ABI

Association of British Insurers

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SUMMARY REPORT

FINANCIAL RISKS OF CLIMATE CHANGE

climaterisk management

Metroeconomica
Economic and Environmental Consultants

An electronic copy of this report, along with supporting technical annexes containing further details of all methods and results, are available from: http://www.abi.org.uk/climatechange

The ABI publishes research that explores public policy and other issues relevant to the insurance industry and its customers. Dr Sebastian Catovsky in the Household and Property Team at the ABI managed this project.

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FOREWORD

Climate change is a key issue for the world in the 21st century. It will feature prominently in 2005, as the UK Government makes climate change one of its top two priorities during its Presidencies of the G8 and the European Union.

To contribute to the international debate, the ABI commissioned this new research to examine in detail how climate change could affect the costs of extreme weather in the future. It builds on our previous research by using insurance industry catastrophe models to quantify regional costs of climate change.

Insurance acts as a financial litmus-test for sustainability. Choices that society makes today will affect future costs. Insurance can help quantify these costs. The study focuses on the most costly aspect of weather today – extreme storms such as hurricanes, typhoons, and windstorms in the major insurance markets of the US, Japan, and Europe.

Our research shows that even quite small increases in the intensity of such storms, as predicted by the latest climate science, could increase damage costs by at least two-thirds by the end of the century. The most extreme storms could become even more destructive, leading to losses greater than we have seen before. Insurance markets could become more volatile, as the costs of capital required to cover such events increased.

Many of the potential costs described in this report could be avoided by taking action now. Decision-makers in government and elsewhere have a real opportunity to make rational choices for the future by taking account of the financial costs of climate change.

Nick Starling

Director of General Insurance

Association of British Insurers

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1. EXECUTIVE SUMMARY

Insurance is a messenger of the costs of climate change

This ground-breaking study uses insurance catastrophe models to examine the financial implications of climate change through its effects on extreme storms (hurricanes, typhoons, and windstorms). By publicising the results, the insurance industry is communicating the potential level of future risk arising from climate change, enabling governments, businesses and individuals to make rational decisions on whether and how to avoid these costs.

Climate change could significantly increase the costs of windstorm damage

Annual losses from the three major storm types affecting insurance markets (US hurricanes, Japanese typhoons and European windstorms) could increase by two-thirds to $27 bn by the 2080s.

Focussing on the most extreme storms (losses occurring once every 100 to 250 years), by the 2080s climate change could:

- Increase wind-related insured losses from extreme US hurricanes by around three-quarters to total $100 – 150 bn. This additional cost would be equivalent to two to three Hurricane Andrews in a single season (at 2004 prices).
- Increase wind-related insured losses from extreme Japanese typhoons by around two thirds to total $25 – 34 bn (¥2,700 – 3,700 bn). The increase alone would be more than twice the cost of the 2004 typhoon season, the costliest in the last 100 years.
- Increase wind-related insured losses from extreme European storms by at least 5% to $32 – 38 bn (€25 – 30 bn). This additional cost would be equivalent to the Martin storm in 1999, which cost $2.5 bn (€2 bn, 2004 prices).

Climate change could also increase costs of flooding, particularly in Europe

Climate change could increase the annual costs of flooding in the UK almost 15-fold by the 2080s under high emissions scenarios. If climate change increased European flood losses by a similar magnitude, annual costs could increase by a further $120 – 150 bn (€100 – 120 bn).

Increased losses could raise the cost of capital and increase the volatility of insurance markets

Under high emissions scenarios (where carbon dioxide levels double) insurers' capital requirements could increase by over 90% for US hurricanes, and by around 80% for Japanese typhoons. In total, an additional $76 bn could be needed to cover the gap between extreme and average losses resulting from tropical cyclones in the US and Japan. Higher capital costs combined with greater annual losses from windstorms alone could result in premium increases of around 60% in these markets.

Socio-economic factors could exacerbate climate change

These loss estimates do not include likely increases in society's exposure to extreme storms, due to growing, wealthier populations, and increasing assets at risk. For example, if Hurricane Andrew had hit Florida in 2002 rather than 1992, the losses would have been double, due to increased coastal development and rising asset values. Adaptive measures to limit vulnerability could prevent costs escalating.

Climate change impacts on other sectors could have financial implications

For other weather-sensitive sectors, like health and agriculture, the overall effects of climate change are likely to be mixed (some positive, some negative). But recent events have shown how harmful the impacts of extreme weather could be.

- Changes in the weather have already doubled the chance of a very hot European summer like 2003, when at least 22,000 people died prematurely.
- In January 2005 Sweden was hit by windstorm Gudrun, causing the largest insured loss ever for the country. Half of the costs comprised losses to commercial forestry ($0.25 bn or €0.2 bn).

Many costs of climate change could be avoided by taking action today

Reducing carbon dioxide emissions from a high to a low scenario would reduce the impact on losses and insurers' capital requirements for extreme windstorms by 80%. Flood risk across Northern Europe may only increase 2 – 4 fold in low emissions scenarios, saving $120 bn (€100 bn) each year by the 2080s.

Action to reduce society's vulnerability to some inevitable impacts of climate change, for example through more resilient buildings and improved flood defences, could also result in considerable, but targeted, cost-savings.

Policy appraisals should take account of extreme events

We need to understand the consequences of climate change to make informed choices about the future. Policy-makers should incorporate financial assessments of the impacts of climate change on extreme weather, as well as on average weather, in cost-benefit analyses of options.

We need to understand more about climate change and its financial consequences

Further studies are needed on climate change impacts where there is limited scientific consensus at present. This will enable further modelling of the financial costs arising from these effects. The effects on European windstorms and flooding are two areas of particular interest to insurers, where more work is needed.

2. CONCLUSIONS

2.1 Insurance as a messenger of the costs of climate change

Assessing the costs of climate change is a critical part of developing proportionate national and international policy responses to manage climate risks. Insurance relies on detailed assessment of weather and its costs in order to price risks and provide a viable risk-transfer mechanism. Insurance acts as a useful messenger of the financial costs of extreme weather, both today and in the future. This study examines these costs under high and low climate change scenarios, enabling a global assessment of impacts and the choices available to reduce them.

Scientific consensus suggests that climate change could increase both global temperatures and the amount of energy available in the climate system. As a consequence, the weather could become more volatile. Previous studies that place the cost of climate change at between 2 – 4% of global GDP by the end of the century take limited account of the costs of possible changes in extreme weather, even though extreme weather today costs $10 – 40 bn each year.

This study is one of the first to use insurance catastrophe models to examine the potential impacts of climate change on extreme storms. It focuses on one of the most costly aspects of today's weather – hurricanes, typhoons, and windstorms, because of their potential to cause substantial damage to property and infrastructure.

2.2 Climate change could significantly increase the costs of storm damage

Recent scientific evidence suggests that warmer temperatures could increase the severity of storms, but may not change the number of major storms forming. If carbon dioxide concentrations double relative to current levels (likely by the 2080s under high emissions scenarios),[1] windspeeds of Atlantic hurricanes affecting the US and typhoons affecting Japan could increase by around 6% compared to present. This could be the difference between a category 4 and category 5 storm (the most severe). For European windstorms, the science is more equivocal, but some evidence suggests that the number of the most severe storms could increase by up to 20%. There may be an impact on less intense storms, but these are not considered here, because quantitative information about the changes is still limited.

Under these climate change scenarios, total average annual damages from these three major storm types could increase by up to $10.5 bn above a baseline of $16.5 bn today, representing a 65% increase.[2] Around 60% of the increase in total damages ($6 bn) would be insured if insurance coverage does not change.

These costs would not be spread evenly over time, but would occur in a series of extreme storms. In some years there might be no storms, in others a few moderate storms, and in rare cases a very severe storm. Extreme losses that only occur once in 100 years to 250 years[3] could be affected by this doubling of carbon dioxide concentrations as follows:

- Insured wind-related losses from extreme US hurricanes could increase by $41- 62 bn above present-day losses of $60 – 85 bn, representing a 70 – 75% increase, which is equivalent to an additional two to three Hurricane Andrews in a single season (2004 prices).
- Insured wind-related losses from extreme Japanese typhoons could increase by $10 – 14 bn (¥1100 – 1500 bn) above present-day losses of $15 – 20 bn (¥1600 – 2200 bn), representing a 67 – 70% increase, which is more than twice the cost of the 2004 typhoon season, the costliest in the last 100 years.

1. For the purpose of this report the doubling of CO_2 refers to a 2.2 times increase. The emissions scenarios were developed by the Intergovernmental Panel on Climate Change (IPCC). No one scenario is more likely than another. For further details, please refer to the technical annexes at http://www.abi.org.uk/climatechange
2. For ease of comparison, all financial costs in this report are given in US $ (2004 prices), with local currency equivalents included where appropriate.
3. Losses with such return periods have a 0.4 – 1 % chance of occurring each year in each of these regions. As seen in 2004, different regions could experience exceptional weather in the same year.

- Insured wind-related losses from extreme European storms could increase by $2 – 2.5 bn (€1.6 – 2 bn) on top of present-day losses of $30 – 35 bn (€24 – 28 bn), representing a 5% increase. This increase excludes any flood costs. The additional wind-related costs are equivalent to the 1999 windstorm Martin, one of the most costly windstorms on record.

These costs underestimate the full potential impacts of climate change on future storm losses because:

- Changes in only certain aspects of storms were modelled. The costs of flooding associated with extreme storm damages through intense precipitation and storm-surges were not explicitly modelled despite evidence to suggest these will increase with climate change. Climate change could also change the frequency of tropical cyclones, or the intensity of less intense European windstorms, both of which could have significant effects on losses, but where the science is still limited.
- The impacts of socio-economic developments, which could substantially increase society's exposure to extreme storms, were not considered. Population sizes are growing and concentrating in urban areas, along with overall wealth, infrastructure and assets at risk. The costs of Hurricane Andrew, for example, would have been double in 2002 compared to 1992, due to increased coastal development and rising asset values. Of course, in some cases, socio-economic factors could reduce vulnerability, e.g. improved housing standards, but current trends of increasing exposures are likely to predominate in the future.

2.3 Climate change could significantly increase the costs of flooding, particularly in Europe, but the impacts need to be quantified better

Worldwide floods are currently the second costliest weather-related catastrophes after windstorms. In Europe, present-day annual average losses from flooding are greater than wind-related losses ($8 – 10 bn vs. $3 bn). In developing countries, particularly South East Asia, damages from flooding typically exceed those from wind damage.

Climate change will increase flood risk on the coast through rising sea-levels and storm-surge heights, inland through increases in seasonal rainfall, and in urban areas through increases in rainfall intensity (flash-floods).

In the UK, climate change could increase the annual costs of flooding by almost 15-fold by the 2080s under the high emissions scenario, leading to potential total losses from river, coastal and urban flooding of more than $40 bn (£22 bn). If climate change increased extreme European flood losses by a similar magnitude, annual costs could increase by a further $120 – 150 bn (€100 – 120 bn). However, more research is needed to quantify these costs more accurately.

2.4 Climate change impacts on other sectors of the economy could have further implications for financial markets

As well as causing damage to property, climate change could affect many other parts of the economy with direct links to the insurance industry. For the weather-sensitive sectors of health and agriculture, the overall effects of climate change are likely to be significant but mixed (some positive, some negative). But recent events have shown how harmful the impacts of extreme weather could be.

- Health and heatwaves. The European heatwave in 2003 resulted in huge increases in hospital admissions and over 22,000 premature deaths. Changes in the weather have already doubled the chance of a very hot European summer like 2003, and by the 2040s, more than half of all European summers are projected to be warmer than that of 2003.
- Agriculture and forestry. In January 2005 Sweden was hit by windstorm Gudrun, causing the country's largest ever insured loss. Half of the costs comprised damage to commercial forestry, affecting over 46,000 hectares (equivalent of 10 years' worth of fellings). Total forestry losses for the storm are currently estimated at $2.5 bn (€2 bn), of which $0.25 bn (€0.2 bn) was insured.

2.5 Increased losses from extreme storms and floods could raise the cost of financial capital, and increase the volatility of insurance markets, if not properly anticipated

Insurers need access to capital to smooth losses from infrequent, very severe weather. Under a high emissions scenario, where carbon dioxide concentrations double by the 2080s, insurers' capital requirements could increase by over 90% for US hurricanes, around 80% for Japanese typhoons, and at least 5% for European windstorms (excluding flood damage and the impact of climate change on less intense storms). In total, an additional $78 bn could be needed to cover the gap between extreme and average losses resulting from changes in the most extreme storms in the US, Japan, and Europe. Capital requirements within European markets are likely to increase further as a result of increases in costs of flooding.

These greater demands for capital could increase costs of capital for the insurance industry. Credit ratings could be affected, with agencies taking into account the increasing number of extreme storms and potential losses. The cost of capital could rise in a finite capital market; investors will demand higher rates of return for placing greater amounts of capital at risk, particularly if property insurance is seen as riskier than the alternatives.

If climate change increases both average losses and insurers' capital requirements, risk premiums could increase. Under the high emissions scenario, and ignoring socio-economic effects, an increase in the aggregate risk premium of 80% might occur for both US hurricane and Japanese typhoon insurance markets by the 2080s. The possible wind-related increase in the aggregate risk premium for European storm would be smaller at 15%, but likely to be higher if flood-related damages and possible impacts on less severe storms were included.

2.6 Many climate change costs could be avoided by taking action today

Many of these additional costs due to climate change could be reduced by taking action to manage the risks. Action to stabilise concentrations of carbon dioxide could reduce the potential impact of climate change on costs of extreme weather.

- Limiting carbon emissions (the low emissions scenario) would avoid 80% of the projected additional annual cost of tropical cyclones by the 2080s. Insured costs from extreme events (1-in-100 and 1-in-250 year losses) would also be reduced by 80%, saving $35 – 50 bn, roughly equivalent to avoiding two Hurricane Andrews in one season (in 2004 prices).
- The effect of this would be to reduce insurers' projected additional capital requirements for extreme storms by more than $60 bn by the 2080s, offering a saving of more than 80%.
- Flood risk across Northern Europe might only increase 2 – 4 fold compared with 10 – 20 fold under the high emissions scenario, offering potential annual savings of $120 bn (€100 bn) each year by the 2080s.

Action to reduce society's vulnerability to the inevitable impacts of climate change through adaptation would bring further benefits. Socio-economic factors have been a strong driver of changes in the costs of extreme weather in recent decades. Managing these effects could play a significant role in reducing society's exposure to weather in the future.

The financial benefits of adaptation were not modelled in this study, but considerable cost savings could be achieved.

- Strong and properly enforced building codes have been shown to prevent and reduce losses from windstorms. If all properties in south Florida were built to meet the strongest local building code requirements, damages from a repeat of Hurricane Andrew would fall by nearly 45%. If design codes for buildings in the South East of the UK were upgraded by at least 10%, increases in climate-induced damage costs from windstorms could be reduced substantially.
- Global damages from a 0.5 metre rise in sea-level have been estimated as $24 – 42 bn per year. Adaptation – in the form of coastal defences – could bring these costs down to $8 – 10 bn per year.
- In the UK, taking account of climate change in flood management policies, including controlling development in floodplains and increasing investment in flood defences, could limit the rising costs of flood damage to a possible four-fold increase (to $9.7 bn or £5.3 bn) rather than 10 – 20 fold by the 2080s.

2.7 Policy appraisals of options for tackling climate change should take account of extreme events

For society to make informed choices about possible responses to climate change, it needs to understand fully the consequences of failing to act, as well as the costs and benefits of acting. Analysis of different policy responses to climate change rarely includes consideration of the financial consequences of very extreme weather events, and the possible knock-on effects through capital markets. Policy-makers should incorporate the potential direct and indirect impacts of climate change on extreme weather in their cost-benefit analyses, given the scale of the possible risks.

The insurance industry can play an important role in communicating climate risks through its detailed assessment of extreme weather risks. But insurance only provides a risk transfer function, and cannot reduce the absolute risk from climate change. The costs of climate change will fall on the wider economy in some form – either through the premiums of those with insurance, through taxes where the government is insurer of last resort, or by the individual where no insurance is in place. Ultimately governments have a responsibility to manage the risks of climate change for society in the long-term.

2.8 More information is needed on the financial impacts of climate change and extreme weather

This study is only the first step towards a more systematic assessment of the impacts of climate change on the costs of extreme weather and their financial implications. Future work should build on the framework set out in this study and:

- Develop more sophisticated analyses of the impacts of climate change on flood risk at a regional level.
- Refine our understanding of the impacts of climate change on European windstorms, where the frequency of less severe storms could also increase.
- Establish integrated models that couple outputs from climate change models with insurance industry catastrophe models.
- Examine how socio-economic factors could exacerbate or alleviate the effects of climate change on costs of extreme weather.

3. INTRODUCTION – CLIMATE CHANGE AND EXTREME WEATHER

The Earth's climate is changing and will continue to change over this century. The 1990s were the warmest decade globally since records began, with the four warmest years all occurring since 1998. In 2003, Europe experienced its hottest summer for at least 500 years, with temperatures more than 2°C warmer than the average. In the UK, temperatures reached a record-breaking 38°C. Temperatures could increase by a further 6°C by the end of the century if there is no action to tackle climate change.

Climate change could increase the frequency and severity of extreme weather events, such as floods, storms, and very dry summers – exactly the kinds of events for which insurance provides some financial protection. Many of the costs of climate change will be reflected in international financial markets, as the insurance industry looks to acquire additional capital for increasingly erratic and more costly weather. Costs of insurance are a useful measure of the financial costs of extreme weather events, so insurance could play a central role in the climate change debate by communicating clearly the financial consequences of taking action vs. no action to manage risks.

Worldwide financial losses due to natural disasters have been doubling every ten years since the 1960s. Total insured losses have also been increasing and could exceed $150 bn annually worldwide in ten years based on current projections. But untangling the influence of climate-related factors from the socio-economic factors that are increasing society's financial vulnerability to weather risks is difficult.

This study had three main aims:

- To add to current estimates of the global financial costs of climate change by providing some estimates of the future costs of extreme weather events based on current scientific evidence.
- To examine the secondary effects of climate change on extreme weather events, as channelled through global insurance markets. Increases in the volatility of extreme weather could also result in changes in the amount of capital that the insurance industry and other catastrophe funds need to hold for claims.
- To quantify the impact of taking action today to limit the causes and consequences of climate change on extreme weather events, including steps to reduce carbon emissions, and measures to adapt to projected changes in weather.

The project focused on the major property insurance markets and the major weather perils affecting these markets – US hurricane, Japanese typhoon, and European windstorm (Table 3.1).

Due to their potential to cause substantial damage, the present study focuses primarily on the impacts of climate change on the costs of severe storms. In addition, it considers other weather-related events, particularly flooding, but also subsidence, and drought and heat impacts on agriculture and human health.

For ease of comparison, all financial costs in this report are given in US $ (2004 prices), with local currency equivalents included where appropriate.

Table 3.1 Insurance industry's current maximum potential event losses from weather catastrophes ($ bn)

Weather Peril	Region	Maximum loss potential[a]
Hurricane	USA/Caribbean	85
Windstorm	Europe	35
Typhoon	Japan	15

a. Based on losses that occur once every 100 years or less.

Source: Swiss Re.

4. PAYING FOR NATURAL CATASTROPHES – WHO BEARS THE COSTS?

4.1 Insurance arrangements

Insurance is one of the main mechanisms used by individuals and business to manage the financial consequences of risk, including the threat posed by natural hazards such as windstorms and floods. Insurance markets work by pooling risks across a large and diverse population. Each individual or business protects themselves against an uncertain loss by paying an annual premium towards the pool's expected losses. The insurer holds premiums in a fund that, along with investment income and supplementary capital (where necessary), compensates those that experience losses.

The extent to which private insurance arrangements cover property damage due to severe weather differs substantially between countries (Table 4.1). In some cases, the private market covers much of the risk (e.g. UK), while in others, the government is more closely involved, either directly carrying the risk (e.g. USA for flood) or acting as "insurer of last resort" (e.g. France). The private insurance market generally covers windstorm risks, whereas flood risks are often provided through a pooled or government-backed insurance arrangement.

The costs of natural catastrophes fall on different parts of society depending on the arrangements.

- Where private insurance covers weather risks, the costs of climate change will be shared among the insured portions of society. With risk-based pricing, those at greatest risk pay most for this risk-sharing, while those who avoid risk pay least. This distributes the costs of weather equitably amongst policyholders.
- Where government carries the risk directly or as "insurer of last resort", the costs of weather events are borne by the taxpayer, contributing according to the tax-regime of the country. There is no reward for avoiding risks, and no personal penalty for accepting them.
- Where there is no insurance or state-backed compensation for weather risks, the costs of natural catastrophes fall on the individual. In many cases, these costs could be a substantial portion of an individual's wealth, leading to devastating personal and business liabilities. The individual can only prevent potentially bankrupting costs by avoiding or carefully managing risk.

For insurance markets that have historically had limited capacity, a pooled or government-backed compensation system may be the only way to deal with the substantial costs of natural catastrophes. In addition, some quite developed insurance markets are faced with single-event losses of such proportions that even this capacity is exceeded. Will this become more common with climate change despite growth of the global economy?

Climate change could alter the viability of these different arrangements by increasing the costs borne through each mechanism, and the relationships between those funding and receiving compensation.

4.2 Reinsurance arrangements

To cover the most extreme events, insurers rely on reinsurance – either through the private market or from the state. The reinsurer assumes responsibility for covering a portion of the risk, especially for rare but extreme event losses. This enables insurers to access greater capital in a cost-effective way, and assist in managing liquidity following a large claim event. In most markets, regulation sets out capital requirements, ensuring solvency for all but the most unusual events.

Extreme weather events place significant demands on the financial capacity of the insurance industry. The loss potential from these types of events can be enormous, with severe financial consequences. After Hurricane Andrew hit Florida in 1992 causing $22 bn of insured damage (in 2004 prices), eleven insurers went into receivership. The size of the global reinsurance market for property in 2004 was only around $55 bn (based on premium volume).

Table 4.1 Comparison of insurance coverage for storm and flood damage in major insurance markets

Country	Insurance coverage	Degree of state involvement
UK	Insurance covers all natural perils including floods, windstorms, and subsidence. Good uptake (> 90%) as required as a condition of mortgage.	None – primary insurance and reinsurance provided through private market.
France	Storm coverage included as standard. All policyholders pay premium surcharge set by the government (12% of the fire premium for most lines of business). Natural catastrophe coverage is mandatory.	Unlimited government guarantee for catastrophes provided through Caisse Centrale de Réassurance. Catastrophes Naturelles (CATNAT) is the national programme which covers floods, subsidence, mud slides, earthquakes, tidal waves and avalanches.
Germany	Storm coverage included as standard. Insurance for natural catastrophe is optional and available from private insurers for an additional premium. Flood uptake is typically low (~ 5%). Natural catastrophe coverage is not mandatory.	None
Rest of Europe	Each market has its own limitations on coverage. Extent of uptake varies by maturity of market, and degree to which cover is required by law or as a condition of other finance-providers (e.g. mortgage lenders).	State does not normally intervene in insurance provision but some countries have a pooled system through the government (e.g. Spain, Norway, Switzerland, Denmark). In the Netherlands, the government acts as insurer of last resort for flood, as the private market does not provide.
Japan	Property policies cover windstorm.	Primary insurance and reinsurance provided through private market.
Australia	Property insurance coverage is available for most perils, with subsidence generally excluded for residential policies. Scope of cover varies from company to company and can range from full (river) flood cover to local flash flood or storm-water only. Few companies offer however full cover for domestic risks.	Primary insurance and reinsurance provided through private market.
USA	Most property insurance policies cover wind damage. Flood is usually excluded.	The federal government covers flood perils. For hurricanes, insurance is provided through the private market. In Florida, primary insurers may purchase reinsurance from the Florida Hurricane Catastrophe Fund.

Sources:
US and European approaches to insure natural catastrophe and terrorism risks, US Government Accountability Office, February 2005.
The world reinsurance market 2004, Guy Carpenter, September 2004.
The insurance of natural events in Europe, Comité Européen Des Assurances, May 2005.

4.3 Alternative risk transfer

Conventional reinsurance arrangements may in future cover a smaller proportion of total losses if extreme events increase in frequency and/or severity. There may be insufficient capital available to insurance markets to cover these losses. Insurers are already looking to other alternative risk transfer mechanisms to help diversify their capital (Table 4.2).

Insurers could limit risk exposure by transferring natural catastrophe risk into the capital markets. Due to their size, financial markets offer enormous potential for insurers to diversify risks: the value of global financial markets currently stands at around $120,000 bn.[4] But transaction costs can be considerable, and the unfamiliarity of investors with insurance risks means that they currently demand a relatively large risk premium.

Catastrophe bonds raise funds through a high-yield debt instrument in case of an extreme event such as a hurricane. They pay out on fulfilment of a trigger condition, e.g. a Category-4 hurricane striking mainland USA, rather than on proof of loss. Investors provide the capital and in return receive a superior interest rate.

Weather derivatives are another financial instrument used by companies to hedge against the risk of weather-related losses. Weather derivatives pay out on a specified trigger, e.g. temperature over a specified period rather than proof of loss. The investor providing a weather derivative charges the buyer a premium for access to capital. If nothing happens, then the investor makes a profit.

Table 4.2 Comparison of alternative risk transfer mechanisms

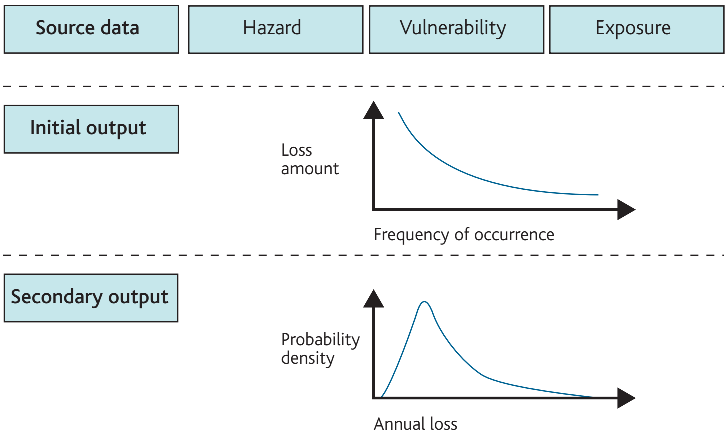
Financial mechanism	Description	Seller / Buyer	Advantages	Disadvantages	Comment
Catastrophe Bonds	Financial contracts which pay out on fulfilment of a trigger condition. They are usually triggered by a loss from a particular pre-defined catastrophe.	Sellers are mostly insurance companies. Buyers are major investors such as mutual and pension funds. The investors provide the capital in return for superior interest rates.	• Simple to administer once set up • Yield is high • Risk is uncorrelated with other asset classes	• Expensive to set up as Special Purpose Vehicle is required • Risk of loss of return on capital	• Diversify funding base for catastrophic risk by accessing capital not normally available to insurance • Help to increase capacity in the market
Weather Derivatives	Pay out on a specific trigger but usually cover a period of time.	Sellers are usually energy companies. Buyers are pension funds, mutual funds and insurance companies.	• Difficult to insure risks can be covered • Cedant loss history is irrelevant as payout determined by index of objective measurements • Catastrophe software modelling error eliminated	• Accurate prediction of information is required • Expensive to set up • Damage incurred may exceed the indemnity covered	• Access investor capital not normally available to insurance • Used to hedge or diversify risk

4. Taking Stock of the World's Capital Markets, McKinsey & Company, February 2005, http://www.mckinsey.com/mgi/publications

4.4 Modelling catastrophic losses

Insurance is underpinned by an understanding of risk. Insurers are increasingly sophisticated in their use of models to understand their exposure to extreme weather events, as better data and computing capacity has enabled more realistic scenarios to be developed. "Probabilistic" models are now used as standard to assess natural catastrophes, such as storms and floods. These models simulate all the possible events that could unfold, and then weight them by chance of occurrence to produce a picture of average and extreme costs from these events (Figure 4.1).

Figure 4.1 Basic structure of an insurance model for natural catastrophes



Source: Natural catastrophes and reinsurance, Swiss Re, August 2003.

The models typically comprise three basic building blocks:[5]

- Hazard – Where, how often and with what intensity do events occur? This is usually the initial input to the model, represented as a frequency distribution of different event intensities.
- Vulnerability – What is the extent of damage for a given event intensity?
- Exposure – What is the value at risk, where is it located, and what proportion of the loss is insured?

5. Natural catastrophes and reinsurance, Swiss Re, August 2003, http://www.swissre.com/INTERNET/pwswpspr.nsf/alldocbyidkeylu/ESTR-5LUA2R?OpenDocument

5. TRENDS IN EXTREME EVENTS TO DATE

5.1 Global trends in extreme weather

Extreme weather results in extreme losses. For example,

- In 2004 the US and neighbouring countries were hit by four hurricanes in the space of a few weeks, making it the costliest hurricane season on record, with around $56 billion in total losses, of which around $30 bn was insured.[6]
- In the same year Japan was hit by ten tropical cyclones – more than any other year in the last century – leading to total losses of more than $14 bn, of which $7 bn was insured.
- In 1999, within the space of a month, three windstorms raged across Europe, causing losses around $23 bn, of which $11 bn was insured.
- Heavy rains and flooding across Europe during July and August in 2002 caused nearly $16 bn in losses, of which $4 bn was insured.

Storms and floods typically contribute over 90% of the costs of extreme weather each year (Figure 5.1). The number and cost of such events have been rising over the past few decades. There have been noticeable increases in the number of severe storms, which also tend to be the most costly insured events, and a more sporadic increase in the number of floods.

Every year since 1990 there have been at least 20 weather events globally that are severe enough to be classified by reinsurers as significant natural catastrophes. Yet in the 20 years prior to 1990, only three years experienced more than 20 such events. Insured losses averaged about $16 bn per year between 1990 and the end of 2004, but only $3 bn per year in the 20 years preceding 1990 (2004 prices).

To date, these trends in the number of events and total losses over time have been driven predominantly by socio-economic factors, including population growth, concentration of population in urban areas and rising amounts of increasingly valuable assets in areas prone to storm and flood risk. There have also been improvements in monitoring capabilities, so that more events are now identified and recorded each year.

5.2 Trends in tropical storms

Tropical cyclones pack a substantial amount of energy, giving them particularly destructive powers, with extremely strong winds, heavy rainfall and storm surges. The most powerful storms have sustained windspeeds in excess of 70 m/s and produce storm surges six metres or more above normal.

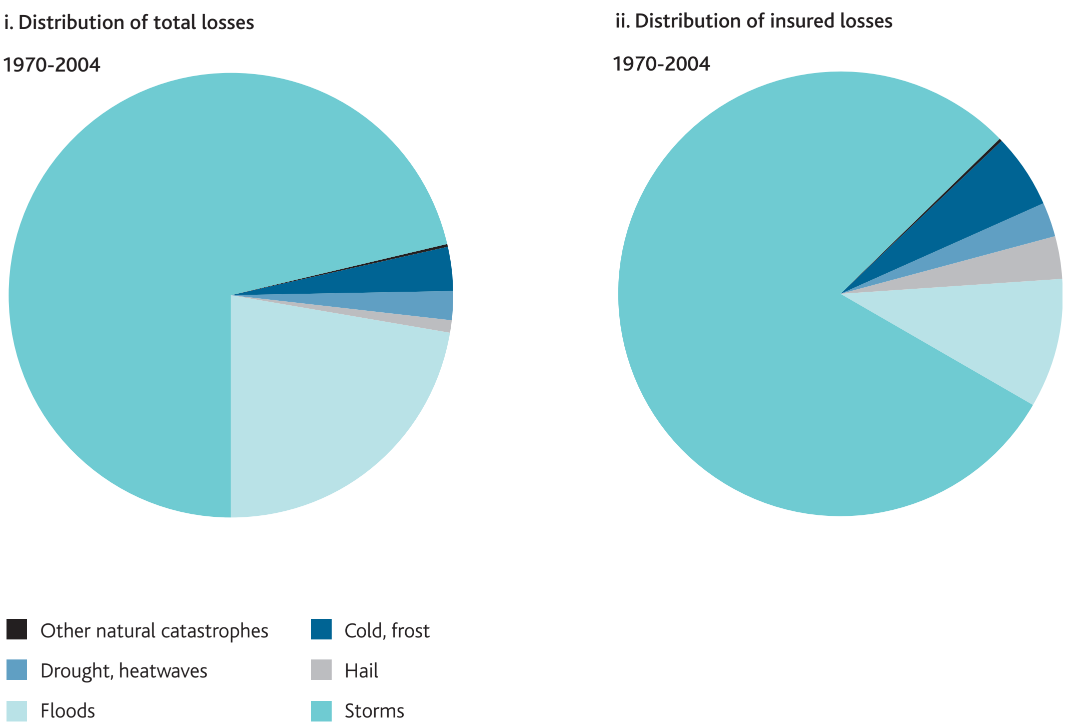
Over the last 100 years the tropical North Atlantic has experienced a gradual warming trend, with sea surface temperatures increasing by about 0.3°C. Hurricane activity in the Atlantic undergoes distinct decadal cycles, governed by gradual changes in the ocean currents. “Warm phases” of the cycle are associated with increased hurricane activity, whereas “cold phases” of the cycle are associated with fewer hurricanes. This observed decadal variability in hurricane activity could, however, be masking an upward trend. The average number of hurricanes during the current warm-phase is higher than during the previous warm-phase (Figure 5.2a). The ten-year moving average of hurricane activity in the Atlantic Basin also suggests a slight upward trend in activity (Figure 5.2b).

A similar inter-decadal tropical cyclone phenomenon may be taking place in the Western North Pacific Basin, although this cycle is much less documented. Within the natural variability, activity in the basin still exhibits a weak upward trend. In the last decade more cyclones formed each year in the Western North Pacific Basin than during any other decade on record. Over the period 1950-2003, 2.6 tropical cyclones made landfall in Japan each year on average. In 2004, by contrast, Japan was struck by ten typhoons, surpassing the six strikes it experienced during its previous worst season.

6. Annual review: natural catastrophes 2004, Munich Re, 2005, http://www.munichre.com/publications/302-04321_en.pdf?rdm=71622

Figure 5.1 Significant weather-related natural catastrophes 1970-2004

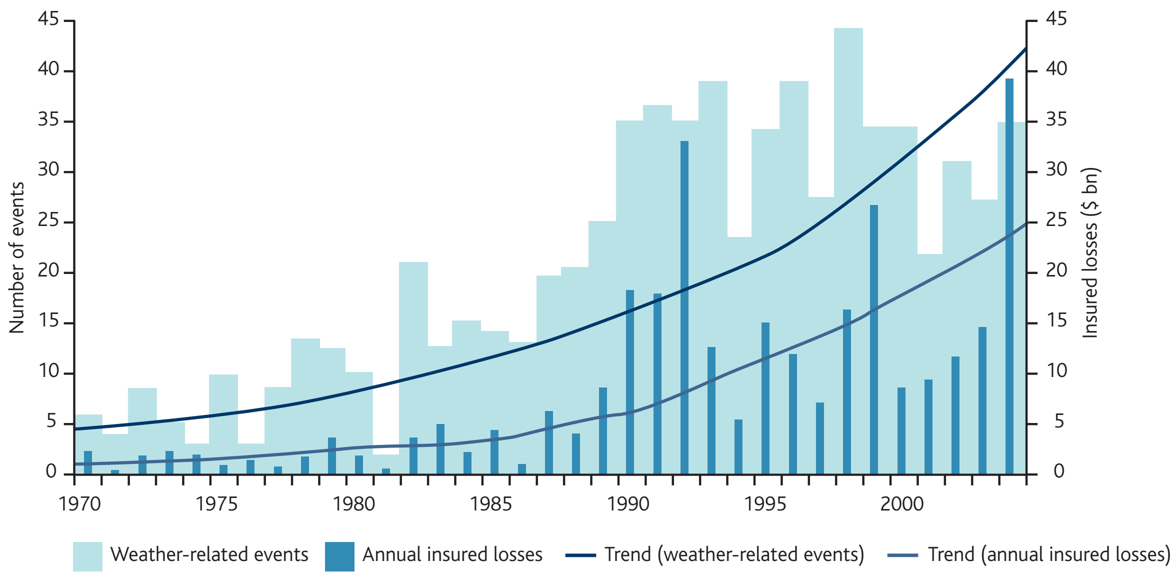
(a) Distribution of total and insured losses by weather-related catastrophe



Note: Since 1970 weather-related catastrophes resulted in about $345 bn in total damage, of which $300 bn was insured.

Source: Sigma Database, Swiss Re.

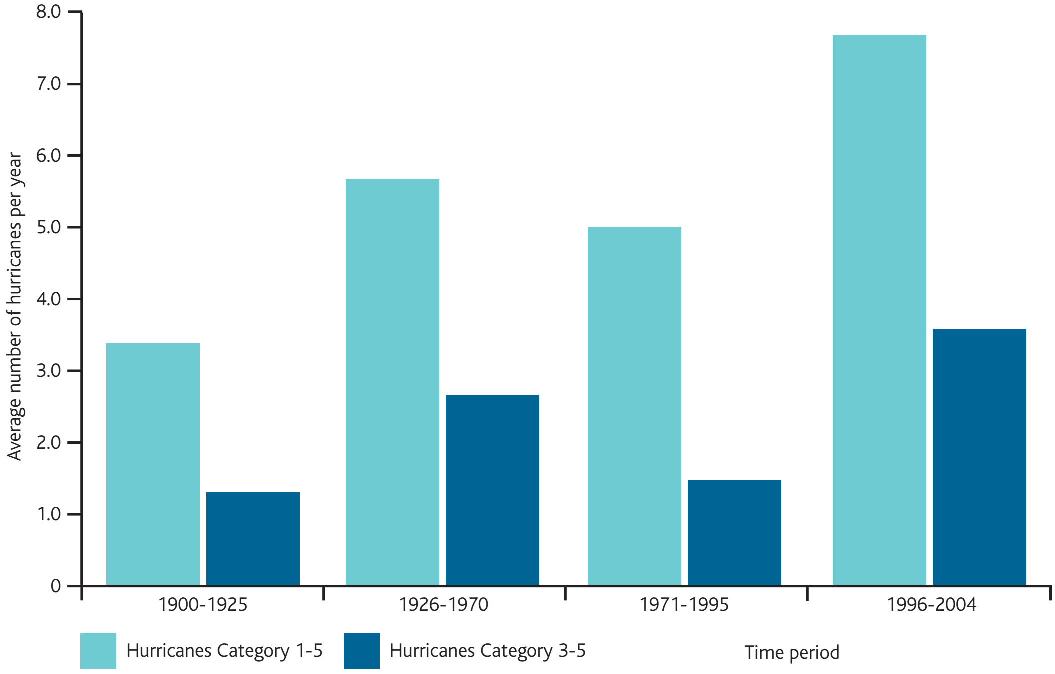
(b) Number of weather-related catastrophes and insured losses (2004 prices)



Source: Sigma Database, Swiss Re.

Figure 5.2 Trends in hurricane formation in the North Atlantic basin

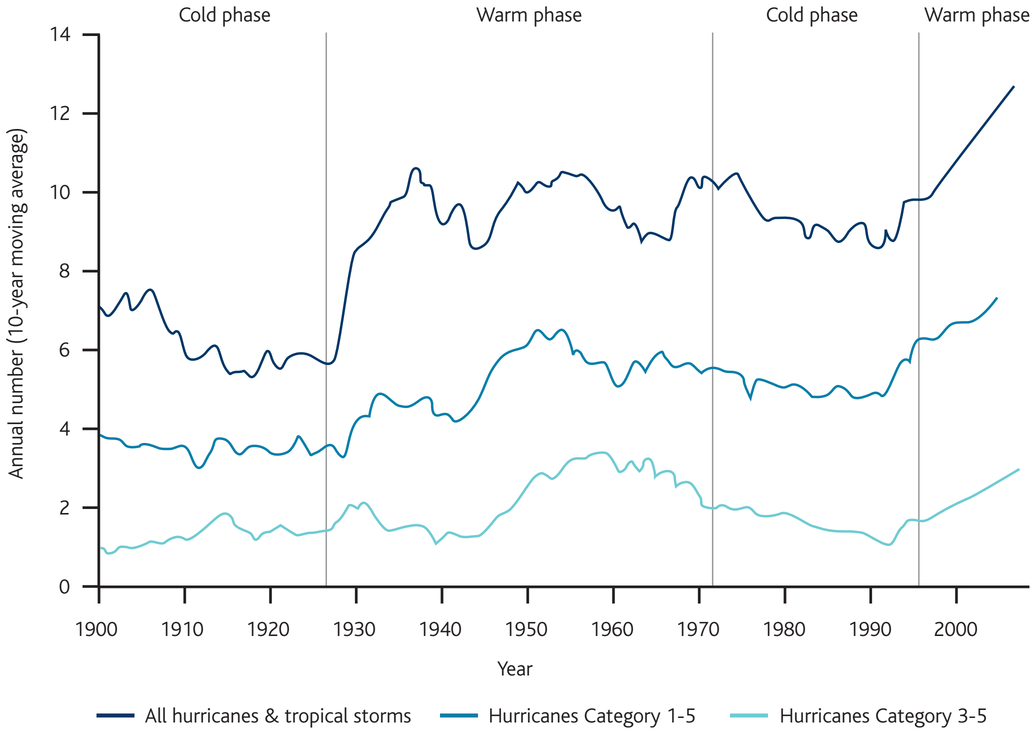
(a) Changes in relation to warm and cold phases



Note: Category 5 represents the most severe class of hurricane.

Source: Based on data from the National Oceanic Atmospheric Administration (NOAA) National Hurricane Centre.

(b) Ten-year moving average for tropical cyclones formed in the North Atlantic Basin



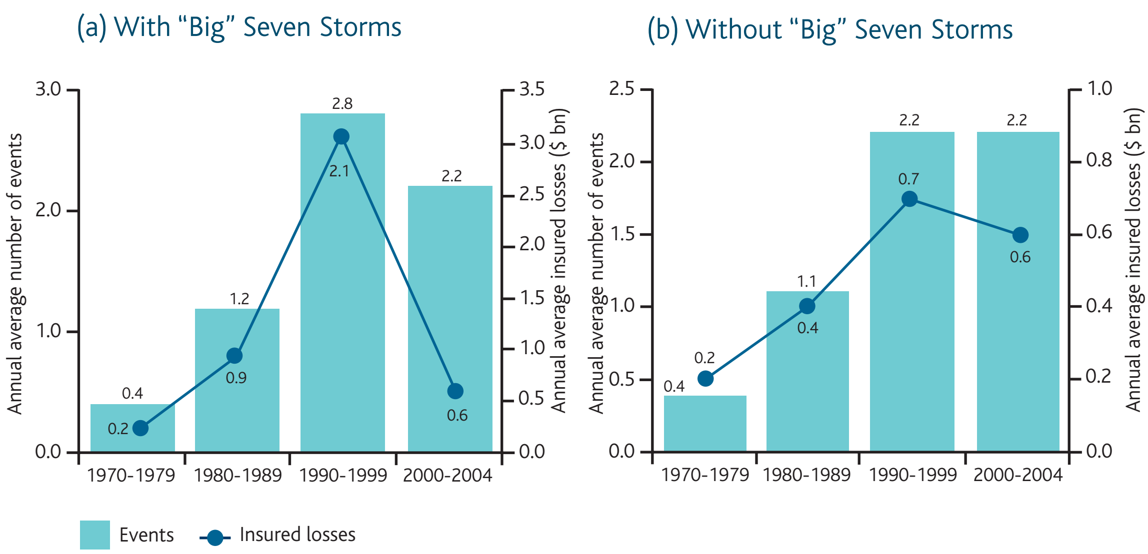
Source: NOAA, with re-handling and calculations by Munich Re.

5.3 Trends in European windstorms

Historically windstorms have been the primary cause of insured losses due to natural events in Europe, although since 1990 flood damage has also emerged as significant. Since 1970 there have been 55 severe windstorm events, resulting in total insured losses of $44 bn (€35 bn). Seven very severe storm events account for 64% of this total. The volatility of losses was exacerbated by the clustering of very severe storms, with three in 1990, and three more in 1999. There may be periods of increased activity where losses from a sequence of storms are likely.

Trends in the insured losses arising from European windstorms are less discernible due to the relative importance of these few very severe events (Figure 5.3). However, there is a slight upward trend in the number of windstorm events: the average number of events between 1970 and 1979 was 0.4 each year, rising to 2.8 each year between 1990 and 1999.

Figure 5.3 Annual average number of severe windstorm events and annual average insured losses (2004 prices) by decade in Europe (1970 – 2004)



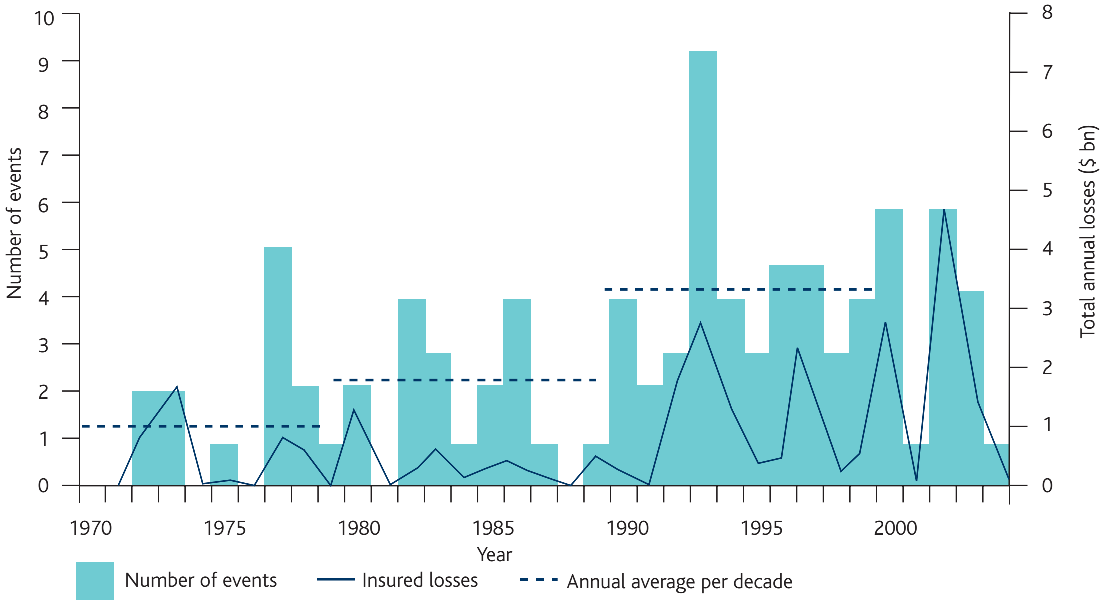
Source: Sigma Database, Swiss Re.

5.4 Trends in flood risk

There is a weak upward trend in the number of significant flood events experienced in the three major insurance markets of the US, Europe and Japan over the period 1970-2004, despite considerable variation in the number of events each year (Figure 5.4). The variability in insured losses is even more pronounced. This trend in the number of significant flood events is very likely due to socio-economic developments, as more people take up residence in risk prone areas. For example in the past 20 years over 350,000 residential properties have been built on floodplains in the UK, with more than 20,000 being built in the last 3 years.[7]

Europe appears to be particularly prone to significant flood risks, with financial losses totalling some $72 bn (€58 bn) since 1990, of which around $14 bn (€11 bn) was insured (2004 prices). This is roughly double the losses from significant floods experienced in the US over the same period, and four times the losses experienced in Japan.

Figure 5.4 Number of significant flood events and insured losses (2004 prices) in the US, Europe and Japan 1970-2004



Source: Sigma Database, Swiss Re.

7. United Kingdom Floods, Guy Carpenter, 2000, http://www.guycarp.com/portal/extranet/pdf/ukflood.pdf?vid=1

6. IMPACTS OF CLIMATE CHANGE ON COSTS OF EXTREME WEATHER AROUND THE WORLD

6.1 Scientific evidence

While individual extreme weather events cannot be attributed directly to climate change, the trends to date are consistent with what we might expect as climate change intensifies (Table 6.1). Sea surface temperatures have been rising in line with global temperatures, increasing moisture evaporation and atmospheric humidity, and providing more energy to fuel tropical and temperate storms.

Table 6.1 Changes in extreme weather events by the end of the century

Anticipated change in extreme weather phenomena by the end of the century	Likelihood[a]
Higher maximum temperatures and more hot days	Very likely, over nearly all land areas
Increased summer continental drying and associated risk of drought	Likely, over most mid-latitude continental interiors
More intense precipitation events	Very likely, over many areas
Increase in tropical cyclone peak wind intensities	Likely, over some areas
Increased intensity of extra-tropical cyclones	Little agreement between current models

a. Likelihood definitions: Very likely = 90 – 99% chance; Likely = 66 – 90% chance.

Source: Third Assessment Report – Climate Change, Intergovernmental Panel on Climate Change, 2001, http://www.ipcc.ch

Current scientific evidence suggests that global warming could increase the severity of tropical storms, with limited evidence that the number of major storms could change in some regions. The Intergovernmental Panel on Climate Change (IPCC) in 2001 concluded for tropical cyclones that: "there is some evidence that regional frequencies of tropical cyclones may change, but none that their locations will change. There is also evidence that the peak intensity may increase by 5% to 10% and precipitation rates may increase by 20% to 30%."[8] Successive studies have narrowed the range of projected increases in cyclone intensity, most recently suggesting that maximum surface windspeeds will increase by an average 6% if carbon dioxide emissions approximately doubled. Precipitation is also predicted to increase by close to 20%.

The impact of climate change on European windstorm activity remains uncertain, despite a growing body of work on the subject. However, some consensus is beginning to emerge of at least an increase in the frequency of "deep" windstorms (with central pressure less than 970 mb) over the North Atlantic. Recent studies suggest a 20% increase in the formation of more extreme storms by the end of the century under a relatively high emissions scenario. These "deep" storms may track further south and deeper into western and central Europe, with the North Atlantic Oscillation (NAO) possibly intensifying as carbon dioxide concentrations increase in the future. There may be an impact on less intense storms, but these are not considered here, because quantitative information about the changes is still limited.

6.2 Climate stress tests

To examine the potential impacts of climate change on the costs of extreme weather events (both insured and total costs), the scenarios set out in these recent climate change studies were used to alter windstorm characteristics in insurance industry catastrophe models.

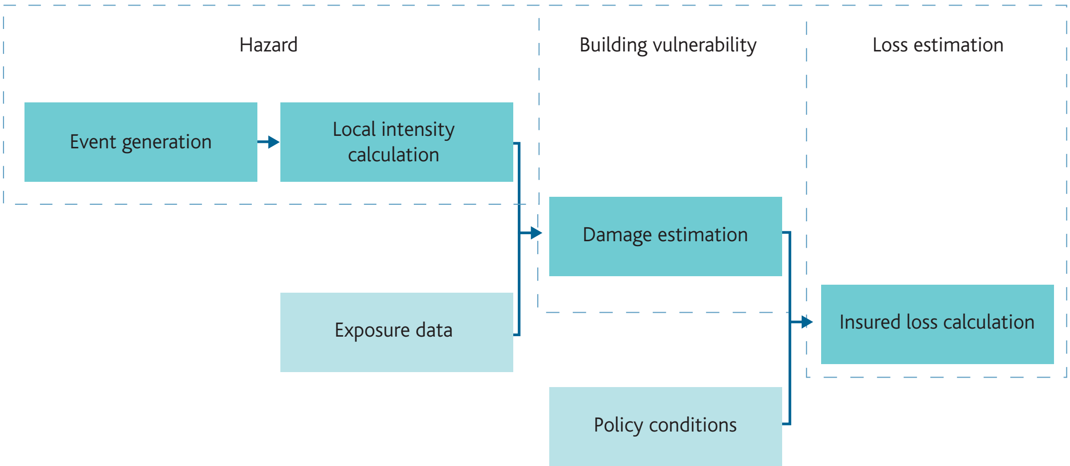
8. Third Assessment Report – Climate Change, Intergovernmental Panel on Climate Change, 2001, http://www.ipcc.ch

Even though there is still uncertainty surrounding the link between projected climate change and severe windstorm activity, the present study has used climate scenarios where there is a degree of scientific consensus developing.

a) Main stress-tests – changes in severity of tropical storms and frequency of windstorms

Three climate change-induced stress tests were performed on insurance industry natural catastrophe models for US hurricanes, Japanese typhoons and European windstorms (Table 6.2). The simulations were undertaken by the natural catastrophe modelling team at AIR-Worldwide,[9] who estimated the incremental impact on property of moving from a baseline set of storms within each of their models to one in which the climate-stress tests and limited sensitivity tests were included (Figure 6.1 for key components of AIR model). All exposure information (location and density of population and property, physical characteristics of the property, asset values) was kept constant at today's values.

Figure 6.1 Component parts of AIR catastrophe model



Source: AIR Worldwide.

Table 6.2 Potential impacts of climate change on storm characteristics towards the end of the century

Weather Feature	Region	Stress-test[a]	Key References
Hurricane	US	Increased average wind-speed by 6%, with sensitivity tests for +4 to +9%	Third Assessment Report, Intergovernmental Panel on Climate Change, 2001, http://www.ipcc.ch Knutson and Tuleya (2004) Journal of Climate, 17(18): 3477–3495.
Typhoon	Japan	Increased average wind-speed by 6%, with sensitivity tests for +4 to +9%	
Windstorm	Europe	Increased frequency of storms that occur once every 20 years (or less) by 20%	Leckebusch and Ulbrich (2004) submitted to Global and Planetary Change. Kuzmina and others (2005) submitted to Geophysical Research Letters.

a. The stress-tests on tropical cyclones were applied to the entire distribution of all possible hurricanes and typhoons, whereas the stress-test on European windstorms was restricted to the extreme upper tail of the distribution of all possible storms. There may be an impact on less intense storms, but these are not considered here, because quantitative information about the changes is still limited. The stress-tests therefore severely underestimate the full potential impact of climate change on European windstorms – particularly, given that a considerable proportion of current insured losses result from more frequent but less intense storms.

9. Further details of AIR's work is available from http://www.air-worldwide.com
This work does not necessarily represent AIR's views on the effects of climate change on windstorm events.

Property damage is a non-linear function of windspeed, so small increases in windspeed could produce relatively large increases in losses. If carbon dioxide concentrations doubled,[10] total average annual damages from US hurricanes, Japanese typhoons and European windstorms combined could increase by up to $10.5 bn (¥1140 bn, €8.5 bn) from a baseline of about $16.5 bn today, representing an increase of around 65% (Tables 6.3 and 6.4). At current market conditions, around $6 bn of these increased damages would be insured.

Very extreme storm losses, occurring once in every 100 or 250 years, could become even more severe.

- Insured losses from extreme US hurricanes could increase by $41 – 62 bn above present-day losses of $60 – 85 bn, representing a 70 – 75% increase, which is equivalent to an additional two to three Hurricane Andrews in a single season.
- Insured losses from extreme Japanese typhoons could increase by $10 – 14 bn (¥1100 – 1500 bn) above present-day losses of $15 – 20 bn (¥1600 – 2200 bn), representing a 67 – 70% increase, which is more than twice the cost of the 2004 typhoon season, the costliest in the last 100 years.
- Insured wind-related losses from extreme European windstorms could increase by $2 – 2.5 bn (€1.6 – 2 bn) on top of present-day losses of $30 – 35 bn (€24 – 28 bn), representing a 5% increase. This increase in cost excludes any flood costs and increases in losses from less intense storms. The additional wind-related costs are equivalent to the 1999 windstorm Martin, one of the most costly windstorms on record.

The terrorist attacks on the World Trade Center and the Pentagon resulted in insured losses of around $66 bn, the worst experienced by the industry for a single event. The total increases in losses from extreme hurricanes are roughly of a similar magnitude.

Even at today's loss potentials these very extreme storms are of great interest to the insurance industry, given their potential to deplete capital, stimulate price volatility, and in rare cases result in insolvency.

10. For the purpose of this report, doubling of CO_2 refers to a 2.2 times increase. For further details, please refer to the technical annexes at http://www.abi.org.uk/climatechange

Table 6.3 Impacts of changing windspeeds in natural catastrophe models on additional costs of storms ($ bn in 2004 prices)

(a) US hurricane

Scenario	Increase in windspeed	Annual average insured loss	Insured loss with chance of occurring once every 100 years	Insured loss with chance of occurring once every 250 years
Lower-bound sensitivity analysis	4%	+2.5	+27	+42
Potential impact of climate change[a]	6%	+4.0	+41	+62
Upper-bound sensitivity analysis	9%	+6.5	+68	+98

(b) Japanese typhoon

Scenario	Increase in windspeed	Annual average insured loss	Insured loss with chance of occurring once every 100 years	Insured loss with chance of occurring once every 250 years
Lower-bound sensitivity analysis	4%	+1.0	+7	+9
Potential impact of climate change[a]	6%	+1.5	+10	+14
Upper-bound sensitivity analysis	9%	+2.5	+17	+25

(c) European windstorm

Scenario	Frequency increase in top 5% of storms	Annual average insured loss	Insured loss with chance of occurring once every 100 years	Insured loss with chance of occurring once every 250 years
Potential impact of climate change[a]	20%	+0.5	+2.0	+2.5

a. The impact of climate change on the majority of less intense storms was not modelled, because quantitative information about the changes is still limited.

Source: AIR Worldwide. This work does not necessarily represent AIR's views on the effects of climate change on windstorm events.

Table 6.4 Comparisons of outputs of climate stress-tests to current industry baseline losses for costs of storms

(a) US hurricane

Scenario		Annual average insured loss	Annual average total loss	Insured loss with chance of occurring once every 100 years	Insured loss with chance of occurring once every 250 years
Current observed baseline[a]	-	$5.5 bn	$9.5 bn	$60 bn	$85 bn
	Increase in windspeed	Loss increase relative to baseline			
Lower bound sensitivity analysis	4%	45%	47%	45%	49%
Potential impact of climate change[b]	6%	75%	75%	70%	75%
Upper bound sensitivity analysis	9%	118%	116%	113%	115%

(b) Japanese typhoon

Scenario		Annual average insured loss	Annual average total loss	Insured loss with chance of occurring once every 100 years	Insured loss with chance of occurring once every 250 years
Current observed baseline[a]	-	$2.5 bn	$4.0 bn	$15 bn	$20 bn
	Increase in windspeed	Loss increase relative to baseline			
Lower bound sensitivity analysis	4%	40%	50%	47%	45%
Potential impact of climate change[b]	6%	60%	63%	67%	70%
Upper bound sensitivity analysis	9%	100%	113%	113%	125%

(c) European windstorm

Scenario		Annual average insured loss	Annual average total loss	Insured loss with chance of occurring once every 100 years	Insured loss with chance of occurring once every 250 years
Current observed baseline[a]	-	$1.5 bn	$3.0 bn	$30 bn	$35 bn
	Frequency increase in top 5% of storms windspeed	Loss increase relative to baseline			
Potential impact of climate change[b, c]	20%	35%	35%	5%	5%

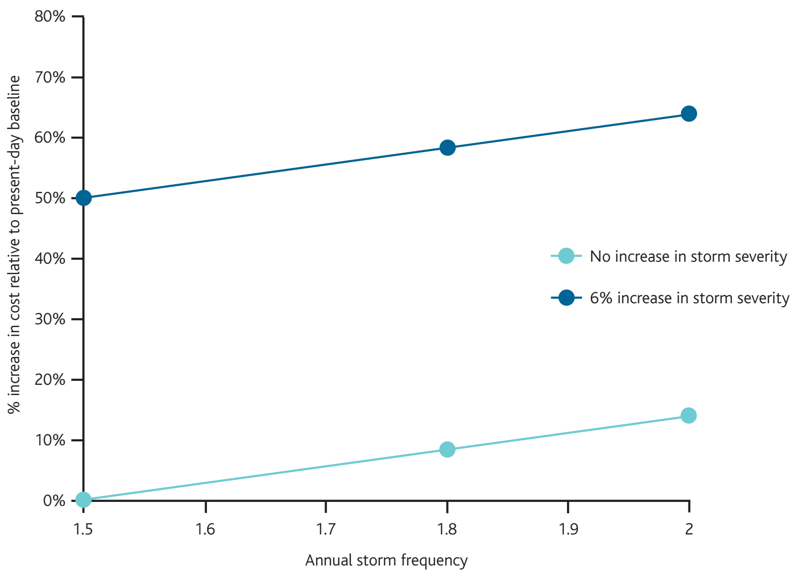
a. Current baseline losses are based on industry experience. The ratio between current insured and total losses was used to derive the climate-induced increments in total losses.
b. Results are shown as proportional increases in loss totals. Percentage changes were calculated by comparing industry baseline losses with incremental increases from climate stress-tests.
c. The impact of climate change on the majority of less intense storms was not modelled, because quantitative information about the changes is still limited.

b) Sensitivity analysis – frequency of tropical storms

The scientific evidence is equivocal on the impact of climate change on the number of tropical storms that may make US landfall. However landfall rates during the last 40 years of the 20th Century were lower than during the most active decades of the 1940s and 1950s. As a further set of sensitivity tests, Risk Management Solutions Inc (RMS) have run a series of tests of hurricane catastrophe losses for the US resulting both from changes in the severity and frequency of hurricanes (Figure 6.2).

RMS found that elevating the windspeeds of all storms by 6% increased the costs of the 1-in-100 year losses by 48% (although this figure may overstate the degree to which an increase in storm intensity tends to be associated with a reduction in storm size). Based on the costs of a 1-in-100 year US hurricanes loss, this would imply an additional $30 bn extra (compared to the calculations derived from the AIR stress-tests of $41 bn). Increasing the number of hurricanes making US landfall from the 1.5 seen over the past 40 years up to 1.8 (as seen during the 1950s) or 2.0 (for the combined 1940s and 1950s) further raised the losses, adding between $8 – 10 bn to the overall costs of the 1-in-100 year hurricane losses.

Figure 6.2 Impact of changes in storm severity and frequency on losses from US hurricanes occuring once every 100 years



Source: Risk Management Solutions (RMS), London.

6.2 Limitations of the simulations

a) Climate science

These assessments only simulate particular changes in wind characteristics (6% increase in wind-speeds for tropical cyclones, 20% increase in the most severe European storms). Changes in other aspects of storms could affect these results, for example changes in storm-track or increases in the frequency of less intense storms. Some studies suggest that climate change could increase the frequency of these less intense storms as well. If this turns out to be the case, the effects of climate change on European windstorms could be much greater than presented here. Ideally, the simulations should be carried out by coupling the insurance-loss model directly to the climate model.

b) Flooding impacts

These climate stress-tests only simulated changes in the wind characteristics of storms, but tropical cyclones and European windstorms also generate storm-surges (resulting in coastal flooding and tidal waves) and intense precipitation (resulting in inland flooding). There is increasing evidence that the rainfall generated by these storms and storm-surges could increase considerably due to climate change. To produce a more complete picture of the potential financial costs of stronger storms, the predicted changes in these other hazards would need to be assessed.

Sea-level rise of 1-m (predicted to occur by end of century under a high emissions scenario) could increase assets at risk from a storm-surge by $1,500 bn.[11] Global damages from a 0.5 metre rise in sea-level have been put at between $24 and $42 billion per year. Incorporating climate change into sea-defences could reduce these damage costs to $8 – 10 bn.[12]

In Europe the current annual total losses from extreme flood events are $8 – 10 bn (€6.5 – 8 bn).[13] If climate change increased these losses by a similar magnitude as the UK (see Chapter 6), European losses could increase by a further $120 – 150 bn (€100 – 120 bn).[14] This is an area of work that needs further study.

c) Socio-economic factors

In assessing the impacts of climate change on the three major storm types, socio-economic developments that could increase society's vulnerability to windstorms have been excluded deliberately. Various factors will make the losses resulting from the same storm, hitting the same area, higher today than in the past:

- Population patterns change with time. More people are now located in vulnerable coastal areas. From 1980 to 2003 the coastal population in the US grew by 33 million, and is projected to increase by a further 12 million by 2015. Simultaneously, household sizes are decreasing. As a result, the number of properties at risk to extreme weather is increasing over time.
- Asset values and repair costs are rising, because of increases in the general price level. Damage costs from Hurricane Andrew could have doubled since 1992 due to a combination of increased development and increasing asset values.
- Real incomes are increasing with time. People are wealthier on average, and tend to have more possessions, including increasing electronic equipment and luxury goods.

So, while the results presented are a useful first indication of the potential impacts of climate change on these windstorms, they are likely to be significant underestimates of the prospective losses facing insurers.

6.3 Managing the impact of climate change on future windstorm losses

Some future climate change could be avoided if carbon dioxide concentrations in the atmosphere are stabilised by reducing future emissions. However, the effects of historic emissions are still working their way through the climate system, such that we are already "locked-in" to some level of climate change. The impacts of unavoidable climate variability and change can only be managed through adaptation.

a) Reducing carbon emissions

Future emissions are influenced by population growth, economic growth, technological change, resource availability and people's tastes. This makes future projection uncertain, and necessitates the use of scenarios incorporating different views of how these various factors will evolve. These can then serve as a benchmark for evaluating policy interventions.

11. Nicholls, R. (2003) "Case study on sea-level rise impacts", OECD Workshop on the Benefits of Climate Policy: Improving Information for Policy Makers, ENV/EPOC/GSP(2003)9/FINAL, OECD: Paris.
12. Darwin, R. and R. Tol (2001), "Estimates of the Economic Effects of Sea Level Rise", Environmental and Resource Economics, 19 (2), 113-129.
13. Based on current insurance industry assessments.
14. The Prudence study has shown that the scale of climate-induced changes in key flood drivers could be similar in the UK and other parts of Europe, e.g. more frequent and intense rainfall, http://prudence.dmi.dk

The Intergovernmental Panel on Climate Change (IPCC) developed scenarios around four different storylines (A1, A2, B1 and B2). Each storyline gives rise to different emission profiles over time, resulting in different concentrations of carbon dioxide in the atmosphere, and in turn, giving rise to varying degrees of climate change (Table 6.5).

Table 6.5 Characteristics of different carbon emissions scenarios by the 2080s

Emission Scenario	IPCC equivalent	Increase in global temperature (°C)	Atmospheric CO_2 concentration (ppmv)
High	A1 FI	3.9	810
Medium-High	A2	3.3	715
Medium-Low	B2	2.3	562
Low	B1	2.0	525

Source: Intergovernmental Panel on Climate Change.

To examine the effects of reducing carbon dioxide emissions, annual average and extreme losses from US hurricanes and Japanese typhoons were calculated under these IPCC emission scenarios for the 2080s (Table 6.6). The high emissions scenario was closest to the 6% stress-test applied to the catastrophe models, so the benefits of emissions reductions could be calculated by comparing lower emissions scenarios to this scenario.

For example, under a low emissions scenario, increased losses from US hurricanes due to climate change were 80% lower than in a high emissions scenario by the 2080s. The increases in insured costs from 1-in-100 and 1-in-250 year losses were also reduced by 80% – saving $35 to $50 bn and roughly equivalent to avoiding two Hurricane Andrews in one season (in 2004 prices). Likewise, insured losses from a 1-in-100 and 1-in-250 year Japanese typhoon were reduced by 80% in moving to a low-emission scenario – a saving of around $9 to $13 billion, more than the cost of the entire 2004 typhoon season.

b) Reducing vulnerability through adaptation

The impact of windstorms depends on their frequency, intensity and duration, and on the vulnerability of buildings, infrastructure, and economic systems. By building properties to withstand higher windspeeds or increasing the flood defences protecting a town, damage levels could be reduced. Socio-economic factors have been a strong driver of changes in the costs of extreme weather in recent decades, showing the potentially significant role that managing society's exposure and vulnerability to weather could have in the future.

The financial benefits of adaptation have not been studied in detail to date, but there are some good initial indications, that in a similar way to emissions reductions, considerable cost-savings could be achieved.

- If all properties in south Florida met the stronger building code requirements for some counties, property damages from a repeat of Hurricane Andrew (taking the same track in 2002 as it did in 1992) would drop by nearly 45%.[15]
- If design codes for buildings in the South East of the UK were upgraded by at least 10%, increases in climate-induced damage costs from windstorms could be reduced substantially.[16]
- Section 7 outlines cost-savings that could be achieved by adaptation to increases in flooding and subsidence in the UK due to climate change.

15. Impact of Building Code Developments on Potential Hurricane Losses in Florida, Applied Insurance Research Inc. in collaboration with the Institute for Business and Home Safety, May 2002.
16. The vulnerability of UK property damage to windstorm damage, Association of British Insurers, July 2003, http://www.abi.org.uk/Display/File/78/windstorm_report.pdf

Table 6.6 Benefit of moving to lower emissions scenario, expressed as reduction in losses relative to high emissions scenario by 2080s (2004 prices)

(a) US hurricane

Emission Scenario	Annual average insured loss	Annual average total loss	Insured loss with chance of occurring once every 100 years	Insured loss with chance of occurring once every 250 years
High	$4.5 bn	$7.5 bn	$45 bn	$67 bn
	Loss reduction relative to high emissions			
Medium-High	20%	20%	20%	15%
Medium-Low	65%	65%	70%	65%
Low	80%	80%	80%	80%

(b) Japanese typhoon

Emission Scenario	Annual average insured loss	Annual average total loss	Insured loss with chance of occurring once every 100 years	Insured loss with chance of occurring once every 250 years
High	$3.0 bn	$1.5 bn	$11 bn	$16 bn
	Loss reduction relative to high emissions			
Medium-High	20%	20%	20%	20%
Medium-Low	70%	70%	70%	70%
Low	85%	85%	80%	85%

7. IMPACTS OF CLIMATE CHANGE ON COSTS OF UK EXTREME WEATHER

7.1 Flooding and subsidence in the UK

The insured consequences of climate change may have significant financial effects at the national scale. In this section, we consider the costs of climate change on flooding and subsidence risks in the UK, and the impacts of policy responses on minimising these costs. Windstorm costs for the UK have already been included in the European-level analysis in the Chapter 6.

Flood and subsidence cost the UK insurance industry a significant amount today. Average annual claims for flood-related property damage are around $1.28 bn (£0.7 bn) while subsidence damage equates to $0.55 bn (£0.3 bn).

But weather claims are much more volatile than many other insured risks, e.g. fire or crime. Typically, weather damage accounts for one quarter of total property claims in the UK, but this may rise to between one third and one half of total claims in event years such as 1990 and 2000. The severe storms in 1990 in the UK led to property claims of more than $4 bn (£2.4 bn, 2004 prices), while the floods in autumn 2000 resulted in insured costs of $1.8 bn (£1 bn, 2004 prices).

7.2 Climate change and weather risk in the UK

Climate change scenarios published by the UK Climate Impacts Programme show that by the end of the century:[17]

- Average annual temperatures across the UK could increase by between 2 and 3.5 °C by the end of the century. Two out of every three summers could be as hot as the very hot summer of 1995.
- Winters are likely to become wetter with heavy winter precipitation (principally rain, but some snow) more frequent. Intense but infrequent (one day in two years) rainfall events may be 5 – 20% heavier by the 2080s.
- Summers may become drier everywhere, but particularly in South-East England. Summer soil moisture may be reduced by 40% across large parts of England by 2080s.
- Normal sea levels will continue to rise around most of the UK's shoreline, particularly South-East England where the rise could be 26 – 86 cm above the current level. Extreme sea levels will be experienced more frequently, particularly on the east coast, occurring between 10 – 30 times current frequency.

These changes may in turn lead to a wide range of impacts including increased flood risk (more winter rainfall, more heavy rainfall, sea-level rise, and larger storm surges) and increased subsidence risk (drier summers). This study used recent research work funded by the UK Government (Foresight[18] and UK Climate Impacts Programme), to assess potential increased costs of flooding and subsidence under alternative climate scenarios (Table 7.1).

Flooding losses represent by far the greater source of climate change impacts on property insurance, with increases of almost 15-fold by the end of the century under the high emissions scenario, leading to potential total losses from river, coastal and urban flooding of more than $40 bn (£22 bn).[19]

17. Climate Change Scenarios for the United Kingdom, UK Climate Impacts Programme, April 2002, http://www.ukcip.org.uk
18. Future flooding, Office of Science and Technology Foresight Programme, April 2004, http://www.foresight.gov.uk/previous_projects/flood_and_coastal_defence
19. The Foresight study built in real increases in value – driven by various factors including growth in GDP. In other words, the values increased over and above general price inflation.

Subsidence accounts for under 5% of the average annual total flood costs in the 2080s. Based on earlier analysis, windstorm costs in the UK are likely to rise by a similar degree to subsidence, suggesting that flood risk could dominate as the major weather peril in the future.

7.3 Policy responses: mitigation and adaptation

a) Flooding

Evidence from the Foresight study suggests that a combined approach of reducing emissions and adapting to increased flooding may be effective in minimising the costs of climate change in the UK. Limiting greenhouse gas emissions could mean that the annual costs of climate change for flooding are $11 bn (£6 bn), compared to $40 bn (£22 bn) under a high emissions scenario.

Flood management actions also bring the costs down considerably, so that annual costs only increase four-fold by the 2080s to $9.7 bn (£5.3 bn), rather than increase 10 – 20 fold (Table 7.1). These adaptation responses include better flood protection, stronger land-use planning, and catchment-wide flood storage schemes. A specific study on costs of flooding for the new developments in East London showed that pro-active steps to prepare for climate change could reduce annual flooding costs by 80 – 90%, saving almost $1 bn (£0.55 bn).[20]

Socio-economic factors can have some unexpected effects. Greater wealth generation in high economic growth, high emissions scenarios could enable greater uptake of adaptive measures, producing a more effective response than economic conditions under some low emissions scenario allows. This emphasises the need for cost-benefit analysis to assess the scale and optimal combination of adaptation and mitigation measures.

Table 7.1 Potential impact of climate change on costs of flooding and subsidence in the 2080s, expressed as annual average damage costs. ($ bn, 2004 prices)

Scenario	River and coastal flooding		Intra-urban flooding		Subsidence	
Current	1.8		0.6		0.6	
Emissions Scenario[a]	Increase in river and coastal flooding		Increase in intra-urban flooding		Increase in subsidence	
	Without adaptation	With adaptation	Without adaptation	With adaptation	Without adaptation	With adaptation
High	26.5	1.8	12.8	5.5	0.9	N/A
Low	7.3	3.3	3.7	0.6	0.4	N/A

a. To estimate climate change induced flooding costs only, we make a conservative assumption – based on interpretation of Chart 2.10 of Foresight Executive Summary – that socio-economic change accounts for 50% of the total cost increases over time.

Sources: Future flooding, Office of Science and Technology Foresight Programme, April 2004; Metroeconomica for UK Climate Impacts Programme.

20. Making communities sustainable: managing flood risks in the Government's growth areas, Association of British Insurers, February 2005, http://www.abi.org.uk/housing

b) Subsidence

Recent work by Metroeconomica provides some initial estimates of the costs and benefits of adaptation measures in response to a summer as dry as 2003, where there was a 25% increase in subsidence claims compared to the average annual number (Table 7.2).

These results suggest that an option of requiring deeper foundations for new-build properties such as the newly introduced Building Regulation is – on balance – likely to produce a net benefit. However, spatial planning options and vegetation management options need to be studied further before an economically efficient adaptation strategy can be developed.

Table 7.2 Aggregate Benefits & Costs (and their distribution) of alternative adaptation options to property subsidence by 2080s

Adaptation Measure	Benefit[a]	Cost[a]	Bearer of Cost Burden
Higher insurance premiums to cover higher remediation costs	Insurer covers costs of increased number of claims	$6.6 – $22.2 bn Increased household insurance costs	House-owner bears increased costs
Withdrawal of insurance cover for properties vulnerable to subsidence	Insurer avoids increased exposure	$6.6 – $22.2 bn Loss of property value	House-owner bears full remediation costs and loss of property value Possible exclusion for low income groups
Underpinning and structural measures	$6.6 – $22.2 bn Maximum avoided loss.	$28 – $69 bn Total cost of measures for all properties at risk	Benefit borne by insurer and house-owner Cost borne by house-builder or owner
Building regulations for: - deeper foundations of 1 metre - building materials	$2.7 – $10.3 bn Not known	$3.7 – $6.4 bn Not known	Benefit borne by insurer and house-owner Cost borne by house-builder or owner
Spatial planning policy	$2.7 – $10.3 bn Maximum avoided loss	Loss of land values and possible social costs of higher density housing	Benefit borne by insurer and house-owner Cost borne by house and land-owners
Clearance of nearby vegetation or restrictions on future planting	$6.6 – $22.2 bn Maximum avoided loss	Not known	Cost borne by house and land owners
Regular water sprinkling of vegetation	$6.6 – $22.2 bn Maximum avoided loss	Not known	Cost borne by house and land owners

a. Ranges reflect estimates made under low and high emission scenarios.

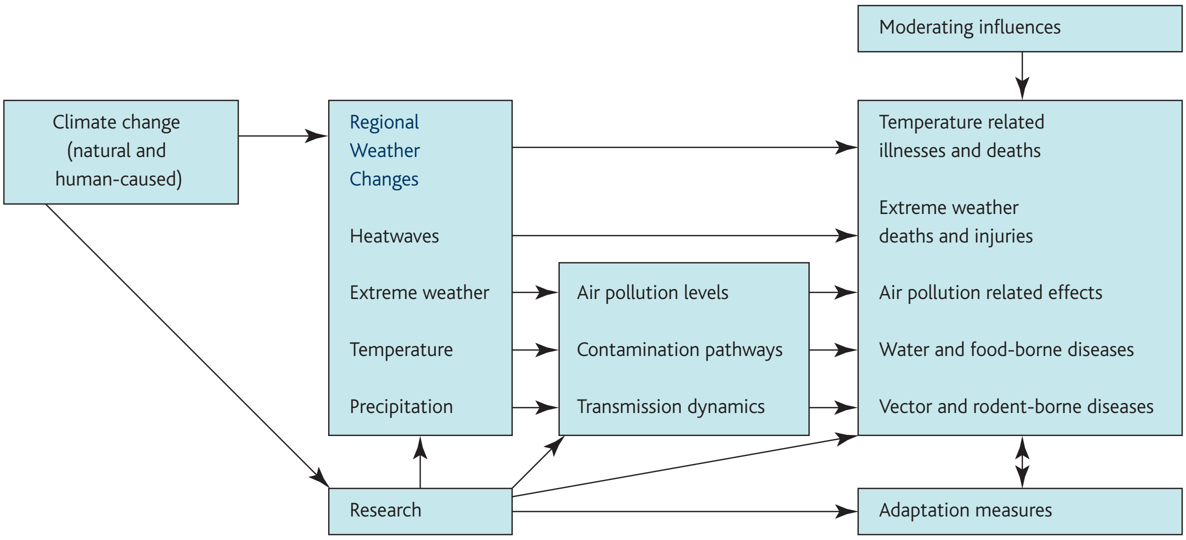
8. WIDER IMPACTS OF CLIMATE CHANGE

This study has focused primarily on the costs of climate change for storm and flood damage to property. There are other effects arising from climate change that could have financial implications. Here we report potential impacts on two other key weather-sensitive sectors: health and agriculture.

8.1 Health impacts

The net effects of climate change on costs of health are uncertain, as the potential impacts are mixed. The impacts vary depending on: the characteristics and vulnerabilities of the population, geographical region, economic prosperity, and level of public health-care provision.

Figure 8.1 Potential health effects of climate variability and change



Source: Patz and others (2000), The potential health impacts of climate variability and change for the United States, Environmental Health Perspectives v108, April 2000.

Temperature-related effects on health include both reduced winter deaths due to milder weather and increased heat stress deaths in hotter summers. Both cold weather and heat-stress affect those with certain pre-existing heart and lung conditions disproportionately. Heat-stress also affects the overweight, unfit, and people suffering dehydration or fatigue.

The heatwave in Europe in 2003 resulted in over 22,000 premature deaths (Table 8.1). These kinds of events could become more common in the future. Climate change has already doubled the chance of a very-hot summer in Europe (e.g. 2003), and by the 2040s, more than half of all European summers will be warmer than that of 2003.[21]

21. Uncertainty, risk and dangerous climate change, Hadley Centre, Met Office, December 2004, http://www.metoffice.com/research/hadleycentre/pubs/brochures/B2004/global.pdf

Table 8.1 Impact of heat-stress on premature deaths in Europe

Heatwave	Attributable mortality	Reference
Birmingham, UK 1976	Number of deaths increased by 10%; excess seen primarily in men and women aged 70-79 years.	Ellis and others (1980)
London, UK 1976	9.7% increase in England and Wales and 15.4% in Greater London. Almost two-fold increase in mortality rate among elderly hospital inpatients (but not other inpatients).	Lye and Kamal (1977)
Portugal, 1981	1906 excess deaths (all causes, all ages) in Portugal, 406 in Lisbon in July including 63 heat deaths.	Garcia and others (1999)
Rome, Italy 1983	65 heat stroke deaths during heat-wave in the Latio region. 35% increase in deaths in July 1983 compared with July 1982 among those 65 years or older in Rome.	Todisco (1983)
Athens, Greece 1987	2690 heat-related hospital admissions and 926 heat-related deaths, estimated excess mortality >2000.	Katsouyanni and others (1988)
London, UK 1995	619 excess deaths: 8.9% increase in all-cause mortality and 15.4% in Greater London compared with moving average of 31 days for that period in all age groups.	Rooney and others (1998)
Europe 2003	Over 22,000 premature deaths in UK, France, Portugal, and Italy; Death rates doubled in Paris during 11-12 August when night-time temperatures reached 25.5 °C.	Kovats and others (2004)

Source: Kovats and Koppe (forthcoming).

Vector-borne diseases may be both more prevalent and adversely affected by climate change. These diseases are closely associated with certain ecosystems which may spread their range, act over a more prolonged season and undergo accelerated maturation in higher temperatures, particularly where this is accompanied by conducive rainfall patterns and standing surface water. However some areas in southern and eastern Europe may become too hot and dry for vectors to survive.

The capacity to adapt to these changing conditions depends on: the ability to increase public health surveillance and intervention against diseases; managing the adverse impacts of severe weather events; maintaining the general health of the population; and designing and managing buildings so that extreme temperatures do not affect internal conditions.

8.2 Agriculture and forestry

Climate change could have a variety of impacts on the agriculture and forestry sectors. But rather like for health, the effects will be mixed, depending on region and the specific impact (Table 8.2).

For the insurance industry, offering financial protection against extreme events, climate change could increase costs of agriculture and forestry cover by increasing the severity of extreme weather events, such as heatwaves, storms, and floods. Extreme weather already brings this sector significant costs:

- The unusually warm summer of 1992 in northern Germany caused crop failures generating losses of approximately $3.1 bn (€2.5 bn) at the then prevailing price levels.[22]
- The unprecedented heat wave across Europe in 2003 led to severe wildfires across Portugal, Spain and France affecting forestry and property, resulting in total losses of around $15 bn (€12 bn).[23] Temperatures were on average 2 °C warmer than the average summer temperature for most of the 20th century, and up to 6 °C higher than average across parts of the continent.
- In January 2005 Sweden was hit by windstorm Gudrun with windspeeds up to 42 m/s, with an associated storm-surge of 1.6 m off the west coast of Sweden. The storm caused the largest insured loss ever for the country. Half of the costs comprised damages to commercial forestry, where there was significant damage to over 46,000 hectares (equivalent of 10 years' worth of timber). Total forestry losses are currently estimated at $2.5 bn (€2 bn) of which $0.25 bn (€0.2 bn) was insured.

Table 8.2 Regional impacts of climate change on agriculture

Impact	North America	Asia	Northern Europe	Southern Europe
Crop ranges	Potential shift northwards.		Shift northwards for some crops.	New crops may need to be introduced to deal with new climatic conditions.
Crop production	6 – 9% increase in cereal production. Generally beneficial but strong regional effects.	Beneficial effects on rice yields in NW Japan and wheat yields in NE China. Reduced yields in SE Japan and central China.	Spring cereal growth could be enhanced, but autumn sown crops may still increase. Overall impact likely to be beneficial.	Generally beneficial but strong regional effects. Increased variability and extreme events may affect crop production.
Water availability	Potential increased drought in US Great Plains/Canadian Prairies.	Water shortages will adversely affect Indian rice yields but have little effect on Indian wheat yields.		Water shortages likely to become greater.
Pests and diseases		Heat stress combined with wetter weather in tropical regions will reduce crop resistance and increase some disease prevalence.	Existing diseases likely to become more abundant and exotic species may spread their ranges, increasing the need for plant protection.	

22. Opportunities and risks of climate change, Swiss Re, 2002, http://www.swissre.com
23. Climate change 2004, Benfield Hazard Research Centre, 2004, http://www.benfieldhrc.org/activities/tech_papers/climate_change.pdf

9. FINANCIAL IMPLICATIONS OF CLIMATE CHANGE

9.1 Insuring natural catastrophes

Insurance is a unique financial instrument. Premiums must be set before costs (claims) are known. Future costs, including frequency of claim events, have to be estimated in advance. Insurers can often use historical data to assess expected losses and administrative expenses, and therefore develop a business model to provide an adequate return on capital. Ideally the frequency of claims over time should be predictable and losses experienced on one policy independent of losses experienced on another. However, risks from natural catastrophes present particular challenges.

- They are not predictable over time. Natural catastrophes are infrequent events, resulting in large losses in a few years and no losses in most years. Loss experience of the past cannot be used as a reliable predictor of future losses.
- They are often highly correlated, affecting many policyholders simultaneously.

Natural catastrophes typically result in very large losses, which can present a significant financial risk to insurers, including insolvency in rare cases, if not appropriately priced. Insurers that offer to cover natural catastrophes have developed specialist tools to assess such risks and strategies to manage them.

An insurance company first defines its "risk appetite" – the maximum loss that is acceptable over a determined period of time, e.g. $1 bn of loss only to be exceeded once in 100 years. Many factors determine the acceptable level of loss, including the availability and cost of reinsurance, solvency regulations, rating agency assessments, market conditions, the capital base and how it is allocated across business lines, and the cost of capital.[24]

Then the company assesses risk across the full distribution of hazards that could occur, including those arising from events that have a small chance of occurring, but have significant consequences when they do, so that they can set appropriate premiums. The key characteristics that an insurer examines are:

- Average (or Expected) Annual Losses: the amount expected to payout, on average, per year for an insured item (e.g. building) or portfolio of items. The expected loss is a key component of the premium calculation.
- Extreme (or Maximum Probable) Losses: the amount that would be needed to be be paid out should a significant catastrophe occur. Information on extreme losses is used by insurers to define their capital base, including reinsurance cover, and is also factored into the premium calculation.

9.2 How climate change could impact insurance

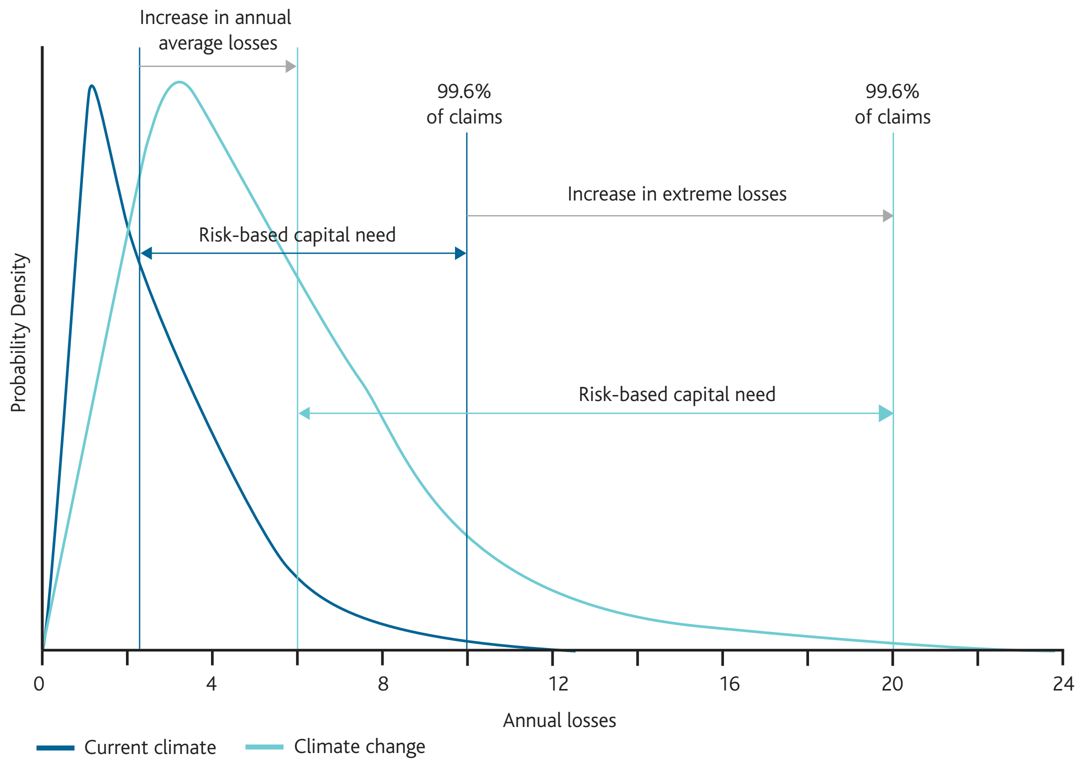
Sufficient capital is needed to bridge the gap between expected and extreme losses (Figure 9.1). This risk capital ensures that the insurer can pay its liabilities, even following a major catastrophe.[25]

Increases in the average annual loss and extreme losses (at 1-in-100 year or 1-in-250 year levels) will shift the loss distribution to the right (for tropical hurricanes and typhoons) or elongate (for European windstorm), as set out in the climate stress-tests. Increases in average and extreme losses will tend to increase the amount of risk capital needed to satisfy the risk appetite of the insurer or the requirement of the regulator.

24. For instance, some rating agencies and regulators may require insurers to set aside enough capital to pay for a 1-in-200 year or 1-in-250 year loss.

25 In this example distribution the annual expected loss is $3 bn. If an insurer wants to be sure that it can pay claims in 99.6% of all cases (i.e. including those arising from a 1-in-250 year event should it occur), they need access to sufficient resources to pay $10 bn, as opposed to $3 bn. The 1-in-250 year event represents an "unexpected" loss, in that the corresponding claim far exceeds the expected or average loss. Unexpected losses are a financial risk to the insurer. In this case, the difference between the unexpected loss and expected loss is $7 bn, and the insurer will need to provide sufficient capital to cover unexpected losses up to chosen threshold (i.e. the 1-in-250 year event). In the example the insurer will need to allocate $7 bn of capital to this line of business.

Figure 9.1 Impact of climate change on probability loss distribution and implications for risk capital requirements



9.3 Capital requirements

For insurers to cover the vast majority of US hurricane, Japanese typhoon and European windstorm claims, except those occurring less than once in 250 years on average, they will need risk capital totalling approximately $67 bn, $18 bn and $33 bn, respectively (Table 9.1). Under a high emissions scenario where carbon dioxide emissions double by the end of the century, modelling from this study suggests that the risk capital requirement could increase by over 90% for US hurricanes, and around 80% for Japanese typhoons. In total, an additional $76 bn would be needed to cover the gap between extreme and expected losses resulting from tropical cyclones.

In Europe, only the impact of climate change on the most severe storms was considered, so the increase in capital requirement is marginal (5%). However, flooding impacts of climate change could have a more significant effect on capital requirements within European markets, adding to that of windstorms: (1) present-day average annual losses for flooding in Europe may be higher than for windstorms ($8 – 10 bn compared to $3 bn), and (2) the projected influence of climate change on flooding could be considerable (potential 10 – 20 fold increase in flood losses under high emissions).[26]

The additional risk capital requirements are substantially lower under the low emission scenario (Table 9.1). For example, moving from the high to the low emissions scenario would reduce insurers' additional risk capital requirement for US hurricanes by over 80% – a saving of about $50 billion in risk capital.

In return for placing additional capital at risk, reinsurers and investors will seek a rate of return at least as high as other investment opportunities of comparable risk. As capital is finite, investors will demand higher rates of return for placing greater amounts of capital at risk. If climate change increases risk capital requirements within the insurance industry, insurers' cost of capital will also rise.

26. Based on work of Foresight http://www.foresight.gov.uk/previous_projects/flood_and_coastal_defence and Prudence http://prudence.dmi.dk

Table 9.1 Potential changes in insurance risk capital to cover hurricanes, typhoons and European windstorms under low and high emissions scenarios by the 2080s

Storm type	Approximate current risk-capital requirement	Additional capital required with low emissions[b]	Additional capital required with high emissions[b]
US hurricane[a]	$67 bn	+20%	+90%
Japanese typhoon[a]	$18 bn	+10%	+80%
European windstorm[a]	$33 bn	no change	+5%

a. Capital requirements to cover a 1-in-250 year loss.
b. Percent changes from baseline (2004 prices).

9.4 Insurance premiums

While the price of insurance will vary according to market location and conditions, premiums will, in general, comprise the cost of annual average losses, the cost of financing the risk capital requirement, and administrative/operational expenses plus relevant taxes. The first two components can be thought of as the "risk premium". An insurer may also opt to transfer the risk of larger losses to reinsurers, in exchange for paying a premium.

The above analyses suggest that climate change could increase both the average annual losses and risk capital requirements of insurers. Other things being equal, this will lead to increases in the risk premium.

Based on the simulated climate-stress tests, under a high emissions scenario the aggregate risk premium could increase by nearly 80% for both US hurricane and Japanese typhoon insurance markets by the 2080s. The increase in the aggregate risk premium for European windstorm insurance markets is considerably smaller by the 2080s, increasing by only 15% under the high emissions scenario. This might be expected as the impact of climate change only on the most severe storms was modelled. Increases in the aggregate risk premium are significantly lower for all windstorm markets under the low-emission scenario.

Actual premiums are unlikely to change by the amounts suggested by this simplified analysis. Market dynamics – where the interaction of supply and demand can lead to marked price cycles – mean that actual premium rates often diverge significantly from the purely "technical premium".

Table 9.2 Potential changes in aggregate risk premiums for hurricanes, typhoons and European windstorms under low and high emissions scenarios by the 2080s

Storm type	Current indicative aggregate risk premium[a]	Increase in risk-premium under low emissions[b]	Increase in risk-premium under high emissions[b]
US hurricane	$17 bn	+20%	+80%
Japanese typhoon	$5 bn	+20%	+80%
European windstorm	$7 bn	no change	+15%

a. Based on an assumed cost of capital of 15%.
b. Results are shown as proportional increases in loss totals from baseline (2004 prices). Percentage changes were calculated by comparing industry baseline losses with incremental increases from climate stress-tests.

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