HAILSTORMS AND THE ESTIMATION OF THEIR IMPACT ON RESIDENTIAL BUILDINGS USING RADAR

Sandra Schuster and Russell Blong
Risk Frontiers – Natural Hazards Research Centre, Macquarie University, Sydney, Australia,
sschuste@els.mq.edu.au
http://www.es.mq.edu.au/NHRC/web/front/homepagetables.htm

Abstract

Hailstorms are by far the costliest insured natural hazard in Australia. Major metropolitan areas like Sydney, in the Eastern Australian State of New South Wales, are especially vulnerable due to building exposure and geographical location. The focus of this study is on comparisons between radar-derived reflectivity, hailstone size data and damage data in the form of insurance claims and roof damage. CAPPI (Constant Altitude Plan Position Indicators) reflectivities are generated from S-band radar at low storm levels (1.5km). Initial results are presented using data from metropolitan Sydney, comprising recent wind and hailstorms, including the April 1999 Sydney hailstorm. The area within the 55dBZ area is a good approximation of the hail swath. Merging hail cells appear to cause substantially more damage than single cells. Initial results indicate a preferred area for hail damage to the left side of storm paths.

Key Words: hail, hailstorm, severe storm, hail damage, insurance, radar, CAPPI

Introduction

As building values increase, and major metropolitan areas expand, so does exposure to thunderstorm and hail losses. The last decade has not only shown an increase in hail losses globally, but also trends towards more damaging events.

The April 1999 Sydney hailstorm clearly demonstrated the destructive power of hail. With insured losses of approximately A$1700m (total estimated costs approximately A$2300m) it ranks as the most expensive natural disaster in Australian insurance history. Blong et al. (2001) consider this event to have an estimated return period of only 25 to 30 years based on its footprint and maximum hailstone size (9cm). An analysis of events on the Insurance Disaster Response Organisation (IDRO) (2003) list shows that eight of the top twenty most expensive insured natural hazard events in Australia are hailstorms with losses between 1967 and 2003 totalling A$3320m. This represents 34% of total insured losses for major events and the largest proportion for any natural peril.

The main variables responsible for hail damage to property are:

- Frequency of hailstorms

- Intensity of hailstorms, dependant on number, size (especially maximum hailstone size) and velocity of hailstones on impact

- Wind speed, which increases the velocity of hailstones

- Vulnerability and exposure of buildings to hailstorms

Most damaging hailstorms occur as supercells, like the April 1999 hailstorm. Supercells often occur singularly and are capable of producing very large hailstones due to exceptionally strong updrafts. Their physical structure often allows them to maintain high intensity for long periods (up to several hours), which further increases the area subjected to large hail. Hail produced within multicell severe storms and squall lines is usually smaller in size and the cells shorter lived (about 15 min up to one hour). The basic surface pattern (footprint) of hail fall under the passage of a thunderstorm cell is called a hailswath. One thunderstorm can produce many hailswaths. Average areas were reported as 10 km wide by 40 km long from a study conducted in Illinois (Changnon, 1977). Hailswaths contain many hailstreaks, defined as areas of hail continuous in space and time, with average areas of 20 km^2 (Chagnon, 1977). Those results were confirmed by a comparative study by Admirat et al. (1985) where 70% of Swiss, Canadian and South African hailstreaks were smaller than 25 km^2. The hail damage pattern on the ground can be represented as ellipses with highest losses in the centre.

This study focuses on comparisons between the radar-derived radar reflectivity, hailstone size data and damage data in the form of insurance claims and roof damage. Initial results are presented using data for the metropolitan Sydney area. Recent wind and hailstorms, including the April 1999 Sydney hailstorm, are considered.

Data

Ground measurements of hailstones are incomplete due to the nature of hailstorm occurrence. It is common to compare hailstones to spherical objects like balls (e.g. golf balls, cricket balls) or fruit (e.g. grapes, oranges). Hailstone size estimations may be erroneous and prone to exaggeration. Remote sensing tools, such as radar, provide consistent measurements and large area coverage with high spatial and temporal resolution. Conditional upon the availability of algorithms validated with property damage information, real-time weather radar information could be used as a near real-time warning tool.

The Australian Bureau of Meteorology (BoM) operates the Weather Watch Radar “Letterbox”, located 60km southwest of Sydney on Letterbox Mountain (350m above sea level). This Enterprise Electronics Corporation WSR74S radar operates with an incoherent magnetron transmitter and uses 10.4cm radio waves with a 1.9º horizontal and 1.8º vertical half-power beamwidth. The typical availability of the non-Doppler radar is 24 hours per day with a 1km range resolution and 10 min time step. Further details can be found in Potts et al. (2000).

Hailstone size data (n=356) with good spatial coverage are available for the April 1999 Sydney hailstorm from a survey conducted by Risk Frontiers, the Natural Hazard Research Centre located at Macquarie University in Sydney (Yeo et al., 1999). However, usually only a few hailstone sizes and locations are available for other thunderstorms, mainly based on the Bureau of Meteorology severe weather database which also provides information on related severe weather, e.g. wind gusts and flash flooding (Bureau of Meteorology, 2003).

Property damage data in the form of insurance claims have been provided for the December 2001 storm, more a destructive windstorm than a hailstorm. Roof damage data were obtained from the New South Wales Department of Housing for the April 1999 hailstorm.

Methodology

CAPPI (Constant Altitude Plan Position Indicators) reflectivities are derived from sector-volume scans at a height of 1.5km. This level was chosen as a low storm level, close to the surface where hailstones occur and a suitable height for the radar. The "cutting method" proposed by Waldvogel et al. (1978) is used to distinguish between hail and rain. Radar reflectivities equal or greater than 55dBZ are assumed to contain significant hail; smaller reflectivities are assumed to be caused by rain. Studies in Switzerland have shown that this threshold corresponds to light damage to crops (Schiesser, 1990). It was also used by Hohl et al. (2002) in a study investigating hail damage to buildings.

Investigations have been conducted on 12 recent severe thunderstorms and their damaging hail cells (Figure 1). More detailed studies have focused on the Sydney storms of October 1995, April 1999 and December 2001 as hailstone and damage data are available.

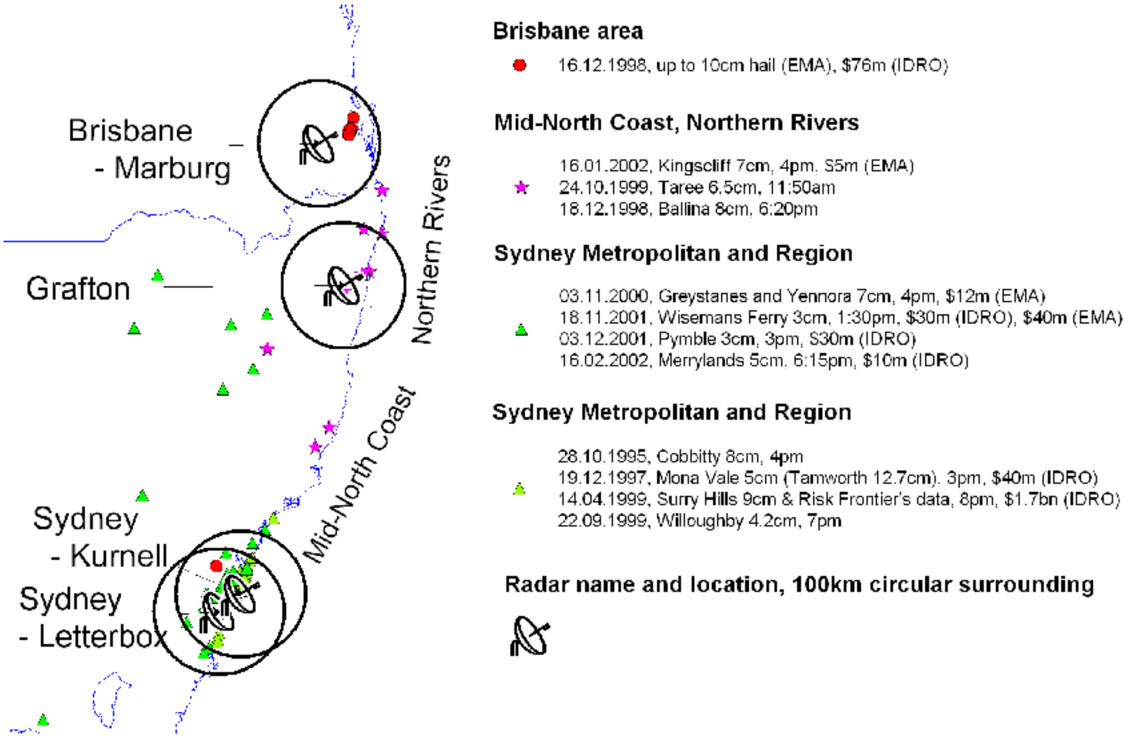
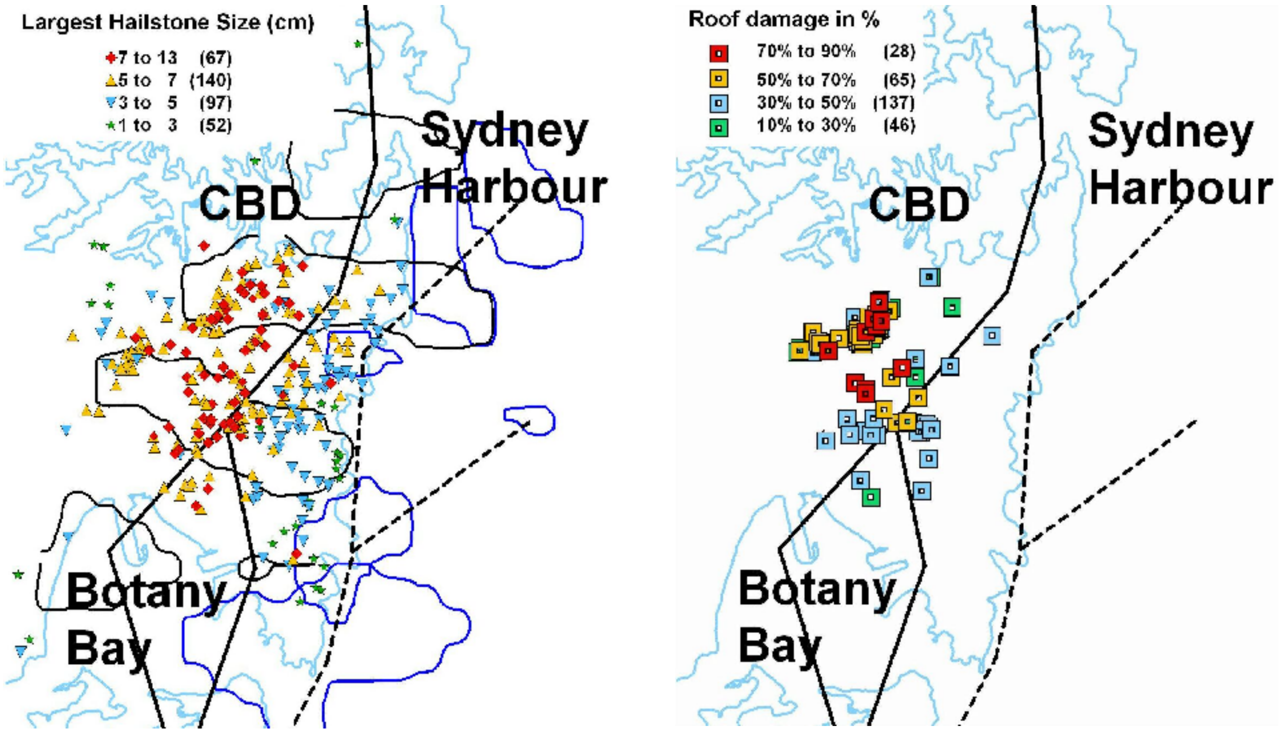


Fig. 1 Map of coastal New South Wales and southern Queensland with Radar and storm locations, dates, times, maximum hailstone sizes and insured losses; radar and hail data were provided by the Bureau of Meteorology, insured losses by IDRO and Emergency Management Australia (EMA).

Results and Discussion

Sydney Hailstorm April 1999

This supercell thunderstorm struck the eastern suburbs of Sydney in the evening of the 14th of April 1999 (Zillman, 1999). Wind gusts of 85 km/h were measured (Emergency Management Australia, 2003). The thunderstorm travelled at a speed of about 38km/h and moved in a north northeasterly direction. Damage to 24,000 homes, 70,000 vehicles and 23 aircraft indicates the scale of the hailstorm. A$10m worth of Tarpaulins and 9,600km of rope were used to make buildings weatherproof in the aftermath of the storm (Emergency Management Australia, 2003).



a) **b)**

Fig. 2 Most affected areas and storm paths with a) hailstone sizes and 55dBZ area and b) percentage of damaged roof

Figure 2 shows the most affected area between Botany Bay in the South and Sydney Harbour with its Central Business District (CBD). The 55dBZ isolines on Figure 2a are derived from the 10 min radar sequence of the 1.5km CAPPI reflectivities and are shown in black for the first cell path (solid, 19:43-20:13) and in blue for the second cell path (dashed, 21:13-21:53). The paths are based on the centroids of these 55dBZ regions. The 55dBZ regions or hail cells are large; they merge and split and eventually dissipate or move out to sea.

Reported hailstone sizes are shown on Figure 2a. There is reasonable agreement between the 55dBZ area and the hail cover on ground. The proportions of roof damage to individual buildings from Department of Housing data are illustrated in Figure 2b.

The largest hailstones were reported to the left of the first storm cell path. This is consistent with the supercell structure and the location of the downdraft. The smaller hail on the coast is likely to have fallen from hail cells related to the second storm path. Major roof damage is also to the left of the path and in good agreement with areas experiencing larger hailstones.

Sydney Hailstorm October 1995

A damaging supercell passed through the western suburbs of Sydney late in the afternoon of the 28th of October 1995. It moved in a northeasterly direction with a speed of about 40km/h. Meteorological conditions were reported by Webb (1995).

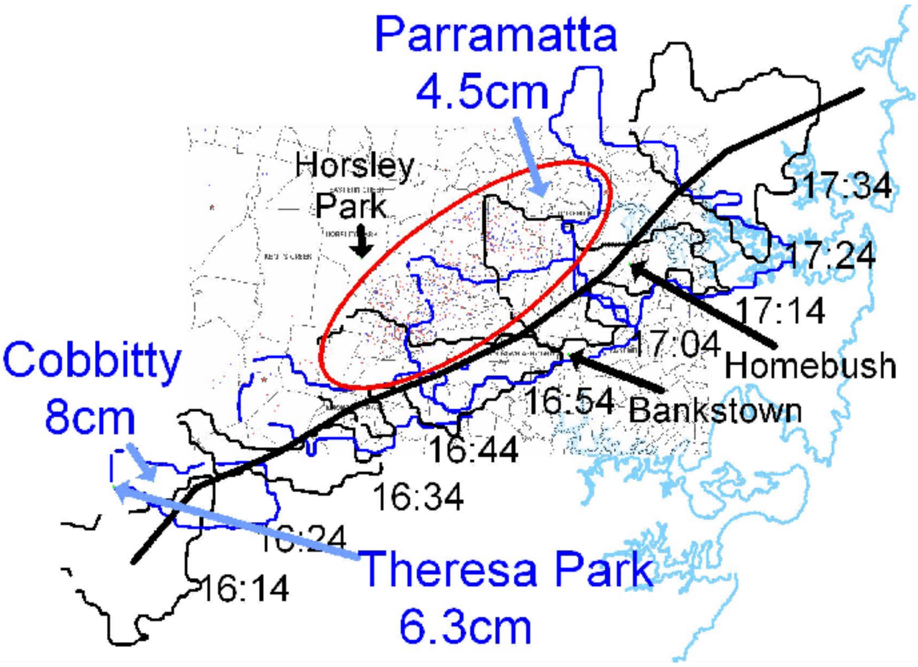
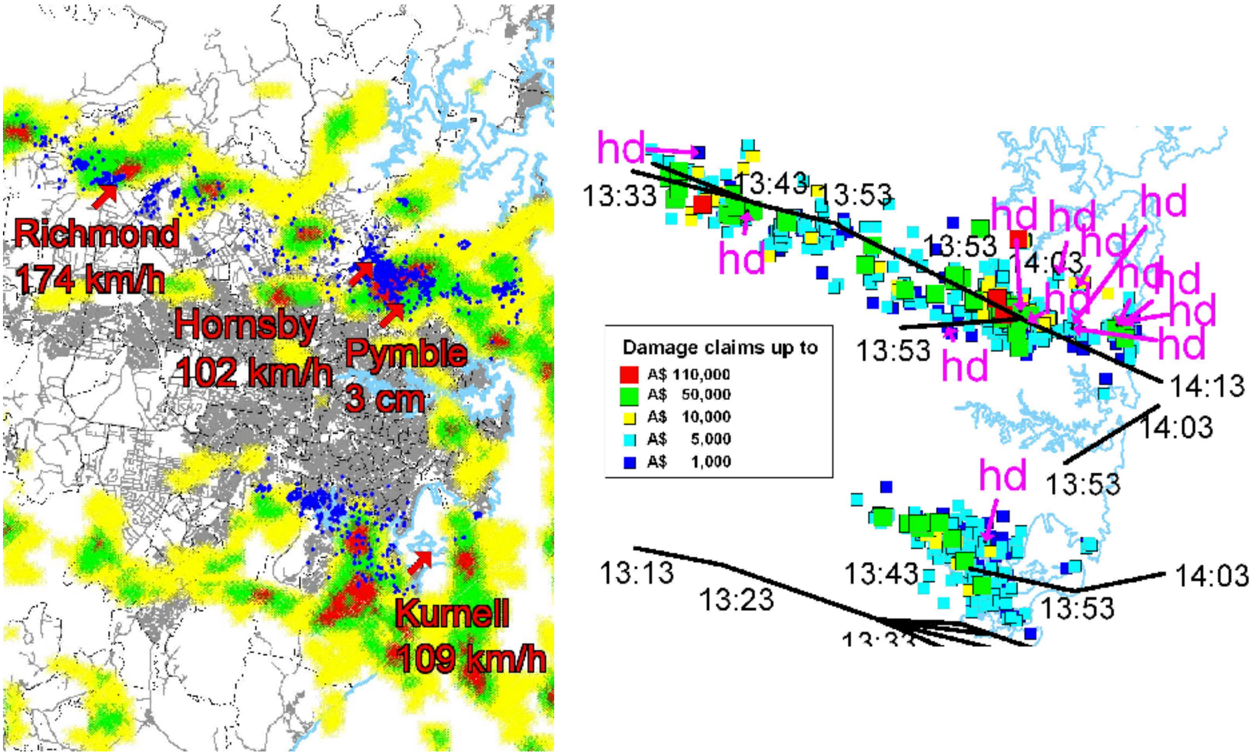


Fig. 3 Storm path with 55dBZ area, hailstone sizes and damage ellipse

Figure 3 shows the path of the hail cells with their 55dBZ areas. Damage, represented by insurance claims, occurred within the ellipse located to the left of the storm path; it has dimensions of about 10km by 25km. The occurrence of large 55dBZ areas is also noted, but it was not possible to quantify the hail cover on the ground in more detail. Hailstone size measurements were only available from the three locations indicated in Figure 3. Comparing the CAPPI reflectivity at 1.5km and 7.5km indicates that the thunderstorm was tilted. This tilt was more pronounced compared to the April 1999 hailstorm, which might explain the location of the damage a little further to the left of the path than in the case of the April 1999 hailstorm.

Sydney Thunderstorm December 2001

A line of severe thunderstorms in the afternoon of the 3rd of December 2001 caused widespread damage with insured losses of approximately A$30m (total estimated costs approximately A$130m) in the Sydney Metropolitan area and on the New South Wales Coast (Emergency Management Australia, 2003). The storms originated in the Blue Mountains to the west of Sydney and moved east south east with an average speed of 80km/h. Figure 4a also shows the location and values of relevant meteorological recordings. Hailstone size is, inter alia, influenced by the topography and the height of the 0ºC isotherm. This distance influences the time for melting during hail fall. The 0ºC isotherm was much higher during this storm (4.2km) compared to the April 1999 hailstorm (2.8km). Additionally the surface air temperature was very high (T=40ºC) and the storm produced moderate hail with only one storm spotter recording in Pymble (hailstone size = 3cm). Rather than a hailstorm, this storm was more a destructive downburst as described by Taylor and Webb (2002) with maximum measured wind gusts of 174km/h. However, even hail smaller than 2 cm can cause damage, especially when wind driven. Insurance claims data show that most of the damage was caused by destructive wind gusts; whereas only a few claims mention hail as the primary cause of damage (Figure 4b), other damage may also have been caused by hail.



a) **b)**

Fig. 4 a) 10 min radar sequence with two distinct storm and damage paths, meteorological recordings and merging hailstorm cells. Blue dots indicate damaged property. The background map shows the street pattern with occupied areas. b) Storm paths and total damage costs with location of specific hail damage (hd).

Figure 4a shows the 10 min radar sequence of the 1.5km CAPPI reflectivities with two distinct storm and damage paths. Blue dots indicate damaged property. Just south of the northern major storm path another hail cell developed and it can be seen that there is substantially more damage at their merging point between the suburbs of Hornsby and Pymble, possibly due to increased available energy. CAPPI reflectivities at 7.5km, show that these cells had already merged one time step earlier. While one would expect more damage in the area southeast of Kurnell due to the large 55dBZ area, the unoccupied Royal National Park is located here.

The areas of the 55dBZ regions in this storm are small compared to those produced by the two supercells discussed earlier. Compared to the April 1999 hailstorm, wind gusts in the December 2001 storm were more severe and the thunderstorm speed much faster.

Figure 4b shows the storm paths and the total cost of damage per individual dwelling. Costlier claims are located near the storm path. Most expensive claims were lodged at the merging point of the northern path. The southern path produced less damage than the northern path. Although this storm was more a windstorm than a hailstorm, hail damage (hd) is still concentrated to the left of the storm path.

Findings

Our preliminary results suggest that the area denoted by the 55dBZ reflectivity is a good indicator of hail and an approximation of the hail swath. The preferred area for hail damage is to the left side of the storm path probably because of the thunderstorm structure. Merging cells tend to cause substantially more damage than single cells, possibly due to more available energy. Further ground damage data from other storms is required to verify these new findings.

Acknowledgements

The authors wish to thank the Bureau of Meteorology for providing the radar data. Special acknowledgements are due to Rodney Potts and Alan Seeds from the Bureau of Meteorology Research Centre for their radar data processing software and their greatly appreciated expertise. We are very grateful to the New South Wales Department of Housing and the insurance company for providing damage data as well as their friendly assistance.

References

Admirat, P., Goyer, G. G., Wojtiw, L., Carte, E. A., Roos, D. & Lozowski, E. P. (1985). "A comparative study of hailstorms in Switzerland, Canada and South Africa", *Journal of Climatology,* **5,** 35-51.

Blong, R., Leigh, R., Hunter, L. & Chen, K. (2001). "Hail and Flood Hazards - Modelling to Understand the Risk", N. R. Britton and J. Oliver, *Enhancing Shareholder Value Through Capital Risk Management, Proceedings of a Conference sponsored by Aon Group Australia limited*, Gold Coast, New South Wales, 25-39.

Bureau of Meteorology (2003). "Severe Storm Events - monthly significant weather summaries", *http://www.BoM.GOV.AU/inside/services_policy/public/sigwxsum/sigwmenu.shtml*

Changnon, S. A. (1977). "The Scales of Hail", *Journal of Applied Meteorology,* **16,** 626-648.

Emergency Management Australia (2003). "EMA Disaster Events Data Tracking System (EMATrack)", *http://www.ema.gov.au/ema/emaDisasters.nsf*

Hohl, R., Schiesser, H.-H. & Aller, D. (2002). "Hailfall: the relationship between radar-derived hail kinetic energy and hail damage to buildings", *Atmospheric Research,* **63,** 177-207.

Insurance Disaster Response Organisation (IDRO) (2003). "Major Disaster Event List Since June 1967 (revised to January 2003)", *http://www.idro.com.au/disaster_list/default.asp*

Potts, R. J., Keenan, T. D. & May, P. T. (2000). "Radar Characteristics of Storms in the Sydney Area", *Monthly Weather Review,* **128,** 3308-3319.

Schiesser, H.-H. (1990). "Hailfall: the relationship between radar measurements and crop damage", *Atmospheric Research,* **25,** 559-582.

Taylor, J. C. and Webb, R. M. (2002). "December 3rd 2001 - Environmental and Radar Characteristics of a Destructive Downburst", *Internal Conference*, NSW Regional Office, Bureau of Meteorology, Australia,

Waldvogel, A., Federer, B., Schmid, W. & Mezeix, J. F. (1978). "The kinetic energy of hailfalls. Part 2: Radar and hailpads", *Journal of Applied Meteorology,* **17,** 1680-1693.

Webb, R. M. (1995). "The Sydney Supercell Thunderstorm 28th October 1995", *Report; NSW Severe Weather Section, Bureau of Meteorology, Australia,*

Yeo, S., Leigh, R. & Kuhnel, I. (1999). "The April 1999 Sydney Hailstorm", *Australian Journal of Emergency Management,* **14,** 4, 23-25.

Zillman, J. (1999). "Report by the Director of Meteorology on the Bureau of Meteorology's Forecasting and Warning Performance for the Sydney Hailstorm of 14 April 1999", *Report; Bureau of Meteorology, Melbourne,* 35pp, *http://www.bom.gov.au/inside/services_policy/storms/sydney_hail/hail_report.shtml*