STORM HAZARD AND RISK IN NEW SOUTH WALES

Supporting Document to the NSW State Storm Plan

December 2023

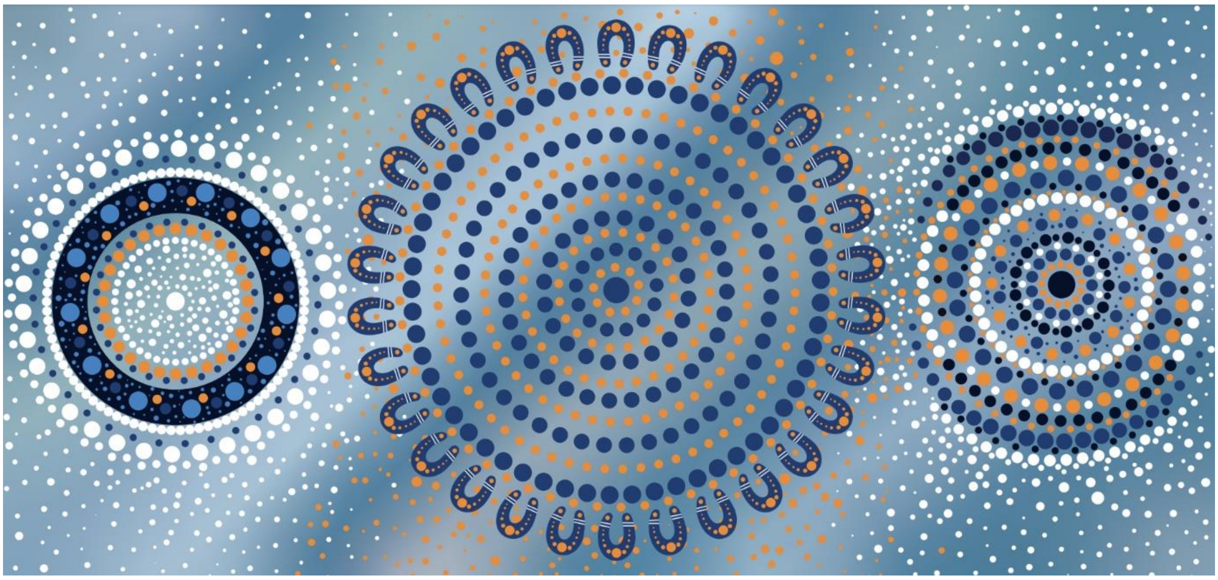
CONTENTS

ACKNOWLEDGEMENTS

ACKNOWLEDGEMENT OF COUNTRY

The New South Wales State Emergency Service (NSW SES) acknowledges and pays respect to the traditional owners and custodians of the land on which we work, volunteer and live. NSW SES recognises the diversity of Aboriginal and Torres Strait Islander peoples and their ongoing culture and continued connection to lands, waters, and the greater communities throughout Australia.

NSW SES appreciates the value of traditional knowledge held by Aboriginal and Torres Strait Islander peoples and its significance in understanding Australia's natural landscape to perform the emergency management procedures detailed in this supporting document.



Artwork: 'Journey after the storm' by Lani Balzan.

STATEMENT ON CLIMATE CHANGE

NSW SES understands that the effects of climate change will continue to increase the severity of disasters including storm, flood, and tsunami disasters and its impacts on life and property in NSW.

It is understood that the changes to natural climate processes, oceanic climate systems, temperatures, and weather pressure systems will affect the extremity of Australia's weather systems and ocean hazards. (1) The increased risk of severe thunderstorms and storm surges (1), flash flooding and large flood events (1), and the possibility of higher levels of tsunami inundation from sea level rise (2) have potential to have a higher impact on communities when they occur.

NSW SES in the management of flood, storm, and tsunami risk must consider the effects of climate change in all phases of Emergency Management. The NSW SES has an important role in planning, preparing for, responding to, and initiating recovery from the environmental impacts of severe weather-related incidents, emergencies, and disasters.

THE STORM THREAT IN NEW SOUTH WALES

GENERAL

- Many distinct types of weather systems can produce storms that cause danger, damage, and disruption in New South Wales (NSW). In terms of property damage, storms cause greater losses to the community than any other single hazard agent in NSW. In FY2021-2022, 83 of 128 LGAs in NSW were impacted by disasters, including storm hazards. (3)

- The Audit Office of NSW estimated that over the FY2021-2022, $1.4 billion was spent by the NSW Government in disaster response, from a budget of $1.9 billion. (3) Total expenses were due to underspend in clean-up assistance (including council grants), temporary accommodation support, and payments relating to the Northern Rivers Business Support scheme. (3)

- The Audit Office of NSW estimated that in FY2021-2022, the damage to council infrastructure assets resulting from disaster impacts totalled to $349 million. (3) Further damage to council infrastructure caused by disasters resulted in the NSW Government spending a further $1.1 billion in the first half of FY2022-2023. (3)

- The most damaging storm in NSW history remains the April 1999 Sydney hailstorm. This event caused damage to approximately 20,000 homes and 70,000 cars across 85 suburbs with hail as large as 9cm recorded in some areas. (4)

- Storms can result in fatalities. On average, four fatalities occur in NSW each year as a primary result of storms and storm impacts for example, lightning strikes, fallen trees, flash flooding. Fatalities can also occur by secondary impacts of storms for example relating to hazardous driving conditions on roads.

- Climate Change has increased the frequency and magnitude of extreme sea level events, including storm surges combined with higher average sea levels. This has led to increased risks of coastal inundation. (5) Climate Change impacts on storm surges is also demonstrated by the increased intensity of tropical cyclones and storm tide heights. (5)

- Different types of storm activity may occur concurrently, compounding the impacts of severe weather events. For example, storm surge combined with rainfall leading to coastal inundation. (6)

TYPES OF STORMS

The following sections describe the different sorts of weather systems associated with severe and potentially damaging storms and briefly outlines the kinds of damage which tends to occur.

THUNDERSTORMS

Types of Thunderstorms

There are **three general types of thunderstorms**, each with a distinct structure, circulation pattern, and set of characteristics: (7)

1. Single-cell (Ordinary cell) thunderstorm: A cloud forms and grows to maturity, produces a heavy downpour, and decays as descending air dilutes the original warm inflow.

- The lifecycle of this storm is limited to the growth and collapse of a single updraught pulse.
- The storm most-often occurs in mid-summer, rarely produces severe weather, and usually lasts no more than an hour.

2. Multicell thunderstorm: The successive, separate updraught pulses help to maintain the thunderstorms system's overall strength, structure, and appearance.

The thunderstorm cycles repeatedly through stronger and weaker phases.

- Multicell thunderstorms are the most common and can produce any of the severe weather associated with thunderstorms, but cause tornadoes only infrequently. (8)

3. Supercell thunderstorm: A highly organised cloud-scale circulation with a continuous large updraught and magnified size and impact, creating a dangerous cloud complex.

- Supercells are formed by a combination of moisture, a lifting mechanism, instability in the atmosphere, and wind shear. (9)
- A supercell is often associated with destructive winds, giant hail, very heavy rainfall, and sometimes tornadoes. (10)
- The supercell can maintain a steady, strong state for many hours. Supercells account for most of the severe thunderstorm experienced in NSW and are the most destructive and long-lasting (up to six hours).

Figure 1: Supercell thunderstorm (7)

Lifespan of a Thunderstorm

The typical lifespan of a thunderstorm exists in three stages:

1. **Developing (Cumulus) stage:** The entire thundercloud consists of updraft (air rising). (11)

2. **Mature (Cumulonimbus) stage:** The thundercloud is at its largest and most organised. An updraft and downdraft (air descending) happen concurrently, at least in the lower half of the cell. A downdraft is where most of the heavy rain occurs. The cloud produces thunder and lightning, taking on an anvil shape (see Figure 1). (11)

3. **Dissipating stage:** The energy supply to the storm subsides. The updraft and downdraft finishes, and the cloud dissolves. (11)

The increase in storm frequency during the 'Severe Thunderstorm Season' (10) is primarily due to the increase in energy from thermal lifting mechanisms provided by the sun, coupled with weather patterns during the warmer spring and summer months, which are favourable for storm growth. (12)

Thunderstorms can also be experienced in NSW's cooler seasons and are often linked to cold fronts, particularly if other lifting mechanisms are strong. (11)

Severe weather from thunderstorms, low pressure systems, and other significant weather systems can occur year-round in NSW, Lord Howe Island, and Norfolk Island, and as such there is no distinct 'Severe Weather Season'. (10)

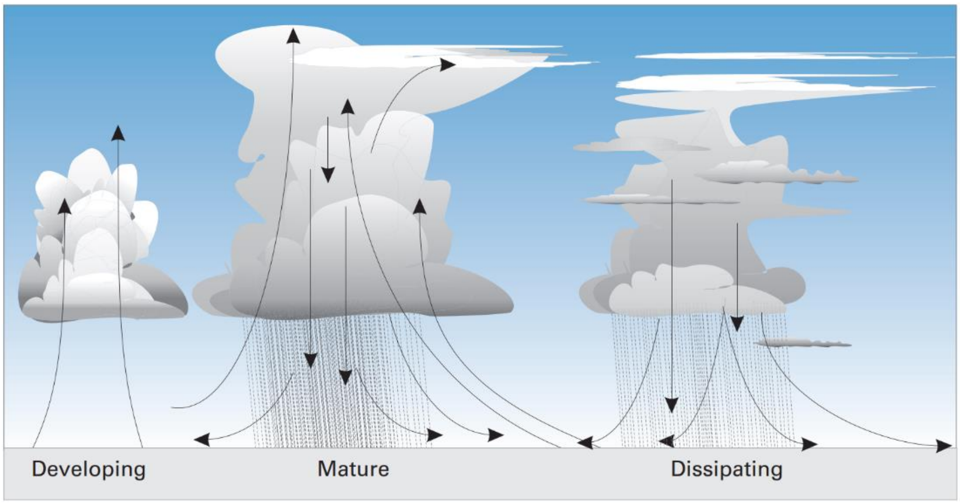


Figure 2. Typical lifespan of a thunderstorm in its Developing, Mature, and Dissipating stages (37)

Thunderstorm 'Season'

Although severe thunderstorms can occur at any time, there are patterns in the distribution of storm events by season.

There is a marked tendency for severe thunderstorms to occur during the months from October through to March, with 90% of annual severe thunderstorm activity in NSW occurring during these months. (10) This period is normally referred to as the 'Severe Thunderstorm Season' in NSW.

Severe Thunderstorms

Severe thunderstorms are the most common and most damaging storm agents in NSW, accounting for the bulk of the total cost of storm damages. They are relatively small-scale systems, with damage often only affecting areas a few kilometres in diameter. These storms have varied life spans, ranging from tens of minutes to several hours.

The products of severe thunderstorms include: (10)

- **Very strong and damaging winds** at least 90km/h and sometimes greater than 200km/h.
- **Tornadoes** (see separate heading).
- **Large or giant hail** (of at least 2cm and 5cm in diameter, respectively).
- **Significant accumulation of hail** (regardless of stone size, covering the ground such that it appears white. This may occur with as little as 2cm depth).
- **Heavy rainfall** (with the potential to lead to flash flooding).

Of these products, hail has been most damaging to property whilst strong winds, flash flooding and tornadoes pose the greatest threat to life. (12)

Severe Thunderstorms can cause severe damage to buildings, especially to roofs and windows, resulting from primary and secondary storm impacts, for example, by fallen trees and branches, and hail damage.

It is also common for storm impact to damage vehicles and down power and telephone lines, resulting in communities being left without electricity and telephone services for several days, in some cases. (12)

Very Dangerous Thunderstorms are a subset of severe thunderstorms. Very dangerous thunderstorms have the potential for giant hail, destructive wind gusts, very heavy rainfall, and tornadoes. (10)

Lightning

Every thunderstorm has lightning associated with it.

Lightning is the electrical discharge produced when voltage differences between the ground and a part of the storm (or between two separate regions of the storm) are large enough to overcome the insulating effect of the air. (13)

Thunder is the sound produced by the explosive expansion of air heated by the lightning strike to temperatures as high as 30,000°C. (13)

Lightning strikes that cause fatalities most often occur in: (14)

- Recreational areas, cultural areas, or public buildings.
- The countryside.
- Or on farms or other place of primary production.

Figure 3: Fallen tree impacting a residential property.
Severe thunderstorms can cause severe damage, especially to roofs and windows.

TORNADOES

Tornadoes are extremely damaging weather phenomena that contain damaging and destructive winds and can occur in conjunction with severe thunderstorms.

A tornado itself is an intense, localised, funnel-shaped vortex that extends from the thunderstorm cloud base to the ground. Tornadoes range in size from a few tens of metres to around one kilometre in diameter.


Figure 4: Fallen tree impacting a residential property. Tornados have can occur in conjunction with severe thunderstorms, with destructive, intense winds that can result the complete destruction of buildings.

Due to their relatively small size, tornado damage is normally restricted to a small area, however, the damage itself can be very intense and may result the complete destruction of buildings. (12)

Most tornadoes in NSW occur in late spring and summer but they have been known to occur at all times of the year. (12) They are most likely to be associated with supercell severe thunderstorms or with thunderstorms embedded within regions of strong wind shear in East Coast Low storms or tropical cyclones.

Tornadoes have been reported across NSW including Sydney, Bulahdelah, Port Macquarie, Cobar, Gilgandra, Dubbo, Moree, Tumbarumba, Merimbula, Pambula, Tucabia, Kiama, and Mulwala. In some of these events, buildings have been demolished by the extreme winds which can range from 120km/h to above 400km/h. (12)

Historical examples of Tornados:

In 2013, up to four tornadoes were surveyed in Kiama, NSW, with one causing significant damage. This tornado was classified as EF1 on the Enhanced Fujita scale of tornado intensity. (14)

Damages included removal of roofing material, damage to walls, and snapping of trees. (14) This led to exposure of asbestos materials, resulting in an exclusion zone being created in parts of Kiama, and the evacuation of 15 residents from their properties. (14) The tornado was estimated to have produced maximum winds of 160km/h. (14)

In 2015, Kurnell and the surrounding coastal region was affected by a tornado associated with a very severe thunderstorm that had peak wind gusts of 213km/h between 10am and 11am. (15)

This was followed by a second storm that brought torrential rain and severe winds to Sydney’s southern coastal region and eastern suburbs between 1pm and 2pm. (15)

TROPICAL CYCLONES AND EX-TROPICAL CYCLONES

Tropical cyclones develop over very warm tropical waters from pre-existing tropical weather disturbances. They have relatively long life cycles of up to two weeks.

Ex-tropical cyclones have a low-pressure circulation that once had tropical cyclone characteristics but has then moved out of the tropics. (10)

Tropical cyclones and ex-tropical cyclones produce gale to storm force winds, embedded tornadoes, flooding rains, very high seas, and storm surges. High seas and storm surges may cause erosion of sand dunes and in severe cases may expose landward areas to sea water inundation. (12)

Tropical cyclone season occurs from November through to April, however, warning and monitoring services may be active outside of this period, if required. (10)

Tropical cyclones have historically affected NSW, including Lord Howe Island (which has recorded hurricane force gusts) over the past century, with several making direct landfall and many others impacting the State as ex-tropical cyclones after moving overland through Queensland.

The northern parts of the state, especially coastal areas, are the most affected, but the impacts of these systems can extend as far south as Sydney.

Historical examples of land falling cyclones: (16)

- **Tropical Cyclone Nancy (February 1990)** was a category 2 system that crossed the NSW coast at Byron Bay.
- **Tropical Cyclone Beatrice (1959)** was a category 2 system that crossed the NSW coast at Byron Bay.
- **Ex-Tropical Cyclone Debbie (March 2017)** originated as a category 4 system in the Whitsunday Islands, before tracking south towards the Gold Coast as a category 3 causing widespread rainfall and flooding in the Northern Rivers area, in addition to the impacts along the Queensland coast.

Figure 5: Debris and flood waters along road in Lismore following Ex-Tropical Cyclone Debbie in March 2017. Cyclones can produce gale to storm force winds, embedded tornadoes, flooding rains, very high seas, and storm surges, with primary and secondary impacts. (32)

- **Tropical Cyclone Zoe (March 1974)** crossed the coast at Coolangatta before recurving back to sea, causing flooding and landslides in the Northern Rivers area.

- **Ex-Tropical Cyclone Violet (March 1995)** came to within 50km of the coast of northern NSW causing very high seas between Coffs Harbour and Ballina.

- **Tropical Cyclone Oswald (January 2013)** tracked from the Northern Territory through Queensland and NSW reaching as far south as Sydney before finally moving off the coast. This system produced significant flooding, heavy rainfall, and several tornadoes along its path.

- **An unnamed Tropical Cyclone** made landfall on the Gold Coast **(February 1954)** before moving southwards into NSW known as "The Great Gold Coast Cyclone" caused disastrous floods and claimed between 26-30 lives with the worst hit areas being Lismore, Casino, Kyogle, and Murwillumbah. (17)

Within the Australian Government Bureau of Meteorology (the Bureau), the Brisbane Tropical Cyclone Warning Centre maintains a cyclone warning service for NSW down to Taree (32° south), however may extend warnings further south in some situations. Cyclone warning services are also provided for Lord Howe Island and Norfolk Island. (18)

MID-LATITUDE LOW-PRESSURE SYSTEMS

More frequent occurrences along the NSW coast are intense low-pressure systems known as East Coast Low-Pressure Systems. These storms generally have much shorter lifetimes than tropical cyclones, usually of the order of only a day or two. (12)

Low-Pressure Systems generally develop over the Tasman Sea close to the coast and often intensify dramatically overnight (they are often known as "Tasman Lows" (10)). They have a compact size and deep low-pressure centre, and like tropical cyclones can produce gale to storm-force winds, heavy rainfall and in some cases very high seas and storm surges. Erosion of sand dunes and the inundation of land by sea water may also occur. (12)

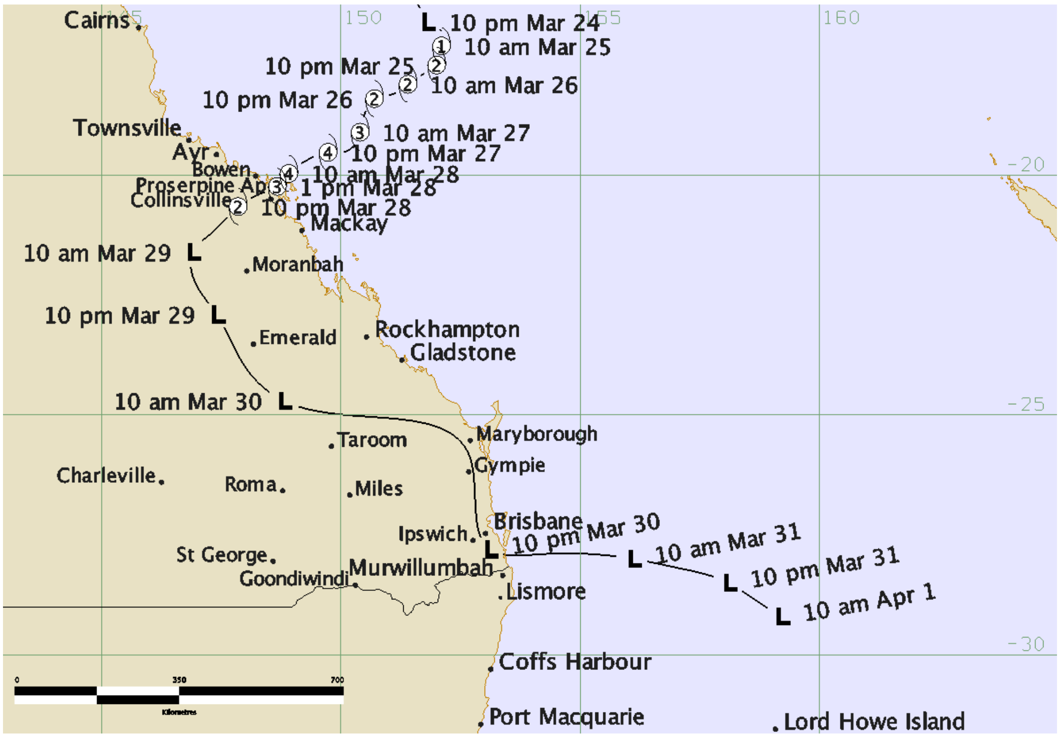


Figure 6: Graph depicting track and intensity of Ex-Tropical Cyclone Debbie (2017). Disastrous flooding occurred in the Logan and Albert Rivers (OLD) and the Tweed River basin (NSW) (39)

The NSW Weather Warning Directive of the Bureau of Meteorology defines and categorises low-pressure systems (Tasman Lows) as follows: (10)

- **Transient Low:** *A cyclonic circulation originating over land, which deepens as it reaches the coast but moves away to the east rapidly. In some situations, these systems produce a brief period of damaging wind or heavy rain*. (10)

- **(Offshore) Tasman Low:** *A cyclonic circulation centred well off the coast (typically more than 200km). If long-lasting, these systems may produce damaging surf conditions, but rarely damaging winds or heavy rain over land areas*. (10)

- **Coastal Trough:** *A low pressure trough lying along, or just off, the coast. Short-lived, small-scale circulations sometimes develop with the trough. Coastal Troughs may produce heavy rainfall (and sometimes damaging wind), even in the absence of small-scale circulations.* (10)

- **Coastal Low:** *A cyclonic circulation that remains centred near the NSW coast (typically within 200km) for at least 12 hours. In some situations, these may produce severe weather, but lack the intensity or high impact of an East Coast Low*. (10)

- **East Coast Low:** *A type of Coastal Low displaying an intense cyclonic circulation and distinct upper-atmospheric characteristics. ECLs are associated with high-impact weather, sometimes bringing extreme rainfall rates, storm force winds and large waves*. (10)

Due to their relative fast development and short life cycle, warnings issued for East Coast Lows will usually have less lead time than their tropical counterparts.

Typically, a land gale warning will provide 6-24 hours lead time of winds expected to average at least 65km/h over land or gust over 90km/h. Routine forecasts issued by the Bureau may also mention locally heavy rainfall and strong winds and dangerous surf in the lead-up to a significant event. (12)

More distant low-pressure systems can create hazardous conditions along foreshores as large swells can extend many thousands of kilometres from their generation zone. (12)

Historical examples of mid-latitude low-pressure systems

The July 2020 storms of Wamberal-Terrigal Beach on the Central Coast was the most destructive erosion event occurring from a major storm in the area. (19)

The storms impacted numerous properties and 54 residents were evacuated. (19) Coastal infrastructure was damaged and emergency rock works were undertaken to ensure that it would not be further damaged by wave action throughout the emergency event. (19)

The June 2016 storm caused varying degrees of erosion of the Collaroy Beach in the Northern Beaches, NSW. (20) As the system moved south and further offshore, the wavelength and the intensity of the system developed, causing serious erosion at Collaroy Beach. (20)

The Beach had previously been identified as an "Immediate Impact Zone" and had no seawall in place. (20) Major beach erosion occurred along the 100m fronting the Stuart/Ramsay Street sector. (20) It is estimated that between 12,000 and 14,000 m^3 of coastline was eroded from the region during this event. (20)

A rapid assessment of the erosion escarpment indicated the need to evacuate residents from Stuart and Ramsay Streets and activation of the Emergency Sub Plan. (20)

The April 2015 storms which comprised of two successive East Coast Lows within a threeweek period. This was the most severe East Coast Low setup in NSW since 2007.

The first low caused widespread rainfall, priming catchments in southeastern NSW.

The second of the lows formed off the Hunter coast, staying near stationary and causing severe weather across the Sydney and Hunter regions.

High localised rainfall of approximately 436mm in two-day totals at Maitland and prolonged severe winds caused very widespread damage to power distribution and telecommunications networks, as well as fatal and damaging flash flooding in Maitland, Dungog, Greta, and Stroud. (21)

The "Queens Birthday Storm" of June 2007 that saw torrential rain with 466mm at Mangrove Mountain, and 350mm in the suburbs of Newcastle in a 36-hour period.

Mean wind on the coast surpassed 83km/h with gusts up to 130km/h along with massive sea swells causing major coastal erosion. 9 deaths and the grounding of the bulk carrier "Pasha Bulker" at Newcastle also resulted from this extra-tropical low-pressure system. (22)

The August 1986 storm, which brought Sydney's highest ever 24-hour rainfall of 327.6mm (23). This caused damage to around 10,000 homes and severely disrupted transport as a result of flooded roads, leaving many people stranded in Sydney City. (23) Electricity supply problems were also reported along with other property damages. (23)

Further shifts in wind direction subsequently caused heavy rains in the Blue Mountains, and flooding in the Cox and Groser rivers. (23) Damage costs in 1986 were estimated by the Insurance Council of Australia to have been $35 million (equal to $215 million in 2011). (23)

The "Sygna Storm" of May 1974, which produced a 165km/h wind gust at Nobby's Head and beached a 30,000-tonne coal carrier on Stockton Beach. (24) Winds of up to 70 miles per hour and the largest swell conditions ever seen at the port's entrance were recorded, with a wave height of 17m. (25)

Figure 7: The "Pasha Bulker" bulk carrier grounded at Newcastle, following the Queen's Birthday Storm of June 2007. This storm was caused by an East Coast Low. (33)

LOW-PRESSURE TROUGHS

Regions of low-pressure that do not possess a closed circulation are known as low-pressure troughs. Although they lack the strong winds typical of cyclones and East Coast Lows, these systems are often the focus for thunderstorms and rain. (12)

Troughs on or near the east coast, combined with very strong onshore winds, have been responsible for very severe flash flooding events such as at Coffs Harbour in November 1996 and Wollongong in August 1998. (12)

The 1998 low-pressure trough moved along the central and southern NSW coast, resulting in a thunderstorm dumping heavy rains over the Wollongong area. (26)

Figure 8: Damage to homes in Wollongong following low-pressure troughs causing flash flooding (1998) (26)

Major impacts included mudslides, railway embankment failure, flooding of homes, coastal erosion, power outages, fallen trees, and 1 fatality. (26)

COLD FRONTS AND SOUTHERLY BUSTERS

Frontal activity can produce strong winds that generally shift from the west or northwest around to the southwest as they pass a location. They are often the focus of thunderstorms.

On hot, dry, and windy days, fronts can pose serious problems in the control of bush fires as they sweep narrow fire flanks into raging fire fronts. Frontal passages can occur all year around, but are more prevalent during Winter and Spring. (12)

Southerly Busters are common during warmer months in NSW, mostly affecting coastal locations in the South Coast, Illawarra, Metropolitan Sydney, and the Hunter districts.

Southerly Busters are southerly winds gusting more than 54km/h, with a three-hour temperature drop of at least 5 degrees. (27) They typically form when a fold front passes over southeast Australia, with cool air becoming trapped against the mountains of the Great Dividing Range. (27)This creates a channelling effect as the southerly winds move north along the NSW coast. (27)

Generally, Southerly Busters reach maximum intensity between Nowra and Newcastle as it travels north. (27) Winds accelerate rapidly in the right conditions, with gusts of 74km/h or more during particularly strong busters. (27)

Winds following a southerly buster can be strong and gusty for several hours, with peak wind gusts of around 90-100km/h. In addition, temperatures can fall by 10-15 degrees, often in less than 1 hour. (27) Gusty conditions generally peak and settle within 30 to 60 minutes of the buster arriving. (27)

Historical examples of Southerly Busters

The strongest Southerly Buster on record at Sydney Airport occurred on **18 December 1948**, where maximum gusts reached 113km/h. (28)

The strongest gust recorded anywhere in NSW was at Port Kembla on **20 November 1973**, at 130km/h. (27) .

In **January 2006**, a southerly buster reached Sydney with a maximum gust of 95km/h. The maximum temperature at Observatory Hill that day was 45.2°C, the second highest on record. (28)

COLD OUTBREAKS

At times from late Autumn through to early Spring, significant outbreaks of cold air advance northwards over NSW resulting in unseasonably cold temperatures and snowfalls on the ranges, (including the Snowy Mountains, Blue Mountains and along the Great Dividing Range), sometimes as far north as the Queensland border.

Cold outbreaks produce snow and ice-related problems on roads over the ranges although they seldom result in deep snow conditions. Vehicles can be stranded on roads which are impassable, and communities can be isolated for hours or days. (12)

In June 2021, a low complex low-pressure system (a cold outbreak) passed over NSW, resulted in heavy rainfall over NSW South Coast and the Snowy Mountain regions, as well as widespread snowfall over the Great Dividing Range. (29)

Widespread snowfalls and blizzard conditions are often associated with persistent north westerly winds over the NSW Alps. These result in heavy accumulations of snow rather than mere showery falls that occur during a true cold outbreak.

Areas in the Alps can be cut off for several days by heavy snowfalls.

Figure 9: NSW SES vehicles are parked on a wet and icy road. Cold outbreaks can produce snow and ice-related problems on roads, impacting vehicles and community accessibility.

COASTAL EROSION

GENERAL

Adverse weather systems can produce storms that generate strong winds, large waves, and elevated ocean water levels along the NSW coastline. These conditions are generally short-lived but can result in extensive erosion along sandy beaches and seawater inundation where wave run-up overtops coastal dunes or sea defence barriers.

Large waves coinciding with elevated ocean water levels commonly results in conditions likely to result in erosion of beaches and inundation by the ocean. During storms, ocean water levels can be significantly elevated above the predicted astronomical tide, particularly due to the combined influences of strong winds (wind setup) and lowering of barometric pressure (barometric setup). The combination of wind setup and barometric setup is more commonly referred to as a Storm Surge..

Storm surge in NSW occurs because of intense low-pressure systems offshore of the NSW coast. These low-pressure systems include tropical cyclones, ex- tropical cyclones, and East Coast Lows.

COASTAL EROSION

Erosion is part of the natural response of a beach to changing wave and water level conditions. Storm wave attack can move significant quantities of sand offshore. The volume of unconsolidated (or sandy) material removed from a beach during an erosion event is commonly termed a “storm bite” or “storm demand”.

The NSW coast is highly vulnerable to climate change. 85% of the population of NSW live within 50km of the coast and already experience some flooding during higher tides. (30) Climate change is projected to make this flooding more common and severe, and is also projected to cause permanent inundation of low-lying areas. (30)

Climate change will increase coastal erosion and the recession of most sandy beaches. (30) Changes to climatic conditions and its effects will also affect coastal landforms and ecosystems, including oceans, beaches, estuaries, lagoons, and rivers. (30)

Climate change impacts will damage coastal ecosystems, coastal infrastructure and industries, coastal communities, and social and cultural activities. (30)

The extent of beach erosion during a particular storm event depends upon a variety of factors that include (but are not limited to):

- The wave conditions and elevated water levels generated by the storm.
- The presence of rip cells.
- The condition of the beach.
- The condition of dune vegetation which can influence the volume of sand in the dunes which help to buffer the effects of storm erosion.
- The presence and influence of adjacent headlands and coastal and offshore structures, which can modify local wave conditions and the supply of sediment.

Storm waves undercut the beach berm and frontal dune to form a pronounced erosion escarpment. Foredunes along the open coast of NSW have been measured to retreat by up to 20m after a single extreme ocean storm event or series of closely spaced storms.

The pronounced lowering of the beach berm during beach erosion events can expose rock outcrops and historical protection works which are normally buried and result in a high, near vertical erosion escarpment formed at the back of the beach.

Over time, near vertical erosion escarpments will slump typically to an angle of repose of between 30 and 35 degrees. Instability of the escarpment may pose a hazard to beach users following storms with recorded instances of beach users buried by the collapsing sand face.

Buildings and facilities located within the "active" beach system, or area subject to erosion, could be undermined, and if not designed for this hazard, may collapse.

In addition to the primary threat posed by erosion of the frontal dune, the remaining dune system immediately landward of an erosion escarpment will be subjected to a zone of reduced foundation capacity, the extent of which will generally be dependent on the height of the dune and the physical properties of the underlying soil mass.

After storms pass, the sand that has been eroded and transported offshore is generally not lost from the overall beach system. The sand is gradually returned onshore following the storm by lower swell waves.

On beaches which are in 'long term equilibrium', the amount of sand which returns to the beach is equal to the amount eroded during the storm. However, for a beach which is experiencing long term recession, the sand may not all be returned with an erosion scarp typically moving landward over time in response to storm activity.

Figure 10: Coastal erosion on a NSW coastline. (34) Climate Change is increasing coastal erosion and beach recession. Increased coastal erosion also affects coastal landforms and ecosystems.

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