Hurricane Risk 1

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Hurricane Risk

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Hurricane Risk

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Preface

This book comprises both extended versions of papers presented at the 6th International Summit on Hurricanes and Climate Change: from Hazard to Impact, held in Heraklion in June 2017, as well as some additional contributions. Talks presented at this conference ranged from numerical simulation of tropical cyclones through tropical cyclone hazard estimation to damage estimates and their implications for commercial risk. This series of conferences has evolved over time to include a substantial component on climate risk, and this shift in emphasis is reflected in the content of this new volume. This book provides a source reference for both risk managers and climate scientists for topics on the interface between tropical cyclones, climate, and risk.

These topics are of particular interest to the insurance industry, and Chap. 1 provides an overview of the tropical cyclone risk issues that are of concern to the industry, with a particular emphasis on the importance to industry of appropriate time horizons for prediction and risk management. A review of the development and processes of the reinsurance industry is also given, to provide useful background for the technical and scientific work required to address industry-specific concerns. Better estimates of tropical cyclone hazard are of course a key concern to industry and policy makers, and Chap. 2 details new methods for assessing the damage potential of tropical cyclones, a key input for estimates of tropical cyclone impacts. Another measure for assessing the intensity of tropical cyclones that is relevant to their total potential impact during a season, namely, their integrated kinetic energy, is discussed in Chap. 3 along with the climatology and year-to-year variations of this parameter. The links between tropical cyclone energy and wind hazards are investigated in Chap. 4, as a visualization tool for hazard impact assessment.

Accurate risk assessment of current tropical cyclone hazard involves an intimate understanding of the specific risks in a particular location, and Chap. 5 gives a detailed description of the current vulnerabilities in the Tampa Bay region, a location that seems particularly at risk due to a combination of substantial hurricane hazard, its geography and its vulnerable infrastructure. Studies of the year-to-year variations in tropical cyclone occurrence and the reasons for this variation are important for understanding what leads to high-impact years, and Chap. 6 details the relationship between the climate conditions during the tropical cyclone season in 2015 and the observed tropical storm and hurricane occurrence in that year. There is a growing body of work on the relationship between variations in climatically important atmospheric conditions and tropical cyclone occurrence, and Chap. 7 investigates the possibility of the influence of dust particles on tropical cyclone incidence in the Australian region, since this continent is a considerable source of dust. While the influence of Saharan dust on Atlantic tropical cyclones appears to be noticeable and is a topic of active research, the effect in the Australian region appears to be much less.

While there have been advances in our understanding of the links between climate and tropical cyclones, we still do not have a general theory of the relationship between climate and tropical cyclones that would enable us to predict the number of tropical cyclones from the current climate, even to within an order of magnitude. Chapter 8 discusses some of the main issues in establishing such a theory, with particular relevance to the possible implications for tropical cyclone risk assessment. Any such well-established theoretical relationship would have implications for future predictions of tropical cyclones in a warmer world, and Chap. 9 provides new estimates of the potential tropical cyclone damage and loss of life due to future climate change. This chapter emphasizes the crucial role of adaptation to future changes in hazards in minimizing the increase in tropical cyclone risk. A possible outcome in a warmer world is the poleward movement of typical regions of tropical cyclone occurrence, a scenario that has received some support from recent research. Chapter 10 outlines some of the challenges for the built environment of this potential risk, with a consideration of possible adaptation options. In addition to possible effects of climate change on the land-based built environment, ocean infrastructure is potentially vulnerable to future changes in hurricane climate. Chapter 11 quantifies some of these future hazards for offshore infrastructure, with a focus on integrating projections of future wave hazards with engineering design. Finally, a tool that is increasingly being used for estimating the effects of climate change on tropical cyclones is the climate model, as constantly improving computing resources enable horizontal resolutions for these models to be increased to the point where their simulations of tropical cyclones are becoming more realistic. Chapter 12 outlines a method whereby very fine resolution simulations of tropical cyclones can be designed to test the hypothesized impact of climate change, including the possible effect on hurricanes of the global and regional warming that has already occurred to date.

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Chapter 1
Issues of Importance to the (Re)insurance Industry: A Timescale Perspective

Tom Philp, Tom Sabbatelli, Christina Robertson, and Paul Wilson

Abstract Of any single weather or climate peril, tropical cyclones constitute the largest annual average loss to the global insurance and reinsurance industry, and in any given year are often the drivers of the largest catastrophic losses to the entire industry. These losses come in the form of payments covering insurance claims, initiated through damage caused by a tropical cyclone's physical effects. They are thus looked upon within the industry as hugely important perils for study and analysis. This chapter provides an introduction to traditional methods for pricing risk, with an emphasis on hurricanes, and how the catastrophe modeling industry has arisen out of limitations with those traditional methods specifically when looking at extreme, relatively rarely occurring perils that have the potential to cause catastrophic loss.

Keywords Insurance · Catastrophe · Modeling · Hurricane

Of any single weather or climate peril, tropical cyclones constitute the largest annual average loss to the global insurance and reinsurance (henceforth "re/insurance") industry, and in any given year are often the drivers of the largest catastrophic losses to the entire industry. Initial estimates of the insured loss caused by Hurricanes Harvey, Irma, and Maria in 2017 total approximately US$92 billion. Another trio of hurricanes – Katrina, Rita, and Wilma – struck the U.S. in 2005, causing losses (trended to 2017 dollars) in excess of US$110 billion (Swiss Re 2018).

These losses come in the form of payments covering insurance claims, initiated through damage caused by a tropical cyclone's physical effects. They are thus looked upon within the re/insurance industry as hugely important perils for study

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and analysis. Although tropical cyclones in all basins are of large concern, those that form in the Atlantic basin usually come in for the highest scrutiny due to the large concentration of insured assets that exist in that basin – particularly along the high population density sections of the U.S. coastline. This chapter will therefore focus on Atlantic hurricanes as its fundamental basis, but the concepts introduced here are easily transferrable to any other basin that experiences tropical cyclones.

In order to give the unacquainted reader a general overview of the industry, a very brief historical background of re/insurance is first provided, before some important operational practices and market dynamics are introduced. The chapter then goes on to provide an introduction to traditional methods for pricing risk, and how the catastrophe modeling industry has arisen out of limitations with those traditional methods specifically when looking at extreme, relatively rarely occurring perils that have the potential to cause catastrophic loss. From this point, the chapter will focus on one of the key debates that is taking place within the industry at present: how to best build a view of Atlantic hurricane frequency risk. This section will constitute the main body of the chapter. It will then provide a discussion on new innovations within re/insurance with regard to alternative risk transfer mechanisms, before concluding with a brief review of ways in which climate change impacts are being explicitly incorporated into industry risk assessments at present.

1.1 An Introduction to the Re/insurance Industry

Insurance, as a concept, can be described as the quantification and securitization (usually via monetization) of a risk, and the subsequent transfer (ceding) of that risk from one party to another, in order that the (re)insured is indemnified from any loss resulting from that risk. It is known to have existed in one form or another since around 2250 B.C., with the Babylonians using it to indemnify traders from losses in cases where they were found to be non-negligent (Trennery 1926). In its more modern form of insurance-specific contracts, the earliest existing (or, at least, surviving) documents provided indemnity to traders susceptible to maritime risk in and around Genoa shortly before 1300 A.D. (Briys and Joos de ter Beerst 2006).

Reinsurance, the concept of an insurer itself ceding the already taken-on risk to another party, was first documented shortly afterward, again in a contract emanating from Genoa in 1340, in which the risk during the most hazardous part of a voyage was ceded to another insurer (Holland 2009). The principles developed in Genoa spread across the Mediterranean and Europe, finding root during the 1600s in Edward Lloyd's coffee house in the City of London, later growing into the Lloyd's of London insurance market. With global marine exploration becoming competitive at this time, the ideas quickly spread throughout the world, leading to the global re/insurance industry.

Today, re/insurance covers all types of risk, from specific natural perils such as hurricanes, to general life insurance and even war and terrorism risk. Policies are sold to individuals, businesses, and governments alike, with insurance products being created for any insurable interest that can be quantified and compensated should deleterious events occur. The transfer of risk from one party to another generally has to involve a "consideration" – effectively, something of value passing from any potential policyholder to a re/insurer – in order for the insurance contract to become active. This consideration usually takes the form of an insurance "premium".

On a simplistic level, it is intuitive to think that the frequency and magnitude of any risk can be directly translated into a fair insurance premium. This type of analysis leads to what is known as a "pure risk" premium, or our best evaluation of the price for the pure risk at a given location. This is, unsurprisingly, known within the industry as insurance pricing, and will be introduced in further detail in the next section.

Before delving into pricing methods, however, it is important to understand that, in reality, premiums are susceptible to market dynamics and business strategies, which can influence the final price – both negatively and positively – that the customer sees. These influences will be introduced below as they have extremely important impacts for the re/insurance industry.

1.1.1 Insurance Cycles

One of the most important of the market dynamics to understand is the concept of insurance cycles. These cycles, although often complex and with influences originating from many sources, can be generally said to exist because of the flow of capital into and out of the re/insurance industry. This capital flow results in changes in supply and demand for insurance products (or vice versa), which drives alternating "hard" and "soft" market conditions. The cycles between the two states are often cited as the top challenge the re/insurance market faces (Lloyd's 2008), mostly due to the potential need to quickly vary business strategy without disrupting client relationships; methods to deal explicitly with minimizing the effects of these cycles have become prevalent within the risk pricing and capital reserving communities in the past 10 years or so following recommendations made by the General Insurance Reserving Issues Taskforce to the Institute of Actuaries (Jones et al. 2006).

Figure 1.1 provides a schematic to describe the cycle and the points of the hard and soft market. In this example, we can see that shortly after a catastrophe, market conditions "harden". This is driven by a flow of capital out of the industry due to claims paid by re/insurers at the point of catastrophe, and of related shareholder losses/lack of return causing a withdrawal of investment. This leads to a less competitive underwriting environment, and thus premium rates increase. However,

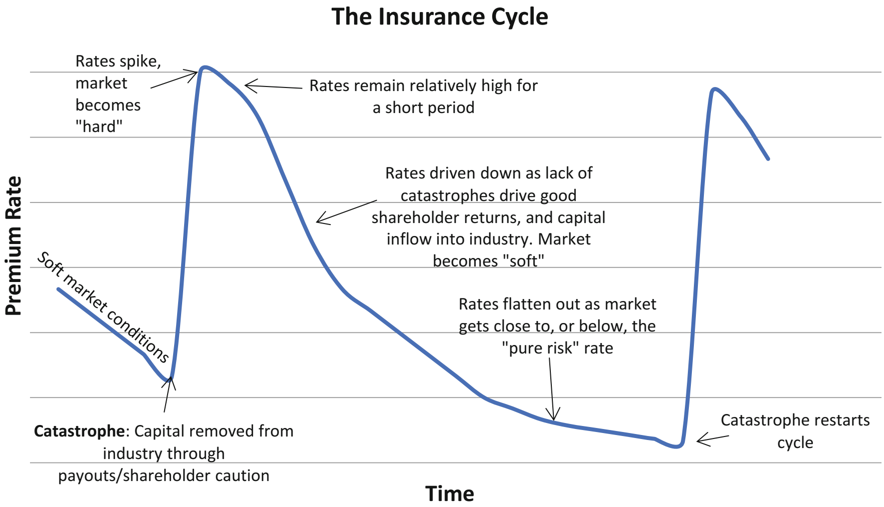

Fig. 1.1 Schematic of the insurance cycle through time

as time goes on without large, industry-impacting catastrophes, returns on investments from shareholders tend to be good, and thus capital begins to flow back into the industry. This leads to more competition, and a general driving down of insurance premiums. It is worth noting that, although the occurrence of catastrophes may cause a shift to hard market conditions, this is not always the case; on a related note, the shift to hard market conditions can also be driven by capital-impacting events other than a catastrophe. Finally, there is an argument to be made that because of recent alternative capital pathways to the market (see later section), the re/insurance market may be shifting away from these cycles. However, in the present, it is necessary to at least acknowledge their historical existence.

1.1.2 Expense Loading

The work done to quantify, price, and then underwrite a risk obviously requires skilled practitioners, processes, and systems, as do claims when they are made. These contribute to what is known as “expense loading” of the pure risk premium. Due to the high level of competition in financial markets, these are usually driven down to as an affordable level as possible and, at present, there are also attempts to minimize these costs through innovative alternative risk transfer solutions, such as insurance-linked securities – these alternative solutions are introduced in more detail later in the chapter.

Background competition and innovation are not the only mechanism through which loading costs of expenses are driven down. Re/insurance brokers, often tasked with the placing a risk for a customer, effectively act as well-informed intermediaries to assess the needs of a customer, and to find them the most appropriate coverage terms and most competitive rates.

1.1.3 Regulation and Market Control

Alongside brokers being a key part of many re/insurance policy chains, regulation has increasingly become an important part of re/insurance practice. Regulation of the insurance industry takes place through multiple regional, national, and international bodies, and exists in order to protect policyholders in two key ways.

The first is through rate regulation which, although not universal, aims to help to protect customers against excessive premiums. Here, the regulator is tasked with independently producing a view on any manner of a risk, and defining appropriate bounds for the pricing of that risk. If re/insurers flaunt those guidelines, they may face financial penalties, or may even be unable to gain access to the market over which the regulator has licensing authority, though these types of penalties are typically only seen for some insurance products (e.g. property and casualty insurance for individuals).

The second way regulation aims to protect policyholders is through solvency capital requirements. Here, regulators require re/insurers to prove, as far as is deemed possible, that they will be able to remain resilient to losses and to pay out insured claims up to a probability that is considered reasonable by the regulator. The meaning of the word "reasonable" can differ between regulators, but the recent EU's Solvency II insurance requirement is that insurers be able to pay out with a 99.5% probability – or, effectively, that in any given year there is only a 1 in 200 chance that the insurer will become insolvent and unable to pay claims. These guidelines are expected to find equivalence in U.S. law in the near future.

A key issue for re/insurers on the regulation front arises from the fact that not all regulators hold the same opinion on best-practice for pricing risk. This can leave re/insurers in difficult situations if a local regulator in one jurisdiction advocates a contradictory method for pricing the risk than a different regulator in another jurisdiction. With specific regard to North Atlantic hurricane risk, this has been a topic of debate within the industry for a number of years. As an example, the Florida Commission on Hurricane Loss Projection Methodology (FCHLPM) has historically approved catastrophe models with a view of Atlantic hurricane frequency risk different from the stance adopted by Lloyd's of London over the past few years. Although Lloyd's isn't strictly an independent regulator, its requirement that syndicates operating within it follow its guidelines effectively means that it has the same effect on re/insurance entities as a regulator.

As this issue on differing views of frequency risk is the focus of the main body of this chapter, these issues will be delved into in more detail later. However, before doing that, let us conclude this section with two more key factors that play a role in re/insurance decision-making.

1.1.4 Ratings Agencies

Although independent of regulators, ratings agencies have a similar effect on re/insurers: in assessing an insurer's ability to remain resilient and profitable, and assigning ratings to those companies based on those assessments, ratings agencies effectively add a second layer of regulation. This again adds more complication to the overall picture, as these assessments are not standardized between ratings agencies, and one ratings agency may have different requirements and techniques for assigning ratings.

However, as re/insurance companies are ultimately accountable to their shareholders, they must operate in a manner that is thought to generally positively impact share prices. As higher ratings from ratings agencies tends to attract capital from market investors, it clearly makes intuitive sense that most re/insurers must align with these independent assessments enough that their ratings will be seen positively.

With these governing market dynamics and practices introduced, it is important to understand how these issues come together from a business planning strategy, and how they impact the decisions that re/insurers make as to how best to operate within the market.

1.1.5 Business Planning: Finding Appropriate Stability

The ultimate purpose of re/insurance is to remove the volatility of loss that could otherwise have long-lasting negative impacts on economic and broader societal development. This implicitly suggests a desire on the part of any potential insured parties to remove the risk of volatility from their business or assets, which in turn suggests that a reasonably stable premium would be anticipated and desired by potential clients. Finding such a stable premium for any risk is indeed something that is often looked upon as a sign of proficiency in the market.

In reality, however, the market dynamics and practices described above make finding and setting a stable premium very difficult. However, the concept of a "pure risk" premium (as mentioned in Fig. 1.1) free from these influences does allow one, at least theoretically, to find a reasonable baseline to work from; this pure risk premium can be loosely thought of as a best estimate of the "current" risk.

With this concept of current risk in mind, it is worth introducing two time-horizon aspects of risk management that are of importance to a re/insurance company building a view of risk; namely, to what timescale would re/insurers ideally:

(i) Price risk?
(ii) Plan broader business operations?

Regarding (i) – although re/insurers typically underwrite policies on an annual basis, it may appear evident, given the description above, that an annually changing view of the risk is not ideal for traditional re/insurance pricing because of the premium (and also the consequent operational) volatility that such a method would introduce. This issue may be more or less important for some re/insurers than others, dependent on business structure and strategy, and also likely varies depending on whether the risk is a direct insurance cover placed with an insurer, or a reinsurance cover placed with a reinsurer. For an insurer, clients not well-accustomed to risk modeling may look on premium stability as desirable for their business and cost planning; yet reinsurers, with clients who themselves are already re/insurers and thus are likely to have direct expertise in risk modeling, may be much less concerned by year-to-year premium volatility and may even seek it.

However, on the assumption that minimizing premium volatility on current risk is an important issue from at least a general insurance perspective, there is a need to define a multi-annual time window that can smooth year-to-year variability in the risk. The question therefore evolves to the following: over what multi-annual time period should insurers (and any similarly concerned reinsurers) look at to price risk? This is a tricky question to answer and, in reality, the time horizon for "current" risk pricing differs between catastrophe models.

For hurricane risk, the minimum length of the multi-year time window is thought to be approximately 5 years, as this is around the time needed to smooth out fairly well known inter-annual effects on Atlantic hurricane activity driven by the El Niño-Southern Oscillation (ENSO) and other short-term climate influences. Defining the maximum length of the window introduces some difficult choices, however, with each carrying benefits and detriments. For example, pricing risk from very long-term historical data (i.e. the entire HURDAT2 record) may not be entirely appropriate given knowledge of a changing climate coupled with potential multi-annual variability, and issues with record certainty as one goes back in time. Yet, in limiting the data to more recent years, we would be shrinking an already small dataset further, while potentially removing useful historical information and extreme event behavior from pricing. Thus, questions arise around whether it should be seen as most appropriate to utilize ideas such as 10–20 year persistence (i.e. beginning to approach levels of multi-decadal variability) or merely just the long-term (i.e. ~100 year) average in order to avoid influence from occasionally uncertain scientific theories.

In reality, there are currently no best-practice answers to the above challenges, and this is a theme which should be encouraged as an area for active research within the scientific community. The catastrophe modeling industry has begun to attempt to answer some of those questions; some of these specific attempts are detailed later in the chapter, including detailing attempts to take forward-looking, multi-year forecasts of the risk.

Before moving forward, however, it is important to introduce the distinction between questions (i) and (ii) above due to the issue of climate change, and how its impact is viewed differently in pricing and business planning.

With regard to question (i): as re/insurance pricing is concerned with the present, climate change research as currently undertaken by the academic community (i.e. projections typically out to 2030, 2050, or even 2100) may not be well-aligned with that needed by the re/insurance pricing community, which is focused chiefly on the present day, and perhaps only looks forward up to 5 years into the future.

However, with regard to question (ii), from a long-term business planning perspective, re/insurers are very mindful of the potentially changing risk landscape, and how they should be evolving their business accordingly. To borrow the language of climate science policy, the re/insurance industry is asking, “What can or should I be doing now to mitigate the impacts of climate change on my business, if any exist?” and secondly, “What can or should I be doing now and in the future to adapt my business to account for the challenges and possible opportunities these changes may represent?”

Thus, there is definite need for explicit climate change work with a more traditional insurance-pricing timeline view in mind. Regarding the business-planning aspect, a secondary issue here arises when we consider explicitly what time horizons are appropriate. From discussions raised at past industry workshops carried out by the SECTEUR project acting on behalf of the Copernicus Climate Change Project (C3S), it is generally believed that the maximum forward looking timescale for appropriate business planning lies at around 10 years (Caron 2017). Longer than this and views of the risk become too abstract and detached from re/insurance practices and strategies that change on an annual basis. The re/insurance industry has contributed to studies related to climate change impacts, to be described later in this chapter, but to date they have been exploratory in nature.

In conclusion to this section, it can be seen that there are many complexities introduced by market dynamics, operations, and business practices that must be taken into account when building the most appropriate view from which to price risk. Although it is hoped that some of the drivers of pricing variability have been elucidated, it is clear that the already complex task becomes even more complicated for risks originating from a background climate that is inherently non-linear and ever-changing. The next section will briefly introduce the traditional framework that has traditionally been used for pricing risk, before it progresses to describe the reasons for, and evolution of, the growth of the catastrophe modeling industry.

1.2 An Introduction to Actuarial Pricing

An insurance entity can loosely be envisaged as having three main components (although a number of other vital functions also exist):

- An actuarial department, in which risks are given a technical price and appropriate financial reserves are calculated.
- An underwriting department, in which risk selection is made, the final price is quoted, and business is written.
- A claims department, in which claims management takes place should deleterious events occur.

Of paramount significance to the understanding of issues of importance to the re/insurance industry is a comprehensive understanding of the interface between the actuarial departments of re/insurance companies, and the research centers that control and produce scientific hazard data.

Actuarial science has a long and storied history, establishing itself shortly after the first published work on probability theory (Huygens 1657). Edmond Halley's "life tables", in which he devised appropriate premiums for life annuities based upon the historical probability of mortality given a person's age (Halley 1693) have provided the blueprint for actuarial science ever since.

Still today, actuaries use mathematical methods to analyze past claims and relevant risk data to build up a representative view of probabilities of loss from which to calculate appropriate premiums. These methods often rely on building ideas about the distribution of losses and perils in order to accurately capture the likelihood of events happening.

However, within the past 30 or so years, the industry has begun to reassess the appropriateness of some of these methods for risks that have not necessarily occurred before, or that have the potential to cause catastrophic losses given the changing demographics, wealth, and insured assets of societies that have the potential to be impacted. A comprehensive evaluation and pricing of tropical cyclone risk, specifically, out to the probability required by many regulators (e.g. 1 in 200 years), would ideally utilize a record much longer than the length of the historical Atlantic hurricane record (HURDAT2), but traditional pricing methods – typically constrained by purely historical data – are somewhat limited in their ability to overcome these issues.

Ideas for progress on these concerns were originally hinted at in decision and policy papers (e.g. Kunreuther and Miller 1985), but did not fully materialize in a very practical way until the foundation of the catastrophe modeling industry in the late 1980s and early 1990s.

1.3 From Actuarial Pricing Models to Hurricane Catastrophe Models

The first catastrophe modeling firm, AIR Worldwide, was founded in 1987 and introduced the re/insurance industry's first catastrophe model devoted to Atlantic tropical cyclones. RMS, a company first established with a focus on earthquake modeling, soon followed in 1989. In the 30 years that followed, other firms and data providers have strived to enhance industry practices through the use of catastrophe models.

During the infancy of catastrophe models, the re/insurance industry, recovering from the 1989 Loma Prieta earthquake in California, primarily focused its attention on natural hazard risk from earthquakes. That focus quickly shifted in 1992 when Hurricane Andrew became a major catastrophe for the re/insurance industry.

Following a long stretch of quiet Atlantic activity, the industry was overwhelmed from a lack of preparedness for such a severe hurricane loss. In the wake of Andrew's devastation, nine companies became insolvent (Towers Watson 2013), leading to a demand for comprehensive hurricane modeling solutions.

Andrew served as the catastrophe modeling industry's first major opportunity to learn from a real-time hurricane and helped define the present-day hurricane model framework. Discoveries from subsequent hurricanes have inspired expanded functionality. While Andrew and other landfalling hurricanes in the 1990s predominantly caused property damage with high winds, a number of hurricanes making landfall in the 2000s, including Ivan, Katrina, Ike, and Sandy, highlighted the importance of capturing loss associated with storm surge. Destructive storm surges caused by these events revealed difficulties in distinguishing between wind and surge damage in the settlement of insurance claims covering only wind damage. Even further still, Hurricane Harvey in 2017 demonstrated that a hurricane's main source of damage could be rainfall-induced inland flooding, rather than the more traditional sources of wind or storm surge. With each event, catastrophe modeling firms expand their archives of data that serve to calibrate, validate, and expand model functionality.

A considerable amount of external oversight ensures the scientific credibility of commercially available hurricane models, particularly in Florida, a U.S. state subject to high annual hurricane risk where insurance rates often permeate political discourse. As discussed previously, an insurance regulator seeks to protect a policyholder through key considerations. The Florida Office of Insurance Regulation (OIR) in part seeks to achieve this goal by relying heavily on the expertise of the FCHLPM to evaluate hurricane risk. Established in 1995, in response to the industry's adoption of hurricane catastrophe models following Hurricane Andrew, the FCHLPM sets standards to rigorously evaluate model methodologies used to calculate insurance premiums. FCHLPM rigorously reviews model methodologies and revises its standards by which it evaluates hurricane catastrophe models every two years. These revisions lead to a regular cycle of frequent updates that ensure a model's timeliness. For model vendors, FCHLPM standards are not mere suggestions; the Florida OIR requires that insurance companies use a catastrophe model certified by FCHLPM when filing insurance rates. Insurance regulators in other hurricane-prone states also survey catastrophe models for robustness but largely rely on the stringent FCHLPM process as an indicator of a model's capability.

In the years after Hurricane Andrew, the use of hurricane catastrophe models became standard practice for most of the re/insurance industry. The industry would not see such devastating losses again until the active 2004 and 2005 hurricane seasons. RMS calculates that insured losses from the 2004 to 2005 hurricanes, trended to 2017, total more than two times the insured loss incurred during Hurricane Andrew, trended in the same manner. However, only one insured company failed under the weight of these losses (Grace and Klein 2009), demonstrating the powerful impact of models on the re/insurance industry's catastrophe preparedness.

1.4 Contemporary Catastrophe Modeling

A vast majority of catastrophe models – whether built for hurricanes, earthquakes, or other perils – follow the same basic framework and include the same components, as illustrated in Fig. 1.2 below.

Each model contains "stochastic" events (1) – a suite of thousands of simulated, physically realistic events designed to expand upon a limited historical data record. This step effectively attempts to negate the aforementioned issue of a short historical record, as the historical record does not provide enough years to sufficiently calculate return periods required by re/insurers and regulators. An important point to note here is that, although the Atlantic hurricane record is shorter than would be ideal, it is much longer and more robust than any other tropical cyclone record for any other basin worldwide; in actuality, HURDAT2 is likely by far the most comprehensive historical record of any natural climate peril that has potentially catastrophic impacts for the re/insurance industry. Thus, these techniques are applicable, and often deemed necessary, for many other extreme perils.

Thus, modelers use statistical techniques to extrapolate the historical record, generating a set of stochastic storm tracks from genesis to lysis with similar characteristics and parameters to past hurricanes. Stochastic storms realistically fluctuate in strength with changes in sea surface temperature while over water and weaken while over land. The modelers' aim is to represent the full distribution of hurricanes that could realistically occur, including hurricanes of intensity or landfall location that have yet to occur.

In catastrophe modeling, "hazard" (2) refers to the means by which a stochastic event can cause damage to each location in a re/insurance portfolio. Commercially available hurricane models measure hazard in the form of high winds, at a minimum, but some also measure storm surge and rainfall-driven flood depths. Much like stochastic track modeling, hazard modeling creates a realistic wind field for each stochastic event based upon observed relationships of parameters (e.g. maximum wind, radius of maximum wind, shape parameters) that defined historical wind fields. As a stochastic event's wind field crosses over land, models approximate wind speeds experienced at the surface through the consideration of man-made or natural friction. This translation occurs at grid cells that span the entire over-land

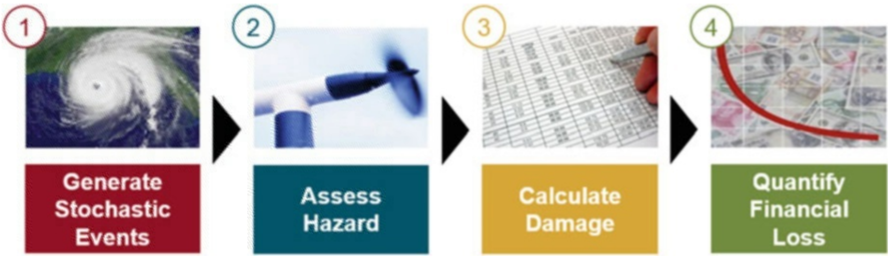

Fig. 1.2 Typical catastrophe model framework. (Image provided by RMS)

domain. Data identifying the local and upstream land use and topography at each cell can inform modelers on the degree to which surface winds should slow down or accelerate, relative to speeds at upper levels. Thus, models can assign surface winds incurred at each property within a re/insurer's portfolio.

Among the commercially available hurricane models, hydrodynamical or statistical modeling evaluates the buildup of storm surge caused by a hurricane's wind stress. Ground elevation and local flood defense data helps define the extent of storm surge inundation as water crosses the shoreline. Model users can further enhance storm surge modeling with property-specific flood mitigation information (e.g. stilts or sea walls).

The susceptibility to property damage caused by a specific hazard is commonly referred to as a structure's "vulnerability" (3), which varies at each property according to its underlying structural components. The most common components that determine a building's vulnerability include:

- Construction type: The material used to construct the building's exterior (e.g. wood, concrete), including possible reinforcement. During hurricanes, concrete and steel buildings tend to perform better than wood and light metal buildings.
- Occupancy type: The building's primary use (e.g. residential, commercial, industrial), used to indicate the predominant type and sensitivity of contents stored within the building.
- Number of stories: The building's height. For example, taller buildings tend to be built to rigid structural standards.
- Year of construction: A building's date of construction typically indicates the standards to which it was built, as catastrophe modelers document historical changes in local and regional building codes over time.
- Floor area: The size of the building's physical footprint. Larger buildings typically tend to be built to better standards than smaller buildings.

Catastrophe models contain relationships, typically stored in "vulnerability curves," that relate wind speeds and storm surge depths to average damage levels, and an uncertainty around that average, for combinations of the aforementioned components.

A number of data sources inform the vulnerability curves embedded within catastrophe models. In some countries and regions, modelers have collected insurance claims that represent billions of dollars in insured losses from past hurricanes. These claims, when used in conjunction with reconstructions of historical hurricane wind and storm surge fields, serve as the "gold standard" in building vulnerability curve relationships. In areas where insurance claims may be unavailable, engineering studies and building codes provide indications of expected amounts of damage.

Although an increasing volume of claims data collected across a number of past hurricanes and varying wind speeds can improve the accuracy of a vulnerability curve, the robustness of damage estimates relies upon the catastrophe model user's understanding of each building. In general, a more complete account of every structure at risk increases the damage estimate accuracy. In some cases, users collect detailed structural data from engineering reports, including features installed to mitigate hurricane damage (e.g. wind shutters, wind-resistant glass panes).

In a final step, financial algorithms translate damage levels into loss (4) incurred at each property and accumulate this loss for the entirety of a company's insurance portfolio. This final step produces a loss distribution, one for each stochastic event, for every property in an insurance portfolio.

These losses constitute a loss distribution, called an exceedance probability (EP) curve, that defines the probability of annual catastrophe losses exceeding loss thresholds. These distributions can define loss probabilities associated with a single event or multiple events in a given year.

Several risk metrics that insurance and reinsurance companies use in their business processes are drawn directly from EP curves. These metrics include:

- Average annual loss (AAL) – the expected value of the loss distribution or, in other words, the average expected loss per year to an asset over the long term. The AAL is frequently used in pricing algorithms that calculate the policy premium charged by an insurer. Since the AAL represents only an average, the actual annual losses will fluctuate around this value in any given year, including years with no losses whatsoever.
- A return period, which corresponds to a point on the EP curve, relating a financial loss to its probability of exceedance in a single year. Each return period is defined as a number of years that is the reciprocal of each loss probability. For example, a 10-year return period corresponds to a loss with a 10% probability of exceedance in 1 year, a 100-year return period with a 1% probability, and a 1000-year with a 0.1% probability. The larger the return period, the higher the loss. These long return periods typically indicate losses to a company's portfolio caused by the severest of catastrophes.

To construct an exceedance probability curve, a catastrophe model must define the likelihood with which stochastic events and their associated losses are expected to occur over time. Loss metrics highly depend on how often events are expected to occur. For example, a loss distribution's AAL would be expected to increase with an increase in hurricane frequency: more landfalling hurricanes each year would increase annual re/insurance losses. Thus, event frequency plays a critical role in the output of a catastrophe model and the use of this output by the insurance industry in business decisions.

1.5 Building a View of Atlantic Hurricane Frequency Risk

Choosing the most appropriate view of hurricane event frequency, however, perhaps remains one of the most contentious and debatable issues in catastrophe modeling. A limited, uncertain history and a continually changing climate open up a number of possible ways to represent frequency risk.

An examination of historical hurricane observations over the past century or more reveal periods lasting up to a few decades of Atlantic basin hurricane frequency higher and lower than the historical average (Goldenberg et al. 2001). The 2004–2005 seasons remain notable in the insurance industry not only for their catastrophic losses, but also for calling the re/insurance industry's attention to the heightened state of Atlantic hurricane activity in the late 1990s and early 2000s. As mentioned earlier, the industry began adopting catastrophe models in the final years of a prolonged period of below average Atlantic hurricane genesis and landfalls.

Up until 2004–2005, catastrophe modelers offered only one view of event frequency in hurricane models: a long-term, historical average. However, this average ignores potential medium-term and multidecadal trends in hurricane activity that may well be of significant interest to re/insurers due to the previously mentioned desire for an outlook that covers the period approximately 5–10 years ahead. Therefore, there is demand for models to consider this multi-annual variability in hurricane frequency.

Multiple theories within the peer-reviewed literature, sometimes conflicting, attempt to connect climatological influences with fluctuations in the mean frequency state. The literature most commonly ties multidecadal trends in cyclogenesis to influence from sea surface temperatures and the Atlantic Multidecadal Oscillation (Goldenberg et al. 2001; Sutton and Hodson 2005), but research describing their impact on hurricane steering and landfall patterns remains less mature (Wang et al. 2011; Kossin 2017). Hindsight allows for modelers to draw correlations between climate indices and historical frequency fluctuations, yet uncertainty exists in forecasting and anticipating future fluctuations (Klotzbach et al. 2015). Less certain are the potential impacts of longer-term climate change on hurricane frequency and severity (Landsea 2005; Emanuel 2005; Webster et al. 2005; Hoyos et al. 2006; Mann and Emanuel 2006; Knutson et al. 2010).

This section will thus focus on summarizing current approaches and debates ongoing within the insurance and catastrophe modeling industries surrounding this topic, in the hope that it will enable the scientific community to become better aligned in order to have direct impacts to these modes of thinking.

1.5.1 Long-Term View

A long-term view represents the viewpoint that current risk can reasonably be assumed stationary, operating around a mean frequency calculated from a significant period of the historical record. This behavior is defined as the observed average of hurricane landfall position and intensity over the most reliable period of past hurricane data. Modelers will commonly count historical hurricane landfalls and intensity in segments of less than 100 miles that divide a country's coastline. A long-term view of frequency risk is calibrated and validated on the resulting landfall distribution.

A vast majority of models construct this average from HURDAT2 data (Jarvinen et al. 1984; Landsea and Franklin 2013) beginning in 1900, a point at which confidence in hurricane landfall information significantly increases. Thus, a long-term view is built from over 100 years of available storm track and intensity data. Confidence in open-water hurricane data in the North Atlantic basin does not extend back as far and begins with the advent of aircraft and satellite reconnaissance in the 1950s and 1960s.

As the HURDAT2 database typically provides historical hurricane intensity measurements in six-hourly increments, track points rarely coincide with a storm's landfall. At present, HURDAT2 assigns specific landfall intensity measurements to only a subset of historical storms. This opens up a number of potential methods of determining the intensity of a tropical cyclone as it crosses a landfall segment. Common methods include drawing from the six-hourly observation point prior to landfall or an interpolation of the observations before and after landfall. A hurricane catastrophe model must also include the loss contribution of bypassing storms (those that cause damaging onshore winds but do not physically make landfall) to capture the full distribution of possible hurricane losses. A modeler's choice in intensity measurement therefore plays a critical role in understanding the construction of a long-term frequency view.

As mentioned previously, although one of the more robust historical datasets available across any geography and peril, a distribution of hurricane landfall location and intensity constructed from the HURDAT2 record cannot represent a complete view of current or future landfall risk. For example, in the United States, parts of the coastline exist where no past hurricanes have historically made landfall, and counts become sparser with increasing intensity. Calibrating a long-term view of the future solely on the historical record introduces potential overfitting to data; a segment with no recorded landfalls since 1900 remains at risk to a future landfall. Modelers therefore use varying techniques to spatially distribute regional landfall counts in a manner that preserves relative risk by segment but also assigns risk to segments with no historical landfalls. Stochastic events in a hurricane model are tuned to occur with a frequency to meet this final distribution.

As an average over this relatively long period, long-term projections of frequency risk and insured loss should not change significantly (i.e. a few percent) annually on a national or regional basis with the additions of future seasons to the record. Some in the insurance industry appreciate the relative stability provided by a long-term view as the historical record expands with time based on the perceived business benefits it can provide, as mentioned previously in this chapter.

1.5.2 Near-Term View

That being said, there are others that believe that varying their view from this long-term history is more likely to capture the potential activity of the near future. This has