Report of the

Catastrophe Modelling Working Party

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1. OVERVIEW

1.1. TERMS OF REFERENCE

The Working Party's aims were to:

"Determine the most appropriate use of natural catastrophe modelling in actuarial work including pricing, reinsurance, reserving, aggregate planning and capital management by understanding the limitations of existing models"

We have concentrated exclusively on natural catastrophe modelling and not considered man-made catastrophes and, in particular, the nascent field of terrorism modelling.

The views in this paper do not necessarily represent the views of any of the individuals on the Working Party or their employers.

This paper was finalised in June 2006, and so does not reflect the experience of the 2006 hurricane season.

1.2 OUTLINE OF PAPER

The first part of the paper gives a brief introduction to catastrophe modelling. We then discuss the uses that actuaries make of catastrophe models in their work.

The subsequent sections of the paper then address in detail various aspects of the models and their inherent limitations.

We have structured this main body of the paper to follow the usual course of any actuarial loss investigation, beginning with the data available, and moving on to consider frequency and severity. We then discuss the design of the models, and the mathematical approximations in them before finally considering those aspects of natural catastrophe losses that are not captured by the models at all.

Catastrophe modelling is a huge subject and this paper only gives an outline of some of the key considerations actuaries should make in using the models. For those who want to investigate further we provide, at the end of the paper, a comprehensive list of references and links to further reading. We also provide a Glossary of useful terms and a summary of some key Atlantic hurricane data by year.

1.3. ACKNOWLEDGEMENTS

We would like to thank Trevor Maynard of the ICA and Climate Change Working Parties for his assistance with section 4.4. of our paper. We would also like to thank the many catastrophe modellers who assisted us with section 3 of the paper.

2. INTRODUCTION TO CATASTROPHE MODELS

2.1. HISTORY OF CATASTROPHE MODELS

Timeline

1987	AIR founded
1988	RMS founded. Hurricane Gilbert
1989	Hurricane Hugo. Loma Prieta earthquake
1990	
1991	Typhoon Mireille
1992	Hurricane Andrew. Bermuda “Class of 1992”
1993	
1994	Northridge Earthquake. EQECAT founded
1995	Kobe earthquake. First Catastrophe bonds
1996	
1997	
1998	
1999	European Winter Storms
2000	
2001	World Trade Centre attack. Bermuda “Class of 2001”
2002	
2003	
2004	Boxing Day Tsunami
2005	Hurricane Katrina. Bermuda “Class of 2005”

A Brief History of Catastrophe Modelling

Catastrophe modelling developed as a discipline in the late 1980s. The increased computing power available made possible the use of the developing area of Geographical Information Systems (GIS) software. These were combined with the results of increasing scientific understanding of natural hazards (particularly hurricanes and earthquakes) to develop the first commercial catastrophe models.

Of the three major catastrophe modelling firms: AIR was founded in 1987, RMS in 1988 and EQECAT in 1994. AIR and RMS were founded into a market hit by a number of natural catastrophe events, including: Hurricane Gilbert in 1988; Hurricane Hugo and the Loma Prieta earthquake in 1989 and Typhoon Mireille in 1991. The first generation of catastrophe models were based on statistical analysis of historical activity rates.

Initially the adoption of catastrophe models within the insurance and reinsurance industry was slow. One reason was that the models predicted potential losses from theoretical events which were far greater than anything observed historically.

The event that changed this was Hurricane Andrew, which made landfall in Florida in 1992. Within hours of landfall, AIR estimated that insured losses could exceed $13 billion – which was an unprecedented figure. The eventual Property Claims Service (PCS) estimate was $15.5 billion.

Hurricane Andrew spawned the adoption of catastrophe models in the insurance and reinsurance industry in two ways:

Firstly: by showing that the magnitude of losses predicted by the models were at least feasible (even if in Andrew and the 1994 Northridge Earthquake the actual modelled loss estimates were inaccurate). Further, modelling firms were able to show that a slightly different track for Andrew (e.g. through downtown Miami) would have produced materially higher losses.

Secondly: by the changes it made to the macroeconomics of the insurance industry. Andrew caused the insolvency of a number of insurers and severe financial losses to a number of other insurers and reinsurers. The management of these insurers, confronted with unexpected levels of loss (at a time of balance sheet pressure due to developing prior losses), and under pressure from shareholders, rating agencies and regulators, embraced more scientific ways of assessing and estimating their exposures. In addition, the market opportunities due to the crunch in capacity caused by the failures and by other market players reducing (or even withdrawing) their involvement in catastrophe exposed areas, led to the emergence of a new breed of reinsurers. This was the second wave of Bermudan start-ups the so-called “Class of 1992” (the first wave being founded in the mid 1980s in response to a capacity shortage in US Excess Casualty and D&O). These mono-line catastrophe reinsurers adopted an extremely model focused approach to underwriting.

Since around 1995, the growing role of catastrophe bonds in spreading some catastrophe risk directly within the financial markets has also helped the rise of catastrophe models. Sophisticated financial investors wish to be able to use objective, quantitative methods to assess the financial risks on the bonds.

The soft market in the late 1990s made life difficult for technically driven, model led underwriters, although the three major European windstorms at the end of that decade – Anatol, Lothar and Martin - proved the ability of the modelling firms to rapidly and accurately assess aggregate losses (albeit that individual insurers losses proved more difficult to model). During this period catastrophe modelling firms were developing a second generation of empirical models calibrated on actual losses.

The World Trade Centre attack in 2001 again provided a two-fold impetus to the adoption of catastrophe modelling. The attacks demonstrated again the importance of understanding and modelling accumulations. Further they bought an end to the soft market and led to a third wave of Bermudan start-ups (the Class of 2001). During this period a third and more complex generation of catastrophe models was developed using numerical/parametric modelling simulating physical processes.

The 2004 Boxing Day Tsunami – while having a relatively low level of insured loss showed the devastating potential of seismic activity to cause huge loss of life, and lead to a re-focus on so-called mega-catastrophes.

Hurricane Katrina – and the unprecedented levels of losses arising - has led to increased pressure from regulators and particularly rating agencies for companies to assess their exposures more accurately and to disclose those assessments. It has also led to a further wave of start-ups, the Bermuda Class of 2005.

2.2. STRUCTURE OF CATASTROPHE MODELS

Catastrophe Modelling versus traditional approaches

Traditional actuarial/underwriter pricing and risk assessment is based on historically observed losses – i.e. a burning cost approach, sometimes adjusted on a relatively crude basis for changes in portfolio over time.

Although this approach may work for a high frequency, low severity risk it is much less appropriate for a low frequency, high severity risk. This is because the observed losses may not be reflective of the true underlying risks as the period over which losses have been observed may be much lower than the return period of the losses under consideration.

In simple terms – a 10-year burning cost model is unlikely to be a reliable method of pricing for earthquake risk on a fault with a 100-year return period.

A catastrophe modelling approach may start with historical events, but often over a much longer timescale (sometimes decades or centuries). This is used as a basis create other possible future events including ones that have never been observed historically.

In addition the catastrophe modelling approach enables allowance to be made for:

- Changing frequencies of events over time
- Changing severity of impact of events
- Changes in portfolio (in a much more detailed way than crude “as-if” calculations)

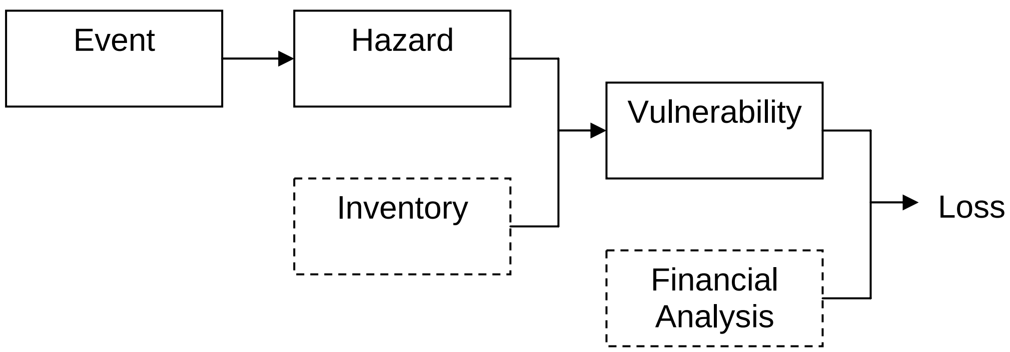
These allowances can be based on the latest research in areas such as: seismology; meteorology; hydrodynamics; structural and geotechnical engineering and can factor in factors such as: building codes; construction types; engineering surveys and loss mitigation.

Basic Structure

Catastrophe models have a number of basic modules:

- Event module
  A database of stochastic events (the event set) with each event defined by its physical parameters, location and annual probability/frequency of occurrence
- Hazard module
  This module determines the hazard of each event at each location. The hazard is the consequence of the event that causes damage – for a hurricane it is the wind at ground level, for an earthquake the ground shaking
- Inventory (or exposure) module
  A detailed exposure database of the insured systems and structures. As well as location this will include further details such as age, occupancy, construction
- Vulnerability module
  Vulnerability can be defined as the degree of loss to a particular system or structure resulting from exposure to a given hazard (often expressed as a percentage of sum insured)
- Financial Analysis module
  Uses a database of policy conditions (limits, excess, sub limits, coverage terms) to translate this loss into an insured loss

Of these modules, two, the Inventory and Financial Analysis modules, rely primarily on data input by the user of the models. The other three modules represent the engine of the catastrophe model, with the Event and Hazard modules being based on seismological and meteorological assessment and the Vulnerability module on engineering assessment.



2.3. ACTUARIES AND CATASTROPHE MODELS

Typically actuaries are users of the outputs of catastrophe models, with the operation of the models themselves a separate and increasingly specialised discipline which sits alongside underwriters and actuaries.

Uses of Catastrophe Models

Actuaries increasingly use catastrophe models in many areas of their work:

- Aggregate modelling

One of the most common uses of catastrophe models is aggregate modelling. Companies use catastrophe models to assess for a given peril (e.g. California earthquake) and given portfolio (typically either a line of business, a legal entity or their whole book) their estimated loss to that peril at different return periods (e.g. 1 in 10 years, 1 in 50 years, 1 in 200 years).

Companies will then set acceptable limits for these losses according to their risk tolerance. E.g. a company might stipulate that its 1 in 100 year loss from a Tokyo earthquake should not exceed $50M – and the underwriters (as well as potentially the reinsurance buyers if the limits are set net of reinsurance) will be required to manage the book within these limits and regularly report on their adherence to these guidelines.

A particular example is Lloyd’s Realistic Disaster Scenarios where Lloyd’s syndicates are required to report to their Managing Agency Boards and to Lloyd’s on their exposure to a series of events (not perils), which are specified in detail. Lloyd’s in turn use these common events to enable them to more readily assess the aggregate exposure across Lloyd’s (and hence the Central Fund exposure). Adding syndicates’ 1 in 250 year events would give a misleading assessment, as each syndicate’s 1 in 250 year event is likely to be different.

- Pricing

Catastrophe models are used by actuaries in reinsurance companies and brokers when pricing catastrophe or event excess of loss reinsurance. As explained above many of the newer Bermudan reinsurers since Hurricane Andrew have built their business models around the use of catastrophe models.

Catastrophe models are also increasingly used in assessing the catastrophe components of other risks both reinsurance (e.g. pro-rata and per risk property or energy excess of loss covers which give implicit catastrophe cover that may be restricted by an event limit) and insurance (e.g. catastrophe exposed property, marine or energy risks). In these assessments catastrophe modelling is often complementary to, rather than a replacement for, a traditional burning cost or exposure rating approach which is still used for the non-catastrophe part of the premium.

- Planning/Forecasting

When planning for the next fiscal or underwriting year, or even when forecasting for the remainder of the current year, the mean losses projected by a catastrophe model for a portfolio may be used to set the expected loss cost for the catastrophe part of losses. Note that catastrophe models are typically calibrated to larger historic events and can be potentially be less accurate in forecasting small, higher frequency events. This in turn can lead to distortions in the average aggregate annual loss and so care needs to be taken in using catastrophe models for this purpose.

- Reserving – assessment of events

Many companies make use of catastrophe models to assess the impact of major catastrophe events. This is best illustrated by considering hurricanes, where the way in which the catastrophe models are used depends on how long before or after landfall the assessment is being made.

From the time a tropical depression reaches maximum sustained surface wind speeds of 17 metres per second (around 34 knots or 39 miles per hour) it becomes a named tropical storm (and if the intensity continues to increase eventually becomes a hurricane). The potential track and intensity of the hurricane is forecast for several days (sometimes even well over a week) before its eventual landfall.

Once such a hurricane is within around 24 hours of estimated landfall, modelling firms will begin to issue the name/number of events in their existing event set which most closely approximate the predicted landfall of the hurricane. Companies can run these against their own portfolio to assess their expected loss from the hurricane. These event identifiers are refined up to and immediately after landfall.

A few days after landfall, modelling firms issue a hazard footprint of the hurricane, which is a detailed assessment of the windspeed intensity of the hurricane that equates to the simulated output of both the Event and Hazard modules. This can then be run on companies' own portfolios.

In addition, the modelling firms and some other industry bodies will issue market loss assessments for the hurricane including total and insured losses and many companies will estimate their exposures by using some form of market share calculation.

In practice companies that rely exclusively on either of these methods are likely to find that their eventual loss estimates differ significantly from their initial estimates. This can be observed historically by e.g. tracing the developments in most companies published assessments of the 2004 and 2005 hurricanes. The event sets in existing catastrophe models while extensive enough to give a good representation of potential exposures are not extensive enough to be likely to give a good match for the exact circumstances of any actual hurricane, while a market share approach is likely to be subject to significant basis risk.

A reliable estimate of hurricane losses to a portfolio involves a contract-by-contract approach. Initial estimates for each contract can be based on catastrophe modelling, but these can then be refined: immediately by underwriters' knowledge of the contract; over the next 1-2 weeks by discussions with brokers and cedants; and over time by detailed on-the-ground loss adjuster assessments.

- Capital allocation and assessment

The use of catastrophe models by UK actuaries has significantly increased due to the introduction of the Individual Capital Adequacy Standard (ICAS) regime for capital assessment. For many companies writing catastrophe exposed business, their catastrophe exposures are perhaps the most crucial element of their 1 in 40 (97.5%) and more especially 1 in 200 year (99.5%) losses.

More generally, catastrophe models are likely to be a key element of any form of capital assessment:

Internally: e.g. for the purposes of capital allocation/setting profit targets – particularly if that assessment relies on the tail of loss distributions rather than on volatility of results

Externally: both by regulators but also increasingly by rating agencies who, particularly in the light of Hurricane Katrina are demanding detailed access to the output of companies' catastrophe modelling (as well as wanting to understand the quality of that modelling).

- Reinsurance purchase

Just as reinsurers use catastrophe models to price inwards reinsurance, cedants will use catastrophe models to assess the appropriate structure of their outwards programme. This assessment will include the level of vertical cover required to protect against a single severe event and the number of reinstatements required for each layer to protect adequately against multiple events. The models are then used by the cedant to compare technical prices of outwards treaties to market prices. They can also be used to assess the capital efficiency and the effectiveness in risk mitigation of a range of programme alternatives.

Communication

Actuaries in fields such as reserving, pricing and capital assessment understand the requirement for the users of their work to understand the large number of assumptions made, the sensitivity of the answer to those assumptions, and the overall uncertainty within their recommendations. The recommendations themselves may depend on the use to which the actuaries report will be put. The new version of GN12 as well as the report of the GRIT Working Party has emphasised the importance of communication.

All of the above apply to catastrophe modelling and the communication of uncertainty is even more of a challenge for actuaries using catastrophe modelling than in other areas such as traditional chain-ladder reserving:

- The uncertainty is greater than in reserving. As well as communicating the uncertainty and assumptions in their own work, actuaries need first of all to understand and be able to communicate the assumptions being made on their behalf by the modelling firms
- Much of reserving has traditionally been concerned with the mean or median of a distribution of possible outcomes. Much use of catastrophe models relies on the tail assumptions (i.e. the extreme of the distribution). Often in the tail, secondary and parameter uncertainty are much greater. In addition, considerations involving inwards or outwards excess of loss reinsurance (which are common in work involving catastrophe modelling) are often highly geared so increasing the importance of understanding and communicating the uncertainty of possible outcomes.

- Frequencies with higher return periods (although not severity assessments of known events) are very hard to back-validate. Mean reserves methods can be reasonably tested over a 5-10 year period but such validation does not work for an assessment of 1 in 100 year exposures. This inability to validate the projected results highlights the importance of effectively communicating the uncertainty of results from catastrophe models.

As part of their communication actuaries need to consider a number of different parties:

- Catastrophe modelling teams: who should be able to impart an understanding of the completeness and quality of the raw data they are receiving as well as to impart an understanding of the models they are using
- Catastrophe model providers: to understand the assumptions inherent in the models being used. As an example, all of the modelling firms are altering their models in light of the 2004 and 2005 hurricanes including in areas such as frequency and severity that we discuss later in this paper. It is important for the actuary to understand what modifications have and have not been made to the models so that they can decide what additional adjustments they may choose to make themselves. In addition actuaries need to understand the modelling methodologies used and mathematical approximations made
- Underwriters: who should be able to perform a reasonability check on the projected results of the catastrophe models and discuss with the actuaries how the catastrophe modelling output interacts with other underwriting considerations
- Users of actuarial output based on catastrophe models: to communicate the uncertainty involved, the assumptions made in modelling and any additional assumptions the actuary has made in using the modelled outputs

In the remainder of this paper, we discuss the areas of: Data, Frequency, Severity, Modelling Approaches and Mathematical Approximations, to give readers of this paper some ideas as to how they can start these discussions.

3 DATA ISSUES

3.1. INTRODUCTION

As with most actuarial modelling, the output of a catastrophe model can only be as accurate as the initial data input to the model. Catastrophe models rely on huge quantities of data of variable quality and so it is vital for the actuary as users of the outputs to understand the data inputs.

Data must be both accurate and complete if results are to be reliable; an additional factor is the level of detail captured within the data - the more detailed the data capture, the better the model results will reflect that specific portfolio rather than the average portfolio.

When data is missing, many modellers select the “unknown” or “default” options. Actuaries need to understand the default options in the models and the sensitivity of the models to the different input options i.e. the hierarchy of the key assumptions. The order in which these inputs affect the results is important. There may be marginal benefit in collecting more data if it is not likely to impact the results significantly. Actuaries then need to communicate the uncertainties that arise due to these data issues. This will allow users of the results, including actuaries, to take account of the uncertainties due to data when making their decisions.

Developments in recent years, especially the North Atlantic hurricanes of 2004 and 2005 have helped the focus on and momentum in capturing better data. After each major market event, in the light of actual versus modelled losses, insurers and model providers tend to reassess: the adequacy and accuracy of data received; the importance of the different data elements and the appropriateness of the default parameters adopted in the model when no data is provided in a particular category.

In many instances the data and the models develop in tandem. The models cannot develop without additional data items being collected, and the data items will not be collected if the models do not use them. In many instances data fields are collected in the hope that a firm link to claims can be demonstrated in the near future and the models can then develop accordingly.

To ascertain the pertinent issues relating to data used by catastrophe models, the Working Party held discussions with a number of individuals who have significant experience with using catastrophe models. We tried to gather common threads from the discussions on key issues relating to data and their associated implications.

3.2. DISCUSSION THEMES

We summarise below the main themes from these discussions.

General Comments on Data Quality

From our discussions it is clear that there is a wide variation within the insurance industry (insurers, reinsurers, brokers) in the amount of effort spent towards collecting data and into ensuring its quality for catastrophe modelling. There are a number of issues with data collection and quality:

- The size of the catastrophe (related) modelling teams across the industry can range from a small number of people who maintain the basic running of the models, to a large team involved in development and enhancements of the usage of the modelling as well as the provision of detailed management information. The level, knowledge and experience of the people dealing with the data collected may also be a factor.

- A large percentage of business is transacted in a concentrated period in the year particularly at the main (re)insurance renewal seasons. This can place significant time and resource constraints on model users.
- The importance attached to accumulation monitoring and catastrophe modelling compared to other competing priorities in the business e.g. top line growth, bottom line performance varies between companies.
- For those companies that insist on a high standard of data, market pressures and commercial realities may influence their ability to insist on receiving this data. As remarked in section 2.1. above, a soft insurance market acts as a hindrance to more detailed modelling
- Improving the standard of data input to models can involve significant efforts in auditing, cleaning up and formatting the initial data received. This has to be balanced against the benefits received, particularly for smaller companies. Some insurers outsource this process either an external party or insource to other parts of the organisation (including offshore). For these approaches to work well, the steps in the process that are not undertaken by the local catastrophe modelling team should be clearly identified and have process specifications that avoid the need for any subjective judgements by the third party / off shore team
- Companies can be burdened with legacy IT systems that cannot easily store the full level of data capture required for detailed modelling.
- Insurers are not always prepared to pass on to their reinsurers the full detailed data set. This is even more of an issue for reinsurers seeking retrocession, where the retrocessionaire might feel that by providing a full and detailed data set they are giving valuable and commercially sensitive information to a potential competitor. Consequently standards can be lower in data provided by insurers/reinsurers to their reinsurers/retrocessionaries. Furthermore there is no accepted standard to how such data should be supplied. For reinsurance, the accurate monitoring of aggregates is made more difficult as the underlying exposure is likely to have changed since the data was collected, and the reinsurer must collate large volumes of data from a range of sources.

The more sophisticated reinsurers will evaluate the quantity and quality of data received as part of their underwriting process. Companies with inadequate data may be subject to loadings on modelled outputs or even to declinature. These loadings can reflect the uncertainty in the data provided as where data is missing altogether or does not include full details, reinsurers will typically make conservative assumptions, and may include a greater loading in their technical rate. They also represent an evaluation of the way in which aggregates are monitored and managed by the cedant. Consequently clients with superior data capture and quality may find that more reinsurance markets are prepared to protect them, and their rates might be more favourable compared to clients with poorer data. However, others feel that these loadings for inadequate data are not enough, as the provision of more detailed data leads to more questions and problems which in turn lead to a higher price.

Some interviewees suggested to us that the market could establish both standardised data formats and some form of central repository to contain data and to avoid duplication of effort. It is not clear how viable or successful this is likely to be.

Location Data

Even within a single company, the level of quality and detail in captured data can vary significantly by territory - for example the data captured for a Florida portfolio might be far more detailed than for a Caribbean portfolio, although both could be impacted by the same event.

The quality of location data received varies significantly by region and peril. In part, this difference is driven by the level of data that can be used within the catastrophe modelling software - typically insurers do not want to capture data unless it can be used in the current version of the modelling software:

- The level of detail available from the US has improved significantly in last few years partly due to the recent hurricanes and is agreed to be significantly better than that in the rest of the world.
- Most US insurers are able to provide street level exposure data to their reinsurers, although insurers without exposure to either California earthquake or US East Coast hurricanes are held to less strict data standards. Existing models produce losses which vary significantly by address within a zip code e.g. earthquake losses differ by soil type
- Outside the US, exposure data is usually aggregated into CRESTA zones (see Glossary).
- Many insurers in the UK are providing data in finer resolution than CRESTA zone, to enable more accurate analysis of flood and windstorm loss potential. Detailed flood mapping has meant that models can be sensitive to a very detailed resolution of risk location. Northern European countries tend not to have as detailed information held by insurers or provided to reinsurers. Southern European countries can provide very detailed information around some earthquake/volcanic areas, but outside of this, the quality and quantity of data tends to be poor in these countries.
- The rest of the world present more challenges e.g. the address system in Japan is difficult to interpret as buildings are numbered by the order in which they are built.
- Exposure data is difficult to obtain in countries where there is no commercially available model (China is one example)

Apart from areas impacted by the North Atlantic windstorms, there is currently little impetus and effort to improve exposure data quality. Most participants think that it will probably take a large market event such as a California or New Madrid earthquake or European windstorm to instigate further research and development in this area.

Other data elements

- Risk characteristics apart from line of business are generally not captured and the line of business splits are very broad (e.g. residential/commercial/industrial /agricultural).
- There is quite good construction information in California for earthquake risks but there is little data to calibrate the models given lack of recent earthquake experience.
- Many interviewees commented to us that occupancy should be a primary driver of the modelling but that there is no universal standard for data collection or consistent "coding" in the market.

- Most insurers have to manually “re-code” or translate into finer detail both occupancy and construction type information from the descriptions provided. This is a huge effort often taking up the majority of the modellers’ time. The likely inconsistency in coding of the risks can have a significant impact in the modelling.
- A common problem encountered is under reporting of sum insured as a result of inflation not being valued accurately. For Hurricane Katrina, consensus estimates were that reported sum insureds were on average around 25% less than the replacement value. Some insurers and reinsurers have made explicit adjustments for underestimation.
- The value of a property is not considered the best rating factor on its own. The number of rooms or floor space will provide better information.

4. FREQUENCY OF LOSSES

In this section we consider the question of frequency of catastrophic events, concentrating on Atlantic tropical storms as the area of greatest topicality and greatest loss to the insurance industry. This includes the frequency of different intensity of events (e.g. the conditional probability of a tropical storm developing into a major hurricane).

4.1. INTRODUCTION TO HURRICANE FREQUENCY

Over the past few hurricane seasons, significantly more severe storms have occurred. In 2004, insured losses from tropical cyclones and hurricanes exceeded US$25bn in what was considered by most at the time to be an unusually severe season with the joint highest ever number of 8 landfalling US storms (tying with 1916). However, 2005 proved to be even more extreme and, despite "only" having 7 US landfalling storms set a number of other records, including:

- The highest number of named storms – 28. The previous record was 21 in 1993
- The highest number of hurricanes – 14. The previous record was 12 in 1969
- The joint (with 1950) highest number of major hurricanes – 7
- The highest number of category 5 hurricanes – 3 (Katrina, Rita, Wilma). The previous records was 2 in 1960 and 1961
- The lowest pressure ever measured in the Atlantic basin – 882 mb (Wilma). The previous record was 888 mb set by Hurricane Gilbert in 1988
- The highest damages both in aggregate and from a single storm (Katrina)
- The most Easterly and Northerly tropical cyclone (Vince). Vince formed near Madeira and also became the first ever tropical storm to strike the Iberian peninsular
- The first ever tropical storm in Canary Islands (Delta)

This has given an additional focus on users of catastrophe models to understand:

- The trends in tropical storm and hurricane frequency
- How such trends are catered for in catastrophe models

Scientists have identified a number of factors that influence hurricane frequency including sea surface temperature, wind shear, atmospheric stratification and the depth reached by warm surface waters.

We consider in turn three major interactions which operate over different timescales influencing these factors and hence hurricane frequency:

- El Niño and La Niña are responsible for short-term changes (over periods of 2-7 years), which directly impact the number of hurricanes experienced mainly by their effect on wind shear
- The Atlantic Multidecadal Oscillation is responsible for medium-term phase changes (with a 20-40 year phase period) in storm frequency due mainly to changes in the sea surface temperature
- Climate change may have a significant effect on hurricane frequency and intensity

4.2. SHORT TERM EFFECTS – EL NIÑO SOUTHERN OSCILLATION (ENSO)

El Niño is Spanish for "the little boy" and is used to refer to the Christ child. The El Niño phenomenon was first named by Peruvian fisherman who noticed every few years particularly poor fishing conditions around Christmas. This was due to unseasonably warm and also nutrient poor waters which replaced the usual flow of colder nutrient rich waters known as the Humboldt current and which are the most productive marine ecosystem in the world.

El Niño is now used to describe a more extensive oceanic anomaly consisting of major positive temperature fluctuations in the surface waters of the tropical Eastern Pacific. The first signs of an El Niño are an unusual warming of the water in the tropical Pacific Ocean. In turn, this results in increases in rising warm air, changes in the air pressure patterns and shifts in the high-level winds that direct the movement of weather.

El Niño and its opposite condition La Niña (with colder than normal temperatures in the Central and Eastern Pacific) are linked closely with an atmospheric phenomenon – the Southern Oscillation – of fluctuations in air pressure between Tahiti and Darwin (with sustained negative differences associated with El Niño events).

The coupled oceanic-atmospheric phenomenon is now known as ENSO. Over time it has become clear it is a complex phenomenon which has a series of wide ranging effects on world climate and which is the best known source of inter-annual climate variability. Analysis of ancient tropical Pacific coral skeletons has led researchers to conclude that ENSO has been happening for over 100,000 years.

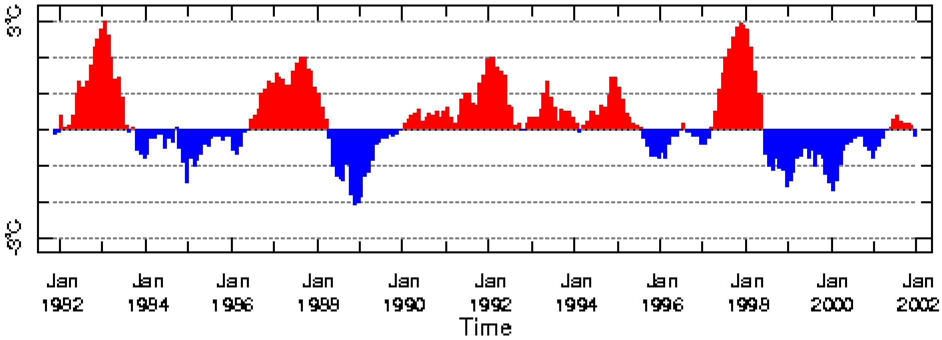
El Niño has historically occurred at irregular intervals of 2-7 years and has usually lasted one or two years. The La Niña condition often follows the El Niño, especially when the latter is strong.

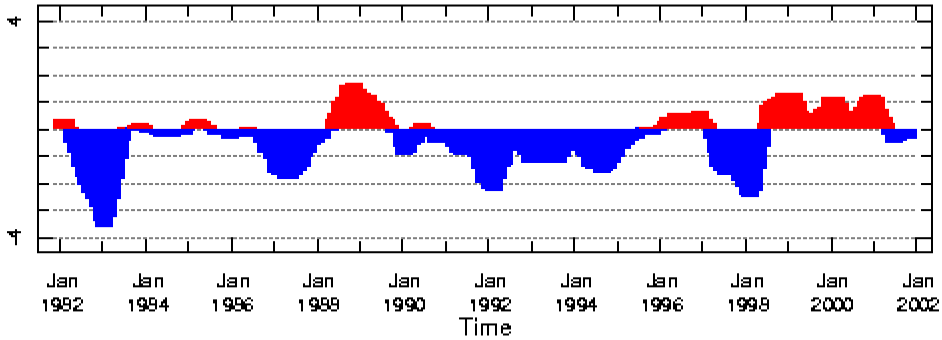
Note that different researchers use different definitions for ENSO phases and so attribute different statuses to different years. The following data is taken from the International Research Institute for Climate and Society (IRI) website (see References) which produced the following classifications for 1950-2001. They define an El Niño or a La Niña year in relation to the Atlantic hurricane season using the Niño3.4 index (5S-5N; 170W-120W) during the months of August, September, October (ASO). The 12 years with the largest (smallest) values of this index over the period are defined as El Niño (La Niña) years (see Figure 2), the other years are called neutral years.

El Niño years	1951, 1957, 1963, 1965, 1969, 1972, 1976, 1982, 1986, 1987, 1991, 1997
La Niña years	1950, 1954, 1955, 1964, 1970, 1971, 1973, 1975, 1988, 1995, 1998, 1999

Recently: an El Niño episode occurred in 2002; a rather weak El Niño occurred in 2004 (see below); we have been in an ENSO-neutral state for most of 2005 and 2006.

The graphs below from the IRI site show the EN (top graph) and SO (bottom graph) separately for a 20 year period and demonstrates the link of the two phenomena:





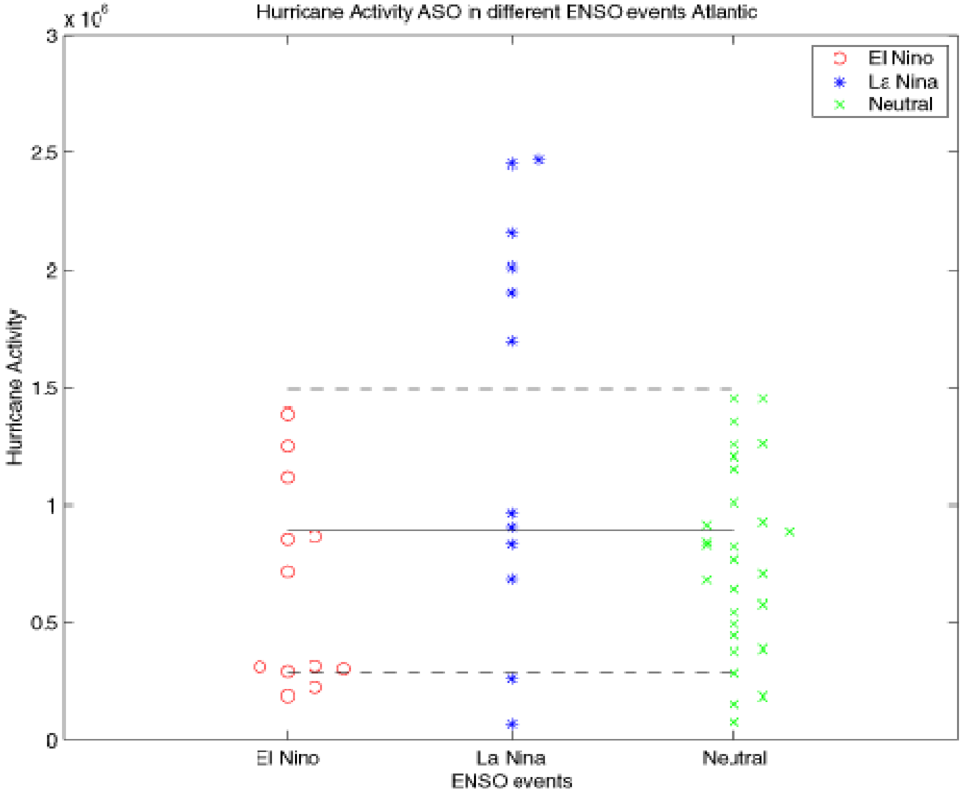
Researchers continue to investigate interactions between hurricane frequency and El Niño/La Niña events. In general, warm El Niño events are characterised by a decrease in tropical storms and hurricanes in the Atlantic, Gulf of Mexico and the Caribbean Sea, and more tropical storms and hurricanes in the eastern Pacific. The opposite occurs during La Niña years.

The primary explanation for the decline in Atlantic hurricane frequency during El Niño years is due to the increased wind shear in the environment. In El Niño years, the wind patterns are aligned in such a way that the vertical wind shear is increased over the Caribbean and Atlantic and decreased over the Eastern Pacific.

Vertical wind shear can be defined as the amount of change in the wind's direction or speed with increasing altitude and is now known to be a major factor in tropical storm development. When wind shear is low or absent, the storms that are part of the nascent system develop vertically and the latent heat from condensations is released directly above the storm helping their development into the familiar spiral pattern around a central eye. When wind shear is high the latent energy is released over a wider area, dispersing its power and preventing the organisation of the storm. Increased wind shear therefore helps to prevent tropical disturbances from developing into hurricanes. Thus ENSO has a particularly strong effect on formation and landfall of major hurricanes as low wind shear is required for these systems to develop and be sustained.

The graph below (source: IRI) shows accumulated hurricane energy in each year (a similar measure to the ACE index defined below). 3 out of the 12 El Niño years have an above average energy compared to 8 out of 12 years La Niña years.

Other graphs from the same source show that over the same period, only 2 El Niño but 8 La Niña years have an above average number of major hurricanes (Category 3 and above).



Our own analysis of 1950-2005 data – see Appendix 3 for data sources and for full data and analysis – using our own ENSO definitions shows the effects of the ENSO oscillation. On average a La Niña year has:

- 60% higher ACE index (see section 4.6. below) than an El Niño year and 10% higher than a neutral year
- Around 30% more tropical storms and hurricanes than an El Niño year, but around the same as a neutral year
- 37% more chance of a named storm becoming a major hurricane than an El Niño year and 30% more chance than a neutral year
- As a result of the above, 3.4 times as many major hurricanes as an El Niño year and 2.7 times as many as a neutral year – demonstrating the statement above that the effect on hurricane development is more significant than on tropical storm formation

This analysis is one-way – i.e. we have not controlled for other factors such as the AMO.

The Accumulated Cyclone Energy (ACE) index is the sum of squares of six-hourly maximum sustained wind speeds for all systems while at least tropical storms and therefore functions as a single measure of frequency, severity and duration of storms in a season

4.3. MEDIUM TERM EFFECTS – ATLANTIC MULTIDECADAL OSCILLATION (AMO)

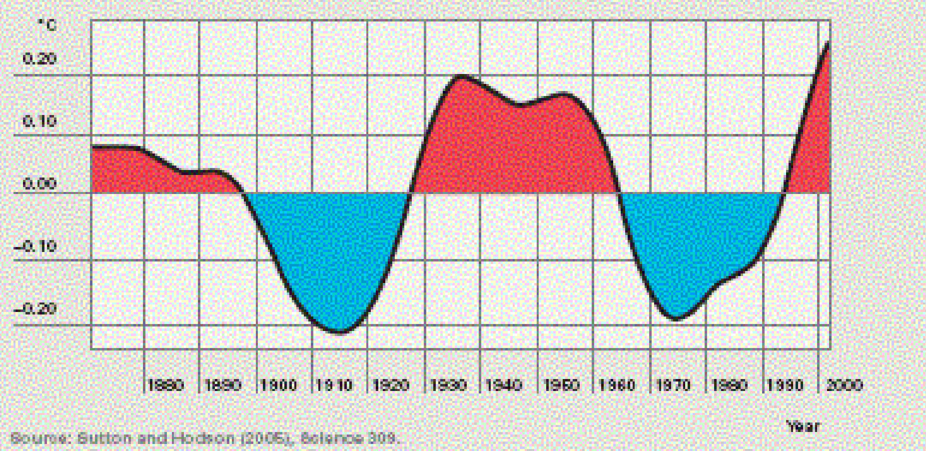
The AMO is an ongoing series of long-duration changes in the sea surface temperature of the North Atlantic Ocean, with cool and warm phases that may last for 20-40 years at a time and a difference of about 1°F between extremes. AMO cycles have been observed for the last 150 years; however some researchers have claimed that analysis of tree rings and ice cores implies that oscillations similar to those observed instrumentally have been occurring for at least the last millennium.

The AMO phenomenon is believed to be associated with oscillations in the more wide ranging Thermohaline Circulation (THC). The THC is a multi-dimensional global scale circulation of oceanic waters arising from temperature and salinity differences. It is often characterised as a slow moving "conveyor belt" in which, over an interdecadal timescale, a continuous flow of upper-level water is drawn from the tropical Atlantic north toward the Pole. There, the water cools, sinks, and cycles back to the southern oceans in deepwater currents.

The graph below taken from Sutton and Hodson (see references) shows the time series and pattern of North Atlantic sea surface temperatures that characterize the AMO during the period 1871 to 2003 calculated by averaging annual mean sea surface temperatures region (0°N to 60°N, 75°W to 7.5°W). These are then detrended and compared to the mean.

There are AMO warm phases in the late 19th century and from 1931 to 1960; cool phases occur from 1905 to 1925 and from 1965/1970 to 1994. We have been in a warm phase since 1995, which can be expected to continue for between 15 and 30 years. As with ENSO events, different scientists produce slightly different attributions of the exact start and ends of the AMO phases, but the broad patterns tends to be consistent with the graph below.

Fig. 5 Atlantic Multidecadal Oscillation (AMO)

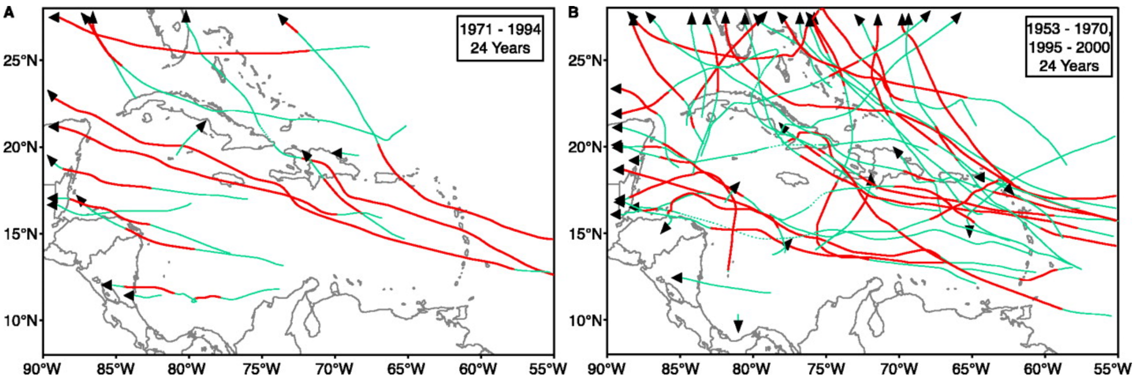


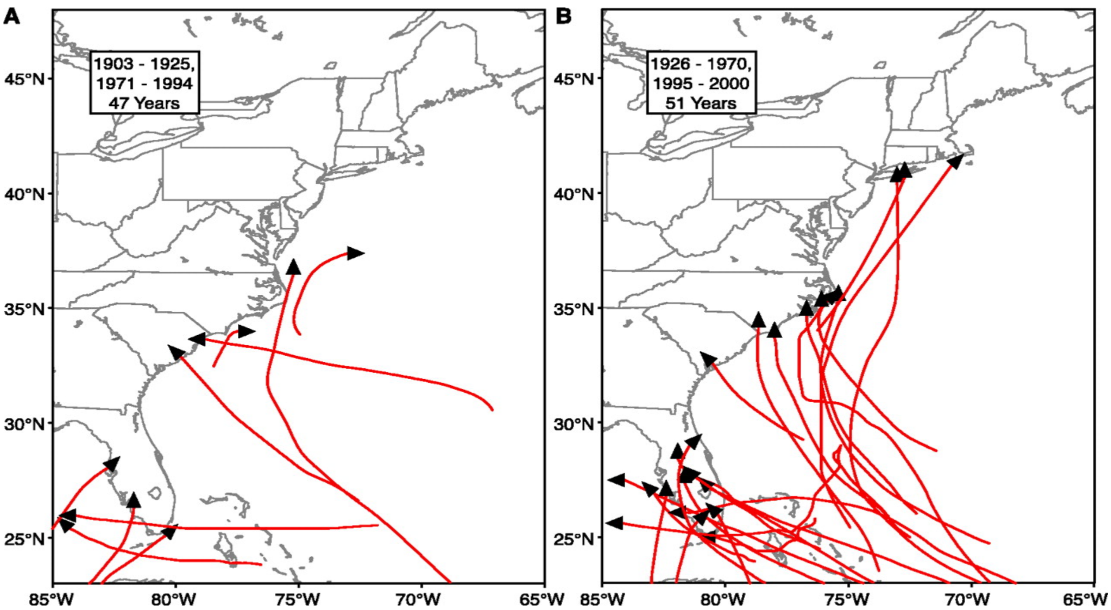
Source: Sutton and Hodson (2005), Science 309.

The warmer sea surface temperatures in the tropical Atlantic also appear to be linked with similar multidecadal trends in wind shear and conducive winds. An active multidecadal signal, or warm phase of the AMO, is associated with: warmer sea surface temperatures in the tropical Atlantic region; reduced vertical wind shear in the deep tropics over the central North Atlantic; and an African Easterly Jet (AEJ) that is favourable for promoting the development and intensification of tropical disturbances moving westward off the coast of Africa.

There appears to be a very strong link between the phases of the AMO and tropical storm and hurricane formation. High sea temperatures are a key ingredient in windstorms. Hurricanes gain their strength from ocean moisture and heat. When the sea surface temperature reaches 26°C (80°F) or higher, it crosses a threshold for hurricane formation. Enough moisture evaporates into the atmosphere to trigger thunderstorms, which can in turn become tropical storms and hurricanes. The heat, released as water vapour, condenses in rainfall and fuels intensifying hurricanes.

The diagrams below are taken from Goldenberg et al (2001) – see references. The first pair of diagrams shows Caribbean hurricanes and the second pair major US East Coast landfalling hurricanes. In each pair the periods of time in each diagram are effectively the same but the left hand side is a cold phase of the AMO and the right hand pair a warm phase (by Goldenberg's definition). These diagrams illustrate starkly the huge difference in hurricane activity between the two phases, which would be even more marked if the period 2001-2005 was added to the right hand side.





Our own one-way analysis – see Appendix 3 – using the same phase definitions shows clearly that the effect of the AMO phases with a year in the warmer phase of the AMO having on average (compared to a year in the colder phase):

- Twice the ACE index (see Hurricane Forecasts below)
- 40% more named storms and hurricanes
- 80% more chance of a named storm becoming a major hurricane
- As a result of the above, 2.5 times as many major hurricanes

4.4. LONG TERM EFFECTS – CLIMATE CHANGE

Another potential influence on hurricane activity is climate change. The world is warming, brought on by industrial and automotive release of carbon dioxide and other greenhouse gasses, causing increases in sea surface temperature and sea level, as well as changes in weather patterns and precipitation.

There is huge debate among scientists as to whether or not climate change is driving the increased frequency of hurricanes (see References for more details).

Many climatic scientists say that the natural, cyclic phenomena that affect ocean currents and atmospheric temperature – in particular ENSO and AMO – are responsible for most of the observed changes in storm intensity and that there is as yet no firm scientific evidence for an observable link between global warming and hurricane frequency.

However, many other climatic scientists are now pointing to global warming as the offender for increasingly vicious hurricanes worldwide. Both scientific theory and computer modelling predict that as human activities heat the world, warmer sea-surface temperatures will fuel hurricanes, increasing wind speeds and rainfall. Several new studies (see below) suggest that climate change has already made hurricanes grow stronger, but the strongest hurricanes in the present climate may be upstaged by even more intense hurricanes over the next century as increasing levels of greenhouse gases in the atmosphere warms the earth's climate.

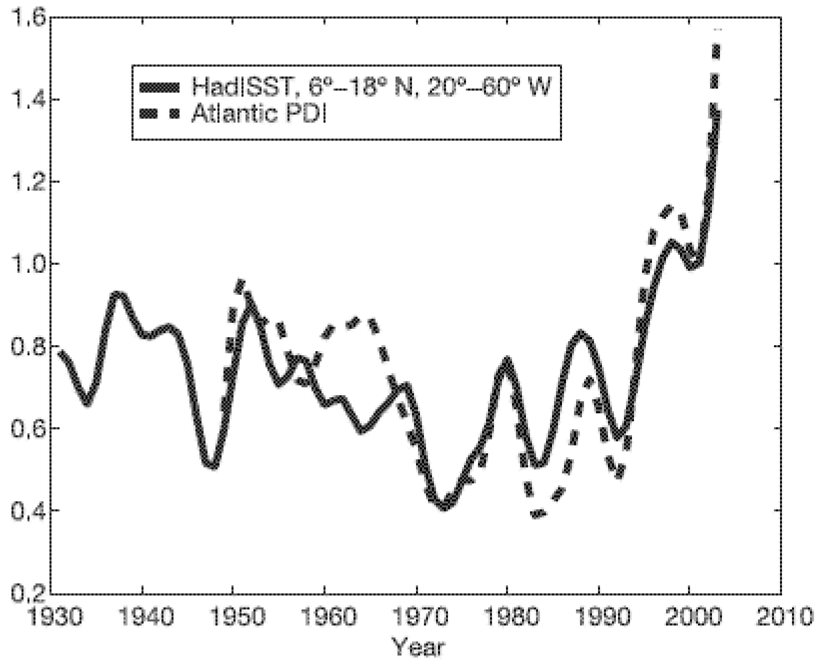
Over the past century overall seawater temperature has risen by between 0.2 C and 0.6 C, and global sea levels have risen 1.25 inches in the past ten years; proof that oceans are getting warmer and expanding.

Two recent papers, the first by Emanuel and the second by Webster et al (see References), have been seen as arguing for a strong link between global warming and increases in the intensity of tropical cyclones due to rises in equatorial sea surface temperature.

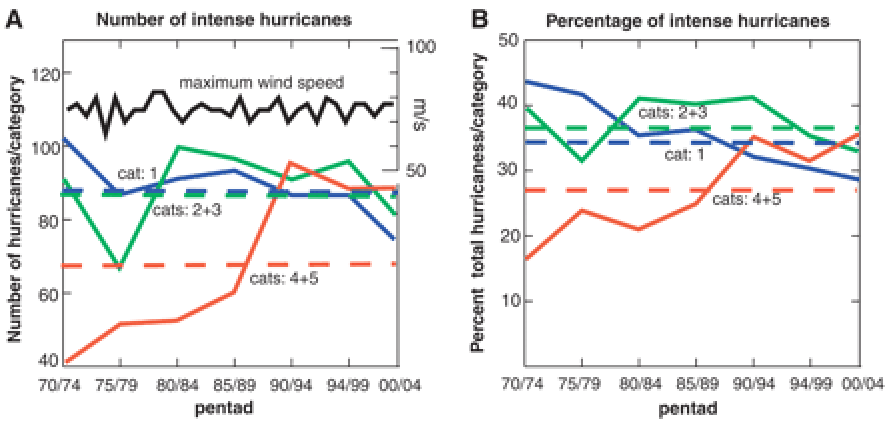
Emanuel reported that current hurricanes are more powerful than those of 30 years ago. To gauge storm intensity, Emanuel developed a measure he calls the power-dissipation index (PDI). For each Northern Hemisphere hurricane in the tropical Atlantic and western Pacific over the past century, he used the maximum wind speed and the life span of the storm to calculate a number that estimates the energy expended by a hurricane (the sum over the lifetime of the storm of maximum windspeed cubed). The measurement also relates to the total damage a hurricane can wreak.

The graph below from Emanuel shows an annual comparison of PDI to annual September sea surface temperature. Both datasets have been smoothed and transformed to ease comparison.

The PDI graph shows the AMO as well as shorter-term oscillations likely to be linked to ENSO, but also show that total Atlantic hurricane power dissipation has more than doubled in the past 30 years. In addition there is a very strong statistical relationship between the two time series suggesting that tropical sea surface temperatures exerts a strong control on the PDI. This leads Emanuel to link his observed rise in tropical cyclone intensity to the effect of global warming (although without any directly causal explanation).



Webster et al, examined changes in tropical cyclone number duration and intensity over a number of different cyclone basins and concluded that there was a 30 year trend towards an increase in category 4 and 5 hurricanes/cyclones across all areas despite overall tropical cyclone frequency being largely unchanged (with an increased frequency in the North Atlantic being offset by decreases elsewhere) – see graphs below (which are across all basins). They, like Emanuel, linked this to an upwards trend in sea surface temperatures.



In addition to the direct effect of sea surface temperature increases on hurricane formation, sea levels are rising and will continue to rise as oceans warm and glaciers melt. Rising sea levels means higher storm surges, even from relatively minor storms, causing coastal flooding and erosion and damaging coastal properties so that severity impact of storms could increase even for the same intensity.

4.5. INTERACTIONS BETWEEN EFFECTS

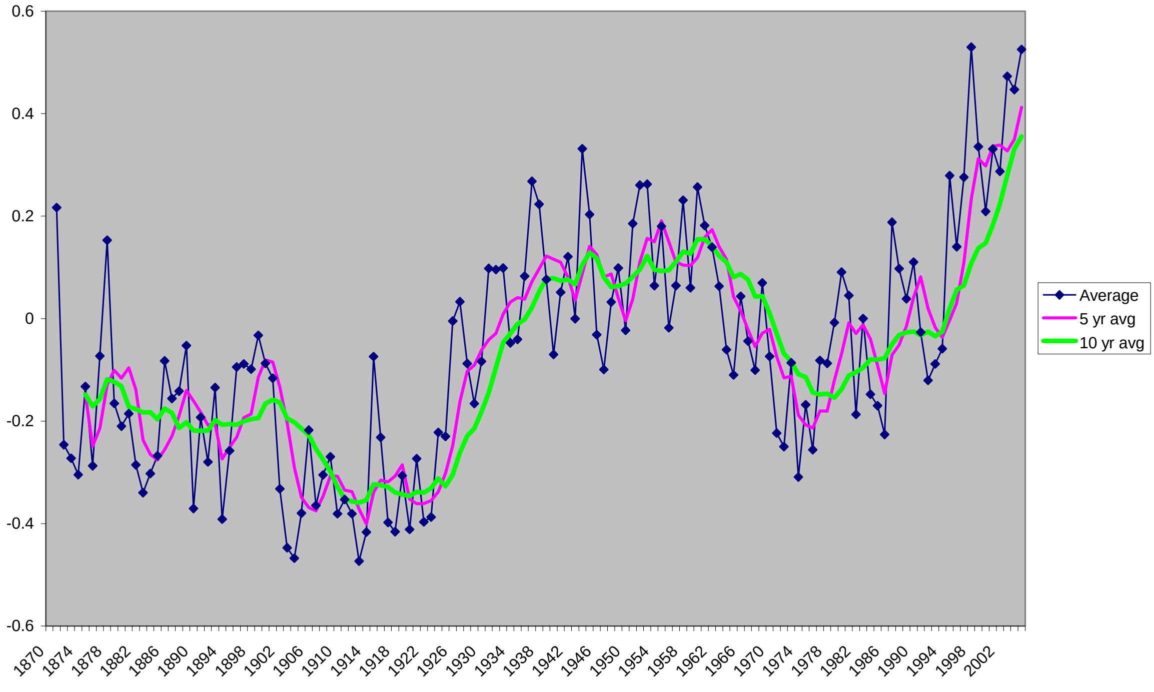
ENSO and AMO

Since 1995, that is in the latest Warm Phase of the AMO, only two years have had below average hurricane activity (1997 and 2002), both of which are strong El Niño years. Weak El Niño conditions also appeared by mid-August 2004, however the enhanced tropical convection normally associated with El Niño did not become established. As a result increased windshear did not occur and the storm season was not mitigated.

There is also evidence of a causal relationship between ENSO and AMO with the warm AMO phases being linked in some 2006 research with weaker ENSO variability.

AMO and Climate Change

In section 4.3. the graph showing the sea surface temperature fluctuations associated with the AMO, which is widely shown in papers on tropical cyclone trends, is in fact detrended. Plotting the raw data (see Data Sources) could be seen as the AMO fluctuations imposed on a linear upwards trend in Atlantic sea surface temperatures. A possible implication of this simple analysis is that the AMO fluctuations do not fully explain the recent rise in sea surface temperatures (and by association the recent increase in hurricane frequency) and that global warming has already had an influence.



As another way of expressing the relative importance of the long-term upward trend to the AMO phases, our own one-way analysis – see Appendix 3 – shows that the ratio of average number of hurricanes between a year in the 1995-2005 warm phase and the previous 1950-1970 warm phase (1.32) is effectively the same as that between the 1950-1970 warm phase and the 1971-1994 cold phase (1.30). For tropical storm numbers, the differential is actually greater between successive warm phases than between a warm to a cold phase. The opposite is true for major hurricanes.

Some very recent research by Mann and Emanuel (see References) has gone further than this and claimed that there is in fact no multidecadal oscillation in Atlantic sea surface temperatures. Instead it claims that the observed pattern in those temperatures can instead be captured by two anthropological (man-made) main factors: global average sea surface temperatures (which show a linear upward trend normally attributed to greenhouse gas emissions) and a reduction from around 1950-1980 in Atlantic sea surface temperatures caused by man-made Northern Hemisphere emissions of aerosols (industrial pollution which reduced after that time due to legislative action). After allowing for these the residual pattern shown no signs of a multidecadal oscillation. Further Emanuel claims that his previous analysis (see above) shows no multidecadal pattern in annual tropical cyclone strength after allowing for Atlantic Sea Surface temperatures, so eliminating the role of other factors believed to vary with the AMO such as vertical wind shear.

Interactions between ENSO, AMO and Climate Change

At present, the relationship between ENSO, AMO and climate change is being investigated, but so far research has been inconclusive, with different models producing different results and with different groups of scientists disputing the relative contributions of the three factors to recent hurricane activity. Since all three phenomena involve large changes in the earth's heat balance, they are likely to be interrelated.

With regard to the impact of climate change on ENSO questions being asked are:

- Will the long term mean ocean temperatures shift towards a more El Niño-like or La Niña-like regime?
- Will El Niño variability (the amplitude and/or the frequency of temperature swings) increase or decrease?
- How will ENSO's impact on weather around the world change?

Some predictions of global warming predict a slowing down (and eventual cessation) of the thermohaline circulation; any slowing down would impact the AMO as well as the NAO (see below).

There is also the possibility of a feedback effect. Hurricanes themselves act on oceanic conditions, churning cold water to the surface and exporting heat to higher latitudes. As a result, scientists have speculated that if global warming does increase hurricane frequency, then global warming will be partly mitigated at the tropics but increased at higher latitudes.

4.6. HURRICANE FORECASTING

A number of bodies now issue forecasts of the upcoming hurricane season, the best known of which are the official forecasts of the National Oceanic and Atmospheric Administration (NOAA) and two independent forecasts: one by Klotzbach and Gray, the other by Saunders and Lea.

NOAA

Forecasts from NOAA are issued mid to late May and early August. Their methodology relies on an assessment of the likely status of a number of oceanic and atmospheric conditions that are believed to influence tropical storm formation and development.

For example, their May 2006 forecast was based on a number of aspects associated with the AMO including:

- warmer sea surface temperatures;
- lower surface air pressure and increased moisture in the tropical Atlantic;
- reduced vertical wind shear in the deep tropics over the central North Atlantic due to higher easterly trade winds in the upper atmosphere
- weaker easterly trade winds in the lower atmosphere.

They forecast the number of tropical storms, hurricanes and intense i.e. major (Category 3-5) hurricanes as well as the Accumulated Cyclone Energy (ACE) Index. This index is the sum of squares of six-hourly maximum sustained wind speeds for all systems while at least tropical storms and therefore functions as a single measure of frequency, severity and duration of storms in a season.

Saunders and Lea

Forecasts from Saunders and Lea are issued monthly from December of the previous year. Their methodology uses two main predictors:

- Predicted July-September trade wind speed over the Caribbean and tropical North Atlantic. This influences the spinning-up of storms (cyclonic vorticity)
- Predicted August-September sea surface temperature in the tropical North Atlantic. This influences the amount of heat and moisture available to power incipient storms in the main track region

In simple terms, these predictions are based on regression models that take recent past and current ENSO conditions and Atlantic sea surface temperatures, and project them forwards based on historical persistence and trends in those factors.

They forecast number of tropical storms, number of hurricanes, number of major hurricanes and ACE index as well as probability of the ACE index being in each tercile of historical records compared to averages since 1950 for total Atlantic as well as USA landfalling and Caribbean Lesser Antilles landfalling.

Klotzbach and Gray

Forecasts from Klotzbach and Gray are issued in December of the previous year, the start of April, the end of May and then monthly from August to October.

Their methodology starts with a statistical analysis of data since 1955 to decide on a series of 4-5 semi-independent climate related atmospheric/oceanic local or global variables that have, with hindsight, been the best predictors of the following Atlantic tropical storm season.

As an example, their April 2006 methodology uses as one variable February sea level pressure in the South East Pacific, which is an indicator of a positive Southern Oscillation index.

As a second stage they check the actual tropical storm experience in historical years that most closely fit either the atmospheric and oceanic conditions observed at the time of the forecast or the projected conditions for August-October for Atlantic sea surface temperatures, ENSO conditions as well as (another atmospheric feature which is related to tropical storm formation but not covered in this paper) stratospheric Quasi-Biennial Oscillation (QBO).

Finally the predicted storm patterns from the statistical fit and the average of the analogous years are combined and modified for subjective factors such as projected AMO conditions.

They forecast the number (as well as days of) tropical storms, hurricanes & intense hurricanes, the net tropical cyclone activity (which is a combined index of the above compared to averages since 1950) and the probability of an intense hurricane landfalling in the US (as well as the East Coast, Gulf Coast and Caribbean region).

4.7 FORECASTS FOR THE 2006 HURRICANE SEASON

As commented in the introduction, this paper was finalised in June 2006, at the start of the 2006 hurricane season. The table below shows the latest forecasts for the 2006 season at the time of finalisation of the paper.

As can be seen from the first three rows, the three main forecasts are fairly consistent in their view for the outlook for the 2006 season. Comparing these consensus outlooks to the next two rows shows that the 2006 season is forecast to be significantly above average for the period since 1950 (when reasonably accurate records began) but well below the record adverse experience in 2005. However a comparison of the top three and bottom three rows shows that the current forecasts for 2006 exceed those for 2005 at the same time last year.

	Named Storms	Hurricanes	Major Hurricanes
NOAA 31-May-06	13-16	8-10	4-6
Gray 31-May-06	17	9	5
Saunders 6-Jun-06	13.9	7.6	3.4
1950-2005 Mean	10.3	6.2	2.7
2005 Actual	28	15	7
NOAA 16-May-05	12-15	7-9	3-5
Gray 31-May-05	15	8	4
Saunders 7-Jun-05	13.8	7.8	3.5

4.8. ALLOWANCE FOR HURRICANE FREQUENCY TRENDS

Up to 2006, catastrophe modelling has used simulations of future storms based on historical long-term average frequencies. For Atlantic hurricanes typically periods since either 1950 (when reliable and reasonably consistent data is available due to the advent of hurricane reconnaissance flights) or 1851 (when detailed data was recorded) have been used.

The events of the 2004 and 2005 hurricane seasons have led users and model providers to realise that this approach is not sustainable in the light of the long known and well documented short term and medium term fluctuations explained above, even putting aside any considerations of long terms trends.

Both sides of the global warming debate agree that the current trend towards extreme events will continue over the next two decades, either due to a continual warming trend or to the AMO being in the warm phase or a combination of both. Most of the model providers are now factoring considerations of the AMO warm phase into their models but it is vital for actuaries, as users of these models, to understand what allowances have already been made within the models (including what form of frequency distribution is used – Poisson or Negative Binomial – which have different impacts on variability of losses).

Actuaries also need to consider whether and how to adjust the models from year to year in the light of the various trends discussed above as well as to cater for the latest hurricane forecasts.

4.9. FREQUENCY – OTHER PERILS

In section 4 of the paper we have concentrated on the area of North Atlantic hurricanes as it has the greatest level of research and the greatest overall impact on the insurance industry. We do however comment briefly on the two other main insured perils. References for further research are given in the Appendix.

Earthquakes

Earthquake prediction is still an evolving science. Deterministic prediction, where scientists can predict earthquake location, magnitude and time of occurrence with some degree of probability (as has been achieved in the areas of tropical cyclones and to a lesser extent volcanic activity) remains an elusive goal.

Time-independent estimation (in actuarial terms estimating return period along different faults) is much more advanced but controversy remains in the area of time-dependent estimation (i.e. estimation of how the seismic hazard varies over time). Clustering models predict that earthquake probability increases after a large event (with aftershocks the most familiar example) while seismic gap models assert that large earthquakes occur at periodic intervals due to stress build up and is then reduced by the quake.

European Storms

The North Atlantic Oscillation (NAO) was identified in the 1920s and can be characterised as a north-south oscillation in atmospheric pressure between the Icelandic low-pressure area and the Azores high-pressure area. The NAO is the Atlantic equivalent of the El Niño phenomenon in the South Pacific and is believed to be an important driver of climate fluctuations in the North Atlantic, Europe, the Mediterranean Sea and as far east as northern parts of central Asia.

The impact of the NAO is particularly felt in the winter months of November to April. A high NAO index means an anomalously strong subtroprical high pressure centre and/or an anomalously deep Icelandic low. This leads to more and stronger winter storms crossing the Atlantic along a more northerly track. These winds bring wetter and moister air to Northern Europe and result in wetter and windier European winters.

Some researchers suggests that the NAO index was high over the period from the 1960s to 1995, and has reduced since (the opposite pattern to the AMO) which would imply a form of negative correlation between European extra-tropical cyclones and Atlantic hurricanes. In addition a high NOA index with a resulting strong Azores high-pressure area favours hurricane recurvature out to sea before US landfall. A low NAO implies a Bermuda high which often steers storms towards US Landfall in Florida and the Gulf of Mexico.

5. SEVERITY

5.1. INTRODUCTION

In this section we will concentrate on pure severity trends in terms of insured loss – i.e. given a natural catastrophe of a certain size what is the likely impact in terms of insured losses resulting.

Advantages of Catastrophe Modelling over other approaches

Modelling of many components of severity trends is fundamental to catastrophe modelling. For example, when modelling likely losses from an earthquake, a sufficiently complex catastrophe modelling approach combined with sufficiently detailed data should automatically allow for the following factors, all of which could only be catered for by approximate adjustments in a traditional burning cost approach. We will not concentrate on these factors in this paper, but some of them e.g. vulnerability curves, while representing fundamental assumptions of the model, are often seen as opaque by users. It is important actuaries work with their catastrophe model providers to understand the assumptions being made.

Event module

- Changes in seismological views: e.g. new scientific information on return periods of earthquakes given magnitude along given earthquake faults – as explained above we will treat this as a frequency rather than severity trend for the purposes of this paper

Hazard module

- Changes in seismological views: e.g. new scientific information on changes in the attenuation for an earthquake of given intensity along a given fault

Vulnerability module

- Changes in building codes: following a major earthquake it is common that the lessons learned about the vulnerability of different building designs leads to the introduction of new seismic building codes leading in turn to reduced vulnerability.
- Inflation in building materials and repair costs

Inventory module

- Changes in population trends: e.g. the well-remarked phenomena of increasing population movement in the US to areas of high natural hazard potential including California and Washington, which is the most significant explanation of the
- Changes in take-up of earthquake insurance: e.g. there has been a significant drop-off in take-up of residential earthquake cover in San Francisco in recent years.
- Changes in the insurers own portfolio: e.g. changes in size, mix or geographical spread

Financial Analysis Module

- Changes in insurance terms and conditions: e.g. the imposition of increased deductibles or increased limits following past losses

As an aside, the above factors (particularly population trends and inflation) are a very significant explanation of the very significant year-on-year increases in annual and individual event insured losses from Natural Catastrophes, which is often loosely attributed to global warming.

5.2. DEMAND SURGE

Definition of Demand Surge

In practice, the modelling of losses following a natural catastrophe is more complex than the above would imply due to interaction effects. In simple terms the consequences of the catastrophe include secondary effects that affect (and normally increase) the loss beyond what would have been expected.

The best known of these effects is demand surge, which reflects the basic economic reality of reduced supply and increased demand following a natural catastrophe. Demand surge can be defined in an insurance context as the temporary increase in repair/mitigation costs above the standard level of costs, resulting from the secondary impacts of the natural catastrophe itself. This increase is typically driven by:

- Shortage of building materials, e.g. damage to timber-yards rendering available materials unusable
- Increased demand for building materials to repair/replace damaged properties
- Shortage of skilled labour e.g. due to people evacuating the area
- Increased demand for skilled labour to repair/rebuild properties

Labour supply is a shorter-term issue, since labour markets are relatively fluid. Increased wages for skilled labour will quickly attract builders from other regions/countries and the population will return to the affected area as buildings get repaired/replaced.

Potential level of Demand Surge

The exact level of demand surge is very difficult to quantify, although it is a long established and observed phenomena.

For example, following the 1906 San Francisco Earthquake it is reported that the cost of a goods-carrying wagon for people evacuating homes increased from $5 to $100. One year after the earthquake, builders' wages in San Francisco were said to be the highest in the world.

Just under a century later, Hurricane Katrina is reported to have led to 15% increases in prices in the well supplied lumber market with much higher increases expected in cement prices and particularly steel prices (already high in light of the huge demand from China).

There have been estimates in the order of 20-40% for the overall effect of demand surge following Hurricane Andrew and the Northridge Earthquake, although this figure is subject to a significant degree of uncertainty.

These examples show it is a non-trivial additional cost to the insured losses, and therefore needs to be considered carefully when using catastrophe models for any internal use. To omit such a cost could lead to the wrong decisions being made, or at least senior management not fully appreciating the risks within their company.

Complexities in assessing Demand Surge

The exact time of a catastrophe will influence the level of demand surge experienced. For example, a hurricane in New Orleans would cost more if it were to occur this year since there is already a level of "background demand surge" in the area following Hurricane Katrina. This means that the allowance for demand surge should be updated whenever there is an actual loss within a region.

The effect of time on demand surge also causes additional complications when considering annual aggregates from catastrophe models. The current models do not include the compounding of demand surge effects, and therefore (arguably) will under-estimate prices where there is the possibility of more than one event occurring in a region within a year.

There is also the possibility of residual demand surge effects hanging over from previous years. For example, the high hurricane activity in the US in 2004 and 2005 would likely have a residual effect on costs in 2006 were further hurricanes to occur. Finally as seen in the case of Katrina the extent of demand surge will vary with the existing supply and demand equation in the market concerned.

There may also be an interaction between location and size of loss. Although models may allow demand surge parameters to be related to the size of market losses, it may also be desirable for this relationship to be allowed to vary with location due to the relative size of the pool of available labour and resources. A particular example of this was Hurricane Fabian, which impacted Bermuda in 2004. Despite its sophistication in the area of insurance Bermuda is one of the most remote islands in the world.

5.3. OTHER EFFECTS

Super Cats

Increasingly, catastrophe modelling firms are realising that in very large natural catastrophes severity inflation may rise even above the level predicated by economic demand surge. RMS has called such catastrophes "Super Cats" drawing on lessons learned from Hurricane Katrina as well as a retrospective assessment of the impact of the San Francisco Earthquake.

Factors that lead to this additional severity included:

- Damage to physical infrastructure e.g. major bridges and primary access routes, making access for fire fighters or emergency services difficult to help contain the loss as well as making post-loss rebuilding more difficult and costly
- Damages to other sources of infrastructure e.g. phone lines, electricity and gas supplies, water supplies which again hamper containment and rebuilding efforts
- Existing loss mitigation devices failing to work due to the initial effects of the natural catastrophe. The levee breech in New Orleans was much more severe than had been expected due to the failure of the pumping system (due both to electricity failure and evacuation of key personnel)
- Cascading losses e.g. a hurricane or earthquake leading to failure of other systems (e.g. dam collapses, major leaks from oil tanks, gas explosions) leading to a secondary source of losses beyond the primary losses caused by the hazard including pollution losses. The breech of the levees in New Orleans could be seen as an example of this

- A breakdown of social conventions e.g. in the event of a contained natural catastrophe voluntary assistance by unaffected residents of their neighbours impacted by the loss (e.g. offering temporary accommodation) can be a significant risk mitigant. By contrast, in the event of a widespread catastrophe, this help can turn to looting for bare necessities (or even rioting and civil breakdown) which exaggerates the loss
- The need for lengthy and wide-ranging evacuation if the results of a natural catastrophe are sufficiently damaging. This can greatly increase the risk of looting and of subsequent losses (e.g. unattended fires in abandoned buildings)

Infrastructure damage, pollution and evacuation can greatly magnify the business interruption, contingent business interruption and additional living expenses elements of the loss, often well beyond the value of the basic property damage cover.

Coverage Inflation

Particularly in the area of personal insurance, existing insurance exclusions or limits can prove politically and legally very difficult to apply.

Again this phenomenon has been observed over a century. Following the San Francisco Earthquake, insurers found it almost impossible to enforce the “fallen building” clause in the policies, which was, prior to the loss, believed to exclude payment for fire following an earthquake. Following Katrina, the Mississippi Attorney General filed a suit asking courts to clarify that insurance companies must cover the water damage following the breach of the New Orleans levees, and that they could not enforce the water damage/flood exclusions in hurricane protection policies.

As another example of the effect of demand surge, the availability of skilled insurance assessors can impede insurance companies’ ability to validate claims, and this can lead to an increase in fraudulent claims with their additional associated cost.

5.4. ALLOWANCE FOR SEVERITY TRENDS

At present, catastrophe modelling firms consider demand surge when re-calibrating their models. For example, following the Northridge Earthquake, the earthquake models were re-calibrated based on the losses excluding the demand surge, and then this was included as an "after the event" adjustment to the losses from the model.

The lessons learned from Hurricane Katrina have led to modelling firms reviewing their whole treatment of demand surge, including allowance for some of the factors discussed under Loss Amplification.

The exact specifics of how the demand surge is modelled vary according to the model provider, although the underlying principles are the same. Once a loss of a given magnitude is simulated, demand surge can be optionally added onto the loss amount. The level of demand surge may be linked to the underlying loss, so that large losses will lead to greater levels of demand surge. Demand surge may only be included in the main models for certain regions.

Demand surge can alternatively be included within company's internal models by taking the output from catastrophe models (pre demand surge) and then uplifting the severities to reflect demand surge. The uplift would need to reflect all of the items discussed above and may need to be complex (e.g. the area of loss amplification would imply a threshold above which demand surge becomes a non-linear function).

If demand surge is applied outside the model then additional thought must be given to what, if any, demand surge is to be applied to the contents and business interruption elements of the total loss. Typically demand surge has only been applied to the buildings element of the loss.

Demand surge is a genuine phenomenon, and its impact can be material. Ignoring demand surge is not an option, since it only hides the real picture from informed decision makers. The importance for actuaries when using catastrophe models is to understand the level of severity adjustments already included in the model and then decide on what other adjustments are appropriate given the use to which the modelled output will be put.

6. MODEL DESIGN

6.1. DETAILED VERSUS AGGREGATE MODELS

Catastrophe models can generally be classified broadly into aggregate and detailed models. These classifications are broadly similar between the different model vendors.

There are a number of reasons why organisations may wish to use either or both of the models to gain an understanding of catastrophe risk. Catastrophe models work by determining the characteristics of a modelled event in a particular area, then estimating the loss that an account/location would suffer from this event. The loss estimation element of this process is very different between detailed and aggregate models.

Aggregate Model Loss Calculation

The aggregate model can be run on data that does not contain property specific information, for example a portfolio where one only knows what sum insured has been written by Cresta zone. The user enters the exposures aggregated to recognised geographic areas – ZIP code, Cresta, City, County etc. The model then uses precompiled information based around industry average assumptions about the types, ages, construction, occupancy etc. of properties in the areas to be modelled, and estimates the associated loss. Alternatively the model may have pre-calculated losses for each county, for each building type, for each event in the model's event set. The loss calculation is then based on the following :

Modelled Exposure / Industry Exposure * Industry Loss = Modelled Loss

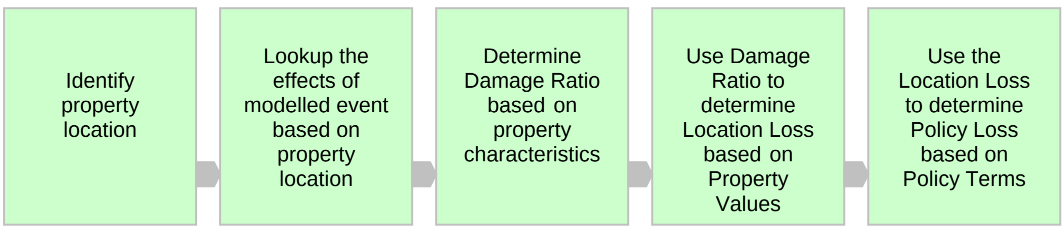
These aggregate approaches are reasonable if the risks being modelled are representative of the average distribution of properties in the area. If the portfolio written comprises a far greater proportion of either primary layers or excess layers compared to the market, then the aggregate model could give results that are materially inaccurate.

Detailed Model Loss Calculation

A detailed model utilises information about properties that are entered by the user into the model. This information typically includes the address of the property to get a good understanding of the precise location of the property in relation to a modelled event. It also includes a range of property information including:

- Property Characteristics (Construction Type, Occupancy Type, Year of Construction, Size of Property)
- Property Values (Location Values Buildings, Contents, Business Interruption)
- Policy Details (Deductible, Limit)

An example of detailed model calculation process is as follows:



This is a simplified view of the calculation, in reality numerous other building characteristics can be entered as parameters in the model, all of which will effect the calculated modelled loss.

This process gives a loss estimate based on the specific properties and values that are being modelled, and which should, therefore, be a more accurate estimate. Where any characteristics are not known for a specific property, the detailed model uses assumptions similar to that in the aggregate model.

Considerations in using aggregate and detailed models

There can be a significant extra cost involved if an organisation wishes to employ a detailed model approach, for this reason many entities use aggregate models. Additionally the run-time for aggregate models is significantly shorter than for detailed models – a portfolio that might take 12 – 24 hours to run through the detailed model might take only 2 or 3 hours in the aggregate model. This could be a significant advantage when underwriting, particularly during periods where the market is more competitive.

However there is a trade-off associated with the aggregate approach to the extent that the properties modelled may not be representative of the average for the area being modelled. This can lead to misleading results.

The dynamics of any decision to model using detailed or aggregate models will differ between insurance and reinsurance entities. While having detailed exposure data for all of the properties insured by an insurer may be manageable exercise but this may not be the case for reinsurers. The extra value gained using a detailed model may be outweighed by the costs involved, and the time taken to produce information. It can also be argued that a reinsurer's portfolio of risk is likely to be closer to the industry average, than that of an insurer.

While catastrophe models have not been entirely successful at predicting losses from recent events it is clear that more information can be gained using detailed models. The significant additional financial and resource costs of employing detailed models need to be weighed up against the catastrophe risk that an organisation is exposed to, and the leverage that detailed catastrophe information has with regards to decision making processes.

If the portfolios to be modelled are unlikely to be representative of the average industry exposure it is unlikely that the aggregate model will produce reasonable results. Even when using the detailed model it is crucial that any shortcomings in the data is understood and incorporated in any analysis.

7. MATHEMATICAL APPROXIMATIONS

An additional consideration with the catastrophe models is the approximations that are introduced to bring mathematical tractability to the process. Without these approximations, catastrophe modelling firms might be constrained to use sub-optimal severity distributions for individual event characteristics, or to generate results sets via simulation rather than calculation.

Catastrophe models that did not enjoy mathematical tractability might take days, or even weeks, to complete a run. The increased run time might be acceptable if we could believe that the accuracy of the model would be significantly improved, but removing the mathematical approximations would do nothing to improve the certainty surrounding the subjective judgements and assumptions that underpin the entire model.

In consequence we accept mathematical approximations as a necessary component of catastrophe models. However it is important that actuaries understand these approximations sufficiently well to know what impact they will have on the particular portfolio being modelling. How concerned should we be about whether the Poisson or the negative binomial is used for the frequency? Are the correlations between risks treated in the most appropriate manner?

Without an understanding of the underlying mathematics that underpins these models, the actuary cannot understand the level of confidence that can be applied to a result set from a given portfolio.

As an example, consider events that involve more than one peril component such as an earthquake shake and a fire following the earthquake. Ideally one might want to have separate distributions for the severity of the shake and the fire following elements (with the ability to combine these into a single severity distribution), in order to assess the impact of different types of insurance and reinsurance coverage. However against an event set of tens of thousands of possible events, this could be computationally very onerous, particularly in constructing the combined distribution.

Consequently a model might take a more approximate method of combining the two distributions for each event. Whilst for some portfolios this approximation would be immaterial, on others it could give rise to significant distortions. It might even give rise to some isolated instances where the combined distribution for shake plus fire following would show a mean value no greater than shake only. By analysing the event peril components both separately and on a combined basis, the actuary can better understand the effect of their own portfolio. The actuary is then in a position where he can make a judgement as to whether it is more appropriate to use the software modelled figures on the combined perils or to adopt an alternative method of including the “fire following” impact outside the catastrophe modelling software, possibly using one of the methods outlined in section 8 of this paper.

8. UNMODELLED ELEMENTS

8.1. INTRODUCTION

Even if models required no approximations, and assumptions were based on such complete, accurate and detailed data that there was little leeway for different opinions, the result set may not truly reflects the total natural peril exposures. This is because no matter how good the models are, they cannot compensate for missing or inaccurate data, or model types of risks or perils for which they have not been programmed.

The Working Party has generated a list of “unmodelled elements” of catastrophe modelling. Some of the “unmodelled elements” are illustrated by example to clarify their meaning, although these examples are by no means exhaustive. For instance there are a whole host of unmodelled perils and territories in addition to the examples given.

We have also set out some “work-arounds” that might provide a temporary solution to a particular unmodelled element until the underlying issue is resolved and that element is incorporated into the catastrophe model.

The permanent solution might be as simple as having sufficient staff to ensure that risks are entered onto the catastrophe system as soon as they are written, could involve working on a bespoke solution with a catastrophe modelling firm, or could be a matter of waiting until a model is released covering the peril, territory or type of risk. However, whilst we should always strive to improve the catastrophe model output in the long term, we must also ensure that the estimates we produce today are as complete, appropriate and accurate as possible.

Some of the approaches we describe are necessarily subjective; all are approximate. We would recommend sensitivity testing of the results where these approaches are adopted, so the end user can understand how the assumptions used have affected the end results.

8.2. UNMODELLED CONTRACTS IN MODELLED CLASS(ES)

It is always sensible before attempting a reconciliation between the underwriting and catastrophe modelling systems to ask the individual(s) who input data onto the catastrophe modelling system and the underwriting system if they have any backlog, and to check whether the underwriter had written any significant new contracts for which insufficient data was available to allow it to be processed onto these systems.

If there is a large volume of individual contracts it may not be possible to match at contract level, particularly if incomplete contract details are held on the catastrophe system. In this case one could compare the aggregate premiums and sums insured by territory (and peril where appropriate).

The approach to use to allow for the unmodelled contracts depends on their significance. One possibility would be to apply the premium for the unmodelled element to an aggregate catastrophe model to obtain a result set for “unmodelled” contracts. The two results sets (full modelled and aggregate “unmodelled”) can then be combined. This approach essentially involves treating the unmodelled contracts as if they are typical of the overall industry average contracts, and “ignores” the information about the modelled contracts.

A less onerous approach would be to simply gross up results on a pro-rata basis for each territory, based on either premium or sum insured for the unmodelled contracts. Note: this cannot be used with any level of detail by territory: for example one could split US hurricane between South East and North East, but not by state or county as the storms hit multiple states. This approach assumes unmodelled contracts are similar to modelled e.g. same split of primary, low excess, high excess etc.

8.3. UNMODELLED COMPONENT OF MODELLED CONTRACTS

e.g. a multi-location contract where only one zip-code has been input, or contingent business interruption where purchased as a contract extension

Multi-location contracts: There are a number of "reasonability checks" that can be introduced at the detailed data input stage, for example testing the exposure data by looking for unusually high exposure values or an unusually high number of buildings per zip code, which may highlight the worst examples on incorrect input of multi-location contracts. However there is no obvious fix for this element if one is presented only with the modelled results.

Contingent business interruption: might possibly be modelled in the manner suggested for item (5) below.

8.4. UNMODELLED CLASSES WITH ESTIMATED PERCENTAGE SHARES OF INDUSTRY LOSS

e.g. catastrophe retrocession (retro)

When considering business lines such as retro, it can be useful to divide the portfolio between those contracts placed on an "ultimate net loss" (UNL) basis and those which contain an industry loss warranty (ILW) or similar trigger. For both parts of the portfolio, one should attempt to produce results by peril and territory that match the modelled classes.

UNL Retro

If there are only a very small number of retro contract missing, one could try to benchmark against the data one has for other cedants. For example, if the underwriter felt that company X wrote business at a similar level to company Y, but with average line sizes 50% bigger, one could clone the ABC data set, increase line sizes by 50% and incorporate into the model. Unfortunately there might be relatively few instances where one reinsurance portfolio is sufficiently similar to another to allow this approach.

An alternative approach, therefore, is to try to relate the UNL retro loss to the market loss. One should start by estimating:

- the market loss threshold below which no loss is anticipated for each peril / territory;
- the market loss threshold at which all exposed first loss policies will (potentially) just become limit losses; and
- the total claims to the retrocessionaire for a number of market losses between these two thresholds identified; depending on the type of retro account written there may be some key market loss points at which additional tranches of policies are likely to be activated.

These estimates should be based on loss experience, conversations with underwriters, claim manager and catastrophe modellers and examination of underwriting submissions.

Based on above estimates, one can develop a function that translates market loss into estimated retro loss; applying this function to the relevant industry loss curve will generate an approximate retro result set that can be consolidated at individual event level with result set for the modelled classes.

We would note that particular care should be taken with multiple loss scenarios, and with the application of aggregate deductibles.

ILW and other market loss trigger contracts

Most commonly, ILW contracts are written with very low attachments points, subject to the trigger being activated. It is therefore reasonable to assume that if a particular trigger is activated, the contract will have a full event limit loss. However, modelling ILW contracts is not quite as simple as picking out from the industry loss curves all those with potential to activate the trigger. If the ILW's represent a substantial proportion of the exposure, one should first identify the relationship between the modelled market loss and the reported loss on which the trigger is based.

For example, PCS reported losses might not include in full the insurance written by non-admitted carriers (USA or overseas). Consequently it may be necessary to modify either the modelled trigger or the industry loss curve to ensure both represent the same base exposures.

8.5. UNMODELLED CLASSES WITH PROBABLE MAXIMUM LOSS (PML) ESTIMATION

e.g. marine hull & cargo, yacht

Here a reasonable approach is to relate the likely losses to either the industry loss curve or the result set for the modelled classes. For each peril/territory, one should examine historic data to identify miss factors, and how these vary by size of loss (the miss factor is the likelihood of nil loss to that class for a modelled peril/territory).

Historic losses and scenario analyses are examined in relation to market loss and/or company loss for modelled classes; one can then estimate the loss for unmodelled class as a percentage of this reference loss – either as a flat percentage or scaled on size of loss. This can then either be used as a deterministic gross-up factor to be applied to the modelled reference losses, or used as data points to fit distribution, which is then strongly correlated to the result set severity.

8.6. UNMODELLED UNCONSIDERED CLASSES, WHERE NATURAL CATASTROPHE EXPOSURE IS NOT CONSIDERED

e.g. medical facility liability, financial institutions crime

The aim here is to identify the point at which many other classes that one would not normally consider exposed to natural catastrophes become impacted. It is unlikely that one can make any accurate estimates by individual class, but it may be possible to generate a total across all such classes that is broadly reasonable.

The approach taken is similar to that for unmodelled classes with PML estimates. However as the underwriters are likely to have less experience of estimating the natural peril impact, more credibility should be given to the examination of past market catastrophe losses, both man-made and natural perils, to see examples of other classes unexpectedly giving rise to losses e.g. the World Trade Centre caused significant specie losses, while Hurricane Katrina gave rise to FI crime losses arising from thefts from cashpoint machines.

8.7. UNMODELLED ELEMENTS OF A MODELLED LOSS

e.g. Caribbean windstorm surge, flood vs. storm surge for Katrina

The sophistication of a catastrophe model depends upon a number of factors, including the availability and accuracy of both current and historic data, the number of likely customers, and the perception of the impact of adding more detail to the model. It is important to understand what, if any, elements of the peril are excluded from the catastrophe model. For example, storm surge has not been included in the Caribbean wind models previously, although this situation is now changing for a number of islands.

Where part of the peril is unmodelled, one can approximate the impact using an approach similar to that outlined to that for unmodelled classes with PML estimates.

The impact of the unmodelled element of the peril can either be set as a set of deterministic gross-up factors or as a stochastic factor for each event for simulation models, for example multiplying the modelled elements of the peril by a lognormal distribution where the mean and coefficient of variation are set as variables for each event.

8.8. UNMODELLED PERILS / TERRITORIES

e.g. East European flood, ice storm, China earthquake

When considering unmodelled perils and / or territories, one should allow for the possibility that data quality and completeness of catastrophe exposure data submitted with each risk is unlikely to be as good as for those perils and territories that have established catastrophe models (see comments in section 3).

If an unmodelled peril or territory is highly significant to a company, it may want to build its own exposure based peril model. Even the most basic such model must include at least the following steps:

- obtain historic peril data – e.g. dates, duration and extend of flood
- adjust for changes in geography/building density and placement, demographics etc
- develop event characteristics for a stochastic event set
- develop damage/vulnerability factors to apply to different building constructions and other types of risk
- develop software to apply stochastic event set and damage factors to specific portfolios

We recognise that this is impractical for all but the very biggest insurers, both from the perspective of technical resources and of having sufficient volume of data.

A more realistic alternative might be to follow the first two steps above, and then fit frequency and severity distributions. Market share (or one of the approaches described above) can be used to generate the equivalent loss distributions at portfolio level.

For less significant perils/territories, one could use a market source of historic market loss data e.g. Sigma loss listings, and treat each (inflated) historic event as equally likely. Based on historic company losses and changes in exposure, t one could estimate company loss for each historic loss to generate a unique loss distribution.

8.9. CORRELATION OF PERIL ZONES

e.g. Gulf & Caribbean wind

The models allow this correlation to be modelled, but some users still consider correlated exposures in separate “silos” when looking at their potential portfolio losses. In practice, it may be appropriate to do so in some cases and not in others, as the application of an "hours clause" (typically 72 hours for wind) may mean that one windstorm will be treated as two separate events for reinsurance.

Essentially, one should aim to model gross exposure based on the combined territory basis but with the US and Caribbean elements shown separately as well as combined. This should be done separately for the insurance portfolio, the assumed reinsurance portfolio with no "hours clause", and the assumed reinsurance portfolio with "hours clause". These can then be combined in a spreadsheet and ceded reinsurance applied in the appropriate manner. For example, to get the full gross value for an event one might take the combined basis values for insurance and “no hours clause” reinsurance, and the sum of the separately modelled US and Caribbean components where an hours clause exists.

9. CONCLUSIONS

In their “Financial Risk Outlook 2006” the Financial Services Authority commented “in the aftermath of Hurricanes Katrina, Rita and Wilma in autumn 2005, it became apparent that some firms may rely too much on the output of their catastrophe models without proper consideration of the inputs … It is imperative that firms address this issue urgently. This is a concern we share with rating agencies and other industry analysts”

It is to address these concerns, shared also by the insurers, that we have written this paper.

As actuaries, we all understand that any model that is based on limited information and tries to capture a complex system must inevitably include subjective judgements and assumptions.

The task of a catastrophe model is not to produce a 100% accurate result (although this would make things much easier), but to demonstrate the potential impact of catastrophic events on a particular insurance/reinsurance contract or portfolio. There is no such thing as an exact modelled loss estimate, as there is always an element of subjectivity involved.

Catastrophe models are a tool and not, on their own, the answer. In addition catastrophe models are still very much a developing tool. Much of the science underlying them is still immature. Following any major event, modelling firms adjust and refine their models in the light of that event and the areas in which their existing models proved to be a good or bad predictor of actual losses.

In this paper we have considered some of the main areas of uncertainty in and limitations in models:

- Data
- Frequency
- Severity
- Model design
- Mathematical approximations
- Unmodelled elements

We have provided some considerations for actuaries in each of these areas. We stress the importance of understanding this tool and communicating effectively with other stakeholders who depend on the results of catastrophe models.

In addition we have provided in the Appendix, detailed reference for further reading for those who would like to develop their knowledge.

APPENDIX 1: REFERENCES

This section contains a list of references and websites we have used in preparing this paper as well as other websites of interest.

GENERAL

Modelling Firms

The websites of the three main modelling firms are excellent sources of information, both on natural catastrophes in general as well as more detailed information on the workings of their own models.

AIR	www.air-worldwide.com
EQE	www.eqecat.com
RMS	www.rms.com

Hurricane Tracking Sites

During the hurricane season, these three sites give the ability to track tropical storm development and forecast a hurricane's track and intensity.

National Hurricane Centre	http://www.nhc.noaa.gov/
Tropical Storm Risk	http://forecast.mssl.ucl.ac.uk/shadow/tracker/dynamic/main.html
AccuWeather	http://hurricane.accuweather.com/hurricane/

FREQUENCY - HURRICANES

El Niño

The International Research Institute for Climate and Society (IRI) at Columbia University has published detailed research into the interaction of the El Niño Southern Oscillation with North Atlantic hurricanes. This can be found at:

http://iri.columbia.edu/climate/

with the part on El Niño and Atlantic hurricanes at:

http://iri.columbia.edu/climate/ENSO/globalimpact/TC/Atlantic/index.html

Another useful paper is “La Niña, El Niño and Atlantic Hurricane Damages in the United States” by Pielke and Landsea (1999) published in the Bulletin of the American Meteorological Society.

Atlantic Multidecadal Oscillation

There are a number of areas covering the Atlantic Multidecadal Oscillation, including the Hurricane and Physical Oceanography Research Divisions of the Atlantic Oceanographic and Meteorological Laboratory (AOML) of the National Oceanic and Atmospheric Administration (NOAA). Their website can be accessed via:

http://www.aoml.noaa.gov/

For this paper we made use of illustrations from a widely quoted research paper “The Recent Increase in Hurricane Activity; Causes and Implications” by Goldenberg, Landsea, Mestas-Nuñez and Gray (2001) published in Volume 293 of Science Magazine.

We also used an illustration of the AMO effect from the paper “Atlantic Ocean Forcing of North American and European Summer Climate” by Sutton and Hodson (2005) published in Volume 309 of Science Magazine.

AXA Re’s Experts’ Study “Evidence for Increasing Hurricane Risk in North Atlantic and the United States” is an excellent non-academic study of the multi-decadal effect.

Climate Change

The Institute of Actuaries Working Party on Climate Change has a Wiki site at:

http://climatechange.pbwiki.com/

Two key reference sites are those of the IPCC – the Intergovernmental Panel on Climate Change:

http://www.ipcc.ch/

and, in the UK, the Hadley Centre for Climate Prediction and Research (which is part of the Met Office):

http://www.met-office.gov.uk/research/hadleycentre/

The effect of Climate Change on hurricane frequency is a controversial and developing area. Research papers we used included:

“Uncertainty in Hurricanes and Global Warming” by Trenberth (2005) published in Volume 308 of Science Magazine

“Impact of CO2 induced warming on simulated Hurricane intensity and precipitation: Sensitivity to the choice of climate model and convective parameterisation” by Knutson and Tuyela (2004) published in the Journal of Climate

“Increasing destructiveness of Tropical Cyclones over the past 30 years” by Emanuel (2005) published in Volume 436 of Nature, together with two follow-up responses “Are there trends in Hurricane Destruction” by Pielke (2005) and “Hurricanes and Global Warming” by Landsea (2005) and a reply by Emanuel (2005) – all published in Volume 438 of Nature

“Changes in Tropical Cyclone Number, Duration, and Intensity in a Warming Environment” by Webster, Holland, Curry, Chang (2005) published in Volume 309 of Science

“Trends in Global Tropical Cyclone Activity over the past 20 years” by Klotzbach (2006) – available on the Tropical Meteorology Project website (see below)

“Atlantic Hurricane Trends Linked to Climate Change” by Mann and Emanuel (2006) published in Volume 87 of EOS Transactions of the American Geophysical Union.

The ABI commissioned a 2005 report on “The Financial Risks of Climate Change”, available at:

www.abi.org.uk

the report reaches similar conclusions on the interaction of global warming and the AMO to our own analysis in Section 4.5.

Lloyd’s recent publication “Climate Change – Adapt or Bust” (2006) provides a good insurance perspective on climate change as well as a detailed series of references and is available from their website

www.lloyds.com\360

The graphs used to illustrate the seeming upward trend in the AMO data was based on this report, which in turn sourced the data from the Climate Diagnostics Centre of the NOAA

www.cdc.noaa.gov

For a good summary of the current research, a flavour of the various key areas of debate, as well as to understand the two main groups of meteorologists on each side of the vigorous debate (which has even led to some of them resigning from the IPCC), the following series of papers are worth reading:

“Hurricanes and Global Warming” by Pielke, Landsea, Mayfield, Layer and Pasch (2005)

“Hurricanes and Global Warming – Potential Linkages and Consequences” by Amthes, Corell, Holland, Hurrell, MacCracken and Trenberth (2006)

“Reply to ‘Hurricanes and Global Warming – Potential Linkages and Consequences’ “ by Pielke, Landsea, Mayfield, Layer and Pasch

all published in the Bulletin of the American Meteorological Society

For a less scholarly debate on the same topics try typing “Hurricanes and Global Warming” into a blog search engine, with the debate temperature only likely to rise after the release of Al Gore’s film “An Inconvenient Truth” (2006).

Two useful Blogs for keeping up with the weekly (sometimes daily) developments in research in this area, from differing perspectives, are:

Real Climate – an objective, although with a bias towards the importance of global warming, commentary site by working climate scientists for the interested public

http://www.realclimate.org/

Prometheus – a University of Colorado site largely maintained by Roger Pielke (see various references), with a mildly sceptical view on the importance of global warming and with lots of insurance references.

http://sciencepolicy.colorado.edu/prometheus/

Hurricane Forecasting

The official prediction of the National Hurricane Centre is issued by the Climate Prediction Centre at the NOAA National Weather Service National Centre for Environmental Prediction.

http://www.cpc.ncep.noaa.gov/products/outlooks/hurricane.shtml

Two main independent forecasters are:

Gray and Klotzbach of the Tropical Meteorology Project at Colorado State University

http://tropical.atmos.colostate.edu/Forecasts/

Saunders & Lea of Benfield Hazard Research Centre at University College London. As well as Atlantic hurricanes, their site includes forecasts of North Atlantic storms (and the NAO index), Northwest Pacific typhoons and Australian cyclones.

http://forecast.mssl.ucl.ac.uk

Each of the above publishes numerous forecasts, commentaries and verifications of past forecasts and academic papers summarising their developing methodology. Examples include:

"The 2005 Atlantic Hurricane Season: A Climate Perspective" by Bell et al (2006) published in the Bulletin of the American Meteorological Society

"Assessing the Skill of Operational Atlantic Seasonal Tropical Cyclone Forecasts" by Owens and Landsea (2003) published in the Bulletin of the American Meteorological Society

"Updated 6-11 Month Prediction of Atlantic Basin Seasonal Hurricane Activity" by Klotzbach and Gray (2004) published in the Bulletin of the American Meteorological Society

"A consolidated CLIPER model for improved August-September ENSO prediction skill" by Lloyd-Hughes, Saunders and Rockett (2004) published in volume 19 of Weather and Forecasting.

"Seasonal Prediction of Hurricane Activity reaching the Coast of the United States" by Saunders and Lea (2005) published in Volume 434 of Nature

FREQUENCY – OTHER PERILS

Earthquakes

Nature (1999) hosted an online debate on earthquake prediction that forms a good introduction to the topic:

http://www.nature.com/nature/debates/earthquake/equake_frameset.html

North Atlantic Oscillation

James Hurrell of the Climate and Global Dynamics Division of the National Centre for Atmospheric Research has published a number of papers on the NAO and its effects on climate, which can be accessed at:

http://www.cgd.ucar.edu/cas/jhurrell/publications.html

Two websites on NAO are maintained by:

Martin Visbeck of the Lamont-Doherty Earth Observatory at Columbia University

http://www.ldeo.columbia.edu/NAO/

and David Stephenson of the Climate Analysis Group of the University of Reading

http://www.met.rdg.ac.uk/cag/NAO/

Mark Saunders and the Benfield Hazard Research Centre at University College London have published a number of papers in the prediction of NAO and the forecasting of North Atlantic storm activity, which can be found under:

http://forecast.mssl.ucl.ac.uk

"European Windstorms and the North Atlantic Oscillation – Impacts, Characteristics and Probabilities" by Malmquist et Al, was published following a 1999 Risk Prediction Initiative Workshop and is an easy to read summary of the NAO phenomenon and its link to storms.

"Tracking Hurricanes" by Elsner (2003) published in the Bulletin of the American Meteorological Society includes details on the link between NOA and tropical cyclone curvature

SEVERITY

In preparing this paper we made use of two RMS publications for a perspective on demand surge and loss amplification in two "super cats" 100 years apart:

"Hurricane Katrina; Profile of a Super Cat" and "The 1906 San Francisco Earthquake and Fire: perspectives on a Modern Super Cat"

"Normalized Hurricane Damages in the United States: 1925-1995" by Pielke and Landsea (1998) published in the Bulletin of the American Meteorological Society, contains an interesting attempt to inflate historical hurricane losses to today's level including allowance for increasing wealth and population trends. Pielke and Landsea are two of the leading sceptics in the debate about how closely global warming is influencing hurricane losses and commonly argue that global warming is far less important, particularly for insured and economic losses, than inflation and population trends.

MODEL STRUCTURE

As stated above, the modelling agencies websites contain detailed technical specifications of their models (normally only available to registered users).

We made use of the paper:

"The Use of Computer Modelling in Estimating and Managing Future Catastrophe Losses" by Clarke (2002) published in Volume 27 of the Geneva Papers on Risk and Insurance

FURTHER READING

Books

Two 2005 publications are recommended:

"Catastrophe Modelling: A New Approach to Managing Risk" edited by Grossi and Kunruther, is a collaborative effort between academics and the three main modelling firms, and is an excellent review of the area.

"Divine Wind: The History and Science of Hurricanes" by Emanuel (2005) is an idiosyncratic coffee table guide to the art, history and science of hurricanes by a leading meteorologist (see Climate change)

Research Papers

A number of Research Journals routinely carry papers relevant to the area of natural catastrophe modelling. Three of the most useful (and cited above) are:

Bulletin of the American Meteorological Society

http://www.ametsoc.org/

Nature Magazine

http://www.nature.com

Science Magazine

www.sciencemag.org

It can be very difficult to keep track of these and other journals, even with the aid of the Internet.

Since 2004, the Benfield Hazard Research Centre have published an annual "Hazard and Risk Science Review" in September of each year (to coincide with the Monte Carlo Rendezvous) of new research published in the twelve months to the preceding June in the areas of atmospheric, geological, hydrological hazards and climate change and likely to be of interest to insurance professionals.

http://www.benfieldhrc.org/

APPENDIX 2: GLOSSARY OF CATASTROPHE MODELLING TERMS

PERIL INTENSITY SCALES

Modified Mercalli Intensity (MMI) – subjective scale used to describe the observed local shaking intensity and related effects of an earthquake. The scale ranges from I (barely felt) to XII (total destruction), with slight damage beginning at VI. In general, the MMI will decrease with distance from the fault, except in regions with poor soils. Intensity is different from magnitude, which is a measure of earthquake dimension, rather than effects.

Scale	Effects
1	People do not feel any Earth movement.
2	A few people might notice movement if they are at rest and/or on the upper floors of tall buildings.
3	Many people indoors feel movement. Hanging objects swing back and forth. People outdoors might not realize that an earthquake is occurring.
4	Most people indoors feel movement. Hanging objects swing. Dishes, windows, and doors rattle. The earthquake feels like a heavy truck hitting the walls. A few people outdoors may feel movement. Parked cars rock.
5	Almost everyone feels movement. Sleeping people are awakened. Doors swing open or close. Dishes are broken. Pictures on the wall move. Small objects move or are turned over. Trees might shake. Liquids might spill out of open containers.
6	Everyone feels movement. People have trouble walking. Objects fall from shelves. Pictures fall off walls. Furniture moves. Plaster in walls might crack. Trees and bushes shake. Damage is slight in poorly built buildings. No structural damage.
7	People have difficulty standing. Drivers feel their cars shaking. Some furniture breaks. Loose bricks fall from buildings. Damage is slight to moderate in well-built buildings; considerable in poorly built buildings.
8	Drivers have trouble steering. Houses that are not bolted down might shift on their foundations. Tall structures such as towers and chimneys might twist and fall. Well-built buildings suffer slight damage. Poorly built structures suffer severe damage. Tree branches break. Hillsides might crack if the ground is wet. Water levels in wells might change.
9	Well-built buildings suffer considerable damage. Houses that are not bolted down move off their foundations. Some underground pipes are broken. The ground cracks. Reservoirs suffer serious damage.
10	Most buildings and their foundations are destroyed. Some bridges are destroyed. Dams are seriously damaged. Large landslides occur. Water is thrown on the banks of canals, rivers, lakes. The ground cracks in large areas. Railroad tracks are bent slightly.
11	Most buildings collapse. Some bridges are destroyed. Large cracks appear in the ground. Underground pipelines are destroyed. Railroad tracks are badly bent.
12	Almost everything is destroyed. Objects are thrown into the air. The ground moves in waves or ripples. Large amounts of rock may move.

Richter Scale – the original magnitude scale developed by Charles Richter in 1935. Usually referred to as local magnitude, this scale is still often used by scientists for measuring earthquake intensity. The Richter magnitudes are based on a logarithmic scale (base 10).

Magnitude	**Effects**
2.5 or less	Usually not felt, but can be recorded by seismograph.
2.5 to 5.4	Often felt, but only causes minor damage.
5.5 to 6.0	Slight damage to buildings and other structures.
6.1 to 6.9	May cause a lot of damage in very populated areas.
7.0 to 7.9	Major earthquake. Serious damage.
8.0 or greater	Great earthquake. Can totally destroy communities near the epicentre.

Saffir Simpson Scale – commonly used to measure windstorm intensity. Uses a range of 1 to 5, with 5 being the most intense storm. Named after Herbert Saffir and Robert Simpson.

Category	**Wind Speed**	**Effects**
One	74-95 mph	No real damage to building structures. Damage primarily to unanchored mobile homes, shrubbery, and trees. Also, some coastal road flooding and minor pier damage
Two	96-110 mph	Some roofing material, door, and window damage to buildings. Considerable damage to vegetation, mobile homes, and piers. Coastal and low-lying escape routes flood 2-4 hours before arrival of centre. Small craft in unprotected anchorages break moorings.
Three	111-130 mph	Some structural damage to small residences and utility buildings with a minor amount of curtainwall failures. Mobile homes are destroyed. Flooding near the coast destroys smaller structures with larger structures damaged by floating debris. Terrain continuously lower than 5 feet ASL may be flooded inland 8 miles or more.
Four	131-155 mph	More extensive curtainwall failures with some complete roof structure failure on small residences. Major erosion of beach. Major damage to lower floors of structures near the shore. Terrain continuously lower than 10 feet ASL may be flooded requiring massive evacuation of residential areas inland as far as 6 miles.
Five	Greater than 155 mph	Complete roof failure on many residences and industrial buildings. Some complete building failures with small utility buildings blown over or away. Major damage to lower floors of all structures located less than 15 feet ASL and within 500 yards of the shoreline. Massive evacuation of residential areas on low ground within 5 to 10 miles of the shoreline may be required.

Fujita Scale – used to rate the intensity of a tornado by examining the damage caused by the tornado after it has passed over a man-made structure

F-Scale Number	**Intensity Phrase**	**Wind Speed**	**Effects**
F0	Gale tornado	40-72 mph	Some damage to chimneys; breaks branches off trees; pushes over shallow-rooted trees; damages sign boards.
F1	Moderate tornado	73-112 mph	The lower limit is the beginning of hurricane wind speed; peels surface off roofs; mobile homes pushed off foundations or overturned; moving autos pushed off the roads; attached garages may be destroyed.
F2	Significant tornado	113-157 mph	Considerable damage. Roofs torn off frame houses; mobile homes demolished; boxcars pushed over; large trees snapped or uprooted; light object missiles generated.
F3	Severe tornado	158-206 mph	Roof and some walls torn off well constructed houses; trains overturned; most trees in forests uprooted
F4	Devastating tornado	207-260 mph	Well-constructed houses levelled; structures with weak foundations blown off some distance; cars thrown and large missiles generated.
F5	Incredible tornado	261-318 mph	Strong frame houses lifted off foundations and carried considerable distances to disintegrate; automobile sized missiles fly through the air in excess of 100 meters; trees debarked; steel reinforced concrete structures badly damaged.
F6	Inconceivable tornado	319-379 mph	These winds are very unlikely. The small area of damage they might produce would probably not be recognizable along with the mess produced by F4 and F5 wind that would surround the F6 winds. Missiles, such as cars and refrigerators would do serious secondary damage that could not be directly identified as F6 damage. If this level is ever achieved, evidence for it might only be found in some manner of ground swirl pattern, for it may never be identifiable through engineering studies

Tropical Cyclone Nomenclature

A tropical cyclone is the generic term for a non-frontal synoptic scale low-pressure system over tropical or sub-tropical waters with organized convection (i.e. thunderstorm activity) and definite cyclonic surface wind circulation.

Tropical cyclones with maximum sustained surface winds of less than 17 m/s (34 knots, 39 mph) are called "tropical depressions".

Once the tropical cyclone reaches winds of at least 17 m/s (34 knots, 39 mph) they are typically called a "tropical storm" and assigned a name. If winds reach 33 m/s (64 knots, 74 mph)), then they are called:

- Hurricane (the North Atlantic Ocean, the Northeast Pacific Ocean east of the dateline, or the South Pacific Ocean east of 160E)
- Typhoon (the Northwest Pacific Ocean west of the dateline)
- Severe tropical cyclone (the Southwest Pacific Ocean west of 160E or Southeast Indian Ocean east of 90E)
- Severe cyclonic storm (the North Indian Ocean)
- Tropical cyclone (the Southwest Indian Ocean)

Hurricanes of categories 3-5 on the Saffir Simpson scale are called major hurricanes (or sometimes intense hurricanes).

AREA / ZONING TERMS

CRESTA - Catastrophe Risk Evaluation and Standardising Target Accumulations – used for Catastrophe Zoning

FIPS Code – Federal Information Processing Standards – County level code. A FIPS code is a five-digit code that identifies a County within a State. The first two digits represent the State code and the following three digits represent the County code.

ZIP Code - Zone Improvement Plan – designed for use by the United States postal service. A ZIP code is a five-digit code that identifies a specific geographical delivery area. ZIP codes can represent an area that may cross County boundaries or even State boundaries (very rare). A single building that has a very high mail volume can have its own ZIP code.

GENERIC LOSS MODELLING ABBREVIATIONS AND TERMS

AAL – Annual Average Loss – average of the annual aggregate losses

AEP - Aggregate Exceedance Probability - the probability that the total cost of all events within a year will combine to exceed a certain threshold. These are the figures that should be used when assessing gross loss ratios.

EML – Estimated Maximum Loss – estimate of the maximum loss on a particular risk as a result of a single incident considered to be within the realms of possibility

MDR – Mean Damage Ratio – loss value as a % of overall exposure value – used for specific buildings

OEP – Occurrence Exceedance Probability - the probability that the most costly event in any one year will exceed a certain threshold. These are the figures relevant for Catastrophe excess of loss reinsurance

PML – Probable Maximum Loss - estimate of the maximum loss on a particular risk as a result of a single event, assessed with due care and taking into account all risk elements

TCE – Tail Conditional Expectation – the average value of all losses greater than a specific return period threshold, i.e. losses in the tail of the EP curve. Used to measure extreme loss thresholds & help with solvency evaluation.

EP Curve - Exceedance Probability Curve – this may be based on AEP or OEP; it shows the likelihood of having either aggregate annual losses (AEP) or a single event (OEP) in excess of a given amount

Demand Surge – 'Post loss inflation' of building materials / labour – typically applied only to the building damage, and not to the business interruption / contents loss components

Deterministic Model - model assumes that the values of all variables such as the number and severity of large claims are known in advance. Examples include calculating the ceded and net positions for specific gross "as if" losses.

Geocoding – the process of associating an address, such as a street or postal address with an estimate of the latitude and longitude coordinates that represent the location on the ground

Probabilistic Model – model uses a stochastic event set made up of many simulated events normally based on historical data. Results are displayed in EP format.

Return Period - the expected length of time between recurrences of two events with similar characteristics. The return period can also refer to specific level of loss.

Secondary Peril – hazards that are an additional source of loss to the primary peril. Examples include ‘storm surge’ as a result of hurricane or ‘fire’ as a direct results of earthquake.

Storm Surge – The effect of flood caused by storm; modelling a portfolio with storm surge will generate larger losses for a given return period than modelling that same portfolio without storm surge

Unicede1 / Unicede2 – Text comma delimited file containing exposure for use in aggregate level exposure models – Unicede 1 or 2 files can be used in AIR, RMS and EQECAT.

Vulnerability – degree of loss to a system or structure resulting from exposure to a hazard of a given severity.

AIR Models, Abbreviations and Terms

CATStation – AIR exposure accumulation management tool

CATRADER – AIR aggregate loss model for County / Cresta Zone level exposure

CLASIC/2 – AIR detailed loss model for detailed location level exposure

CLF - Company Loss File - produced from a detailed 'Clasic/2' analysis, containing loss information by Event ID, area & sub-area code and line of business.

DLF - Detailed Loss File - produced from an aggregate 'CATRADER' analysis, containing loss information by Event ID, area & sub-area code and line of business.

ALF - Analysis Loss File - essentially a slimmed down version of a CLF or DLF file, containing loss results from either a 'Clasic/2' or 'CATRADER' analysis. An ALF only contains one loss figure per Event ID and does not break the loss out by area, sub-area or line of business (which a CLF or DLF would do).

CLF / DLF / ALF files can ONLY be viewed in 'CATRADER'. CATRADER will use the loss information by Event ID and calculate overall return period losses for the portfolio. Clients using 'CATRADER' obviously prefer CLF or DLF files where possible, rather than the less detailed ALF files.

UFX – UNICEDE/fx – text file containing the same data found in a CEDE file. This can be imported into another users CLASIC/2 software. Designed exposure data for facultative reinsurance certificates.

UPX - UNICEDE/px – text file containing the same data found in a CEDE file. This can be imported into another users CLASIC/2 software. Designed for detailed exposure data for primary insurance policies.

EQECAT Model

WORLDCATenterprise – EQECAT model for detailed location level or County / Cresta Zone level exposure

RMS Models, Abbreviations and Terms

ALM - Aggregate Loss Model - RMS model for County / Cresta Zone level exposure

DLM - Detailed Loss Model - RMS model for detailed location exposure

PTM – RMS Property Terrorism Model

DTM – Digital Terrain Model – used for flood modelling allowing for terrain architecture, height and river depth.

EDM - Exposure Data Module - SQL database file containing exposure and insurance/reinsurance structure information.

ELT – Event Loss Table - table showing the RMS event set for a specific territory / peril, showing the annual occurrence rate, mean loss, independent and correlated standard deviation and the exposure value

IFM – Industrial Facilities Model –heavy industrial portfolio model

RDM - Results Data Module – SQL database file containing analysis results

VRG – Variable Resolution Grid – used for very high resolution terrain modelling, breaking up exposure into small grids

Centroid – a point latitude and longitude, which represents the centre of a defined geographical area

Distributed Mode – Losses calculated taking into account the uncertainty around the mean for each individual event (RMS typically assume a Beta distribution to represent the distribution in the severity of a particular event)

Expected Mode – Losses calculated based on mean weighted average, not allowing for uncertainty around the mean - standard deviation.

Hyper Surge – Extreme storm surge – term introduced by RMS post Katrina

Loss Amplification – RMS term that includes loss elements from demand surge, claims inflation, infrastructure disruptions, expansion of policy coverage, civil disorder, claims fraud, pollution and contamination.

Primary Characteristics – major characteristics of a structure on a location. These include construction class, year built, number of stories, floor area and type of occupancy.

Primary Uncertainty - the uncertainty around whether or not an event will occur, reflected in the annual rate (RMS typically use this rate as the mean for a Poisson distribution of the event frequency)

Pure Premium – essentially the "expected loss cost" component of a technical premium

Rmax – Radius to Maximum Winds – distance measured normal to the track of the storm to the location where winds experienced throughout the storm were highest.

Secondary Characteristics – characteristics of a structure other than the primary characteristics. These can be specified to differentiate vulnerability, such as year of upgrade, soft story, setbacks and overhangs, torsion and cladding.

Secondary Uncertainty - the uncertainty in the size of the loss given that a specific event has occurred. The size of a specific event loss can be in a range of values, some of which are more likely than others. AEP / OEP / TCE may all be calculated with or without secondary uncertainty. For pricing purposes is would be normal to include secondary uncertainty.

APPENDIX 3: HURRICANE DATA

The table below summaries the hurricane data on which we have drawn for some of our analysis.

SOURCES

ENSO

The data is taken from the Climate Prediction Centre of the NOAA :

http://www.cpc.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml

The data there shows 3 month running mean of sea surface temperature anomalies in the Niño 3.4 region (5oN-5oS, 120o-170oW)], based on the 1971-2000 base period. For historical purposes cold and warm episodes (blue and red coloured numbers) are defined when the threshold is met for a minimum of 5 consecutive over-lapping seasons. We have used the August-September-October period below.

AMO

The data is taken from the Climate Diagnostics Centre of the NOAA :

http://www.cdc.noaa.gov/Correlation/amo.us.long.data

where it is available since 1871. We have averaged the monthly sea surface temperatures for each year. AMO phases though are taken following Landsea's phase classification (see References)

Storm and Hurricane Frequency

The data is taken from the Tropical Cyclone Frequently Asked Questions part of the Atlantic Oceanographic and Meteorological Laboratory of the NOAA

http://www.aoml.noaa.gov/hrd/tcfaq/E11.html

http://www.aoml.noaa.gov/hrd/tcfaq/E23.html

Caveats

As mentioned above there is no universal method of attributing either ENSO or AMO phases, and the data shown is not fully consistent with that used in the Research papers quoted.

Starting in 1944, systematic aircraft reconnaissance was commenced for monitoring both tropical cyclones and disturbances that had the potential to develop into tropical cyclones. Hurricane data before that time is therefore less reliable.

APPENDIX 3: Atlantic Hurricane Data - by Seasons

Season	Ace Index	Number of Tropical Storms	Number of Hurricanes	Number of Major Hurricanes	Landfalling Hurricanes	Landfalling Major Hurricanes	El Niño La Niña Neutral	AMO Index	AMO Phase
1950	243	13	11	8	3	2	Niña	(0.023)	Warm
1951	137	10	8	5	0	0	Niño	0.185	Warm
1952	87	7	6	3	1	0	Neutral	0.261	Warm
1953	104	14	6	4	3	0	Neutral	0.263	Warm
1954	113	11	8	2	3	3	Niña	0.065	Warm
1955	199	12	9	6	3	2	Niña	0.180	Warm
1956	54	8	4	2	1	0	Niña	(0.018)	Warm
1957	84	8	3	2	1	1	Niño	0.064	Warm
1958	121	10	7	5	0	0	Neutral	0.231	Warm
1959	78	11	7	2	3	1	Neutral	0.060	Warm
1960	88	7	4	2	2	1	Neutral	0.257	Warm
1961	205	11	8	7	1	1	Niña	0.182	Warm
1962	36	5	3	1	0	0	Neutral	0.140	Warm
1963	118	9	7	2	1	0	Niño	0.063	Warm
1964	170	12	6	6	4	1	Neutral	(0.061)	Warm
1965	85	6	4	1	1	1	Niño	(0.110)	Warm
1966	145	11	7	3	2	0	Neutral	0.043	Warm
1967	122	8	6	1	1	1	Neutral	(0.044)	Warm
1968	35	7	4	0	1	0	Neutral	(0.100)	Warm
1969	158	17	12	5	2	1	Niño	0.070	Warm
1970	34	10	5	2	1	1	Niña	(0.074)	Warm
1971	97	13	6	1	3	0	Niña	(0.223)	Cold
1972	28	4	3	0	1	0	Niño	(0.250)	Cold
1973	43	7	4	1	0	0	Niña	(0.086)	Cold
1974	61	7	4	2	1	1	Niña	(0.309)	Cold
1975	73	8	6	3	1	1	Niña	(0.168)	Cold
1976	81	8	6	2	1	0	Niño	(0.256)	Cold
1977	25	6	5	1	1	0	Niño	(0.082)	Cold

Season	Ace Index	Number of Tropical Storms	Number of Hurricanes	Number of Major Hurricanes	Landfalling Hurricanes	Landfalling Major Hurricanes	El Niño La Niña Neutral	AMO Index	AMO Phase
1978	62	11	5	2	0	0	Neutral	(0.087)	Cold
1979	91	8	5	2	3	1	Neutral	(0.008)	Cold
1980	147	11	9	2	1	1	Neutral	0.091	Cold
1981	93	11	7	3	0	0	Neutral	0.045	Cold
1982	29	5	2	1	0	0	Niño	(0.187)	Cold
1983	17	4	3	1	1	1	Niña	0.000	Cold
1984	71	12	5	1	1	1	Neutral	(0.148)	Cold
1985	88	11	7	3	6	2	Neutral	(0.170)	Cold
1986	36	6	4	0	2	0	Niño	(0.226)	Cold
1987	34	7	3	1	1	0	Niño	0.188	Cold
1988	103	12	5	3	1	0	Niña	0.098	Cold
1989	135	11	7	2	3	1	Neutral	0.039	Cold
1990	91	14	8	1	0	0	Neutral	0.111	Cold
1991	34	8	4	2	1	0	Niño	(0.027)	Cold
1992	82	6	4	1	1	1	Neutral	(0.121)	Cold
1993	39	8	4	1	1	1	Neutral	(0.088)	Cold
1994	32	7	3	0	0	0	Niño	(0.059)	Cold
1995	228	19	11	5	2	1	Niña	0.279	Warm
1996	166	13	9	6	2	1	Neutral	0.140	Warm
1997	40	7	3	1	1	0	Niño	0.276	Warm
1998	182	14	10	3	3	0	Niña	0.530	Warm
1999	177	12	8	5	3	1	Niña	0.335	Warm
2000	116	14	8	3	0	0	Neutral	0.209	Warm
2001	106	15	9	4	0	0	Neutral	0.331	Warm
2002	66	12	4	2	1	0	Niño	0.287	Warm
2003	175	16	7	3	2	0	Neutral	0.473	Warm
2004	225	14	9	6	6	3	Niño	0.447	Warm
2005	248	27	15	7	5	4	Neutral	0.525	Warm

APPENDIX 3: Atlantic Hurricane Data - Analysis

	Seasons	Ace Index	Number of Tropical Storms	Number of Hurricanes	Number of Major Hurricanes	Landfalling Hurricanes	Landfalling Major Hurricanes	Major Hurricanes % TS
ENSO								
Niño	16	75.8	8.4	5.0	1.9	1.3	0.4	23%
Neutral	25	107.8	11.2	6.6	2.7	1.7	0.7	24%
Niña	15	121.9	10.7	6.8	3.4	1.8	0.9	32%
Niña/Neutral		1.13	0.96	1.03	1.25	1.07	1.37	1.30
Niña/Niño		1.61	1.28	1.36	1.75	1.44	2.49	1.37
AMO								
Warm	32	129.5	11.6	7.1	3.6	1.8	0.8	31%
Cold	24	66.3	8.5	5.0	1.5	1.3	0.5	18%
Warm/Cold		1.95	1.35	1.44	2.38	1.48	1.77	1.75
AMO & Climate Change								
1950-1970 Warm		115.0	9.9	6.4	3.3	1.6	0.8	33%
1971-1994 Cold		66.3	8.5	5.0	1.5	1.3	0.5	18%
1995-2005 Warm		157.2	14.8	8.5	4.1	2.3	0.9	28%
1995-2005 / 1950-1970		1.37	1.50	1.32	1.25	1.40	1.19	0.83
1950-1970 / 1971 - 1994		1.73	1.15	1.30	2.19	1.30	1.66	1.90