Chapter One

Geography and Climate

Contents **Page**

Contents **Page**

GEOGRAPHY OF AUSTRALIA

Position and area

Australia comprises a land area of 7,682,300 square kilometres. The land lies between latitudes 10°41'S. (Cape York) and 43°39'S. (South Cape, Tasmania) and between longitudes 113°09'E. (Steep Point) and 153°39'E. (Cape Byron). The most southerly point on the mainland is South Point (Wilson's Promontory) 39°08'S. The latitudinal distance between Cape York and South Point is about 3,180 kilometres, while the latitudinal distance between Cape York and South East Cape, Tasmania, is 3,680 kilometres. The longitudinal distance between Steep Point and Cape Byron is about 4,000 kilometres.

1.1 AREA, COASTLINE, TROPICAL AND TEMPERATE ZONES, AND STANDARD TIMES

	Estimated area			*Percentage of total area*		*Standard times*	
State/Territory	*Total*	*Percentage of total area*	*Length of coastline*	*Tropical zone*	*Temperate zone*	*Meridian selected*	*Ahead of GMT(a)*
	km^2		km				hours
New South Wales	801,600	10.43	1,900	. .	100	150°E	10.0
Victoria	227,600	2.96	1,800	. .	100	150°E	10.0
Queensland	1,727,200	22.48	7,400	54	46	150°E	10.0
South Australia	984,000	12.81	3,700	. .	100	142°30'E	9.5
Western Australia	2,525,500	32.87	12,500	37	63	120°E	8.0
Tasmania	67,800	0.88	3,200	. .	100	150°E	10.0
Northern Territory	1,346,200	17.52	6,200	81	19	142°30'E	9.5
Australian Capital Territory	2,400	0.03	(b)35	. .	100	150°E	10.0
Australia	**7,682,300**	**100.00**	**36,735**	**39**	**61**	. .	. .

(a) Greenwich Mean Time. During daylight saving periods, an hour should be added to the times in this column. (b) Jervis Bay Territory.
Source: Bureau of Meteorology.

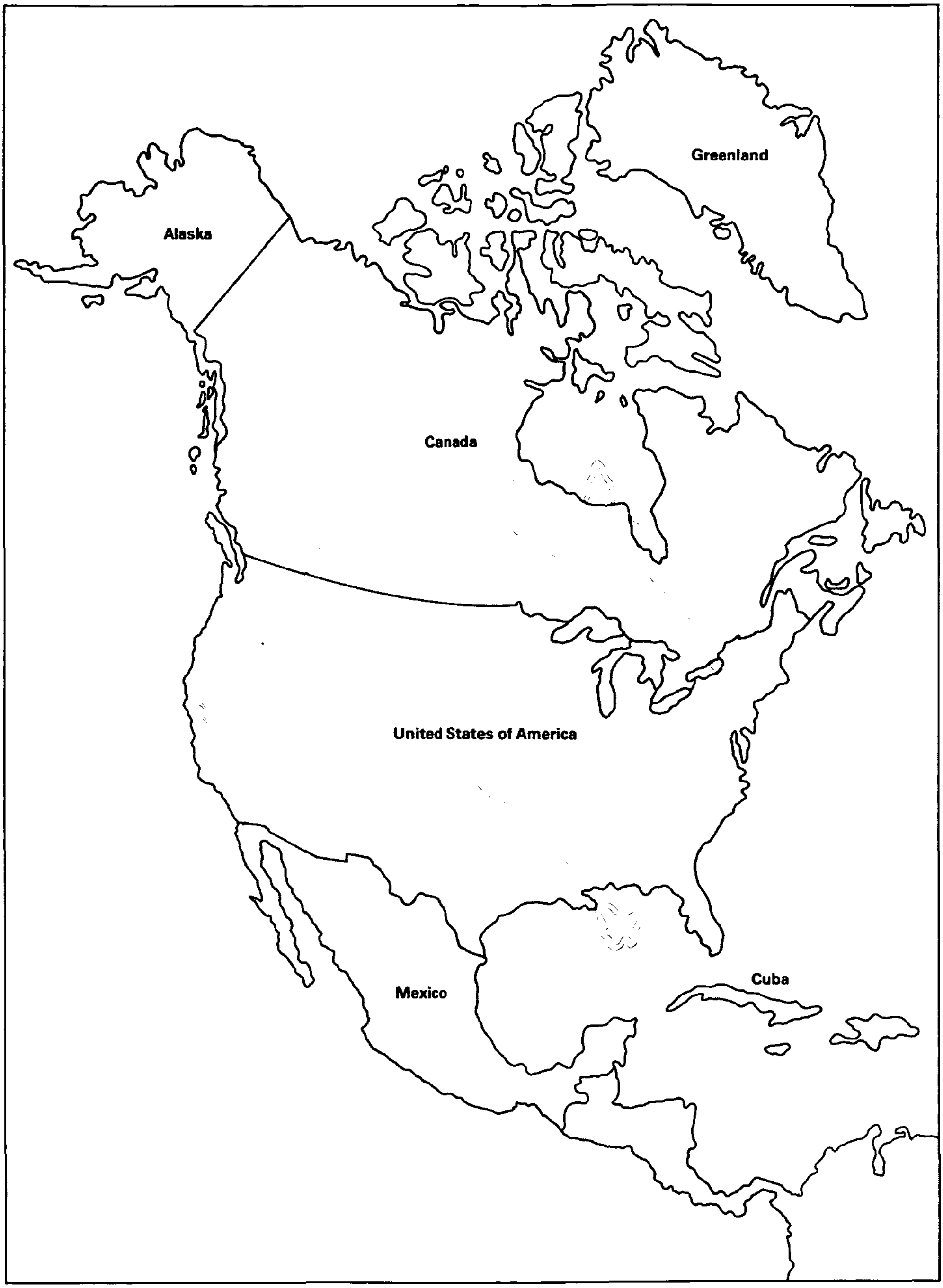
The area of Australia is almost as great as that of the United States of America (excluding Alaska), about 50 per cent greater than Europe (excluding USSR) and 32 times greater than the United Kingdom. The following table and maps show the area of Australia in relation to areas of other continents and selected countries.

1.2 AREAS OF CONTINENTS AND SELECTED COUNTRIES
('000 square kilometres)

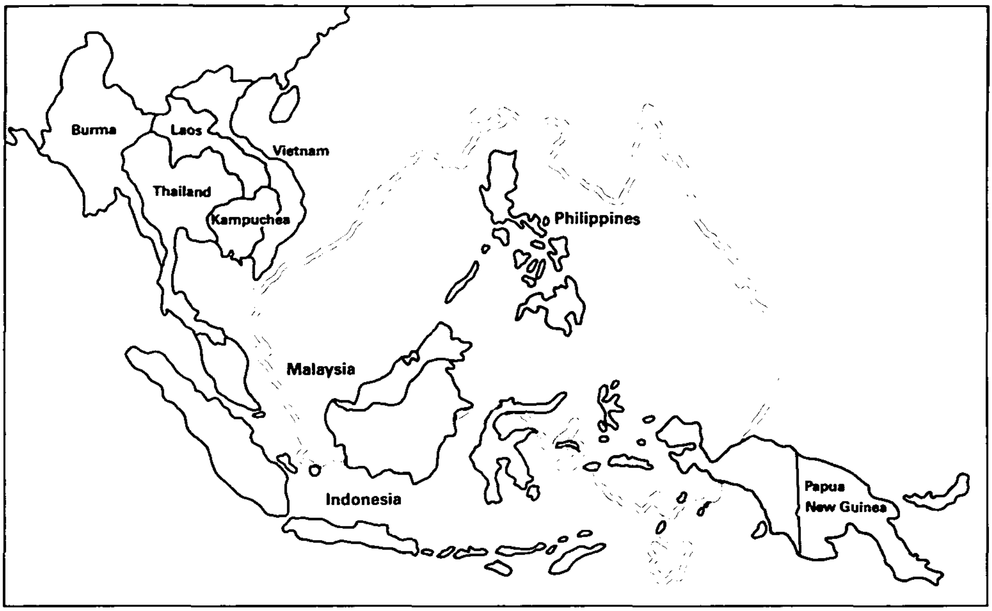
Country	*Area*	*Country*	*Area*
Continents		India	3,288
Asia	44,614		
Africa	30,319	Selected other countries	
North, Central America		Belorussia	208
and West Indies	24,247	France	544
South America	17,834	Germany	357
Europe	10,600	Indonesia	1,919
Australia and Oceania	8,504	Japan	372
		Kazakhstan	2,717
Countries (seven largest)		Papua New Guinea	462
Russia	17,073	New Zealand	269
Canada	9,976	Ukraine	604
China	9,590	United Kingdom	244
United States of America	9,363		
Brazil	8,512	**Total land mass excluding Arctic**	
Australia	**7,682**	**and Antarctic continents**	**135,774**

Source: Encyclopedia Britannica and The World Book Encyclopedia.

FIGURE 1.3


Greenland
Alaska
Canada
United States of America
Mexico
Cuba

FIGURES 1.4 AND 1.5



Landforms and their history

Australia is the lowest, flattest, and, apart from Antarctica, the driest of the continents. Unlike Europe and North America, where much of the landscape dates back to 20,000 years ago when great ice sheets retreated, the age of landforms in Australia is generally measured in many millions of years. This fact gives Australia a very distinctive physical geography.

The continent can be divided into three parts — the Western Plateau, the Central Lowlands and the Eastern Highlands.

The Western Plateau consists of very old rocks (some over 3,000 million years old), and much of it has existed as a landmass for over 500 million years. Several parts have individual 'plateau' names (for example, Kimberley, Hammersley, Arnhem Land, Yilgarn). In the Perth area, younger rocks along a coastal strip are separated from the rest by the Darling Fault escarpment. The Nullabor Plain is virtually an uplifted sea floor, a limestone plain of Miocene age (about 25 million years).

The Central Lowlands stretch from the Gulf of Carpentaria through the Great Artesian Basin to the Murray–Darling Plains. The Great Artesian Basin is filled with sedimentary rocks which hold water that enters in the wetter Eastern Highlands.

Much of the centre of Australia is flat, but there are numerous ranges (for example, Macdonnels, Musgrave) and some individual mountains of which Ayers Rock (Uluru) is the best known. Faulting and folding in this area took place long ago, the area was worn to a plain, the plain uplifted and then eroded to form the modern ranges on today's plain. In looking at Ayers Rock the remarkable thing is not how it got there, but that so much has been eroded from all around, leaving it there.

In the South Australian part of the Central Lowlands fault movements are more recent, and the area can be considered as a number of blocks that have been moved up and down to form a series of 'ranges' (Mt Lofty, Flinders Ranges) and 'hills' (such as the Adelaide Hills) with the downfaulted blocks occupied by sea (for example, Spencer Gulf) or lowlands including the lower Murray Plains.

The Eastern Highlands rise gently from central Australia towards a series of high plateaus, and even the highest part around Mt Kosciusko (2,230 metres) is part of a plateau.

There are a few younger faults and folds, such as the Lake George Fault near Canberra, and the Lapstone Monocline near Sydney.

Some plateaus in the Eastern Highlands are dissected by erosion into rugged hills, and the eastern edges of plateaus tend to form high escarpments. Many of these are united to form a Great Escarpment that runs from northern Queensland to the Victorian border. Australia's highest waterfalls (Wollombi on the Macleay, Wallaman Falls on a tributary of the Herbert, Barron Falls near Cairns, and Wentworth Falls in the Blue Mountains) all occur where rivers flow over the Great Escarpment. For most of its length the Great Divide (separating rivers flowing to Central Australia from rivers flowing to the Pacific) runs across remarkably flat country dotted with lakes and airstrips, and there is no 'Great Dividing Range'. In eastern Victoria, however, the old plateau has been eroded into separate High Plains (such as Dargo High Plain), mostly lying south of the Divide which here runs across rugged country.

The present topography results from a long landscape history which can conveniently be started in the Permian, about 290 million years ago, when much of Australia was glaciated by a huge ice cap. After the ice melted, parts of the continent subsided and were covered with sediment to form sedimentary basins such as the Great Artesian Basin. By early Cretaceous times, about 140 million years ago, Australia was already so flat and low that a major rise in sea level divided it into three landmasses as the shallow Cretaceous sea spread over the land.

In the following Tertiary times Australia can be regarded as a landscape of broad swells varied by a number of sedimentary basins (Murray, Gippsland, Eucla, Carpentaria, Lake Eyre and other basins). These slowly filled up and some are now sources of coal or oil. The Eastern Highlands were uplifted about this time.

Throughout the Tertiary, volcanoes erupted in eastern Australia. Some individual volcanoes were the size of modern Vesuvius, and huge lava plains covered large areas. Volcanic activity continued up to a few thousand years ago in Victoria and Queensland. Australia's youngest volcano is Mt Gambier in South Australia, about 6,000 years old.

Between 55 and 10 million years ago Australia drifted across the surface of the earth as a plate, moving north from a position once adjacent to Antarctica. There have been many changes in the climate of Australia in the past, but oddly these are not due to changing latitude. Even when Australia was close to the South Pole the climate was warm and wet, and this climate persisted for a long time despite changes in latitude. It was probably under this climate that the deep weathered, iron-rich profiles that characterise much of Australia were formed. Aridity only seems to have set in after Australia reached its present latitude, and the northern part was probably never arid.

Today a large part of Australia is arid or semi-arid. Sand dunes are mostly longitudinal, following the dominant wind directions of a high pressure cell. The dunes are mostly fixed now. Stony deserts or gibber plains (covered with small stones or 'gibbers') are areas without a sand cover and occupy a larger area than the dunefields. Salt lakes occur in many low positions, in places following lines of ancient drainage. They are often associated with lunettes, dunes formed on the downwind side of lakes. Many important finds of Aboriginal prehistory have been made in lunettes. Despite the prevalence of arid conditions today, real aridity seems to be geologically young, with no dunes or salt lakes older than a million years.

The past few million years were notable for the Quarternary ice age. There were many glacial and interglacial periods (over 20) during this time, the last glacial about 20,000 years ago. In Tasmania there is evidence of three different glaciations — the last glaciation, one sometime in the Quaternary, and one in the Tertiary. In mainland Australia there is evidence of only the last glaciation, and the ice then covered only 25 square kilometres, in the vicinity of Mt Kosciusko.

The broad shape of Australia is caused by earth movements, but most of the detail is carved by river erosion. Many of Australia's rivers drain inland, and while they may be eroding their valleys near their highland sources, their lower courses are filling up with alluvium, and the rivers often end in salt lakes which are dry for most of the time. Other rivers reach the sea, and have dissected a broad near-coast region into plateaus, hills and valleys. Many of the features of the drainage pattern of Australia have a very long history, and some individual valleys have maintained their position for hundreds of millions of years. The salt lakes of the Yilgarn Plateau in Western Australia are the remnants of a drainage pattern that was active before continental drift separated Australia from Antarctica.

During the last ice age, sea level was over 100 metres lower than it is today, and rivers cut down to this low level. When sea level rose again the lower valleys were drowned. Some make fine harbours (for example, Sydney Harbour), whilst others have tended to fill alluvium, making the typical lowland valleys around the Australian coast.

Coastal geomorphology is also largely the result of the accumulation of sediment in drowned coasts. In some areas, such as Ninety Mile Beach (Victoria) or the Coorong (South Australia), there are simple accumulation beaches. In much of the east there is a characteristic alternation of rocky headland and long beach, backed by plains filled with river and marine sediments.

The offshore shape of Australia, revealed in isobath contours, results mainly from the pattern of break-up of the super-continent of which Australia was once a part. There is a broad continental shelf around most of Australia, bounded by a steeper continental slope, except in New South Wales where the continental shelf is very narrow. The Queensland coast is bounded by a broad plateau on which the Great Barrier Reef has grown in only the last two million years. In South Australia the continental shelf is grooved by submarine canyons.

The Australian landforms of today are thus seen to result from long-continued processes in a unique setting, giving rise to typical Australian landscapes, which in turn provide the physical basis for the distribution and nature of biological and human activity in Australia.

Rivers and lakes

The rivers of Australia may be divided into two major classes, those of the coastal margins with moderate rates of fall and those of the central plains with very slight fall. Of the rivers of the east coast, the longest in Queensland are the Burdekin and the Fitzroy, while the Hunter is the largest coastal river of New South Wales. The longest river system in Australia is the Murray–Darling which drains part of Queensland, the major part of New South Wales and a large part of Victoria, finally flowing into the arm of the sea known as Lake Alexandrina, on the eastern side of the South Australian coast. The length of the Murray is about 2,520 kilometres and the Darling and Upper Darling together are also just over 2,000 kilometres long. The rivers of the north-west coast of Australia, for example, the Murchison, Gascoyne, Ashburton, Fortescue, De Grey, Fitzroy, Drysdale and Ord, are of considerable size. So also are those rivers in the Northern Territory, for example, the Victoria and Daly, and those on the Queensland side of the Gulf of Carpentaria, such as the Gregory, Leichhardt, Cloncurry, Gilbert and Mitchell. The rivers of Tasmania have short and rapid courses, as might be expected from the configuration of the country.

There are many types of lake in Australia, the largest being drainage sumps from the internal rivers. In dry seasons these lakes finally become beds of salt and dry mud. The largest are Lake Eyre 9,500 square kilometres, Lake Torrens 5,900 square kilometres and Lake Gairdner 4,300 square kilometres.

Other lake types are glacial, most common in Tasmania; volcanic crater lakes predominantly in Victoria and Queensland; fault angle lakes, of which Lake George near Canberra is a good example and coastal lakes formed by marine damming of valleys.

CLIMATE OF AUSTRALIA

The island continent of Australia features a wide range of climatic zones, from the tropical regions of the north, the arid expanses of the interior, to the temperate regions of the south.

Widely known as 'The Dry Continent', the land mass is relatively arid, with 80 per cent having a median rainfall less than 600 millimetres per year and 50 per cent less than 300 millimetres. Seasonal fluctuations can be great, with temperatures ranging from above 50°C to well below zero. However, extreme minimum temperatures are not as low as those recorded in other continents because of the absence of extensive mountain masses and because of the expanse of the surrounding oceans.

Although the climate can be described as predominantly continental, the insular nature of the land mass produces modifications to the general continental pattern.

Australia can be host to any of nature's disasters, particularly droughts, floods, tropical cyclones, severe storms and bushfires.

Climatic controls

The generally low relief of Australia causes little obstruction to the atmospheric systems which control the climate. A notable exception is the eastern uplands which modify the atmospheric flow.

In the winter half of the year (May–October) anticyclones, or high pressure systems, pass from west to east across the continent and often remain almost stationary over the interior for several days. These anticyclones may extend to 4,000 kilometres along their west–east axes. Northern Australia is then influenced by mild, dry south-east trade winds, and southern Australia experiences cool, moist westerly winds. The westerlies and the frontal systems associated with extensive depressions travelling over the Southern Ocean have a controlling influence on the climate of southern Australia during the winter season, causing rainy periods. Periodic north-west cloud bands in the upper levels of the atmosphere over the continent may interact with southern systems to produce rainfall episodes, particularly over eastern areas. Cold outbreaks, particularly in south-east Australia, occur when cold air of Southern Ocean origin is directed northwards by intense depressions having diameters up to 2,000 kilometres. Cold fronts associated with the southern depressions, or with secondary depressions over the Tasman Sea, may produce large day-to-day changes in temperature in southern areas, particularly in south-east coastal regions.

In the summer half of the year (November–April) the anticyclones travel from west to east on a more southerly track across the southern fringes of Australia directing easterly winds generally over the continent. Fine, warmer weather predominates in southern Australia with the passage of each anticyclone. Heat waves occur when there is an interruption to the eastward progression of the anticyclone (blocking) and winds back northerly and later north-westerly. Northern Australia comes under the influence of summer disturbances associated with the southward intrusion of warm moist monsoonal air from north of the intertropical convergence zone, resulting in a hot rainy season. Southward dips of the monsoonal low pressure trough sometimes spawn tropical depressions, and may prolong rainy conditions over northern Australia for episodes up to three weeks at a time.

Tropical cyclones develop over the seas around northern Australia in summer between November and April. Their frequency of occurrence and the tracks they follow vary greatly from season to season. On average, about three cyclones per season directly affect the Queensland coast, and about three affect the north and north-west coasts. Tropical cyclones approaching the coast usually produce very heavy rain and high winds in coastal areas. Some cyclones move inland, losing intensity but still producing widespread heavy rainfall.

The climate of eastern and northern Australia is influenced by the Southern Oscillation (SO), seesawing of atmospheric pressure between the northern Australian/Indonesian region and the central Pacific Ocean. This oscillation is the second most important cause of climatic variation after the annual seasonal cycle, over eastern and northern Australia. The strength of the Southern Oscillation is determined by the Southern Oscillation Index (SOI) which is a measure of the difference in sea level atmospheric pressure between Tahiti in the central Pacific and Darwin, northern Australia. At one extreme of the oscillation, the pressure is abnormally high at Darwin and abnormally low at Tahiti. Severe and widespread drought over eastern and northern Australia generally accompanies this extreme. These conditions generally commence early in the year, last for about 12 months, and have a re-occurrence period of 2 to 7 years.

The above extreme is generally immediately preceded or followed by the opposite extreme where pressures at Darwin are abnormally low and those at Tahiti are abnormally high. In this case, rainfall is generally above average over eastern and northern Australia.

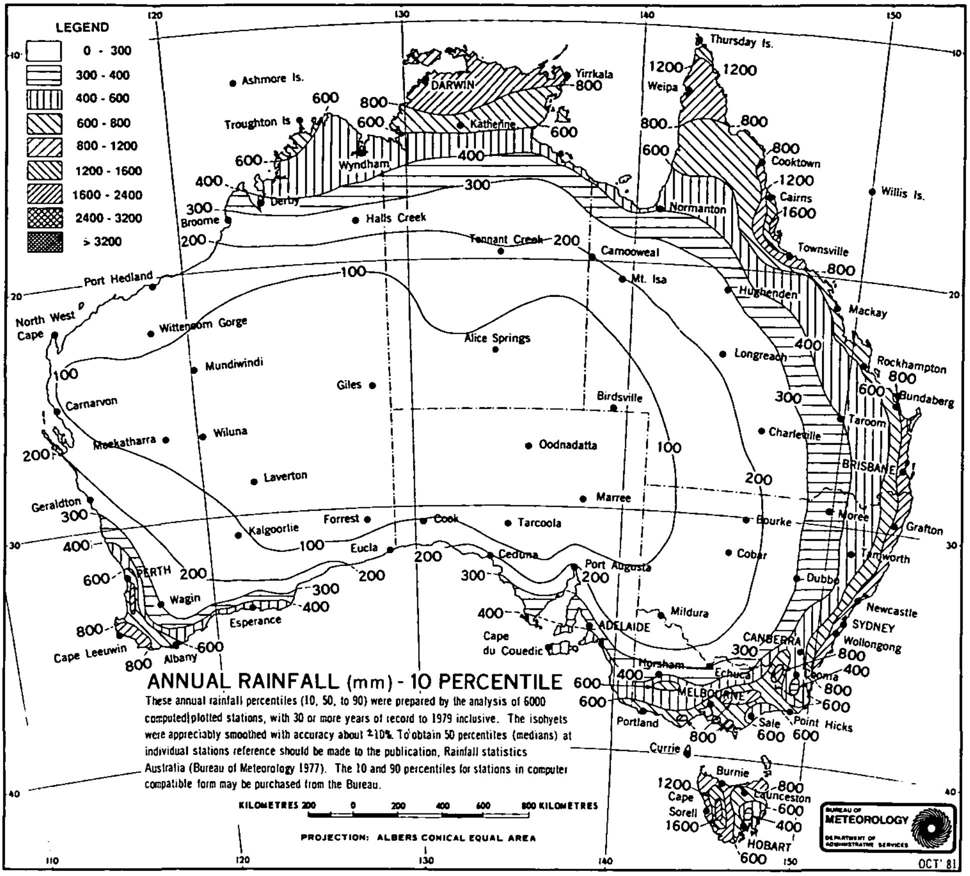
The SO is linked to sea surface temperatures (SSTs) in the Pacific Ocean. Dry extreme SO years are accompanied by above normal SSTs in the central and/or eastern equatorial Pacific and vice versa. Dry extreme years are called El Nino years. Wet extreme years are called La Nina years.

Rainfall and other precipitation

Annual. The annual 10, 50 and 90 percentile rainfall maps are shown on figures 1.6, 1.8 and 1.9 respectively. The area of lowest rainfall is in the vicinity of Lake Eyre in South Australia, where the median (50 percentile) rainfall is only about 100 millimetres. Another very low rainfall area is in Western Australia in the Giles–Warburton Range region, which has a median annual rainfall of about 150 millimetres. A vast region, extending from the west coast near Shark Bay across the interior of Western Australia and South Australia to south-west Queensland and north-west New South Wales, has a median annual rainfall of less than 200 millimetres. This region is not normally exposed to moist air masses for extended periods and rainfall is irregular, averaging only one or two days per month. However, in favourable synoptic situations, which occur infrequently over extensive parts of the region, up to 400 millimetres of rain may fall within a few days and cause widespread flooding.

The region with the highest median annual rainfall is the east coast of Queensland between Cairns and Cardwell, where Tully has a median of 4,048 millimetres (63 years to 1987 inclusive). The mountainous region of western Tasmania also has a high annual rainfall, with Lake Margaret having a median of 3,565 millimetres (76 years to 1987 inclusive). In the mountainous areas of north-east Victoria and some parts of the east coastal slopes there are small pockets with median annual rainfall greater than 2,500 millimetres, but the map scale is too small for these to be shown.

FIGURE 1.6



NOTE: The amounts that are not exceeded by 10, 50 and 90 per cent of all recordings are the 10, 50 and 90 percentiles or the first, fifth and ninth deciles respectively. The 50 percentile is usually called the median.
Source: Bureau of Meteorology.

The Snowy Mountains area in New South Wales also has a particularly high rainfall. The highest median annual rainfall isohyet drawn for this region is 3,200 millimetres, and it is likely that small areas have a median annual rainfall approaching 4,000 millimetres on the western slopes above 2,000 metres elevation.

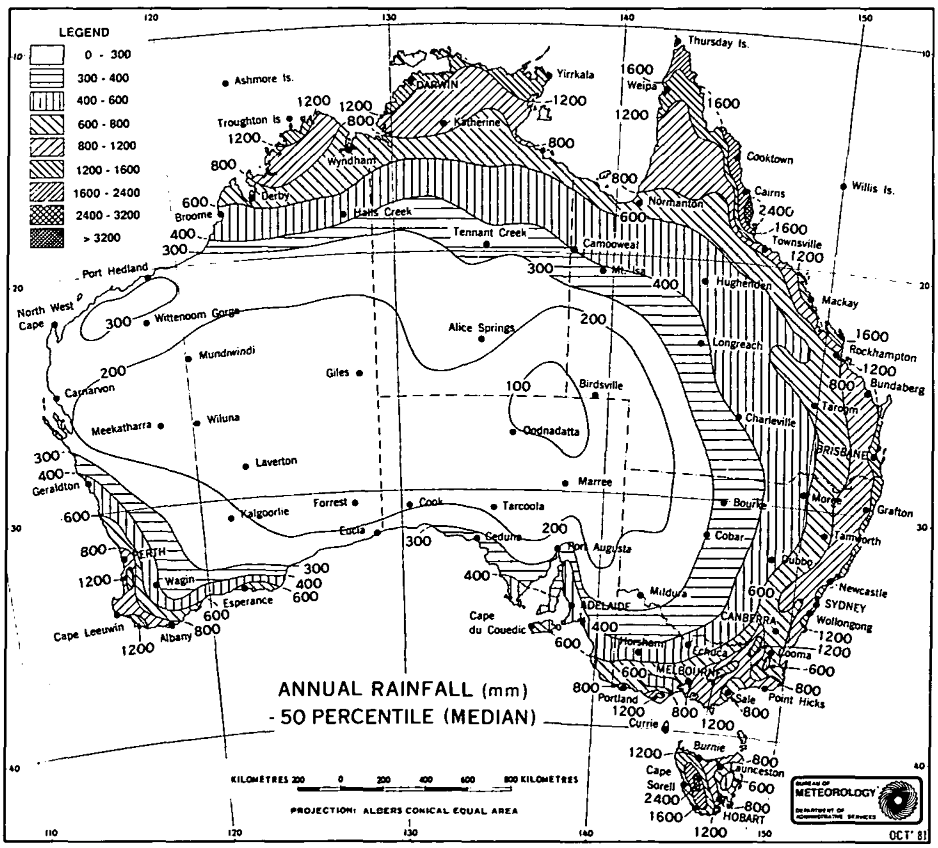
The following table shows the area distribution of median annual rainfall.

1.7 AREA DISTRIBUTION OF MEDIAN ANNUAL RAINFALL
(per cent)

Median annual rainfall	*NSW(a)*	*Vic.*	*Qld*	*SA*	*WA*	*Tas.*	*NT*	*Aust.*
Under 200 mm	8.0	. .	10.2	74.2	43.5	. .	15.5	29.6
200 to 300 mm	20.3	6.3	13.0	13.5	29.6	. .	35.6	22.9
300 to 400 mm	19.0	19.2	12.3	6.8	10.5	. .	9.0	11.2
400 to 500 mm	12.4	11.8	13.5	3.2	4.3	. .	6.6	7.6
500 to 600 mm	11.3	14.1	11.6	1.8	3.1	12.2	5.8	6.6
600 to 800 mm	15.1	24.5	20.5	0.5	4.6	18.2	11.6	10.7
800 to 1,200 mm	11.3	17.7	12.6	. .	3.7	25.0	9.6	7.7
Above 1,200 mm	2.6	6.4	6.3	. .	0.7	44.6	6.3	3.7
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

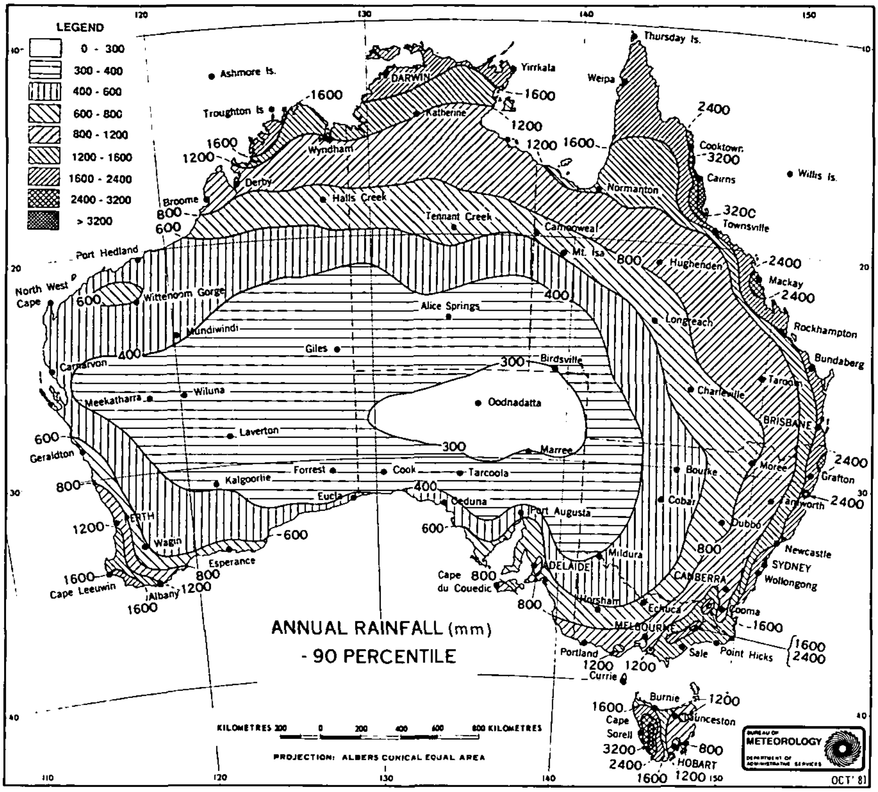
(a) Includes Australian Capital Territory.
Source: Bureau of Meteorology.

FIGURE 1.8



Source: Bureau of Meteorology.

FIGURE 1.9



Source: Bureau of Meteorology.

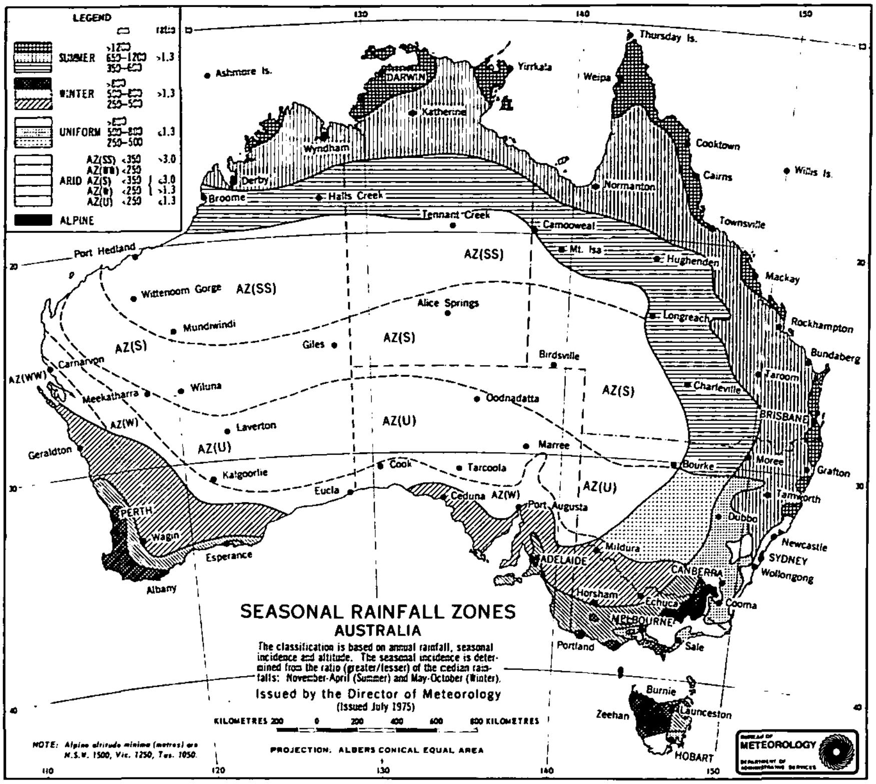
Seasonal. As outlined above, the rainfall pattern of Australia is strongly seasonal in character with a winter rainfall regime in the south and a summer regime in the north.

The dominance of rainfall over other climatic elements in determining the growth of specific plants in Australia has led to the development of a climatic classification based on two main parameters. The parameters are median annual rainfall and seasonal rainfall incidence. Figure 1.10 is a reduced version of the seasonal rainfall zones arising from this classification (*see* Bureau of Meteorology publication *Climatic Atlas of Australia, 1988*).

Evaporation and the concept of rainfall effectiveness are taken into account to some extent in this classification by assigning higher median annual rainfall limits to the summer zones than the corresponding uniform and winter zones. The main features of the seasonal rainfall are:

- marked wet summer and dry winter of northern Australia;
- wet summer and relatively dry winter of south-eastern Queensland and north-eastern New South Wales;
- uniform rainfall in south-eastern Australia — much of New South Wales, parts of eastern Victoria and southern Tasmania;
- marked wet winter and dry summer of south-west Western Australia and, to a lesser extent, much of the remainder of southern Australia directly influenced by westerly circulation; and

FIGURE 1.10



Source: Bureau of Meteorology.

- arid area comprising about half the continent extending from the north-west coast of Western Australia across the interior and reaching the south coast at the head of the Great Australian Bight.

The seasonal rainfall classification (*Climatic Atlas of Australia, 1988*) can be further reduced to provide a simplified distribution of seven climatic zones as shown in figure 1.11.

Variability. The adequate presentation of rainfall variability over an extensive geographical area is difficult. Probably the best measures are found in tables compiled for a number of individual stations in some of the Climatic Survey districts. These tables show the percentage chances of receiving specified amounts of rainfall in monthly, seasonal or annual time spans. Statistical indices of rainfall variation based on several techniques have been used to compile maps showing main features of the variability of annual rainfall over Australia.

One index for assessing the variability of annual rainfall is given by the ratio of the 90–10 percentile range to the 50 percentile (median value), that is:

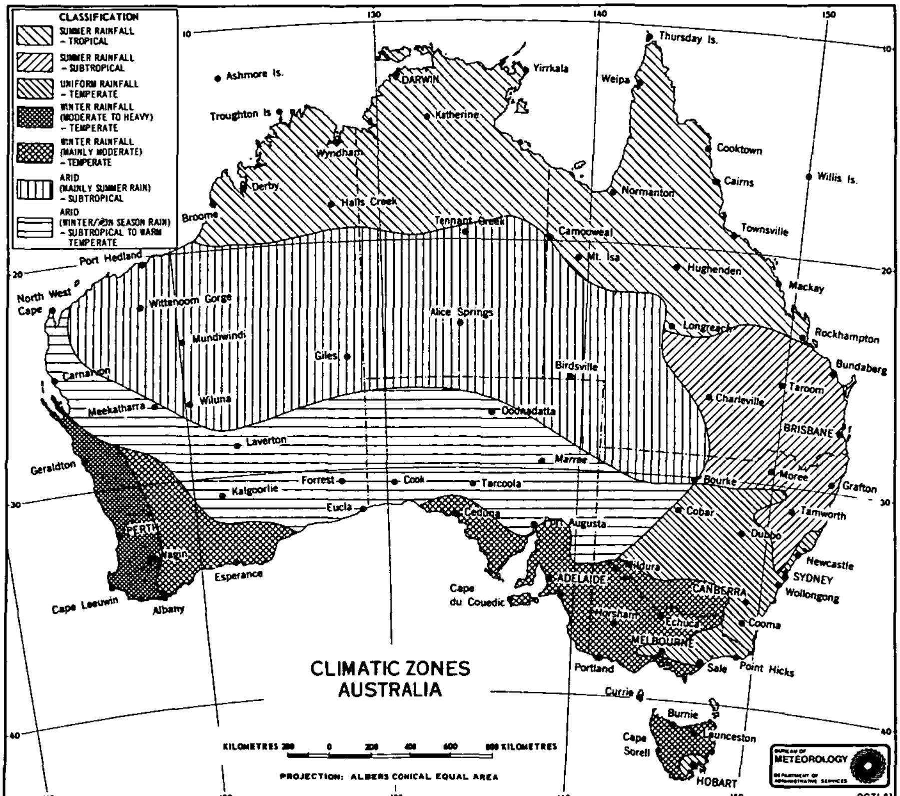
$$\text{Variability Index} = \left\{\frac{90\text{–}10}{50}\right\} \text{ percentiles.}$$

Variability based on this relationship (Gaffney 1975 and Lee and Gaffney 1986) is shown in figure 1.12. The region of high to extreme variability shown in figure 1.12 lies mostly in the arid zones with summer rainfall incidence, AZ (S) defined on figure 1.10. In the winter rainfall zones, the variability is generally low to moderate as exemplified by the south-west of Western Australia. In the tropics, random cyclone visitations cause extreme variations in rainfall from year to year: at Onslow (Western Australia), annual totals varied from 15 millimetres in 1912 to 1,085 millimetres in 1961 and, in the four consecutive years 1921 to 1924, the annual totals were 566, 69, 682 and 55 millimetres respectively. At Whim

Creek (Western Australia), where 747 millimetres have been recorded in a single day, only 4 millimetres were received in the whole of 1924. Great variability can also occur in the heavy rainfall areas: at Tully (Queensland), the annual rainfalls have varied from 7,898 millimetres in 1950 to 2,486 millimetres in 1961.

Variability of rainfall in eastern Australia is strongly linked to the Southern Oscillation — *see* under Climatic controls. High SOI values relate to above average rainfall over eastern Australia, and low SOI values relate to below average rainfall over the area. Table 1.13 illustrates the significance of this SOI/rainfall relationship.

FIGURE 1.11

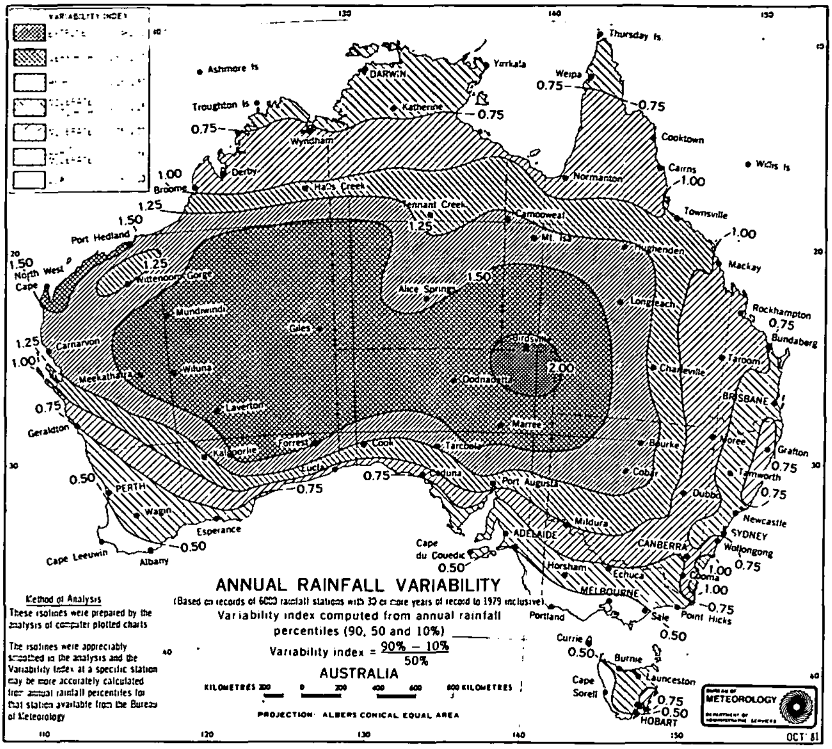


CLASSIFICATION	SEASONAL CHARACTERISTICS SUMMER	WINTER
Summer Rainfall - Tropical	Heavy periodic rains (heavier in coastal & highland areas) Hot generally Humid in coastal areas	Generally rainless Mild to warm Dry
Summer Rainfall - Subtropical	Heavy periodic rains (heavier in coastal & highland areas) Mainly hot Humid in highlands & coastal areas	Some significant rain Mild
Uniform Rainfall - Temperate	Mainly reliable rain Warm to hot	Mainly reliable rain Cool to cold
Winter Rainfall (moderate to heavy) - Temperate	Irregular rain, mostly light Warm to hot	Reliable rain (moderate to heavy) Cool to mild
Winter Rainfall (mainly moderate) - Temperate	Mostly light irregular rain Warm to hot	Reliable rain (mainly moderate) Cool to cold
Arid (mainly summer rain) - Subtropical	Variably rain Hot to extreme Very dry	Mainly irregular light rain Mild to warm Dry
Arid (winter or non-seasonal rain) - Warm Temperate to Subtropical	Very irregular rain Hot to extreme Very dry	Variable rain, mainly light Cool to mild Dry

[Reference:- Climatic Atlas of Australia, Map set 5, Bureau of Meteorology 1975]

Source: Bureau of Meteorology.

FIGURE 1.12



Source: Bureau of Meteorology.

1.13 AVERAGE AREA OF EASTERN AUSTRALIA(a) WITH ANNUAL RAINFALL IN SPECIFIED RANGES BY SOUTHERN OSCILLATION INDEX RANGE

SOI range	Number of years (1913–91(b))	Average SOI	Percentage of area within percentile limits: ≤30 percentile	31–70 percentile	>70 percentile
<–10	4	–12.8	47.0	30.8	22.2
–5 to –10	11	–7.4	46.7	37.6	15.7
0 to –5	18	–2.2	33.3	40.7	26.0
+5 to 0	28	2.2	25.5	49.5	25.0
+10 to +5	8	8.0	10.3	24.4	65.3
>+10	4	14.0	3.8	28.7	67.5

(a) Queensland, New South Wales, Victoria and Tasmania. (b) 1914, 1915, 1921, 1927, 1931 and 1932 not included due to missing monthly data.
Source: Bureau of Meteorology.

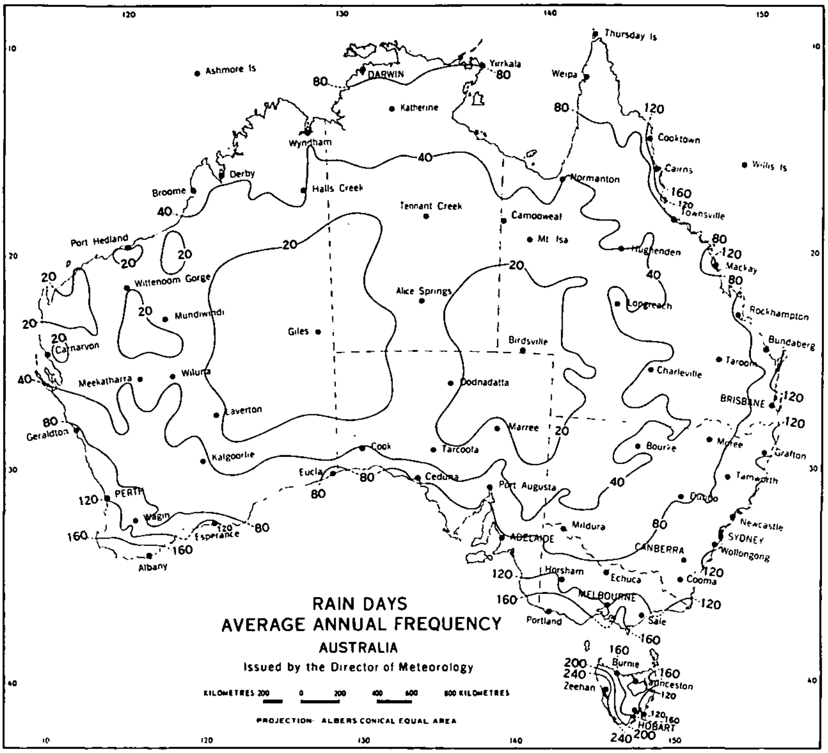
Rainday frequency. The average number of days per year with rainfall of 0.2 millimetres or more is shown in figure 1.14.

The frequency of raindays exceeds 150 per year in Tasmania (with a maximum of over 200 in western Tasmania), southern Victoria, parts of the north Queensland coast and in the extreme south-west of Western Australia. Over most of the continent the frequency is less than 50 raindays per year. The area of low rainfall with high variability, extending from the north-west coast of

Western Australia through the interior of the continent, has less than 25 raindays per year. In the high rainfall areas of northern Australia the number of raindays is about 80 per year, but heavier falls occur in this region than in southern regions.

Intensity. The highest rainfall intensities for some localities are shown in table 1.15.

FIGURE 1.14



Source: Bureau of Meteorology.

1.15 HIGHEST RAINFALL INTENSITIES IN SPECIFIED PERIODS

Station	*Period of record*	*Years of complete records*	*Period in hours* 1	3	6	12	24
			mm	mm	mm	mm	mm
Adelaide	1897–1979	79	69	133	141	141	141
Alice Springs	1951–1986	36	75	87	108	133	150
Brisbane	1911–1987	77	88	142	182	266	327
Broome	1948–1983	36	112	157	185	313	353
Canberra	1938–1982	37	40	57	67	76	120
Carnarvon	1956–1982	27	44	63	83	95	108
Charleville	1953–1987	35	42	66	75	111	142
Cloncurry	1953–1981	23	59	118	164	173	204
Darwin (Airport)	1953–1987	35	89	138	214	260	291
Esperance	1963–1979	15	23	45	62	68	79
Hobart	1911–1985	75	28	56	87	117	168
Meekatharra	1953–1982	30	33	67	81	99	112
Melbourne	1873–1986	100	76	83	86	97	130
Mildura	1953–1986	34	49	60	65	66	91
Perth	1946–1983	37	31	37	48	64	80
Sydney	1913–1987	71	121	194	200	244	340
Townsville	1953–1987	34	88	158	235	296	319

Source: Pluviograph records in Bureau of Meteorology archives.

These figures represent intensities over only small areas around the recording points because turbulence and exposure characteristics of the measuring gauge may vary over a distance of a few metres. The highest 24 hour (9 a.m. to 9 a.m.) falls are listed below. Most of the very high 24 hour falls (above 700 millimetres) have occurred in the coastal strip of Queensland, where a tropical cyclone moving close to mountainous terrain provides ideal conditions for spectacular falls.

The highest annual rainfalls are listed by State in the table 1.17.

1.16 HIGHEST DAILY RAINFALLS

State	*Station*	*Date*	*Amount*
			mm
New South Wales	Dorrigo (Myrtle Street)	21.2.1954	809
	Lowanna (Yalamurra)	22.4.1974	662
Victoria	Tanybryn	22.3.1983	375
	Nowa Nowa (Wairawa)	11.3.1906	275
Queensland(a)	Beerwah (Crohamhurst)	3.2.1893	907
	Finch Hatton PO	18.2.1958	878
South Australia	Motpena	14.3.1989	273
	Nilpena	14.3.1989	247
Western Australia	Roebourne (Whim Creek)	3.4.1898	747
	Broome (Kilto)	4.12.1970	635
Tasmania	Cullenswood	22.3.1974	352
	Mathinna	5.4.1929	337
Northern Territory	Roper Valley Station	15.4.1963	545
	Angurugu (Groote Eylandt)	28.3.1953	513

(a) Bellenden Ker (Top Station) has recorded a 24 hour total of 960 mm from 3 p.m. to 3 p.m. on the 3rd and 4th January 1979. The standard daily rainfall period is 9 a.m. to 9 a.m.

Source: Bureau of Meteorology.

1.17 HIGHEST ANNUAL RAINFALLS

State	*Station*	*Year*	*Amount*
			mm
New South Wales	Tallowwood Point	1950	4,540
Victoria	Falls Creek SEC	1956	3,739
Queensland	Bellenden Ker (Top Station)	1979	11,251
South Australia	Aldgate State School	1917	1,853
Western Australia	Armadale (Jarrahdale PO)	1917	2,169
Tasmania	Lake Margaret	1948	4,504
Northern Territory	Elizabeth Downs	1973	2,966

Source: Bureau of Meteorology.

Thunderstorms and hail. A thunderday at a given location is a calendar day on which thunder is heard at least once. Figure 1.18 shows isopleths (isobronts) of the average annual number of thunderdays which vary from 74 per year near Darwin to less than 10 per year over parts of the southern regions. Convectional processes during the summer wet season cause high thunderstorm incidence in northern Australia. The generally high incidence of thunderdays (40–60 annually) over the eastern upland areas is caused mainly by orographic uplift of moist air streams.

Hail, mostly of small size (less than 10 millimetres diameter), occurs with winter–spring cold frontal activity in southern Australia. Summer thunderstorms, particularly over the uplands of eastern Australia, sometimes produce large hail (greater than 10 millimetres diameter). Large hail capable of piercing light gauge galvanised iron occurs at irregular intervals and sometimes causes widespread damage.

Snow. Generally, snow covers much of the Australian Alps above 1,500 metres for varying periods from late autumn to early spring. Similarly, in Tasmania the mountains are covered fairly frequently above 1,000 metres in these seasons. The area, depth and duration are highly variable. In some years, snow falls in the altitude range of 500–1,000 metres. Snowfalls at levels below 500 metres are occasionally experienced in southern Australia, particularly in the foothill areas of Tasmania and Victoria, but falls are usually light and short lived. In some seasons, parts of the eastern uplands above 1,000 metres from Victoria to south-eastern Queensland have been covered with snow for several weeks. In ravines around Mount Kosciusko (2,228 metres) small areas of snow may persist through summer but there are no permanent snowfields.

Temperature

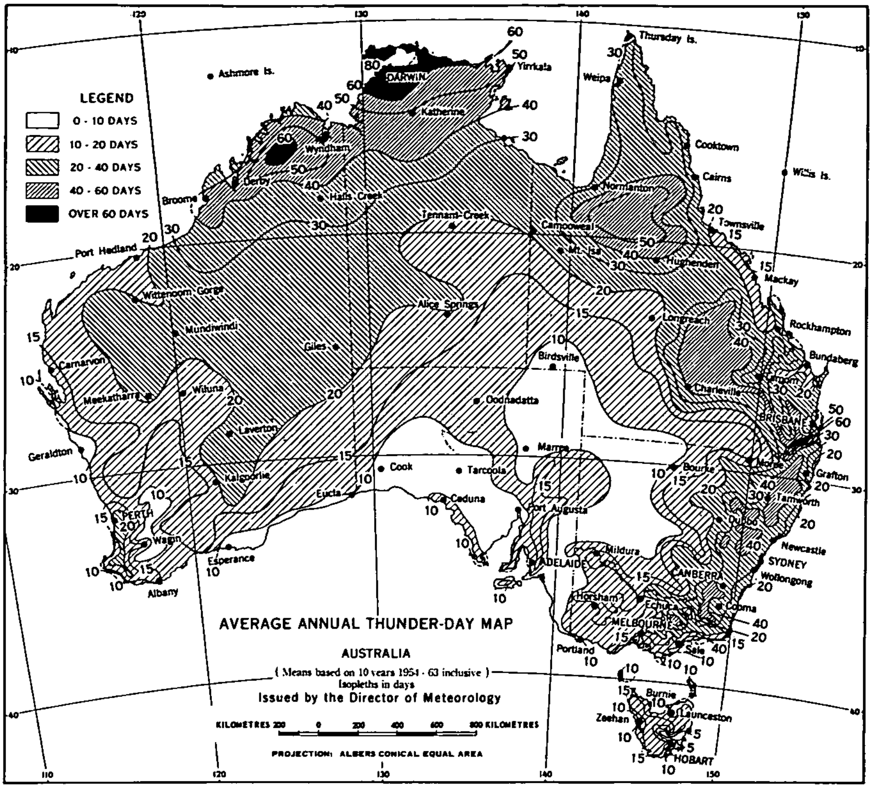
Average temperatures. Average annual air temperatures, as shown in figure 1.19, range from 28°C along the Kimberley coast in the extreme north of Western Australia to 4°C in the alpine areas of south-eastern Australia. Although annual temperature may be used for broad comparisons, monthly temperatures are required for detailed analyses.

July is the month with the lowest average temperature in all parts of the continent. The months with the highest average temperature are January or February in the south and December in the north (except in the extreme north and north-west where it is November). The slightly lower temperatures of mid-summer in the north are due to the increase in cloud during the wet season.

Average monthly maxima. Maps of average maximum and minimum temperatures for the months of January and July are shown in figures 1.20 to 1.23 inclusive.

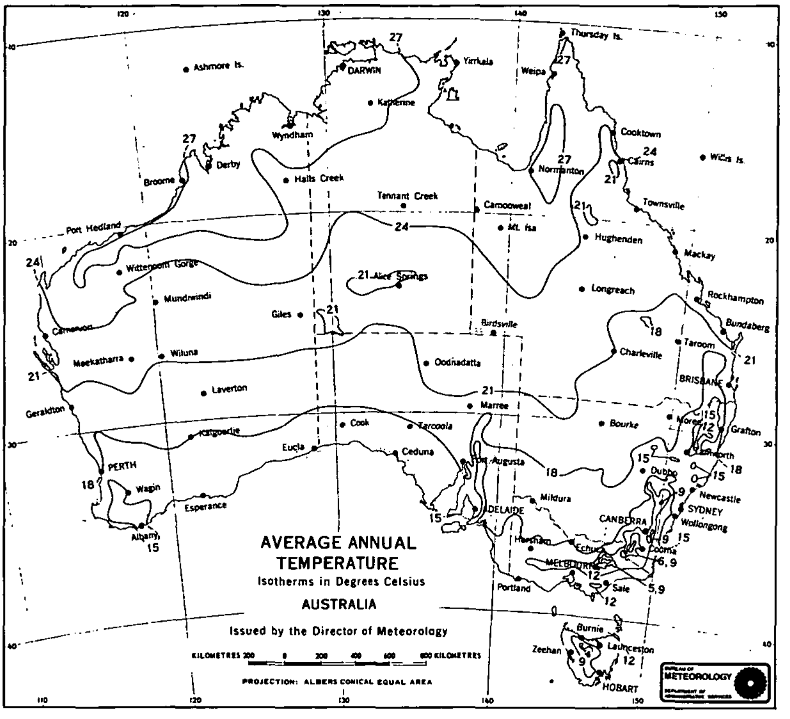
In January, average maximum temperatures exceed 35°C over a vast area of the interior and exceed 40°C over appreciable areas of the north-west. The consistently hottest part of Australia in terms of summer maxima is around Marble Bar in Western Australia (150 kilometres south-east of Port Hedland) where the average is 41°C and daily maxima during summer may exceed 40°C consecutively for several weeks at a time.

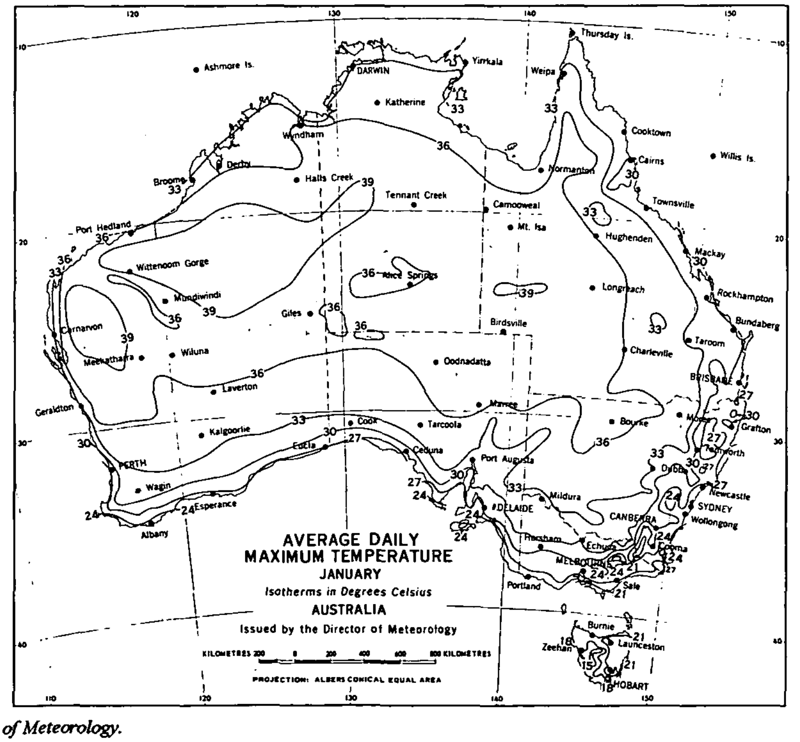
FIGURE 1.18



Source: Bureau of Meteorology.

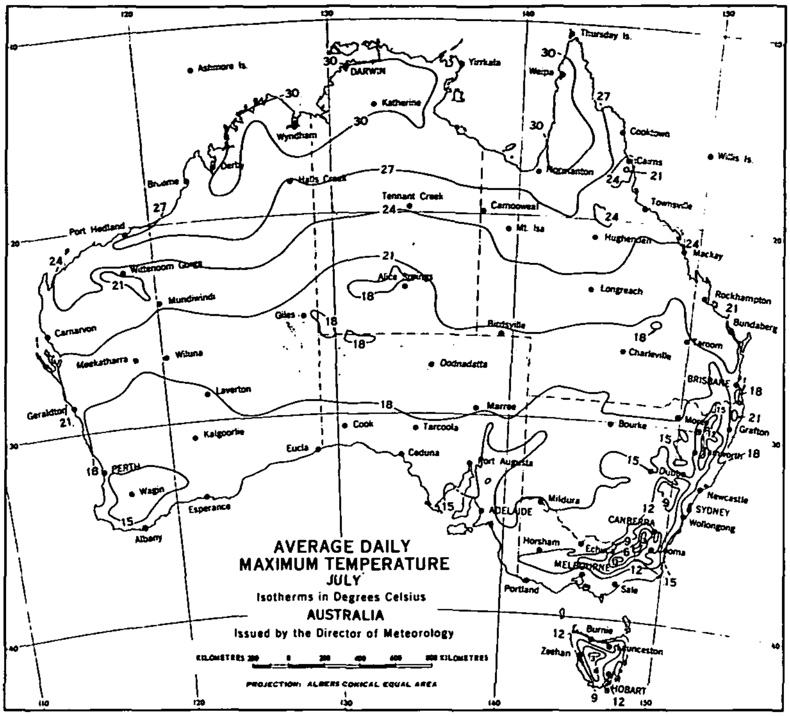
FIGURES 1.19 AND 1.20

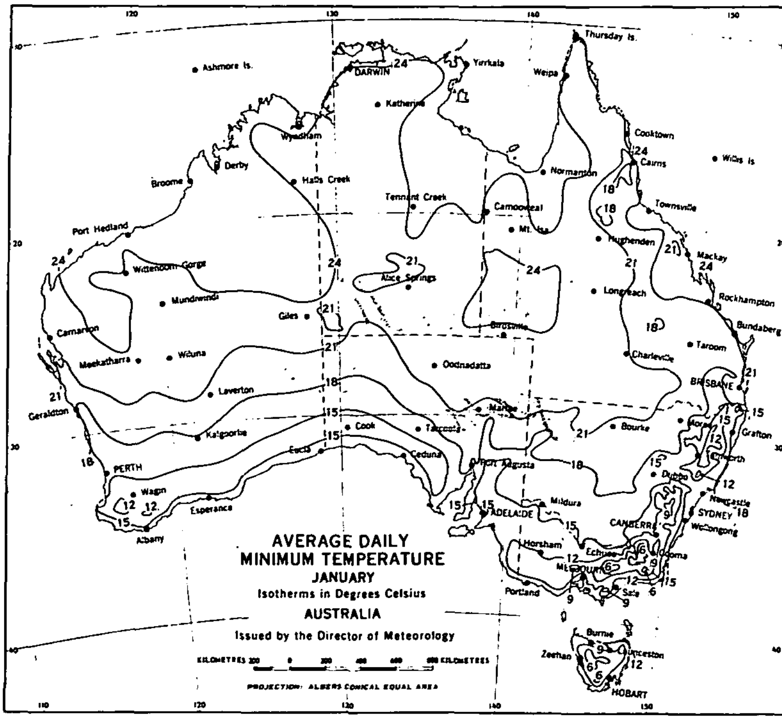




Source: Bureau of Meteorology.

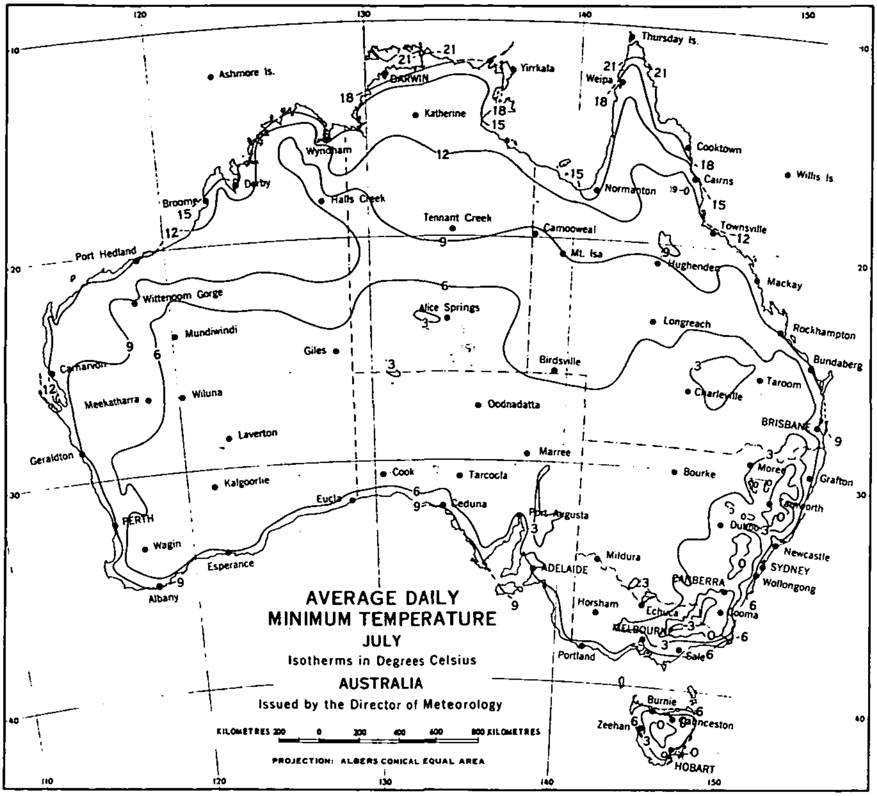
FIGURES 1.21 AND 1.22





Source: Bureau of Meteorology.

FIGURE 1.23



Source: Bureau of Meteorology.

The marked gradients of isotherms of maximum temperature in summer in coastal areas, particularly along the south and west coasts, are due to the penetration inland of fresh sea-breezes initiated by the sharp temperature discontinuties between the land and sea surfaces. There are also gradients of a complex nature in south-east coastal areas caused primarily by the uplands.

In July, a more regular latitudinal distribution of average maxima is evident. Maxima range from 30°C near the north coast to 5°C in the alpine areas of the south-east.

Average monthly minima. In January, average minima range from 27°C on the north-west coast to 5°C in the alpine areas of the south-east. In July, average minima fall below 5°C in areas south of the tropics (away from the coasts). Alpine areas record the lowest temperatures; the July average is as low as −5°C.

Extreme maxima. Temperatures have exceeded 45°C at nearly all inland stations more than 150 kilometres from the coast and at many places on the north-west and south coasts. Temperatures have exceeded 50°C at some inland stations and at a few near the coast. It is noteworthy that Eucla on the south coast has recorded 50.7°C, the highest temperature in Western Australia. This is due to the long trajectory over land of hot north-west winds from the Marble Bar area. Although the highest temperature recorded in Australia was 53.1°C at Cloncurry (Queensland), more stations have exceeded 50°C in western New South Wales than in other areas due to the long land trajectory of hot winds from the north-west interior of the continent.

Extreme maximum temperatures recorded at selected stations, including the highest recorded in each State, are shown in the following table.

1.24 EXTREME MAXIMUM TEMPERATURES

Station	*°C*	*Date*	*Station*	*°C*	*Date*
New South Wales			Western Australia		
Bourke	52.8	17.1.1877	Eucla	50.7	22.1.1906
Wilcannia	50.0	11.1.1939	Mundrabilla	49.8	3.1.1979
Menindee	49.7	10.1.1939	Forrest	49.8	13.1.1979
Victoria			Madura	49.4	7.1.1971
Mildura	50.8	6.1.1906	Tasmania		
Swan Hill	49.4	18.1.1906	Bushy Park	40.8	26.12.1945
Queensland			Hobart	40.8	4.1.1976
Cloncurry	53.1	16.1.1889	Northern Territory		
Winton	50.7	14.12.1888	Finke	48.3	2.1.1960
Birdsville	49.5	24.12.1972	Jervois	47.5	3.1.1978
South Australia			Australian Capital Territory		
Oodnadatta	50.7	2.1.1960	Canberra (Acton)	42.8	11.1.1939
Marree	49.4	2.1.1960			
Whyalla	49.4	2.1.1960			

Source: Bureau of Meteorology.

Extreme minima. The lowest temperatures in Australia have been recorded in the Snowy Mountains, where Charlotte Pass (elevation 1,760 metres) has recorded −22.2°C on 14 July 1945 and 22 August 1947. Temperatures have fallen below −5°C at most inland places south of the tropics and at some places within a few kilometres of southern coasts. At Eyre, on the south coast of Western Australia, a minimum temperature of −4.3°C has been recorded, and at Swansea, on the east coast of Tasmania, the temperature has fallen as low as −5.0°C.

In the tropics, extreme minima below 0°C have been recorded at many places away from the coasts — as far north as Herberton, Queensland (−5.0°C). Even very close to the tropical coastline, temperatures have fallen to 0°C, a low recording being −0.8°C for Mackay.

1.25 EXTREME MINIMUM TEMPERATURES

Station	*°C*	*Date*	*Station*	*°C*	*Date*
New South Wales			Western Australia		
Charlotte Pass	−22.2	14.7.1945	Booylgoo Springs	−6.7	12.7.1969
Kiandra	−20.6	2.8.1929	Wandering	−5.7	1.6.1964
Perisher Valley	−19.5	23.7.1979	Tasmania		
Victoria			Shannon	−13.0	30.6.1983
Mount Hotham	−12.8	30.7.1931	Butlers Gorge	−13.0	30.6.1983
Omeo	−11.7	15.6.1965	Tarraleah	−13.0	30.6.1983
Hotham Heights	−11.1	15.8.1968	Northern Territory		
Queensland			Alice Springs	−7.5	12.7.1976
Stanthorpe	−11.0	4.7.1895	Tempe Downs	−6.9	24.7.1971
Warwick	−10.6	12.7.1965	Australian Capital Territory		
Mitchell	−9.4	15.8.1979	Gudgenby	−14.6	11.7.1971
South Australia					
Yongala	−8.2	20.7.1976			
Yunta	−7.7	16.7.1976			
Ernabella	−7.6	19.7.1983			

Source: Bureau of Meteorology.

Table 1.25 shows extreme minimum temperatures recorded at specified stations, including the lowest recorded in each State.

Heat waves. Periods with a number of successive days having a temperature higher than 40°C are relatively common in summer over parts of Australia. With the exception of the north-west coast of Western Australia, however, most coastal areas rarely experience more than three successive days of such conditions. The frequency increases inland, and periods of up to ten successive days have been recorded at many inland stations. This figure increases in western Queensland and north-west Western Australia to more than twenty days in places. The central part of the Northern Territory and the Marble Bar–Nullagine area of Western Australia have recorded the most prolonged heat waves. Marble Bar is the only station in the world where temperatures of more than 37.8°C (100°F) have been recorded on as many as 161 consecutive days (30 October 1923 to 7 April 1924).

Heat waves are experienced in the coastal areas from time to time. During 11–14 January 1939, for example, a severe heat wave affected south-eastern Australia: Adelaide had a record of 47.6°C on the 12th, Melbourne a record of 45.6°C on the 13th and Sydney a record of 45.3°C on the 14th.

The Kimberley district of Western Australia is the consistently hottest part of Australia in terms of annual average maximum temperature. Wyndham, for example, has an annual average maximum of 35.6°C.

Other aspects of climate

Frost can cause serious losses of agricultural crops, and numerous climatic studies have been made in Australia relating to specific crops cultivated in local areas.

Under calm conditions, overnight temperatures at ground level are often as much as 5°C lower than those measured in the instrument screen (base height 1.1 metre) and differences of 10°C have been recorded. Only a small number of stations measure minima at ground level, the lowest recordings being –15.1°C at Canberra and –11.0°C at Stanthorpe (Queensland). Lower readings may be recorded in alpine areas.

Frost frequency depends on location and orography, and even on minor variations in the contour of the land. The parts of Australia which are most subject to frost are the eastern uplands from north-eastern Victoria to the western Darling Downs in southern Queensland. Most stations in this region experience more than ten nights a month with readings of 0°C (or under) for three to five months of the year. On Tasmania's Central Plateau similar conditions occur for three to six months of the year. Frosts may occur within a few miles of the coasts except in the Northern Territory and most of the north Queensland coasts.

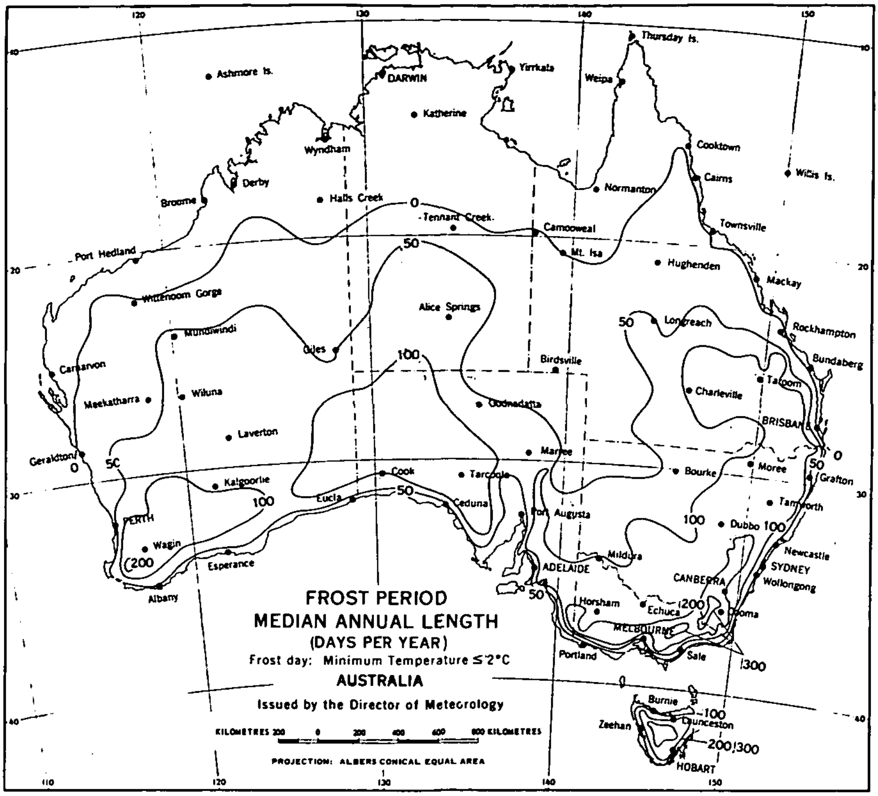
Regions in which frosts may occur at any time of the year comprise most of Tasmania, large areas of the tablelands of New South Wales, much of inland Victoria, particularly the north-east, and a small part of the extreme south-west of Western Australia. Over most of the interior of the continent, and on the highlands of Queensland as far north as the Atherton Plateau, frosts commence in April and end in September. Minimum temperatures below 0°C are experienced in most of the subtropical interior in June and July.

The length of the frost period for the year is taken as the number of days between the first and last recording of an air temperature of 2°C or less. The median duration of the frost period in days per year is shown in figure 1.26.

The median frost period over the continent varies from over 200 days per year in the south-eastern uplands areas south of the Hunter Valley, to zero days in northern Australia. In the southern regions of the continent, the annual frost period generally decreases from about 100 days inland to below 50 days towards the coast. However, there are appreciable spatial variations depending mainly on local orography. In Tasmania the frost period exceeds 300 days on the uplands and decreases to 100 days near the coast.

More strictly, a frost is taken as corresponding to a minimum screen temperature of 2.2°C or less. A light frost is said to occur when the screen minimum temperature is greater than 0°C but less than or equal to 2.2°C. A heavy frost corresponds to a minimum temperature of 0°C or less.

FIGURE 1.26



Source: Bureau of Meteorology.

Table 1.27 includes the average annual frequency of minima of 2.2°C or less for a wide selection of stations, particularly those prone to frosts. These data show the high spatial variability of frost frequency across Australia. The south-eastern alpine areas, as represented by Kiandra (elevation 1,400 metres), have a frequency exceeding 200. At Kalgoorlie the average annual frequency is 20.4 days, at Alice Springs 32.7, Charleville 32.3, Canberra 101.1 and Essendon Airport (Melbourne) 14.2.

The regions of mainland Australia most prone to heavy frosts are the eastern uplands and adjacent areas extending from Victoria through New South Wales to south-eastern Queensland. Stations above 1,000 metres in altitude in the southern parts of these uplands have more than 100 heavy frosts annually, and in the upland areas below 1,000 metres the annual frequency ranges from 100 to about 20. Over the remainder of southern Queensland, New South Wales and Victoria, although there are great spatial variations, the average annual frequency of heavy frosts typically ranges from about 20 inland to 10 towards the coast.

1.27 FROST FREQUENCY

Station	*Period of record*	*Elevation (metres)*	*Average number of frosty nights ≤2.2°C*	*Average number of heavy frosts ≤0°C*
Adelaide Airport	1956–90	6.0	5.8	0.8
Alice Springs	1942–90	537.0	31.7	12.2
Ballan	1957–68	442.0	62.3	20.5
Birdsville	1957–90	47.0	4.3	0.3
Brisbane Airport	1950–90	4.0	0.2	0.0
Canberra Airport	1940–90	571.0	99.8	62.1
Ceduna Airport	1943–90	15.0	18.2	4.0
Charleville Airport	1943–90	306.0	31.7	12.6
Essendon Airport (Melbourne)	1940–70	86.0	14.2	2.6
Hobart	1944–90	55.2	11.4	1.6
Kalgoorlie Airport	1943–90	360.0	20.4	4.7
Kiandra	1957–68	1,395.4	228.3	176.7
Mount Gambier Airport	1943–90	63.0	24.4	6.3
Perth Airport	1945–90	20.0	2.9	0.2
Walgett	1957–89	132.0	22.4	5.3

Source: Bureau of Meteorology.

In Tasmania, uplands above 1,000 metres have more than 100 heavy frosts annually and, in neighbouring areas, the frequency is about 100 decreasing to 20 towards the coasts. Even some coastal stations have a relatively high frequency (Swansea, for example, has 15.7).

The southern half of Western Australia, the whole of South Australia, and the Alice Springs district of the Northern Territory experience heavy frosts. Differences in annual frequencies between places are great but in general the frequency is about 10 inland decreasing towards the coasts. Some places average more than 20 heavy frosts annually, notably Wandering, Western Australia (21.5) and Yongala, South Australia (41.8). At Alice Springs the annual average frequency is 11.9.

Humidity. Australia is a dry continent in terms of the water vapour content or humidity of the air and this element may be compared with evaporation to which it is related. Humidity is measured at Bureau of Meteorology observational stations by a pair of dry and wet-bulb thermometers mounted in a standard instrument screen. These measurements enable moisture content to be expressed by a number of parameters, the most commonly known being relative humidity.

Relative humidity at a given temperature is the ratio (expressed as a percentage) of actual vapour pressure to the saturated vapour pressure at that temperature. As a single measure of human discomfort, relative humidity is of limited value because it must be related to the temperature at the time.

Since the temperature at 9 a.m. approximates the mean temperature for the day (24 hours), the relative humidity at 9 a.m. may be taken as an estimate of the mean relative humidity for the day. Relative humidity at 3 p.m. occurs around the warmest part of the day on the average and is representative of the lowest daily values. Relative humidity on average is at a maximum in the early morning when air temperature is minimal.

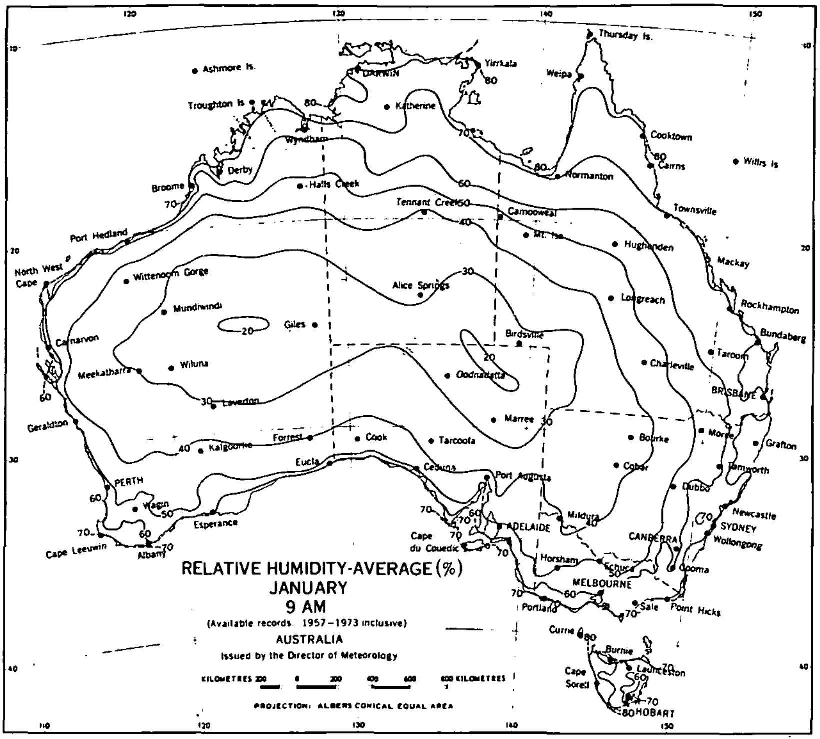
Relative humidity isopleths for January and July at 9 a.m. and 3 p.m. shown in figures 1.28 to 1.31 are extracted from the *Climatic Atlas of Australia, 1988.*

The main features of the relative humidity pattern are:

- over the interior of the continent there is a marked dryness during most of the year, notably towards the northern coast in the dry season (May–October);
- the coastal fringes are comparatively moist, although this is less evident along the north-west coast of Western Australia where continental effects are marked;

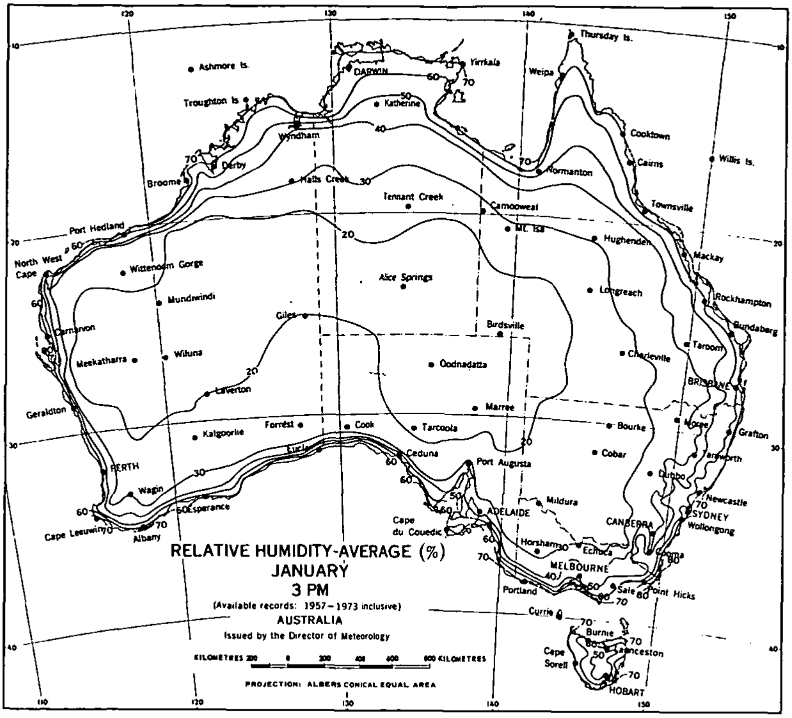
- in northern Australia, the highest values occur during the summer wet season (December–February) and the lowest during the winter dry season (June–August); and
- in most of southern Australia the highest values are experienced in the winter rainy season (June–August) and the lowest in summer (December–February).

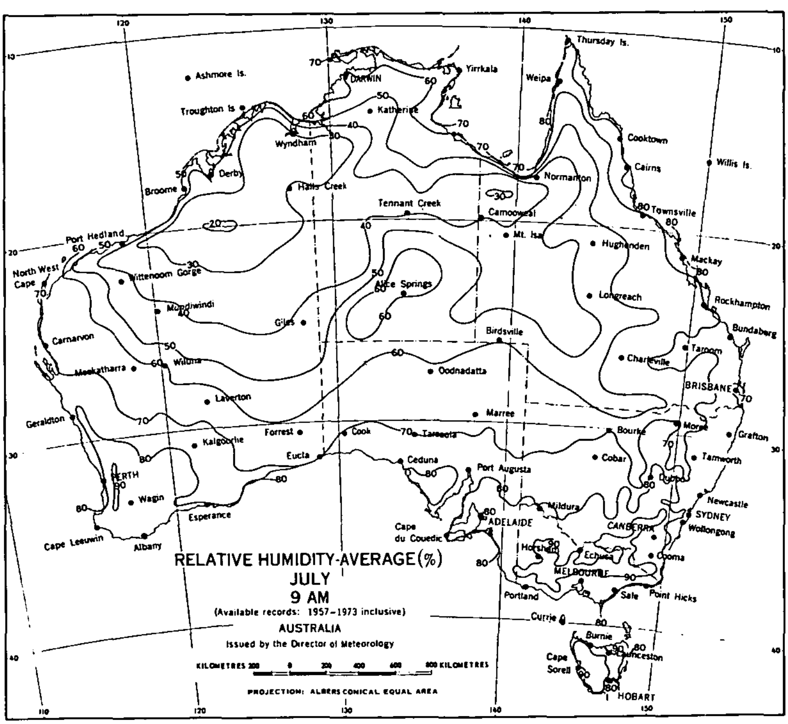
FIGURE 1.28



Source: Bureau of Meteorology.

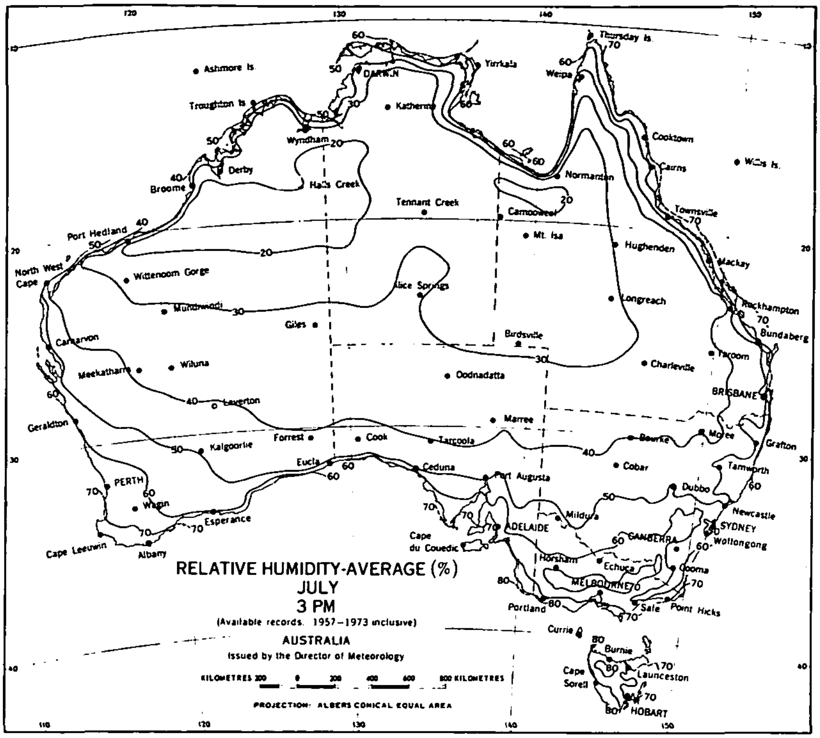
FIGURES 1.29 AND 1.30





Source: Bureau of Meteorology.

FIGURE 1.31



Source: Bureau of Meteorology.

The tables below contain average relative humidity at 9 a.m. and 3 p.m. for each month and the year, for selected stations.

1.32 AVERAGE RELATIVE HUMIDITY AT 9 A.M. (per cent)

Station	*Period of record*	*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	*Year*
Alice Springs	1941–91	33	39	40	45	56	65	59	46	34	30	28	30	42
Armidale	1907–91	63	69	70	73	78	80	77	71	61	57	56	57	68
Broome	1939–91	70	73	69	56	49	48	47	44	47	53	58	64	56
Carnarvon	1945–91	59	57	56	57	59	69	69	63	54	51	53	57	59
Ceduna	1939–91	53	60	60	66	76	81	80	75	63	54	50	52	64
Charleville	1942–91	46	52	52	54	63	71	66	56	44	40	37	39	52
Cloncurry	1939–75	52	60	52	45	47	51	45	37	31	31	31	40	43
Esperance	1969–91	57	59	64	69	74	77	77	74	68	61	59	57	67
Halls Creek	1944–91	51	55	45	34	35	34	30	25	22	24	29	40	36
Kalgoorlie	1939–91	44	50	53	59	68	74	75	66	54	47	44	43	56
Katanning	1957–91	56	63	66	74	83	88	88	86	80	68	59	55	72
Kiandra	1907–74	61	66	72	79	84	89	90	87	76	67	62	62	75
Marble Bar	1937–91	44	47	40	33	39	43	39	32	26	26	26	32	36
Mildura	1946–91	50	55	59	70	82	88	86	79	67	57	52	48	66
Mundiwindi	1938–81	31	35	34	37	44	53	49	39	28	23	22	23	35
Thursday Island	1950–91	84	86	85	82	81	81	80	78	75	73	73	78	80
Townsville	1940–91	72	75	73	69	68	67	67	63	60	61	63	67	67

Source: Bureau of Meteorology.

1.33 AVERAGE RELATIVE HUMIDITY AT 3 P.M.
(per cent)

Station	*Period of record*	*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	*Year*
Alice Springs	1941–91	20	23	23	25	31	34	30	24	19	18	18	19	23
Armidale	1909–91	44	47	47	47	52	56	52	47	41	42	40	41	46
Broome	1939–91	65	66	59	43	38	36	33	33	42	52	57	60	49
Carnarvon	1945–91	59	58	57	56	52	53	52	52	51	53	54	58	54
Ceduna	1939–91	42	44	44	45	50	54	55	50	44	43	40	42	46
Charleville	1942–91	7	32	32	31	36	39	35	29	23	23	21	23	29
Cloncurry	1939–75	32	38	34	29	29	30	26	22	20	19	19	24	27
Esperance	1969–91	56	57	57	56	58	60	59	56	57	56	57	57	57
Halls Creek	1944–91	33	37	31	25	26	25	22	18	17	17	20	26	25
Kalgoorlie	1939–91	24	29	31	37	43	49	47	39	30	27	25	23	·33
Katanning	1957–91	29	33	37	47	56	66	66	62	55	44	36	30	46
Kiandra	1912–74	50	52	55	61	70	75	78	73	62	58	54	51	62
Marble Bar	1937–91	25	28	24	23	26	28	25	20	17	16	16	19	23
Mildura	1946–91	26	29	33	40	51	57	55	47	39	33	28	26	39
Mundiwindi	1938–81	19	22	21	22	27	32	28	22	15	13	13	14	20
Thursday Island	1951–91	78	81	79	74	71	69	67	65	64	64	65	71	71
Townsville	1940–91	66	67	65	60	57	52	51	51	52	55	57	60	58

Source: Bureau of Meteorology.

Relative humidity is dependent on temperature and if the water content of the air remains constant, relative humidity decreases with increasing temperature. For instance Perth, for January, has a mean 9 a.m. relative humidity of 50 per cent, but for 3 p.m., when the mean temperature is higher, the mean relative humidity is 41 per cent.

Global radiation. Global (short wave) radiation includes that radiation energy reaching the ground directly from the sun and that received indirectly from the sky, scattered downwards by clouds, dust particles, etc.

Figures 1.34 and 1.35 show the average global radiation for the months of January and July.

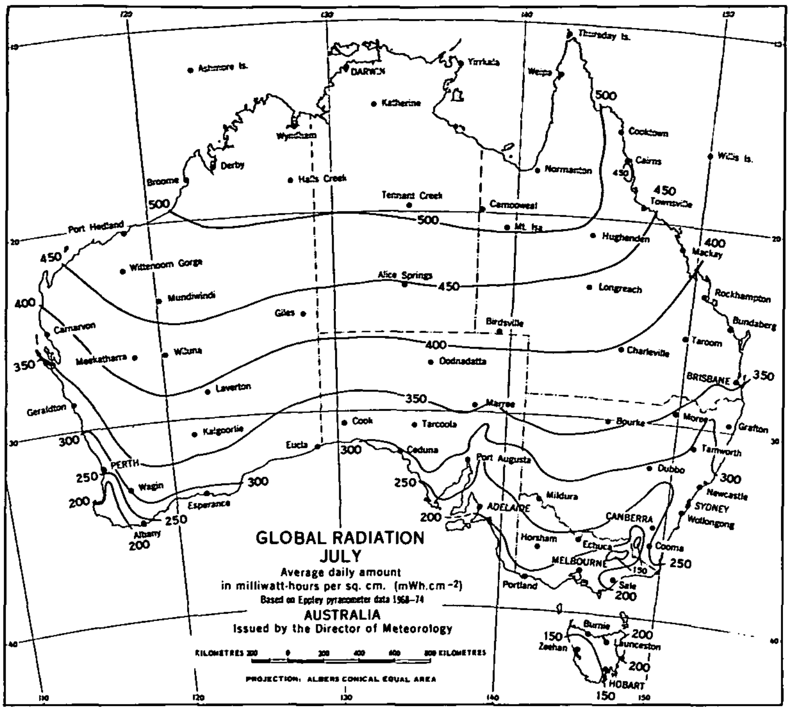
A high correlation exists between daily global radiation (figures 1.34 and 1.35) and daily hours of sunshine (figures 1.37 and 1.38). On the north-west coast around Port Hedland, where average daily global radiation is the highest for Australia (640 milliwatt hours), average daily sunshine is also highest, being approximately 10 hours. Sunshine is more dependent on variations in cloud coverage than is global radiation, since the latter includes diffuse radiation from the sky as well as direct radiation from the sun. An example is Darwin where, in the dry month of July, sunshine approaches twice that of the wet (cloudy) month of January but global radiation amounts for the two months are comparable.

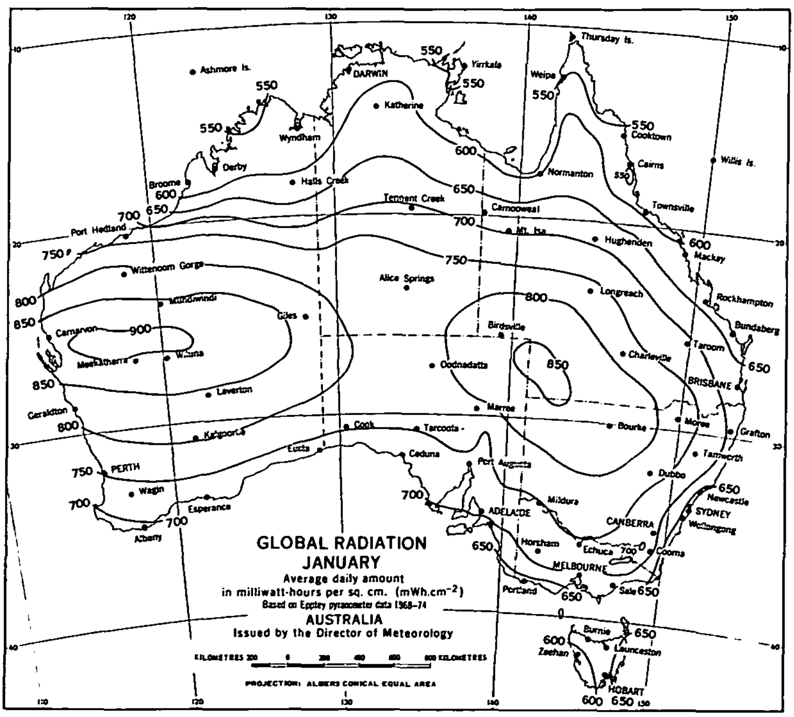
Sunshine as treated here refers to bright or direct sunshine. Australia receives relatively large amounts of sunshine although seasonal cloud formations have a notable effect on its spatial and temporal distribution. Cloud cover reduces both incoming and outgoing radiation and thus affects sunshine, air temperature and other climatic elements at the earth's surface.

Average daily sunshine (hours) in January and July based on all available data to August 1974 is shown in figures 1.37 and 1.38. Sunshine for April and October and annual amounts are included in the *Climatic Atlas of Australia, 1988.* In areas where there is a sparsity of data, estimates of sunshine derived from cloud data are used. Most of the continent receives more than 3,000 hours of sunshine a year, or nearly 70 per cent of the total possible. In central Australia and the mid-west coast of Western Australia, totals slightly in excess of 3,500 hours occur. Totals of less than 1,750 hours occur on the west coast and highlands of Tasmania; this amount is only 40 per cent of the total possible per year (about 4,380 hours).

In southern Australia the duration of sunshine is greatest about December when the sun is at its highest elevation, and lowest in June when the sun is lowest. In northern Australia sunshine is generally greatest about August–October prior to the wet season, and least about January–March during the wet season. The table below gives the 20, 50 and 80 percentiles of daily bright sunshine for the months of January and July at selected stations. These values give an indication of the variability of daily sunshine hours. Perth, for example, has a high variability of daily sunshine hours in the wet month of July and a low variability in the dry month of January. Darwin has a low variability in the dry season month of July and a high variability in the wet season month of January.

FIGURES 1.34 AND 1.35





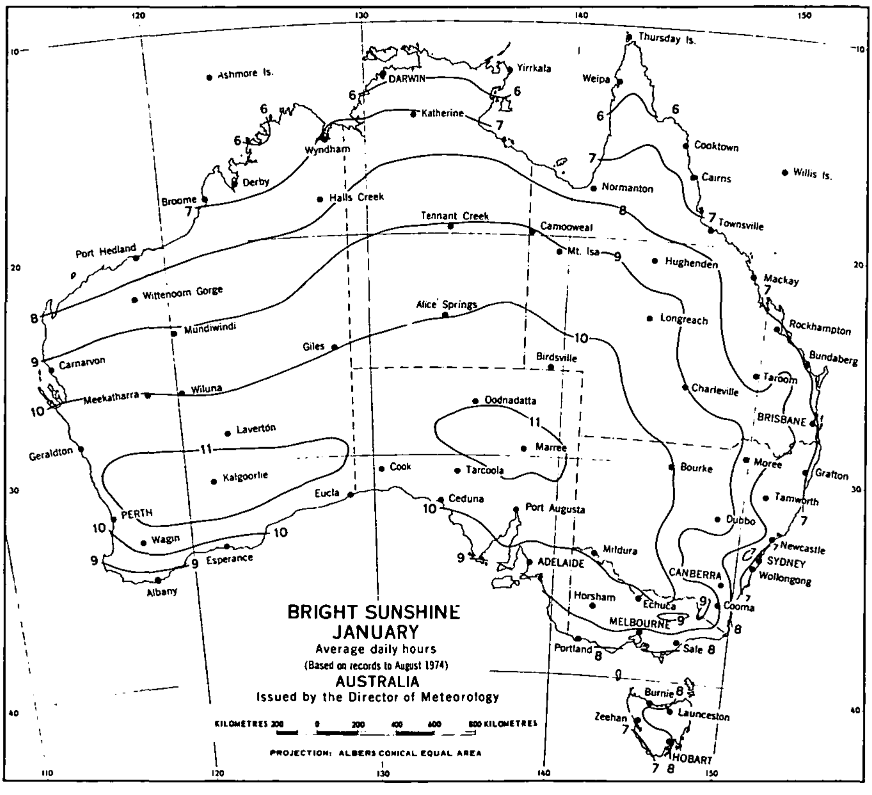
Source: Bureau of Meteorology

1.36 BRIGHT SUNSHINE, VARIABILITY OF DAILY HOURS (20, 50 and 80 percentile values)

Station	*Period of record*	*January percentile* 20	50	80	*July percentile* 20	50	80
Adelaide	1955–86	6.8	11.9	13.3	1.1	4.0	7.3
Alice Springs	1954–86	7.8	11.8	13.0	7.6	10.4	10.7
Brisbane	1951–85	2.6	8.4	11.5	4.5	9.0	9.9
Canberra	1978–86	7.0	11.3	12.7	2.4	6.4	8.3
Darwin	1951–86	1.5	5.9	9.4	9.8	10.6	10.9
Hobart	1950–86	4.3	8.7	12.1	1.5	4.4	7.2
Melbourne	1955–86	5.5	9.9	12.6	0.8	3.6	6.3
Perth	1942–86	9.2	12.0	12.7	2.5	5.4	8.6
Sydney	1955–86	1.9	8.1	11.6	3.2	7.5	9.3
Townsville	1943–86	3.0	9.0	11.3	6.7	10.0	10.6

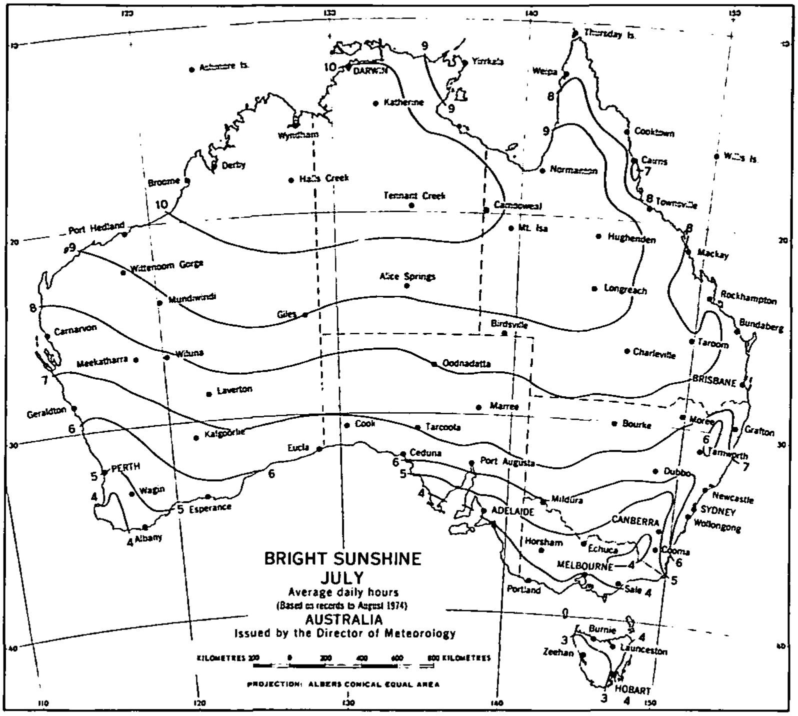
Source: Bureau of Meteorology.

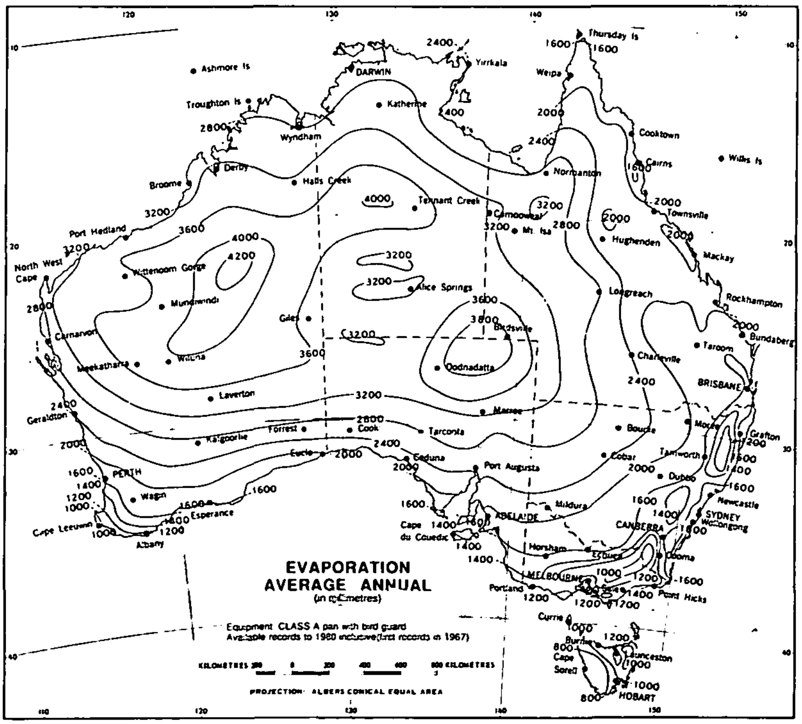
FIGURE 1.37



Source: Bureau of Meteorology.

FIGURES 1.38 AND 1.39





Source: Bureau of Meteorology.

Evaporation is determined by measuring the amount of water evaporated from a free water surface exposed in a pan. Evaporation from a free water surface depends on a number of climatic elements, mainly temperature, humidity and wind. Evaporation data are useful in water conservation studies and estimating potential evapotranspiration for irrigation and plant growth studies. In Australia, where surface water storage is vital over large areas, evaporation is a highly significant element.

Average January, July and annual (Class A) pan evaporation is mapped in figures 1.39, 1.40 and 1.41 respectively. Evaporation maps for other months of the year and a more comprehensive commentary are given in the *Climatic Atlas of Australia, 1988.*

Due to the relatively short records at some stations, the maps may not be representative of climate averages in some areas. Dashed isopleths on the maps over some coastal fringes to aid interpolation do not represent evaporation from ocean surfaces or expanses of water.

Evaporation varies markedly with exposure of the instrument. Sheltering from wind and shading of pans cause local variations in measured evaporation of as much as 25 per cent. Instruments near expanses of water such as coastal inlets, rivers, reservoirs or irrigation systems may record lower evaporation than the surrounding country due to local effects on meteorological elements, notably humidity. Such reductions are about five to ten per cent.

The Class A pan instruments have a wire mesh bird guard, which reduces the measured evaporation. An estimate of the unguarded average Class A pan evaporation for any locality may be derived by applying a seven per cent increase to the value interpolated from the maps.

Average annual Class A pan evaporation ranges from more than 4,000 millimetres over central Western Australia to less than 1,000 millimetres in alpine areas of south-east Australia and in much of Tasmania.

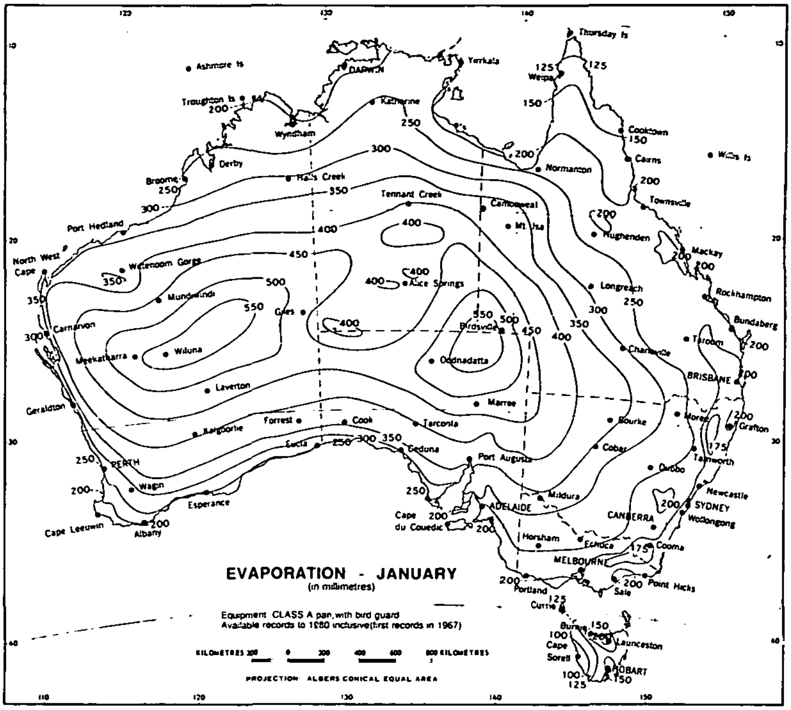
In areas south of the tropics, average monthly evaporation follows seasonal changes in solar radiation, giving highest evaporation in December and January, and lowest in June and July. In the tropics, onset of summer brings increasing cloudiness and higher humidity, causing reduced evaporation in these months. Maximum evaporation in tropical areas occurs around November on average, but high evaporation is sustained when summer rains are delayed or are persistently below average.

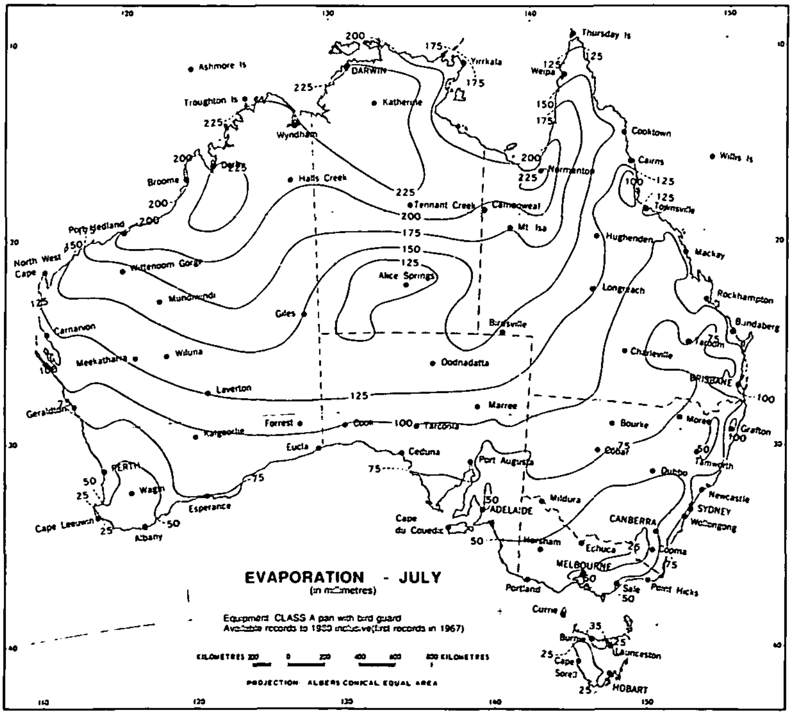
Cloud. Seasonal changes in cloudiness vary with the distribution of rainfall. In the southern parts of the continent, particularly in the coastal and low lying areas, the winter months are generally more cloudy than the summer months. This is due to the formation of extensive areas of stratiform cloud and fog during the colder months, when the structure of the lower layers of the atmosphere favours the physical processes resulting in this type of cloud. Particularly strong seasonal variability of cloud cover exists in northern Australia where skies are clouded during the summer wet season and mainly cloudless during the winter dry season. Cloud coverage is greater near coasts and on the windward slopes of the eastern uplands of Australia and less over the dry interior.

Fog. The formation of fog depends on the occurrence of favourable meteorological elements — mainly temperature, humidity, wind and cloud cover. The nature of the local terrain is important for the development of fog and there is a tendency for this phenomenon to persist in valleys and hollows. The incidence of fog may vary significantly over distances as short as one kilometre.

Fog in Australia tends to be greater in the south than the north, although parts of the east coastal areas are relatively fog prone even in the tropics. Incidence is much greater in the colder months, particularly in the eastern uplands. Fog may persist during the day but rarely until the afternoon over the interior. The highest fog incidence at a capital city is at Canberra which has an average of 47 days per year on which fog occurs, 29 of which are in the period of May to August. Brisbane averages 20 days of fog per year. Darwin averages only 2 days per year, in the months of July and August.

FIGURES 1.40 AND 1.41





Source: Bureau of Meteorology.

Winds. The mid-latitude anticyclones are the chief determinants of Australia's two main prevailing wind streams. In relation to the west–east axes of the anticyclones these streams are easterly to the north and westerly to the south. The cycles of development, motion and decay of low pressure systems to the north and south of the anticyclones result in diversity of wind flow patterns. Wind variations are greatest around the coasts where diurnal land and sea-breeze effects are important.

Wind roses for the months of January and July at 9 a.m. and 3 p.m. at selected stations are shown in figures 1.42 to 1.45 inclusive, extracted from *Climatic Atlas of Australia, 1988.*

The wind roses show the percentage frequency of direction (eight points of compass) and speed ranges of winds.

Orography affects the prevailing wind pattern in various ways such as the channelling of winds through valleys, deflection by mountains and cold air drainage from highland areas. An example of this channelling is the high frequency of north-west winds at Hobart caused by the north-west – south-east orientation of the Derwent River Valley.

Perth is the windiest capital with an average wind speed of 15.6 kilometres per hour; Canberra is the least windy with an average speed of 5.4 kilometres per hour.

The highest wind speeds and wind gusts recorded in Australia have been associated with tropical cyclones. The highest recorded gust was 259 kilometres per hour at Mardie (near Onslow), Western Australia on 19 February 1975, and gusts reaching 200 kilometres per hour have been recorded on several occasions in northern Australia with cyclone visitations. The highest gusts recorded at Australian capitals were 217 kilometres per hour at Darwin and 156 kilometres per hour at Perth.

Droughts. Drought, in general terms, refers to an acute deficit of water supply to meet a specified demand. The best single measure of water availability in Australia is rainfall, although parameters such as evaporation and soil moisture are significant, or even dominant in some situations. Demands for water are very diverse, hence the actual declaration of drought conditions for an area will generally also depend on the effects of a naturally occurring water deficit on the principal local industries.

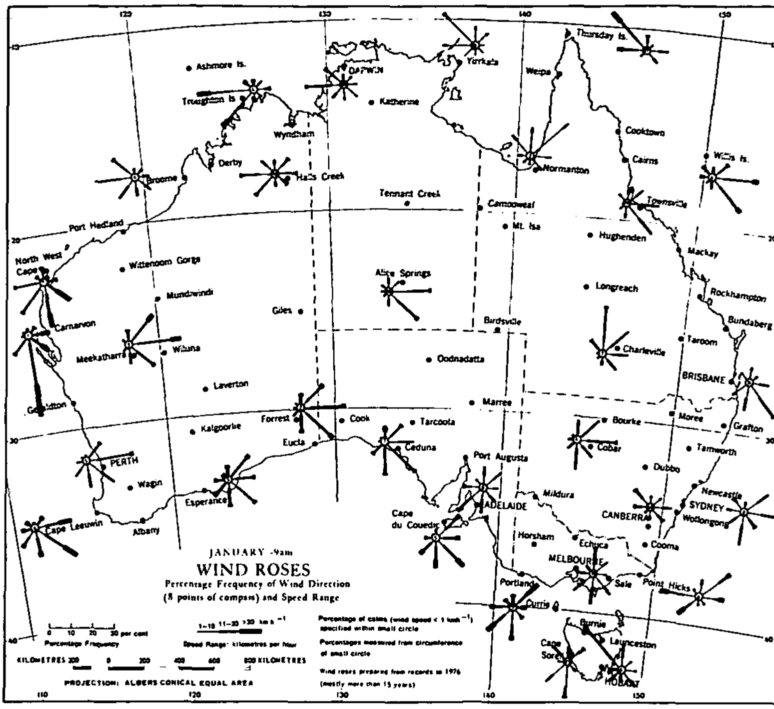
Since the 1860s there have been nine major Australian droughts. Some of these major droughts could be described as periods consisting of a series of dry spells of various lengths, overlapping in time and space, and totalling up to about a decade. The drought periods of 1895–1903, 1958–68 and 1982–83 were the most devastating in terms of their extent and effects on primary production. The remaining major droughts occurred in 1864–66 (and 1868), 1880–86, 1888, 1911-16, 1918–20 and 1939–45.

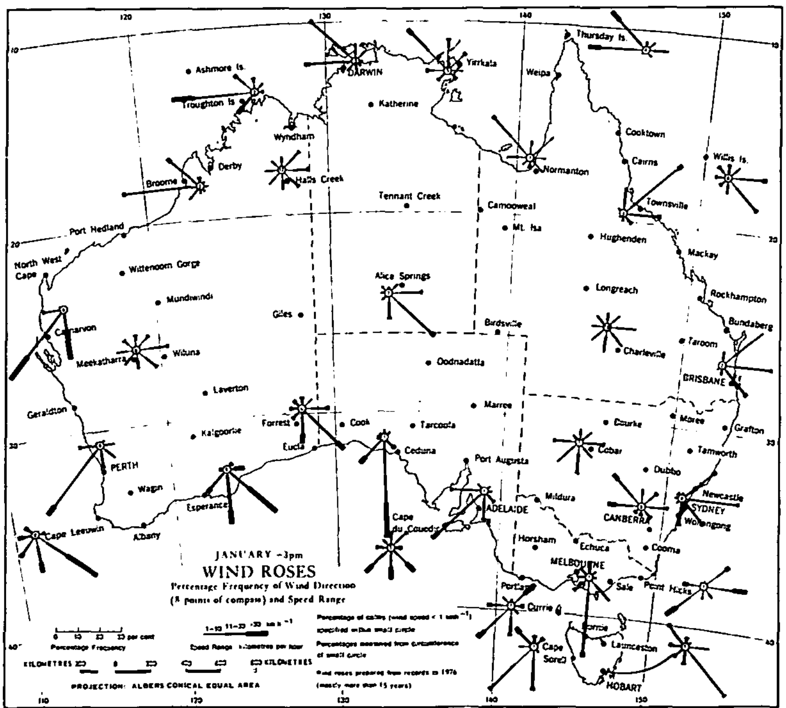
In this same period, several droughts of lesser severity caused significant losses over large areas of some States. They occurred in 1922-23 and 1926-29, 1933-38, 1946–49, 1951-52, 1970–73 and 1976.

South-eastern Australia (New South Wales, southern Queensland, Victoria, Tasmania and the settled parts of South Australia) contains about 75 per cent of the nation's population, and droughts affecting this region have a markedly adverse impact on the economy. There have been eight severe droughts in south-eastern Australia since 1888, and these were encompassed within the major Australian droughts specified previously, except for the severe drought in 1972–73. Drought definitions and the area of coverage and length of these droughts, together with related information may be obtained from *Year Book Australia 1988.*

Floods. Widespread flood rainfall may occur anywhere in Australia but it has a higher incidence in the north and in the eastern coastal areas. It is most economically damaging along the shorter streams flowing from the eastern uplands eastward to the seaboard of Queensland and New South Wales. These flood rains are notably destructive in the more densely populated coastal river valleys of New South Wales — the Tweed, Richmond, Clarence, Macleay, Hunter and Nepean–Hawkesbury — all of which experience relatively frequent flooding. Although chiefly caused by summer rains, they may occur in any season.

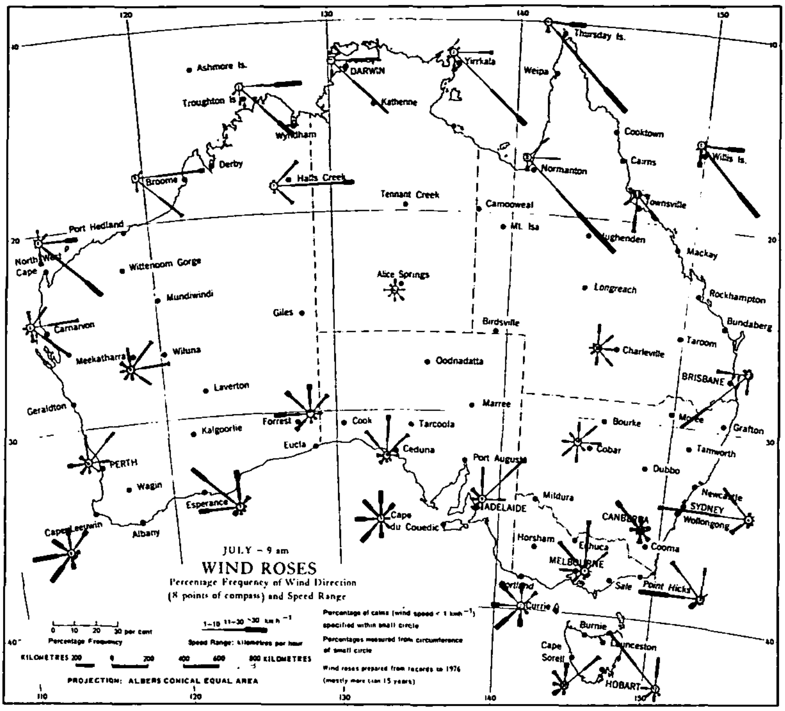
FIGURES 1.42 AND 1.43

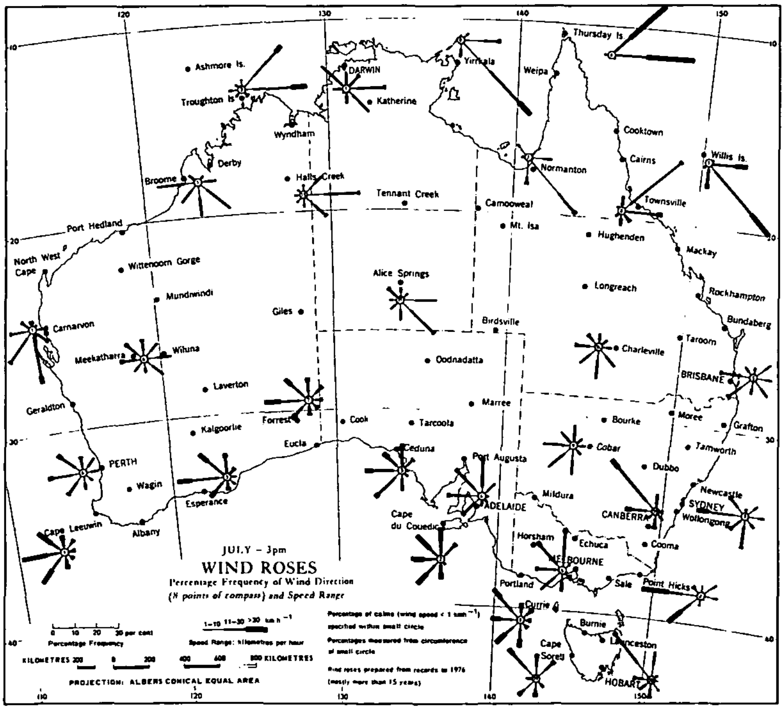




Source: Bureau of Meteorology.

FIGURES 1.44 AND 1.45





Source: Bureau of Meteorology.

The great Fitzroy and Burdekin river basins of Queensland receive flood rains during the summer wet seasons. Much of the run-off due to heavy rain in north Queensland west of the eastern uplands flows southward through the normally dry channels of the network of rivers draining the interior lowlands into Lake Eyre. This widespread rain may cause floods over an extensive area, but it soon seeps away or evaporates, occasionally reaching the lake in quantity. The Condamine and other northern tributaries of the Darling also carry large volumes of water from flood rains south through western New South Wales to the Murray and flooding occurs along their courses at times.

Flood rains occur at irregular intervals in the Murray–Murrumbidgee system of New South Wales and Victoria, the coastal streams of southern Victoria and the north coast streams of Tasmania.

Climatic discomfort. In Australia climatic discomfort is significant in most areas. During the summer half of the year (November–April), prolonged high temperatures and humidity around the northern coasts and high temperatures over the inland cause physical stress. In winter, low temperatures and strong cold winds over the interior and southern areas can be severe for relatively short periods. However, cold stress does not cause prolonged physical hardship in Australia at altitudes lower than 1,000 metres, that is, over more than 99 per cent of the continent.

The climatic variables determining physical discomfort are primarily air temperature, vapour pressure and wind. The complete assessment of physical discomfort also requires analyses of such parameters as thermal conductivity of clothing, vapour pressure at the skin and the metabolic heat rate arising from activity of the human body. The cooling system of the human body depends on evaporation of moisture to keep body temperature from rising to lethal levels as air temperature rises. Defining criteria of discomfort is difficult because personal reactions to the weather differ greatly according to a number of variables including health, age, clothing, occupation and acclimatisation (Ashton, 1964). However, climatic strain has been measured experimentally, and discomfort indices based on the average response of subjects under specified conditions have been derived. One of the most commonly used indices is the relative strain index. The index, derived by Lee and Henschel (1963), has been applied in Australia to measure heat discomfort. The results obtained with Australian data are useful for purposes of comparison but interpretation of the actual results is tentative until empirical environmental studies are carried out in this region. In addition to temperature, humidity and air movement, the relative strain index has facilities for the incorporation of metabolic heat rate, net radiation and insulation of clothing. It has the advantage of being applicable to manual workers under shelter and expending energy at various metabolic heat rates.

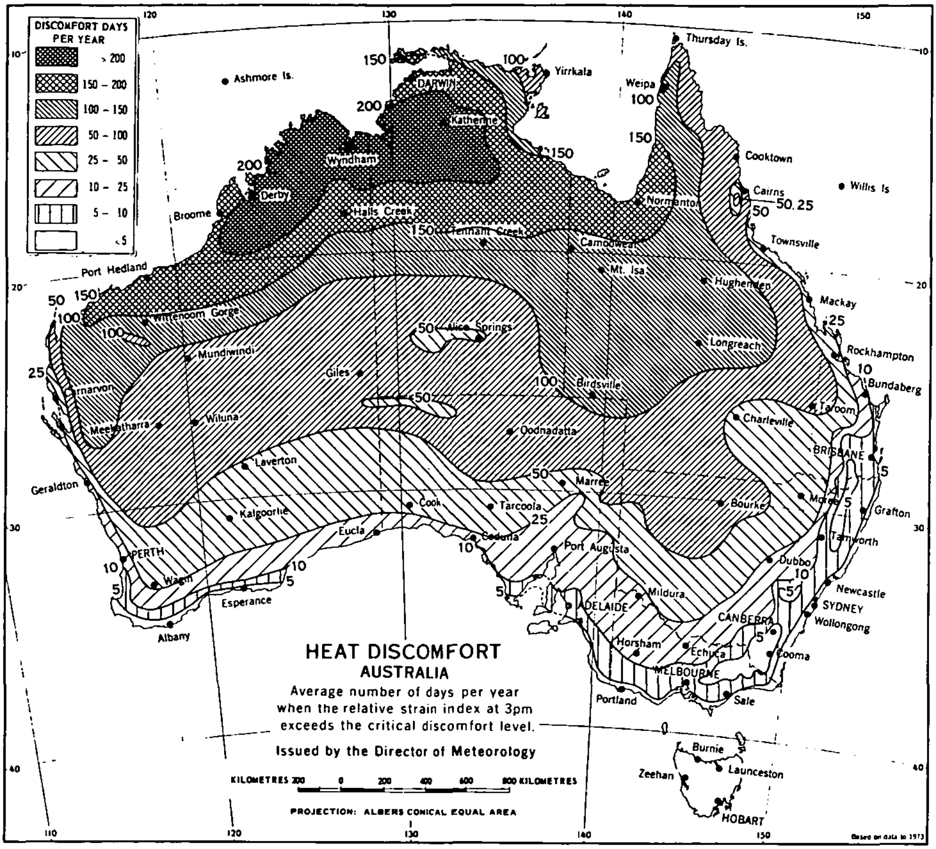
The discomfort map, figure 1.46, shows the average number of days per year when the relative strain index exceeds 0.3 discomfort level at 3 p.m. assuming standard conditions as defined (*see* table 1.47). Maximum discomfort generally occurs around 3 p.m. on days of high temperature.

A notable feature is the lower frequency of days of discomfort in Queensland coastal areas in comparison with the northern coastal areas of Western Australia. This is due to the onshore winds prevailing on the Queensland coast and the cooling effect of the adjacent eastern uplands. Lower frequencies on the Atherton Plateau in the tropics near Cairns show the advantage of altitude. Relatively low heat discomfort frequencies are evident in upland and coastal areas of south-east Australia. Tasmania is entirely in the zone of least discomfort, experiencing on the average less than one day of heat discomfort per year. In Western Australia most of the Kimberley region in the north lies in the highest discomfort zone with the frequencies decreasing southwards to a strip of lowest discomfort towards the south-west coast. A steep gradient of discomfort frequency on the west coast shows the moderating effect of sea-breezes.

The average annual frequency of days when the relative strain index at 3 p.m. exceeds specified discomfort levels is shown in table 1.47. The Sydney frequencies were derived from observations at the regional office of the Bureau of Meteorology, which is representative of eastern coastal suburbs; frequencies are higher in western suburbs. The

Melbourne frequencies were derived from observations at the Bureau's regional office, which may be taken as fairly representative of inner northern and eastern suburbs; frequencies are lower in bayside suburbs. Similarly, in other capital city areas significant variations occur with distance from the coast.

FIGURE 1.46



Source: Bureau of Meteorology.

1.47 HEAT DISCOMFORT(a)

Station	Period of record	Greater than — 0.3 RSI	0.4 RSI
Adelaide	1956–86	6	2
Alice Springs	1942–87	52	4
Brisbane	1951–85	7	2
Broome	1941–67	163	66
Canberra	1940–87	3	<1
Carnarvon	1950–87	25	6
Ceduna	1943–87	15	3
Charleville	1943–87	45	6
Cloncurry	1942–74	132	37
Cobar	1964–85	23	3
Darwin	1943–87	173	32
Hobart	1944–87	<1	<1
Kalgoorlie	1943–87	28	4
Marble Bar	1957–74	179	86
Melbourne	1955–87	6	2
Mildura	1947–87	20	4
Perth	1942–87	13	2
Rockhampton	1940–87	42	8
Sydney	1955–86	3	<1
Townsville	1941–87	48	5
Wagga	1945–85	12	2
Woomera	1950–87	28	5

(a) Average number of days per year when relative strain index (RSI) at 3 p.m. exceeds 0.3 (discomfort) and 0.4 (high discomfort) under standard conditions (indoors, manual activities, light clothing, air movement 60 metres per minute).
Source: Bureau of Meteorology.

At inland places, relatively low night temperatures have recuperative effects after hot days.

Acclimatised people would suffer discomfort less frequently than shown by the relative strain index figures. For example, Australians living in the north evidently experience less discomfort at high air temperatures than those in the south, if humidities are comparable.

Both direction and speed of prevailing winds are significant for the ventilation of buildings. In the tropics, for instance, windward slopes allow optimal air movement enabling more comfortable ventilation to be obtained. Regular sea-breezes such as those experienced at Perth reduce discomfort although on some days their full benefit may not be experienced until after 3 p.m.

Further climatic data. The means and some indication of the variation for a number of meteorological elements for various localities are contained in *Climatic Averages Australia, 1988*. Useful rainfall statistics can be found in *Selected Rainfall Statistics, 1989*. Climatic data for Australia are available on microfiche, computer diskettes and compact discs from the Bureau of Meteorology.

Year Book Australia 1991 and earlier editions contain the means and/or extremes, based on long-term records, of the following climatic conditions in State and Territory capital cities — barometer readings, evaporation, thunder, cloudy and clear days, temperature and sunshine, humidity, rainfall and fog.

BIBLIOGRAPHY

ASHTON, H.T. Meteorological Data for Air Conditioning in Australia. Melbourne, Bureau of Meteorology, Bulletin No. 32, 1964

BUREAU OF METEOROLOGY. Climatic Atlas of Australia. Canberra, 1988

BUREAU OF METEOROLOGY. Climatic Averages, Australia. Canberra, 1988

BUREAU OF METEOROLOGY. Selected Rainfall Statistics Australia. Canberra, 1989

Encyclopedia Britannica

GAFFNEY, D.O. Rainfall deficiency and evaporation in relation to drought in Australia. ANZAAS Congress, Canberra, 1975

LEE, D.M. AND GAFFNEY, D.O. District Rainfall Deciles — Australia. Meteorological Summary, Bureau of Meteorology. Melbourne, 1986

The World Book Encyclopedia

Reading the Weather Map

(This special article has been contributed by the Bureau of Meteorology.)

The weather map is one of the most familiar images in the community. The best known map is the mean sea level analysis, compiled from hundreds of weather observations (synoptic data) taken simultaneously around the Australian region. It is seen daily on television and in the newspapers.

Its dominant features are the smooth, curving patterns of sea level isobars — lines of equal atmospheric pressure — which show the central elements of our weather systems: highs, lows (including tropical cyclones) and cold fronts. It incorporates the effects of atmospheric processes at higher levels.

Television and newspapers also often carry forecast weather maps which indicate how the weather patterns are expected to develop.

Meteorologists use a wide range of information and techniques to formulate weather forecasts. The weather map does not and cannot show all of these factors. It is a fairly simple representation of past and probable future locations of surface weather systems (highs, lows, fronts, etc.). Nevertheless it provides a useful guide to the weather.

Everyone benefits from a better understanding of the weather map, especially people whose activities are particularly weather-sensitive — pilots, farmers, mariners, builders, outdoor sports enthusiasts — who often find the maps valuable, sometimes essential, to enhance their understanding of forecasts and help form their own ideas based on local experience.

Preparing the weather map

The weather map can be likened to a giant jigsaw, assembled several times a day (usually three-hourly) from thousands of observations taken at internationally-agreed times. The Bureau of Meteorology, like all the world's weather services, operates a network of its own stations to gather surface and upper air observations. More than 440 paid and volunteer part-time observers also make daily surface observations essential to the national picture.

Surface reports usually comprise observations of mean sea level pressure, wind direction and speed, present and past weather, temperature, dew point (a measure of atmospheric moisture), cloud and visibility. Their information is formatted in an international code and transmitted nationally, often globally. Complementary, if less detailed, surface data comes from the Bureau's expanding system of more than 100 automatic weather stations, and from drifting buoys in the surrounding oceans.

Specialist observers gather **upper air** information on wind speed and direction by radar-tracking weather balloons, which may also carry instrument packages to transmit temperature and dew point information at various heights (pressures) in the atmosphere.

Weather satellite data are a vital part of the analysis process. Australian meteorologists focus on hourly images from the Japanese Geostationary Meteorological Satellite operating in geostationary orbit 36,500 kilometres over the equator. Computer enhancement adds colour for easier interpretation. The animated sequences often shown on television are a particularly powerful analysis tool.

The Bureau's National Meteorological Centre in Melbourne also draws on similarly enhanced images from USA and European geostationary satellites, as well as high-resolution images and atmospheric temperature profiles from polar-orbiting USA satellites.

Vast numbers of observations on national and global scale flow to the supercomputers at the Bureau's Melbourne headquarters. The computers' mathematical models (equations) simulate atmospheric processes to produce three-dimensional broad-scale weather analyses and prognostic maps forming the basis of weather forecasts for up to four days ahead. The models simulate the physical processes that determine how the atmosphere reacts to constantly changing pressures, temperatures and humidities.

Fine-scale surface weather maps are prepared manually in Bureau forecasting offices, particularly the Regional Forecasting Centres in each State capital and Darwin, and Meteorological Offices in Canberra and Townsville.

Meteorologists take account of the centrally-produced computer surface and upper air predictions, local data and manual charts, and animated satellite and radar images when preparing forecasts and warnings.

What do weather maps show?

The most obvious feature of the media's weather maps (figure 1 is an example) are the patterns of high and low pressure, and the barbed lines identifying cold fronts. In the southern hemisphere, the earth's rotation causes air to flow clockwise around low pressure systems and anticlockwise around high pressure systems. (The opposite applies in the northern hemisphere.) Friction on the earth's surface causes the winds to be deflected slightly inwards towards low pressure centres, and slightly outwards from high pressure systems. Wind strength is directly proportional to the distance between isobars — the closer the lines, the stronger the winds. This rule does not apply in the tropics where the effect of the earth's rotation is weak. For this reason, tropical meteorologists usually replace isobars with streamline arrows which indicate wind and direction without directly relating to the pressure gradient. Shaded areas on weather maps show where there has been rain in the previous 24 hours, and wind direction is shown with arrows that have a series of barbs on their tails to indicate speed.

The coverage on media weather charts is usually limited to the continent and surrounding oceans. The Bureau also produces global charts to take account of weather systems interacting with each other rapidly over great distances. Global charts are necessary when preparing forecasts up to four days ahead, and framing the monthly climate monitoring bulletins.

Typical weather map patterns

An understanding of some systematic weather patterns is needed when interpreting a map.

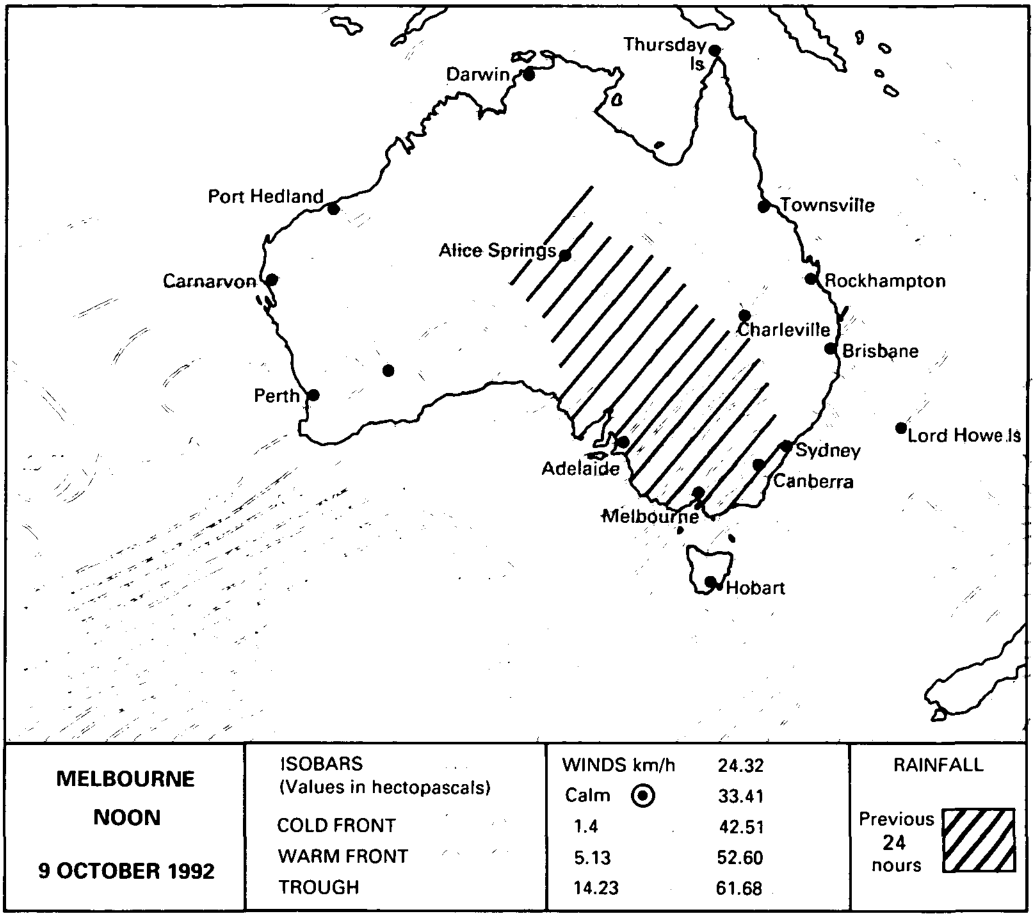
- Easterly winds over the tropics and subtropics, with wavelike disturbances which usually travel westward. The tropical easterlies' important features include the south-east trade winds, monsoon lows and sometimes tropical cyclones (known as hurricanes in the Americas and typhoons in Asia).
- A high pressure belt in the mid-latitudes (usually 30-50 degrees latitude) contains centres of varying strengths which generally move from west to east. Fluctuations in the intensity of these highs ('anticyclones') strongly influence the behaviour of the trade winds and the development and decay of tropical lows.
- The belt of westerly winds south of the high pressure region contains disturbances which usually travel from west to east. Barbed lines indicate the leading edge of travelling cold (and occasionally warm) fronts, the boundaries between different types of air. The term 'front' was applied during World War I by European meteorologists who saw similarities between atmospheric structures and the large-scale conflict along battle fronts.
- Nearer the pole, a series of deep subpolar lows is usually centred between latitudes 50-60 degrees South.
- A high pressure area over Antarctica — associated with extremely cold and dense air — is ringed by easterly winds which form the boundary with the subpolar low pressure belt.

These typical features vary in intensity and location according to the season. For instance, in **summer** the high pressure belt is usually found just south of Australia, while the subtropical easterlies cover most of the continent. Monsoon flows and associated lows over the tropics bring significant summer rain; tropical cyclones may develop. In **winter** the high pressure belt is usually located over the continent, allowing westerlies and strong cold fronts to affect southern Australia.

It is important to be alert to significant exceptions to this 'normal' situation, when e.g., strong high pressure systems move slowly across the oceans well south of Australia. Closed or 'cut off' lows may then move across southern Australia or intensify over the Tasman Sea, possibly causing prolonged heavy rain.

It is also important to remember that all weather systems have a life cycle of development, maturity and decay. They occasionally show unusual behaviour. They may become stationary or even briefly reverse their normal eastward progression.

FIGURE 1 EXAMPLE OF MEDIA WEATHER MAP



Source: Bureau of Meteorology.

Hot or cold?

Remembering that air flows clockwise around low pressure systems and anticlockwise around high pressure systems, a fairly typical summer weather map (figure 2) shows:

- Northerly winds over eastern Australia on the western flank of a Tasman Sea high. They carry hot, dry air from inland Australia southward over Victoria and Tasmania. With winds strengthening ahead of an approaching front, this represents a classic weather situation with extreme bushfire risk.
- Moist, easterly flow from the Coral Sea onto the Queensland coast causes very warm, humid and sultry weather east of the Great Dividing Range. This air, often susceptible to the development of showers and thunderstorms, is described as 'unstable'.
- The cold front passing South Australia replaces the hot, dry north-westerlies with southerlies carrying cooler, often relatively humid air from waters south of the continent. Such summer fronts are often quite shallow and may not penetrate far inland, particularly if they are distorted and slowed over the Victorian mountains.

In figure 3, a relatively common winter weather map shows:

- Very cold, unstable air from well south of Tasmania flows northward over Tasmania, Victoria and south-east New South Wales, reducing normal day temperatures typically by five degrees or more. Note the cold front, the deep low pressure (pressures below 976 hectoPascals) south of Tasmania, and the high (1020 hectoPascals) south of the Bight. Occasionally, rapid interaction with other weather systems around the southern hemisphere can almost halt the pattern's eastward movement, causing successive cold fronts to bring a prolonged spell of cold, showery weather to southern Australia.
- Easterly winds over inland Australia. Although southern cold fronts become shallow and diffuse as they move into northern Australia, they often trigger a surge in the strength of the easterlies and this, combined with their extreme dryness, creates a very high fire danger in the tropical savanna region.
- An active low pressure near Perth is 'cut off' from the southern westerlies. Situations of this type may cause rain and rather cold weather over southern parts of Western Australia.

How strong will the winds be?

A mean sea level pressure chart shows the direct relationship between isobar spacing (pressure gradient) and orientation, and the strength and direction of surface winds. The general rule is that winds are strongest where the isobars are closest together. Thus the strongest winds are usually experienced near cold fronts, low pressure systems and in westerly airstreams south of the continent. Winds are normally light near high pressure systems where the isobars are widely spaced.

However, because of a latitude effect, winds in middle latitudes are lighter than those in the tropics with similarly spaced isobars.

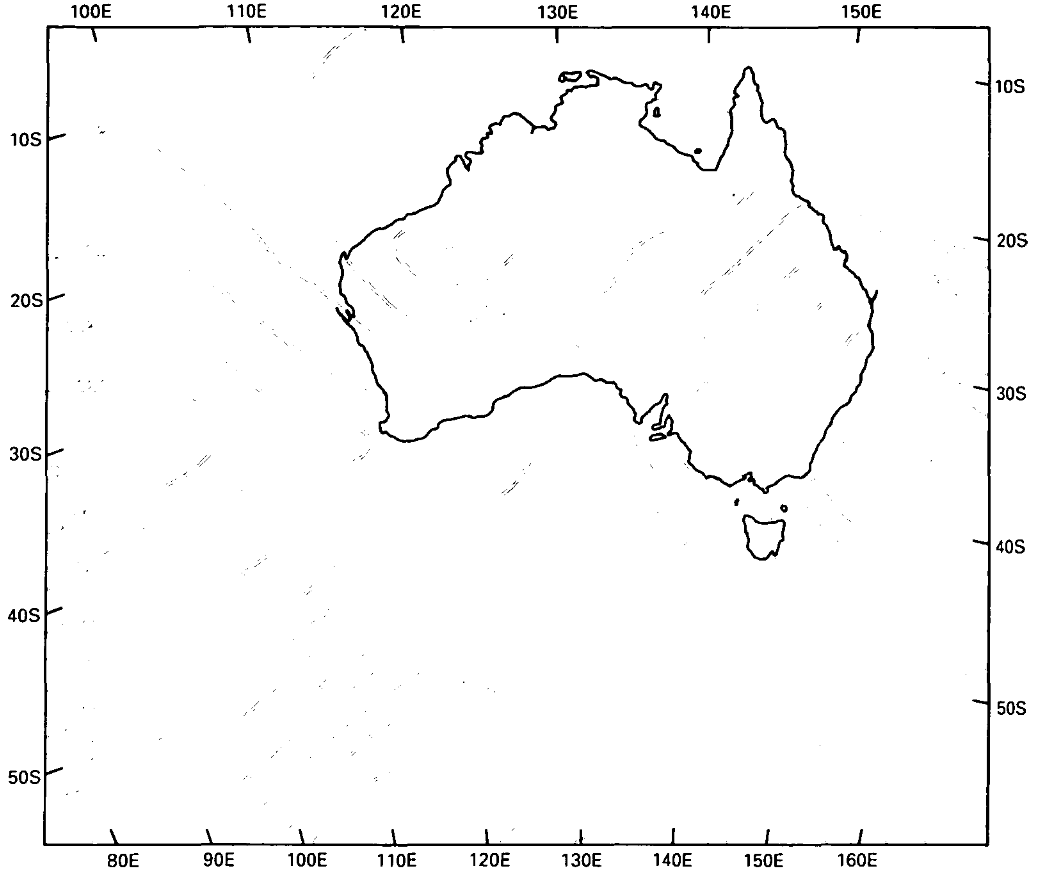
The most destructive winds in Australia are generated by tropical cyclones. Figure 4 illustrates the relationship between wind and pressure distribution in tropical cyclone Winifred which affected Queensland in February 1986. The relationship is typical.

In the southern hemisphere, tropical cyclones are defined as warm cored low pressure systems in tropical latitudes with clockwise wind circulation and surrounding average winds above gale force (63 kilometres per hour). Tropical cyclones typically exhibit a relatively clear eye, surrounded by dense wall clouds and a series of spiral rain bands. The Bureau tracks cyclones with weather watch radar, special surface reports and frequent satellite images. Figures 5(a) and (b) show a tropical cyclone approaching, and crossing, the Queensland coast near Rockhampton. The pressure gradient is very steep towards the cyclone's centre and windspeeds on the nearby coast in this case may be 110 kilometres per hour, with gusts 40 per cent higher. In figure 5(b), 12 hours later, the cyclone has moved inland. Cut off from its heat energy from the ocean (it requires sea surface temperatures above 26.5°C), its intensity has decreased and wind speeds have dropped to 85-95 kilometres per hour.

Rain or fine?

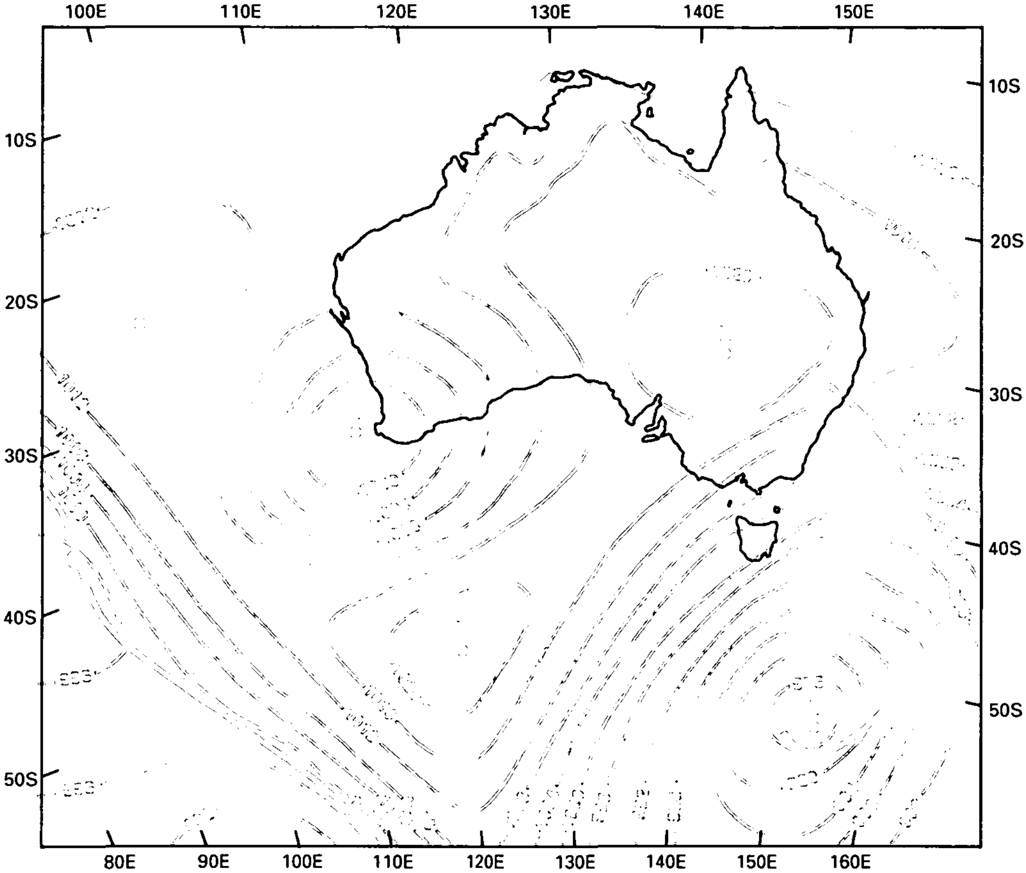
Features on the surface weather chart indicate likely rainfall patterns as well as temperature distribution and wind strength. In general, highs tend to be associated with subsiding (sinking) air and generally fine weather, while lows are associated with ascending (rising) air and usually produce rain or showers.

FIGURE 2 TYPICAL SUMMER WEATHER CHART



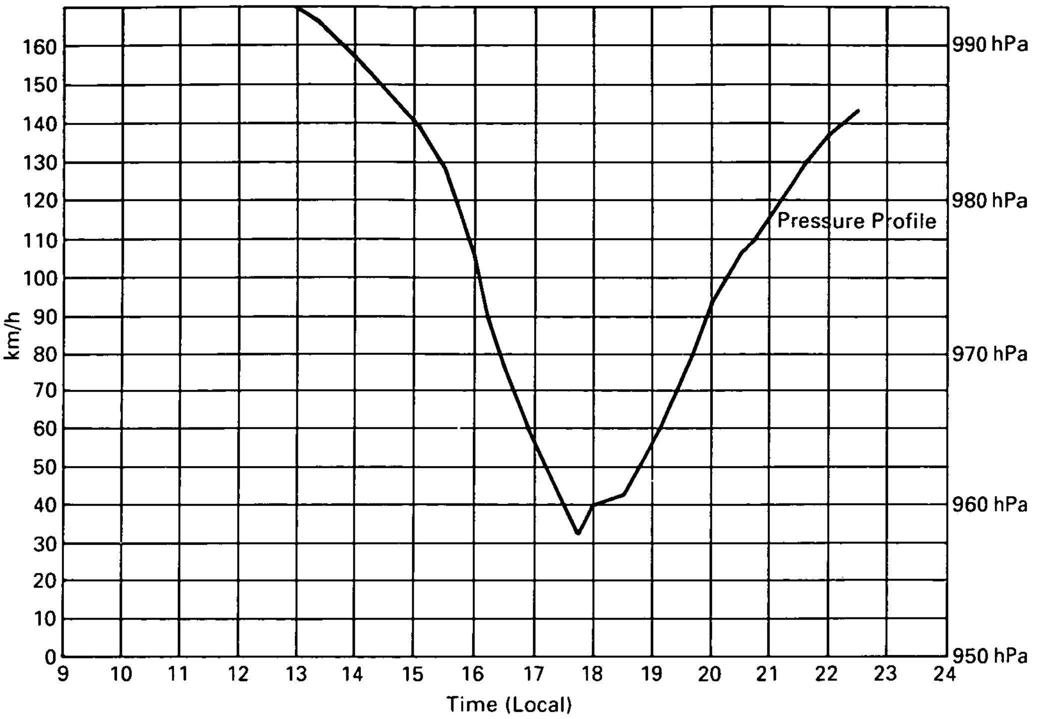
Source: Bureau of Meteorology.

FIGURE 3 TYPICAL WINTER WEATHER CHART



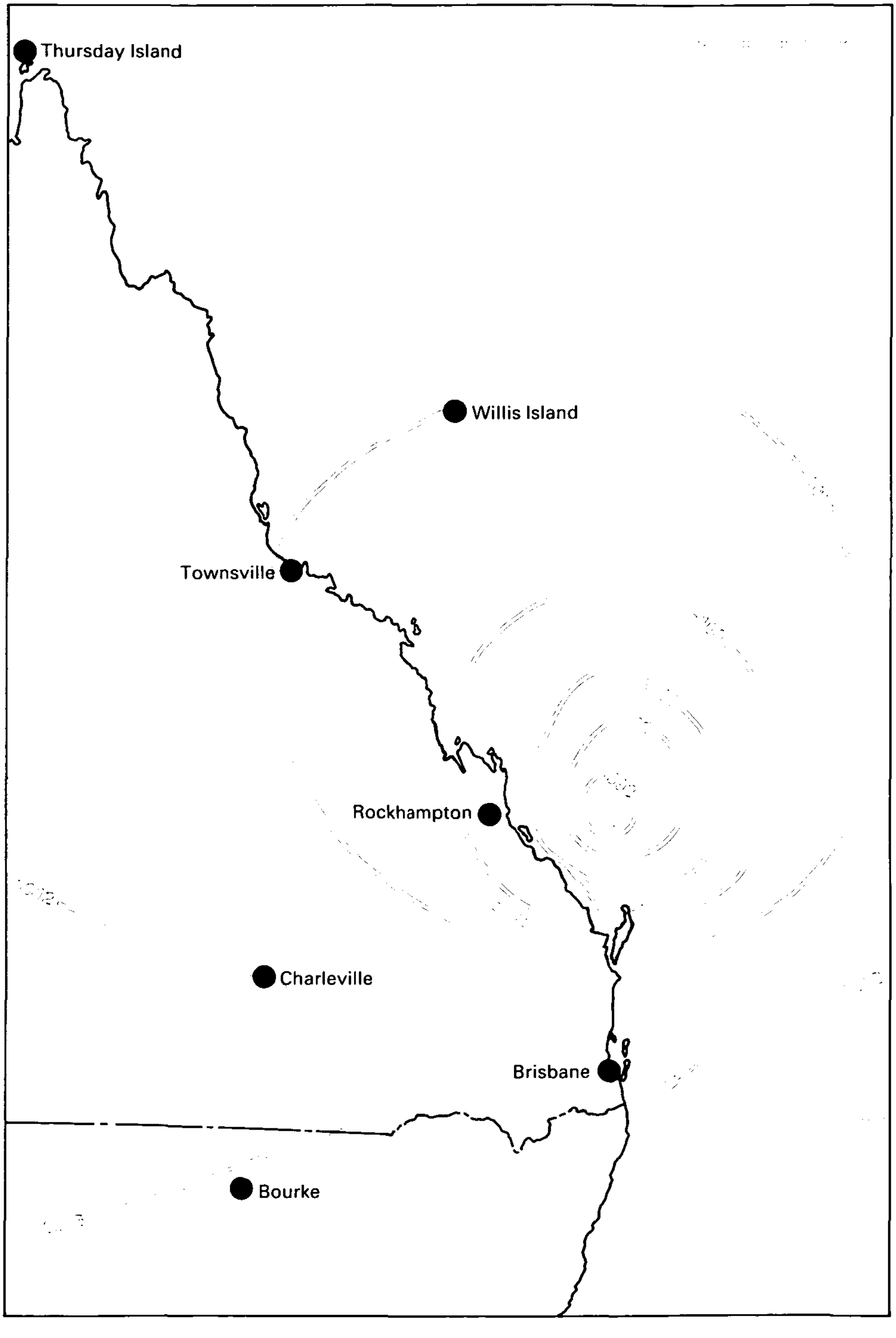
Source: Bureau of Meteorology.

FIGURE 4 . TYPICAL WIND SPEED AND PRESSURE RELATIONSHIPS FOR A TROPICAL CYCLONE, CYCLONE WINIFRED, COWLEY BEACH, QUEENSLAND, FEBRUARY 1986



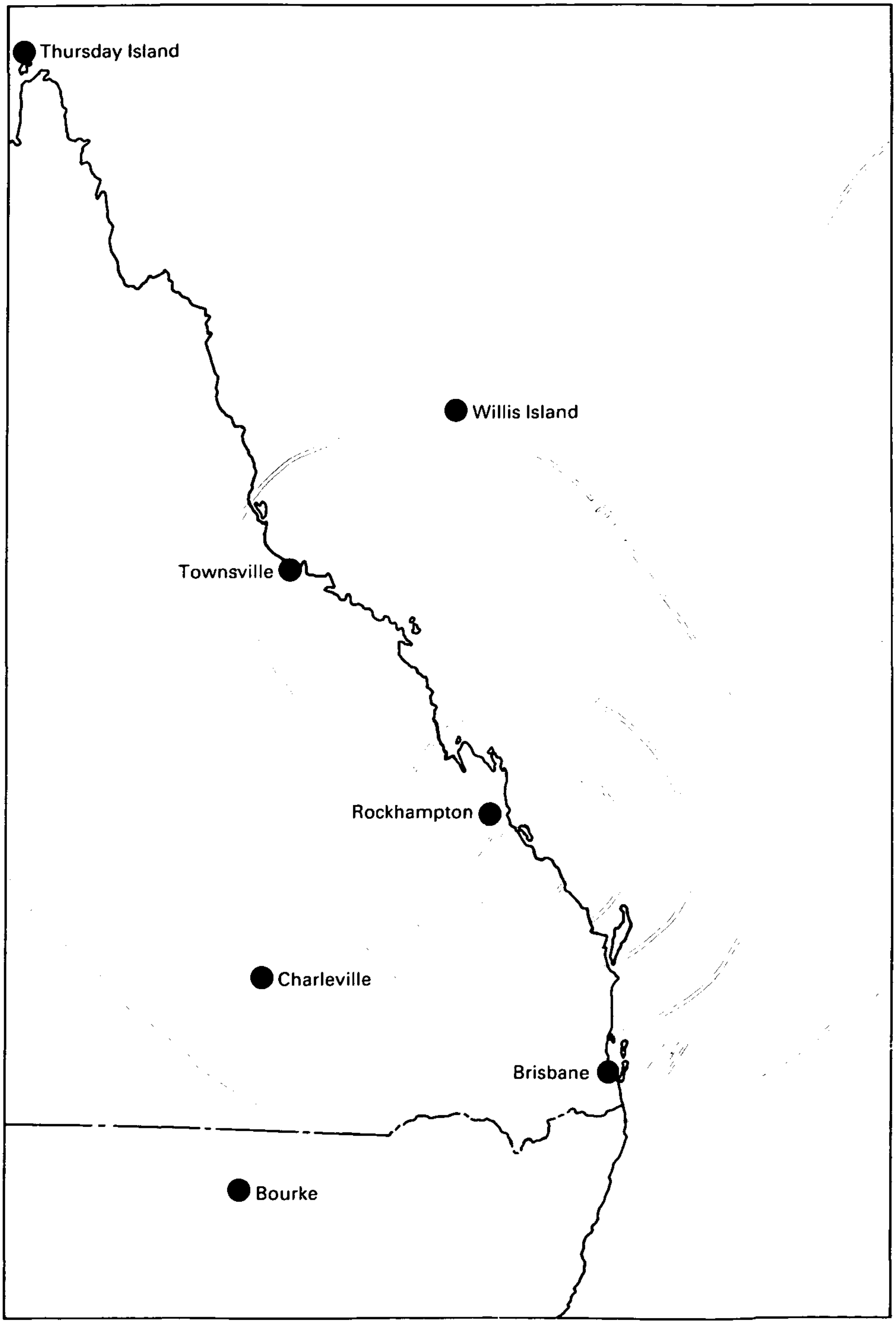
Source: Bureau of Meteorology.

FIGURE 5a TROPICAL CYCLONE APPROACHING QUEENSLAND COAST NEAR ROCKHAMPTON, AT 9AM



Source: Bureau of Meteorology.

FIGURE 5b TROPICAL CYCLONE CROSSING QUEENSLAND COAST NEAR ROCKHAMPTON, AT 9PM



Source: Bureau of Meteorology.

While you can have cloud without rain, you cannot have rain without clouds.

Clouds form by the condensation of water vapour through cooling. Causes of cooling include:

- **Convection,** which may be caused through air mass instability. It may be initiated by warming of low level air, forced ascent over mountainous country, or dynamic causes associated with severe weather systems. Convection usually involves cumulus clouds, the most intense forms of which are often associated with severe thunderstorms and occasionally, tornadoes. Cumulonimbus, for instance, may reach altitudes above 15,000 metres.
- **Systematic ascent of moist air** over large areas linked with large-scale weather systems such as low pressure systems, including tropical cyclones. In mid-latitudes this systematic ascent often occurs ahead of active fronts, or with 'cut off' lows. This type of rain may be persistent and heavy and cause floods, especially if enhanced by forced (orographic) ascent over mountains.
- **Orographic ascent** occurs when air is forced upwards by a barrier of mountains or hills. Cloud formation and rainfall is often the result. Australia's heaviest rainfall occurs on the Queensland coast and in western Tasmania, where prevailing maritime airstreams are forced to lift over mountain ranges.
- **Cold and warm fronts** also cause systematic ascent. A cold front is the boundary where cold air moves to replace, and undercut, warmer and less dense air. Associated cloud and weather may vary enormously according to the properties of the air masses, but tends to be concentrated near the front. As a typical cold front approaches, winds freshen from the north or north-west, and pressure falls. After the front passes, winds shift direction anticlockwise ('backing' to the west or south-west) and pressure rises.
  Cold fronts are much more frequent and vigorous over southern Australia than elsewhere. Warm fronts, relatively infrequent over Australia, are usually found in high latitudes where they can occasionally cause significant weather. They are often shown on weather charts over the southern ocean. Warm fronts progressively displace cool air by warmer air.
- **Convergence lifting** occurs when more air flows into an area at low levels than flows out, leading to forced rising of large air masses. Convergence is often associated with wave-like disturbances in tropical easterlies and may also occur with broad tropical air masses flowing to the south. Given sufficient atmospheric moisture and instability, it may cause large cloud clusters and rain.

Using weather charts to prepare forecasts

Preparation of weather charts which predict surface and upper level flow patterns up to several days ahead is integral to weather forecasting. The best and most objective way of doing this is to use computer models incorporating the equations which govern the motion of the atmosphere, and its associated physics. The Bureau's supercomputers run mathematical models on a global and regional scale for both daily forecasting and for research.

While predicted (prognostic) weather charts are essential to the forecast process, they must be interpreted by meteorologists to prepare specific weather forecasts and warnings. Forecast errors still occur, due to limitations in data or the forecast models, and the inherent complexity of the atmosphere, but forecast accuracy has increased very significantly since the introduction of satellite information and mathematical modelling. Prognostic charts shown routinely on television and in newspapers predict conditions up to three days ahead.

An inexpensive aneroid barometer enables weather map watchers to follow changes in surface air pressure over time, giving important clues to subtle alterations in weather systems. By combining information from the barometer, weather maps and forecasts from the media, and personal experience of sky watching, they can make the most of the Bureau's weather service.

It will be realised by now that a single weather map is only a forecasting aid and that a great deal of other data and information must be gathered and processed before a forecast is issued. However, the information in this article should assist people to understand and interpret the map and forecasts, and enable them to make more informed judgments about the effect of weather on their activities.