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The Use of Computer Modeling in Estimating and Managing Future Catastrophe Losses

by Karen M. Clark*

Overview

Over the past two decades, the use of computer modeling to estimate future losses from natural catastrophes has gone from being virtually unheard of to being the standard global risk assessment technology. This is primarily the result of the unprecedented and unexpected losses sustained by insurance and reinsurance companies from actual catastrophe events, most notably the series of winter storms that struck Europe in 1990, Hurricane Andrew in 1992 and the 1994 Northridge Earthquake. By the mid-1990s it was apparent to all that the catastrophe loss potential was far greater than had previously been thought possible, even though some computer models available much earlier had been providing loss estimates well in excess of the losses sustained from Andrew and Northridge. However, these larger loss scenarios were not taken seriously by most in the industry without the actual occurrence of a major loss-producing event.

Today, catastrophe modeling is used extensively for pricing, risk selection and underwriting, loss mitigation activities, reinsurance decision-making and overall portfolio management. This paper presents a history of catastrophe modeling technology and an explanation of how catastrophe models work. It also reviews recent advances in catastrophe modeling and concludes with a discussion of how insurers and reinsurers can derive maximum value from this technology.

The author also hopes to dispel some of the common misconceptions about catastrophe modeling technology, which include:

- Catastrophe modeling was invented in response to Hurricane Andrew;
- Catastrophe models are "black boxes";
- All catastrophe models are the same so it doesn't matter which one I use;
- I can only use a catastrophe model if I have very high quality, detailed exposure data;
- If I have already received a probable maximum loss (PML) estimate (from my broker or reinsurer, for example), then I do not need to use a catastrophe model "in-house".

History of catastrophe modeling technology

Insurance companies are well equipped to manage the potential losses associated with claims from individual fires and automobile accidents. There exists a wealth of historical data

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associated with such losses that enable actuaries to determine, with a high degree of confidence, what future losses are likely to be. The relative infrequency of catastrophe events, however, and the resulting scarcity of historical loss data make it virtually impossible to reliably estimate potential future catastrophe losses using standard actuarial techniques. Before the advent of catastrophe modeling, underwriters had to rely on rule-of-thumb formulas to calculate PMLs, or on "guesstimates" of what losses could be from a few subjectively derived deterministic scenarios.

In the years immediately preceding Hurricane Andrew (1992), the prevailing wisdom within the insurance industry was that the largest possible insured loss from a single hurricane might be $7 billion, a figure suggested by an AIRAC publication.[1]

This was so despite the fact that in 1987, Applied Insurance Research (AIR) introduced to the insurance industry for the first time a fully probabilistic catastrophe model capable of providing credible, scientifically-based loss estimates for thousands of potential scenarios representing the complete probability distribution of losses. These probabilistic estimates clearly showed that the industry could experience $20 to $30 billion dollar hurricane losses with a reasonably significant probability. Furthermore, as Hurricane Andrew made landfall on the coast of south Florida, AIR produced "real time" loss estimates indicating that this single event could cost the insurance industry in excess of $13 billion. It took several months for the industry to realize that they would, in fact, pay out losses of this magnitude.

As a result of the losses from Hurricane Andrew, which turned out to be over $15 billion, catastrophe modeling started to take hold. *Even though catastrophe modeling technology was available to companies well before Hurricane Andrew*, it took this event to convince companies that they should be using it.

Since Hurricane Andrew, economic losses from natural disasters have continued to escalate, increasing the demand for effective and reliable risk assessment tools. From 1990 to 1999, total insured losses from natural disasters in the United States exceeded $87 billion according to Property Claims Services. While losses from Hurricane Andrew and the Northridge earthquake make them the costliest natural hazard events ever to have affected the United States, total losses from the 1995 Great Hanshin (Kobe) earthquake are estimated at over $100 billion, making that the costliest natural disaster worldwide. More recently, the winter storms of 1999 that swept across Europe caused damage in excess of $17 billion according to Swiss Re.

The chart below shows worldwide catastrophe losses over the past three decades. When viewing this chart, it is important to recognize that the significant increases over the past several years are not due to an upward trend in the frequency or severity of natural hazard events, but rather to increasing concentrations of population and property values in hazard prone areas. Also, the decades of the 1970s and 1980s experienced a relative lull in major events, particularly severe windstorms.

As losses continue to mount, insurers and reinsurers have become acutely mindful of the need to assess accurately their catastrophe risk. As a result, catastrophe modeling technology is now used by almost all reinsurers around the world, by most primary insurers in the United States, and by an increasing number of primary insurers outside the United States. Along with AIR there are two other globally recognized catastrophe modeling companies, Risk

[1] The Insurance Research Council, formally known as The All-Industry Research Advisory Council (AIRAC), *Catastrophic Losses – How the Insurance System would Handle Two $7 billion Hurricanes*, November 1986.

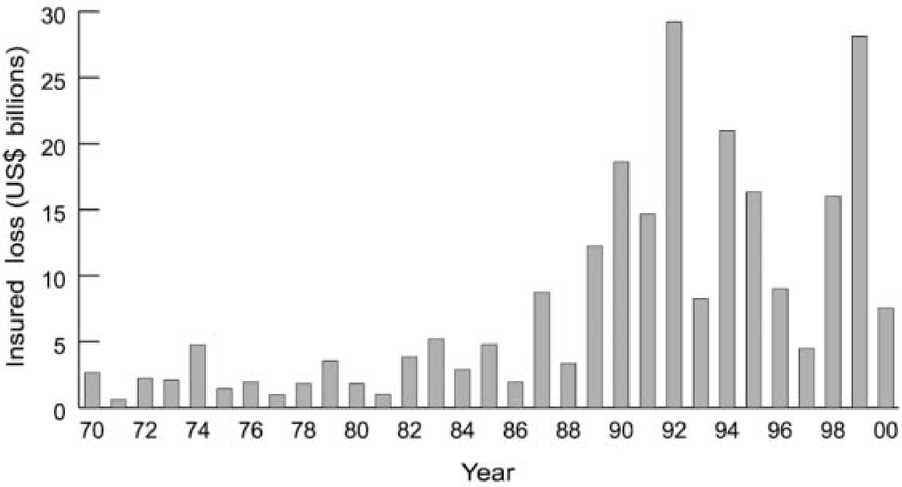

Figure 1: Annual insured losses from natural catastrophes worldwide, 1970–2000 (US$ billion, 2000 prices)

Management Solutions (RMS) and EQECAT, that serve the worldwide market for catastrophe risk management products and services.

How catastrophe models work

By combining mathematical representations of the natural occurrence patterns and characteristics of hurricanes, tornadoes, severe winter storms, earthquakes, and other catastrophes with information on property values, construction types, and occupancy classes, these simulation models provide information to companies concerning the potential for large losses *before* they occur. That is, the purpose of catastrophe modeling is to anticipate the likelihood and severity of potential future catastrophe events so that companies can appropriately prepare for their financial impact.

In view of the limitations presented by the historical data as previously discussed, catastrophe modelers have developed alternative methodologies, based on sophisticated stochastic simulation techniques, that are designed to produce a complete range of potential annual aggregate and occurrence loss experience from natural catastrophes. The resulting models are actually computer programs that give mathematical representation to the physical phenomena of catastrophe events. The primary components of the catastrophe risk analysis model are illustrated below.

Event generation

This first model component addresses the hazard itself and answers the questions of where the events are likely to occur, how large or severe they are likely to be, and how

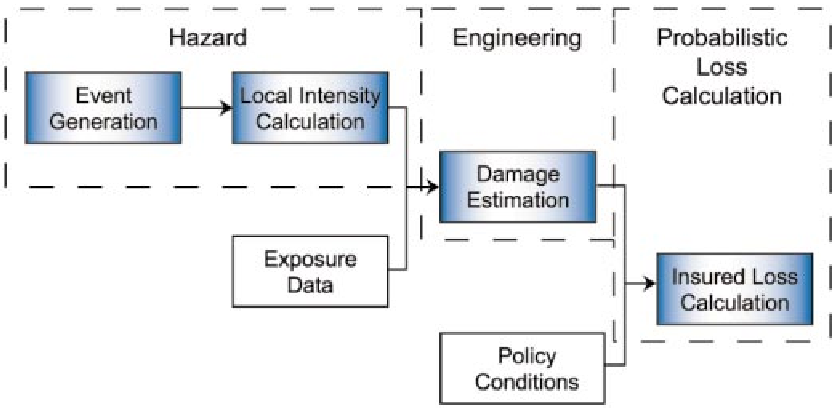

Figure 2: Catastrophe model components (shaded)

frequently they are likely to occur. Most catastrophe modelers employ their own internal staffs of scientists, including meteorologists, seismologists, and geophysicists, who combine their knowledge of the underlying physics of natural hazards with the historical data on past events.

Using a deterministic approach to estimating potential catastrophe losses, one might ask, for example: what would losses be today from a repeat of the 1923 Great Kanto earthquake in Japan? Or of Daria, the winter storm that caused significant losses in the United Kingdom and continental Europe in 1990? It is interesting to speculate on these questions and catastrophe models are, in fact, well equipped to provide reliable loss estimates in response.

As intriguing as such questions are, however, we also know that an exact repeat of these or other historical events has near zero probability of occurrence. Perhaps a more interesting question, then, is: what would losses there have been had Daria taken only a slightly more northerly course than it did and swept directly across London, much as winter storm Lothar roared through Paris in late 1999? What about a "Super Daria" that is more intense and larger than the real Daria? There are many more scenarios that one might imagine.

This is exactly what the event generation component of catastrophe models is designed to do: generate all types of possible, yet realistic, scenarios. Furthermore, because these events are being generated using high-speed computers, many thousands of potential events can be simulated in accordance with their relative probability of occurrence. Detailed scientific analyses are performed on the historical and geophysical data to develop the probability estimates. Through this large sample, or catalog, of simulated events, the event generation component determines the frequency, magnitude, and other primary characteristics of potential catastrophe events by geographical location.

Local intensity calculation

Once the model *probabilistically* generates a potential future event, it propagates the event across the affected area. For each location within the affected area, local intensity (e.g. wind speed, ground motion) is estimated. In this component as well as in the event generation component, detailed scientific and geophysical data and algorithms are employed to model the local effects of each simulated event.

For example, windstorm models use high-resolution digital land use/land cover data to calculate surface frictional effects. Estimates of surface roughness dictate, in part, the behavior of ground level wind speeds. Earthquake models employ detailed soil data that provide information about the material properties of the soils through which seismic waves pass. These, in turn, determine the degree of soil amplification and potential for liquefaction at specific sites affected by the event.

Damage estimation

The local intensities of each simulated event are superimposed onto a database of exposed properties, and then the damage estimation component calculates the resulting monetary damage. Intensity may be defined in terms of wind speed, the impact energy of hailstones, the spectral displacement of buildings when subjected to ground shaking, the number and intensity of fires spawned by earthquake, the depth of flood waters, and so on. Mathematical relationships, called damage functions, describe the relationship between the intensity of the event, which varies by location, and the exposed buildings and contents.

Catastrophe modelers also employ experienced engineers who develop damage functions for many different construction types and occupancies for building, contents, and time element loss.

These functions are region specific and reflect a thorough and detailed understanding of local building codes and construction practices. Damage functions provide not only estimates of the mean, or expected, damage ratio corresponding to each level of intensity but, in addition, provide a complete probability distribution around the mean. Because different structures experience different degrees of damage for a given level of intensity, the damage functions need to capture this variability.

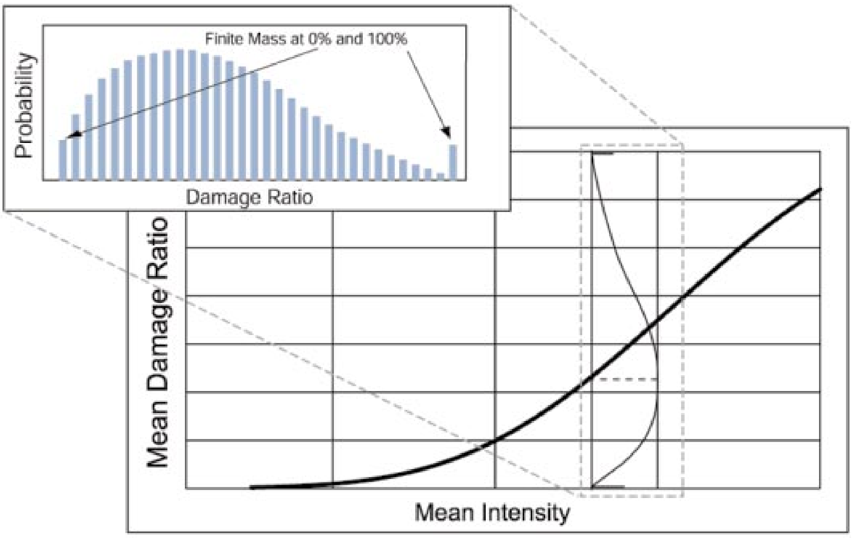

Figure 3: Sample damage function

Insured loss calculation

In this last component of the natural hazard model, insured losses are calculated by applying the specific policy conditions to the total damage estimates. Policy conditions may include deductibles by coverage, site-specific or blanket deductibles, coverage limits and sublimits, coinsurance, attachment points and limits for single or multiple location policies, and risk- or policy-specific reinsurance terms. Explicit modeling of uncertainty in both intensity and damage calculations enables a detailed probabilistic calculation of the effects of policy conditions.

Example: An illustrative exercise might be to examine the modeling process in the context of an actual event. Winter storm Lothar brought havoc to parts of Europe during the Christmas weekend of 1999. On Friday 24 December, AIR meteorologists who monitor global atmospheric and environmental data noticed the unmistakable signs of an impending storm. These data consist of surface observations, satellite data, aircraft reconnaissance data and radiosondes.

By extracting all of this atmospheric data for the region of interest at periodic intervals over the next 24 hours, "snapshots" of the atmospheric pressure field were taken. Each snapshot was used to initialize and run the AIR European windstorm model's event generator in order to produce forecasts of the storm one and two days ahead. One such snapshot taken on the evening of 24 December is shown in Figure 4a below. In it, shades represent wind speeds, the arrows indicate wind direction, and the solid black lines are mean sea level pressure isobars.

These atmospheric data provided the "initial conditions" that were used to evolve the storm in three-dimensional space over time, the process performed in the event generator.[2] The local intensity calculator, using meteorological equations, then estimated ground level wind speeds at each geographical location of interest as shown in Figure 4b.

By applying damage functions developed for each modeled country and for regions within each country to estimated property values, total damages were calculated. Insured losses were estimated by applying country-specific policy conditions. These loss estimates, derived solely from the catastrophe model before the storm had even completed its course, very well represented the actual losses both in terms of magnitude as well as geographic location. The case of Lothar demonstrates that catastrophe models do have the capability to accurately reflect the local intensities and the damages and losses caused by specific events.

Now imagine repeating the process just described many thousands of times, not for actual storms, but for *potential* future storms. By generating a very large sample of potential events, the process becomes probabilistic, rather than deterministic. Maps illustrating one such stochastic event, the potential "Super Daria" described earlier, are shown in Figure 5.

This Super Daria could certainly occur with only small variations in the real Daria's initial conditions and environment. AIR estimates that the insured losses from such a storm could exceed €20 billion, and this is not the worst possible event by far.

The preceding paragraphs have provided a brief overview of how catastrophe modeling technology works. For more detailed descriptions, the catastrophe modeling companies have produced thousands of pages of documentation on the specific models for specific perils and

[2] The event generator in the AIR European windstorm model is based on advanced Numerical Weather Prediction technology that will be described later in this paper.

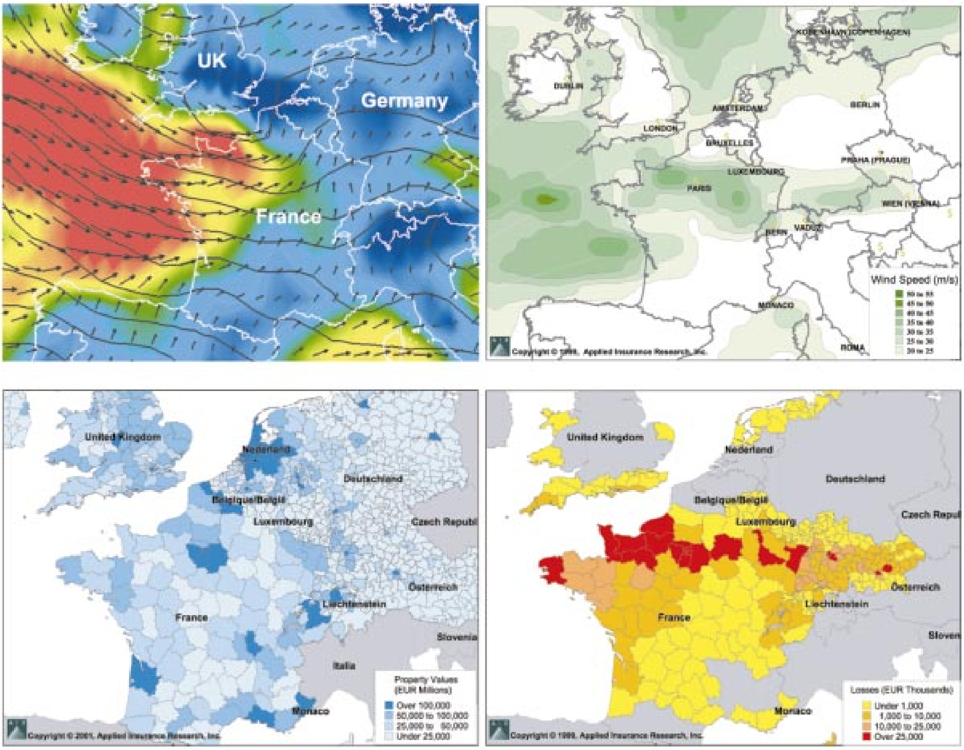

Figure 4: Clockwise from top left, (a) "Snapshot" of pressure field used to initialize event generator for winter storm Lothar; (b) Local intensity calculation; (c) Total property values; (d) Insured loss calculation

regions. This documentation includes explicit scientific formulae, detailed descriptions of analytical techniques, and references for source documents. It is true that it may take a lot of effort for a non-technical reader to understand all of the details underlying the models, but the documentation does exist for those who are interested. The modelers are well prepared to review in detail all aspects of the models with outside entities such as client companies, state insurance departments and rating agencies, *so there is no validity to the claim that catastrophe models are black boxes.*

Model validation: The scientists and engineers who develop the models also validate them at every stage of their development by comparing model results with actual data from historical events. Simulated event characteristics should parallel patterns observed in the historical record and resulting loss estimates should correspond closely to actual claims data provided by clients and other insurance industry sources. In addition to the detailed analysis of actual loss data, the models are also validated and calibrated through the use of extensive post-disaster field survey data.

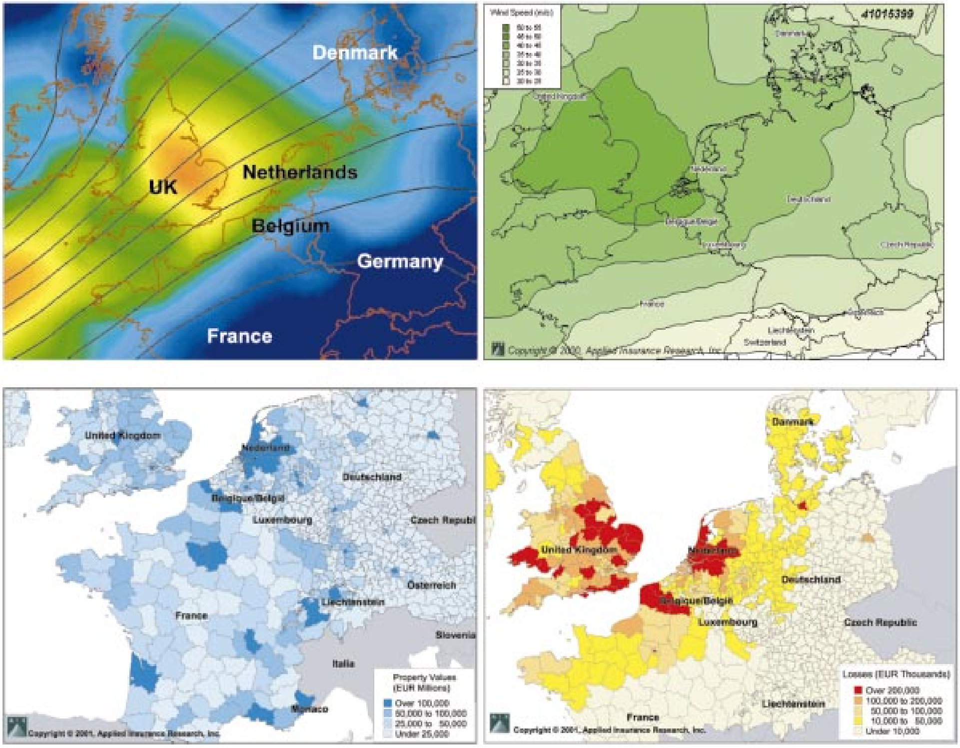

Figure 5: Clockwise from top left, (a) Snapshot of pressure field used to initialize event generator for stochastic winter storm "Super Daria"; (b) Local intensity calculation; (c) Total property values; (d) Insured loss calculation

The models also undergo intensive peer review, both internal and external. Recent years have witnessed a transfer of catastrophe risk to the capital markets through the issuance of catastrophe, or "cat", bonds and investors rely on the research and due diligence performed by the securities rating agencies to make their investment decisions. As part of the due diligence process, the models and their underlying assumptions undergo extensive scrutiny by experts hired by these rating agencies. Detailed sensitivity analyses of the major components of the models are performed, stress-testing each for model robustness.

Recent advances in catastrophe modeling technology

A very important job of the scientists and engineers responsible for developing catastrophe models is to keep abreast of the scientific literature, evaluate the latest research findings, and conduct original research of their own. To achieve the most reliable loss estimates, catastrophe models must be continually updated to incorporate new technologies, research results, and current scientific knowledge in climate science, meteorology, seismology, and wind and earthquake engineering.

Until relatively recently, model updates involved incorporating more recent data and/or fine tuning certain model formulae such as damage functions after actual events. All models produced by the modeling companies were quite similar in structure and design and used the same historical data for model development. The reason for the close similarity is that first-generation catastrophe models are exclusively historical data-driven statistical models, in that the events themselves are simplified by characterizing them using a limited set of parameters, or model variables. The historical data on these event parameters are fit to probability distributions that are used to generate potential future events. Furthermore, the model damage functions are fine tuned and calibrated to actual loss data from recent events.

In 2000 the modeling technology used by the different companies began to diverge in a very fundamental way. In an attempt to reduce the uncertainty associated with the various model components, a *physically-based* modeling technology was introduced. This new technology replaces some of the simplified components of the models that are based on extrapolations of limited historical data, with much more realistic components that embody the actual physics of the events themselves and the damages they cause. With the new technology, events are simulated using physical laws of nature and the equations that embody them. These can much more realistically represent the evolution of the events in three-dimensional space. This is in contrast to the traditional methodology in which events are simulated in two-dimensional space using a relatively small set of parameters.

This means that there are today very significant differences between the models that should be understood and evaluated by their users. The benefit of using a catastrophe model based on the new technology is, of course, reduced uncertainty in the model and therefore higher confidence in the resulting loss estimates. This reduction in uncertainty has already been recognized by various external groups, such as securities rating agencies.

A catastrophe modeling company is not likely to develop a full-scale physical model of a natural hazard internally. Such models are highly complex, and typically require hundreds of man years to develop, as well as a highly specialized supporting infrastructure. What a catastrophe modeler can do is take a physical model that has been developed by the wider academic and scientific community and adapt it to uses required by the insurance industry. The example of Numerical Weather Prediction technology is a good illustration of this.

Numerical Weather Prediction

Numerical Weather Prediction (NWP) technology is used by atmospheric scientists to provide short-, medium- and long-range weather and climate forecasts by dynamically solving the equations that govern the earth's physical systems. NWP has been the focus of decades of intense research conducted by the global scientific community. Billions of dollars have been invested in its development, and NWP is the current state-of-the-art technology used by all of the advanced meteorological agencies around the world including the U.K. Met Office, Météo-France, the European Centre for Medium-Range Weather Forecasts, and NOAA.[3] Now, insurers can benefit directly from this highly advanced weather and climate forecasting technology.

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[3] For more information about NWP, go to the U.K. Met Office's website at www.meto.govt.uk/research/nwp/index.html.

Recent events have demonstrated that European winter storms can cause considerable property damage, much of which is paid by insurance companies. These winter storm systems are typically comprised of multiple areas of relatively low and high pressure, the locations of which can change quickly and frequently. As the storm evolves, the interaction of these lows and highs creates changes in the horizontal pressure gradient field, which, in turn, results in a complex and dynamic windfield. Small differences in the initial conditions that spawn such storms can result in large differences in storm evolution. Given their complex and dynamic nature, these storms are extremely challenging to model.

However, as was seen in the Lothar example, event generation using NWP can capture the initial conditions of a storm accurately, and is then able to realistically evolve the storm over space and time. Using NWP technology, a large set of potential future storms is generated by taking data sets comprising the initial pressure fields of historical storms, perturbing them both temporally and spatially, and moving them forward in time through the application of a set of partial differential equations governing fluid flow. The resulting event set is rigorously tested to ensure that it provides an appropriate representation of the entire spectrum of potential storm experience – not just events of average probability, but also the extreme events that make up the tail of the loss distribution.

Therefore NWP can be very effectively used in the hazard component of a European windstorm catastrophe model. While the investment required to adopt and adapt this technology to the uses of insurance companies is many times larger than the investment required to develop a first generation statistical model of European windstorms, the enormous benefit to insurers in terms of reduced model uncertainty justifies this significant investment.

As was mentioned earlier, the process by which simulated events are generated within other catastrophe models uses extrapolations from a limited amount of historical data. These other models employ a limited number of variables to "define", or characterize, the catastrophe peril. The available scientific data pertaining to these variables are collected, cleaned and verified. Probability distributions are developed for each variable, and these distributions are used to generate the characteristics of potential future events.

Such "parameterized" models perform quite well for many hazards. They do a very reasonable job, for example, of capturing the relatively simple, symmetric structures that characterize hurricanes. They are unable, however, to realistically capture the complex pressure gradient fields of mid-latitude storms, such as the winter storms that cause large losses in Europe. NWP and dynamical weather modeling techniques in which differential equations based on general physical laws replace many of the statistically-based parameterizations are much better suited to capturing the complexity of these types of catastrophe events.

The Advanced Component Method™

Traditionally, catastrophe modelers have estimated building damage from earthquakes based either on some subjective measure of intensity, such as Modified Mercalli Intensity (MMI), or on a single parameter of ground motion, such as Peak Ground Acceleration (PGA). But the effects of ground motion on the structural characteristics of individual buildings cannot be captured using a single ground motion parameter as an index of intensity. Using PGA, for example, implicitly assumes that, for all buildings, the top of the building moves exactly in unison with the bottom, that is, like the ground itself. While this may be a reasonable approximation for rigid, low-rise buildings, it provides a misleading picture of how other building types and portfolios of buildings will move and deform in response to the ground motion they experience. In other words, knowing how the ground moves during an earthquake gives only a partial picture of how buildings move (and deform) in response to that ground motion. Most earthquake models fail to predict the wide variation of damage that is observed in the aftermath of actual earthquakes. It is this "selectivity" of damages caused by earthquakes that ACM™ is designed to capture.

The ACM methodology is summarized in the figure below. Building types typical of each modeled region are identified and their general configuration and characteristics are defined. Local design firms are enlisted to ensure conformity with local and regional construction practices and provide design documents, or specifications, that include the physical dimensions and material properties, such as their moment and shear capacities, and yield strength. Variability in each of these and other properties is explicitly modeled.

Non-linear seismic analysis is performed on each "virtual" building. That is, using a well-known engineering software application, computer models of three-dimensional buildings are subjected to incremental amounts of lateral load until the building collapses. At each increment, as the joints where beams and columns connect fail, the load is redistributed to those that remain.

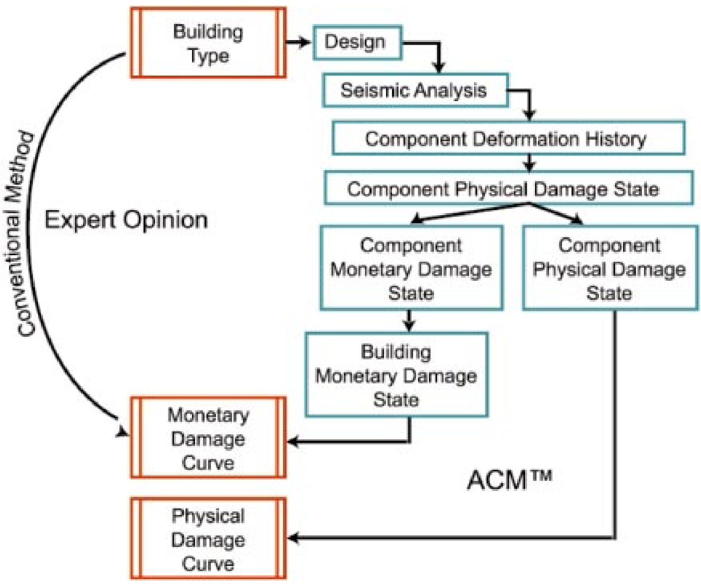

Figure 6: ACM versus "Expert Opinion"

ACM calculates the damage ratio to individual components of each building type. Damages to all components are then combined using a weighting mechanism such that the importance of each component to total building damage is a function of the story on which that component resides. Once the damage ratios for each component type are estimated, they are combined to achieve the total building damage ratio.

To translate physical damage into monetary damage, ACM employs a comprehensive cost model to estimate the cost of repair for each damaged component. Repair costs are determined by identifying the appropriate repair strategy for each damaged component on each floor of the building, given its physical damage state. Finally, the repair costs of each individual component are combined to achieve an estimate of the monetary damage to the building as a whole. Actual data on repair and replacement costs is incorporated, thus ensuring that the model can be updated every year using the most current cost information available.

ACM is a physically-based technique for estimating earthquake damage because it attempts to capture the dynamics of how buildings fail. It captures the complexity of how damage occurs much more realistically than traditional approaches relying on expert opinion-based damage curves calibrated to limited historical loss data. Again, as with NWP, the benefit is reduced uncertainty in the model itself, leading to higher confidence in the resulting loss estimates.

How to derive maximum value from catastrophe modeling

Simulation models of all types provide a rich variety of output that can be used for many different applications. Probability distributions of losses and their complement, the exceedance probability curve, are estimated for potential levels of annual aggregate and occurrence losses that a company may experience given their portfolio of property exposures. Catastrophe models are very flexible in that the information may be customized to any desired degree of geographical resolution down to location, or site, level, by line of business and, within line of business, by construction class, coverage, etc., for each simulated event. The results of a catastrophe risk assessment also provide the necessary detail to determine which perils, regions, lines of business, policy forms, etc. drive the company's large loss potential, including probable maximum losses (PML).

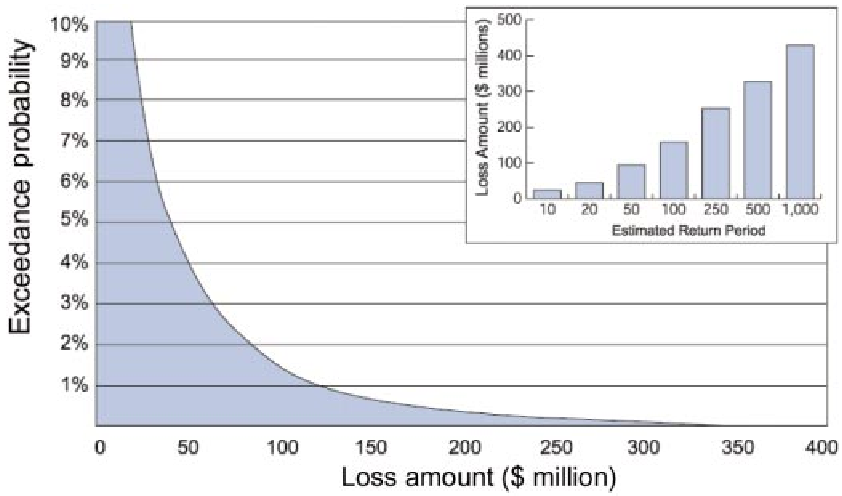

Figure 7: Exceedance probability curve

Catastrophe modeling can bring enormous value to primary insurers with access to detailed risk information. Analyses run at the location (i.e., geocode) level can take full advantage of information on risk-specific structural details, occupancy, age and height, locational characteristics, such as site-specific geographical and geological information, and insurance policy and reinsurance treaty terms. *However, significant value is to be gained even when detailed data on individual risks is not available*. This is because catastrophe modelers have developed "aggregate applications" that can provide results even when detailed data is not available. These aggregate applications are based on "average" assumptions with respect to the nature of the property insured, and they will provide reliable results for many companies.

Additionally, some catastrophe modelers have developed detailed databases of total property values. Information on a wide variety of buildings typical to each region is embedded in these high-resolution databases, with values broken down by line of business, by coverage, by occupancy and a large number of construction classes. This information can also be adapted and used by insurers who lack detailed information on their own books of business.

Uses of model output

The primary purpose of catastrophe modeling is to give insurers as accurate a picture as possible of the catastrophe loss potential derived from their book of business and to give them the tools they need to consider alternative strategies for managing that risk. Model output may be used to perform sensitivity tests, develop underwriting guidelines, analyse policy conditions, make sound decisions regarding the purchase of reinsurance, estimate consistent loss costs for catastrophe-prone areas, and for overall catastrophe risk management. Other important applications are discussed below.

Exposure management

Gaining insight into more effective ways of managing exposure to catastrophe risk is one of the most important benefits of catastrophe modeling. Model output provides a clear picture of a company's geographical distribution of exposures and potential catastrophe losses on those exposures. The key drivers of a company's catastrophe risk are determined, including which perils, regions, and lines of business have the greatest marginal impact on probable maximum losses. Such information can help clients fine tune their underwriting guidelines and growth strategies to better manage future catastrophe loss potential. The analyses clearly show where business can be expanded without increasing large loss potential, as well as areas in which a company is already over exposed to catastrophe losses.

Development of mitigation strategies

A detailed analysis of how a property's structural characteristics affect its vulnerability to natural hazards and how modifications to those characteristics impact potential losses can help clients plan their overall catastrophe loss reduction program. Wind-specific characteristics include roof geometry, pitch, covering and attachment systems, wall siding, percent of the exterior covered by glass, type of window protection, etc. Earthquake-specific characteristics include building shape, presence of soft story, foundation type, building-foundation connections, presence of earthquake resistive systems, and so on.

Through an extensive analysis of engineering principles, results of damage surveys and expert knowledge, modifiers to the damage functions have been developed that take into account all possible combinations of and correlation between secondary risk characteristics. "What if" analyses can be performed to measure the impact on loss estimates of various scenarios, such as adding storm shutters or retrofitting with cross bracing. The results of detailed sensitivity analyses are used to provide guidance for enhancing underwriting and pricing strategies, including determining the appropriate level of credit for the presence of various loss mitigation devices.

Portfolio optimization

Companies are frequently looking for ways to grow their books of business *and* improve profitability. To avoid future earnings shocks, companies need to account for catastrophe in their growth strategies. The output from catastrophe models can be used to help clients incorporate portfolio optimization techniques into overall strategic plans and growth objectives by geographic area, non-catastrophe profitability, and other lines of business.

Identification, assessment, and precise quantification of catastrophe risk form the basis of a portfolio optimization analyses. The detailed loss information obtained in thoroughly analysing exposures can be used to develop a formal optimization plan involving two phases: establishing the conceptual framework and creating and applying a mathematical optimization model. It is important that a company's objectives are well defined and that business issues such as growth, stability, solvency, feasibility, and profitability are addressed. Profitable growth, for example, may be constrained by market factors and costs that limit a company's ability to modify its portfolio of exposures quickly. By taking all such issues into consideration, a template for the optimal diversification of a company's portfolio can be derived.

Reserving and ratemaking

The output from catastrophe models includes the estimated "pure premium" or long-run expected losses due to catastrophes. This information is available by class of business and geographic area as well as by individual policy. This amount should be accounted for in the actual rates charged on individual policies and classes of business in order for the insurer to pay the losses out over time and to maintain a profitable book of business. Another way to view the long-run expected losses is the amount of money that needs to set aside each year to pay for the losses that will result from future catastrophes.

An increasingly important aspect of the rate filing process is the quantification and justification of the catastrophe risk component of proposed rates. Catastrophe modeling has come to play an instrumental role in bridging the information gap between insurance companies, on the one hand, and the various departments of insurance and their constituencies, on the other, about the nature and significance of catastrophe risk.

These are just examples of the many ways in which insurers and reinsurers are using catastrophe models to better manage their risk and to improve their financial results. More and more companies are integrating this technology within their internal underwriting, pricing and corporate risk management areas. *Tremendous value can be reaped from installing and using this technology "in house" even if a PML has already been estimated for the purchase of reinsurance*.

Concluding remarks

Catastrophe modeling technology has evolved in many ways since it was first introduced in 1987. While providing reliable loss estimates for actual events in real time, as well as *probabilistic* loss estimates to the industry well before the major events of the early 1990s, extensive use of this technology has come about only over the past several years. This technology is based on advanced scientific techniques and current knowledge in meteorology, seismology, wind and earthquake engineering.

Catastrophe modeling technology is not static and the models themselves continue to evolve in terms of detail, realism and accuracy. Today, all catastrophe models are not equal. Significant distinctions exist that should be recognized and evaluated by the users.

Catastrophe modeling offers enormous value — value that continues to increase as the technology continues to evolve. Catastrophe modeling enables proactive decision-making and strategic planning and is an essential component to any company's efforts to manage enterprise-wide risk.