Catastrophe Modelling
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This paper consist of three sections

- **A Short Introduction** - Which discusses the role Catastrophes have played recently and some of the reasons they can be expected to continue to cause severe human and economic dislocation.

- **A Review of Scientific Issues associated with Catastrophes** We will then discuss some of the scientific issues surrounding these catastrophes, the subject of climate change and the steps that may be taken to mitigate the damage caused by these events.

- **A Review of Insurance Issues and Catastrophe Modelling** In this section we address background to models, how they came into more common usage, overview their construction, give some basic information on some of the models and discuss how they are used in practice.

We have attempted to ensure that each section can be read independently of the rest of the article. So, for instance, if you are already familiar with the scientific issues, (or simply not as interested in them) you can simply skip section 2 and go directly to section 3 and you should not have trouble following the material there.

We have included several tables at the back of the paper, taken reports published by Swiss Re and the ABI which show:

- Natural catastrophes 1970-96 ranked by insured loss, in US$ at 1996 values

- Natural catastrophes 1970-96 ranked by number of deaths.

- Analysis of catastrophes 1993-96 by category

- Major UK weather incidents 1970-93.

Section 1

A Short Introduction

1 Introduction

Catastrophes have caused significant damage over the last few years. There have been more catastrophes causing more damage over the last few years than in the recent past. In this section we will review this increase and some of the possible reasons for this increase.

1.1 Motivation

The table below shows the number and cost of catastrophes in the past few decades.

Decade	1960-69	1970-79	1980-89	1987-96
Number	16	29	70	64
Economic Losses	48.4	93	147.6	404.4
Insured Losses	6.5	10.9	29.8	98.8
% Insured/Economic	13%	12%	20%	24%

Source: Munich Re, figures are US$ Billions in 1996 values.

This table indicates that the numbers and costs of catastrophic losses are increasing. Also, the share of the losses which are insured is increasing.

There are several factors which could be causing the apparent increase in catastrophe losses, including:

Population growth

The population of the world has increased from approximately 2 billion in 1945 to approximately 6 billion in 1990. The world's population is forecast to increase to at least 10 billion before stabilising, unless war, disease or some other disaster prevents this. More people means more property at risk.

Most of this growth is expected to be in the developing world. The impact of catastrophes in such countries is characterised by the loss of many lives, but relatively little insured loss. The disease and deaths that follow catastrophic events in such countries may be exacerbated by the relatively low levels of health care and the lack of resources available to provide disaster relief.

The pressure for land in the developing world is leading to the use of unsustainable land uses that degrade the environment and increase the vulnerability to future events. For example, deforestation increases the rate of rainwater run-off, and hence increases the probability of flooding downstream.

Urbanisation

The percentage of the population which lives in increasingly densely populated urban areas is expected to increase, mainly caused by the reduction in the number of people required to work in agriculture and by the demand for labour produced by the expanding global economy. It is estimated that more than 30 million people move from rural to urban areas each year. As town and cities expand property may be built on more hazardous sites that were previously less well developed. For example, new developments may be built on reclaimed swampland or landfill sites which may be more prone to liquefaction in the event of an earthquake.

Coastalisation

The population increase in coastal regions, especially in the USA, has been greater than elsewhere. Hurricanes, tsunami and floods have the greatest impact in coastal regions, so this concentration of population, property and industry near to the coast has increased the exposure to loss. The major tectonic boundaries of the world are located along coastlines, so there are more people exposed to the risk of earthquakes, too. It is estimated that 50% of the population of the USA lives within 80km of the coast. In summer the population at the coast will be even greater.

Economic growth

The world economy continues to expand, partly fuelled by the increasing population, partly by economic and technological change. New industries have sprung up which are increasingly capital-intensive, replacing labour-intensive industries such as agriculture as major sources of wealth-creation. Large manufacturing plants are very expensive to replace and the business interruption losses whilst they are out of service can be very large. The increasing use of "just in time" stock-keeping may mean that in the event of a disaster a company is more likely to run out of supplies before deliveries resume, leading to greater business interruption losses.

Future evolution of the developed economies may be in the direction of knowledge-intensive industries. Although these may be less dependent on physical buildings to operate they will depend to a greater extent on the operation of other infrastructure such as electricity supplies to operate computers and telecommunications links to communicate with the outside world. This leads to the possibility that damage in a small area can have repercussions over a wider area in terms of business interruption.

Climatic Conditions

The frequency, severity and location of some catastrophes may be affected by changes to the global climate. This topic is discussed in greater length in this paper.

Social attitudes to insurance

As the standard of living of a population increases they may be less inclined to risk suffering hardship. They may be more inclined to purchase insurances to protect their property, if such insurance is available. The availability of insurance cover may be a disincentive to taking loss mitigation measures.

These factors may be expected to lead to an increase in the level of exposure to catastrophic events in the foreseeable future.

The insurance industry has become increasingly concerned with trying to quantify their exposures to catastrophe losses in recent years. This has been spurred on by the difficulties caused in the insurance and reinsurance markets in the late 1980's and early 1990's by a succession of large catastrophe losses. These difficulties were at least partly caused by a less than thorough understanding of the exposures that insurers and catastrophe reinsurers were underwriting.

As part of the reconstruction and renewal process Lloyds has recently introduced the requirement for Syndicates to divulge their exposures to what are called Realistic Disaster Scenarios (RDS's). This requirement helps to improve the level of awareness of the exposures that Syndicates are writing. In order to comply with this requirement many Syndicates are, or will be, using software catastrophe models to help to determine their exposure to RDS's.

When catastrophes are mentioned in the insurance literature there is generally a focus on the cost of insured losses. As actuaries are mainly employed by the insurance industry it is only proper that we equip ourselves with the tools and knowledge required to estimate the amounts of insured losses. However, we should remember that much of the property damage caused will not be insured. Also, catastrophes claim the lives of tens of thousands of people each year, mostly in the developing world. The insured losses are the tip of the iceberg. Is there a role for the actuarial profession in quantifying these other losses?

In the paper we consider two types of model, those that represent the weather or climate, and those that represent the impact of catastrophe events. The intensity of scientific research directed at the climate models has led to such models evolving rapidly. The models of only a few years ago are now known to be too simplistic. No doubt in a few years scientists will consider today's models to be similarly naive. We may observe a similar evolution in the state of catastrophe models. However, the rate of evolution may be much slower. The climate modelers have new information raining down from earth-gazing satellites at a rate of megabytes per second. Catastrophe modelers can only revisit old data and wait for the next Big One to arrive.

The climate models of the 1980's produced pretty pictures showing the earth coloured in reds and yellows representing the projected global warming. Nowadays they're also painted with hints of blue representing areas that are predicted to cool, and the red tones have lightened a little. Perhaps we should be a little wary of the outputs of the current catastrophe models which also impress with their colourful maps of red and yellow.

Section 2

A Review of Scientific Issues associated with Catastrophes

Introduction

This portion of the paper will discuss natural sudden-onset catastrophes. These can be split into three types:

- **Atmospheric:** caused by the release of energy stored in the atmosphere and surface water; including winds, floods and hail, but excluding drought and conflagration.

- **Geophysical:** caused by the release of energy stored below the surface of the earth; including earthquakes and volcanoes.

- **Extraterrestrial:** caused by energy introduced by the impact of physical bodies from outside of the earth; including meteorites and comets.

It is hoped that this paper will be useful for a wide range of readers. We have attempted to make the paper as accessible as possible for readers who may not be familiar with the subject. In particular we are aware that the growth in numbers of actuaries and students practising in general insurance has been partially funded by the influx of actuaries and students from other fields.

In this Section we hope to cover

Section 2.1
We will start from first principles, examining the scientific understanding of the causes of these catastrophes. This section provides background information which will assist in the understanding of long-term and short-term changes in the climate. We also describe the damage that is caused by these events.

At the present time there are commercially available software models which cover various hazards including wind, flood, earthquake, fire following quake, and tornado. We will not limit our investigation to these hazards, although we will concentrate on these as they are the most costly in terms of insured losses. However, we consider other catastrophic losses as these are responsible for significant losses of life and property.

Section 2.2
We will discuss the subject of climate change. This is important as changes in the climate may affect the frequency, severity and location of the atmospheric catastrophes. If the climate will change in the future then we may need to beware of using the recent past as a guide to the near future. Similarly, if the climate of the recent past was not the constant, then we should beware of using historical experience which does not allow for this.

Section 2.3
We will discuss steps that may be taken to mitigate the damage caused by catastrophic events. This will include loss prevention measures such as sea defences, loss warning measures such as earthquake prediction, loss reduction measures such as evacuation procedures.

2.1 Causes and effects: the science of catastrophes

In the following sections we describe the causes of the major catastrophes, and describe the impacts that each has and the nature of the damage that they cause.

2.1.1 Atmospheric Events

In this section we consider the scientific understanding of the movement of the fluids which lie on the surface of the planet: the atmosphere, the oceans and the non-oceanic surface water.

In particular, we will consider:

- Tropical Cyclones (Hurricanes and Typhoons)
- Extra-tropical cyclones (Winter Storms)
- Tornadoes
- Flooding

These catastrophes are the most significant. In the period 1960-1996 storms and flooding accounted for 62% of natural catastrophes, causing 85% of the catastrophe-related deaths and 90% of the catastrophe-related losses.

Understanding the atmosphere

The atmosphere is a layer of gases and suspended particles which extends for more than 300km above the surface of the earth, although it is very sparse at the higher levels.

The lower layer of the atmosphere which extends to about 15km above the surface of the earth is known as the troposphere. The troposphere is warmed by a process known as the greenhouse effect which is described below.

The Greenhouse Effect

The greenhouse effect is colloquially equated with global warming. The topic of global warming is discussed in a later section. At this stage we are considering this effect in general, which is not the same as global warming.

The effect known as the greenhouse effect has been known about since the early nineteenth century. It is the process which warms the lower part of the atmosphere. *Without the greenhouse effect the surface of the Earth would be about 33°C lower* than it actually is these days.

A large part of the electromagnetic energy emitted by the sun has wavelengths that we label as "visible light". [It is precisely because the Sun emits so much energy at these frequencies that our eyes have evolved to make use of it]. Electromagnetic energy at these frequencies is not absorbed very much by the atmosphere. The photons of light pass through the atmosphere and strike the ground. Some of the light will be reflected back into space, the remainder will be absorbed by the oceans and land. These lose energy in the form of heat by conduction, convection and the radiation of infra-red energy. Energy transferred to the atmosphere will be dissipated by further convection, and by re-radiation at increasingly lower frequencies of infra-red light. This effect slows the rate at which heat escapes from the lower atmosphere.

Some chemicals, notably water, carbon dioxide (CO_2) and methane, are very good at absorbing the infra-red light radiated by the atmospheric gases and the surface of the planet. This electromagnetic energy is converted into heat. If the proportion of such "greenhouse gases" increases in the atmosphere then it is expected that the amount of infra-red energy that is absorbed by the atmosphere and converted to heat will increase, leading to an increase in the temperature of the troposphere. See the later section on climate change for a discussion of the effect of increased levels of greenhouse gases in the atmosphere.

The most important greenhouse gas is water vapour with 98% of the greenhouse effect being due to this.

The temperature of the troposphere decreases with altitude. This allows convection to take place, as warm, less dense air from the lower atmosphere rises through the colder, denser, air immediately above. The pressure of the atmosphere is caused by the weight of air above. As warm air rises by convection it expands due to the lower pressure at higher altitudes and reduces in temperature. If the rising air contains water vapour, then as the air cools some of the water vapour may condense into liquid water if there are dust particles in the air which act as seeds for droplet formation. As the water vapour condenses it releases latent heat which warms the remaining air. This will allow the rising air to continue convecting upwards.

In this way some heat is transferred from the lower troposphere to the upper troposphere. In equatorial regions air rising by this mechanism can attain altitudes of around 16km.

The stratosphere is the layer which lies above the troposphere, extending for about another 35km. Unlike the troposphere the temperature of the stratosphere increases with altitude. The stratosphere is heated by ultra-violet light being absorbed by oxygen molecules, a process which creates ozone. The ozone created absorbs ultra-violet light, too, at a slightly different frequency. This process warms the stratosphere, the level of warming being greater with increasing altitude. As the temperature of the stratosphere increases with altitude, convection does not occur. The behaviour of the stratosphere is therefore rather different to that of the troposphere. As the air in the stratosphere is more stratified than the troposphere it acts as a sort of lid which contains the bubbling troposphere beneath. Virtually all of the weather patterns that concern us depend almost exclusively on the behaviour of the troposphere.

The troposphere-stratosphere boundary, the tropopause, occurs at the point where the rate of change of warming from below is exactly balanced by the rate of change of the warming from above. At this point the temperature of the atmosphere is at a local minimum. The temperature at the tropopause varies from about -80^{o}C at the equator, to about -40^{o}C at the poles.

Air that rises near the equator moves polewards before descending again at about 30^{o} of latitude. This causes surface winds to flow towards the equator within the tropics. This pattern of circulation of air within the tropics is known as a Hadley Cell. As the air rises at the equator much of the water vapour it contains condenses out as clouds. When this air then descends again just outside the tropics it is therefore relatively dry. This is why the tropics are humid, and the world's deserts tend to be located just outside the tropics.

As the earth rotates it drags along the atmosphere with it. However, the atmosphere tends to lag behind. This results in the tendency for winds to blow in an easterly (ie from east to west) direction at the equator. The surface velocity of the earth relative to the axis of rotation decreases with latitude as the circle traversed by a point on the surface has a smaller radius with increasing latitude. Air which moves polewards has momentum imparted from the more rapidly moving surface nearer the equator and travels at a greater speed in the direction of rotation of the earth than the earth underneath it, as the velocity of the surface decreases with latitude. This results in polewards moving air to be deflected towards the east. Similarly, winds blowing towards the equator are deflected towards the west.

The prevailing winds caused by the above process push along the surface of the oceans and cause large scale oceanic currents to form. For example, in the North Atlantic the prevailing wind which starts as an easterly wind between west Africa and Brazil is gradually deflected northwards, through the Caribbean, along the eastern coast of Florida before setting off in a north-easterly direction towards Europe. This prevailing wind produces the warm ocean current known as the Gulf Stream which flows across the Atlantic towards Europe. If it were not for the warming effect of the Gulf Stream then northern Europe, particularly the UK, would be about 5^{o}C colder than it is.

Another effect of these prevailing winds is that they tend to push the warm surface waters of the tropics towards the western edge of the ocean basins - the eastern edge of the land. The sea level at the western edges of the ocean basins is a metre or so higher than the sealevel at the eastern edges. As the warm tropical surface waters are pushed westwards they are replaced from below by colder waters which have risen from the depths of the oceans. The waters on the eastern edges of the oceans - the western coasts of land - then tend to be colder than those on the eastern coasts. As we shall see below, the surface temperature of the oceans is a major driving force of tropical cyclones, and so we tend to see more violent tropical cyclones on eastern coastlines of the continents. For example, we are more concerned about hurricanes hitting Florida than California.

The Oceanic Conveyor Belt

The circulation of the oceans is more complicated than as described above.

As the Gulf Stream moves northwards it loses heat to the atmosphere partly via the evaporation of water. This makes the remaining water saltier and colder, and hence denser. The waters around the North Atlantic are less salty as they are watered down by rivers, rain and melting snow and are therefore less dense than the Gulf Stream's water. This predisposes the denser waters of the Gulf Stream to sink in the area near Iceland. The sinking waters are pushed downwards by the following waters, as these are pushed along by the trade winds blowing across the Atlantic. This water then flows southwards at a depth of around 2-3 km where it is known as the North Atlantic Deep Water. This underwater current flows all the way to the Antarctic ocean where it joins the Antarctic Circumpolar Current. How this water returns to the Atlantic is still not fully understood, but it is believed that it contributes to deep water currents that return to the surface in the Indian Ocean, the Pacific, and joins other currents which pass around Cape Horn.

The sinking of the Gulf Stream around Iceland is the main driving force which causes these cold deep sea currents. A similar process occurs in the Labrador Sea between Canada and Greenland. These two areas are called the "Pumps". If it wasn't for this pumping process the warm surface currents would circulate around the ocean basins as gyres, and the Gulf stream would pass southwards towards the west coast of Africa rather than coming so far north in the Atlantic.

See the section on climate change for a discussion of the impact of global warming on the oceanic conveyor belt.

El Nino events

El Nino is the name originally given to a warm current which appears along the coast of Peru and Ecuador, usually around Christmas time (El Nino is Spanish for "boy child"). Nowadays the term "El Nino Event" refers to an exceptionally warm current that occurs every two to seven years along the Peruvian coast which usually begins in the summer and can last for up to two years. An El Nino event occurred this spring (1997) some months earlier than meteorologists had predicted.

El Nino events affect the global climate, leading to a redistribution of rainfall and changes in average temperatures for different regions. There is therefore the potential that El Nino may be a precursor for a change in the frequency, severity and location of catastrophic atmospheric events such as hurricanes.

The causes of El Nino events are reasonably well understood, and in the past decade climatologists have been able to predict El Nino events with some success.

Normally the prevailing winds blowing from east to west across the Pacific drive the warm surface waters westwards. As they are pushed away from the Peruvian coast colder waters rise from the depths to replace them. The warm surface waters are pushed towards Australia and the Philippines, where the temperature of the water is several degrees warmer than near Peru and the sea level is a metre or so higher. If the prevailing winds slacken slightly these warmer waters tend to flow back eastwards across the Pacific, pressed down by the weight of water that the wind is no longer pushing up.

Once this starts to happen it is reinforced by a positive feedback mechanism. As the eastern waters warm they warm the air above them warms too, becoming less dense and more similar to the air to the west. This reduces the propensity for winds to be generated which blow from east to west. This tends to make the prevailing winds weaker still, which allows more water gathered up around Australia to flow back eastwards towards Peru.

Although the immediate impact of El Nino events is felt in South America, they are associated with changes in the climate all over the world. The following table shows the main areas that are known to be affected:

	Reduced Rainfall	Unchanged rainfall	Increased rainfall
Hotter than normal	SE Africa	Japan NE Canada SW Canada SE Australia	Mid Pacific
Normal temperature	N Australia, SE Asia N Brazil		Central Africa Argentina
Colder than normal			SE USA

Hot and/or dry weather can lead to drought and an increased propensity for large forest fires. Also, as prolonged hot weather can warm the surface of the ocean it may lead to a higher number and/or increased severity of tropical cyclones. In particular, El Nino events may reduce the level of hurricane activity.

Wet weather can lead to a propensity to flooding.

The climate change can affect agricultural production. The increased warm, damp weather in some areas can also affect the amount of malaria and cholera.

Changes in the temperature difference between the poles and the temperate regions can have an impact on the frequency and severity of extra-tropical cyclones.

Feedback mechanisms

There are many factors which influence the atmosphere. Some of these factors act to reinforce themselves (positive feedback), others act to counteract themselves (negative feedback). The complex interactions between the different factors which influence the weather and climate make them very difficult to model. We list below several factors and indicate how they may cause positive or negative feedbacks:

Positive Feedback

(1) If the temperature of the oceans increase then we may expect there to be more evaporation of water vapour into the atmosphere. This is the major greenhouse gas and so we may expect the temperature of the atmosphere and oceans to increase as more heat is retained in the atmosphere.

(2) If surface temperatures increase the increased amount of water vapour in the atmosphere it will tend to increase the cloud cover which will trap heat near the surface of the earth like a blanket, leading to an increase in the rate of evaporation.

(3) Researchers at Princeton University have suggested that if the oceanic conveyor belt slows down due to global warming, then the amount of CO_2 absorbed by the oceans will decrease, leading to higher concentrations of CO_2 in the atmosphere and therefore an enhanced greenhouse effect.

(4) If the temperature of Greenland or the Antarctic increases, then the icecaps will tend to retreat as they will thaw more in the summer. As the bare ground revealed will be less reflective than the ice and snow then more sunlight will be absorbed. Hence the temperature may be expected to increase.

(5) If surface temperatures rise previously inhospitable regions become habitable for many species of plants. Plants are better at absorbing energy than bare earth, and so more sunlight will be absorbed, leading to increased warming.

Negative Feedback

(1) An increase in level of cloud cover caused by increased surface temperatures will result in more sunlight being reflected back into space before it reaches the ground, tending to result in surface cooling.

(2) Increased water vapour in the atmosphere will tend to lead to greater precipitation. Precipitation falling as snow will make the surface of the planet more reflective of sunlight than bare earth, so will tend to cause greater cooling.

Types of windstorm

Windstorms come in several flavours, each of which is caused by a different physical process. These include tropical cyclones (including hurricanes), extra-tropical Cyclones (also known as winter storms) and tornadoes. The causes of each of these is described below:

2.1.1.1 Tropical Cyclones

Tropical cyclones which affect the USA and Caribbean are called hurricanes. A typhoon is the name given to such windstorms in Southeast Asia. In Northern Australia such storms are known as willy-willies. These are all the same type of storm.

Tropical cyclones form over warm oceans where the surface temperature is at least 27°C. The seed for tropical cyclones is an area of thundery rain. The warm air rising in such areas causes a drop in air pressure at the surface of the earth. This low pressure draws in warm, humid air from the surrounding atmosphere. This spirals towards the centre of the low pressure system due to the Coriolis effect caused by the earth's rotation. (This is the effect that causes water to spiral down into a plughole). Tropical cyclones do not form within about 5 degrees of latitude from the equator as the Coriolis effect is not sufficiently powerful at low latitudes to cause the air to spiral into a low pressure area.

As water vapour in the rising moist air condenses it releases latent heat which warms the residual, dry air. This makes it expand which reduces its density and leads to further convection which leads to a further fall in the air pressure at the surface. This causes yet more warm, moist air to be drawn in, and so the cycle repeats. This positive feedback causes the pressure to continue to reduce at the heart of the forming cyclone, which increases the rate at which air is drawn in. This results in the windspeed of the air being drawn in to increase.

The forming cyclone is initially blown westwards by the winds flowing in the medium-level troposphere. However, as it becomes larger it may be influenced by the effect of land, even islands, several hundreds of kilometres away. This is partly because the storm will attempt, to some extent, to follow a path which provides it with the maximum amount of energy, so will avoid land as this may provide it with less of the warm, moist air that fuels it. When a storm reaches land it said to make landfall. At the present time the science of predicting the track of cyclones is not sufficiently advanced to enable precise landfall predictions to be made. Instead meteorologists can only make probabilistic estimates based on the paths of previous cyclones. Owing to the general pattern of atmospheric circulation, and the effect this has on the ocean currents and the oceans' surface temperature, tropical cyclones are most intense on the western edges of the ocean basins (the eastern edges of land.

At its very centre, the eye, there is a point of calm. Just around the eye windspeeds for the strongest cyclones may be in excess of 250km/h. To be classified as a tropical cyclone the storm must have windspeeds of at least 120km/h.

The low pressure at the centre of the cyclone will cause the sea over which the storm is passing to be sucked up by up to several metres. The winds of the cyclone will cause the sea to be pushed upwards in the direction of the wind, also by up to several metres. Also, the winds will generate large waves on the surface of the ocean. The combined effect of these factors may raise the level of the sea by several metres. This is known as **storm surge.**

When a cyclone makes landfall the storm surge can lead to flooding. If the storm makes landfall at high tide the effect is exacerbated. Up to 90% of hurricane-related deaths and property damage are caused by the flooding associated with storm surges.

Tropical cyclones also produce up to 30cm of rain which is precipitated in a short space of time. This can lead to flooding in addition to that caused by storm surge.

When a cyclone makes landfall it will tend to decrease in severity as it is cut off from the warm, moist water which fuels it. In fact, a cyclone may already have lost some of its strength by the time the centre of the storm makes landfall due to the leading edge of the storm already having been over land for some time.

The intensity of cyclones is measured on the Saffir-Simpson Hurricane Scale which extends the Beaufort Scale, which is the scale that is used to measure more moderate winds. This gives a number from 1 to 5 depending on the maximum mean wind velocity, as shown in the table below:

Saffir-Simpson rating	Description	Mean wind velocity in km/h
1	Weak	118-153
2	Moderate	154-177
3	Strong	178-209
4	Very Strong	210-249
5	Devastating	250+

In the table above the mean velocity is measured over a period of 10 minutes, standardised to a height of 10m to reduce the effect of friction with the ground.

There are approximately 65 tropical cyclones in the world each year, on average, which have a Saffir Simpson rating of 1 or higher, of which 2, on average, will make landfall on the continental USA.

2.1.1.2 Extra-tropical Cyclones

Extra-tropical cyclones (ETC's) are caused by the interaction between cold air masses above the poles and the warmer air at mid-latitudes. These windstorms occur mainly in the late autumn and winter when the temperature difference between the polar air which receives little solar warming in winter, and the temperate air at lower latitudes which is warmed by ocean currents, is the greatest.

As cold polar air moves towards lower latitudes it comes up against warmer, moister air. The warmer air will tend to be forced upwards as the cold air front, being denser, pushes underneath the warmer air. The water vapour in this warm air will tend to condense as it rises, releasing its latent heat which warms the remaining air. This causes the air to rise more rapidly, which leads to a reduction in the atmospheric pressure below, which will then suck the cold polar air further equator-wards, and more warm air upwards. This process is another example of positive feedback which will tend to make the effect self-sustaining or will even aggravate the intensity of the effect. It is therefore similar in some ways to the process which generates tropical cyclones.

The low pressure area created by this procedure will cause winds that spiral in to the centre of the depression due to the Coriolis effect. In the northern hemisphere ETC's rotate anti-clockwise, whereas in the southern hemisphere they rotate clockwise.

The winds generated by ETC's are not often as strong as those produced in tropical cyclones, and rarely exceed 200 km/h. However, they affect large areas. We are mainly concerned with those ETCs which occur in the northern hemisphere as the southern hemisphere has less land and hence a lower population density. In particular, the densely populated European continent lies at the latitudes where ETCs tend to form.

The translational speed of the ETC itself will affect the windspeed experienced on the ground. These speeds can be quite high, for example 87J had translational speeds of up to 100 km/h. For an ETC moving eastwards the combined effect of the rotational windspeed and translational speed is such that the windspeed on the ground is the highest to the south of the centre of the cyclone.

The winter storms known as 87J and 90A which affected large parts of Northern Europe, and the UK in particular, are examples of ETC's. ETC's will generate storm surges in the same way that Tropical Cyclones do.

2.1.1.3 Tornadoes

These are caused by the interaction between cold polar air and the warmer air of lower latitudes. They form just ahead of advancing cold fronts. If cold air has been forced to move above the warmer air below it is unstable as it is denser. In some places the denser cold air from above can tunnel through the warmer air. This pumps warm air from below upwards, leading to the formation of thunderclouds as the water vapour condenses. If a packet of descending cold air rotates due to the Coriolis effect it can descend through the warm air more rapidly. Where the descending cold air packet touches the warm air being pumped upwards it can cause rapid condensation of the water vapour in the warmer air. This may be visible as spinning funnel-clouds beneath the thundercloud. If conditions are right this funnel-cloud can reach to the ground where it becomes a tornado.

The winds in the funnel of a tornado can exceed 400 km/h. Tornadoes travel at around 20-60 km/h relative to the ground. The destruction that they cause is usually limited to a path less than 500 metres wide and less than 25km long. However, a tornado in

1917 travelled about 500km and lasted for several hours, so the potential for large aggregations of loss is certainly possible.

Tornadoes mainly occur in the USA, which suffers from 900 each year, although all of the deaths and most of the property damage is caused by about 30 of these. The mid-west, in particular central Oklahoma, is particularly prone to them. This is mainly because the absence of any major mountain ranges between this area and the cold polar air to the north. However, tornadoes do occur in many other areas. It has been claimed by Fujita, after whom the tornado intensity scale is named, that the frequency per unit area of tornado production is just as high in other mid-latitude countries, such as Italy, as in the USA.

Tornadoes in the USA tend to occur in the period from April to July, May in particular.

Luckily tornadoes tend not to occur over cities, where the resulting damage would lead to large losses. This is believed to be due to the air above cities being drier than over rural areas and also because cities introduce turbulence into the atmosphere which prevents tornadoes from forming.

The severity of tornadoes is measured on the Fujita Tornado Scale as shown below:

Scale number	Description	Velocity in km/h
0	Weak	62-117
1	Moderate	118-180
2	Strong	181-253
3	Devastating	254-332
4	Annihilating	333-418
5	Disaster	419+

Factors which influence the amount of damage caused by a windstorm

These following factors apply to a greater or lesser extent to each of the windstorm types described above:

- Mean velocity: the stronger the wind the more momentum is imparted on the property in its way.

- Turbulence: eddies within the mainstream wind can have somewhat higher velocity than the mean. This is known as gusting. The peak-gust (average over two seconds) of a windstorm has been shown to have the best correlation with the amount of damage that is caused.

- Direction: the resilience of a structure to damage can be affected by the angle of attack of the wind. This is because the wind will create both impact forces when it hits a building head-on, and suction forces where turbulence creates eddies with low air pressure, particularly on the leeward side of buildings.

- Duration: greater damage will be caused as materials become fatigued by the stress.

- Projectiles: impacts from items carried in the airflow can cause much damage.

- Location: more damage will be caused if the severest part of a storm passed over an area with a concentration of physical assets.

- Tide at landfall: this can affect the amount of coastal flooding created by the storm surge.

- Time of year: if an ETC strikes before the autumnal leaves have fallen from the trees then the amount of damage caused by falling trees can be increased.

The impact of Windstorms

The damage caused by severe winds comes from many sources. Some of these are described below:

Roofs

Damage to roofs causes most of the losses due to windstorms. Roofs are often damaged in severe winds. There are several reasons for this, including:

- Windspeeds generally increase with height as the airflow is less hindered by obstructions and turbulence.

- Roofs are generally relatively light compared to the rest of a building and may not be fastened strongly enough to the rest of the building, gravity being sufficient until the windstorm hits.

- Sharp edges under the eaves create turbulence which can have an upwards component, tending to lift the roof away from the building.

Roof damage allows the wind to penetrate into a building causing further damage. Also, the loss of a roof will allow the heavy rains that often accompany windstorms to cause yet more.

Falling trees

Falling trees can damage buildings, cars and can also bring down power and telephone cables. Fallen trees can block roads, hampering the work of the emergency services.

Flooding

Coastal areas may suffer from flooding caused by the effects on sea level described above. Also, the heavy rain from the storm can cause flash flooding further inland.

Windows

Glass will be easily broken by projectiles carried in the wind. Also, the wind may cause resonance in panes of glass which may lead to them shattering.

Pylons

These not only suffer the direct force of the wind, but also stresses caused by the effect of the wind on the cables. The cables carried by the pylons may be forced to resonate which can cause a series of pylons to topple over in a domino-effect.

Bridges

There have been some spectacular suspension bridge collapses in the past caused by the action of the wind. This can induce resonance, causing the bridge to sway to and fro with increasing amplitude, causing increasing amounts of fatigue and possible structural failure.

Motor

Losses arise from damage to parked cars caused by airborne projectiles and falling trees. Severe wind can also cause motorists to have accidents while driving. High-sided vehicles such as trucks have the greatest risk.

Marine

About one third of all marine losses are attributed to storms. The destructive force of winds at sea can be more than on land due to the lack of obstructions to the airflow, and the additional momentum exerted by the sea spray. Also, severe winds can generate waves which may be higher than a ship, rig or other marine structure is able to withstand.

Increasing affluence has resulted in an increase in the number of leisure boats which are easily damaged in severe weather.

Agriculture

Losses may be caused by the damage to forests, fruit orchards, greenhouses and their contents. Hailstorms can also cause extensive damage to crops. Coastal flooding caused by storm surge can cause salt contamination of farmland, reducing yields.

2.1.1.4 Flooding

Flooding is the most common catastrophe, causing more deaths than other events, although causing less insured losses. This is partly explained by the high death toll in one country alone, Bangladesh, of which more than half of the total country is expected to be flooded to a depth of at least 1 metre each year. Half of the population of China live on the flood plains. 10% of the population of the USA live within the flood plain of a 1 in 100 year flood.

When we consider flooding we need to consider both the rate of drainage of groundwater away from the area of potential flooding and the rate of drainage from upstream. In flat low lying areas the rivers will tend to flow slowly as the gradient of the river will be slight. This reduces the rate at which excessive rainwater can be drained from the area. In hilly areas the rate of drainage can be much quicker. However, this merely shifts the problem downstream. Flat areas lying downstream of hilly areas are at particular risk of flooding. This is part of the reason that Bangladesh is so prone to flooding as it lies downstream of rivers which are fed by Himalayan snow meltwater.

The speed of onset of flooding is a major factor in determining the loss of life that flooding causes. In general, the more rapid the onset, the more lives will be lost, as there may be insufficient time to alert people to the problem. However, sudden-onset flooding will generally be confined to a relatively small area, and so the amount of property damage that is caused will be less. Although floods which affect large areas can cause extensive property damage, there will often be sufficient time to issue flood warnings. This hazard is more amenable than most to loss mitigation measures if sufficient warning is given.

Flash flooding

This usually occurs when a large amount of rain occurs in a short space of time in a concentrated area. They occur mainly in areas with steep hills and little vegetation to slow down to rate of drainage. Typically they are caused by particularly heavy thunderstorms which release a large amount of rain which cannot be absorbed by the ground. Flash floods can occur without warning and so pose a danger to life. The rapid flow of flash-floods can lead to additional damage being caused by items carried along with the flow.

The sudden collapse of upstream dams can result in sudden floods downstream. Dams may be damaged if the water levels exceed the design tolerances. The weight of water stored behind dams is known to exert additional seismic tensions in the crust below, and triggers earth tremors. These can lead to structural weaknesses in the dam. Also, silt which builds up behind a dam exerts additional pressure at the base of the dam. The frequency of dam collapses has reduced in the past century as these dangers are better understood.

Ice jams can form in some rivers when blocks of ice are carried in meltwaters. In some circumstances these can aggregate and form natural, temporary dams. These can suddenly collapse, resulting in a surge of water flowing downstream.

River flooding

This occurs when the a river overtops its banks, as a result of it being forced to carry an unusually large volume of water. There are several potential causes of this, including:

Rainfall in the areas upstream has been particularly heavy. This can result in the ground being unable to absorb the rainfall at the rate that it is falling. The excess water then feeds into the river system, raising the level of the river waters.

If particularly heavy rainfall, and the associated run off of water, occurs over a short period of time and a relatively small area, this can cause a surge. Such a surge can exacerbate the general rise in the river level. If a surge overtops the river banks, or breaches levees or other flood defences, the erosion caused may reduce the efficacy of these defences. Major flooding can result if the damage to flood defences allows the swollen river to escape, too.

If snows upstream thaws at an unusually rapid rate, then the resulting runoff of water can cause flooding downstream. Sudden thawing can arise if unusually warm air remains over snowfields in the late spring. This is a major risk for areas in the USA and the former Soviet Union. The risk is exacerbated if the melting is caused by rain falling on the snow, causing it to melt, producing a double-whammy effect.

Unlike most other catastrophic events, river flooding has positive effects, too. The silt deposited by floods (alluvium) increases the fertility of farmland. The floodwaters also wash away salts that accumulate in the soil. Also, the moist soil left when the floods subside allows increased agricultural yields to be produced.

Coastal Flooding

This generally occurs when a storm surge coincides with the high tide. The risk of flooding is increased at a spring tide. A spring tide occurs at just after a new or a full moon. In these circumstances the sun and the moon are aligned along a line passing through the earth, and their combined gravitational influence results in the high tide being at its maximum. The maximum amount of flooding will occur if the storm surge coincides with the maximum astronomical tide. This occurs if the spring tide happens when the earth is at the perihelion of its orbit around the sun ie. it is when the elliptical orbit of the earth is closest to the sun. Perihelion currently occurs during winter of the Northern hemisphere.

Much of the damage caused by tropical cyclones is as a result of coastal flooding caused by the storm surge created by the intense low pressure at the eye of these weather systems.

Unlike other catastrophes the impact of loss mitigation methods has a significant impact on the risk of flooding and the associated damage. In particular, the existence of sea defences such as sea walls will have a major impact. These are discussed in a later section.

When the area inland from the sea is below the height of the surge-level then a breach of the sea defences can result in extensive flooding as such floodwaters can flow to all areas of a similar elevation unless other defences are in place.

If the sea defences are breached then the vulnerability of these defences may be increased. This is due to a positive feedback mechanism whereby the initial breach may erode or weaken the defence, allowing further overtopping, which leads to further damage to the defences. The increased rate of flow through the damaged section with cause damage to occur to the defence at an increasing rate.

Once a sea defence is breached then the amount of flooding will depend mainly on the height of the surge and the elevation of land behind the damaged defences. Unlike river flooding, where the volume of water available to cause flooding is limited by the size of the river, once a coastal defence is breached, the huge volume of water in the surge is not generally the limiting factor. Therefore, once a sea defence has been breached flood waters will pour through the breach until the water level of the flooding inland is the same as the surge level at sea.

Once the surge subsides, due to the storm moving on, the tide falling, or a combination of these, then the flood waters maybe able to flow back through the breach in the defences, which can cause further damage to these defences. If the defences are not repaired before the next high tide, flooding may occur again.

The impacts of flooding.

The damage caused by flooding includes:

- Crop damage
- Salt contamination of farmland
- Damage to buildings.
- Undermining foundations of buildings
- Rupture of sewerage pipes.
- Damage to contents of buildings
- Damage to motor vehicles.

- Deaths.
- Business interruption.

The amount of damage that is caused at a particular location is mainly dependent on the following factors:

Depth of flooding:

This is the major factor which determines the amount of damage. Clearly as water levels get higher more property is damaged.

Duration of flooding:

Flooding lasting only a few hours may be expected to cause less damage than longer-term flooding. This partly because the shorter duration of inundation will allow less water to seep into the lower soil levels, which could weaken foundations. Also, crops may be able to recover after a short duration of inundation, but would be unable to recover if immersed for longer. Furthermore, business interruption losses will be increased the longer that the operation is disrupted.

Floodwaters may be unable to drain from the lowest-lying areas. In coastal flooding the drainage of the seawater back to the sea may be prevented by the sea defences which are, by definition, higher in elevation than the inland areas they are intended to protect. This is known as ponding. Ponding can greatly increase the duration for which an area remains flooded.

Velocity of floodwaters:

The force exerted on buildings will increase as the velocity of the water impacting on them increases. Damage may be increased by projectiles carried in the flow such as trees and other debris. The velocity of water will also affect the amount of erosion. The erosion of buildings' foundations may ultimately lead to their collapse, or require extensive repairs to be made.

2.1.2 Geophysical Events

In this section we consider the scientific understanding of the movements of the solids, liquids and gases which form the body of the planet.

Until about 4.2 billion years ago the planet was a spinning drop of liquid, as it was too hot for solid rocks to form. This liquid is called magma. As the planet cooled by radiating heat into space, solid minerals formed by crystallisation. These crystalline minerals were less dense than the molten magma, and so floated on the surface, forming a solid crust. Initially the crust was made from basalt, a hard, black rock.

This balsatic crust was being forced around by convection currents in the underlying liquid magma. This forced adjacent pieces of the solid crust against each other. When two pieces collided, one piece may have slipped under the other in a process known as subduction. When this occurred the downward-moving piece would have heated up as it passed into the liquid magma beneath. This released water vapour, carbon dioxide and other materials which would percolate up through the overlying magma causing granite to form when the magma cooled. Granite is less dense than basalt. Therefore in collisions between basaltic pieces of crust and less dense granitic pieces of crust the granitic piece will tend to float, and the balsatic piece to sink on subduction, leading to the formation of yet more granite by the process described above. This process continues to the present day. The continental crust is mainly made up of granitic material made in this way.

Nowadays the solid crust of the earth is made up of more than 15 "plates", which are floating on the liquid mantle beneath, and are carried around at a rate of 20 to 50 millimetres per year by convection currents in the mantle. Most of the geophysical catastrophes that we are interested in are directly caused by the movement of these tectonic plates against each other.

2.1.2.1 Earthquake:

Most earthquakes are caused by adjacent tectonic plates slipping against each other, and occur along the boundaries of the plates. These boundaries are known as faults. However, it is also possible for earthquakes to occur at weak points within plates. For example, the Newcastle, Australia, 1989 quake is an example of the latter.

There are three ways in which plates can move relative to each other:

(i) Transcursion. This occurs when plates are moving relative to each other in a direction parallel to their boundary. That is, they are slipping past each other. An example of this is the San Andreas Fault.

(ii) Divergence. This occurs when the plates are moving apart from each other. When this happens a fissure is formed which is filled by molten magma welling up from below. Such a fissure is the Mid-Atlantic Ridge.

(iii) Collision. This is caused by plates moving towards each other. When plates collide they can push against each other, forcing each other upwards, forming mountain ranges known as fold ranges, or one of the plates can subduct under the other. The most destructive earthquakes are often produced in subduction zones.

Earthquakes are caused by sudden slippages at faults. The relative movement of adjacent plates along a fault is held back by friction between the plates. This causes rocks around the fault to become deformed which creates elastic energy within the rocks. When a slippage occurs the elastic energy released is radiated outwards as seismic waves. These seismic waves are caused by the juddering of the earth around the slippage as the fault rebounds after the initial slippage until a new position of equilibrium is reached.

The seismic waves are classified into three groups:

Primary, P-waves: These are longitudinal waves that travel through the earth in much the same way that sound travels through fluids. They travel at around 8 km/s. At the surface they cause horizontal displacements as they pass by and thus cause horizontal shaking.

Secondary, S-waves: These are transverse waves that have vertical vibrations, such as those that one might observe by dropping a pebble in a pond. They travel at around 4 km/s. At the surface they cause vertical shaking.

Surface waves: There are two main types of surface wave:

- Love waves: these are similar to S-waves, but the direction of vibration is along the plane of the surface. These therefore cause horizontal shaking.

- Rayleigh waves: these travel in a similar manner to waves on the sea, and cause vertical shaking.

Measuring the magnitude of earthquakes.

It is colloquially known that the Richter scale is used to measure the magnitude of earthquakes. This is not strictly correct. A Richter scale is one that is based on the energy contained in the seismic waves created by a quake. Richter scales use the readings in seismographs, standardised to be as if they were located 100km from the epicentre of the quake, to convert the amount of ground-shaking to a magnitude.

For smaller magnitude earthquakes, the local magnitude (ML) version of the Richter scale is generally used, measuring the amplitude of the surface wave vibrations. This is defined as:

ML = Log_{10} [maximum amplitude on seismograph in micrometres @100km from epicentre]

For larger magnitude earthquakes this is not appropriate as the surface waves will tend to be generated at only a small section of the ruptured fault, and the ML scale will therefore tend to understate the amount of energy released in the event. For such large events a different scale is used, called the moment of magnitude, which is based on a variety of factors such as the surface area of a rupture and amount by which the fault slipped

Scales of magnitude such as those above are quoted in numbers. A quake of 6 or more would be considered to be large. A quake of 9 or more would be cataclysmic.

A further scale is available. This is a scale of intensity, and aims to rate quakes by the effects that they produce which are noted by human observers. It is called the Modified Mercalli scale. It used the Roman numerals I to XII, where I is "not noticeable" and XII is "Damage total". It has several benefits:

(i) it can be used in regions where little seismic recording is done,

(ii) it can be used to estimate the magnitude of historical losses for which we have written eye-witness data, and

(iii) it makes allowance for factors such as the local geology which may amplify the seismic waves, causing more damage than the magnitude as measured some distance away may imply.

A further scale is sometimes used in Japan. It is the Japanese Meteorological Agency Scale (JMS). This is similar to the Modified Mercalli in that the magnitude of a quake is determined by reference to the observed damage and other phenomena. This scale goes from zero (not felt) to seven (over 30% of houses will collapse).

The impacts of Earthquakes

The following table shows some of the damage-causing features of earthquakes, the damage that these cause and some factors which influence the amount of damage:

Effects	Damage	Risk Factors
Ground-shaking	Building collapse	Magnitude
Fault rupture	Ruptured pipes	Location of hypocentre
Tectonic deformation	Road damage	Type of fault
Soil liquefaction	Fires	Local geology
Land slides	Explosions	Time of day
Submarine avalanches	Floods	Resonance
Tsunamis	Dam failures	
Seiches/avalanches	Pollution	

Source : based on K Smith. Note that the table is not intended to read horizontally.

We will discuss the most significant of these below.

Ground-shaking

The shock-waves generated by the quake cause the surface of the earth to shake as they pass outwards from the source of the quake, the hypocentre. The epicentre is the point on the surface of the earth directly above the hypocentre.

The most damaging type of shaking is horizontal. This is because buildings are designed to cope with the force of gravity, and vertical shaking is effectively a rapid fluctuation in the force of gravity. However, most buildings are not designed to be able to withstand much horizontal shaking.

A building has a resonant frequency, just as a string on a guitar does. If the seismic shock waves of a quake are at this frequency, or a harmonic of the frequency, then the building may resonate. This happens because the oscillations of the vibrating ground coincide with the swaying of the building and serve to reinforce the amount of movement. The amount of damage to such a resonating building may be much more than to a nearby building with a different resonant frequency.

The design of a building can affect the type and amount of damage that shaking causes. For example, problems are caused by "soft storeys", where the lower storey of a building is not strong enough to support the upper storeys. This can occur, for example, where the lower storey of an apartment block is used to provide car-parking for the residents. Another design feature which could cause problems is asymmetry, for example an L-shaped building. In this case a building may be composed of two, or more, separate elements, each of which may have a different resonant frequency, so that each tends to vibrate at a different rate, causing further strain and damage.

If two adjacent high-rise buildings vibrate, the amount of lateral movement at the highest storeys may be sufficient to cause the buildings to collide. This is known as "pounding". Building codes, if enforced, can be used to prevent this from occurring.

Liquefaction

When a water-lubricated granular solid, such as sand, is vibrated, it becomes more like a liquid than a solid. This is a serious contributor to the damage caused by earthquakes. Liquefaction contributes to the damage in several ways:

- Loss of bearing strength: buildings may subside, or even partially sink, if built on ground which is unsound. Much new property development occurs on sites, such as those previously used for land-fill, which may not have fully settled prior to the quake, so may be more prone to liquefaction..

- Flow failure: where liquefaction occurs on slopes the fluidity of the ground may allow it to flow like a viscous syrup, possibly for several kilometres, at velocities of several kilometres an hour. When this happens underwater, Tsunami may result.

- Flotation: ground which is liquefied by shaking will behave like a liquid. Therefore if objects which are buried in the liquefied ground have a lower density than the ground, they will tend float. Liquefied soil has a specific gravity of around 1.6. So, anything buried underground with a density of less than this will tend to rise to the surface. The tanks holding petrol at filling stations are an example of such objects. Some underground pipelines such as those carrying natural gas may also have a lower density; the forces acting on such pipes may lead to ruptures and the release of their contents.

It is worth noting that a large part of Tokyo is built on reclaimed swampland, and so would suffer from liquefaction in the event of there being a quake in that area.

Landslides, rock avalanches and snow avalanches

As many earthquake-prone areas are quite mountainous, being at the junction of colliding tectonic plates, there is the danger of landslides and avalanches. It is estimated that in Japan half of all earthquake-related deaths since 1964 have been caused by landslides. These landslides or avalanches can travel at speeds of up to several hundred kilometres per hour, and can inundate whole villages with little, or no, warning.

Tsunami

These are large sea-waves caused by seismic activity. Generally they are caused by vertical displacements on the sea floor caused by a seaquake. They can also be caused by submarine volcanic eruptions, or the explosion of volcanic islands such as Krakatoa. Most Tsunami occur in the Pacific Ocean, with a quarter of the total occurring along the Japan-Taiwan island chain.

A large Tsunami may have a wave height of, say, 30 metres when it reaches land. Until it reaches land it will be very low, say 0.5 metre high, will have a very long wavelength (100-200km), but will travel at a speed of around 600 km/h. When the shallower waters surrounding the coast are reached, the wave's velocity and wavelength decrease, the kinetic energy of the wave is transformed in potential energy as the wave rears up.

When such a high wave strikes land the damage is caused in several ways:

- Direct impact - as the shore-front take the brunt of the force of the wave.

- Flooding.

- Indirect impact - caused by cars, etc. being thrown as projectiles by the wave.

- Drag forces - the drawback of water can undermine foundations, etc.

- Salt contamination - caused by sea water infiltrating farmland, the water table, and may lead to an increased rate of corrosion of metallic structures.

Fires

Much property damage is caused by fire following the quake (FFQ). For example, 80% of the property damage caused by the San Francisco quake of 1906 was fire-related. Fires can be started in many ways, such as the short-circuiting of electrical systems, and can be sustained when gas pipelines are ruptured. In the developing world fire may be directly used in homes for cooking, so the risks of fire may be greater there.

The rupture of water pipelines may impede attempts at firefighting. Also, damage to and blockage of roads will further impede the ability of the fire fighting services to extinguish fires.

The weather conditions prevailing at the time of a quake will also have a significant impact on the amount of fire damage. The spread of fire will be determined by the wind's speed and direction and the natural or artificial firebreaks that may contain, or at least slow, its spread. Rainfall may help to slow the rate of spread.

The density and combustibility of the buildings in the quake zone will impact on the amount of fire damage. For example 85% of the buildings in the metropolitan area of Tokyo are made of wood. A study by Japan's Land Agency estimated that if a large quake of similar intensity to the Great Kanto Quake of 1923 hit Tokyo, then up to 30% of the buildings in Tokyo's metropolitan area would be destroyed by fire and around 150,000 people would be killed.

The petrol and diesel in cars is a cause for concern. If a quake were to hit a congested city it may cause cars to ignite, possibly as a result of crashes. A chain reaction may then occur, especially of the quake were to occur during a busy rush-hour period when cars were in close proximity to each other, as burning petrol streaming from one car sets light to those nearby.

Chemical pollution

Damage caused to industrial installations may lead to the breakage of pipelines and reaction vessels containing noxious chemicals. This may lead to the production of further poisonous substances as volatile chemicals react. This may happen with explosive force. Thus there is the potential for clouds of poisonous vapours to be released in Bhopal-like incidents. Claims produced by such events may be recoverable from the General Liability insurances of the company.

This risk is not restricted to large chemical plants as nowadays noxious chemicals are used in a large number of smaller industrial operations, too.

As for FFQ the extent of the damage and pollution will depend on the weather conditions prevailing at the time of the quake. If it is raining the pollution may tend to precipitate out sooner. The water in rain may react with the pollution. Although early precipitation will reduce the spread of the pollution, it will mean that it will be more concentrated when it falls. Thus damage may be caused by extremely acidic or alkaline rainfalls. The direction and speed of the wind at the time of the event will determine where the pollution will be greatest.

2.2.2.2 Volcanoes

Volcanoes are caused when the liquid magma of the earth's mantle break through the crust. The most active volcanoes are located at the boundary of the tectonic plates. 80% of active volcanoes occur where one tectonic plate subducts under another, and are known as subduction volcanoes. Most of the rest occur where two tectonic plates are diverging, and are known as rift volcanoes. The remainder occur at weak spots within the tectonic plate and are known as hot spot volcanoes.

Unlike some hazards the exact location of volcanoes are generally known in advance. The uncertainty with predicting a volcanic eruption is the timing and the intensity.

The nature of a volcanic eruption will depend on the type of volcano. Hot spot and rift volcanoes do not generally erupt violently, whereas subduction volcanoes can erupt with extreme force. This is mainly due to the viscosity of the magma: the more viscous, the more explosive will be the eruption. The violence of an explosion is caused by the release of the pressure caused by bubbles of water vapour and other gases trapped within the magma. The less viscous the magma is the more gas will have seeped out of it by the time of the eruption and the less violent will be the explosion. The magma at subduction zones will generally be more viscous than other magma as it has a higher concentration of silicates. The explosive subduction volcanoes are the more life-threatening, although the other volcanoes, whose lava spreads quickly are more of a threat to property.

The areas surrounding volcanoes often have mineral rich soils which can be very good agriculturally, so such areas are often also relatively densely populated.

Measuring the magnitude of volcanoes.

There is no agreed international scale to measure the violence of a volcanic eruption.

The impacts of Volcanoes

The table below indicates the main hazards from volcanic eruptions:

Effect	Damage	Risk Factors
Pyroclastic flows	Destruction of property	Viscosity of magma
Pyroclastic falls	Fire	Location
Air fall tephra	Climate change	Time of day
Lava flows	Sterilisation of farmland	Amount of warning
Volcanic gases	Suffocation	Local topography
Ground deformation	"Bombing"	
Mudflows		
Landslides		
Tsunamis		

Source: based on K Smith

Pyroclastic flows/falls

These are clouds of ash, gas, glass, pumice, dust, rock, etc. which are emitted by the most powerful volcanic eruptions. These can be have temperatures of up to 1000°C, and may travel outwards from the volcano at speeds of more than 120 km/h, possibly for a couple of dozen kilometres. Such clouds cause most of the deaths in eruptions. The force of the flow may be sufficient to destroy buildings within its path.

Air fall Tephra

This is the solid material which is ejected in the explosion and falls to the ground later. Generally the heavier objects will land relatively close to the volcano where they may cause extensive damage on impact. Lighter particles such as ash and dust may fall several kilometres away, which may cause the collapse of some roofs if a sufficiently thick layer accumulates..

Lava flows

These are generally more threatening when the lava is the rapidly-flowing type that comes from rift or hot-spot volcanoes. Apart from the obvious danger presented by molten rocks, there are potential risks from the melting of glaciers , for example in Iceland, and the diversion of rivers.

Mudflows (Lahars) and Landslides

Mudflows can be caused in a variety of ways, for example, if an eruption frees a lake trapped in the caldera of a volcano, or if pyroclastic flows cause the rapid melting of the snow-cap on the top of a volcano. The released water mixes with ash, dust and other debris to form a hot muddy fluid. This can flow at speeds of more than 80 km/h, inundating anything downhill.

Landslides may be triggered by the ground deformation, or the seismic shock of an explosion. They may also be triggered by the earthquakes which sometimes precede major eruptions.

Tsunamis

These may be caused by submarine explosions, or even by the explosion of volcanic islands such as Krakatoa (1883). The risks posed are covered in the section on earthquakes.

Atmospheric Dust

In June 1982 all of the engines of a British Airways 747 cut out when it flew through a dust cloud emitted by an Indonesian volcano 140 km from the flight path. It descended from 12km to 4km in altitude in a matter of 16 minutes before power was restored, narrowly averting disaster. Two weeks later a Singapore Airlines 747 lost power in three of its engines for the same reason and had to perform an emergency landing.

Although lessons have presumably been learned from these events they do indicate that losses can arise from natural events some distance away.

Climate Change

The damage caused by volcanoes is not limited to the neighbourhood of the eruption itself. The ash and dust which are thrown into the upper atmosphere are capable of changing the global climate in several ways. The eruption of Mount Pinatubo in the Philippines in 1991 is estimated to have caused the troposphere to cool by about 0.5^{o}C on average in the period 1992-3. In 1815 the eruption of Mount Tambora in Indonesia produced such severe cooling that 1816 became known as "the year without summer", when it snowed in June in New England and it rained almost continually across Europe from May to October (plus, no doubt had impacts in other regions). The disruption of the climate led to failed harvests which led to food riots and general social unrest. The 1883 eruption of Krakatoa is estimated to have led to a similar level of global cooling as Mount Pinatubo.

The main effect is of blocking out the sun's light before it reaches the surface of the earth, thereby leading to cooling of the troposphere.

The chemicals in the volcanic dust can also lead to depletion of the ozone layer, which can have impacts on the climate.

A more subtle, gradual, change may be caused by the effect of iron contained in the volcanic dust. This can fertilise the growth of oceanic plankton. The growth rate of plankton is often limited by the amount of iron in the oceans. When the volcanic dust precipitates out into the ocean the iron it contains can increase the growth rate of plankton. As the plankton grows it removes carbon dioxide from the atmosphere. This reduces the concentration of carbon dioxide in the atmosphere and thereby, possibly, the strength of the greenhouse effect. In fact it has been proposed that one method of (temporarily) halting global warming would be to dump large amounts of iron fertiliser in the oceans in order to increase the growth rate of plankton. The concentration of CO_2 in the atmosphere measured at Mauna Loa, Hawaii showed a sudden fall in the period 1992-3. It is suspected that this is due to the eruption of Mount Pinatubo in 1991 which released 500 million tonnes of iron into the atmosphere. The link between CO_2 and global warming is discussed in a later section.

It is not necessary to have a single spectacular eruption to have volcano-related climate change. It can also be caused by a higher than normal rate of attritional eruptions. The amount of dust in the stratosphere is measured by the Dust Veil Index, and changes in the value of this index may be related to changes in the global climate.

Thus, volcanic eruptions may have economic impacts beyond the local damage to property. For example, if the amount of dust in the upper atmosphere were to lead to a global cooling which caused a reduction in global agricultural production by even a fraction of a percent then the overall economic loss could be tens of billions of dollars. Also, changes in the climate may disrupt weather patterns potentially leading to changes in windstorm strengths and locations, flooding and drought. This further underlines the inter-connectedness of the global environment. See the section on climate change for further discussion of this topic.

2.1.3 Extraterrestrial Causes

In this section we consider the potential catastrophes which may be caused by impacts from astronomical bodies.

Interest in this subject has been spurred by the collision of comet Shoemaker-Levy 9 with Jupiter in 1994. Also interest in catastrophism has increased by the increasing amount of evidence that shows that a large impact occurred about 65 million years ago which, it has been suggested, was at least partially responsible for the extinction of the dinosaurs. This is known as the K/T boundary event as it marks the boundary between the Cretaceous and Tertiary geological periods (the K comes from the German word for Cretaceous, Kreide).

Although, at the time of writing, there has been no major impact in the recent past there is ample evidence that there have been impacts ranging from those that cause mass extinctions of life on earth every few million years, to smaller impacts which severely disrupt the climate every few hundred years. Extrapolation of these historical losses indicates that smaller impacts that will cause localised devastation may be expected every few dozen years.

For example, it is now known with a large degree of certainty that a cosmic impact occurred in 1908 at Tunguska, Siberia, which released the energy equivalent of 2,000 of the atomic bombs which destroyed Hiroshima, felling trees over an area of 2,000 square kilometres. This is believed to have been caused by an asteroid with an estimated diameter of 40 metres which exploded before reaching the ground. If such an event were to occur today over a heavily populated area, the scale of devastation could be greater than anything experienced in recent history. Impacts of this size have been variously estimated to occur with a return period of between 100 and 500 years.

Also, about 800 years ago the South Island of New Zealand was the site of an airburst explosion which flattened trees within a radius of 40km leaving a crater several hundred metres in diameter located near the town of Tapanui. Maori legends tell of a great explosion in the sky which caused huge fires. The name Tapanui means "the big explosion" in Maori.

Much of the literature on this topic seems to dwell on the possibility of there being a cataclysmic catastrophe which could lead to mass extinctions. We are more concerned here with the smaller, more frequent, impacts that would not be expected to destroy the world as we know it.

It is interesting to note that in recent trials of the new Intel Teraflops processor the topic of modelling an ocean impact of a billion tonne comet was used. Such a comet is expected to hit the earth with a return period of approximately 300,000 years. The results of the simulation predicted that an explosion ten times more powerful than would have been produced if all the nuclear weapons at the height of the Cold war were detonated. This would instantly vaporise about 500 cubic kilometres of ocean and cause huge Tsunami that would inundate low lying areas such as Florida.

Lumps of solid matter which fall from the sky are called meteorites. There are two sources of meteorite: asteroids and comets. In what follows below the term meteorite generally means an asteroid or a comet impacting on the earth or the atmosphere.

Asteroids are rocky fragments that did not merge to form fully-fledged planets when the solar system formed. The majority of asteroids are located in the asteroid belt which lies between the orbits of Mars and Jupiter. It is believed that the asteroid belt is the remains of a planet which failed to form due to the gravitational influence of Jupiter which prevented these rocky fragments from accreting. There are millions of asteroids, about 250 of which have diameters greater than 100km. Some asteroids have been disturbed by the gravitational influence of Jupiter and other planets to such an extent that they follow elliptical orbits which take them inside the orbit of the earth for part of their orbit around the sun. At least 26 asteroids with earth-crossing orbits have been catalogued. However we can only see the larger of such objects. It has been estimated that there are at least 1,300 asteroids with earth-crossing orbits that have diameters of at least 1km. Any of these will be enough to cause severe devastation should it collide with the Earth.

Comets are believed to have been formed in the far reaches of the solar system and are made of ice, frozen ammonia and other chemicals, as well as rocky fragments. There are estimated to be between 10 trillion and 100 trillion comets in the solar system, the vast majority lying beyond the orbit of Neptune. These comets will be disturbed by the gravitational influence of nearby stars and may occasionally be pushed into orbits which take them to the inner solar system. Some will have earth-crossing orbits. As a comet approaches the sun its surface is heated and the ice and other frozen chemicals evaporate, or sublime. Comets can lose tens of tonnes of material each second as they evaporate. This material forms the tail that distinguishes comets from other heavenly bodies. This process of evaporation can also result in the release of rocky objects contained in the comet's body. It is the tails of long-passed comets which are responsible for the meteor showers that are observed from the earth. These are usually seen in the same few days each year as the earth passes through the remains of a comet's tail.

Some authors quote the annual probability for a US citizen of being killed by a cosmic impact as being estimated to be about 1 in 20,000, compared to the probability of being killed by Flood (1 in 30,000) or Tornado (1 in 60,000) [Source: Chapman and Morrison, Nature 6/1/94 Vol. 367 p33)]. This probability is calculated by assuming the a cosmic impact large enough to kill 25% of the world's population will occur each 375,000 years, the average lifetime is assumed to be 75 years. It does not take into account the possibility of death from smaller, more frequent events, and the impact of larger, less frequent events. It is claimed by some authors that such statistics indicate the relative importance of cosmic impacts compared to other catastrophic events.

Our understanding of the potential damage caused by cosmic impacts is derived mainly from research performed during the Cold War into the potential impact of nuclear explosions on the environment. The damage caused by cosmic impacts comes from a variety of sources. In particular, such an impact has the potential to trigger many of the other catastrophes covered in this paper, and more. Note that the effects discussed below may be triggered by impacts with relatively low return periods (e.g. 100 - 500 years), and do not represent the "end-of-civilisation-as-we-know-it" end of the scale.

Explosion: The energy of the impact would be converted from kinetic to heat. Only the largest and densest of meteorites would reach the ground. The smaller meteorites would explode in the atmosphere. For those that did hit the surface the meteorite and the impact site would both vaporise, causing a tremendous explosion. The atmospheric shock waves would flatten many things that stood in their way. Fires would start spontaneously over a wide area. Ash and dust would be convected high into the atmosphere along with large amounts of water vapour. Much damage could be caused by shrapnel - large boulders landing many kilometres from the impact site.

Earthquakes: Earthquakes could be triggered as the shock waves from the impact reverberate around the world, causing stressed faults to slip across the whole surface of the earth. In particular, the place diametrically opposed to the impact site would be expected to suffer as the shock waves converged there.

Volcanoes: as faults rupture, and pressure waves are transmitted through the liquid mantle, we may observe an increase in vulcanism. This could throw yet more dust and ash into the atmosphere increasing the global cooling mentioned below.

Tsunami: if the impact occurred at sea, which is quite likely given that the oceans cover more than 75% of the earth's surface, then Tsunami would circle out from the impact, inundating any bordering coastline. Quakes triggered by the impact may cause secondary Tsunami.

The height of the wave for a given size of impactor will depend on its energy, which will depend on its mass, and therefore its density. Therefore iron meteorites will tend to be more destructive than rocky cometary fragments. For impacts with estimated return periods of 100 years it has been estimated that an ocean impact would produce Tsunami with heights of up to 80 metres at a distance of 1000km from the impact site.

Waves of these heights will clearly cause much damage wherever the landfall is. Increasing coastalisation will increase the risks. The number of lives lost will depend to a large extent on evacuation procedures. For example, it is difficult to imagine how cities such as New York would be able to raise the alarm and evacuate a significant proportion of its citizens in time to avoid disaster, should an impact occur in the Atlantic. It is unlikely that many people would believe such a warning in any case.

Hurricanes: the heat of the impact would disturb the atmosphere, possibly leading to hurricane-force winds.

Flood: the water vapour thrown into the atmosphere by the impact by the impact, would tend to cause a greater level of precipitation.

Oceanic Conveyor Belt: it is not clear what effect an impact would have on the oceanic conveyor belt. However, if it were to change the pattern of circulation, then we would expect there to be climatic changes, too.

Global Cooling: the amount of dust thrown into the atmosphere may be block out so much sunlight that the earth below cools significantly. There may be other long-range effects as discussed in the section on volcanoes.

2.2 Climate change and Climate models

In this section we will examine the evidence for climate change and the scientific understanding of how the climate may change in the near future.

We will first look at some the evidence that the climate is changing. We will then discuss two theories which purport to explain this change, namely the "Enhanced Greenhouse Effect" theory, and the "Solar" theory.

We will discuss how climate change may affect the frequency, severity and location of catastrophic events. We will be concerned here with atmospheric and hydrological catastrophes. This is an important section as we will need to consider how similar the climate of the future will be to that of the past. If there is to be a change in the climate then we need to beware of using historical event data to predict the future.

We will consider global climate models and weather models. These are being used to project the future climate, and the impact of changes in the composition of the atmosphere such as increases in the concentration of greenhouse gases, or the destruction of stratospheric ozone.

When considering the subject of the climate we should bear in mind that current global climate is atypical of the long-term average climate for the planet. The normal pattern of climate is to be in a state that we recognise as an "ice-age", when sheet ice spreads much further south than at present. In the recent geological era ice ages will typically last from 50,000 to 100,000 years, separated by interglacial periods which are generally shorter, lasting around 10,000 years, during which time the glaciers retreat polewards. We are currently in an interglacial period. The last ice-age finished about 10,000 years ago. Once an ice-age or an interglacial period has begun it is believed that it is sustained by positive feedback mechanisms which tend to reinforce the factors leading to the switch between states.

2.2.1 Climate Change

When we mention climate change we are usually referring to the change in the mean global temperature of the atmosphere and the oceans, rather than the "average weather" meaning of climate. This is because the weather is driven by temperature differences between different parts of the atmosphere and changes in the overall global temperature will have different effects on weather-climate in different regions.

In the past decade there has been much talk of Global Warming which has been inspired by the observed increase in mean global temperatures in recent years. In the previous decade it was fashionable to talk in similarly heated terms about the impending ice-age that some climatologists were predicting. The terms "global warming" and "greenhouse effect" are currently colloquial synonyms and climate change is part of the popular vocabulary. There are relatively frequent "Earth Summits" where heads of State gather to debate the need to cut "greenhouse emissions", raise carbon taxes, and other measures intended to prevent, or at least delay, what is perceived to be an impending world-wide catastrophe.

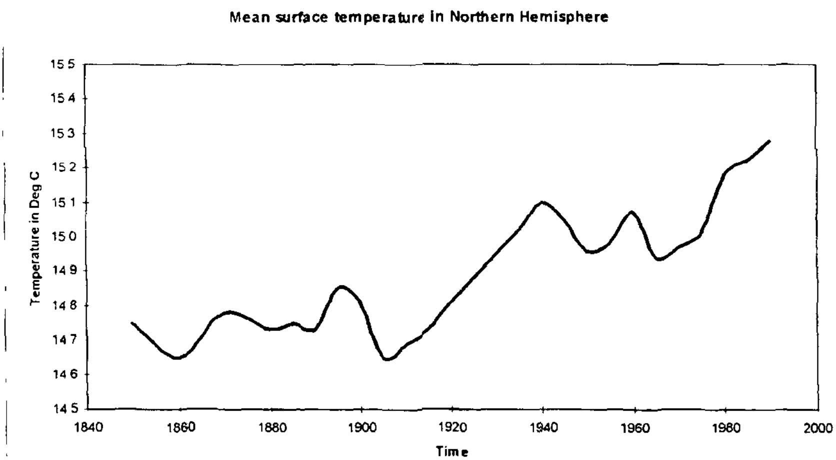
The insurance industry is more exposed to the impacts of climate change than most other industries. The reinsurance industry is particularly exposed to any changes in the frequency and severity of catastrophic events. It is in the insurance industry's best interests to be at the forefront of research into climate change.

The Intergovernmental Panel on Climate Change (IPCC) was set up in 1988 by the United Nations to co-ordinate and collate the work of multi-disciplinary teams of scientists who would report in 1990 and every few years thereafter on the current state of knowledge about the state of the changing climate. Billions of dollars has been spent on research into the climate in the past few years: climatologists use some of the most powerful computers in the world and have dozens of satellites launched in order that they can research this subject.

In 1993 the Atlantic Global Change Institute (AGCI) was set up in Bermuda to study global environmental change. A research program organised by the AGCI called the Risk Prediction Initiative (RPI) is sponsored by about a dozen large insurance entities. This program is designed to foster interactions between the science and business communities, in particular it is intended to provide an interface to convey the most up-to-date scientific understanding of environmental prediction with the insurance and *reinsurance industry*.

It is important that actuaries understand the results of the scientists' labours. A changing climate will affect us not only on a personal level, but may also impact on the key assumption that many of us regularly make in the course of our work: the past may be used as a guide to the future.

The graph below shows that warming that has been observed in the past century as measured on land in the northern hemisphere.



There are significant year-on-year fluctuations around the trend-line shown on the above graph.

One theory for why the surface temperature cooled in the 1960's is that atmospheric nuclear weapon tests in the 1950's until the partial test ban treaty of 1963 had resulted in the creation of large amounts of nitrous oxides in the upper atmosphere. These are known to destroy ozone in the presence of sunlight, absorbing some of the energy of the sunlight. These reactions therefore reduce the amount of energy which reaches the surface of the earth.

Scientists have spent a great deal of effort in trying to determine the causes of this warming. The theories that are proposed to explain the warming may then be used to try to predict what the future trend in climate change will be. If a theory identifies an underlying cause to the warming that can be influenced by human technology, then it identifies an area where positive steps can be taken to try to control the amount of climate change in the future.

We present below two theories which purport to explain the observed warming.

The Enhanced Greenhouse Effect Theory

This theory explains the observed rise in the mean temperature as follows:

(1) CO_2 *is a greenhouse gas.*

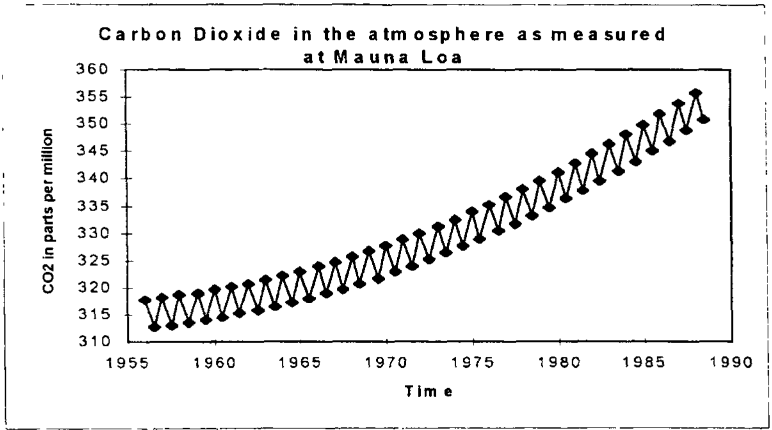
(2) The main greenhouse warming is not caused by the CO_2 directly. Increases in the concentration of CO_2 are hypothesised to cause a small amount of warming which causes more water vapour to evaporate. It is the increase in atmospheric water vapour which cause the majority of the enhanced greenhouse effect.

(3) The concentration of CO_2 in the atmosphere has been closely correlated with the mean global temperature, at least over the past 150,000 years or so. This is shown by *analysis of the amount of carbon dioxide trapped in bubbles of air inside ice cores drilled* from the icecaps of Antarctica and Greenland. The ages of the air bubbles are determined by counting the layers of ice in the cores which is apparently similar to the counting of tree-rings to determine the age of trees. The temperature at the time these layers were laid down is determined by the proportion of the Oxygen 18 isotope to Oxygen 16 in the ice.

(4) The rate of burning of fossil fuels has accelerated exponentially in the past few hundred years since the start of the Industrial Revolution.

(5) Burning fossil fuels releases CO_2 into the atmosphere.

(6) The amount of CO_2 in the atmosphere has been steadily increasing over the past 30 years as shown by the measurements made at Mauna Loa. [See the graph below]. The graph shows that the concentration of CO_2 rises and falls each year, but there is a definite upwards trend. This semi-annual fluctuation is due to the plant growth in the northern hemisphere during the northern summer which soaks up a lot of CO_2. This demonstrates that there is a net input of CO_2 into the atmosphere each year.



(7) Therefore as temperature and CO_2 levels have been shown to be correlated historically, rising levels of CO_2 will result in increases in temperature due to an enhanced greenhouse effect.

The Enhanced Greenhouse Effect Theory is that endorsed by the IPCC.

This theory predicts that as CO_2 concentrations in the atmosphere are likely to increase in the foreseeable future then the global temperature is likely to continue increasing. Proponents of this theory contend that in order to control the rise in global temperature we must curtail our output of CO_2 and other greenhouse gases.

The Solar Theory

The theory as outlined below was developed by scientists at the Danish Meteorological Institute. Piers Corbyn, who is famous for his success at betting against the UK Meteorological Office and who runs a company called Weather Action, is believed to use a variant of this theory for medium range weather predictions.

This theory explains the observed rise in the mean temperature as follows:

(1) When cosmic rays arriving from outside the Solar System enter the Earth's atmosphere they trigger the formation of water droplets by a process of ionisation. This process of droplet formation is the same as that used by high-energy particle physicists in their "cloud chambers" which are used to study the results of subatomic collisions in particle accelerators. Cosmic rays are positively charged clumps of protons and neutrons ejected from collapsing stars which travel at great speeds. When they enter the atmosphere they can collide with the nuclei of atoms in the air which may result in the fission of these nuclei, which then shoot off and collide with further nuclei in a chain reaction. A single primary particle can trigger a cascade of a million or more further particles, each of which can trigger the formation of a water droplet.

(2) Changes in the amounts of cosmic rays entering the atmosphere will change the rate of droplet formation.

(3) The water droplets which make up clouds form when water vapour condenses around a "seed" particle. This seed is usually a speck of atmospheric dust. Such water droplets do not normally form spontaneously without such a seed.

(4) The droplets formed by the impact of cosmic rays will act as the requisite seeds for cloud formation.

(5) Changes in the level of cosmic rays entering the atmosphere will therefore have an impact on the amount of cloud formation.

(6) Clouds reflect some of the incoming sunlight back into space before it has had the chance to warm the lower atmosphere.

(7) Increased cloud cover will therefore tend to lead to a cooling effect. However, this cooling effect will be partially offset by the way that cloud cover acts like a blanket and helps to prevent heat from escaping into space.

(8) The number of cosmic rays which enter the earth's atmosphere is affected by the level of the solar wind as the incoming cosmic rays will tend to interact with the solar wind before they reach the earth. The solar wind consists of charged particles which are emitted by the Sun during magnetic storms in its upper atmosphere. They cause the Aurora observed at high latitudes.

(9) The strength of the solar wind varies over time. The strength of the wind is connected with oscillations in the magnetic field of the Sun. The number of sunspots is a symptom of the magnetic turmoil within the Sun, and these are known to vary in cycles of variable length of between 9 and 13 years. There are also longer cycles in solar activity as shown in the sunspot cycles. Furthermore the magnetic poles of the Sun swap over every 22 years which will affect the strength and properties of the solar wind.

(10) The strength of the solar wind can be measured on earth by variations in the strength of the earth's magnetic field.

(11) Measurements from the past 130 years of the earth's magnetic field exhibit the same 9 to 13 year cycle as sunspots, but show a rising trend in solar wind strength.

(12) Therefore, the increasing strength of the solar wind is reducing the number of cosmic rays which are entering the atmosphere, which is reducing the amount of cloud formation, which is allowing more sunlight to reach the surface of the earth, which is causing the observed warming.

This theory explains almost all of the observed warming in the past century.

Furthermore, it is possible to backtrack further into time. The level of cosmic radiation affects the level of certain radioisotopes in the atmosphere, radioberyllium being of particular interest. Analysis of ice-cores taken from Greenland and Antarctica showed that the levels of this isotope were particularly high around the period 1700. The Solar theory would predict that the high levels of radioberyllium imply that there was an abnormally high number of cosmic rays entering the upper atmosphere which would cause high levels of cloud cover leading to reduced surface temperatures. The "Little Ice Age" occurred around 1700.

This theory does not directly explain why the levels of CO_2 in the atmosphere should be closely correlated with the surface temperature, which is the central piece of evidence for the Enhanced Greenhouse Theory. In order to explain the correlation it would appear to be necessary to show that the changes in CO_2 concentrations were caused by the changes in temperature, rather than the other way around. Thus Solar theory implies that the Enhanced Greenhouse Theory has been putting the cart before the horse, as it were. A possible solution to this conundrum is the hypothesis that in colder periods a greater proportion of vegetation on land was in the form of woody plants thereby locking away CO_2 in the form of carbohydrates, or that oceanic plankton was more prolific.

This theory predicts that if the cycle of minima of solar wind strengths of years 1320, 1440, 1690 and 1890, as determined from radioberyllium samples from ice-cores, continues, then a further minimum may be expected within about 100 years. If so, then we may expect the resulting increase in cloud cover to lead to a reduction in the global temperature during the next century.

The effects of Global warming on natural catastrophes.

Whatever is the correct theory it is an inescapable fact that global surface temperatures have risen as shown above. We discuss below the impact that this may have on the catastrophes which are the subject of this paper.

If global warming leads to an increase in the temperature in the troposphere, then the troposphere-stratosphere boundary may be expected to increase in altitude. As all of the planet's climate occurs within the troposphere, this change will increase the volume of space in which the climate is generated. There will therefore be a larger amount of material which is available to absorb, store and transport energy from one part of the atmosphere to another. There is therefore the potential for more energy to be suddenly released than there was previously and hence for the frequency and severity of windstorms to increase.

Changes in sea level

Global warming leads to several changes which have an impact on sea levels. Some of these will tend to increase sea levels, some will tend to decrease sea levels. Overall sea levels are expected to rise as a result of global warming. There are three main factors which impact on sea levels:

- Thermal expansion of the oceans, increasing sea level.

- Melting of land ice, mainly on Greenland and Antarctica. This clearly will increase sea level. The melting of Arctic icecaps will have little effect as the amount of water released will lead to a reduction is weight of the icecap, so less water will be displaced by this floating body of ice. There may be a small effect due to the different specific densities of the freshwater released and the seawater no longer displaced.

- Increased water vapour in the atmosphere, leading to increased precipitation as snow in the Antarctic and Greenland where it builds up the height of the ice caps. This reduces the sea level. The same effect does not happen for changes in snowfall in the Arctic as the Arctic icecap floats on the Arctic ocean, so any snow falling there will displace an equal mass of seawater.

Impact on oceanic conveyor belt

The oceanic conveyor belt depends crucially on the "pumps". As the warm tropical water moving northwards in the Gulf Stream lose water to evaporation, it becomes saltier, colder, and more dense. It then sinks when it reaches the Northern Atlantic. There is the potential that as increasing amounts of fresh water will be released into the Northern Atlantic as the icesheets covering Greenland melt at an increased rate, and if rainfall increases. This will change the density of the seawater at high latitudes sufficiently to disturb the operation of these pumps.

As more water vapour evaporates from the warmer oceans they become more salty, and hence more dense. If the rate of evaporation increases, then the oceanic currents will tend to become dense enough to sink earlier in the "conveyor belt" cycles. If this occurs than less heat energy will be transferred from the tropics to the northern latitudes. This could cause a temperature drop in northern Europe of several deg C. We may expect the northern latitudes to become cooler, and the tropics to warm. If the tropics warm then the frequency and severity of tropical cyclones may increase as there will be a greater supply of the energy which fuels them. The temperature difference between the tropics and the polar regions may also be higher which may allow more powerful ETC's to form. ETC's may also be able to form at lower latitudes than at present.

Some studies show that the rate of flow of the conveyor belt has slowed down in the last 30 years.

Computer models of the conveyor belt show that the current state of the process is only one possible equilibrium position. The flow of the conveyor belt is sensitive to the salinity of the water around the "pumps", and switches between equilibrium states can occur in a short period of time. The flow rate of conveyor belt has been linked to sudden climate changes in the past. At the present time it is not known what effect changes in the global surface temperatures may have on the conveyor belt, although this mechanism does provide an indication that gradual changes in the climate can lead to sudden catastrophic change if the system switches to an alternative state of equilibrium.

The effects that global warming may have will be on the frequency, severity, location and timing of catastrophic events. We will discuss each of the major atmospheric catastrophes and how we may expect these to be affected by global warming.

Hurricanes and Tropical Cyclones

If the tropical oceans are warmer then more energy may be absorbed by hurricanes and tropical cyclones, making them more intense. The greater amount of available energy may also increase the frequency of such storms. If the oceans are warmer at higher latitudes then there is the potential for more energetic storms to make landfall at such latitudes than at present.

If the depth of such low pressure systems increases then the height of storm surges associated with these storms may increase, leading to greater levels of coastal flooding.

Extratropical Cyclones

The driving force behind these winter storms is the temperature difference between the cold air piling up above the poles and the warmer air at temperate latitudes. Climate models which are based on the enhanced greenhouse theory predict that the rate of future warming will be greater over the poles than at temperate latitudes. Therefore the temperature differences between these air masses may be smaller. However, there is not yet any conclusive evidence that the air above the poles is warming at a faster rate than at lower latitudes, so it may be premature to expect the frequency or intensity of ETC's to change due to this effect.

Flooding

Changes in the climate could affect the amount and distribution of rainfall. Some areas may have increased levels of rainfall whilst other areas may have reduced rainfall. This may lead to increased flooding in some areas, but could lead to drought and subsidence in others. The redistribution of rainfall may cause the deserts to expand, or to contract.

Also, rising sea levels will lead to a greater frequency of coastal flooding.

Some mechanisms which may reduce effectiveness of the enhanced greenhouse effect

- CO_2 is used by plants in the process of photosynthesis. Increases in the levels of CO_2 in the atmosphere may lead to more vigorous plant growth, which will tend to lock up Carbon in the form of the complex carbohydrates of plant tissue (e.g. wood), thereby reducing the amount of carbon dioxide in the atmosphere.

- If plant growth increases, say in previously inhospitable areas, then more CO_2 will be taken out of the atmosphere and stored in the carbohydrates in plant tissues.

- An increase in the temperature of the oceans may result in increased plankton growth. This will absorb some of the additional carbon dioxide. Also, the plankton will be eaten by shellfish and corals. When these die they sink to the floor of the ocean, locking away the carbon compounds contained in their shells. There may therefore be a reduction in CO_2 concentrations in the atmosphere and thus a reduced greenhouse effect.

- Emissions by industry of Sulphur Dioxide and other sulphates into the atmosphere have a cooling effect as they tend to form small dusty grains in the atmosphere which reflects sunlight away before it reaches the ground.

- If the deserts expand due to changes in the distribution of rainfall then the amount of iron dust carried from the deserts and deposited in the oceans may then increase. This iron could lead to increased growth rates for plankton, which would remove CO_2 from the atmosphere and may thus reduce the amount of the greenhouse effect.

- Increased dustiness of the atmosphere, possibly caused by expanding deserts could reduce the levels of sunlight reaching the surface. Also, increased dustiness may lead to a higher level of cloud formation which would again tend to reduce surface temperatures.

2.2.2 Climate and Weather Models

These are discussed for several reasons:

Weather models are discussed briefly as these are used to forecast the intensity and location of storms in the short-term future. The ability to produce accurate forecasts can allow advance warning to be given to those people most at risk in order for them to take loss mitigating actions. Weather models' forecasts are only reasonably reliable for short periods of time of less than one week.

As liquid financial instruments whose return depends on the catastrophe experience of insurance portfolios become available, then it will become possible for weather models to be used as the basis for investment decisions. This arises if the price of such instruments changes to reflect the forecast experience in the short term. For example, a Cat bond whose return depends on the loss experience of a portfolio exposed to Florida hurricanes may drop in value if a hurricane appears to be heading towards Florida. Investors who are able to forecast such hurricanes ahead of the market would be able to sell before the price fell. Similarly, investors who were able to forecast that the such a hurricane would in fact veer away back out to sea would be able to purchase more bonds at the reduced price, and wait for the price to rise again once the storm had passed.

Climate models are discussed as they allow us to predict the likely state of the climate in the medium term future. Climate models, for the purpose of this section, include both those which forecast the likely state of the climate over the next year or two as well as those that are used to forecast the climate over a period of decades. The ability to produce reasonably accurate forecasts of the climate over the next year or two may allow us to infer, for example, when El Nino events are likely to occur. Longer term forecasts may be used to estimate the impact of an enhanced greenhouse effect, such as rising sea levels.

Although the nature of these models is similar they are different in important ways. For example, weather models are not concerned with changes in the extent of the icecaps, and climate models are not concerned with the tracks that individual hurricanes take.

Weather models.

These are computer models of the atmosphere that are used for forecasting the weather up to a week or two in advance for a particular region. There are two main types of model. A grid-point model is one the discretises the atmosphere into a set of cells and uses various statistics of these cells to determine how the characteristics of a cell affect the adjoining cells as time is stepped forward. A spectral model determines the evolution over time of certain features of the atmosphere, such as the paths of winds around the equator. We will discuss the grid-point model below as it is the easier of the two to grasp.

A grid-point model divides the atmosphere up into a set of boxes. Such a model may typically extend up the tropopause, splitting the troposphere up into around 30 layers. These layers won't be of uniform thickness, but will have approximately uniform relevance. There will generally be a large number of layers near the surface and a number at the level of the Jet Stream, with relatively few elsewhere. The horizontal grid will depend on the area of the region that is covered by the model.

Weather models generally have the form of nested limited area models (LAMs). This is because the weather in a few hours time depends on what is now happening in the atmosphere a few hundred kilometres away, and the weather in a few days time will depend on what is now happening in the atmosphere a few thousand kilometres away. The shortage of computing power makes it impractical, at the moment, to model the whole of the atmosphere at a fine resolution. Instead, a model which covers a wide area, such as the whole of the Northern Hemisphere is used to forecast the general weather for the next week. A model with a finer resolution then takes the results of that model and produces a more detailed forecast for a smaller area, such as Europe and the North Atlantic. A yet finer model then takes those results and produces a forecast for a smaller region, such as the UK.

Each of these models uses more grid-points, and will use smaller steps in time between iterations. The table below shows how a typical LAM may be divide the labour:

Region	Grid Size	Time between steps	Forecast period
Northern Hemisphere	100 Km	10 minutes	1 week
Europe & N. Atlantic	50Km	5 minutes	48 hours
United Kingdom	10Km	1 minute	18 hours

Source: based on Weather Facts p202-203

The coarsest model will forecast the track of large storms as they are influenced by low and high pressure zones thousands of kilometres away, the medium coarseness model would be able to make more allowance for the effect of factors such as the shape of the land, the smallest model would allow for the effect of local topography.

The initial conditions of each cell will be either determined by direct measurement, or will be estimated. Weather balloons will be used to provide data about the temperature and other characteristics of the atmosphere above ground. This may be complemented by data from satellites. Sea-based or ground-based weather stations will be used to provide data about the surface. Estimation may be required for areas where no recent data is available, or if the grid resolution is finer than the data.

<u>Climate models.</u>

There are several types of climate model with different levels of complexity. These include:

- Energy Balance models

These are simple one-dimensional models that predict the surface temperature for a range of latitudes. These model the electromagnetic energy flows in and out, along with the horizontal transfer of energy from the equator to the poles.

- Radiative-Convective models

These compute the vertical temperature profile of the atmosphere by explicit modelling of the solar and terrestrial radiation streams and atmospheric convection processes. The result is a global average vertical temperature profile.

- Two dimensional (Statistical Dynamical) models

These combine the above two models and represent latitude and altitude simultaneously. They include a set of statistics summarising wind speed and direction thus giving a more realistic parametrisation of horizontal energy transfers.

- General Circulation models (GCMs)

These are full three dimensional models of the global atmosphere, oceans, land and icecaps. A set of equations describes the properties of the atmosphere and oceans, including: conservation of energy, conservation of momentum, conservation of mass and the ideal gas law. A grid-point model is used where the properties of a cell at a given time influence the properties of the cell and adjoining cells at the next time period.

The increasing complexity of each of these models shows the evolution of the science of climatology over the past few decades. The increasing complexity has become necessary as the complexity of the climate is more fully appreciated, and has been made possible by the increase in computing power.

The simpler models have the benefit that their operation is more transparent. Although they may not be as useful for making reliable forecasts of the future climate as the more complex models they do make it easier to understand certain important processes that shape the future climate.

When we mention climate models below we are generally referring to the GCMs.

GCMs are similar to the weather models, although they also incorporate variables which are thought to have more long-term effects, such as ocean circulation and certain chemical processes such as ozone destruction. The grid which is used to divide the atmosphere is generally coarser than the large-scale weather models, and the time intervals between iterations will be longer. The oceans will also be discretised, although the scale of the grid may be even coarser than that which is applied to the land.

Modelling the climate is a virtually intractable problem. In order to be realistic, climate models need to allow for as much of the real world as possible. As indicated above, the atmosphere is rather complex, with many interacting factors and feedback mechanisms. The sophistication of climate models increases in line with the amount of computing power of the latest computers. As the number of factors which are shown to influence the climate increases the number of potential interactions increases exponentially.

The climate models used by meteorologists are undergoing continual refinement as new factors that affect the climate are discovered. As more scientific observations are made, especially by satellites, the shortcomings of each generation of models is revealed. Also, as computing power increases the coarseness of the three-dimensional grid that is used to subdivide the oceans and the atmosphere can be reduced.

An increasingly vocal number of scientists are critical of the way that the results of climate models have been used by the international political community to bolster the program of measures which are intended to curb greenhouse emissions. They claim that the models being used to project future climate are currently too naive. They claim that the continual tinkering with the models that is required for them to reflect actual observations demonstrates that they are not yet ready to be used as a basis for enforcing punitive measures on the world. The proponents of using climate model forecasts retort that by the time reliable models are available it may be too late to counteract any negative impacts. They claim that it would be better to try to achieve a stable state of greenhouse emissions until the scientific understanding has advanced sufficiently to understand the problem than to continue with the currently rising level of emissions.

GCMs are used to estimate the impact of changes in the level of greenhouse gases such as CO_2 in the atmosphere. This is generally done by simply increasing the level instantaneously and then running the model until it settles in a new position of equilibrium. Critics have argued that in practice the levels of CO_2 will increase gradually, and that the instantaneous injection applied in the models may be causing systematic error in the projections.

Critics of the current generation of climate models point out that their predictions about how the temperature of the atmosphere at different altitudes should have changed over the past few decades does not agree with observations made by weather balloons and satellites. Also, the temperature changes at the surface predicted by the models at different latitudes does not agree with the observed changes, either. In particular, the temperature rises at the poles are not similar to those predicted.

The fact that the climate models do not accurately predict the temperature changes at different heights within the atmosphere is of particular concern. The models predict that the troposphere will warm at all altitudes as the surface warms. However, it has been observed that in the last 20 years temperatures have been falling at heights of around 3km above the surface for large parts of the world. From the early 1960's to the late 1970's it has been observed that although surface temperatures fell slightly, the mid-troposphere was warming. Thus temperature rises at the surface have not been reflected by changes higher in the atmosphere. This indicates that the interaction of the surface and the troposphere is not yet sufficiently well understood. Some climatologists suggest that as the surface and the lower atmosphere warm, the increase in the amount of water vapour in the troposphere, which may have been expected to lead to an enhanced greenhouse effect throughout the troposphere may not have the effect. It is suggested that warmer clouds will produce rain more easily, which will mean that less water vapour reaches the higher levels of the troposphere. So, although there is more water vapour near the surface, where its greenhouse efficacy will lead to warming, there will be less water vapour higher in the troposphere, and hence a reduced greenhouse warming higher in the troposphere, leading to the upper troposphere cooling.

It may be better not to place too much faith in the predictions of climate models at the current time. However, we should not simply ignore their predictions. We can be sure that the models will improve greatly in the near future as the scientific understanding of the earth and its atmosphere improve. It may be in the insurance industry's interests to speed up the rate of understanding, possibly by the funding of research programs such as those implemented by the AGCI.

Chaos theory

Chaos theory arose from observations on early work on computerised climate modelling. It is now widely known that the climate models are chaotic in the mathematical sense in that the outturn of running a simulation is sensitively dependent on the initial starting parameters.

Chaos theory has several implications for our understanding of weather systems.

It indicates that the state of a climate system is sensitively dependent on initial conditions. That is, the smallest difference in the state of a system will be magnified over time and the evolution of very similar positions will increasingly diverge over time. To partially overcome this problem weather and climate models are usually run using several initial starting condition vectors that are slightly different. In this way the most likely weather or climate in the forecast period is estimated as the average of the positions predicted by each simulation.

Chaos theory also includes the concepts of attractors and dynamic equilibrium. This means that for some non-linear dynamical systems there are several potential states of equilibrium. Dynamical equilibrium means that the system doesn't settle in on a stationary state, but it will be contained within an envelope of potential states. Small changes to the system may induce the system to switch over, possibly quite suddenly, *to a different state of dynamical equilibrium. As climate is a non-linear dynamical* system it may have several distinct equilibrium states. For example, ice-ages and interglacial periods may both be equilibrium states, such that once attained the climate will tend to remain in that state. The oceanic conveyor belt may also have several distinct equilibrium states, at least one with a Gulf Stream, others without.

2.3 Loss mitigation

In this section we will consider the steps that may be taken to reduce the impact of potential catastrophic losses.

Losses can be mitigated in one of two main ways: by the application of technological measures, or indirectly through social control measures.

2.3.1 Technological Measures

The aim of such measures is to reduce the physical damage caused by an event by the application of technology to either dissipate the energy released in an event over a larger area, or over a longer period of time, thereby reducing the intensity of energy transfer at any one place, or to increase the ability of property to withstand the energy released in an event. Examples of the former include sea defence schemes, or dams used to capture floodwater. Examples of the latter include the application of hazard resistant building codes. As each catastrophe type can be modified in different ways, these are discussed for several examples below.

2.3.1.1 Windstorm

Cloud Seeding

In the 1960's the USA tried to reduce the strength of hurricanes by seeding clouds with dry ice. The theory was that by reducing the amount of water vapour in the atmosphere around the storm the energy supply of the storm would be reduced. The results of this experiment were not clear-cut and there were political problems of implementing this strategy over international waters, so funding for the project was withdrawn. Similar experiments which attempted to reduce cyclone intensities in the Australian area were also tried without great success.

Hazard resistant design

Trees should not be planted too close to buildings.

Buildings can be designed with some consideration given to their aerodynamic properties such as the slope of the roof. The optimum angle for roofs is 30°.

Smaller areas of glass, or smaller panes will help to reduce damage. The type of glass used can have a large impact.

As much damage can be caused by storm surge coastal flooding the same considerations apply here as mentioned in the section on flooding.

Traditional buildings in some parts of the world have open structures which offer less resistance to the wind, which will then impart less energy on the building.

Storm shutters can be used to protect windows from impact forces and projectiles.

2.3.1.2 Inland Flood

Flood reduction.

Flood reduction measures try to pre-empt flooding by controlling the use of land which is within a flood-prone drainage basin. Examples of this include limiting deforestation and other measures intended to slow down the run-off of rainwater, thus helping to prevent flash-flooding.

Flood diversion

Flood diversion aims to control the flow of flood waters once they have been produced. Examples of this include:

- upstream dams which can be used to help control the water level downstream.

- levees or dykes which are used to contain the flood waters to areas of low value land. These may be further heightened, if an impending flood is projected to rise above the level of the levee,

- dredging of rivers to increase surge capacity, and

- sandbagging can be used to provide additional protection for individual properties, and may be particularly useful if used to make doorways and other entrances to buildings more watertight.

Hazard resistant design

Buildings in areas prone to flooding may be built on stilts which raise the building above the water level expected from moderate floods. Similarly, buildings can be elevated above the floodplain by building them on elevated plots. It has been suggested that inflatable rafts could be used in some areas to allow buildings to float above the flood waters if suitably moored.

Basements of buildings in flood-prone areas should be made watertight.

2.3.1.3 Coastal Flood

Sea Defences

The aim of these measures is to either reduce the height of the surge waters, or to raise the height of the land at the land-sea boundary. The quality of a sea defence will depend partly on the area of land that it is designed to protect. For low-value areas of land the cost of construction of some types of defence may not be justified by a cost-benefit analysis. The main types in use include:

- Concrete sea walls: these are the most effective form of defence, but are also the most expensive. They generally have a curved surface which directs the force of waves away from the land. Without this feature the momentum of an advancing wave may cause overtopping. Sea walls will generally be used to protect more valuable areas.

- Embankments: these are relatively cheap and quick to build. These may also be used as a second line of defence behind sea walls.

- Breakwaters and groynes: these aim to reduce the wave action of the sea and so reduce the risk of overtopping of other defences due to wave action complementing the storm surge. They also reduce the amount of coastal erosion which can lead to the weakening of other sea defences.

Hazard resistant design

Similar considerations as for inland flooding apply.

2.3.1.4 Earthquake

Earthquakes are too powerful for us to be able to control using present technology. Therefore we will concentrate on how technology can minimise the damage caused by the energy released in the event.

Hazard resistant design

The choice of building materials is of great relevance. Flexible and ductile materials will be able to absorb more energy without failing than stiff and brittle materials. So, steel framed buildings will generally be better at withstanding shaking than brick-built ones. In many quake-prone areas houses are often of wood-frame construction as these are relatively ductile. The damage to such buildings in a quake is more likely to arise from the breakage of windows and the cracking of the brittle plaster on the walls.

The shape of a building will also affect its vulnerability. Quake-resistant design will aim to reduce the asymmetry of a building.

The height of a building was once thought to be a factor in the vulnerability to damage, and building codes in some areas limited the number of storeys that were allowed. However, good design of tall buildings can allow the energy at lower levels to be dissipated to the higher storey's which may sway with increasing amplitude. As long as a building is sufficiently flexible this spreads the energy imparted by the shaking over a larger area, and the intensity of vibration at any stage is reduced. Thus skyscapers constructed in a quake-prone zone may be safer than shorter buildings.

In the developing world it is common for people to build their own houses using traditional methods and locally available materials. Buildings constructed from sun-dried clay bricks, adobe, such as those that provide most of the accommodation in South American and the Middle East are easily damaged in quakes. This can lead to the collapse of roofs, which in turn causes many deaths and injuries. Some simple methods of improving the resistance to quakes have been shown to be effective in reducing the damage, such as the insertion of bamboo canes during the construction of adobe walls.

Buildings may be mounted on shock-absorbing pads made from layers of rubber and steel. The inertia of the building means that the earth may tend to vibrate under the building and cause less shaking of the building itself. This technique is rather expensive to implement, so is generally only applicable to large, high value buildings.

Valves can be fitted to the fuel supply pipelines to buildings which automatically shut off the supply if earth tremors exceed to given level of intensity. This help to reduce the spread of fires following a quake. Such devices ensure that the fuel supply is switched off if a quake occurs during the night when residents may be asleep, or if the residents panic.

2.3.1.5 Volcanic eruption

Control of lava flows.

Barriers can be constructed which aim to divert lava flows away from property. These need to be built from resistive materials. This technique is only useful for the more fluid lava such as that found in Hawaii and Iceland.

Bombing has also been used to try to divert lava flows. The sides of an advancing lava flow may have solidified, so bombing of such solidified lava may allow the molten lava inside to spill out rather than continuing with the main flow.

Spraying a lava flow with water can cause the drenched area to cool and solidify, slowing, or stopping the flow.

Hazard resistant design

The main hazard from volcances that can be designed against is the ashfall. Towns up to a dozen or more kilometres downwind of the eruption may suffer from ashfalls of upwards of several centimetres. This ash may cause roofs to collapse, especially if it is wet, possibly leading to deaths and/or increased property damage. Sloped roofs are recommended in areas with the potential for severe ashfalls.

2.3.1.6 Tsunami

Similar considerations apply as for coastal flooding.

2.3.1.7 Cosmic Impact

If an asteroid were found to be on a collision course with the earth then the only known way to avoid this would be to detonate a nuclear bomb in the vicinity of the asteroid in order to deflect it. There are many problems associated with this:

- We need to detect the object: this is not easy as we will need to look for dark objects which are 1km, or less, in diameter, travelling at many thousands of kilometres per hour relative to the earth.

- We would need to deflect the object a long time before it came near the earth. Apart from the risks of nuclear fallout, we would need to ensure that it missed by a large enough margin.

- We may risk making the problem worse if we miscalculate the deflection required.

- If the explosion shatters the object then one of the pieces may still strike the earth.

2.3.2 Social Control Measures

The aim of such measures is to influence the attitudes and behaviour of people to these hazards. Whereas technological measures attempt to improve the "hardware", social control measures attempt to improve the "software". Examples include: earthquake prediction and warning, evacuation procedures, land use management and insurance availability. As for technological measures each event type will have varying types of solution, so these are discussed for the same event types as shown above .

General

The following measures may be applied to any of the named events discussed below, so are mentioned here to avoid repetition.

Insurance

The price and availability of insurance cover can have an effect on the behaviour of a population at risk from catastrophic losses.

An important role of insurance is to spread the loss experience over a period of time. This should encourage economic decisions to be made which take account of the long-term risks involved. Thus if insurance premiums take account of the full expected catastrophic loss experience of an area this will discourage development in catastrophe-prone areas, and encourage development in less hazardous regions. This will reduce the long-term expected losses.

If insurance premiums do not include adequate loadings to cover the catastrophe risk then further development in hazard-prone areas will increase the long-term expected losses.

Insurance premiums may be reduced if some steps in loss-mitigation have been taken. For example, an insured may have retro-fitted a factory in a quake-prone region. The reduction in premiums may be sufficient to repay the cost of such retro-fitting in a matter of years. Furthermore, some businesses suffer from business interruption long after an event if they lose customers to a competitor during the period of initial disruption, so the benefits extend beyond reduced property damage.

Conversely, insurance may reduce the incentive for an insured to take loss mitigating steps. This can arise if the insured prefers to make a claim, which may be fraudulently inflated, rather than take the effort to reduce the loss. In some circumstances insurance may positively lead to more damage. For example, it is believed that some of the fire damage following the San Francisco quake of 1906 was a result of arson by homeowners whose properties were damaged in the quake. This was because fire following quake damage was not a common exclusion in buildings insurance, but quake damage was excluded. Therefore a policyholder who could not have claimed for quake damage had a great incentive to make sure that the building was destroyed by fire.

In the USA, the National Flood Insurance Program (NFIP) is used to provide an incentive to restrict development in areas which are expected to be affected by 100-year floods. It was introduced in 1968 due to the reluctance of the private insurance sector to offer flood cover. The NFIP provides insurance cover for flood-prone communities if they comply with certain restrictions on developments within the 100-year floodplain. The insurance premiums charged are determined actuarially and vary depending on factors such as elevation. This is an example of insurance being used as an incentive to implement better loss mitigation measures.

Early warning procedures

By disseminating advance warnings of events lives can be saved and property damage reduced. A warning may also include advice on what steps should then be taken. A advanced warning will allow actions to mitigate the loss to be taken, such as the boarding up of windows and the garaging of cars as a hurricane approaches. Evacuation may also be an option if the lead-in time is sufficient.

The ability to predict the onset of various events is discusses separately below for each major catastrophe.

In order to be effective, early warning procedures need to be credible. The credibility of warnings will be severely reduced if warnings of events which do not transpire are made. The public will be less receptive to future warnings, and may ignore them.

Furthermore, the business interruption losses once a warning has been issued can be significant. If a warning turns out to be unnecessary then unnecessary losses will have been caused. For example, it has been estimated that if a quake warning was issued in Tokyo, and emergency measures such as the shutting of schools and stopping of trains were implemented, the economic cost would be around £5Bn per day (Economist 2/8/97).

We consider factors applicable to individual events below:

2.3.2.1 Windstorm

Building codes and Land use restrictions

In order to comply with requirements of the National Flood Insurance Program all newly constructed houses on the US coastline have had to be built with floors at least 2.4m above the mean sea level, which represents the level of the 100-year flood.

The application of building codes and land use restrictions is made more difficult by political considerations. Local governments who are empowered to determine and enforce such regulations may be torn between the long-term desire to reduce hazard vulnerability, and the short-term goal of increased economic activity in their region. Applying onerous restrictions may cause potential property purchasers or business investors to consider other districts with more lenient regulations. Furthermore, democratically elected government officials may prefer to pamper their electorates' short-term wishes rather than take unpopular actions for which the benefits will only appear in the long term.

Prediction

As meteorologists' understanding of the world's climate and atmospheric systems improves, the ability to forecast windstorms is expected to improve. There are three elements to a good windstorm prediction: where, when and how intense. Of these, the intensity is reasonably predictable, but meteorologists are still struggling with predicting the future track of storms.

Medium-range predictions of windstorm activity may be made based on historical statistics. These predictions may be based on recent trends, or linked to other measurable factors such as the occurrence of El Nino events.

Short-range forecasts are improving continually, as the meteorological models improve to reflect increased understanding of the physics of windstorms. However, the confidence intervals around the predictions of the site of landfall of the eye of a hurricane are still of the order of 150km for a 24-hour forecast.

2.3.2.2 Coastal Flood

Prediction

The amount of coastal flooding depends crucially on the level of storm surge along with the timing of the surge relative to the tide. The amount of surge will depend on the pressure of the depression, which is reasonably simple to predict, but the actual *location of the landfall of the eye of the depression, where the surge will be greatest is* not reliably predictable (see Windstorm).

2.3.2.3 Inland Flood

Prediction

Flash flooding, by its very nature is rather unpredictable.

The science of hydrology has progressed to the stage where models of water drainage can be combined with meteorological forecasts of rainfall to produce reliable forecasts of floods. Remote sensing instruments can track the rising river levels upstream so that warnings of imminent rises, and potential flooding further downstream can be issued. If sufficient time of warning is issued then some mitigation measures can be implemented such as shoring up levees, sandbagging and evacuation.

2.3.2.4 Earthquake

Prediction

At present earthquake prediction is not sufficiently reliable to be of much practical use. This is despite large amounts of funding which quake-exposed countries have applied to academic research into the subject. The USA and Japan, in particular, have much to gain by being able to forecast the strength and timing of future quakes with a high degree of accuracy.

Various methods of predicting earthquakes have been proposed, but none, as yet, has proved sufficiently accurate to use. Methods include:

- Observing animal behaviour
- Measuring the level of the water table near a fault
- Measuring the level of radon gas - which is released by stressed rocks
- Magnetometers - measuring changes in the magnetic field
- Tiltmeters - measuring ground deformation
- Creepmeters - measuring lateral movement along a fault
- Gravity Meters - measuring changes in gravity due to subterranean movements
- Voltmeters - to measure electricity produced by stressed rocks.

- Volcanic activity at nearby volcanoes, mud springs, etc..

A few decades ago geologists hoped to be able to predict earthquakes with some precision as to location and timing. Little progress has been made, despite much effort, as the complexity of the problem is so great. Nowadays most geologists apparently believe that they can only hope to quote estimated return periods for quakes of a given intensity for a particular region. The Japanese government is expected to stop funding research into earthquake prediction in 1999 when the current 5-year research programme ends.

Building codes and Land use restrictions

The amount of damage that a quake will cause may be limited by regulating the location, design and construction of development in hazard-prone areas. Examples of this include:

- controlling the erection of new buildings within a certain distance of know geological fault lines.

- restricting the development of areas prone to liquefaction such as reclaimed land-fill sites, or soft soils.

- regulating the maximum heights of building allowed.

- regulating the proximity of adjacent high-rise buildings.

- a requirement for new constructions to meet minimum construction standards.

Although land use restrictions may exist in principle, it is necessary to take into consideration how strictly they are applied in practice. Also, regulations may have been less strict in the past, so some buildings may exist which would not be allowed to be constructed in future, but for which exemptions were granted at the time that regulations were implemented.

Older buildings that were originally constructed to lower standards of hazard resistance can be retro-fitted to improve their resistance. However, the cost of doing this in some cases may approach that of demolition and rebuilding.

2.3.2.5 Volcanic eruption

Prediction

There are a variety of measurable environmental changes which tend to precede volcanic eruptions. These include earthquakes, ground deformation, temperature, chemical changes in volcanic gas emissions. However, there is presently no reliable method of forecasting when an eruption will occur.

2.3.2.6 Tsunami

Prediction / monitoring

There is a Pacific-wide monitoring and warning system for large tsunamis. If there is a large magnitude quake then tide stations near the epicentre are alerted. These then note any unusual wave activity. If anything unusual is observed than all countries bordering the Pacific are alerted. This can allow the authorities in each country to issue warnings to their populations at risk, and can activate evacuation plans. This can give many hours of advance warning. For example, it takes about 10 hours for a tsunami to travel from Japan to the west coast of the USA.

Regional tsunami warning systems are also used in some areas. For example, Japan has a system which is designed to issue warnings within 20 minutes of a tsunamigenic earthquake within 600km of its shores. As such tsunami would arrive within approximately one hour of being generated such systems require rapid response times and decision procedures.

3.1 Background on Models, Uses of Models, Advantages and Disadvantages of these models, and Basic Model Construction

Introduction

Catastrophe Models were originally developed to quantify exposures for insurers writing property risks. They came into extensive use after Hurricane Andrew, enabling risk takers to bring additional information into the analysis of the cost and frequency of catastrophes. In section 3.1 we will review the role that models play in the general insurance industry, advantages and disadvantages of these models and review their basic construction.

Models Have Gained Acceptance Within The Insurance Industry

Hurricane Andrew caused considerably more damage and financial loss than those in the industry would have previously thought possible. The Andrew loss not only exhausted the reinsurance protection of many US primary companies but also caused extensive losses to their reinsurers.

That such a large unanticipated loss was possible was disturbing enough, but the fact that it occurred in a sparsely populated area of Florida was frightening. If this relatively innocuous event could cause such damage, what were the potential losses from a more serious catastrophe? What would happen, for instance, if Hurricane Andrew had hit downtown Miami? Or if a major storm went through Miami, strafed New Orleans and hit Houston?

In response, the management of US primary insurance companies were forced to consider a different approach to managing their business. As they began to focus on exposure management, they found that their current management systems were not structured to evaluate and react to these exposures. The type of information generally required to perform this type of exposure management (ie. insurance limits information at a fine geographical split) was not what they had historically used to manage their business. As a result, they found that they had to invest significantly in new IT and management systems in order to obtain quality exposure tracking reports and to ensure that these were used effectively in managing the business.

It was in this environment that catastrophe modelling in the insurance industry developed. Not surprisingly, it was the US companies that were significantly affected by hurricanes Andrew & Iniki and the Northridge earthquake that became the market leaders in making effective use of these models.

The focus however, even among US insurers, has been very much towards managing probable maximum loss (PML) from natural catastrophic events. Companies have also realised the enormous potential of catastrophe modelling for a host of other purposes, such as:

- assessments of underlying profitability,
- stochastic modelling of earnings, called Dynamic Financial Analysis or DFA,
- capital assessment and allocation studies,
- determination of appropriate premium loadings for different regions in respect of their exposure to catastrophic events,

- assisting in the development of business strategy,
- pricing of catastrophe excess of loss reinsurance,
- design of catastrophe-based financial instruments such as Cat Bonds.

Indeed all areas of corporate financial and actuarial analysis will be affected by the power of this modelling tool.

The Use of Models has Spread

Hurricane Andrew also caused havoc within the reinsurance markets: as capacity was taken out of the insurance and reinsurance industry, dramatic rate increases occurred. Obtaining adequate coverage became difficult, if not impossible in some areas and when cover was available, prices increased significantly.

The capacity crisis and increased rates brought new entrants to this reinsurance market, many of whom used the new catastrophe modelling tools to reassess appropriate rates.

The development of capital market products which provide this cover is partly due to this capacity crisis, but has been made possible by the availability of catastrophe models that the investment community consider to be sufficiently reliable. These models have allowed potential investors to attempt to assess the risks involved in a more objective way than was previously possible. It is not clear whether these investors understand the limitations of these models.

At the same time, reinsurers and model builders began to globalize their models to include natural catastrophes in other geographic regions of the world. Exposure modelling had become fairly common among US insurers, in part because of the requirements from rating agencies, such as Best's, to include this information in a rating application. As insurers began to understand and use US models, other perils and regions of the world were considered appropriate candidates for this type of modelling.

Not surprisingly, the current state of acceptance of catastrophe modelling varies greatly between different markets and is highest in areas that have been affected by a large number of catastrophes over the last few years. In the next decade, as insurers, reinsurers and large conglomerates continue to look for a more uniform way of assessing risks across regions and types of perils, we expect further expansion of modelling capabilities in areas and hazards not previously covered.

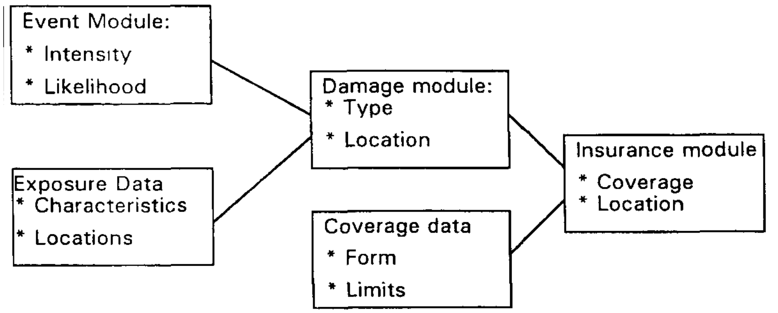
As the capabilities develop and begin to supplant the crude historic rules of thumb used to assess catastrophe risks, the models will gain more universal usage and acceptance in these other areas.

Model Construction

The main components of a model, be it deterministic or probabilistic, include three main modules. The main modules included are:

- Event Module
- Damage Module
- Insured Module

How these modules fit together can be seen below. A discussion of each of these modules as described by Kozlowski and Lebens in "Opening the Black Box" follows.



Event Simulation

The science module transforms meteorological or seismological parameters into the damaging forces of a catastrophe using a series of meteorological and seismological equations.

Windstorm modelling uses variables such as central pressure, radius of maximum winds, forwards speed, landfall location, storm direction, and others to estimate the windspeeds at different locations. The lower the central pressure, or the greater the difference in pressure between the eye and outer layer of the maximum winds, the stronger the winds. The radius of maximum winds refers to the distance of the storm centre to the outer band of strongest winds. Forward speed refers to the movement of the storm centre from one location to another.

Landfall location and storm direction are used to measure the time and distance since landfall, as windstorm strength diminishes as it moves away from water.

(Coastal) flood modelling is made more complicated by the impact of flood defences which are designed to prevent floods of a certain return period (if there were no such defences) from occurring. Flood models need to allow for the potential failure of such defences, as well as the potential for an event more severe than that which the defences are designed to withstand. Flood models also incorporate variables such as depth and duration of flooding, and the velocity of flood waters, which may be estimated based on the distance from the coast, or the predicted breach in defences. In order to determine the depth of flooding a model needs to have details of the topography of the area being modelled. These models will generally work by determining which areas will be flooded if a given section of defence fails. The depth of flooding at each inundated location will be determined by comparing its elevation with that of the surge sea level. A significant factor in these calculations is the probability that the model allocates to the potential for the failure of the flood defences. Different probability of failure functions will be required for each type of flood defence. Also, the surge level will be different at different points along the coastline as the storm surge coincides to a greater or lesser extent with the tide. A model will therefore also need to consider the effect of the conjunction of storm surge and tide.

Earthquake modelling uses variables such as magnitude, epicentre, fault location and type, depth, soil conditions, and others to estimate the shaking intensity at different locations. The magnitude of an earthquake is a rating of the strength of an earthquake. The epicentre refers to the point on the earth's surface directly above the beginning of a fault rupture (the focus). A fault is a break in the rock beneath the earth's surface, often identified by breakage of the soil at the surface. There are types of faults (eg strike-slip, normal, thrust) that move in different ways. The depth of the earthquake refers to the depth of the focus below the earth's surface. Earthquake waves move differently through different soil types, so geological maps are important in determining damage.

An earthquake model may incorporate the damage caused by fire following the quake in the damage curve used to convert shaking intensity into the proportion of property destroyed. A more sophisticated model would also make allowance for construction density, construction material, wind direction, and so on. For urban areas with a high density of insured values it is useful to have a limited area catastrophe model which has a finer resolution than the other models.

Science modules vary significantly from modeler to due to different theories and additional variables used to produce the damaging forces. For instance, not all scientists agree as to which formulas product the most accurate representation of a wind field. This source of variation may in part explain the differences among catastrophe modelers.

Catastrophe modelling can be done on a deterministic or probabilistic basis. Early catastrophe modelers used to simulate historical or hypothetical events over a set of exposures (ie estimate the losses from Hurricane Hugo if it hit Boston). Probabilistic modelling refers to the simulation of a large number of events that could occur reflecting different event intensities and locations.

For windstorm, modelers divide or segment a coastline and fit distributions to the various storm parameters in a particular region. Regional differences are important since as storms move further polewards, the ocean temperature becomes cooler, weakening the storms.

Correlations between storm parameters are also studied. For example, some modelers may reflect hypothetical correlations between central pressures and radius of maximum winds. Some meteorologists believe that the lower the central pressure, the narrower the radius of maximum winds. Using various sampling techniques, modelers select parameters from the various distributions and create hypothetical hurricanes. One such modeler creates 100 storms for each 50 mile segment of the US east coast generating nearly 6,000 US Atlantic and Gulf Coast hurricanes.

Damage Simulation

The engineering module calculates the damage based upon the severity of the damaging forces and the physical characteristics of the exposure. Damage functions or damage curves reflect the percentage damage at different windspeeds, flood depths or ground shaking. Damage functions should vary by coverage, construction, and surrounding terrain or geology.

Damage functions should vary by building, contents, appurtenant structures, loss of use or time element. Appurtenant structures such as sheds and free-standing garages suffer damage at the lowest windspeeds and weakest shaking intensities. For wind, damage occurs to the building before contents are damaged. The converse is true for earthquake and flood damage. Loss of use or time element damage does not occur until significant damage occurs to the building or contents.

Damage functions could potentially vary by many different components of construction. For example, for wind damage calculations, residential construction may vary by building construction (eg frame, brick); building design (eg ranch, three-story colonial); roof type (eg hip, gable, flat); roof construction (eg barrel tiles, asphalt shingles); age of roof; or area of windows/doors. For commercial properties wind damage functions may vary by building construction (eg steel frame, brick); building design (eg, strip mall, office complex); building height; or cladding. Other important wind damage variables might include surrounding terrain, which contributes to flying debris or projectiles.

Many of the physical building characteristics that are important to wind damage are also important to earthquake damage. Also, different terrain characteristics that refer to landslide or liquefaction potential are important to earthquake modelling. In addition, fire following earthquake loss potential considers availability and responses tactics of the fire department, building density, and weather conditions.

Damage factors are created primarily in two different ways. The first method is to analyse actual insurance company claim statistics. Unfortunately, insurance companies typically retain claim information in little detail. For instance, the loss may not be split by coverage. Insurance company statistical plans retain construction information on building construction (eg frame, brick), since it is used for fire rating purposes. However, this construction information does not identify all of those building components that are important to wind and earthquake perils.

The second method is to use engineering studies to create damage factors. Unfortunately, engineering studies tend to analyse damage in ways that are difficult to convert for catastrophe modelling purposes. For example, engineering studies tend to separate damage into wind and non-wind damage rather than damage by coverage type (building and contents). This difference in definitions complicates the analysis.

Where the data which may be used to determine appropriate damage curves for a territory are unavailable, or are scanty, experience from other territories may be used to supplement the available data. For example, at least one UK flood model uses data from Australia relating to the impact of flood water velocity to modify the damage curves to allow for this.

Insured Losses

The insurance module limits or enhances the damage due to coverage conditions. Policy characteristics such as coverage limits, deductibles, and actual cash value might limit the amount of loss, while replacement cost coverage and loss adjustment expenses increase the amount of loss. Insurance to value coverage can increase or decrease the insured loss depending upon the relationship between the amount of insurance and the value of the property. Additional components such as demand surge and theft also influence company's losses.

In theory, the insurance coverage module is straightforward; in practice, the insurance coverage and engineering module are significantly intertwined. When using actual insurance company data to validate damage factors, the modeler attempts to back out the influence of the insurance coverages. Creating ground-up losses to build damage factors might sound simple but assumptions need to be made concerning losses that did not exceed the deductibles. Claim detail does not identify the influence of replacement cost coverage or other insurance coverage options. When using actual insurance company data to verify damage functions, a modeler must assess whether the damage functions are really ground up damage or reflect the use of deductibles or replacement costs-provisions

Primary Advantage and Disadvantage of Catastrophe Models

The primary advantage of these models is their ability to incorporate information from a number of difference sources and disciplines to attempt to answer questions about the extent of possible damage to an insured portfolio.

The primary disadvantage is their complexity and the black box nature of the output to many of the end users of these products. Many insurance professionals, and especially actuaries, are disturbed by their inability to fully understand the model output or be able to validate all of the assumptions underlying these models.

Primary Advantage: Models Allow Additional Information to be Used to Quantify Risk

Historically, very crude estimates were used to assess probable maximal losses (PMLs) of catastrophes. These estimates primarily relied upon actual losses from prior events. For example, a US national primary writer might use its Hurricane Hugo loss, or some multiple thereof, as its PML for its reinsurance buying.

After Hurricane Andrew it became clear that the historical mechanisms used to assess PMLs were inadequate. It was also clear to insurance practitioners, academics, engineers, meteorologists, actuaries and other experts that significantly more information could be brought to bear to address the insurance managers' questions about how severe these types of catastrophes could be and how often they could be expected to occur.

Catastrophe modelling brings together a number of different skill sets and disciplines.

Historically catastrophe PML's may have been determined as a simple ratio of exposed premiums, or as a multiple of a previous large claim. Over time PML estimation has become more sophisticated. Catastrophe modelling allows the following factors to be taken into account when assessing exposure to catastrophic loss.

Growth - if a direct insurer is writing significantly more exposures in a catastrophe prone area, the risk taker should expect more losses in the event of a catastrophe.

Concentration - since many of these events cause massive damage in a relatively small geographic area, the concentration of exposures has a significant impact on the size of losses one could expect.

Building Codes - the type of construction in an area, as well as the mechanisms used to protect insureds from windstorm damage, should be incorporated into any assessment of loss.

Engineering Studies - engineering assessments of the protection afforded to different types of constructions for different uses are valuable. Wind tunnel studies are used to assess the amount and type of damage that will be inflicted on different insured construction types.

Meteorological Information - historically, assessments of a number of variables that describe a hurricane's behaviour have been recorded. These variables include central pressure, radius of maximum winds, speed and direction of the storm, as well as many other variables.

Hurricane Studies - meteorologists have built a number of models of hurricane behaviour that will allow one to translate weather station information, as above, into wind speeds at different locations. These models incorporate the meteorological information as well as information on the terrain and other elements of exposure studies.

Loss Mitigation measures - these may be allowed for by modifying the damage curves used, or may be allowed for by modifying the event severity or frequency (eg sea defences)

Although previous methods of estimating PML's may have taken some, or all, of these factors into account, catastrophe models make their inclusion explicit.

Because of the significant investment required to bring these elements and the skill sets together, specialist service providers have developed capabilities in this area and act as service providers to the industry.

Role of Research Science in Catastrophe Modelling

Some catastrophe modelers are funding focused scientific research in order to assist them in improving these models. As scientists come up with new findings, these modelers attempt to incorporate them into their subsequent versions. For certain types of focused scientific questions these assessments can assist the modelers to incorporate this information. Unfortunately, because the scientific community does not always agree on the answers to some fundamental questions about basic scientific issues and how they will impact future catastrophic events, catastrophe modelers are sometimes put in a quandary in determining which of differing scientific assessments should be incorporated into their models.

Primary Disadvantage: Validation is Difficult

The primary disadvantage is their complexity and the black box nature of the output to many of the end users of these products. Many insurance professionals, and especially the actuaries, are disturbed by the inability of them to fully understand the model output or be able to validate all of the assumptions underlying these models.

Reasons Why Validation is Difficult

For a number of reasons actuaries and other insurance professionals have some difficulty in validating the output of catastrophe models. The main reasons the insurance professionals cannot internally validate the model output are highlighted below. However, although there are difficulties in the validation of these models actuaries are better placed than most other insurance professionals to try to straddle the scientific, engineering and insurance disciplines which are combined in the models, and to provide a critical review of the different components. For example, actuaries' training includes assessing the goodness-of-fit of statistical models. Actuaries are also familiar with some of the difficulties in designing models which attempt to represent complicated processes, such as model offices.

These Models are Complicated - The complexity of these models makes them difficult to review. However, the complexity alone would not be a significant factor if it was not for the other impediments to validation.

Lack of Expertise - Due to the wide array of expertise required to create these models, insurance practitioners generally do not have the expertise required to fully assess the validity of the number of assumptions and judgements that have to be made within these models.

Lack of Transparency The specialist service providers that create these models will undertake proprietary studies to assess the appropriate factors to incorporate into their models. When done properly, these studies are expensive and these service providers are naturally reluctant to share these studies or their conclusions with clients for the fear that in doing so they will lose the competitive advantage that these studies allow them.

How to Deal with this lack of Transparency

The inability to truly validate the output of these models causes some significant problems for insurers that are using this output to make some significant business decisions. While they will not allow the output of some black box to run their underwriting and reinsurance purchasing for them, they do wish to incorporate the expertise of these other disciplines into their underwriting and reinsurance purchasing decisions.

Some purchasers of modelling services only attempt to perform some superficial validations in order to gain some comfort that these models are producing reasonable results. Others will try to delve deeper into the guts of a model in order to come to a fuller understanding of its operation. These validations may be required when a company is first considering leasing or purchasing the model, but may also be required when an updated version of the model is released.

We describe below several ways in which model validation may be attempted:

Comparison to Actual - Model purchasers regularly ask how the modelled estimate of losses compared to actual losses. For example, they may ask "how a model did" in predicting Andrew, or 90A, 87J or Kobe. Since the model builders use these actual events to help calibrate their models, these assessments are not, in the end, especially helpful.

Find out about the underlying assumptions and data - By asking a number of detailed questions about the models and their scientific underpinnings, some model purchasers believe that they can differentiate between models.

Questions that may be asked include:

- What is the source of the data used to construct the event library?
- How extensive was this database?
- How was the event library extended to include potential events outside of the actual experience, especially the rare, highly damaging events?
- For flood models, how was the vulnerability of flood defences quantified?
- For flood models, how fine were the contours on the topographical model of the area?
- What is the source of the data used to determine the damage curves?
- How extensive is the database used to determine damage curves?
- How was the impact on damage curves of the various risk factors such as construction type allowed for?
- What damage do the damage curves represent? For example, do they include business interruption loss for commercial property, do they include fire and tsunami damage for earthquake?

- How were the damage curves extended to determine the damage that would be caused by events more severe than have been experienced?

Some models have used the fact that they require address level (instead of postcode level) information to project an image of enhanced precision to primary insurers. A purchaser, having some difficulty understanding the difference between two models may rely upon this fact to determine a preference for one model over another. Similar assessments are occasionally made on the basis of the number of storms in a probabilistic library, the type of sampling methods used, or the granularity of building types that are requested.

For many territories the amount of historical experience may not be sufficiently extensive to be used to determine a credible event library. In any case, even for territories with relatively extensive detailed records, such as those of the NHC, these may not be reliable for periods more than 100 years ago. There is therefore the problem of how to extrapolate the available data to allow for events more extreme than may be included in the database. For example, how do you determine the 500-year storm?

One method to estimate the extreme events would be to look at indirect evidence of past events. This may include:

(i) looking through books, newspapers, diaries and other records for descriptions of past events. These eye-witness accounts can then be used to determine the severity of event that would be required to cause the damage reported as being caused.

(ii) analysis of sediments of lakes, or silt deposits can give indications of the extents of past storms or floods. The date when the events occurred can be estimated from historical records, or indirectly via other scientific methods.

Another method to estimate extreme events would be to fit statistical distributions to the parameters and extrapolate. This is an example of the use of Extreme Value Theory.

Some studies have shown that climate/weather models (GCMs) can produce simulated experience which is reasonably similar to historical experience. This should not be surprising as such models are calibrated using historical experience. This allows the possibility that potential events may be generated using GCMs. It will generally be more efficient to distil the experience simulated by GCMs into a library of sampled events with known characteristics than to use a GCM to simulate new experience each time the catastrophe model is run. However, the use of GCMs would at least allow events more extreme than are contained in the historical experience to be generated in a deterministic, and hopefully realistic way.

The actual method, or combination of methods, used by the modeller should be determined.

X-raying the model - To perform a more detailed validation of a model it is necessary to perform analyses of each of the components of the model: the event module, the damage module and the insurance module. We discuss below how each of these may, in principle, be validated.

<u>Validating the damage module</u>

We discuss this module first as the results of this validation may be required in order to validate the event module.

We wish to determine the validity of the damage curves used by the model to convert simulated event severities into property damage amounts. To do this we will need to obtain some damage curves from external sources. There are various potential sources of such damage curves. For example, a UK flood damage database is maintained by the Flood Hazard Research Centre of Middlesex University, UK windstorm damage experience is held by the Building Research Establishment. A damage curve for windstorm is shown in Munich Re's 'Windstorm' publication.

In principle, the damage curves being used by a model could be roughly extracted using the following techniques:

(i) using a portfolio consisting of a single exposed cell with a single construction type, apply events of known intensity, and find the relationship between the damage and the intensity.

(ii) where it is possible to enter a user-defined damage curve, use trial and error to determine a curve which produces similar overall damage results for a range of event severities as the in-built damage curves.

However, in practice these approaches are not always possible, and the validator is limited to considering the extent and appropriateness of the data and assumptions underlying the damage curves.

In principle separate damage curves would be required for each combination of risk factors eg. Construction type, roof type, soil type, ... etc. However, in practice a much smaller subset of damage curves is likely to be used. It may be informative to examine the variation between damage curves for different types of building (eg masonry highly protected risks vs. wood frame unprotected risks).

Validating the event module.

We wish to check that the frequency, severity and location of events generated by the module are reasonable. We are interested in validating both the event library of potential events and the damage distribution caused by a single event.

There are two main ways that this can be achieved:

(i) comparison with historical experience, or

(ii) comparison with meteorological or seismic models.

There are several databases which may be used to provide the historical experience. For example, the US National Hurricane Center (NHC) has a database of hurricanes dating back to 1886. The NOAA/National Weather Service have used this data to determine the probability distribution of Hurricanes along the eastern coast of the USA [Ho,Neumann].

The catastrophe modeller may have used the same source of information when calibrating the model that the validator is using to check it. A modeller may have simply used the historical event library as it stands, or may fit statistical distributions to the experience and then sample from these distributions in order to generate a probabilistic event library.

Historical meteorological or seismic information will generally show certain statistics which measure the severity of an event such as peak gust speeds, or magnitude of shaking. The output of a catastrophe model is the estimated damage that a simulated event will cause. In order to convert the meteorological or seismic information into an estimate of the damage one could apply damage curves obtained from another source to convert these event severity measures into damage ratios, and hence to determine an expected amount of damage to a given portfolio. However, this entails going some way towards the construction of an in-house model, and is likely to be somewhat time-consuming. Differences between the results of this exercise and those produced by the model being validated could be due to different assumptions, or lack of expertise of the validator.

In practice, event validation is likely to take the form of comparison of simulated amounts of damage to amounts observed for experienced events.

The results of the probabilistic event modelling may be compared to other studies which estimate the frequency/severity distributions of events. For example, for UK windstorm losses, the distribution of damages produced by a model could be compared to the distribution suggested by Christophides et al in the 1992 GISG paper known as "Storm rating in the 90's". Such a comparison is made later in this paper.

Validating the insurance module.

This module is generally the simplest to validate, and the potential difficulties are relatively small compared to the other modules.

Purchase Multiple Models - Some companies will purchase numerous models in order to gain a better sense of the volatility in the estimates of expected costs by region for a given portfolio. While hard numbers are difficult to obtain, there is some anecdotal evidence that the models can, in certain circumstances, produce materially different results. In order to protect themselves from this parameter risk, some insurers simply purchase multiple models, or use one model on a regular basis and have an annual review of their exposures using another vendor.

Build Your Own - Some insurers and reinsurers have determined that they should get around these problems by building their own model so that they can control the assumptions underlying them. This option is not only expensive and time consuming, but these models tend not to have as much specialised academic research supporting them and there is still no guarantee that those making the decisions from the model output will have a better understanding of the workings of the model than they currently have of external service providers models.

Validation Summary

None of these validation options are perfect, and they can be frustrating to actuaries and others wishing to incorporate all the information available into their business decisions, but are nevertheless wary of the mechanisms used in these models to incorporate this information.

Types of Model Output

There are essentially two types of outputs to these models, deterministic and probabilistic. In this section we will review these two types of output as well as overview the basic process generally used in model construction.

Deterministic - Deterministic output is generally used to perform "what if" scenarios and to model actual events. This type of output generally gives a loss value for certain types of events. For example, one might ask, what would be the cost of a Category 4 windstorm that hit Long Island, or, what would happen if the Thames barrier fails, or 90A occurs again. This type of output has a number of uses. It can help the management of a company understand the impact of an individual event or change in policy, if for example management was contemplating writing only highly protected risks in a certain region and they would like to know how their largest loss would have differed had they a similar premium volume, but they were all highly protected risks. In *this instance a deterministic scenario could be very useful.*

Deterministic output is generally used in two ways. First to understand the magnitude of potential nightmare scenarios, and second, to calibrate the models from actual events and ensure that the models damage module is working properly.

Probabilistic - Deterministic output's primary failing is that it cannot assist the user in assessing the value of 1 in 50, 1 in 100 or 1 in 200 year events. This generally requires probabilistic output. This estimates the amount and probability of different types of loss and can therefore give estimates of loss amounts at different probability levels. This type of output is of more use to an actuary attempting to understand the expected cost of loss, as well as the probability of ruin or the probability of blowing different types of reinsurance programmes.

Understanding Model Differences

Conceptually, catastrophe models have simple designs. However, in practice, catastrophe models are intricate models with thousands of assumptions.

Why do loss costs and PMLs from the different catastrophe models produce different results? If different models produce very different results it is clearly important to try to determine what is the cause of the difference.

The use of unit uniform portfolios can help to determine whether the difference is geographical, whether it is due to the use of different damage curves, or some other reason. If one of the models allows the user to enter her own damage curve, then this will clearly make it easier to remove this source of difference between models.

Even if the cause of a difference is found, it may not be possible to determine which model is the more correct as the validator may not have the expertise to make this judgement.

Let's look at the sources of variability by module.

For the science module, basic information regarding historical parameters are obtained from public sources. Hurricane parameters are available from sources such as the National Oceanic and Atmospheric Administration (NOAA) and the National Weather Services. Earthquake information is available from sources such as the US Geological Survey. The difference in probabilistic modelling comes from the interpretation of this information and the simulation of hypothetical events. For example, scientists disagree on the probability of severe hurricanes hitting New England or the return period of a severe New Madrid earthquake.

Academic research groups like the Risk Prediction Initiative (RPI) are funding research to tackle such issues as geographic landfall probabilities, interdecadal weather patterns, and global warming. This type of research and academic interaction may promote some form of consensus among the science communities. The Risk Prediction Initiative is a program of the Atlantic Global Change Institute at the Bermuda Biological Station for Research. The goal of the RPI is to provide a rapid and up-to-date connection between the science of environmental prediction and parts of the business community that are affected by environmental change and catastrophe.

The damage factors underlying the engineering module use a multitude of sources. However, a number of studies form the backbone of these modules. The wind studies include work done by Don Friedman (Travelers), J H Wiggins company, Army Corps of Engineers, Federal Emergency Management Administration (FEMA), and a number of academic studies at major universities. The earthquake studies include work done by Applied Technology Council (ATC), Earthquake Engineering Research Center, California Department of Insurance, and a number of academic and professional studies. Each of these studies, along with professional judgement, are used to form damageabilty curves. Professional judgement may be used to separate damage functions by coverage or construction. As was seen in the study of wind damage factors by the Florida Commission on Hurricane Loss Projection Methodology, damage factors vary considerably by modeler, especially by coverage. The insurance industry needs to retain and aggregate catastrophic damage information to provide validation data for regulators and modelling sceptics.

What do we do when different models produce different results? Do we take the average? Do we take the higher as this is more prudent? Does it depend on what we are using the output for - purchasing or selling reinsurance? How do we determine which model we have more faith in?

There is hope for the future. Recently, the Insurance Services Office, Inc. (ISO) enhanced its statistical plan to include building height and more detailed building construction descriptions. The Insurance Institute for Property Loss Reduction (IIPLR) has started a catastrophe database that could someday be used to verify the coverage damage factors. The IIPLR has also created a detailed claim form to help insurance companies and engineers learn more about wind damage and talk the same language.

The variation in catastrophe models due to the insurance modules is minor in potential variability compared to the science and engineering modules.

Additional research within the science, engineering, and insurance communities should bring catastrophe modelling closer together now that these communities have begun to understand the assumptions inherent in catastrophe models.

Section 3.2

There are a number of commercially available models. They cover a variety of perils and regions. While this list of models is not complete, we felt that it does represent a valuable overview of some of the models available.

Provider	CARtograph	EQECAT	Ventech Systems
Model	3 Models	USWind USQuake UKWind UKFlood	VENTECH
Clients	Primary insurers, reinsurers, brokers, Lloyd's syndicates	Axa Re Cat Limited NAC Re Renaissance Re Swiss Re	NIG Skandia Four more under development
Cost	£50,000 ($81,000) - £150,000 ($234,000) per year - varies on application	Priced on application	£65,000 ($105,300) - £300,000 ($486,000) per year - varies on application
Hardware details	PC Driven, Windows 95, Windows NT, Pentium Processor; all common databases can be imported and converted	PC-driven, varies for each model	UNIX, information can be transferred onto PC
Regions covered	Comprehensive throughout US, UK, France, Germany, Italy Mexico, South America, Puerto Rico, The Caribbean, Japan, Australia, New Zealand[1], Turkey[1], Miami[1], Lisbon[1], Tokyo[1], Mexico City[1], Los Angelos[1], Northern Europe 1 under development	Comprehensive throughout US, UK, Europe, Central and Southern America, Asia, Australia, South Africa, Indonesia, The Caribbean	England, Scotland, Wales
Perils covered	Fire, flood, winter freeze, subsidence windstorm	Earthquake, fire, flood, subsidence, windstorm, winter freeze	Flood, subsidence, windstorm
Guarantees for accuracy	Includes calculations of margin of error	Includes calculations of margin of error	Currently analysing predictable accuracy
Distinguishing features	Provides systematic vulnerability assessment capable of classifying 42 different buildings type structures to postcode level Can use historical events or hypothetical for hazard analysis	EQE International's engineering specialist background combined with Guy Carpenter's reinsurance and insurance expertise accounts for the necessary technical and practical knowledge for top-notch product Integration with Travellers Model, with access to loss experience data from 58 hurricanes since 1958	Has an exclusive marketing arrangement with Cranfield University to obtain the soil analysis data carried out by the Soil Survey and Land Research Centre dating back 50 years Providing soil data 100m x 100m resolution

Provider	Risk Management Solutions	Applied Insurance Research	Tillinghast-Towers Perrin
Model	Aggregate Loss Model Detailed Loss Model	CATMAP CATRADER CIAS/CLASIC	TOPCAT
Clients	American International Group American Re-Insurance Company Mid Ocean Reinsurance The Prudential Insurance Company of America SCOR Swiss Re America	Primary insurers and reinsurers	Insurers, reinsurance, large corporations, pools, and insurance departments
Cost	$10,000 - $1,000,000 per year - *varies on application*	Dependent on size, usage, and perils analysed	Dependent on scope of project
Hardware details	PC-based or Client server	Pentium processor, CD-ROM, Windows NT, Windows 95; Depending on model used	Don't licence software, so no hardware requirements
Regions covered	Comprehensive throughout US, UK, Europe, Canada, Chile, Colombia, Netherlands, Indonesia, Jamaica, Japan, Mexico, New Zealand, Portugal, Puerto Rico, China[1], Hong-Kong[1], Pan-Caribbean[1], Philippines[1], Taiwan[1] 1. Under development	Comprehensive in US, UK, Europe Caribbean[1], Canada[1], Japan[2], Australia[2], New Zealand[2], 1. Available by end of 1997 2. To be release in 1998	Comprehensive throughout the US, Japan, Australia, Canada and the Caribbean, and more under development
Perils covered	Fire following earthquake, flood, earthquake, hailstorm, theft, windstorm	Earthquake, fire following earthquake, flood[3] hail and *other windstorms*, hurricane, tornado 3. Under development for UK	Earthquake, fire following earthquake, tornado, winter storm, windstorm
Guarantees for accuracy	*Includes calculations of margin of error*	*Includes calculations of* margin of error	Includes calculations of margin of error
Distinguishing features	Independent company Large client service team: one person for every three clients Invests 25% of revenue into R&D	provides real-time loss estimates within 12 hours of a land falling hurricane Has the longest track record for providing accurate loss estimates	Has *a unique peer review* process to ensure clients needs are being met Has extensive insurance knowledge and expertise

Section 3.3

Underwriting Catastrophic Exposures

The objective of this section of the paper is to give a brief description of the practical aspects of underwriting catastrophe exposures in the insurance market. We look at underwriting from both an insurers and a reinsurers perspective. Whilst there are a number of underwriting criteria that will apply to both insurers and reinsurers, there will also be a number of different considerations from each perspective that we attempt to highlight below. This paper covers underwriting issues at a very general level. In practice, the wide range of policies available will command different underwriting treatment. The underwriter will always need to be flexible in his approach.

3.3.1 The Insurer's Perspective

An insurer may have a book of thousands of homeowners policies. Every day the company will have to deal with transactions on current and new business. Most of these policies can be rated based on a standard questionnaire, designed by the insurer, and filled in by the applicant. Discounts or additions may be added to predefined rates if the details of a particular insured require this. Less standard risks will involve more attention and perhaps a more experienced underwriter to determine the appropriate rate. Ignoring the influence of State or Government legislation, the insurer has much more control over the risk and the price paid for the insurance than the underwriter.

Intervention from governing bodies is discussed briefly below.

Commercial policies are likely to be less standardised in general but the same underwriting considerations will be applicable.

Rating Factors

There are numerous rating factors that can be used to rate homeowners business. Some of these are particularly applicable to assess the potential exposure to catastrophes. As for most types of business, the company has to recognise which of these factors should be used for rating from a practical perspective. One of the easiest factors to measure is the post code or zip code. The address will immediately identify property exposed in quake, wind, or flood prone areas. Different constructions suffer very different levels of damage in the event of a catastrophe. For example, the shape of the building, the type of roof, the construction material, the age of the building, the proximity of other buildings will influence the extent of the damage. It will not be practical to account for all these issues in practice. In some cat prone areas, minimum construction requirements have been put in place. In this case, the age of the building is a particularly useful rating factor.

Deductibles play a very significant role in the pricing of cat risks. Increasing the deductible will help turn an unmarketable rate into one which seems to be much more affordable to the insured.

Aggregate Monitoring

Monitoring of exposures by territory is very important for both insurers and reinsurers. This aspect is discussed elsewhere in the text Assessment of total exposure by cat prone zones is vital to ensure that the company can afford to pay loss costs in a realistic worst case scenario. Simply summing total insured values will not provide a realistic estimate. Severe catastrophe events will not cause a total loss from each and every property in the portfolio and so using total insured value is likely to significantly overstate the true exposure. The company will need to get a handle on the PML (probable maximum loss) from each risk. This can be expressed as a percentage of the total sum insured for a particular building. Catastrophe models are useful tools in such an exercise. The losses from a 1 in 100 year loss (99% percentile) or a 1 in 250 year loss could be compared to the total sum insured to get an approximate percentage. The greater the degree of conservatism required the higher the point on the distribution will be used for the PML. The user of the model will, of course, need to be confident in the results. The black box characteristic of these models was discussed above. Such results should not be accepted blindly.

In cases where there are no models and to help substantiate model results, the underwriter may have a "rule of thumb" PML percentage that will be used.

Aggregate monitoring will be an onerous task for the insurer from an IT perspective. Simply managing the numbers of policies, recording the relevant information and validating this information will be a very time consuming exercise.

Influence from External Bodies

Rating agencies are currently putting a strong emphasis on the need to monitor catastrophe aggregates and the use of models for this exercise. Companies are therefore spending more and more time and money analysing and validating the different models. From a corporate perspective the creation of teams responsible for the smooth running of regular aggregate monitoring reviews is becoming more and more common.

Regulators from the different states in the US will often intervene with respect to rate setting. Since in some states the Insurance Commissioners must both stand for election on a regular basis and must approve all increases in rates before they go into effect, there is a tendency in some insurance departments to suppress rate levels in order to maintain popular support. Since these models generally produce indicated rate levels that are much higher than those that are currently in effect, state insurance departments have been reluctant to accept these indications.

Outwards Reinsurance

The amount of business the insurer can afford to write will be influenced by the outwards program in place. The company will be concerned about the net retention after a given event. From the opposite perspective, the diversity of the book, the adequacy of the rates and the thoroughness of the underwriting will also effect the availability and cost of the outwards program.

3.3.2 The Reinsurer's Perspective

A reinsurer's property book of business can show very volatile experience in terms of loss ratio and return of capital over a period of several years. For cat free years, the profit made should be exceptionally high compared to, for example, a proportional casualty book. The higher the layers the reinsurer participates on, the higher still is the volatility of the results. The underwriters objective is to ensure that the rates the business is written at are adequate to make, over a period of time, the required return.

Transacting Business

Consider a scenario where broker X approaches underwriter Y with a new property submission. There are a number of factors that the underwriter must either quantify or qualify before assessing or setting the rate.

What territories does this contract cover?

Reinsurers see a wide variety of territorial scope on the different submissions: World-wide, US Nation-wide, Europe, Pacific Rim, a single country or even a single state in the US. There has been a recent increase in the number of Special Purpose Insurers (who insure property in Florida only, for example). The underwriter will want to ensure that the property book remains diversified and that it is not over-exposed to any one region. For example, additional quake cover in California to a book which is already heavily weighted to that region would be undesirable.

Monitoring of Aggregate Exposures

Monitoring of aggregate exposures is an important exercise for the reinsurer as it is for the insurer. This will enable the underwriter to measure where the company has more capacity available and where further exposure could prove costly in the event of a cat. With the use of an appropriate model expected losses for a given portfolio can also be assessed. Taking into account the outwards protection of the company, the maximum loss the company wants to support can be used to help set limits on the aggregate exposure.

Aggregates should be recorded by country and by 'zone' for the most cat prone zones. If earthquake cover, wind cover and flood cover can be identified separately, then these should be measured separately. In practice, this is often difficult as many contracts will cover both quake and wind.

Aggregate exposure can be easier to measure in some cases than others. The maximum exposure for excess of loss contracts with limited reinstatements is simply:

limit * (number of reinstatements + 1) * signed line

Per risk excess contracts and proportional contracts may have occurrence limits. In this case, the aggregate is simply this limit * signed lines. For example, a risk excess contract may be structured as follows:

Cover	£1.0M
Deductible	$1.0M
Reinstatements	4
Event Limit	$2.5M
Signed line	100%

In this case the non-catastrophe aggregate exposure is $5.0M, but the limit in respect of a single catastrophe event is limited to $2.5M.

For unlimited contracts, the reinsurer needs to use a PML figure in a similar way to the insurer. For some countries it is particularly difficult to get an indication as there are no established market "rules of thumb" , nor are there adequate simulation models available.

Monitoring aggregate exposure from LMX business (or Retrocessional business) is a very difficult exercise. Market standard questionnaires summarise the aggregates for a particular syndicate. This information may be used as a base for assessing the aggregate exposure to the reinsurer but is in no way an exact science. Different companies will have their own approximate methods of calculating this exposure.

Underlying Business

Another important factor is the type of underlying business. Is it personal or commercial property? Is the business mobile homes only, for example? For all reinsurance business, it is vital that the reinsurer knows and understands the underlying business. For example, the line of business, the deductibles used, etc. The extent to The question on underlying business is important in terms of maintaining a diversified portfolio. Also, when considered in conjunction with the territory the underwriter will be able to judge how cat prone the business is, whether this class is currently generally over or under priced, whether there are any state/ government rules that will effect the cover. For example, in the Caribbean, there are minimum construction requirements that have to be met before the owner is able to purchase reinsurance. The reinsurers cover will therefore be very different from a property account where the government plays no role in Homeowners insurance.

Historical and future planned changes in the make up of the book is also an important consideration.

The Cedant

The underwriter will need a minimum amount of information about the cedant. The cedant may be a large reputable company who already deals with the reinsurer through other contracts. The underwriter may have already met members of management and underwriting teams. Alternatively, the company and its underwriting ability may be unknown to the reinsurer. The extent of the reinsurers confidence in the cedant will have a significant influence on whether the business is written. In particular, this may be the overriding factor in a soft market. Rates in a soft market are very rarely adequate to cover expected losses plus profit loadings. The reinsurer will not want to reject all new and renewal business however because of the costs and difficulty associated with regaining this business once the market hardens again (usually after a major catastrophe). A cedant who can show they have a thorough underwriting team, who take significant measures to limit their losses from catastrophes and who are prepared to "ride the cycle" with the reinsurer are likely to be a more reliable write. In a hard market, the reinsurer is in a much stronger position in respect of being able to increase rates or change terms, whoever the cedant. The submission will generally contain current underwriting procedures and strategy, future plans for the business and historical profitability. Other sources of information will be the report and accounts and meetings directly with the management.

Quantifying the Rate

The underwriter may then turn to measuring the adequacy of the rate. If a suitable model is available and the cedant provides the appropriate data then the model may provide an estimate of pure expected losses. Different models calculate expected losses in different ways as discussed earlier in this paper.

Loadings for profit and expenses should then be added to the pure loss cost. If the model is stochastic, the standard deviation of the resulting distribution of losses may help indicate a suitable profit loading. Different companies will have different ways of dealing with profit loadings.

There may be no suitable model available. The next section covers a number of rating methods that could be used in such a case.

Other Sources of Information

One source of information is CRESTA (Catastrophe Risk Evaluating and Standardising Target Accumulations). This is a summary of historical cat information collated and distributed by Swiss Re, Munich Re and Gerling-Konzern Globale Re.

Another source is the market survey reports from Axco Insurance Intelligence Services Ltd. These reports also include details of Government control and legislation in the insurance markets, information on the economy and details of reinsurance arrangements as well as historical cat losses.

Practical Influences

The underwriter will also be aware of the current rates that are available in the market for a given area and attachment point. This will help the underwriter to identify whether the deal is relatively good or not.

3.4 Simplistic methods used in rating

It may not always be practical to use a sophisticated software package to estimate the catastrophic loss potential. There are many reasons for this including:

- Software packages may not exist for the territory being rated
- The data provided may not be in sufficient detail to be entered into such a model
- A treaty may cover exposures in several territories.
- There may not be a sufficient volume of business in a given territory to make the leasing or purchase of a software model commercially viable.
- The catastrophe exposure may be a small proportion of the total exposure.
- A reinsurance underwriter may be a "follower" and will not be setting the rates, so will mainly be interested in verifying that the rates to be charged are reasonable.

In such circumstances approximate methods are often used by underwriters to price the catastrophe exposures. We will examine some of the rules of thumb which we understand may be applied in the market.

Simple methods include:

1. Frequency/severity models
2. Market share methods
3. "As if" burning cost using historical losses
4. Wind speed and damage ratio tables
5. Comparison with historical catastrophe premium rates.
6. Subjective judgement about return periods.

3.4.1 Simple Frequency/Severity models

Simple distributions for the severity component, such as the Pareto or Exponential, are sometimes used.

This is the kind of model that is often used in model office packages such as GISMO (See GISG 1996).

The actual severity distribution of losses is a complex compound distribution. The distribution is a conjugation of the severity distribution of events (i.e. the amount of energy released), the distribution of amounts of property damage for a given event severity, the distribution of insured losses for a given level of property damage, and so on.

We then need to determine an appropriate frequency distribution. A Poisson distribution is often selected.

However, the use of a Poisson distribution implies that the events are generated by a Poisson process, which implies that events are independent. It could be argued that the physical conditions which generate an event may indicate that a Poisson process is not appropriate. For example, some climatic conditions which may affect the frequency of hurricanes, such as El Nino events, may persist after the occurrence of particular hurricane, so that the probability of further hurricanes remains higher or lower than average. Conversely, after an earthquake has occurred which releases the stress along a fault, the probability of further quakes at the same location may decrease. A different distribution may be more appropriate. The negative binomial distribution, for which an interpretation of one parameter is of a measure of "contagion" may be appropriate.

An example:

In 'Storm Rating in the Nineties' from GISG 1992, an analysis of UK windstorm experience led to the following frequency/severity parameters being selected:

Frequency	Poisson, parameter 0.634 = 45/71
Severity	56% of events are below 0.14 per mille - uniformly distributed on 0 to 0.14
	44% are above 0.14 per mille - European Pareto, scale = 0.14, shape = 1.26

An example:

At the GISG 1996 Catastrophe modelling workshop, and the April 1996 London Market Actuaries Group Andrew Hitchcox provided the following statistics which were said to represent an approximation to typical output of a UK windstorm catastrophe model (EQECAT's UKWIND).

Return Period	Cost / Total Sum Insured
20 years	1.0 per mille
100 years	2.5 per mille
500 years	4.0 per mille

We interpret this to mean that the probability of a loss at least as great as 1.0 per mille has a 5% annual probability. The above figures imply that the severity distribution is exponential. It is relatively simple to calculate the parameter.

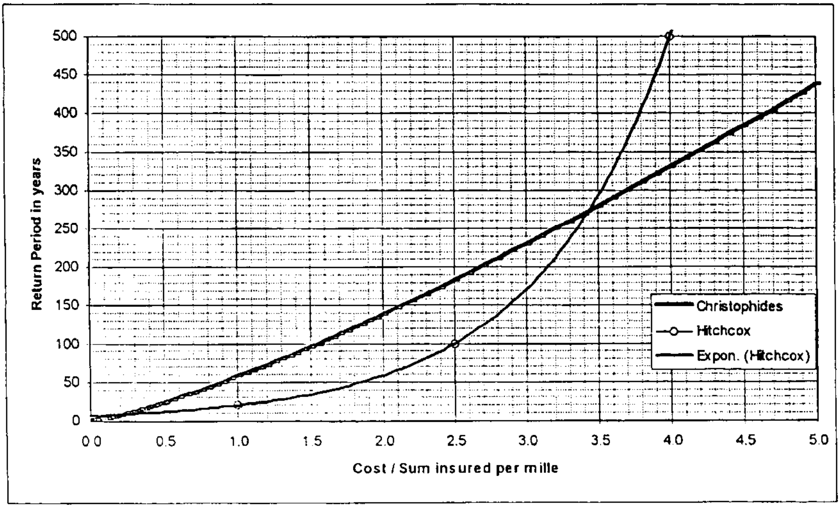
The 500 year return period Cost/ TSI is less reliable than the other points. Therefore we could try fitting other distributions, such as a Pareto, which passed through the first two points, but give a different Cost/TSI figure for the 500 year event.

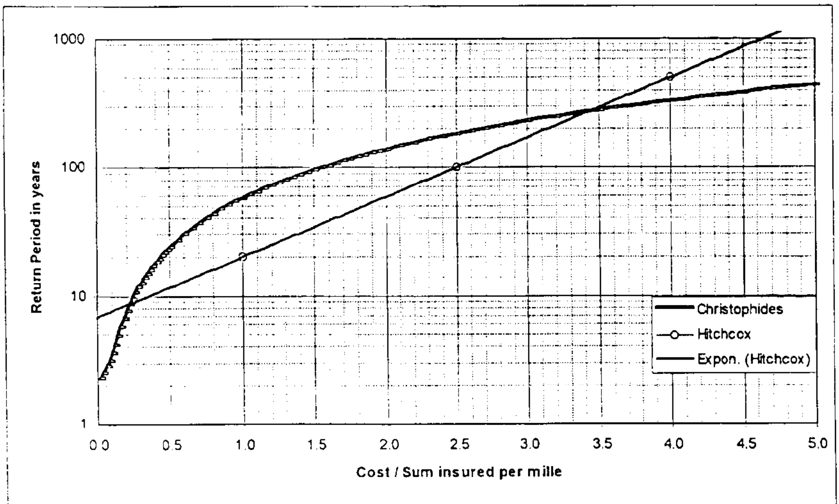
It is then relatively simple to use the resulting distribution to calculate mathematically the expected loss costs for a given catastrophe excess of loss contract. When this was done in practice it was found that the expected loss costs produced were generally 25-30% of the actual premiums charged for each layer of several UK insurers' catastrophe 1996 programmes when the possibility of more than one loss in a year, and the cost of reinstatements, was ignored. The difference may be partly explained by the exposure to catastrophe losses other than windstorm, and of course loadings and profit margins in the reinsurance premiums.

The same method may be appropriate for other territories and hazards. The main problem to be solved is the selection of the parameters.

For some catastrophes the frequency/severity approach may be the only one appropriate. For example, the extraterrestrial risk can only be handled in this way.

The graphs below compare the frequency/severity distributions described in the two examples above. The line labelled Expon. (Hitchcox) is the exponential trendline fitted to the data points quoted above.





3.4.2 Market share

In this method the underwriter will postulate the market size of loss for future catastrophic losses. The size and frequency of future market losses may be estimated based on the size of historical market losses after adjusting for factors such as inflation and changes in market exposures. The size of loss to the reinsured for a given catastrophe will then be estimated by applying their market share to the postulated market loss.

The underwriter will need to make judgements about how relevant historical losses are to the future due to changes in market share, and geographical concentrations of market share.

3.4.3 "As if" using historical losses

This is simply experience rating. It will be most appropriate in territories where there is sufficient historical experience to draw on. The underwriter will make adjustments to allow for changes in the underlying business and policy conditions which may influence to expected loss.

The amount of each historical catastrophe loss in the database of the reinsured will be inflated to present day monetary values using an appropriate inflation rate, and adjusted to allow for the level of exposure which generated the loss (e.g. policy years). The losses can then be applied to the proposed reinsurance program to determine what recoveries would have been made. The total amount recovered from each layer will then be divided by amount of exposure which generated these losses (e.g. the number of policy-years). This will give an expected loss cost to the layer per unit of exposure. The rate to be charged for the forthcoming exposure period can then be determined. This may be adjusted to allow for residual trends in the "as if" loss experience after the known quantifiable risk factors have been allowed for.

Clearly there are serious drawbacks to this method. The main assumption being made is that historical loss experience is a reliable guide to future loss experience. The rate determined in this manner will depend very much on the experience and skilfulness of the underwriter. This method requires there to be a sufficiently credible database of losses. A particular drawback of this method is that it can't be used to determine appropriate rate for coverage higher than the "as if" loss in the database.

3.4.4 Wind speed and damage ratio tables

For some territories, notable the Caribbean, there are wind speed and damage ratio tables available. The underwriter can estimate the expected loss cost by using the figures contained in these tables. This method is similar to the operation of some of the software windstorm models.

3.4.5 Comparison with historical market rates

This is the simplest method of all, and is not rating as such, but merely compares the rates for the forthcoming period with those charged in the past. This method is used in conjunction with the loss experience in the past. If a reinsurance programme has produced a profit over the past 5-10 years such that the accumulated profit is more than the coverage being given in the coming year, then it is not unusual to see the rates being charged decrease. This implicitly assumes that the rates have been too high in the past and thus should be reduced. When a loss does occur the reinsurance rates may tend to increase again. This will tend to create a cycle in rating levels.

3.4.6 Subjective judgement

For non-CatXL treaties a method often used is to add a loading to the expected loss cost derived from the analysis of the non-catastrophic experience. The loadings applied are sometimes subjectively selected with little, if any, attempt at quantitative justification.

Proportional treaties often include event limits. These limit the amount of the claims that may be recovered from the treaty in respect of losses caused by a catastrophic event. When rating such treaties it is often assumed that a catastrophic loss will breach the event limit. The expected annual cost is then calculated as the event limit divided by the return period, which is often judgmentally selected, of such catastrophe losses. Proportional treaties are often rated using return on capital methods. The expected catastrophe loss cost can be easily factored into the return on equity calculation.

An example:

Expected treaty premium	£1,000,000	
Event limit	£2,000,000	
Estimated return period	20 years	
Expected Cat losses	£100,000	£2M / 20 years
Expected non-Cat loss ratio	50%	from analysis of experience
Expected Cat loss ratio	10%	£100,000 / £1,000,000
Total expected loss ratio	60%	50% + 10%

A similar method may be applied to non-CatXL excess of loss treaties.

3.4.7 Uninsured losses

Actuaries are trying to assert their expertise in the field of producing and using catastrophe models as part of the management of insurance entities. However, much of the property damage caused by catastrophic losses is uninsured. This is partly because much of the damage occurs in the developing world, where people may not be able to afford insurance. However, there is a great deal on uninsurance in the most developed countries. For example, it is estimated that only 3% of the households affected by the Kobe had bought earthquake insurance. Furthermore, insurance cover may simply not be commercially available for some hazards.

The following table shows the insured and total economic cost of major natural catastrophes in the past 36 years as shown in a report by Munich Re this year.

Decade	1960-69	1970-79	1980-89	1987-96
Number	16	29	70	64
Economic Losses	48.4	93	147.6	404.4
Insured Losses	6.5	10.9	29.8	98.8
% Insured/Economic	13%	12%	20%	24%

Figures are US$ Billions in 1996 values.

Source: Munich Re

An example of the significance of the uninsured cost is the 1996 Yangtze River flooding in China. The economic loss is estimated to be more than US$20 Billion, of which only $0.4 Billion (2% of the economic cost) was insured.

Also, a large proportion of the damage caused by a catastrophe will be within the public sector, such as damage to roads, schools, hospitals, council offices, and so on. Although there may be some coverage of these from commercial insurance, large retentions are likely to be in place, so the aggregate loss would still be large.

It is the view of some members of the working party that the actuarial profession should get involved in the modelling of catastrophe losses for bodies other than insurance entities.

There are several bodies who would appear to have an interest in obtaining estimates of the potential losses caused by natural catastrophes, including:

- International governmental organisations

Bodies such as the UN take an active role in disaster relief via bodies such as the United Nations Disaster Relief Organisation (UNDRO). Catastrophe models allow such organisations to budget for their potential outgoings in advance, so that it is less necessary to make cash calls on member states when disasters do occur.

- National governments

Catastrophic losses would have an impact on the economy of a country. In the short term this may require more borrowing to finance the repair of major infrastructure. The effect on the economy in the longer term is more ambiguous, as the demand for labour and materials to repair the damage may result in an overall growth in economic activity. When damaged buildings and infrastructure are replaced this may make use of more modern technologies and designs which may result in efficiency gains.

The improved frequency and severity quantification of potential damage produced by the models will allow governments to use cost-benefit analyses to determine national policies on disaster mitigation, such as the level of central funding required to improve sea defences.

The national government also needs to consider to what extent the regions affected by a catastrophe should be expected to fund the cost of repairs to infrastructure such as roads and schools. Where regions are expected to carry a significant share of repair costs, then an actuarial approach to the building up of contingency funds out of local taxation may be appropriate.

- Regional governments

The regional authorities will generally be affected in many ways. Buildings will be damaged in much the same way as occurs in the private sector. However, the local government may also be responsible for repairing damage to roads, schools, hospitals and other public sector buildings. Also, public areas such as parkland or the coastline may suffer damage. In the aftermath of a catastrophe many of the affected population may have suffered financial losses and may not be able to easily pay increased levels of local taxation. Also, the emergency services are likely to have expended more than normal in the period following a disaster.

- Disaster Relief organisations

These organisations are generally more interested in the numbers of people who will be injured and made homeless following a disaster, rather than the amount of property damage. However, there does not appear to be any great difficulty, in principle, from converting models which apply damage ratios to property values to models which apply a damage ratios to populations.

- The construction industry

In the aftermath of a disaster reconstruction contracts may tend to be awarded to those companies who have the resources to do the job immediately. It may become a sellers market for construction, and so large profits may be possible to those companies who have the spare capacity to provide the labour at once.

A rapid assessment of the extent of damage would allow companies that produce building materials to gear up their production levels to appropriate amounts. If they produce too much material they may find that they have large unsold stocks left over once the majority of the reconstruction is completed. If they produce too little then they risk losing out on the large profits to be made in the sellers market.

- Investors

In the aftermath of a disaster the value of some companies' shares and bonds decreases, whilst those of others will tend to increase. For example, we may expect the steel and construction industries to perform better than average as their products are used in the reparations. Insurance company shares may decline in value. Many share deals will take place in the few hours following the event and prices may be rather volatile in this period. Companies whose only, or main, offices and factories were in the affected area may suffer business interruption, and their value may fall. Companies located just outside the affected area may benefit as they pick up business from competitors who were adversely affected. The effect may be more or less pronounced for companies who operate in several regions: what would happen if the office that was damaged contained a company's only mainframe computer holding all of the records?

An investor who was able to estimate reliably and quickly the potential effect of a catastrophic event would have the potential to make more objective reinvestment decisions.

3.5 The Future

Catastrophe models have become useful tools for many to start to assess the likelihood and magnitude of catastrophic events. As they continue to gain acceptance outside the US, more models will be developed and these models will play an increasingly significant role in shaping decision-makers' views on the types of risks they are taking on.

Quantification studies currently fall well short of ideal but represent a much more scientific approach to evaluating exposure and risk than was commonplace just a few years ago. Although the models are still developing, they represent the state of the art in catastrophe assessment because they are currently the best way to bring the meteorological, engineering, and insurance expertise to the problem.

1. References and reading list

General

K. Smith	Environmental Hazards: Assessing Risk and Reducing Disaster ISBN 0-415-12004-X
New Scientist	Various articles, including: Ice-cold in Paris (Oceanic Conveyor Belt) Electric Shockers (Quake prediction) And the Earth did swallow them up. (Liquefaction) Far out forecasting (Extreme Value Theory) When Volcanoes get Violent (Volcanic eruptions)
The Economist	Various articles, including: Nature rarely repeats itself (2/8/97) (Earthquake prediction) An Act of God (19/7/97) (El Nino)
Sterling Offices	Catastrophe Insurance for tomorrow: planning for future adversities.
Swiss Re	SIGMA, various dates.

Meteorology and Climatology

J. & M. Gribbin	Watching the Weather ISBN 0-09-476539-8
D. File	Weather Facts ISBN 0-19-286143-3
A. Gore	Earth in the Balance ISBN 0-452-26935 0
E.B. Jobe	Managing Hurricane Exposure American Re-Insurance 1994 publication
Munich Re	Windstorm Hailstorm
S. Christophides	Storm Rating in the 90's The Actuary , July and August 1993.
Ho-F and others	Hurricane climatology for the Atlantic and Gulf Coast of The United States, NOAA technical report NWS 38, April 1987
C. Neumann	The National Hurricane Center risk analysis program NOAA Technical memo NWS NHC 38, November 1987
McGuffie	A Climate modelling browser
Barry & Chorley	Atmosphere, weather & climate
M.L.Selby	Fundamentals of atmospheric physics
C. Roberts	Meteorology

Seismology

P. Hadfield	Sixty seconds that will change the world ISBN 0-330-34580-X

Dr. R. Muir Wood	Earthquakes and Volcanoes: causes, effects and predictions ISBN 0-85533-657-9
Strahler & Strahler	Modern Physical Geography ISBN 0-471-53392-0

<u>Cosmic Impacts</u>

J. & M. Gribbin	In search of the Doomsday Asteroid ISBN 0-684-81689-X
D.H. Levy	The Quest for Comets ISBN 0-19-286181-6
G.L. Vershuur	Impact! The threat of comets and asteroids ISBN 0-19-510105-7

<u>*Catastrophe models*</u>

Walters/Morin	Catastrophe Ratemaking Revisited (Use of Computer Models to Estimate Loss Costs) CAS 1996.
Reactions, *July 1997*	*Models are here to stay (list of catastrophe models in section 3)*
Contingencies Mar 97	Managing risk in the 21st century-computer modelling comes of age.

<u>Climate Change</u>

POST 9/1/97	Taking a global view
POST 14/11/96	Stormy Weather
ABI	Review of the potential impacts of Climate Change in the UK 1996
N. Calder	The Manic Sun ISBN 1-899044-11-6
J. Emsley	The Global Warming Debate
IPCC	Climate Change 1995: The science of climate change Cambridge University Press
J. Gribbin	Our Changing Climate
H.H. Lamb	The changing climate - selected papers

Table 1: The worst natural catastrophes in terms of insured cost, 1970-96

Event	Location	Date/start	Insured cost (US$'m at 1996 prices)	Fatalities (dead and missing)
Hurricane Andrew	USA	24-Aug-92	17,945	38
Northridge earthquake in southern California	USA	17-Jan-94	13,277	60
Tornado Mireille	Japan	27-Sep-91	6,420	51
Winter storm Daria (90A)	Europe	25-Jan-90	5,531	95
Hurricane Hugo	Puerto Rico	15-Sep-89	5,326	61
Autumn storm	Europe	15-Oct-87	4,151	13
Winter storm Vivian	Europe	26-Feb-90	3,844	64
Great Hanshin earthquake in Kobe	Japan	17-Jan-95	2,554	6,000
Hurricane Opal	USA	04-Oct-95	2,170	59
Blizzard over east coast	USA	10-Mar-93	1,906	246
Hurricane Iniki	USA	11-Sep-92	1,795	4
Tornado Frederic	USA	03-Sep-79	1,629	-
Hurricane Fran in the southeast	USA	05-Sep-96	1,600	39
Tropical cyclone Fifi	Honduras	18-Sep-74	1,595	2,000
Tropical cyclone Gilbert	Jamaica	12-Sep-88	1,481	350
Snowstorms, frost	USA	17-Dec-83	1,389	500
Forest fire which spread to urban area, drought	USA	20-Oct-91	1,386	26
Tornadoes in 14 US states	USA	02-Apr-74	1,373	350
Tornado Celia	USA	04-Aug-70	1,314	31
Flooding caused by Mississippi	USA	25-Apr-73	1,310	-
Loma Prieta earthquake	USA	17-Oct-89	1,270	63
Wind, hail and floods	USA	05-May-95	1,173	21
Storms over northwestern Europe	Europe	02-Jan-76	1,127	100
Hurricane Alicia	USA	17-Aug-83	1,065	20
Forest fire which spread to urban area	USA	26-Oct-93	1,035	3
Storms and floods in northern Europe	Europe	21-Jan-95	1,033	40
Storm Herta	Europe	03-Feb-90	1,003	28
Typhoon Yancy	Japan	03-Sep-93	976	47
Hurricane Bob	USA	18-Aug-91	970	13
Floods in California and Arizona	USA	16-Feb-80	954	36
Storms and floods	France	30-Apr-83	947	-
Winter storm Wiebke	Europe	28-Feb-90	919	15

Hurricane Marilyn	Caribbean,	14-Sep-95	904	108
Earthquake in Newcastle	Australia	28-Dec-89	885	11
Storm, hail, tornadoes in Oklahoma and Texas	USA	28-Apr-92	852	-
Freezing weather and snowstorms on east coast	USA	17-Jan-94	850	-

Source: Swiss Re, isigma no. 3/1997

Table 2: The worst natural catastrophes in terms of fatalities, 1970-96

Event	Location	Date/start	Insured cost (US$'m at 1996 prices)	Fatalities (dead and missing)
Tropical cyclone	Bangladesh	14-Nov-70	-	300,000
Earthquake in Tangshan	China	28-Jul-76	-	250,000
Tropical cyclone Gorky	Bangladesh	29-Apr-91	-	140,000
Earthquake	Peru	31-May-70	-	60,000
Earthquake	Iran	21-Jun-90	139	50,000
Earthquake in Armenia	Former USSR	07-Dec-88	-	25,000
Earthquake	Iran	16-Sep-78	-	25,000
Volcanic eruption Nevado del Ruiz	Columbia	13-Nov-85	-	23,000
Earthquake	Guatemala	04-Feb-76	207	22,000
Earthquake	Mexico	19-Sep-85	471	15,000
Flood	India	01-Sep-78	-	15,000
Flood	India	31-Oct-71	-	10,800
Tropical cyclone	Bangladesh	25-May-85	-	10,000
Tropical cyclone	India	20-Nov-77	-	10,000
Earthquake in Maharashtra	India	30-Sep-93	-	9,500
Earthquake on Mindanao	Philippines	16-Aug-76	-	8,000
Typhoons Thelma and Uring	Philippines	05-Nov-91	-	6,304
Great Hanshin earthquake in Kobe	Japan	17-Jan-95	2,554	6,000
Earthquake	Pakistan	28-Dec-74	-	5,300
Earthquake in Fars	Iran	10-Apr-72	-	5,000
Earthquake in Managua	Nicaragua	23-Dec-72	378	5,000
Earthquake	Indonesia	30-Jun-76	-	5,000
Earthquake	Italy	23-Nov-80	-	4,800
Earthquake	Algeria	10-Oct-80	-	4,500
Storm and snow	Iran	15-Feb-72	-	4,000

Earthquake in Van	Turkey	24-Nov-76	-	4,000
Floods in Punjab	Pakistan	08-Sep-92	-	3,800
Tornado	Réunion	04/16/78	-	3,200
Flood	Bangladesh	01-Aug-88	-	3,000
Earthquake	Iran	11-Jun-81	-	3,000
Earthquake	Yemen	13-Dec-82	-	2,800
Floods in northern provinces	Bangladesh	31-Jul-74	-	2,500
Earthquake in Flores Island	Indonesia	11-Dec-92	-	2,484
Tropical cyclone	Bangladesh, India	29-Nov-88	-	2,300
Earthquake	Turkey	06-Sep-75	-	2,300
Tropical cyclone over southeast coast	India	06-Nov-96	-	2,000
Tropical cyclone Fifi	Honduras	18-Sep-74	1,595	2,000

Source: Swiss Re, sigma no. 3/1997

Table 3: Analysis of catastrophes by category, 1993-96

Type	Number	Fatalities (dead *and missing)*	Insured Cost (US$'m)
Flood	186	24,580	3,580
Storm	194	14,650	18,716
Earthquake (incl. seaquake/tsunami)	47	22,133	12,950
Drought, bush fire (incl. heat wave)	24	2,115	0
Cold, frost	31	1,626	4,446
Miscellaneous (incl. hail, avalanche)	31	1,221	2,010
All natural catastrophes	513	66,325	41,702
Man-made catastrophes	800	34,351	15,676

Source: Swiss Re, sigma nos. 2/1994, 3/1995, 2/1996, 3/1997

Table 4: Major UK weather incidents, 1970-93

Event	Date	Insured cost (£'m at 1994 prices)
Gales and floods nation-wide	Jan-76	213
Frost and snow nation-wide	Jan/Mar-79	200
Gales and floods, mainly in the west	Dec-79	73
Severe snow and freezing, followed by flooding	Dec-81/Jan-82	459
Gales, followed by snow and flooding, particularly bad in the north	Jan/Feb-84	289
Snow and freezing temperatures, especially bad in southern England	Jan/Feb-85	228
Gales nation-wide	Mar-86	81
Severe snow nation-wide, especially bad in southeast England	Jan-87	399
Hurricane force winds throughout the south and southeast of England	Oct-87	1,465
Storms and flooding across Great Britain	Jan/Feb-90	2,491
Snow and freezing temperatures, followed by flooding	Feb-91	203
Storms and flooding across Great Britain, particularly Scotland	Jan/Feb-93	192

Source: ABI Insurance Statistics, 1981-1993