Fog

Fog is cloud at ground level. Radiation fog (Figure 2.33) is formed in low-lying areas during calm weather, especially during spring and autumn. The surface of the ground, cooled rapidly at night by radiation, cools the air immediately above it. This air then flows into hollows by gravity and is cooled to dew point (the temperature at which condensation occurs). Ideal conditions include a surface layer of moist air and clear skies, which allow rapid radiation cooling.

Figure 2.33 Fog in the Wicklow Mountains, Ireland

The decrease in temperature of the lower layers of the air causes air to go below the dew point. With fairly light winds, the fog forms close to the water surface, but with stronger turbulence the condensed layer may be uplifted to form a low stratus sheet.

As the Sun rises, radiation fog disperses. Under cold anticyclonic conditions in late autumn and winter, fog may be thicker and more persistent, and around large towns smog may develop under an inversion layer. An inversion means that cold air is found at ground level, whereas warm air is above it – unlike the normal conditions in which air temperature declines with height. In industrial areas, emissions of sulphur dioxide act as condensation nuclei and allow fog to form. Along motorways, the heavy concentration of vehicle emissions does the same. By contrast, in coastal areas the higher minimum temperatures means that condensation during high-pressure conditions is less likely.

Fog commonly occurs over the sea in autumn and spring because the contrast in temperature between land and sea is significant. Warm air from over the sea is cooled when it moves on land during anticyclonic conditions. In summer, the sea is cooler than the land so air is not cooled when it blows onto the land. By contrast, in winter there are more low-pressure systems, causing stronger winds and mixing the air.

Fog is more common in anticyclonic conditions. Anticyclones are stable high-pressure systems characterised by clear skies and low wind speeds. Clear skies allow maximum cooling by night. Air is rapidly cooled to dew point, condensation occurs and fog is formed.

Advection fog is formed when warm moist air flows horizontally over a cooler land or sea surface. Steam fog is very localised. Cold air blows over much warmer water. Evaporation from the water quickly saturates the air and the resulting condensation leads to steaming. It occurs when very cold polar air meets the surrounding relatively warm water.

Section 2.3 Activities

1. Distinguish between *radiation fog* and *advection fog*.
2. Under which atmospheric conditions (stability or instability) do mist and fog form? Briefly explain how fog is formed.
3. Under which atmospheric conditions do thunder and lightning form? Briefly explain how thunder is created.

2.4 The human impact

Global warming

The role of greenhouse gases

Greenhouse gases are essential for life on Earth. The Moon is an airless planet that is almost the same distance from the Sun as is the Earth. Average temperatures on the Moon are about –18 °C, compared with about 15 °C on Earth. The Earth's atmosphere therefore raises temperatures by about 33 °C. This is due to the greenhouse gases, such as water vapour, carbon dioxide, methane, ozone, nitrous oxides and chlorofluorocarbons (CFCs). They are called greenhouse gases because, as in a greenhouse, they allow short-wave radiation from the Sun to pass through them, but they trap outgoing long-wave radiation, thereby raising the temperature of the lower atmosphere (Figure 2.34). The greenhouse effect is both natural and good – without it there would be no human life on Earth. On the other hand, there are concerns about the enhanced greenhouse effect.

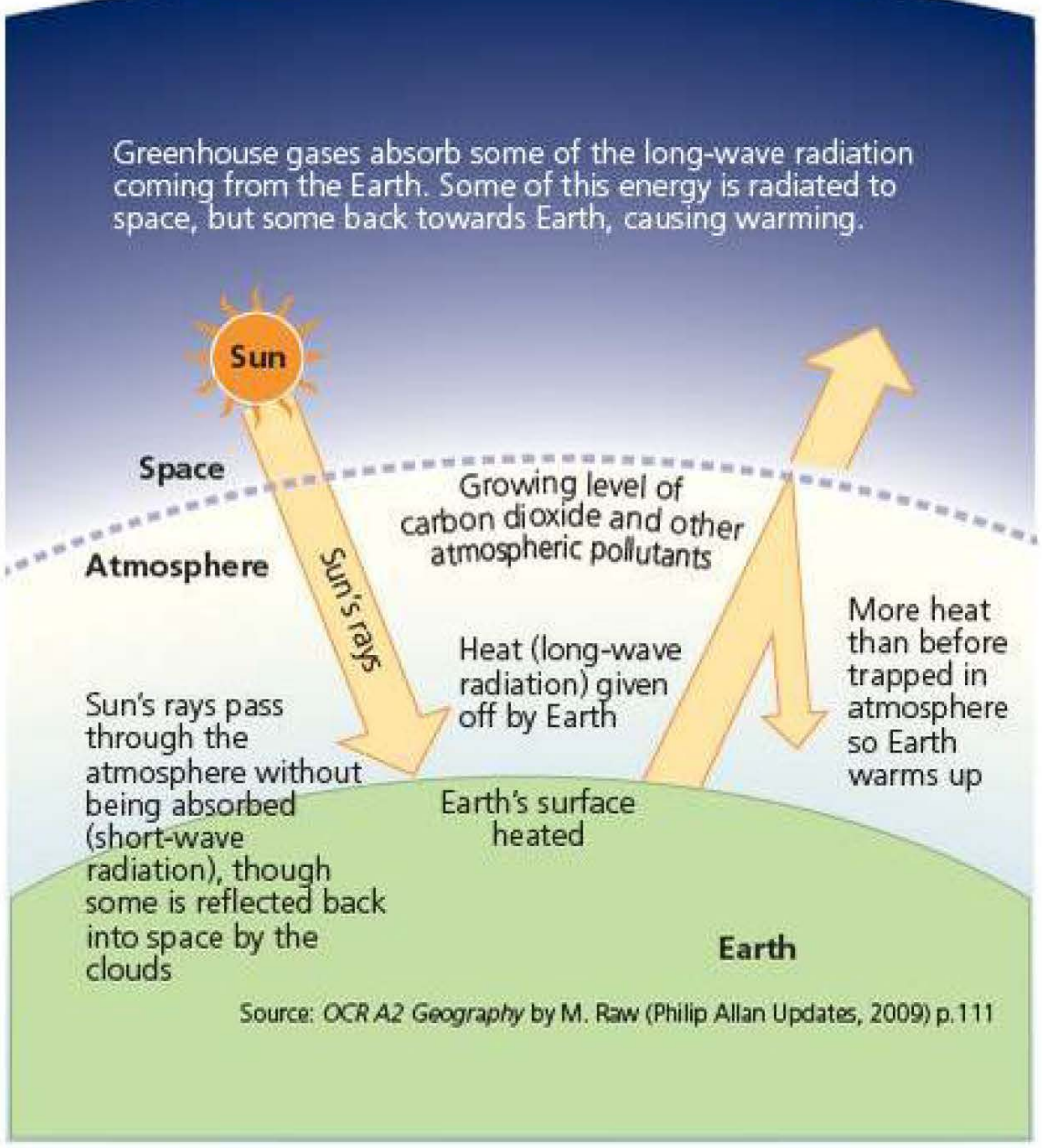


Figure 2.34 The greenhouse effect

The enhanced greenhouse effect is built up of certain greenhouse gases as a result of human activity (Table 2.2). **Carbon dioxide** (CO_2) levels have risen from about 315 ppm (parts per million) in 1950 to over 400 ppm and are expected to reach 600 ppm by 2050. The increase is due to human activities: burning fossil fuels (coal, oil and natural gas) and deforestation. Deforestation of the tropical rainforest is a double blow – not only does it increase atmospheric CO_2 levels, it also removes the trees that convert CO_2 into oxygen.

Methane is the second largest contributor to global warming, and is increasing at a rate of between 0.5 and 2 per cent per annum. Cattle alone give off between 65 and 85 million tonnes of methane per year. Natural wetland and paddy fields are another important source – paddy fields emit up to 150 million tonnes of methane annually. As global warming increases, bogs trapped in permafrost will melt and release vast quantities of methane. **Chlorofluorocarbons** (CFCs) are synthetic chemicals that destroy ozone, as well as absorb long-wave radiation. CFCs are increasing at a rate of 6 per cent per annum, and are up to 10000 times more efficient at trapping heat than CO_2.

As long as the amount of water vapour and carbon dioxide stay the same and the amount of solar energy remains the same, the temperature of the Earth should remain in equilibrium. However, human activities are upsetting the natural balance by increasing the amount of CO_2 in the atmosphere, as well as the other greenhouse gases.

How human activities add to greenhouse gases

Much of the evidence for the greenhouse effect has been taken from ice cores dating back 160000 years. These show that the Earth's temperature closely paralleled the levels of CO_2 and methane in the atmosphere. Calculations indicate that changes in these greenhouse gases were part, but not all, of the reason for the large (5°–7°) global temperature swings between ice ages and interglacial periods.

Accurate measurements of the levels of CO_2 in the atmosphere began in 1957 in Hawaii. The site chosen was far away from major sources of industrial pollution and shows a good representation of unpolluted atmosphere. The trend in CO_2 levels shows a clear annual pattern, associated with seasonal changes in vegetation, especially those over the northern hemisphere. By the 1970s there was a second trend, one of a long-term increase in CO_2 levels, superimposed upon the annual trends.

Studies of cores taken from ice packs in Antarctica and Greenland show that the level of CO_2 between 10000 years ago and the mid-nineteenth century was stable, at about 270 ppm. By 1957, the concentration of CO_2 in the atmosphere was 315 ppm, and it has since risen to about 360 ppm. Most of the extra CO_2 has come

Table 2.2 Properties of key greenhouse gases

	Average atmospheric concentration (ppmv)	Rate of change (% per annum)	Direct global warming potential (GWP)	Lifetime (years)	Type of indirect effect
Carbon dioxide	400	0.5	1	120	None
Methane	1.72	0.6–0.75	11	10.5	Positive
Nitrous oxide	0.31	0.2–0.3	270	132	Uncertain
CFC-11	0.000255	4	3400	55	Negative
CFC-12	0.000453	4	7100	116	Negative
CO				Months	Positive
NOx					Uncertain

from the burning of fossil fuels, especially coal, although some of the increase may be due to the disruption of the rainforests. For every tonne of carbon burned, 4 tonnes of CO_2 are released.

By the early 1980s, 5 gigatonnes (5000 million tonnes, or 5 Gt) of fuel were burned every year. Roughly half the CO_2 produced is absorbed by natural sinks, such as vegetation and plankton.

Other factors have the potential to affect climate too. For example, a change in the albedo (reflectivity of the land brought about by desertification or deforestation) affects the amount of solar energy absorbed at the Earth's surface. Aerosols made from sulphur, emitted largely in fossil-fuel combustion, can modify clouds and may act to lower temperatures. Changes in ozone in the stratosphere due to CFCs may also influence climate.

Since the Industrial Revolution, the combustion of fossil fuels and deforestation have led to an increase of 26 per cent of CO_2 concentration in the atmosphere (Figure 2.35). Emissions of CFCs used as aerosol propellants, solvents, refrigerants and foam-blowing agents are also well known. They were not present in the atmosphere before their invention in the 1930s. The sources of methane and nitrous oxides are less well known. Methane concentrations have more than doubled because of rice production, cattle rearing, biomass burning, coal mining and ventilation of natural gas. Fossil fuel combustion may have also contributed through chemical reactions in the atmosphere, which reduce the rate of removal of methane. Nitrous oxide has increased by about 8 per cent since pre-industrial times, presumably due to human activities. The effect of ozone on climate is strongest in the upper troposphere and lower stratosphere.

- The increasing carbon dioxide in the atmosphere since the pre-industrial era, from about 280 to 382 ppmv (parts per million by volume), makes the largest individual contribution to greenhouse gas radiative forcing: 1.56 W/m² (watts per square metre).
- The increase of methane (CH_4) since pre-industrial times (from 0.7 to 1.7 ppmv) contributes about 0.5 W/m².
- The increase in nitrous oxide (NOx) since pre-industrial times, from about 275 to 310 ppbv3, contributes about 0.1 W/m².
- The observed concentrations of halocarbons, including CFCs, have resulted in direct radiative forcing of about 0.3 W/m².

Figure 2.35 Changes in greenhouse gases since pre-industrial times

Arguments surrounding global warming

There are many causes of global warming and climate change. Natural causes include:

- variations in the Earth's orbit around the Sun
- variations in the tilt of the Earth's axis
- changes in the aspect of the poles from towards the Sun to away from it
- variations in solar output (sunspot activity)
- changes in the amount of dust in the atmosphere (partly due to volcanic activity)
- changes in the Earth's ocean currents as a result of continental drift.

All of these have helped cause climate change, and may still be doing so, despite anthropogenic forces.

Complexity of the problem

Climate change is a very complex issue for a number of reasons:

- Scale – it includes the atmosphere, oceans and land masses across the world.
- Interactions between these three areas are complex.
- It includes natural as well as anthropogenic forces.
- There are feedback mechanisms involved, not all of which are fully understood.
- Many of the processes are long term and so the impact of changes may not yet have occurred.

The effects of increased global temperature change

The effects of global warming are varied (see Table 2.3). Much depends on the scale of the changes. For example, some impacts could include:

- a rise in sea levels, causing flooding in low-lying areas such as the Netherlands, Egypt and Bangladesh – up to 200 million people could be displaced
- 200 million people at risk of being driven from their homes by flood or drought by 2050
- 4 million km² of land, home to one-twentieth of the world's population, threatened by floods from melting glaciers
- an increase in storm activity, such as more frequent and intense hurricanes (owing to more atmospheric energy)
- changes in agricultural patterns, for example a decline in the USA's grain belt, but an increase in Canada's growing season
- reduced rainfall over the USA, southern Europe and the Commonwealth of Independent States (CIS), leading to widespread drought (Figure 2.36)
- 4 billion people could suffer from water shortages if temperatures rise by 2 °C
- a 35 per cent drop in crop yields across Africa and the Middle East expected if temperatures rise by 3 °C
- 200 million more people could be exposed to hunger if world temperatures rise by 2 °C; 550 million if temperatures rise by 3 °C
- 60 million more Africans could be exposed to malaria if world temperatures rise by 2 °C
- extinction of up to 40 per cent of species of wildlife if temperatures rise by 2 °C.

Table 2.3 Some potential effects of a changing climate in the UK

Positive effects	Negative effects
■ An increase in timber yields (up to 25% by 2050), especially in the north (with perhaps some decrease in the south). ■ A northward shift of farming zones by about 200–300 km per 1°C of warming, or 50–80 km per decade, will improve some forms of agriculture, especially pastoral farming in the north-west. ■ Enhanced potential for tourism and recreation as a result of increased temperatures and reduced precipitation in the summer, especially in the south.	■ Increased damage effects of increased storminess, flooding and erosion on natural and human resources and human resource assets in coastal areas. ■ An increase in animal species, especially insects, as a result of northward migration from the continent and a small decrease in the number of plant species due to the loss of northern and montane (mountain types). ■ An increase in soil drought, soil erosion and the shrinkage of clay soils.

The Stern Review

The Stern Review (2006) was a report by Sir Nicholas Stern that analysed the financial implications of climate change. The report has a simple message:

- Climate change is fundamentally altering the planet.
- The risks of inaction are high.
- Time is running out.

The effects of climate change vary with the degree of temperature change (Figure 2.37). The report states that climate change poses a threat to the world economy and it will be cheaper to address the problem than to deal with the consequences. The global-warming argument seemed a straight fight between the scientific case to act, and the economic case not to. Now, economists are urging action.

The Stern Review says that doing nothing about climate change – the business-as-usual (BAU) approach – would lead to a reduction in global per person consumption of at least 5 per cent now and for ever. According to the report, global warming could deliver an economic blow of between 5 and 20 per cent of GDP to world economies because of natural disasters and the creation of hundreds of millions of climate refugees displaced by sea-level rise. Dealing with the problem, by comparison, will cost just 1 per cent of GDP, equivalent to £184 billion.

Main points

- Carbon emissions have already increased global temperatures by more than 0.5 °C.
- With no action to cut greenhouse gases, we will warm the planet by another 2–3 °C within 50 years.
- Temperature rise will transform the physical geography of the planet and the way we live.
- Floods, disease, storms and water shortages will become more frequent.
- The poorest countries will suffer the earliest and the most.
- The effects of climate change could cost the world between 5 and 20 per cent of GDP.
- Action to reduce greenhouse-gas emissions and the worst of global warming would cost 1 per cent of GDP.
- With no action, each tonne of carbon dioxide we emit will cause at least $85 (£45) of damage.
- Levels of carbon dioxide in the atmosphere should be limited to the equivalent of 450–550 ppm.
- Action should include carbon pricing, new technology and robust international agreements.

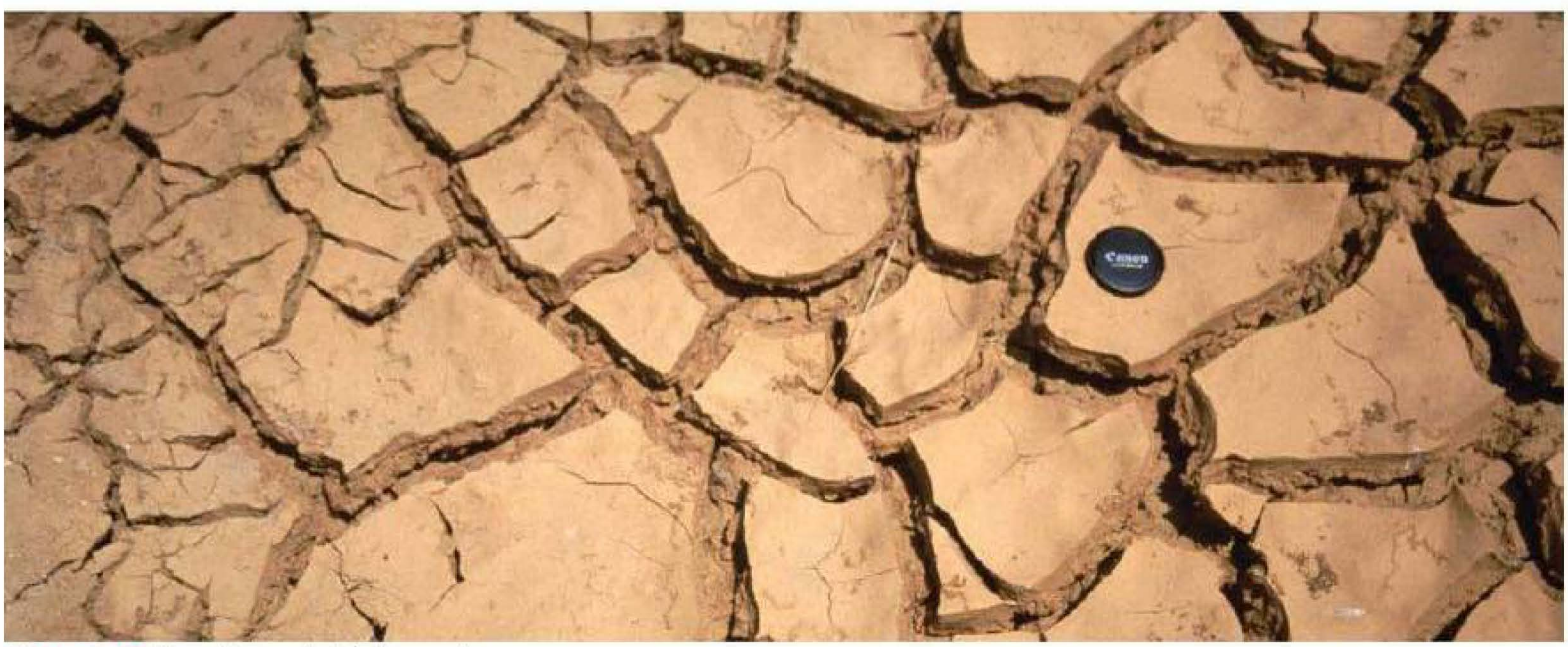


Figure 2.36 The effects of global warming

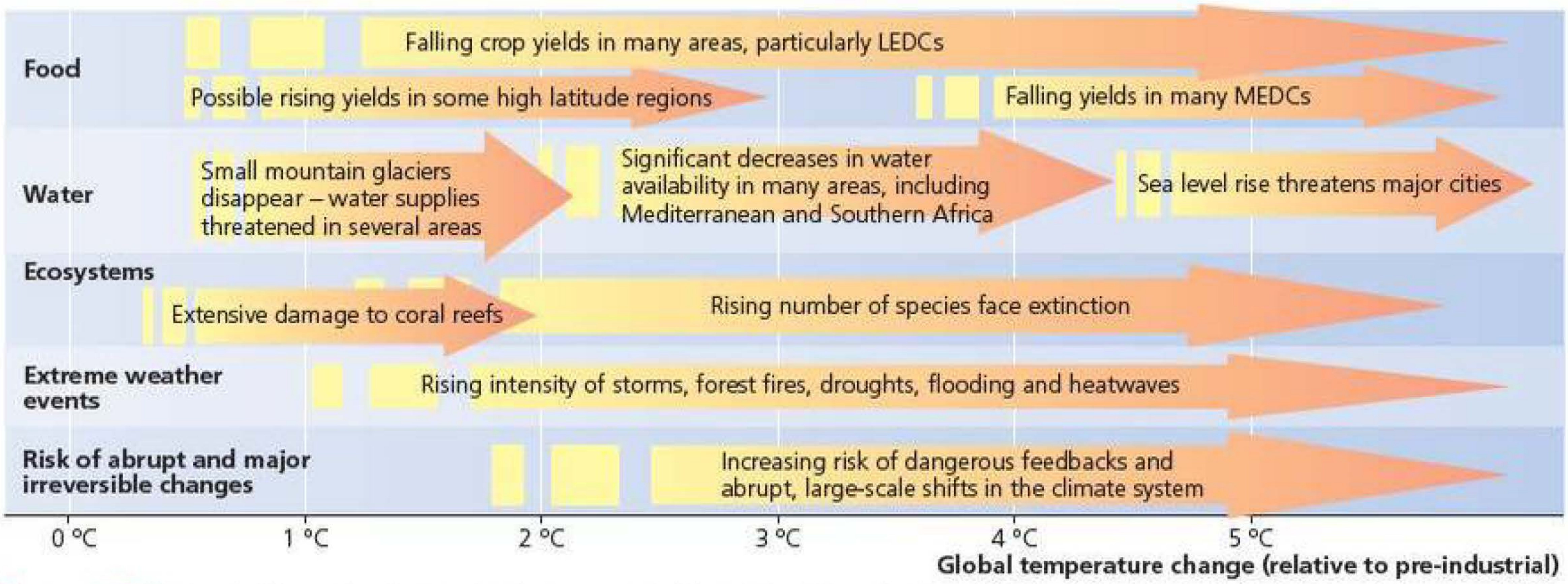


Figure 2.37 Projected impacts of climate change, according to the Stern Review

International policy to protect climate

The first world conference on climate change was held in Geneva in 1979. The Toronto Conference of 1988 called for the reduction of carbon dioxide emissions by 20 per cent of the 1988 levels by 2005. Also in 1988, UNEP and the World Meteorological Organization established the Intergovernmental Panel on Climate Change (IPCC).

> 'The ultimate objective is to achieve ... stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.'

The Kyoto Protocol (1997) gave all high-income countries (HICs) legally binding targets for cuts in emissions from the 1990 level by 2008–12. The EU agreed to cut emissions by 8 per cent, Japan 7 per cent and the USA by 6 per cent. The Paris round of global climate-change talks (2015) attempted to bring all countries in line with plans to reduce climate change. However, many of the plans discussed had a very long time frame and there appeared to be little hope for a quick solution.

Section 2.4 Activities

1 Figure 2.37 shows some of the projected impacts related to global warming.
  a Describe the potential changes as a result of a 3 °C rise in temperature.
  b Explain why there is an increased risk of hazards in coastal cities.
  c Outline the ways in which it is possible to manage the impacts of global warming.
  d Evaluate the potential impacts of global warming.
2 Figure 2.38 shows variations in mean air temperature between 1880 and 2000.
  a i Identify the reason that the temperature in the early 1960s fell below 15 °C.
    ii Describe the impact of Pinatubo on global climate in the 1990s.
  b Outline the natural sources of greenhouse gases.
  c Using an annotated diagram, explain what is meant by the term *the greenhouse effect*.
  d Outline the benefits of the greenhouse effect.

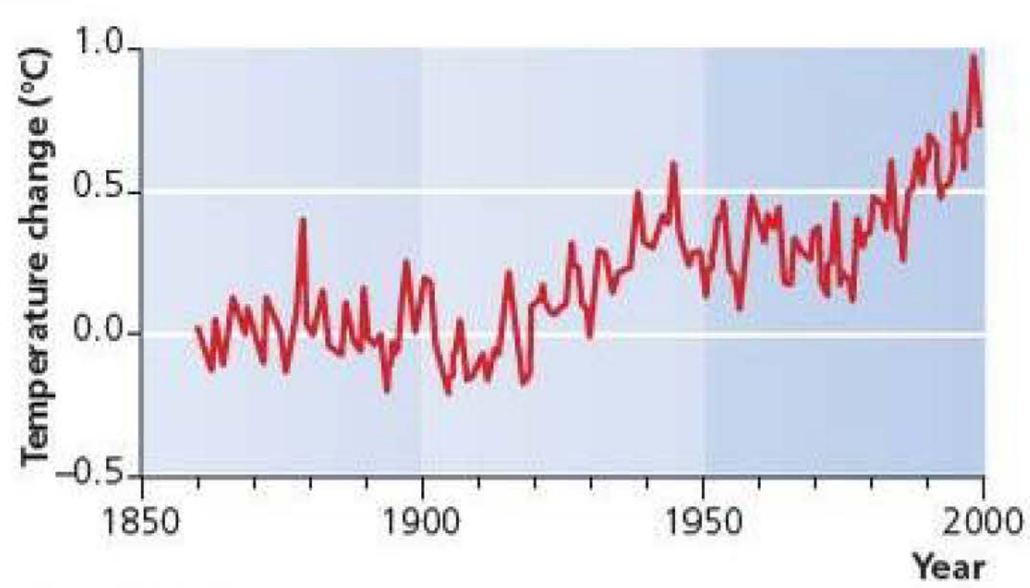


Figure 2.38 Variations in mean air temperature, 1880–2000

Urban climates

Urban climates occur as a result of extra sources of heat released from industry; commercial and residential buildings; as well as from vehicles, concrete, glass, bricks, tarmac – all of these act very differently from soil and vegetation. For example, the albedo (reflectivity) of tarmac is about 5–10 per cent, while that of concrete is 17–27 per cent. In contrast, that of grass is 20–30 per cent.

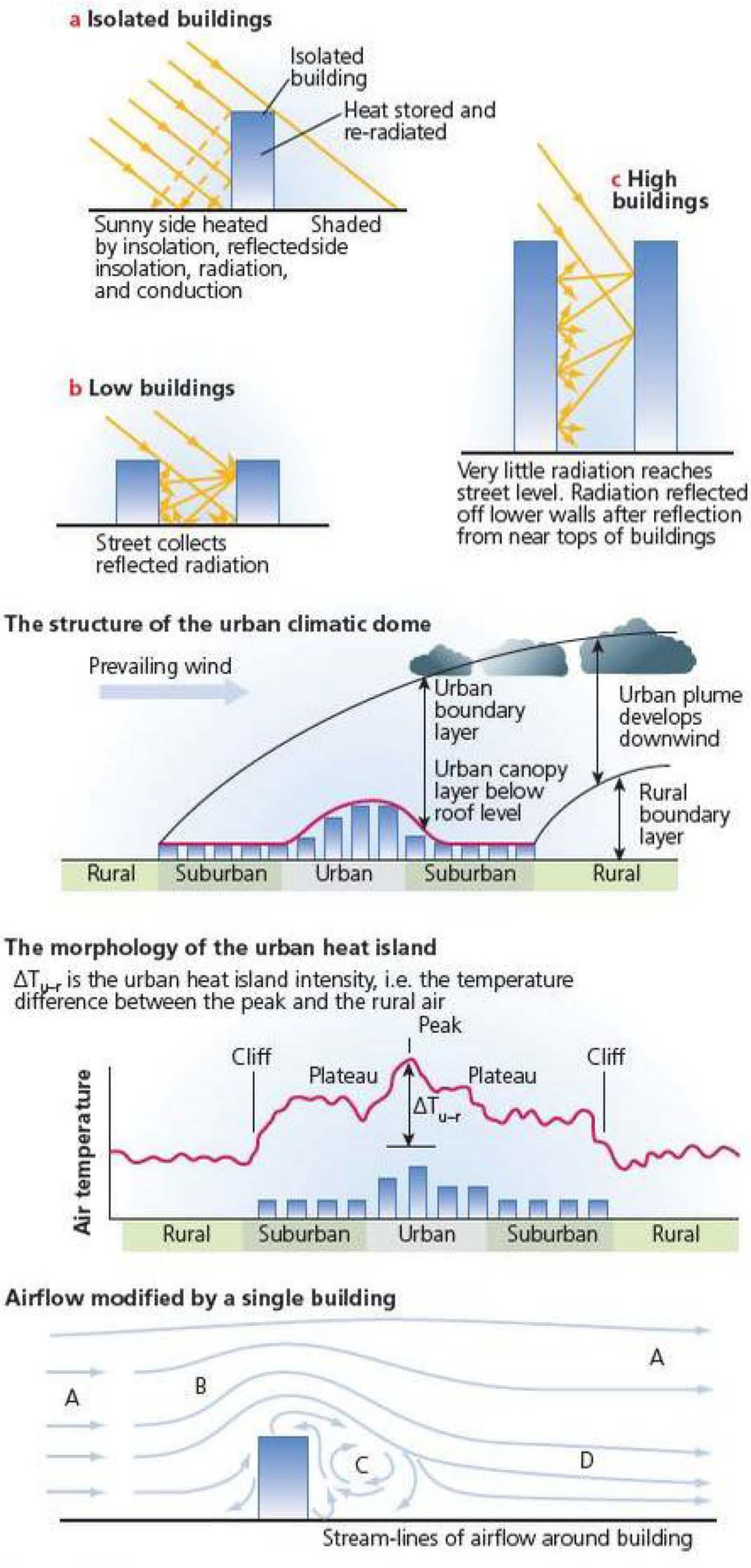


Figure 2.39 Processes in the urban heat island

Some of these – notably dark bricks – absorb large quantities of heat and release them slowly by night (Figure 2.39). In addition, the release of **pollutants** helps trap radiation in urban areas. Consequently, urban microclimates can be very different from rural ones. Greater amounts of dust mean an increasing concentration of hygroscopic particles. There is less water vapour, but more carbon dioxide and higher proportions of noxious fumes owing to combustion of imported fuels. Discharge of waste gases by industry is also increased.

Urban heat budgets differ from rural ones. By day, the major source of heat is solar energy; and in urban areas brick, concrete and stone have high heat capacities. A kilometre of an urban area contains a greater surface area than a kilometre of countryside, and the greater number of surfaces in urban areas allow a greater area to be heated. There are more heat-retaining materials with lower albedo and better radiation-absorbing properties in urban areas than in rural ones.

Moisture and humidity

In urban areas, there is relative lack of moisture. This is due to:

- a lack of vegetation
- a high drainage density (sewers and drains), which removes water.

Thus there are decreases in relative humidity in inner cities due to the lack of available moisture and higher temperatures there. However, this is partly countered in very cold, stable conditions by early onset of condensation in low-lying districts and industrial zones.

Nevertheless, there are more intense storms, particularly during hot summer evenings and nights, owing to greater **instability** and stronger convection above built-up areas. There is a higher incidence of thunder (due to more heating and instability) but less snowfall (due to higher temperatures), and any snow that does fall tends to melt rapidly.

Hence little energy is used for evapotranspiration, so more is available to heat the atmosphere. This is in addition to the sources of heating produced by people, such as in industry and by cars.

At night, the ground radiates heat and cools. In urban areas, the release of heat by buildings offsets the cooling process, and some industries, commercial activities and transport networks continue to release heat throughout the night.

There is greater scattering of shorter-wave radiation by dust, but much higher absorption of longer waves owing to the surfaces and to carbon dioxide. Hence there is more diffuse radiation, with considerable local contrasts owing to variable screening by tall buildings in shaded narrow streets. There is reduced visibility arising from industrial haze.

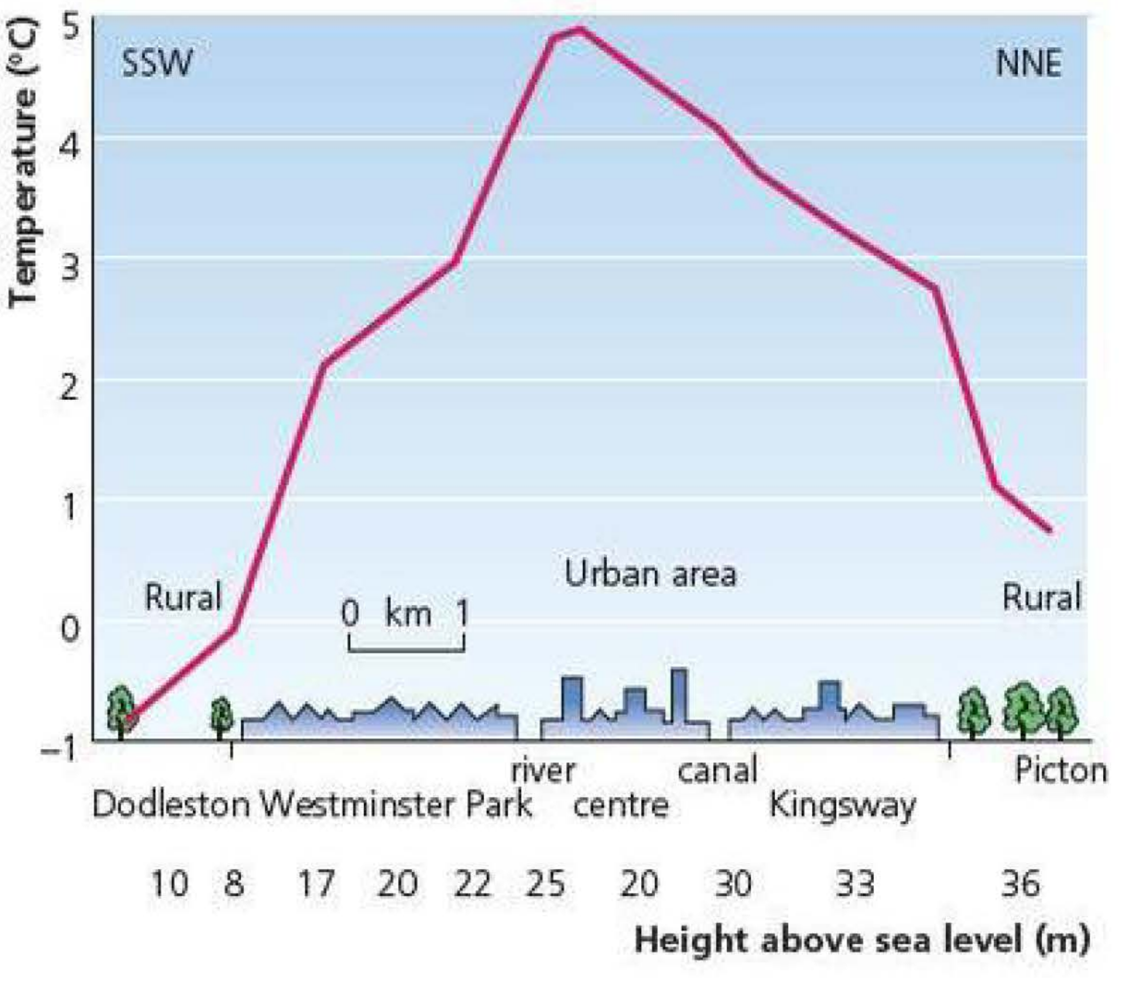
There is a higher incidence of thicker cloud cover in summer because of increased convection, and radiation fogs or smogs in winter because of air pollution. The concentration of hygroscopic particles accelerates the onset of condensation. Daytime temperatures are, on average, 0.6°C higher.

Urban heat island effect

The contrast between urban and rural areas is greatest under calm high-pressure conditions. The typical heat profile of an urban **heat island** shows a maximum at the city centre, a plateau across the suburbs and a temperature cliff between the suburban and rural areas (Figure 2.40). Small-scale variations within the urban heat island occur with the distribution of industries, open spaces, rivers, canals, and so on.

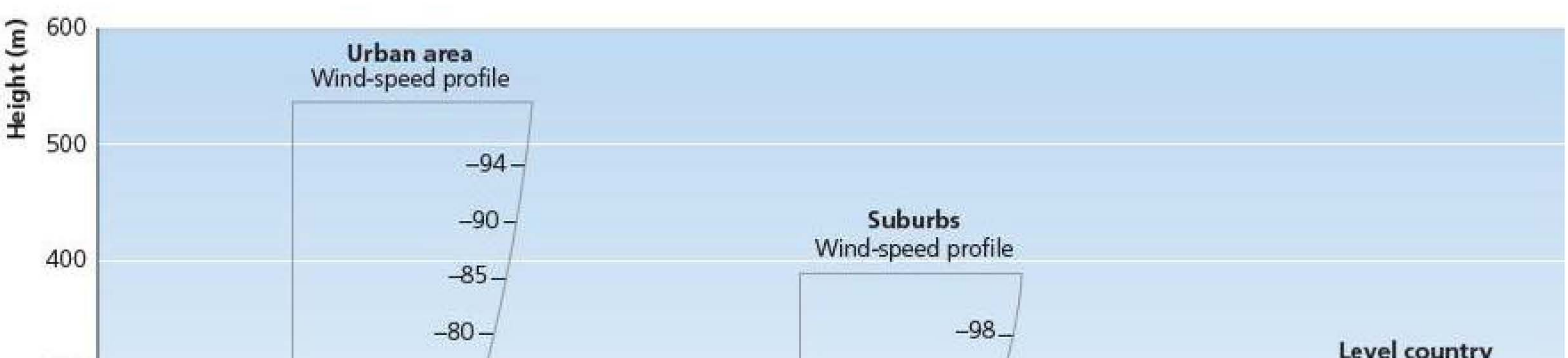
The heat island is a feature that is delimited by isotherms (lines of equal temperature), normally in an urban area. This shows that the urban area is warmer than the surrounding rural area, especially by dawn during anticyclonic conditions (Figure 2.41). The heat-island effect is caused by a number of factors:

- heat produced by human activity – a low level of radiant heat can be up to 50per cent of incoming energy in winter
- changes of energy balance – buildings have a high thermal capacity in comparison to rural areas; up to six times greater than agricultural land
- the effect on airflow – turbulence of air may be reduced overall, although buildings may cause funnelling effects
- there are fewer bodies of open water, so less evaporation and fewer plants, therefore less transpiration
- the composition of the atmosphere – the blanketing effect of smog, smoke or haze
- reduction in thermal energy required for evaporation and evapotranspiration due to the surface character, rapid drainage and generally lower wind speeds
- reduction of heat diffusion due to changes in airflow patterns as a result of urban surface roughness.



Source: Briggs, D. et al., *Fundamentals of the Physical Environment*, Routledge, 1997

Figure 2.40 The urban heat island (Chester, UK)



Source: Briggs, D. et al., *Fundamentals of the Physical Environment*, Routledge, 1997

Figure 2.41 The effect of terrain roughness on wind speed – with decreasing roughness, the depth of the affected layer becomes shallower and the profile steeper (numbers refer to wind strength as a percentage of maximum air speed)

Air flow

Urban areas may also develop a pollution dome. Highest temperatures are generally found over the city centre – or downwind of the city centre if there is a breeze present. Pollutants may be trapped under the dome. Cooler air above the dome prevents the pollutants from dispersing. These pollutants may prevent some incoming radiation from passing through, thereby reducing the impact of the heat island. By night, the pollutants may trap some long-wave radiation from escaping, thereby keeping urban areas warmer than surrounding rural areas.

Airflow over an urban area is disrupted; winds are slow and deflected over buildings (Figure 2.41). Large buildings can produce eddying. Severe gusting and turbulence around tall buildings causes strong local pressure gradients from windward to leeward walls. Deep narrow streets are much calmer unless they are aligned with prevailing winds to funnel flows along them – the 'canyon effect'.

The nature of urban climates is changing (Table 2.4). With the decline in coal as a source of energy, there is less sulphur dioxide pollution and so fewer hygroscopic nuclei; there is therefore less fog. However, the increase in cloud cover has occurred for a number of reasons:

- greater heating of the air (rising air, hence condensation)
- increase in pollutants
- frictional and turbulent effects on airflow
- changes in moisture.

Table 2.4 Average changes in climate caused by urbanisation

Factor		Comparison with rural environments
Radiation	Global	2–10% less
	Ultraviolet, winter	30% less
	Ultraviolet, summer	5% less
	Sunshine duration	5–15% less
Temperature	Annual mean	1°C more
	Sunshine days	2–6°C more
	Greatest difference at night	11°C more
	Winter maximum	1.5°C more
	Frost-free season	2–3 weeks more
Wind speed	Annual mean	10–20% less
	Gusts	10–20% less
	Calms	5–20% more
Relative humidity	Winter	2% less
	Summer	8–10% less
Precipitation	Total	5–30% more
	Number of rain days	10% more
	Snow days	14% less
Cloudiness	Cover	5–10% more
	Fog, winter	100% more
	Fog, summer	30% more
	Condensation nuclei	10 times more
	Gases	5–25 times more

Source: J. Tivy, Agricultural Ecology, *Longman 1990 p.372*

Section 2.4 Activities

1 Describe and account for the main differences in the climates of urban areas and their surrounding rural areas.
2 What is meant by the *urban heat island*?
3 Describe **one** effect that atmospheric pollution may have on urban climates.
4 Explain how buildings, tarmac and concrete can affect the climate in urban areas.
5 Why are microclimates, such as urban heat islands, best observed during high-pressure (anticyclonic) weather conditions?

Case Study: Urban microclimate – London

The heat island effect

Urban microclimates are perhaps the most complex of all microclimates. The general pattern in Figure 2.42 shows the highest temperatures in the city centre, reaching 10–11°C, compared with the rural fringe temperature of 5°C. Temperature falls more rapidly along the River Thames to the east of the City. The temperature gradient is more gentle in the west of the city, due to the density of urban infrastructure. Over steep temperature gradients there is a low density of urban infrastructure, for example the river and its vegetated banks. Where there is a gentle temperature gradient, there is a high density of urban infrastructure. Effectively from the map we can see that the east of London is less built up than the west. Temperature remains relatively constant for approximately 15 kilometres west of the city centre before rapidly falling within a 5–6 kilometre distance.

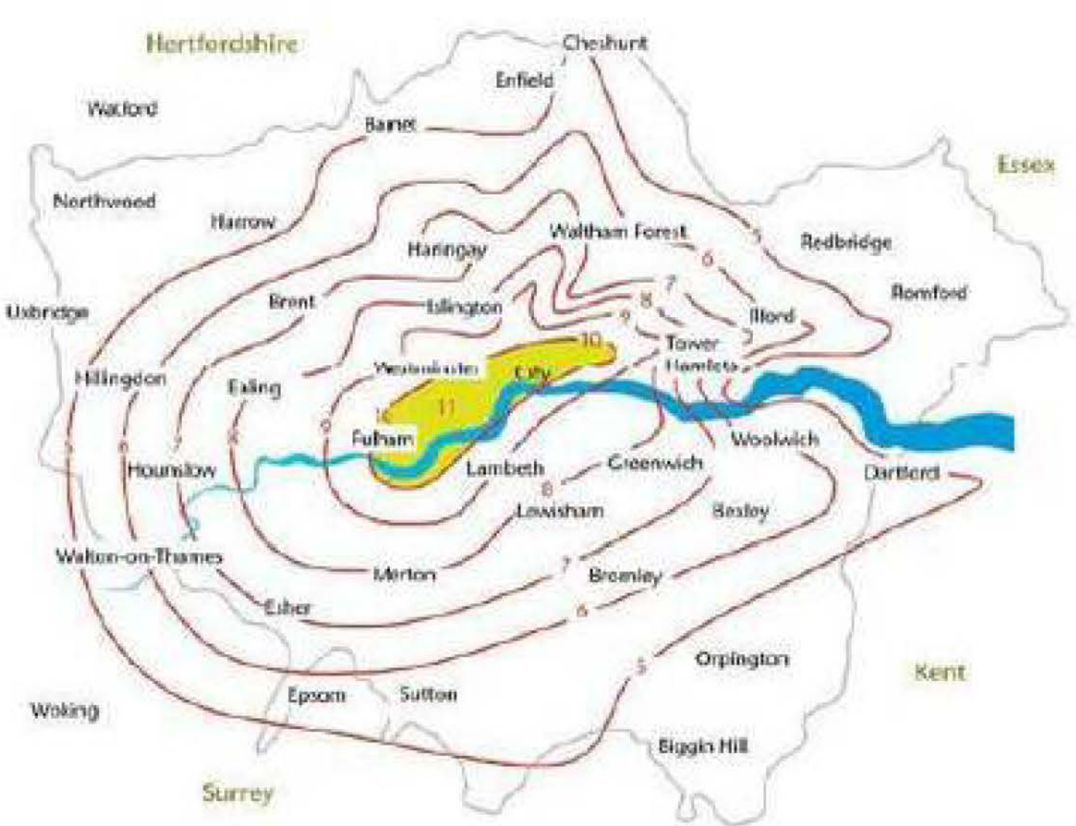
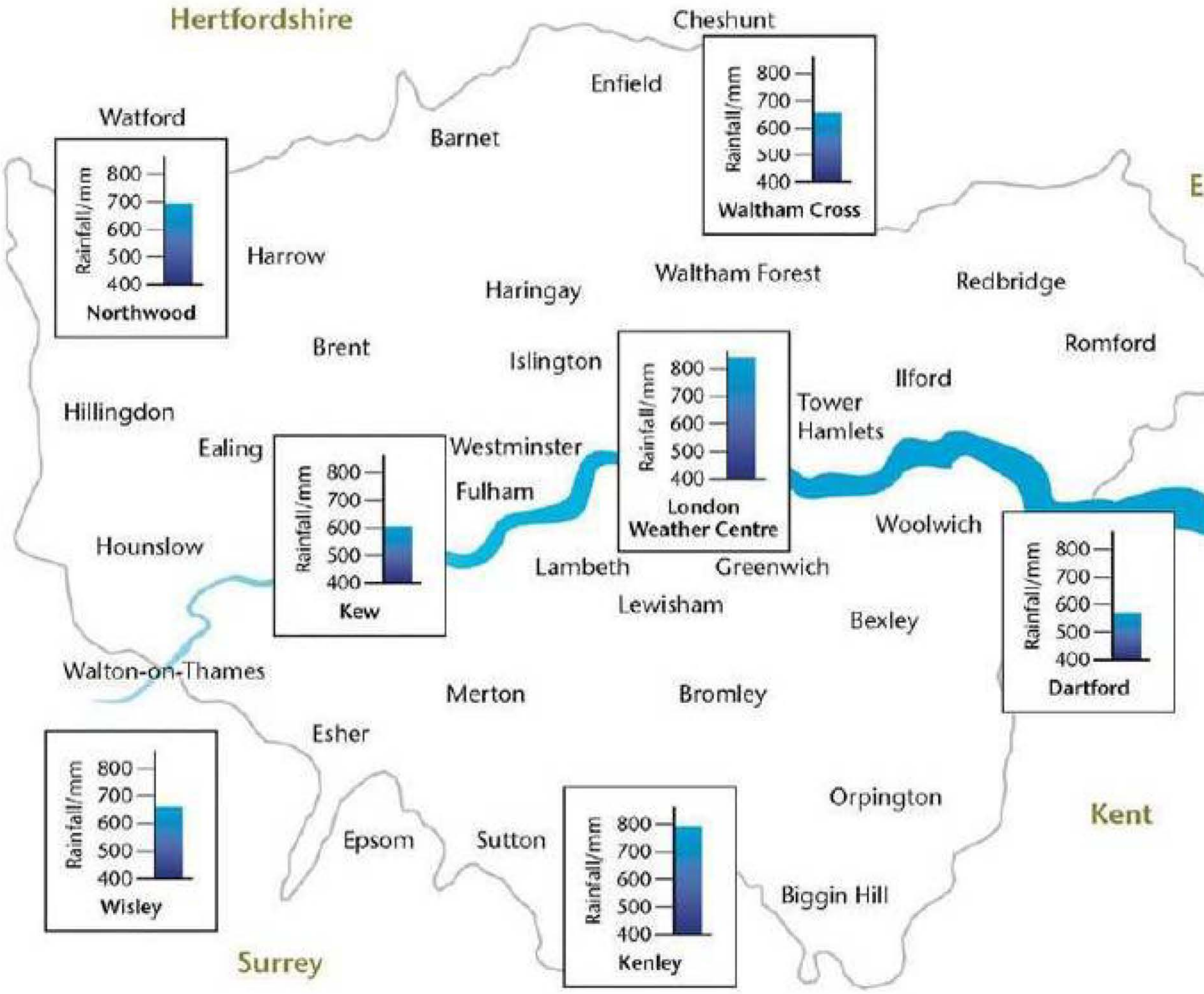


Figure 2.42 London's heat-island effect, showing minimum temperatures (°C) in mid-May



Source: National Meteorological Library and Archive Fact sheet 14 — Microclimates; Figure 16. Mean annual rainfall totals for a number of stations around London. www.metoffice.gov.uk/media/pdf/n/9/Fact_sheet_No._14.pdf

Figure 2.43 Variations in mean annual rainfall around London

Recent research on London's heat island has shown that the pollution domes can also filter incoming solar radiation, thereby reducing the build-up of heat during the day. At night, the dome may trap some of the heat accrued during the day, so these domes might be reducing the sharp differences between urban and rural areas.

There is an absence of strong winds both to disperse the heat and to bring in cooler air from rural and suburban areas. Indeed, urban heat islands are often most clearly defined on calm summer evenings, often under blocking anticyclones.

The distribution of rainfall is very much influenced by topography, with the largest values occurring over the more hilly regions, and lowest values in more low-lying areas. Figure 2.43 illustrates this point quite clearly. Kenley on the North Downs, at an altitude of 170 metres above mean sea-level, has an average annual rainfall of nearly 800 millimetres, whereas London Weather Centre, at 43 metres above mean sea-level, has an average annual rainfall of less than 550 millimetres. Overall, humidity is lower in London than surrounding areas, partly due to higher temperatures (warm air can hold more moisture, hence relative humidity may be lower), but water is removed from large urban areas due to the combination of drains and sewers, the large amount of impermeable surfaces and the reduced vegetation cover.

The urban heat island creates the urban boundary layer, which is a dome of rising warm air and low pressure. As ground surfaces are heated, rapid evapotranspiration takes place. This evapotranspiration, although lower compared to rural areas, occurs more rapidly and can result in cumulus cloud and convectional weather patterns. Due to the low pressure caused by rising air, surface winds are drawn in from the surrounding rural fringe. This air then converges as it is forced to rise over the high urban canopy. The urban boundary essentially creates an orographic process similar to a mountain barrier. The movement of winds contributes to increased rainfall patterns over the city that are most pronounced to the leeward side of the city core. However, as air passes over the urban boundary layer it begins to sink, leading to lower precipitation at the leeward rural area. These differences are also more pronounced in the summer compared to the winter.

Some studies have demonstrated a pattern of increased rain through the week and have shown Saturday rain to be a result of a build-up of pollutants due to five consecutive commutes. By Monday, pollutants have fallen and rainfall is less likely to form.

Case Study: Urban microclimate – Cheong Gye Cheon, Seoul, South Korea

The impact of river restoration on urban microclimates

In Seoul, capital of South Korea, there has been a very marked change in the urban microclimate following the removal of a large, downtown elevated motorway, and the restoration of a river and floodplain that had been built over. Since the restoration of the stream, air temperature has decreased by up to 10–13 per cent; that is, by 3-4 °C during the hottest days. Before the restoration, the area was showing a temperature about 5 °C higher than the average temperature of the city. The decrease in the number of vehicles passing by also contributed to the drop in the temperature. The heat island phenomenon used to be observed in the Cheong Gye Cheon Stream area under the impact of the heavy traffic, concentration of commercial facilities and the impermeable surface.

Following the completion of the restoration, the wind speed has become faster (by 2.2–7.1 per cent). The average wind speed measured at Cheong Gye Cheon is up to 7.8 per cent faster than before, apparently under the influence of the cool air forming along the stream.

Figure 2.44 Cheong Gye Cheon – **a** when the area was developed with an elevated highway and **b** after restoration

Case Study: Urban microclimate – Melbourne, Australia

With increasing distance from the city centre, the amount of tree cover in a suburb decreases, while the amount of green space, such as lawns and parks, increases. In Melbourne, for every 10 kilometres from the city centre, the tree cover drops by more than 2 per cent. That means Melbourne's inner suburbs might have more than 15 per cent cover, but an outer suburb could have less than 10 per cent. A 5 per cent fall in urban tree cover can lead to a 1–2 °C rise in air temperature. This matters for community health and well-being, especially for the vulnerable – the elderly, young children and those with existing health issues.

Trees are missing from back gardens – partly because modern houses in the outer suburbs take up more space, leaving less room for trees – and they are missing from the streets. The property boom led to a gradual thinning out of tree cover in established suburbs, as residential plots were sub-divided.

Melbourne aims to increase tree cover by 75 per cent before 2040, Sydney by 50 per cent before 2030 and Brisbane is targeting tree cover for cycleways and footpaths.

Microclimate mitigation

Increasingly, there are attempts to reverse urban microclimates. Heat-island mitigation strategies include urban forestry, living/green roofs and light surfaces.

In general, substantial reductions in surface and near-surface air temperature can be achieved by implementing heat-island mitigation strategies. Vegetation cools surfaces more effectively than increases in albedo, and curbside planting is the most effective mitigation strategy per unit area redeveloped. However, the greatest absolute temperature reductions are possible with light surfaces.

Table 2.5 Characteristics of the London Plane tree

Characteristic	The London Plane tree
Aesthetic value	A tall elegant tree providing pleasant shade in summer and a pleasing winter silhouette. Flaking bark creates attractive colours on trunk.
Does it make a mess?	Leaves, fruit and bark need clearing from streets and pavements.
Pollution tolerance	Very tolerant of air pollution. Hairs on young shoots and leaves help to trap particulate pollution.
Pests and diseases	Rarely affected by disease and pests (although some shoots are killed each year by fungal infection).
Soil conditions	Very tolerant of poor soil conditions, including compacted soil (although some stunting of growth is caused by road salt).
Space	Grows vigorously and is very tolerant of pruning.
Safety hazards	Trees rarely blow over or shed branches. Fine hairs on young shoots, leaves and fruit may cause irritation and even allergies in some people.
Microclimate	Open canopy produces light shade. Will intercept some rain, especially when in leaf.
Biodiversity	Provides valuable nesting sites for birds. Sufficient light below canopy to allow significant plant growth.

Source: Adapted from the Field Studies Council's Urban Ecosystems website www.field-studies-council.org/urbaneco

The London Plane tree – urban saviour

With an extensive and healthy urban forest, air quality can be drastically improved. Trees help to lower air temperatures through increasing evapotranspiration. This reduction of temperature not only lowers energy use, it also improves air quality, as the formation of ozone is dependent on temperature. Large shade trees can reduce local ambient temperatures by 3 to 5 °C. Maximum midday temperature reductions due to trees range from 0.04 °C to 0.2 °C per 1 per cent canopy cover increase.

Living roofs offer greater cooling per unit area than light surfaces, but less cooling per unit area than curbside planting.

Although street trees provide the greatest cooling potential per unit area, light surfaces provide the greatest overall cooling potential when available area is taken into account because there is more available area in which to implement this strategy compared to the other strategies.

Section 2.4 Activities

1 State the conditions in which London's heat island is most pronounced.
2 Briefly suggest reasons for variations in temperature as shown in Figure 2.42.
3 Describe and explain how the urban microclimate in Seoul changed after river restoration.
4 Explain the advantages of the London Plane tree for urban areas.