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Risk models with dependence between claim occurrences and severities for Atlantic hurricanes

Mathieu Boudreault [a,*], Hélène Cossette [b], Étienne Marceau [b]

[a] *Université du Québec à Montréal, Département de mathématiques, C.P. 8888, succ. Centre-Ville, Montréal, QC, H3C 3P8, Canada*
[b] *Université Laval, École d'actuariat, Québec, QC, G1V 0A6, Canada*

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ABSTRACT

In the line of Cossette et al. (2003), we adapt and refine known Markovian-type risk models of Asmussen (1989) and Lu and Li (2005) to a hurricane risk context. These models are supported by the findings that El Niño/Southern Oscillation (as well as other natural phenomena) influence both the number of hurricanes and their strength. Hurricane risk is thus broken into three components: frequency, intensity and damage where the first two depend on the state of the Markov chain and intensity influences the amount of damage to an individual building. The proposed models are estimated with Florida hurricane data and several risk measures are computed over a fictitious portfolio.

1. Introduction

Supported by natural and economic phenomena, there has been a rising interest in the risk theory literature on models linking claim occurrence and severity. Two important classes of dependence between the latter two components are: (1) renewal models in which the interarrival time and claim size are dependent (see for instance Albrecher and Teugels (2006), Boudreault et al. (2006), Cossette et al. (2008), Badescu et al. (2009), Cheung et al. (2010) and references therein) and (2) risk models with a Markovian environment where interarrival times and claim sizes (and possibly premiums as well) all depend upon the state of a common Markov chain (see for example Asmussen (1989), Lu and Li (2005), Lu (2006) and Ng and Yang (2006) and references therein). For a general review of the latter models, see Chapter 7 in Asmussen and Albrecher (2010).

In the climatology and meteorology literature, it is well known that the phenomenon known as El Niño/Southern Oscillation influences both the number of hurricanes and their strengths (wind speed, amount of precipitation, etc.) (see for example Gray (1984), Meyer et al. (1997) and Landsea and Pielke (1999); Pielke and Landsea (1998) among others). A dependence relationship between hurricane frequency and intensity is thus obvious allowing Markovian models cited above to be adapted and refined to suit such a hurricane context. Note that in all the aforementioned risk theory papers, the focus has been put mostly on deriving ruin measures. In this paper, we extend the previous class of Markovian models in the line of Cossette et al. (2003) by decomposing natural catastrophe risk into frequency, intensity (strength of the event) and damage.

Based upon the literature in climatology and meteorology, we propose different joint hurricane frequency and intensity models. We represent by a latent process the current state of hurricane activity, which can be influenced by many physical phenomena. We first introduce a Markov-switching framework where both frequency and intensity are allowed to be state-dependent. Models with two states or three states are considered. We also extend the frequency models of Lu and Garrido (2006, 2005) such that hurricane frequency and intensity are dependent. Using Florida landfalling hurricane data (both frequency and intensity) and civil engineering approaches to quantify damage, we estimate and compare the latter models in order to analyze various risk measures of a fictitious portfolio of policyholders.

The paper is structured as follows. Section 2 introduces the general modeling framework for hurricane risk. In Section 3 we detail the joint frequency and intensity models proposed, while Section 4 focuses on the damage component. In Section 5, we apply the models to Florida data. Finally, Section 6 ends the paper with a conclusion.

* Corresponding author. Tel.: +1 514 987 3000; fax: +1 514 987 8935.
E-mail addresses: boudreault.mathieu@uqam.ca (M. Boudreault), helene.cossette@act.ulaval.ca (H. Cossette), etienne.marceau@act.ulaval.ca (É. Marceau).

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Table 1
Saffir–Simpson hurricane intensity scale.

Category	Description	MSWS (m/s)	Past count
1	Minimal	33–42	22
2	Moderate	43–49	18
3	Extensive	50–58	20
4	Extreme	59–69	7
5	Catastrophic	over 69	1

2. Modeling hurricane risk

2.1. Introduction

According to the National Hurricane Center (of the National Oceanic and Atmospheric Administration (NOAA)) and to Federal Emergency Management Agency (FEMA), a hurricane is "[...] a type of tropical cyclone, the generic term for a low pressure system that generally forms in the tropics. A typical cyclone is accompanied by thunderstorms, and in the Northern Hemisphere, a counterclockwise circulation of winds near the earth's surface." Depending on the tropical cyclone's location or strength, a tropical cyclone may be known as a hurricane, typhoon, tropical storm or depression (for more details, see Neumann (1993)).

Hurricane activity in the Atlantic Ocean and on the American East Coast is known to be influenced by many phenomena such as the Atlantic Multidecadal Oscillation (AMO) (see Chylek and Lesins (2008), and the NOAA Frequently Asked Questions), El Niño/Southern Oscillation (ENSO) (see Gray (1984), Meyer et al. (1997) and Landsea and Pielke (1999); Pielke and Landsea (1998) among others) and climate change (see Emanuel (2005) and WMO (2006)).

For example, ENSO represents the cyclical patterns observed in the surface temperature of the Pacific Ocean and its changes in air surface pressure. During cycles that may last months or years, ocean temperatures in the central tropical Pacific Ocean tend to warm (El Niño) and then cool (La Niña) in a cyclical pattern. Accompanying these temperature variations are changes in air surface pressure across the Pacific. During El Niño (La Niña), higher (lower) pressures are observed in the Western Pacific and lower (higher) pressures are observed in the Eastern part of the basin. The cyclical changes in air pressure is known as the El Niño Southern Oscillation (ENSO). Many authors have reported that ENSO is known to have an important influence on hurricane frequency and intensity in the Atlantic Ocean (see aforementioned authors). Indeed, during La Niña, more hurricanes are generated (on average) and these hurricanes are generally stronger. This is the usually the opposite in El Niño. This means that frequency and intensity are dependent components of hurricane risk. Note that frequency represents the number of hurricanes that made landfall in a given region within a specific time period (year, month).

Intensity is defined as the strength of a hurricane at a given location and is generally measured on the Saffir–Simpson scale, which is based upon wind speeds. The latter classifies hurricanes according to five levels (see Table 1 for a description), which are distinguished on the basis of the 1-min maximum sustained wind speed (MSWS). We mention that instruments measure the average wind speed within 1-min time intervals. The MSWS is the highest of these means. Moreover, the approach is not limited to the Saffir–Simpson scale. One may also include less severe tropical storms or classify hurricanes in more categories based on the MSWS or other measures. When winds are between 18 and 32 m/s (meters per second), the cyclone is classified as a tropical storm and below 17 m/s, the storm is a depression. In the latter cases, the Beaufort scale is used. In the fourth column of Table 1, we indicate the distribution of hurricane intensity, for hurricanes that made landfall in Florida. The dataset used to compute the numbers in this column is discussed in Section 5.

Finally, damage is related to the amount of losses suffered by a policyholder for a given hurricane. This component is closely linked to the intensity of the hurricane and is presented in more detail in Section 4.

2.2. General modeling framework

Let $\underline{N} = \{N(t), t > 0\}$ represent the counting process of the number of hurricanes that make landfall in a given region during the time interval $(0, t]$. Let also the random variable (r.v.) I_k represent the intensity of the k-th hurricane, which is, as discussed earlier, the strength of a given hurricane on a given scale. We also define the process $\underline{X}_i = \{X_i(t), t > 0\}$ where $X_i(t)$ is the total amount of losses suffered by policyholder i due to the $N(t)$ hurricanes that occurred in $(0, t]$ i.e.

$$X_i(t) = \begin{cases} \sum_{k=1}^{N(t)} C_{i,k}, & N(t) > 0, \\ 0, & N(t) = 0. \end{cases} \quad (1)$$

The amount of loss due to the k-th hurricane is defined by the r.v. $C_{i,k}$ with

$$C_{i,k} = U_{i,k} \times b_i, \quad (2)$$

where the scalar b_i is the exposure or the value of the insured building and the r.v. $U_{i,k} \in [0, 1]$ represents the proportion of damage. The information regarding the type of building and its construction will be embedded in $U_{i,k}$. Moreover, the intensity of the k-th hurricane will influence the extent of damage to a property so that the conditional distribution of $U_{i,k}$ depends upon the intensity r.v. I_k. The specific relationship between $U_{i,k}$ and I_k will be defined later in Section 4.

The way that we define $C_{i,k}$ assumes that losses to an individual building cannot be larger than its given value b_i, or in other words, $C_{i,k} \in [0, b_i]$. The type of building and the force of the hurricane will determine the distribution of $C_{i,k}$ and thus the total loss suffered by policyholder i for hurricane k.

For a portfolio of n policyholders living in a hurricane-prone area, the process for the aggregate losses is defined by $\underline{S} = \{S(t), t > 0\}$ where $S(t)$ is the aggregate losses for the time period $(0, t]$ e.g.

$$S(t) = \sum_{i=1}^{n} X_i(t) = \begin{cases} \sum_{k=1}^{N(t)} \sum_{i=1}^{n} C_{i,k}, & N(t) > 0, \\ 0, & N(t) = 0. \end{cases} \quad (3)$$

We interpret $\sum_{i=1}^{n} C_{i,k}$ as the aggregate amount of losses due to the kth hurricane. There are two sources of dependence within this model. First, the number of hurricanes and their intensities are common to all policyholders of the same region. Second, as mentioned in the Introduction, ENSO induces a dependence relation between hurricane frequency and intensity. This is detailed next.

2.3. El Niño/Southern oscillation

As previously mentioned in Section 2.1, various phenomena such as AMO, ENSO and climate change influence the hurricane activity level. Although ENSO is observed via the Oceanic Niño (ONI) and Southern Oscillation Indices (SOI), the fact that many meteorological phenomena interact to influence the hurricane activity level (not just ENSO) justifies the use of a latent process approach. However, to lighten the presentation, we will interpret the latent stochastic process as ENSO with states corresponding roughly to El Niño and La Niña even though there might not be an exact correspondence with the ONI and SOI. Thus, the interpretations that we attribute to the states of ENSO can be described