Catastrophe Modeling for Climate Hazards: Challenges and Climate Change

By: Steve Jewson, Celine Herweijer and Shree Khare, Risk Management Solutions.

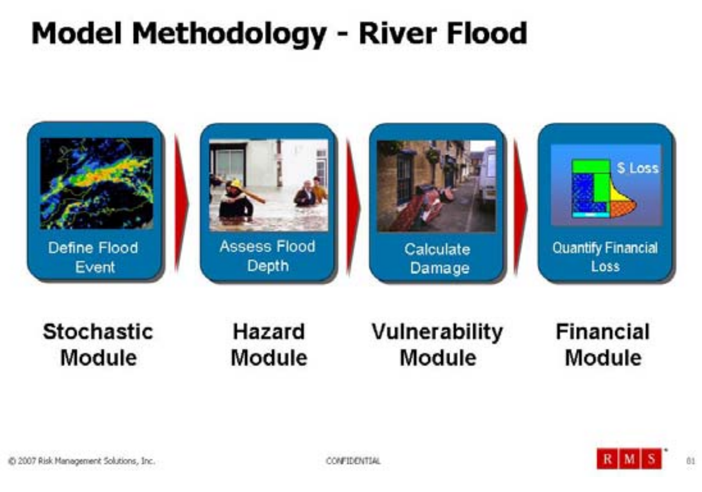
Introduction

Catastrophe Modeling is the science of making probabilistic predictions of financial risk due to natural and non-natural catastrophic events. Catastrophe (Cat) Modeling has developed almost exclusively in the private sector, driven by the needs of financial institutions such as insurers and reinsurers to understand and quantify their risk. It is currently both a hundreds of millions of dollars industry, and an innovative and exciting area of scientific research. From its start in earthquake modeling in the 1980's, it soon expanded to include hurricanes. It has now covers a wide range of perils, including winter storms, severe convective storms, floods and non-natural catastrophes such as terrorism and pandemic flu. Cat modeling companies today employ more PhDs than many academic departments, and hire dozens of academic consultants from a wide range of disciplines. In this short article, we describe cat modeling from the point of view of the world's leading cat modeling organization, Risk Management Solutions. We begin by reviewing the goals of cat modeling, describe the basic methodologies, and then discuss some of the particular challenges of modeling climate hazards. Finally, we discuss how climate change is relevant to cat modeling.

The current state of the art in cat modeling

The basic goal of cat modeling is to produce probabilistic predictions of future losses to property from catastrophic events, for both individual properties, of any type, and for portfolios of properties, however large. The basic structure of cat models takes an event-based approach to modeling. That is, the core of most cat models consists of a simulated set of events occurring with some specified annual rate. This approach is more or less essential in order to capture the details of the dependency structure between losses at different locations that is created by the physical structure of the catastrophic events themselves. Cat models are typically structured into various components, such as a rates module that simulates appropriate numbers of events over a specified length of time, a hazard module that simulates the events themselves, a vulnerability module that derives loss ratios from hazard values and engineering principles, and an exposure module that captures the exposed properties (Figure 1).

Figure 1: Typical components of a cat model – the example of flood.



To achieve their goals, cat modellers use a wide variety of tools designed to suit the particular task at hand. Most models use an appropriate combination of statistical and dynamical (derived from physical laws) modeling methods. The statistical modeling methods used include classical statistics, non-parametric statistics, and Bayesian statistics where appropriate. Methods such as Principle Component Analysis, time-series analysis, regression, kriging, Bayesian filtering, Bayesian networks, Bayesian decision theory, shrinkage and low-discrepancy simulation methods are commonly used. The dynamical modeling methods used typically include hydrological runoff models, computational fluid dynamics models, shallow-water equations, atmospheric boundary layer models, mesoscale atmospheric models, atmospheric general circulations models and coupled climate models. One of the most important skills in building a cat model is in the judicious use of these different modeling methodologies to answer the problem at hand, at the resolution being modelled.

Difficulties and Challenges in Weather Related Cat Modeling

To illustrate exactly where effort is being spent in the development of today's cat models, we now list 10 key challenges that we see in weather-related cat modeling (the effects of climate change will be discussed in the following section).

1) <u>Accurate representation of uncertainty</u>

Baysesian statistics can be used in a rather straightforward manner to quantify and understand the uncertainty around model parameters and the impact that has on losses. Some parameters are well estimated, and others are rather poorly estimated. Some affect losses at short return periods, while others affect losses at longer return periods. Additional challenges include how to quantify hazard uncertainty, and even more challenging is the quantification of uncertainty driven by model choice. To address such issues, cat modeling is starting to move in the same direction as climate modeling, with multiple models and multiple versions of models being developed.

2) <u>Modeling loss amplification</u>

Cat modeling started as a local calculation: given a certain wind speed at a location, it was assumed that the distribution of possible losses for a building at that location could be calculated. In recent years, and especially following hurricane Katrina in 2005, it has become abundantly clear that the total loss from very large catastrophic events can only be modelled by considering a number of additional factors, such as demand surge, risk and cost associated with evacuation, sociological factors and risk and costs associated with political interference in the insurance process. These factors can only be modelled using combinations of economic and sociological modeling.

3) <u>Data</u>

Relative to what cat modellers would ideally like, the network of surface observing stations is not necessarily adequate, the principle problem being geographic coverage. Another problem is consistency, even within a single country, wind speed measurements may be taken in many different ways. One challenge is therefore to combine measurements in such a way as to make the best use of what is available. One response to the lack of data is that cat modellers themselves are now setting up their own networks of measuring stations to supplement those available from government agencies and universities.

4) <u>Extracting information from loss data</u>

Whereas surface weather observations during extreme events are typically very sparse, observations of loss, almost by definition, are often very extensive. If used correctly, loss observations can be a mine of information. In development of cat models, loss data could be exploited by formulating and solving a filtering / data assimilation problem with non-linear and unknown transfer functions. In the next decade, significant efforts will put forth into trying to decode this information to tell us more about the detailed structure of wind fields, especially for smaller wind events such as tornadoes.

5) <u>Understanding and predicting decadal and interdecadal variability</u>

The occurrence rates and intensities of many weather-related perils vary on multi-year to decadal multi-decadal timescales. Driven by the needs of their clients, cat modellers today are primarily interested in quantifying risk in the next 1-5 years. In academic realms of atmospheric science / geophysical fluid dynamics, the emphasis is on understanding and modeling of the phenomena. In cat modeling, the emphasis is on trying to produce a reasonable prediction, whatever the current level of understanding. This is particularly difficult in two instances: prediction of tropical Atlantic sea surface temperatures which influence hurricanes, and north Atlantic circulation patterns which are related to storm activity over Europe.

6) <u>Avoiding overfitted models</u>

In cat modeling, the emphasis is on prediction. In order to make accurate predictions, it is necessary to ensure that statistical models are not overfitted to observations. Early generation cat models were overfitted, and thus represented historical data very well but had poor forecasting performance. The danger of overfitting is very high in cat models, because of their large numbers of parameters, and the small amounts of available data. There is a current trend, therefore, towards models that are built very rigorously to avoid overfitting in statistical components. Such methods are computationally intensive, and have only recently become feasible.

7) <u>Modeling the infinite variety of building types</u>

No two buildings are the same in every detail. This makes the modeling of building vulnerability difficult. State of the art cat modeling of the vulnerability of buildings combines both empirical data from past catastrophic events with engineering and physical models of the performance of buildings and building components under different forms of stress. The challenges in this are in trying to extract the most information from empirical data, without oversmoothing, and in building physical models of building performance that are consistent with real data and represent the observed variability between different building types accurately.

8) <u>Modeling the correlations between perils</u>

At some level, hurricane and winter storm activity are not entirely independent. In current day cat models, it is a challenge to understand and model such weak correlations.

9) <u>Modeling at sufficient resolution</u>

Ideally, cat models would capture the effect of kerb stones on flood waters and adjacent buildings on local wind speeds. Currently, that level of detail is a long way off. The challenge, then, is to model at sufficient resolution to capture the most important factors that determine flood depths and wind speeds at individual locations, even if many details must be ignored.

10) <u>Modeling turbulent processes in the atmospheric boundary layer and other weather-related perils</u>

Atmospheric boundary layer flows are turbulent, in part arising from the interaction of air flows over the rough earth surface. Appropriate parameterization of such turbulent flows using statistical and physical models is a challenge. While the focus of the discussion above has been on loss due to wind, weather-related perils can generate loss from rain, snow, freeze and hail. The challenge is to build accurate models of these additional perils, and quantify the relative contributions to a given loss.

The Effects of Climate Change

Anthropogenic climate change means that for some climate perils, and for some regions, the frequency and/or intensity of events is changing the hazard. For catastrophe modelling, this means that so-called statistical stationarity will not necessarily give the best representation of the real-time risk. As such, leading catastrophe modelling firms today look for where clear long-term trends in climate signals can be observed, and determine how best to adjust the models from the long-term baseline. Methodology differs from peril to peril in accordance with the observed trends in the relevant datasets of principal climatic drivers for a particular peril (e.g. precipitation and temperature for flood; storm tracks, temperature and wind for winterstorms; hurricane activity, sea surface temperatures and wind shear for hurricanes). Adjustment or no adjustment, each climate peril model in each region is considered individually, and a comprehensive literature review and data analysis is involved. This process is repeated whenever models are updated.

Using Catastrophe Models to explore Climate Change in 2020 and Beyond

Whilst the traditional users of cat models – insurers - are primarily focused on the 1-5yr timeframes of underwriting, a surge in the demand to understand climate change impacts in decades to come, has highlighted the potential to use cat models as a tool to explore risk and the financial value of adaptation on these longer timescales. This drive for longer-term risk assessment has come from public policymakers, planners, investors and corporate risk managers. The insurance industry itself, on the heels of nearing disclosure requirements around climate change, and a growing realisation that 20 year plus timeframes do impact upon investment decisions and long-term business sustainability, are also showing interest in such longer term risk analysis.

Climate models of different resolution are used by academics worldwide to explore the range and uncertainty of changes in mean and extreme climate over the coming century and longer. Whilst there are clear limitations in these models (forcing uncertainty, model inadequacy, model uncertainty, theoretical limitations), their value lies in understanding the ramifications of the broadest changes both for society and for spurring effective climate change policymaking aimed at mitigating rising greenhouse gases.

The science of linking climate models together with impact models is relatively young, yet already in high demand given the value of the output to increasingly aware decision making. Catastrophe models can be viewed as one such impact model, and academics and cat modelers are increasingly working together to achieve this.

By adjusting the stochastic event set and hazard module to represent the range of projections from climate models, we have a window into what future risk and associated losses may be. The output of a climate model is translated into the output of a cat model, enabling us to address different questions than a climate model can address. This can be achieved through stress testing the cat models with different scenarios, or by incorporating probabilistic climate model output. The granularity of the cat models can be used to explore impacts to particular geographies and infrastructure types. Vulnerability modifiers can be applied to investigate the most effective ways of minimizing future risk given future hazard. However, the limitations of interpreting climate model output for 2020 and beyond apply, as do the limitations of cat models outlined above. Nevertheless, there is a clear value to communicating climate change impacts in the language that risk managers across finance and government use to analyse risk today – cat modelling.

With growing demand for such output there are clearly many exciting opportunities for partnership between the insurance and cat modelling community and the climate modelling community.   Building climate change into cat models can be achieved in a myriad of ways. Determining which is best, is where the challenge lies.