CHAPTER 5

Precipitation and evapotranspiration

This is a long but important chapter about the input of water to Earth's surface as precipitation, and the output of water from the surface as evapotranspiration. There are many types of precipitation and not all of them may be important locally. For most parts of the world the majority of the precipitation will fall as rain, but locally snowfall and even fog drip may be significant.

With the main types of precipitation identified, the methods of measuring them are described and the potential errors identified. Experiments could be done with containers of different height or diameter to check the volume of water caught after a rainstorm. Find out what the standard rain gauge is like in your country.

Having appreciated the accuracy of the data, we examine the ways in which precipitation varies temporally and spatially. Water is arguably the most important climatic resource, so it is discussed in some detail. The pattern of precipitation distribution varies with time. An instantaneous view would give a very complex pattern, as indicated in a radar image of rainfall intensity (see Figure 7.9). Mean annual precipitation distribution is less variable but does demonstrate many of the controls of precipitation formation.

The chapter concludes with the reverse flow of moisture back to the atmosphere. The processes are described and the importance of energy and air movement is stressed. Differences in the rates of evaporation in winter (low energy but high wind speeds) and summer (high energy and low wind speeds) can be illustrated by noting how long it takes to dry an impervious surface such as a road or pavement. If a surface is dry, the amount of evaporation is likely to be small, however sunny and windy the weather is. Hence we have to distinguish between the atmospheric conditions favouring evaporation, which we call the potential rate, and the actual rate of evaporation, which is determined by atmospheric conditions and the state of the ground. Actual evaporation or evapotranspiration, if the effects of transpiration through the plant leaves are also included, can be much less. In an extreme case, potential evapotranspiration in a desert is very high but actual evapotranspiration may be almost zero. Unfortunately it is difficult to measure. Methods of measuring evapotranspiration are described, together with a variety of estimation methods. Students should also be reminded that the process of evaporation involves latent heat (see Chapter 2).

For those with access to the Internet there are a number of sources of precipitation data. The National Climate Data Center, amongst others, provides both long-term averages and actual monthly totals for some other parts of the world and the Australian Bureau of Meteorology has almost real-time maps showing monthly totals and percentage of average rainfall for Australia (see web resources below).

Precipitation

Types of precipitation

- Rain is the most frequent form of precipitation on a global scale.
- Rain consists of innumerable drops of water with diameters up to about 6 mm.
- Rainfall from layer clouds tends to be less intense and with smaller drops than rain from convectional clouds associated with unstable air.
- Larger drops have greater kinetic energy and so have a greater impact on soil. They may cause erosion of the soil surface if the rain is sustained for any length of time.
- Snow occurs mainly in high latitudes, or high altitudes, and in the winter season.
- Because of its distinctive radiative properties, the presence of snow has a major impact on surface climate. If it does not melt, it may remain on the surface for many years, gradually turning to ice as subsequent snowfalls compact it.
- Wind is very important in determining where snow will accumulate. Drifts tend to be deposited in quieter areas and be blown away in windier locations.
- Other types of precipitation are rarely significant in terms of the amount of moisture they add to the surface.

Measurement of precipitation

- Rainfall is easy to measure but standardization is important if the results are to be meaningful. You should not compare readings from gauges set at different heights above the ground surface or of different diameters. International comparisons are difficult for this reason though there are standards issued by the World Meteorological Organization (WMO).
- Over ocean areas, satellite information is used to infer precipitation amounts from cloud top temperatures, through cloud density, or by passive microwaves (see Figure 5.5 in text)
- Snowfall is the least well monitored form of precipitation. It is easily blown away from gauges and has to be melted before its water equivalent is known.

Temporal variations in precipitation

- Rainfall amounts vary greatly over time, and intensity is rarely uniform. The most intense rainfall is associated with convectional cloud, especially in tropical areas.
- Many climates have strong seasonality in rainfall, with clear wet and dry seasons. The monsoonal areas of the world are the best examples.
- Variability of rainfall can be expressed statistically by the coefficient of variation.
- Some information about rainfall reliability can be obtained by calculating the probability of particular values, or by specifying how many years in, say, ten, particular amounts of monthly or annual rainfall may be received.

Spatial variations in precipitation

- Rainfall is spatially variable; the variability is inversely related to time. Short time periods of rain tend to be most variable, as from an individual cloud; annual rainfall amounts are least variable.
- Spatial variability is also related to the mechanisms producing the rain. Convectional rainfall is more variable spatially than cyclonic rainfall.

Surface modifications of precipitation

- The nature of the underlying ground surface has a major influence on precipitation mechanisms.
- Where air is forced to rise, the processes of precipitation formation will be assisted. Usually precipitation will increase with altitude. Maps of mean annual precipitation have strong similarities with topographical maps.

Evapotranspiration

- Evaporation is the process of converting liquid water to a vapour state.
- Transpiration is the process of water loss through plant leaves and adds to the overall transfer of water from the ground to the atmosphere.
- Potential evapotranspiration is a climatically defined concept which indicates how much evapotranspiration would take place if the ground surface was continuously moist.
- For evapotranspiration to take place, we need an energy supply, usually heat from the sun, air movement to remove the evaporated moisture, and a humidity gradient so that the air above the surface is not saturated.
- Actual evapotranspiration depends not only on atmospheric factors but on the amount of moisture and the nature of the vegetation at the surface. A barren and totally dry ground surface, as in some deserts, will generate no actual evapotranspiration, though its potential rate would be high.

Plant responses to moisture stress

- If moisture losses from the soil become high, plants may no longer be able to transpire sufficient moisture and so they wilt. At this stage the soil is said to be at wilting point.

Measuring evapotranspiration

- Evapotranspiration can be measured directly by pans, lysimeters or eddy correlation systems.
- Evapotranspiration can be estimated indirectly by meteorological formulas or moisture budget estimates.
- The method to be used will depend upon resources or data availability and the climate regime.

- Where only standard climate data are available the Thornthwaite formula is often used to estimate potential evapotranspiration. It is based on monthly temperatures and a heat index together with an allowance for day length.
- Where more meteorological information is available the Penman or Penman–Monteith method is used. It is a more physically based method.
- If information about the movement of water in a river basin is available, the evapotranspiration rate can be obtained indirectly as a residual in the water budget. This is possible only for long-term values.
- There is no 'true' standard method of measuring or estimating evapotranspiration under all conditions.

Evapotranspiration in the hydrological cycle

- Evapotranspiration plays a vital role in the global hydrological cycle. Much evapotranspiration takes place from the subtropical ocean areas where clear skies and the trade winds provide ideal conditions. This moisture is then transported via the wind systems and may eventually condense and even give precipitation in other parts of the globe.

CASE STUDY – Australian droughts

Rarely does a year pass without the international media reporting severe drought in one part of the world or another. The United States experienced a severe drought in the mid-west in the 1930s; the Sahel of West Africa has had varying levels of drought since the late 1960s, South Africa, Kenya, Somalia and Ethiopia in the same continent have also experienced periods of well below average rainfall. Even the normally well-watered United Kingdom has had droughts when water use has had to be curtailed through hose-pipe bans, such as in several summers of the 1990s. One particularly drought-prone continent is Australia where the agricultural lands of the south-west, south and south-east are subject to phases of above and below average rainfall. Australia is one of the countries affected by the atmospheric oscillation known as ENSO (El Niňo-Southern Oscillation) where the sea-surface temperatures in the Pacific Ocean undergo quasi-cyclic changes from periods of below average to much above average temperatures. In some years, sea surface temperature anomalies have reached 5^{o}C which is very large for sea surface temperature changes. These sea temperature oscillations have a dramatic impact on the atmospheric circulation of the Pacific, which in turn produces periods of above and below average rainfall. Australia does seem particularly affected by ENSO with most of the eastern side of the continent experiencing drier than average conditions during the warm phase of an ENSO.

Although ENSO may be the dominant effect on atmospheric circulation and rainfall, droughts do continue even when normal conditions return in the eastern Pacific. For example, large parts of southern and eastern Australia have experienced drier than average conditions between October 1996 and December 2007. In the agriculturally important Murray-Darling Basin of Queensland/New South Wales, the period from November 2001 to October 2007 has been equal driest period (with 1939-45) since records began. The annual average for the six year period is only 389 mm which is approximately 20% below the long-term annual average of 480 mm. (Figure 1) For the second year running, the duck shooting season of 2008 in the state of Victoria has been cancelled because of the drought. The dry conditions have reduced the success of breeding so that duck numbers have declined from an estimated 25-year average of 187,500 to the current levels of 68,500.

Figure 1 Australian rainfall deciles for the six-year period November 2001 to October 2007: For this illustration please link to:
http://agencysearch.australia.gov.au/search/search.cgi?query=australian

The Murray-Darling Basin is outlined in bold.

Below average rainfall can cause problems on its own, but often, the dry conditions are associated with less frequent cloud and therefore higher temperatures during the day. Four of the ten hottest years in the Murray-Darling Basin for the period after 1910 have occurred since 2001 - during the present drought. The combination of reduced rainfall and higher temperature make the impact of the drought through increased evapotranspiration even greater than might be expected from the lower rainfall alone.

Fortunately it is rare for the whole of Australia to experience drought conditions at the same time or for the same duration. Some droughts are long-lasting, some are brief but intense. Where droughts affect the main agricultural areas then the consequences can be severe. Australian history is littered with examples of droughts. Between 1895 and 1903, sheep numbers were halved and more than 40% of the cattle were lost through widespread drought; it was the most devastating in terms of animal losses. From 1958-67 there was widespread drought with even less rain than normal in arid central Australia. Wheat harvest declined by 40% in the last two years of that period and 20 million sheep were estimated to have died. In the period 1982-83 there was a severe El Niňo which led to extremely low rainfall throughout much of eastern Australia – the main agricultural area. Total agricultural losses were estimated to be in excess of A$3000 million. Between 1991 and 1995 there was a long-lived but El Niňo-related drought which only affected the eastern part of Queensland leading to a reduction of about 10% in production in rural industries. So the current drought is hardly exceptional in terms of Australian climatic history but as the population expands demands for water increase and so a drought of similar intensity can cause greater hardship.

The indirect consequences of a drought can be significant to the economy of a country which has a strong agricultural base. In the current Australian drought, wheat yields have declined and together with international competition for static supplies on a global scale there has been an increase in the price of wheat. In the period June 2006 to December 2007, the price of wheat in Australia doubled. This has an impact on food prices, both directly via bread, and indirectly on feedstocks that use wheat as a base. For example, wheat is the largest component of pig feed and the rise in price has pushed up the cost of pig rearing. Unless this can be recovered through increased prices, pig farming will be less profitable and there will be a cut back in pig breeding for future stocks. So as well as the direct effect of drought on wheat production, its influence can extend far beyond this single crop.

Essay and discussion questions

1 Why is rainfall more reliable in some parts of the world than in others?

2 Find out the mean annual precipitation of your home area. Are the monthly totals spread uniformly through the year? How much fell in the last calendar year?

3 Using a container and funnel, collect rainfall and note how it varies from week to week. When it rains, can you explain what caused that particular rainfall? Although your gauge will not be comparable with standard gauges it will give you a relative measure of falls.

4 Have there been any floods in your area? If so, what caused them? What were their effects and consequences?

5 Explain the differences between the concept of potential evapotranspiration and that of actual evapotranspiration.

6 In what ways do the presence and type of surface vegetation affect the amount of evapotranspiration?

7 Discuss the limitations of the Thornthwaite method for estimating potential evapotranspiration. Under which climates is it most effective?

Further reading

Jackson, I.J. (1989) *Climate, Water and Agriculture in the Tropics*, Harlow: Longman.

Primarily concerned with the tropics, rainfall is examined in terms of its origins, seasonality, variability and intensity in chapters 1–4. Intermediate level.

Shaw, E.M. (1994) *Hydrology in Practice*, third edition, London: Chapman and Hall.

A third edition of a popular book giving a practical approach to the problems of measuring and calculating evapotranspiration. Intermediate level and requires some mathematical expertise.

Sumner, G. (1988) *Precipitation: Process and Analysis*, Chichester: Wiley.

An extensive survey of all elements of precipitation from its formation in the atmosphere to how precipitation data can be analysed to draw meaningful conclusions. Intermediate to advanced level but very readable.

Website addresses

http://www.cpc.ncep.noaa.gov/products/global_monitoring/precipitation/global_precip_accum.shtml
For daily rainfall totals in a variety of climates, this site provides information about areas that are believed to be influenced by El Nino (see Chapter 6). The data are only about three days after recording and are displayed for the previous twelve months. At many of the stations, the observed accumulated totals are compared with the long-term average. Useful as a resource of current rainfall and incidence of drought and floods.

http://hadobs.metoffice.com/hadukp/charts/charts.html
The UK Meteorological Office provide a range of information about rainfall from recent monthly totals relative to the long-term average to the historic record of England and Wales precipitation going back to 1766.

http://www.metoffice.gov.uk/education/secondary/students/water.html
Aimed at students, the Met Office outlines the types of precipitation and their formation using animation where appropriate. Also includes examples of case studies about weather extremes in the UK.

http://www.sws.uiuc.edu/data.asp

If you ever wished to know what use precipitation data was, then browse through this site. It contains a vast array of information about precipitation and water in the State of Illinois, U.S.A., may provide good ideas about what to analyse from your own data.

http://www.drought.gov

It was created to provide comprehensive information on emerging and ongoing droughts, and to enhance drought preparedness in the US. Hence it gives much current information about the state of moisture availability throughout the US

http://www.drought.unl.edu/

An American site that is concerned both with the occurrence of drought and its mitigation. Provides a definition of drought together with planning for drought, monitoring drought, risk and impact assessment of drought and a section on mitigation.