CHAPTER 6

The atmosphere in motion

This chapter provides a broad view of why the wind blows at the surface and in the atmosphere in order to explain the patterns of mean wind flow around the globe. Descriptively the pattern of winds is relatively easy. The main problem about air motion concerns the movement in the atmosphere in relation to the rotating ground surface. It has to be explained that we are on a rapidly rotating sphere even though it may not be immediately apparent. Movements in the atmosphere have to be related to this moving surface.

As a starting point, it is useful to ask students which way Earth rotates; where does the sun rise and where does it set? They could then be asked at what latitude rotation will be greatest. If we have air moving away from the equator it will have a higher rotation velocity than the surface over which it is blowing. It will therefore appear to be moving more rapidly than the surface and so appear as a westerly wind. An alternative is to use a model sphere and try to draw straight lines and note the effect. Videos are available which show the effect of rotation and try to explain the Coriolis force.

Atmospheric circulation and winds

- Forces act on particles of air, causing them to accelerate or decelerate or to change their direction.

- One of the basic forces influencing air movement is the horizontal pressure gradient force. Air tends to move from higher pressure towards lower pressure, down the maximum gradient of pressure.

- The closer the lines of equal pressure (isobars) are together, the faster will be the acceleration down the gradient.

- Because of Earth’s rotation, we need to involve a mythical force to explain the actual air movement down a pressure gradient; this is called the Coriolis force. It has the maximum effect at the poles and least at the Equator.

- The balance of forces between the pressure gradient force and the Coriolis force is known as the geostrophic wind. It blows parallel to the isobars.

- Friction operates only near the ground surface. It is the result of the interaction between air movement and the surface. It has the effect of deflecting airflow across the isobars towards the lower pressure; rougher surfaces cause greater deflection.

- In practice, the balanced flow that would be predicted from these forces does not occur because of divergence and convergence associated with vertical movements of air.

The global pattern of circulation
• Theoretically, the differential heating of the globe starts a circulation, with rising air over the warmer zones and sinking air over the cooler zones. In practice this is complicated by the rotation of Earth and the variable nature of the surface.

• The zone of rising air at the thermal equator forms the equatorial trough or Intertropical Convergence Zone with its belt of heavy rainfall.

• Sinking air takes place in the latitude of the subtropical anticyclones at about 30° from the equator. The air diverges as it sinks favouring clear skies and providing the basis for the subtropical deserts at these latitudes.

• Taken overall, the atmospheric circulation helps to transfer the surplus radiative energy from tropical regions towards the polar regions.

• In the tropics, the transfer resembles a circular overturning, called the Hadley cell, modified by Earth’s rotation, to produce the trade winds.

• In temperate latitudes the flow is more strongly zonal, with longitudinal variations. Warm air moves polewards ahead of low-pressure systems or downstream of a trough in the upper westerlies. Cold air moves equatorwards to the rear of low-pressure systems or upstream of a trough in the upper westerlies.

Wind patterns

• At the surface four main wind belts are distinguished: the equatorial trough, the trade winds, the westerlies and the polar easterlies. They are closely related.

• The equatorial trough is a area of shallow low pressure generally situated close to the equator. Over continental areas it moves polewards during the summer period in that hemisphere. Over the oceans its poleward movements are limited.

• The trade winds occupy a large area of the globe. They are renowned for their constancy of direction and speed. Over the oceans they pick up vast quantities of moisture through evaporation. Some of it is released as precipitation in the equatorial trough zone.

• The westerlies are a variable wind belt containing major eddying systems like cyclones and anticyclones. They are very important in determining weather and assisting in energy flows through the temperate latitudes.

• The polar easterlies are weak and shallow. They are produced by the polar anticyclones which are also shallow. In the upper atmosphere a westerly circulation dominates.

Upper winds

• Flow in the upper troposphere more closely resembles the geostrophic wind.

• The dominant flow in the upper atmosphere is the westerly circulation. Only in the equatorial zone do easterly winds dominate at all levels of the troposphere.

• The strength of the westerlies is related to the poleward temperature gradient and hence increase in speed in winter, when the poles get very cold.
The westerly flow is not circular. It extends around the globe in a wave-like form. The larger waves are called Rossby waves, after the Swedish meteorologist, Carl-Gustaf Rossby.

The waves are better developed in the northern hemisphere, where differences in surface characteristics, such as mountains and oceans, are greater than in the southern hemisphere.

Jet streams

- Jet streams are narrow currents of air, travelling at great speed, formed in areas of steep temperature gradient.
- Both easterly and westerly jets are found at different heights within the troposphere and the stratosphere.
- They are very important in determining low pressure tracks and their areas of formation.

El Niño – Southern Oscillation

- In the Pacific Ocean east–west contrasts in ocean temperature produce a zonal cell called the Walker circulation. Periodically changes in sea temperature reverse the pattern and affect the air circulation. This then has major impacts on the weather of the Pacific Ocean basin and elsewhere.

CASE STUDY – Jet streams and the summer of 2007 in the UK

As explained in Chapter 6 and in the Key Concepts Box, page 126, jet streams are an important element of surface weather. Across the Atlantic there is a ribbon of high-speed wind that blows roughly west to east at an altitude of about 11 kilometres somewhere between latitudes 40° and 60°N. It is associated with a sharp temperature contrast between tropical and polar areas and is one of the influences on the tracks of low pressure systems. If you want to find its current and forecast position for the next few days, http://www.metcheck.com/V40/UK/FREE/jetstream.asp will provide that information as well as much additional information about cyclone tracks, the North Atlantic Oscillation and a variety of other weather and climate information.

The track of this polar jet stream, as it is called, varies in its wave amplitude from an almost continuous band around the globe to a very wavy pattern with broad swings between higher and lower latitudes. This occurs more frequently when the jet stream is less strong and is called a low index cycle mode. Seasonally the most frequently occurring track of the jet stream moves polewards into summer, then gradually moves equatorwards to a more southerly track in mid-winter. When the jet is strong, low pressure systems move rapidly across the British Isles but when there is a low index cycle, we can experience frequent, slow-moving lows or highs depending upon where the wave axes are. If the UK is near a wave trough, surface low pressure will dominate whilst if we are near a wave ridge, surface high pressure will persist.
A good example of the influence of the jet stream’s position on the resulting weather occurred in summer 2007. For much of the summer, the jet stream was much further south and stronger than normal and the extension of the Azores high pressure cell failed to become established. Instead the high pressure became dominant over southern and eastern Europe where very hot, sunny and dry conditions were favourable for fires. Parts of Greece suffered severely with much loss of life. In NW Europe and over the UK in particular, the persistent jet spawned many deep low pressure systems, some of which stagnated to give prolonged and heavy rainfall. (Figure 1)

![Image of Burbage Brook near Sheffield on the evening of June 25, 2007. Sheffield recorded 87 mm in the previous two days and major flooding occurred on the Don floodplain. In this small moorland valley, the water level had risen above bank level onto the small floodplain. Water was flowing down the hillside as overland flow. Debris had piled up against the footbridge. The colour of the water is because of peat and chemical discolouration in the acid water. Source: Adam Smithson](image)

**Figure 1** Burbage Brook near Sheffield on the evening of June 25, 2007. Sheffield recorded 87 mm in the previous two days and major flooding occurred on the Don floodplain. In this small moorland valley, the water level had risen above bank level onto the small floodplain. Water was flowing down the hillside as overland flow. Debris had piled up against the footbridge. The colour of the water is because of peat and chemical discolouration in the acid water.

Source: Adam Smithson

In summer with higher temperatures than winter, air is able to hold more moisture so that when conditions favour precipitation it is likely to be heavier. This fact, coupled with the strong convergence and uplift generated in the low pressure systems meant that rates of rainfall were much higher than normal. For example on July 20th 2007, warm and moist
air crossed from France associated with a low pressure system and at Pershore in Hereford and Worcestershire 145 mm of rain was recorded. Localised storms of tropical intensity are a feature of many English summers (with the highest daily total being at Martinstown in Dorset when 279 mm fell on 18 July 1955). However what distinguished the summer of 2007 was the large spatial extent of the area of heavy rain. Figure 1 shows rainfall between June 1 and August 28 as a percentage of the 1971-2000 average. Virtually the whole of England experienced values over 150% though a few areas, where the rain areas were not persistent, did experience below average rainfall. (See also chapter 17, p.333 for the impacts of the rains during this summer). August was much drier over England than the previous two months so percentages would have been higher for these two months alone. The figure also clearly shows the inverse correlation of rainfall between SE England and NW Scotland; if it is wet in the former it is usually drier than average in the latter and vice versa.

Rainfall 1 June - 28 August 2007
Percent of long-term average (1971-2000)

![Rainfall map](http://www.metoffice.gov.uk/corporate/pressoffice/2007/pr20070831.html)

**Figure 2** Rainfall 1 June to 28 August 2007 as a percentage of the long-term average 1971 to 2000 from:


Whilst lots of rain may be of interest to climatologists, this water had to go somewhere. Normally in summer, soil conditions are fairly dry and heavy rain can be absorbed. In
2007, after a dry March and April, persistent rain led to wet soils and high groundwater levels by July. On 20 July the exceptional rainfall triggers a sequence of flood episodes; firstly localised flooding in urban areas with their largely impermeable surfaces; secondly, extreme flows in small catchments that respond quickly to rainfall and thirdly, extensive floodplain inundations as the run-off became concentrated into the major lowland rivers of England – the Severn, Thames, Ouse and Trent. These floods caused severe disruption of transport and widespread damage to crops. Livestock had to be moved to higher ground as soon as possible, a task made difficult by the flood problem on the roads.

Water flows in some of the rivers of southern Britain exceeded previous maximum recorded flows, in some cases for the summer half-year (April-September). In parts of the lower Severn, the Avon and the upper Thames, flood flows probably were higher than those of March/April 1947, which was the most severe flood for over 100 years.

The results of the jet stream following an unusual flow pattern were clearly dramatic. We have used this as an example to show how a persistent anomaly in its flow can have such an impact on the resulting weather. The example taken was of high rainfall totals, but equally we could have chosen droughts when low pressure systems are infrequent because the jet stream path is well away from the British Isles. There have been a number of occasions in the 1990s and 2000s when summer heatwaves and droughts corresponded with anomalous jet stream positions.

**Essay and discussion questions**

1. Why do winds not blow directly from high to low pressure?
2. What changes might you expect to see in the atmospheric and oceanic circulations if Earth rotated from east to west?
3. What makes the Trade Winds have such a high degree of constancy in their direction and speed?
4. What happens during a major El Niño event? How might it affect the global wind and precipitation patterns?
5. Explain how the general circulation of the atmosphere determines where the wettest and driest parts of Earth are located. In which areas is it not useful?
6. Choosing one of the satellite photos of half the globe in the core text, interpret the cloud patterns in relation to what you know about the global circulation.
7. Using the internet, see how many examples of jet streams you can find in our atmosphere.
Further reading


Website addresses

http://www.metcheck.com/V40/UK/FREE/jetstream.asp

Many features are available at this site. As well as the current and forecast positions of the Atlantic jet stream referred to above, you can view current areas of low pressure in the Atlantic and their forecast positions, as well as weather information from around the world. For those interested in weather around the UK, it hosts a series of webcams allowing you to see current weather at a large number of locations over the UK. Useful for checking areas of rain falling and snowcover.

http://ww2010.atmos.uiuc.edu/(Gh)/guides/mtr/fw/gifs/coriolis.mov

There are a number of sites from academic institutions that show animations of the Coriolis force. The above site has a video of children playing with a ball on a roundabout. Viewed from above the ball moves in a straight line, but when viewed from the roundabout the ball clearly is deflected. Other animations using models of the earth are widely available.

http://www.cru.uea.ac.uk

The Climatic Research Unit at the University of East Anglia has an extensive database of atmospheric information such as the North Atlantic Oscillation index, the Southern Oscillation Index of the South Pacific, Lamb Weather type classifications for the last 140 years and a variety of others. A series of information sheets are also available providing more information about the indices and about climate modelling.

http://www.ecmwf.int  The website for the European Centre for Medium-range weather forecasting. It provides a web-based atlas of many aspects of the atmospheric circulation for different seasons and pressure levels. If interested in future weather, maps are available for the predicted surface and 500 hPa pressure levels for 10 days into the future for all parts of the globe.

http://www.cdc.noaa.gov/ENSO

The website of the Climate Data Center provides a scientific background of ENSO together with animations of the current situation using sea surface temperature...
anomalies. Historical patterns of ENSO are available and global climatic links, or teleconnections, with ENSO are outlined.