COMMONWEALTH

BUREAU OF METEOROLOGY

A HUNDRED YEARS OF SCIENCE AND SERVICE

AUSTRALIAN METEOROLOGY THROUGH THE TWENTIETH CENTURY

Front cover: From the time of its creation in 1908, through to 1974, the headquarters of the Bureau of Meteorology was located at 'Frosterley', 2 Drummond Street Melbourne. 'Frosterley' was built circa 1890 for Dr William Snowball (1853-1902), a children's specialist, who moved his practice and his family into the building in 1891. The name of the building is related to the fact that Dr Snowball's parents came from the village of Frosterley, County Durham, England.

In 1907 the Commonwealth Government leased 'Frosterley' to house the newly formed Bureau. In 1924 it purchased the building. The growth of the Bureau staff after 1937 required temporary accommodation in a number of other buildings in Melbourne. A new wing was added to Frosterley in 1939.

Back cover: Since 1974 the Head Office of the Commonwealth Bureau of Meteorology has been located at 150 Lonsdale Street Melbourne. The office occupies approximately 15 of the 27 floors of the building. The Bureau's Victorian Regional Office was co-located in the same building in 1986.

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AUSTRALIAN METEOROLOGY THROUGH THE TWENTIETH CENTURY

Introduction

Australia's weather and climate inspired the dreamtime legends of its first inhabitants and shaped its development as an infant nation. The violent thunder squalls which greeted the First Fleet as they rounded Van Dieman's Land provided a foretaste of worse to come, and the shipwrecks which soon littered the southern coastline reminded recent arrivals from Europe, if reminder were needed, of the ferocity of the storms which swept in without warning from the Southern Ocean. The extremely dry conditions in the early years at Sydney Cove (Tench 1789; Blainey 1980; Nicholls 1988) exacerbated the trauma of the starvation years (Hughes 1987). And the nineteenth century manifestations of what we now know as El Niño and the Southern Oscillation soon brought the droughts and flooding rains that wrought great hardship on the early settlers and established, in prose and verse, the enduring images of the Australian bush.

Meteorology has a proud place in the early life of the colonies and the birth of the Federation. Australia's meteorological pioneers established observing networks throughout the length and breadth of the continent, and collected the data needed to map the climate of the interior and develop a scientific basis for forecasting of events as diverse as the southerly busters of the NSW coast and the monsoon rains and cyclones of the tropical north. Nothing mattered quite so much in the preparations for the opening of the first Federal Parliament in Melbourne as the timing of the arrival of the deep depression which threatened to add fierce wintery squalls and driving rain to the pageantry of the occasion.

That Parliament was subsequently to put in place the legislation which led to the establishment of the Commonwealth Bureau of Meteorology by bringing together the separate colonial/State Meteorological Services that had existed up to that time, in an arrangement which has provided Australia with one of the most effective national meteorological service systems in the world. The remarkable advances that have occurred in the science and practice of meteorology through the twentieth century have greatly reduced the toll of natural disasters and brought enormous benefits to virtually all walks of life. They have laid the foundation for even greater benefits from meteorological science and services in the twenty-first century.

The origins of Australian meteorology

Meteorology, along with astronomy, is one of the oldest sciences we have. Although the systematic study of Australia's weather and climate began with the arrival of the First Fleet in January 1788, the origins of Australian meteorology go back long before the time of European settlement to the observations, belief systems and lifestyle of the Aborigines who, over a period of 40,000 years or more, had witnessed the retreat of the last ice age and learned to live with the rhythm of the seasons and the extremes of weather and climate.

In the beginning

All the weather and climate phenomena we know today played a part in the lives of the early inhabitants of the Australian continent. But in different parts of Australia there were different names and different explanations for the various atmospheric forces – thunder, lightning, rainbows, clouds and winds – and the march of the seasons. The peoples of Arnhem Land defined the seasons in terms of the 'balmarrk wana' or 'big winds' with the wet season brought on by barra the northwest monsoon (Jones and Meehan 1997). The Aboriginal people of central Australia

Figure 1. *The Sound of Lightning: a Dreamtime Legend depicted by artist Ainslie Roberts. The Aborigines of northern Australia have a number of myths that explain the thunder, the lightning, the wet-season clouds and the rain. In the wet season, the thunder man Mamaragan, roaring with laughter, beats the great stones of the sky together. His laughter is the rolling thunder, the sharper crack of lightning is the sound of the stones striking each other and the lightning is the sparks flying from them. The rain caused by this disturbance falls to the thirsty earth and gives life and food to mankind and all other creatures.*

developed a very different understanding of the seasons, and their influence on the land and its animals and plants. Further south in Tasmania, they had learned to recognise the signs of changing weather and to make use of fire for protection against the cold.

Much of the modern understanding of the Aboriginal interpretation of weather and climate in various parts of Australia has been captured in a series of writings and paintings by anthropologist Charles P. Mountford, and artist Ainslie Roberts (Figure 1).

Australia's meteorological pioneers

The foundations of Australia's meteorological records were laid at Sydney Cove by Lieutenant William Dawes who built a small observatory there and commenced regular observations in September 1788 (McAfee 1981). While participating fully in local exploration and other aspects of the early life of the colony, Dawes maintained his observations with great dedication, often making readings up to six times per day, through until December 1791, shortly before he returned prematurely to England, having incurred the displeasure of the Governor for his refusal to participate in reprisal raids against the Aborigines.

Following Dawes' departure, the systematic collection of meteorological observations in the colony lapsed until the arrival of the soldier-scientist, Sir Thomas Brisbane, as Governor. He established an observatory at Parramatta where records were maintained from 1822 until 1826. The next systematic series of observations in the Sydney area was begun in 1832 by Commander Phillip Parker King, who had already, in 1822, published the first description of Australian climate *On the maritime geography of Australia*. These were maintained only until 1848. However, in 1858 continuous observations recommenced at the newly constructed Sydney Observatory on what is now known as Observatory Hill. Meteorological observations were also commenced at other locations in New South Wales, including at Port Macquarie (1840), and in Adelaide (1839), Brisbane (1840), Hobart (1841), Melbourne (1856) and Perth (1876).

The first thorough study of the Australian climate was published in 1859 by William Stanley Jevons, a gold assayer at the Sydney Branch of the Royal Mint who was subsequently to make major contributions in the fields of logic, statistics and economics and who has been variously described as Australia's first social scientist and 'one of the greatest Englishmen of the nineteenth century'. Jevons' 52-page study of the climate of Australia and New Zealand covers the general characteristics of Australian temperature and rainfall and patterns of drought and flood. Among the achievements of his pioneering study, he correctly recognised the highly variable nature and spatial coherence of Australian rainfall (Nicholls 1998).

At about the same time as Jevons was beginning his studies, a series of remarkable figures arrived on the Australian meteorological landscape (Gibbs 1975). In Melbourne, Georg von Neumayer, a young Bavarian ship's officer, established an observatory at Flagstaff Hill in 1856 (Figure 2) and maintained a meticulously compiled set of meteorological observations until he left Australia in 1863, when his work was taken over by Robert Ellery. In 1855, Charles Todd, aged 30, arrived in Adelaide from Cambridge as Superintendent of Telegraphs. Over the succeeding decades he constructed telegraph lines to New South Wales, Victoria and Darwin, establishing meteorological stations all the way. He organised the realtime collection of the data by telegraph and began the preparation of synoptic maps.

With the ability to collect meteorological data by telegraph established, the 1870s, 80s and 90s saw the increasing use of synoptic charts of pressure, wind, temperature and rainfall for daily weather forecasting. On 5 February 1877 the NSW

Figure 2. *The meteorological stand of Georg von Neumayer's Flagstaff Observatory established in Melbourne in* 1856.

Australia's meteorological pioneers

William Dawes

William Dawes arrived in Australia with the First Fleet as a Lieutenant in the Royal Marines, having served in the American War of Independence, and subsequently pursued studies in engineering and surveying. Equipped with meteorological and astronomical books and instruments provided by the Royal Astronomer, he immediately began construction of an observatory at what is now known as Dawes Point, near the southern pylon of the Harbour Bridge. Dawes' meteorological journal provides a detailed chronology of the early weather of the colony from September 1788 until his departure for England in December 1791.

Thomas Brisbane

Thomas Brisbane arrived in Sydney as Governor of NSW in 1821 and, building on his scientific background (he was a graduate of the University of Edinburgh) and a deep interest in meteorology and navigation, acquired during his many sea voyages, he immediately established a meteorological and astronomical observatory at his own expense at Parramatta. He maintained detailed observations at Parramatta from 1822 until he left the Colony in 1824. While in Sydney, he founded the Philosophical Society of Australia for the presentation of scientific papers in meteorology and other fields.

Georg von Neumayer

Georg von Neumayer, a Bavarian Ship's Officer who had obtained his doctorate at Munich in 1849, first arrived in Melbourne in 1852. Convinced of the importance of meteorology, he returned to Europe in 1854 and obtained the instruments necessary to establish an observatory in Melbourne. Initially working as a private citizen, he established a number of observing stations throughout Victoria, mainly at lighthouses. In 1859, he was appointed as Government Astronomer. He gradually built up the observatory recruiting, inter alia, W.J. Wills who was subsequently to perish in the ill-fated Burke and Wills expedition. Neumayer played a leading role in the early scientific life of Melbourne before returning again to Europe in 1863.

Robert Ellery

Robert Ellery arrived in Melbourne in 1852 and set up practice as a doctor at Williamstown where he established an observatory in 1853. Following Neumayer's departure from Australia in 1863, he was appointed as Government Astronomer and Meteorologist. He expanded the Victorian observing networks and began collecting observations by telegraph from further afield as a basis for the preparation of daily synoptic charts which first appeared in the *Melbourne Argus* in September 1881. Ellery became a leading figure in the Melbourne scientific community and served for almost 20 years as President of the Royal Society of Victoria.

Charles Todd

Charles Todd became Superintendent of Telegraphs and Government Astronomer and Meteorologist in South Australia in 1855 at the age of 30. By 1858 he had completed telegraph links to Victoria and NSW and, by 1872, the overland telegraph to Darwin. As Superintendent of Telegraphs, he made it a duty of all his telegraph operators to make and transmit meteorological observations and he had soon established extensive observing networks throughout South Australia and the Northern Territory, and into Western Australia. Elected a Fellow of the Royal Society of London in 1869, he played a leading role in the scientific life of South Australia, even after his formal retirement, until his death in 1909.

Clement Wragge

Clement Wragge arrived in Australia from England as a seaman at a young age and, after some years in New South Wales and Queensland, left for the US, but returned to South Australia and came under the influence of Sir Charles Todd. He returned to England in 1878 and established the Ben Nevis Observatory in Scotland in 1881. Back in Australia, he established observatories on Mt Lofty (SA), Mt Wellington (Tasmania) and Mt Kosciusko (NSW) before being appointed Queensland Government Meteorologist in 1887. From there he began issuing weather maps and forecasts for the whole of Australia. When passed over for the post of Commonwealth Meteorologist in 1907 he moved to Auckland and established a private weather service.

Henry Chamberlain Russell

Henry Chamberlain Russell was Australia's first native-born Government Meteorologist, the first graduate of Sydney University to be elected a Fellow of the Royal Society, and the first President of the Australasian Association for the Advancement of Science. After his permanent appointment as Government Astronomer and Meteorologist in 1870 he initiated a rapid expansion of the observing networks throughout New South Wales. In 1877 he issued the first synoptic chart published in an Australian newspaper, and in 1879 he convened the first of the intercolonial meteorological conferences aimed at achieving uniformity in data collection. He wrote extensively on scientific matters and was the first to describe the behaviour of the migratory southern hemisphere anticyclones. He retired in 1905.

Government Meteorologist, Henry Chamberlain Russell, published Australia's first newspaper weather map. Russell went on to become one of the leading scientific figures in the colony, becoming the first President of the then Australasian Association for the Advancement of Science in 1888. Clement Wragge was appointed Government Meteorologist in Brisbane in 1887 and quickly emerged as the most colourful and controversial meteorologist on the Australian scene. He also became involved in controversial experiments in rainmaking and introduced the practice of naming Southern Ocean storms and tropical cyclones, initially after mythological figures, but later after politicians who incurred his displeasure.

The lead-up to Federation

Already by the 1870s, the need for standardisation and coordination of data collection was becoming apparent, and intercolonial meteorological conferences were held in Sydney in 1879 and in Melbourne in 1881 and 1888 aimed at achieving national uniformity in observational practices, improving the telegraphic collection of weather bulletins and ensuring that weather forecasts and bulletins issued by the separate colonial observatories were confined to their own colonies. By and large, these arrangements worked well. Only Clement Wragge in Queensland continued to defy the understandings reached, and despatched his forecasts far and wide throughout Australia. It was becoming clear, however, that the weather did not recognise the colonial boundaries and that meteorology should become a Commonwealth function on Federation. Because of the long-standing links between the meteorological and astronomical activities of the colonies, astronomy was eventually included along with meteorology in the provision of Section 51 (viii) of the Constitution that the Commonwealth Parliament would have the power to make laws 'for the peace, order and good government of the Commonwealth with respect to...astronomical and meteorological observations'.

Meteorology in the 20th century

Although meteorological influences had shaped the development of the colonies through most of the nineteenth century and the Centennial Drought of 1888, which had followed several decades of generally plentiful rains, was still fresh in the minds of the participants in the Constitutional debates, these paled into insignificance with the onset of the Federation Drought and the inauguration of the Commonwealth on the first day of the new century.

The forecast for the First Parliament

Unlike Posts and Telegraphs and some other former colonial functions, the responsibility for meteorology did not automatically transfer to the Commonwealth on 1 January 1901. It was thus some time before the new meteorological arrangements could be negotiated, and none of the necessary understandings were in place in time for the opening of the First Parliament in Melbourne on 9 May 1901. The most ominous forecasts over the previous week, and right up to the day before the opening, came from Clement Wragge in Brisbane: 'Fierce westerly squalls with driving rain are (now) tearing through the channel between Cape Otway and Flinders Island, and the Federal Parliament will be opened amid the blustering grandeur of a blow from Antarctica'. His South Australian and Victorian counterparts had been more optimistic early, but eventually conceded the possibility of showers (Souter 1988). In the event, the crowds who lined the streets of Melbourne to greet the royal procession on its way to the opening ceremony were well and truly wind blown, if not completely drenched. Wragge felt vindicated.

The Meteorology Act 1906

Difficult negotiations lay ahead. Not all of the State Governments were happy at the prospect of transferring their meteorological records, facilities and staff to the Commonwealth, and a conference in Adelaide in May 1905 failed to reach agreement, with several States arguing that, while there should be a central Commonwealth institution for theoretical meteorology, the collection of data and provision of services should remain with the State Meteorologists. In the end, the Premiers' Conference of April 1906 agreed that there should be a single Federal Meteorological Department responsible for both science and services meeting the needs of both the Commonwealth and the States. The Premiers also resolved 'that the (State) astronomical and meteorological departments be transferred to the Commonwealth together'.

The Minister for Home Affairs and father of the House, the Hon. William H. Groom, introduced the Bill for a Meteorology Act into the House of Representatives on 1 August 1906. There was a high level of bipartisan support for the proposed consoli-

dation of meteorological functions, with debate centering mainly on whether the astronomical function should be taken over by the Commonwealth at the same time (it was not) and on whether some local meteorological functions should remain with the States (they were not). Future Prime Minister Joseph Cook was forthright in stressing the importance of a unified federal service and the benefits that would result from its establishment.

The expectations of the proposed Meteorological Department were high. In the words of the member for Echuca (Mr James McColl): 'In our present complex civilisation where interests are so inter involved and worldwide, the discovery and formulation of laws governing the weather are of first importance. To obtain an accurate meteorological system throughout Australia, the government would be justified in incurring almost any expenditure. To all sections of the community the matter is one of great importance - to those interested in commerce, transportation, navigation, agriculture, and trade of all descriptions. In short, it concerns everybody whose living and comfort depend upon the seasons and upon the weather'.

The *Meteorology Act 1906,* establishing the position of Commonwealth Meteorologist, setting down the functions of what was soon to become known as the Commonwealth Bureau of Meteorology, and authorising the conclusion of arrangements for transfer to the Commonwealth of the meteorological records and facilities of the States, received Royal Assent on 28 August 1906.

The birth of the Bureau

The Bureau of Meteorology formally commenced operation on 1 January 1908 under the first Commonwealth Meteorologist, Henry Hunt, who had been appointed in 1907 ahead of the controversial Queenslander Clement Wragge. The Bureau was housed in the 'Frosterley' building at the corner of Victoria and Drummond Streets, Carlton (Figure 3), a home which was to serve as its national headquarters until it consolidated its by then dispersed Melbourne operations in a new high rise building at 150 Lonsdale Street in 1974 (back cover).

On 18 January 1908, a full page article in the *Melbourne Argus* asserted that 'There is probably no other country in the world – not excepting even the United States of America – which is so vitally affected by its varying weather conditions as Australia', and described in detail the working of the new Bureau including the combined role of the Melbourne Office as both a national headquarters and a Divisional Office for Victoria. It noted that each morning the Melbourne Office received a total of 217 reports from across the Commonwealth as the basis for preparation of guidance forecasts for the Divisional Meteorologists in the other capitals. The centrally produced forecasts were initially not well received in distant capitals, and so began the ebb and flow of pressures for greater decentralisation of forecasting which characterised Australian meteorology through most of the twentieth century.

The early years

The early years of the Bureau were a period of great scientific progress in the face of a difficult struggle for the funds to pay staff salaries and maintain operations. Henry Hunt, who had worked under H.C. Russell in Sydney, already had a distinguished scientific record and, with the assistance of colleagues Griffith Taylor (later Professor of Geography at Sydney, Chicago and Toronto Universities) and E.T. Quayle, soon published a definitive treatise `The Climate and Weather of Australia` (Hunt, Taylor and Quayle 1913).

By 1919 the permanent staff of the Bureau had grown from an initial Australia-wide complement of 30 (supported by several thousand volunteer observers) to 71. These included two future Directors of the Bureau (W.S. Watt and E.W. Timcke).

Figure 3. *'Frosterley' at No. 2 Drummond Street, the headquarters of the Commonwealth Bureau of Meteorology from 1908 until 1974.*

The Depression years of the late 1920s and early 30s, with their severe restraint on government spending, were a difficult time for the Bureau. This was exacerbated by the lack of understanding on the part of the Public Service authorities of the need for scientific qualifications for Bureau staff, a problem which was to impair the work of the Bureau for most of the following half century (Gibbs 1982). With the loss of Edward Kidson in 1927 to become Director of the New Zealand Meteorological Office and the retirement of Hunt in 1931, the Bureau lost its scientific leadership and fell into a period of scientific stagnation.

Meteorological services for civil aviation

Major new requirements for meteorological services emerged with the rapid growth of civil aviation throughout the 1930s. Initially the services for aviation were supplied from the capital city Divisional Offices but, following the loss of the *Southern Cloud* and *Kyeema* due to weather, and the opening of the Imperial Airways Service in 1934, it was soon realised that a much expanded and improved weather service was required. The first meteorological office for purely aviation purposes was established in Darwin in 1934 to support the Empire Flying Boat route and, by 1939, the Bureau was operating a total of 23 aerodrome observing offices, including ten providing forecasts and briefing for pilots.

The arrangements for provision of weather services for civil aviation were to undergo many changes through the rest of the century, particularly following the establishment of the International Civil Aviation Organization (ICAO) in 1946. The extension of forecasting offices to more and more airports came to an end in the early 1970s with the consolidation of most of the Bureau's forecasting staff in capital city Regional Forecasting Centres, with only briefing and very short-term forecasting functions remaining at a few airports. This was later further centralised, mainly for cost-reduction reasons, in the early 1990s.

Meteorology at the universities

Despite some useful work in a few geography departments, the Australian universities showed little interest in meteorology through the 1920s and 30s. In a report to the Prime Minister in 1937, the UK aviation expert H.E. Wimperis recommended, inter alia, the initiation of university research aimed at more accurate weather forecasting and improved understanding of the structure of the atmosphere. This led to Bureau funding for a small meteorological department at Melbourne University. The first Reader-in-Charge was the distinguished German polar scientist Dr Fritz Loewe, who provided inspiration to a generation of Bureau meteorologists from the late 1930s onwards. The Wimperis report was followed by a further report on meteorological research and training in the universities and the Bureau, by the then Director General of the UK Meteorological Office, Sir George Simpson.

Under Loewe, and subsequently Dr Uwe Radok, the Meteorology Department at Melbourne University played a leading role in the development of Australian Antarctic meteorology and glaciology, but struggled for recognition and critical mass. It did not achieve professorial status until 1980. With the departure of Dr Peter Schwerdtfeger to Adelaide and Professor Bill Budd to Hobart, Melbourne retained only a small, albeit productive, meteorological effort in the School of Earth Sciences, with Monash University emerging as the strongest Australian university in meteorological research and teaching during the 1970s and 80s. Initially, under the leadership of Professor Bruce Morton, it developed as a centre of excellence in geophysical fluid dynamics and a source of many of those who were to later assume important roles on the Australian meteorological scene. Significant university groups in meteorology also developed at Macquarie University (under Dr Edward Linacre and subsequently Professor Ann Henderson-Sellers), Murdoch University and the James Cook University of North Queensland.

The RAAF Meteorological Service

With the outbreak of World War II, the Bureau of Meteorology passed from the Department of the Interior to the Department of Air in July 1940, with responsibility for providing all meteorological services needed by the defence forces while still continuing to meet civil requirements.

From April 1941 to July 1946, most of the staff of the Bureau served in uniform throughout Australia and the islands as members of the RAAF Directorate of Meteorological Services under the leadership of Group Captain H.N. Warren. Many of the leaders of the civilian Bureau over the following thirty years were first recruited as forecasters during the period of rapid expansion which followed the outbreak of the war. Whether as members of Mobile Met Flights in Timor, New Guinea, Borneo, Malaysia or the New Hebrides, on station around Australia or, later in the war, at Allied Headquarters in Brisbane, the staff of 'The Met' distinguished themselves through their rapid mastery of the challenges of forecasting in the tropics and

Commonwealth meteorologists of the twentieth century

Henry A. Hunt

Henry A. Hunt (1907-31) began his meteorological career as an assistant to H.C. Russell in Sydney. He had already won an international prize for his work on the southerly buster when appointed as Australia's first Commonwealth Meteorologist in 1907. He was immediately despatched on a world trip to assess the latest developments in meteorology. Although he provided outstanding scientific leadership to the early Bureau, he fought a long and difficult battle through the period of the First World War and the Great Depression to obtain the resources needed to build the networks and scientific basis for Australia's meteorological services.

William S. Watt

William S. Watt (1931-40) had been assistant to Henry Hunt and was appointed as Commonwealth Meteorologist following successful appeal against the promotion of Henry Barkly. He presided over a difficult period for the Bureau with little support for its scientific development and little awareness in government of the imminent need for major expansion to meet the needs of civil aviation and subsequently the war effort. He participated in the 1935 IMO (International Meteorological Organization) Conference of Directors in Warsaw and the 1937 meeting of IMO Regional Association V (South West Pacific) in Wellington.

H. Norman Warren

H. Norman Warren (1940-50) was Public Service Inspector for Tasmania before being appointed as Assistant Director of the Bureau in 1938 and shortly thereafter as Director of Meteorology. Almost immediately, as Group Captain Warren, he was called on to manage the transformation of the Bureau into the RAAF Meteorological Service. After return of the Bureau to civilian status in 1946, he became deeply involved in international meteorology, chairing the committee which drafted the final text of the WMO Convention in Washington DC in October 1947. He died in office on his way home from a session of the WMO Executive Committee in August 1950.

Edward W. (Tim) Timcke

Edward W. (Tim) Timcke OBE (1950-55) joined the Bureau in Adelaide in about 1911 as a meteorological assistant. After service in France in World War I, he returned to the Sydney office of the Bureau in 1919 and moved to Melbourne in 1929. He was a candidate for the post of Director of Meteorology when Warren was appointed. He then served as deputy to Warren through and after World War II and represented him at several international meetings. As Director, he presided over a period of consolidation and staff reductions brought on by general government cutbacks in the Public Service. He was, however, able to expand the Bureau's upper air networks and establish observing stations at Heard and Macquarie Islands.

Leonard J. (Len) Dwyer

Leonard J. (Len) Dwyer (1955-62) joined the Bureau in September 1937 as a meteorological assistant and soon became a trainee meteorologist. By 1940 he headed the Bureau's Training Section and subsequently became responsible for the RAAF Mobile Meteorological Flights during World War II. After the war, he worked in the Aviation Section of the Bureau's Central Office before being recruited to the position of Chief Clerk. An aggressive personality with a flair for management, he presided over a period of rapid technological progress, and improvement and extension of Bureau services. He served as President of WMO Regional Association V from 1957 until 1962. He died in office in May 1962.

William J. (Bill) Gibbs

William J. (Bill) Gibbs OBE (1962-78) was born in Sydney and joined the Bureau of Meteorology in 1939 on the eve of World War II. After almost two years in Port Moresby, he was posted to Allied Headquarters in Brisbane. After the war, he accompanied H.N. Warren to the Washington Conference of Directors which finalised the WMO Convention, and returned to the US for study in 1952 as a Fulbright Scholar. Dr Gibbs served as the Bureau's Assistant Director Research from 1958 until 1962 and became Director of Meteorology in 1962. He was First Vice President of WMO from 1967 until 1978. He played a pioneering role in Australian tropical meteorology and Antarctic meteorology and in the study of Australian drought. He retired in July 1978.

John W. Zillman

John W. Zillman AO (1978-) joined the Bureau of Meteorology as a Cadet Meteorologist in Brisbane in 1957. After a period in operational forecasting in NSW and Queensland, he was appointed to the Southern Hemisphere Analysis Centre in Melbourne in 1966 and subsequently to the International Antarctic Meteorological Research Centre. After study in the US (1970-72) he became Assistant Director Research in 1974 and succeeded Dr W.J. Gibbs as Director of Meteorology in July 1978. He coordinated Australia's participation in the 1979 Global Weather Experiment and negotiated the strengthening of the research role of the Bureau in the early 1980s. He was First Vice President of WMO from 1987 to 1995, and became its President in 1995.

provision of outstanding weather support for allied operations (Gibbs 1999). In the words of the War Report of the Chief of Air Staff, 'The Met earned and retained the confidence of Allied operational commanders and of associated Allied weather organisations'.

CSIR Meteorological Physics

The 1945 decision of the CSIR (Council for Scientific and Industrial Research), now CSIRO, to establish a Section for Meteorological Physics to carry out fundamental studies of atmospheric processes was to have a profound impact on the development of Australian meteorology (Garratt et al. 1998). Located at Aspendale, Victoria, under the leadership of Dr C.H.B. Priestley AO from the UK Meteorological Office, the CSIRO Section (later Division) of Meteorological Physics (now CSIRO Atmospheric Research) went on to become a world leader in atmospheric boundary-layer processes, micrometeorology and atmospheric chemistry. Throughout its history, it has had just three Chiefs – Priestley (1946-73), Dr G.B. Tucker (1973-92) and Dr G.I. Pearman AM (1992-). At various stages, it has been involved in cosponsorship of joint research centres with the Bureau, including the Commonwealth Meteorology Research Centre (CMRC) from 1969 to 1974 and the Australian Numerical Meteorology Research Centre (ANMRC) from 1974 to 1984. The two organisations joined together again in the 1990s as partners in a Cooperative Research Centre for Southern Hemisphere Meteorology located at Monash University.

The Meteorology Act 1955

One of the main purposes of the *Meteorology Act 1906* had been to provide the legislative basis for the appointment of the Commonwealth Meteorologist and authority for negotiations on transfer of the State meteorological observatories to the Commonwealth. The title of Commonwealth Meteorologist had unofficially been changed to Director of Meteorology in the 1930s and, although widely known as the Commonwealth Bureau of Meteorology, no such title had been included in the original Act. By the early 1950s, especially following the establishment of the World Meteorological Organization (WMO) as a specialised agency of the United Nations in 1950, the Meteorology Act had become seriously out of date. In December 1954, the Government decided on its repeal and replacement by a new Act defining the purpose and functions of the Bureau in line with the requirements of the WMO and contemporary practices in other countries.

The Bill for the new Act was introduced into the House of Representatives on 21 April 1955 by the Minister for the Interior, the Hon Wilfred Kent-Hughes. It received strong bipartisan support with special mention made of the need for improved fire, cyclone and flood warning, expanded observation networks and locally based forecasting services. The Bureau was also urged to pursue research into long-range forecasting. The Act was assented to on 23 May. It became the basis for a significant reorganisation of the Bureau under the incoming Director of Meteorology, L.J. Dwyer, who had been appointed on the retirement of E.W. Timcke on 1 April 1955. The new Act established the office of Director of Meteorology and the statutory basis for the operation of the Bureau, which continued to be staffed under the Public Service Act as an outrider to the Department of the Interior.

Figure 4. *Former members of the RAAF Meteorological Service gather in Melbourne in August 1995, fifty years after the end of* the war.

Flood warning

Following widespread pressure for upgraded flood warning services in the wake of the disastrous Hunter floods of 1955, and realisation that the Premiers' Conference agreement of 1936 that the Bureau should assume national responsibility for flood warning had not been explicitly reflected in the new Act, the Government decided, in April 1957, that the Bureau should establish a hydrometeorological service to serve as the national authority for hydrological and water resources data collection, provision of hydrometeorological advice and flood warning.

An extensive program of upgrading of flood warning arrangements commenced in the early 1960s but, following the report of the 1976 Committee of Inquiry into the Bureau of Meteorology (CIBM), a hiatus developed in the early 1980s until new collaborative Commonwealth-State-local government arrangements were finally put in place in 1987 under the auspices of State Flood Warning Consultative Committees.

Long-range forecasting

Australian farmers have always had an insatiable appetite for long-range weather forecasts and, for many years, the late Inigo Jones, who had worked under Clement Wragge in Brisbane, provided seasonal forecasts from his privately operated Crohamhurst Observatory in southeast Queensland. Despite two Ministerially commissioned investigations which concluded that his forecasting methods had no scientific basis, the demand for his forecasts remained and after his death the service continued under Lennox Walker. Through the 1950s and 60s, Bureau, CSIRO and university scientists and several private individuals continued to experiment with long-range forecasting, but it was not until scientists gained a better understanding of the influence of the ocean and the mechanisms of the El Niño and the Southern Oscillation in the 1970s and 80s that some forecasting skill emerged. During the 1990s, through the work of the Bureau's National Climate Centre and other groups including the Queensland Centre for Climate Applications, Australian scientists have emerged as world leaders in the preparation of seasonal outlooks and their practical application to agriculture and other important economic sectors.

Antarctica

The Bureau of Meteorology is statutorily responsible for Australian meteorological activities in Antarctica and has, from the beginning, been a key member of ANARE (Australian National Antarctic Research Expeditions), often co-located in the same portfolio as the Australian Antarctic Division.

As well as opening observing stations at Australia's Antarctic bases and seconding staff to the IGY (International Geophysical Year) Antarctic Weather Central at Little America, the Bureau took the lead in convening a post IGY international symposium on Antarctic meteorology and subsequently hosting the International Antarctic Analysis Centre (IAAC) and International Antarctic Meteorological Research Centre (IAMRC) in Melbourne. These were headed, over the period 1959-68, by Mr H.R. (Henry) Phillpot, who continued in Antarctic research long after his retirement in 1980 and who, in 1999, was honoured as an 'Australian Science Hero'. Two Australians, Dr N.A. Streten and Mr H.A. Hutchinson, have subsequently chaired the WMO's Working Group on Antarctic Meteorology.

World Meteorological Centre, Melbourne

Following the launch of the first artificial earth satellites and the development of plans for the World Weather Watch (WWW) drawing on the emerging capabilities of meteorological satellites and digital computers, the Australian Government offered, in November 1964, to host one of the proposed three World Meteorological Centres of the WWW. Under the guidance of Dr W.J. (Bill) Gibbs, who had been appointed Director of Meteorology in September 1962 following the death of L.J. Dwyer, and with the Bureau's installation of its first powerful computers in 1968, Australia emerged as the leading meteorological nation of the southern hemisphere and one of the key players on the global meteorological research and service scene.

Regional Forecasting Centres

One of the most significant steps in the history of the Bureau was the decision in the late 1960s to consolidate the public weather and aviation forecasting staff of the Bureau into Regional Forecasting Centres (RFCs) in the capital cities. Although it led to the need for new mechanisms for meeting the needs of many geographically dispersed and specialised user communities, the establishment of the RFCs, beginning in Tasmania in 1971, enabled the Bureau to absorb the greatly increased demands for service which flowed from its increased forecasting capabilities and the increased weather sensitivity of such important industry sectors as agriculture,

coastal tourism and offshore oil and gas operations.

The Bureau's capabilities were further enhanced through the progressive installation of its Automated Regional Operations System (AROS) through the 1980s and its subsequent replacement by AIFS (Australian Integrated Forecasting System) which now provides the main specialised technological support for Australia's weather services nationwide.

Global Weather Experiment

The Global Weather Experiment, the field phase of which took place in 1979, was the largest fully international scientific experiment ever undertaken. It was aimed at improving the accuracy and time range of weather forecasting, guiding the design of the most cost-effective observing systems for operational forecasting and pointing the way towards a scientific basis for climate prediction.

Australian meteorologists were deeply involved in the planning of the Experiment from the early 1970s, and Australian support for the specialised observing systems (such as drifting buoys) deployed during 1979 was critical to its success. For the first time, the global meteorological research community turned their primary attention to the problems of the southern hemisphere (Figure 5) and so laid the foundation for the enormous progress in southern hemisphere meteorology that took place in the closing years of the twentieth century.

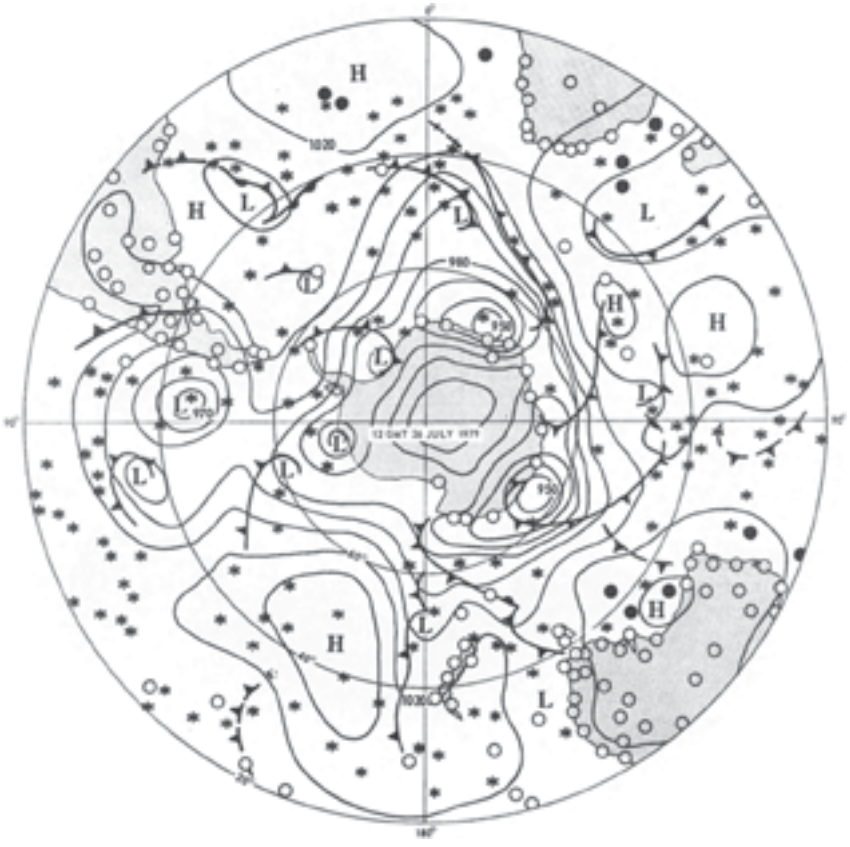


Figure 5. *Typical distribution of data over the southern hemisphere during the 1979 Global Weather Experiment. Open circles are land-based synoptic stations, solid circles are ships and asterisks are drifting buoys.*

Research in the Bureau

After several decades of unsuccessful efforts to obtain Public Service Board agreement to the upgrading of the research role and staffing of the Bureau to enable it to discharge its statutory responsibilities on a sound scientific basis, agreement was finally reached in 1983 to the disbandment of the joint Bureau-CSIRO ANMRC and the establishment of the Bureau of Meteorology Research Centre (BMRC), with Research Scientist staffing, as the upgraded research arm of the Bureau. Under the guidance of former ANMRC Officer-In-Charge, Dr D.J. (Doug) Gauntlett, and the newly appointed BMRC Chief, Dr M.J. (Mike) Manton, the BMRC developed into a world leading research group in southern hemisphere meteorology. It works in close partnership with CSIRO Atmospheric Research under Dr G.I. (Graeme) Pearman AM, and the two organisations have collaborated in a number of major research programs including research associated with Australia's operation of a WMO Global Atmosphere Watch station at Cape Grim in Tasmania.

Committees of Inquiry

The 1976 Committee of Inquiry into the Bureau of Meteorology (CIBM) set in train a lengthy process of restructuring of the Bureau's operations, as well as the establishment of the Meteorology Policy Committee (MPC) which served as a non-statutory external advisory body to the Minister until its disbandment in 1990. It played a major role in inspiring and guiding the re-equipment of the Bureau and the upgrading of its warning services during the 1980s.

Further external inquiries and reviews followed, including a 1987 *House of Representatives Expenditure Committee Inquiry into the Provision of Meteorological Services* ('Gone with the Winds') and a major external *Review of the Operation of the Bureau of Meteorology* in 1996, with a follow-up study on *Capturing Opportunities in the Provision of Meteorological Services,* both led by former Chief Scientist, Professor R.O. Slatyer AC FRS FAA FTSE.

The weather and climate of the twentieth century

The twentieth century began with Australia still in the grip of the Federation Drought. It witnessed several extended periods of drought and flood associated with the irregular fluctuations of the Southern Oscillation (Figure 6), many dramatic individual weather events in all States and a gradual overall warming trend across the continent. The general features of the twentieth century climate have been described in various publications (Bureau of Meteorology 1989; Zillman 1994; Bureau of Meteorology 2000). Some of the more notable individual events and trends in Australian weather and climate over the century are described in the following pages.

Rainfall

The average annual rainfall over Australia from 1900 to 1999 is shown in Figure 7 along with an eleven-year running mean. The very dry period following Federation and the above average rainfall in the 50s and 70s are clearly evident. Overall, there is a very weak rising trend in total rainfall during the century, although individual districts have experienced much stronger trends, both positive and negative, as shown in Figure 8.

The maps comprising Figure 9 show the distribution of annual rainfall over the continent in terms of the three terciles – above average, near average and below average – for each year from 1900 to 1999.

Temperature

The history of annual mean temperature over Australia through most of the twentieth century is shown in Figure 10.

The overall warming trend during the second half of the century evident in Figure 10 is much more strongly evident in minimum temperatures than in maximum temperatures and it is not uniform over the continent. In fact, some parts of NSW and northern Queensland experienced a slight cooling trend over the century as a whole, as shown in Figure 11.

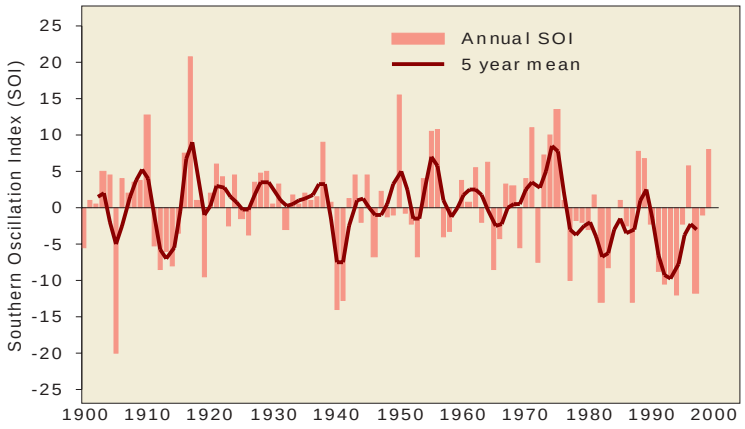


Figure 6. *Annual values of the Southern Oscillation Index (SOI), a measure of fluctuations in the surface pressure difference between Tahiti and Darwin and a useful indicator of the broadscale controls on Australian weather.*

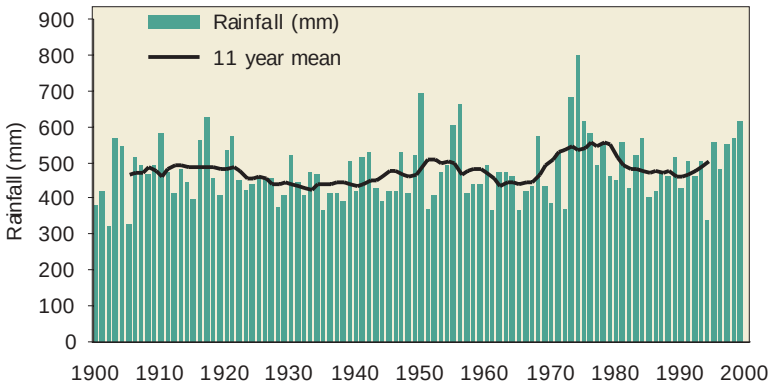


Figure 7. *Averaged annual mean rainfall (mm) over Australia, 1900-99. The solid line shows the eleven-year running mean.*

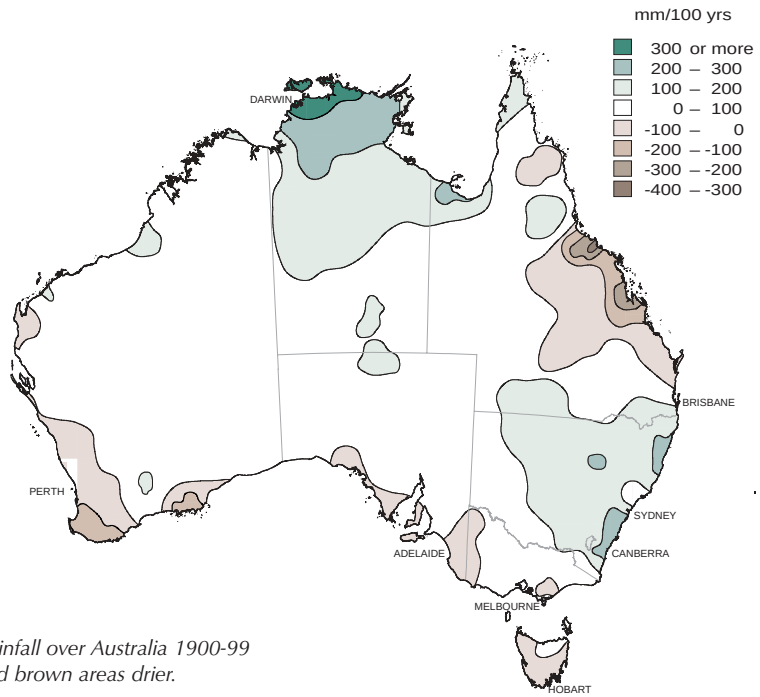


Figure 8. *The spatial pattern of trends in annual mean rainfall over Australia 1900-99 in mm per century. Green areas have become wetter and brown areas drier.*

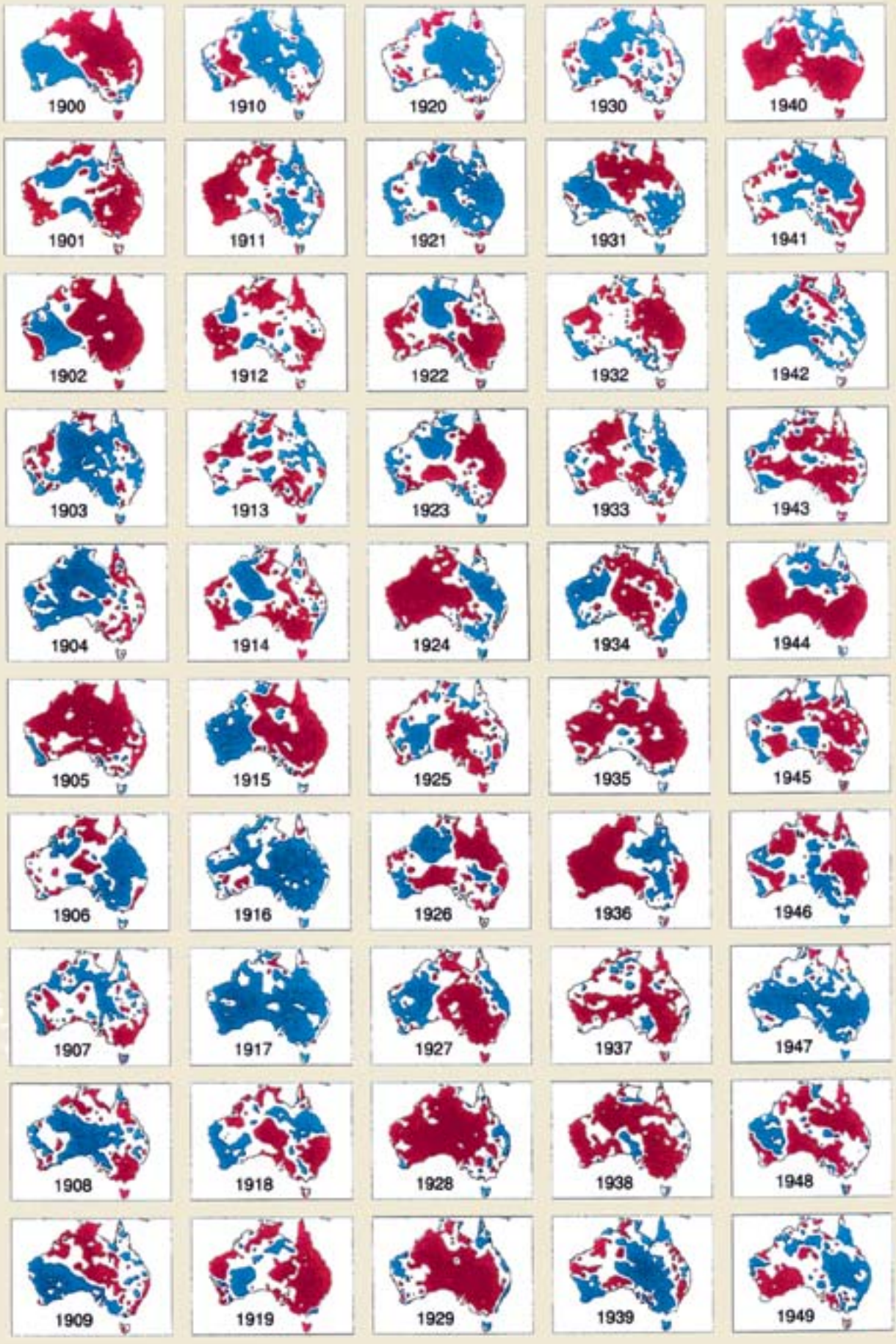
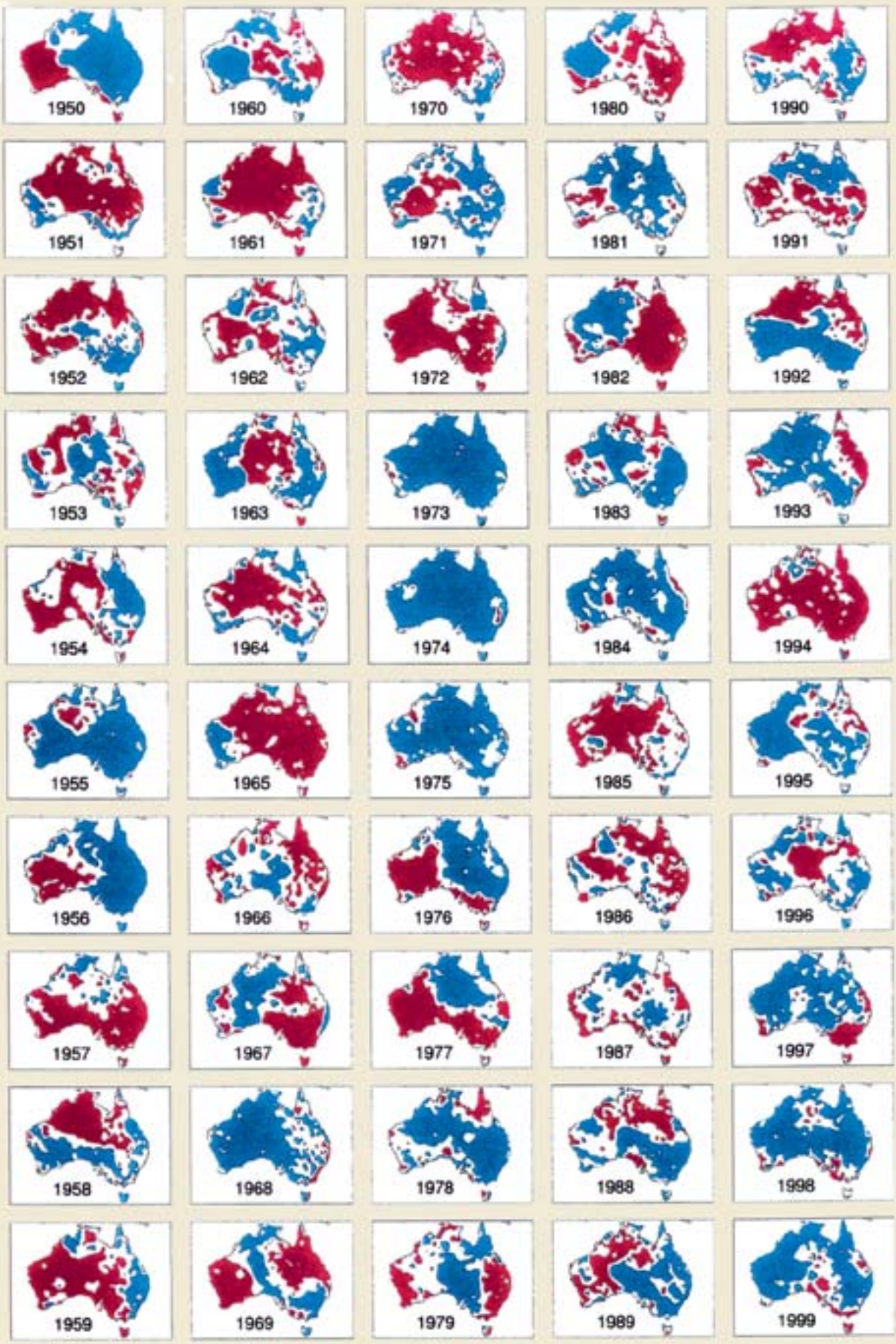


Figure 9. *These two pages show the distribution of annual rainfall over Australia during the twentieth century. Above normal rainfall (third tercile) is shown as blue, near normal (second tercile) as white and below normal (first tercile) as red.*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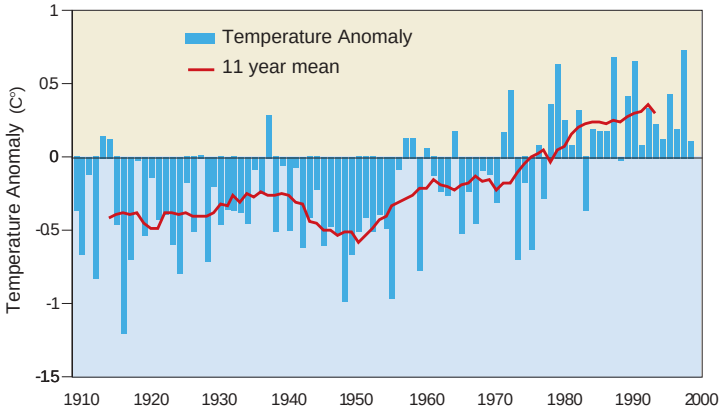

Figure 10. *Areal average temperature anomalies (°C) over Australia relative to the 1961-90 normals for the period 1910-99.*

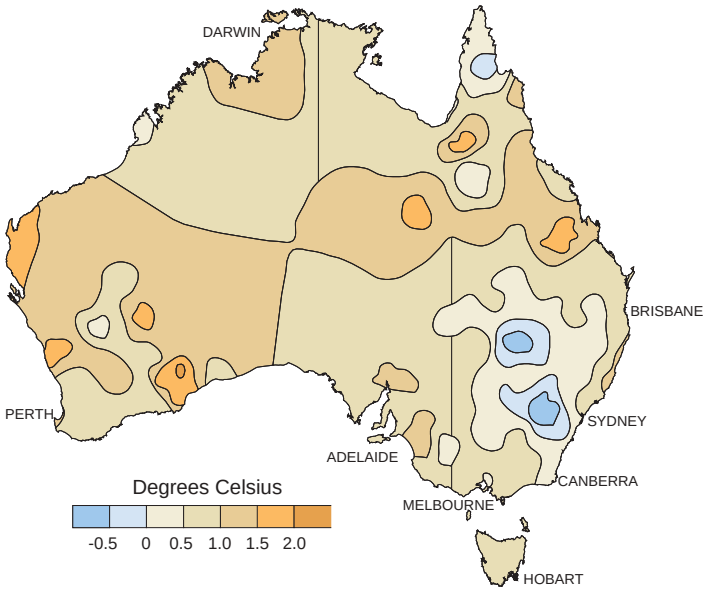

Figure 11. *The trend in annual mean temperature over Australia for the period 1910-99 in °C per century.*

Tropical cyclones

Although a number may have gone undetected in the early years and the apparent increase in frequency in the middle part of the century may not be real, it appears that some 800-1,000 tropical cyclones have developed in the Australian region (105-165°E) during the twentieth century, with as few as one and as many as nineteen in a single season (Figure 12). Figure 13 shows their tracks for the ten-year period 1970-80.

The loss of life from tropical cyclones was greatest in the early part of the century, with several infamous cyclones of the early years striking almost without warning. Among the best known are the Broome cyclone of 1908 (loss of 50 lives), the Mackay cyclone of 1918, the Darwin cyclone of 1939, cyclone *Ada* (which struck the Whitsunday Islands in January 1970 with a loss of 13 lives), cyclone *Tracy* in 1974 and cyclone *Vance* (which produced the strongest measured wind gust on mainland Australia (267 km/h) as it passed close to Exmouth, Western Australia, on 22 March 1999).

Floods

The twentieth century witnessed many disastrous floods including both flash floods and riverine floods along the eastern, western and northern coasts as well as in the westward and southwest flowing rivers of the Murray Darling system. Six years: 1954, 55, 56, 59, 71 and 74, stand out as the major flood years of the century, with the Hunter floods of February 1955 and the Brisbane flood of January 1974 perhaps the worst. Other notable floods included the Todd River flood at Alice Springs in March 1910, the Latrobe River flood in Victoria in December 1934, the Charleville flood of April 1990, the northeastern Victorian floods of October 1993 and the Katherine (NT) flood of January 1998.

Droughts

The great Australian droughts of the twentieth century have mostly been closely linked with the major swings in the Southern Oscillation Index (SOI) (Figure 6), with drought in eastern Australia coinciding with the El Niño (warm central and eastern Pacific Ocean) phase of the El Niño-La Niña cycle.

The major drought years included:

- 1901-03, the final years of the Federation Drought during which sheep and cattle numbers were halved;
- 1911-16, which saw the loss of 19 million sheep and 2 million cattle;
- 1918-20, which affected virtually all of the continent except for parts of Western Australia;
- 1939-45, a protracted drought with the loss of 30 million sheep between 1942 and 1945;
- 1958-68, a prolonged period of widespread drought with a 40% drop in wheat harvest in the final two years, a loss of 20 million sheep and a decrease of farm income of $300-500m;
- 1982-83, a relatively short but severe drought over eastern Australia with total losses in excess of $3b;
- 1991-95, one of the most severe droughts of the century over eastern Australia, with total losses estimated in excess of $5b.

Bushfires

Major bushfires have occurred in most parts of Australia over the past century, many causing significant loss of life and extensive property damage. In the southern States, they have usually been associated with the onset of hot dry northerly winds following extended drought conditions, but in Western Australia they have also been associated with the southern fringe of tropical cyclone circulations such as cyclone *Alby* in 1978.

Among the most notorious bushfires have been:

- 13 January (Black Friday) 1939, the most disastrous fires experienced to that time extending over three quarters of Victoria with the loss of 71 lives;
- 10 December 1944, devastating fires in the Blue Mountains and other parts of NSW;
- 16 February (Ash Wednesday) 1983, disastrous fires in South Australia and Victoria with the loss of 75 lives and more than 2,000 houses;
- 1-8 January 1994, more than 200 major fires along the NSW coast and ranges with the loss of four lives and 185 houses.

Severe storms

Severe thunderstorms with lightning, hail, tornadoes and strong winds have affected most parts of Australia, with the southwest coast of Western Australia and the central coast of NSW having been particularly affected.

Some notable storms have occurred on:

- 26 November 1971, when severe storms over the Woden Valley (ACT) caused disastrous flash flooding and loss of life;
- 13 November 1976, when the Sandon (Vic) tornado left a 6km long path of destruction and two persons dead;
- 23 May 1994, when large areas of southwestern Western Australia experienced violent gales with the loss of two lives and severe damage to some 600 houses;
- 29 September 1996, when widespread severe storms broke out over NSW with three tornadoes and hail up to 7cm. Total damage was estimated at $340m;
- 14 April 1999, when an unseasonal hailstorm struck the eastern suburbs of Sydney at night with damage to 63,000 cars, 22,000 homes and several commercial aircraft.

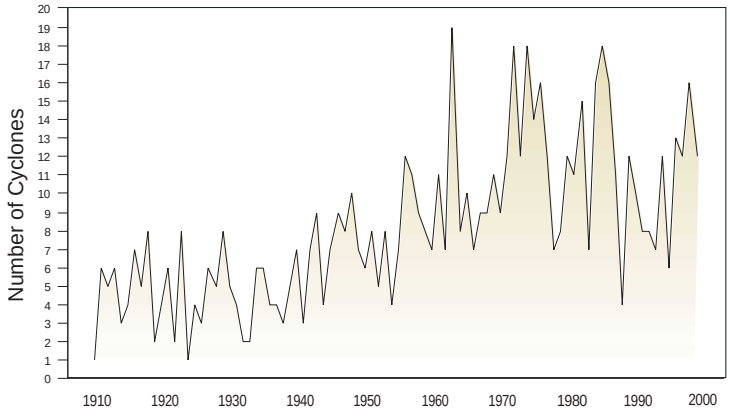

Figure 12. *The annual occurrences of tropical cyclones in the Australian region (105 – 165°E) from July 1909 to June 2000.*

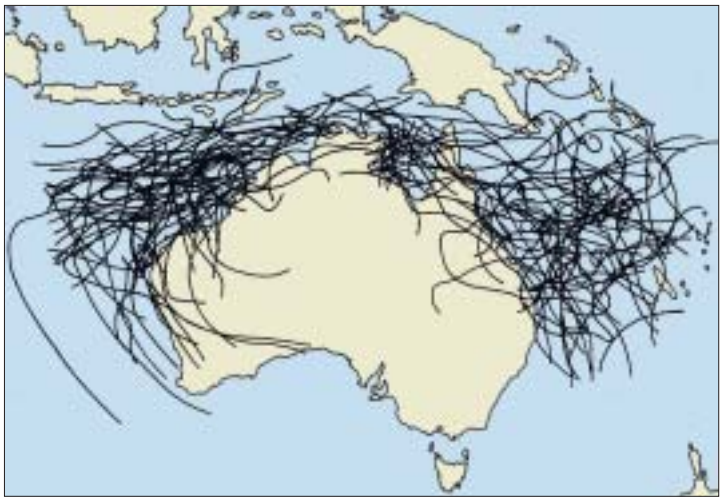

Figure 13. *Tropical cyclone tracks in the Australian region, 1970-80.*

The great weather and climate events of the twentieth century

The Federation drought, 1895-1902

The five years preceding Federation had been intermittently dry over most of the country. Very dry conditions set in across eastern Australia during the spring of 1901, and became entrenched over the following months. As the drought worsened, enormous sheep and cattle losses were reported from Queensland, and many rivers dried up. The Darling River at Bourke virtually ran dry, while Murray River towns such as Mildura, Balranald and Deniliquin – at that time dependent on the river for transport – suffered badly. The Australian wheat crop was all but lost. Rain in December 1902 brought temporary relief, with a more substantial break in autumn

1903. The long drought and its severe climax in 1902 had devastated stock numbers, and began focusing attention on planning for irrigation, especially in the three States through which the Murray River flows.

The Mackay cyclone of 1918

The Mackay cyclone was the first of two cyclones to inflict heavy damage on significant population centres in northern Queensland during early 1918. Moving in from the Coral Sea late on 20 January, its devastating winds terrified residents as buildings disintegrated, gas and water supplies failed, and roofing iron scythed though the air. A storm surge inundated the town around 5am, with large waves reportedly breaking in the centre of Mackay. Phenomenal rainfall – 1,411mm in three days at Mackay Post Office – generated the worst flooding in Mackay's history. Some 30 people lost their lives, mainly in Mackay and Rockhampton.

Northeastern Tasmanian floods, April 1929

Although northeastern Tasmania's climate is normally relatively benign, it is prone to intense rainfall over short periods. The worst event of the century occurred in April 1929, when 22 people died. Rain commenced late on 3 April and, in three days, up to 500mm fell over the high country of the northeast, and over a smaller area south of the Burnie/Ulverstone area. The Briseis Dam on the Cascade River crumbled, and the resulting torrent, carrying thousands of tons of trees, rocks and gravel, overwhelmed houses and offices, with 14 deaths. Over 1,000 houses in Launceston were inundated, and most other north coastal rivers were heavily flooded. Scenes of devastation – to man-made structures and natural features – were widespread across northern Tasmania. It took many weeks to repair the damage.

Black Friday in Victoria, January 1939

Following an exceptionally dry winter and spring, vegetation over most of Victoria was in an extremely hazardous condition by January 1939. Heatwave conditions from early in the second week of January saw many large fires break out, especially on the 10th when Melbourne registered a maximum of 44.7°C. Twenty-one people died in these fires, which could not be extinguished despite milder conditions in southern Victoria on the 11th and 12th. On the 13th the onset of strong and even hotter winds (Melbourne reaching a record 45.6°C) coalesced these fires into a sea of flame. Several timber towns were burnt to the ground, extensive tracts of mountain forest (including Melbourne's main catchment area) were incinerated, and 50 more people died, many trapped in timber mills. In the ensuing Royal Commission, many changes to rural fire fighting practices in Victoria were proposed, and eventually implemented.

Record floods in New South Wales, February 1955

The Hunter Valley floods of late February 1955 have, in many people's minds, come to symbolise flooding in Australia. A monsoon depression moving south from Queensland deposited up to 250mm of rain in 24 hours over the already-saturated Hunter region. The Hunter, and several west-flowing rivers, swiftly rose to record levels, drowning the surrounding country. In East Maitland, water completely submerged houses, and 15,000 people were evacuated. It was a similar story throughout the Hunter, Macquarie, Namoi and Gwydir River Valleys, with houses destroyed, metres of flood waters in the streets, and many thousands of stock drowned. In all, 14 people died, and damage to bridges, roads, railways and telephonelines took months to repair. This event was the most spectacular of many heavy rain episodes over eastern Australia between late 1954 and the end of 1956.

Fire and storm – southwest WA, 1961, 1978

Perhaps Western Australia's worst bushfire disaster – the Dwellingup fires – occurred in January 1961. An intense cyclone off the northwest coast led to five days (20 to 24 January) of gusty winds and 40°C temperatures over the lower southwest. Fires, many started by lightning, burnt uncontrolled through this period. Strong northwest winds on the 24th drove the fires southward, destroying the township of Dwellingup, and many houses in other small settlements. Fortunately there was no loss of human life. A similar event occurred in early April 1978, when cyclone *Alby* swept past the southwest of Western Australia, generating severe gales (gusts to 150km/h) between Kalbarri and Albany, and causing widespread damage and coastal (storm surge) flooding, as well as raising large dust clouds. Over 360 separate fires flared, more than 114,000 hectares of forest and farmland were burned, and many buildings and homes destroyed.

Brisbane floods, January 1974

Following a very wet 1973, the month of January 1974 featured probably the biggest continent-wide drenching since European settlement, with vast areas of the country inundated. In Brisbane, preceding heavy rain had already produced some flooding when, on 24 January, cyclone *Wanda* came ashore north of the city. *Wanda* inflicted relatively little wind damage, but produced record rains over the Australia Day weekend. In three days, Brisbane received 580mm, with much higher falls over river catchments near the city (1,300mm in five days at Mt Glorious). Many houses bordering rivers and creeks were washed away as rivers rose to their highest levels since the disastrous 1893 floods (Figure 14). Fourteen people died, some trapped in offices by the rising waters.

Cyclone Tracy, Christmas 1974

The year 1974 started with cyclone *Wanda* bringing devastating floods to Brisbane, and ended with Darwin devastated by cyclone *Tracy*. Small but compact by world standards, *Tracy* packed unusually strong winds (gusts to 217km/h at Darwin Airport before the recorder failed). *Tracy* moved in from the Arafura Sea, skirted Bathurst Island, then, swinging sharply south, struck Darwin early on Christmas Day. Good warnings had been issued, but the combination of public indifference (it was Christmas and no severe cyclone had affected Darwin for years), extremely fierce winds, and the loose design of many buildings at that time, led to wholesale destruction. Sixty-five people died and most buildings were totally destroyed or badly damaged (Figure 15). Most of the remaining population was swiftly evacuated. In the wake of *Tracy*, much more attention was given to building codes and other aspects of disaster planning.

Figure 14. *Brisbane floods, January 1974.*

Figure 15. Darwin after cyclone Tracy, December 1974.

Figure 16. *Fire in the Penola Forest (SA), Ash Wednesday 1983.*

Figure 17. *Tennis ball-sized hail, Sydney, April 1999.*

The 1982-83 drought

In terms of short-term rainfall deficiencies (up to one year) and their impacts, the 1982-83 drought was probably Australia's worst in the twentieth century. It started in autumn 1982, with severe rainfall deficiencies over eastern Australia exacerbated by frequent sharp frosts in June and July. Dry conditions persisted, and by year's end extensive areas of eastern Australia had had record or near-record low April to December rainfall. The upper Murrumbidgee River became a chain of waterholes. Reservoirs throughout the southeast fell to levels unknown for many years. The northern Australian wet season failed, with record low summer rain in some areas. In February 1983, dust-storms and devastating fires swept the southeastern States, before heavy rain in late March broke the drought. In all, this drought caused losses in excess of $3b, and first brought into public prominence the link between El Niño and Australian drought.

Ash Wednesday fires, February 1983

The severe drought over eastern Australia in 1982 led to tinder dry conditions throughout the grasslands and forests of southeastern Australia. On 16 February 1983, near-gale force northerly winds, and temperatures well over 40°C drove huge fires (many started by arsonists) across Victoria and southeastern South Australia (Figure 16). Seventy-five people died (47 in Victoria, 28 in South Australia), and nearly 2,500 houses were destroyed. The worst affected areas were Victoria's Dandenong Ranges and the Macedon area, and South Australia's Mt Lofty Ranges, all scenic areas with considerable residential populations. Forests in southeastern South Australia and Victoria's Otway Ranges were incinerated. Most deaths occurred in the hour following the cool change, when strong, gusty westerly winds turned long, narrow corridors of flame into wide fronts. The enquiry that followed led to many changes in fire weather briefing procedures, most notably the provision for regular updates on the progress of wind changes.

Sydney hailstorm, April 1999

NSW and southern Queensland are particularly prone to large hail, normally accompanying severe thunderstorms developing along low pressure troughs. Late on 14 April 1999, a storm moving parallel to, and just off the southern NSW coast, swung north over the eastern suburbs of Sydney. Huge hailstones, some the size of tennis balls (Figure 17), and driven by squally winds, struck the city and eastern suburbs. The onslaught of ice badly damaged or destroyed many cars, partly destroyed many homes, and damaged several commercial aircraft. Many thousands of buildings, mostly homes, suffered serious roof damage.

Insurance losses exceeded $1.7b, replacing the Newcastle earthquake of 1989 as Australia's costliest natural disaster (in terms of insured losses).

A century of progress in science and service

The science and practice of meteorology have made enormous progress through the twentieth century, with very large benefits flowing to all nations, but especially to Australia, from the unique system of international cooperation in the collection and exchange of data and products and through a series of globally coordinated research programs aimed at improved understanding and prediction of weather and climate. The development of Australian meteorology is documented in such publications as Crowder (1995), Webb (1997) and the various annual and research reports of the Bureau and CSIRO. There has been great progress in several areas.

Observing the structure and behaviour of the atmosphere

Australian meteorology in the twentieth century was magnificently served by a tradition of excellence in observational practices and high quality climate records inherited from its pioneers, but these were all simple measurements of quantities such as temperature, wind and rainfall or visual observations of weather, visibility and cloud. After early experiments with balloons and aircraft, a comprehensive upper air (rawinsonde) network for the measurement of temperature, humidity and wind speed up to 25km or more was progressively established from the mid 1940s onwards, and there are now 50 such stations, some automated. At the same time many surface observating stations have been replaced by automatic weather stations to provide information for both day-to-day weather forecasting and the long-term national climate record. These are complemented by many thousands of volunteer observers whose outstanding contribution to Australian meteorology is celebrated in 2001, the United Nations International Year of Volunteers.

Radar and satellite meteorology

Two major developments during the twentieth century greatly enhanced the capability for studying the three-dimensional structure of the atmosphere and monitoring individual weather systems. Weather radars were introduced into Australia during the 1950s and 60s and have revolutionised the detection and tracking of severe weather systems, including the tropical cyclones that threaten the northern coastline. The Australian weather radar network now consists of some 50 stations covering the capital cities and most of the tropical coastline.

The launch of the first weather satellites in the early 1960s and the special arrangements put in place for accessing their data enabled meteorologists for the first time to track reliably the major Southern Ocean synoptic systems which largely determine the weather across the southern States. By the close of the century, international weather satellites were providing continuous hour-by-hour monitoring of weather patterns over the entire Australian region as well as detailed vertical profiles of temperature and wind to complement and integrate the data from the surface-based rawinsonde network.

Numerical weather prediction

Following the establishment of the World Weather Watch in 1964, and the Australian commitment to operating one of the three World Meteorological Centres, Australian meteorologists moved quickly to develop a world class research effort in the then emerging field of numerical weather prediction.

Research carried out in the Australian Numerical Meteorology Research Centre (ANMRC), and subsequently the Bureau of Meteorology Research Centre (BMRC) in close collaboration with overseas research centres, has enabled the Bureau, with the aid of powerful computers first installed in 1968 and progressively upgraded in line with the international state of the art, to operate global, regional and local numerical weather prediction models providing skilful guidance to weather forecasters throughout Australia and its neighbouring countries.

The steady increase in skill since the first introduction of numerical prediction models into the operations of the Bureau in the early 1970s is shown in Figure 18.

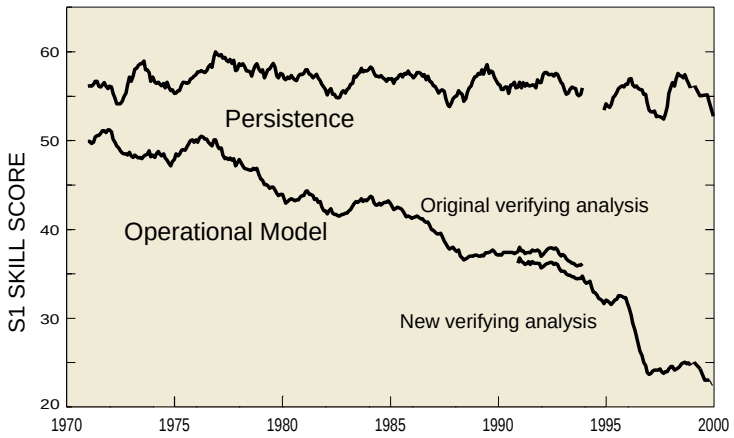

Figure 18. *The S1 skill score (a measure of forecast error) for operational 24-hour prediction of mean sea-level pressure in the Australian region. The increasing skill is evident as an increasing margin over 'persistence', the forecast that would result from assuming that tomorrow's pattern will be the same as today's.*

Modelling of climate

Essentially the same models used for numerical weather prediction have, over the past twenty-five years, been progressively converted into climate simulation models by building in the longer term influence and behaviour of the oceans. Both the Bureau and CSIRO now operate sophisticated atmosphere-ocean general circulation models capable of simulating the behaviour of the global climate system – for use both in predicting the natural (El Niño and related) fluctuations of Australian climate on time-scales of months to years and projecting future patterns of greenhouse-induced climate change over Australia under various greenhouse gas emission scenarios. Although these models have demonstrated significant skill for seasonal to interannual prediction, there is, so far, little confidence in their ability to provide reliable guidance on greenhouse time-scales beyond indicating a general warming trend over the continent during the twenty-first century, with more warming in the interior than near the coast.

Service to the community

Meteorology is one of the most scientifically challenging but also most practically useful fields of science there is. The observing, data collection and modelling work of the Bureau provides the basis for a wide range of services to the Australian community at large and to most major economic sectors including agriculture, transport, energy and the information industries.

Although limited in scope and accuracy in the early part of the century, the Bureau's forecasts have steadily increased in lead time, skill and utility and now provide the basis for many millions of important weather and climate sensitive decisions every day. Economic valuation studies suggest that the overall benefit to the Australian community from the services of the Bureau at the close of the twentieth century exceed their cost by at least an order of magnitude. The continuing progress in national and international meteorological science and technology suggests the opportunity for even greater benefits in terms of safety of life, environmental protection and enhanced social and economic wellbeing through the twenty-first century (Zillman 1999).

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Australian meteorological milestones of the 20th century

1906 First Meteorology Act establishing the Commonwealth Bureau of Meteorology as the authority responsible for providing meteorological services.

1907 Mr H.A. Hunt appointed Commonwealth Meteorologist.

1908 The new Commonwealth Bureau of Meteorology commences operations.

1911 Mr George Ainsworth, a member of Mawson's expedition to Macquarie Island, becomes the first Bureau staff member to tour Antarctica.

1931 Mr W.S. Watt appointed Commonwealth Meteorologist.

First meteorological aircraft flights to obtain temperature and humidity profiles over Melbourne.

1934 First synoptic studies of upper air characteristics over southeast Australia.

1937 H.E. Wimperis' report, 'Inauguration of Aeronautical Research in Australia' resulted in the establishment of the Aviation Meteorological Service.

Establishment of the Bureau's Central Training School.

1940 Mr H.N. Warren appointed Commonwealth Meteorologist.

1941 The Bureau is placed under the Department of Air (RAAF).

1942 Commencement of balloon-borne radiosonde flights for upper air measurement.

1943 Radar first used for upper wind measurement at Williamtown.

1945 Post War reorganisation leading to the establishment of divisional offices in each State with responsibility for forecasting.

1950 Australia becomes one of the first members of WMO.

Mr E.W. Timke appointed Commonwealth Meteorologist.

1954 Commencement of continuous meteorological observations on the Antarctic continent at Mawson.

Commencement of facsimile transmission of weather charts.

1955 Second Meteorology Act in which the functions of the Bureau and the powers of the Director were defined.

The title Commonwealth Meteorologist changed to Director of Meteorology.

Mr L.J. Dwyer appointed Director of Meteorology.

1956 First TV weather segment – Channel 9 Sydney.

Fire weather organisation commenced.

1957 Establishment of the Hydrometeorological Section to provide river height information and flood forecasts for river sysytems in eastern Australia.

1958 Bureau reorganisation establishing three Divisions within Head Office – Research, Services and Management.

1959 Establishment of the International Antarctic Analysis Centre (IAAC) in collaboration with the Australian Academy of Science.

1962 First Automatic Weather Station installed at Ashmore Island off the northwest coast of WA.

Dr W.J. Gibbs appointed Director of Meteorology.

1964 Reception of the first TIROS satellite photo.

1965 IAAC ceases operational analysis function and reconstituted as IAMRC (International Antarctic Meteorological Research Centre).

1966 World Meteorological Centre, Melbourne, commences operations through SHAC (Southern Hemisphere Analysis Centre) assuming operational function of former IAAC.

1968 Commissioning of the Bureau's IBM computers.

1969 Issue of the first operational numerical analysis.

IAMRC closed and CMRC (Commonwealth Meteorology Research Centre) established as a joint venture between the Bureau and CSIRO.

1970 First operational numerical prognosis issued – 500 mb.

1971 First Regional Forecasting Centre commences operation in Hobart.

1972 First issue of a numerical analysis and prognosis for the southern hemisphere.

1974 CMRC renamed ANMRC (Australian Numerical Meteorology Research Centre).

Head Office moves from 2 Drummond Street to 150 Lonsdale Street.

1978 Dr J.W. Zillman appointed Director of Meteorology.

Operational reception of satellite photos from the Japanese Geostationary Satellite GMS 1 commences.

Australia commenced launchings of 47 ocean buoys as part contribution to the Global Weather Experiment.

1979 First reconnaissance flight into a tropical cyclone (Kerry) in the Australian region.

Introduction of computerised communications systems (CMSS).

1980 First AROS minicomputer installed as prototype for trials in the Victorian Regional Office.

1981 Opening of Bureau's field training annex at Broadmeadows.

1982 Bureau hosts the eighth session of WMO Commission for Atmospheric Sciences and eighth session of Regional Association V.

1983 Bureau of Meteorology Research Centre established.

1990 Bureau transferred to the Environment Portfolio.

1995 Dr J.W. Zillman elected president of the WM0

1996 Review of the Operation of the Bureau of Meteorology.

1997 Establishment of joint Bureau-CSIRO High Performance Computing and Communications Centre (HPCCC)

2000 Bureau support for the Sydney Olympic Games.