Structural property losses from tornadoes in Florida

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ABSTRACT

Property losses from tornadoes in Florida are estimated by combining a one-km spatial grid of structural values from the Department of Revenue's 2014 cadastral database with historical tornado events since 1950. There are 91,180 cells in the state with at least some structural value. Total and residential structural values total \$942 Billion and \$619 Billion, respectively. Over the period 1950 through 2015 there were 3,233 individual tornado reports in the state with a peak frequency during July. Property value exposed to tornadoes is estimated using a geometric model for the path. Annual statewide total and residential structural property exposure to tornadoes is estimated at \$171 Million and \$103 Million, respectively. Property exposure to tornadoes peaks in February although the number of tornadoes peaks in September. A regression model quantifies the relationship between actual losses since 2007 and exposures. A doubling of the residential exposure increases actual recorded losses by 26% since 2007 and a doubling of non-residential exposure increases losses by 21% controlling for changes over time. Randomization of the historical tornado paths provides alternative exposure scenarios that are used to determine the probability of extreme loss years. Results from the Monte Carlo algorithm indicate a 1% chance that the annual loss will exceed \$430 Million and a .1% chance that it will exceed \$1 Billion. These findings, and the procedure to obtain them, should help property insurance and reinsurance companies gauge their risk of losses and prioritize their management actions.

29 1. Introduction

30 A tornado is a violently rotating vortex of winds beneath a thunderstorm. Broadly, tornadoes
31 in Florida occur within lines of thunderstorms ahead of an advancing cold front from the north-
32 west, within single isolated thunderstorms, or within the rotating thunderstorms associated with
33 a tropical cyclone (Hagemeyer 1997; Hagemeyer and Schmocker 1991; Gentry 1983). Since the
34 atmosphere across Florida typically has enough water vapor to support thunderstorms due to its
35 proximity to the Gulf of Mexico and the Atlantic Ocean, the essential ingredient for tornadoes are
36 winds above the ground moving with increasing speeds and with veering directions (wind shear).
37 The frequency of tornadoes in Florida rivals that of states better known for tornadoes including
38 Kansas, Illinois, Iowa, and Oklahoma and the frequency is similar to other southern states includ-
39 ing Mississippi, Alabama, and Louisiana (Table 1). The annual statewide tornado rate in Florida
40 over the past 30 years is four reports per 10,000 km², which is the same as in Kansas and which
41 exceeds that in Oklahoma by 22%.

42 Built structures in the path of a tornado are vulnerable to destruction from winds that can exceed
43 80 m s⁻¹. Tornadoes are rated based on the severity of the worst structural damage found within
44 the path. The rating is done with an ordered scale (EF-scale) from 0 to 5 (worst). The frequency
45 of strong (EF2+) tornadoes in Florida is the lowest of the top ten tornado-prone states (Table 1).
46 But strong tornadoes do occur in the state, including the April 1925 Miami Tornado which caused
47 five deaths and produced damage totals that were estimated between \$200 and \$300 Thousand
48 (1925 USD) (Gray 1925), which would be \$2.7–\$4.1 Million in 2014 dollars according to the U.S.
49 Bureau of Labor Statistics Consumer Price Index adjustment.

50 Knowing the range of possible future losses from tornadoes is important for insurance. There are
51 two kinds of wind damage deductibles on an insurance policy in Florida: hurricane deductibles,

52 which apply to damage solely from hurricanes, and windstorm or wind/hail deductibles, which
53 apply to any kind of wind damage, including tornadoes. Structural property losses from past
54 tornado events can be used to estimate the range of potential future losses but the variability is
55 largely dependent on where the tornado occurs and how broad and intense the associated wind
56 field. Changes to property value over time increase the difficulty in getting useful information
57 about what could happen in the future.

58 The purpose of the study is to estimate tail statistics of potential total and residential property
59 losses from tornadoes in Florida. Estimates are made by leveraging a new property value dataset
60 from Florida's Department of Revenue and a simulation method afforded by spatial process mod-
61 eling technology. The paper describes the data and methods and provides an estimate of annual
62 expected and worse-case residential and non-residential exposures. In short, paths of tornadoes
63 are placed on top of the property value cells to get an estimate of the structural property exposed
64 to each tornado. The procedure answers the hypothetical question of what historical tornado, if it
65 occurred in 2014, has the potential to cause the greatest amount of damage in terms of property
66 loss because of where it occurred. Moreover, the sum of all per tornado exposures relative to 2014
67 divided by the number of years provides an estimate of the average annual exposure to the state. A
68 statistical model for known losses from exposure together with a Monte Carlo procedure is used
69 to get estimates of the probable maximum property loss.

70 **2. Data and methods**

71 *a. Florida property value data*

72 Tornadoes result in real estate financial losses. Risk assessment of property structural values
73 is difficult due to the large number of individual properties and inconsistent tools for measure-

74 ment. The dataset used in this study was developed to provide a consistent method for measuring
75 property values across Florida. The source information is from the 2014 Florida Department of
76 Revenue cadastral database. Property values are determined by each county's local property ap-
77 praiser. Property values are aggregated to the U.S. National Grid 1-kilometer grid cells. Records
78 include assessed property value, land value, and structural (material) value for all land use types
79 and for residential parcels. The data is available through the Florida Resources and Environmental
80 Analysis Center.

81 Interest centers on the residential and non-residential structural values in each grid cell, which
82 are calculated by subtracting the land value from the assessed value then aggregating to the one-
83 km cell. At locations where the land value is unreasonable (e.g., it is zero or it is greater than
84 the assessed value), the structural value is 90% of the assessed value. The total structural value is
85 based on all land use categories and the residential structural value is based on the residential land
86 use category only. The difference between the total and the residential value is the non-residential
87 value.

88 *b. Tornado data*

89 The Storm Prediction Center's (SPC) database is the most readily available set of tornado records
90 in the world. The database is compiled from the National Weather Service's (NWS) *Storm Data*,
91 and includes all known tornadoes dating back to 1950. Tornado records contain information on
92 initiation point (latitude and longitude), date, length and width of the damage path, and maximum
93 damage rating on a scale from zero to five (Enhanced Fujita (EF) damage scale). They also contain
94 an estimate of actual property loss in millions of dollars since 1996 and in whole dollar amounts
95 since 2007. A zero value in the loss column does not necessarily mean no losses.

96 Reports in the database are compiled by the NWS offices and reviewed by the National Centers
97 for Environmental Information (formerly known as the National Climate Data Center) Verbout
98 et al. (2006). The database is available in a shapefile format with each tornado represented as
99 a straight line track. The tornado track is the great circle line (no width) between the estimated
100 start (initiation point) and end locations. Locations in the attribute table are recorded with two
101 digit decimal precision prior to 2009 and four digit precision afterwards. Locations have greater
102 precision later in the record when estimates are made with a Global Positioning System (GPS).

103 *c. Property Exposure and Losses*

104 For each tornado report in the database we estimate an approximate path by buffering the track
105 using the width (Fig. 1). The average path widths given in the data set after 1995 are decreased
106 by 25% to better match the average widths given in the database prior to that time (Grieser and
107 Terenzi 2016). We then overlay the tornado path onto the cells containing the property values
108 (see Fig. 2) to determine the per tornado exposure assuming the tornado occurs in 2014. We use
109 the proportion of path area in each cell to apportion the structural property exposure for each
110 tornado. The actual loss from a tornado should be less than the total property value in the path and
111 will depend on many factors including the vulnerability of the structures to strong winds and the
112 proportion of the path experiencing the strongest winds (Grieser and Terenzi 2016). These data
113 are not available so we regress per tornado loss estimates available since 2007 (log scale) onto
114 the logarithm of exposure controlling for year to determine the percentage change in losses for a
115 percentage change in exposure. We use this average relationship to estimate losses from exposure.

116 To provide uncertainty bounds on the annual losses and to get an estimate of extreme losses
117 we run a Monte Carlo simulation (Strader et al. 2014). The simulation randomly permutes loca-
118 tions, orientations, and path characteristics of the historical tornadoes to generate synthetic tornado

119 paths. The simulation is done by year for 10,000 years where the number of tornadoes in a year
120 is chosen from a Poisson distribution with a rate equal to the long-term annual rate of 49 per
121 year. The synthetic paths are overlaid onto the exposure cells to determine exposure values, which
122 are subsequently multiplied by the corresponding regression coefficients to obtain loss estimates.
123 We use the proportion of path area in each cell rather than a simple intersection to apportion the
124 structural property values.

125 **3. Results and Discussion**

126 There are 91,180 one-km cells with at least some structural property (Fig. 3). The statewide
127 total structural value of all property is \$942 Billion and the total residential structural value is
128 \$619 Billion. At the per cell level, the statewide average total value is \$10 Million with a median
129 of \$484,881. The values are strongly right skewed (long right tail). The cell with the highest total
130 structural value (\$8.8 B) includes Allen D. Nease Senior High School in Ponte Vedra, in St. John's
131 County. The cell with the highest residential structural value (\$411 M) includes the area around
132 Lake Eola Park in downtown Orlando.

133 On average, residential property values exceed non-residential values (Fig. 4). The most com-
134 mon residential exposures at the cell level are between \$100,000 and \$1,000,000 while the most
135 common non-residential exposures are between \$50,000 and \$500,000. The percentage of cells in
136 the state with values exceeding \$50 M is 3.3% for residential values and 1.2% for non-residential
137 values.

138 There are 3,233 tornado reports with genesis locations attributed to the state in the 66-year period
139 1950–2015 for an annual average of 49 reports per year. Sixty-one percent of the tornadoes are
140 rated F/EF0 and 28% are rated F/EF1 (Table 2). There are only 37 F/EF3 and two F/EF4 reports

141 since 1950. Frequency of tornadoes peaks in June with the June, July, and August being the three
142 months most active for tornadoes in the state.

143 Slightly less than four percent of tornado paths have an area that exceeds one square km. The
144 total area of all paths with genesis in Florida is 713 km², which is .5% of the total area of the state.
145 There is an upward trend in the annual total path area since 1988.

146 The total number of cells affected by tornadoes is 10,936 with 8,080 of the cells having been
147 hit only once and 791 cells having been hit twice. The average number of tornadoes per cell with
148 property is .12 with a minimum of zero (82,020 cells have never been hit) and a maximum of 20
149 (once every 3 or 4 years on average) in the Palmetto Park area of St. Petersburg likely due to the
150 convergence of sea breezes from the Gulf of Mexico and Tampa Bay.

151 Averaging over all exposures we determine the annual property exposure is \$156.6 Million with
152 \$94.4 Million of that as residential property. In contrast with tornado frequency, property exposure
153 to tornadoes peaks in February with February, March, and April the three months with the highest
154 average exposures. This is due to the fact that longer, and wider tornadoes tend to occur with
155 springtime weather systems (Fuhrmann et al. 2014). While EF0 tornadoes account for 59% of all
156 Florida tornadoes they represent only 9% of the property exposure. In contrast, tornadoes rated
157 EF2 or higher account for less than 12% of all tornadoes but 64% of residential and 69% of non-
158 residential property exposure. Twenty one percent of all residential and 17% of all non-residential
159 property exposure is due to tornadoes associated with tropical cyclones.

160 Results from the regression of losses onto exposure reveal that a doubling of the residential
161 exposure increases actual recorded losses by 26% since 2007 and a doubling of non-residential
162 exposure increases losses by 20% controlling for changes over time (see Fricker et al. (2017);
163 Ashley and Strader (2016)). The regression coefficients multiplied by the corresponding annual
164 exposure rate indicates an annual expected loss of \$48 million.

165 More relevant for insurance is the possibility of a big loss. We estimate the annual probable
166 maximum loss (PML) as the value of the largest loss that could occur. Results from a Monte
167 Carlo algorithm that randomly permutes the historical tornado paths indicate a 1% chance that the
168 annual loss will exceed \$430 million and a .1% chance that it will exceed \$1 billion (Fig. 5). For
169 comparison, in 2016 there were 15 weather and climate disaster events with losses at or exceeding
170 \$1 billion each across the United States (NCEI 2017) including the May 2nd and May 11th tornado
171 outbreaks resulting in losses of \$2.4 B and \$1.7 B, respectively.

172 **4. Conclusion**

173 Each year Florida sees property losses from tornadoes. The amount of loss varies widely de-
174 pending on location, strength, and size of the tornado strike. This variability along with large
175 changes in structural property values over time make it difficult to use historical losses to estimate
176 future losses. In this study annual expected property losses from tornadoes in Florida are estimated
177 by combining a one-km spatial grid of structural values from the Department of Revenue's 2014
178 cadastral database, a regression model for losses, and a geometric model for historical tornado
179 events.

180 The annual statewide total and residential structural property exposure to tornadoes is estimated
181 at \$171 million and \$103 million, respectively with the largest exposures occurring during the
182 month of February. Using data since 2007 and controlling for changes over time, a doubling of the
183 residential exposure was associated with a 26% increase in actual recorded losses and a doubling
184 of non-residential exposure was associated with a 21% increase in actual losses. Results from a
185 Monte Carlo algorithm that randomly permutes the historical tornado paths indicate a 1% chance
186 that the annual loss will exceed \$430 million and a .1% chance that it will exceed \$1 billion.

187 These findings and the methodology to obtain them should be of wide interest to the property
188 insurance and reinsurance industries, including the risk modeling companies, for helping them
189 gauge the risk of losses and prioritize management actions. For instance, the probable worse case
190 loss can help insurance underwriting decisions including the amount to cede to a re-insurer. The
191 work can be expanded by examining exposures in other states and by considering the potential
192 influence of climate factors (e.g., El Niño) on losses. It would also be of interest to consider how
193 the changing characteristics of tornadoes (e.g., path length and clustering) influence the results in
194 the future.

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232 TABLE 1. Tornado reports per 10,000 square km at the state level over the past 30 years (since introduction of
 233 Doppler radar). All tornadoes and EF2+ tornadoes.

Rank	State	All Tornadoes	EF2+ Tornadoes
1	Florida	117	5
2	Kansas	117	10
3	Mississippi	106	18
4	Illinois	100	13
5	Iowa	99	12
6	Oklahoma	96	13
7	Maryland	94	6
8	Alabama	92	16
9	Louisiana	88	10
10	Nebraska	79	8

234 TABLE 2. Frequency and percentages of Florida tornado reports over the period 1950–2015. The US percent-
 235 age is median percentage for all US tornadoes after Feurestein et al. (Feuerstein et al. 2005)

EF Rating	FL Freq.	FL Perc.	US Perc.
0	1959	60.6	61.2
1	917	28.4	27.4
2	318	9.83	8.75
3	37	1.14	2.06
4	2	0.06	0.36
5	0	0.00	0.05

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Fig. 5. Annual exceedance probabilities. Values are estimated using a Monte Carlo procedure that generates 10,000 years of synthetic tornado paths across Florida. 20

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