Chapter Six:
Severe Storm

Lightning strikes through a roll cloud near Alstonville, New South Wales, January 2003
Photo courtesy: NSW Storms/Dave Ellem.

Severe Storm

Severe storms can range from isolated thunderstorms that affect only a few square kilometres to intense low-pressure systems that affect thousands of square kilometres. They can be associated with tropical cyclones, a type of low-pressure system originating over the tropical oceans (covered in Chapter 4), and can be a substantial contributor to flooding (covered in Chapter 5).

From 1967 to 1999, severe storms have been estimated to cost Australia about $284 million each year (BTE 2001), representing just over one quarter of the average annual cost of natural disasters in Australia. Storm damage is a significant issue for the insurance industry: paid insurance claims for severe storm damage are greater than those for tropical cyclones, earthquakes, floods or bushfires. Thunderstorms have killed over 770 people since 1824 (Blong 2005), and large-scale storms often cause deaths through flooding or shipwreck.




Damage caused by hail and wind, Brisbane, Queensland, January 1985
Photo courtesy: Emergency Management Australia.

Cars left stranded during a flash flood in Melbourne, Victoria, January 2004
Photo courtesy: Glenn Gibson.

A car lies crushed by a tree brought down by a storm in Fairfield, New South Wales, October 2003
Photo courtesy: NSW SES.

Storm damage to a building at Tara, Queensland, March 2007
Photo courtesy: Emergency Management Queensland.

This chapter deals in detail with aspects of severe storms not covered in earlier chapters, including the risk analysis process for tornadoes, hail and lightning risks. The impact of climate change on these phenomena remains a significant gap in understanding the risk associated with severe storms, and several other gaps are identified. The roles and responsibilities in minimising the impacts of severe storms are shared between governments and community members, with the media also playing an important role.

Hazard Identification

Severe storms are atmospheric disturbances usually characterised by strong and hazardous winds, frequently combined with heavy rain, snow, sleet, hail, ice and/or lightning and thunder. This definition includes unusual meteorological disturbances, such as tornadoes or waterspouts, caused by severe thunderstorms. Severe storms are defined in two broad categories: large-scale storms and thunderstorms.

On the largest scale, severe storms are associated with the intense low-pressure systems depicted on weather maps. These low-pressure systems are also called synoptic storms or extratropical cyclones. These systems, and the associated cold fronts, can bring hazardous winds and heavy rain that may extend over large areas, causing both local flash flooding and riverine flooding. Such weather systems may also cause coastal erosion, as a result of the combined effects of large waves and increases in the sea level because of storm tide.

Often, the main wind damage from these low-pressure systems occurs in coastal areas and along mountain ranges. A notable example is the severe storm that tragically affected the Sydney–Hobart yacht race in December 1998.

There are several types of synoptic storms that can be categorised as severe storms: mid-latitude lows and cold fronts, east coast lows and decaying tropical cyclones.

Mid-latitude lows and cold fronts form in the westerly wind band over the Southern Ocean. These affect Tasmania and the southern parts of Western Australia, South Australia, Victoria and New South Wales. They occur mainly between winter and early summer and commonly produce sustained gale force winds (exceeding 63 kilometres per hour) and gusts exceeding 90 kilometres per hour, reaching speeds as high as 150 kilometres per hour in exposed areas.

East coast lows form along the east coast from southeast Queensland to Tasmania. These systems are often quite small, usually only a few hundred kilometres across, and can be quite short lived (Holland and others 1987). East coast lows are most common during autumn and winter and can generate storm force winds (wind gusts exceeding 150 kilometres per hour), flooding and damaging seas.

Decaying tropical cyclones are discussed in Chapter 4. One example is the decaying Cyclone *Wanda*, which contributed to the 1974 floods in southeast Queensland.

Synoptic storms can exacerbate other hazards, such as bushfires. The strong winds associated with synoptic storms can heighten the likelihood of bushfires becoming destructive events. During winter months, deep low-pressure systems can result in snowfalls to very low elevations, which can cause serious stock and crop losses and significant disruption to communities that are not equipped to cope with heavy snowfalls.

The term 'thunderstorm' is a general term for relatively small-scale convective processes that develop when warm, humid air near the ground receives an initial upward push from converging surface winds and rises rapidly in an unstable atmosphere (as shown in Figure 6.1). Cumulonimbus clouds may rapidly develop, potentially reaching heights of up to 20 kilometres, with associated lightning, thunder, hazardous wind gusts, heavy rain and hail.

Thunderstorms are typically short lived (up to a few hours) and can be of limited size (up to 10 kilometres in diameter). They generally move in the direction of winds in the lower atmosphere, but not necessarily in the direction of the surface winds.

The most common region for thunderstorms in Australia is the tropical north, where the supply of warm, moist air is greatest (Figure 6.2). Southeast Queensland and eastern New South Wales also experience a significant number of thunderstorms, while southern Tasmania experiences an average of only five thunderstorms annually.

Thunderstorms may at times be arranged in lines several hundreds of kilometres in length (i.e. 'squall lines'), or in clusters. Thunderstorms may be embedded in synoptic storm systems or generated along cold fronts. The strong cold fronts that affect southern coastal areas during winter and spring may also spawn severe localised winds, including tornadoes that may be strong enough to unroof houses.

A 'severe' thunderstorm is a thunderstorm that produces one or more of the following phenomena (BoM 2007a):

- a tornado
- hail of diameter 2 centimetres or greater
- wind gusts of 90 kilometres per hour or greater
- very heavy rain leading to flash flooding.

Only about 10% of thunderstorms are severe, but these account for approximately 90% of the damage produced by all thunderstorms (BoM 2007a). All thunderstorms can produce lightning which can cause death, injury and damage.

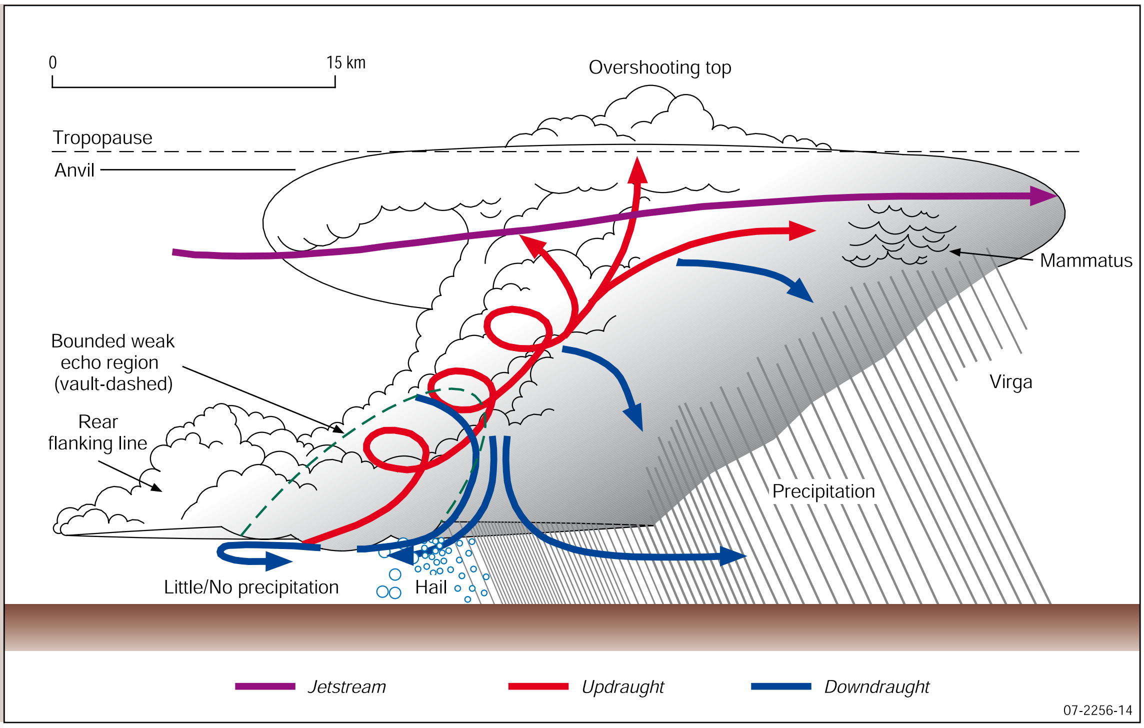

Figure 6.1: The development of severe thunderstorms
Source: Based on Rauber and others (2005), Figure 17.18.

Severe thunderstorms can occur at any time of the year, although they occur very rarely during the dry winter months in the north. Most thunderstorms strike between September and March, when the supply of solar energy is greatest. Severe thunderstorms linked to cold fronts also occur from autumn to spring in southwest Western Australia, southeast South Australia, Victoria and Tasmania. Severe thunderstorms are most common in New South Wales, Queensland and parts of Western Australia, and least common in Tasmania.

Useful introductory studies of the nature of severe storms and their occurrence in Australia are given in Colls and Whitaker (2001), Crowder (1995), and Sturman and Tapper (2006), as well as on the Bureau of Meteorology website (BoM 2007a). Reports of noteworthy storms are included in BoM (2004) and Whitaker (2006).

The meteorological phenomena associated with large-scale low-pressure systems (storm tides) and severe storms (lightning and thunder, hail, tornadoes, water spouts, damaging winds and flash floods) are described in more detail below.

Storm Tide

Strong winds pushing on the ocean surface and the reduced atmospheric pressure within a low-pressure system can cause the water to pile up higher than the normal sea level. The movement of the storm ashore can cause a storm tide, resulting from the combination of the surge, wave run-up, the astronomical tide and any freshwater flooding. Storm surges accompany a tropical cyclone as it comes ashore (as discussed in Chapter 4). They may also be formed by intense low-pressure systems, in non-tropical areas; or sustained winds blowing along the coastline, with the coast to the left, in the mid-latitudes, such as on the coast of South Australia. The worst impacts occur when the storm surge arrives on top of a high tide. Large waves generated by powerful winds can add to the impact of a storm tide.

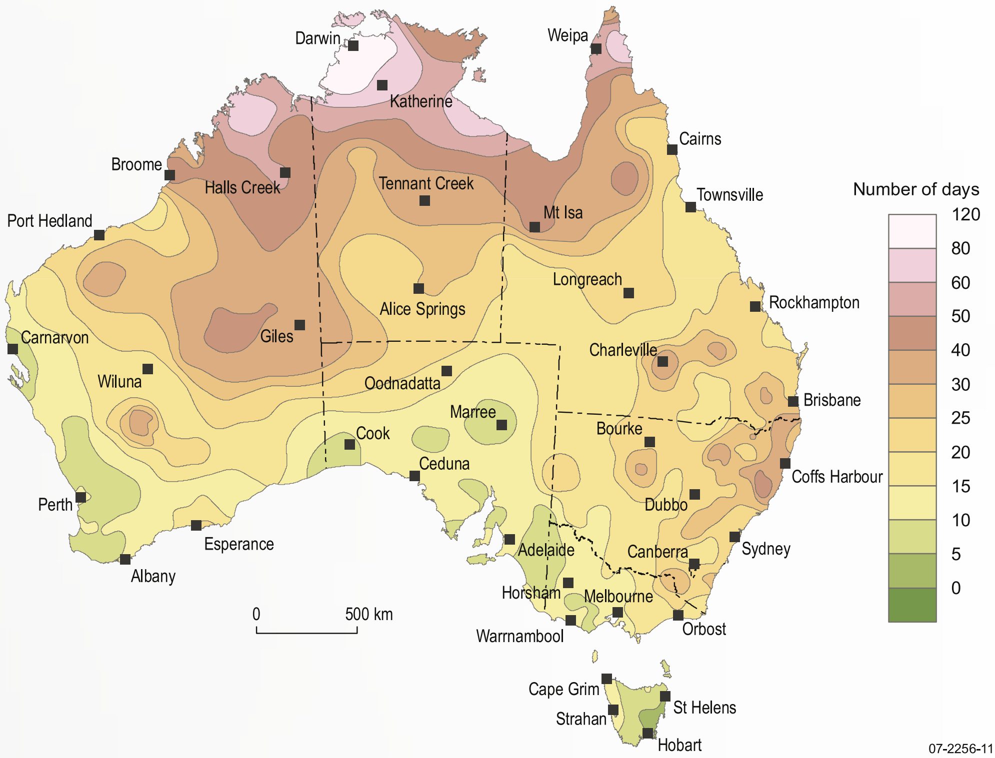

Figure 6.2: Average annual thunder-day map of Australia, derived from Bureau of Meteorology climatological records from 1990 to 1999
Source: Kuleshov and others (2002), Figure 2.

Devastation caused by the Bucca tornado north of Bundaberg, Queensland, November 1992
Photo courtesy: Emergency Management Australia.

Lightning and Thunder

Lightning and thunder are the defining characteristics of thunderstorms. Lightning can occur between the cloud and the ground, within the cloud, or from the cloud into the surrounding air. It is possible for lightning to strike the ground tens of kilometres from the thunderstorm, making it extremely dangerous.

Hail

Hailstones form in thunderstorms with a strong updraught when frozen rain droplets suspended in the updraught grow rapidly through accretion (Iribarne and Cho 1980). Hailstones larger than cricket balls have been recorded in Australia: for example, in Sydney in April 1999.

The potential for damage from large hail is clear. However, storms where there have been copious amounts of small hail have also caused property damage, because blocking of roof gutters and drains has led to inundation into roof spaces or the collapse of flat roofs. Examples include the hailstorms that struck Brisbane in May 2005 and Canberra in February 2007.

Tornado

Tornadoes are rapidly rotating columns of air that descend from the base of a thunderstorm, forming the recognisable funnel-shaped cloud. Tornadoes can range in size from a few metres to more than a kilometre. The winds associated with weak tornadoes can reach 125 kilometres per hour, but winds are estimated to exceed 400 kilometres per hour in the largest tornadoes.

While most common in North America, tornadoes are a global phenomenon that have been observed across Australia. Approximately 360 tornadoes were recorded in New South Wales from 1795 to June 2003 (BoM 2007b), but the incidence is certainly far greater given that many tornadoes occur in uninhabited areas and go unreported.

Tornadoes are usually thought of as being associated with severe thunderstorms in spring and summer. 'Cool-season' tornadoes occur in winter in the southern part of the continent, often associated with the passage of cold fronts and synoptic storms. They are generally different from those that occur in the warmer months; they are relatively weak, usually only rating F0 (estimated wind speeds of 62–117 kilometres per hour) or F1 (118–178 kilometres per hour) on the Fujita tornado scale (Fujita 1971), which is based on the extent and severity of damage. Some, such as the tornado in Collie, Western Australia, in April 1960, reach the F2 category (179–250 kilometres per hour).

The most intense tornado officially reported in Australia—the only example in the F4 category (334–419 kilometres per hour winds)—occurred at Bucca, Queensland, on 29 November 1992. Another intense tornado occurred in Brighton, a suburb of Melbourne, on 2 February 1918. In the few minutes that the tornado lasted, two people were killed and many others were injured. From the damage, wind speeds were estimated as being up to 320 kilometres per hour (BoM 2007a).

Water Spout

Water spouts are similar to tornadoes, but generally smaller and weaker, and are not necessarily associated with a thunderstorm (Crowder 1995). Water spouts moving over adjacent land have the potential to be dangerous and have caused both property damage and loss of life in Australia.

Damaging Wind

Intense low-pressure systems are able to generate damaging winds over a large area. The intensity of the winds may be enhanced on the exposed sides of mountain ridges, or downwind of mountains, because of atmospheric waves and turbulent eddies. These winds can also generate large waves on beaches, with persistent intense synoptic storms causing significant beach erosion.

Downdraughts from thunderstorms can generate short-lived wind squalls (i.e. 'downbursts') that can be much stronger and from a different direction to the winds experienced before or after the thunderstorm. Downbursts are a particular hazard to aviation.

Severe thunderstorms can, by definition, produce wind gusts of at least 90 kilometres per hour, but peak winds may exceed 160 kilometres per hour in the most damaging thunderstorms. The strongest measured wind gust during a thunderstorm is 196 kilometres per hour, recorded at Double Island Point, Queensland, on 16 December 2006.

Flash Flood

Strong low-pressure systems often have extensive rain bands associated with them. Such rain bands may lead to flash flooding, especially in

A crushed caravan following a storm in Coffs Harbour, New South Wales, October 2004
Photo courtesy: AAP Image/Bruce Thomas.

areas of steep terrain. The intense updraughts of thunderstorms can suspend huge amounts of rain before releasing a deluge; such rainfall can reach intensities of more than 200 millimetres per hour. Flash floods often result when the storm moves slowly, but the drainage and run-off characteristics of the ground determine the impact.

Cost of Severe Storm

Severe storms can occur anywhere in Australia, and they occur more frequently than any other major natural hazard. Synoptic storms can cause heavy economic losses as shown in Figure 6.3. They can impact large areas, particularly through associated flooding. However, a severe thunderstorm was responsible for the most costly storm event in Australia—the Sydney hailstorm of April 1999, with a total insured loss of approximately $1.7 billion (ICA 2007). Annually, severe storms cost approximately $284 million, exceeded only by the cost of floods (BTE 2001). The total cost of severe storms from 1967 to 1999 is estimated at $9.4 billion (BTE 2001).

Severe thunderstorms have resulted in over 770 deaths in Australia since 1824 (Blong 2005). Of those, 650 were attributed to being struck by lightning (Coates and others 1993). Other causes of death included being struck by a falling tree limb or drowning as a result of the capsizing of small boats. Contrary to the popular belief that tornadoes do not occur in Australia, tornadoes have caused 41 deaths (BoM/EMA 2004).

The number of deaths caused by synoptic storms is unknown. Many of the deaths associated with these large-scale storms are a result of shipwrecks (EMA 2007), but deaths may also have been attributed to flooding or severe thunderstorms embedded in a larger storm.

Potential Influence of Climate Change

Neither global climate models nor regional, high-resolution models are able to accurately capture thunderstorm characteristics. Therefore, it is difficult to infer the impact of climate change on thunderstorms using a modelling approach. One possible methodology is to use the large-scale environment parameters of climate models to infer the impact of climate change on thunderstorm numbers and severity. Results

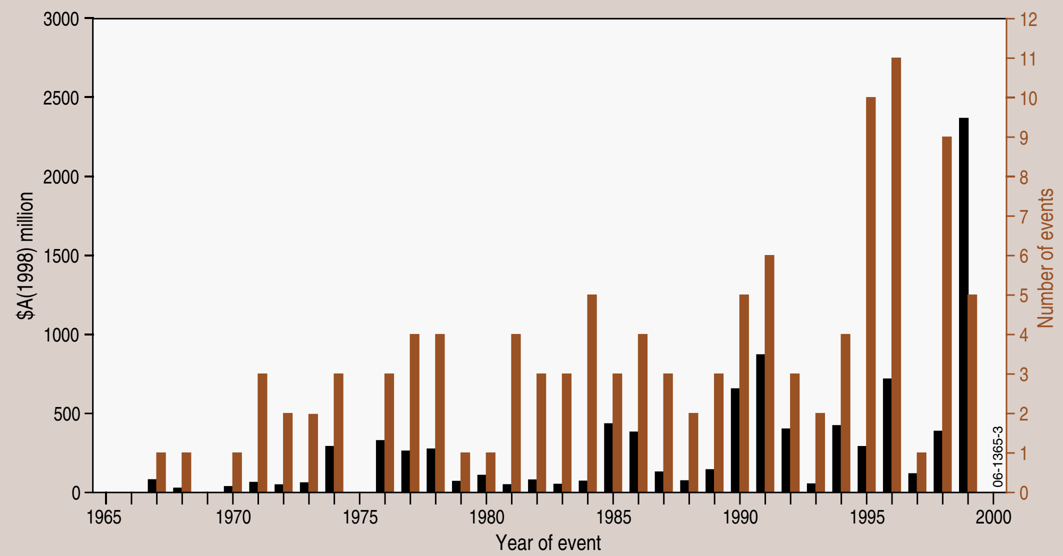

Figure 6.3: Annual cost and number of severe storms in Australia, 1967 to 1999
Source: Based on BTE (2001), Figures 3.18 and 3.20.

using this methodology indicate a decrease in the probability of conditions conducive to thunderstorm development over southern parts of Australia (Kounkou and others 2007).

The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report reported that trends had been observed in the intensity and frequency of synoptic storms, with increases observed in both cases (Trenberth and others 2007). Under future climate scenarios, the most consistent outcome is a southward shift in the tracks of these storms (Meehl and others 2007). There is little consensus on the likely frequency or intensity of synoptic storms in the future.

Cold fronts that traverse southern Australia are generally associated with synoptic storms located between 45 degrees south and 60 degrees south. This band of high storm activity is often referred to as the 'storm track'. Several recent studies show a poleward movement of the mid-latitude storm tracks with fewer but possibly more intense systems occurring along Australia's south coast (Yin 2005).

The potential impact of climate change on storm tides has been investigated along Victoria's eastern coastline (McInnes and others 2005; McInnes and others 2006). The studies found that, under the worst case scenario of wind speed change for 2070, the one-in-100-year storm tide event increased in height by about 0.18 metres on average, while sea level rise added a further 0.07–0.49 metres to the total sea level. In all regions of Australia's coastline, it is sea level rise rather than changes in the intensity of storms that will have the greatest impact on extreme sea level events in the future (as discussed in Chapter 4).

Risk Analysis

For synoptic storms, the impact of the individual meteorological elements, including winds, rain, lightning, large waves and embedded thunderstorms, will vary considerably within the storm. Thunderstorms are a more discrete event and their occurrence, along with their destructive features such as hail and lightning, can be considered more random. The analysis below considers the methods of modelling the likelihood of severe storms and the separate meteorological elements associated with severe storms. Models of vulnerability that are used to determine the consequences of the various hazards are described.

Likelihood Analysis

Because of the range of storm types—both synoptic storms and thunderstorms—and the range of phenomena these events can cause, there are no models which determine the combined likelihood of all these events.

One approach is to analyse the underlying meteorological conditions for the likely occurrence of severe storms or the destructive phenomena they bring (e.g. Kounkou and others 2007). For some hazards, such as hail, stochastic models of frequency are applied in risk modelling (Leigh and McAneney 2005).

The difficulty of developing a likelihood analysis for severe thunderstorms is highlighted in a comprehensive study of natural hazards for southeast Queensland (Harper and others 2001, p. 6.13):

'Whilst it can be anticipated that at least one damaging thunderstorm could have an impact somewhere in any given year, and that their impact could be both lethal and destructive, their impacts will tend to be localised and somewhat random in their distribution.'

A more realistic approach for both synoptic storms and severe thunderstorms is to study the risks from individual phenomena associated with severe storms. The processes specific to analysing the risk from each hazard are outlined below.

The collapsed part of the road along the Old Pacific Highway following a severe storm near Somersby in the central coast region, New South Wales, June 2007 *Photo courtesy: AAP Image/Dean Lewins.*

Wind gusts and tornadoes

Wind loading standards for Australia are based on analysis of extreme, three-second duration wind gusts recorded at observation stations (AS/NZS 1170.2:2002). The localised nature of tornadoes and other strong winds associated with severe thunderstorms may mean these events are not well represented in the observations, even with many years of record.

Substantial improvements to the assessment of risk can be made by improving the hazard assessment of severe winds. By using high-resolution terrain and topographic data, the regional hazard (e.g. from AS/NZS 1170.2:2002) can be modified to determine the site-specific hazard (Cechet and others 2007). In some cases, the regional hazard can also be modified to account for the distance from the coast (Lin and Nadimpalli 2005). Peak wind gusts for locations can be stochastically modelled using extreme value distributions, based on historical observations (Sanabria and Cechet 2007).

Probabilistic models of thunderstorm downburst occurrence can be used to determine the likelihood of damaging winds affecting structures such as power transmission lines (Oliver and others 2000; Harper and Hawes 2004). A detailed study of thunderstorm characteristics that was undertaken for the insurance industry in southeast Queensland identified the significant climatology elements in that area (Harper and Callaghan 1998).

No systematic assessment of the likelihood of tornadoes over all parts of Australia has been carried out. Lists of tornado events have been compiled in disaster databases held by agencies such as the Bureau of Meteorology, Emergency Management Australia and the Insurance Council of Australia, as well as the computer tool PerilAUS, a searchable database prepared by Risk Frontiers.

Analysis of historical records can provide valuable information on the regional likelihood of damaging wind events. For example, Foley and Hanstrum (1990) analysed press reports of severe local wind storms, combining tornadoes and damaging downbursts, during the cooler months in the southwest of Western Australia. An alternative method to assess the frequency of severe local wind storms is to identify the atmospheric environmental features in which they occurred (Hanstrum and others 1998).

Lightning

Lightning strikes have the capability to destroy life and property almost instantaneously. As lightning is the defining characteristic of thunderstorms, the likelihood of lightning strike is closely related to the likelihood of thunderstorms. Because of the slightly different characteristics between thunderstorms in the tropics and the mid-latitudes, thunderstorms across northern Australia tend to generate more lightning.

Hail

Primarily, models of hail occurrence are closely related to models of thunderstorm occurrence. Models of loss caused by hail are generally based on stochastic models of hailstorm frequency (Leigh and McAneney 2005). The main limitation of this approach is the lack of observations of hail size distribution over much of the country.

Flash flood

The likelihood of flash floods is closely linked to the likelihood of thunderstorms and synoptic storms. Flash flood is covered in greater detail in Chapter 5.

Storm tide

Storm tides can occur in coastal areas where winds associated with intense weather systems can blow over large bodies of water. Storm tide is covered in greater detail in Chapter 4.

Data requirements

The core data elements required are the meteorological observations of wind speed, including gusts, and rainfall rate; and visual observations of hail, thunderstorms and tornadoes. Hail size measurement and hail size distribution data are largely restricted to Bureau of Meteorology observation sites. Other types of meteorological data, such as radar echoes and lightning detection, may be useful as indirect data sources.

For large-scale storms the wind and rainfall patterns are reasonably well sampled by the observing network. However, due to the small scale of severe thunderstorms, and their generally very small impact areas, vital information on extreme wind gusts and hail size will require on-the-spot observations from those in the affected area, or indirect evidence from damage assessments.

Consequence Analysis

Severe storms can have several adverse impacts on a community and related infrastructure. These can include disruption of power supply, as a result of lightning strike or downed power lines, or flooding of property. Crop damage caused by severe winds, hail or heavy rainfall can result in significant economic impacts. Injury or death to humans and animals from both direct and indirect causes, such as lightning strike and flooding, are all too common consequences of severe storms. In this section, only residential building vulnerability is examined, though it is acknowledged that other assets are vulnerable to damage from severe storms.

Wind and hail vulnerability models for key infrastructure components are essential to the assessment of damage. Building vulnerability to wind is significantly influenced by the regulations in force at the time of construction. While tropical regions of Australia have seen marked changes in regulations that have led to significant reductions of wind vulnerability in recent decades, the regulatory changes in non-cyclonic

Hailstones compared with a 7 centimetre diameter cricket ball, Sydney, New South Wales, April 1999
Photo courtesy: Bureau of Meteorology.

regions have been more gradual and the changes to vulnerability have been correspondingly gradual.

For hail hazard, changes in roof materials, from the slate used during the Victorian period to less vulnerable modern metal sheeting have been driven by construction preferences rather than changes in building regulations. The age of a building is a useful indicator of what regulations are likely to have influenced its construction, as well as other vulnerability factors such as the likely deterioration of materials and the nature of roof construction. The lack of published vulnerability relationships is even more acute for hail than for wind (discussed in Chapter 4), although several consultants and researchers have developed models for commercial use.

Available residential wind models typically have been derived from empirical insurance data from a handful of tropical cyclone events, and relate the overall population damage loss to an incident peak gust wind speed. Vulnerability models for the types of exposed structures and shorter duration extreme winds associated with severe storm events outside tropical regions are essentially non-existent. However, some private risk consultants have developed non-cyclonic wind vulnerability relationships based on insurance loss data (Harper 2007).

Limited quantification of post-event damage has been undertaken, more recently for tornado-related winds (Edwards and others 2004), but this work has been limited by the reliability of assessed local wind speed data. Notwithstanding these limitations, a small number of relationship models for severe storm events have been derived heuristically through a series of wind vulnerability expert workshops (TimberED Services 2006). These models are presently being used by Geoscience Australia to obtain an emerging picture of non-cyclonic wind risk.

The currently employed wind vulnerability relationships are also limited in that they do not provide information on the variation in damage outcomes within a population. This variation influences the assessment of other impact measures, such as casualties and temporary accommodation requirements. Furthermore, the approach of utilising loss data and assessed causative wind speed provides some limited information on existing building stock vulnerability but not on the effectiveness of mitigation options.

To address these limitations, vulnerability relationships are being developed that are based on an understanding of the wind loads on building elements and of how buildings resist and transmit these forces. The outputs of this engineering modelling approach, applied in the first instance to North Queensland structures (Henderson and Harper 2003), are fragility curves that define the range of damage for a given gust wind speed. The engineering approach also provides a measure of the uncertainty of the vulnerability model predictions.

Data requirements

The vulnerability of buildings varies and depends on the material choice and architectural features, and the standard in place at the time of construction. Specific data on these key parameters are required to better understand the risks posed by severe wind and hail.

Insurance loss data are very valuable to the development and validation of wind vulnerability models. For hail damage, insurance data are the primary source of loss data, along with reliable information on the size of hail that caused the damage.

Other key data requirements concern the relationships between the meteorological phenomena and the losses incurred.

Information Gaps

Complete assessments of the risk posed by severe storms are hampered by several gaps in information. These include an understanding of thunderstorm behaviour, the influence climate change will have on severe storms, and the vulnerability of infrastructure and communities to the impacts of these events. The following section provides more details on some of these areas.

Behaviour of Severe Storms

Increasing the knowledge of the formation and behaviour of severe storms will greatly enhance the understanding of the risks they present. Increased observation of storms will provide more information on the storm formation regions and tracks, as well as the severe meteorological phenomena of damaging hail, wind gusts, heavy rainfall and tornadoes associated with severe thunderstorms.

Better knowledge of the near-surface boundary layer wind structure of severe thunderstorms is especially important, as current design standards do not completely cover this phenomenon. Much denser instrumentation than is presently available from the Bureau of Meteorology observation network is required to capture the climatology of these systems.

Detailed knowledge of the spatial distribution of hail frequency, size and damage is required to fully assess the risk to buildings and vehicles. A database of hail size distributions collected by observation in the aftermath of hailstorms would increase the information crucial to hail risk assessments for cities and regions beyond Sydney and Brisbane (Leigh and McAneney 2005).

Increased meteorological observations of thunderstorms will allow more detailed warning information to be disseminated to the public and emergency managers. For example, the increased use of Doppler radar information will improve the ability of forecasters to observe the signatures of downbursts, tornadoes and the presence and size of hail. The ability to accurately detect these signatures is a major step in increasing the lead time of warnings for these phenomena which will provide communities with more opportunity to take preventative action.

A tornado below a thunderstorm cloud in Port Hedland, Western Australia, December 1975
Photo courtesy: Bureau of Meteorology/Peter Mudra.

A severe thunderstorm approaching the beach suburbs of Adelaide, South Australia, December 1986
Photo courtesy: Emergency Management Australia.

Influence of Climate Change

It remains difficult to determine the influence of climate change on severe thunderstorms, largely due to the coarse resolution of existing climate models. Improvements in the resolution of climate models and the parameterisation of deep convection associated with thunderstorms will aid in improving estimates of changes in thunderstorm behaviour. There is also evidence that thunderstorm activity is modulated by El Niño–Southern Oscillation (ENSO). The interrelationship between thunderstorm activity and ENSO should also be fully explored.

One component of the influence of climate change on severe storms, a southward movement in the mean synoptic storm path, was reported by Yin (2005). Expected changes in the intensity of these synoptic storms are less clear. Changes in the frequency of east coast lows, decaying tropical cyclones and other synoptic storms also require investigation. Secondary impacts, such as changes to peak rainfall rates, may change under a future climate, and the magnitude of these changes also requires quantification.

Vulnerability Research

The range of infrastructure elements present in a typical community is very broad, and there are several gaps in the information on their vulnerability. The vulnerability of critical infrastructure components—such as power, telecommunications, water, sewerage, gas and transport—to the impact of severe storms remains unclear. Collaboration with private operators of these infrastructure components would greatly benefit future risk assessments.

There is a need to advance the present work programme on building vulnerability and to engage industry in a gap analysis of vulnerability definition. This process will enable targeted research to provide a more comprehensive range of vulnerability relationships and to give a more complete assessment of wind and hail risk.

An essential part of this vulnerability research is ongoing storm impact survey activity and the assessment of local wind speeds at the sites of individual infrastructure components. This activity provides loss data for the refinement of empirical models that are presently being used to assess wind risk to communities. It also identifies the range and predominance of failure types, and provides validation data for the more rigorous engineering approach. Post-disaster assessments also contribute a significant amount of information to the meteorological knowledge base. As these tools mature they will provide a means of assessing the most cost-effective measures for reducing community risk.

Roles and Responsibilities

The roles and responsibilities for minimising risk associated with severe storms cover all parts of the community, from government through to individuals. For many of the groups, the role in risk reduction remains static. However, the increased privatisation of utilities such as power, water and telecommunication services is one area where the responsibilities for risk management are changing.

Australian Government

The Australian Government has similar roles and responsibilities for reducing the risk posed by severe storms as it has for tropical cyclone and flood risk. The Australian Government provides severe weather warnings to minimise damage and injury to members of the public, as well as to industries such as agriculture, fishing, aviation and surface transport. Severe weather warning services are provided through radio, television and email, to authorities such as the police and emergency services, and to public access systems which include recorded telephone services, automated facsimile messages and the internet. The Australian Government also assists state agencies in disaster situations and acts as an overarching policy and educational resource for emergency services across the country.

After major events, Australian Government agencies work with state and territory agencies to conduct post-disaster impact assessments as part of research into improving knowledge of storm behaviour and impacts. The Australian Government also maintains a database of severe storms and the impacts of those storms.

State and Territory Governments

State and territory governments are responsible for the overarching planning laws and building regulations (administered through the Australian Building Codes Board) that ensure that infrastructure and housing are built to an acceptable level of resistance to severe storm impact.

State and territory governments, through the relevant emergency services agencies, work closely with the community to develop plans of action to minimise impacts. This includes logistical planning under various scenarios, developing structured chains of command, robust means of communication and evacuation plans. They also involve themselves in public education activities, such as presentations in open public forums, publication of brochures and media advertising. The focus of this public education is on action plans to reduce the risk of injury or material loss. The defensive action statements in Bureau of Meteorology warnings are provided by state emergency agencies.

Some variation exists between the states and territories, with some delegating greater responsibility to local agencies.

State Emergency Service volunteers assist with roof damage following a storm, New South Wales, January 1991
Photo courtesy: Emergency Management Australia.

A gustnado, a type of tornado on the leading edge of a wind squall, just ahead of a ragged shelf cloud, Melbourne, Victoria, December 1995   Photo courtesy: Bureau of Meteorology/Andrew Treloar.

Local Government

Local governments are responsible for town-planning decisions which are critical in ensuring that future development does not increase the vulnerability of the community. The planning responsibilities include keeping housing and critical or vulnerable buildings or facilities in safe locations.

Local governments, in collaboration with state government and Australian Government agencies, often lead the development of regional emergency management and disaster response plans. They also conduct community awareness and preparedness programmes aimed at reducing the impacts of severe storms. In the response and recovery phases, local government agencies are responsible for repairing and maintaining key infrastructure components.

Industry, Coordinating Groups, Professional Bodies and Research Institutions

Standards Australia has responsibility for developing relevant design standards, such as lightning risk and protection (AS 1768:2007), the Australian/New Zealand wind loading code (ASNZS 1170.2:2002) and the standard on wind loading of residential housing (AS 4055:2006).

The insurance industry has become increasingly active in risk assessment, including vulnerability modelling for residential buildings and vehicles. The overall increase in weather-related damage claims, and the IPCC's indication that there will be a continuing increase in climate extremes (Solomon and others 2007), has caused some insurance companies to take a strategic view of their future operations (Lloyd's 2007).

Lightning and wind damage can cause major interruptions to electrical power transmission. The power industry has an interest in risk assessment and mitigation activities, and has been active in public awareness campaigns, particularly in New South Wales and Queensland. Some power companies have already undertaken extensive risk assessments of their networks and become proactive in monitoring thunderstorms and taking measures to respond to disruptions.

Telecommunications may also be disrupted by severe storms. Issues for telecommunications companies are sustainable supply of communications infrastructure, and awareness of the risk related to telephone use during thunderstorms.

Property Developers

There are planning issues relating to property development in areas prone to flash flooding or coastal areas subject to erosion resulting from the action of large waves. The risks of high wind and large hail should be considered in building design.

Courts and Legal Institutions

The courts play a role in settling litigation among parties seeking compensation for damage caused by natural hazards.

Media

The media play a vital role in delivering Bureau of Meteorology forecasts and warnings. During severe thunderstorms, radio is quite often the most effective medium for distributing warnings. Media outlets can also play an educational role, distributing information on mitigation actions the general public can take in advance of severe storms, such as tidying properties at the start of the thunderstorm season.

General Community

A network of approximately 3000 volunteer storm spotters, who provide valuable reports of severe weather to weather forecasters, is coordinated by the Bureau of Meteorology.

Individuals have a basic responsibility to be aware of any storm risk posed to them. Property owners are responsible for the continued maintenance of houses to reduce the potential damage suffered in severe storms. Individuals should also know how to respond effectively to severe weather warnings.

Conclusion

Severe storms represent approximately 26% of the average annual cost of natural disasters in Australia, costing around $284 million each year. They have been responsible for some of Australia's costliest natural disasters and caused over 770 deaths. The responsibility for reducing the impact of severe storms is shared across all levels of government, while state and territory governments often lead the response to severe storms through their emergency services agencies.

Risk assessments for severe storms require a wide range of hazard models, because of the number of damaging phenomena these events can produce. As for tropical cyclones, the risk models must also comprise information on the vulnerability of buildings and other infrastructure to the hazards associated with severe storms.

The phenomena which cause the greatest impact, such as large hail, extreme winds (including tornadoes) and heavy rainfall that induces flooding are highly localised. The records of many of these events are based on their impacts rather than direct measurement by weather instruments. This limits our ability to conduct accurate likelihood analyses for these events, which in turn affects the risk analysis.

Advances in technology such as satellites and radar are improving observations and will contribute to improved assessments of the level of hazard. The improved observations will also permit a better assessment of the influence that climate change may have on severe storms. Further research into the likelihood of destructive phenomena such as hail will greatly benefit future analysis of risk. The vulnerability of buildings and other infrastructure, such as power supplies and telecommunications, also requires significant research to improve analysis of severe storm risk.

A State Emergency Service volunteer next to a large tree that has fallen on to a house during storms in the central coast region, New South Wales, June 2007 Photo courtesy: NSW SES.