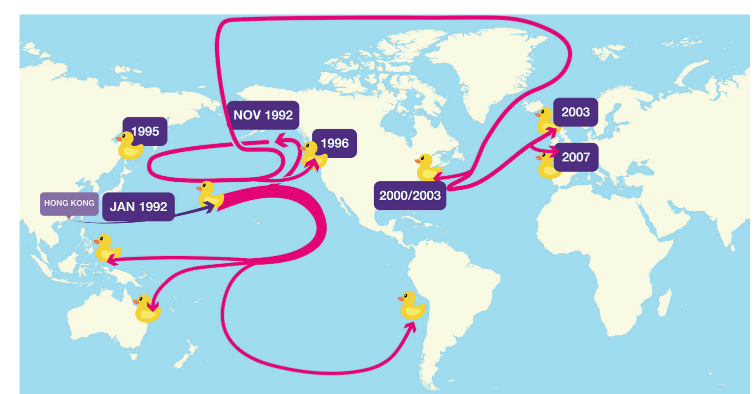
Under the Hadley cell the returning air heads along the ground towards the Equator. Deflected by the Coriolis effect (to the right in the Northern Hemisphere and to the left in the Southern Hemisphere), the returning air becomes the Easterly (i.e. they are blowing from the East) Trade winds. In the Ferrel cell, the ground level winds blowing towards the Poles are also deflected by the Coriolis effect, giving mid-latitude westerlies.

Where air is rising – near the Equator and where the Polar and Ferrel cells meet – the air pressure is lower as friction with the ground means air cannot flow in along the surface fast enough to replace the air that is rising. Where air is sinking – at the Poles and where the Hadley and Ferrel cells meet – the air pressure is higher as air cannot flow away along the surface as fast as it is descending. The patterns move through the year as the latitude facing the Sun varies with the seasons.

The higher heat capacity of the oceans means that they are slower to respond to seasonal changes. It takes over four times the energy to heat a gram of water as it does to heat a gram of air by 1 °C. The oceans are mostly heated by absorbing the Sun's light and heat. At the poles and the mid-latitudes in winter, the warmer oceans heat the cooler atmosphere. As water cools it begins to freeze, during which process the salt is left behind in the liquid ocean. This increases the salinity of the water – its salt content – and therefore its density. As warmer water rises in the tropics and colder/more saline water sinks near the poles a global circulation is created called the thermohaline circulation. The pattern of circulation is influenced by land masses and the ocean floor.

In 1992, a container ship spilled a large number of rubber ducks into the North Pacific. The ducks subsequently reappeared around the world; an unintended illustration of the thermohaline circulation (**Figure 4.2**). The oceanic circulation is very slow – water that sinks in the North Atlantic may not rise to the surface on the other side of the planet for hundreds of years.

Atmospheric and oceanic circulations are coupled systems – each affects the other. For example, the surface westerlies blowing across the North Atlantic drive the Gulf Stream with significant energy and moisture exchange between them.



▲ Figure 4.2

As the climate warms the Hadley Cell will widen – extending to higher latitudes and pushing the tracks of mid-latitude depressions further polewards too. In addition, the band of rainfall associated with the Inter Tropical Convergence Zone will become narrower. In the North Atlantic, a rapidly warming Arctic will weaken the thermohaline circulation.

Chapter 5

Climate Zones

metlink.org/resource/5-climate-zones/

WEATHER MEASUREMENTS

WEATHER AND CLIMATE

ATMOSPHERIC AND OCEANIC CIRCULATION

Lesson overview: In the accompanying online lesson resources, we explore the main climate zones, their link to the global atmospheric circulation and the influence of the oceans.

Skills: Interpreting images | Mapping skills | Climate graphs | Describing and explaining | Basic number

Climate zones describe parts of the Earth that have similar climate – the characteristics of the seasonal variations in weather. These relate to physical factors such as latitude and altitude, in association with their position relative to the global atmospheric and oceanic circulation. Although there are only five top-level categories – Tropical, Dry, Continental, Temperate and Polar – it is possible to define a total of 30 categories using the Köppen-Geiger classification system. This system considers a range of data that includes typical weather data such as temperature and precipitation, and supplements this with evaluation of other variables such as soil temperature and the frequency of specific weather phenomena. These data allow climatologists to differentiate between similar climates and describe the characteristics of specific climates very precisely. Projections of climate change suggest climate zones show significant, although complex, change.

Learning objectives of online lesson resources:

- To be able to describe the major world climate types.
- To know where the world's major climate types are found.
- To understand what happens to precipitation and temperature with increasing distance from the sea.

Thunk: Is the climate zone inside the building the same as the one outside?

Climate zones describe areas of the Earth that have a similar climate. When defining climate zones, typical weather data such as precipitation, temperature, humidity, hours of sunshine, wind speed and other variables such as soil temperature, minimum ground temperature, cloudiness, average and extreme weather data, and the frequency of specific weather phenomena such as fog, lightning or gales are considered. These data allow us to differentiate between areas that might superficially seem to share the same climate, although in reality have distinct differences in one or more of the variables considered.

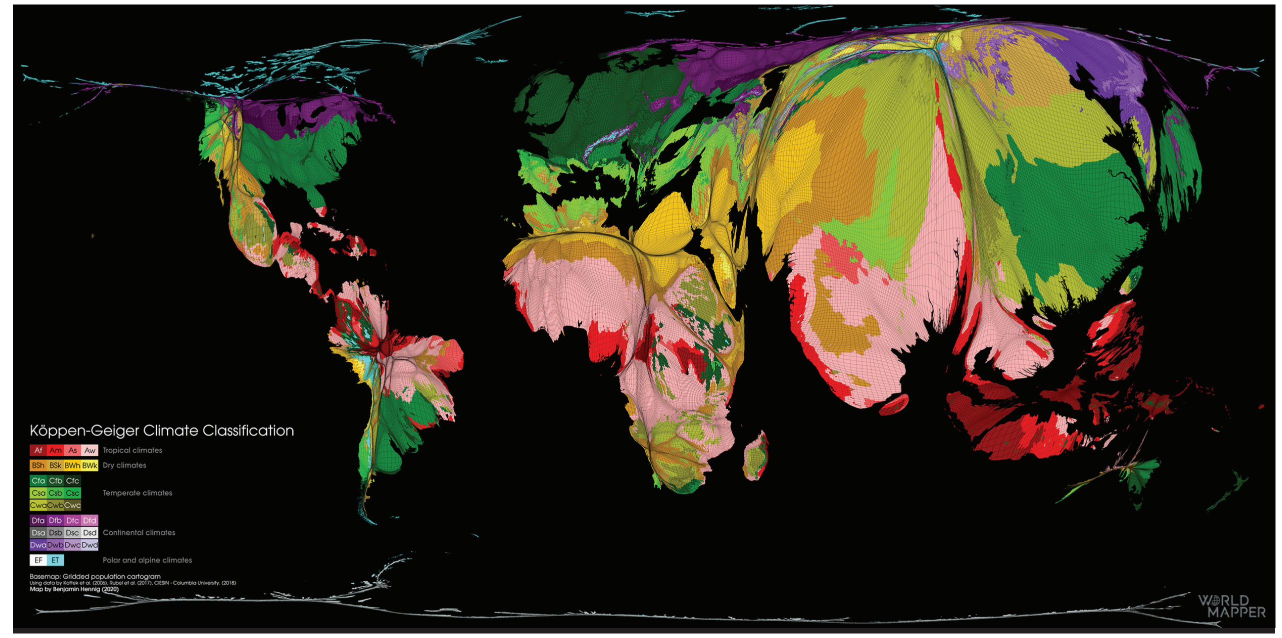
The Köppen-Geiger classification system is most commonly used to categorise climates, grouping the world into five main climate groups – Tropical, Dry, Temperate, Continental and Polar. Tropical climates will vary little throughout the year, with high rainfall, humidity, and temperatures between 25–35 °C. Dry climates occur on the edge of the Hadley cell when dry air is descending and have large diurnal temperature ranges. Temperate climates lie in the Ferrel cell – their characteristics vary significantly, though all are seasonal. Continental climates are found in the middle of large land masses, far from the moderating effects of oceans – they have large annual and diurnal temperature changes and low rainfall. Finally, Polar climates are never warm, but can also be extremely dry.

Misconception

Everywhere is the same as here.

The climate in any given place is determined by a combination of many factors. A particularly striking difference between our climate and others nearer the Equator is that they have little or no seasonal variation. The seasons are a consequence of the movement of the Earth around the Sun and the tilt of its axis. The further you are from the Equator, the greater the seasonal variation in energy received from the Sun and as a result the greater the seasonal variation in climate, although proximity to an ocean also has a significant impact. These differences are often expressed in climate graphs; a place like Singapore with a Tropical climate has no significant variation in temperature or rainfall throughout the year, whereas somewhere in northern Europe (about 65° North) might see temperatures range from −20 °C to +20 °C, and experience a wet winter and dry summer.

The Köppen-Geiger groups are in turn split into sub-categories. The Tropical climate zone, for instance, is divided into rainforest (wet all the time), monsoon (wet, and even wetter) and savanna (wet with dry season). Each sub-climate shares broad characteristics with the primary climate but has distinct features that define it.



A world map showing the countries classified according to Köppen-Geiger classification but resized according to the population size of the country. This clearly shows which climate types support the greatest populations.

Unsurprisingly, climate zones correspond to the distribution of biomes and the habitats, vegetation and species they contain because temperature and the availability of water define the primary productive capacity of an ecosystem and the plant and animal species that are able to survive.

Modelling allows us to project how global climate zones will change. Because each zone is defined by a combination of meteorological and geographical variables it is possible to predict how the distribution and extent of climate zones will evolve as the global climate changes over coming decades and centuries. **Figure 5.1** compares a map of present-day climate zones in Europe with a projection for 2070–2100 based on a climate change scenario that assumes 'business as usual' greenhouse gas emissions. This suggests the change in Europe will be widespread and complex, with impacts on both human populations and the natural world. As the climate changes, climate zones do not simply move northwards as they are influenced by so many other factors besides temperature. Oceanic climate zones (dark green) and humid-subtropical (light green) climate zones will dominate in this forecast and Mediterranean (beige/yellow) and desert (red) will become more prevalent.

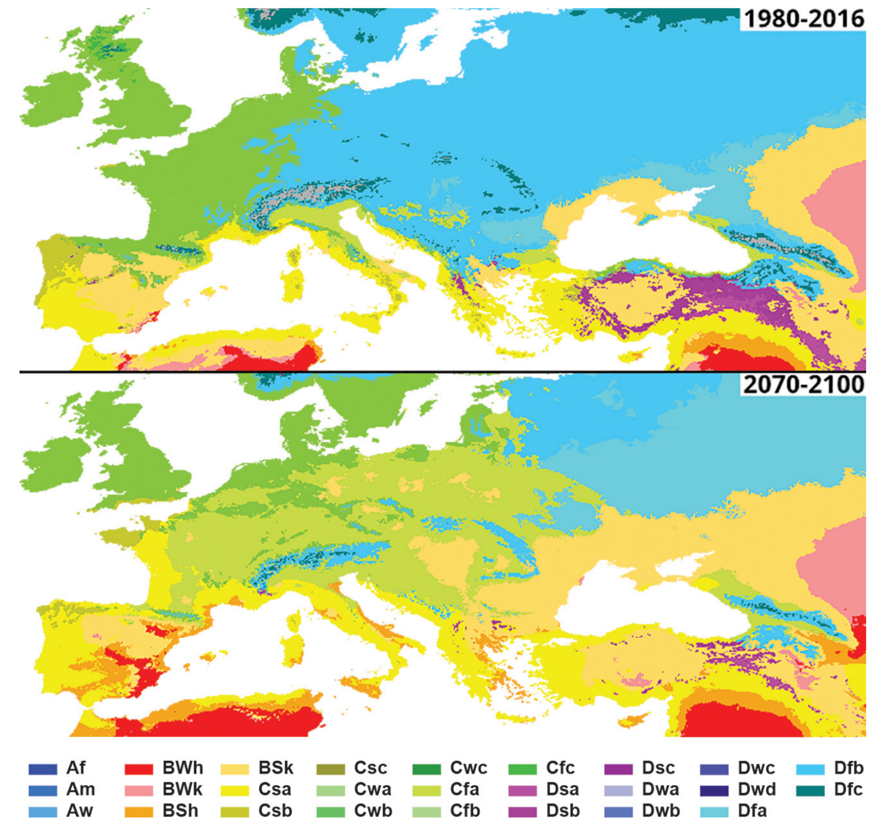


Figure 5.1

Misconception

Climate change means that the climate zones will shift towards the Poles – the UK will have a Mediterranean climate.

This misconception suggests that as temperatures rise, climate zones will simply move poleward to remain in their temperature zone. However, although climate zones will shift, their distribution is not solely determined by temperature but is affected by many other variables, not least latitude and therefore seasonality, topography, global atmospheric and oceanic circulation and distance to the ocean. Changes to climate zones are therefore complex.

Chapter 6
Past Climate Change

metlink.org/resource/6-past-climate-change/

- WEATHER AND CLIMATE
- ATMOSPHERIC AND OCEANIC CIRCULATION
- CLIMATE ZONES

Lesson overview: In the accompanying online lesson resources, we look at how global temperatures have changed over the last 400 000 years and investigate volcanoes and the Milankovitch cycles as the drivers of change, in preparation for a more detailed look at anthropogenic climate change in later lessons.

Skills: Graph interpretation and data visualisation | Thinking skills | Data extraction

We know about the past climate of Earth from instrumental records and paleoclimatology in which we reconstruct global climate from proxy variables including air trapped in ice bubbles and preserved organic remains. There are several major natural influences on the climate including the Milankovitch cycles, which describe the combined effect of changes to our planet's orbit around the Sun, volcanic activity, the Sun and continental drift. By understanding these, we are able to model past climates and improve our understanding of the Earth's climate system.

Learning objectives of online lesson resources:
- To be able to describe the major changes to temperature over long periods of time.
- To be able to explain why climate changes over time.

Thunk: Weather matters more than climate.

The Earth's climate varies naturally and continuously over long and short periods of time, responding slowly to the factors that control the climate system. At some points in the past, the Earth has been warmer than it currently is; at other points, it has been significantly colder.

Humans are now significantly altering the planet – physically, chemically and biologically, controlling the evolution of climate. 'Anthropocene' is the name of a proposed new section of the Earth's history where humans dominate. The precise start of the Anthropocene is a matter for debate.

There are several influences on the climate over long periods of time including Milankovitch cycles, volcanic activity, changes in the Sun and continental drift. Milankovitch cycles describe the regular and predictable variation in the Earth's orbital eccentricity (how circular the Earth's orbit around the Sun is), the tilt of the Earth's axis (obliquity) and axial wobble (precession).

Misconception

The Milankovitch cycles change the Earth's distance from the Sun.

The Milankovitch cycles do not change the average distance of the Earth from the Sun through the year. However, they do change the amount of solar energy received at different parts of the Earth's surface. Variations in the angle of the Earth's axis of rotation have an impact on the seasons – the greater the angle, the greater the seasonal variations in climate. Variations in the eccentricity of the Earth's orbit around the Sun have an impact on how close the Earth is to the Sun at different times of the year – at the moment, the Earth is closer to the Sun during Southern hemisphere summer. If ice which accumulates during the winter does not melt during the summer because of these factors (together with feedback mechanisms), then a glacial period can develop.

▲ *The temperature of the Earth over the past 2.6 million years*

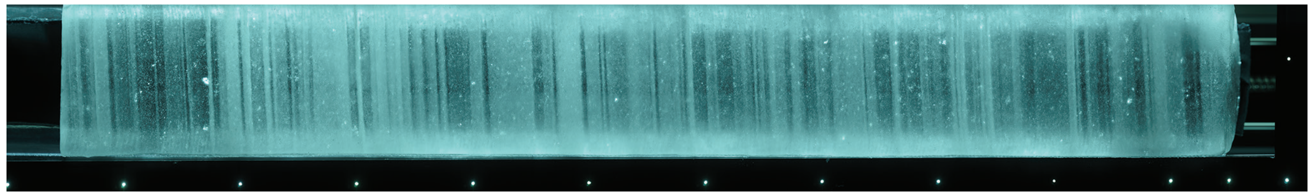
Volcanoes emit carbon dioxide (a greenhouse gas) and sulphur dioxide. Sulphur dioxide ejected into the stratosphere can form sulphate aerosols which can persist for several years, cooling the climate. Periods of intense volcanic activity have been associated with extreme changes to the Earth's climate and mass extinctions. Although some recent volcanic eruptions have had measurable cooling effects on the global climate, only supervolcanoes have long lasting climatic impacts.

Continental drift – the slow movement of the continental plates around the world – changes the distribution of land and water and consequently the response of the climate system to the Milankovitch cycles.

Misconception

We are currently not in an Ice Age.

There is often confusion between an Ice Age and a glacial period. An Ice Age is a period of geological time when there are ice sheets on the continents and poles of both hemispheres and alpine glaciers. The current Quaternary Ice Age began 34 million years ago. During an Ice Age there will be glacial periods in which ice extent grows and interglacial periods in which it retreats. The current interglacial period began 11 700 years ago.



▲ **Figure 6.1**

The longest instrumental temperature record is the Central England Temperature Record which starts in 1659. For longer paleoclimate data, proxy data from preserved pollen, shells and sediments are used. Bubbles of air trapped in ice have provided climate information for the past 800 000 years (**Figure 6.1**). Information from preserved tree rings (**Figure 6.2**) can tell us about temperature and precipitation at the time when the tree was growing.

▲ **Figure 6.2**

There is no scientific doubt that the driving cause of current climate change is the impact of humans on the climate system. If there had been no anthropogenic impact on greenhouse gas concentrations in the atmosphere, and the natural carbon dioxide levels had got down to 240 ppm, then the Earth would be cooling to a glacial phase within the next 1500 years. Otherwise, the next glacial would be in 50 000 years. However, with greenhouse gas levels as they currently are, without any further emissions, it will be at least 100 000 years before the Earth experiences another glacial period.

Misconception

Don't changes in temperature cause changes in carbon dioxide?

Data from Antarctic ice, such as the Vostok ice core, show that carbon dioxide (CO_2) levels in the atmosphere and atmospheric temperatures fluctuate roughly together. The initial changes in temperature during interglacial periods are explained by the Milankovitch cycles. As ocean temperatures start to rise, the solubility of CO_2 in water decreases and so the oceans release CO_2 into the atmosphere. In turn, this release amplifies the warming trend, leading to yet more CO_2 being released. This positive feedback is necessary to trigger the shifts between glacials and interglacials as the effect of the Milankovitch cycles alone is too weak. Additional positive feedbacks which play an important role in this process include other greenhouse gases and changes in ice and vegetation patterns. The increase in carbon dioxide lags behind the increase in temperatures. In much more recent times, changes in carbon dioxide concentrations in the atmosphere have preceded temperature increases.

Chapter 7
Air Masses

metlink.org/resource/7-air-masses/

- WEATHER AND CLIMATE
- ATMOSPHERIC AND OCEANIC CIRCULATION
- CLIMATE ZONES

Lesson overview: In the accompanying online lesson resources, we investigate the characteristics of the major air masses which can affect the British Isles and introduce wind roses to investigate common wind directions and associated air masses.

Skills: Information extraction and synthesis | Drawing compass rose diagrams | Analysis and interpretation

Air masses are large volumes of air that have relatively uniform characteristics and can extend over hundreds of miles. Classified according to the region in which they formed and the path they take to reach us, air masses strongly influence the weather we experience in the UK. Air masses that affect the UK are predominantly Polar maritime and Tropical maritime but also Polar continental, Tropical continental and Arctic maritime. The source regions of air masses are the high pressure regions associated with the Global Atmospheric Circulation. One air mass brings different weather to different parts of the country, for instance warming as it travels southwards, or drying out as it progresses over land. The temperature and humidity characteristics of air masses will change with climate change.

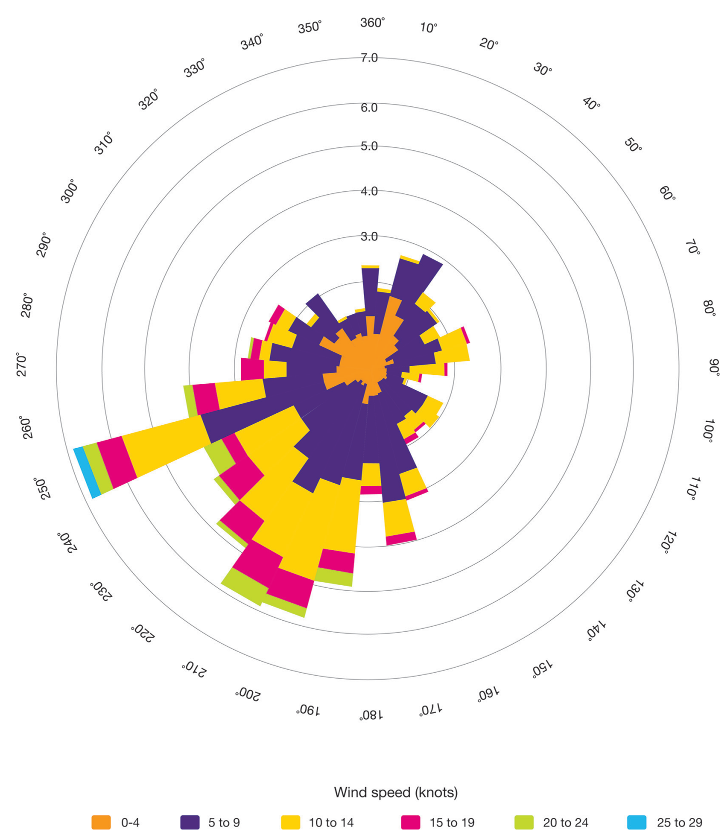
Learning objectives of online lesson resources:
- To be able to describe the five major air masses that affect the UK.
- To be able to draw and interpret a wind rose diagram.
- To be able to describe and explain the weather associated with different air masses and how they affect day-to-day life in the UK.

Thunk: Where in the UK is there most weather?

Air masses are classified according to the region in which they formed and the path they took to the point of observation. In general, they form in the semi-permanent areas of high pressure associated with the global atmospheric circulation in the Sub-Tropics and Polar regions.

As an air mass passes over the Earth's surface its characteristics are modified. Warm/hot land or warm water will increase its temperature, whereas cool/cold land or water will decrease it. Air passing over water will pick up humidity. Cloud evaporates in air that is getting warmer but forms in air that is cooling.

▶ *A wind rose from Heathrow Airport, close to London, showing predominant returning Polar maritime and Tropical maritime air masses.*



There are six air masses that affect the weather of the British Isles: Polar maritime, Polar continental, Tropical maritime, Tropical continental, returning Polar maritime and Arctic maritime. Maritime indicates the air mass has predominantly passed over water and continental indicates air that has predominantly passed over land before reaching the UK. The most common air masses in the UK are Polar maritime (arriving from the north-west), returning Polar maritime (Polar maritime air that has changed direction over the Atlantic Ocean to reach us from the west or even slightly south of west) and Tropical maritime (arriving from the south-west).

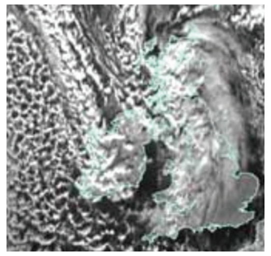
Each air mass has specific characteristics and brings different weather to different parts of the country.

Misconception

The south-west of the UK always gets Tropical maritime air masses.

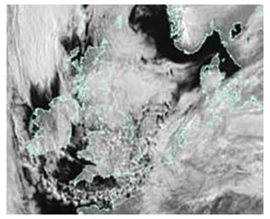
Although the prevailing wind direction across the UK is south of westerly (due to the Ferrel cell's westerlies), air masses can arrive in the UK from all directions and normally cover most, if not all, of the country (unless a front is present). Although a Tropical maritime air mass may reach the south-west *first*, such an air mass would go on to cover the whole of the UK. However, passing over land will modify the characteristics of the air mass – for Tropical maritime air, any rainfall is likely to be deposited on the south and west leaving much drier air further east. Similarly, a Polar continental air mass will affect the whole country but will bring wetter and colder weather to the north-east than it will to the south-west.

Polar maritime air originates north-west of the British Isles. It warms as it passes over the Atlantic Ocean, becoming more humid and tending to rise convectively creating puffy isolated cumulus clouds and rainfall over the sea (**Figure 7.1**). This rainfall is enhanced when the wind is forced to rise over the western side of the British Isles.



▲ Figure 7.1

Polar continental air typically originates over Siberia, warming as it moves towards the south-west. It is very dry as it has passed over land. Cloud-free as it passes over Scandinavia (**Figure 7.2**), cloud forms over the North Sea as it progressively accumulates moisture, leading to precipitation over the east coast of the British Isles. In winter, the precipitation is frequently snow. An example of this was the 'Beast from the East' which, combined with Storm Emma, brought widespread snow in February/March 2018.



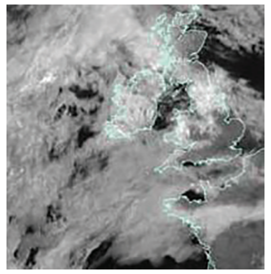
▲ Figure 7.2

Tropical maritime air cools as it moves northwards from its origin in the high pressure found under descending air at the poleward edge of the Hadley cell – typically the Azores High. Convection (rising air leading to cumulus clouds and potential rainfall) is suppressed in the cooling air but as the air cools water may condense to form flat, uniform stratus cloud (**Figure 7.3**) – the grey skies so well-known in the UK, and with them a persistent drizzle.

Tropical continental air flows up from high pressure air over the Sahara, sometimes bringing dust with it. It is the warmest and driest air mass to affect the UK, producing clear skies and high temperatures, with the possibility of localised thunderstorms.

Arctic maritime air moves directly southwards from the North Pole and is colder than Polar air, gaining enough moisture from the Arctic Ocean to bring sleet or snow to north-facing coasts and hills (particularly in the north of the UK). Inland, this air mass generally causes isolated snow showers.

Both Tropical continental and Arctic maritime air masses rarely affect the British Isles. The effects of any air mass will vary seasonally; the temperature of Polar continental air arriving from Siberia, for instance, is much lower in January than it is in July. A Polar maritime air mass will always be colder than a Tropical maritime air mass.



▲ Figure 7.3

Misconception

We have Tropical air masses in summer and Polar in winter (which is why it is hot and cold at these times).

Although some air masses are more common at certain times of year – for example Arctic maritime is most common in winter and Tropical continental is most common in summer – the temperature change between seasons is caused predominantly by the changing levels of light and heat from the Sun.

As the climate changes in the coming decades, changes in the atmospheric and oceanic circulation, increasing global average temperature and changes in the patterns of precipitation, will cause the characteristics of air masses to change and, more critically, the frequency with which each air mass affects us.

When two differing air masses meet, they create a front. In the UK, the fronts associated with wet and stormy weather (caused by low pressure weather systems – depressions) typically form between Polar maritime and Tropical maritime air masses.

Chapter 8

Pressure and Winds

metlink.org/resource/8-pressure-and-wind/

- ATMOSPHERIC AND OCEANIC CIRCULATION
- CLIMATE ZONES
- AIR MASSES

Lesson overview: In the accompanying online lesson resources, we introduce air pressure, how differences in pressure can lead to air motion (wind) and how rising and sinking air can lead to low and high pressure respectively. We also introduce the Coriolis effect and demonstrate how it can lead to rotating weather systems.

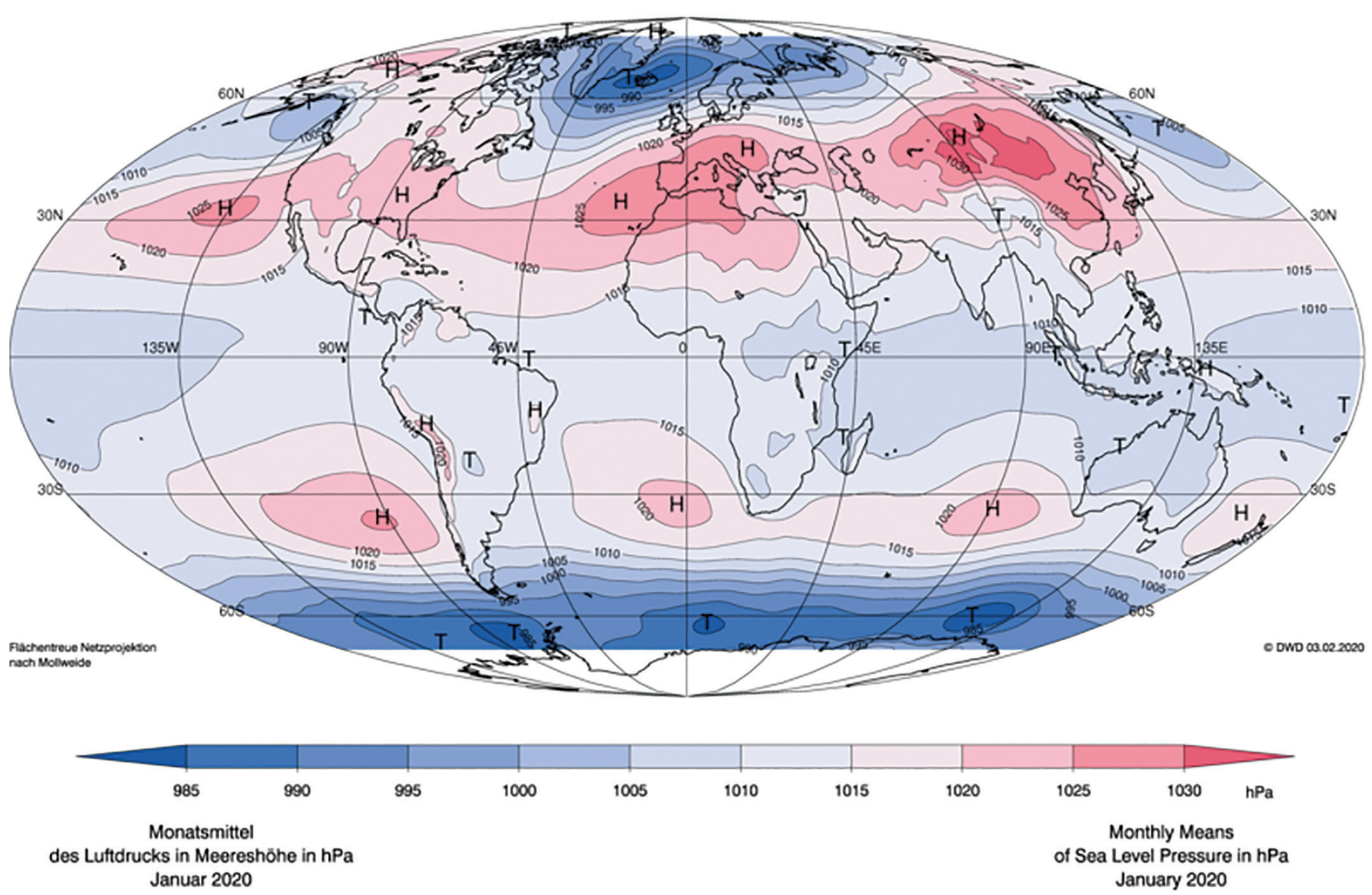
Skills: Data interpretation and analysis | Map interpretation | Reading synoptic charts

The action of the global atmospheric circulation cells, incoming and outgoing heat energy and the influence of upper-atmosphere winds, creates areas of ‘high’ and ‘low’ pressure across the world – places where there is more or less atmosphere above the surface of the Earth. Air is constantly pulled from areas of high pressure towards areas of low pressure, being deflected by the Coriolis effect as it does so, to create winds that circle around high/low pressure systems. Pressure is shown on synoptic weather maps using isobars – lines of equal pressure – and winds blow approximately along these lines.

Learning objectives of online lesson resources:
- To understand that air has a mass and exerts a pressure.
- To contrast high and low pressure.
- To be able to explain why winds are created and the factors that affect the wind.
- To be able to interpret weather charts.

Thunk: Where does the wind matter most?

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



▲ *Persistent global areas of high and low pressure that correspond to global atmospheric circulation cells.*

Atmospheric pressure is a consequence of the mass of air above the surface of the Earth at any given time and is presented in millibars (mbar) or hectoPascals (hPa) in the UK. Every square centimetre of ground at sea level has, on average, 1.03 Kg of air above it which equates to a mean sea level pressure of 1013.25 mbar.

Rising through the atmosphere, there is less air above and so atmospheric pressure decreases. At 1 km altitude, average air pressure has fallen to 899 mbar, at 5 km it is 540 mbar and at the highest point on Earth – the summit of Mount Everest at 8848 m altitude, it has dropped to 314 mbar.

On the Earth’s surface, areas of high and low pressure are caused by rising or falling air. Descending air hits the ground and spreads out, but friction slows it down – so the descending air accumulates behind it and the pressure builds. Where air is rising it cannot flow inwards near the surface as quickly as it rises, so pressure falls.

Misconception

‘High’ air pressure occurs because the air is pushing down on the surface.

This is a very common misconception, but when the pressure is high, do you actually notice the descending air slowing down as it hits you or the ground? The pressure change is actually caused by the accumulating air above. Consider the eye of a Tropical cyclone – the eye is clear because the air here is descending, but the surface air pressure is very low because it is part of a much larger system which has removed air from the area.

Some areas of high and low pressure are persistent as they are associated with the Global Atmospheric Circulation. Large land and ocean masses have a significant influence on the pressure pattern.

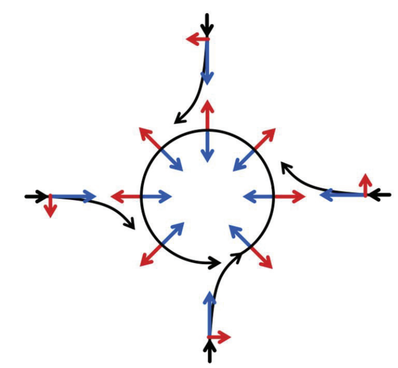
Pressure is shown on weather maps using isobars – lines that connect areas of equal pressure on the surface of the Earth – and the symbols H for high pressure and L for low pressure. These are synoptic charts and typically also indicate fronts between air masses, using blue triangles along the line of a front to indicate a cold air mass behind it and red semi-circles to indicate a warm air mass behind the front.

Air is pulled from areas of high pressure to areas of low pressure. On a synoptic chart, the bigger the pressure gradient, the closer the spacing of the isobars and the stronger the wind.

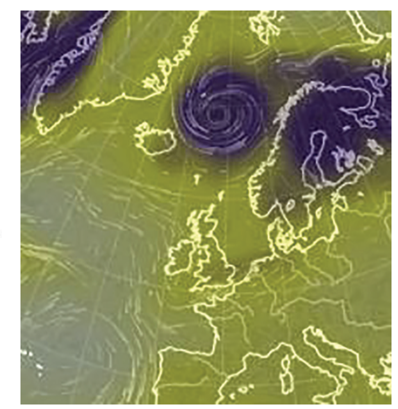
Misconception

The wind blows directly from ‘high’ to ‘low’.

Winds do not blow directly from high to low pressure because of the Coriolis effect. In the Northern Hemisphere the Coriolis force will deflect winds to the right and in the Southern Hemisphere to the left. Using the Northern Hemisphere as an example, imagine an area of low pressure. Air is flowing in towards the low pressure from all directions but is deflected to the right by the Coriolis effect. This creates an anticlockwise rotation – at all points around the centre of the Low, the pressure force pulling the wind inwards (**Figure 8.1**: blue arrows) is balanced by the Coriolis force pulling the wind to the right (**Figure 8.1**: red arrows). Similarly, if air is flowing outwards from a high pressure area it is deflected to the right and creates a clockwise rotation.



▲ **Figure 8.1**



▲ **Figure 8.2**

On the synoptic chart this means that winds do not blow in a straight line between areas of high and low pressure but tend to blow along the isobars around these areas. **Figure 8.2** shows a low pressure area (purple) with wind (white lines) blowing around it in an anticlockwise direction.

In the UK, we are expecting the wind speeds associated with low pressure systems to increase as the climate changes.

Misconception

The Coriolis effect makes water going down a plughole rotate in a different direction in the Northern/ Southern Hemispheres.

A persistent myth which is untrue! The direction in which the vortex forms in water as it goes down a plughole is determined by the way that the plug is removed and/or the shape of the bowl from which the water is draining, unless the experiment is performed in extremely strictly controlled circumstances. The plughole is simply too small. In addition, no pressure vortices are seen within 5 degrees north or south of the Equator – which is why no Tropical cyclones are found there – so anyone demonstrating plug hole vortices at the Equator is bluffing.

Chapter 9
Water in the Atmosphere

metlink.org/resource/9-water-in-the-atmosphere/

- CLIMATE ZONES
- AIR MASSES
- PRESSURE AND WIND

Lesson overview: In the accompanying online lesson resources, we focus on cloud formation due to convection, relief and frontal uplift.

Skills: Interpreting numerical data | Extracting data from media | Describing and explaining | Interpreting map data | Diagrams

The atmosphere is one of the smallest reservoirs of water in the hydrosphere. Clouds form when air is cooled. Air can cool due to convection, when air is heated from below and rises, or when air is forced to rise at a front between two air masses. When air is forced to rise over hills and mountains, cloud formation is enhanced. Climate change will intensify the water cycle, increasing the amount of water vapour in the atmosphere. As water vapour is a greenhouse gas this creates a positive feedback loop, amplifying climate change.

Learning objectives of online lesson resources:
- To understand why clouds form in the atmosphere.
- To be able to explain two ways in which clouds form.

Thunk: Is a river an ex-cloud?

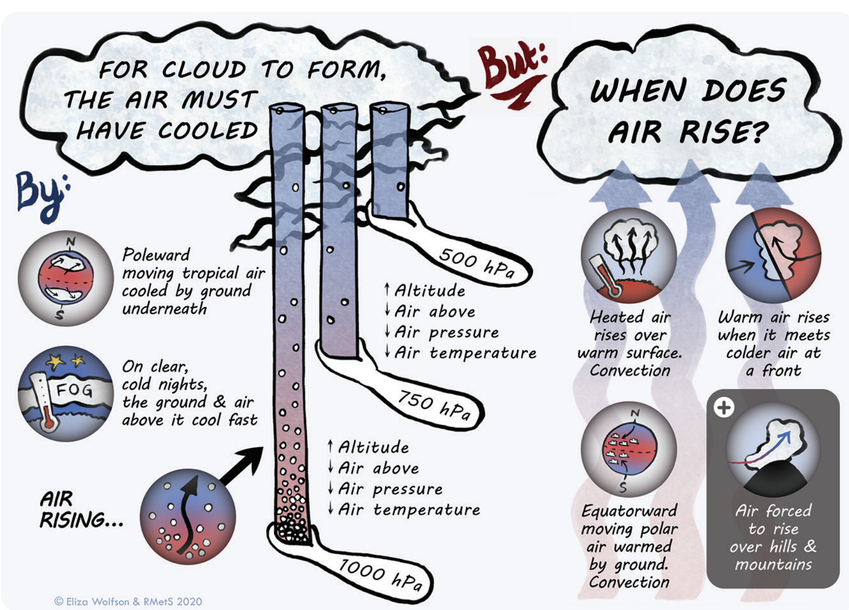
The atmosphere is an extremely small reservoir in the water cycle, holding only 0.001% or around 12 700 km³ of water. If all this water were condensed, it would form a 2.5 cm deep layer over the surface of the Earth. A typical fluffy cumulus cloud 1 km³ in size contains about 550 tonnes of water. The amount of water in the atmosphere is determined by the balance between evaporation, which changes water from liquid water or ice to water vapour, and condensation, which changes it back to a liquid.

Misconception
Clouds are made of water vapour.

Water exists in three states – solid (ice), liquid and gas (water vapour). Water vapour is not visible – what we see in the atmosphere, whether it is a cloud or our breath on a cold day, is small droplets of liquid water. These will form around condensation nuclei and if they grow large enough, fall to the ground as precipitation.

For cloud to form, condensation must occur faster than evaporation. The rate of evaporation slows as the air cools, so for cloud to form, the air must be cooling. One way that air can cool is by rising. In the rising air, the pressure and therefore the temperature falls. At some height it is cold enough for cloud droplets to start forming. The cloud droplets grow and eventually fall as precipitation; rain, sleet, hail, snow, etc.

▶ *Cloud formation, and therefore precipitation, occurs when air cools. This can be due to several different mechanisms, not all of which are associated with rising air.*



Misconception
Air can 'hold' a certain amount of water vapour.

The concept of air acting like a sponge for water vapour is extremely common, but misleading. Water is continuously evaporating and condensing, at all temperatures. Although the rate of evaporation depends on temperature, the rate of condensation does not. As the temperature increases, the rate of evaporation increases. Conversely, when the temperature falls, the rate of evaporation falls and may reach the point at which more water is condensing than is evaporating – and cloud droplets and/or dew will form. Water vapour condenses around condensation nuclei – small particles (e.g. salt, pollen, soot) in the atmosphere. When the rate of evaporation equals the rate of condensation the air is saturated and there is 100% relative humidity.

There are several ways in which air can be forced to rise.

- At weather fronts: a front usually marks the boundary between warmer and cooler air masses. The warmer air will always rise over the colder air. This leads to frontal rainfall.
- On a clear, hot sunny day, some parts of the land surface may heat up more than others – maybe because of their aspect (facing the Sun) or the surface colour. The air in contact with the ground will be warmed in turn and subsequently rise. This gives convectional rainfall.
- Polar air: if air of polar origin is travelling south then it will gradually get warmer as it travels over increasingly warm land and sea. The air will eventually start rising, giving rise to puffy cumulus clouds – again, this gives convectional rainfall.

Misconception
Falling pressure is a useful indicator of rain.

Wet and stormy weather is produced by low-pressure systems (depressions) with the frontal formation of cloud and rain already described. Many simple weather gadgets therefore use falling pressure to predict rain. However, in the UK, a Polar maritime air mass will usually bring precipitation to the west coast and dry conditions to the east coast and a Polar continental air mass will usually bring precipitation to the east coast and dry conditions to the west coast. Therefore, wind direction can be a more accurate indicator of precipitation than pressure for many places.

Where air is converging, or coming together, at the ground (for example because of a sea breeze) then the air is squeezed together and forced to rise. Conversely, where the air high up is diverging (for example where the jet stream is slowing down) and spreading out, then air is drawn upwards from below.

If air is forced to rise because of the underlying orography (relief such as hills and mountains), then it may reach the temperature at which cloud droplets form. Frequently, orography just enhances the rising that is already occurring. This is why the wettest inhabited place in England is in Seathwaite (**Figure 9.1**) where rising Polar maritime air is pushed further upwards by the Cumbrian mountains. Annual rainfall at Seathwaite is 3552 mm, Crib Goch in Wales receives over 4600 mm and several places in India receive over 10 000 mm. There is less rainfall downwind of the hills or mountains – an area known as rain shadow clearly illustrated in **Figure 9.2**, which shows one day's accumulated rainfall over the UK on a day when Polar maritime air dominated.

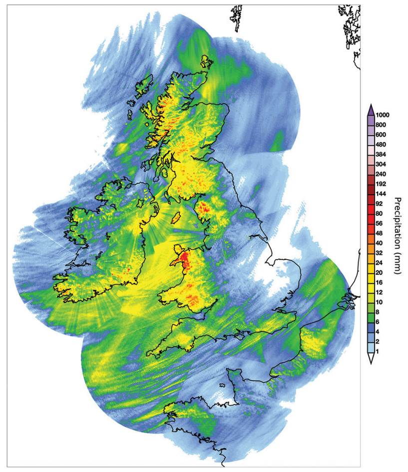
▲ Figure 9.1

However, cloud, and therefore rain, can form when the air is cooled by other mechanisms as well.

Air travelling north from the Tropics, particularly over the oceans, is cooled from below as it travels north. As this air is not rising, any cloud formed is of level sheets – stratus clouds, rather than puffy convective cumulus. The cloud droplets rarely get big enough to fall as anything heavier than drizzle.

The air can also be cooled from below in late autumn, winter and early spring when there are clear skies overnight – the Earth's surface loses heat to space, cooling and in turn cooling the air directly in contact with it. This can lead to fog or low cloud forming. This sort of cloud rarely produces anything more than a very light drizzle.

Climate change is projected to intensify the water cycle as higher global temperatures increase evaporation and the amount of water vapour in the atmosphere. Many of the Earth's natural systems, processes and populations (including humans) are sensitive to changes in the water cycle. Some areas will have more rainfall and some will have less. Water vapour is also, itself, a greenhouse gas and will act to further increase average global temperature, creating a positive feedback loop in which there is even more evaporation.



▲ Figure 9.2

Chapter 10

Polar Climate

metlink.org/resource/10-polar-climate/

- ATMOSPHERIC AND OCEANIC CIRCULATION
- CLIMATE ZONES
- PAST CLIMATE CHANGE

Lesson overview: In the accompanying online lesson resources, we investigate why polar climates are so extreme and how it can be too cold to snow in Antarctica.

Skills: Synthesis | Research/data presentation | Basic number skills | Interpreting data

The extremes of Polar weather – the lowest temperatures on Earth and little precipitation – vary significantly throughout the year. Antarctica has the harshest conditions, recording an annual mean low of nearly −60 °C due to its elevation and distance from the sea. Low levels of precipitation define Polar regions as deserts and it can be too dry to snow. The effects of climate change are amplified in these regions through feedback mechanisms which in turn affect global climate.

Learning objectives of online lesson resources:

- To understand why it is cold in Polar regions.
- To understand why our Polar regions are classified as deserts.
- To be able to calculate mean temperature and total precipitation and interpret a climate graph.

Thunk: Would you rather live somewhere with an extreme hot climate or an extreme cold climate?

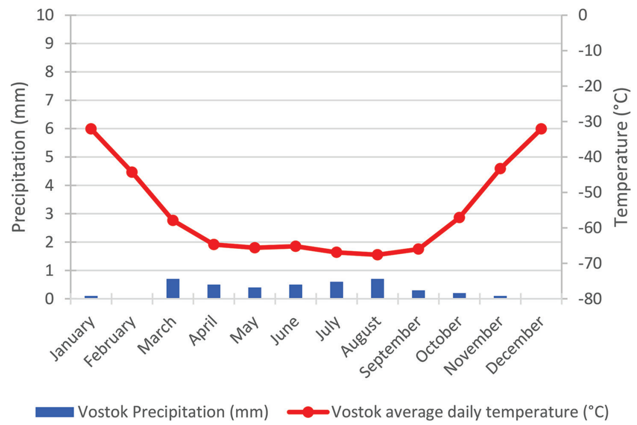
Polar weather is characterised by extremes of temperature, precipitation and seasonal variation that are a consequence of the significant variation in incoming energy from the Sun through the year due to the tilt of the Earth's axis.

Polar weather data is generally collected remotely using automated weather stations (**Figure 10.1**) and satellites.

Much of the Arctic region is covered by sea ice. It has an annual average temperature of −3.4 °C, with average monthly temperatures reaching a low of −24.2 °C in January and a high of 15.9 °C in July. Annual precipitation is 344 mm, with the wettest months being June to September.

The South Pole is in the centre of the continent of Antarctica, at an altitude of 2835 metres and around 1300 km from the moderating influence of ocean water. It has an average monthly temperature reaching of −59.8 °C in July and −28 °C in December. The coldest recorded temperature on Earth, −89.2 °C, was measured at the Russian Vostok station around 800 miles from the South Pole. The climate here is particularly cold (**Figure 10.2**) as it is both at high altitude (3489 m) and far from the moderating influence of the Antarctic Ocean.

▲ Figure 10.1



▲ Figure 10.2

In both polar regions, the local variations in daylight length are an important factor. At mid-summer, there is 24 hours of daylight everywhere within the Arctic or Antarctic circles. At the South or North Pole, the Sun is above the horizon for half the year, and below the horizon for the other half. However, although the Sun is visible, it is low in the sky and the energy received is spread over a large area – it does not have the capacity to warm the surface much. In addition, the Earth loses heat to space, especially during the long polar night, as there are few clouds to insulate the ground.

Low levels of cloud and precipitation in polar regions are a consequence of their location under the descending air of the Polar cell in the Global Atmospheric Circulation – surface pressure is high. In addition, low temperatures limit evaporation or sublimation (where ice changes directly into water vapour, without first becoming a liquid) and this lowers the moisture content of the atmosphere and inhibits the formation of clouds, which in turn lowers the probability of snowfall. It is too dry for snow (**Figure 10.1**).

Misconception

It snows a lot in Antarctica.

Antarctica has extremely low levels of precipitation and is classed as a desert. At the South Pole, annual precipitation is 2.3 mm, with no significant variation between the months. There is greater snowfall near the coastline, particularly around the Antarctic Peninsula.

The polar mass of cold, dry air is largely contained in the polar regions by the polar vortex.

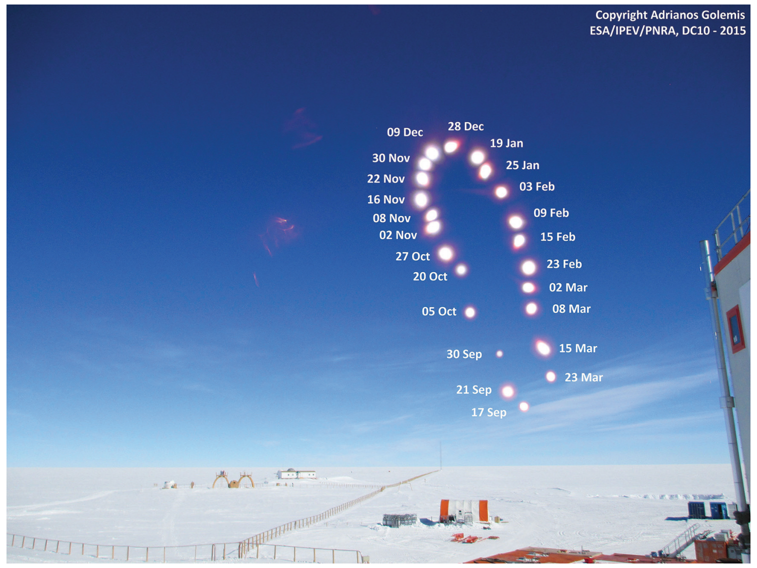
Misconception

Media misuse of the term 'Polar vortex'.

The extreme cold of Polar winters is generally contained by the Polar vortex; an encircling stream of fast-moving air in the upper troposphere and stratosphere, over about 5000 m. When these jet streams are disrupted, the containment of the Polar air is weakened and may fail, allowing extremely cold Polar air to move southwards. In the UK this Polar air mass can bring snow if the UK is on the boundary between the Polar air and warmer mid-latitude air. Some weather reports, particularly in North America, incorrectly describe this Polar air mass as a Polar vortex. The Antarctic Polar vortex is stronger and more symmetrical than that in the Arctic, becoming disrupted less frequently.

Antarctic weather is also influenced by the hole in the ozone layer. This is a part of the stratosphere that blocks ultraviolet radiation from reaching the surface of the Earth. In the Antarctic spring, sunlight causes a reaction with ozone-depleting chemicals (chlorofluorocarbons or CFCs) that humans have released into the atmosphere.

Greenhouse gases in the troposphere have enhanced this process, through cooling the stratosphere. However, as ozone is itself a greenhouse gas, the ozone hole cools the stratosphere which enhances the polar vortex and even influences the global circulation and levels of rainfall all the way to the Tropics.



▲ *The position of the Sun at the same time of day over the Antarctic in summer.*

Climate change is generally occurring faster in polar regions due to Polar amplification – positive feedback mechanisms. For example, when sea ice melts exposing darker water, the albedo of the surface falls and the ocean absorbs more heat, which melts more ice, creating a positively reinforced loop. The Arctic is warming faster than the Antarctic partly due to the hole in the ozone layer over Antarctica. As the Antarctic ozone hole slowly recovers, faster Antarctic warming can be expected.

Misconception

Melting sea ice in the Arctic leads to sea level rise.

Global sea levels are primarily rising for two reasons – the melting of ice on land and the heating of the water itself which causes it to expand slightly.

When sea ice melts it does not change the sea level – the water displaced by the ice is equal to the volume of liquid water created by the melting of the ice (something which is easily confirmed with a glass of water and a few ice cubes). However, when ice melts on land – for example when ice sheets in Greenland or Antarctica melt and meltwater flows into the sea – this does increase sea levels.

Between 1993–2010, sea levels rose 1.1 mm due to thermal expansion and 1.46 mm due to melting ice.

Chapter 11

Hot Deserts

metlink.org/resource/11-hot-deserts/

- CLIMATE ZONES
- PAST CLIMATE CHANGE
- POLAR CLIMATE

Lesson overview: In the accompanying online lesson resources, we look at the characteristics and locations of hot deserts and the adaptations of animals and vegetation found there.

Skills: Plotting climate graphs | Interpretation of photographs and maps | Synthesis of knowledge and understanding

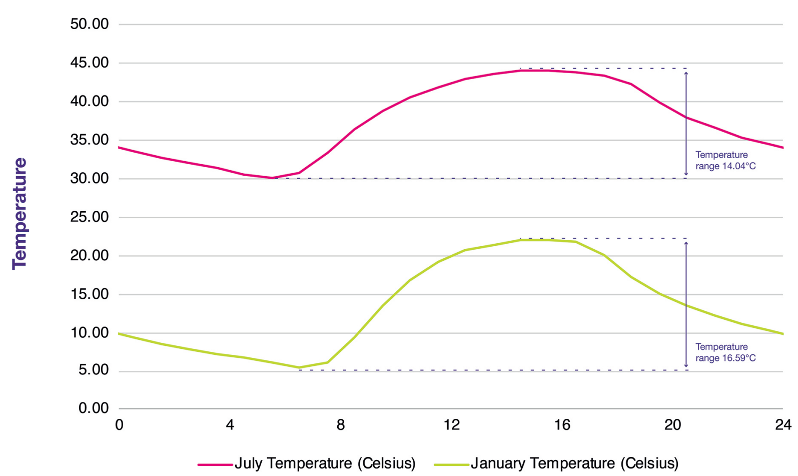
Hot deserts have less than 250 mm precipitation per year and daytime temperatures that may approach 50 °C. Hot deserts cover 14.2% of the Earth's surface, their distribution largely determined by the global atmospheric circulation. Physical factors such as altitude or latitude determine deserts with the most extreme values of precipitation/temperature. Their characteristics and distribution will change over long periods of time due to the Milankovitch cycles and Continental drift. Climate change is projected to have complex effects and the size of arid regions is expected to grow. The plants and animals that live in the deserts around the world have adapted to cope with the extreme climate.

Learning objectives of online lesson resources:

- To be able to describe the characteristics and location of at least one hot desert.
- To understand why hot deserts are hot and dry.
- To be able to draw and interpret a climate graph of a hot desert.
- To understand animal and plant adaptations to the hot desert climate.

Thunk: Is someone in Africa seeing the same sky as someone in Antarctica?

Deserts are second only to Polar climates in geographical extent, covering 14.2% of the Earth's land surface. The Köppen–Geiger climate classification system defines two types of desert – hot and cold. Although both have extremely low levels of precipitation, less than 250 mm/year, a hot desert will reach significantly higher daytime temperatures (up to around 50 °C). Night-time temperatures drop quickly even in hot deserts as the clear dry air allows heat from the ground to escape into space, creating a regular daily cycle (**Figure 11.1**).



▲ **Figure 11.1**

Misconception

Desert temperatures drop below 0 °C at night.

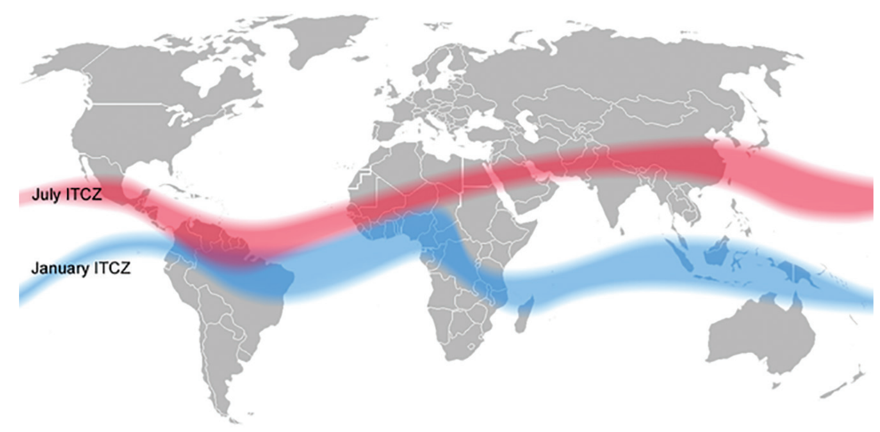
A typical daily surface air temperature range in a hot desert is between 10 and 20 °C, with both maximum and minimum temperatures varying through the year (**Figure 11.1** shows mean data for a location in the Sahara desert in Southern Algeria). Land surface temperatures can vary far more – and a ground frost could be experienced even if air temperatures have not dropped below freezing.

The highest official land temperature, 56.7 °C, was recorded in the Mojave Desert in California.

The distribution of hot deserts relates to the atmospheric circulation cells. Hot deserts are found where air is descending at the poleward edge of the Hadley cells. In the descending air at the edges of the Hadley cells, the air pressure rises (as there is progressively more air above) and so the air warms, evaporation increases and skies are clear. This allows the Sun's light and heat to reach the ground without being reflected, scattered or absorbed. In the Sub-Tropics, the Sun is high in the sky which also promotes high temperatures. Precipitation is unlikely in largely cloud-free skies.

▲ *The Atacama desert is the driest hot desert in the world. However, during El Niño events the normally cold waters of the eastern South Pacific warm, resulting in evaporation and subsequent rainfall. Seeds that have remained dormant for years or even decades, such as these pink Malva flowers, burst into life.*

However, the Inter Tropical Convergence Zone (ITCZ) moves seasonally (**Figure 11.2**). Those deserts which remain in the zone of dry air for the whole year have the lowest rainfall, whereas those which are sometimes beneath the descending air, and sometimes not, may experience some seasonal rainfall. Cold ocean currents also affect some deserts, such as the north flowing Humbolt current near the Atacama Desert in Chile. Little water evaporates from the cold surface water and, in addition, the relatively cold air temperatures above the cold water cause a temperature inversion in the atmosphere (colder air is found below warmer air) which further suppresses convection and therefore rainfall.



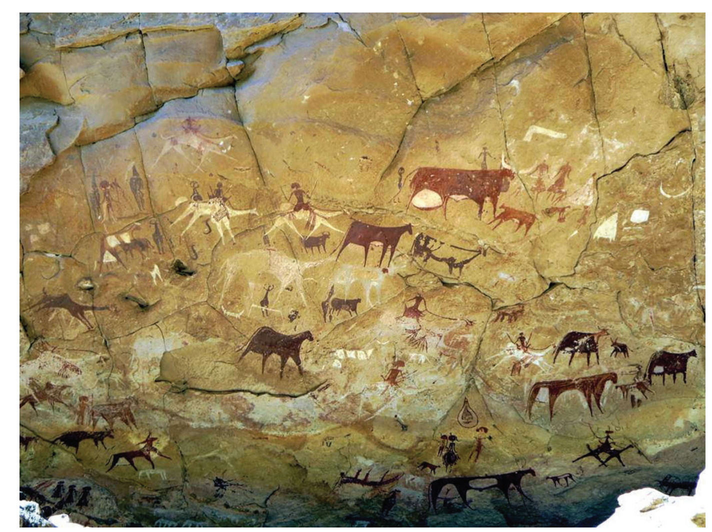
▲ **Figure 11.2**

Misconception

Deserts are always sandy.

Deserts will always have low levels of precipitation, but they do not have to be sandy. They may be stony or rocky and may have a variety of desert vegetation.

The distribution of hot deserts is not fixed and changes with the Milankovitch cycles – for example, when the tilt of the Earth's axis increases, the annual variation in the latitude of the sinking edges of the Hadley cells is greater. Between 12 000 and 7000 years ago such a shift led to increased precipitation in the Sahara, enabling shrub-land to develop and support a human population. As the ITCZ shifted back towards the equator around 5000 years ago, the area moved to its present climate. The changing vegetation, and related human activity, is captured in preserved rock art (**Figure 11.3**).



▲ **Figure 11.3**

Climate change is projected to broaden the Hadley cell and narrow the zone of rainfall associated with the ITCZ. The size of arid regions is expected to grow, enhanced by human activities which change the albedo of land and deplete water reserves and vegetation. The climate effects of desertification are complex and interrelated. For example, although decreased vegetative land cover reduces evapotranspiration and makes cloud formation and precipitation less likely, as vegetation is lost, sand and dust is blown away creating aerosols which reflect the Sun's light and lower local temperatures. The resilience of natural vegetation to changes in climate and the ability of ecosystems to adapt is reduced by human activities.

Chapter 12

Changing Global Climate

metlink.org/resource/12-changing-global-climate/

- PAST CLIMATE CHANGE
- POLAR CLIMATE
- HOT DESERTS

Lesson overview: In the accompanying online lesson resources, we look at this historical relationship between carbon dioxide (CO_2) and global temperature and the greenhouse effect, before moving on to consider future greenhouse gas emission scenarios.

Skills: Sketching | Interpreting graphs | Synthesis of information

Greenhouse gases warm the Earth through intercepting the flow of heat from the Earth into space. The Intergovernmental Panel on Climate Change (IPCC) has co-ordinated research that shows unequivocally that global climate has changed as a result of the impact of humans on the concentration of greenhouse gases in the atmosphere and other aspects of the climate system and will continue to do so. Neither the magnitude nor impacts of climate change will be uniformly felt around the world. As our understanding of predicted impacts continues to improve, so does our ability to prepare for them. Uncertainty stems from several sources – the response of governments, human populations, complex interactions and feedback effects between different components of the climate system.

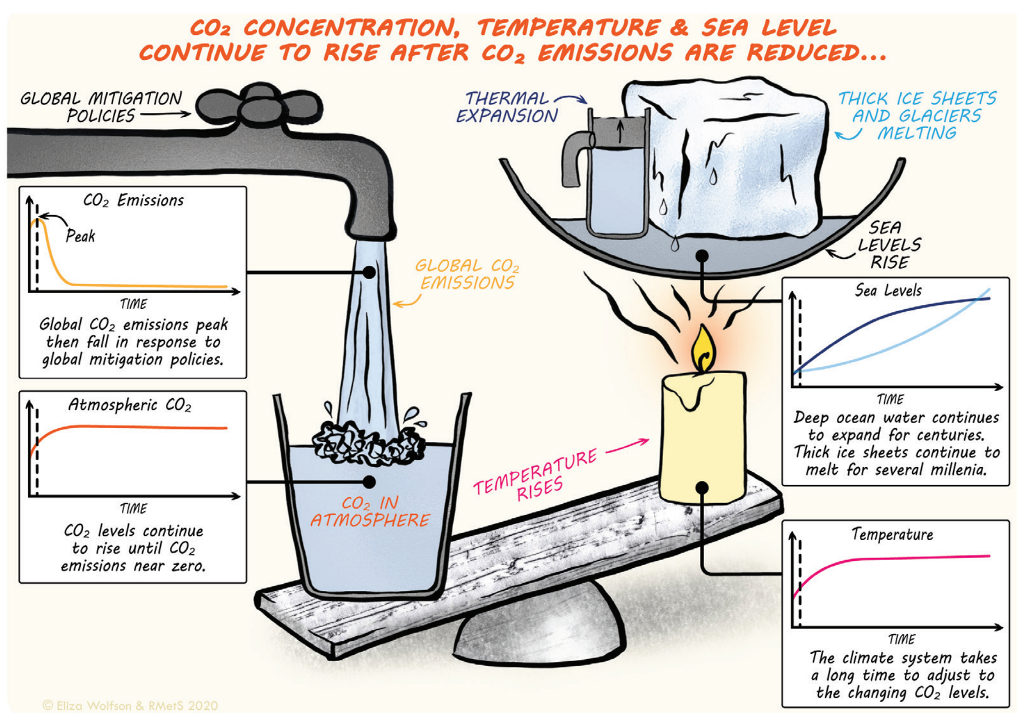
Learning objectives of online lesson resources:

- To be able to describe the major changes to temperature and CO_2 over short and longer periods of time.
- To be able to explain global warming and reasons why climate changes.
- To evaluate what might happen to CO_2 levels and temperature in the future.

Thunk: Is the sunlight ever yours?

The greenhouse effect is ultimately due to the fact that the Earth is much, much cooler than the Sun and so the energy we get from the Sun (light, ultraviolet light and short wavelength heat or infrared) is very different from the energy the Earth emits to space (long wavelength heat). Different atmospheric processes operate on different kinds of energy. When longwave infrared radiation interacts with a greenhouse gas (GHG) the gas absorbs the energy and then re-emits it back into the atmosphere (where it may be absorbed and re-emitted again by another GHG molecule) or to the surface. As a result, less heat escapes into space and the Earth is insulated. When greenhouse gas concentrations increase, for example through human activity, the greenhouse effect is enhanced and the Earth warms.

▶ *Even once global mitigation policies and economic forces lead to a reduction in greenhouse gas emissions, the concentration of greenhouse gases in the atmosphere will continue to rise until emissions have fallen to near zero. As a result, global temperatures and consequently sea levels, will continue to rise far into the future.*



Misconception

Everywhere gets warmer with climate change.

Warming has not and will not occur uniformly across the Earth for several reasons. Land warms faster than ocean and a complex interaction of global atmospheric and oceanic circulation, changes to ice and cloud cover, the hydrological cycle, latitude and topography create significant spatial and seasonal variations.

The impact of a GHG depends on the quantity of the gas in the atmosphere, the amount of warming per unit mass (its warming potential) and the length of time the gas persists in the atmosphere. For example, SF6, used in trainer soles amongst other places, persists for 800–3200 years in the atmosphere with a warming potential of 23 500 but only 10 000 tonnes are manufactured annually. In comparison, CO_2 persists for 300–1000 years with a warming potential of 1 and over 37 000 000 000 tonnes were emitted in 2019.

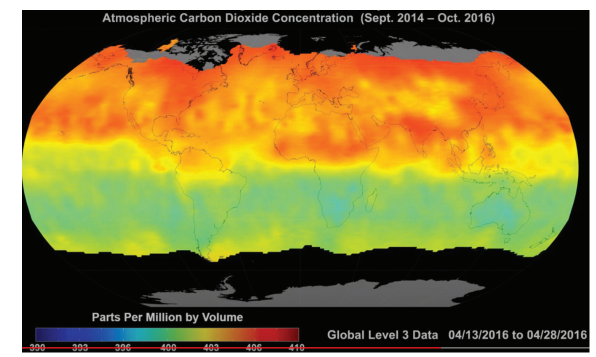
Misconception

Water vapour is the main greenhouse gas.

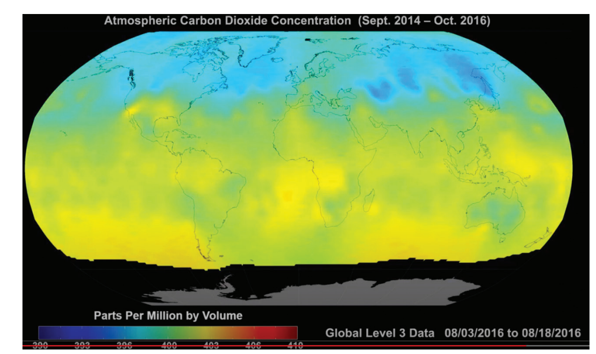
Water vapour is the most prevalent greenhouse gas, but the concentration of water vapour in the atmosphere is determined only by the temperature of the atmosphere. As the concentration of other greenhouse gases in the atmosphere increases, the temperature of the atmosphere warms and so the concentration of water vapour in the atmosphere also rises, enhancing the greenhouse effect. With every degree of air temperature, the atmosphere can retain around 7% more water vapour. Water vapour is a positive feedback mechanism rather than a driver of climate change itself.

Greenhouse gases are produced naturally through respiration and decomposition – the annual cycle of CO_2 in the atmosphere demonstrates the take-up of carbon as plants grow in the spring and summer, and the decomposition of leaves in the autumn and winter. The principal anthropogenic sources of greenhouse gases relate to the burning of fossil fuels and agriculture. Both the natural and human sources of greenhouse gases vary significantly with the seasons (**Figure 12.1**, April 2016, and **Figure 12.2**, August 2016).

The concentration of carbon dioxide, nitrous oxide and methane in the atmosphere have all shown steady growth since humans began to cultivate the land, with a dramatic and ongoing increase since the Industrial Revolution.



▲ **Figure 12.1**



▲ **Figure 12.2**

Misconception

The greenhouse effect is caused by humans.

Although greenhouse gases are a natural component of the atmosphere and the greenhouse effect is a natural phenomenon (without which the planet would be, on average, 33 °C colder), anthropogenic emissions are increasing concentrations of atmospheric greenhouse gases far quicker than natural processes can remove them.

The Earth is currently warming because an enhanced greenhouse effect means that the Earth is losing less heat to space than it is absorbing from the Sun.

The IPCC estimates that anthropogenic climate change has already increased global temperatures by around 1 °C (relative to pre-industrial conditions) and that temperatures are increasing at a rate of around 0.2 °C per decade.

The warming caused by anthropogenic GHG emissions is not immediate as the climate system takes time to respond. The lag of sea level change in response is hundreds of years, for instance, whereas the lag in the response from the cryosphere can be even longer.

The IPCC currently projects a warming of between 1.1–6.4 °C by 2100. The uncertainty in projections arises from several sources. Some of these relate to human populations – how the world will change in terms of economic development, population growth and action to reduce climate change, whereas others relate to the natural world – the impact of natural events (such as volcanic eruptions) and the response of aspects of the climate system that we do not fully understand (such as the role clouds will play). Climatologists determine the most likely changes to the climate by making an 'ensemble' of forecasts which consider many possible futures.

Chapter 13
UK Climate

metlink.org/resource/13-uk-climate/

- CLIMATE ZONES
- PAST CLIMATE CHANGE
- CHANGING GLOBAL CLIMATE

Lesson overview: In the accompanying online lesson resources, we revisit climate zones before exploring regional climate differences across the UK and the reasons for them.

Skills: Extracting data | Reading climate maps | Comparing and describing | Synthesis

Although the climate of the UK is largely Oceanic, some upland areas are Subpolar Oceanic and some small regions of Scotland are Subarctic or Tundra. Physical factors including prevailing winds, topography, altitude, latitude, distance to the sea, aspect and urbanisation are the primary factors influencing smaller scale regional variations within the UK's climate.

Learning objectives of online lesson resources:
- To understand how the UK's climate varies regionally.
- To be able to explain why the UK's climate varies regionally.
- To be able to relate the UK's climate to where you live.

Thunk: We don't get extreme weather in the UK.

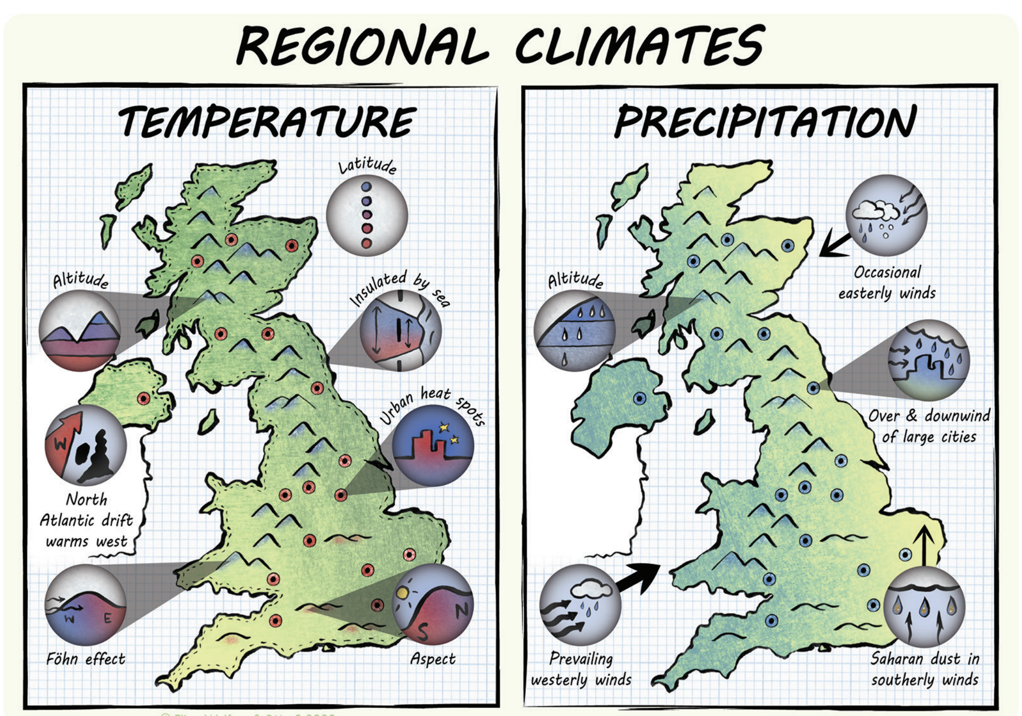
Misconception
We don't get extreme weather in the UK.

Although extreme weather, by definition, is uncommon in the UK, it does occur. Defined as any weather which is significantly different to normal weather and which occurs less than 10% of the time, extreme weather can occur over hours or weeks, for example flash flooding caused by heavy localised precipitation or a summer heatwave.

The UK has around 30 tornados each year and in 1981 had 104 in the space of 24 hours. UK tornados are generally small, although occasionally cause damage, as was the case in Birmingham in July 2005 when tornado damage cost £40 m.

Some of our most extreme weather events are associated with Sting jets – narrow areas of damaging high winds that can form near the centre of depressions (the Great Storm of 1987 being an exceptional example). The jet forms when descending cold air is cooled further by evaporation, accelerating its descent towards the ground.

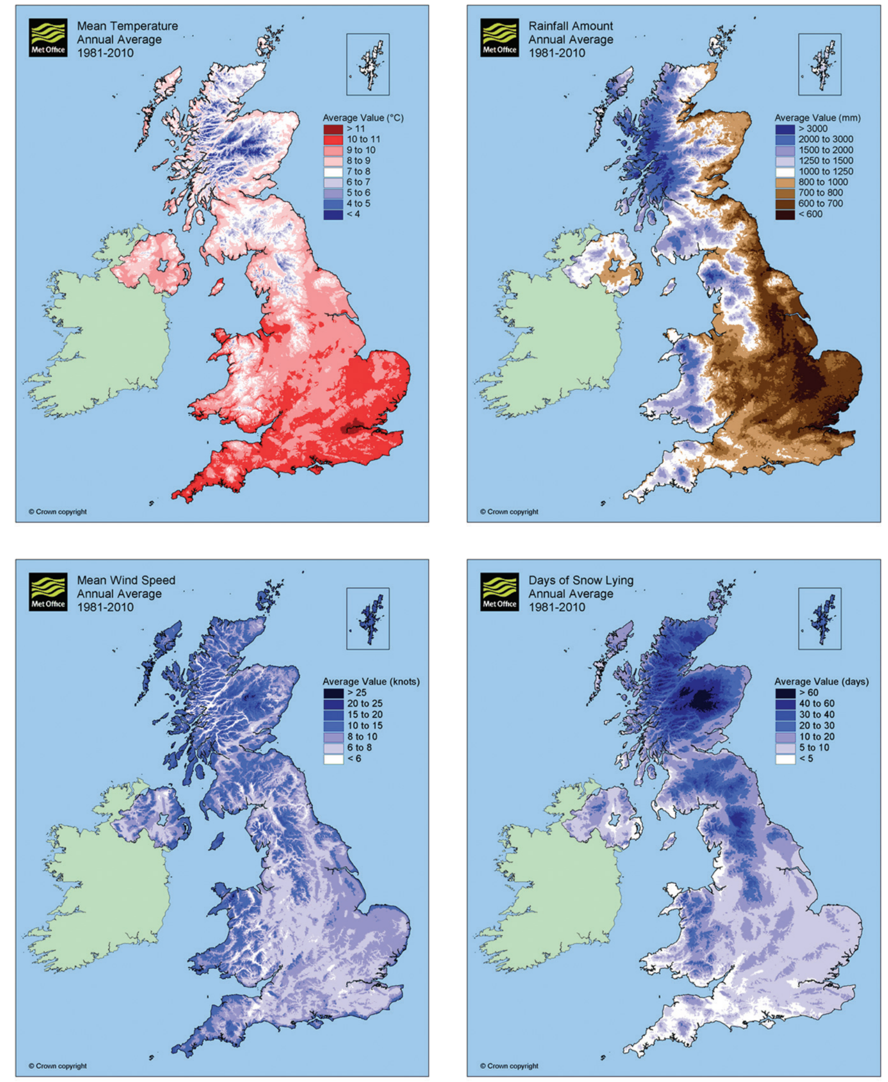
▶ Many factors such as latitude, altitude, proximity to the sea and aspect can have an impact on climate. However, in the UK, the location relative to the prevailing, westerly, winds also has a significant impact on both precipitation and, to a lesser extent, temperature.



The UK has four Köppen–Geiger climate types – Oceanic, Subpolar oceanic, Subarctic and Tundra. Most of the UK is Oceanic, with Subpolar oceanic restricted to upland areas in the Lake District, Pennines, Scottish Borders and the Highlands and Islands. Areas of Subarctic and Tundra are largely confined to the Cairngorms plateau.

However, within the dominant Oceanic climate type, there are distinct variations. The north-east has cold winters, cool summers and consistent rainfall throughout the year. The south-east has cold winters, warm summers and little rainfall. The south-west has mild winters, warm summers and regular rainfall, and the north-west has mild winters, cool summers and the highest rainfall, as shown by choropleth maps of the UK climate showing mean temperature, annual average rainfall, wind speed and 'days of snow lying' (**Figure 13.1**).

The distribution and characteristics of the regional variations in the UK's oceanic climate are the result of several factors.



▲ **Figure 13.1**

The prevailing wind direction determines the characteristics of the air masses as they arrive in each region (such as temperature and humidity), strongly influencing regional rainfall. Moist Polar maritime and returning Polar maritime air masses, for instance, are the primary source of moisture for the rainfall in the north-west and west of the UK.

Misconception
It rains more in the winter than it does in the summer.

Many parts of the UK have fairly consistent year-round rainfall as the prevailing wind direction does not change much with the seasons. However, depressions, which can bring rainfall to the whole of the UK, usually track further north in the summer than in the winter, as the Inter Tropical Convergence Zone (ITCZ) and so the whole global atmospheric circulation moves. In addition, depressions tend to be less active in the summer. As a result, there can be a summer dry season, particularly in the south-east of England.

The level of rainfall on the western side of the UK is also enhanced by the relief which encourages cloud formation and rainfall as moist maritime air is forced to rise over high ground in western areas. Rainfall on the west leads to rain shadow on the east of the country. In addition, the further air travels over land, the drier it gets.

The influence of the sea on the climate of the UK is clear given the dominance of the oceanic climate type. Heat capacity is a physical property of matter and describes the amount of energy needed to heat a substance. It takes just 1000 Joules to warm 1 kg of air by 1 °C but 4200 Joules to warm 1 kg of water. This is how the ocean moderates climate – it warms and cools more slowly than air. The closer you are to any large body of water, the smaller the daily and seasonal variation in climate – water is nature's storage heater!

The North Atlantic Drift (the poleward extension of the Gulf Stream) brings warm water to the UK, which further warms and moistens westerly winds and can increase temperatures by up to 5 °C in winter.

Urbanisation has a series of complex and interrelated effects that extend far beyond the urban areas themselves. The larger the urban area, the bigger the area it influences.

Chapter 14

Changing UK Climate

metlink.org/resource/14-changing-uk-climate/

- PAST CLIMATE CHANGE
- CHANGING GLOBAL CLIMATE
- UK CLIMATE

Lesson overview: In the accompanying online lesson resources, we use the Central England Temperature record to explore changing UK weather and look at the projected impacts of climate change on the UK.

Skills: Numerical skills | Interpreting line and bar graphs | Synthesis

The UK climate has always changed and in over recent decades has become warmer. Over the coming century it is projected to become warmer and wetter in winter and hotter and drier in summer. Although change is unlikely to be dramatic, its cumulative impact will be significant and will affect human populations, landscapes and the natural world. Adaptation and mitigation can help to ameliorate some of the negative impacts of our changing climate, although some populations, landscapes and ecosystems could be severely affected if the most extreme forecasts are realised.

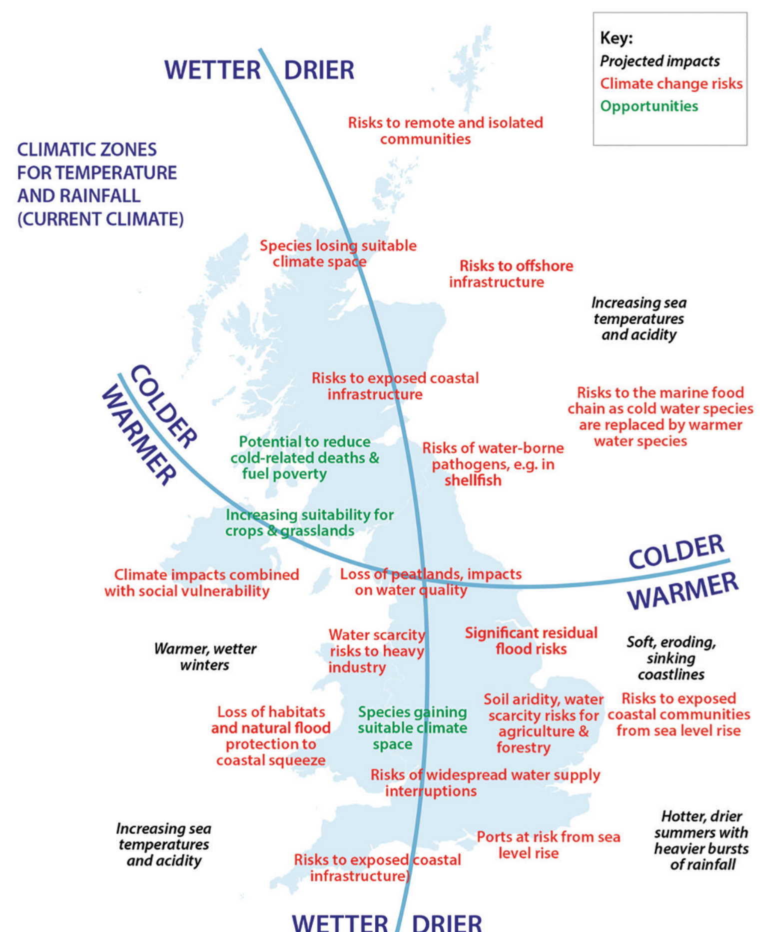
Learning outcomes of online lesson resources:
- To understand how climate (precipitation and temperature) has changed over time in the UK.
- To be able to classify the potential impacts of changing climate on the UK.

Thunk: Who owns the water in clouds?

The UK climate has always changed and there is unequivocal evidence that it will change rapidly during the 21st century as a consequence of past, current and future anthropogenic interventions in the climate system.

Over recent decades the UK climate has become warmer and extreme rainfall events have become more common. In the UK we have excellent historical climate data thanks to the Central England Temperature (CET) Record – the longest instrumental temperature record in the world – which relates to an area in England between Lancashire, London and Bristol. Beginning in 1659, the record becomes more detailed and precise as time passes.

▶ *The projected risks and opportunities of climate change in the UK*



The Met Office produces an annual 'State of the UK climate' report that summarises current weather and climate in a historical context as well as the UK Climate Projection (UKCP) report summarising current projections of how the climate will change. Over the next 80 years the UK climate will have warmer, drier summers and milder, wetter winters, as well as more extreme weather and an increased risk of flooding due to both increased rainfall and rising sea levels.

Misconception

The Gulf Stream will stop and we'll freeze.

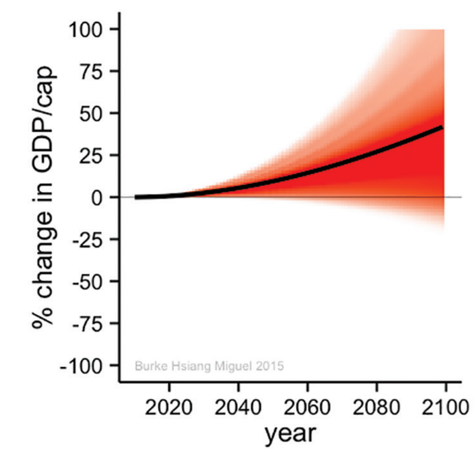
The Gulf Stream is a surface current in the North Atlantic driven by westerly winds. It brings warm water towards the UK and will not be significantly affected by climate change. However, its poleward extension, the North Atlantic Drift, is a component of the global oceanic thermohaline circulation and will be disrupted as the Arctic warms and ice melts. However, the cooling this will cause the UK is projected to be less than the warming caused by other changes to the climate system.

The impacts of the changing climate will not be evenly distributed either spatially or temporally and the effect on our daily lives, landscapes and natural world will be significant and profound.

Projected climate impacts in the UK relate to heat and air quality in urban areas, a loss of peatlands and species in upland areas, increased flooding and loss of fertile soil in rural areas, infrastructure and habitat loss in coastal areas and water borne pathogens in marine areas.
There are potential opportunities in increased farmland productivity, tourism and new species in marine areas leading to a projected increase in GPD per capita in the UK as a result of climate change in the 21st century (**Figure 14.1**) – in stark contrast with most of the rest of the world.

Some estimates suggest that the likelihood of climate change reducing the UK's GDP per capita by:

- more than 0%: 13%
- more than 10%: 6%
- more than 20%: 3%
- more than 50%: 0%



▲ **Figure 14.1**

Misconception

Climate change won't affect us.

Climate change is forecast to make the UK climate stormier and warmer in winter, and hotter and drier in summer, leading to winter flooding and summer drought. In addition, rising sea levels will have significant implications for coastal locations. The changes to our climate will not be distributed uniformly and will grow in magnitude as time passes. In addition, climate change in the rest of the world will have an impact on food supplies, trade, global security and migration which will have an indirect impact on the UK.

Mitigation or avoidance seeks to prevent or minimise changes by reducing anthropogenic influence as quickly as possible and in so doing limit the scale of change. Mitigating climate change can have associated benefits, such as improving air quality and reducing inequalities – both nationally and globally. Anthropogenic climate change cannot be fully avoided, however, as historic emissions are already causing the climate to warm and will continue to do so for many decades. Adaptation seeks to reduce the impacts of changes, principally on human populations. There are two strategies to reduce the effect of climate change in the UK: mitigation (such as moving to renewable energy sources, **Figure 14.2**) and adaptation (such as improved coastal defences, e.g. the Thames Barrier, **Figure 14.3**).

▲ **Figure 14.2**

▲ **Figure 14.3**

Chapter 15

The Climate Crisis

metlink.org/resource/15-climate-crisis/

- CHANGING GLOBAL CLIMATE
- UK CLIMATE
- CHANGING UK CLIMATE

Lesson overview: In the accompanying online lesson resources, we explore the language used to talk about climate change and look in detail at sea level rise, tipping points and UN climate negotiations.

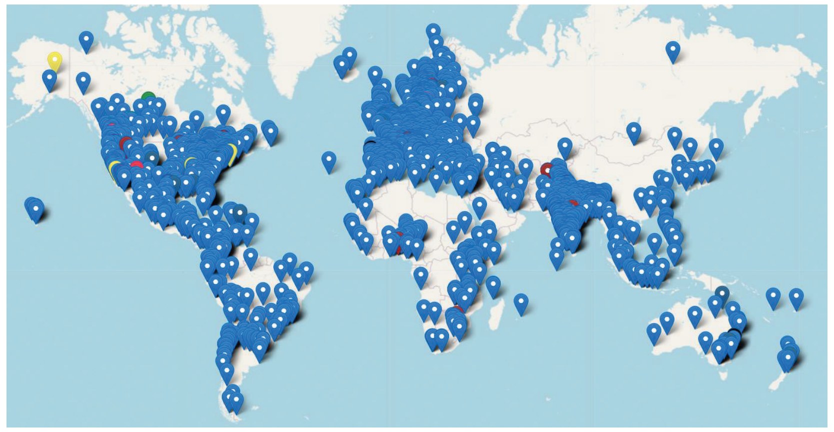
Skills: Interpreting line graphs | Data skills | Critical thinking | GIS

The climate crisis movement grew during 2018 with the formation of Extinction Rebellion and Greta Thunberg's School Strike for Climate. The language used by both politicians and the public to describe climate change was transformed over the space of a few months; Blue Planet 2 sensitised the UK public to the environmental impacts of our lives, Extinction Rebellion was formed to demand greater and faster action to reduce the impacts of climate change and Greta Thunberg's School Strike for Climate spread across the world. The discourse changed and legally binding commitments were demanded from national governments to reduce emissions and limit warming to 1.5 °C following an Intergovernmental Panel on Climate Change (IPCC)report.

Learning objectives of online lesson resources:
- To consider a range of facts and opinions on climate change.
- To decide if we are in a climate crisis.
- To understand what tipping points are and their impact on climate change.

Thunk: Is a student strike the same as a teacher strike?

The language used to describe our changing climate reflects a variety of socio-economic, political and scientific factors. In the 1970s and 1980s, we talked about global warming or global cooling, then, as our understanding of the complexity of processes and impacts grew, we used the term climate change. At COP21, held in Paris during 2015, the goal of limiting global temperature change to 1.5 °C was introduced as the potential impacts of climate change became clearer. The discourse changed to become about the climate crisis, the climate emergency or the climate catastrophe.



▲ Figure 15.1

In 2018 two important events and one report changed the discourse about climate change. The IPCC's 2018 Global Warming of 1.5 °C report made clear the significant difference in impacts between 2 °C and 1.5 °C warming. Extinction Rebellion was formed in May and Greta Thunberg began her School Strike for Climate in August. Both proved to be influential voices in changing perception, particularly amongst young people, of the impacts of climate change and the action that should be happening, as illustrated by **Figure 15.1** which shows the location of climate strikes across the world in 2019.

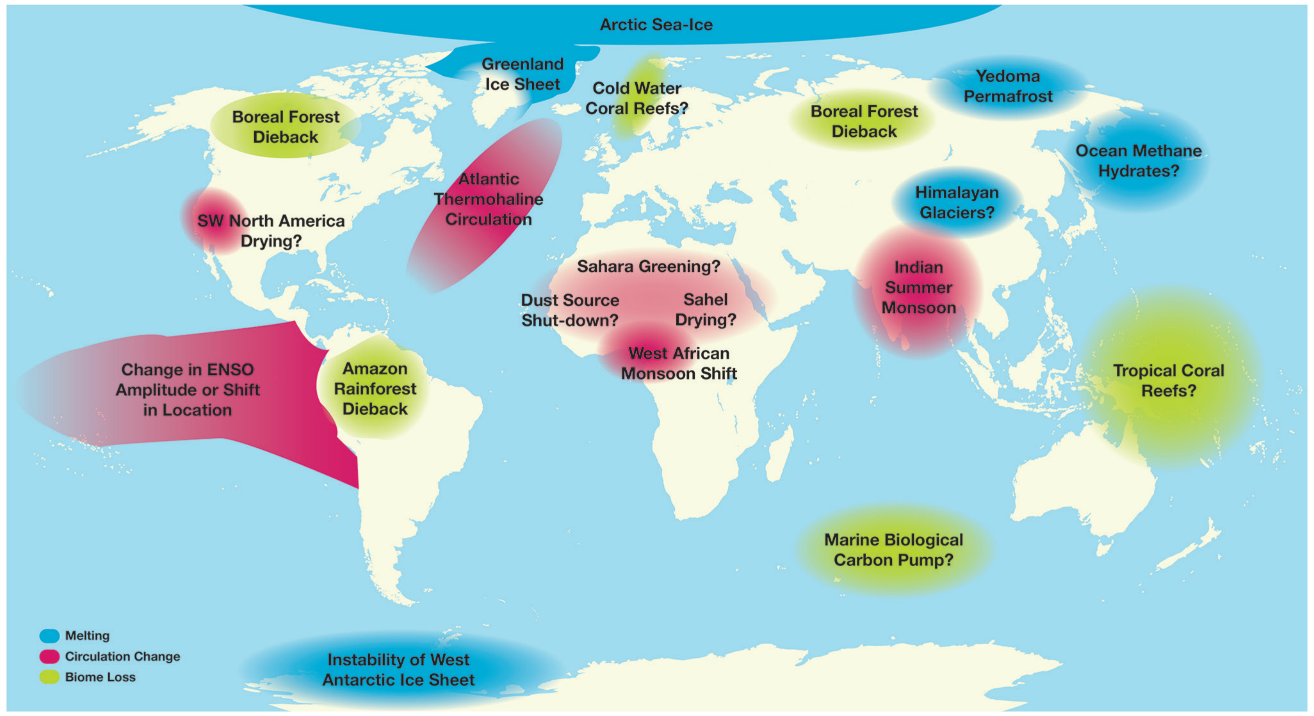
Misconception

We have 12 years to save the climate.

This idea originated in media interpretation of a sentence in the IPCC's 2018 Special Report on Global Warming of 1.5 °C. The sentence stated that 'limiting warming to 1.5 °C would require "rapid and far-reaching" transitions in land, energy, industry, buildings, transport and cities' and that "global net human-caused emissions of carbon dioxide would need to fall by about 45% from 2010 levels by 2030".' Through the media, this became '12 years to save the climate'.

Although statements implying a deadline or time-limit can galvanise action (or cause panic and a sense of helplessness and hopelessness), in reality, emissions could fall abruptly and meet the target or take another route that might miss the 2030 target but meet 'net zero' emissions soon after.

Tipping points represent perhaps the greatest uncertainty in determining the extent to which our climate is in crisis. This is the concept that aspects of the climate system change slowly up to a point and then change abruptly as they move to a new, different, state. Potential tipping points have been identified across the world related to melting ice, a change in the global atmospheric/oceanic circulation, or biome loss (**Figure 15.2**). We have evidence that aspects of the climate have tipped in the past, and we have already experienced biological tipping points, such as the sudden collapse of the Grand Banks cod fishery in the 1990s. Tipping points are not necessarily irreversible, although large changes to atmospheric greenhouse gas concentrations may be required to return to the previous state.



▲ Figure 15.2

Misconception

Melting sea ice leads to sea levels rising.

Sea ice is ice which is floating on the ocean surface. The volume of water it displaces as ice is the same as the volume of water it adds to the ocean as it melts. As a result, sea level does not rise much when sea ice melts – although there may be a small effect due to the fact that the melting ice adds fresh water to the oceans, changing its density. Sea level rises more significantly because water expands as it warms. As it will take tens or even hundreds of years for the extra heat in the atmosphere to reach some parts of the deep ocean, the oceans will carry on warming for some time. However, much more significant sea level rise will occur as the ice sheets on land – Greenland and Antarctica – slowly melt in a warmer atmosphere.

By 2100, global sea level rise would be 10 cm lower with global warming of 1.5 °C compared with a warming of 2 °C.

▲ *The climate change messages presented by scientists, politicians and the media can sometimes be confusing and misleading. Continual portrayal of climate change as a threat, rather than an opportunity for positive change, can make people fearful and leave them feeling helpless and less likely to act.*

Chapter 16

Anticyclones

metlink.org/resource/16-anticyclones/

- AIR MASSES
- PRESSURE AND WIND
- WATER IN THE ATMOSPHERE

Lesson overview: In the accompanying online lesson resources, we look at the weather associated with anticyclones in summer and winter and its potential impacts.

Skills: Reading synoptic charts | Interpreting satellite images

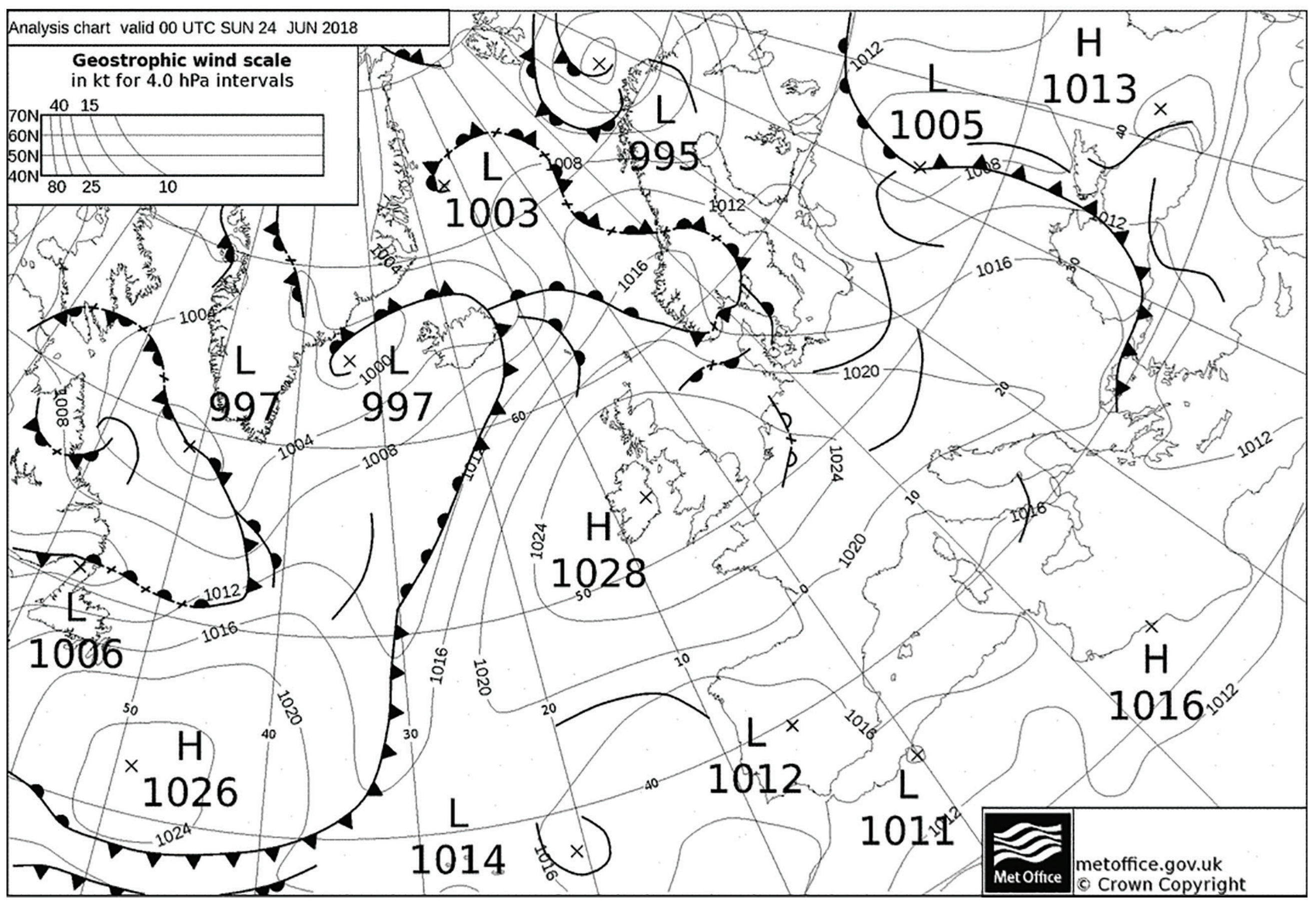
Anticyclones are high pressure weather systems caused by descending air. They rotate clockwise as outflowing air at ground level is deflected by the Coriolis effect and bring light winds and warm sunny days in the summer, but also crisp winter days and endless gloom in spring. Large high pressure systems can sit in place for long periods of time and deflect low pressure weather around the UK. This can lead to protracted periods of stable weather with little precipitation.

Learning objectives of online lesson resources:
- To understand what an anticyclone is.
- To be able to distinguish between the weather in a winter and summer anticyclone.
- To be able to explain why we get high pressure in an anticyclone.
- To evaluate the positive and negative impacts of anticyclones in summer and winter.

Thunk: How old is the wind?

An anticyclone is an area or system of high atmospheric pressure.

On a synoptic chart an anticyclone is identified by the letter H and will have a maximum pressure value next to the letter. The isobars – lines of equal pressure – around an anticyclone tend to be widely spaced, indicating light winds over an extremely large area. Anticyclones can be 2000–3000 km across.



▲ *A synoptic chart illustrating a significant blocking high pressure area across the UK during the 2018 summer heat wave.*

Misconception

Any pressure over 1000 hPa is High pressure.

There is no threshold to determine high or low pressure. The classification of a pressure system depends only on the pressure that surrounds it. Generally, pressure tends to be higher in summer than winter, so a winter High may have a maximum pressure that is below 1000 hPa (1000 mbar) whereas a summer Low may have a minimum pressure that is above 1000 hPa. The highest pressure recorded in the UK is 1053.6 hPa in Aberdeen on 31 January 1902 and the lowest is 925.6 hPa at Crieff (Perthshire) on 26 January 1884. Pressure readings over 1050 hPa were recorded during the UK lockdown of Spring 2020.

High pressure may occur due to local patterns of air movement or to descending air associated with the global atmospheric circulation. The descending air spreads out when it reaches the ground but is slowed down by friction with the Earth's surface, allowing air to build up above and the surface pressure to rise. The descending air warms up as it sinks, which increases the rate at which water droplets in the sinking air evaporate and therefore usually inhibits the formation of cloud.

The air moving outwards from an anticyclone at ground level is deflected to the right by the Coriolis effect in the Northern Hemisphere, causing anticyclonic pressure systems to rotate clockwise.

There are significant differences in the weather associated with high pressure systems in winter and summer.

In the summer, anticyclones bring dry, settled conditions, clear skies and warm temperatures (**Figure 16.1**), with occasional thunderstorms if conditions are hot enough locally. In winter, the same clear skies typically allow significant cooling overnight. This causes frost (**Figure 16.2**).

▲ **Figure 16.1**

▲ **Figure 16.2**

Misconception

The skies are always clear when the pressure is high.

In late winter/early spring the cold ground can cool the air in contact with it, leading to the formation of fog and low cloud (**Figure 16.3**). With low wind speeds and weak sunlight, the outcome may be an extended period of anticyclonic gloom. The fog and any pollution are trapped near the ground. The same process can lead to fog and low cloud forming in the moisture rich air over the sea and coastal areas, sometimes leading to drizzle.

▲ **Figure 16.3**

Blocking Highs are large high pressure systems which persist for days or weeks and are able to deflect smaller low pressure systems Pole-wards, leading to extended periods of stable weather with little precipitation.

Although high pressure can be associated with good weather, it can also lead to very poor air quality, particularly in urban and industrial areas, and to high pollen counts, as the very light wind speeds do not blow any pollutants or pollen away.

Large semi-permanent high pressure regions such as the Azores High and the high pressure region over the Poles are the source regions for the air masses which bring us our weather.

Chapter 17

Depressions

metlink.org/resource/17-depressions/

- PRESSURE AND WIND
- WATER IN THE ATMOSPHERE
- ANTICYCLONES

Lesson overview: In the accompanying online lesson resources, we look at the causes of low pressure systems and the weather they bring to the UK.

Skills: Reading synoptic charts

Depressions or low pressure weather systems, bring most of the 'normal' and 'extreme' weather that we experience in the UK. Driven by rising air, they mix colder and warmer air masses, forming fronts where these meet and bringing a predictable progression of weather as they pass over the UK. Their approach is typically first signalled by high cirrus cloud, which eventually develops into rain-bearing stratus. Once this passes there may be higher temperatures and less precipitation for a while, before towering cumulonimbus clouds arrive bringing heavy rainfall followed by lower temperatures and scattered showers.

Learning objectives of online lesson resources:

- To understand what low pressure is.
- To know what weather a depression system brings to the UK.
- To be able to draw and explain weather fronts.
- To understand how weather changes in the UK as a depression passes over.

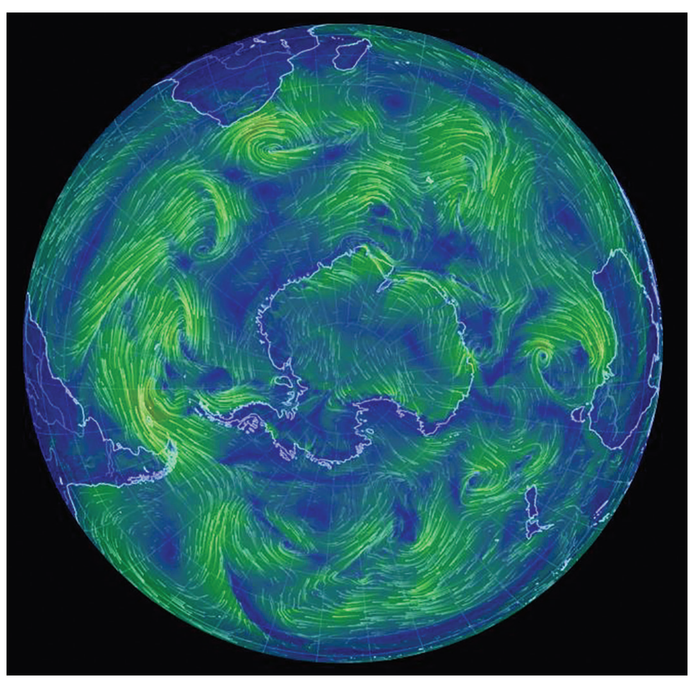
Thunk: Is any weather bad for everyone?

A depression is the meteorological term for a low pressure weather system in the mid-latitudes. A depression is driven by rising air.

Misconception

Rising air leads to lower pressure.

Air pressure relates to the amount of atmosphere above the ground. If there is less air, there will be lower pressure. Rising air itself does not reduce pressure – the air will still be there, pressing down, even if it is moving upwards. The effect that reduces pressure when air is rising relates to the difference in speed between air rising and spreading out at altitude, and air flowing in along the surface to replace the air that has risen. If air is leaving faster than it is arriving then the total amount of air and therefore the pressure will fall. Friction with buildings, vegetation, topography, etc. will slow the flow of air inwards. The Coriolis effect deflects the inward flow of air and causes the storm to rotate.



▶ *Wind patterns on 7 August 2019. Depressions rotate in a clockwise direction in the Southern Hemisphere. As Antarctica and the Southern Ocean are very symmetrical, there is often a regular pattern of depressions in the mid-latitudes of the Southern Hemisphere.*

In addition to the global atmospheric and oceanic circulation, depressions are responsible for transporting a significant quantity of heat from the Tropics towards the Poles. Depressions form every few days, last a few days and are of roughly the same size as the UK.

A weather map will mark depressions with the letter 'L'. The mid-latitudes – between 23.5° and 66° from the equator – tend to have a steady stream of depressions, carried on the Ferrel cell's surface westerlies. Their formation is a consequence of the pole to equator temperature gradient – surface temperatures fall fastest in the mid-latitudes.

Depressions are associated with fronts. A front is simply the boundary between different air masses. Typically in the UK, depressions form where Polar maritime and Tropical maritime air meet. On a synoptic chart, fronts are drawn as lines showing where the air masses meet at the surface. A cold front is lined with triangles (which may be blue) and indicates where cold air is pushing into warm air. A warm front is lined with semi-circles (which may be red) and indicates where warm air is pushing into cold air. The triangles or semi-circles indicate the direction in which the front is moving. Fronts slope gently up through the atmosphere – the gradient of a warm front may be as little as 1 in 150.

Situated in the mid-latitudes, UK weather can be dominated by depressions. In the summer, the northward migration of the global atmospheric circulation tends to push the track of depressions to the north of the UK and the weather associated with them tends to be less severe.

Each depression presents typical weather as it approaches, passes over and departs. On the ground you initially see high cirrus cloud (**Figure 17.1**), then stratus will cover the sky, and eventually nimbostratus (**Figure 17.2**) may bring rain as the warm front arrives. The temperature will rise as the warm air passes until the cold front arrives behind it. The denser, colder air arrives much more abruptly with large cumulonimbus clouds (**Figure 17.3**) and precipitation. The temperature will fall and as the front moves on, showers will follow in the Polar maritime air behind it (**Figure 17.4**).

'Red sky at night, shepherd's delight' is a piece of weather folklore whose accuracy lies in the fact that depressions usually approach the UK from the west and tend to be at least a few days apart. If the Sun, setting in the west, shines its light on a depression in the east giving a red sky, it is a sign that the depression has passed and better weather can be expected for a few days. On the other hand, if the Sun, rising in the east, shines its light on a depression in the west, then that depression has yet to hit the observer and is about to bring bad weather.

Misconception

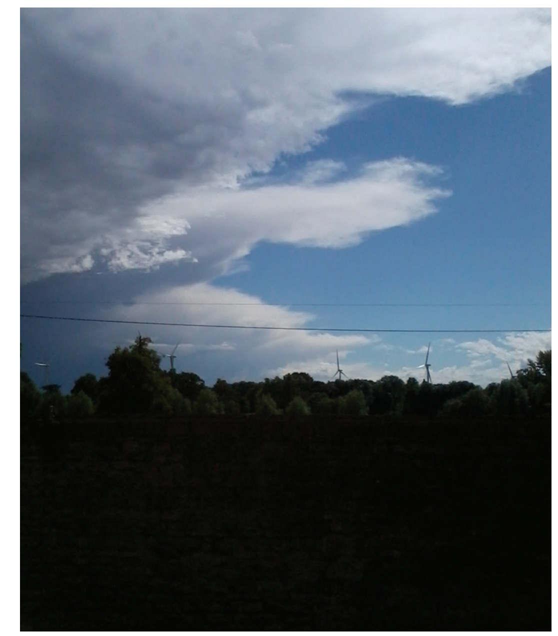
The jet stream acts as a hoover/vacuum.

The jet stream is a fast-flowing ribbon of air in the upper troposphere which tracks the position of the polar front on the surface.

A common image is that of the jet stream acting as a 'hoover', removing the rising/diverging air from above the depression. Specifically, you sometimes see reference to depressions developing where the jet stream is accelerating (for example when it loops towards the equator). However, the air rising in the depression because of the differences in temperature as warm air meets cold is rising much faster than any air 'sucked' up by the accelerating jet stream. In practice, depressions are more likely to form or intensify to the right (equatorward side) of an accelerating jet stream, or to the left (poleward side) of a jet stream that is slowing down.

▲ Figure 17.1

▲ Figure 17.2



▲ Figure 17.3

▲ Figure 17.4

Chapter 18
Microclimates

metlink.org/resource/18-microclimates/

- UK CLIMATE
- ANTICYCLONES
- DEPRESSIONS

Lesson overview: In the accompanying online lesson resources, we investigate the factors that can help create a microclimate and introduce fieldwork opportunities within the school grounds.

Skills: Reading synoptic charts | Mind mapping | Fieldwork

A microclimate exists when the climate in a small area is sufficiently different to the climate in the larger area around it as to be distinct. Some microclimates are very localised, whereas others are found across relatively large areas, such as forests, coasts and upland areas. Human modification of the Earth's surface can have unintended consequences on microclimates, but also offers tools to mitigate the effects of climate change and for active management to deliver improved food production, landscape resilience and ecosystem services. Microclimate fieldwork is easily accessible to all.

Learning objectives of online lesson resources:
- To understand that climate can vary over short distances.
- To be able to define what a microclimate is.
- To be able to explain how six major factors can contribute to the microclimate of an area.

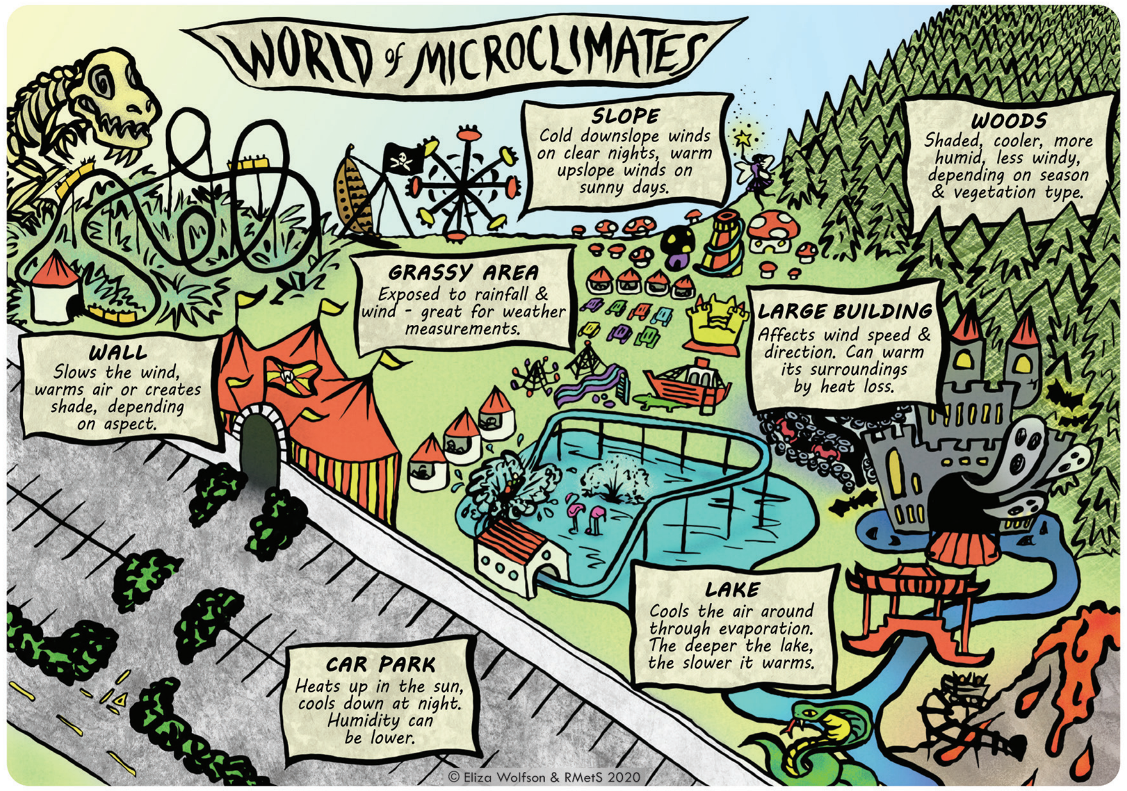
Thunk: Do some classrooms have a better microclimate than others?

A microclimate describes a climate found in a small area in which distinct conditions prevail to the surrounding climate. Microclimates are evident all around us. Although differences may vary in magnitude, weather variables, including temperature, precipitation, humidity, wind and their statistical characteristics over varying periods of time, will all differ to such an extent as to describe a distinct climate.

Misconception
A microclimate covers only a very small area.

Although a microclimate may cover a small area, it may also extend over several square kilometres.

▶ *Many factors including aspect, surface materials, vegetation, altitude and the proximity to water can affect microclimates.*



There are many factors that determine the formation and characteristics of a microclimate. Which factors are relevant and to what extent they influence the microclimate varies between locations and may vary throughout the year and with the type of weather.

Animals frequently exploit microclimates (**Figure 18.1**). **Figure 18.2** shows Ben More's Cuidhe Chrom (the 'bent or curved wreath') on 8 June 2019. It is the only year-round snow patch named on Ordnance Survey maps, found where local conditions are cold enough for the snow to persist.

▲ Figure 18.1

▲ Figure 18.2

Large-scale microclimates occur in upland areas (colder, windier, wetter), coastal areas (milder winters, cooler summers) and forests (less windy). The orientation of valleys in mountainous regions can increase or decrease average wind speeds and in turn affect rates of evaporation. Aspect describes the orientation of the ground. Slopes facing the Sun receive more of the Sun's light and heat than slopes in shadow.

Altitude has several effects. Temperature decreases with height. Precipitation is higher on the windward side of mountains than on the downwind side, as air forced to rise over the high ground cools with height, causing cloud to form. This can also lead to temperatures being higher on the downwind side of the mountains – the Föhn effect.

The surface of the Earth also influences the strength and direction of winds. Obstacles create turbulence with complex eddies and vortices. The characteristics of the obstacle are important; a large area of vegetation may act as a significant source of friction and reduce wind speeds, whereas a tall building can channel air causing fast surface winds in places.

Mountains can create their own winds, too. When south-facing slopes heat up in the day, they warm the air above them and create anabatic winds which rise up the slope. Similarly, at night, as land cools, katabatic winds form as the ground cools the air above it, making it flow downslope into nearby valleys. This cooling also creates frost hollows – local depressions in which colder air collects and temperatures can be significantly lower than the surroundings.

The colour of the Earth's surface determines its albedo (reflectivity). The darker the surface, the more heat it will absorb (and subsequently emit) and conversely the lighter the surface, the more it will reflect. The varying heat capacity of different substances impacts how quickly they warm up and cool down in sunlight. Large bodies of water heat up slowly. As a consequence, sea temperature lags about 3 months behind the temperatures on land and coastal areas have smaller diurnal and seasonal variations in temperature than those inland.

Vegetation can have a local cooling effect as evapotranspiration cools plants' leaves in the same way that sweating cools our skin.

Any human modification of the landscape affects local microclimates.

As climate change increases the likelihood of water scarcity in the UK, farmers will increasingly have to manage local microclimates to adapt to limited water supplies. For example, maintaining greater vegetative cover will increase evapotranspiration and reduce local heating, hedgerows reduce wind speeds and more integrated land management strategies enable farmers to maintain healthy ecosystems which increase the climate resilience of their business. Similarly, microclimates can be managed to protect ecosystems from the impacts of climate change.

Microclimates offer a great opportunity to undertake fieldwork in school grounds. Simple measurements using simple observations and low-cost instruments can be made in any indoor/outdoor location and can integrate consideration of a range of factors that might influence results, such as land use or building surface materials. Data gathering can be extended with loggers which are useful for recording night-time variations in microclimates. The impact of people on their immediate (and wider) environment can be studied, as can the impact of microclimates, inside and out, on human comfort and activities.

Chapter 19

Urban Climates

metlink.org/resource/19-urban-climates/

- ANTICYCLONES
- DEPRESSIONS
- MICROCLIMATES

Lesson overview: In the accompanying online lesson resources, we look at how urban areas have an impact on temperature, wind, air quality and precipitation.

Skills: Describing and explaining | Decision making | Drawing isotherms | Interpreting maps

Even a single building can have an impact on its surrounding microclimate. The larger the built-up area, the greater its potential influence on the microclimate of it and its surrounding area. The physical properties of urban areas – their structure, the materials they are made from and the relative lack of vegetation create a localised climate with unique characteristics. Urban areas can influence temperature, wind speed and direction, air quality, precipitation and humidity. As the climate changes, urban microclimates can be managed to keep towns and cities as cool as possible and to improve air quality. Temperature differences between urban and rural areas are greatest during the night and when there is little wind.

Learning objectives of online lesson resources:

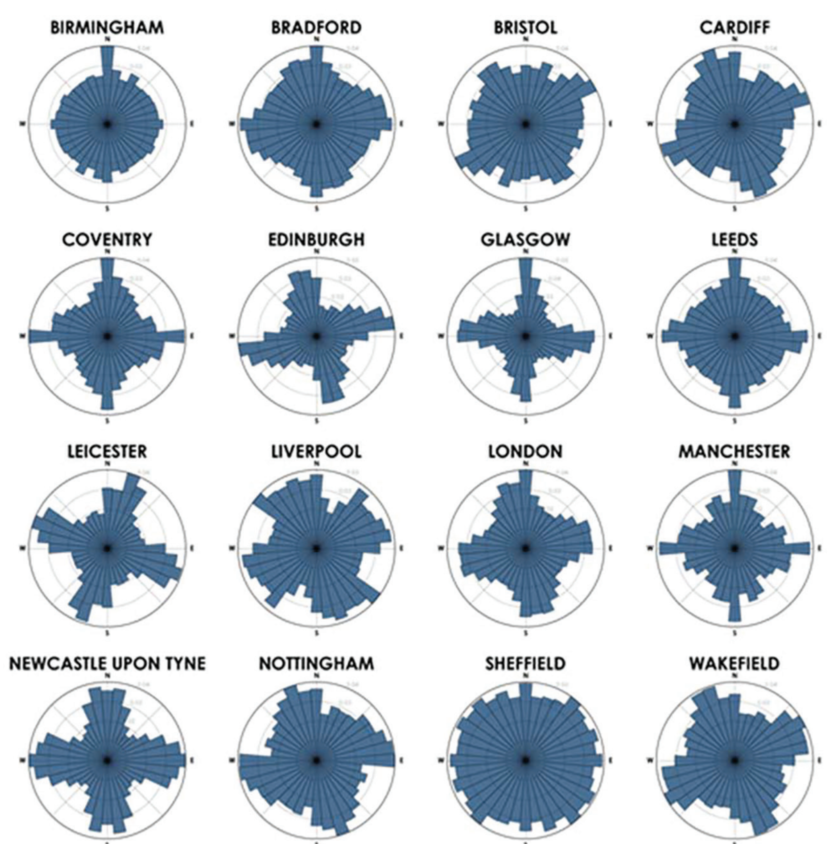
- To understand how urban areas affect temperature, wind and precipitation levels.
- To be able to explain why urban areas affect temperature, wind and precipitation levels.
- To create a plan to combat urban climate effects.

Thunk: I live in a rural area so urban climates can't affect me.

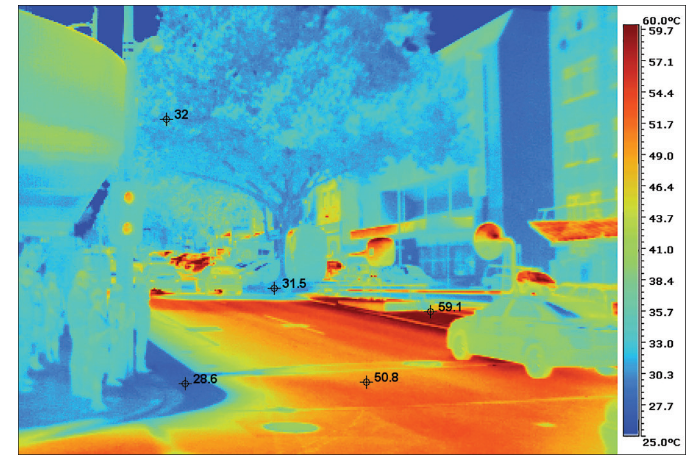
The UK Government considers urban areas to be settlements with a population of over 10 000. An urban microclimate is largely determined by the physical properties of the built environment – the shape, size, orientation and distribution of buildings, the materials used in the urban fabric and the prevalence of vegetation and water.

In the UK's urban areas there tends to be 5–15% less sunshine and 5–10% more precipitation. Mean temperatures are 0.5–1°C higher (with the annual maximum being 1–2°C higher) than nearby rural areas and consequently there are up to 21 days fewer in which frosts can occur and 14% fewer days on which it snows. There is twice as much fog in winter but 8–10% lower relative humidity in summer.

▶ *This image shows city street network orientation. Some cities can be more grid-like in their street layout than others. If the grid is aligned with the prevailing wind, there may be more opportunity to 'channel' the flow along the streets and blow pollution away – or trap it in side streets. Other factors such as building height and topography also have a big impact on the dispersion of pollutants. Sheffield has quite random street orientation, but is in a big valley, so pollution may accumulate overnight at the valley bottom.*

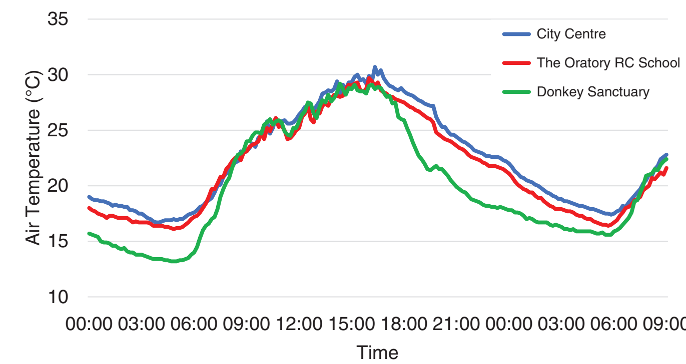


Urban temperature is increased by several factors. Urban activity itself releases waste heat into the environment – from vehicles and the heating and cooling systems of buildings. As the fabric of the built environment is generally dark and made of materials which are capable of absorbing significant quantities of the Sun's light and heat, this increases surface temperatures in the daytime, as shown by the daytime infrared image of a street in **Figure 19.1**. During the night, these surfaces release their heat, warming air temperatures – as shown by the differing rates of night-time cooling for 7 August 2020 in Birmingham in **Figure 19.2**. Evaporation cools surfaces. However, with little standing water (e.g. lakes and reservoirs) and fast runoff from impermeable surfaces, there are only low levels of evaporation. Equally, with less exposed soil and vegetation, there is relatively little evapotranspiration.



▲ **Figure 19.1**

The increased temperature in urban areas compared to nearby rural areas is called the urban heat island.



▲ **Figure 19.2**

Misconception

Urban areas are always warmer than surrounding rural areas.

The urban heat island effect tends to be more apparent the larger the urban area, during the night (as insulated buildings and heated surfaces slowly release their heat), in the summer and when winds are weak and skies are clear. At other times, urban and rural temperatures can be very similar. Within an urban area, open water or areas of green space significantly lower local temperatures, bringing them closer to rural temperatures.

Although most of the longest instrumental temperature records come from in or near urban areas, research has shown that the urban heat island has a negligible effect on these records and our understanding of climate change in the recent past.

The Met Office forecasts that heat waves (three or more consecutive days above a threshold temperature) are likely every other year by 2050. In urban areas, heat tends to build and the cumulative effect after several days of high temperatures can be dangerous to human health, causing heat exhaustion and heat stroke. Those with a range of existing conditions, the very young and adults over 75 are most at risk. Night-time temperatures, which are particularly enhanced in urban areas, have the most significant impact on heat wave deaths. Public Health England estimates the death toll from the 2018 heat wave to be over 860.

Urban areas also have significant effects on winds, cloudiness and even precipitation. Buildings divert winds, funnelling the air in some places and creating turbulence in others. Streets can form 'canyons' which interact with the prevailing wind. In warm weather the increased heat of urban areas enhances convection, generating or intensifying thunderstorms over the urban areas itself and downwind of it.

Urban areas also have impact on air quality. Historically, fog resulted from the burning of wood and coal in both homes and factories and was particularly bad during the winter months. Modern photochemical smog is largely composed of vehicle exhaust gases which react with UV light to create a brown haze. The weather associated with high pressure is linked to particularly poor air quality. Air pollution is especially harmful to those with chronic lung or cardio-pulmonary conditions. COVID19 deaths were higher amongst those living in polluted air. For this reason, urban authorities have sought to improve urban air quality.

Managing urban micro-climates will become increasingly necessary as global temperatures increase. Increasing vegetation, designing buildings and surfaces to reflect more heat, and facilitating plant growth, will help keep cities cooler for longer.

Chapter 20

Tropical Cyclones

metlink.org/resource/20-tropical-cyclones/

Lesson overview: In the accompanying online lesson resources, we explore the structure, location and names for Tropical cyclones as well as some of their potential impacts.

Skills: Data interpretation | Mapping | Memory skills | Diagrams

Tropical cyclones are intense and extremely damaging storms. Fuelled by the transfer of heat from the ocean to the atmosphere, they can grow into some of the most destructive weather systems on Earth. Tropical cyclones need specific conditions to form and intensify. These limit the locations in which Tropical cyclones are able to form. Called Tropical cyclones anywhere in the world, they are classified as typhoons in the North-West Pacific and hurricanes in the Atlantic and North-East Pacific. A Tropical cyclone has a distinctive structure, consisting of a clear central 'eye', surrounded by extensive cloud bands which spiral outwards and which may be hundreds of kilometres long. They can have severe impacts, causing coastal flooding and widespread damage to both the natural world and human infrastructure. As the climate changes, the most damaging Tropical cyclones are expected to increase in intensity.

Learning objectives of online lesson resources:

- To understand what weather and hazards are associated with a Tropical cyclone.
- To be able to describe the structure of a Tropical cyclone.
- To be able to explain how and why Tropical cyclones form.

Thunk: Does the sky weigh more on a cloudy day?

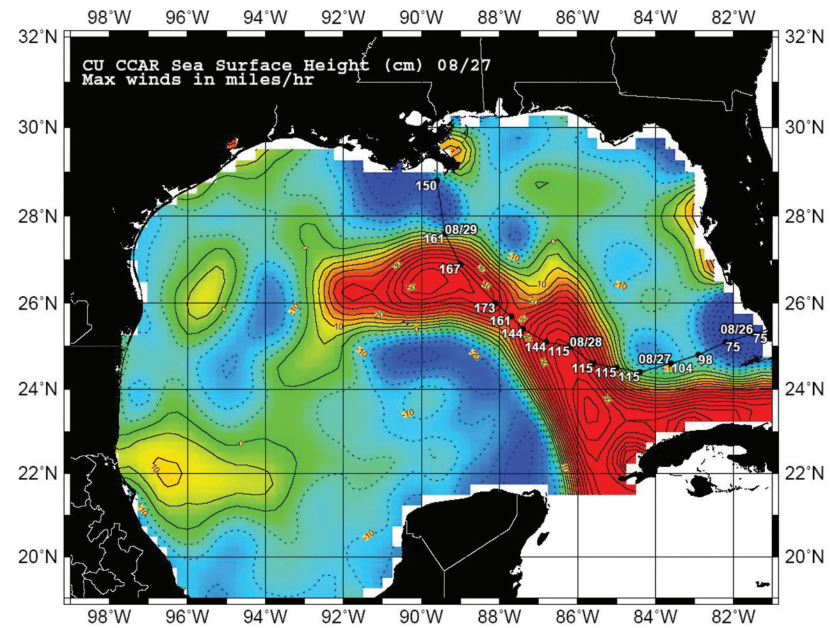
A Tropical cyclone is a large rotating storm that originates over warm tropical waters where there is a pre-existing disturbance – such as the messy remains of a mid-latitude depression. In addition, it also requires a specific set of atmospheric and oceanic conditions to develop.

Misconception

Tropical depressions, Tropical storms, Tropical cyclones, hurricanes and typhoons

There are many names associated with low pressure systems in the Tropics. At their weakest, all are called Tropical depressions, which can strengthen into Tropical storms. The umbrella term for anything stronger than a Tropical storm (typically when sustained wind speeds exceed 104 km/h or 64 mph) is a Tropical cyclone. However, Tropical cyclones are called hurricanes in the North Atlantic and North-East Pacific and are called typhoons in the North-West Pacific.

The sea surface height, position and wind speeds as Hurricane Katrina developed in August 2005. Whereas the sea surface temperature was fairly uniformly around 30 °C, Katrina developed fastest where the ocean height was highest. As water expands as it gets warmer, sea surface height is a proxy for depth throughout the depth of the ocean, rather than just the temperature of the sea surface. Hurricanes develop fastest where the water is warm to at least 60 m depth.



Sea temperature must be over 26 °C to a depth of at least 60 m – any shallower and as winds increase, they mix the top layer of water with colder water below. Warm water is at the heart of a Tropical cyclone – evaporation and subsequent condensation drives its formation. Warm sea water warms and moistens the air above it which rises. As the warm, humid air rises it cools until the rate of condensation exceeds the rate of evaporation and water vapour condenses into water droplets and forms clouds. As water changes from a gas into a liquid it releases latent heat. This warms the air further and causes the air to rise higher. In turn, this draws in fresh warm, moist air near the surface. Once a Tropical cyclone passes over land the source of moisture driving the storm is removed and it weakens.

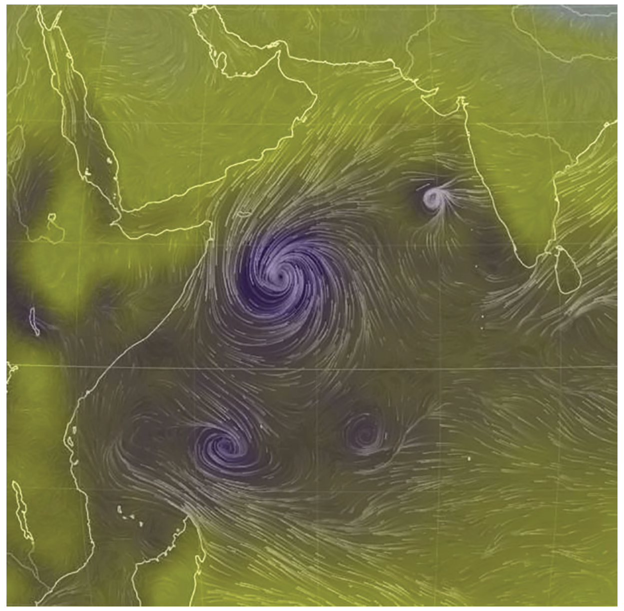


Figure 20.1

The storm must also begin to form at least 5° from the Equator so that the Coriolis effect can cause the system to rotate. The surface air being drawn inwards is deflected to the right in the Northern Hemisphere (creating anticlockwise rotation) and to the left in the Southern Hemisphere (creating clockwise rotation). **Figure 20.1** shows an image from December 2019 when Tropical cyclones developed in the Indian Ocean – to the south and north of the Equator, but not within 5° of the Equator. The storms are carried on the large-scale easterly trade winds.

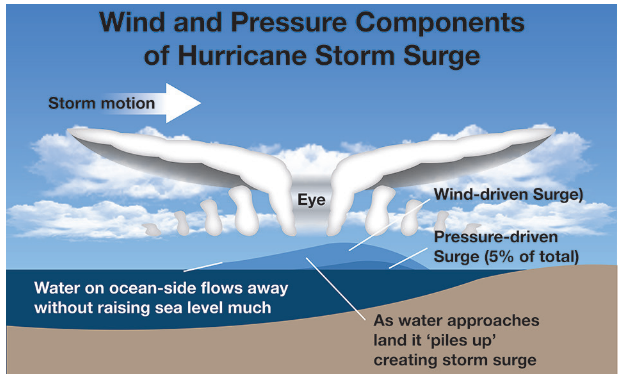


Figure 20.2

The atmosphere must have lots of moisture and little wind shear – wind speed and direction cannot vary significantly with height. The 10 km high columns of convective cumulus cloud at the centre of a Tropical cyclone cannot form if they are constantly blown apart, or if the air is too dry.

A Tropical cyclone has a typical structure. At the centre is the eye in which air sinks and is characterised by clear skies and low winds. Around the eye are some of the strongest winds in the storm. Moving outwards there are thick bands of cloud, with rapidly rising air and heavy rain. The low pressure at the centre of the storm causes the sea to bulge upwards, partly accounting for coastal flooding when the storm makes landfall. Although, as seen in **Figure 20.2**, the flooding is dominated by the water piled against the shore by the surface winds.

Misconception

You can only get hurricane force winds with a hurricane.

The Beaufort wind scale is a general scale for use in all weather conditions and with 12 categories spanning wind speeds of 0–118 km/h+. Wind speeds over 118 km/h are defined as 'hurricane force'. The Saffir-Simpson scale is used specifically for hurricanes – it is a 1–5 rating based on sustained wind speeds. Category 1 hurricanes have a sustained wind speed of over 104 km/h and a Category 5 hurricane has sustained winds greater than 222 km/h. So, the term 'hurricane' is used to refer to a very specific storm type, found in limited regions of the world, but hurricane force winds may be found anywhere, from Antarctica to the UK.

Although Tropical cyclones and mid-latitude depressions form in very different ways, either can develop into the other. The remnants of Atlantic hurricanes often make their way over the UK, though by the time they pass they have weakened and reformed into mid-latitude depressions.

The influence of climate change on the frequency of Tropical cyclones is still uncertain. However, it is expected that the intensity of the most extreme storms will increase and consequently represent a greater hazard. The precipitation associated with Tropical cyclones is expected to increase, which, when combined with rising sea levels suggests increased risk of coastal flooding. The impacts on the natural world are likely to overwhelm the ability of ecosystems to recover. Some ecosystems are already retreating and causing secondary changes to the services they provide to human populations. Mangrove swamps, for instance, protect coastal areas from the worst flooding associated with Tropical cyclones so their loss significantly increases the risk of damage to coastal areas in vulnerable locations.

Acknowledgements

Authors

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The Royal Meteorological Society would also like to thank the following for their contribution to *Weather and Climate: a Teachers' Guide:*

Philip Monk
Tara Barney
Mat Collins
Adam Corbridge
Susannah Costley-White
Robyn Gager
Jo Haigh
Ed Hawkins / showyourstripes
Ben Hennig / World Mapper
Britta Jarvis
Hannah Mallinson
Margaret McMullan
Ben Pickering
David Preece
Alex Roberts
William Roberts
Shantelle Robinson
Stephen Roulston
Catrina Shaw
Mark Stewart

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During the autumn season, in the very early hours of the morning, thanks to some particular climatic conditions it is possible to witness the formation of the 'river of clouds' in this valley. With the high pressure and the absence of wind, thick layers of fog thicken due to the humidification of the air mass present near the ground and flow along the Adda river, thus giving rise to a muffled landscape. In this period (October to November) the sun rises just behind a dense group of trees: therefore, if the sky is clear, for a few minutes it is possible to observe the formation of these intense rays of light. The photo is taken from a sanctuary, located on a hill overlooking the whole valley. On clear and calm nights, often during winter, radiation fog can form. Overnight, the air near the ground is cooled by the land surface losing heat through radiation. If the air is cooled sufficiently (to the dew point temperature), condensation occurs and fog forms. The cool, dense air will always sink to the lowest point it can, which is why it is common to see fog in river valleys and other low-lying areas. In this image, the fog and early morning mist have been illuminated by crepuscular rays. These are beams of sunlight, which usually radiate through gaps in the clouds. The sunlight is scattered by small water droplets, dust or other dry particles, resulting in the crepuscular rays we see. Here, the trees stand in for clouds and the fog acts as the reflecting medium.

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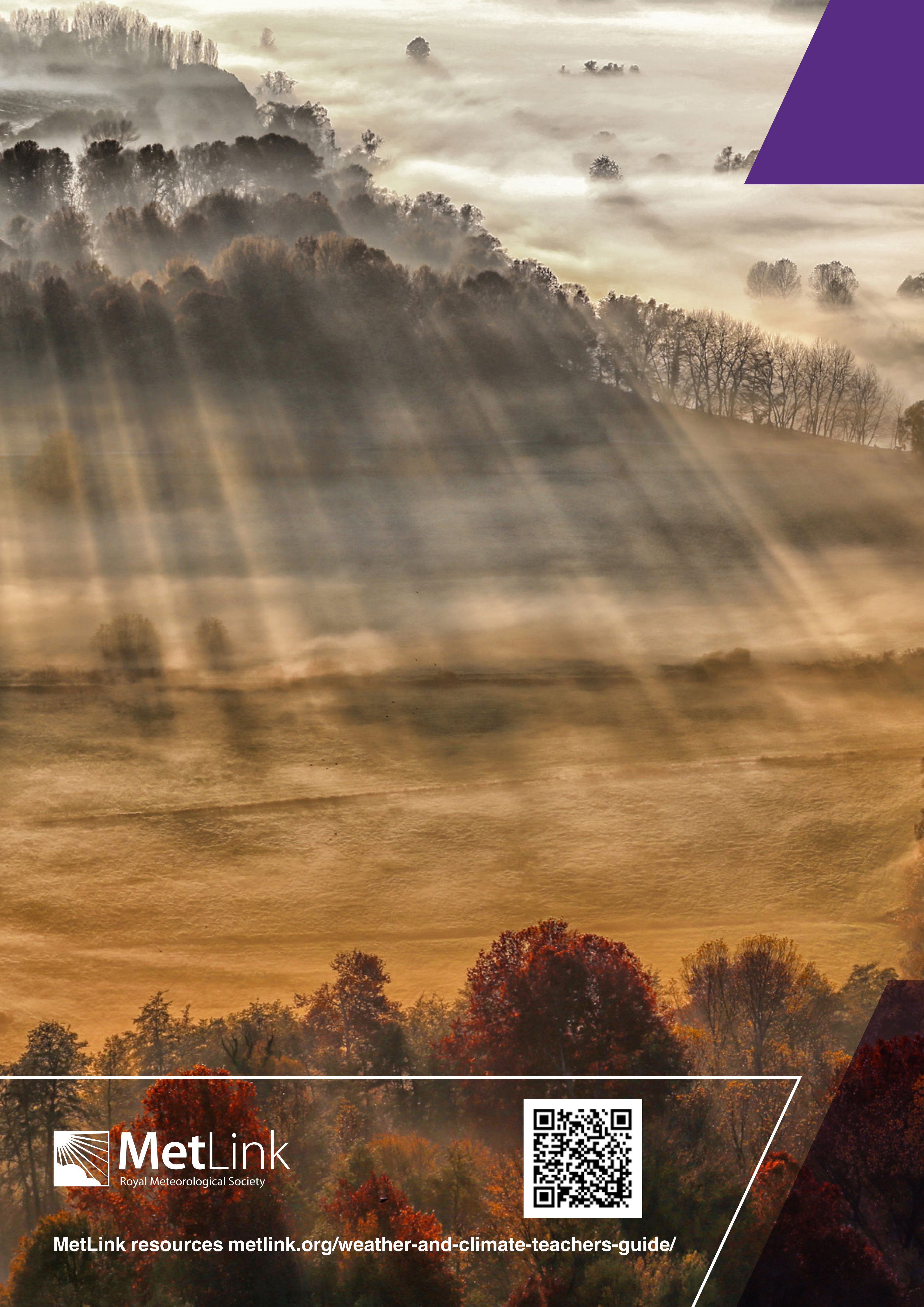

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