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Peter J. Holmes , Norma Catherine Winearls , Helen Collett
Excerpt
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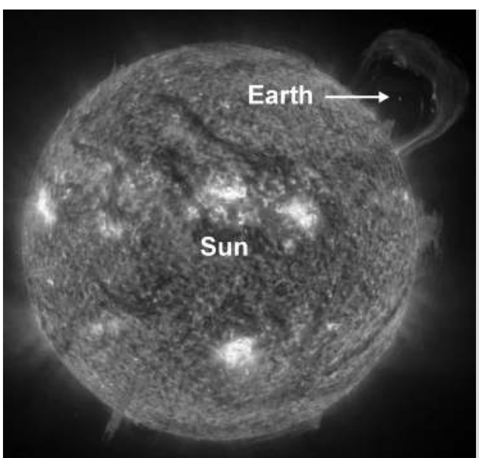
MODULE 1
GEOGRAPHICAL KNOWLEDGE

THE ATMOSPHERE



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UNIT 1: The Earth's energy balance

It is the imbalance in energy received at different times and different places that drives the Earth's weather. You are going to learn and understand more about this, and how the Earth attempts to balance out the situation.

Unequal heating of the atmosphere – latitudinal and seasonal

The Earth's atmosphere is heated by radiation from the Sun. Not all parts of the atmosphere receive the same amount of insolation (incoming solar radiation) (see Figure 1.1). This results in unequal heating; tropical areas receive too much heat energy, and **polar regions** do not receive sufficient heat.

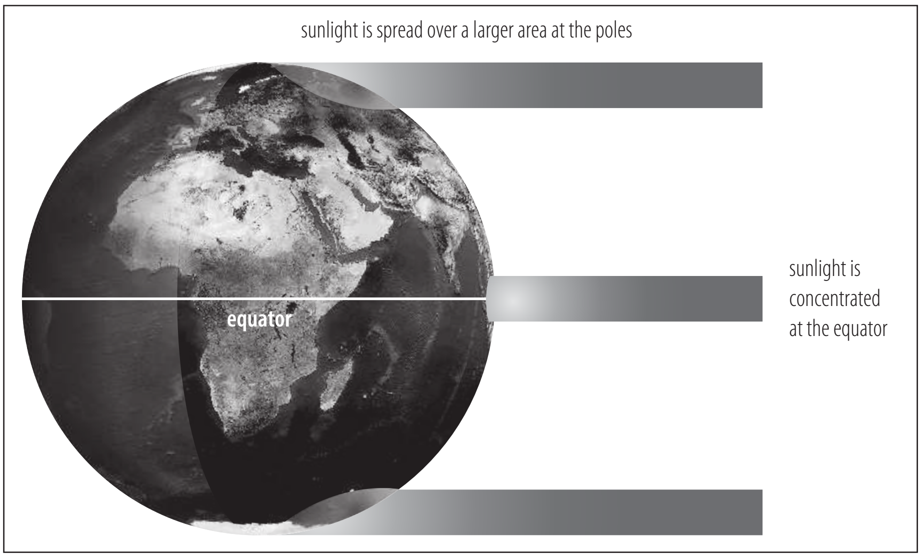

Figure 1.1 Equal amounts of insolation do not heat equal areas of the Earth's surface. The angle at which the insolation strikes the surface (called the angle of incidence) also differs, making it less effective towards the poles.

Activity 1.1 Define terms related to heating of the atmosphere

Define these terms:

1. energy
2. energy balance
3. insolation
4. polar regions
5. equatorial or tropical regions
6. angle of incidence

Significance of Earth's axis and revolution around the Sun

In many of the diagrams that follow, the Sun is shown as a small orange ball in the sky, or as a small ball close to the Earth. This can be very misleading, but it is the only practical way of showing the Earth and the Sun in one diagram. The Sun is on average 150 million km from the Earth. Its size in relation to the Earth is shown in Figure 1.2.

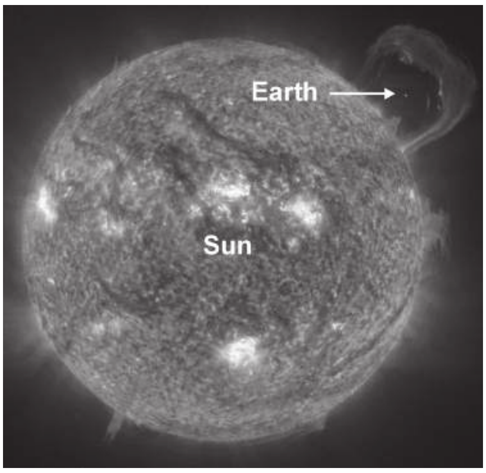

Figure 1.2 Relative sizes of the Sun and the Earth. In this image the distance between the two is not at all to scale.

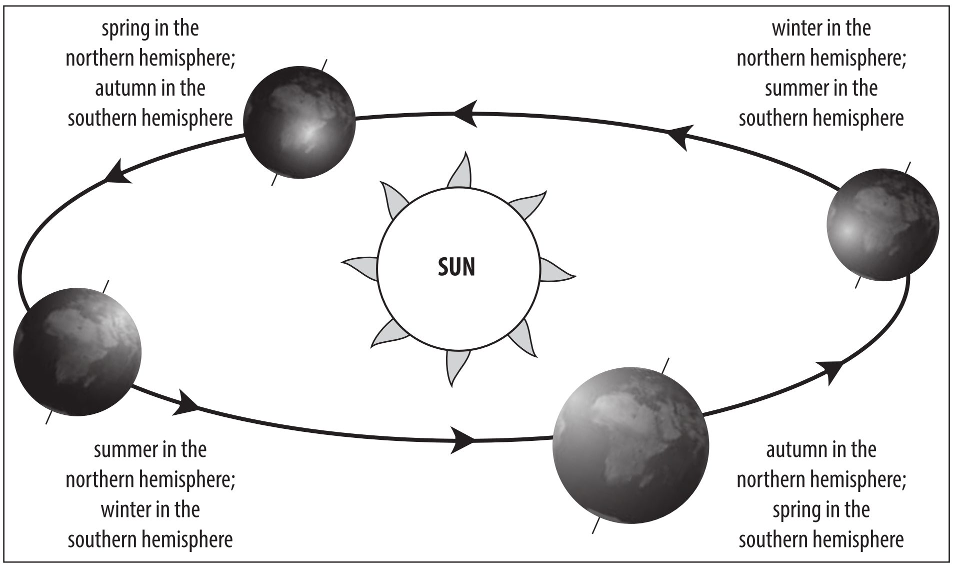

Figure 1.3 The Earth revolves around the Sun once in 365,25 days. It is the constant inclination of the Earth's axis (see Figure 1.4) that gives rise to seasons (summer – winter) as either the northern or the southern hemisphere is more inclined towards the Sun.

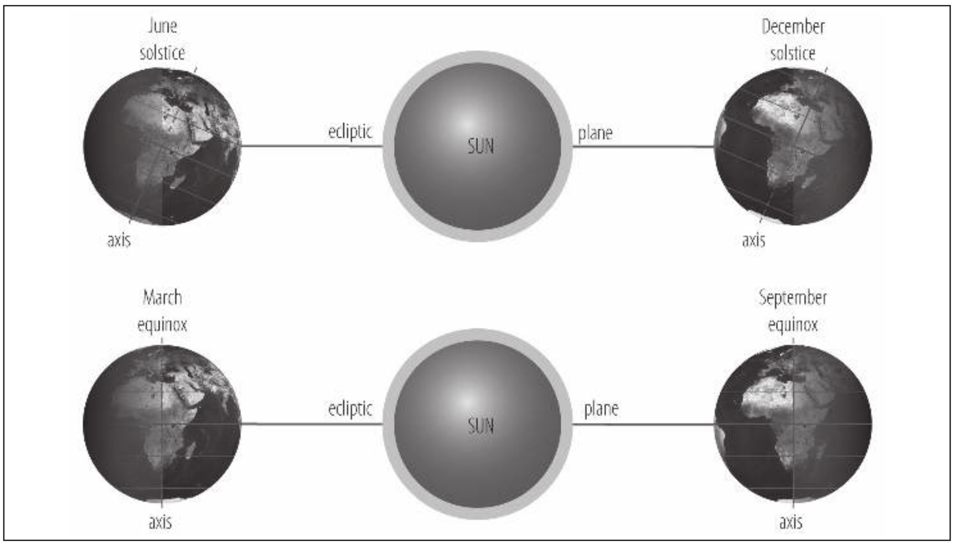

Figure 1.4 The plane of the ecliptic: the Earth's spin axis is tilted with respect to the plane of the Earth's solar orbit by 23,5°.

Activity 1.2 Explain the significance of Earth's axis and revolution around the Sun

Say whether each of the following is TRUE or FALSE. If false, explain why.

1. The Sun is a small, hot orange-coloured ball which pops up into the sky every morning to heat the Earth, and disappears at night time.
2. The Sun revolves around the Earth once in 365,25 days.
3. The distance between the Earth and the Sun is about 150 million kilometres.
4. The Earth's axis has a constant inclination in relation to the plane of the ecliptic.
5. This inclination is 32,5°.
6. If the Earth's axis were not inclined, we would not have seasons.
7. If the Earth's axis were not inclined, it would be just as hot at the poles as at the equator.
8. The Earth's rotation on its axis gives us seasons.

Question
How is heat energy transferred across the Earth?

Transfer of energy and energy balance – role of ocean currents and winds

The best way to transfer heat energy from one part of the Earth to another is via moving air or moving water. Technically, both air and water are fluids, and behave in a similar way when heated or cooled. Both can move huge amounts of energy via convection.

An air conditioner doesn't make things cold. It simply removes heat from one mass of air and transfers it to another mass of air. Does the atmosphere work in the same way?

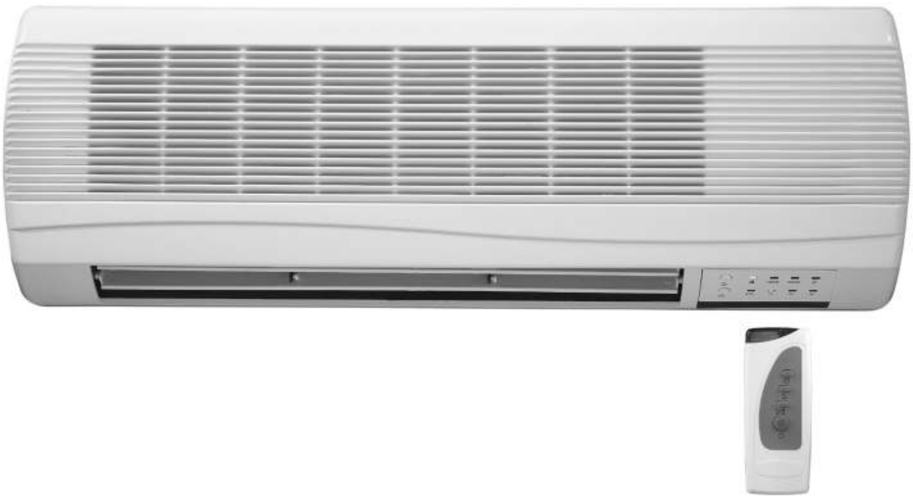

Figure 1.5 An air conditioner; think of it as a heat-transfer machine.

Question
How is the energy balance of Earth's atmosphere maintained?

Ocean currents

Ocean water in polar regions is colder than ocean water in tropical regions. Can you think why? There is a tendency to cancel out these imbalances. Cold water is conveyed, via **wind**, towards the **equator**, while warm water is moved towards the **poles** (see Figure 1.6). The situation is greatly complicated and influenced by land masses in the form of continents and islands, which influence the passage of these ocean currents. **Ocean currents** play an important role in maintaining the energy balance of the Earth's atmosphere.

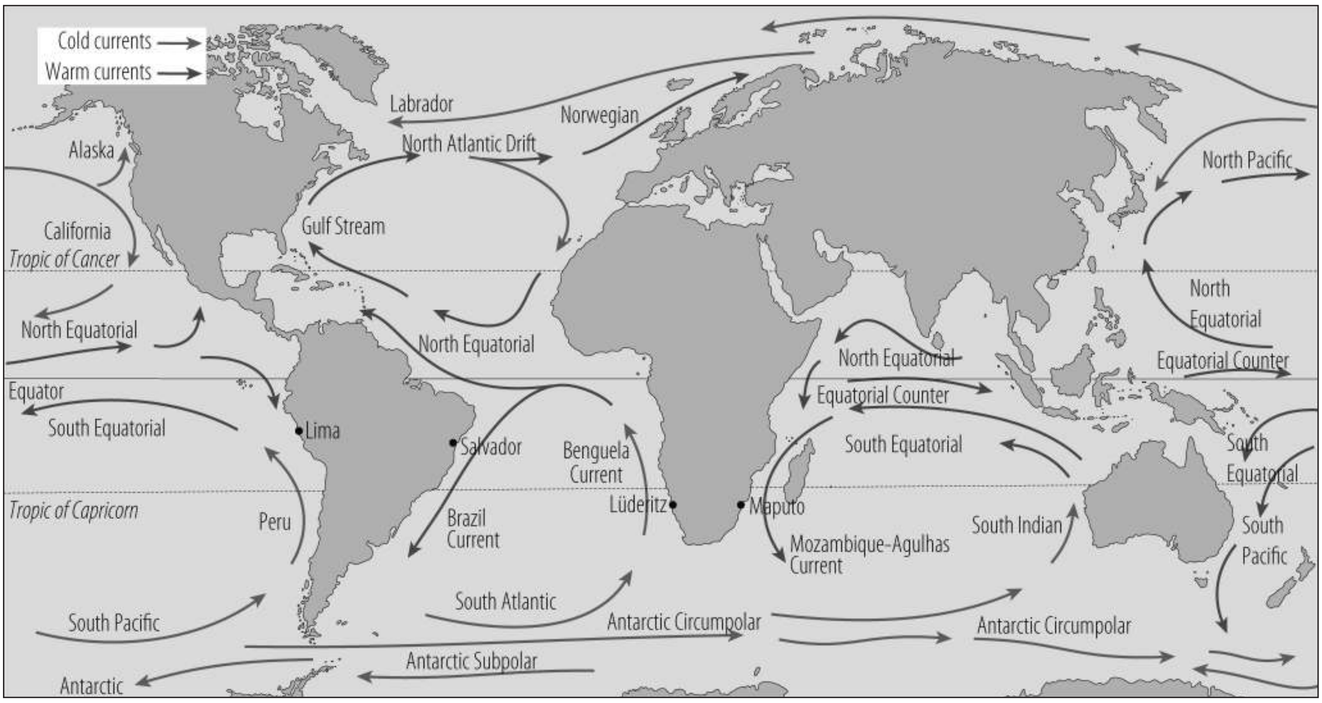

Figure 1.6 Warm ocean currents transfer warm water away from tropical regions, while cold ocean currents move cold water from polar regions towards the tropics.

Winds

Wind is air movement across the surface of the Earth. On a simple, non-rotating Earth, made up of land (or water) only, warm air would rise at the equator and move towards the poles, where it would sink towards the surface. At the surface, air would return from the poles towards the equator in a simple unicellular (one cell for each hemisphere) atmospheric circulation pattern (see Figure 1.7).

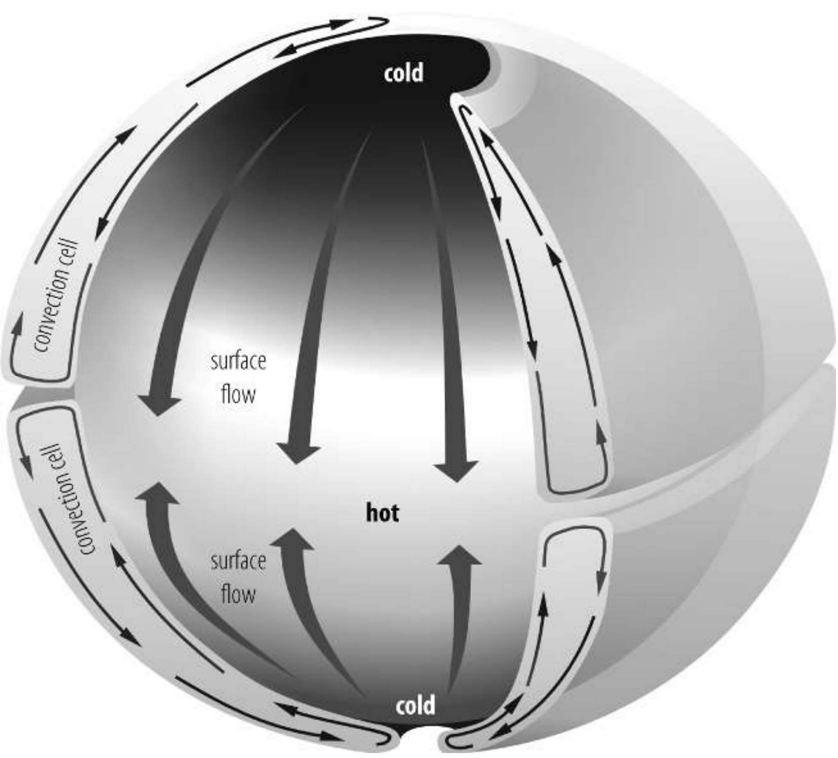

Figure 1.7 A simple, unicellular (one cell for each hemisphere) atmospheric circulation pattern, which would move heat energy from the equator towards the poles if the Earth did not rotate on its axis

Activity 1.3 Define heat transfer

1. What is heat transfer?
2. Explain how ocean currents and winds assist with heat transfer on a global scale.
3. Why is heat transfer necessary?

UNIT 2: Global air circulation

Global air circulation – a response to the unequal heating of the atmosphere

You have already seen that moving air plays an important role in redistributing heat energy in the Earth's atmosphere. You have also looked at the reasons why there is an energy imbalance in the Earth's atmosphere. The response of the atmosphere to this unequal heating is a complex, three-dimensional system of pressure belts, surface winds, upper-atmosphere winds, and ascending and descending air on a global scale.

World pressure belts

The diagram in Figure 1.8 shows, in static (not moving) two-dimensional form, the Earth's pressure belts. In reality, this is a dynamic three-dimensional system.

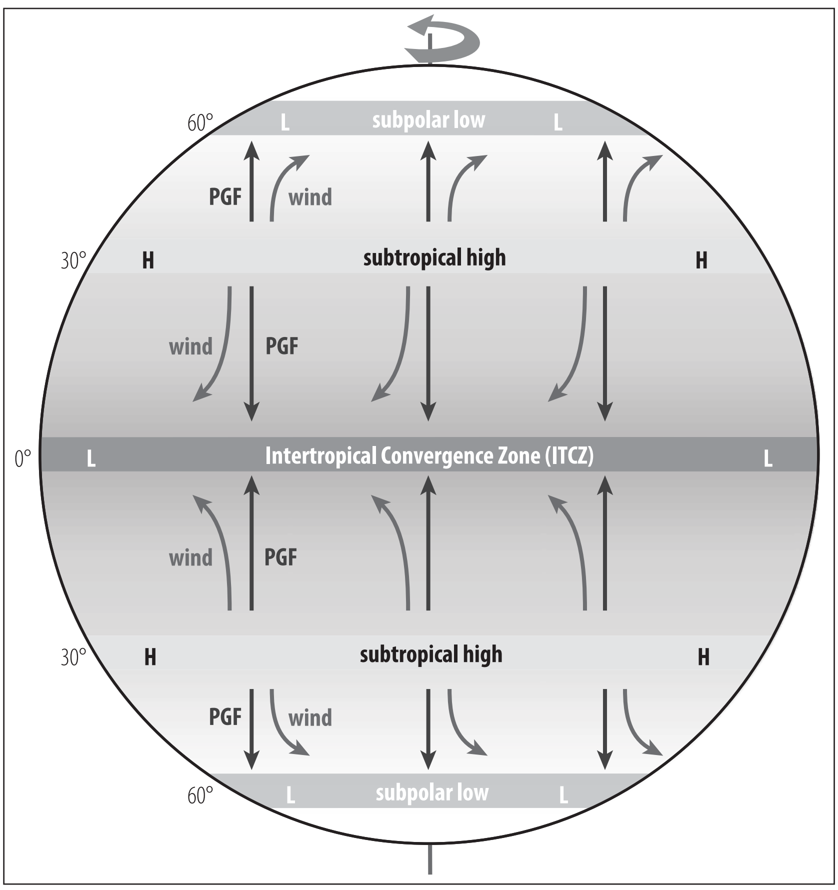

Figure 1.8 A simplified representation of the Earth's pressure belts

Activity 1.4 Analyse pressure belts

Look at Figure 1.8. There are symbols and letters on the diagram, but few labels. Use Figure 1.7, as well as what you have learned above, and provide labels for the following by thinking and reasoning as to what is happening in the diagram. (You will be able to check your answers further on in this guide.)

1. What does the circular arrow at the top of the diagram represent?
2. a) What do the letters H stand for?
   b) What do the letters L stand for?
   c) What do the letters PGF stand for? (Hint: see Figure 1.11.)
3. Why are the wind arrows deflected, rather than being straight?
4. What do the values 0°, 30° and 60° represent?
5. Explain the term Intertropical Convergence Zone (ITCZ) by breaking down these words to form a simpler meaning.

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Question

What is tri-cellular circulation?

George Hadley was an English lawyer and amateur meteorologist who lived in the eighteenth century, while William Ferrel was a nineteenth century American meteorologist. Both were interested in, and wrote about, air circulation in the atmosphere. The **Hadley** and **Ferrel cells** were named in their honour.

Tri-cellular circulation: Hadley, Ferrel and polar cells

Look again at Figure 1.7. In fact, because the Earth is rotating on its own axis, and because of **Coriolis force** (see below), there is not simply a single circulation cell in each hemisphere. Rather than a unicellular arrangement, there are three cells in each hemisphere (see Figure 1.9). This is called a **tri-cellular arrangement**.

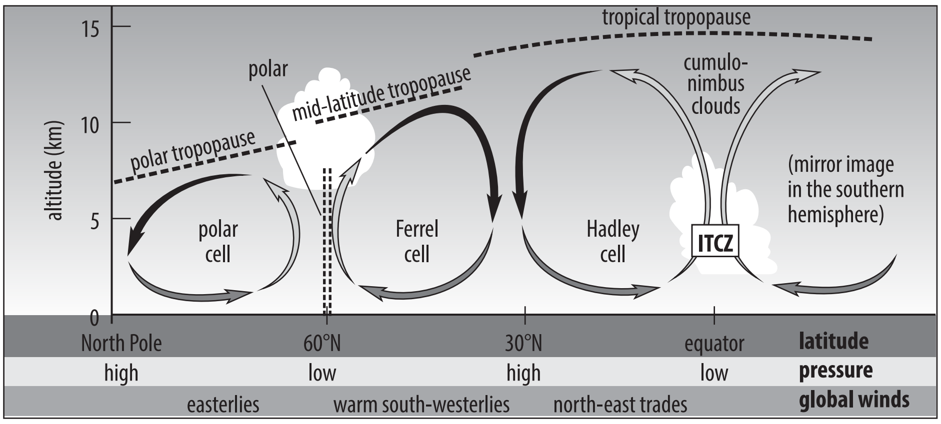

Figure 1.9 Tri-cellular circulation in one hemisphere, shown on a flat Earth, in two dimensions only

The relationships between air temperature, air pressure and wind

Once again, look at Figure 1.7 and also look at Figure 1.10 below. Here, the imbalance between heat (more at the equator than the poles) causes warm, heated air to rise at the equator (1) resulting in low pressure at the equator. Thunderstorms may occur because the rising air is very moist. Cooling and condensation occur as the air rises. In the upper atmosphere, this cool air circulates towards the pole (2) as an upper air wind, where it descends (3) creating a zone of high pressure. Air moves on and near the surface as a surface wind towards the equator (4).

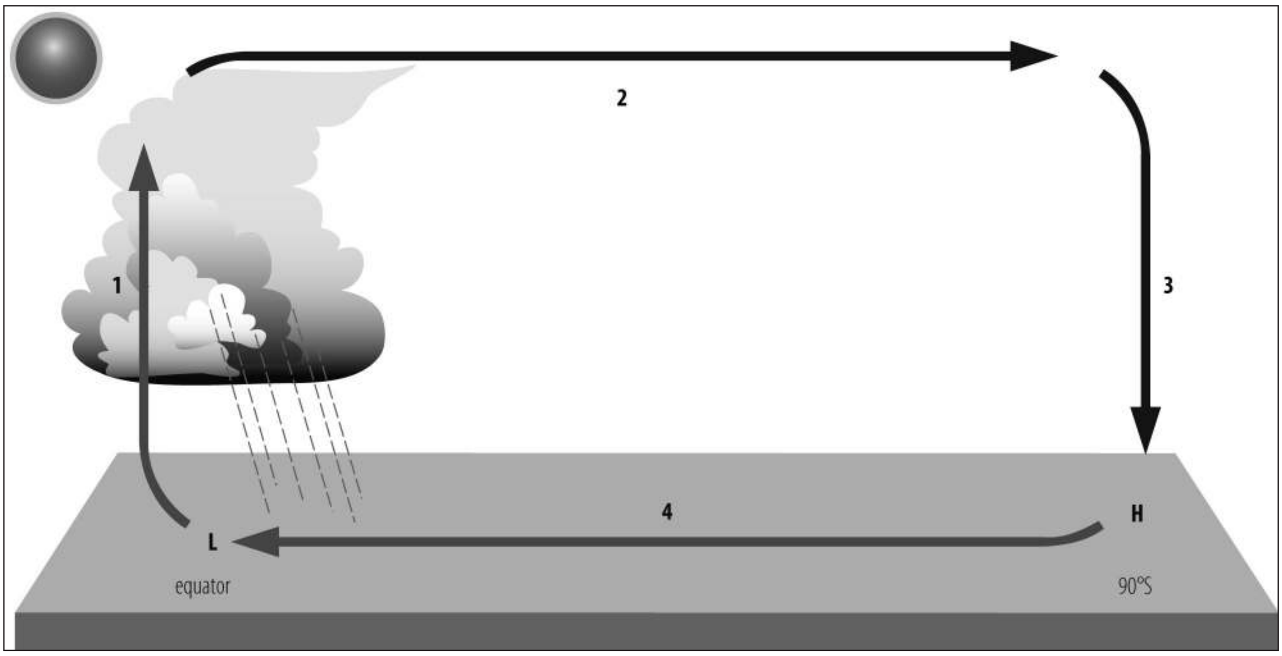

Figure 1.10 Simple diagram of unicellular circulation of air in one hemisphere

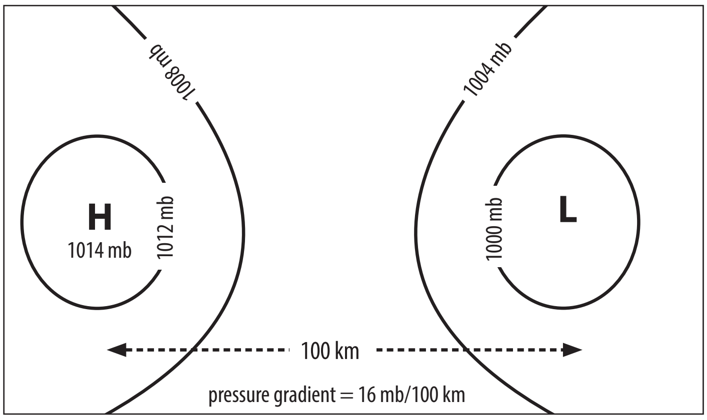

Figure 1.11 Pressure gradient force is the force that causes air to move across isobars (lines joining points of equal pressure) from high to low. See Figure 1.10 for the reason for this difference in pressure.

Pressure gradient, Coriolis force and geostrophic flow

Pressure gradient

Figure 1.10 shows the driving mechanism for air movement from an area or zone of high pressure towards an area or zone of low pressure. Figure 1.11 picks up on this by showing, in plan view (from above), what is meant by **pressure gradient** force (PGF).

Question

What is the effect of the Coriolis force?

Coriolis force: golden rule

Moving air (wind) will be deflected to your right in the northern hemisphere, and to your left in the southern hemisphere, when standing with your back to the wind.

Coriolis force

This is the force which causes moving air (wind) to deviate from its intended straight-line path. The Earth rotates on its axis once in 24 hours. All objects on the Earth's surface are rotating with it. The atmosphere is also spinning around with the Earth at the same rate. The speed of movement is highest at the equator and decreases towards the poles, where it reaches zero. Therefore, the Coriolis effect is greatest near the equator, and decreases towards the poles.

Now, think about an upper air wind (see Figure 1.10) blowing from the equator towards the pole. Figure 1.12 shows this happening in both hemispheres. Because the Earth is rotating, and because the equator is moving faster than the poles, the wind is moving from a faster-spinning zone towards a slower-spinning zone. This causes an apparent curve or bend as the wind arrives ahead of where it intended to go. The opposite happens with wind blowing from the poles (slower revolving) towards the equator (faster revolving) as the arriving wind gets 'left behind'.

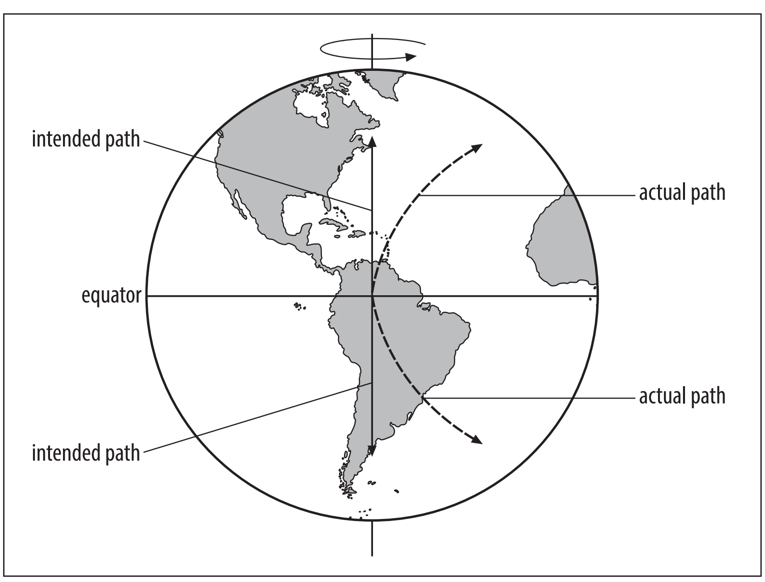

Figure 1.12 Coriolis force acting on winds in both hemispheres. In both cases, air is moving from the equator towards the poles. Deflection is to the right in the northern hemisphere and the left in the southern hemisphere, if your back is to the wind.

Geostrophic flow

To complete an understanding of the behaviour of moving air, you need to master the concept of geostrophic flow. This is also best understood by using a diagram. Refer to Figure 1.13. Air starts to move, under pressure gradient force, at right angles to the isobars from high (H) to low (L). As soon as this movement starts, the wind comes under the influence of Coriolis force, which causes it to deviate from its path. Note how the influence of Coriolis force becomes greater (shown by the length of the arrows). Eventually, a situation is reached where the wind is blowing parallel to the isobars, and pressure gradient and Coriolis force balance each other (arrows of equal length). This wind blowing parallel to the isobars is called a **geostrophic wind**. Geostrophic winds blow in the upper atmosphere, where there is little or no friction or drag between the moving air and the Earth's surface.

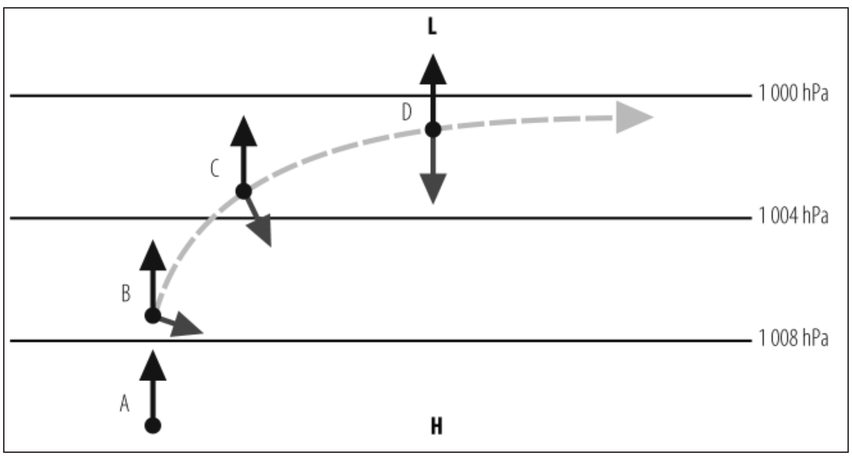

Figure 1.13 Geostrophic flow

Activity 1.5 Define air movement terms

Match the statement in Column B of the table with the word or phrase in Column A.

Column A	Column B
1. Coriolis force	A. geostrophic winds occur here
2. geostrophic wind	B. drag between two things along a plane separating them
3. pressure gradient force	C. unit of atmospheric pressure
4. wind	D. deflection caused by Earth's rotation
5. isobar	E. blows parallel to isobars
6. millibar	F. imaginary line joining points of equal pressure
7. upper atmosphere	G. the cause of wind
8. friction	H. moving air
9. hemisphere	I. divides Earth into two hemispheres
10. equator	J. half a sphere

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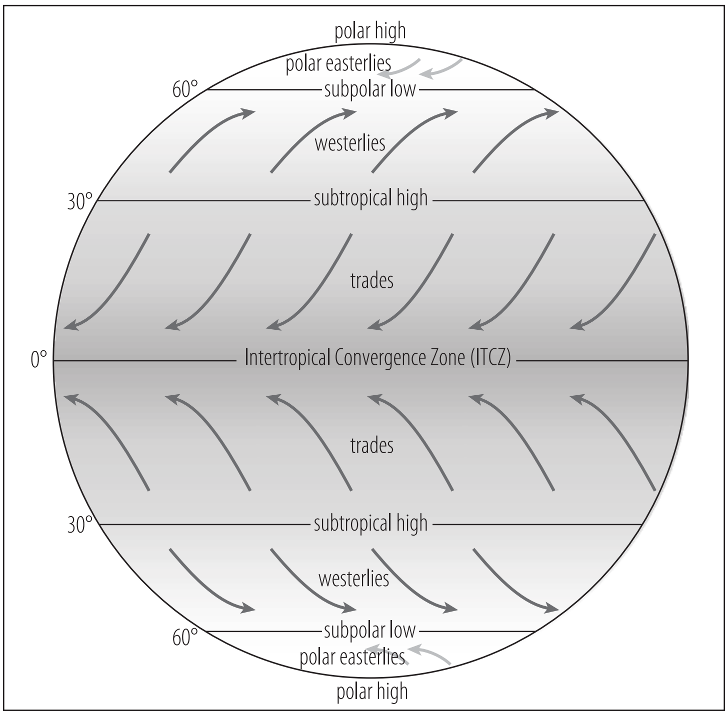

Figure 1.14 Global air circulation (winds) on a two-dimensional Earth

Winds related to global air circulation: westerlies, tropical easterlies and polar easterlies

Now that you have a good understanding of air circulation, it is time to look at **global air circulation** in terms of winds. If the Earth's surface were homogenous (all the same), there would be an ideal circulation pattern of surface winds as shown in Figure 1.14. In reality, the situation is much more complex (see Figure 1.15), because the Earth's surface is made up of sea (oceans and their currents) and land (continents and islands with their different shapes, altitudes, surface features and vegetation). There are three major winds with an identical pattern in each hemisphere:

- **Tropical easterlies** or trade winds blow from the **mid-latitudes** towards the equator.
- **Westerlies** blow from the mid-latitudes towards the poles.
- **Polar easterlies** blow from the polar regions towards the high latitudes.

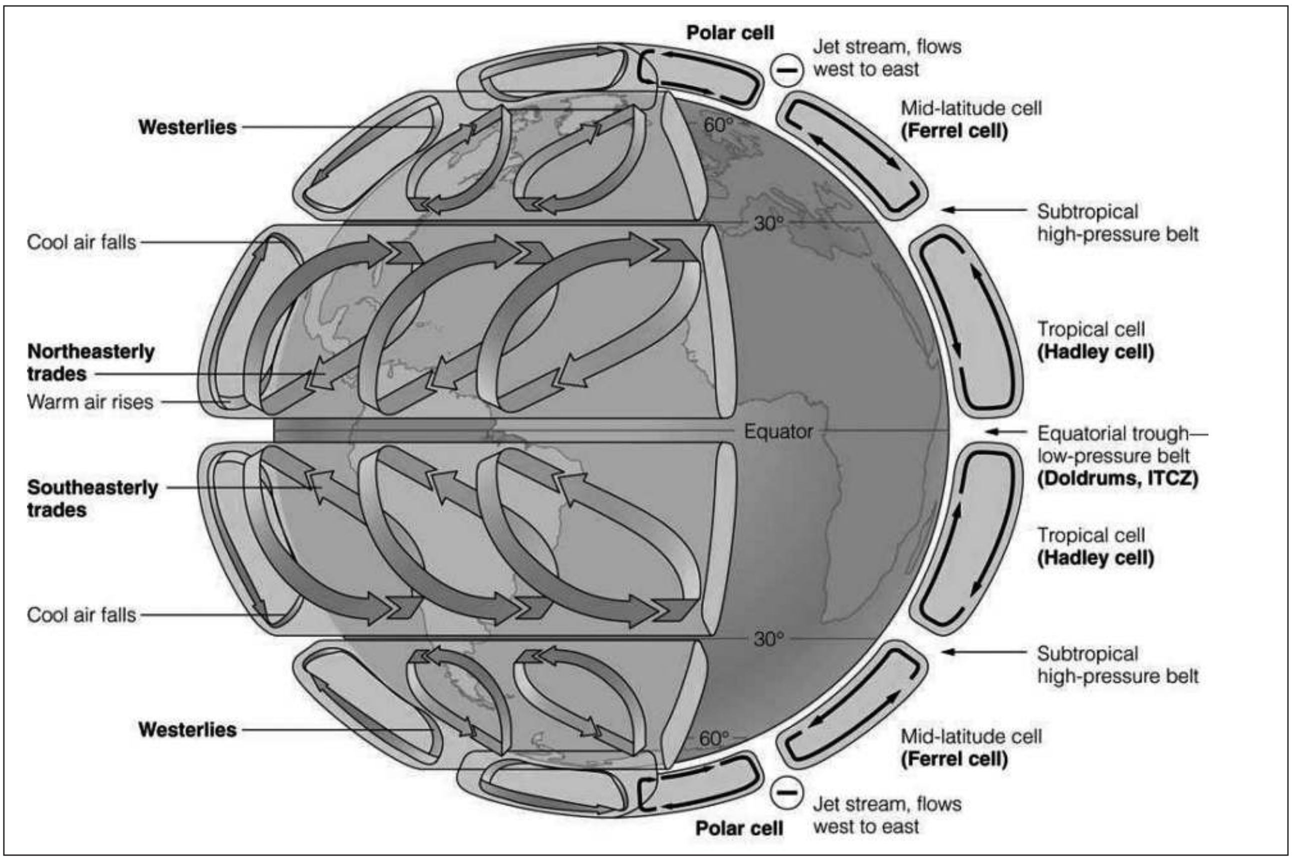

Figure 1.15 Three-dimensional model of equatorial warming, pressure cells and surface and upper air circulation in a tri-cellular arrangement