Modelling of Severe Thunderstorms in South East Queensland

BRUCE HARPER
Systems Engineering Australia Pty Ltd, Brisbane.
and
JEFF CALLAGHAN
Bureau of Meteorology, Brisbane.

Abstract:

This paper summarises some aspects of work done for a 1997 risk assessment study of severe thunderstorms in the South East Queensland region undertaken for SUNCORP General Insurance by Systems Engineering Australia Pty Ltd, with cooperation from the Severe Weather Section, Brisbane Regional Office. Storm archive material from the Bureau was used to assist in the development of a numerical-statistical model of thunderstorm frequency, scale and intensity which included consideration of extreme winds, hail and also tornadoes. Examples are provided of the data sets compiled for the study, the overall modelling approach and the resulting verification of the model.

Introduction

South East Queensland is a region especially prone to the damaging effects of severe thunderstorms. In the past 30 years there have been several instances of very severe hail (> 70 mm), damaging winds (> 35 ms^{-1}) and several tornadoes. Brisbane residents are very familiar with the late afternoon arrival of severe storms, often a welcome relief to hot and humid summer days, but turning peak hour into chaos and often causing widespread loss of electrical supply. What is less well appreciated by many members of the public, however, is just how little is known about the detailed physics of these storms and the difficulty of forecasting their severity. Unfortunately, lack of adequate mesoscale monitoring in the region continues to hamper forecasting efforts and this in turn affects the amount and quality of quantitative data which can be interpreted for later risk analysis purposes. This paper outlines some aspects of a 1997 study commissioned by SUNCORP General Insurance to assist in their risk management and planning for potential storm losses affecting residential property.

Regional Storm Climatology

Some of the earliest known specific analyses for the region date back to the 1940s (Martin 1944). During the 1960s, much work was undertaken into the electrical impacts of thunderstorms (Prentice 1965), leading to the establishment also of operational lightning tracking systems. The most complete and up-to-date description of severe thunderstorm occurrence and behaviour in the region is Callaghan (1988), supported in part by Crane (1989) with later updates such as Callaghan (1996). In addition to these works, there were three principal sources of raw data which were utilised in the study, viz

- A 10 year detailed data base of severe storms from 1978 to 1987 (the Terminal Area Severe Turbulence project or “TAST”)
- A more recent but less complete data base using the new National Severe Thunderstorm Database (“NSTD” set), and
- Specific paper-based files of each severe storm reported in the region since the late 1970’s

The development by Callaghan (1988), which is strongly based on the TAST data set, was used extensively in the study. This data set focused only on storms with high radar reflectivity regions (> 60 dbZ) thus ensuing potentially severe storms only were considered. After some simplification to assist modelling, Callaghan’s analysis leads to the adoption of essentially 4 classes of severe thunderstorms in the region, based on broad synoptic pre-cursor types as follows:

Type A: SE Change	(23%)
Type B: Strong NW Flow	(17%)
Type C: Weak NW Flow	(43%)
Type D: Other	(17%)

Figure 1 schematises the typical approach tracks for the severe storms in each of these categories, superimposed on a topographic map of the region. Callaghan proposes a strong association between both storm intensity and track as a function of the regional topography; these being related to:

- the generally westerly steering current for storms in the region
- the highland regions to the south and west providing elevated convective heat sources
- vertical wind shearing created by the elevated regions
- low level convergence on the coastal plain

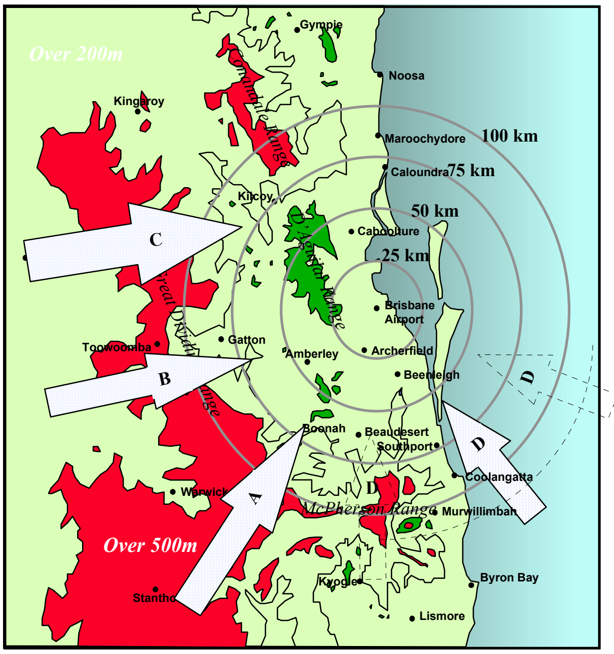


Figure 1 - Schematised Synoptic Track Classes

Many specific instances have been recorded by Callaghan where the interplay of the topography and coastal plain convergence directly impact storm intensity and track over the metropolitan region. Unfortunately the available dataset is still inadequate for a broad statistical treatment of intensity versus track or location. The impact of topography on track is however supported by experience with the real-time lightning tracking system operated jointly by SEQEB (now Energex) and Telstra (personal communication), collected since the late 1980's but unfortunately not able to be obtained for use in the study.

Although detailed data on storm tracks was not available it was still possible to amass a large amount of information on severe storms in the region based on the following sources:

- the 10 year TAST data set
- the NSTD data base
- insurance industry loss figures
- SUNCORP insurance loss figures
- newspaper reports (include police, SES, SEQEB etc)
- other Bureau of Meteorology material

The earliest datum recovered was December 1967, this being the oldest reported significant insurance loss which was available from SUNCORP records. While newspaper reports alone could be scanned prior to this date, the accuracy of such data is generally poor. The growth in population since that time also means that early data suffers from reduced reporting and areal impact.

A total of 48 events was compiled, spanning 29 years and consisting of the following information:

- date and name/location of each event
- peak gust wind speed (measured/estimated) and duration
- maximum rainfall and duration
- reported maximum and average hail size and duration
- tornado sightings by F scale and swath width X and length Y
- maximum cloud tops associated with the event
- primary storm cell direction and speed of movement
- incidence of supercells
- insurance industry losses and claim numbers
- areal extent of major damage zone
- postcode(s) mainly affected
- State Emergency Service (SES) or Police statistics from newspaper reports
- SEQEB blackout statistics as reported in newspaper accounts
- injuries and deaths associated with the event
- other details

Interestingly, only four of these 48 events are shared with the data set recording the highest wind speeds in the region. This reflects both the small scale of these storms, making single-site wind measurements infrequent, plus the relative high-loss impact of hail without damaging winds being present.

In summary, some of the major conclusions which can be drawn from this database are:

– there are an average of about 20 days each year when severe thunderstorms occur
– on each of these days there are often up to 5 individual storm systems involved
– the thunderstorm "season" is mainly October through April
– predominant approach direction is from SW
– typical forward speed is 12 m/s
– approximately 30% of severe storm days involve severe hail
– tornadoes occur on average about 1 day per year in the region
– the most damaging storms appear to be of Type A (SE Change)

Model Basis

A severe thunderstorm risk model was then developed based on a combination of the known regional climatology, some specific local storm analyses and also US experience from the detailed mesoscale monitoring during the JAWS program in Colorado (Hjelmfelt 1988). The model operation was then incorporated into the existing MIRAM (Monte Carlo Insurance Risk Analysis Model) originally developed for tropical cyclone conditions (Harper 1996).

The model consists of the following major elements:

- a description of the storm climatology of a region in terms of synoptic classes, tracks, frequency of occurrence, scale and overall intensity estimates
- details of the built environment such as the spatial distribution of housing
- a model of downburst wind field patterns
- a model of hail size and distribution within thunderstorms
- a tornado wind swath model
- relationships linking wind speed and hail size to damage and hence to potential insurance losses

In order to develop predictive relationships for storm features such as size, forward speed and relative intensity, a number of specific severe storms were examined in considerable detail. Table 1 presents a summary of the storms considered, together with the subjective TAST severity and damage indices, the assigned synoptic type and also the peak measured wind speeds in each case. A total of 16 storms were analysed; 4 being associated with severe recorded wind gusts (but little damage); 6 associated with severe damage (but modest recorded winds); 5 associated with severe damage as well as high recorded gusts. This set contained the region's highest wind gust of 51.5 m/s, recorded on 18-Jan-1985 at Brisbane Airport, as well as 8 of the top 20 recorded wind speeds from the 44 years of regional wind speed archive (across Brisbane, Amberley and

Table 1 - Selected Severe Storm Case Histories

		TAST Set			Measured Wind Gust		
Date	Description	Severity Index	Damage Index	Synoptic Type	V_3 ms^{-1}	Anemom Site	Regional Ranking
4-Nov-73	Brisbane Tornado	3'	3'	B'	14.4	Brisbane	-
16-Dec-77	Yeronga/Bulimba/Nundah	3	2	D	34.5	Brisbane	10
20-Dec-79	Ipswich	2	2	D	32.9	Amberley	14
20-Jan-80	Chermside	2	2	A	32.4	Brisbane	16
22-Nov-80	Sunnybank/Murarrie/Wynnum	3	3	A	34.5	Brisbane	9
15-Dec-80	Ipswich/Archerfield	2	1	C	32.9	Amberley	15
16-Dec-80	Archerfield Tornado	3	3	C	30.4	Amberley	21
16-Dec-80	Brighton Hailstorm	3	3	C	21.6	Brisbane	231
29-Nov-81	Beaudesert	3	3	A	29.3	Brisbane	26
18-Jan-85	Brisbane Hailstorm	4	3	A	51.5	Brisbane	1
6-Mar-85	Inala/Holland Park	2	1	A	29.3	Brisbane	25
19-Oct-87	Booval/Kedron/Nundah	3	3	C	16.5	Brisbane	-
11-Nov-87	Expo Sails Damage	2	2	C	26.8	Brisbane	51
24-Nov-87	Ipswich/Tennyson	3	3	B	27.3	Brisbane	44
24-Dec-89	Redcliffe Tornado	3'	3'	A'	29.3	Archerfield	28
6-Nov-95	Bellbowrie Hailstorm	3'	3'	C'	17.0	Amberley	-

Archerfield airports).

Time series developments of these storms based on radar reflectivity were then studied to extract a range of temporal and spatial scales which would be amenable to modelling. Principal amongst the parameters of interest was the typical spatial scale of influence of these storms, for example measured by the 60 dBZ plan area. Figure 2 summarises some of

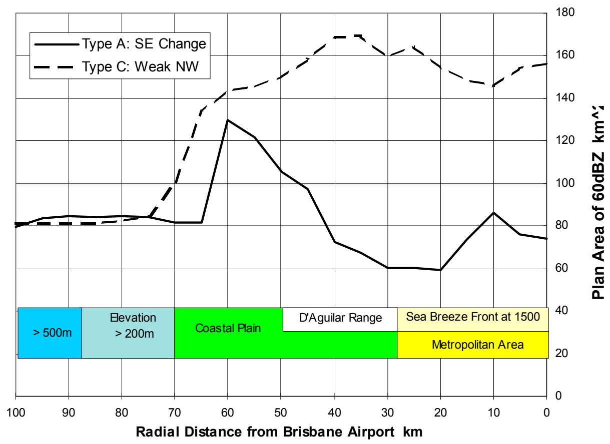


Figure 2 - Evolution of Storm 60dBZ Reflectivity

these results for the Type A and C synoptic classes (where there were 6 of each type examined). It shows the variation in mean 60 dBz plan area as a function of radial distance from Brisbane Airport (the radar site), and also indicates relevant topographic zones. Both types show the possible influence of the coastal plain around 60 to 70 km from the radar site. Type A then tends to shrink but grow again later in the vicinity of the sea breeze region whereas Type C appears to maintain or even increase in size. The Type A variation also seems associated with intensity “pulsing” such as that clearly portrayed by the January 1985 event (see later).

In addition to examining the reflectivity data, the downburst wall-jet model by Holmes and Oliver (1996) was used to estimate the peak downburst intensity which, when combined with storm forward movement, would have produced the observed wind speeds and directions at a number of the anemometer sites. Accumulated storm information was then compared with the more detailed data available from the JAWS project to define characteristic parameters for modelling.

Figure 3 shows schematically how the model operates at a postcode level, where insurance risk data is generally collated. The progression of a single model thunderstorm is indicated, creating a swath of potential wind and hail damage across a region. A tornado damage swath is also depicted, being typically of a much narrower swath dimension than the hail and downburst winds. The model discretely represents individual storms at a timestep of 1 minute so as to resolve the rapid evolution of the wind and hail components. Using the regional climatology as reference, a synthetic storm history spanning many thousands of years of occurrences is then generated. The resulting ground-level wind and hail magnitudes are then spatially integrated with the underlying built environment to accumulate statistics of insurance loss which can be interpreted in terms of probability of occurrence and exceedance.

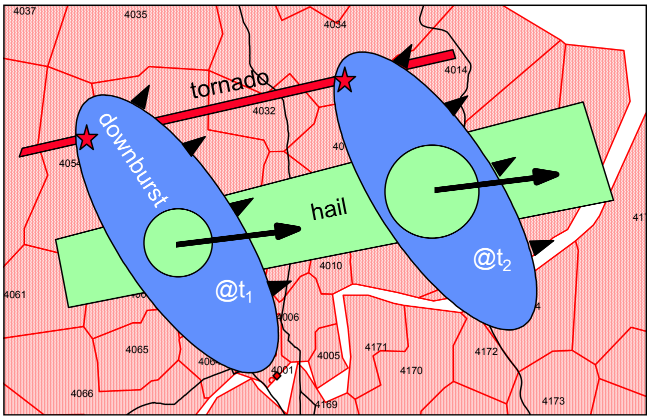


Figure 3 - Schematic Model Storm Interaction

Model Verification

A number of different methods were available to test the accuracy of the model predictions. Firstly, the model estimates of site specific wind speed were compared with an extreme value analysis of the 44 year record from Brisbane Airport. This is shown in Figure 4 where the agreement is extremely good from the onset of severe winds at 25 ms^{-1} through to even the upper tail of extreme winds. This provides a high degree of confidence in the basic space and time scales chosen plus the assumed downburst magnitude distribution. In regard to hail, for which there is less collaborative data, the model predicts an average of 0.5 haildays per year for > 20 mm versus the recorded average of 0.7 days per year for all hail sizes at Brisbane Airport. Given the generally poor quality of hail data this is considered a reasonably good result.

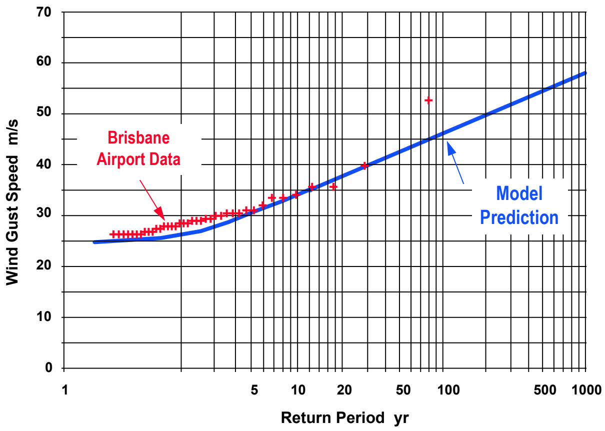


Figure 4 - Modelled versus Measured Wind Gusts at Brisbane Airport

Approximately 20 years of SUNCORP insurance loss data was also analysed as part of this study and, as well as providing an estimate of average annual losses, this allowed specific events to be examined and compared with the model to test its overall calibration.

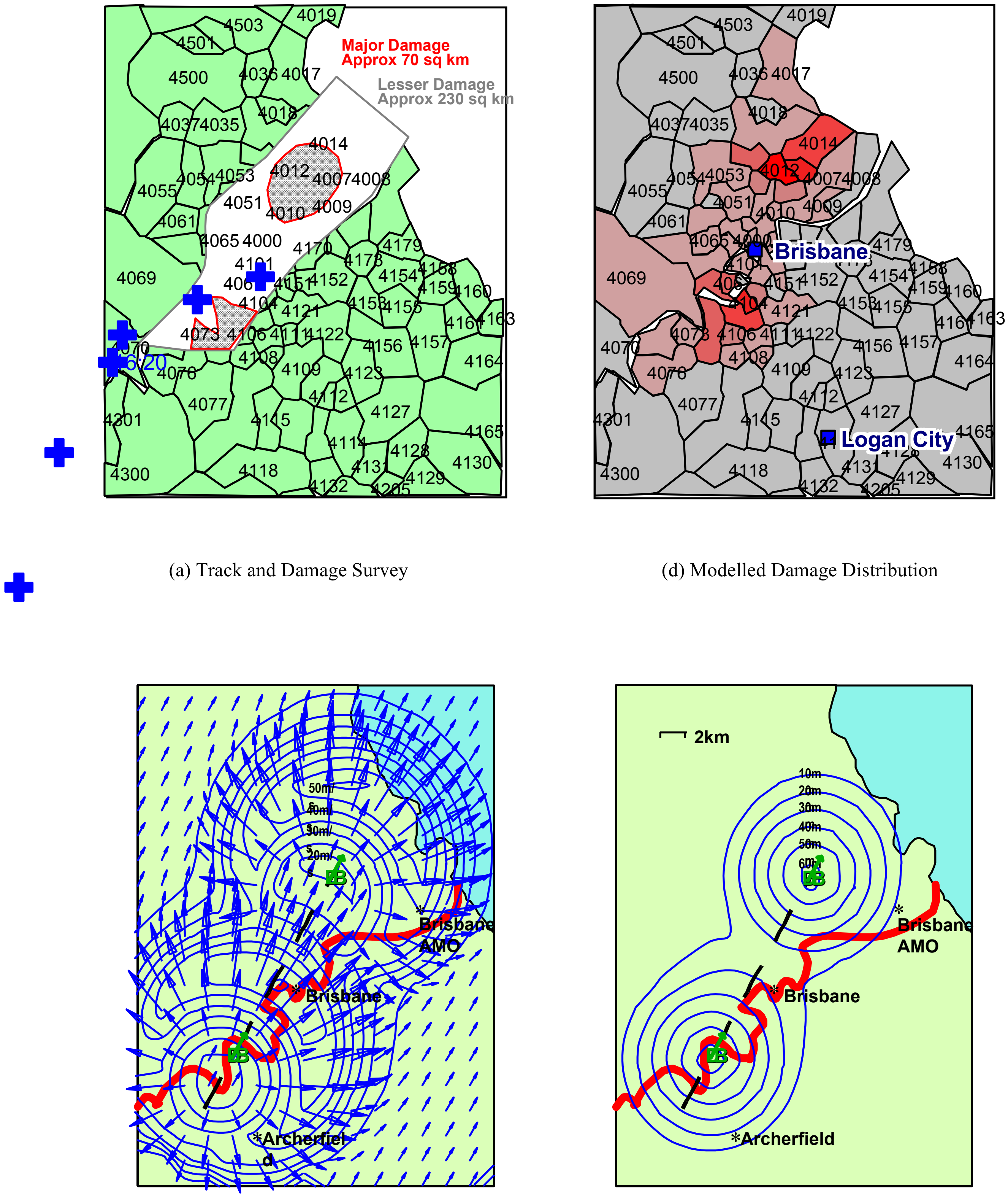
The January 1985 hailstorm still ranks as the single greatest insurance industry loss for the region at \$180M (ICA 1994; 1985 values). Figure 5(a) shows the radar path of the storm centre, which was a Type A event traversing the city from SW to NE at a speed of about 12 ms^{-1}. Also superimposed on the figure is the extent of a subsequent qualitative building damage survey (Jhamb et al 1985). The survey identified “major” damage covering some 70 km^2, concentrated in two distinct regions, and predominantly attributed to hail alone. Figure 5(b) shows the corresponding modelled wind gust envelope which assumes a pulsed storm behaviour over a 20 minute period delivering two distinct (and assumed equal here) downburst centres. The modelled destructive wind regions (say > 40 ms^{-1}) are shown as being limited to the forward regions of each modelled downburst. The second burst, for example, could have been responsible for the 51.5 ms^{-1} recorded at the Airport site, although the limited damage there suggests it was of a much smaller microburst spatial scale. These results are however consistent with the approximately 40 ms^{-1} values recorded in the city and by a second airport anemometer. The first downburst may also not have been as severe as the second, but no measured winds are available near that location. Also shown in (c) is the modelled hail size variability based on reported peak hail sizes during the storm of about 60 mm. The “major” damage region in (a) is approximated by the 35 mm modelled hailsize contour. Finally (d) indicates the predicted % insured loss spatial variation on a postcode basis, which matches estimated total SUNCORP losses for this event.

Conclusions

This study is perhaps the most detailed of its type yet undertaken in considering the actual mechanics of severe storm behaviour across the South East Queensland region, leading to quantitative impact assessment. It has relied on a variety of largely descriptive data available from the archives but is underpinned by a small number of critical observational data sets, namely wind measurements and radar data. It provides a firm basis for extending the model capabilities as more and better quality data becomes available over the years. In this regard, the importance of post-storm survey information cannot be understated in allowing quantitative estimates of damage to be assembled.

Acknowledgments

The authors wish to acknowledge the support of Mr Richard Fagan, SUNCORP General Insurance and Mr Rex Falls, Regional Director, Bureau of Meteorology, Brisbane for permission to present this paper. The high level of cooperation from all Brisbane Regional Office staff is also gratefully appreciated.



(a) Track and Damage Survey

(d) Modelled Damage Distribution

(b) Modelled Wind Field Envelope

(c) Modelled Hail Size Distribution

Figure 5 - Model Calibration versus the January 1985 Hailstorm

References

Callaghan J., 1988: Severe Thunderstorms Brisbane, *Bureau of Meteorology*, Brisbane.

Callaghan J.,1996: Review of Severe Weather Forecasting and the Severe Thunderstorm Warning Service in the Southeast Coast District of Queensland. *Proc 5th Aust Severe Thunderstorm Conf,* Bureau of Meteorology, Avoca, July.

Crane G D, 1989: Severe Local Storms: Hail. In Oliver J and Britton N R (Eds) *Proc Conf Natural Hazards and Reinsurance*, Sterling Offices (Australia) Ltd, p29 - 44.

Jhamb H K, Hornsby R G and Gordon B, 1985: Storm Damage - Brisbane 18 January 1985. *Dept of Housing and Construction*, Brisbane, 13pp.

Harper B A, 1996: Risk Modelling of Cyclone Losses, *Proc IEAust Annual Engin Conf*, Institution of Engineers Australia, Darwin, April, pp.53-88.

Hjelmfelt M R, 1988: Structure and Life Cycle of Microburst Outflows Observed in Colorado. *Jnl Applied Meteor*, Vol 27, Aug, pp 900 - 927.

Holmes J D and Oliver S E, 1996: An Empirical Moving Jet Model of a Downburst. *Proc Aust Wind Engin Soc 5th Workshop*, Tanunda.

ICA, 1994: Risk Accumulation Guide. *Insurance Council of Australia*, Melb.

Martin G R, 1944: Notes on Migrating Thunderstorms over the Brisbane Area in the Early Summer of 1943-44. *Tropical Res Bull*, Bureau of Meteorology, May.

Prentice S A, Mackerras D and Robson M W, 1965: A Ten Year Survey of Thunderstorms in Queensland. Univ of Qld, Dept Elec Engin, *Report to the Electrical Research Board* UQ/ERB/5, Nov.