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MODELING AND QUANTIFICATION OF SEVERE HAILSTORM RISK IN SPAIN FROM RE/INSURANCE PERSPECTIVES

Bo Yu[1], Jianming Yin[2], Junwa Shimada[3]

[1]*Tokio Marine Technologies LLC, Duluth, Georgia, USA, Bo.Yu@tokiomarinetech.com*
[2]*Tokio Marine Technologies LLC, Duluth, Georgia, USA, Jianming.Yin@tokiomarinetech.com*
[3]*Tokio Marine & Nichido Risk Consulting Co., Ltd., Tokyo Japan, Junwa.shimada@tokiorisk.co.jp*

I. INTRODUCTION

Hailstorm is one of the costliest natural disasters in Spain. In 2003, a severe hailstorm caused severe floods, damaged cars and street furniture in the town of Alcaniz in the Ebro Valley (Garcia-Ortega et. al., 2007). The indemnification for the hailstorm-caused crop losses reached 12.5 million euro in 2007 in Lleida alone (Farnell, et al., 2009; Saa-Requejo et al., 2011). A severe hailstorm is defined by European Severe Storm Laboratory (ESSL) as a hailstorm with hailstone size of 2 centimeter or larger in diameter. Severe hailstorm risk in Spain is a significant issue for the re/insurance industry. Therefore, re/insurance companies are in need for reliable models to analyze and quantify severe hailstorm risk in Spain. While there are a few studies on severe hailstorm climatology on a regional scale in Spain based on regional hailpad measuring networks (Fraile et al., 1999) and studies on meteorological and climatological interpretation of individual severe hailstorms in Spain (Tudurí, et al., 2003), there has been a lack of consistent and reliable severe hailstorm data to investigate severe hailstorm climatology at the country level in Spain.

The paper starts by discussing the historical severe hailstorm data in Spain and data compilation. The discussion extends then onto the application a two-dimensional Gaussian kernel smoother to the European Severe Weather Data (ESWD) severe hail reports to derive the empirical severe hailstorm climatology in Spain. Severe hailstorms and events are then simulated based on the empirical hailstorm climatology. Simulation results are compared to ESWD reports and other independent studies. Simulation of hailstorm parameters and development of vulnerability functions for assessing severe hailstorm losses are also described.

II. SEVERE HAILSTORM DATA AND COMPILATION OF HISTORICAL EVENTS

After reviewing the quality of available Spain hailstorm data required for simulation of severe hailstorm risks, historical hailstorm reports from the ESSL ESWD were used to model the severe hailstorm risk in Spain. ESWD is a database of severe weather reports for Europe and the Mediterranean Region. It contained over 39, 000 individual reports and much more single data entries that are primarily associated with severe convective weather such as tornadoes, severe hailstorm, heavy precipitation, and lesser whirlwinds (Holzer, et al., 2011).

ESWD hailstorm data in the early years were recovered from newspaper recounts and hence are incomplete on a yearly basis. As evidenced in Figure 1, the annual number of severe hailstorm reports appeared to be stabilized only after 2006. This sudden increase in the number of severe hailstorm reports around 2006 is unlikely due to any abrupt change in climate. Rather, it is a result of improved concerted hailstorm reporting and archiving efforts promoted and implemented by ESSL. In this endeavor, we only used ESWD severe hailstorm reports from 2006 through 2010 to derive the empirical severe hailstorm climatology in Spain because these are the only data we consider to be relatively reliable and complete enough for hailstorm risk modeling purposes.

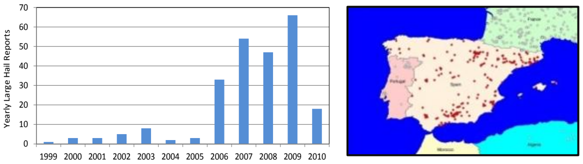

FIG. 1: (left) ESWD annual numbers of severe hailstorm reports in Spain; (right) locations of severe hailstorm reports since 2006

It is known that ESWD might receive multiple hailstorm reports from the same hailstorm. Following the severe hailstorm definition recommended by the US Storm Prediction Center (Schaffer et al., 2004), we applied a 15 minute/16 km rule to remove the suspected duplicates in the ESWD database. This rule implies that only the reports separated either more than 15 minutes in time or greater than 16 km in distance are considered to be independent hailstorm reports. After applying the 15 minute/16 km rule, 60 entries out of 218 hailstorm reports in ESWD in Spain were deemed as duplicates and hence removed from the ESWD database. The locations of the remaining hailstom reports are shown in Figure 1.

For re/insurance purposes, the concept of severe hail event is introduced and defined as a conglomeration of individual hailstorms spawned by the same convective precipitation system crossing Spain within a continuous 72-hour timeframe. Two or more hail events will be counted when a convective precipitation system lasts more than 72 hours. In this study, ESWD severe hailstorm reports were compiled into severe hail events according to this definition.

A total of 46 historical hail events were extracted for Spain using ESWD severe hail reports from 2006 to 2010. The average number of hailstorms in a hail event in Spain was found to be around 3.4. Both the number of hail events in a year and the number of hailstorms in an event estimated using ESWD historical severe hailstorm reports will likely underestimate the true severe hailstorm risk in Spain due to the quality and completeness of the ESWD hailstorm reports. Adjustments will have to be made using an approach that will be discussed later in Section III.

III. SEVERE HAILSTORM CLIMATOLOGY AND STOCHASTIC EVENTS IN SPAIN

(1) Severe Hailstorm Climatology in Spain

ESWD severe hailstorm reports from 2006 through 2010 in Spain and its neighboring two longitude/latitude degree buffer zone were used to derive the climatology of severe hailstorms in Spain. Hailstorm climatology is defined in this endeavor as the probability of hailstorm occurrence at 0.01 degree grid resolution in Spain. It was achieved by smoothing the historical hailstorm reports in Spain and within the two degree buffer by applying a two-dimensional Gaussian kernel smoother. The smoothed hailstorm occurrences by grid were then normalized using the total hailstorm occurrences from all grids in Spain. The normalized hailstorm occurrence became then the probability of hailstorm for a grid given there will be a hailstorm in Spain.

The optimal bandwidth or standard deviation of Gaussian kernel density smoother for Spain was determined using Jackknife out-of-sample likelihood maximization procedure (Hall and Jewson, 2007; Yin, et al., 2011). The maximum log-likelihood is achieved at a bandwidth of 70 km (the optimal bandwidth). The empirical severe hailstorm climatology derived using this optimal bandwidth is shown in Figure 2. High hailstorm activity peaks occurs in two severely hailed regions, i.e., the Middle Ebro Valley in the northeast of Spain, and Mulhacen region in the south of Spain. The hailstorm occurrence peaks in the empirical severe hailstorm climatology appear to be in line with ESWD hailstorm reports (2006-2010), as shown in gray circles in Figure 2.

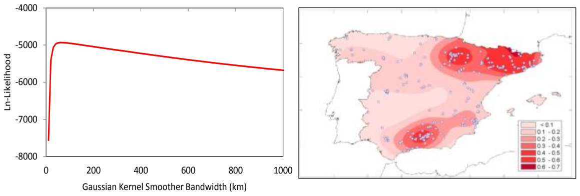

FIG. 2: (left) Log-likelihood versus Gaussian Kernel Bandwidth; (right) Empirical climatology of severe hailstorm in Spain. The legend shows a relative scale that indicates the contrast of the severe hailstorm frequency in various regions across Spain

(2) Statistical Modeling of Annual Number of Hail Events

The empirical severe hailstorm climatology derived so far provided only the probability of the hailstorm, i.e., the likely location for a simulated hailstorm given there will be a hailstorm in Spain. Reliable estimate of the annual number of hailstorms was in need in order to adequately quantify the hailstorm risk and its loss potential in Spain. Direct use of ESWD data will likely result in underestimating the true hailstorm risk in Spain, because of the underreporting bias inherited in ESWD hailstorm reports for Spain. To avoid underestimation, an empirical augmentation approach was developed to help determine the average annual number of hail events and the average number of hailstorms in a hail event in Spain.

The Laboratory for Atmospheric Physics at the University of Leon has established a network of 250 hailpads spreading over an area of about 1000 km^2 in Leon in north-western Spain (Fraile et al., 1999) and has been commissioned to detect and collect hailstorm activity in that region ever since 1990. Using the empirical severe hailstorm climatology derived earlier in this endeavor, the probability of hailstorms occurring within the Leon hailpad network area was estimated to be about 0.237% to the total hailstorm occurrence rate for the whole Spain. During the period of 1990 to 1995, three severe hailstorms have been detected by the Leon hailpad network. An annual number of 211 hailstorms for the entire Spain can thus be roughly estimated.

Average number of hailstorms in a hail event is difficult to estimate with precision due to the lack of reliable historical data. We hence started with a simple assumption that the average number of hailstorms per event is roughly proportional to the size of country of concerns. France and Spain cover areas of 675,000 and 504,000 square kilometers, respectively. According to a hailstorm risk analysis for France, the average number of hailstorms per event in France was estimated to be around 22.0 (Yin, et al., 2011). An average number of 16 hailstorms per event can thus be estimated for hail events in Spain based purely on the sizes of the two respective countries. However, meteorologically speaking, cold fronts tend to lose their intensities as they move further to the low latitudes and hence will likely spawn fewer hailstorms in the area of same size down the south. Considering Spain is south to France, we reduced the average number of hailstorms in a hail event in Spain by 25% from 16 to 11.7. We then estimated on average 18 hail events per year in Spain which holds the annual average number of hailstorms in Spain to be 211, the average annual number of hailstorms in Spain derived based on Leon hailpad network observations.

(3) Stochastic Simulation Approach

Monte Carlo techniques were employed to simulate stochastic severe hail events and hailstorms in Spain. The simulation process starts with simulating the number of severe hail events in a simulation year by sampling from the Poisson distribution fitted by the annual number of ESWD hail events. The number of hailstorms in a hail event was modeled by an exponential distribution with the mean being equal to 11.7. The starting date of a stochastic hail event was modeled by a Weibull distribution derived based on historical ESWD hail events in Spain.

Given the annual number of hail events and the number of the hailstorms in a hail event, the empirical severe hailstorm climatology was used to simulate the likely location of a stochastic hailstorm assuming that the locations of severe hailstorms in a hail event are mutually independent. Physical parameters of a hailstorm required for hailstorm loss estimation were also simulated using statistical distributions fitted for these parameters using observation information from various field studies. The hailstorm parameters include storm path length and width, orientation, hailfall intensity and duration, maximum hailstone size, and accompanying wind speeds. The simulation process repeats to simulate up to 1,000,000-year worth of future possible severe hailstorm events in Spain.

(4) Simulated Hailstorm Occurrence Rate

The 1,000,000-year simulation results were expressed in average annual number of hailstorms per square miles, as shown in the left pane in Figure 3. To compare the hailstorm simulation results with ESWD historical hailstorm data (2006-2010), both the number of ESWD hailstorm reports and the simulation results were aggregated to 0.5 degree cell in Spain and shown in the right pane in Figure 3. Colored dots show the

ESWD hailstorm data in a grid and colored contour regions indicate the simulation results. The legends shown in Figure 3 are average annual number of hailstorms in a 0.5 degree grid multiplied by 1,000.

Comparisons show that the simulated severe hailstorm results match reasonably well with historical ESWD hailstorm reports. We fully acknowledged that the empirical severe hailstorm climatology were derived using very limited data. Improvement will be made as more and more reliable data become available.

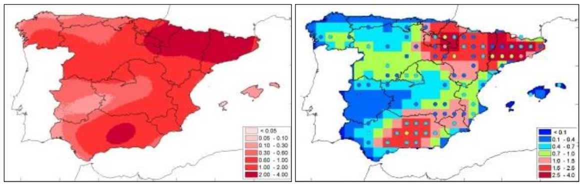

FIG. 3: (left) Simulated severe hailstorms in Spain. Values are the average annual number of hailstorms and in 0.05 degree grid multiplied by 1,000; (right) Comparison of severe hailstorm results based on a 1,000,000-year simulation with hailstorm reports.

IV.VULNERABILITY FUNCTIONS AND LOSS ESTIMATION

In this endeavour, total hailstorm impact energy accumulated through the lifetime of a hailstorm over a unit area in a hailstorm was employed as hailstorm hazard measure to estimate hailstorm damage to automobiles. The approach suggested in Matson and Huggins (1980) was used to estimate the total hailstorm impact energy. Innovative hailstorm vulnerability functions for manufacturer automobile policy were developed in this endeavour. Three separate vulnerability functions were developed to explicitly account for the dent repair labour, parts replacement and depreciation cost, respectively. The depreciation cost is particularly applicable to manufacturer automobile coverage since an automobile can no longer sell at its original price even after it is fully repaired. These hailstorm vulnerability functions better reflects the hailstorm loss claims adjustment process for manufacturer automobile policies and hence were believed to provide more realistic loss estimates.

Insurance losses caused by severe hailstorms were estimated using exposure information, insurance policy terms and conditions, hailstorm hazard intensity, and vulnerability functions. Losses from locations falling into the same hailstorm were aggregated to the hailstorm level. Hailstorm level losses were then aggregated to hail event level to estimate event losses. Event losses were further aggregated by year. Occurrence Loss Exceedance Probability (OEP) and Aggregate Loss Exceedance Probability (AEP) curves can be achieved from the event and annual aggregate loss information, respectively.

V. CONCLUSION REMARKS

In this study, historical hailstorm data from ESWD and Leon hailpad network were used to model the severe hailstorm risk in Spain. Monte Carlo techniques were employed to simulate up to 1,000,000-year worth of future severe hail events in Spain. Coupled with the automobile vulnerability modeling and insurance portfolio exposures, the model can help re/insurance companies to quantify the severe hailstorm loss potentials in Spain at both individual location and at portfolio level.

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