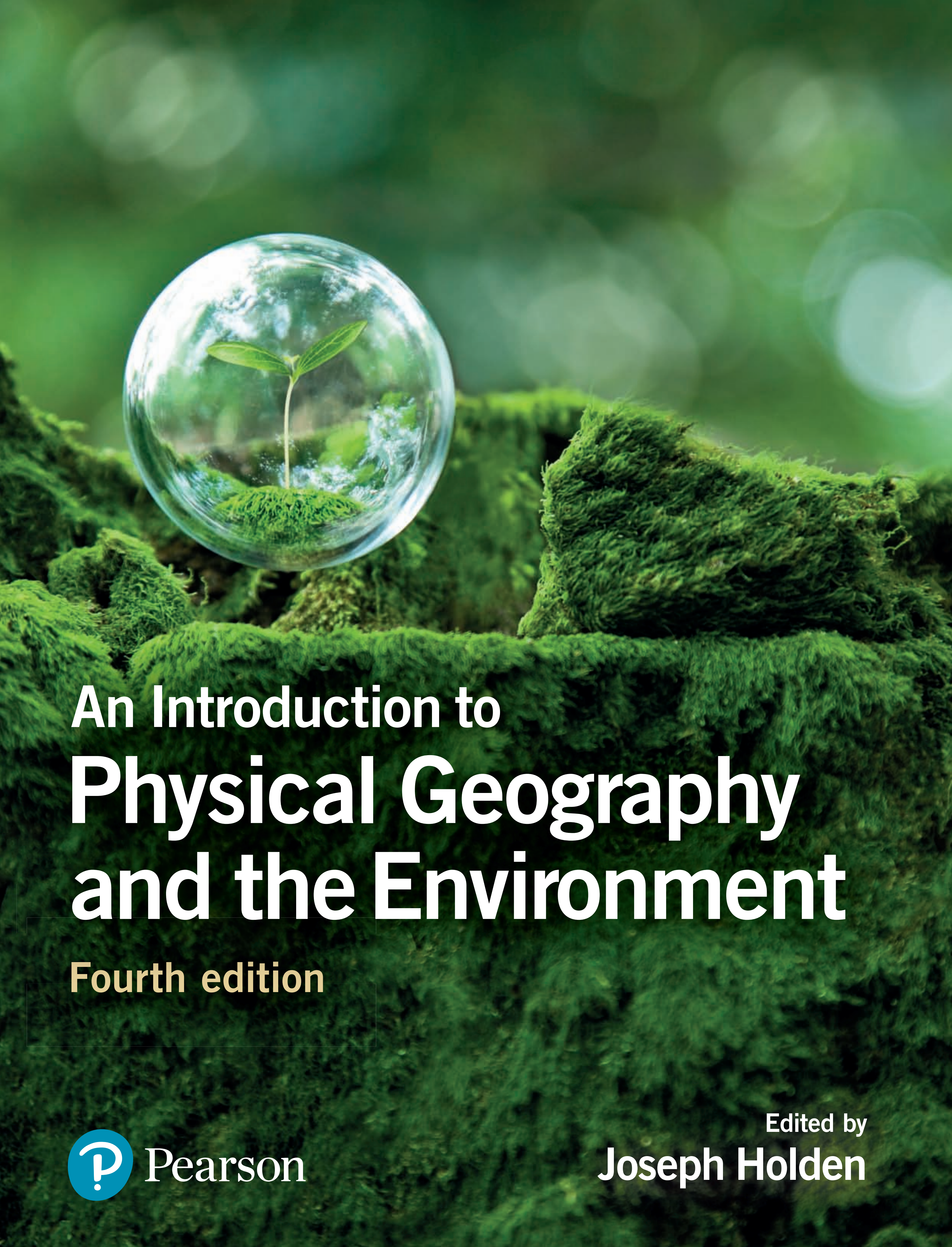

An Introduction to Physical Geography and the Environment

Fourth edition

Pearson

Edited by
Joseph Holden

An Introduction to

Physical Geography and the Environment

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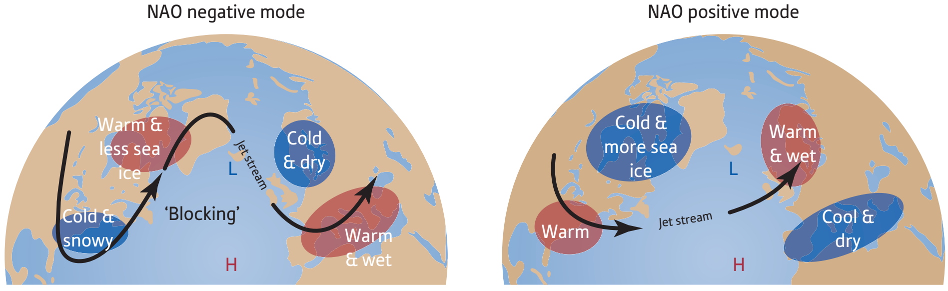

Figure 8.31 Phases of the NAO.

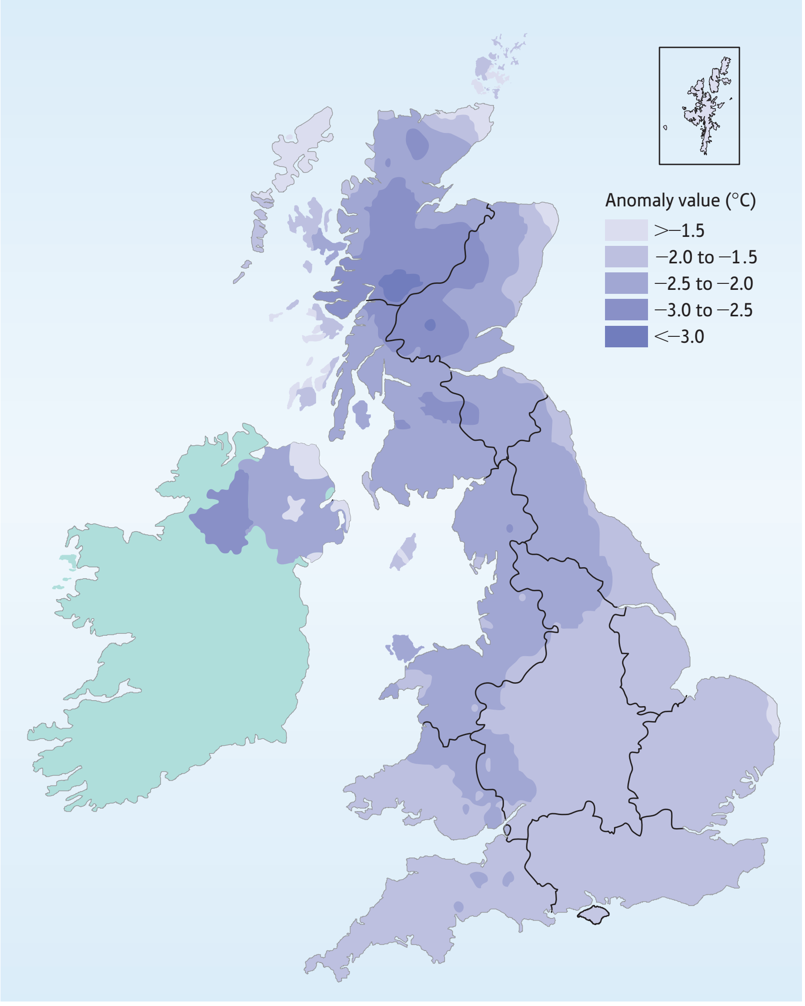

Figure 8.32 Winter 2010 mean temperature anomaly from the 1971–2000 average. (Source: Met Office, 2011)

BOX 8.5 ➤

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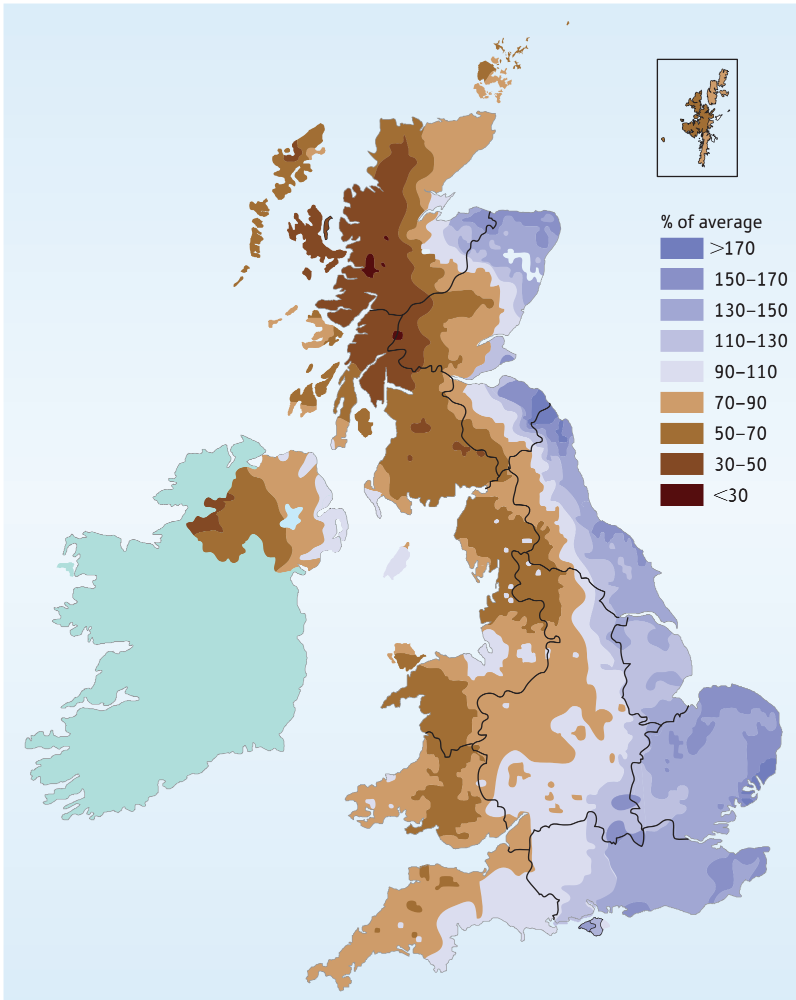

Figure 8.33 Winter 2010 rainfall amount (% of 1971–2000 average). (Source: Met Office, 2011)

BOX 8.5

Reflective question

➤ The raw data for the global temperature series can be found on the Climatic Research Unit website (www.cru.uea.ac.uk/cru/data/temperature/#datdow) with the temperatures being given as anomalies from the 1961–1990 average of 14.0°C. The ENSO data can be found at www.esrl.noaa.gov/psd/people/klaus.wolter/MEI/table.html. Does there appear to be a relationship between the ENSO values and the global temperature anomalies? (Hint: do not look at absolute values but at the direction of change: are the anomalies getting larger or smaller as the ENSO Index changes in particular years? Look especially at the El Niño years of 1982–1983, 1986–1988, 1997–1998, 2009–2010 and 2015–16 and in the La Niña years of 1988–1989, 1998–2001, 2006–2008 and 2010–2012. Do not assume that any signal will be clear.)

8.7 Summary

This chapter has shown that the climate of any region is a result of the type and frequency of the weather systems found in that region. Major features of atmospheric circulation including zones of ascending and descending air such as the ITCZ (ascending), the subtropical anticyclones (descending) and the slantwise convection at the polar front (ascending) play an important role in climate.

Equatorial climates are dominated by movements of the ITCZ whereas at higher latitudes in the tropics the easterly wave, monsoonal conditions and tropical cyclones may be more important, although it is still the movement of the ITCZ that partly controls these. Thus, some regions may have a fairly constant climate but are subject to occasional extreme events that have a substantial impact (e.g. regions prone to tropical cyclones). At still higher latitudes in the tropics, desert conditions are prevalent associated with the anticyclonic conditions related to the descending limb of the Hadley cell.

The distribution of land masses and oceans play an important role in global climates. Thus the southern hemisphere experiences different mid and high-latitude climate conditions to the northern hemisphere owing to the lack of land masses within these regions. Air masses are important in the middle and high latitudes. They are distinguished by the source area from which they originate (continental or maritime, polar or tropical). The boundaries between air masses are known as fronts and represent sharp contrasts in temperature and moisture contents of the air. At fronts the warm air rises above the cooler air, often resulting in condensation and precipitation. Continental interiors tend to have different climates from those close to oceans even at the same latitude.

Individual climate elements and their changes through the year vary in their importance between different climates. For example, the distribution of precipitation during the year as well as annual precipitation totals is important because a region may not be arid if there is a winter rainfall maximum, even if it has a fairly low annual total and a hot summer. In some regions the heat and humidity of the summer are the dominating features of the climate while in others it may be precipitation totals or winter cold. There are also some climate types where there may be large differences between individual locations in one or more climate element (this is discussed further in Chapter 9). It is also important to recognize that climate types do not have distinct boundaries, as unless there is a major mountain barrier one type of climate usually merges gradually into another.

Finally, it is clear that far from being constant, the climate, even as measured over the normal 30 year climate period, is not constant. During the instrumental record before the twentieth century these climate changes were relatively small, but the last 100 years have been marked by a period of increasing temperatures.

Further reading

Ahrens, C.D. (2015) *Meteorology today – An introduction to weather, climate, and the environment*, 11th edition. Cengage Learning, Boston.
This American textbook provides a good clear overview and is very nicely illustrated with colourful figures. There are lots of reflective and essay-style questions.

Barry, R.G. and Chorley, R.J. (2009) *Atmosphere, weather and climate*, 9th edition. Routledge, London.
This book contains useful chapters on air masses, fronts and depressions and on climates of temperate and tropical zones. It has been a very popular book over the years.

O'Hare, G., Sweeney, J. and Wilby, R. (2005) *Weather, climate and climate change*. Prentice Hall, Harlow.
Excellent and accessible introduction to the area.

Robinson, P.J. and Henderson-Sellers, A. (1999) *Contemporary climatology*. Pearson Education, Harlow.
This book contains good sections on tropical and mid-latitude climates.

Wang, S.-Y., Huang, W.-R Hsu, H.-H. and Gillies R. R. (2015) Role of the strengthened El Niño teleconnection in the May 2015 floods over the southern Great Plains. *Geophysical Research Letters*, 42, 8140–8146, doi:10.1002/2015GL065211
An important research paper highlighting teleconnections that have been strengthened due to global warming focusing on the case of the severe flooding in Texas and Oklahoma in May 2015.

CHAPTER 9

Regional and local climates

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Learning objectives

After reading this chapter you should be able to:

- **understand how local factors can modify regional climate**
- **understand how altitude and topography control local and regional climates**
- **describe how large water bodies influence local and regional climates**
- **recognize how human activity can have a deliberate or inadvertent impact on local climate**

9.1 Introduction

There is substantial variation at the local and regional scales within the global climate zones discussed in Chapter 8. In some places the variation is part of a relatively gradual change from one climate type to another. For example, in the mid-west states of the United States, moving north from Tennessee through Kentucky to Illinois (Figure 9.1) there is a steady change in climate. The whole of this large area north of the southern half of Missouri, Illinois and Indiana and north of the whole of Ohio (i.e. the coverage of Figure 9.1) is within the humid continental climate type. However, there are more gradual regional variations. Tennessee has a humid subtropical climate but from Illinois to the north into Canada the climate is described as humid continental (see Chapter 8). In moving northwards the winters become increasingly severe. Northern Iowa has summers that are noticeably cooler than the hot humid summers experienced in the south of Missouri. This cooling of the summers continues into Canada. North of Winnipeg the summers become much shorter with less than four months having temperatures above 10°C. Iowa, Wisconsin and Michigan are within the same climate subtype with at least four summer months with temperatures above 10°C. However, even within this area, there are marked regional variations in climate on top of the gradual change northwards. The most obvious of these differences are associated with the areas bordering the Great Lakes of Michigan and Superior.

In any climate region, there can be very marked local variations in certain climate elements. For example, over a distance of little more than 100 km across Scotland there are places in the west where the total annual precipitation is nearly 10 times greater than that in parts of the east. However, on a global or even European scale the whole of Scotland falls well within the limits of a single climate

Figure 9.1 The mid-west United States and the Great Lakes.

type. The classification or description of a climate at a particular place therefore depends on the scale at which that climate is being considered. The smaller the geographical extent of the area of interest, the more important it becomes to have detailed climatological observations and statistics in order to specify the climate of an individual location. It is also important to note that regional and local climates are a feature of the land and not the oceans because altitude, topography and proximity to the sea (or large bodies of water) are the key features that lead to the development of local and regional climates. These factors and associated processes will be discussed in this chapter as it is important to understand how both local and global processes interact at different scales. This interaction helps to explain the nature of local and regional climate across the Earth's surface.

9.2 Altitude and topography

The climate of mountains has always been of interest to scientists. Early studies helped establish that pressure and temperature fell with height and in the latter part of the nineteenth century a number of mountain observatories were established in Europe and North America to support astronomical studies and weather forecasting. Examples include Mount Washington (New Hampshire, established 1870), Sonnblick (Austria, 1886) and Ben Nevis (Scotland, 1883). Some of these mountain observatories closed after 10–20 years of observations (e.g. Ben Nevis, 1883–1904) but many are still in existence. The rate of fall of temperature with altitude (the **lapse rate**, see Box 9.1) varies in different parts of the world. The amount of solar radiation that can potentially be received by the ground surface actually increases with height. This is because less radiation has been absorbed or reflected by components of the atmosphere back into space by the time it reaches the ground at higher altitudes. The lower the altitude, the thicker the layer of atmosphere that can reflect solar radiation back into space. However, whether solar radiation received at the ground surface actually increases with height in any particular mountain range depends upon local cloudiness. Harding (1979) reported that in the mountains of the United Kingdom, which tend to be cloudy, solar radiation decreased by 2.5 to 3 million J m^{-2} day^{-1} km^{-1}, which was regarded as typical by Grace and Unsworth (1988). Nevertheless, even in those areas where received solar radiation increases with altitude, temperature is still likely to decline upwards because of **adiabatic** processes (see Table 9.1). In many places, wind speed and precipitation increase with altitude but this is not true everywhere. Substantial mountain ranges can also act as a barrier to the movement of

Table 9.1 Predicted change of pressure and temperature with height based on a lapse rate of 6.5°C per 1000 m (pressure *P* in hPa or millibars and temperature *T* in °C)

Height (m) (above mean sea level)	Tropical		Mid-latitude		High-latitude	
	P	*T*	*P*	*T*	*P*	*T*
0	1013	25.0	1013	15.0	1013	5.0
1000	902	18.5	899	8.5	894	−1.5
2000	801	12.0	795	2.0	788	−8.0
3000	710	5.5	701	−4.5	691	−14.5
4000	627	−1.0	616	−11.0	605	−21.0
5000	552	−8.5	541	−17.5	527	−27.5

FUNDAMENTAL PRINCIPLES

LAPSE RATES

The rate at which temperature falls with increasing altitude is known as the **environmental lapse rate**. An air parcel will rise if it is warmer than the surrounding environment. Once the air parcel reaches the same temperature as the surrounding environment it will stop rising (Figure 9.2). When air rises (ascends) it expands. This is because the air pressure decreases. Conversely if air sinks (descends) it is compressed as the pressure increases. If no energy is added to or lost from that air as it rises (or falls), the changes in pressure and temperature are the result of what is termed an adiabatic process. When air rises and the pressure falls, the energy for the expansion of the air comes from the air itself. As temperature is a measure of the energy of air, if energy is removed by expansion of the air then the temperature of the air decreases. The reverse is true if air sinks and is compressed, in which case the temperature of the air increases.

If air expands adiabatically as it ascends, the temperature of the air falls at a constant rate of 9.8°C km^{-1} (Figure 9.2). If air is compressed adiabatically as it sinks the temperature of the air increases at the same rate. This rate of temperature change is called the dry adiabatic lapse rate and applies only if the atmosphere remains unsaturated. Air can hold only a certain amount of water vapour at any temperature and if the temperature falls or if more water is evaporated into the atmosphere then once saturation is reached water vapour will condense out of the atmosphere. When water condenses out of the air, energy is released. This energy is the **latent heat** of vaporization and is the energy released when gaseous water vapour condenses into liquid water. When water evaporates or ice melts, this uses up energy in order to change the state of the water but without changing the temperature of the water (see Chapter 6). When the reverse occurs energy is released. This energy release reduces the cooling rate of the air as it rises and expands. In the absence of any loss of total water content (gaseous, liquid or solid water) from the air, the rate of change of temperature with height is given by what is termed the saturated adiabatic lapse rate.

Unlike the dry adiabatic lapse rate, the saturated adiabatic lapse rate depends on the amount of water vapour the air can hold at any temperature. The amount of water vapour air can hold more than doubles for each 10°C increase in temperature (Table 9.2). This means that the amount of latent heat released is much less at low temperatures than at high temperatures as less water vapour will condense out of the air at lower temperatures. The saturated adiabatic lapse rate therefore varies from around 0.3°C per 100 m close to the surface in the tropics, where air temperatures are over 30°C, to close to the dry adiabatic rate at temperatures below −40°C. Temperatures of below −40°C are normally found at heights of between 5 and 10 km in mid-latitude regions.

When saturated air ascends, the temperature decreases at the saturated adiabatic lapse rate and the water that condenses out of the air forms a cloud. However, when saturated air descends, it will warm at the saturated adiabatic rate only if all of the liquid or solid water (cloud droplets or ice crystals) is evaporated back into the air. If any of the water has fallen out of the cloud as precipitation there will be less water to evaporate and the air will therefore warm more on descent than it cooled on ascent.

The difference between the dry and saturated adiabatic lapse rates is crucial

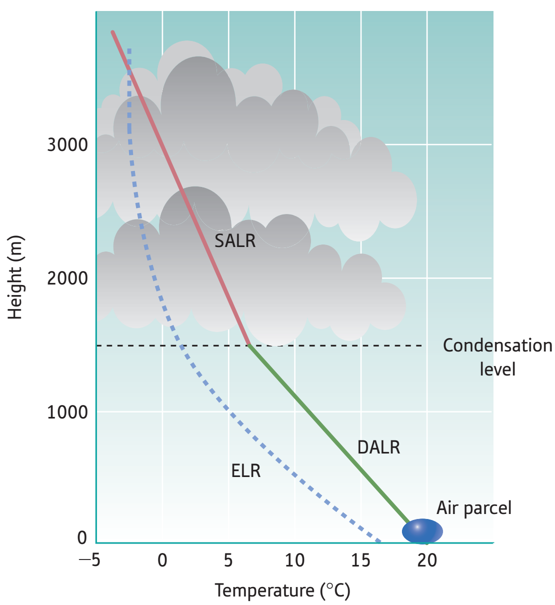

Figure 9.2 Air parcel buoyancy. A parcel of air warmed at ground level will rise if it is warmer than its surroundings and will cool at the environmental lapse rate (ELR). Note that the top of the cloud occurs where the air parcel temperature is the same as its surroundings. DALR – dry adiabatic lapse rate (9.8°C/1000 m); SALR – saturated environmental lapse rate.

BOX 9.1 ➤