Uncertainty in Real-time Hurricane Loss Estimation

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ABSTRACT

Four hurricanes – Charley, Frances, Ivan and Jeanne pounded the United States coastline in 2004 within a span of six weeks and left in their wake a huge path of destruction. As these hurricanes were brewing up in the Atlantic and approaching the United States mainland, the forecasters at the National Hurricane Center (NHC) were busy predicting their path, size, and intensity at landfall. The forecast information disseminated by the NHC was employed by AIR catastrophe modelers to get reliable loss estimates in real-time. Obtaining reliable catastrophe loss information as quickly as possible when an actual event unfolds has become increasingly important for insurers, reinsurers, investors and emergency managers. The real-time loss estimates are used by emergency managers to plan evacuation and post-disaster recovery. Insurers employ them in multiple ways including planning on where to dispatch the claims adjusters in the aftermath of the hurricane, adopting appropriate strategies to protect a company from financial insolvency, etc. However, these loss estimates that are imperative both for the insurance industry and emergency planners for their decision-making have a number of sources of uncertainty. These uncertainties arise both due to uncertainty in the catastrophe loss estimation model itself as well as uncertainty in the meteorological parameters, for e.g., track, intensity, and size, forecasted by the NHC. The current study focuses on the uncertainty in the loss estimates associated with the storm parameters forecasted by the NHC. The methodology developed to capture the uncertainties in the loss estimates is explained and the results are presented for Hurricane Frances (2004).

KEYWORDS: Hurricanes; Uncertainty; Catastrophe Modeling; Frances

DESCRIPTION OF HURRICANE LOSS ESTIMATION MODEL

For the purpose of the current study, AIR's Hurricane Loss Estimation model [1] has been used to calculate losses in real-time. Figure 1 illustrates three basic components of AIR's Hurricane Loss Estimation model: hazard, engineering, and loss estimation.

The hazard component comprises of stochastic event generation and local intensity calculation modules. Each hurricane in the stochastic event set is defined by its track and a set of other variables that capture the physical characteristics, including intensity. For a given event, the hazard module employs the wind field equation as described in [2] to calculate the intensity or wind speed at a location of a property, using characteristic storm parameters, namely, track, central pressure, radius of maximum winds (R_{max}), forward velocity, and track angle. Calculations of wind speed at a location take into account the effects of the asymmetric nature of the hurricane wind field, storm filling over land, and surface roughness.

The engineering or the vulnerability module applies mathematical functions called damageability functions to describe the relationship between hurricane intensity, or wind speed, and the consequent physical damage and loss to property. These functions relate the mean damage level as well as the variability of damage to the wind speed at each location. Since different structural types experience different degrees of damage, the model has a set of vulnerability or damage functions for various construction types. For a hurricane, the intensity, at each location is superimposed onto a database of exposed properties. Damage functions are employed to provide estimates of the resulting monetary damage to each individual property. Aggregation of these individual property losses leads to an estimate of total damage. The exposure database used in this study is AIR's proprietary dataset of countrywide residential and commercial properties. This database has been developed at a postcode resolution and includes information on replacement values, construction type, occupancy type, building height etc., all necessary for estimating damage.

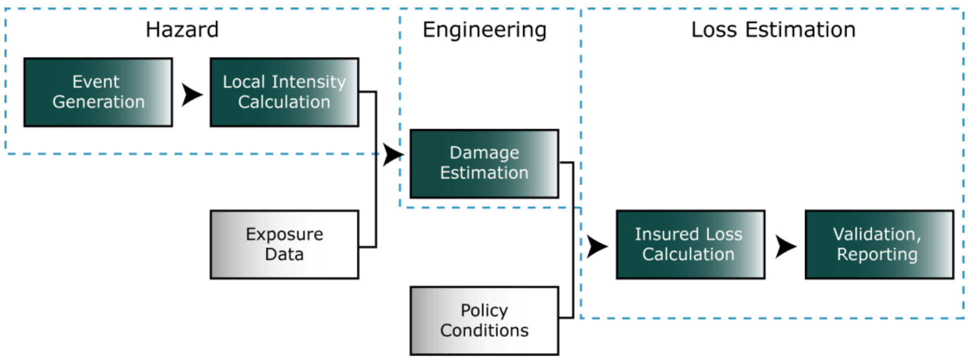

Figure 1: AIR Hurricane Loss Estimation model components

In the loss estimation module, total insured losses are calculated by applying policy conditions to the total damage estimates. Policy conditions may include deductibles by coverage, limits and sublimits, loss triggers, coinsurance, and the like.

In this paper, Hurricane Frances (2004) will be used as an example. The methodology described here, to estimate losses in real-time is general enough to be applied several days prior to a hurricane landfall as well as at the time of landfall. In the current study, it is applied to calculate the uncertainty in the losses for Hurricane Frances (2004) two days prior to landfall and at the time of landfall.

NHC FORECAST

The estimation of losses for a hurricane in real-time requires three primary storm parameters – storm track, central pressure, and R_{max}. Soon after the genesis of a tropical storm in the basin, the NHC provides information on these parameters in their forecast advisories issued every six hours for a period of 3-days. The track forecasts are the storm latitude and longitude (to the nearest tenth of a degree) and the intensity forecasts are the 1-minute maximum sustained surface wind (to the nearest 5 knots) at 12, 24, 36, 48 and 72 hour. These forecast advisories are obtained using various track and intensity guidance models that range in complexity from simple statistical models to three-dimensional primitive equation models. Since there is uncertainty in the forecast of the center of the storm (the black line and dots in Figure 2), the NHC also provides an area of uncertainty around the forecast center as shown in Figure 2 (solid white area). This area of uncertainty is constructed using the average track forecast errors that have been observed in recent years.

It is also imperative to account for the uncertainty in the intensity forecast. Hurricane Charley (2004) that struck the southwestern coast of Florida on August 13th is a perfect example of how rapidly a storm can change intensity. A few hours before landfall, it intensified into a Category 4 hurricane with maximum wind speeds increasing from 125 mph to 145 mph. To account for the uncertainty in the intensity, the NHC provides a table that shows the probability that the maximum 1-minute wind speed of the hurricane will be within any of the eight intensity ranges, namely, Dissipated, Tropical Depression, Tropical Storm, Hurricane, Category 1, Category 2, Category 3, Category 4-5, during the next three days. These probabilities are based on the outcomes of similar NHC wind speed forecasts during the period from 1988 to 1997.

The information on R_{max} is not provided in the NHC forecast advisories. However, eye diameter that correlates closely with it, is often reported. Since R_{max} is a critical parameter in the wind field calculation, information on R_{max} is extracted from various other meteorological sources like, vortex report on the storm structure [3], radar images [4] etc. Vortex data messages are coded reports issued by the NHC whenever a reconnaissance aircraft penetrates the center of the storm. In addition to the information on position of the storm, wind, pressures, and temperatures, these messages also include information on the eye size, shape, and status if an eye is present. A weather radar image shows the area of precipitation in the atmosphere. Since the eye of a hurricane is a calm area with least precipitation, it can easily be spotted in a radar image.

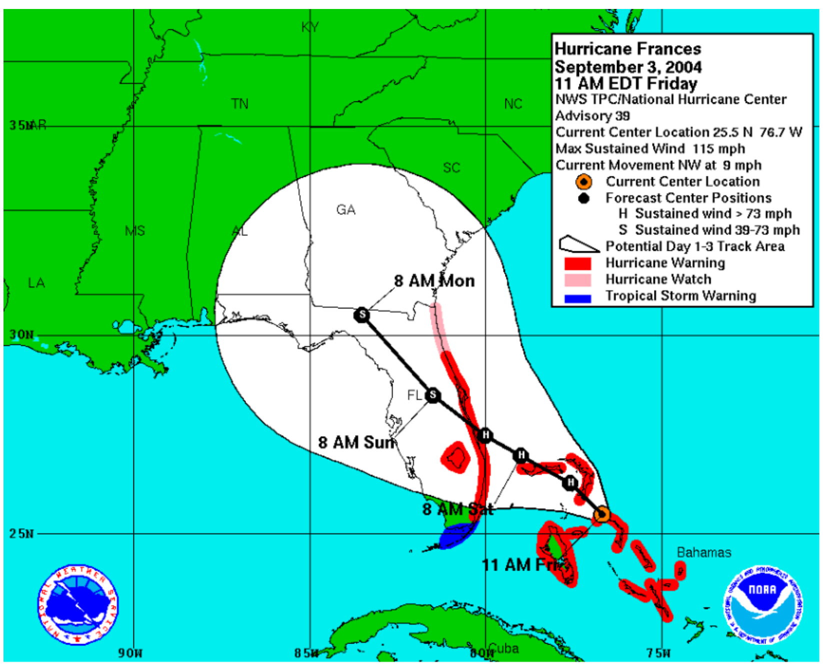

Figure 2: The NHC forecast track for Hurricane Frances (2004) two days prior to landfall

EVENT GENERATION METHODOLOGY

Probabilistic loss estimation in the current methodology requires simulation of a large set of possible hurricane tracks with their associated storm characteristics. As mentioned above, the primary variables in the simulation are storm track, central pressure, and R_{max}. The first step in this process is to define the probability distributions for these three variables. The underlying data for these distributions is derived from information provided by the NHC in their forecast advisories.

For generation of storm tracks, forecast of the center of the storm and the area of uncertainty, provided by the NHC, is used. In this study, we assume that the storm track is normally distributed around the forecast of the center of the storm (black line or dots in Figure 2) and the area of uncertainty (solid white area) reflects the 95% confidence bounds. For the purpose of simulation, we represent the area of uncertainty using 11 discrete tracks. Each track is assigned a relative frequency according to a normal distribution.

For Hurricane Frances (2004), the NHC forecast at 11:00 AM EDT on September 3rd (Friday) is shown in Figure 2. The 11 tracks used to capture uncertainty are shown in Figure 3. The tracks are generated using GIS tools by shifting the NHC forecast of the center of the storm (black line and dots in Figure 2) normal to the direction of forward motion. Track 6 in Figure 3 corresponds to the forecast of the center of the storm (black line and dots in Figure 2) and is assigned the highest relative frequency.

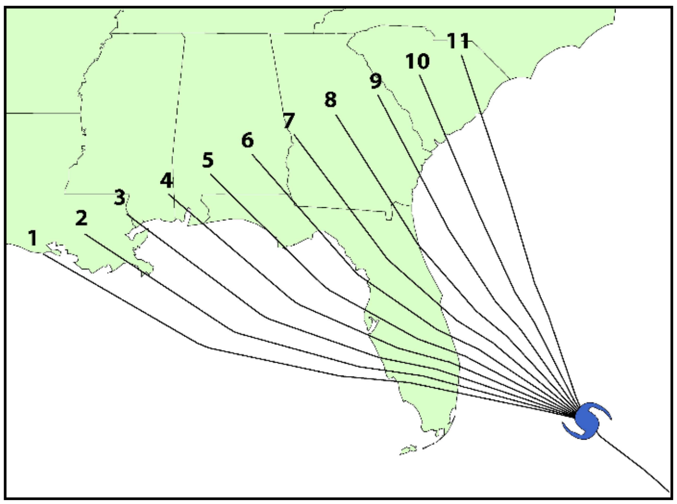

Figure 3: 11 tracks generated to capture the area of uncertainty shown by white solid area in Figure 2.

In AIR's Hurricane Loss Estimation model, central pressure defines the intensity of a hurricane. As described above, the NHC forecast provides maximum 1-minute wind speed and the probability it will be within any of the eight intensity ranges, namely, Dissipated, Tropical Depression, Tropical Storm, Hurricane, Category 1, Category 2, Category 3, Category 4-5, during the next 3 days. In the present study, this information is used to simulate a range of central pressures at landfall. First, the maximum 1-minute sustained wind speed is converted into central pressure using the standard meteorological relationship given in [2]. Using the discrete probabilities provided by the NHC, a uniform distribution of central pressure is assumed within each intensity range. The intensity ranges considered in the current methodology are limited to Category 1, 2, 3, and 4-5 hurricanes. The other intensity ranges – Dissipated, Tropical Depression, Tropical Storm, and Hurricane, are not taken into account since they do have significant loss implications. The probabilities for the intensity ranges considered are renormalized so that probabilities sum to one. For the most important intensity range – Category 4-5, which can significantly impact the loss estimates, a critical step is to decide the lower bound of the central pressure. The choice of the lower bound of the central pressure is largely based on meteorological guidance provided by the NHC in their forecast discussions.

In the forecast advisory issued by the NHC on September 3rd at 11:00 AM EDT, the storm was expected to make a landfall 36 hour later. Using the 36 hour forecast data from this advisory; the renormalized probabilities for intensity ranges Category 1, 2, 3, and 4-5 were estimated as 20%, 30%, 35% and 15%, respectively. At the time advisory was issued, the storm had a central pressure of 959 mb and had considerably weakened in the last 24 hours. The forecasters at the NHC, who provide a discussion on the likely evolution of the storm, suggested that the storm would weaken further before landfall. Therefore, a central pressure lower bound of 929 mb was chosen for Hurricane Frances. This implies that the strongest members in the simulated storm set were mid Category 4 hurricanes.

The third variable in the simulation is the radius of maximum winds (R_{max}). R_{max} is an important variable in the loss simulation for two primary reasons. First, it determines the overall size of the footprint of a hurricane and therefore impacts the extent of damage and losses. Second, given the location of the storm center, R_{max} determines the region of strongest wind speeds. If the region of strongest winds coincides with an area of high population concentration, the resulting losses can be significant. Because of this, the losses can be sensitive to small variations in R_{max}. As mentioned earlier, the NHC does not provide values of R_{max} in its advisories. Therefore, we derive a best estimate and a range for R_{max} and use a probability distribution to reflect the uncertainty in the estimate. In the current study, R_{max} is modeled using a normal distribution, truncated at two standard deviations using the estimated range. For Hurricane Frances (2004), on September 3rd, a mean value of 20 miles and a range from 16 to 24 miles was used.

The probability distributions for the three primary storm variables – storm track, central pressure, and R_{max}, for Hurricane Frances (2004), based on the forecast advisory issued by the NHC at 11:00 AM EDT on September 3rd are shown in Figure 4.

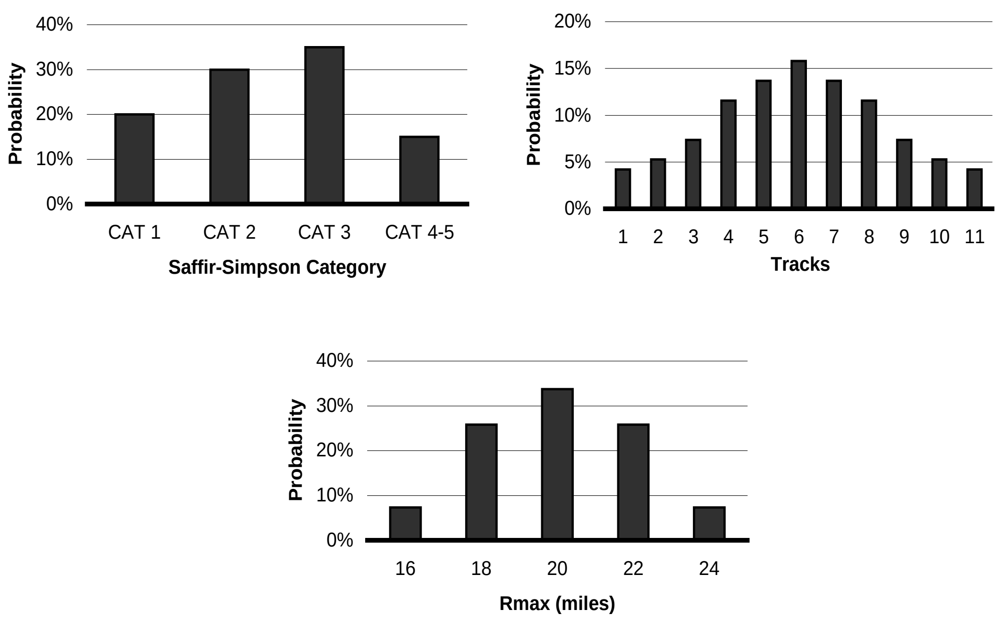

Figure 4: Probability distributions of the three model variables for Hurricane Frances.

Having specified probability distributions for tracks, storm intensity, and R_{max}, a stratified sampling technique is used to draw a large set of storms from the joint probability distribution of the three model variables. The sampling plan ensures that the relative frequency for each storm follows the specified joint probability distribution. Each storm in this set is analyzed using AIR's Hurricane Loss Estimation model, described earlier, to calculate the total insured losses.

RESULTS AND DISCUSSION

The resulting probability distribution of total insured property losses for Hurricane Frances (2004) two days prior to landfall is shown in Figure 5. Excluding 5% from each tail, the losses range from $168 million to $30 billion with a median loss of $2.17 billion. The coefficient of variation is 1.59.

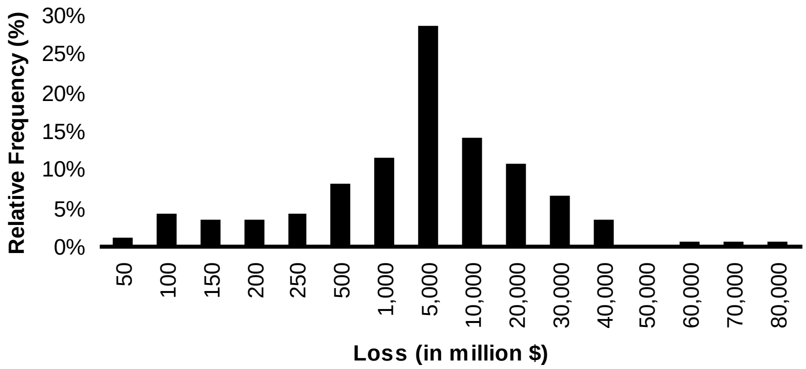

Figure 5: Probability distribution of total insured property losses for Hurricane Frances (2004) two days prior to landfall.

A large part of the variation in losses can be explained by the tracks of the simulated storms. In the present study, we used a set of 11 different tracks, as shown in Figure 3. The mean, standard deviation and coefficient of variation of the losses associated with these tracks are shown in Table 1.

Table 1: *Mean, standard deviation and coefficient of variation of the losses by track*

TRACK	MEAN	STD DEV	COV
1	17,426,621,599	20,762,006,616	1.19
2	16,384,456,421	18,343,458,133	1.12
3	13,765,949,419	20,234,919,743	1.47
4	9,127,375,912	11,031,361,449	1.21
5	7,201,821,140	9,189,575,648	1.28
6	5,233,768,476	7,103,394,729	1.36
7	4,646,242,900	6,610,982,381	1.42
8	6,869,513,566	9,406,714,977	1.37
9	2,264,190,786	3,600,012,974	1.59
10	1,889,392,059	2,743,908,713	1.45
11	3,105,691,655	4,554,902,435	1.47

The mean losses vary from a low of $1.9 billion for Track 10 to a high of $17.4 billion for Track 1. The wide variation in mean losses is due to the non-uniform distribution of the insured property in areas impacted by the storm. Figure 6 shows the distribution of insured property in billions of dollar for the region impacted by Hurricane Frances. Two days before projected landfall, the NHC forecast of the center of the storm (Track 6 in Figure 3) was north of West Palm Beach region with a mean loss of $5.2

billion. However, the southern tracks in the forecasted area of uncertainty would have impacted the Miami metropolitan area. Therefore, the southern tracks, which would have impacted a region of high concentration of insured property, have a higher mean than the northern tracks.

The relatively narrow range of coefficient of variation by track (1.12 to 1.59) suggests that the degree of uncertainty in losses is similar across different tracks. For a given track, uncertainty arises primarily because the damage is a highly non-linear function of wind speed and therefore, slight changes in the meteorological variables (central pressure and R_{max}) translate into significant variation in losses. A multiple regression analysis of the losses for Track 6 in Figure 3 showed that the central pressure and R_{max} could explain 78% of the variance. The remaining variance can be attributed to geographical inputs like the spatial distribution of land-use land-cover and insured property within the impacted region of each track.

As the storm approaches land, the uncertainty in storm parameters reduces resulting in a narrower range of losses. Once the hurricane has made a landfall and has dissipated to a tropical storm, final losses are estimated. At this stage, the storm track is known but there still exists some uncertainty in the intensity and R_{max} of the hurricane. The final estimated losses for Hurricane Frances ranged from $4 billion to $7 billion with a median loss of $5.4 billion. The current estimates of actual insured property losses are $4.4 billion (US) and $5.5 billion (Florida only) as reported by Property Claims Services (PCS) and Florida Office of Insurance Regulation, respectively. While the final insured losses are still being tallied and uncertain, we expect the total losses for the United States to be approximately $6 billion. This loss amount falls around the 68th percentile in the loss distribution shown in Figure 5.

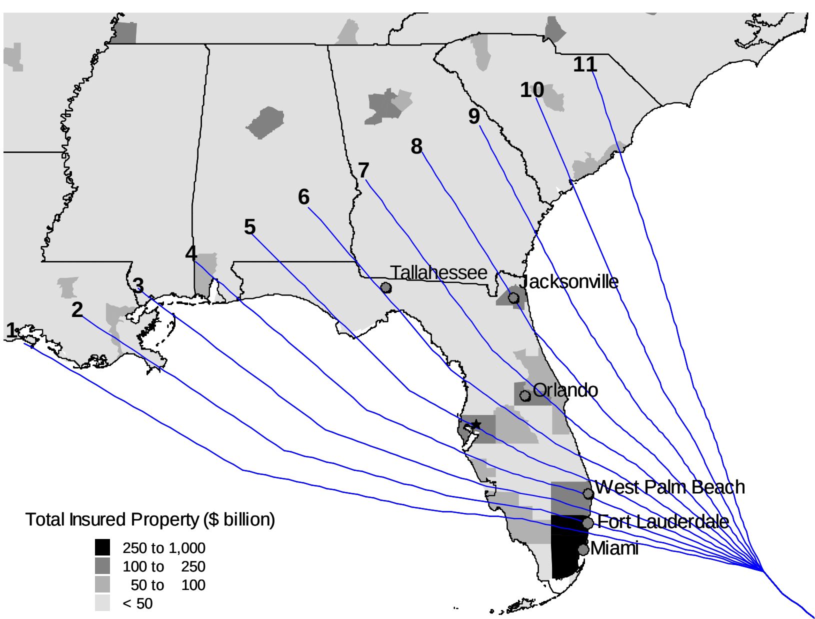

Figure 6: Total insured property in billions of dollar.

In the case of Hurricane Frances (2004), the forecast of the center of the storm (Track 6), was reasonably close to the actual track as shown in Figure 7. Also, the storm intensity at the time of landfall agreed well with the NHC forecast issued two days prior to landfall. Because of this, the mean loss for Track 6, $5.2 billion, is comparable with the actual insured property loss. However, this might not always be the case. If the actual track and intensity changes drastically before the landfall, then the loss estimates might deviate significantly from the estimates two days prior to landfall.

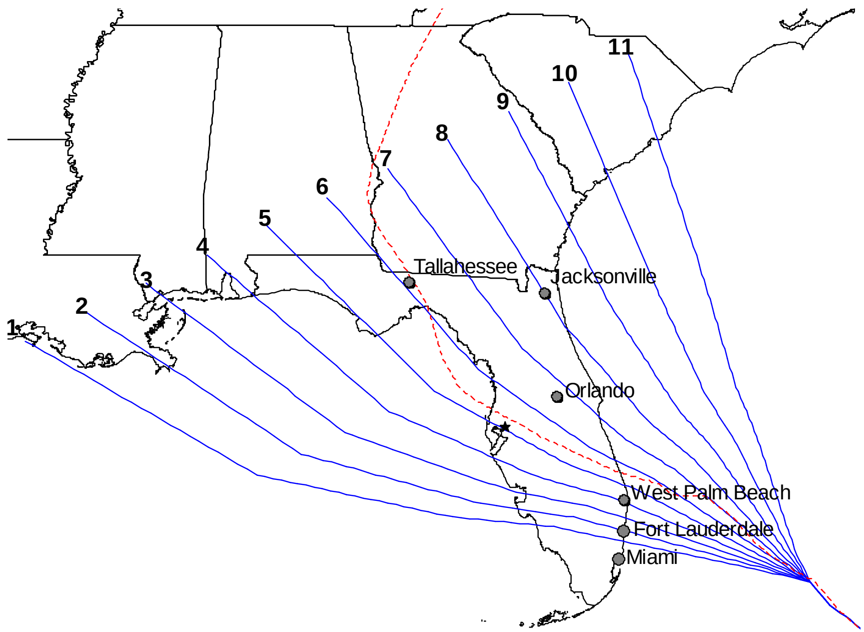

Figure 7: The actual track of Hurricane Frances (dotted line) overlaid on the forecast tracks two days prior to landfall.

CONCLUSIONS

A new methodology for forecasting hurricane losses in real-time has been presented. This methodology utilizes forecast provided by the NHC and allows for quantitative estimation of uncertainty in loss estimates in real-time. Results presented for Hurricane Frances (2004) illustrate that the uncertainty results primarily from two factors. First, damage is a highly non-linear function of wind speed and therefore, slight changes in the meteorological variables translate into significant variation in losses. Second, the insured property that gets impacted by a storm depends upon the track and the size of the storm. The probabilistic loss estimates, generated using this methodology, is a valuable tool for insurance companies and emergency management agencies for planning purposes.

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