

P8.27 TWO RECORD BREAKING AUSTRALIAN HAILSTORMS: STORM ENVIRONMENTS, DAMAGE CHARACTERISTICS AND RARITY

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1. INTRODUCTION

Historically the eastern capital cities of Sydney and Brisbane (see Figure 1) have experienced impacts from severe hailstorms on numerous occasions, including one of Australia's most devastating natural disasters, April 14, 1999 hailstorm (Buckley et al (2001)) that produced \$AUD 1.7 billion damage (original cost – ICA 2010) across Sydney. However, the more southern and western capital cities of Melbourne and Perth, both with weather records dating back close to 150 years, had never reported major damage from giant hail. This changed for both cities in March 2010 when, within the space of 16 days, both experienced their largest natural disaster on record - from giant hail producing severe thunderstorms. These two storms are described more fully in the following sections.



Figure 1: Map showing locations of Australia's capital cities.

2. MELBOURNE SEVERE HAILSTORM

Australia's second largest city, Melbourne (Population 4.0 million in June 2009), experienced its worst hailstorm in 156 years of weather records

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during Saturday afternoon on March 6, 2010.

The thunderstorm complex formed over the northwest of the state early in the afternoon and became severe as it tracked over high ground approximately 100km northwest of the city. During the initial intense phase the first cell tracked over the rural town of Melton, located around 30km to the west of Melbourne, dropping 4cm diameter hail on the region before collapsing over the western suburbs of the city.

During this phase a new thunderstorm cell formed on the northeastern flank of the original cell, moved towards the southeast across the central business district of the city then became a left moving supercell as it tracked towards the east southeast across the eastern and outer eastern suburbs of the city. There were multiple thunderstorm cells associated with this event although the main damage was caused by a single thunderstorm that could be continuously tracked across the greater Melbourne region.

The storm track is best illustrated through the use of radar data as this storm was well monitored by weather watch radar throughout its life cycle. The aggregated volumetric radar data for this event, presented here as a Vertically Integrated Liquid (VIL) field using reflectivities capped at 60dBZ that has been found to be useful to highlight intense phases of thunderstorms for damage analysis, based upon raw data from the Australian Bureau of Meteorology's Melbourne (Laverton) Doppler weather watch radar (1° beam width M1500-S1 S Band Doppler radar) at six minute volumetric scan intervals, is shown in Figure 2.

2.1 Historical perspective

Industry wide insurance claims for damage associated with this event, the most expensive natural disaster to affect Melbourne, (Insurance Council of Australia 2010) totaled \$AUD 1,044 million (\$USD 1 billion) but this figure excludes damage to public infrastructure, community disruption and uninsured or uninsurable property. A total of 129,292 insurance claims were lodged for this event, the largest number of claims ever received for any event across the state. Fortunately no one was killed during this event and reported injuries were relatively minor.

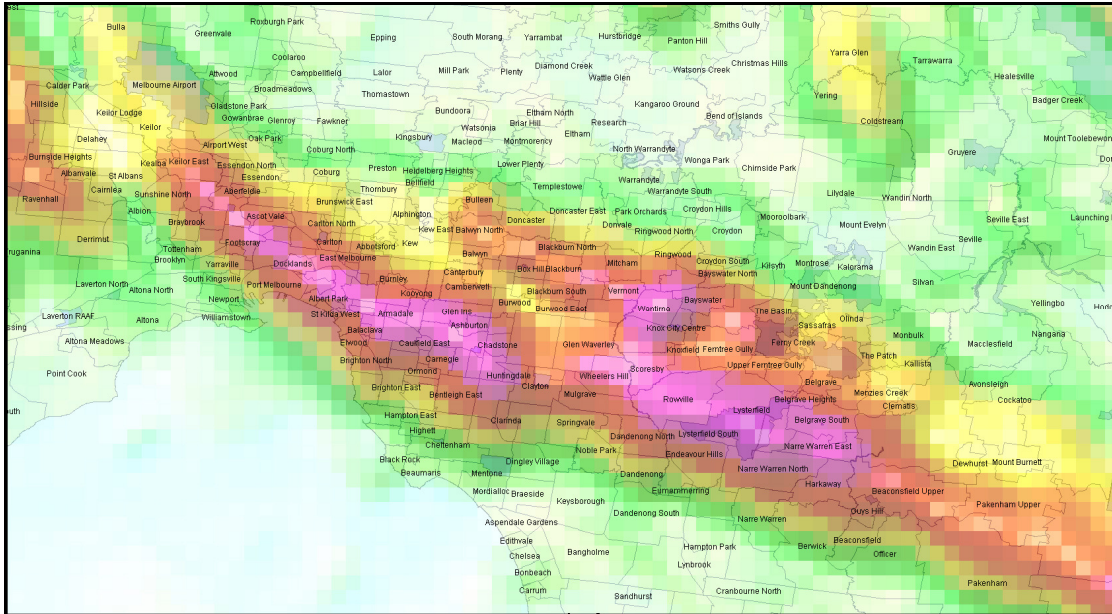


Figure 2: Aggregated radar 60dBZ capped VIL image of the severe thunderstorm complex showing the structure and path of the severe thunderstorm complex across the north and east of Melbourne. Highest values of VIL were near 97 kg/m² with the lower threshold used in this image near 20 kg/m².

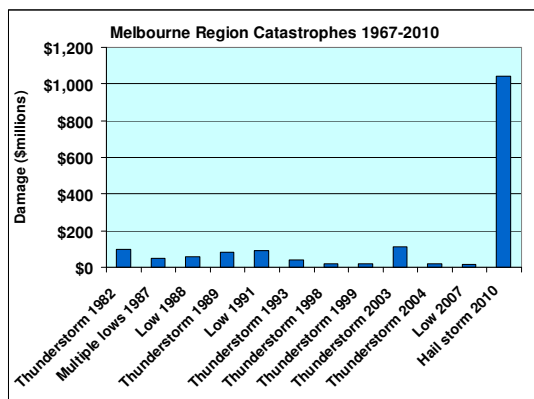


Table 1: Comparison of historical insured damage costs for weather related events affecting Melbourne from 1967 to 2010 (Data source Insurance Council of Australia 2010).

To illustrate the extreme nature of this storm relative to historical storm events, damage statistics from the Insurance Council of Australia since 1967 show the largest and costliest thunderstorm related weather event for Melbourne prior to this event occurred in 1982 with \$AUD 98 million (adjusted to 2007 dollars) damage.

In Table 1 the scale of this event compared to historical catastrophes that have affected the Melbourne area over the 45 years since 1967, based upon statistics held by the Insurance Council of Australia, is shown. It is an order of magnitude greater than any previously experienced weather related natural disaster for this part of Australia. Although there are no statistics for the pre-1967

period, weather records do not indicate there have been any hailstorms of this magnitude since Melbourne was first settled.

2.2 Severe Characteristics.

In the early stages of the severe thunderstorm large quantities of small hail (see Figure 4) and very heavy rainfall were produced. The heaviest recorded rainfalls included 5.6mm in 2 minutes at Essendon and 46mm in 15 minutes at Maribyrnong, which is a 1 in 5 year Average Recurrence Interval (ARI). Both suburbs are to the northwest of the city centre. The strongest measured wind gust was 102 km/h at Melbourne Airport, although damage to housing and trees indicates there were far stronger wind gusts elsewhere.



Figure 3: Flash flooding along a main street in central Melbourne illustrating the severe disruption to traffic caused by the storm.

The damage during this phase of the storm was exacerbated by the large quantities of small hail and hail produced debris blocking roof gutters and storm water drainage systems, causing water to back up into the roof spaces of houses and also exacerbate the flow of runoff down the roadways and into buildings. Flash flood depths down urban roadways reached 1 meter in depth through many suburbs (see Figure 3).



Figure 4: Large quantities of small hail fell across the northwestern and central suburbs of Melbourne.

Once the storm changed into a left moving supercell the size of the hail increased with 3 to 4cm hail typically experienced through the inner eastern and southeastern suburbs. The largest and most catastrophic hail damage was experienced through the outer eastern suburbs of Roweville, Lysterfield and Ferntree Gully where 6 to 10cm hail was reported. The largest hail in the storm, which was solid, nearly spherical and at least 10cm in diameter, fell over the east of Ferntree Gully, severely damaging houses and cars.



Figure 5: Giant hail from the Ferntree Gully area of Melbourne with typical windscreen damage in the background.

The extreme damage produced by this storm was so great due to the very rare coincidence of several factors. These include: heavy short duration rainfall (1:5 year ARI) with large quantities

of small hail, severe wind squalls across a significant proportion of the urban area and, over the outer eastern suburbs, giant (>5cm diameter) hail. The extremely large physical size of the storm footprint coupled with a storm path that encompassed some of the most densely built areas of Melbourne was also a key factor in increasing the magnitude of the total storm damage. As the storm path took it over the most heavily populated parts of Melbourne. Post analyses of the storm involving alternative positions of the storm track showed that even relatively slight reductions to any one of the severe storm characteristics or changes to the path followed by the storm would have significantly reduced the total damage produced by this severe thunderstorm event.

2.3 Meteorological Setting

The severe thunderstorm complex formed on a mobile prefrontal trough (Figure 6) over elevated ground to the northwest of Melbourne. Climatologically the low level moisture is insufficient for high precipitation supercells to form in these troughs. On this occasion near surface moisture from a 120 year ARI flood event over one thousand kilometers to the north was drawn southwards into this trough (see climate data section of the Australian Bureau of Meteorology <http://www.bom.gov.au/cgi-bin/climate/>).

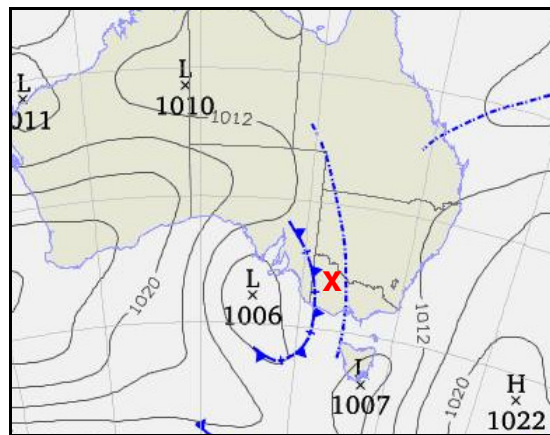


Figure 6: Mean sea level pressure analysis valid 00 UTC March 6, 2010. The severe thunderstorm formed on the prefrontal trough with the approximate genesis location shown by the red cross. Map courtesy of the Australian Bureau of Meteorology.

A mature upper level cut-off low, uncommonly strong for March, completed the meteorological picture, producing a rarely seen storm environment for the Melbourne region. In the upper levels there was a split jet stream with wind speed maxima over 125 knots. The upper level flow was also very meridional in this region with the severe thunderstorm complex forming ahead of the

main frontal cloud band in a transition region between mid and upper level dry air to the east and very moist air to the west, as can be seen from the MT-SAT1 water vapor image in Figure 7.

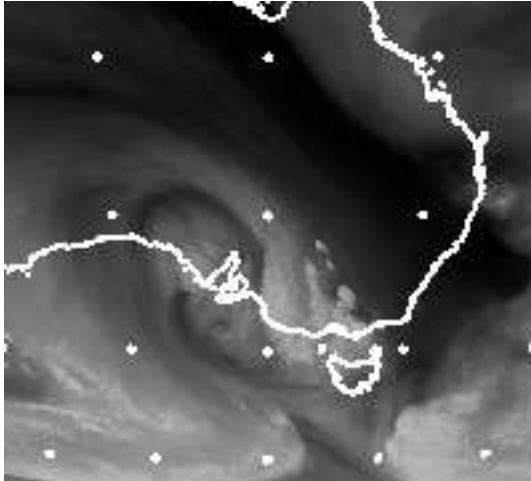


Figure 7: Water vapor image from MT-SAT 1 at 06 UTC March 6, 2010. Image courtesy of the Japanese Meteorological Agency and the University of Dundee.

The morning temperature trace (00:00 UTC or 11:00 Eastern Daylight Savings Time) from Melbourne Airport, which is located within 50km of the location where the thunderstorm formed, is shown in Figure 8. The Total Totals Index was 51, a pointer towards likely severe convection later that day, although there were low level temperature inversions that had to be overcome. The Lifted Index (LI) from this radiosonde flight was near zero although a Lifted Index analysis spanning the prefrontal trough region indicated LI values in the severe thunderstorm genesis area were close to -4.

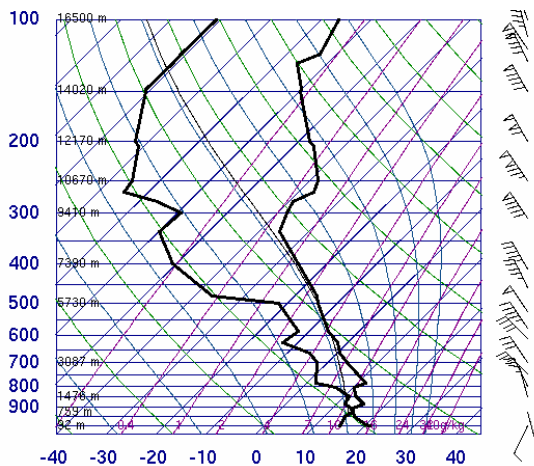


Figure 8: Vertical temperature and humidity profile for Melbourne Airport for 00 UTC March 6, 2010. Image courtesy of the University of Wyoming.

Convection occurred when the surface temperature reached 28°C, indicating some destabilization of the temperature profile probably occurred on the prefrontal trough, although orographic lift on the ranges to the northwest of Melbourne would also have played an important role.

2.4 Damage Distribution

The changing nature of the damage produced by the storm throughout its lifecycle is illustrated by the Victorian State Emergency Service's descriptions of the storm impacts associated with its responses to emergency call outs following the storm event. These are depicted in Figure 9. The dominance of flood / flash flood related damage during the early part of the storm life cycle can clearly be seen with increased damage to housing as the hail size increased further to the east. Most wind related damage appeared to occur on the northern side of the main storm cell with the wind damage continuing well after the giant hail had ceased falling from the thunderstorm complex.

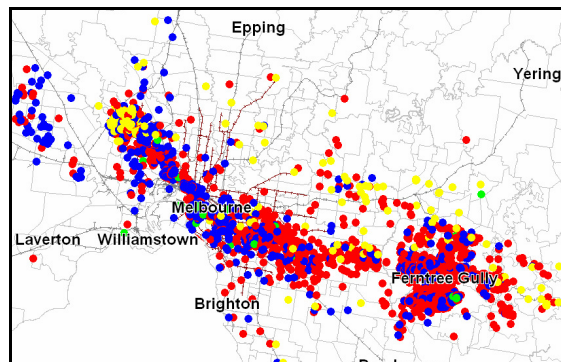


Figure 9: Victorian State Emergency Service storm damage types for the emergency callouts following this storm. Red relates to building damage, blue to flooding, yellow to falling tree related damage and green to other causes.

A post-event damage survey revealed that the giant hail damage was greatest along several narrow, parallel swathes, 50 to 100m wide and around 3 km long with extensive hail damage to cars and major roof and window damage to houses.

3. PERTH SEVERE HAILSTORM

Climatologically Perth (Population 1.665 million in June 2009) is considered a very low risk for giant hail damage, based upon the historical record with no major hail damage ever being reported from this city or its suburbs. However, sixteen days after the Melbourne severe hailstorm on March 22, the Western Australian capital city

experienced its most damaging weather event in 135 years of official weather records. Further studies of Perth newspaper records extending back to 1848 have not identified any other comparable severe hailstorm.

This storm formed over a sparsely populated area around 170km north of the city and tracked southwards. Part of the track of this multi-cellular thunderstorm complex is shown in Figure 10. This image is a combination of the aggregated radar derived VIL from the 10 minute update frequency volumetric scans from the Serpentine weather radar (EEC TVDR2500C C band), located approximately 50km south of the city, insurance claims and manually drawn storm cell ellipses that define regions with similar damage characteristics, drawn with the benefit of extensive on ground post event damage surveys. The weather radar lost power as the storm approached, which is the reason for the abrupt cessation of the radar based VIL data at the southern end of this image.

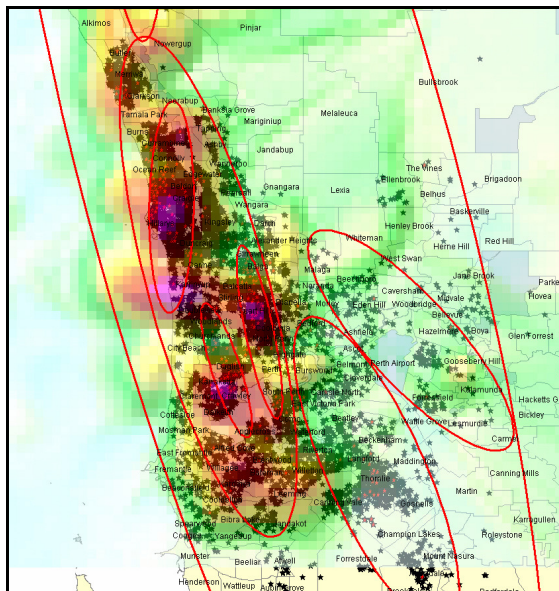


Figure 10: Image showing the aggregated radar derived VIL pattern of the severe thunderstorm complex from the Serpentine weather radar, insurance claims and storm cell ellipses based upon post event damage surveys.

3.1 Historical perspective

Historically Perth has had no major damaging hailstorms. Prior to this storm the two most damaging weather events producing insurance claims (2007 dollars) of \$AUD218 million (TC Alby,1978) with a 1994 winter-time low producing \$AUD117 million damage (see Table 2). Over 156,000 damage claims were received for the Perth hailstorm event and the industry wide insurance

damage bill has reached \$AUD1,056 million (approximately \$USD1 billion).

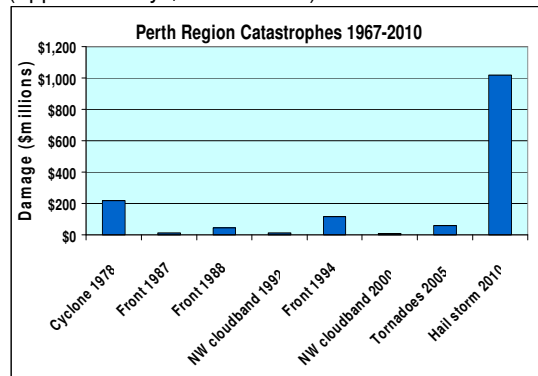


Table 2: Comparison of historical insured damage costs for weather related events affecting Perth from 1967 to 2010 (Data source Insurance Council of Australia 2010).

An analysis of climate and newspaper records dating back 150 years have not revealed the occurrence of any other hailstorms close to the same magnitude as this storm. Perth has been inhabited across the area affected by the largest hail from this storm for over 180 years. These records have identified major weather events, including extreme bushfires, severe winter storms, other severe thunderstorms and tropical cyclones back into the 1800s, so some historical indication of storms of the size and intensity of this severe hailstorm would be expected.

3.2 Severe Characteristics.

The severe thunderstorm initially produced a combination of large volumes of small hail and very heavy rain across the northern suburbs with local and narrow wind downbursts. The main thunderstorm cell then encountered the coastal sea breeze and regenerated as a left moving supercell. During this phase it produced giant hail to 8cm diameter in the Perth inner northern suburb of Osborne Park, although large hail to 6cm diameter was reported over the next 5km to the south of this suburb, passing over the heavily populated inner western suburbs of the city (see damage at the University of Western Australia in Figures 11 and 12). Severe hail and flash flood damage occurring in this area with land slides reported in the steep slopes of Kings Park, a large natural bush land reserve surrounded by high density urban and commercial developments.

Extensive flash flooding continued across large parts of the east and southeastern metropolitan area associated from secondary thunderstorm cells that formed on the eastern flank of the main cell. The most severe and extensive wind damage occurred over southeastern suburbs where down burst strengths were estimated to have reached near 150km/h, based upon the damage to

power poles in this region. The strongest measured wind gust was 128km/h at the township of Cunderdin, 135km to the east of Perth, from a thunderstorm to the east of the storm complex that passed over Perth.



Figure 11: Photograph of 6cm hail damage to 80 year old stained glass windows at Winthrop Hall at the University of Western Australia.

The heaviest rainfall reports, all in excess of the 1:100 year ARI for this region, included 28mm in 10 minutes at the northern suburb of Wanneroo, 54mm in one hour at the southeastern township of Jarrahdale, around 50km southeast of Perth, highlighting the long lived nature of the storm complex.



Figure 12: Photograph of major flash flood damage to a library in the University of Western Australia.

As was the case for the Melbourne severe storm, it was a combination of extreme rainfall, large quantities of small hail and destructive wind gusts over a very large part of Perth, as well as a region of giant hail over the inner suburbs of Perth centered

on some of the most vulnerable property in the city that lead to the very high total damage bill for this storm. Post analyses investigating potential storm tracks for a severe thunderstorm complex of this type revealed that this storm track was close to the optimum for maximizing damage across Perth.

3.3 Meteorological Setting

The Perth event was a multi-cellular severe thunderstorm outbreak. The synoptic weather pattern was a surface west coast trough (Figure 13) with a well developed middle level low centered to the west (See Figure 14), an unusual combination of features for the west coast of Australia in March. The presence of the middle level cut off low was essential to the development of this hailstorm as it produced the middle level northerly steering winds that pushed the storm southwards parallel to the coast, rather than steering the storm inland which is normally the case.

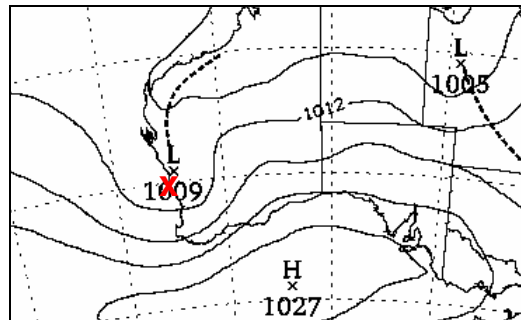


Figure 13: Mean sea level pressure analysis valid 06 UTC March 22, 2010. The severe thunderstorm formed on the west coast trough with the genesis location shown by the red cross. Map courtesy of the Australian Bureau of Meteorology.

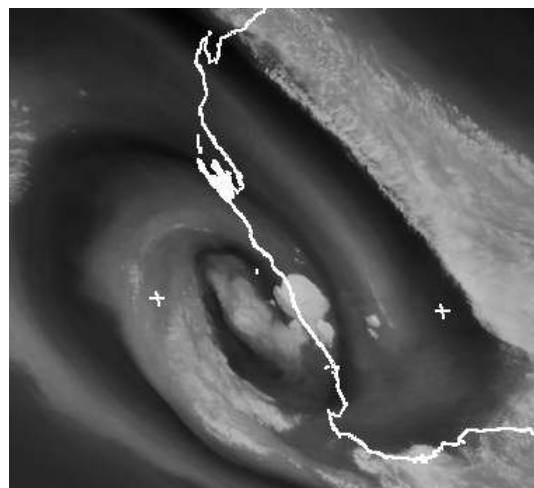


Figure 14: Water vapor image from MT-SAT 1 at 06UTC March 22, 2010 showing thunderstorm development on the mid west coast. Image

courtesy of the Japanese Meteorological Agency and the University of Dundee.

Another important factor that contributed to the rarity of this storm was the heavy antecedent rain that fell in the region immediately over and northeast of its genesis area over the week leading up to this event. This rainfall was a one in 20 year event for this region and lead to surface dew points around 19°C in this region rather than near 10°C, which is a more typical value in west coast troughs.

This combination of factors provided the necessary instability, as indicated by the morning stability indices from the most representative radiosonde station of Geraldton (Figure 15) - a Lifting Index of -4.1 and CAPE of 477 J/kg. Northerly steering winds, rare for Perth, were around 40 knots in the storm layer with a NNW jet stream maximum at 250 hPa of close to 100 knots.

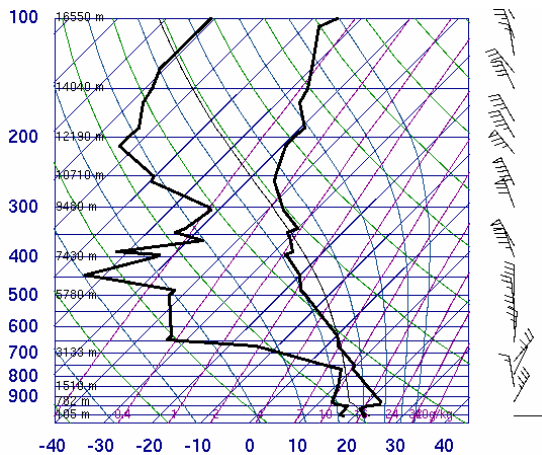


Figure 15: Vertical temperature and humidity profile for Geraldton Airport for 00 UTC March 22, 2010. Image courtesy of the University of Wyoming.

The convection was triggered by strong daytime heating with temperatures reaching 33°C in the thunderstorm genesis area, and low level convergence into the trough. As mentioned earlier, surface dew points in this area were abnormally high with reported values near 19°C, assisting in the formation of what was to become a high precipitation supercell. The lead thunderstorm was the most intense, tracking southwards - first across a market garden region where crops were severely damaged, then across the densely populated northern suburbs. Here the storm had similar characteristics to the first stage of the Melbourne storm. Large quantities of small hail stripped trees and blocked drains and roof gutters. Then very heavy rain produced deep flash floods with water related damage being the major feature in this part of Perth. The storm then encountered a coastal sea breeze convergence zone and transitioned into a left moving supercell.

During this phase of its life it reached its greatest intensity and continued to move southwards across the inner northwest then west of Perth. Largest hail fell over car dealerships in Osborne Park with hail to 8cm diameter, severely damaging thousands of cars and buildings. Giant hail continued to fall across western Perth and Nedlands, severely damaging one of Perth's largest hospitals and the state's oldest university. Stained glass windows over 80 years old were destroyed by hail of up to 6cm diameter. Extreme flash flooding produced land slides in the nearby Kings Park area with extensive damage being experienced at a university library and to a block of apartments.

Once the storm complex moved over the south and southeast of the Perth metropolitan area the hail rapidly vanished from the storm, although severe wind squalls and major flash flooding continued for the next couple of hours of the storm complex's life.

4. Role of Natural Variability and Climate Change

The key issue relating to the rarity of the two severe hailstorms is the identification of the critical meteorological factors that produced the severe storm environments that occurred on these occasions. Previous research work investigating the effects of natural variability and climate change on severe hailstorms affecting the greater Sydney area (Leslie et al 2008) showed that severe thunderstorm activity is prone to large natural variability on decadal scales near Sydney (Figure 16).

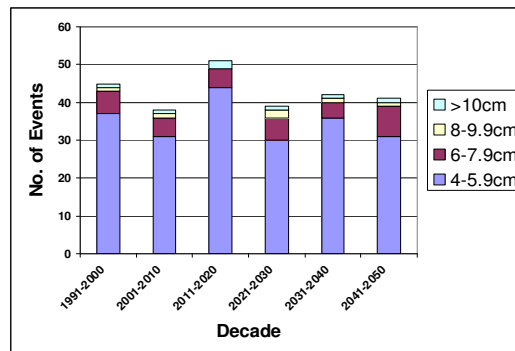


Figure 16: Decadal distribution of giant hail sizes under the "natural variability" scenario for the greater Sydney region (see Leslie et al 2008).

As the key severe storm environment factors were not individually beyond the realms of current climate capability, it is possible to argue that the storm environments could be produced by natural variability alone, although the coincidence of these factors is very rare.

However the influence of climate change cannot be ruled out. Leslie et al 2008 (see Figure 17 for the Sydney severe hailstorm enhanced greenhouse gas study results) found that the key

factors for severe thunderstorm activity in Sydney included increasing afternoon warm season temperatures, increased availability of low level moisture, the availability of mid-level dry layers in the atmosphere and increased low level convergence into surface heat troughs.

Storms over the Sydney Basin: A Climate Modelling Study. *Atmos. Res.*, 87, 37-51.

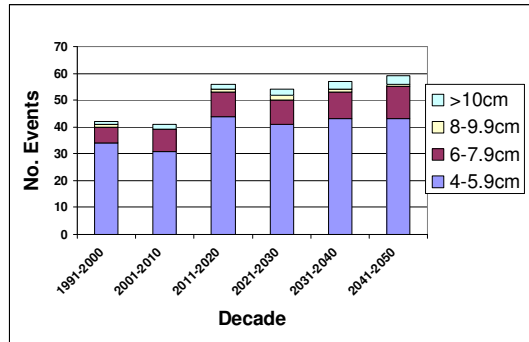


Figure 17: Decadal distribution of giant hail sizes under a “business as usual” enhanced greenhouse gas scenario for the greater Sydney region (see Leslie et al 2008).

These are also known to be important factors for severe hailstorm formation near Melbourne and Perth. All of these were found to be present or increase in the case of the Sydney climate change research and hence there is reason to believe they may also increase for the Melbourne and Perth regions. It is important to note that some areas of Australia could potentially see a decline in the coincidence of these factors and hence subsequent hailstorm occurrence e.g. south east Queensland could be one such region. None-the-less, from an insurance perspective the fact that both the hailstorms to impact upon Melbourne and Perth happened to follow tracks that almost optimized damage would intuitively point to a low probability of a similar magnitude of damage occurring given future severe hailstorms of this intensity and size.

A research proposal has been prepared to investigate these factors, although the research is yet to commence.

5. REFERENCES

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