P11.6 MODELING AND QUANTIFICATION OF SEVERE THUNDERSTORM RISK IN AUSTRALIA FROM RE/INSURANCE PERSPECTIVES

Jianming Yin*, *Tokio Marine Technologies LLC*
Bo Yu, Tokio Marine Technologies LLC
David McComas, Tokio Millennium Re.

1. INTRODUCTION

A severe thunderstorm is defined by the Australian Bureau of Meteorology (BoM) as a thunderstorm which causes one or more of the following phenomena: hails with diameter of 2 cm or more at the ground; or wind gusts of 90 km/h or greater at 10 m above the ground; or flash floods; or tornadoes, or any combination of the above. Severe thunderstorms can occur anywhere in Australia. From 1967 to 1999, severe thunderstorms have been estimated to cost Australia about $284 million each year (BTE, 2001), responsible for more than one quarter of the average annual cost of natural disasters in Australia. Severe thunderstorm risk is a significant issue for the Australian insurance industry: paid insurance claims for severe thunderstorm damage are greater than those for tropical cyclones, earthquakes, or bushfires. The Sydney hailstorm of April 1999 was the single largest insured natural disaster in Australia at a cost of $1.7 billion (BTE, 2001). Therefore, Re/insurance companies need reliable models to analyze and quantify severe thunderstorm risk in Australia.

The paper starts by discussing the Australian BoM historical severe thunderstorm data and data compilation. The stochastic simulation approach is then described and employed to simulate the severe thunderstorm climatology in Australia by using the compiled BoM data. Simulated severe thunderstorm climatology is compared to BoM historical data. The simulation of the spatial variability of thunderstorm intensity and the development of vulnerability functions for assessing losses associated with severe thunderstorm damage are also described.

2. SEVERE THUNDERSTORM DATA AND COMPILATION OF HISTORICAL EVENTS

The severe thunderstorm data used in this study are the historical data from BoM. BoM has collected and maintained a severe thunderstorm database and the data go back as far as 1900. However, as shown in Figure 1, the annual average numbers of the hail storm reports have stabilized only after 1990. This is because of the establishment of the severe weather forecasting sector in BoM in 1987 and the initiation of a storm spotters' network in 1990. The reports since 1990 also became more complete due to the increased public awareness of the thunderstorm risks after the 1990 catastrophic hailstorm in Sydney. We only use BoM historical data from 1990 through 2009 to derive the empirical severe thunderstorm climatology in Australia, because these are the only data that we consider to be sufficiently reliable and complete.

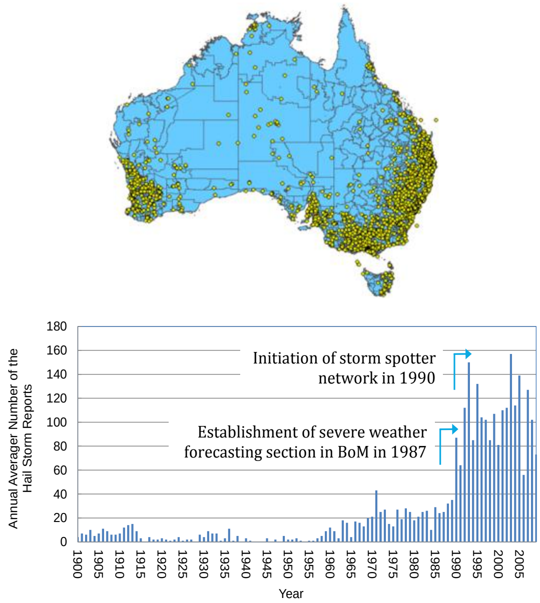

Figure 1: (top) BoM storm reporting locations of severe hailstorm reports since 1900; (bottom) milestones and hailstorm reports by year

The BoM severe thunderstorm database might receive multiple hail or wind reports from the same storm. We applied a 30 minute/25 km rule to remove the suspected duplicate reports from BoM database (Schuster et al., 2005). This rule implies that only the reports separated either more than 30 minutes in time or greater than 25 km in distance are considered to be independent hail or wind storm reports. After applying the 30 minute/25 km rule to remove the duplicate reports, the annual average numbers of historical thunderstorm are 91.4, 187.5 and 20.3 per year for hailstorm, downburst straight-line wind, and tornado, respectively.

To allow companies to assess their reinsurance needs at a portfolio level, the concept of severe thunderstorm event is introduced and defined as a

* Corresponding author: Jianming Yin, Tokio Marine Technologies *LLC*, 3097 Satellite Blvd. Building 700, Suite 250, Duluth, GA 30096 USA; *E-mail*: Jianming.Yin@tokiomarinetech.com

congregation of individual hailstorms, straight-line winds, and tornadoes spawned by the same convective precipitation system moving across Australia within a continuous 7-day timeframe and within a circular area of 1,000-km in radius. In this study, severe thunderstorms are compiled into severe thunderstorm events according to this definition.

3. SIMULATION OF STOCHASTIC EVENTS AND THUNDERSTORM CLIMATOLOGY IN AUSTRALIA

3.1 Stochastic Simulation Approach

After reviewing various modeling approaches for severe thunderstorm risks and the availability and quality of the severe thunderstorm data required for each of the approaches, a statistical modeling approach developed by TMTech (Yin et al., 2007) appears to be the most suitable approach given the amount and completeness of the severe thunderstorm data available in Australia. Monte Carlo technique is employed to simulate the stochastic severe thunderstorms. In this study we consider three major perils associated with a severe thunderstorm, that is, hailstorm with hailstones of diameter of 20 mm or more, downburst straight-line wind, and tornado.

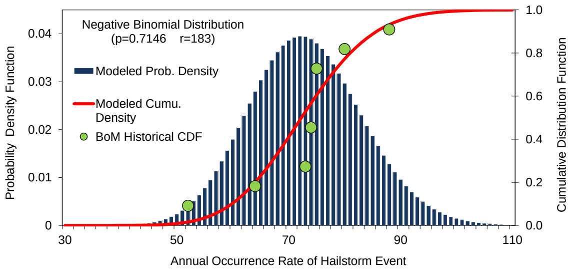

Figure 2: Simulated annual occurrence rate of severe thunderstorm events in Australia

The simulation process starts with simulating the probable number of severe thunderstorm events in a simulation year by sampling from a Negative Binomial (NB) distribution fitted by the historical annual thunderstorm events, as shown in Figure 2. The starting date of a stochastic thunderstorm event is sampled with equal probability from the seasonal BoM historical events. The sampled candidate date is then perturbed using a Gaussian distribution with standard deviation of one day. This sampling approach reflects the seasonal patterns of BoM historical thunderstorms. The location of a stochastic thunderstorm is simulated by perturbing the location of the candidate historical thunderstorm in both longitude and latitude directions using a bivariate Gaussian distribution. The stochastic thunderstorm path length, width, orientation, and intensity are simulated using different statistical distributions fitted by the BoM historical thunderstorm data. The same simulation process repeats for all simulation years to simulate up to 100,000-year worth of future possible severe thunderstorm events in Australia.

3.2 Simulation of Thunderstorm Climatology in Australia

The thunderstorm climatology is derived using the BoM historical thunderstorm data from 1990 through 2009. Figure 3 shows the 100,000-year simulations of the empirical climatology for hailstorm, downburst straight-line wind and tornado, respectively.

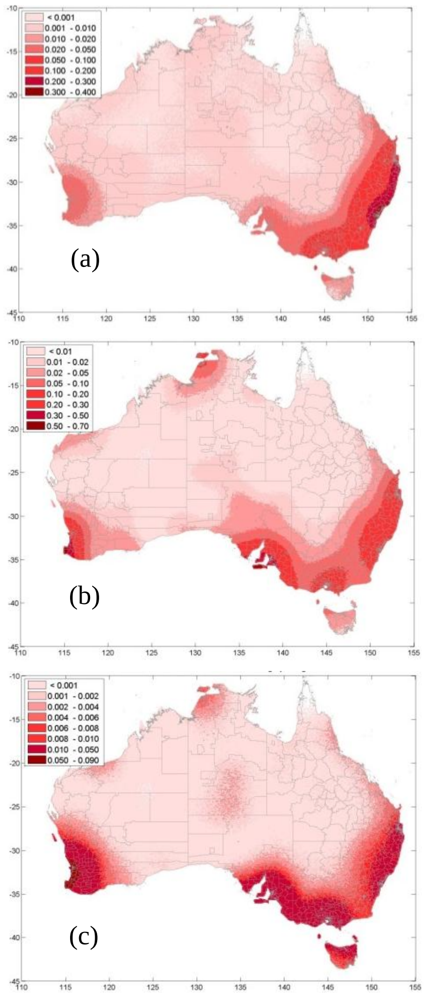

Figure 3: simulated climatology of (a) severe hailstorm, (b) down burst wind, and (c) tornado in Australia derived from BoM historical severe thunderstorm data (1990-2009). Colored circles indicate the historical annual occurrence rate, and colored contour regions indicate the simulated annual occurrence rate.

In Figure 3, the legends indicate the annual number of simulated storms aggregated in 0.1 degree cell (approximately 120 square kilometers) and multiplied by 10. The legends are relative scales that indicate the contrast of the severe thunderstorm frequency in various regions across Australia. As shown in the Figure, the most hail-prone regions are located at the southeast of Australia, particularly the New South Wales coast, Victoria coast, as well as part of the southeast of Queensland.

Combination of the atmosphere circulations and orographic effects can partly explain this spatially uneven distribution of hail risk in Australia. Cold fronts occur most frequently in southeast of Australia during the summer (Reeder and Smith. 1992), although they occasionally do penetrate across the continent to low latitudes. In particular, the southerly buster is a type of intense cold front that affects the southern Australia. Those busters move rapidly up the coast and bring sudden cool changes and favorable conditions for thunderstorm development to the passage regions, particularly in the New South Wales coast. Those busters partly explain why the majority of hailstorms occur in the eastern Australia during the summer, in stark contrast to the tropical northern Australia.

Combination of the westward wind and the orographic effect also has an important influence on hailstorm development in Australia. During summer months, strong westward winds drive a large amount of moisture from the South Pacific Ocean and bring humid and rainy conditions to the east coast of New South Wales. Due to orographic uplift effects, the windward sides of the Great Dividing Range often create condensation and lead to severe thunderstorms along the south coast of New South Wales, while inland leeward sides are drier with less favorable conditions for storm development. As westward winds move across the Range and further flow into the inland, the air humidity is decreased by drier air from the arid interior. The warm and dry condition may not be moist or unstable enough to form storms, causing the absence of occurrence of hailstorms in the vast region of the interior plains in Australia.

3.3 Comparisons of Simulated Thunderstorm Climatology to Historical Data

To compare the simulated storm occurrence rates to BoM historical data from 1990 to 2009, both the annual number of historical storm report data and the annual number of simulated storms are shown in Figure 4 in one degree resolution for hailstorm, downburst straight-line wind, and tornado, respectively. In Figure 4, colored circles indicate the historical annual occurrence rate, and colored contour regions indicate the simulated annual occurrence rate, The legends indicate the annual number of storms per square mile multiplied by 1000.

Comparisons show that the estimation of the climatology of the severe thunderstorm matches reasonably well in relative scale to the BoM historical data. For example, the high hailstorm activity occurs in two severely hailed regions, the coastal region in the southeast of Australia, and the coastal region in southwest of Australia. This is consistent with the observation from BoM. We recognize that this is only an empirical hail climatology using very limited data of low quality. Improvement will be made as more reliable data become available.

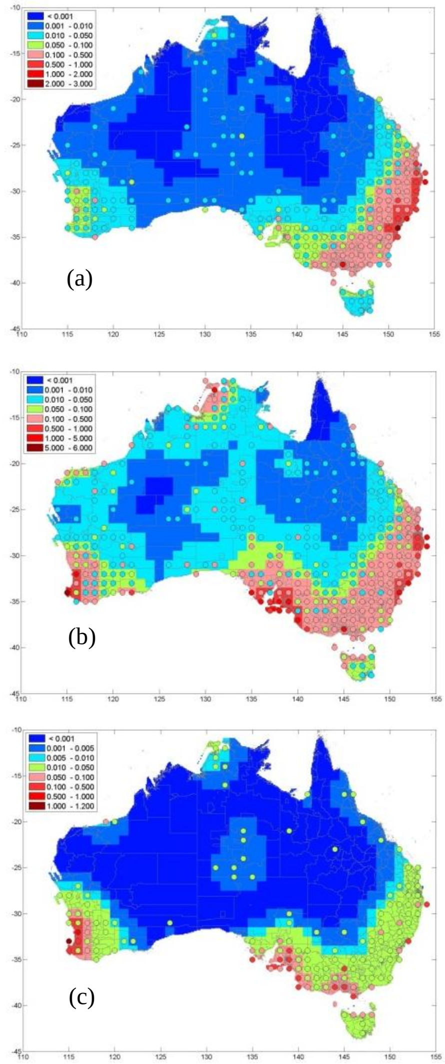

Figure 4: Comparisons of storm occurrence rate between BoM historical data and 100,000-year simulation for (a) severe hailstorm, (b) down burst wind, and (c) tornado in Australia.

4. SIMULATION OF STORM INTENSITY VARIABILITY

In this study, the shape of a simulated storm is represented by an ellipse centered at the storm centroid, and with the major axis oriented along the length direction of the storm path. To avoid the assumption of a uniform damage characteristics associated with a severe thunderstorm, the intensity variability is estimated on various concentric ellipses based on the damage analysis of historical thunderstorms. Variations in intensity within the storm affected area can be explained by a change in hailstone size for a hail storm, and a wind speed for a downburst straight-line wind or a tornado.

4.1 Intensity Variability for Hailstorm

Using the hailstorm data in east-central Illinois (Changnon, 1992) and data in Eastern Australia (Schuster, el al., 2006), intensities of various regions within the storm affected area are normalized by the maximum storm intensity. Distances between the locations of interest and the storm centre are normalized by the storm dimensions. Figure 5 (a) presents the regression equation of the normalized damage intensity on the normalized distances, as well as the regression equation for severe hailstorms. The normalized intensity indicates the variation of the storm damage intensity and can provide potential loss estimate for any location within the storm affected area.

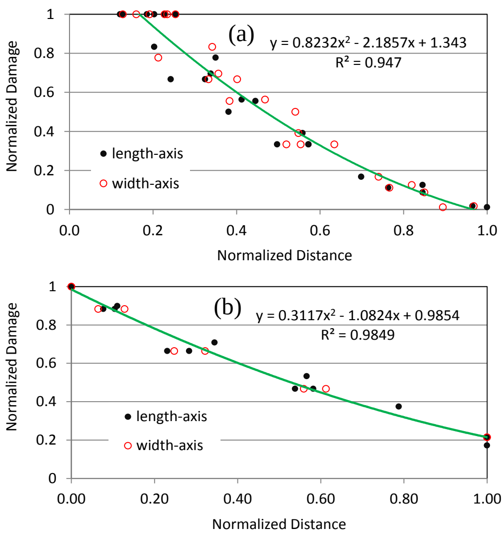

Figure 5: Regression of normalized (a) hailstorm damages and (b) down-burst wind or tornado damages on normalized distances

4.2 Intensity Variability for Downburst Straight-line Wind and Tornado

Tornado wind field and damage surveys performed by Matson and Huggins (1980) and McDonald and Marshall (1983) in Oklahoma provided valuable data to derive the variability of the damage intensity within the tornado affected area. Figure 5 (b) presents the regression equation of the normalized damage intensity of the tornado on the normalized distances, as well as the regression equation for tornadoes. The normalized intensity indicates the variation of the tornado damage intensity and can provide potential loss estimate for any location within the storm affected area. Because no observational data on downburst straight-line wind intensity and damage are available, the same intensity variability model is applied to the downburst straight-line wind.

4.3 Intensity Variability Patterns for Hailstorm, Downburst Straight-line Wind and Tornado

Figure 6 shows simulation examples of the storm intensity variability for (a) hailstorm, and (b) downburst straight-line wind and tornado, respectively. Different colors in the contour areas represent different levels of storm intensity, dark red for higher intensity and light red for lower intensity. Intensities of various regions within the storm affected area are normalized by the maximum storm intensity, as shown in the parentheses in the legends. Because a 3-second gust speed of 65 mph at 10 meter above the ground is the threshold of visible damage for a tornado (TTU, 2006), and 90 km/h (56 mph) of a downburst straight-line wind speed is the minimum wind speed qualified as a severe thunderstorm wind based on the BoM definition, we set a gust speed 40 mph as the threshold without causing any damage for both downburst straight-line winds and tornadoes.

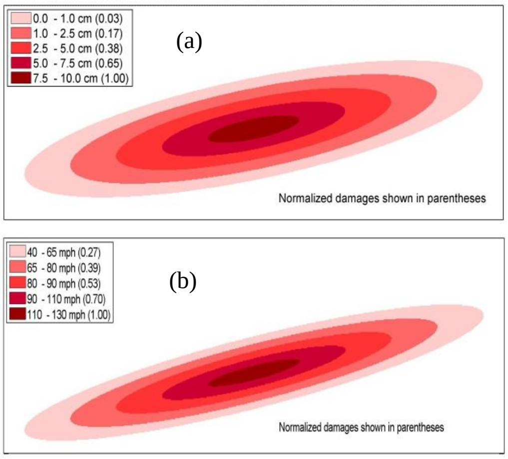

Figure 1: Spatial variability of the simulated intensity for (a) severe hailstorm and (b) tornado or downburst straight-line wind

5. VULNERABILITY FUNCTIONS

The measure of a severe thunderstorm intensity used in this study is the maximum hail stone size for a hailstorm, or the maximum wind speed for a downburst straight-line wind or a tornado. The vulnerability function relates a selected measure of the thunderstorm intensity to the damage of motor vehicles or residential, commercial, industrial, religious buildings and contents.

Separate wind and hail storm vulnerability functions have been developed for assessing losses associated with the main building, as well as the building contents, and time element (time interruption) coverage. Various types of vulnerability functions are applicable to different types of business structures, such as residential buildings, commercial buildings, industrial buildings, agriculture buildings, religious buildings, utility substations, and other infrastructures, respectively. For a given construction type, damage to the structure itself is a function of wind speed or hail stone size. Regardless of the type of structure, both content damage and time element damage are functions of the main building damages. For automobiles, separate vulnerability functions related wind speed or hail stone size with the damage for

(a)

personal, dealer, transportations/trucks/airplanes, and other vehicles, respectively.

Insurance losses caused by severe thunderstorms are estimated based on the exposure information, policy conditions, the simulated hazard intensity, and the vulnerability functions for different construction types and automobiles. The distribution of the aggregate loss from all simulated events can produce an appropriate probabilistic description of the loss estimation.

6. CONCLUSION REMARKS

In this study, historical thunderstorm data from the Australian BoM are used to model the severe thunderstorm risk in Australia. Three major perils associated with a severe thunderstorm are considered, hailstorm with hailstones of diameter of 20 mm or more, downburst straight-line wind, and tornado. Monte Carlo technique is employed to simulate up to 100,000-year worth of future possible severe thunderstorm events in Australia. Comparisons show that the simulated climatology of severe thunderstorm risk matches reasonably well with the BoM historical data. The severe thunderstorm model developed in this study provides a reasonable quantification of the severe thunderstorm risk in Australia from Re/insurance perspectives. Coupled with the severe thunderstorm damage modeling and insurance portfolio exposures, the model can help re/insurance companies to quantify the severe thunderstorm loss potentials in Australia at both individual location and at portfolio levels.

REFERENCES

Australian Bureau of Meteorology (BoM), http://www.bom.gov.au/info/thunder/

Bureau of Transport Economics (BTE), 2001. Economic Costs of Natural Disasters in Australia, Report 103.

Changnon, Stanley A., Temporal and Spatial Relations between Hail and Lightning, 1992, Journal of Applied Meteorology, vol. 31, Issue 6, pp.587-604.

Matson, R. J., Huggins A. W., 1980: The Direct Measurement of Sizes, Shapes, and Kinematics of Falling Hailstones. *J. of Atmos. Sci*., 37 1107-1125.

McDonald, J. R., and T. P. Marshall, Damage survey of the tornadoes near Altus, Oklahoma, on May 11, 1982, Publ. 68D, Tex. Tech Univ., Lubbock, 1983.

Reeder, M. J. and R. K. Smith, 1992: Australian spring and summer cold fronts. Aust. Meteor. Mag., 41, 101-124.

Schuster, S. S., Blong, R. J. and McAneney, K. J., 2006. Relationship between radar derived hail kinetic energy and damage to insured buildings for severe hailstorms in Eastern Australia. Atmospheric Research, 81, 215-235.

Schuster, S. S., Blong, R. J. and Speer, M. S., 2005. A Hail Climatology of the Greater Sydney area and New South Wales, Australia. International Journal of Climatology, 25: 1633-1650.

TTU, 2006. A recommendation for an enhanced Fujita Scale (EF-Scale), Wind Science and Engineering Center, Texas Tech University, Lubbock, Texas 79409-1023.