P3.1 CHARACTERISTICS OF SEVERE HAIL EVENTS IN EASTERN AUSTRALIA

Donna F. Tucker
University of Kansas
Lawrence, Kansas

1. INTRODUCTION

Australia is not usually considered to be one of the major hail areas of the world. It is not listed among the sites with much hail by Wenland (1992). Court and Griffths (1986) noted that hail occurs there and can be very damaging, but they considered them rare events occurring less than once per year. Part of this attitude stems from the lack of reporting of hail in Australia. Severe weather there was not officially recorded until 1990, although records for major cities may exist before then. Only severe hail (> 2 cm diameter) is generally reported. Smaller hail may be reported, especially if it is accompanied by other severe weather.

Some of the hail in Australia can be very large and Australia's costliest natural disaster was a hail storm (Leigh and Kuhnel 1999). Hail sizes of 4-5 cm are not uncommon. Most studies of hailstorms in Australia have concentrated on New South Wales (e.g. Griffiths et al. 1993; Buckley et al. 2001). Severe hail occurs along most of the east coast of Australia. It occurs in substantial amounts in parts of South Australia and Western Australia also but, due to their small population densities, reporting is not as good as that on the east coast. Even on the east coast problems with verification arise (Mills and Colquhoun 1998).

Hail forecasting in Australia has often been based on techniques which originated in North America. Mills and Colquhoun (1998) include a number of references to papers with techniques designed for North America.. Their severe weather decision tree modifies actual criteria somewhat to correspond with conditions they have observed in Australia. Yet we have no guarantee that the conditions leading to severe weather in North America will work in other parts of the world. Tuduri and Ramis (1997) showed that several parameters associated with severe weather in North America were not that useful in Europe. Specifically, they showed that hailstorms were more likely to be associated with situations having relatively little CAPE. High values of CAPE have been associated with hailstorms in the U.S. (Johns and Doswell 1992; LaPenta et al. 2000). Yet Nelson (1983) argued from numerical simulations that the shape and orientation of the updraft was more important in hail production than a large amount of static instability.

It might be expected, because of the oceanic climate, that environments for hailstorms in Australia might resemble those of supercells in California. Monteverdi and Quadros (1994) have argued that supercells can develop in an environment with low buoyancy and high low level shear. They claim these environments are similar to those of the tropical storm supercells studied by McCaul(1991). McCaul and Weisman (1996) argued that supercellular convection can develop in low buoyancy environments when the low level shear is large. Rotunno and Klemp (1984) had previously shown that dynamically induced pressure forces associated with strong wind shear can augment the buoyancy by a factor of 2 or 3.

Due to space limitations, this paper will concentrate soley on the climatological distribution of hail and on the characteristics of atmospheric soundings associated with severe hail events.

2. TEMPORAL DISTRIBUTION

Reports of severe hail were extracted from the Australian Severe Storms Archive which was obtained from the Bureau of Meteorology in Australia. Dickins et al. (1996) describe this database, which contains reports of tornadoes, high winds, heavy rain, and killer lightning in addition to large hail (> 2 cm diameter). An event in the database is generally a single severe thunderstorm. Reports or observations which are more than 30 minutes or 25 km apart are considered separate events unless there is some other evidence to link then to the same storm. Thus, it is not uncommon for several events to occur on one day. For hail events, the beginning time, the latitude and longitude, the hail size, a confidence marker for the hail size and a comment field are generally included. In some instances, the duration of the event, the amount of damage, the amount of insurance payout, and the number of injuries are also included. Radar data were not available for the vast majority of the events. Thus, it would not be possible to obtain a radar derived storm motion or cloud top. As mentioned above, severe weather in Australia was not generally reported before 1990. Some areas which have a number of hail reports since 1990 have no hail reports prior to then. Nevertheless, severe weather reports improved throughout the 1980s. As has been noted by Griffiths et al. (1993) and Mills and Colquhoun (1998) the population in many areas in Australia outside major cities is fairly sparse and many events no doubt still go unreported.

There are some differences in average hail size across eastern Australia. Means were only computed for the major cities since these reports are less likely to be biased towards larger hail sizes. Mean hail size over the for the period 1982-2001 for Melbourne, Sydney and Brisbane are 3.0, 4.0, and 3.8 cm respectively. Thus, Melbourne has smaller hail sizes than areas further north. Brisbane and Sydney have overall hail sizes which are comparable. It is not clear whether Melbourne's lower hail sizes are due to lower temperatures and smaller atmospheric water vapor contents there or due to general differences in the average storm structure in the Melbourne area.

The seasonal distribution of hail events for the entire period of record for Victoria, New South Wales (NSW) and Queensland are presented in Fig. 1. The

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* Corresponding author address: Donna F. Tucker, University of Kansas, 1251 Wescoe Hall Dr., Lawrence, KS 66045-7582; email: dtucker@ukans.edu

similarities are striking. In each area the maximum number of hail events occurs in the late spring or early summer. North America also has a maximum number of severe hail events during late spring and early summer. During winter, few hail events occur. Victoria has a secondary maximum in January indicating that the warmer summer temperatures have more influence on encouraging the production of hail here than farther north. The hourly distribution of hail events for the entire period of record is given only for Queensland (Fig 2). Queensland had fewer missing data than the other states. Excluding missing values, results for the other states were almost identical to those of Queensland. Hail events center around 6 UTC or 5 p.m. LDT. Hail events during the late evening or morning hours are rare. This outcome is consistent with the general late afternoon maximum observed for thunderstorms in many parts of the world.

3. VERTICAL ATMOSPHERIC STRUCTURE

To examine the vertical atmospheric structure associated with these hail events, 106 events were chosen in five geographical regions. For each event, a sounding is available no more than 6 hours before the event or no more than 6 hours afterwards. The sounding would be within 150 km of where the event occurred. In most cases, the sounding would have been taken at 0 UTC or 11 LDT. Sydney often had a sounding taken between 3 and 5 UTC in addition to the 0 UTC sounding from Williamstown (125 km north of Sydney). The geographical regions are Melbourne, 22 cases, northeast Victoria, 6 cases, Sydney, 31 cases, north central NSW, 17 cases and Brisbane, 30 cases. Mean values of sounding parameters for these cases are displayed in Table 1. An overall mean is computed weighing each area by the number of its cases. Only cases with positive Convective Available Potential Energy (CAPE) are included in the means. In a few cases where the sounding was more than 4 hours after the event and the sounding from the radiosonde observation yielded no CAPE, the 6 UTC data from the NCEP reanalysis for the nearest grid point was used to estimate sounding parameters. For Melbourne, there were 19 cases with positive CAPE, including four computed from the reanalysis data. For Sydney there were 30 cases with positive CAPE. For north central NSW there were 16 cases with positive CAPE, including one computed from the reanalysis data. For Brisbane, all 30 cases had positive CAPE with four computed from the reanalysis data. Northeast Victoria cases all had positive CAPE with one computed from the reanalysis data. The later cases are not shown separately due to the small sample size but are included in the weighted mean. For consistency, CAPE shown is computed from a surface (or in the cases of the reanalysis, 1000 mb) parcel. For a couple of the cases without positive CAPE, a parcel starting above the surface would yield positive CAPE, indicating elevated convection.

The average Total Totals (TT) values approach those generally considered favorable for severe thunderstorms (> 50). They are slightly larger for Sydney and slightly smaller for Brisbane but do not vary greatly from one part of the region to the other. CAPE values are smaller than those observed for severe thunderstorms in the United States (Rasmussen and Blanchard, 1998). They are more similar to those observed for ordinary thunderstorms in the United States or tornadic thunderstorms in California (Monteverdi and Quadros, 1994). Tuduri and Ramis (1997) found that hailstorms in the western Mediterranean were likely to occur with relatively small values of CAPE. These results would indicate that the development of hailstorms does not require large amounts of CAPE under some circumstances. The CAPE values do show a latitudinal gradient with smaller values in the south and larger values in the north. The TT and CAPE values in eastern Australia are not well correlated, a number of cases have a relatively large value of one and small value of the other. Very few cases, however, have both small CAPE and small TT. The absolute value of the Convective Initiation (CIN) is fairly high indicating that in most cases some sort of a moderately strong trigger will be required to initiate convection. Every sounding contained at least one layer which was potentially unstable ($\partial\theta_e/\partial z < 0$). Therefore some upward motion will generate further instability in the vertical.

The bulk Richardson Number (BRN) was difficult to compute in many cases because winds were frequently

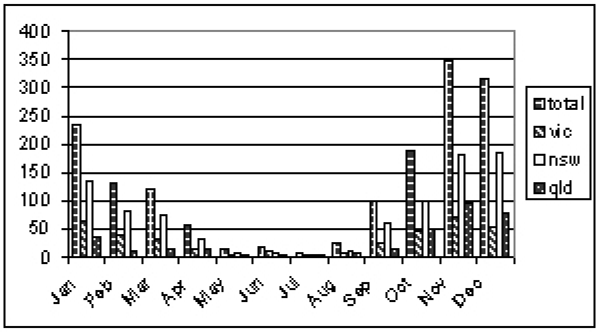

Figure 1. Number of severe hail events by month and state for the entire period of record (ending with 2001).

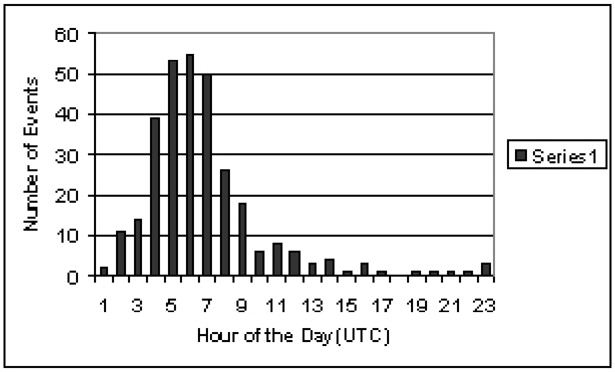

Figure 2. Number of severe hail events by hour of the day for Queensland. Hour 0 is not shown as that category was used for missing data.

Table 1. Mean sounding parameters for eastern Australia severe hail cases.

Location	Total Totals	CAPE	CIN	Equil. Pressure	LFC	Richardson Number	Precipitable Water (mm)	WBZ (ft)
Melbourne	48.6	285.1	-144.7	462.1	751.0	3.67	27.3	9434.3
Sydney	49.9	619.7	-129.2	339.1	755.5	10.7	31.2	10242.4
N. Central NSW	48.7	754.8	-134.2	319.7	742.6	22.6	29.1	10742.0
Brisbane	47.6	704.9	-114.7	332.4	769.0	42.5	33.3	10922.4
Weighted Mean	48.6	575.4	-127.3	363.1	755.7		30.6	10366.3

not available in the boundary layer. Generally it was possible to compute the BRN for about half of these events. Of these about a quarter were computed with the lower layer 1000 m thick instead of the standard 600 m. Even so, some interesting patterns emerge. The BRN is generally quite low for all locations except Brisbane. Even Brisbane's average is well within the range for development of supercells (<50) (Weisman and Klemp, 1984). BRN values in the Melbourne area are especially low, but most of the difference in the BRN values between Melbourne and Sydney can be explained by Melbourne's lower CAPE values. Melbourne's values for BRN are so low that it would raise the concern that the storm could be sheared apart. In the vast majority of the cases, most of the shear is directional shear as opposed to speed shear. This situation would support the idea that the wind shear is causing pressure perturbation forces which serve to augment the CAPE (Rotunno and Klemp 1984). The BRN increases more north of Sydney but the reduced wind shear does not appear to inhibit the formation of severe hailstorms.

Precipitable water is lowest in Melbourne (whose temperatures are generally lower) and highest in Brisbane (whose temperatures are generally higher). It does appear from the data set that severe hailstorms do not occur when the precipitable water is less than 20mm. The WBZ values observed are slightly higher than the 7000-9000 feet considered optimum by Doswell (1986). They reflect the moderately unstable environment in which the Australian severe hailstorms form.

4. TYPES OF HAIL EVENTS

Even though the study region stretches from the middle latitudes into the tropics, there are a lot of similarities between the hailstorms in different parts of the region. There are also some differences. To examine typical conditions associated with eastern Australian hailstorms and to bring out the similarities and differences, the events studied are broken into four different categories. Two categories include events associated with a midtropospheric vorticity maximum. The other two categories are dominated by high static instability or by a surface front or strong trough. Note that the events associated with the midtropospheric vorticity maximum may also have a surface front or trough associated with them. The midtropospheric vorticity maximum was such a distinctive feature of so many events that it appeared to be more useful to put these events in separate categories. The events associated with high instability may have a weak surface trough (no closed isobars) associated with them. A few cases of all types occur on the front poleward or rear equatorward side of a jet maximum but generally winds associated with the hailstorms are light and jet streaks do not consistently play a role.

The distribution of these events for the 106 cases from 1982-2001 is given in Table 2. Events in the Melbourne area are dominated by the midtropospheric vorticity maximum with more than 80% of events falling into one of those categories. None of the Melbourne events are associated with high instability in the absence of a surface front or strong trough. Thus, synoptic scale forcing would appear to be mandatory for hailstorms to occur in this part of the region. In northeast Victoria, the sample size is small but one event is primarily associated with high instability. This part of Australia is more mountainous and orographic forcing could be important in some instances with synoptic scale forcing not as necessary. Hail events in NSW are still primarily associated with midtropospheric vorticity maximums but those with frontal or strong trough systems alone are more common than they are in Victoria. Events without synoptic forcing are still rare although this area is getting close to the tropics. In Brisbane, events associated with a midtropospheric vorticity maximum are still important but not as dominant as they were farther south. Frontal/trough events are most important and high instability cases occur in significant numbers. Thus, the same sorts of severe hail events occur throughout the east coast of Australia, but the frequency of different types varies from south to north.

5. CONCLUSIONS

Severe hailstorms in eastern Australia bear more resemblance to the supercells in California than to nontornadic supercells elsewhere in the United States.

Table 2. Distribution of different types of hail events

	Vorticity Maximum South	Vorticity Maximum North	Front or Strong Trough	High Instability
Melbourne	12	7	3	0
NE Victoria	3	0	2	1
Sydney	19	0	11	2
N. Central NSW	8	2	6	1
Brisbane	9	0	12	9

Their CAPE values are closer to those of European hailstorms than Great Plains ones. Those in the north do show the effects of warmer temperatures with more CAPE and higher precipitable water. The magnitude of the wind shear is not always that large although the directional shear may be substantial. It would appear that parameters based on shear magnitude, such as helicity and BRN, might not be the best measures of the potential of the environment to produce hailstorms. These results emphasize that severe storm environments are not necessarily the same in all parts of the world. Under a variety of conditions several types of environments can lead to severe weather.

6. REFERENCES

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