Evaluating the Impact of the Increase in Hurricane Frequency Using an Internal Model. A Simulation Analysis

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Abstract

There is an ongoing debate about the change in frequency and intensity of hurricanes due to climate change. In addition to the variety of opposing arguments that have arisen in this discussion, available data shows that while hurricane frequency in the Atlantic basin seems to increase, hurricane frequency in the Pacific basin seems to decrease. This phenomenon is very important to the insurance sector, especially in a country like Mexico which is very exposed to this kind of catastrophes and that, in recent years, has reported its highest losses due to hurricanes. In this paper we analyze the impact of the increase in hurricane frequency and intensity on the portfolio an insurance firm with a complex reinsurance scheme. We use an internal simulation model based on a model commissioned by the insurance regulatory body in Mexico, whose use is compulsory for computing catastrophic reserves.

KEY WORDS: Quantile, Reinsurance, Catastrophe, Hurricane Insurance, Simulation.

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Introduction

The measurement and transfer of risk are at the essence of the insurance business. This has prompted the development of quantitative techniques to achieve both. They are important for all the stakeholders in the industry: the direct insurer, a potential reinsurer, regulators, rating agencies, and consumers. In the case of catastrophic risks (defined for the purpose of this paper as those with low frequency and high severity), they become particularly relevant due to the magnitude of potential losses, Woo (1999). A large hurricane (or sequence of them) will impact losses in an extreme fashion, such that if not adequately reserved and capitalized, or covered by reinsurance or retrocession, it can cause the ruin of either the insurer or the reinsurer, with "catastrophic" consequences for stockholders and society.

Due to its geographical location, Mexico is highly exposed to hurricane impacts. According to the National Meteorological Service (SMN) on average, between 1970 and 2006, Mexico was reached by 1.6 hurricanes each year. Figure 1 shows impacts of moderate hurricanes and Figure 2 those of intense hurricanes. It should be noted that 36% of the time Mexico was hit by hurricanes with wind speed above 177 kph (category III or more in the Saffir-Simpson scale). Just in 2005, a year of very high cyclonic activity in the Atlantic Ocean, the Mexican Association of Insurance Institutions (AMIS) estimated that Mexico had losses up to 2,282 million USD due to hurricanes Emily, Stan and Wilma (Figure 3). Moreover AMIS classifies these three hurricanes as part of the ten most expensive catastrophes for the Mexican Insurance Sector (Table 1).

Figure 1. Moderate Hurricanes that hit Mexico from 1970 to 2006. From National Meteorological Service, *http://smn.cna.gob.mx*

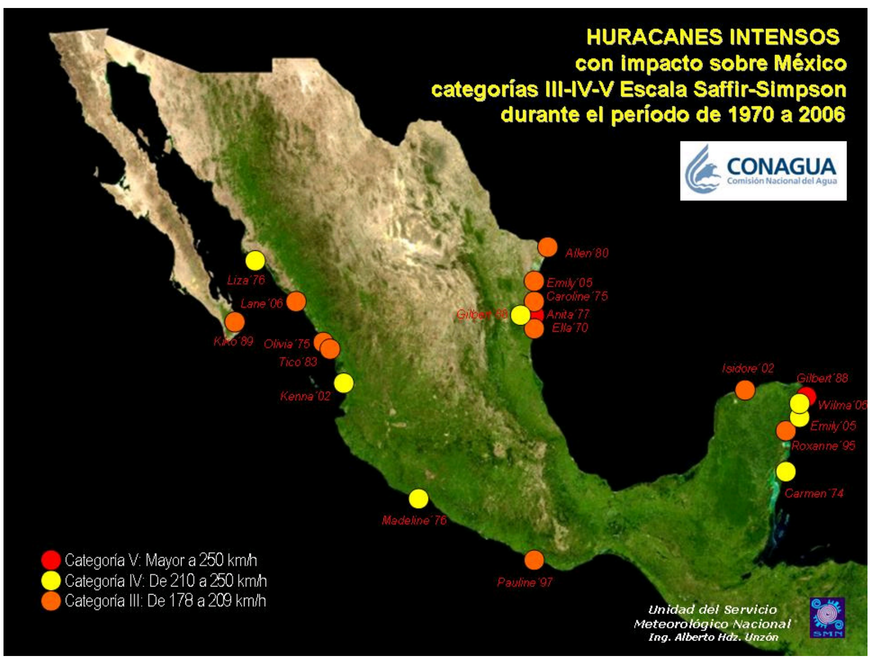

Figure 2. Intense Hurricanes that hit Mexico from 1970 to 2006. From National Meteorological Service, *http://smn.cna.gob.mx*

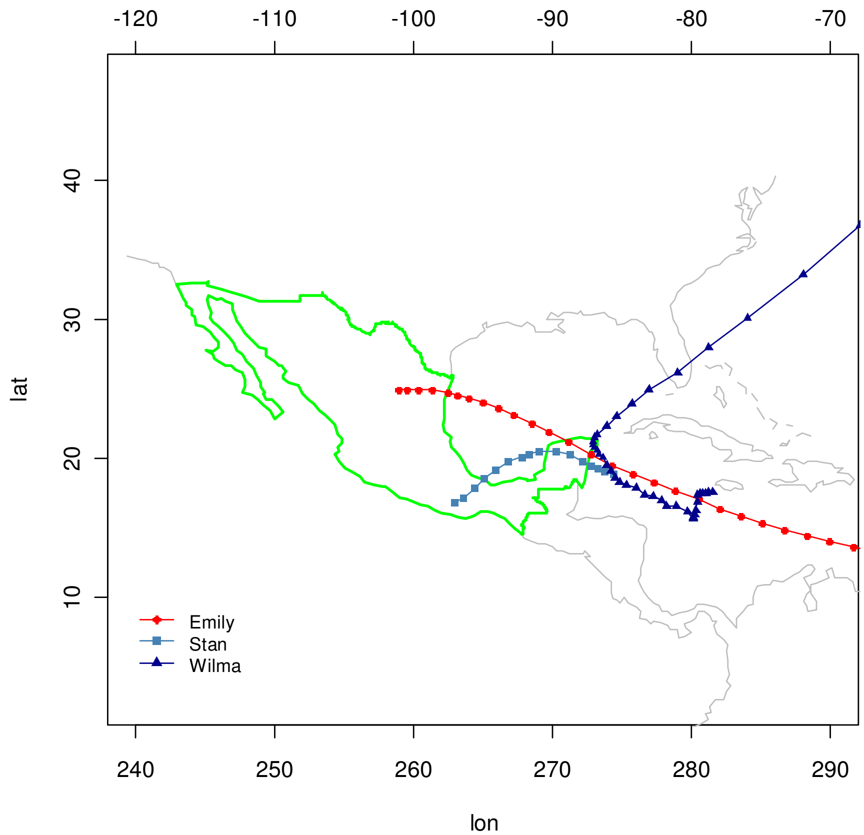

Figure 3. Trajectories of hurricanes Emily, Stan and Wilma.

Catastrophe	Loss (million USD)
Hurricane Wilma (2005)	1,752
Tabasco Flood (2007)	700
Hurricane Gilbert (1997)	567
Mexico City Earthquake (1985)	473
Hurricane Isidore (2002)	308
Hurricane Emily (2005)	302
Hurricane Stan (2005)	228
Hurricane Kenna (2002)	176
Hurricane Julliette (2001)	90
Hurricane Pauline (1997)	62

Table 1. Most expensive catastrophes in Mexico. From Mexican Association of Insurance Institutions.

The available information allows us to analyze tropical cyclone intensity and trajectory since 1851 in the Atlantic Ocean and since 1949 in the Pacific Ocean.

Nevertheless, it is important to notice that before the 1970s there was no geostationary satellite monitoring and that routine aircraft reconnaissance started in the 1940s, so that the earliest information is not as reliable as the latest and therefore comparisons through long periods of time are not valid.

Given the available information it can be very difficult for an insurer to measure this risk. Since the distribution of losses due to hurricanes for a large portfolio of risks will usually be unknown the only way to quantify risk may be through simulation. That is the process we follow here.

The fact that the processes of hurricane generation, wind field expansion, damage to buildings, etc. are very complex and their interaction makes their analysis even more so. It is necessary to bring together the expertise of meteorologists, structure engineers, actuaries, financial experts and others in order to construct a model that represents the overall process reasonably well. Clark (2002) explains how computer models can be used in estimating catastrophe losses. She points out the various components of such models and stages in their construction and application. Those components are present in the modeling process followed by ERN (2007) to develop the models used here. McNeil et al. (2005) distinguish several approaches to measuring risk. Here we concentrate on risk measures based on the loss distribution.

Because of the magnitude of potential losses, risk mitigation in this type of insurance is usually implemented through diverse types of traditional reinsurance (proportional and non-proportional) and alternative (cat-bonds and the like) risk transfer schemes. To clearly understand the exposure of the portfolio and achieve effective risk mitigation from financial and regulatory points of view, proper measurements of the magnitude of the losses, with and without the risk transfer chosen, are needed. Non-proportional reinsurance can greatly reduce the extreme tail of the cedant's loss distribution. Standard operating conditions, insurers use several "layers" of non proportional reinsurance that will be combined with some type of proportional reinsurance. The resulting reinsurance structures will then be very complicated to analyze, Verlaak and Beirlant (2003). This is further complicated if the probability distribution of losses is not known analytically. In fact most of the literature on optimal reinsurance assumes it is known.

Trends in Tropical Cyclone Activity

In recent years, there has been a strong discussion between different authors about the existence of an increasing trend in the number and intensity of hurricanes and tropical storms due to climate change. In general, the arguments that stand in favor of an increasing trend are based on the global warming phenomenon and the fact that hurricanes need a warm sea surface to be formed, Emanuel (2005) and Agata (2007). The opposing arguments claim that fictitious trends are observed because of the undercount of hurricanes prior the satellite or aircraft reconnaissance eras, Landsea (2005); or that the increasing destructiveness of hurricanes is an artificial effect due to societal changes, Pielke

(2005); or simply that if there is a trend it is negligible, Landsea et al. (2006). Trenberth (2005) indicates that "The key scientific question is not whether there is a trend in hurricane numbers and tracks, but rather how hurricanes are changing." Nevertheless, initially we will analyze the impact of a potential increase in the number.

In Figure 4, we show the number of tropical cyclones and hurricanes per year separately for the Pacific and the Atlantic basins. Notice that in the last 30 years (the period between the vertical lines) there has been a slight increase in the frequency of tropical cyclones in the Atlantic Ocean; however in the same period, in the Pacific Ocean there was an increasing trend until the beginning of the 1990s, when the number of tropical cyclones and hurricanes started to decrease. Since the analysis of trends in tropical cyclone activity is beyond the objectives of this work, and since the observed trends may be caused by multidecadal variations, Goldberg et al. (2001), our analysis considers two cases: one assuming no trend in the number of hurricanes and tropical storms, and another assuming that the number of hurricanes and tropical storms increases.

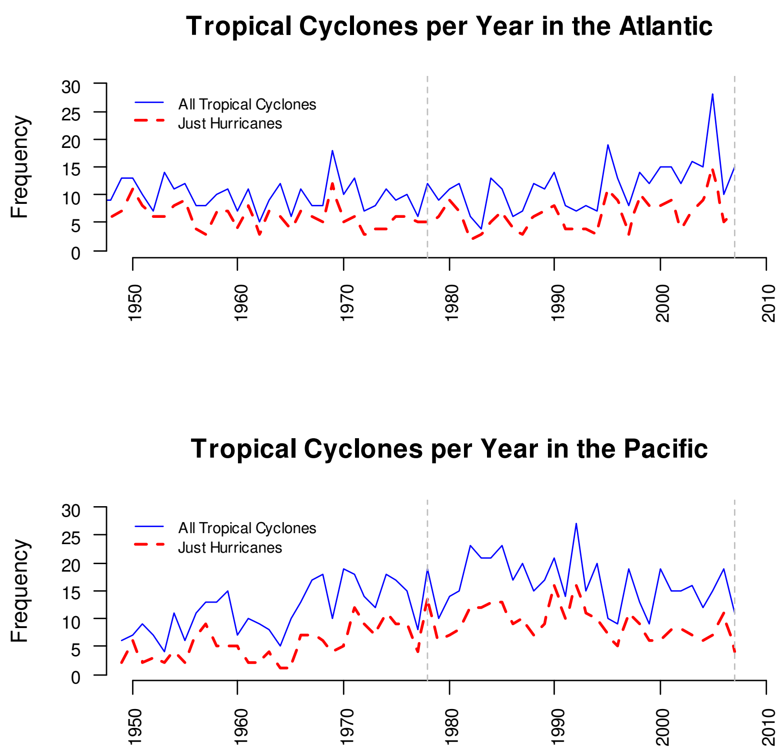

Figure 4. Tropical Storm Frequency from 1950 to 2007.

The Model

In general, models developed to estimate catastrophic losses are based on the physical laws of nature that govern the specific phenomena, in our case hurricane occurrence, and on the equations that embody them. Thus by combining mathematical representations of the natural occurrence patterns and characteristics of hurricanes, with complementary information on property values, construction types, and other characteristics, as well as information on insurance and reinsurance contracts, these models can provide extensive information to companies concerning the potential for large losses before they actually occur.

In terms of risk management, the correct measurement of the risk of a succession of catastrophic events and not only a single one is a must, specially in countries exposed to both seismological and hydrometeorological dangers, such as the USA, Japan, México and others.

In Mexico, the insurance regulatory body (Comision Nacional de Seguros y Fianzas, CNSF) has commissioned the construction of a hurricane loss model that must be used to compute the pure risk premium as well as the PML. These results are used to verify compliance with corresponding regulation and compute statutory reserves.

The initial component of this model is the frequency of hurricane occurrence, which is simulated by a Wiener Process, using as seed the trajectory of registered hurricanes (the information was obtained from the NOAA Hurricane Database). So, for a hurricane trajectory defined by the points $\{(x(t), y(t))\},\ t \in \mathbb{N}$, the corresponding points of the simulated trajectory are given by

$$(x_S(k), y_S(k)) = \left(x(k) + \sum_{t=1}^{k} e_{x(t)}, y(k) + \sum_{t=1}^{k} e_{y(t)}\right), \tag{1}$$

where $e_{*(t)} \sim \mathrm{N}(0, \sigma_*^2)$. Figure 5 shows an example of a set of simulations generated by perturbing hurricane Wilma's observed trajectory.

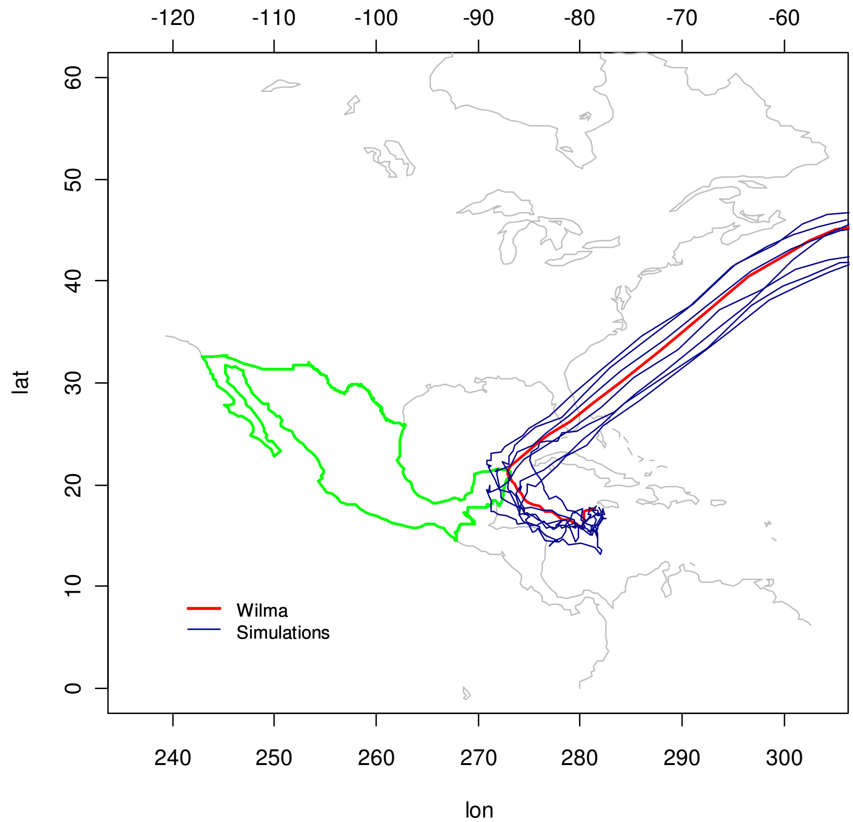

Figure 5. Simulations generated by perturbing hurricane Wilma's observed trajectory.

The ERN software produces additional output that can be used for simulation. These simulation exercises can provide a rich output that can be used for many different applications. Probability distributions of losses and their complement, exceedance probabilities, etc., can be estimated for potential levels of annual aggregate and per-occurrence losses that a company may experience given its portfolio of property exposures, Clark (2002). There are several commercial simulation models (AIR, EQECAT, RMS) that do this. Here we intend to show how a similar internal model can be used by the insurance companies.

Hence, based on the arguments put forth by international associations, such as the International Association of Insurer Supervisors (IAIS) and the International Actuarial Association (IAA), that encourage the use of mathematical models and simulation methods, we have used this output and constructed a program that allows the actuary to generate the distributions of gross yearly losses for an insurance portfolio. The algorithm includes the possibility of simulating the occurrence of one or several hurricanes in a year, their impact on the insured portfolio, or the risk transfer effect of reinsurance programs that mix different types or reinsurance, as well as other quantities.

These distributions are obtained using information on the construction characteristics for each insured building combined with wind field expansion and local effects from hurricanes at the given ‘site-magnitude’; they lead to a ratio damage distribution for each building. The individual distributions for the loss proportions in each building are then aggregated over the whole portfolio, for a detailed description see ERN (2007).

This process is applied as many times as there are hurricanes in a year to derive a figure of total yearly losses. As many yearly replications are generated as are needed according to the required precision.

Models for the Number of Hurricanes per Year

ERN’s software considers not only hurricanes, but also some tropical storms, so that on average Mexico is hit by three events of this kind per year. In order to have results compatible with ERN’s, we used a similar criterion to define the universe of “hurricanes” that hit Mexico.

In our analysis the number of hurricanes per year was defined using three different approaches: first, it was defined as the average number (rounded) of hurricanes per year from 1950 to 2007; second, for each year it was randomly chosen as the sum of two Poisson Distributions corresponding to the number of hurricanes coming from the Atlantic and from the Pacific; third, for each year it was randomly chosen as the sum of two Discretized Gumbel Distributions for the number of hurricanes coming from the Atlantic and from the Pacific.

The Gumbel Distribution is given by

$$F(x) = \exp\left(-\exp\left(\frac{-(x-\alpha)}{\beta}\right)\right), \qquad (2)$$

where $x \in \mathbb{R}$, $\alpha \in \mathbb{R}$ and $\beta \in \mathbb{R}^+$. Strictly speaking, it is not adequate to fit a continuous distribution to discrete data; however we are interested in the heavy tail property of the Gumbel Distribution. Therefore to use this distribution we truncated the negative values of *x* and discretized it, so that the (Truncated) Discretized Gumbel Distribution, as we call it, is given by

$$G(x) = \frac{F(x+.5)-F(x-.5)}{1-F(-.5)}, \qquad (3)$$

where $x \in \mathbb{N} \cup \{0\}$ and $F(x)$ is the Gumbel Distribution defined in equation (2). Figure 6 shows the histograms of the number of hurricanes per year and the fitted distributions.

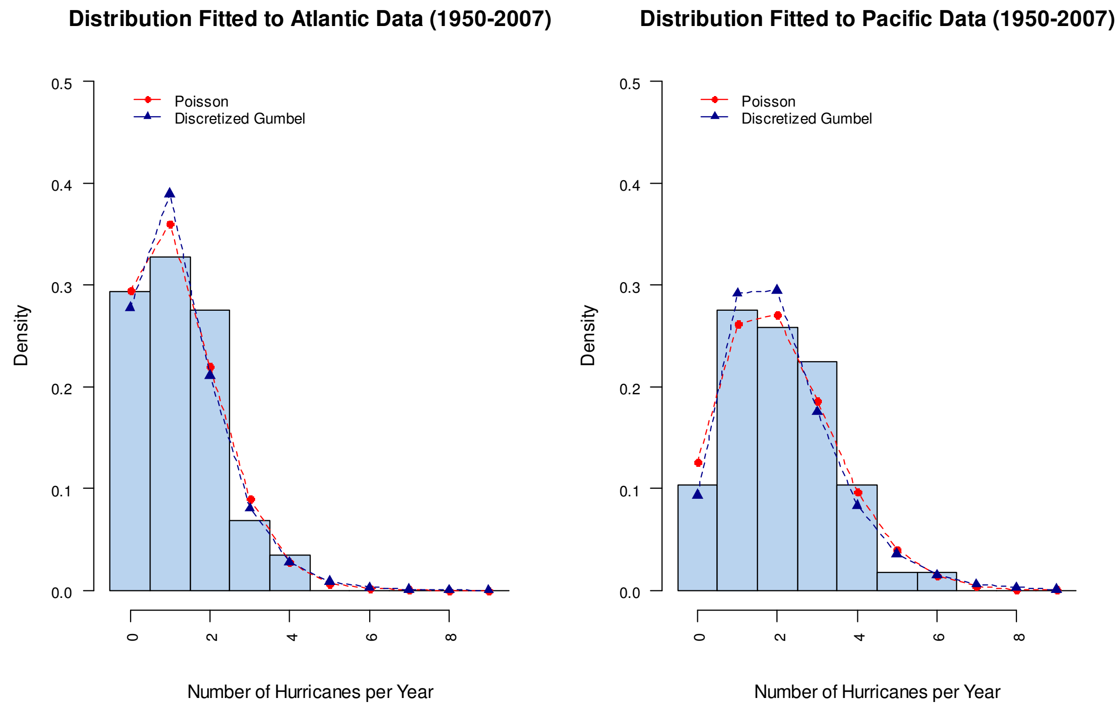

Figure 6. Poisson and (Truncated) Discretized Gumbel Distributions fitted.

Simulation Results

We apply the algorithm to a (disguised) portfolio from a real Mexican insurance company. The portfolio consists of 25,000 buildings. The non-proportional reinsurance scheme (in thousands of dollars) is as shown in Table 2. The insurance company also has a quota share with 10% retention for losses below 7,500, the priority. In this table, the heading 'RoI' stands for the Rate on Line cost of the reinsurance premium for the specific layer. In turn 'Reins' indicates the number of reinstatements that the reinsurance contract establishes for each layer.

Layers	Priority	Cover	Reinstatement Premium	RoI	Reins
1	$ 7,500	$ 7,500	$ 1,586	21.1%	2
2	$ 15,000	$ 15,000	$ 1,890	12.6%	2
3	$ 30,000	$ 30,000	$ 2,268	7.6%	1
4	$ 60,000	$ 40,000	$ 1,548	3.9%	1
5	$ 100,000	$ 130,000	$ 2,574	2.0%	1

Table 2

The kind of business questions that can be answered with the analysis described in the following lines are of the type: Is total coverage adequate for the company?

Does the program have enough reinstatements? How much risk relief is achieved with the program, in monetary terms? But our main interest here is to evaluate the effect of an increase in the number of hurricanes that hit Mexico.

Tables 3, 4 and 5 show some statistics for the gross losses (without any reinsurance) and for losses net of all reinsurance. The second row of these tables shows net losses including reinstatement costs; in turn the third row shows net losses without these costs. The resulting retention level for the whole portfolio is given in the last row. Note that the right tail of the loss distributions generated using a Poisson or a (Truncated) Discretized Gumbel model are heavier than the one of the loss distribution generated using a fixed number of hurricanes per year, so that the later has larger values in its first quartile, but lower values in the third quartile. In general, the values of the second quartile of the loss distributions (gross, net or net without reinstatements) are very similar between the three simulations, but the values of the third quartile are around 14% larger when using the probabilistic models than when using a deterministic model for the number of hurricanes. Note also that the mean gross loss obtained using a probabilistic model for the number of hurricanes is around 10% larger than the mean gross loss obtained with the deterministic model for the number of hurricanes. The last can be explained because in the first case the mean of the number of hurricanes per year is around 3.3, i.e. 10% larger than in the second case; however this difference is not immediately reflected when analyzing the net loss or the net loss without reinstatement.

Hurricanes Per Year = 3							
	Min	Q1	Q2	Mean	Q3	Max	Std. Dev.
Gross loss	$ 0	$ 40	$ 698	$ 7,915	$ 5,192	$1,345,075	25,646
Net loss	$ 0	$ 4	$ 70	$ 1,061	$ 519	$1,124,755	9,144
Net loss w.o. reins.	$ 0	$ 4	$ 70	$ 526	$ 519	$1,114,889	8,702
Retention	4.2%	10.0%	10.0%	10.6%	10.0%	83.6%	1.9%

Table 3

Hurricanes Per Year ~ Poisson							
	Min	Q1	Q2	Mean	Q3	Max	Std. Dev.
Gross loss	$ -	$ 14	$ 682	$ 8,658	$ 5,897	$1,344,035	26,762
Net loss	$ -	$ 1	$ 68	$ 1,135	$ 590	$1,124,651	8,861
Net loss w.o. reins.	$ -	$ 1	$ 68	$ 550	$ 590	$1,114,785	8,379
Retention	0.0%	10.0%	10.0%	10.2%	10.0%	83.7%	2.7%

Table 4

Hurricanes Per Year ~ Discretized Gumbel							
	Min	Q1	Q2	Mean	Q3	Max	Std. Dev.
Gross loss	$ -	$ 17	$ 709	$ 8,749	$ 5,996	$1,344,000	27,004
Net loss	$ -	$ 2	$ 71	$ 1,152	$ 600	$1,125,000	9,048
Net loss w.o. reins.	$ -	$ 2	$ 71	$ 562	$ 600	$1,115,000	8,564
Retention	0.0%	10.0%	10.0%	10.3%	10.0%	83.7%	2.5%

Table 5

Provided the hurricane model is available. It is shown how a relatively simple simulation model can provide a wealth of information not obtainable by analytic procedures.

Increase in Hurricane Frequency

In order to compare the effect on insurer losses due to an increase in the annual number of hurricanes it would be ideal to have a model that tells us how much we can expect hurricane frequency to increase. However, as we explained before, there is not a general agreement about the existence of a trend in the number of hurricanes, and therefore there is not a generally accepted model. Using a Bayesian analysis with a hierarchical model, assuming that the total number of hurricanes that hit Mexico follows a Poisson distribution with parameter lambda, we found that the third quartile in lambda's distribution is 3.78 (15% larger than the mean). We think this value of lambda is reasonable to build a hypothetical extreme scenario. We made another simulation assuming that the number of hurricanes follows a Poisson distribution with parameter 3.78.

Table 6 shows the results of this new simulation. Comparing these results with the ones in Table 4 (the first simulation with a Poisson model), we have that the three losses (gross, net and net without reinstatement) change in the same proportions. The main differences are in quartiles 1 and 2 (218% and 61%, respectively); the mean increases around 15%, which is similar to the increase in the mean of annual simulated hurricanes. Finally, the third quartile increase around 30%.

Extreme Scenario							
	Min	Q1	Q2	Mean	Q3	Max	Std. Dev.
Gross loss	$ -	$ 45	$ 1,096	$ 9,958	$ 7,620	$ 1,427,000	28,476
Net loss	$ -	$ 4	$ 110	$ 1,298	$ 766	$ 1,129,000	9,118
Net loss w.o. reins.	$ -	$ 4	$ 110	$ 626	$ 750	$ 1,116,000	8,592
Retention	0.0%	10.0%	10.0%	10.4%	10.0%	79.8%	2.5%

Table 6

So far we have just worked on increasing hurricane frequency; however some authors argue that hurricanes are also becoming wilder. In particular, Knutson and Tuleya (2004) claim that under climate-change conditions intense hurricanes become more likely to occur. In addition, Webster et. al (2005) warn that the proportion of hurricanes in categories 4 and 5 has increased over the last 30 years, as shown in Table 7; although there are also arguments to the contrary, Kerr (2008). In Figure 7, we show how the percent of hurricanes in categories 4 and 5 (in both basins) has changed in the last decades. However, we are interested in analyzing how potential increasing trends could affect the insurance sector. We have a Bayesian model that considers this effect so that we can include it in our simulations. For instance, we know that under a non-proportional reinsurance scheme a change in the proportion of hurricanes categories may have a strong impact due to the change in the distribution of losses among the layers.

Basin	Period			
	1975-1989		1990-2004	
	Number	Percentage	Number	Percentage
East Pacific Ocean	36	25	49	35
North Atlantic	16	20	25	25

Table 7. Change in the number and percentage of hurricane in categories 4 and 5 for the 15-year periods 1975-1989 and 1990-2004 for the different ocean basins. *From Webster et al. (2005).*

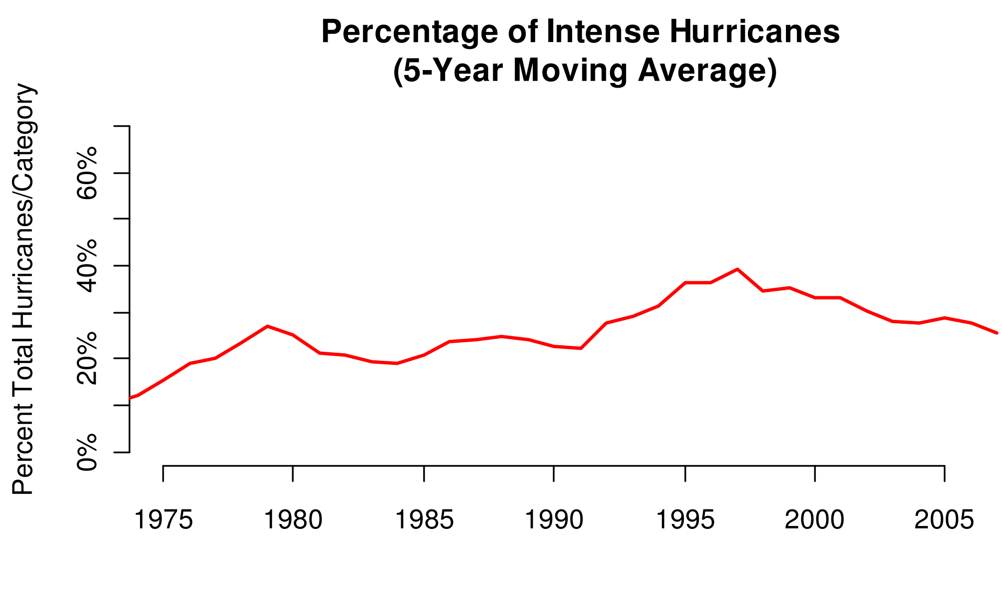

Figure 7. Evolution of the proportion of intense hurricanes (categories 4 and 5) in North Atlantic and East Pacific Basins.

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