THE 1999 SYDNEY HAILSTORM: 10-YEAR RETROSPECTIVE

RMS Special Report

INTRODUCTION

On April 14, 1999, a supercell thunderstorm developed south of the New South Wales (NSW) capital city of Sydney, Australia. As the storm moved through the densely populated eastern part of the city, lightning, high winds, heavy rain, and large hailstones were observed. According to Emergency Management Australia (EMA), the winds, rains, and in particular, the large hail associated with storm damaged 24,000 homes and 70,000 automobiles along its path (EMA, 2007; Figure 1). At the time of the 1999 Sydney Hailstorm, the insured loss totaled AUD$1.7 billion (US$1.04 billion), and this cost remains the largest absolute insured loss in Australian history (Insurance Council of Australia, 2009). If one considers population, inflation, and wealth adjustments, it still ranks third behind 1989's Newcastle Earthquake and 1974's Cyclone Tracy (Crompton and McAneney, 2006). The hailstorm affected an approximate 130,000 individuals and caused one death, when a fisherman's boat was struck by lightning.

The event was remarkable in a number of ways, including the timing of its occurrence, the track of the storm, and the size of the hailstones. Occurring in mid-April, outside the conventional hail season lasting from September to March, the 1999 storm also occurred late in the day, hitting the Sydney area just before 8 p.m. local time. This is an unusual time to strike, as hailstorms most commonly occur in the late afternoon between 2:00 pm and 6:00 pm due to atmospheric conditions (Schuster et al., 2005a). The storm dropped the largest hailstones ever recorded in the region, described as the size of "grapefruit," "melons," or "cricket balls", with the largest official hailstone measuring 9 cm (3.5 in).

Ten years later, Risk Management Solutions (RMS) revisits the 1999 Sydney Hailstorm, investigating the storm's origins, its development over the region, and the resulting damage and property loss. The report discusses the vulnerability of Australia's building stock to hail damage, as well as the recurrence probability of similar-sized events in the future. Finally, the impacts of the 1999 storm on risk modeling and management are highlighted.

Figure 1: Blue covers on roofs damaged by hail during the 1999 Sydney Hailstorm (Source: Emergency Management Australia)

SEVERE CONVECTIVE STORM RISK IN AUSTRALIA

Severe convective storms are a common occurrence in Australia and can produce damage from large hailstones, straight-line wind gusts, lighting strikes, flash floods, and tornadoes. Convective outbreaks can range from the local development of a single thunderstorm to large multi-day, multi-state events that can cause billions of dollars in insured losses. The Australian Bureau of Meteorology (BoM) defines a severe convective storm as a thunderstorm which produces any of the following: hailstones greater than or equal to 2 cm (0.8 in) in diameter; wind gusts equal to or greater than 90 km/hr (56 mph); flash flooding; or one or more tornadoes. While there are thousands of thunderstorms each year, only 10% are classified as severe. Furthermore these severe thunderstorms are responsible for 90% of the convective storm damage to people and property in Australia (Bureau of Meteorology, 2009a).

As the different convective storm perils (i.e., hail, wind, flood, lightning, and tornado) vary considerably, the type and scope of damage in each individual event varies as well. For instance, the January 21, 1991 storm that impacted Sydney was predominantly a straight-line wind event, while the 1990 and 1999 events were dominated by hail.

Large hailstones, defined as 2 cm (0.8 in) in diameter or greater, are common in the state of New South Wales (NSW) and the Australian Capital Territory (ACT) located within the boundaries of NSW (Figure 2). From 1990–2003, an average of 45 reports of large hailstones were reported each year across the districts within NSW—with the largest confirmed hailstone reported in 1991 in the district of Northern Rivers and measuring 14 cm (5.5 in). According to Schuster and others (2005a), from 1968 to 2005, the damage from hailstorms (i.e., hail producing severe convective storms) was responsible for over one-third of total insured loss from all natural hazards across Australia, which includes bushfire, cyclone, earthquake, flood, landslide, severe weather, tsunami and volcano. Moreover, 75% of these insured losses occurred in the state of NSW.

Figure 2: Location map of the state of New South Wales (NSW) and the Australian Capital Territory (ACT) in Australia

Comparison to U.S. Severe Convective Storm Risk

While the perils associated with severe convective storms in Australia and the United States are the same—hail, tornado, flash flood, lightning, and straight-line winds—there are some marked differences in the risk from the various perils.

Straight-line winds in the U.S. and Australia are caused by downbursts from individual storm cells. However, in the U.S., bands of thunderstorms can become organized to produce large-scale, long-lived, straight-line windstorms, called derechos. In contrast, no derechos have ever been reported in Australia.

While Australia does experience tornadoes, it is rare that there is a tornado event on the scale of outbreaks in the U.S., such as the "Super Tuesday" outbreak of February 5–6, 2008 in the Southeast U.S. (For more information, see Risk Management Solutions, 2009). According to the U.S. National Oceanic and Atmospheric Administration (NOAA), 75% of worldwide tornadoes occur in the U.S. In Tornado Alley[1] of the U.S., 42% of the average 40 tornadoes per year (for every 100,000 km^2 or 38,600 mi^2) reach F2 strength or higher on the Fujita Scale[2]. Australia experiences, on average, 8 tornadoes per year for every 100,000 km^2, with approximately 20% to 30% of these tornadoes reaching F2 strength or above on the Fujita Scale (Geerts and Linacre, 1998).

Hail climatology varies enormously across the U.S., as evidenced by research compiled at NOAA's National Severe Storm Laboratory (NSSL) (Brooks, 2009). Therefore, a straightforward comparison between hail risk in the U.S. and Australia cannot be made. Moreover, historical hail data sets suffer from biases toward populated areas and biases in reported hail sizes, due to comparisons with common objects, such as coins (Schuster et al., 2005b) that vary from country to country.

A simple analysis of the Australian Bureau of Meteorology (BoM) severe storm database against the NSSL research indicates that the frequency of large hail (≥ 2 cm or 0.8 in diameter) and the frequency of giant hail (≥ 5 cm or 2 in diameter) in the Sydney region, in the lee of the Great Dividing Range, is comparable to that of Hail Alley, located in the lee of the Rocky Mountains of the U.S., where the states of Colorado, Wyoming, and Nebraska meet. In addition, Sydney's hail activity is comparable to that of Kansas, but not as frequent as hail events occurring in Oklahoma and northern Texas.

[1] Tornado Alley is the general area of the Central U.S. between the Rocky Mountains and Appalachian Mountains; in this reference, the states of Oklahoma and Kansas are considered within the 100,000 km^2.

[2] The Fujita Scale or Fujita-Pearson Scale, first developed by Ted Fujita and Allen Pearson in the early 1970s, measures the strength of a tornado based on the damage it causes. Notably, the Enhanced Fujita (EF) Scale was implemented in the U.S. in 2007 to replace the Fujita Scale.

THE 1999 SYDNEY HAILSTORM

Development and Characterization of the Storm

There are three basic meteorological conditions needed to develop and sustain a severe convective storm: instability, a trigger, and wind shear. First and foremost is instability—warm, moist air near the Earth's surface trapped beneath cooler, dryer air at higher levels by an inversion. For the storm to develop, however, a trigger such as a front, a sea breeze or flow over a mountain range is needed to provide localized lifting strong enough to carry surface air above the inversion. Once this happens, free convection can produce storm clouds with tops 10 to 15 km (6.2 to 9.3 mi) or higher. Finally, wind shear is needed to organize the updrafts and downdrafts to prevent the storm from collapsing onto itself. When conditions are favorable, many individual storm cells can form.

Several storm cells formed on April 14, 1999. The strongest of these was classified as a "high precipitation supercell" by the Australian Bureau of Meteorology (BoM). Supercell thunderstorms are characteristically quite different from other types of thunderstorms; they are the largest, longest-lasting type of thunderstorms, which are capable of producing very large hailstones. The 1999 Sydney Hailstorm lasted over 5 hours, traveling over 160 km (100 mi) from Berry to the east of Gosford in New South Wales. The storm dropped an estimated 500,000 tons of hailstones (Steingold and Walker, 1999), with measurements as large as 9 cm (3.5 in) in diameter in Sydney's eastern suburbs (Figure 3), the largest ever recorded in the Sydney area. Reports of hailstones up to 13 cm (5.1 in) in diameter were reported, though unconfirmed. Giant hailstones (≥ 5 cm in diameter) were reported as far south as Port Hacking and as far north as McMasters Beach. At its widest point, the hail swath producing giant hail was 7 km (4.3 mi) wide, and was at least 28 km (17.4 mi) long. The hail swath dropping large hailstones (≥ 2 cm in diameter) was 10 km (6.2 mi) wide at its broadest point and at least 58 km (36 mi) in length. While the storm was primarily a hail event, it also brought with it strong winds and rain.

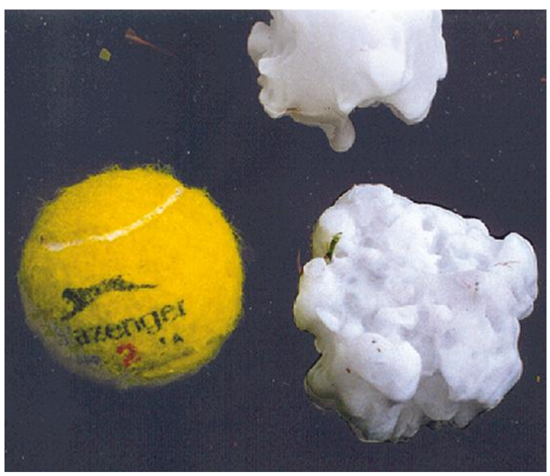

Figure 3: Hailstones from the 1999 Sydney Hailstorm, alongside a tennis ball, illustrating the large size of the hailstones (Source: Australian Science and Technology Heritage Centre)

Synopsis of the Storm[3]

The storm developed around 4:25 p.m. local time on April 14, 1999, over land near Berry, approximately 115 km (71.5 mi) south-southwest of Sydney. Following the steering winds, the storm tracked northeast (NE)

[3] This synopsis is derived from the Australian Bureau of Meteorology's report on their forecasting and warning performance during the 1999 Sydney Hailstorm (Bureau of Meteorology, 2009b).

toward the coast. Approximately 50 minutes later, at 5:05 p.m., the storm matured into a severe thunderstorm as it tracked just west of Kiama, traveling at 26 km/hr (16 mph) and dropping significant amounts of hail. Ten minutes later, at approximately 5:25 p.m., the storm reached the NSW coast, gaining speed as it moved farther from the coast. The storm was expected to continue tracking northeast out to sea, where it was forecast to dissipate.

However, at 5:45 p.m., the storm, which was still largely offshore, changed direction to a north-northeast (NNE) track, re-intensifying as it tracked parallel to the coast. The storm's western edge reached Wollongong around 6:05 p.m. as a severe thunderstorm. The storm then tracked parallel to the coast in a NNE direction for the next 70 minutes, until the storm's center neared land again around 7:15 p.m. just to the east of Bundeena, traveling at a speed of 37 km/hr (23 mph). Over the next hour and thirty minutes, the severe thunderstorm tracked across the coastal and eastern suburbs of Sydney, tracking east of the Sydney Airport around 7:45 p.m. (Figure 4), weakening briefly after crossing the Sydney Harbour and shifted to track due north. The storm re-intensified just south of Mona Vale around 8:35 p.m., changing back to its more prominent direction of NNE.

Finally, the storm started to move offshore around 9:05 p.m. as it passed to the east of Pittwater, weakening as it moved over the water. The storm continued to weaken as it traveled along a NE track farther out to sea. At 9:55 p.m. local time, the storm began to collapse and had dissipated by 10:00 p.m.

The first storm cell was followed by a second system, which developed in a similar location. This system tracked northeast—a path slightly to the east of the first storm. This storm was significantly weaker than the first, never reaching severe classification or acquiring supercell characteristics like its predecessor.

Rainfall

Analysis of the rainfall that fell over Sydney on the evening of April 14, 1999, shows three distinct heavy rainfall events. The rainfall associated with the first, supercell storm, between 7:30 p.m. and 9:00 p.m., was relatively light as the storm entered the Sydney metropolitan area, with 1.5 cm (0.6 in) of rain in 20 minutes at Caringbah, NSW, south of Sydney. The rainfall intensified as it crossed the city, dropping 3.9 cm (1.5 in) in 20 minutes by the time the storm reached Warriewood to the north. The heaviest rainfall, which occurred just after 9:30 p.m., was associated with the second storm system; the reported flash flooding in Bondi, a suburb of Sydney along the coastline, was likely due to this second storm. Lastly, the third and smallest rainfall event was from less intense storms which moved across Sydney just before midnight.

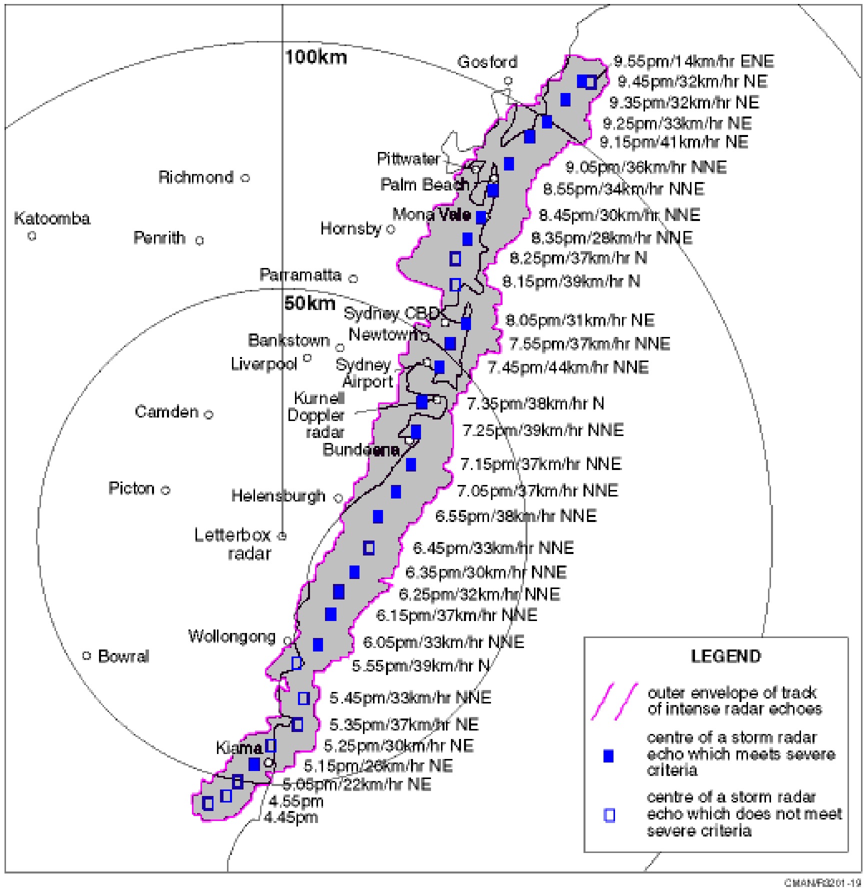

Figure 4: Track of the 1999 Sydney Hailstorm, derived from radar data; location, speed, and direction of the storm are shown at 10-minute intervals, starting at 4:45 p.m. and ending at 9:55 p.m. local time on April 14, 1999 (Source: Bureau of Meteorology, 2009b)

Unique Characteristics of the 1999 Sydney Hailstorm

While it is possible for severe convective storms in New South Wales to occur at any time of year, the required meteorological conditions and favorable weather patterns for severe convective storm development occur more frequently in the warmer spring and summer months. An analysis of severe thunderstorm days in New South Wales from 1989 to 2006 illustrates this seasonality, showing a tendency for severe thunderstorms to occur during the months September through to March (Figure 5(a)). There is also a tendency for severe thunderstorms to occur in the afternoon, when the daily heating of the Earth's surface by the sun is at a maximum (Figure 5(b)).

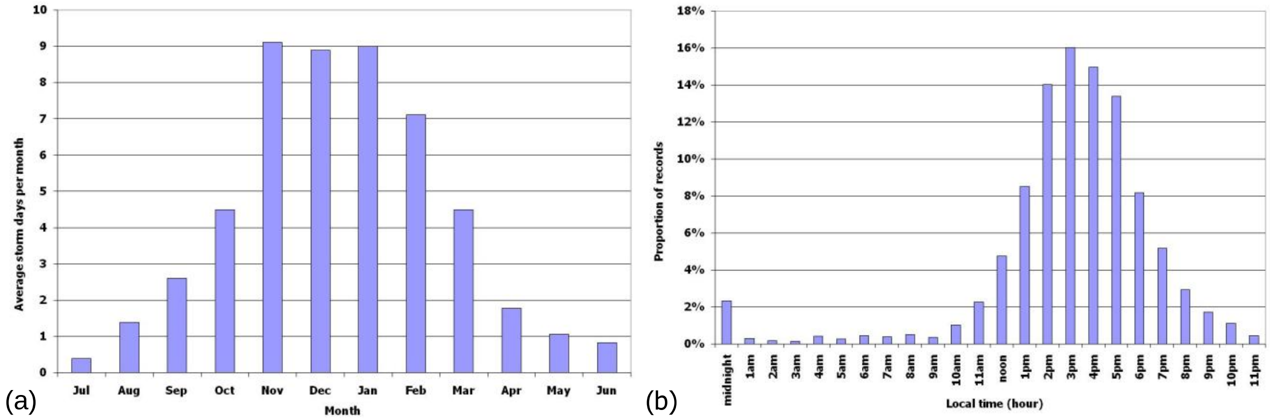

Figure 5: Distribution of severe convective storms in NSW: (a) on a monthly basis (i.e., average storm days per month) and (b) on an hourly basis (i.e., as a proportion of all records). Note that the spike at midnight is associated with a default for an uncertain, overnight time in the BoM severe storm database.

The 1999 Sydney Hailstorm was a highly unusual—though not unprecedented—severe storm, occurring outside the typical time of year (April) and time of day (4:25 p.m. to 10:00 p.m.). The 1999 storm was only the fifth recorded hailstorm to hit Sydney during April over the past 200 years with hail larger than 2 cm (0.8 in) in diameter. Moreover, the atmospheric conditions present early on April 14, 1999 gave few clues as to what was to happen later in the day. While conditions could not be considered unfavorable for storm development, they were not so favorable as to warrant major concern. As a result, the Sydney Regional Forecasting Centre (RFC) of the Australian BoM did not issue Severe Weather Warnings during the development of the storm (Bureau of Meteorology, 2009b).

The track the storm followed was also rather unusual. Most severe storms in the Sydney region track in a roughly west-to-east direction. The 1999 storm tracked predominantly south-to-north, as evidenced by the hail footprint.

DAMAGE AND LOSS FROM THE 1999 SYDNEY HAILSTORM

The 1999 Sydney Hailstorm resulted in an estimated AUD$2.2 billion in damage (EMA, 1999; in 1999 dollars), making it Australia's most costly severe convective storm to date. With insured losses reaching AUD$1.7 billion, it is additionally the largest absolute insured loss in Australian history.

According to Emergency Management Australia (EMA), 130,000 people were affected by the 1999 Sydney Hailstorm, with 500 left homeless (EMA, 2007). A total of 50 people were injured and there was one fatality, which was attributed to lightning. Approximately 24,000 homes, 70,000 vehicles, and 2,800 commercial and industrial buildings were damaged by the storm, with over 90% of the damaged homes and vehicles insured. Additionally, 23 aircraft and several hangers at Sydney Airport were damaged due to the storm, resulting in severe air transport delays. At the peak of disruption, approximately 15,000 homes were without power along the Sydney coast from Engadine to Narrabeen, NSW.

Drivers of Damage

The severe convective storms of April 14, 1999, produced giant hail, strong winds and rain. One of the main reasons the 1999 Sydney Hailstorm caused so much property damage is the high concentration of exposure affected by the storm. Sydney, the state capital of New South Wales, is the most populous city in Australia. According to the Australian Bureau of Statistics, the 2007 metropolitan area population (the latest figure available) was approximately 4.3 million people. In 1999, at the time of the event, the population was approximately 4 million people. The area principally affected by the storm has a mixture of commercial, industrial, and residential properties. The commercial and industrial facilities were highly concentrated toward the inland side of the hail swath, and older, relatively affluent housing was concentrated toward the coast. The roofs on these residential structures were predominantly terra-cotta tiles, which are easily damaged by large hailstones. As a result, many of these buildings suffered serious damage to their roofs, and subsequent rain damage to the building interiors and contents. Similarly, many of the industrial buildings had asbestos fiber cement roofs, which also perform poorly under the impact of large hail (Steingold and Walker, 1999).

However, the impact from the storm could have been significantly worse. The storm's path tracked over several large open areas, such as parks, golf courses, and a race course, resulting in gaps between areas with major damage. Had the storm tracked a few kilometers to the east or west, the resulting damages would have been far greater, with many more impacted properties (Figure 6). Moreover, if the 1999 storm had struck earlier in the afternoon, more injuries could have potentially occurred, as happened during the 1947 Sydney Hailstorm on New Year's Day. On New Year's Day 1947, large hail from the storm caused hundreds of injuries at Bondi Beach from hailstone impacts and flying debris, particularly broken glass, hospitalizing many individuals who were enjoying the holiday (Whitaker, 2005).

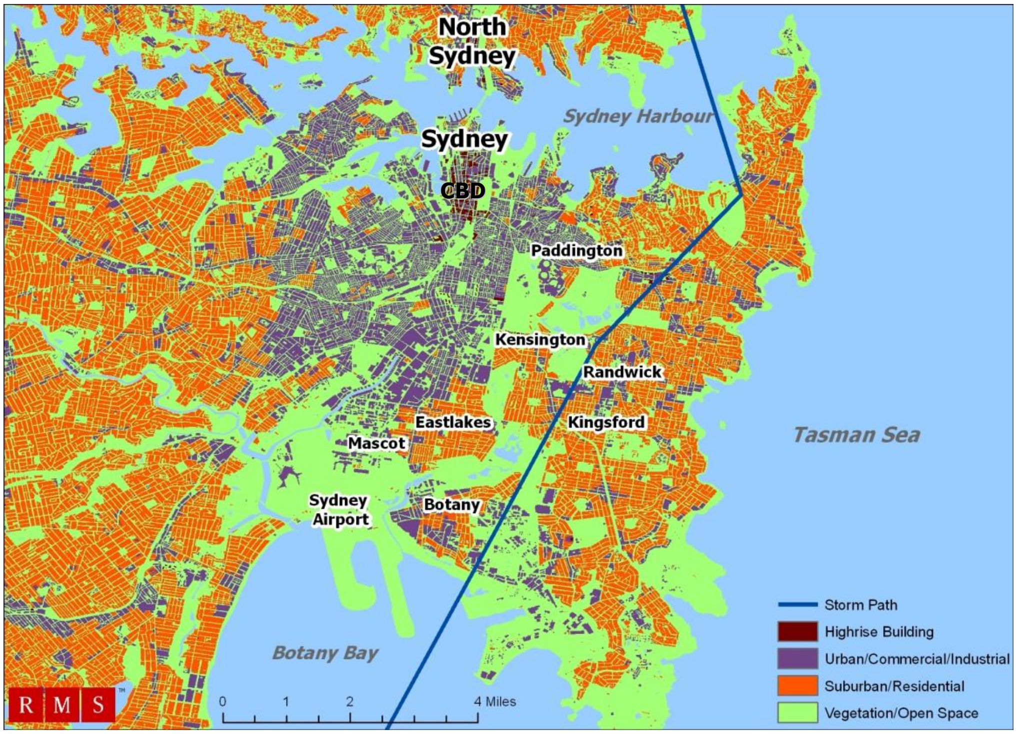

Figure 6: Map illustrating the concentration of exposure in Sydney and the worst-affected suburbs, with the path of the 1999 Sydney Hailstorm highlighted

Property Damage

Major hail damage to buildings and vehicles was experienced in 85 Sydney suburbs. The areas experiencing severe hail extended from the Sydney Airport to the central business district (CBD). The worst affected regions included the southeastern and eastern suburbs of Kensington, Eastlakes, Kingsford, Botany, Mascot, Randwick, and Paddington (Figure 6). The Eastlakes and Kensington areas experienced the heaviest concentration of damage, with some streets experiencing damage to every home.

The hail from the 1999 event broke roof tiles, skylights, and solar panels, as well as damaging antennas and gutters. Windows were also broken by hailstones, and some external walls were dented. Many houses suffered water damage, as rain poured through the holes in the roofing caused by the hail, causing damage to the homes' interiors, saturating carpets and walls, and destroying the contents. Some ceilings completely collapsed under the weight of the broken tiles and water-saturated insulation. Much of the water damage to homes was due to the second, smaller storm which passed over Sydney two hours after the main event, as this storm was primarily a heavy rainfall event.

Many vehicles suffered broken windshields and dents to the bodywork (Figure 7), and several motorists became trapped by floodwaters.

Figure 7: Damage to a car roof as a result of the 1999 Sydney Hailstorm (Source: http://ozthunder.com/chase/chase13.htm)

It took up to 2 weeks to cover every damaged roof with tarpaulins to protect the buildings from the elements (Figure 8 and Figure 1). However, further damage was experienced in the subsequent weeks as more strong winds and heavy rains tore away the tarpaulins, allowing more water into the buildings. Many tarpaulins had to be refitted each time they were blown loose by strong winds, multiplying the workload of the emergency responders.

Figure 8: Tarpaulins covering the roof of a residential structure in the eastern suburbs of Sydney following the 1999 Sydney Hailstorm (Source: http://willoughby.ses.nsw.gov.au/Hail.html)

Insured Loss

Approximately 60% of the AUD$1.7 billion insured loss was paid out for damage to residential, commercial, and industrial properties, with an additional 29% for damage to motor vehicles. The 23 aircraft that were damaged at the Sydney Airport as a result of the storm accounted for close to $100 million dollars of damage, or another 6% of the total insured payout. The remaining insurance payments were losses due to business interruption (Schuster et al, 2005a).

Full recovery from the storm took many months and in some cases years, due to delays with insurance claims and rebuilding efforts. According the Emergency Management Australia (EMA, 2007), the extraordinary amount of roofing materials needed to repair the damaged properties led to a shortage of supplies as well as skilled tradesman, leaving thousands of homes protected from the elements only by tarpaulins. Terra-cotta tile roofs accounted for over 70% of roofs in need of repair after the storm. The stockpiles of terra-cotta tiles maintained

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by the major suppliers were quickly exhausted, leading to severe delays in repairs as new tiles were produced or imported from elsewhere. Similarly, an abnormally large quantity of slate tiles were needed to repair the damaged slate roofs, which had to be sourced and then imported from overseas, primarily from Wales, again leading to long lead times on roof repairs (Henri, 2000).

THE 1999 SYDNEY HAILSTORM IN PERSPECTIVE

For the 10th anniversary of the 1999 Sydney Hailstorm, RMS worked with Professor Alan Jeary of the School of Engineering of University of Western Sydney[4] to investigate the vulnerability of the roofing of Sydney's building stock to future hail damage, based on the existing Australian building design code, construction practices, and roofing materials. In addition, the probability of such a future event is explored in the context of climate change and increased knowledge of storm generation and impacts over the past 10 years.

Susceptibility of Roofing Material to Hail Damage

Size, density, kinetic energy, and the number of stones per unit area have all been used for a possible correlation with damage to roofing elements. The ambient air temperature at the time of impact has also been identified as having a small modifying effect. However, Changdon (1977) established that the diameter of a hail stone is a better predictor of probable damage than any other parameter, and this has therefore been used as the prime predictor of damage to roofs.

The parts of a building most susceptible to damage from hailstones are, not unexpectedly, those parts facing the sky. Hailstones are not moved significantly in a horizontal direction (TORRO, 2006), and so windows on the sides of houses are less affected by hailstones, whereas roofs, skylights, antennas, and coverings incur the most damage. Of course, other flying debris during a storm can cause damage to windows and walls, as seen during the 1999 Sydney Hailstorm. TORRO—the TORnado and storm Research Organisation—also reported that smaller hailstones have been observed to affect glazing on side walls, but that there are no reports of damage associated with this mechanism.

TORRO's work (2006) in the U.K. has been correlated with work performed in Australia by SGIO, a subsidiary of Insurance Australia Group (IAG) (SGIO, 2004), to produce Table 1. This table suggests that the threshold for significant damage to the predominant roof types in Sydney are hailstones that are in the region of 5 cm (1.9 in) in diameter. At or above this level, tiled roofs can be broken, and as a result, the weather-tightness of the roofing system is compromised.

Currently available information also suggests that, irrespective of the materials used for roof construction, once the roof tiles are cracked, water penetration will result, even when sarking (i.e., a flexible membrane installed under the tile battens) is present. Stronger (or more resistant) sarking is available, but is not currently commonly used, and no research has yet been conducted to show whether this extra resistance would alter the risk.

[4] Professor Alan Jeary is consulting with Risk Management Solutions as part of its development of the RMS® Australia Severe Convective Storm Model, scheduled for future release.

Table 1. Effects of hail of different size diameters on roof building materials

Hail Diameter (cm)	Damage (TORRO, 2006)	Damage (SGIO, 2004)
0–1.5	Slight crop damage	—
1.5–2.0	Significant crop damage	—
2.0–3.0	Glass and plastic damaged	—
3.0–4.0	Vehicle and widespread glass and plastic roofing broken	Glass and plastic roofing broken
4.0–5.0	Tiled roofs damaged, slate broken	Old slate 100+ years old, Old tiles 50+ years old, cracked
5.0–6.0	Tiled roofs broken, metal roofs dented	Old slate tiles broken, new tiles crack
6.0–7.5	Severe roof damage, tiles broken, slate shattered	New concrete tiles and terra-cotta tiles break
7.5–8.5	Severe damage to aircraft bodywork, tiles shattered, slate destroyed	Sheet metal dented – all other roofing broken
8.5–9.0	Severe damage to aircraft bodywork, tiles shattered, slate destroyed	Sheet metal dented – all other roofing smashed
>9.0	Extensive structural damage & sheet metal penetrated	Sheer metal roofing penetrated/ cracked

During the 1999 Sydney Hailstorm, 70% of damaged roofs were constructed of terra-cotta tiles, with another 5% constructed of slate tiles and the remainder constructed with other types of roofing materials (e.g., concrete tiles, metal roofs). At the time of the storm, the majority of damaged homes were built before the 1930s with the predominant roofing material being terra-cotta tiles. Since this time, the majority of residential structures in NSW have continued to be built with terra-cotta roofing tiles (Housing Industry Australia, 2006). As illustrated in Figure 9, approximately 75% of new homes in 2006 were constructed with tiled roofs, with an additional 12% of the roofs constructed using sheet metal and 10% of roofing using slate tile.

As the materials damaged in 1999 are the same as the ones being used to build homes in NSW today, the damage patterns in future events will be the same as those seen in the past.

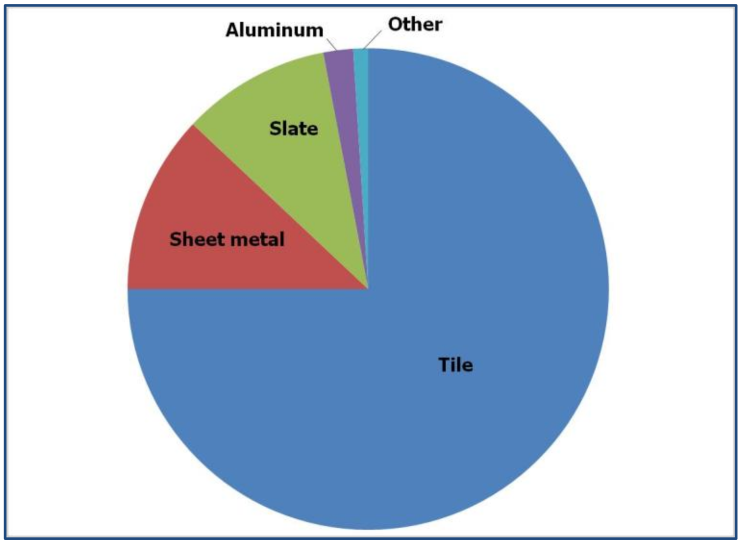

Figure 9: Distribution of roof type for new construction in New South Wales, based on 2006 data (Source: Housing Industry Australia, 2006)

Recurrence of Hailstone by Diameter Size

The Australian Bureau of Meteorology (BoM) collects data on severe storms in NSW, including maximum hail size. Although the database's first hail entry is 1795, the early part of the record is far from complete. It is only since the introduction of BoM's network of storm spotters in 1989 that the database's consistency has stabilized. The short reliable record makes it difficult to discuss return periods of extreme events. Therefore, a rigorous statistical analysis of the recurrence of hailstones by diameter size is not attempted here. Instead, some simple observations are noted.

In the Sydney metropolitan weather forecast district, storm days with maximum recorded hail 4 cm (1.6 in) in diameter or larger have occurred, on average, more than once per year since 1989. Storm days with hail 6 cm (2.4 in) in diameter or larger have occurred on average every two years and storm days with hail 8 cm (3.15 in) in diameter or larger have occurred, somewhere in the Sydney Metropolitan district, every 5 to 10 years.

The massive 9 cm (3.5 in) hailstones recorded during the 1999 Sydney Hailstorm, therefore, cannot be considered a "once-in-a-lifetime" occurrence. Indeed, reports from the 1947 Sydney Hailstorm on New Year's Day suggest hailstones of this size fell in that event (Newman, 1947). Modeling work by Blong and others (2001) indicate that the combination of location, track and hail size of the 1999 event has a return period of 25 to 30 years. This figure is supported by the more recent numerical simulations of Leslie and others (2008).

It is clear that the return period of hailstones of a size sufficient to cause damage to tiled roofs somewhere in Sydney, is very short. Arguably, the return period of large hail *at a location* could be used for the design of roofs to withstand hail damage, in much the same way that the Building Code of Australia (BCA) establishes return periods for wind storm and earthquake risk for construction purposes. In Australia, the design return period used for earthquake risk is 500 years and for wind risk, it is approximately 1,000 years. For an individual location in Sydney, winds at this return period are driven by downburst winds from thunderstorms (Holmes, 2002). In addition, the BCA is primarily designed to meet life safety standards. Although there are some provisions to minimize loss of amenity associated with lateral loading due to wind or earthquake perils, there are currently no provisions specifically targeted to minimizing damage from hail.

Loss Recurrence of the 1999 Sydney Hailstorm

The return period of loss is very different to the return period of hailstone size, as the damage and subsequent loss depends upon where and when a storm strikes. One analysis, performed by Blong and others (2001), estimate that the return period associated with the residential loss from the 1999 Sydney Hailstorm is less than 100 years.

Historical loss data in Australia, with which most researchers based their analyses, have only a few decades of reliable data. Moreover, the population of Australia is concentrated into a small number of cities and large towns with vast, almost empty areas. Any future trends that one can determine through analysis of the historical loss data are fraught with uncertainty. Moreover, one big loss event will significantly change the characteristics of the historical data set (Blong et al., 2001).

As the historical record is so short, there is even more uncertainty associated with the return period for the largest losses, as these are associated with lower probabilities (or higher return periods). However, if one considers the Insurance Council of Australia's (ICA) historical disaster statistics from 1967 through 2006 (ICA, 2009), adjusted to current values by Crompton and McAneney (2008), a severe convective storm loss in the Sydney metropolitan area on the order the 1999 event has a return period of several decades—and not more than 100 years.

Climate Change

There is a lot of concern in Australia about the impacts of climate change on future event occurrence—and hence, future losses. Moreover, large losses have become more frequent. For example, the 2007 winter storm in New South Wales caused AUD$1.48 billion of insured loss and the latest insured estimate from the 2009 Victorian brushfires stand at AUD$1.12 billion, with losses still being reported (See Table 2).

However, Crompton and McAneney (2008) thoroughly re-examined historical events to update the ICA's historical loss data set. They conclude that the strong upward trend in losses is due predominantly to increases in population and wealth. A climate change signal is not yet visible in the available loss data, although it may emerge over time. From high resolution numerical simulation work, Leslie and others (2008) conclude that severe hailstorm events are likely to become more frequent and severe in New South Wales although it may be a few decades until climate change can be differentiated from natural inter-decadal variability.

INSURANCE MARKET IMPLICATIONS

In New South Wales, hail and wind storms are frequent events, accounting for approximately one-third of all severe weather events (Natural Hazards Research Centre, 2000). While the majority of these events result in relatively minor losses, large-scale events that impact an urban area can, and do occur.

Top 10 Insured Losses: Absolute versus Adjusted

As Table 2 illustrates, five of the top 10 absolute insured losses dating back to 1967 are from hail or wind storm events. Moreover, five of the top 10 insured losses were from events in NSW. The 1999 Sydney Hailstorm was the most costly of these storms, with AUD$1.7 billion in insured damage, the single largest insured loss in Australia's insurance history.

Table 2. Top ten insured losses in Australia from 1967 through 2009 (Source: Insurance Council of Australia, 2009)

Natural Disaster Event	Date	Location	Insured Loss (AUD$ millions)
Hailstorm	April 14, 1999	Sydney, NSW	1,700
Severe Storm	June 6-8, 2007	Newcastle & Hunter Valley, NSW	1,480
Victorian Bushfires	February 2, 2009	VIC	1,120*
Earthquake	December 28, 1989	Newcastle, NSW	862
Cyclone Larry	March 20, 2006	North QLD	540
Severe Hailstorms	December 9, 2007	Western Sydney, Blacktown, NSW	415
Bushfire	January 18, 2003	Canberra, ACT	350
Flood storm	February 14, 2008	Mackay, QLD	342
Hail	March 18, 1990	Sydney, NSW	319
Hail, Storm	February 2, 2005	NSW/TAS/VIC	216.7

** AUD$ millions in 2009 dollars, as losses are on-going. This estimate is accurate as of 03/13/2009. See:*
http://www.insurancecouncil.com.au/Default.aspx?tabid=1684

If one considers population, inflation and wealth adjustments, the insured loss from the 1999 Sydney Hailstorm is AUD$3.3 billion, ranking third behind a normalized loss of AUD$3.65 for Cyclone Tracy in 1974 and AUD$4.3 billion for the 1989 Newcastle Earthquake (Table 3). The top 10 adjusted losses from 1967 through 2006, based on the work by Crompton and McAneney (2006) are illustrated in Figure 10.

Table 3. Top Ten normalized insured losses in Australia from 1967 through 2006 (Source: Crompton and McAneney, 2008)

Natural Disaster Event	Date	Location	Normalized Loss in 2006 AUD$ millions
Newcastle Earthquake	December 28, 1989	Newcastle, NSW	4,300
Tropical Cyclone Tracy	December 24, 1974	Darwin, NT	3,650
Hailstorm	April 14, 1999	Sydney, NSW	3,300
Cyclone Wanda, Flood	January 25, 1974	Brisbane, QLD	2,090
Hailstorm	January 18, 1985	Brisbane, QLD	1,710
Ash Wednesday Bushfires	February 16, 1983	VIC/SA	1,630
Hailstorm	March 18, 1990	Sydney, NSW	1,470
Cyclone Madge	March 4, 1973	QLD/NT/WA	1,150
Hailstorm	November 10, 1976	Sydney, NSW	730
Hailstorm	October 3, 1986	Sydney, NSW	710

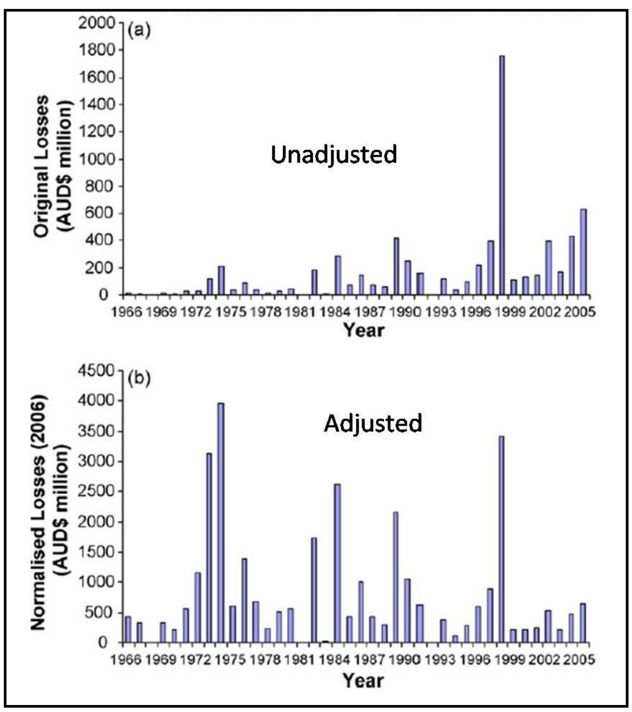

Figure 10: Australian insured losses from meteorological hazards (1967–2006) at the time of occurrence (above) and normalized to 2006 dollars (below) (Source: Crompton and McAneney, 2006)

Challenges for Insurers

Losses from recent large events in Australia are driving insurance prices up, making affordable insurance in Australia an issue. While there is no evidence that these recent losses are a result of climate change, climate change is now widely accepted by the scientific community, and the Intergovernmental Panel on Climate Change (IPCC) believes that it will lead to more frequent and more extreme weather events in the future (Garnaut Climate Change Review, 2008). An increase in the frequency and severity of weather events will have an impact on the global reinsurance market. Extreme weather events which hit urban areas, such as Sydney and Brisbane, can incur large insurance losses well beyond an insurer's retention layer, triggering reinsurance placements. For example, a substantial portion of the AUD$1.7 billion loss from the 1999 Sydney Hailstorm was borne by the reinsurance market.

How a severe convective storm event is defined can also impact reinsurers. Large losses from severe storms are not necessarily due to one large hailstorm event impacting a densely populated area. A large loss could result from a series of severe storm days. Defining a loss event from a severe storm as one event or multiple events can be difficult, as conditions favorable to the formation of severe storms can persist for several days and cover large areas. Additionally, there are competing definitions in the insurance market on the definition of an event. For instance, the storms which hit southeast Queensland from November 16–20, 2008 were defined as one loss event by some companies, while others defined the storms as two loss events. Depending on a company's reinsurance arrangement and the cumulative losses from weather-related events in that year, the definition of such events could determine whether or not a reinsurance layer is triggered.

Extreme weather events also impact the cost and duration of recovery, driving up the costs to insurers. The 1999 Sydney Hailstorm triggered shortages in roofing materials and the availability of skilled laborers, causing severe delays in repairing damaged roofs on the order of months in some circumstances. In addition, almost $100 million of the AUD$1.7 billion was paid out for time element coverages (e.g., business interruption).

While it is expected that, at very long return periods, earthquakes in NSW will drive the tail of the loss exceedance curve, at shorter return periods, flood, windstorm and severe convective storm risk must be managed.

Severe Convective Storm Modeling

The 1999 Sydney Hailstorm is a clear example of the damaging impacts of a severe convective storm on an urban area. If the storm had taken a slightly different path through the Sydney area, the damage would have been much greater. At the time of the 1999 storm, no previous severe convective storm event had ever produced that much damage. It caught the insurance industry off guard, leading many to believe that the hailstorm was an anomaly. However, research shows that the probability of a similar event occurring is much higher—it was not a once-in-a-lifetime storm.

The frequency of severe convective storms in Australia, and their ability to cause a significant amount of damage, highlights the importance of severe convective storm risk assessment and management. Catastrophe models are valuable tools for risk management purposes, providing a probabilistic view of the risk from various perspectives.

In 2009, RMS is actively developing a fully probabilistic severe convective storm model for the Sydney region to assist companies in the Australian insurance market to manage and prepare for the pervasive threat from severe convective storms in Australia. Initially developed only for the Sydney region, the RMS® Australia Severe Convective Storm Model will complement the existing RMS® Australia Earthquake and Australia Cyclone models, allowing (re)insurers a more comprehensive view of the risks to their portfolios.

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