# 1 The tropical environment and climate

Alphonse de Candolle in 1855 proposed that the boundaries to major plant formations were set by climate. He suggested that the limits to deserts and grasslands were set by moisture, but that the latitudinal arrangement of the other plant formations indicated temperature as the dominant factor. Köppen (1884, 1931) developed climate maps based on vegetation types. In this way, he was able to produce a climate map of the world even though he had very little climatic data from many parts of it. He assigned to each plant formation the climate that seemed appropriate to it. Since his climate map was based on the global distribution of vegetation types, it is not surprising that climate and vegetation maps were similar. It has subsequently been shown that the distribution of the world's climatic regions is indeed closely related to vegetation and Köppen's vegetation-derived climate map has now been verified through climatic measurements. Clearly climate plays a major role in determining the global distribution of plants and animals and Figures 1.1 and 1.2 show the close relationship between rainfall and vegetation in Africa.

This chapter describes climate in the tropics and how it differs from that found in temperate regions. It describes how the world's climate is changing through an enhancement of the greenhouse effect (global warming), and how this climate change is impacting tropical ecosystems. Variations in climate regime and soil type mainly determine the regional distribution of vegetation types and, hence, animal communities, and these patterns are studied by biogeographers. An explanation of these plant and animal distributions also requires an understanding of the theory of plate tectonics.

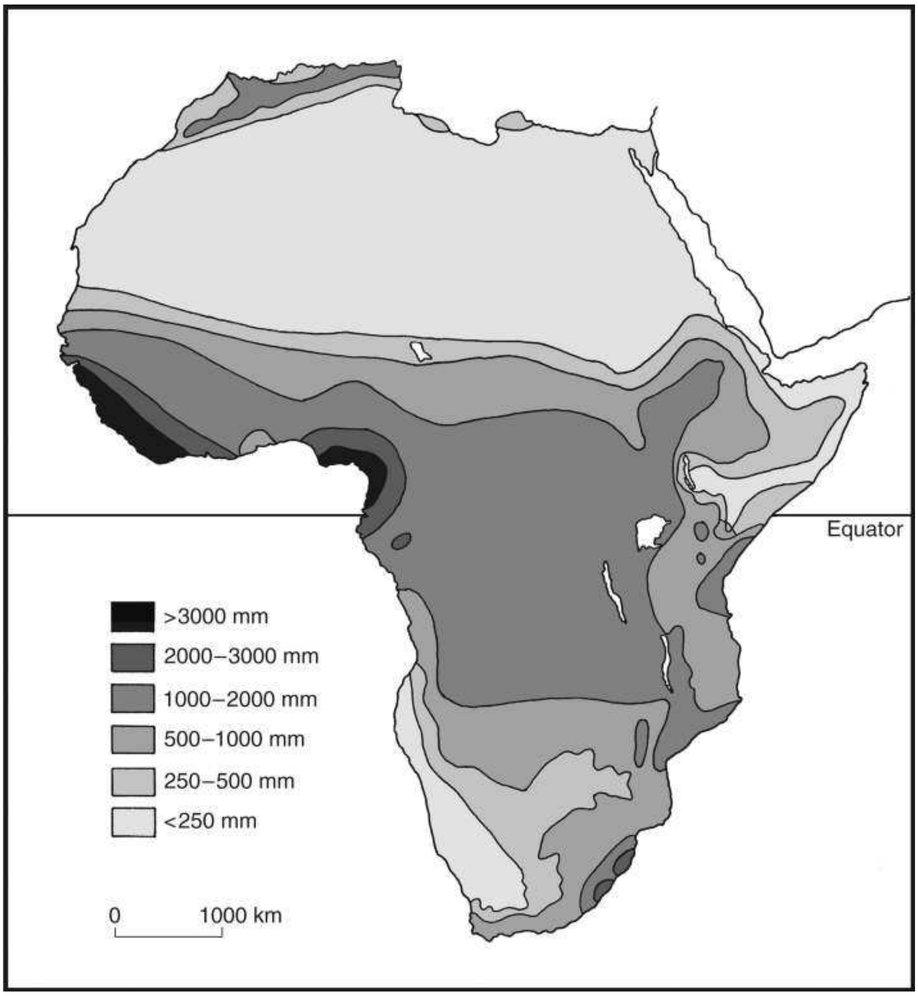


**Figure 1.1** Distribution of total annual rainfall in Africa (after Pomeroy and Service 1986, with kind permission from Pearson Education Limited.

## 1.1 The tropics

The tropics may be defined as that portion of the Earth situated between the Tropics of Cancer (23° 28′N) and Capricorn (23° 28′S). This area includes about 50 million km$^2$ of land, with almost half of it in Africa. Other substantial portions lie in Central and South America, southern Asia and northern Australia, with smaller areas in the Pacific Islands. Plant and animal distributions are not constrained by these lines on the globe but are determined by variations in climate, soil type and other features of the environment. However, it is interesting that the distribution of tropical rain forests, mangroves and coral reefs do largely fall between these lines (Figures 8.2, 10.2, 11.10). Therefore, it would seem appropriate to use the Tropics of Cancer and Capricorn as guides to the parts of the Earth described in this book even though the distribution of tropical plants and animals may not, in some places, extend as far as these lines or, in others, extend north or south of them.

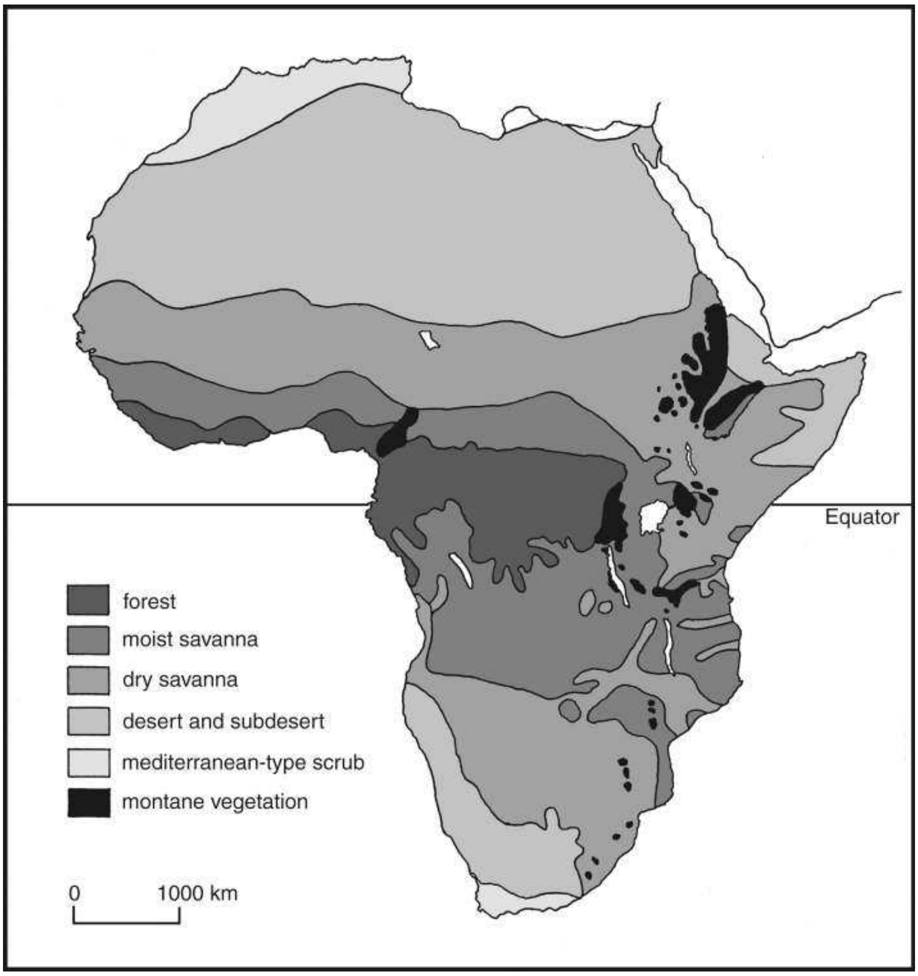


**Figure 1.2** Distribution of the main types of vegetation in Africa. Note the relationship between the distribution of rainfall (Figure 1.1) and vegetation type (after Ewer and Hall 1978, with kind permission from Pearson Education Limited).

## 1.2 Tropical and temperate environments

Climatic variations are largely determined by latitude and altitude. Tropical lowlands are warm throughout the year with daily variation often exceeding seasonal changes in temperature. There is no winter in the tropical lowlands. Even at higher altitudes, diurnal temperature variations are more significant than seasonal changes (see chapter 9). This contrasts with temperate mountains where climate is markedly seasonal. Seasonality in the tropics is more strongly imparted through variation in rainfall rather than temperature. In temperate areas rainfall is generally more uniformly spread throughout the year, and temperature is the key seasonal factor. Seasonal extremes in temperature in the temperate zones of the northern hemisphere are greater than those in the southern hemisphere since the larger area of the southern oceans moderates temperature extremes.

Surviving a temperate winter is a challenge to many organisms and mechanisms to do this include physiological and behavioural adaptations (losing leaves, sequestering food), hibernation or a life history that includes an over-wintering, dormant stage. Another strategy for mobile organisms such as birds is to migrate to a warmer climate. Most bird species that breed in the tropics remain there throughout the year and are able to survive even in areas with a pronounced dry season. Many birds which breed in temperate areas migrate to the tropics to avoid low winter temperatures and poor food availability. These birds require suitable habitats in both the temperate and tropical expanses of their ecological range as well as along their migration route. These species provide an excellent example of a link between tropical and temperate regions and their conservation will require co-operative efforts between temperate and tropical countries. Numerous migrants move from the vast area of North America and congregate in much smaller areas in Central America and the Caribbean. This influx exerts considerable pressure on food supplies in these areas and disrupts the resource partitioning patterns (see section 4.9.5) established when the migrants were absent.

Rainfall seasonality in the tropics drives the life-history strategies of many tropical organisms and we will see examples throughout this book: wildebeest migration in the Serengeti (section 4.5), reproduction and resource allocation in savanna grasses (section 3.2), breeding in riverine fish (section 6.3.7) and mangrove leaf production (section 10.5).

In the wet, tropical lowlands, plant growth is more uniform and trees tend not to exhibit the annual growth rings found in their temperate counterparts. Fruit production by tropical trees is less seasonal and therefore specialist frugivores are more common in the tropics. Leaves on tropical trees tend towards a more uniform shape and are heavier than those on trees in temperate areas. As tropical trees retain their leaves for longer, it is worth investing resources in them and to protect those resources from herbivores. Trees in temperate regions produce thin leaves that can be shed in the autumn with less loss of resources.

## 1.3 Tropical climates

In concentrating on tropical latitudes, we have narrowed the latitudinal range but significant climatic shifts can still be related to geographical position. The major climatic factors are temperature (daily and seasonal variations) and rainfall (total rainfall and its seasonal distribution).

### 1.3.1 Temperature

In contrast with temperate regions, the most significant climatic feature of the tropics at sea level is the absence of a cold season. The mean annual temperature at sea level usually exceeds 18 °C and seasonal fluctuations in temperature and daily solar radiation are small (Table 1.1). Consequently, seasonality in temperature has less effect on biological activity in the tropics than it has in temperate regions. At higher altitudes in the tropics, diurnal temperature fluctuations can be significant: high during the day and down to, or below, freezing at night (see section 9.1).

Temperatures on the Earth's surface follow daily and seasonal cycles; daily because the Earth rotates on its axis and seasonal because the Earth's axis of rotation is not at right angles to the line joining the Earth and sun (Figure 1.3). If it were at right angles, the sun would be overhead at the Equator every noon throughout the year. As the Earth is tilted, the noon position of the sun moves progressively north after 21 March (**equinox**) and at noon on 21 June (**summer solstice**) it is directly overhead the Tropic of Cancer. The sun then appears to move south, crossing the Equator on 23 September (equinox) to be directly over the Tropic of Capricorn at noon on 22 December (**winter solstice**). The solstices are named after the prevailing season in the northern hemisphere. After 22 December, the sun appears to move north again and is directly over the Equator at noon on 21 March.

The tropics are hotter than temperate regions because the sun's rays strike almost at right angles near the Equator, but at an increasingly acute angle towards the poles. Therefore the same amount of radiant heat is concentrated over a smaller area in the

Table 1.1 **Annual range of daily solar radiation at the top of the atmosphere at tropical and temperate latitudes**

| Latitude | Daily max J $cm^{-2}$ $d^{-1}$ | Daily min J $cm^{-2}$ $d^{-1}$ | Maximum/ minimum | [(Max–Min) × 100]/Min |
|---|---|---|---|---|
| 0° | 3890 | 3430 | 1.13 | 13.4 |
| 10°N | 3786 | 3180 | 1.19 | 19.1 |
| 23°N | 4100 | 2552 | 1.61 | 60.7 |
| 50°N | 4309 | 878 | 4.90 | 390.7 |

*Note*: At the Equator, the annual maximum solar radiation is only 13% higher than the minimum. This percentage increases sharply outside the tropics and reaches almost 400% at 50°N and S.
*Source*: List (1971).

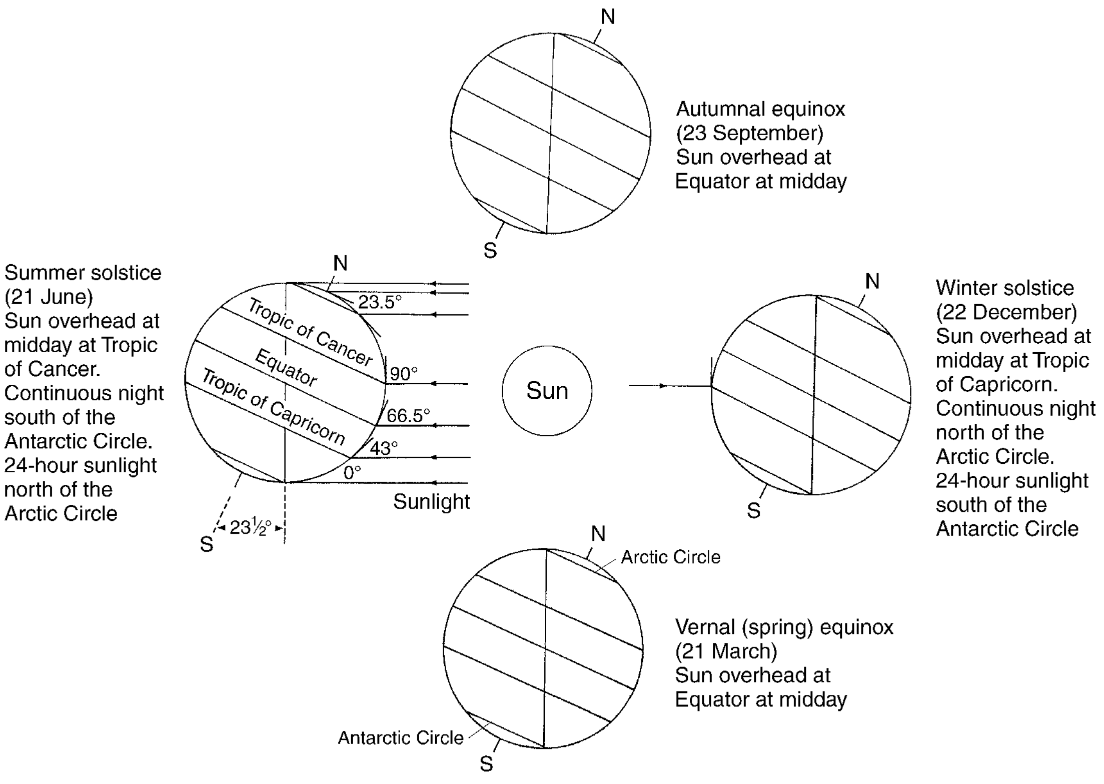


**Figure 1.3** Rotation of the Earth around the sun. The axis of rotation is tilted at 23.5° from the vertical. At the summer solstice (northern hemisphere summer) the sun is overhead at midday at the Tropic of Cancer. At the winter solstice (northern hemisphere winter), the sun is overhead at midday at the Tropic of Capricorn (after Pomeroy and Service 1986, with kind permission from Pearson Education Limited).

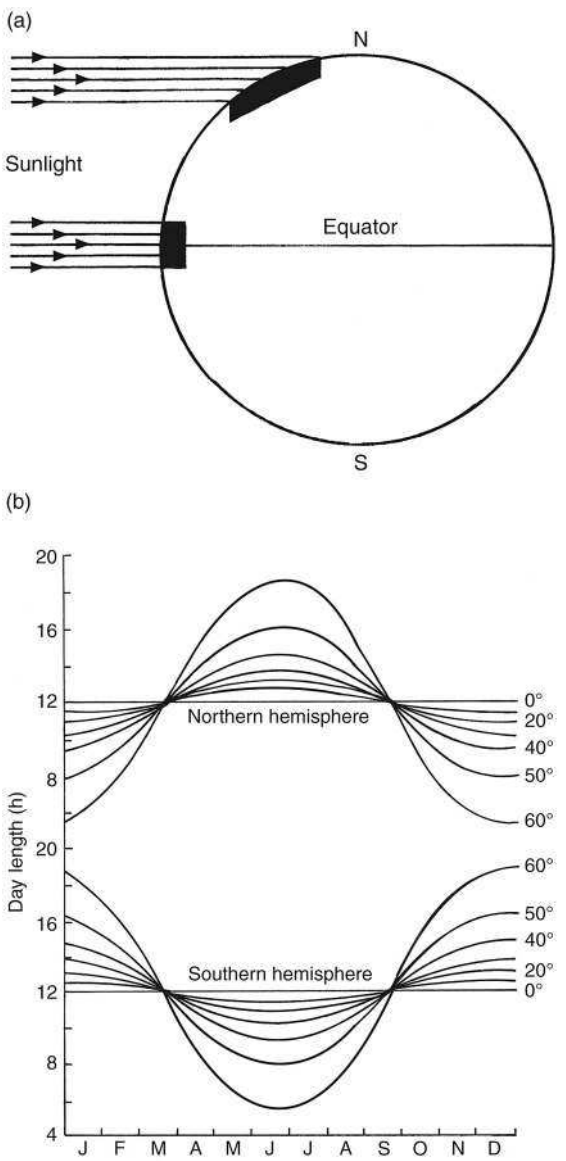


**Figure 1.4** (a) Owing to the spherical shape of the Earth, solar energy is concentrated over a smaller area in equatorial regions than in polar regions. Distance travelled through the atmosphere is also shorter at the Equator. Consequently, tropical regions are warmer than polar regions. (b) Variations in day-length throughout the year in relation to latitude in the northern and southern hemispheres.

tropics than it is nearer the poles (Figure 1.4a). Moreover, near the poles the sun's rays have to pass through a deeper layer of atmosphere and lose more energy by absorption, reflection and scattering.

Within the tropics, daily mean temperatures vary between 25–30 °C in lowland areas within 10° latitude of the Equator. At higher tropical latitudes, daily mean temperatures are higher (30–35 °C), owing to the lower moisture content of the atmosphere in this region. The annual range in daily mean temperature is 1–4 °C in lowland regions straddling the Equator, but this increases to 12–16 °C towards tropical margins (Lewis 2008). Day-length changes at latitudes away from the Equator partially compensate for the reduced heat input (Figure 1.4b), but total annual insolation is still lower at higher latitudes.

Through these variations in energy supply with latitude, lower latitudes have more heat, delivered at a more constant rate than higher latitudes. There is a mass transfer of heat away from the Equator, towards the poles. This transfer occurs in the oceans and the atmosphere. Oceanic heat transfer is significant since the heat capacity of water (see Box 2.2) is high, but heat transfer through the atmosphere is more rapid and is mostly responsible for the climatic shifts we observe on a daily basis.

### 1.3.2 The inter-tropical convergence zone and rainfall

The concentration of radiant heat above the Equator warms the air and it expands and rises. As it rises, the air cools and, since cold air holds less moisture, rain falls. The air near the ground is replaced by air from the north and south. The rising air spreads out and falls again at about 30°N and S (see Figure 2.2). In this region, cool, dry air warms as it falls to Earth and this explains why deserts are found at these latitudes (chapter 2).

The rotation of the Earth results in the deflection of these northerly and southerly winds so that they blow from the north-east (northern hemisphere) and south-east (southern hemisphere) respectively. This deflection is brought about by the **Coriolis force**. The Earth rotates from west to east. At the Equator, the rate of rotation is faster than it is either to the north or south, since, at the Equator, the Earth's surface is furthest from the axis of rotation. This force causes oceanic and atmospheric currents to be deflected to the right in the northern hemisphere and to the left in the southern hemisphere.

These winds (north-east (northern hemisphere) and south-east (southern hemisphere)) are known as **trade winds** (they were so named because of their consistent speed and direction (or trade), but they also powered sailing ships carrying trade goods to Europe from the Orient and America). These winds meet in an equatorial low-pressure trough, warm air ascends and precipitation results. This zone, the **Inter-Tropical Convergence Zone (ITCZ)**, is where mixing of trade winds from the northern and southern hemispheres often results in zones of low atmospheric pressure (depressions) or cyclones.

The ITCZ is not a continuous feature in either time or space. The ITCZ moves north of the Equator during the northern summer (June–August) bringing rain to the underlying regions. At the end of the northern summer, the ITCZ migrates south of the Equator and these regions have a wet season between November and January. Equatorial regions exhibit a bimodal rainfall pattern, with peak rainfall occurring each time the ITCZ crosses the Equator and adjacent areas. Hence, there is a seasonal migration of a rain belt which follows the seasonal movement of the sun. There may be a time lag between the apparent seasonal movement of the sun and the movement of the ITCZ owing to the time required for solar heating to impact the climate of the underlying region. There are days when ITCZ-generated clouds may stretch in an almost unbroken band around the globe, but it is often broken into strips and may disappear entirely. The mean position of the ITCZ in January and July is shown in Figure 1.5. Note that the ITCZ is not a straight line but is bent in places by the trade winds and topography.

### 1.3.3 Monsoons, typhoons and tropical storms

To the north and south of the trade winds, beyond 40°, lie the westerlies. The equatorial westerlies are responsible for the monsoons that occur over West Africa and the Indian sub-continent (Figure 1.5). Land masses heat more rapidly during summer than do the adjacent oceans and, conversely, the land cools more rapidly following the onset of winter. These differential rates of heating and cooling cause seasonal switches in winds. From May to October, air rises over the warm Asian interior and draws in moisture-laden air from the Indian Ocean over the Indian sub-continent (**south-west monsoon**) and air drawn from the Pacific flows over Asia (**south-east monsoon**). From November–April, air sinks over the cold Asian interior resulting in the north-east monsoons. Monsoons also occur in northern Australia and West Africa.

Air converging upon a low-pressure cell (**cyclone**) rises, the air cools, clouds form and rain falls. This contrasts with the warming and drying that occurs in a high-pressure cell (**anticyclone**). In the tropics, cyclones may form a rotating storm known as a **hurricane** (Atlantic Ocean), **typhoon** (Pacific Ocean) or **cyclone** (Indian Ocean). These storms can be devastating, causing flooding in coastal areas through storm surges and torrential rains. High wind speeds wreak further havoc. In 2005, Hurricane Wilma destroyed communities on Cuba and the Yucatan peninsula in Mexico. Cyclone Nargis made landfall over the low-lying Irrawaddy River delta of Burma in 2008, killing over 150 000 people (Figure 1.6). Recent computer models suggest that with global warming (see section 1.4) there will be a decrease in the overall frequency of tropical cyclones, but a doubling in the frequency of the strongest storms (categories 4 and 5) by the end of the twenty-first century (Bender *et al.* 2010). These storms not only affect the lives of humans living in their path but also cut a swath through forests, resulting in the destruction of large trees and providing an opportunity for their replacement with new individuals. This regeneration process can play a role in maintaining species diversity in tropical forests (see section 8.16).

### 1.3.4 Rainfall patterns and seasonality

Since land and sea absorb heat at different rates, diurnal and seasonal changes are larger on land than

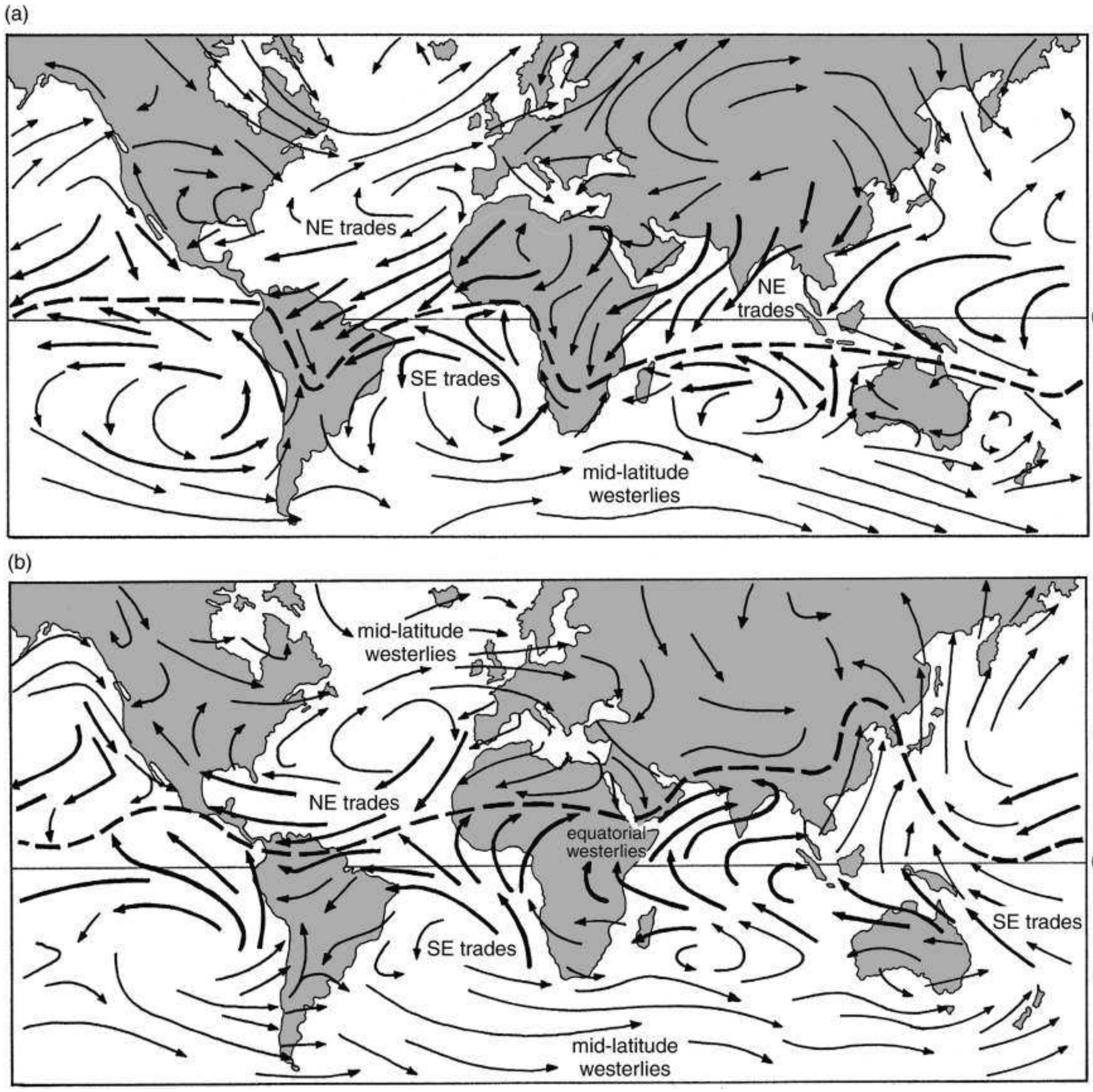


**Figure 1.5** Mean surface winds over the Earth in (a) January and (b) July showing the approximate position of the Inter-Tropical Convergence Zone (dashed line) (after White *et al.* 1993, with kind permission from Kluwer Academic Publishers).

in water. Tropical deserts are hot during the day but they lose heat rapidly at night by radiation of infrared energy and by conduction and convection (Figure 1.7). In contrast, tropical rain forests, with their mantle of cloud and vegetation are much cooler by day and retain warmth at night. The vegetation and clouds act as a blanket absorbing and reflecting radiation. Loss of heat by conduction and convection is minimised because the thick forest undergrowth reduces heat gradients and wind speeds (Table 1.2).

Variations in rainfall and humidity are extreme within the tropics and largely determine the suite of organisms that live in a particular region. Some desert areas receive no rainfall; rain forests may be deluged

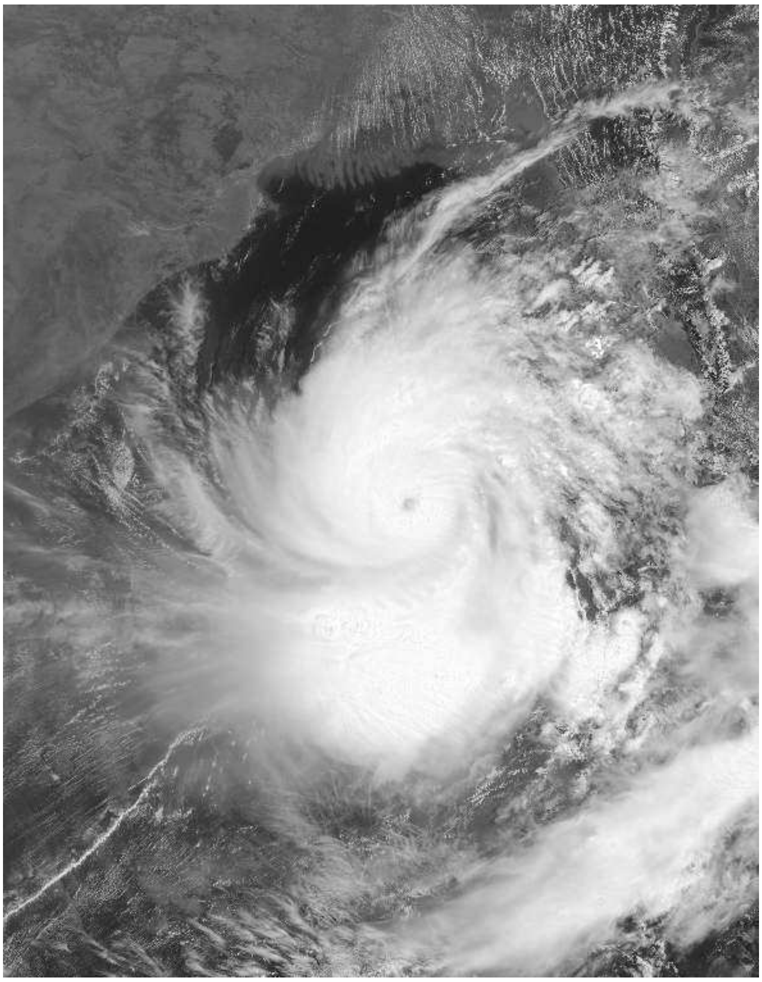

**Figure 1.6** Cyclone Nargis over the Bay of Bengal churns towards Burma in May 2008 (photo: NASA).

with more than 10 m of rain annually. The intensity of storms and the total amount of rain falling in heavy storms are considerably higher in the tropics than in temperate areas. Raindrops in tropical downpours are often larger and contain more potential energy and, therefore, more erosive power.

Considerable variation in rainfall can occur within a relatively short distance, especially where the topography is steep and mountainous. Rain may fall in heavy, localised storms and therefore rainfall, even within a small area, may be highly variable and unpredictable (Figure 1.8). The impact of this variability (and indeed the variability itself) is probably greater in areas where water is scarce (see chapter 2). In higher rainfall areas, where variability receives less attention, it is likely that variability is similar to that recorded at higher latitudes.

Rainfall intensity in the tropics is commonly so high that infiltration capacity is exceeded regardless of land management. This leads to water-logging on flat ground or soil erosion on slopes. The ratio run-off: infiltration depends on the rate of precipitation (drizzle or downpour), vegetation cover, soil porosity, litter cover and organic matter content of the soil, soil moisture level and topography.

The decrease in mean annual rainfall at increasing distances from the Equator is accompanied by increasing seasonality. The increase in seasonality is

Table 1.2 **Mean maximum temperatures and daily temperature range at two heights above the ground in tropical rain forest**

| | Dry season | | Wet season | |
|---|---|---|---|---|
| Sampling height (m) | 0.7 | 24.0 | 0.7 | 24.0 |
| Mean maximum (°C) | 29.7 | 33.9 | 26.8 | 30.9 |
| Daily range | 5.8 | 9.9 | 5.5 | 9.2 |

*Source*: Richards (1952).

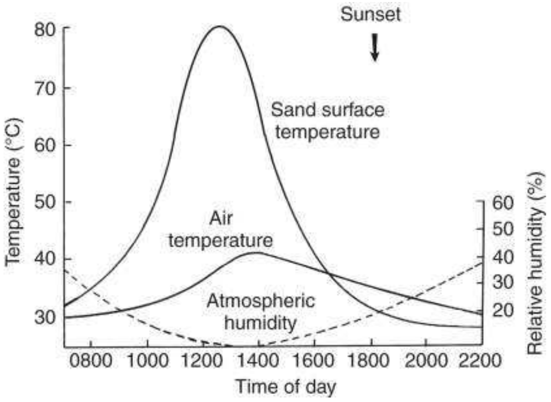


**Figure 1.7** Diurnal variations in air and soil surface temperature and humidity recorded in September at Wadi Halfa, Sudan (after Cloudsley-Thompson and Chadwick 1964, with kind permission from Cambridge University Press).

linked even more closely with the magnitude of change in day-length with increasing latitude (Figure 1.4b). In temperate regions, day-length plays a key role in providing organisms with a biological clock. However, within the tropics, seasonality in rainfall has greater impact on the life of tropical organisms. Germination, flowering and fruiting in tropical plants and breeding, feeding and life-history strategies in tropical animals are markedly affected by rainfall (see section 8.4.2).

Seasonal movements of animals (migration) are often made in response to food supply which, in turn, fluctuates in abundance with rainfall. The influence of environmental factors on organisms and their populations will be discussed in chapters 2, 3 and 4. An important general difference between tropical and temperate environments is that the wet tropics have seasonal rainfall and near-constant temperatures, whereas, in temperate areas, rainfall varies less during the year but temperature is markedly seasonal. Climate diagrams provide a convenient way to display temperature and rainfall patterns, and construction and interpretation of these diagrams is described below.

### 1.3.5 Climate diagrams

A good, comparative way of presenting climatic data is through climate diagrams developed by Walter and Leith (1967). In these figures, seasonal variations in temperature and rainfall are plotted on one diagram (Figure 1.9). The lower curve shows the mean monthly temperature (10 °C intervals on the y-axis); the upper curve presents mean monthly rainfall (20 mm intervals on the y-axis, except where rainfall exceeds 100 mm when the scale is reduced by 10:1). The area under this reduced scale is conventionally shaded black to indicate very wet periods. The reduced scale serves to keep the diagrams to a manageable size. Periods in which the curve for rainfall falls below that for temperature indicate arid months.

Another important convention in drawing these diagrams is that data from the northern hemisphere are plotted from January to December, those from the southern hemisphere from July to June. This facilitates visual comparison of diagrams from opposite sides of the Equator (Figure 1.10). These diagrams are compiled from mean values and therefore do not provide information on inter-annual or diurnal variations.

### 1.3.6 Distribution of tropical climates

Climate not only varies spatially and seasonally but variations also occur from one year to the next. We are beginning to understand some of these variations between years, and significant progress has been made in documenting and predicting the occurrence of one process which has worldwide impact. In the 1920s, attention was drawn to an oscillation in atmospheric