Extreme Losses from Natural Disasters - Earthquakes, Tropical Cyclones and Extratropical Cyclones

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Introduction

Economic losses from natural disasters have increased ninefold over the last 40 years. During the 1960s, for example, economic losses from natural disasters were estimated at $73 billion; the decade of the 80s brought losses of $204 billion. From 1990 to 1999, total economic loss from natural disasters exceeded $630 billion (Fig. 1). Losses from Hurricane Andrew ($26.5 billion) and the Northridge earthquake ($44 billion) make these the costliest events to affect the United States. In Japan, losses from the Great Hanshin (Kobe) earthquake are estimated at $100 billion. More recently, the winterstorms of 1999 that swept across Europe caused damage in excess of $17 billion. While the debate over whether catastrophe events are actually occurring with greater frequency remains inconclusive, there is a consensus of opinion that the trend toward increasing economic losses is largely due to two reasons: (1) population density is increasing worldwide and densely populated large cities continue to grow in areas of high hazard; (2) at the same time population density is increasing, standards of living have increased, resulting in huge increases in the concentration of property values. Regions that were formerly shunned because of their high hazard potential are now heavily populated. Over the last decade, for example, catastrophe-prone Florida has experienced a population growth of 20%, or nearly twice the national trend.

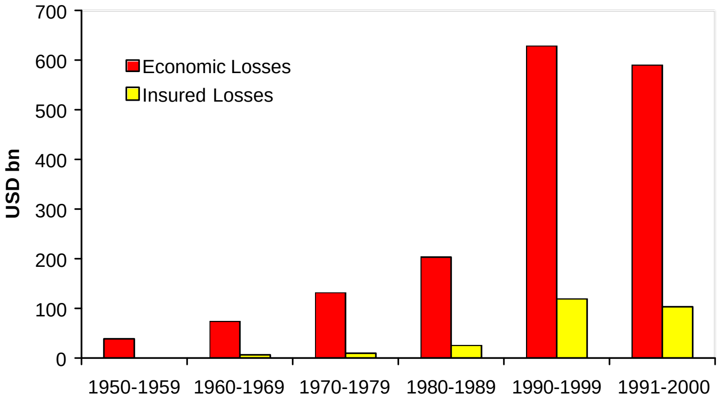


Figure: 1 - Comparison of losses due to natural disasters from recent decades
(Source: Munich Re)

Natural disasters are, fortunately, rare events. That means, however, that assessing and quantifying potential losses from future catastrophes is a difficult task given the limited loss information that is available from past events. A quick look at the top natural disasters in recent decades reveals that earthquakes and cyclones, both tropical and extratropical, are the perils that contribute most to losses worldwide. This paper outlines a catastrophe loss estimation methodology developed at Applied Insurance Research Inc. (AIR) for assessing risk arising from these three perils; the extent of potential economic loss arising from them is then examined. We consider earthquakes and tropical cyclones in the United States and Japan, and extratropical cyclones in Europe. Within the United States, two highly seismically active regions are examined: California and the New Madrid Seismic Zone (NMSZ), which extends from northwest Arkansas to southern Indiana. For the tropical cyclones, the state of Florida is selected. In the case of extratropical cyclones, we look at twelve European countries: Belgium, Denmark, France, United Kingdom, Germany, Ireland, Luxembourg, Netherlands, Norway, Scotland, Sweden and Switzerland. It should be noted that the goal of this paper is not to discuss the details of the modeling methodology but instead to focus on the potential loss impact of these perils.

The paper first discusses the specific nature, frequency, severity, and spatial distribution of the individual perils. Secondly, it describes a generalized formulation of the catastrophe loss model. Finally, comparison of model results in terms of probability distributions of loss from these perils is presented for the regions chosen in this study. Both annualized risk as well as exceedance probabilities of loss is evaluated. This detailed information derived from the model will help provide a better understanding of the geographical distribution, frequency, and magnitude of potential future losses.

The Nature of the Hazard - An Introduction

Earthquakes

An earthquake is the rapid relative displacement of the rock on either side of a fracture, or fault, in the interior of the solid earth. The energy released by a sudden slip along a fault plane produces seismic waves that radiate outward in all directions from the initial point of rupture and that cause the ground to shake at the earth’s surface. The area over which these seismic waves propagate is primarily a function of the amount of total energy released and the characteristics of the underlying rocks in the region.

Certain regions of the earth's crust are geologically young and tend to attenuate, or dampen, wave propagation at a faster rate. California in the western part of the United States is such a region. In contrast, the NMSZ in the central United States is geologically much older; the underlying rocks are harder and less fractured and can therefore propagate seismic waves over longer distances. Fig. 2 below illustrates this contrasting behavior between the two regions. For two historical earthquakes of similar magnitude, the figure shows maps of the modeled ground motion. Although the most severely damaged areas are usually confined to relatively short distances from the fault, the total area impacted is significantly higher in the case of the NMSZ than in western U.S.

The distribution of global seismic activity is very well explained by the theory of plate tectonics. In broad terms, the theory describes the earth's lithosphere, which extends from the earth's surface down to a depth of approximately 80 kilometers, as consisting of several large and fairly stable slabs of relatively rigid rock called plates. Motion along the boundaries of these plates, can result in earthquakes of very large magnitude. Most of the earth's seismic energy is released along these plate boundaries. Other earthquakes are associated with crustal faults; still others, so-called intraplate earthquakes, occur within the interior of seemingly stable tectonic plates. Japan is located at the confluence of three tectonic plates (Pacific plate, Eurasian plate and Philippine plate) and is also characterized by a high density of surface faults. This unique setting makes Japan one of the most seismically active regions of the world.. It must be emphasized that although earthquakes that occur on crustal faults contribute only to a small fraction of the total seismic energy released, they can potentially cause extremely high damage because they can be located closer to population centers e.g. 1994 Northridge earthquake in California. The NMSZ is a region of intraplate seismic activity. Typically, the recurrence rate of significant events in intraplate zones is relatively low.

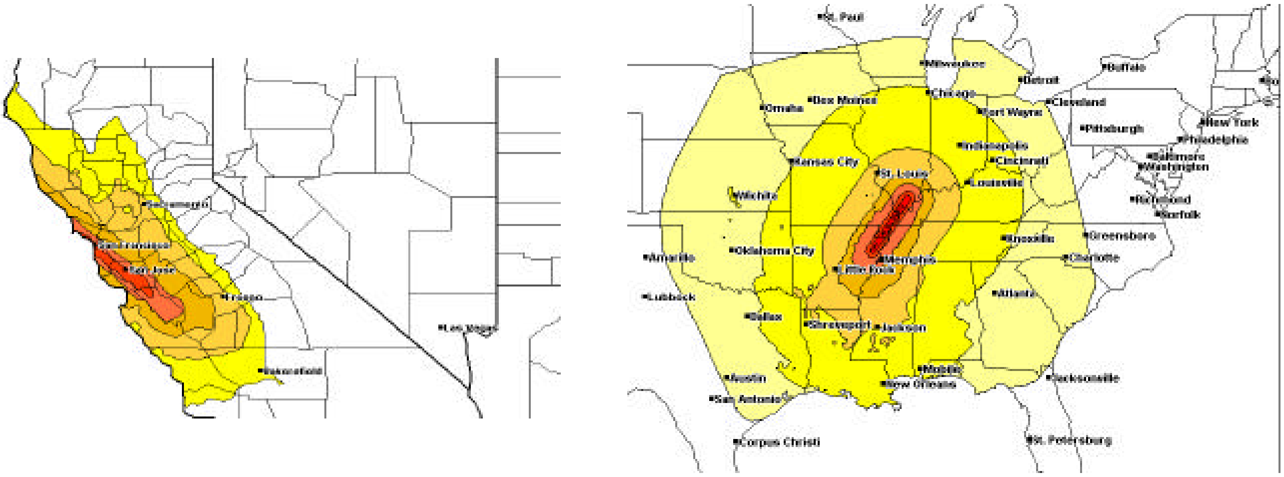


Figure: 2 a) 1906, San Francisco, M=7.9 b) 1811 - 1812, New Madrid, M=8.0

Tropical Cyclones

Tropical cyclones form where there is a convergence of the necessary conditions, which include a large expanse of warm ocean water (generally, water temperatures must be at least 80 degrees Fahrenheit) and the relative absence of “vertical shear,” or winds that change appreciably in either magnitude or direction, thus “shearing off” the cyclonic outflow at high altitudes. As the name suggests, tropical cyclones are most likely to form in the tropical regions of all of the earth’s ocean basins, between about 5 degrees and 20 degrees latitude. The most active months are August and September in the Northern Hemisphere, and January and February in the Southern Hemisphere.

The rising warm, dense air near the ocean's surface creates an area of low pressure, technically known as a depression. When wind speeds reach 40 miles per hour, the depression reaches tropical storm status. At wind speeds of 74 miles per hour, the storm is designated as a hurricane, or typhoon.

Fig. 3 indicates the average annual frequency of tropical storm formation in each of the world's major ocean basins. The number given on the left bar for each basin includes all cyclone formation of tropical storm strength or greater whereas the number given on the right side bar indicates the ones that are of hurricane strength and above.

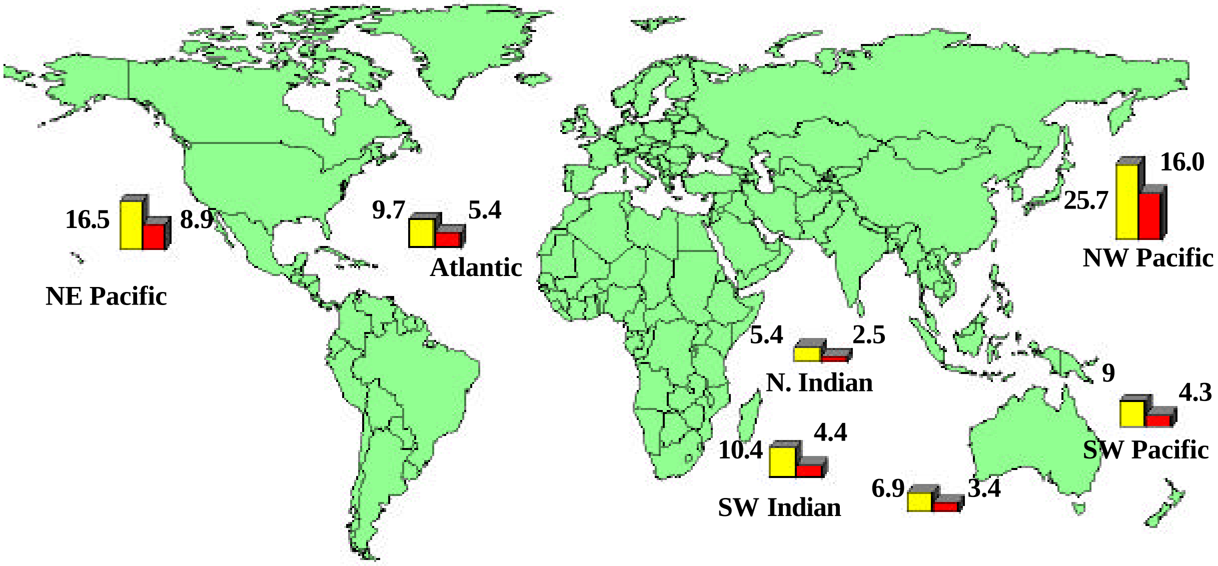


Figure: 3: Tropical Cyclone Formation, Average number per year by Ocean Basin

Extratropical Cyclones

Extratropical cyclones arise through a process called cyclogenesis, in which cold and warm air masses interact in an unstable environment. Extratropical storm systems are typically comprised of multiple areas of relatively low and high pressure, the locations of which can change quickly and frequently. This is in sharp contrast to the simple, symmetric structure that is observed for tropical storm systems in low latitudes. As an extratropical system evolves, the interaction of these low and high-pressure areas creates changes in the horizontal pressure gradient field. The windfield associated with such a system is driven as a response to the evolving pressure gradient field. The mid-latitudes (between 35 and 60 degrees latitude) of both the Pacific, near the Asian coast, and the Atlantic, near Greenland and the North American coasts are the most favorable for extratropical cyclone formation. Storms affecting Europe typically originate to the east of North America or Greenland and subsequently move eastward across Europe. While cyclogenesis occurs every month of the year, formation into significant extratropical storms almost always occurs during the late fall, winter, or early spring. These systems are, therefore, often referred to simply as “winter storms”.

Extratropical cyclones typically do not achieve the intensity, in terms of wind speeds, that tropical cyclones achieve. However, a single extratropical cyclone can affect an area of tens of thousands of square miles and can subject individual locations to high winds for up to several days. In Europe, on average, 25 storms form each year of which five have the potential to cause substantial damage.

Catastrophe Loss Estimation Methodology

Through the application of a stochastic simulation process, AIR catastrophe loss estimation methodology involves estimating the probability that events of particular intensities will occur. In the next step, the potential financial loss to a property/building or a portfolio of buildings as a percentage of the replacement value of the building is estimated. From an insurance perspective, the estimated loss is the sum of loss to the building, the contents and time element loss (that is, expenses associated with the loss of use in the case of residential properties and with business interruption in the case of commercial properties). Fig. 4 below illustrates the various components of the catastrophe risk analysis model. All the AIR models for each peril and region follow this generic framework.

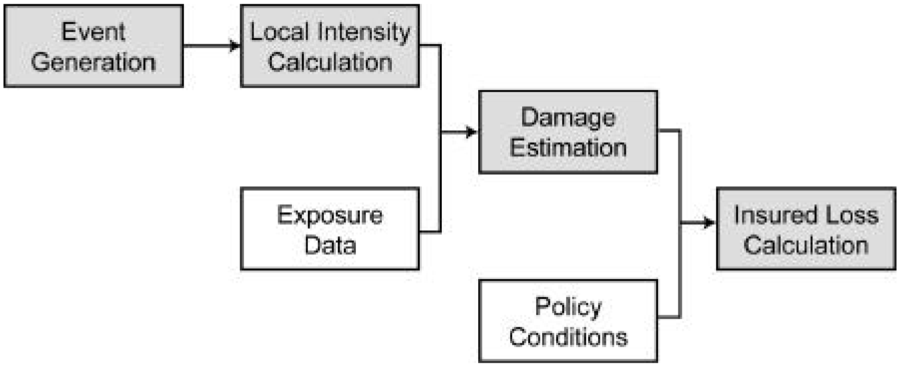


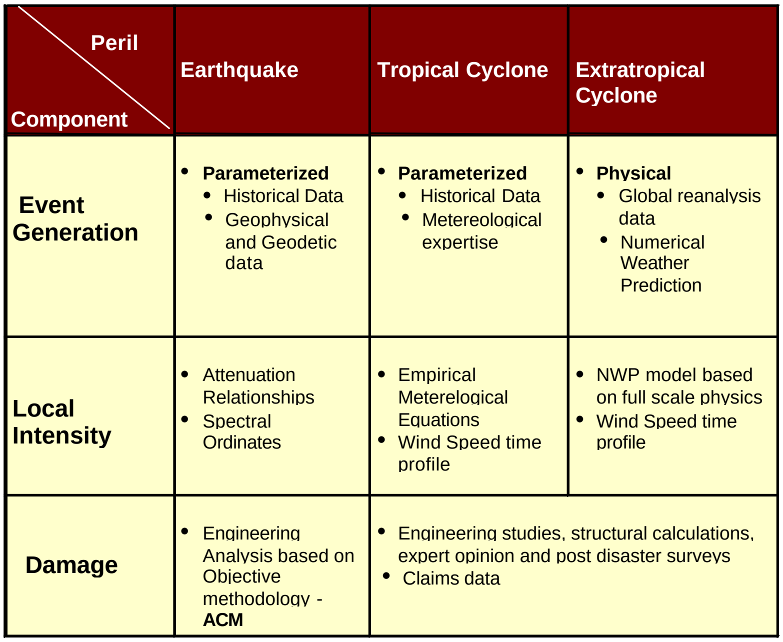
Figure 4: Catastrophe Model Components (in gray)

Event Generation and Local Intensity

The event generation component of the models determines the frequency, magnitude, and other characteristics of potential catastrophe events by geographic location. This requires, among other things, a thorough analysis of the characteristics of historical events as well as an understanding of the region-specific features, whether seismotectonic, geological, topographical, or atmospheric, those are likely to influence the behavior of future catastrophe events.

Catastrophe models can vary in their approach to event generation. Some are parameterized models, as in the case of the earthquake and tropical cyclone models discussed here. Others are physical models; that are more appropriate for capturing complex phenomena, such as extratropical cyclones. Fig. 5 summarizes the difference among the model components for the three perils chosen in this study.

All catastrophe events are complex and their characterization requires the use of large numbers of variables. In the case of the parameterized models, event generation begins by collecting the available scientific data pertaining to these variables from many different sources. The data are cleaned and verified. After a rigorous data analysis, researchers develop probability distributions for each of the variables, testing them for goodness-of-fit and robustness. The selection and subsequent refinement of these distributions are based on statistical techniques, on well-established scientific principles and on an understanding of how catastrophic events behave. The resulting distributions are used to produce a large catalog of simulated events. That is, by sampling from these distributions, the model generates simulated “years’ of event activity. Many thousands of these scenario years are then generated to produce a stochastic catalog that represents the complete and stable range of potential catastrophe event activity.



Peril Component	Earthquake	Tropical Cyclone	Extratropical Cyclone
Event Generation	• **Parameterized** • Historical Data • Geophysical and Geodetic data	• **Parameterized** • Historical Data • Metereological expertise	• **Physical** • Global reanalysis data • Numerical Weather Prediction
Local Intensity	• Attenuation Relationships • Spectral Ordinates	• Empirical Metereological Equations • Wind Speed time profile	• NWP model based on full scale physics • Wind Speed time profile
Damage	• Engineering Analysis based on Objective methodology - **ACM**	• Engineering studies, structural calculations, expert opinion and post disaster surveys • Claims data	

Figure 5: The methodological approach to the model components

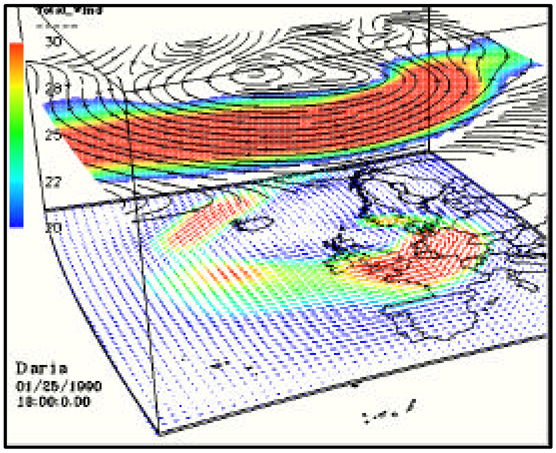
Seismologists typically fit historical data on the frequency and magnitude of earthquakes to an exponential distribution called the Gutenberg-Richter (GR) relationship. The GR relationship applies globally and allows an extrapolation from the limited historical record to estimate a more complete picture of seismicity in an area. The GR relationship holds over a wide range of magnitudes and can be described by two parameters: one describing the occurrence rate of earthquakes of magnitude greater than or equal to some reference magnitude, and another representing the rate at which the log of the cumulative annual frequency of earthquakes decreases, as the magnitude increases. Each of these parameters depends upon the geology of the seismic zone under consideration. Scientists usually truncate this relationship at a limiting magnitude above which the probability of occurrence is zero. While the GR relationship holds on a regional or global scale, it may not hold for individual faults. For some seismic zones, there exists evidence that earthquakes of a certain magnitude occur with a frequency that is not consistent with the rate predicted by the GR relationship. Scientists now believe that many faults tend to produce repeated earthquakes of a size that is "characteristic" of that particular fault or fault segment.

Each of the seismicity models developed for the regions of interest in this paper has features that capture the unique tectonic setting of the region. In general, plate margin earthquakes associated with subduction zone regions, such as along the East Coast of Japan are modeled primarily as characteristic events. Known active crustal faults are modeled using a weighted combination of characteristic earthquakes and seismicity as generated by the Gutenberg-Richter relationship. Finally, a smoothed background seismicity distribution is used to capture the small to moderate events that could occur as a result of as yet unknown or unmapped faults.

Some of the other key earthquake model variables include depth, rupture length, azimuth, dip angle and rupture mechanism. After the model generates the location, magnitude, and other fundamental characteristics of the simulated earthquake, it calculates intensity at each location affected by the event. To do this, the model uses attenuation relationships, which mathematically describe the rate at which the amplitude of the seismic waves decreases as the waves propagate outward from the source of the rupture. The shaking intensity derived from these attenuation relationships is then modified to reflect specific local site conditions such as ground motion amplification and soil liquefaction.

In the case of tropical cyclones, some of the primary model variables are the annual frequency, landfall location, minimum central pressure, radius of maximum wind, forward speed, track angle at landfall and the storm track. The available historical data pertaining to chosen parameters is collected and probability distributions for each of these parameters are derived based on historical data combined with meteorological expertise. For example, the model uses a weibull distribution for the central pressure, lognormal distribution for forward speed and a normal distribution for the radius of maximum wind in Florida hurricane. The local wind speed profile for each simulated event is calculated using empirical meteorological equations with adjustments made for asymmetry effects, storm filling over land and surface friction.

The model developed for extratropical cyclones, is not a traditional parameterized model, but is a physical model that employs, Numerical Weather Prediction (NWP) techniques. Such models can capture the evolution of a storm due to small changes in the initial conditions of the atmosphere. This attribute is leveraged in the event generation by perturbing, both temporally and spatially, the initial conditions of a set of "seed" storms drawn from the historical data. NWP models use global environmental data such as sea surface temperatures, wind speed and pressure in conjunction with governing equations based on known physical laws, to model the evolution of circulation patterns in three-dimensional space. The data are used to define the “state-of-the-atmosphere variables” (SAVS). The process begins with an initial three-dimensional field of these SAVS flow (see Fig. 6), that is, an initial snapshot at the surface and at multiple upper atmospheric layers. Because the motion of air depends on the pressure gradient, from this pressure field a windfield is generated.



The windfield of each of these perturbed seed storms is then moved forward in time through the application of a set of partial differential equations governing fluid that have, as their basis, the law of conservation of mass and energy.

Vulnerability /Damage Estimation

Vulnerability relationships or damage functions relate the mean damage as well as the variability of damage to the measure of intensity. They implicitly describe the interaction between buildings, both their structural and nonstructural components as well as their contents, and the local intensity to which they are exposed. Because different structural types experience varying degrees of damage, the vulnerability relationships are developed according by construction types and occupancy. In the model, damage is expressed by means of a damage ratio between the repair cost of the damaged property and the replacement value of the property. The probability distribution of damage is calculated by applying the appropriate function to the replacement value of the property.

Damage to buildings from earthquakes is both structural and non-structural in nature and can be modeled using certain objective parameters such as inter-story drift, base shear, ductility ratio etc. For earthquakes, structural damage can be extremely severe even for engineered buildings. This was the case for Kobe earthquake in Japan, where the seismic building codes are considered to be one of the most advanced in the world. On the other hand, damage due to wind is primarily non-structural, involving different components of the building envelope and, in most cases, is localized in nature. Under extreme wind events, even if structural collapse occurs, it is usually restricted to non-engineered buildings such as wood frames. Due to the lack of test data on component or envelope resistances, most of present day knowledge of wind damage comes from damage investigations conducted in the aftermath of an event. Recourse is frequently made to engineering experience and knowledge to develop vulnerability functions for wind-induced damage.

In the AIR model for earthquakes, building vulnerability to ground shaking is developed using a rigorous engineering-based methodology known as ACM™ (Advanced Component Method™) which uses spectral displacement (S_d) as a measure of earthquake intensity. In the case of wind damage from tropical and extratropical cyclones, the model vulnerability relationships are based on engineering studies, structural calculations and expert opinion. The resulting relationships are extensively validated using actual claims data obtained from insurance companies for various windstorm events. Fortunately, windstorm events are quite frequent and hence sufficient data is available to perform these validations at detailed geographic resolutions. In the model, based on the local intensity calculated for each simulated event, the corresponding damage estimates for exposed property are obtained from the associated vulnerability relationship. The damage estimates are translated into monetary losses due to direct structural and non-structural damage and due to business interruption. The final output of the catastrophe loss model is the probability distributions for losses (refer Fig. 7). Output from the model can be easily customized to any desired degree of geographical resolution down to location level, by construction class, aggregation of property classes etc.

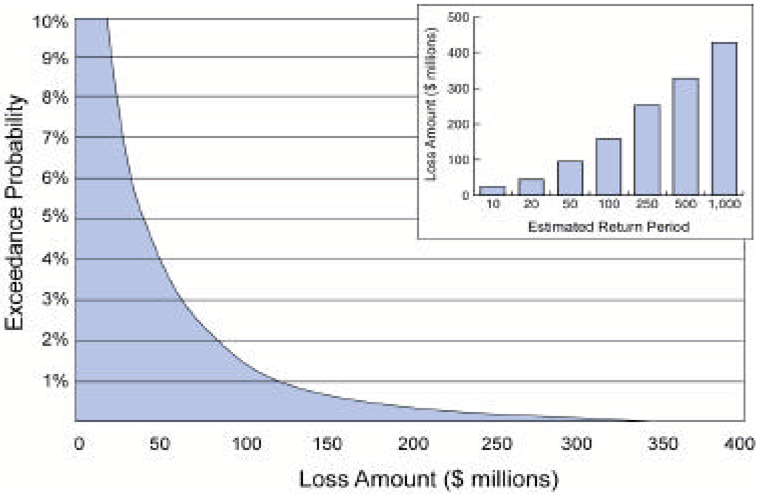


Figure 7: Exceedance Probability Curve

Property Values Exposed to Catastrophes

The landscape of insured properties is constantly changing. Property values change with time, along with the cost of repair and replacement. Building materials and design change, and new structures may be more or less vulnerable to catastrophe events than the old ones. In addition, the concentration of both people and property in areas of high hazard has grown considerably over the last several decades. In United States, for example, there has been a tremendous growth of high-value properties built along the coast of Florida, despite the fact that the risk from hurricanes is widely known and understood. In this paper, the potential direct losses to property generally insurable under the residential, commercial and industrial market segments are examined. This includes damage to building, contents, loss of use (for residential properties) and business interruption (for commercial and industrial properties). Losses to this inventory of properties constitute a very significant part of the direct economic losses resulting from natural hazards, the other significant component being damage to infrastructure.

Figure 8 below shows a relative ranking of exposed property values for the five principal regions of interest: California, Florida, the NMSZ, Europe and Japan. The property values calculated in U.S. dollars are normalized with respect to property values in Florida. The figure shows that Japan has the highest value of exposed property even when compared to the twelve European countries combined. In the United States, exposures in the seven states that comprise the NMSZ are comparable to those in the state of California alone.

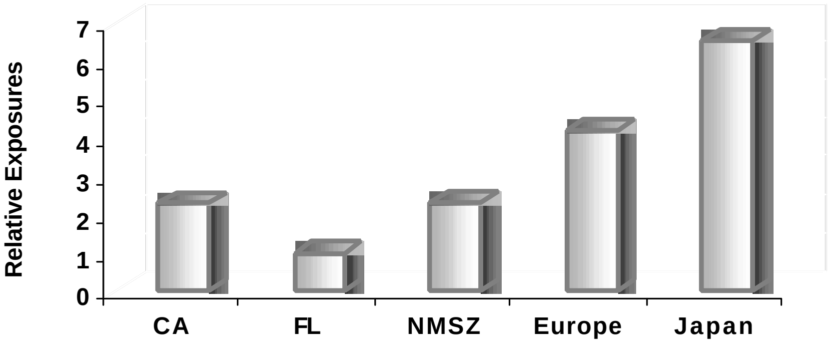


Figure 8: Relative Exposure Values by Region and Peril

Within these five principal regions, there are certain high hazard areas that have a greater concentration of population and hence property values. For example, California’s Los Angeles County, which accounts for only 2.5% of the total area of the state, contains 30% of the state's property value. Similar areas of concentration include Dade County (14%) in Florida and Tokyo prefecture (10%) in Japan. Both Los Angeles county and Tokyo prefecture have well over a trillion dollars of property value. It is therefore becomes evident why a repeat of some historical events in these areas of exposure concentration could lead to economic losses not previously contemplated.

Regional Risk Comparison

For each of the regions of interest, the exposure database is analyzed through the risk analysis model for the appropriate peril. The output from such an analysis is used to construct a complete probability distribution of potential losses. From this distribution, different measures of risk can be derived, including traditional measures such as annual aggregate loss or probable maximum loss (PML). With this information at hand, a risk manager can make informed decisions based on risk tolerance level.

Mapping the simulated scenario events that could lead to extreme losses provides useful information that can be used to compare the risk in different regions. Figs. 9 through 11 show model output for potential events causing a 250-year loss (i.e. exceedance probability of 0.4%) for the different regions. Fig. 9 shows the ground motion contours measured in terms of spectral acceleration, for Japan and California. The two scenario events illustrated here are of moment magnitudes greater than seven and affect the highly populated areas of San Francisco and Tokyo bay areas. The wind speed footprints of

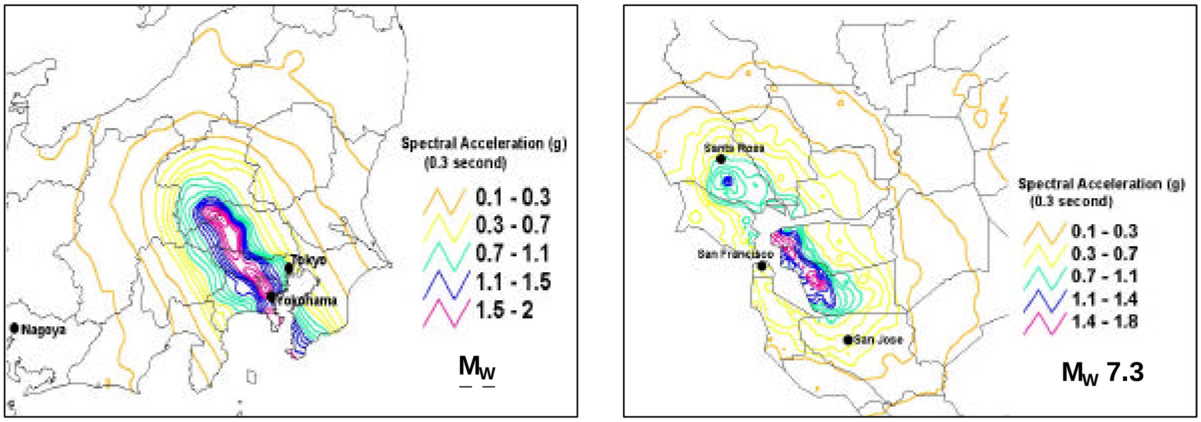


Figure 9: Ground Motion Contours for Potential Event causing 250-Year Loss

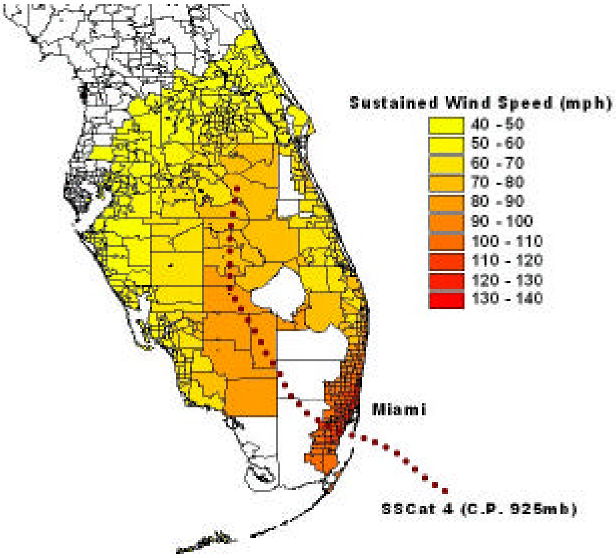


Figure 10: Wind Speed Footprint of a Potential Tropical Cyclone Event Causing 250-Yr Loss

potential events of similar return period for Florida hurricane and Europe extratropical cyclone are shown in Figs. 10 and 11. The hurricane scenario illustrated here represents a Saffir Simpson Category 4 storm making a landfall in Miami, Florida.

The simulated extratropical cyclone event illustrated below affects parts of Ireland, England, Netherlands and Northern Germany with a peak three-second gust wind speed in the range of 40 - 45 meters per second.

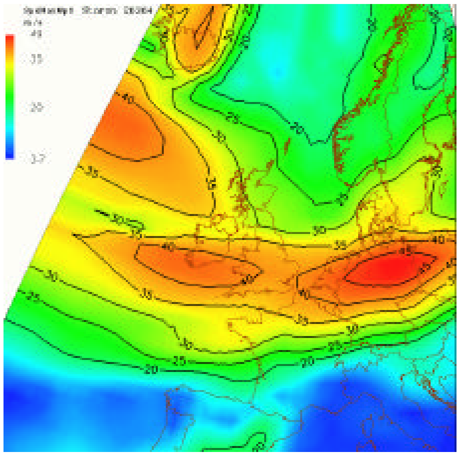


Figure 11: Wind Speed Footprint of a Potential Extratropical Cyclone Event Causing 250-Yr Loss

A comparison of results for the 100, 250, 500 and 1000-year return period losses is given in Fig. 12 for each region and its associated peril. In this figure, the absolute dollar loss values for each region have been normalized by the 100-year return period loss for California earthquake in order to compare the relative risk by region and peril. It should be noted that the losses from windstorms in the figure are due to wind damage only and do not include losses from rain and flooding often associated with such events.

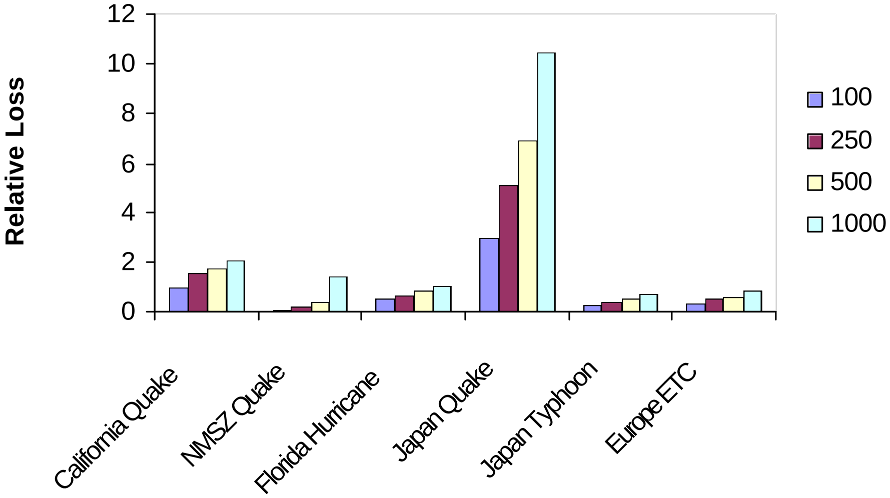


Figure 12: Relative loss distribution by region and peril

A striking result evident from this figure is that the absolute monetary risk from earthquakes in Japan is significantly higher than the risk in all other regions. Also it can be seen that the return period losses from earthquake events are significantly higher than for extratropical and tropical cyclones. Further, even though the dollar loss from earthquake in Japan is higher than in other regions, the losses due to Japan typhoon are significantly lower than losses due to hurricanes for the state of Florida. Because Japan lies further to the north, that country generally experiences less intense storms than does Florida. Another reason is that the southern part of Japan, which is the area of high wind hazard, has relatively less concentration of exposures. For Europe, the total losses from extratropical cyclones are lower than from Florida hurricane. This is consistent with the earlier discussion that wind speeds and therefore severity of damage is lower for extratropical cyclones than for tropical cyclones.

The preceding paragraph discusses the high return period events of the loss distribution. From the risk manager's point of view, it is the tail of the loss distribution that is of particular importance because it captures the low probability/high consequence events. Another measure of risk is the average annual normalized risk or loss cost for a territory, which is calculated by dividing the average annual loss amount for each territory by the corresponding exposures. Fig. 13 gives the comparison of this normalized risk for the five regions. The results indicate that the industrywide risk is highest for Florida hurricane, followed by Japan and California earthquake. Annualized expected can be very useful for setting insurance premiums rates and understanding the relative spatial distribution of risk within a region, but it can be misleading in terms of assessing the potential for extreme events. For example, in Fig. 13 the annualized risk in the NMSZ is the lowest of all the regions in this study, but this is because the annual frequency of occurrence is significantly lower than in California or Japan. This characteristic of the hazard in this region is reflected in the distinctly more skewed loss distribution than is

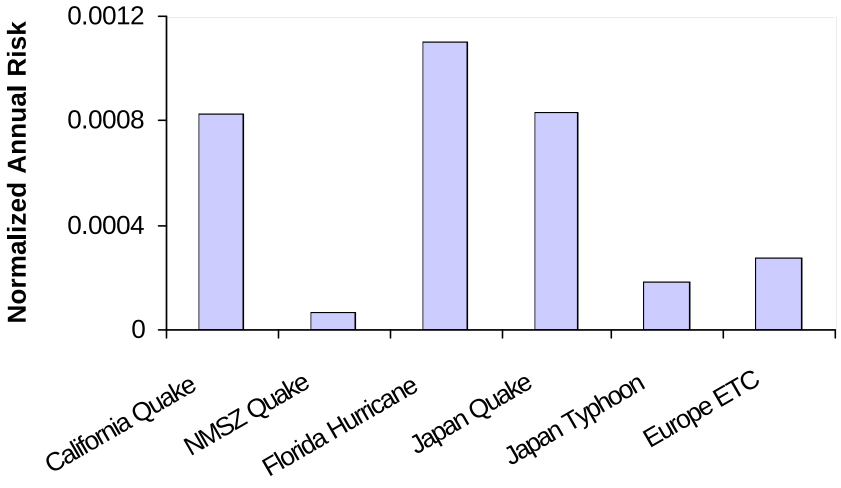


Figure 13: Comparison of Annual Risk

observed for the perils in other regions. A critical objective while evaluating the risk in the NMSZ is to determine how often an event similar to the 1811-1812 series of earthquakes is likely to occur. Therefore, in addition to the annualized risk it is important to look at the entire probability distribution of loss in order to make meaningful conclusions.

Summary

The ever-increasing cost of natural disasters in the past several decades has warranted commitments and cooperative endeavors by the insurance sector, as well as the emergency management agencies at a national and international level, toward reducing the losses caused by natural disasters. In this paper, a brief overview of a methodology for estimating losses due to natural hazards is presented. The nature of hazard associated with three different perils — earthquakes, tropical cyclones and extratropical cyclones and earthquakes is discussed. The monetary risk from these hazards, as evaluated by the model, is compared for three different regions: the United States, Europe and Japan. Sample potential scenario events resulting from these perils, which correspond to 100, 250, 500 and 1000 year return period losses, or exceedance probabilities of 1%, 0.4%, 0.2% and 0.1 %, are presented. The results from the analysis indicate that expected monetary loss is highest from earthquakes in Japan followed by earthquake in California. Estimates of monetary loss from tropical cyclones are higher than from extratropical cyclones. For tropical cyclones, the relative risk in state of Florida alone in the United States is greater than from typhoons in Japan.