

Attachment 3 – Ausgrid’s pass through application
Bureau of Meteorology: A history of stormy weather
August 2015



Stormy **WEATHER**

A century of storms, fire, flood and drought in New South Wales



Australian Government
Bureau of Meteorology



The Australian Bureau of Meteorology celebrated its centenary as a Commonwealth Government Agency in 2008. It was established by the *Meteorology Act 1906* and commenced operation as a national organisation on 1 January 1908 through the consolidation of the separate Colonial/State Meteorological Services.

The Bureau is an integrated scientific monitoring, research and service organisation responsible for observing, understanding and predicting the behaviour of Australia's weather and climate and for providing a wide range of meteorological, hydrological and oceanographic information, forecasting and warning services.

The century-long history of the Bureau and of Australian meteorology is the history of the nation – from the Federation Drought to the great floods of 1955, the Black Friday and Ash Wednesday bushfires, the 1974 devastation of Darwin by cyclone *Tracy* and Australia's costliest natural disaster, the Sydney hailstorm of April 1999. It is a story of round-the-clock data collection by tens of thousands of dedicated volunteers in far-flung observing sites, of the acclaimed weather support of the RAAF Meteorological Service for southwest Pacific operations through World War II and of the vital role of the post-war civilian Bureau in the remarkable safety record of Australian civil aviation. And it is a story of outstanding scientific and technological innovation and international leadership in one of the most inherently international of all fields of science and human endeavour.

Although headquartered in Melbourne, the Bureau has epitomised the successful working of the Commonwealth with a strong operational presence in every State capital and a strong sense of identity with both its State and its national functions and responsibilities. The Bureau has played an especially active role in support of agriculture, the environment, water resource management and natural disaster mitigation.

Stormy weather

A century of storms, fire, flood and drought in New South Wales

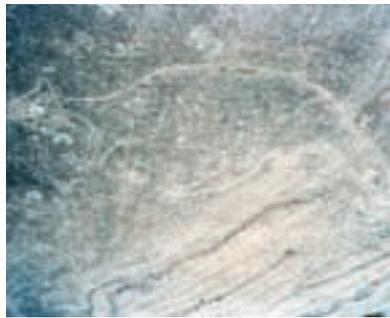
Aboriginal storytellers had passed weather lore down some 1600 generations before the First Fleet came to Sydney Cove on 26 January 1788.

The European newcomers applied their science and technology to measure and analyse the weather and climate on a continent where seasons were reversed and the dramatic variability of the climate was far beyond their experience.

We have a few general weather observations from the first day of European settlement. For instance, First Lt William Bradley of the *Sirius* noted 'at day light, Fine weather with a moderate breeze at SE'. But not until Lt William Dawes built his small observatory where a south pylon of the Sydney Harbour Bridge now stands did we have detailed observations. His records from 14 September 1788 to 6 December 1791 launched the collection of weather and climate data critical to helping the newcomers survive, and eventually thrive, in what they finally accepted as a notoriously variable climate.

Decades later records revealed that the most diverse environments and climates on the continent, from tropical to temperate, from arid to alpine, are found in New South Wales.

From the Bureau's birth in 1908 as the national successor to State weather services, meteorologists



Speared kangaroo: Aboriginal rock carving, Sydney

laboured for decades with modest resources to improve scientific understanding of the atmosphere, and to monitor it adequately. Their prospects of success increased immeasurably from the 1960s with ever-more-productive weather computers, weather satellites and radars, and more recently the creation of the New South Wales network of more than 100 automatic weather stations.

In this welter of automation, it's heartening to find that non-urgent rainfall and storm information still finds its way to the Bureau on handwritten forms – and is, ironically, perhaps more valuable than ever to scientists monitoring climate change. All of us indirectly profit from the tireless efforts of around 1500 rainfall and 1500 storm

spotter volunteers in New South Wales.

This booklet commemorates the Bureau's century of service to the community and also highlights significant New South Wales weather and climate events. Here are snapshots of particularly damaging Southerly Busters, East Coast Lows and tropical cyclones; the creeping catastrophe of drought; the brief violence of a tornado; massive fires; the Hunter floods of 1955, which resulted in the Bureau being given flood forecasting responsibilities; and the devastating Sydney hailstorm of 1999.

We should look back to remind us why, and how, we must prepare communities for weather extremes like flooding, fire and storm; we must also look forward to prepare for even greater extremes projected under climate change. This may prove to be as big an adaptation challenge to our community as that faced by Governor Phillip confronting, in the words of an old English ballad, 'the world turned upside down'.

Barry Hanstrum
*Regional Director for
New South Wales
Australian Bureau of Meteorology*

Before the Bureau



Lt William Dawes

Lt William Dawes of the Royal Marines earned a place in Australia's scientific pantheon with his astronomical measurements and observations of the wind, weather, temperature and barometric pressure five or six times daily from 1788 to 1791, when he returned to England.

For the next 70 years, weather observations were fragmentary, and of little value to today's climatologists. Some records were kept at Government House but unfortunately most of these have been lost or destroyed. Measurements were mostly taken by interested individuals at different sites for only a few years, and come largely from private journals and expedition reports. Some valuable contributors were:

Sir Thomas Brisbane, Governor between 1821 and 1825, set up a private observatory in Parramatta where regular observations were taken for some years.

Reverend William Braithwaite Clarke, another keen amateur who was primarily a geologist, left numerous weather records, articles and theories about weather phenomena.

George Peacock, a Yorkshire solicitor transported to Australia in 1837 for forgery, was trained as a weather observer at the Parramatta Observatory. At South Head he compiled New South Wales' longest early record, from 1840 to about 1855. While climatologists regard his measurement of 20.41 inches of rain (518 mm) on 16 October 1844 as the highest recorded 24-hour total in the

Sydney metropolitan area, his community fame rests primarily with his sought-after romantic paintings of the harbour, its important homes and prominent buildings—a valuable record of early Sydney.

William Jevons, an English polymath, who took readings near Sydney from 1855 to 1858, published the first thorough study of Australian climate in 1859.

Sydney Observatory

The building of the Astronomical Observatory in 1858 on a slight headland overlooking Miller's Point— with Sydney Harbour (Port Jackson) to the north, Darling Harbour to the west and southwest, and Circular Quay (Sydney Cove) to the east—brought the first full-scale official meteorological observations at the beginning of 1859, under the direction of the newly appointed Astronomer for New South Wales, Reverend William Scott. The only other station within the region to submit reports, Parramatta, was soon joined by Windsor, Liverpool and Botany. The observations made daily at 9 am, 3 pm, and 9 pm were fairly comprehensive, even at this early stage: pressure, wind, cloudiness, dry and wet-bulb temperatures, maximum and minimum temperatures both in the shade and in the sun, humidity, vapour pressure and rainfall. At Observatory Hill, ground minimum temperatures, evaporation and ozone measurements were also made and later, soil temperature and adjacent harbour water



Sydney Observatory staff by instrument enclosure, 1887. Henry Hunt, chosen as the first Director of Meteorology in 1907, is third from left.



temperature readings were added. (The latter four elements are no longer measured there.) Instruments were first kept in a Glaisher stand (similar to that used at Greenwich, UK) on the south side of the Observatory. George Smalley, who succeeded Reverend Scott as Government Astronomer after 1862, designed a replacement shed 3.4 m square, with latticed sides and a louvred conical roof rising to 4 m. From 1910, the Stevenson screen became the national standard for instrument screens in the Bureau

of Meteorology's drive towards standardisation and consistent weather data. Henry Chamberlain Russell followed Smalley as Government Astronomer from August 1870 and systematically expanded the service and the reporting network until November 1903. In 1877 he began publication of a daily weather map in the *Sydney Morning Herald*. It showed observations from 77 locations in New South Wales, Victoria, Queensland, along the overland telegraph route from Adelaide to Darwin, and New Zealand.

Birth of the Bureau

In 1903, Henry Hunt was appointed New South Wales State Meteorologist; in 1907 he was chosen as the first Commonwealth Meteorologist, based at the Bureau's Melbourne headquarters. Observations continued in the Observatory grounds for a while but as the instrument shed fell into disrepair, from about 1910 a duplicate set of instruments was set up nearby in a large Stevenson Screen. In 1917 this screen was moved 135 m downhill to where a new Weather Bureau building was to be built. Observations have been taken there ever since.

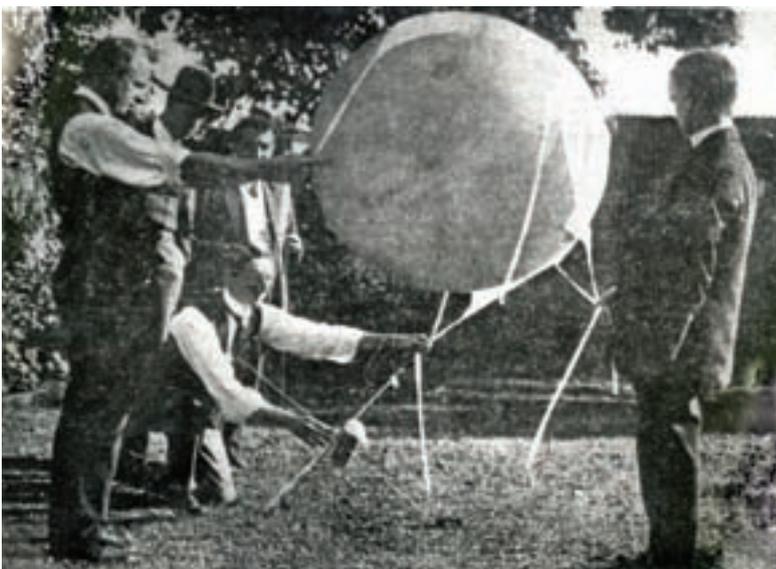
The 1917 change affected readings of various elements, especially temperature. Since then the surrounding area has altered markedly. The Weather Bureau building was built nearby in 1922 and the new Fort Street Primary School was built in 1946

immediately opposite the Bureau. Many nearby houses were demolished in 1932 to make way for the Harbour Bridge approaches, both elevated and open cut, which now surround the old Bureau building and instrument enclosure. The mushrooming of high-rise office blocks to the east and south also significantly changed the exposure of the site. Forecasters left Observatory Hill in 1963 to work from the central city. While the many 'discontinuities' meant the Observatory site just 500 m from Lt William Dawes' 18th century observatory site has no value as a high-quality long-term climate station, the automatic weather station installed in 1990 (eventually replacing human observations) provides real-time weather observations for the forecasters.

Under Hunt's leadership, New South Wales shared in the Bureau's slow growth in its first three decades. Richmond Field Office opened in 1928. Several aviation disasters in the 1930s persuaded the government to greatly expand the Bureau's aviation services and infrastructure. Canberra and Lord Howe field offices opened in 1939.

WWII saw the Bureau 'put into uniform' as the RAAF Meteorological Service. The Wagga Wagga office opened in 1941, continuing observations taken at the airport since 1924. Routine surface observation at Williamstown began in 1942. Coffs Harbour started as a USAF Observer Meteorological Office in 1942 and was taken over by the RAAF in 1943. During WWII the RNZAF took upper air observations at

Experiment to measure temperature at high altitudes, Sydney, 1915. Photograph courtesy of the *Sydney Morning Herald*.





WWII Royal Navy radar turned weather radar, Lord Howe Island field office, 1958.



Lowering an automatic weather station on to the Homebush site, 2000 Sydney Olympics.

Norfolk Island. Upper air observations using weather balloons began at Williamtown in 1950.

New South Wales' first Weather Watch and Wind-finding radars (from a batch of 17 recycled WWII Royal Navy gunlaying radars) were installed at Williamtown (1953) and Lord Howe Island (1954). New South Wales now has Weather Watch radars at Canberra, Sydney and Newcastle, and a Doppler radar at Kurnell. There is also part-time coverage from Norfolk Island, Wagga Wagga and Moree.

Just as weather services were transformed from the 1960s by the maturing of weather computing, radars and weather satellite imagery, the great community appeal of the Bureau's website from 1996 revolutionised delivery of forecasts, warnings

and general meteorological information. The Bureau's intense forecasting support for the 2000 Sydney Olympics refined short-term severe weather warnings.

Although weather forecasts for aviation generally come from Regional Forecasting Centres in the State capitals, the Bureau created the Sydney Airport Meteorological Unit in 1994 to support operations at Australia's busiest airport. In 2008 the Bureau established a meteorological unit within the Airservices Australia national operations centre in Canberra, which coordinates Australian air traffic.

Complementing the current 130 Bureau staff in New South Wales are 105 cooperative observers, 1426 volunteer rainfall observers and 1500 volunteer storm spotters.

The climate of New South Wales

The considerable climatic variation across New South Wales ranges from the hot, dry, continental conditions in the west, to the subtropical, wet conditions in the northeast, to the alpine cold of the southeast.

The warmest town is Tibooburra, with a mean annual temperature of 20.6°C. The coldest place is Charlotte Pass, the highest village in Australia, with a mean annual temperature of 4.5°C. The State record temperature extremes range from a high of 50°C at Wilcannia on 10 January 1939 to a low of -23°C at Charlotte Pass on 29 June 1994. The Wilcannia record was set during the longest-running heatwave for the State in January 1939. Places such as Bourke, Walgett and Dubbo experienced higher than 40°C for at least 10 days in a row.

The average annual rainfall is also highly variable with more than five times as much rain falling along the coast as in the west. Byron Bay, the most easterly part of Australia, has an annual average rainfall of just over 1716 mm. On the western border, the average annual rainfall is only about 200 mm. The

highest daily total on record is 809.2 mm at Dorrigo on 21 February 1954. The highest monthly total was 1620.6 mm at Upper Crystal Creek (Mid North Coast) in January 1974.

The Great Dividing Range runs approximately north to south in the east, parallel to the coast. Its large impact on the State's climate – particularly distribution of rainfall – results in four distinct climate zones:

The Coast

The coastal strip has a generally mild climate, ranging from subtropical near the Queensland border, with a warm humid summer and mild winter, to the cool temperate climate of the south, with a warm summer and cold winter. The climate of the coastal strip is strongly influenced by the warm waters of the Tasman Sea and the East Australian Current, which in general keep the region free from extremes of temperature and provide moisture to increase rainfall. Average annual rainfall varies from more than 2000 mm in the north to 800 mm in the south. East Coast Lows typically associated with heavy, often flooding, rain and damaging winds are also a feature of the climate of the coastal strip.

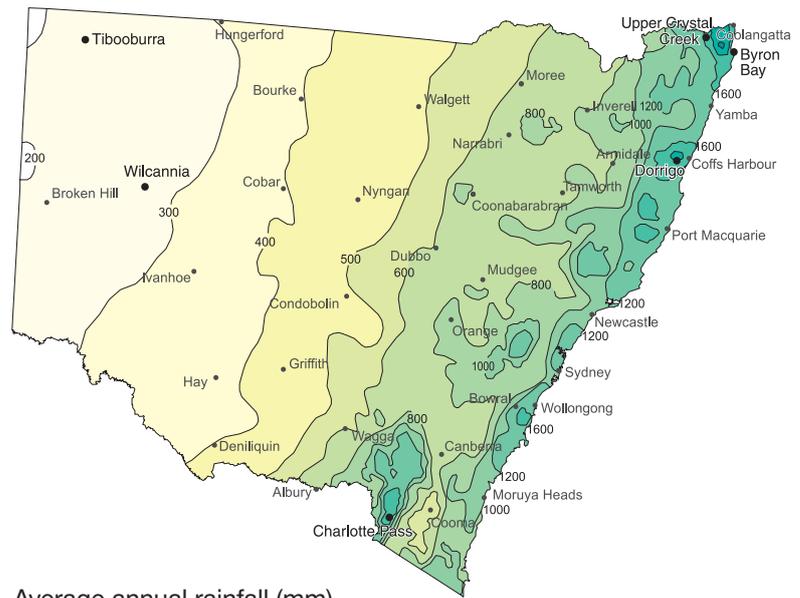
The Ranges and Tablelands of the Great Dividing Range

Much of this area is above 1000 m in elevation. The highest peak of the Great Dividing Range is Mt Kosciuszko

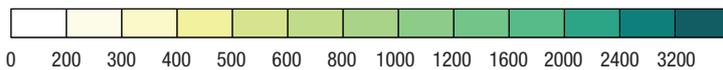
Lightning over the Sydney Harbour Bridge, 1996.
Photograph courtesy of Sister Veronica Rahill.



(2228 m) in the south and there are several peaks above 1500 m. The climate ranges from temperate in the north, with a warm summer and cool winter, to cool temperate in the south, with a mild to warm summer and cold winter. Areas above 1200 m, particularly in the south, have an Alpine climate. Snowfalls occur regularly on the Southern Alps mainly in winter and occasionally a cold outbreak causes snowfalls to spread further north to the elevated regions of the Central and Northern Tablelands. Annual rainfall averages from more than 1000 mm in the north and in alpine areas in the south, to less than 800 mm in areas of the Southern Tablelands. Rainfall is generally greater to the east of "The Divide" where the abrupt rise of the Ranges from the coastal plain enhances rainfall through orographic lift of moist easterly winds.

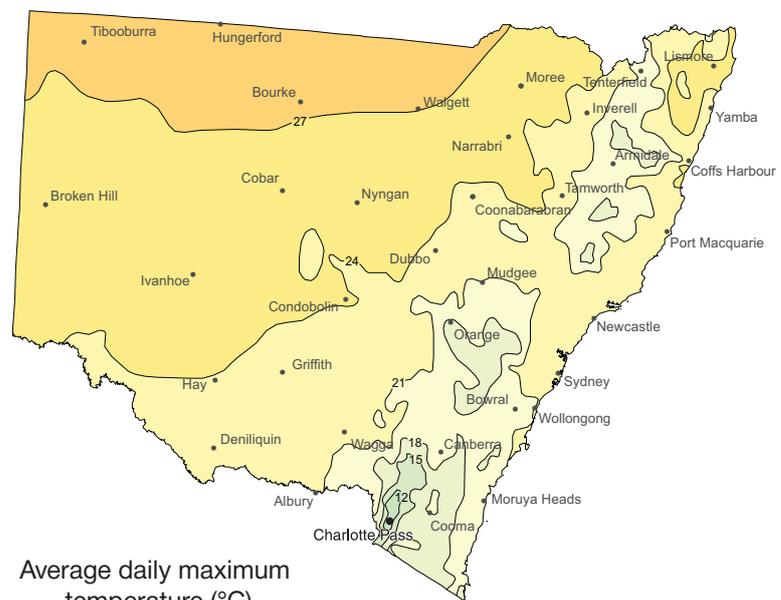


Average annual rainfall (mm)

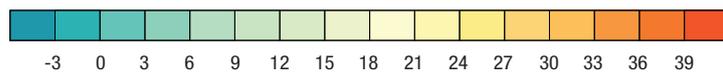


The Western Slopes and Plains

West of "The Divide," the Ranges and Tablelands gradually descend into the Western Slopes and Plains. With this gradual descent, and consequently less pronounced orographic lift effect on generally drier westerlies, average annual rainfall also drops gradually away from around 800 mm to around 500 mm on the Plains. In warmer months a heat-related inland trough can generate significant thunderstorm activity, particularly in the north. The climate of the Western Slopes and Plains is generally hot and dry with a cooler winter. Average maximum temperatures gradually increase as height above sea level decreases and summer can be very hot. In winter, mild, dry, sunny days are the norm, but winter nights can be very cold.



Average daily maximum temperature (°C)



The Arid Plains

Continuing west into the central and far northwest regions of the State, the climate becomes hotter and semi-arid to arid, with average annual rainfall dropping below 500 mm and reaching as low as 200 mm in the far west and northwest. Though winter days are often mild, winter nights can be very cold.

New South Wales has a northeast to southwest variation in the seasonality of rainfall. Summers in the northeast are wet, due to moist onshore easterly trade winds and frequent intrusions of tropical air from the north. However rainfall is lower in winter when this region lies beneath the subtropical ridge. In contrast, southwest winters are showery under the influence of prevailing westerlies while summer rainfall is low. In southeast and central New South Wales, where these two regimes overlap, rainfall is spread more uniformly through the year. The northwest is arid with low average rainfall in all seasons.

Wind speed and direction varies from day to night, from season to season and from place to place. The most marked daily and seasonal variations occur on the coast and adjacent tablelands. In summer, the sea breeze brings considerable relief to coastal areas as a 'cool change' during the afternoon. In winter, the westerly land breeze is prominent between the tablelands and the coast, especially when reinforced by seasonal southwest to west winds over the south of the State. While

these seasonal winds cause cold, showery weather on the western slopes and parts of the tablelands, they reach the coast as dry and rather cool westerlies, associated with clear skies and sunshine. Over the State, seasonal winds are predominantly southeast to northeast in the summer when the subtropical ridge lies to the south of the State, and southwest to northwest in the winter when its average position is across the north of the State.

The highest incidence of strong wind gusts occurs on the Snowy Mountains and coastal New South Wales. The maximum recorded wind gust on the New South Wales mainland was 174 km/h at Richmond during a thunderstorm on 3 December 2001. At Lord Howe Island a tropical cyclone brought a 178 km/h gust on 30 January 1948. Coastal NSW can experience gale to storm-force winds from East Coast Lows, and also powerful wind gusts when strong southerly changes known as Southerly Busters make their way up the coast.

Lord Howe and Norfolk Islands are both within the New South Wales Bureau's area

Storm front approaching Sydney Harbour and the Opera House, New South Wales. Photograph courtesy of *Randy Brophy*.



of responsibility. Their subtropical climate is tempered by the surrounding sea, with small daily and annual temperature ranges, particularly compared with the continental climate of the mainland. Median annual rainfalls are 1587 mm and 1293 mm respectively.

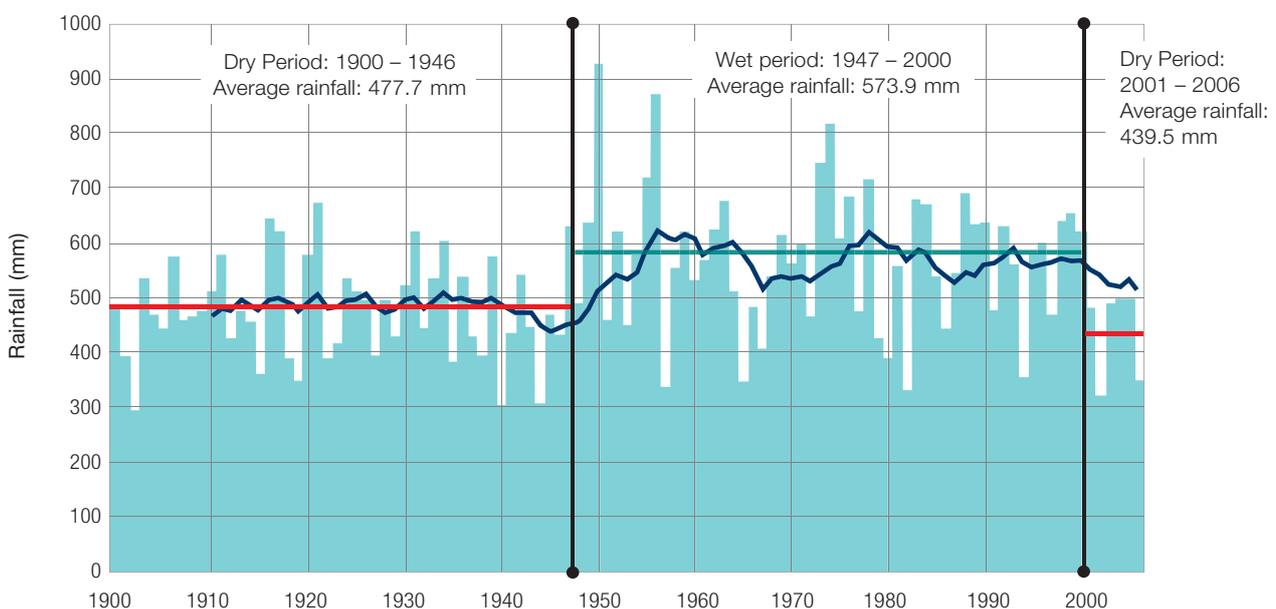
As well as the geographical variability described above, another significant feature of the climate of New South Wales, along with much of Australia, is its high interannual and interdecadal variability. This variability is caused by the interplay of continual changes in the oceans and atmosphere around Australia and Antarctica and the associated broad scale climate influences and circulations. The most well known of these is the El Niño/La Niña cycle in the Pacific Ocean which alternatively can bring (or exacerbate) drought and wet conditions across inland New South Wales, in particular. On the decadal time scale this naturally occurring variability has resulted in extended periods of cooler, flood-dominated and warmer, drought-dominated conditions over the past 100 years. The high rainfall of the 1950s and 1970s contrasts with the low rainfall of the 1940s and the most recent extended drought, 2001 to 2008 (see graph below).

A changing climate

Climate change and its effects have become a critical issue for governments worldwide. The plants and animals of our planet, including humans, are dependent on the specific climates to which they have adapted. According to the United Nations' Intergovernmental Panel on Climate Change (IPCC) 'most of the warming observed over the last 50 years is attributable to human activities.' Anthropogenic, or human-induced climate change is rapidly altering climate regimes around the globe. The transition to these new climate states has the potential to devastate ecosystems and the human populations that depend on them. The economic and human health ramifications of anthropogenic climate change have become a focus of much research and global discussion.

Over the 100 years of the existence of the Bureau of Meteorology, average temperatures have steadily increased. According to the IPCC, hot days, hot nights and heatwaves have become more frequent around the globe. Additionally, 'eleven of the twelve years in the period 1995-2006 rank among the top 12 warmest years for the planet in the instrumental record since 1850'.

New South Wales annual average rainfall 1900 - 2006.



The Bureau's climate data record for Australia, built up over 100 years, is a resource tool for monitoring how the Australian and New South Wales climate is changing. These data show that average Australian temperatures have increased by nearly 1°C with more heatwaves and fewer frosts. New South Wales itself became nearly 1°C warmer between 1950 and 2008, with more hot days and nights and fewer cold days and nights across much of the State. The five warmest years on record for New South Wales were, from the hottest, 2007, 2005, 2006, 2002, 1980 and 1973. Most recently, the State recorded its fifth consecutive summer (2006 – 2007) with above-average maximum temperatures.

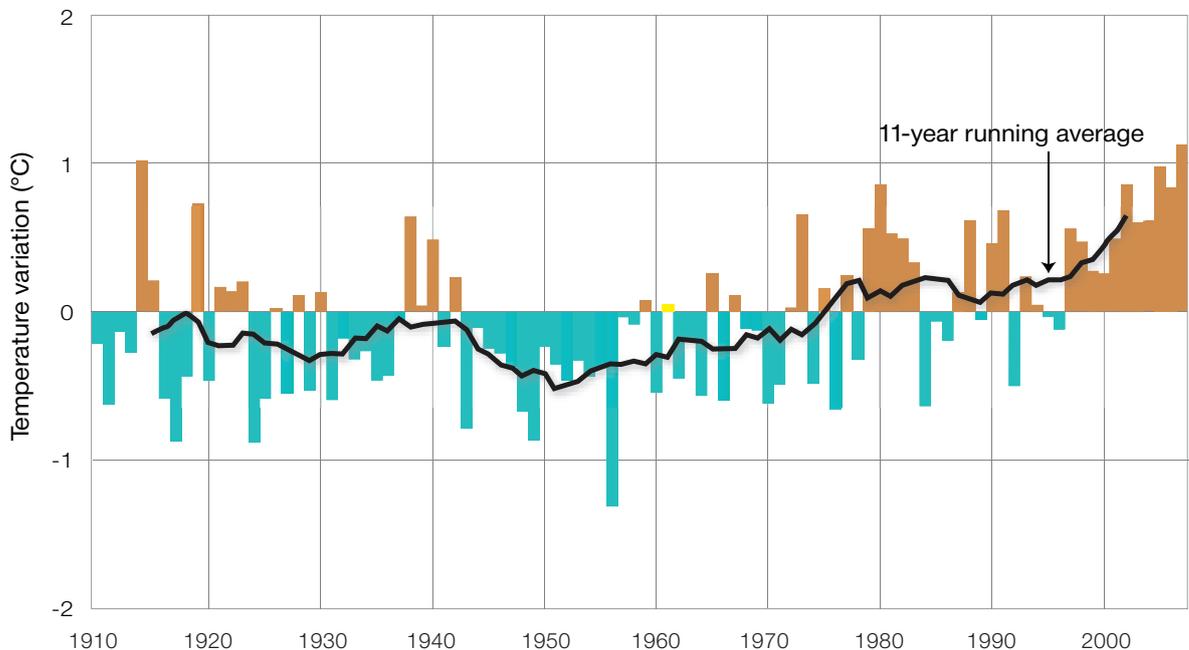
The effects of global warming on New South Wales climate are, however, complicated by its strong natural climate variability. This is particularly the case with rainfall,

where it is not yet clear whether recent dry conditions, particularly in the south of the State, are a result of anthropogenic climate change or an expression of the natural interdecadal variability.

The Bureau will continue to play an important role in monitoring and analysing the climate, through its daily observations network, State climate services centres and the National Climate Centre. Maintaining comprehensive records of daily temperature, rainfall, humidity, wind and other variables through a national climate data bank enables Bureau scientists, and those from other organisations and agencies, to not only study past climate, but to monitor current conditions and project future trends. The monitoring services benefit the Australian economy, particularly in the agricultural sectors, through routine climate analysis and seasonal outlooks.

A WARMING TREND: 1910 – 2007

Variations from New South Wales average temperatures (base 1961 – 90)



Precious legacy - our reference climate stations

While the Sydney Observatory climate record has been compromised by the many changes in the surrounding buildings, topography, and the heat island effect over 150 years, the Bureau has put intense effort into identifying reference climate stations nationwide that provide high quality data for research.

Of the 100 reference climate stations, 24 are in New South Wales and include Yamba Pilot Station, near Clarence Heads, the longest serving manually operated weather station in New South Wales with minimal changes to the site. Francis Freeburn recorded the first observations on 22 May 1877— clear skies and smooth seas with a maximum temperature of 75°F (24°C) and light westerly winds.

To qualify as a reference climate station, a station needs more than 30 years of homogeneous records, where human-influenced environmental changes have been and/or are expected to remain at a minimum. Yamba's site has changed little, although the instruments and communication technology have evolved. Francis Freeburn estimated the wind speed, and read the pressure from a mercury-in-glass barometer; today we have electronic wind and pressure sensors.

Francis and his successors reported observations to the Bureau by telegram; then came telex (1979), an

electronic terminal (1985) and a laptop computer (1996). The ideal site (which probably does not exist anywhere in the world) would offer:

- long period of records with a healthy history;
- few changes in exposure and measurement techniques;
- instrument sites which have not been moved;
- a small turnover of enthusiastic and diligent observers;
- location away from urban influences; and
- few changes to the local environment, including trees and buildings.

Dave Smith (left), weather observer at Yamba Pilot Station for over 26 years, and pilot Alan Jones mark the 126th birthday of the weather station in 2003. (Photograph courtesy of *The Daily Examiner*).



Recording and recalling our significant weather

From sport to science, Australians watch keenly to see records broken

'I was there' makes for powerful meteorological memories: many of us pass on tales of 'the day when the floods cut off our property...the dust storm blanketed the city... the giant hailstones hit... the cyclone ruined our holiday... the bushfires burned a huge area and sent smoke half way to New Zealand.' For those on the land, it is often the lingering assault of a particularly infamous drought.

Significant weather events may cost lives, buffet the economy, change insurance procedures, or in contemporary language, trigger the revision of risk management strategies. For instance, the Queen's Birth-

day storm of 2007 saw parts of New South Wales declared a natural disaster area with widespread wind and flood damage, and almost 20,000 calls to the State Emergency Service.

Communities affected by such natural disasters often wonder what makes a certain event 'significant'. Did they endure one of the most intense events of its type? Have frequencies increased, are trends changing?

Add to such familiar ponderings the projected greater extremes under climate change scenarios, and our tendency to make lists and rankings becomes even more compelling.

Sydney storm, 2008.
Photograph courtesy of
the *Daily Telegraph*.



Some of the answers are in this snapshot of New South Wales meteorological history since the Bureau of Meteorology was born in 1908. We sought a balance across districts and decades, basing the first half century on our 1958 publication "50 Years of Weather – New South Wales 1908-57". The subsequent revolutions in weather observing technology and communications, and population growth, naturally provide much more detail for recent decades.

If you find some long ago weather tale of your family is 'lost', check our references. We have a comprehensive data-bank of New South Wales weather, much of it online. You're invited to further explore the climate of the State via the internet (www.bom.gov.au) and our publications.

Life's certainties include death, taxes and wild weather; that's why the Bureau was created as a scientific shield to help protect Australians and their property from meteorological impacts.



The 76,000 tonne coal carrier *Pasha Bulker* grounded on Nobbys Beach at Newcastle during an East Coast Low on 8 June 2007. Photograph courtesy of Peter Stoop of the *Newcastle Herald*.

Features of New South Wales Weather

Severe thunderstorms

Each year on average, several people die and damage worth more than \$100 million is caused as a result of more than 100 severe storms across New South Wales and the Australian Capital Territory.

Severe thunderstorms are defined as those producing:

- hail 2 cm or larger in diameter
- wind gusts of 90 km/h or stronger
- a tornado; or
- intense rainfall resulting in flash flooding.

For the catastrophic severe thunderstorms listed below, these criteria are far exceeded with maximum hail sizes commonly reaching 7 cm, measured wind gusts up to 153 km/h, numerous tornadoes and sometimes

deaths. Severe thunderstorms can occur in any month but are much more frequent from late spring through to mid-summer. More than 70 per cent of the following storms occurred during this peak period, with nearly one-third in January alone.

Many of the events described here are from Sydney primarily because it is a large and densely-populated area with long and detailed records. It is fair to say that many other areas of New South Wales, particularly about the coast and ranges north of Sydney, are equally if not more at risk from these destructive phenomena. Any damage estimates listed were made at the time of the storm. In many cases the cost of earlier events would easily exceed \$25-50 million in current values.

Hailstones from the Sydney hail storm of 14 April 1999, compared with a seven centimetre diameter cricket ball.



- 1914 On 25 November 1914, a severe thunderstorm, possibly accompanied by a tornado, struck Sydney's northern and harbour-side suburbs. The storm tore through a row of shops opposite Lindfield railway station before moving over Middle Head to Watsons Bay where winds lifted a 16' (5 metre) skiff 50' (15 metres) into the air.
- 1919 In Sydney city an exceptionally heavy fall of hail just after midnight on 25 October 1919 caused great damage to buildings when the hail blocked gutters and drains allowing heavy rainfall to overflow into ceilings and basements.
- 1931 On the morning of 6 July 1931, a heavy hailstorm caused £200,000 (\$400,000) worth of damage in Sydney city and suburbs. The Manly ferry service was temporarily suspended, following the onset of southerly gales.
- 1937 One of the more disastrous storms in Sydney's history occurred on the afternoon of 25 January 1937 when a tornadic thunderstorm tore through suburbs including Marrickville, Mascot, Botany and Matraville. Five people died and many more were injured as buildings collapsed and heavy rain generated flash floods.
- 1940 On the afternoon of 31 October 1940, a tornado carved a narrow damage path 12 miles (19km) long through thousands of Sydney houses, resulting in two deaths. A well-developed waterspout was seen as the storm moved out to sea. Sydney city recorded a wind gust of 153 km/h as the storm passed overhead.
- 1941 A tornado swept through Orange on 8 June 1941. It was said to be the fiercest storm ever known in the district up to that time.

Lightning strike near Canberra, ACT, on 16 January 2003, two days before the fire storm that destroyed 400 homes and claimed four lives in the nation's capital city. Photograph courtesy of Chris Arndt.



- 1947** On 1 January 1947, a violent thunderstorm pounded Sydney city and the eastern suburbs with hailstones larger than cricket balls (7 cm) causing widespread damage to tiled roofs and cars. Hundreds of people were injured by flying glass and the damage bill reached hundreds of thousands of pounds.
- 1957** A tornadic squall at Warriewood and Narrabeen caused more than £40,000 (\$80,000) worth of damage on 9 July 1957. The tornado moved inland from the sea for about 3 miles (5 km), un-roofing houses.
- 1967** On 28 January 1967, thunderstorms left a trail of damage 100 km long through the New South Wales Riverina towns of Finley and Tocumwal and into Victoria. Severe winds, hail as large as tennis balls and possibly several small and transient tornadoes uprooted trees and damaged buildings.
- 1970** On 1 January 1970, a massive tornado, 'probably more intense than any other documented in Australian literature' at that time, carved a damage path 22 km long and up to 1.6 km wide through the Bulahdelah State Forest. Over one million marketable trees were damaged or destroyed by the tornado and cricket ball-sized hail.
- 1971** On 26 January 1971, torrential rainfall from a thunderstorm over southern Canberra caused severe flash flooding in stormwater channels adjacent to roads in the Woden Valley. Seven people died when their cars were swept into the flood waters. Rainfalls of up to 100 mm in one hour were recorded. Damage was around \$9 m.
- A long-lived complex of thunderstorms brought widespread hail to Sydney on 21 August 1971, with the heaviest falls from Ashfield to Bondi. While the largest hail was generally only up to 2 cm diameter, it accumulated to depths of around 10-15 cm over flat ground and in drifts more than one metre high in some streets.
- 1975** Flash flooding from thunderstorms resulted in \$15 m worth of damage in the Gosford, Sydney and Illawarra regions during 10-11 March 1975. Sydney airport recorded 174.7 mm in the six hours to 3 pm on 10 March, and Mt Kiera in the Illawarra received 591 mm in a 30-hour period.

Violent hailstorm at Rose Bay, Sydney Harbour, New Year's Day 1947. Photograph courtesy of the *Sydney Morning Herald*.





Mounds of hail entrench cars and taxis after a passing storm in Rushcutters Bay, 21 August 1971. Photograph courtesy of Australian Consolidated Press.

- 1976** A series of severe thunderstorms on 10 November 1976 caused considerable damage in western and southern Sydney with tennis-ball size (6 cm) hail and wind damage reported around Lidcombe/Auburn. Damage reached \$40 m, with 10 people injured.
- 1978** Severe thunderstorms struck between Newcastle and Wollongong on 10-11 February 1978, causing extensive damage to buildings and eight injuries. Wind gusts reached 141 km/h at Newcastle and a tornado damaged many homes in the Drummoyne / Hunters Hill area of Sydney. The total damage bill was \$15 m.
- On 1 March 1978, severe thunderstorms on the north coast injured two people, left 15 homeless and caused damage estimated at approximately \$5 m.
- 1984** Late in the evening of 8 November 1984, torrential rainfall from thunderstorms caused flash flooding and \$80 m in damage to homes and vehicles in Sydney city and the eastern suburbs. Observatory Hill in Sydney city recorded its highest-ever hourly rainfall of 120.3 mm between 10 and 11 pm.
- 1986** On 22 January 1986, a severe hailstorm in the Orange district caused extensive damage to homes and vehicles and destroyed much of the apple crop at a cost of \$25 m.
- On 3 October 1986, hail up to 6 cm diameter injured at least 10 people and caused \$104 m damage to hundreds of homes in Sydney's western suburbs, including Hurstville and Rockdale.
- 1990** On the afternoon of Sunday 18 March 1990 a violent thunderstorm with hailstones up to 9cm diameter battered western Sydney suburbs, with Auburn and Bankstown receiving the most serious damage. Three people were reported injured and the damage bill was over \$319 m.
- 1991** A severe thunderstorm accompanied by destructive winds estimated at 230 km/h, 7cm diameter hail and flash flooding caused over \$138 m damage to northern Sydney suburbs on the afternoon of 21 January 1991. The ferocious storm claimed one life and damaged more than 10,000 houses and 50,000 trees.
- 1992** On 12 February 1992, severe thunderstorms left a trail of damage through Sydney's western and north-western suburbs, the central coast and as far north

as Williamstown in the Hunter district. They brought hail up to 7.5 cm diameter, flash flooding, severe winds and possibly a tornado. Damage was estimated at \$118 m.

- 1994 A severe storm caused \$29 m damage in the Sydney metropolitan area on 20 November 1994, with many trees brought down and houses damaged, particularly north of the harbour. Property damage was also reported from inland areas including Narromine and Dubbo where wind gusts reached up to 140 km/h.
- 1995 A tornado in the Merimbula and Pambula areas on 16 April 1995 injured 34 people and damaged or destroyed more than 100 homes along with vehicles and other buildings. Damage estimates exceeded \$25 m.
- 1996 There were widespread reports of severe thunderstorms across New South Wales on 29 September 1996, with large hail, destructive winds and at least three tornadoes. The worst impact was in Armidale where hail up to 8 cm diameter and 156 km/h wind gusts caused \$104 m damage to thousands of homes, public buildings and vehicles.

During the evening of 23 November 1996, a band of near-stationary thunderstorms brought torrential rain to the Coffs Harbour Creek catchment with rainfall up to 400 mm recorded in just 4.5 hours. One person drowned as a flash flood combined with a high tide flooded most businesses in the town centre. The total damage bill reached \$20 m.

On 11 December 1996, Singleton in the Hunter Valley was declared a natural disaster area after a thunderstorm with 7 cm diameter hail damaged roofing on more than 1000 houses and buildings at a cost of \$49 m. Severe thunderstorms were reported from many other areas of the State including Springwood, Bundanoon and Kyogle.

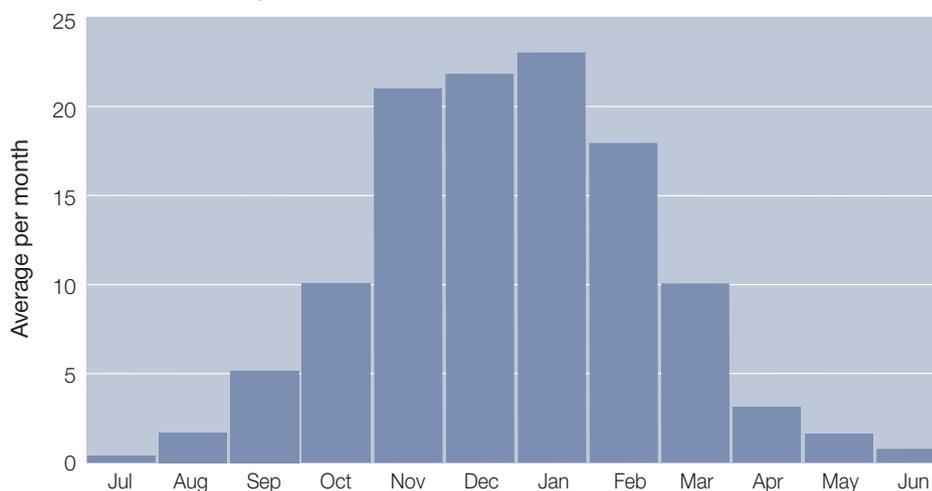
- 1997 Severe thunderstorms were widespread over much of the Central and Northern Tablelands and Sydney metropolitan area with hail up to 5cm diameter, severe winds and flash flooding reported. The damage in Sydney alone reached \$40 m.

The base of a tornadic thunderstorm at Coonabarabran, New South Wales, 20 January 2005. Photograph courtesy of Vivian Evans.



- 1998** A severe thunderstorm with destructive winds and golfball-sized hail struck the western New South Wales town of Nyngan about 3:15 pm on 5 January 1998. Three houses were destroyed, 18 wholly unroofed and many other houses, businesses and public buildings were damaged. The damage estimate was \$12 m.
- 1999** The most damaging Australian thunderstorm to date, with a cost of \$1.7 billion, savaged Sydney's eastern suburbs and parts of the city on the evening of 14 April 1999. Hail of at least 9 cm diameter damaged 22,000 homes and 63,000 cars and injured many people. A man died when struck by lightning.
- 2001** Winds up to 130 km/h, large hailstones and flash flooding caused extensive damage in Dubbo on 6 January 2001. About 400 buildings and 150 motor vehicles were damaged and hundreds of trees uprooted in what locals described as 'the worst storm in living memory'. Dubbo was declared a natural disaster area with a total damage bill exceeding \$25 m.
- On 17 January 2001, hail up to 7cm diameter, high winds and flash flooding devastated Casino in northeast New South Wales, damaging 800 homes and 300 motor vehicles at a cost of \$35m. Severe thunderstorms hit many other towns in northern New South Wales, including Grafton where wind gusts were measured at 135 km/h.
- On 3 December 2001, a thunderstorm at Richmond produced the highest wind gust ever recorded on mainland New South Wales – 174 km/h. Later that afternoon two schoolchildren died when a tree fell on their tent in the northern suburbs.
- 2005** Broken Hill was declared a natural disaster area after a severe thunderstorm caused extensive damage at 9 pm on 6 November 2005. Around 20 houses were unroofed, another 20 partially unroofed and powerlines brought down. Two people were rescued from a car trapped in floodwaters. The damage bill was \$3.8 m.
- A severe thunderstorm with heavy rain and strong winds, and possibly a tornado, caused widespread damage to more than 50 suburbs in Canberra on 2 December 2005. The storm brought down hundreds of trees and power lines, unroofed buildings and resulted in one death. The total damage bill was \$15 m.
- 2006** On 31 December 2006, a severe late afternoon thunderstorm brought exceptionally heavy rainfall, wind damage and deep drifts of hail to Canberra's southern suburbs. Lake Tuggeranong was clogged with debris and livestock in rural areas was lost.

Monthly distribution of severe thunderstorms 1989–2008



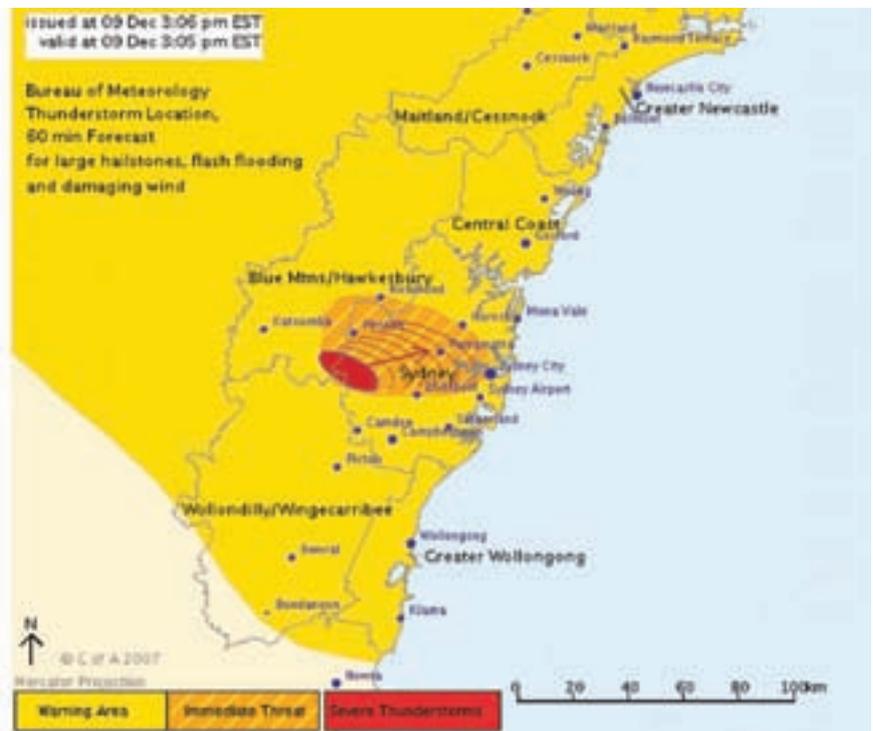
Frequency distribution of reported severe storms in New South Wales. The preference for the late spring–summer period is shared with many other parts of Australia.

2007 On 27 February, the Civic Centre and the Australian National University in Canberra were blanketed in hail at least 20 cm deep. Many vehicles were damaged and more than 1100 homes and buildings were flooded due to blocked drains and gutters. On 10 February, very heavy rain caused flooding and damage to houses in Weston Creek and Kambah.

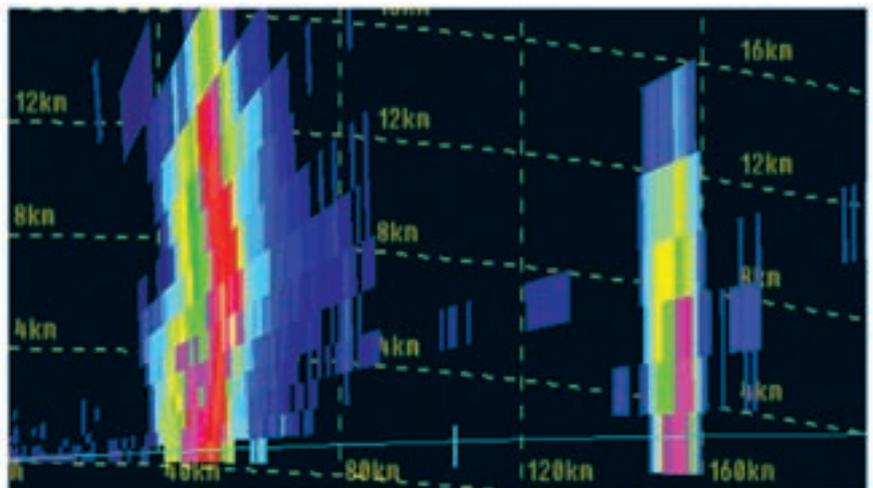
On 8 October 2007, Lismore was declared a natural disaster area after a severe thunderstorm with 7 cm diameter hail and high winds caused \$59 m worth of damage and injured more than 17 people. Another severe hailstorm hit South Lismore the following day and on 26 October a tornado damaged the nearby town of Dunoon.

On 9 December 2007 a severe thunderstorm devastated western and north-western Sydney with hail up to 7 cm diameter. The State Emergency Service received over 6000 calls for assistance and Blacktown, Baulkham Hills, Hornsby and Penrith were declared natural disaster areas. The damage bill reached \$201 m.

Warning graphic showing the forecast path of the thunderstorm that produced giant hail in Blacktown and parts of western Sydney on 9 December 2007. This detailed warning was issued 30 minutes prior to any reports of hail being received.



Radar imagery of the 9 December 2007 hailstorm at its peak when giant hail was being produced. A vertical slice through the storm shows the high reflectivity extended to a height of over 12 kilometres.



Floods

Floods have provided dramatic evidence of Australia's climate variability since records began. In New South Wales, floods are often associated with East Coast Lows, or in some cases, tropical cyclones. Other causes include weather systems (inland troughs) that bring tropical moisture from

the north, cold fronts and thunderstorms. Thunderstorms often generate flash floods with little time between the rainfall and the ensuing flood. Listed below are some of the State's most dramatic floods. Any cost estimates were made at the time of the event.

- 1910s** Northwest New South Wales suffered destructive floods in 1910, with numerous places experiencing their highest river heights on record up until that time. In 1917, the Murray River and its tributaries were at their highest for 28 years.
- 1920s** In the 1920s numerous locations recorded their highest-ever floods up until that date, including Coonamble on the Castlereagh River in 1920, Cooma in 1922, Queanbeyan on the Molonglo River in 1925 and Ungarie on the Lachlan River in 1928. In 1929 flood waters in Taree reached 18 inches (557 mm) above the record set 63 years before.
- 1930s** The most dramatic floods during the 1930s occurred between 1930-34. In 1931 Adelong recorded its 'most serious flood for 50 years' and in 1934 Bombala experienced its 'highest flood on record' up until that time.
- 1940s** Significant floods were recorded in Tamworth in 1941, and in other parts of the northwest and the coast in 1945 and 1946. In 1949, most buildings in central Kempsey were washed away by the largest recorded flood up until that time on the Macleay River. There were six deaths and damage was estimated at \$200 m.
- 1954** In February 1954, torrential rainfall from a category 3 severe tropical cyclone produced disastrous floods in Lismore, Murwillumbah and Casino. Thirty people died. (See also Tropical Cyclone impacts, page 27).
- 1955** The Hunter, Gwydir, Namoi, Macquarie and Castlereagh catchments reported record flood levels in February 1955, and there was major flooding in the Macintyre and Darling. Twenty-five people died and destruction exceeded \$700 m.
- 1956** In 1956, floodwaters from the Darling and Murray rivers peaked simultaneously,



Maitland flooded, 1955.
Photograph courtesy of the
Maitland Mercury.

forcing urgent construction of a levee around Wentworth near the junction of the two mighty rivers. This was the biggest flood on the Murray River since 1870, with some areas flooded up to 100 km from the natural flow of the river.

- 1971** On 26 January 1971, torrential rainfall from a thunderstorm over southern Canberra caused severe flash flooding in stormwater channels in the Woden Valley. Seven people died when their cars were swept into the flood waters. Rainfalls of up to 100mm in one hour were recorded and damage was estimated at around \$9 m.
- 1974** In March 1974, category 2 tropical cyclone Zoe produced major flooding in northern New South Wales where 200 people were evacuated from Murwillumbah and 500 families evacuated from Lismore. Landslides cut the main railway line in four places between Casino and Coffs Harbour. (See also Tropical Cyclone section, see page 28).
- On 24 April 1974, severe flash flooding in Sydney's western suburbs and the Blue Mountains resulted in \$20 m worth of damage and one death following about 200 mm of rain in three days.
- 1984** On 18 February 1984, intense rainfall with totals exceeding 800 mm in 24 hours fell on the escarpment west of Wollongong, causing severe erosion and flash flooding. Six hundred people were evacuated from Dapto as the surging waters overturned cars and damaged houses in Dapto. Remarkably, nobody died.
- 1986** An East Coast Low passing close to Sydney on 6 August 1986 brought the city's highest 24-hour rainfall to date – 327.6 mm. There was serious flash flooding and traffic chaos in western Sydney with the final damage bill exceeding \$35 m. The Georges River reached major flood level and the Hawkesbury River peaked at 11.3 metres at Windsor Bridge.
- 1990** In April 1990 a record flood in Nyngan breached levee banks, causing damage estimated at \$65 m. The population was evacuated by helicopter. Major flooding also occurred along the Castlereagh, Lachlan, Macquarie, Darling, Paroo, Warrego and Namoi Rivers.
- 1996** During the evening of 23 November 1996, a band of near-stationary thunderstorms brought torrential rain to the Coffs Harbour Creek catchment with up to 400 mm rainfall recorded in just 4.5 hours. One person drowned as a flash flood combined with a high tide flooded most businesses in the town centre. Damage reached \$20 m.

Maitland's levee banks hold near the Belmore Bridge, June 2007. Photograph courtesy of the *Maitland Mercury*.



- 1998** On 17 August 1998, flash floods and resultant landslides cut all major roads and train lines into Wollongong. Two people died and damage to suburban homes exceeded \$40 m. Some 24-hour rainfall totals in the area included 445 mm at Mt Ousley, 410 mm at Bulli Pass and 337 mm at Keiraville.
- 2001** In the late summer an East Coast Low brought serious flooding to northeast New South Wales. Floodwaters up to half a metre deep engulfed buildings in Lismore and natural disaster areas were declared in Lismore, Kyogle and Bellingen. In a separate event, Moree was marooned when rainfall up to 300 mm cut roads. Damage exceeded \$100 m and one person was believed to have drowned north of Lismore.
- 2007** The worst flooding in the Hunter Valley since 1971 came during an East Coast Low in June which set many new long-term rainfall records. Nine people died in the Hunter River and Newcastle area. There were nearly 20,000 calls to the State Emergency Service, and more than 4000 people were evacuated from Maitland. Damage exceeded \$1.4 billion. (See also East Coast Low section).

Flood Warnings

The frequency and severity of floods in the 1940s and 1950s inspired the establishment of Flood Warning Networks across Australia. In New South Wales, the Bureau of Meteorology combines with the State Emergency Service to provide timely warnings, reducing the threat to life and property.

New South Wales now has flood warning networks and flood warning methodologies for 33 major river valleys, providing flood forecasts to 163 places, and flash flood forecasts to 12 locations.

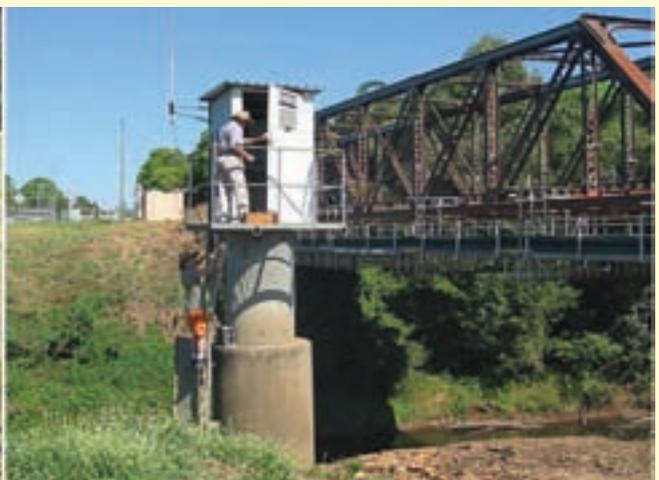
Data come from approximately 830 automated river-gauges and 640 automated rain-gauges. They are transmitted to the Bureau both in real time (radio or mobile phone systems) and on request (telephone telemetry).

The New South Wales Flood Warning Consultative

Committee coordinates cooperative funding by the Federal Government (rain-gauges) and State and local governments (river-gauges). The continuing improvement of the flood warning networks has brought significant improvements in the forecasts of the time of arrival and height of floods. For instance, the percentage of river height forecasts accurate to within 0.3 metres has risen from approximately 40 per cent in the early 1980s to 80 per cent today.



Testing the radio signal from an automatic rain-gauge at Nundle, near the head of the Peel River.



Maintenance on an automatic river height gauge on Wilsons River near Lismore.

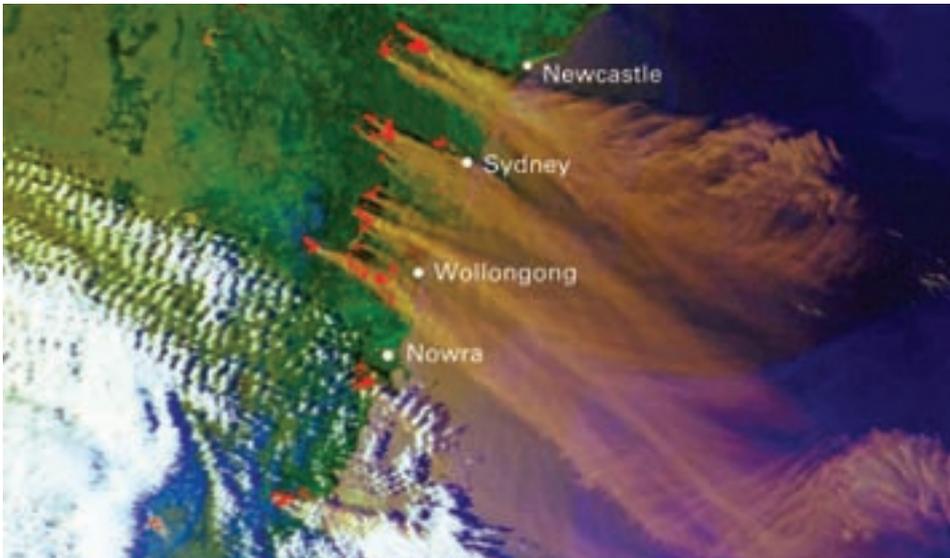
Bushfires

Bushfires have had devastating impacts on New South Wales communities. On average a major fire involving loss of life and property occurs every 10 years or so. Both the grassed western areas and the forests along and east of the Great Dividing Range have endured major fires. The bushfire season typically starts in early spring in northern areas, and spreads to

the remainder of the State by late spring into early summer. The worst fires in the forest areas typically follow droughts, occurring late in the year or early in the New Year when unseasonal westerly winds bring very hot, dry air from the interior. Later in the summer and autumn, the fire risk eases with the coming of cooler, moister easterly winds.

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|----------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1926/27 | Eight people died and more than two million hectares were burnt along the North Coast of New South Wales and in Canberra, Albury, Dubbo and Griffith. |
| 1938/39 | Thirteen people died and many houses and plantations were lost as fires raged through the Blue Mountains, Dubbo and the Snowy Mountains. There were significant fires in the Australian Capital Territory, where a huge fire front swept through Mt Franklin, Uriarra, Tidbinbilla, Cuppacumbalong and Lanyon. |
| 1951/52 | There were 11 reported deaths when around 5000 fires burned out 4.5 million hectares of western New South Wales. In November, 371,000 hectares of cypress pine and timbered land were burned in the Pilliga area, and 266,000 hectares of grass-land burnt in the Dubbo /Forbes district. In January, 330,000 hectares were burned out at Mangoplah near Wagga Wagga. Two people died and 10,000 hectares were burnt in the ACT. |
| 1957/58 | In December 1957 gale-force winds drove fires through Leura and Wentworth Falls in the Blue Mountains, burning more than 200,000 hectares. There were five deaths and around 160 buildings were destroyed. |
| 1968/69 | Some 1.2 million hectares were burned, chiefly between 18-20 November in the North Coast district, and between 28-29 November in the Blue Mountains, where five people died and 150 homes were destroyed in Blaxland, Springwood and Falconbridge. |
| 1974/75 | Bushfires were widespread across Australia, and New South Wales suffered most. In the western districts, three people died at Balranald, and losses included 5 million hectares of grassland, more than 10,000 km of fencing and 50,000 stock. |
| 1984/85 | This was the worst fire season in 10 years for the grassed western areas. Lightning strikes started over 100 fires on Christmas Day alone. The largest single fire was near Cobar in mid-January, with 516,000 hectares burned. The toll from 6000 fires included five deaths, 3.5 million hectares burned, 40,000 stock losses and damage around \$40 m. |
| 1993/94 | From December 1993 through January 1994 more than 800 bushfires burned along the eastern seaboard from the Queensland border to the Hunter Valley, Blue Mountains, Sydney suburbs and as far south as Batemans Bay. In the Sydney suburbs of Janali and West Como, many homes were destroyed and four people died. Overall, 225 buildings were lost, another 150 homes damaged and more than 800,000 hectares of bushland burnt. |

- 1997/1998** More than 250 fires burned between late November 1997 and late February 1998 in difficult and sparsely populated terrain in the Pilliga, Hawkesbury, Hunter, Blue Mountains, Central Coast and Shoalhaven areas. At least three people died. More than 500,000 hectares were burnt and at least 10 houses were lost in Menai in southern Sydney on 2 December.
- 2001/02** The majority of more than 450 bushfires were in the Greater Sydney, Hunter, North Coast, mid-north coast, Northern Tablelands and Central Tablelands areas. Many were started by lightning over the Great Dividing Range. Losses included 750,000 hectares burnt out, 109 houses and 6000 cattle.
- 2002/03** The frequency of extreme fire weather days was unprecedented, running from early spring 2002 to late summer 2003. Three people died in New South Wales and almost 1.5 million hectares were burned. Catastrophic fires burned into the southern suburbs of Canberra on 18 January claiming four lives, causing 450 injuries and destroying 488 houses. Damage exceeded \$350 m.



Smoke from New South Wales bushfires being blown over the Tasman Sea, 1 January 2002 (Bureau of Meteorology enhancement of image from a National Oceanic and Atmospheric Administration polar-orbiting satellite).



Fires rage through the Royal National Park near Bundeena during the January 1994 fires in eastern New South Wales. Photograph courtesy of the *Sydney Daily Telegraph, News Ltd.*

Tropical cyclones

Tropical cyclones have affected New South Wales in various ways over the last century with five making direct landfall on its coast. Five others have made landfall in Queensland, usually in the Gulf of Carpentaria, before moving southwards over land into New South Wales as severe low-pressure systems and then crossing back out to sea across the coast. Several others have moved close to the New South Wales coast without making landfall and

many more have remained well offshore but caused significant waves on its beaches. Tropical cyclones are characterised by their peak wind gusts (see table below). During the Bureau's first century, two Category 3 cyclones hit New South Wales. The Bureau initially numbered tropical cyclones, then formally named them from 1964. Following are significant tropical cyclone impacts on New South Wales over the past 100 years.

- 1911** Tropical cyclone *No. 1B* made landfall in the Gulf of Carpentaria on 5 January 1911. It moved south over inland Queensland and New South Wales as an intense low-pressure system before crossing out to sea again near Wollongong around 14 January. Wind gusts of 74 knots (137 km/h) were recorded in Sydney.
- 1928** A category 1 tropical cyclone, *No. 50*, made landfall south of Brisbane on 14 February 1928 and then moved inland north of the New South Wales border. There was severe wind damage to houses, buildings and trees in many areas of northern New South Wales including the Tweed Valley, Murwillumbah, Mullumbimby, Byron Bay, Kingscliff, Bangalow and Casino. South Grafton was flooded and at Glen Innes there was immense damage to crops from wind and rain.
- 1934** Tropical cyclone *No. 69* made landfall in the Gulf of Carpentaria then moved inland over Queensland and New South Wales to Coffs Harbour on 2 February. This very

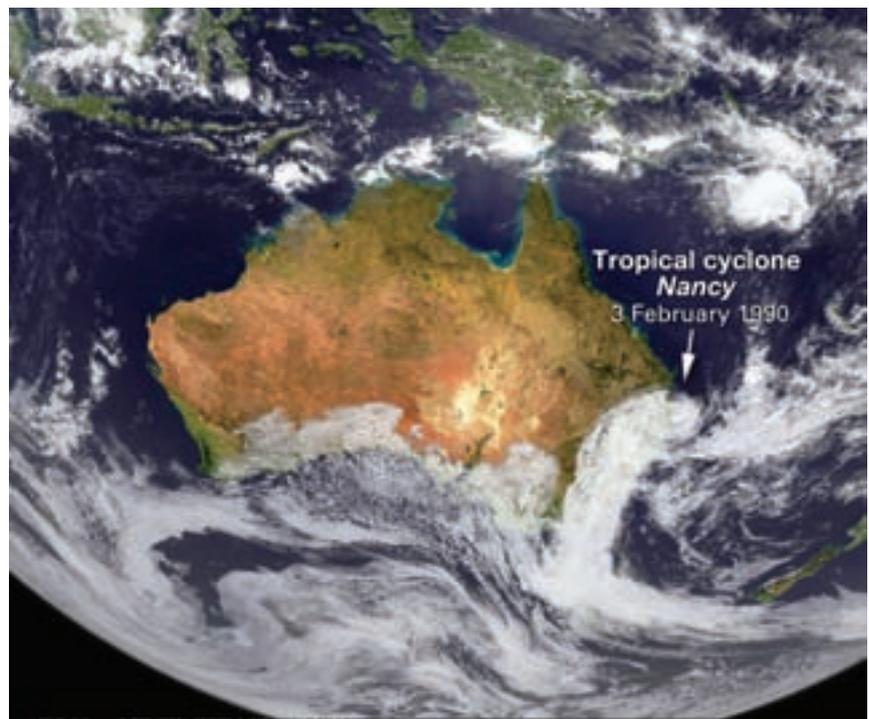
Category	Strongest gust	Typical effects
1	Less than 125 km/h	Gales. Minimal house damage. Damage to some crops, trees and caravans. Boats may drag moorings.
2	125 - 164 km/h	Destructive winds. Minor house damage. Significant damage to signs, trees and caravans. Heavy damage to some crops. Risk of power failure. Small boats may break moorings.
3	165 - 224 km/h	Very destructive winds. Some roof and structural damage. Some caravans destroyed. Power failure likely.
4	225 - 279 km/h	Very destructive winds. Significant roofing and structural damage. Many caravans destroyed and blown away. Dangerous airborne debris. Widespread power failures.
5	More than 280 km/h	Extremely destructive winds.

severe coastal storm brought flooding rains to the New South Wales coast. A heavy swell with 12 metre waves was reported at Bondi beach, Sydney.

- 1938** Tropical cyclone *No.77* made landfall at Bundaberg in Queensland as a category 1 system on 19 January before moving southwards into New South Wales and crossing to the sea near Yamba on 22 January. Waves broke as far as 1.6 km off Tweed Heads and flood water was up to three metres deep in the main street of Kyogle. One person drowned.
- 1939** A category 1 tropical cyclone, *No.80*, moved southwards from the Coral Sea touching the coast at Cape Byron on 5-6 March. Shipping was disrupted and gales extended possibly as far as the New South Wales south coast.
- 1950** Tropical cyclone *No.119* made landfall in the Gulf of Carpentaria on 16 January then moved south over Queensland and into New South Wales on 18-19 January. Sydney recorded its second-lowest barometric pressure of 988 hPa when the remains of the cyclone crossed out to sea. Ten lives were lost, mostly through drowning in swollen rivers, and seven yachts were wrecked in Sydney Harbour.
- 1954** Category 3 severe tropical cyclone *No.137* made landfall on the Gold Coast on 20 February then moved south over the New South Wales Northern Rivers during the next 24 hours. Torrential rainfall produced disastrous floods in Lismore, Murwillumbah and Casino and high winds destroyed houses and twisted large trees out of the ground. Thirty people died. The sea broke through and flooded parts of Byron Bay, where the outer section of the town jetty was swept away, taking all 22 vessels of the fishing fleet.
- 1959** Tropical cyclone *Beatrice* moved across the Coral Sea from New Caledonia, crossing the coast at Cape Byron on 21 January as a Category 2 system with a central pressure of 986 hPa. *Beatrice* damaged infrastructure along the north coast and eroded beaches.



- 1964 Category 2 tropical cyclone *Audrey* made landfall in the Gulf of Carpentaria on 11 January then tracked across Queensland and Northern New South Wales to Coffs Harbour on 14 January. There was extensive flooding and stock losses and buildings were badly damaged in many areas including Glen Innes and Grafton. Every building at Boggabilla was partially or completely unroofed.
- 1967 Category 3 tropical cyclone *Dinah* made landfall at Fraser island in Queensland on 29 January. Although it re-curved out to sea, it still brought a large storm surge to the Tweed River, isolating Fingal. Around Brunswick Heads several banana plantations were wiped out, and hundreds of hectares of sugar cane in the Tweed Valley were blown over.
- 1974 Tropical cyclone *Pam* passed around 500 km east of Brisbane and the northern New South Wales coast in February bringing powerful waves, record high tides and a storm surge to the east coast. Palm Beach residents abandoned their properties as seawater drove over the top of 6.2 m boulder walls and surged through their premises.
- Category 2 tropical cyclone *Zoe* made landfall at Coolangatta/Tweed Heads on 13 March, then re-curved into the Tasman Sea. It produced major flooding in northern New South Wales where 200 people were evacuated from Murwillumbah and 500 families were evacuated from Lismore. Landslides cut the main railway line in four places between Casino and Coffs Harbour.
- 1990 Tropical cyclone *Nancy* (satellite image shown below) crossed the New South Wales coast at Cape Byron on 3 February as a category 2 system, bringing heavy rain and flooding as far south as Sydney. Five people drowned, and damage in Queensland and New South Wales reached \$36 m.



East Coast Lows

Some of Australia's worst maritime disasters are caused by the destructive winds, torrential rainfall and rough seas of East Coast Lows, very intense low-pressure systems characteristic of the eastern coastline of Australia. The tragedies include the *Dunbar* in 1857 (21 lives lost), the *Sumatra* in 1923 (46 deaths) and the six lives lost in the 1998 Sydney-Hobart yacht race.

Although they are meteorologically distinct from tropical cyclones, East Coast Lows bring similar weather effects including coastal erosion and inundation. Gener-

ally short-lived, lasting for several days at most, they will often intensify rapidly overnight within a pre-existing trough of low pressure, or in the wake of a cold front moving into the Tasman Sea. They can occur at any time but are most common during autumn and winter months with a cluster of significant events often occurring over a period of several weeks. Fifty-six per cent of the major events listed below occurred during July. These are the East Coast Lows which caused significant damage and/or deaths during the Bureau's first century.

- 1912** On 14 July 1912 an East Coast Low deepened offshore from Newcastle, halting shipping and ferry traffic. There was exceptional beach erosion, even inside Sydney Harbour where erosion washaways of three metres were noted. Waves reportedly lifted a 235-ton boulder onto Bondi beach.
- 1917** A very severe East Coast Low moved south parallel to the New South Wales coast from 18-20 September 1917. The *Nerong* foundered 2 km off Norah Head on 19 September in gale-force winds, with the loss of three lives. "Much damage" was reported in Sydney and Newcastle.
- 1921** There were two significant East Coast Lows in the winter of 1921. The first, from 25-26 June, resulted in 26 lives lost when the steamers *Fitzroy* and *Our Jack* foundered off Cape Hawke near Forster in gales and heavy seas. Between 22-24 July, an intense low pressure system brought gales to the New South Wales coast, damaging the Manly ferries and disrupting shipping.



Winds from an East Coast Low flattened this sugar cane at Condong on 3 May 1996. Photograph courtesy of Tweed River Regional Museum.

- 1923 During late June 1923, an East Coast Low developed rapidly on the Mid-North Coast. On June 26, the SS *Sumatra* was lost with 46 lives between Crescent Head and Port Macquarie in “fresh to strong south to south east gales” while on Sydney harbour, passengers were injured when the Manly ferry *Burraba* nearly sank in fierce squalls.
- 1927 An intense East Coast Low developed off Port Macquarie between 18-19 April 1927, causing “great damage” further south in Sydney. There were “terrific gales” with a launch lost on Botany Bay and the SS *Riverina* driven ashore near Gabo Island.
- 1935 An East Coast Low damaged all areas of the central and southern coast, including Sydney and Newcastle, between 18-20 June 1935. Five people drowned in small ship sinkings, and very high tides and huge seas demolished the surf life saving pavilion at Coogee beach.
- 1937 A very severe East Coast Low, said to be the ‘worst since 1927’, tracked southwards along the New South Wales coast between 19-23 June 1937. It reached a central pressure of 995 hpa and caused severe delays to shipping.
- 1945 Between 10-13 June 1945, the Northern Rivers experienced flooding rains and significant erosion on the foreshore as a deep East Coast Low moved slowly southwards along the New South Wales coast. The steamer *Coweambah* was lost off Southwest Rocks, with at least one death.
- 1950 A series of East Coast Lows developed off the New South Wales coast in June 1950, a month which saw Sydney register a record monthly rainfall of 642.7 mm. The Macleay River flooded disastrously and the heavily-flooded Clarence River carved a new path to the sea. At least five people drowned in floods during the month and the Navy motorship *Fairwind* was lost with a crew of 17 during a storm that raged between 23-26 June.
- 1966 An intense East Coast Low off the New South Wales south coast brought gales and rough seas in May 1966. During the early hours of 21 May the dredge *WD Atlas* foundered with the loss of 13 lives. Helicopters despatched from the RAN air station *HMAS Albatross* rescued four survivors.

Erosion from East Coast Lows at Old Bar near Taree on the NSW mid-north coast, winter 2008. The houses were subsequently demolished as hazards. Photograph courtesy of Phil Watson, NSW Department of Environment and Climate Change.



- 1974 A major East Coast Low which caused widespread damage to the coastline between Seal Rocks and Wollongong on 27 May is known as the *Syigna Storm* from the grounding of a 30,503 tonne coal ship of that name on Stockton Beach. Nobby's Signal at Newcastle recorded a wind gust of 165 km/h, equivalent in strength to a category 3 severe tropical cyclone, and phenomenal waves overtopped sand dunes 5-6 metres above sea level. Six people died.
- 1986 An East Coast Low passing close to Sydney on 6 August 1986 brought the city's highest 24-hour rainfall to date, 327.6 mm. There was serious flash flooding and traffic chaos in western Sydney with the final damage bill exceeding \$35 m. The Hawkesbury River reached moderate flood level, peaking at 11.3 metres at Windsor Bridge.
- 1996 An East Coast Low between 30-31 August 1996 caused almost \$20m damage and cost two lives. The highest rainfall total was 386 mm at Darkes Forest in the Illawarra. Wind gusts peaked at 119 km/h near Wollongong.
- 1998 On 23 June 1998 an East Coast Low caused more than \$12 m in damage and brought significant disruption to the Hunter and Northern Tablelands. Boats were blown from their moorings and washed ashore between Port Stephens and Lake Macquarie, and heavy snowfalls blocked roads in the Barrington Tops near Gloucester. A peak wind gust of 152 km/h was recorded at Nobby's Signal at Newcastle.
- 2005 Between 1-2 February 2005, an intense East Coast Low brought widespread severe weather conditions to southeast Australia. There were numerous reports of 3-6cm diameter hail across Sydney and the Blue Mountains, flash flooding in Bexley and roofs were blown off buildings in Gladesville. The damage in New South Wales, Victoria and Tasmania reached \$216.7 m.
- 2007 Five East Coast Lows occurred during June 2007—a rare, if not unprecedented sequence. The first (8-9 June), known as the Queen's Birthday Storm, had the most impact, resulting in nine deaths and widespread damage along the Hunter, central coast and Sydney coastlines associated with sustained heavy rain, flooding, strong winds and large ocean waves and swell. The coal carrier *Pasha Bulker* (76,741 tonnes) ran aground at Nobby's Beach in Newcastle.



East Coast Low image from the Japanese geostationary meteorological satellite MTSAT at 9.30 am Eastern Standard Time on 27 June 2007.

Droughts

Periodic droughts have had a major impact on New South Wales, sometimes threatening the livelihood of entire rural communities, especially when they span several seasons. On average a drought

seriously affects the State every 10-20 years. Drought is often associated with the El Niño weather phenomenon; the 1982/83 drought over southeastern Australia was a classic example.

- 1914-15** Northern Victoria and New South Wales were in severe drought for the 10-12 months up to June-July 1915.
- 1918-20** The 1918-20 drought was one of the major droughts in New South Wales history. The wheat yield dropped to a disastrous 4 million bushels in 1919 and sheep numbers dwindled from 42 m to 33 m.
- 1939-45** Drought was generally endemic in North South Wales from 1939 to August 1945. During one severe period in 1944, numerous districts recorded their lowest rainfall on record up until that time and the wheat yield totalled only 17 million bushels. By December, the Hunter River had ceased to flow along most of its course and by January 1945 the Hawkesbury River was dry at North Richmond.
- In December, Sydney reported a series of severe dust storms.
- 1957** There was a prolonged period of drought around Australia between 1957-68. In New South Wales in 1957, many inland districts reported their lowest twelve months of rain on record up until that time, and in scores of other areas 1957 rainfall figures were only slightly above those recorded during the 1901-02, 1918-20 and 1944 droughts. The wheat yield fell dramatically to around 4-5 million bushels compared with 50 million bushels in other years. Devastating bushfires swept through the Blue Mountains in December 1957.
- 1967-68** New South Wales was again in severe drought for the 14-15 months to May 1968.
- 1972-73** Western and central New South Wales were in severe drought for 9-10 months ending February 1973.
- 1982-83** 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 the twentieth century. This drought caused losses in excess of \$3 billion, mostly in crop and livestock, with dust storms blowing away millions of dollars worth of topsoil. This event first brought into prominence the link between El Niño and Australian drought.
- 2002-03** 2001 to the present has been the driest on record over parts of eastern Australia, and arguably the worst on record financially for New South Wales with 99.5 per cent of the State drought-stricken in April 2003. In 2002-03 wheat production was down 69 per cent to 2.5 million tonnes and sheep and lamb numbers dropped to their lowest numbers since 1947, with 4.8 million lost in New South Wales.

On 23 October 2002 a severe dust storm engulfed New South Wales with visibility west of the divide just 300 metres in many areas. Dust was reported up to 3 km above the ground.



Hand-fed sheep at Warialda, northern NSW, 1994 drought. Photograph by Graham Johnson. Photograph courtesy NSW Department of Primary Industry.



Dustorm approaching vineyard at Gundaroo, early 2003. Photograph courtesy of Anthony Ritchard.

Southerly Busters

One of Australia's best known 'local winds' is the Southerly Buster (also known as Southerly Burster), a surge of cool air that moves rapidly northward along the coast of New South Wales. Southerly Busters are often accompanied by winds exceeding gale force, and rapid temperature drops. They usually arrive after some days of hot dusty weather in southeastern Australia.

Sydney has recorded more than 200 Southerly Busters in the past 70 years, 22

with peak wind gusts of at least 100 km/h. The record gust was 113 km/h on 18 December 1948. Temperatures preceding Southerly Busters are often hot, with 38°C or more measured in 33 events, the highest being 44.2°C in January 2006. More than 90 per cent of Southerly Busters hit between October and February, with 45 per cent recorded in December and January. The Southerly Busters listed below include those which brought gusts of at least 100 km/h to Sydney.

-
- 1942** Two notable Southerly Busters were recorded in 1942. The first reached 104 km/h at 4 pm on 25 January 1942 and was followed by severe thunderstorms. The second recorded 109 km/h at 4:40pm on 4 October.
- 1943** Significant Southerly Busters in 1943 struck on 23 March (maximum of 95 km/h at 3:40 pm) and on 28 March (108 km/h at 9:50pm.)
- 1945** On 9 November 1945 a Southerly Buster of 105 km/h occurred at 6:10 pm, accompanied by thunderstorms.
- 1946** An early Southerly Buster reached Sydney at 11:50am on 27 November 1946 with a strength of 96 km/h. The temperature before the change reached 37.4°C.
- 1948** The strongest Southerly Buster on record at Sydney Airport hit at 6:40 pm on 18 December 1948 with a maximum wind gust of 113 km/h. The maximum temperature that day was 34.8°C.
- 1951** On 6 December 1951, wind gusts from a Southerly Buster reached 98 km/h.

Southerly Buster, Boxing Day 1996, Narrabeen. Photograph courtesy of John Grainger.



- 1957 After a maximum temperature of 40.4°C on 2 December 1957, a squally Southerly Buster reached Sydney at 5:30 pm, with a peak gust of 104 km/h.
- 1958 Wind gusts in a Southerly Buster reached 100 km/h at 5:10 pm on 10 January 1958.
- 1973 Notable Southerly Busters in 1973 struck on the evening of 6 February (maximum gust 98 km/h) after a maximum that day of 39.7°C, and at 5:10 pm on 20 November (maximum gust 96 km/h) after a maximum of 38.4°C.
- 1979 On 13 February 1979, a peak gust of 98 km/h was reached at 8:20 pm during a Southerly Buster. Sydney's maximum temperature reached 39.8°C.
- 1982 A Southerly Buster on 25 November 1982 was accompanied by dust storms and preceded by a record November maximum temperature of 41.8°C at Sydney. The maximum wind gust at Sydney Airport was 89 km/h at 4:10 pm.
- 1994 A very late Southerly Buster arrived at 2:00 am on 29 December 1994, with a peak gust of 98 km/h at 3:09 am.
- 1995 A Southerly Buster on 12 March 1995 brought a peak gust of 98 km/h at 6:25 pm.
- 2001 On 15 January 2001, a Southerly Buster with a maximum gust of 100 km/h caused blackouts, property damage and uprooted trees. Temperatures reached 46°C at Penrith. This was the hottest day in Sydney's western suburbs since 1939.
- 2003 The second strongest Southerly Buster on record reached a maximum gust of 109 km/h at 5:22 pm on 8 January 2003. Thunderstorms with small hail followed the change and 70 suburbs lost power after lightning strikes.
- 2004 A Southerly Buster with a maximum gust of 91 km/h reached Sydney at 4:30 pm on 4 December 2004 after a maximum temperature of 41.8°C.
- 2006 On 1 January 2006, a Southerly Buster reached Sydney at 8:17 pm with a maximum gust of 95 km/h. The maximum temperature at Observatory Hill that day was 44.2°C, the second highest on record.



Snowfalls

In a meteorological sense, New South Wales alpine areas are defined as those above 1200 metres where snow could reasonably be expected to fall during the winter months. Snow becomes a major weather event when it occurs outside these normal bounds. Cold outbreaks can bring heavy snowfalls well north to the New South Wales/Queensland border during winter,

causing major disruption to communities and infrastructure all along the Tablelands. In some instances snow can even fall on the New South Wales coastal strip. In one rare event in 1836, snow settled to a depth of 2.5 cm in Sydney city. Snow can also occur at unseasonable times. Alpine areas experienced a white Christmas several times during the Bureau's first 100 years.

- 1910** Very heavy snowfalls on the Central Tablelands from 18-19 July 1910 disrupted rail traffic and isolated communities. Snow was 61 cm deep at Blackheath, 55 cm deep at Mount Victoria and 46 cm deep at Oberon.
- 1946** Heavy snowfalls in the Monaro district on 20 June 1946 disrupted communications and caused heavy stock losses. Local newspaper reports described it as one of the worst snowstorms in the region's history. Snow depths of 75-105 cm were recorded at Adaminaby, isolating the town for six days.
- 1949** From 19-20 July 1949 Canberra had its biggest snowfall on record with up to 22 cm of snow making all roads in and out of the city impassable. Canberra Airport was closed for two days. The Monaro district suffered one of its bleakest winters. In Nimmitabel, snow lay continuously on the ground through July.
- 1956** The greatest snow depth ever recorded in Australia was on 6 September 1956 when the then Snowy Mountains Hydro-electric Authority measured a depth of 197 inches (five metres) at Wilkinson's Valley snow course (near Mount Kosciuszko) at an elevation of 1981 metres.
- 1964** The winter of 1964 was the second biggest snow season on record, dubbed 'the year of the shovel' after almost continuous blizzards in the mountains buried cars and ski lifts. The newly-built chairlift between the Alpine Way at Thredbo and Charlotte Pass had to be abandoned after people became trapped for hours due to massive snowfalls and high winds.
- 1965** There were heavy snowfalls in the Blue Mountains and Central Tablelands from 18-20 July 1965 with areas around Lithgow reporting 30-60 cm snow on ground, their heaviest snow since 1900. Roads were blocked and power and phone services cut for more than 24 hours. Snow fell as far north as Gunnedah on the North West Slopes and there were reports of snow settling in outer northern Sydney suburbs such as Dural and Glenorie.
- 1981** The winter of 1981 had the greatest snow depth (3.62 metres) measured at the Snowy Mountains Hydro-electric Authority's site at Charlotte Pass.
- 1984** An intense cold outbreak from 3-4 July 1984 saw snow as far north as Toowoomba in southeast Queensland, and moderate to heavy falls to the Northern Tablelands. The town of Guyra experienced possibly the coldest mid-afternoon temperature ever recorded outside the Snowy Mountains with -3.2°C recorded at 3:00 pm, more than 12°C below normal.

- 1986** On the afternoon of 28 July 1986, snow fell in Sydney city and other locations including Sydney Airport and Bankstown, but did not settle on the ground. The last fall that actually settled in the city was on 28 June 1836 when snow 'nearly an inch (2.5 cm) in depth' covered the streets while a 'razor-keen wind' blew from the west.
- 1987** On 1 July 1987 the Monaro region, Snowy Mountains, Blue Mountains and the Southern Highlands suffered some of the heaviest snowfalls since 1949. Areas around Bombala, Nimmitabel and Delegate had between one and two metres of snow, closing roads and bringing down power and telephone lines. The snow remained on the ground for up to two weeks and a million sheep were caught without shelter and food.
- 1990** From 24 June to 6 July 1990 persistent strong southwest winds caused regular snowfalls on the Central Tablelands and in the Snowy Mountains. Oberon on the Central Tablelands recorded 13 consecutive days of snow with wind-blown snow drifts up to a metre deep in the area.
- 2004** On 17-18 July 2004 snowfalls were reported as far north as Glen Innes on the Northern Tablelands and to low elevations on the Southern Tablelands. The snow closed all roads in the Cooma/Bombala/Jindabyne area of the Southern Tablelands, the Great Western Highway at Blackheath and the road between Scone and Gloucester in the Hunter.
- 2005** Snowfalls of up to 40 cm were recorded in the Jindabyne area from 8-10 July 2005, isolating towns for several days and cutting power supplies for two days. At Nimmitabel, roofs collapsed and large tree branches fell onto roads due to the weight of snow. Snow extended as far north as Guyra on the Northern Tablelands which had up to 5 cm of snow.
- 2006** On 16 November 2006 Canberra had its first November snow since 1949, although it did not settle on the ground. The snow extended to the Northern Tablelands where the Uralla district reported 4cm of snow.
- Residents of the Snowy Mountains had a white Christmas on 25 December 2006 with about 15 cm snow recorded over the Alps. A similar snowfall occurred on Christmas Day 1968.



An unseasonal snow storm at Danglemah Road, Woolbrook, New South Wales 2006. Photograph by Ruth Watson.

Tsunami

While tsunamis are rare events, the catastrophic 2004 Indian Ocean tsunami prompted improved tsunami warnings worldwide. Australia, for example, established the Joint Australian Tsunami Warning Centre, pictured below, operated by the Bureau of Meteorology (Melbourne) and Geoscience Australia (Canberra). A new network of deep ocean buoys and an expanded tidal gauge network support the warning system.

A severe undersea earthquake in the volcanically active areas around New Zealand could bring tsunami waves to the southern New South Wales coastline in

about 1.5 hours, and to the northern New South Wales coastline in around 2.5 hours.

Nine tsunami waves measured along the New South Wales coast over the past century are listed below. The most significant came in May 1960. The measurements of wave height in the table refer to fluctuations between the peak of the wave and the subsequent trough, corresponding to wave heights specified on Bureau marine forecasts. In tsunami reference literature, the height is normally specified as the fluctuation about the expected tidal level – for example a fluctuation of 0.5 metres equates with a wave height of one metre.

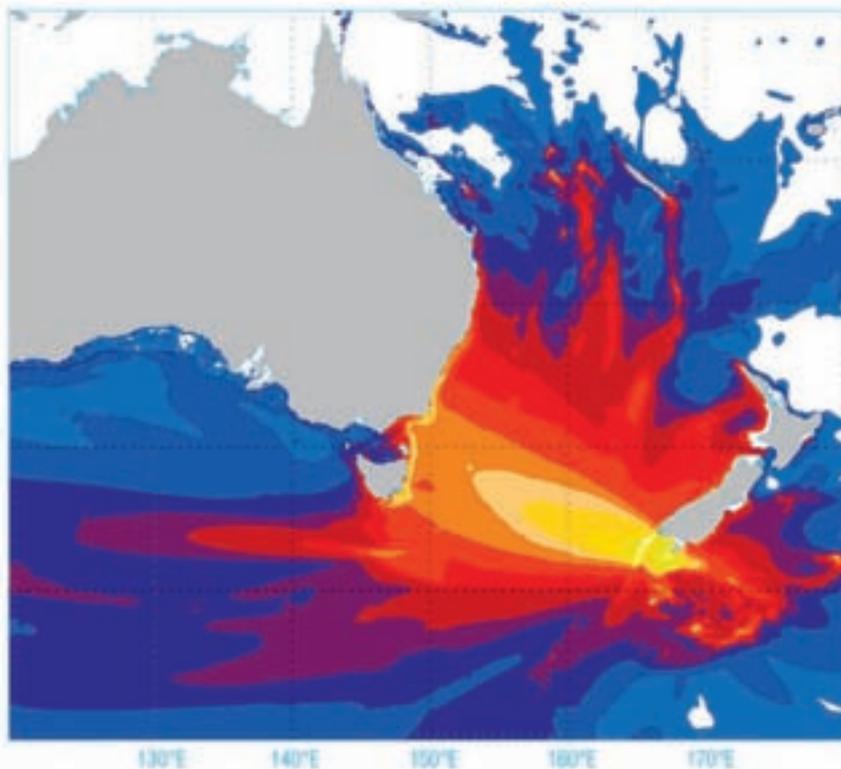
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|------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1922 | On the morning of 13 November 1922 a tsunami wave height of 0.4 metres was recorded in Sydney harbour after a magnitude 8.5 earthquake in Chile the previous day. |
| 1929 | A magnitude 7.6 earthquake near the South Island of New Zealand on 17 June 1929 generated a tsunami which measured 0.2 metres at Fort Denison in Sydney Harbour. |
| 1931 | During the afternoon of 13 February 1931 a magnitude 7.1 earthquake near New Zealand generated a tsunami measured at 0.2 metres in Sydney Harbour. |
| 1960 | The most significant tsunami impact on the New South Wales coast in recent times occurred on 23 May 1960 following a magnitude 9.5 earthquake in Chile about 17 hours earlier. The tsunami measured up to one metre in Sydney Harbour, |

Joint Australian Tsunami Warning Centre, Bureau of Meteorology, Melbourne



1.2 metres at Iluka and 1.8 metres at Eden. It caused rapid fluctuations in water levels in many enclosed harbours including Evans Head, Newcastle, Sydney, Batemans Bay and Eden. In Sydney Harbour boats were damaged when torn from their moorings. The Chilean earthquake is to date the largest recorded by modern instruments.

- 1964** On 29 March 1964 a tsunami generated by a magnitude 9.2 earthquake in Alaska brought a wave height of 0.4 metres to Sydney Harbour. The Alaskan earthquake intensity is second only to the 1960 Chilean earthquake.
- 1989** A tsunami generated by a magnitude 8.1 earthquake near Macquarie Island in the Southern Ocean was measured at 0.2 metres in Sydney Harbour on 23 May 1989.
- 2004** On 26 December 2004 a magnitude 9.0 earthquake in Indonesian waters south of Banda Aceh produced a catastrophic tsunami that resulted in over 200,000 deaths across the Indian Ocean. The oceanographic effects of the Asian tsunami were felt over much of the globe. In New South Wales the tide gauge at Port Kembla recorded a fluctuation of around one metre 12 hours later.
- Only two days previously, a magnitude 8.1 earthquake near Macquarie Island generated a tsunami that registered 0.2 metres high at Port Kembla.
- 2007** A magnitude 8.0 earthquake in the Solomon Islands on 2 April 2007 triggered a tsunami warning for locations along the east coast of New South Wales, resulting in the closure of Sydney's beaches, the suspension of Manly ferry services and the evacuation of students from some beachside schools to higher ground. Sea level rises of 0.1 metres were recorded at Port Kembla on the New South Wales south coast, and the warning was cancelled with no damage reported.



Computer simulation of a tsunami spreading from an undersea earthquake off New Zealand.
(yellow/green = highest waves).

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