

CLIMATE CHANGE AND DISASTER LOSSES WORKSHOP

Understanding and Attributing Trends and Projections



25 - 26 May 2006
Hohenkammer
Germany

We would like to thank the workshop sponsors:

Munich Reinsurance Company AG

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Tyndall Centre for Climate Change Research

U.S. National Science Foundation

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Tyndall Centre
for Climate Change Research



Münchener Rück
Munich Re Group



Workshop Agenda - Day 1

Wednesday, 24 May 2006

- 4:00pm WOT Executive session
- 7:00pm Informal evening reception

Thursday, 25 May 2006

- 8:45am *Gutshof-Saal Room*
Welcome, Introductions, Goals
- 9:00am Peter Höppe
- 9:15am Roger Pielke, Jr.

Part I: Trends in Extreme Weather Events

Richard J. T. Klein, Chair

- 9:30am Tropical Cyclones
 - 5 minute perspectives
 - Faust, Knutson, Grenier
- 10:30am Break
- 11:00am Extra-tropical and Convective Storms, Floods
 - 5 minute perspectives
 - von Storch, Brooks, Brazdil
- 12:30pm Lunch
- 2:00pm Discussion on Trends in Extreme Weather Events
Hans von Storch, Chair

Part II: Trends in Damage

Andrew Dlugolecki, Chair

- 2:45pm Tropical Storms
 - 5 minute perspectives
 - Faust, Pielke, Crompton
- 3:45pm Break
- 4:30pm Extratropical and Convective Storms, Floods
 - 5 minute perspectives
 - Bouwer, Ye, Kemfert, Weymann
- 5:15pm Discussion on Trends in Damage
Thomas Loster, Chair
- 6:00pm Adjourn
- 7:00pm Reception
- 7:30pm Dinner

Workshop Agenda - Day 2

Friday, 26 May 2006

Part III: Data Issues -- Extreme Weather Events and Damage

Emma Tompkins, Chair

- 9:00am Event Data
- 5 minute perspectives
 - Brazdil, Helminen, von Storch
- 9:45am Impacts Data
- 5 minute perspectives
 - Wirtz, Schmidt, Gurjar
- 10:30am Break
- 11:00am Discussion on Data Issues
- Harold Brooks, Chair*

Part IV: Synthesis

Peter Höppe and Roger Pielke, Co-Chairs

- 11:30am Initial Remarks
- 5 minute perspectives
 - Epstein, Burton, Goklany, Jun
 - Dlugolecki, Muir-Wood, Palutikof, Zapata-Marti
- 12:30pm Lunch
- 2:00pm Synthesis Forum
- Peter Höppe and Roger Pielke, Co-Chairs*
- 5:00pm Closing remarks and Adjourn

Saturday, 27 May 2006

- 9:30am Workshop Organizing Team Executive Session

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INCREASED SCIENTIFIC EVIDENCE FOR THE LINK OF CLIMATE CHANGE TO HURRICANE INTENSITY

Christoph Bals
Germanwatch

Until recently, most scientists would have said that there was no or no clear evidence that global warming has had any effect on the planet's most powerful storms- dubbed hurricanes, typhoons, or cyclones depending on the ocean that spawns them. They would have argued that the changes of the past decade in these metrics are not so large as to clearly indicate that anything is going on other than the multi-decadal variability that has been well documented since at least 1900 (Gray et al. 1997; Landsea et al. 1999; Goldenberg et al. 2001).

2005 a Turning Point of the Debate?

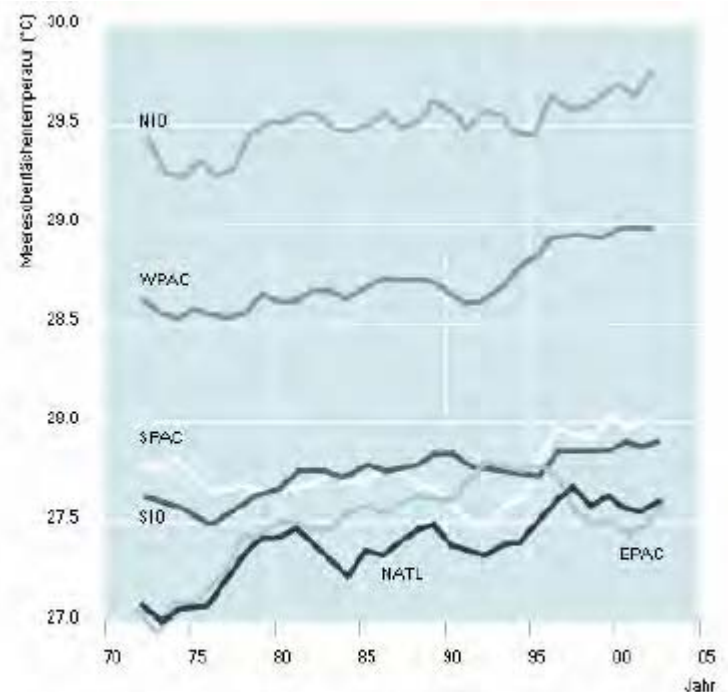
2005 might prove as a turning point of the debate. Two developments came accompanied. First, the two extreme hurricane years 2004 and 2005 increased attention of scientists: At the latest when Wilma's internal pressure hit 882 millibars, beating a record held by 1988's Gilbert, climatologists took notice. It was the first time a single season had produced four Category 5 hurricanes, the highest stage on the 5-step Saffir-Simpson scale of storm intensity. The 28 tropical storms and hurricanes, that the world faced in 2005, crushed the old mark of 21, set in 1933.

Second, a number of new scientific studies provided much more support to the hypotheses by showing that „now ... a connection is emerging between warming oceans and severe tropical cyclones " (Kerr, 2005, 1807). Two papers published in Science and Nature in 2005 started a development described as "Birth for Hurricane Climatology" (Kerr, 2006) by identifying the impact of climate change on hurricane intensity, number and regional distribution. Many other interesting papers added new information. The debate is by far not over yet.

Increase in Sea Surface Temperature

One argument is an observed increase in sea surface temperature. Torre and White (2005) could show an increase in sea surface temperature since 1960. The following graph (Faust, 2006) shows the development of surface temperature in relevant ocean basins:

Barnett et al. (2005) compared sea temperatures with model simulations and found a high probability, that global warming is strongly influencing the increase in sea surface temperature. If this conclusion is accepted, it would mean, that global warming has already now – in its early status – a significant influence on sea surface temperature.



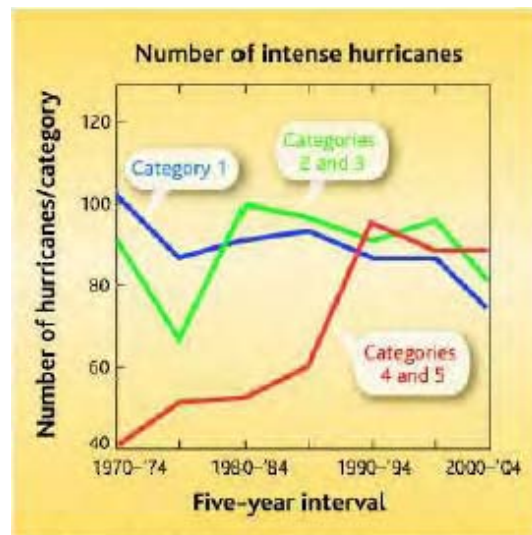
Entwicklung der Meeresoberflächentemperaturen in Ozeanbecken mit Wirbelsturmaktivität seit 1970. Quelle: nach Webster et al. (2005), Science Vol. 308.

■ NATL = North Atlantic
■ NIO = North Indian Ocean
■ WPAC = West Pacific
■ SIO = South Indian Ocean
■ SPAC = South Pacific
■ EPAC = East Pacific

Increase in Most Intense Hurricanes

The next argument is based on the observation that the most intense hurricanes increased over time. Alone in 2004 and 2005 four of the ten strongest hurricanes ever have been registered (Faust, 2006, 1). Kerry Emanuel (MIT) showed for the first time that major tropical storms, both in the Atlantic and the Pacific region, have already increased since the 1970s in duration and intensity by about 50 percent (Emanuel, 2005). He concluded: "My results suggest that future warming may lead to an upward trend in tropical cyclone destructive potential." In the years before Emanuel had asserted often that no firm link had been established between warming and the intensity and frequency of hurricanes. But then in August 2005, just two weeks before Hurricane Katrina struck the Gulf Coast, Emanuel's article in 'Nature' was published, pointing out, that he had discovered statistical evidence that hurricanes were indeed affected by global warming. He linked the increased intensity of storms to the heating of the oceans.

Peter Webster (Georgia Institute of Technology, Atlanta) and his colleagues examined in another study satellite records of storms around the tropics, a history which started 35 years ago. They haven't found a long-term trend in the number of storms per year, only natural ups and downs, even as summer tropical sea surface temperatures rose 0.5°C. In the North Atlantic, where hurricane numbers have surged since 1995, such variability arises from changes in the strength of warm ocean currents (Science, 1 July 2005, p. 41). But more relevant is another part of the results: "The researchers did find a sharp increase during the past 35 years in the intensity of storms: The number of category 4 and 5 tropical cyclones, the most intense storms that cause most of the damage on landfall" (Kerr, 2005, 1807.) Globally, category 4 and 5 storms increased regarding to his calculation by 57 percent from the first half of the period to the second.



Bad trend rising. The number of the most intense tropical cyclones is increasing worldwide.

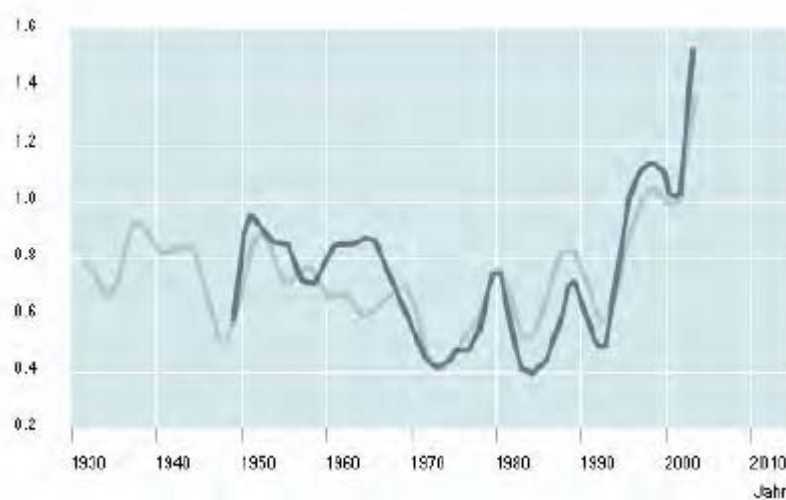
Source: Kerr, 2005, Science, p. 1807

At this point the main criticism of opponents starts. They have suggested, that the upward trend of storm intensity might be artificially produced by the insufficient state of tropical cyclone intensity measurements. And two groups – led by John Knauf of CSU and Bruce Harper of Systems Engineering Australia Proprietary Limited in Brisbane – attempted to correct intensity records from parts of the Pacific Ocean for now-obvious errors. Both reanalyses reduced upward trend of storm intensity (See Kerr, 2006). Therefore it seems to make sense to check the reliability of the data base used by Emanuel and Webster. On the other hand, it also has to be noted, that both reanalyses did not eliminate the trend (Kerr, 2006). Webster agrees, that "the data's not very good". But he also adds: "However, to say it's all artificial is an exaggeration. We would have had to have misidentified 160 to 180 category 4's and 5's" (Kerr, 2006).

And a new study by Ryan Sriver and Matthew Huber, which soon will be released in *Geophysical Research Letters*, supports the results of Emanuel and Webster with a different set of data. It uses a compilation of the world's weather data developed at the European Centre for Medium-Range Weather Forecasting in Reading, UK. They found a 25% increase in storm power between the first half of the 45-year record and the second, consistent with Emanuel's analyses (Kerr, 2006).

Strong Correlation between Sea Surface Temperature and Hurricane Intensity in the North Atlantic

A further aspect of the argument is based on the validity of the data. In his article, Emanuel displays (Emanuel 2005) that there is a strong correlation between sea surface temperature and hurricane intensity in the relevant part of North Atlantic. In the area just north of the equator in the Atlantic Ocean, where most hurricanes get their start, the power released during their lifetimes is "spectacularly well correlated with sea surface temperature", (Emanuel in Kerr 2006). It is interesting to note that this correlation has been strongest since 1970. This is the period where the best data exist. Only since the 1970s researchers had satellites that allow them to look directly at hurricanes. This is the reason why it seems unlikely that the quality of data since 1970 will be criticised. Based on this strong correlation Emanuel expects that the trend of more intense hurricanes, induced by global warming, will continue in the future, if sea surface temperature is to be further increased.



Correlation between sea surface temperature in the part of north atlantic, where most hurricanes have their origin (bright curve), and the annual intensity of the hurricanes (Power Dissipation Index – PDI (dark curve)). (Faust, 2006 based on Emanuel, 2005). Using data from six ocean basins in the last 35 years, Carlos Hoyos and colleagues at the Georgia Institute of Technology in Atlanta have

Only Climate Change can Explain this Correlation

Carlos Hoyos and colleagues from *Georgia Institute of Technology* (GIT) in Atlanta et al. (2006) have shown in an additional study based on statistical models and data from six ocean basins in the last 35 years, that all other known factors – as humidity in the lower troposphere, vertical wind shear and the changes in "zonal" winds with longitude - which might potentially be able to explain the increase in intense hurricanes don't show a stable trend over the last 35 years. The new Georgia Tech study has now clarified this issue, showing that while hurricane intensity may be substantially influenced by these other factors for an individual storm or storm season, only an increase in sea surface temperatures can account for the long term increase in hurricane strength. The results show that the trend of increasing numbers of category 4 and 5 hurricanes for the period 1970–2004 is directly linked to the trend in sea-surface temperature; other aspects of the tropical environment, although they influence shorter-term variations in hurricane intensity, do not contribute substantially to the observed global trend.

If this conclusion is accepted, it would be clear that global warming has an impact on the intensity of hurricanes.

Wrong Observations or wrong Theory?

The debate is not, whether there exists a link between global warming and hurricane intensity at all, but whether it is really so unexpected strong as the observations from Emanuel, Webster, Srivier and Huver suggest.

Doubtlessly, theory and computer models so far didn't support such a strong connection between global warming and hurricane intensity. Pielke argues that the global modelling studies suggest the potential for only relatively small changes in tropical cyclone intensities related to global warming. And as Landsea stated, according to theory and computer models the intensification by now should be only a sixth of what Webster and Emanuel have reported. Consequently, the current question is: are the observations, which support an anomalous strengthening trend of hurricane intensity wrong and a fiction, based on a deeply flawed hurricane record? Or are the theory and modelling wrong? As Emanuel puts it: „They tend to count [the anomalous strengthening] against observations. I count it against the theory, although I helped develop the theory.“ (Kerry, 2006).

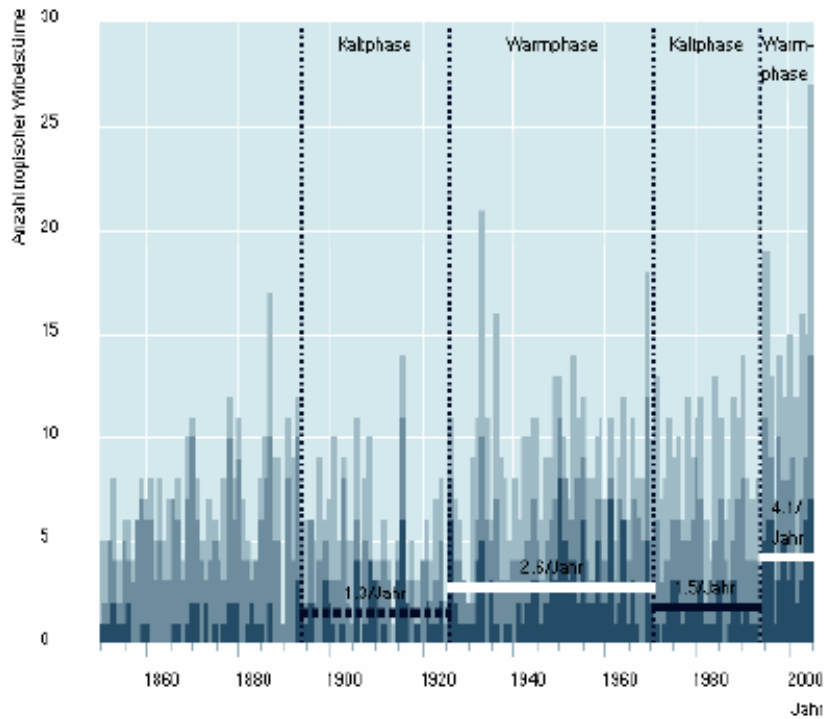
A new simulation from Kazuyoshi Oouchi et al. of the Advanced Earth Science and Technology Organisation in Yokohoma, Japan, runs on Japan's Earth Simulator, the world's most powerful supercomputer devoted to earth sciences. The result supports the idea, that improved models could reconcile ones with the observations. Global climate models typically calculate climate at points of 200 kilometers or more apart. The resulting pictures of climate are too fuzzy to pick up anything as small as a tropical cyclone. But the Japanese group simulated the present climate and the warming climate near the end of the century at a resolution of just 20 kilometers, thanks to the Earth Simulator's power. That was detailed enough for tropical cyclones to appear in the model, allowing the researchers to roughly gauge their intensities. In fact, in the warmer world, the total number of storms over the globe had actually decreased by 30%. „But the number of the rarer category 3 and 4 storms had increased substantially, not unlike observational results“ (Kerr, 2006).

How Big is the Impact of Global Warming in Relation to the Natural Cycle?

Pielke further argues that the relevance of global warming is exceedingly small in the context of, for example, the more than doubling in numbers of major hurricanes between quiet and active decadal periods in the Atlantic (Pielke, 2005, based on Goldenberg et al. 2001). Also the U.S. National Oceanic and Atmospheric Administration (NOAA) stated 2005 in press releases, that „longer-term climate change appears to be a minor factor“ in „the most devastating hurricane season the country has experienced in modern times“. The surge in Atlantic hurricane activity since 1995 is the latest upswing in a natural cycle, the releases said: As the Atlantic Ocean warms and wind patterns shift, hurricanes increase for a decade or two until a lull sets in again (see Kerry, 2006). Christopher Landsea of the Hurricane Center in Miami, Florida, recently claimed that NOAA public affairs staff members writing the press releases had overstated the case for natural cycle. The warming may well be largely human-induced, cited Kerry Landsea. (Kerr, 2006). As all oceans basins show a warming of sea water surface, it seems very likely that it also plays a significant role in this case.

Faust (2006) used the data provided from NOAA to show a remarkable increase of strong hurricanes over time both in cold and warm phases since 1860. The new warm phase shows more intense hurricanes than former the warm phase. The last cold phase showed more intense hurricanes than the former one.

Abb. 4
 Jährliche Häufigkeiten tropischer Wirbelstürme unterschiedlicher Kategorie



Jährliche Häufigkeiten tropischer Wirbelstürme unterschiedlicher Kategorie. Horizontale Linien bezeichnen die mittlere jährliche Anzahl von Hurrikans der Kategorie 3-5 während der Warm- und Kaltphasen im Nordatlantik. Abgrenzung der Phasen nach Landssea et al. (1999) und Goldenberg et al. (2001). Datenquelle: NOAA, Unisys; Grafik: Münchener Rück

- Tropische Stürme und Hurrikane
- Hurrikane (Kategorien 1-3)
- Starke Hurrikane (Kategorien 3-5)
- Mittlere jährliche Anzahl starker Hurrikane während einer Kaltphase
- Mittlere jährliche Anzahl starker Hurrikane während einer Warmphase

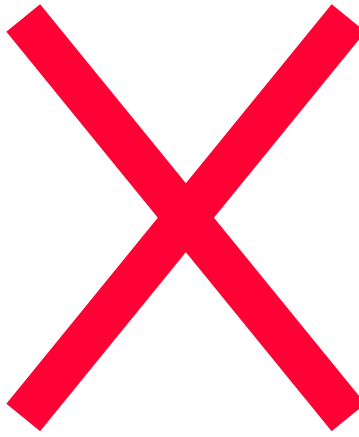
Because of lack on reliable data only four time periods have been compared. These data doesn't allow to base a strong argument, about to what extent anthropogenic global warming contributes to the actual increase of intense hurricanes. But at least they demonstrate, that the existing data better support the claim, that climate change is a relevant co-driver of record hurricane intensity than its opposite claim, that the natural cycle is the only driver.

Are Category 4 and 5 Storms also Stronger after Land Fall?

There is still a debate, whether category 4 and 5 storms are not only stronger at sea, but also at the time of landfall (Kerry, Emanuel in Dreifus, 2006). However, Faust has shown, again based on NOAA-data, that between the last (1926 until ca. 1970) and the actual warm period (since ca. 1995) also the number of landfalls has dramatically increased:

- category 3-5 hurricanes: +67 %
- category 1-5 hurricanes: + 28%
- tropical storms and category 1-5 hurricanes: +47.

Faust does consider global warming as the main driver for this difference (Faust, 2006).



The record years 2004 and 2005 further support the assumption of a new trend. But for really seeing a new trend rather than just some extreme years, the timeline from 1995 to 2005 alone is too short to show this. If we see from now on an increase of 70 % or (with increasing sea surface temperature) even more 3-5 hurricanes, in all warm phases, then this would be extremely significant. The record numbers of the last years could support such an expectation. Still, there is also the possibility that we have only experienced some extreme years and the rest of the decade will be more like past warm phases.

Is Climate Change a Significant Factor for Increased Hurricane Impacts on Society?

So far there has been a broad consensus that *for the past* the most significant factor underlying trends and projections associated with hurricane impacts on society is societal vulnerability to those impacts and not the trends or variation in the storms themselves (see Pielke and Landsea 1998; Pielke 2005). Consensus seems to be that growing population and wealth in exposed coastal locations guarantee increased economic damage in coming years, regardless of the details of future patterns of intensity or frequency (Pielke et al. 2000).

But whether already in the past the impact of climate change – not as the primary but as a secondary factor – on societal impacts can be shown; and whether climate change is becoming an increasingly significant factor for the increase of hurricane impacts on society up to now constitutes an open debate.

A further question is, whether the methodology of Pielke really can support his strong hypothesis that „long-term records of economic damages show no upward trend, once the data are normalized to remove the effects of societal changes“ (Pielke, 2006; Pielke et al., 2005).

An additional debate of interest could be, whether other methodologies would be more appropriate, to look at the impact of hurricanes on society. One example: As we know, the poor and marginalised population is most affected from weather extremes. Only 11 percent of the people exposed to natural disasters lived in countries classified, according to the UNDP Human Development Index (HDI), as those with a low HDI. But still, these countries account for more than 53 percent of the total recorded deaths (see UNDP 2003). Even more striking is the fact, that over 96 percent of disaster-related deaths in recent years have taken place in developing countries (World Bank 2001). Also the data for weather-related disasters in 2004 show, that countries with a low ranking on the Human Development Index and people living there are more vulnerable:

It is questionable whether Pielke's methodology would adequately reflect significant effects of increased hurricane intensity for the poorest and marginalised part of the population. Such a change might not be relevant in economic terms but most relevant for many people.

Even more relevant might be, whether the conclusion of Pielke (2005) regarding *the future* can be defended. He not only sees no trend identified in various metrics of hurricane damage over the 20th century. While he accepts, that scientists may identify discernible changes in storm behavior, he also argues regarding the future, that it is „exceedingly unlikely that scientists will identify large changes in historical storm behavior that have significant societal implications“. (Pielke, 2005).

Rahmstorf et al. (2005) come to a different conclusion: "The current evidence strongly suggests that:

- a) hurricanes tend to become more destructive as ocean temperatures rise, and
- b) an unchecked rise in greenhouse gas concentrations will very likely increase ocean temperatures further, ultimately overwhelming any natural oscillations. Scenarios for future global warming show tropical SST rising by a few degrees, not just tenths of a degree." (Rahmstorf et al. 2005)

As windstorm damages are exponentially related to wind speed (see for example Dlugolecki et al. 1996, in IPCC WG2 SAR), even small changes could have some effect. The force of increased velocity is proportional to the cube of the velocity. So it is not a linear function. So if we see a significant increase in 4-5 hurricanes and in related landfalls the impact on damage will even be more compelling.

New Regions, New Risks

Another risk for societies, not acknowledged in Pielke's hypotheses regarding the future, is that societies which so far didn't have to expect hurricanes could face this risk in future.

For most tropical meteorologists the most astonishing storm of 2004 took place in March 2004. Hurricane Catarina -- so named because it made landfall in the southern Brazilian state of Santa Catarina -- was the

first recorded south Atlantic hurricane in history. Textbook orthodoxy had long excluded the possibility of such an event; sea temperatures, experts claimed until then, were too low and wind shear too powerful to allow tropical depressions to evolve into cyclones south of the Atlantic Equator.

Two other extremely unusual, as far as we know unique, hurricanes emerged in 2005. Hurricane Vince developed in the eastern North Atlantic, a region not previously affected by hurricanes. It passed Madeira as a full-blooded hurricane and even reached the European mainland in southern Spain, but only caused minor damage.

At the end of November 2005, the Canary Islands were hit by Hurricane Delta, the first such storm there since the recording of tropical cyclones in the Atlantic began.

Sea Level Rise Increases Risk

Global warming also makes hurricanes more destructive by raising the sea level. So even if we wouldn't see any increase in number, intensity and regional distribution of hurricanes, they will become more destructive because of rising sea level: Assuming current trends of development practice continue, a FEMA study (1991) found that an increase in the expected annual flood damage in the US by the year 2100 for a representative NFIP insured property subject to sea level rise is estimated to increase by 36-58 percent for a 1-foot rise, and by 102-200 percent for a 3-foot rise in sea level. IPCC 2001 expected an increase of 9 to 88 cm during this century. Using the altimetry satellites TOPEX/Poseidon and Jason, a global mean sea-level rise of 2.8 ± 0.4 mma was estimated (Cazenave & Nerem, 2004). If this is the actual rate of sea level increase it would be at the upper range of the IPCC 2001 expectations (see Summary for Policy Makers, figure 5; see also Rahmstorf and Schellnhuber, 2006: 63f) and a 3-foot rise seems possible. Also the newest scientific evidence from an unexpected melting dynamic in Greenland and West Antarctica points in a direction, that even the extreme scenarios of IPCC 2001 (88 cm this century) might now be a very realistic one.

Ready to Agree on Rules of the Game to Test the Different Hypotheses?

Pielke et al. have given some criteria, under which circumstances they would be ready to accept that climate change increases significantly the hurricane risk for society. „Looking to the future, until scientists conclude (a) that there will be changes to storms that are significantly larger than observed in the past, (b) that such changes are correlated to measures of societal impact, and (c) that the effects of such changes are significant in the context of inexorable growth in population and property at risk, then it is reasonable to conclude that the significance of any connection of human-caused climate change to hurricane impacts necessarily has been and will continue to be exceedingly small.” (Pielke et al., 2005). It would be very interesting if different parties of this debate could agree about similar criteria, which are able to shift evidence to one side or the other. And about that every year new observations, new scientific studies and model results would jointly be tested in order to find out whether they support the one or the other side. The balance of evidence has been shifted. Strong arguments now point in direction of a hypotheses, which had few supporters only two years ago: that global warming has an increasing effect on the planet’s most devastating storms. But there might be much more left to say.

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THE BENEFITS OF DISASTER RISK REDUCTION AND THEIR EFFECTS ON LOSS TRENDS

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Abstract

Trends in economic losses from weather related disasters have often been attributed to both changes in weather extremes as well as to changes in exposure. Exposure is generally expressed as the number of people, or the economic value of capital, that are put at a certain risk. The reduction of disaster risk may affect exposure, but is often ignored. In this short paper I argue that effective disaster risk reduction may change exposure over time. Studies that do not consider disaster risk reduction may overestimate the effects of socio-economic factors that drive loss trends, such as population growth and the accumulation of capital. These studies may also underestimate the impacts of historic and future changes in climate and extreme weather events.

1. Introduction

Worldwide direct economic losses from natural disasters have been increasing considerably over the last (e.g. Munich Re 2005). Time-series analysis of loss records has shown that this increase for some weather related hazards in the US can largely be explained by changes in socio-economic factors, most importantly population growth and the accumulation of capital in areas that are at risk from natural hazards (e.g. Pielke and Landsea 1998; Changnon, 2003). These factors together have resulted in an increasing exposure. Some other scholars however have argued that climate change and consequent shifts in extreme weather events may have an important contribution to the increase in losses from weather related disasters (e.g. Mills, 2005).

Another important factor that may also affect losses is often ignored in the analyses of loss trends. That factor consists of efforts aimed at reducing risks from natural hazards. Increased efforts to reduce risks over time may decrease losses that result from extreme events. These efforts may consist of land-use planning, constructing dikes, improving and enforcing building codes, as well as the implementation of forecasting and early warning systems.

The Intergovernmental Panel on Climate Change (IPCC) stated in 2001 in its Summary for Policymakers of Working Group II: "The costs of weather events have risen rapidly despite significant and increasing efforts at fortifying infrastructure and enhancing disaster preparedness" (McCarthy *et al.*, 2001). It appears therefore that the many efforts around the world to reduce risk have not been able to curb the impacts from increasing exposure. At the same time, many efforts have been put in place over time, and may in recent times have mitigated the increasing losses to some extent.

The goal of this paper is first to present some examples of how risk reduction may influence the impacts from weather related disasters. Secondly, it aims to argue why it is important to consider the effects of disaster risk reduction.

2. Definition and benefits of disaster risk reduction

Disaster risk reduction can be defined as "The conceptual framework of elements considered with the possibilities to minimize vulnerabilities and disaster risks throughout a society, to avoid (prevention) or to limit (mitigation and preparedness) the adverse impacts of hazards, within the broad context of sustainable development"

(<http://www.unisdr.org/eng/library/lib-terminology-eng%20home.htm>).

Disaster risk reduction may address the extreme event itself, as well as the vulnerability to losses associated with that event. For example, one may try to reduce the peak height of a flood in a river basin, by implementing flood mitigation measures, such as the building of weirs, or by promoting afforestation of uplands. As a result, the probability of the extreme event (high water levels/flooding) may decrease. But additionally, one can make sure that the consequent losses are reduced while the extreme event still has the same probability of occurrence, for instance by improving the construction of houses. This makes disaster risk reduction simply one of the many factors that affect risk (Table 1).

Natural factors	Socio-economic factors
<ul style="list-style-type: none"> - Frequency of extreme event - Intensity of extreme event - Duration of weather events 	<ul style="list-style-type: none"> - Increasing population - Habitation of particularly vulnerable areas (coastal zones, flood plain areas) - Increasing wealth (more expensive construction of buildings, larger amount of increasingly expensive goods, larger stocks, larger number of increasingly expensive vehicles) - Increasing urbanisation - Change in management of rivers and coastal zones - Land use change (environmental deterioration, changed agricultural techniques, vegetation cover) - Changing or negligence of building codes and construction methods - Improving forecast, warning, and evacuation schemes - Increasing awareness of population

Table 1. Factors that may influence natural disaster risk (from Bouwer and Vellinga, 2002).

It is important to note that risk reduction may affect the impacts of different natural disasters in different ways. For instance, in a particular region one may be successful in reducing the risks of storm damage by enforcing building codes, but one may be less successful in reducing the risks of damage resulting from heavy rainfall due to the low-lying nature of the area.

3. Some examples of successful risk reduction

One clear example of the success of mitigating disaster risk is the reduction of the number of worldwide fatalities due to natural disasters (Figure 1). This reduction is likely to be due to a combination of increasing understanding of processes behind natural disasters, the ability to create structural as well as non-structural mitigation measures, such as the implementation of early warning systems and education of populations at risk.

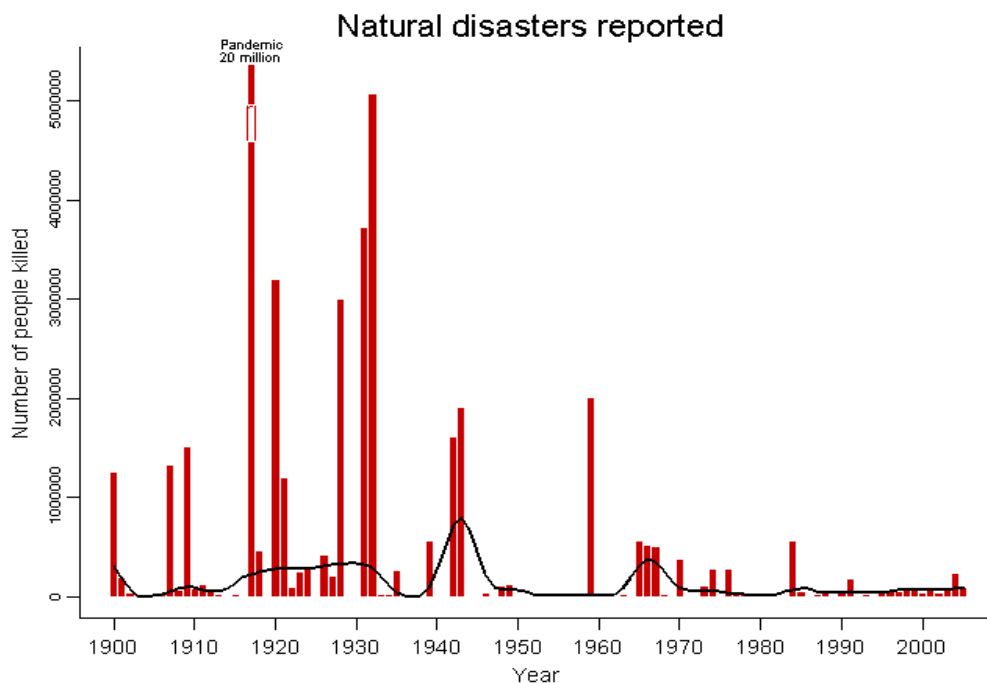


Figure 1. Number of fatalities from natural disasters (including diseases, source: <http://www.em-dat.net>).

An analysis of the improvement of building codes in Florida (USA) has shown that these codes were rightfully developed, as they help to reduce direct economic losses, as well as reduce the risk of casualties (Englehardt and Peng, 1996).

Another analysis of flood losses in the 2002 flood in Germany showed that local household protection measures may influence losses to a considerable extent (Kreibich *et al.*, 2005).

The reduction of the amount of losses from extreme events is an important prerequisite for implementing risk reduction measures. Within the evaluation of costs and benefits of risk reduction measures, the avoided damages are an important benefit, next to other indirect and often non-priced benefits, such as public safety. For instance, cost-benefit analyses are being performed for justifying investments in flood control and determining the optimal design of the measures (Brouwer and Kind, 2005; Pearce and Smale, 2005).

In The Netherlands, improving protection against storm surges was motivated by the benefit of protecting the assets present in the areas that lie below sea-level. Over centuries, the flooding frequency has varied considerably, depending on climatic factors, but according to Tol and Langen (2000) above all depending on factors such as technological developments, institutional change, and risk perception (Figure 2).

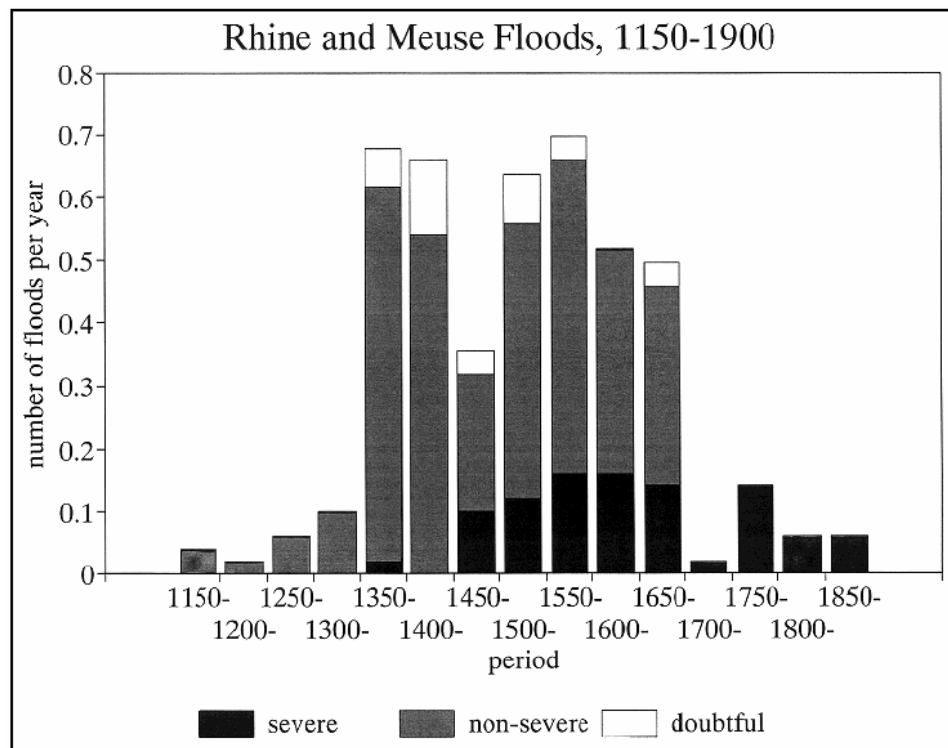


Figure 2. (from: Tol and Langen, 2000).

Awareness may be an important factor, as people may be able to better anticipate to floods, and prevent damage from occurring if they prepare for a disaster. This can for instance be illustrated by the two Rhine floods in Germany that occurred in December 1993 and January 1995. As these two floods quickly followed one another, the population living along the river was prepared for the next flood. People cleared their belongings to above the 1993 flood level, and consequently the damage of the second flood was reduced. The costs reflected this, as the flood in 1995 in Cologne caused half the damage of the flood in 1993 (1202 and 617 million DM total economic losses, respectively), despite the same water level (Bavaria Re, 1994; Bavaria Re, 1995).

Analyses of benefits of risk reduction are not commonplace, and are probably unknown for most locations around the world. Many efforts have been made to reduce risks from natural hazards (ISDR, 2004), although an exact number of

the total amounts of investments, let alone their direct benefits, is lacking. A good understanding of the effects and effectiveness of risk reduction is missing as well.

Tools to determine the benefits of natural disasters are available (e.g. Benson and Twigg, 2004), but may need to be further improved and applied more widely. A proper analysis of the effects would need to discriminate between different world regions, as risk reduction may have been implemented differently and at different times in the various regions.

4. The importance of analysis of risk reduction benefits

It appears that a good understanding of the effects of risk reduction is not present at this time. There is a need to further analyse the benefits of risk reduction, for a number of reasons. First of all, the analyses of the success of risk reduction may help to gain further support for the reduction of the impacts of natural disasters. Secondly, it may show that part of the effects of increasing exposure due to population growth and increases in wealth and the amount of capital may have been curbed, for some hazards in some areas.

Such analyses may have implications for disaster risk reduction policy and efforts in development cooperation, as it shows to what extent the efforts are successful. It may further show that there are opportunities for integrating climate change adaptation into efforts aimed at reducing risks from weather related disasters (e.g. Bouwer and Vellinga, 2005; Thomalla *et al.*, 2006). Also the financing of adaptation efforts could perhaps be largely integrated into risk reduction efforts (Bouwer and Aerts, 2006)

These analyses may also have implications for our understanding of and analyses of historic disaster losses. Loss records that are only adjusted for population growth and increases in wealth and the amount of capital may show a decrease in losses over time that is the result of risk reduction efforts. Adjusting for risk reduction effects may still show a climate signal in the record, that is, the effects of interannual climate variability, but it could reverse the long-term trend of losses and thereby show the impact of other environmental factors, such as climate change.

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CLIMATE CHANGE AND LOSSES THROUGH NATURAL DISASTER: SOME REMARKS FROM EXPERIENCE IN THE CZECH REPUBLIC

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Of all natural disasters, floods and windstorms are the most devastating in the Czech Republic. They often involve loss of human life and extensive material damage. The most spectacular cases to date have been the July 1997 flood in the eastern part of the Czech Republic (52 dead, material damage 63 billion Czech crowns) and the August 2002 flood in the western areas (19 dead, material damage 73 billion Czech crowns). Events of lesser extent occurred in July 1998 (flash flood in eastern Bohemia with 6 dead and damage estimated at 2 billion Czech crowns) and March/April 2006 (9 dead, damage 5 billion Czech crowns).

Recent developments in climate change, floods and windstorms in the Czech Republic

The process of global warming is reflected in the Czech Republic by statistically significant increases in air temperature with reference to the average series for 1848–2000, with the following linear trends: winter 0.93, spring 0.88, summer 0.36, autumn 0.52 and year 0.69°C/100 years. These trends are even more marked in the case of some individual stations. On the other hand, series of seasonal and annual precipitation totals show no significant linear trends, with the exception of an increase in winter.

Some important conclusions may be derived from analysis of floods in the instrumental and pre-instrumental periods in the Czech Republic (Brázdil et al., 2005a). In the period covered by systematic hydrological observations (i.e. since around the mid-19th century), the total numbers of the floods, as well as their extremities expressed through the N-year return period of maximum peak discharges, have been falling (Fig. 1). This decline may be ascribed primarily to a reduction of the frequency of floods of the winter synoptic type, those related to snow melting and ice damming accompanied by rain. This, in turn, is a consequence of global warming in which, following on from a later onset of winters and lower accumulation of water in snow cover, the number of floods has decreased, mainly in the months of February to April. Information held in documentary evidence makes it possible to extend the flooding information base back for several centuries. A synthesis of floods based on instrumental data and documentary sources indicates long-term trends, with a maximum of floods in the 19th century and the second part of the 16th century. From this analysis it becomes evident that, although several destructive floods occurred in the 20th century, it could well be classed as a very favourable hundred years (with the exception of the flood of July 1997).

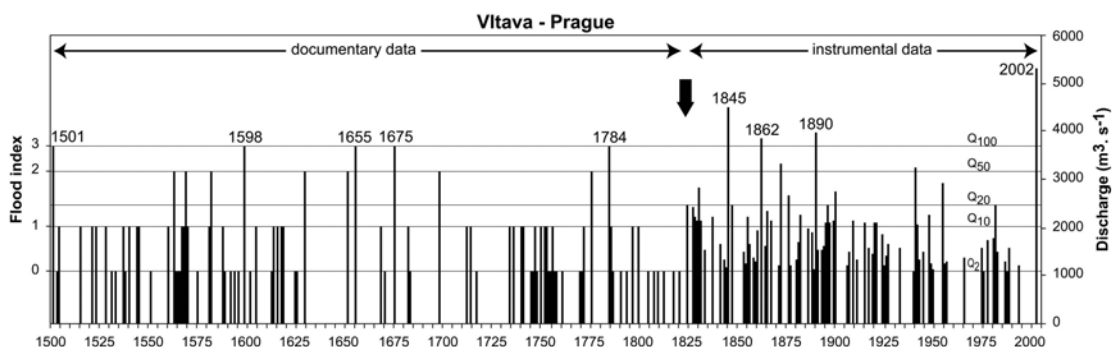


Fig. 1. Chronology of floods on the River Vltava at Prague in 1500–2002 – a synthesis of documentary data and instrumental records. Left axis: flood indices with reference to documentary data interpreted on an intensity scale of 0–3. Right axis: measured maximum peak discharges during floods with N-year water levels; for example, Q20 corresponds to a maximum peak discharge with a return interval of 20 years (Brázdil et al., 2005b)

The state of knowledge about changes in windstorm conditions (Brázdil et al., 2004) is blurred by far more complication than that involved in floods. Wind speed measurement data are significantly biased by changes in instruments over time, rendering the matter of obtaining homogeneous series complex, at best. The apparent frequency of strong winds reflects, at least to some extent, an increase in the number of documentary sources from the past. Despite this, it remains possible to speak of a higher frequency of strong winds at the cusp of the 16th and 17th centuries and largely in the years 1800–1830 and 1900–1940. On the other hand, the series of strong winds created does not allow presentation of any serious conclusions about long-term trends; the documentary records are simply incomplete (Fig. 2).

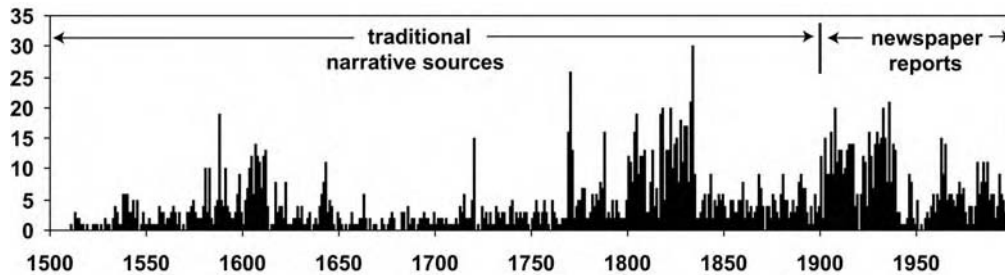


Fig. 2. Annual frequencies of strong winds derived from documentary evidence in the Czech Republic in the period 1500–1999 (Brázdil et al., 2004)

Factors accounting for increased costs associated with disasters in recent decades

No series of calculations of the costs of disasters exists for the Czech Republic. No institution systematically collects this type of data, while problems remain inherent to any comparison of recent costs of disastrous natural events with historical ones. Regardless of this, meteorological and socio-economic factors contribute to loss of human life and material damage in the course of disasters. With respect to climate change, it is expected that changes in the mean values will accompany changes in the simple occurrence of extreme weather patterns, followed by changes in the frequency and severity of extremes. The impacts proper can be then modulated by various socio-economic circumstances:

- **failure of historical memory**

It appears that people quickly forget that floodplains are not suitable places for building and other localised human activities. Lack of foresight in the utilisation of such areas increases material damage during floods. Historical buildings, such as churches, have not usually been flooded in the course of recent events because more care went into selecting safe areas for them.

- **changes in the landscape**

Considerable changes in land-use have taken place that largely reduced the water-retention capacity of the landscape. This is related to a significant increase in the area of arable land, expanding through deforestation and the drying-out of water-meadows and wetlands. Forestry management has concentrated on the production of monocultural fast-growing trees, growths that not only influence the water-bearing capacity of the land, but are not resistant to weather extremes such as wind, snow, ice deposits, drought and pollution. The canalisation of rivers is also an important factor. Original riverbeds have often been significantly shortened, straightened and reshaped by various water structures. In many cases, this has resulted in acceleration of runoff and the parallel occurrence of flood waves on different rivers.

- **the more complicated structure of human society**

An increasing number of inhabitants and the extension of human activities have increased pressure on the landscape and extended its use. In comparison with the past, significant changes in life-styles, as well as the use of more developed equipment in households, increase the potential for loss in recent events.

- **mistakes in planning and zoning**

An important means of diminishing losses is sensible territorial planning and zoning. Although information on

potentially inundated areas by floods of various return periods is freely available, building permission has nevertheless often been given in potentially dangerous areas.

– **poor social education about disasters**

Disastrous natural events have a long return period. The severity of floods is expressed in terms of the N-year return period of culmination discharges in which the corresponding value is achieved, or higher on average, than once per N-years. This is, however, confusing for lay people who often believe that, for example, “a hundred-year water will not occur twice in my lifetime”. On the other hand, people believe in the potential for technological protection; the system of water reservoirs on the Vltava below Prague (known as the Vltava Cascade) was built in the 1950s and a relatively quiet period followed. Many believed, until the catastrophic events of 2002, that Prague had been exempted from floods by the intervention of civil engineering.

Recent insights into natural disasters: implications for research and policy

Research related to natural disasters should address the following questions:

- Is the occurrence and severity of natural disasters part of a random process, or is it already a reflection of recent global warming (e.g. as reflected in the increased frequency of flood disasters in the Czech Republic, or Central Europe since the 1990s, or in the course of the past 10 years in the Czech Republic)?
- Can local or regional data on disasters indicate anything about larger trends and relationships?
- What conditions are necessary and sufficient to identify signals of climate change in disasters on local or regional scales?
- Are instrumental records long enough for useful insight into disastrous events with long return periods? For example, on the Vltava in Prague, a flood with a return period of $N \geq 100$ years recurred after 112 years (September 1890 and August 2002), but before 1890 similar floods occurred in February 1784, February 1799, March 1845 and February 1862
- How useful is information about extremes derived from documentary (the past millennium) and palaeoclimatological sources (before that) in the study of the severity, seasonality and impacts of past disasters – mainly in terms of the magnitude of events not experienced in recent time.

The recent behaviour of the insurance industry raises problems, in that it is now impossible to insure a house and/or property if they are located in a potential floodplain. In concrete terms, this entails a shift of responsibility for assistance in such events to the government (politicians) or to other parts of the decision-making sphere (managers).

It becomes clear that only one alternative exists for the future – to cope with natural disasters. Society, managers and politicians must have only one aim in preparation for extreme situations: to save human lives and diminish potential material damage. This needs organisation of all the activities that might make any contribution whatsoever in such critical situations.

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TORNADO AND SEVERE THUNDERSTORM DAMAGE

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ISSUES IN REPORT DATABASES

The historical records of the occurrence of and losses from severe thunderstorms and tornadoes present significant challenges in attempting to establish trends, if they exist. Very few countries collect data on events as an activity of the national meteorological service. Within those that do, spatial and temporal differences in reporting procedures or effort mean that consistency is rarely achieved (e.g., Doswell et al. 2005). It is likely that the highest-quality dataset of significant length is the tornado dataset of the United States, which began in the early 1950s. Even these data have serious problems with consistency (Brooks 2004; Verbout et al. 2006) (e.g., Fig. 1). Even though the vast majority of the increase has been in the weakest tornadoes (Brooks and Doswell 2001b), serious inhomogeneities exist even when consideration is restricted to the strongest tornadoes, which have typically been viewed as being better reported (Fig. 2). Recent and planned policy changes within the US National Weather Service may add even more problems to the interpretation of the record.

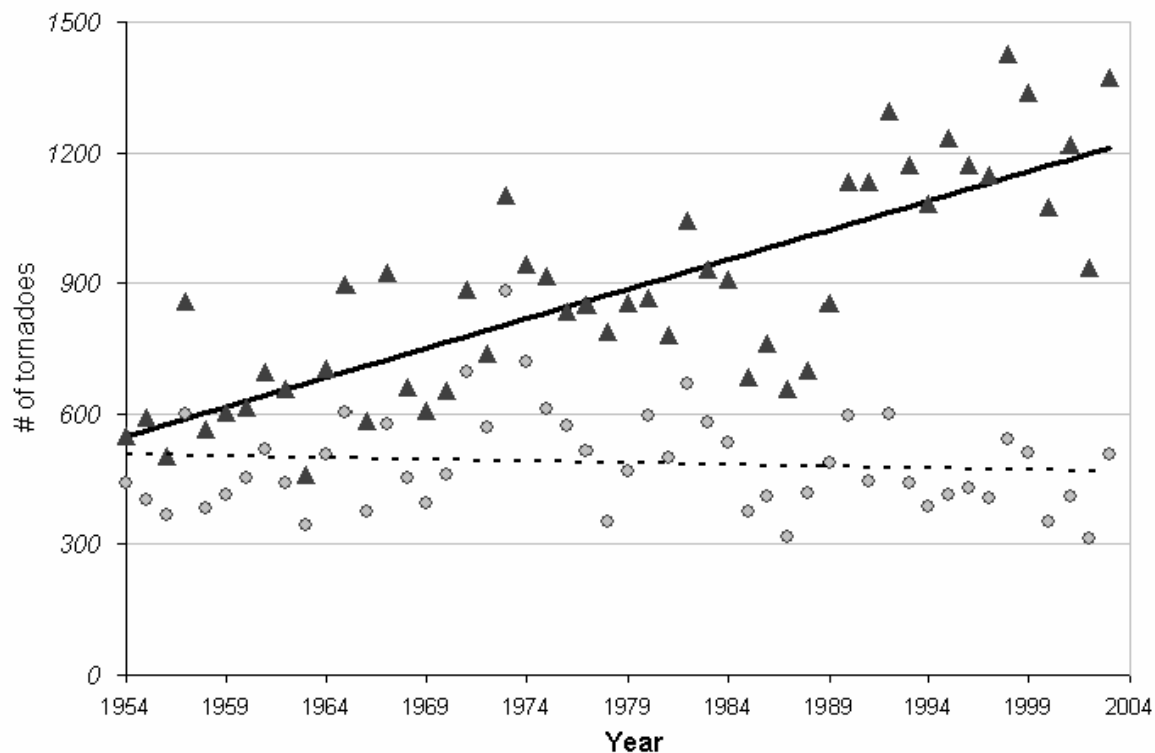


Fig. 1: 1954-2003 annual tornado reports in US. Total (black triangles), and tornadoes rated F1 or higher (gray circles). Linear regression fits to time series in solid and broken lines, respectively. (From Verbout et al. 2006).

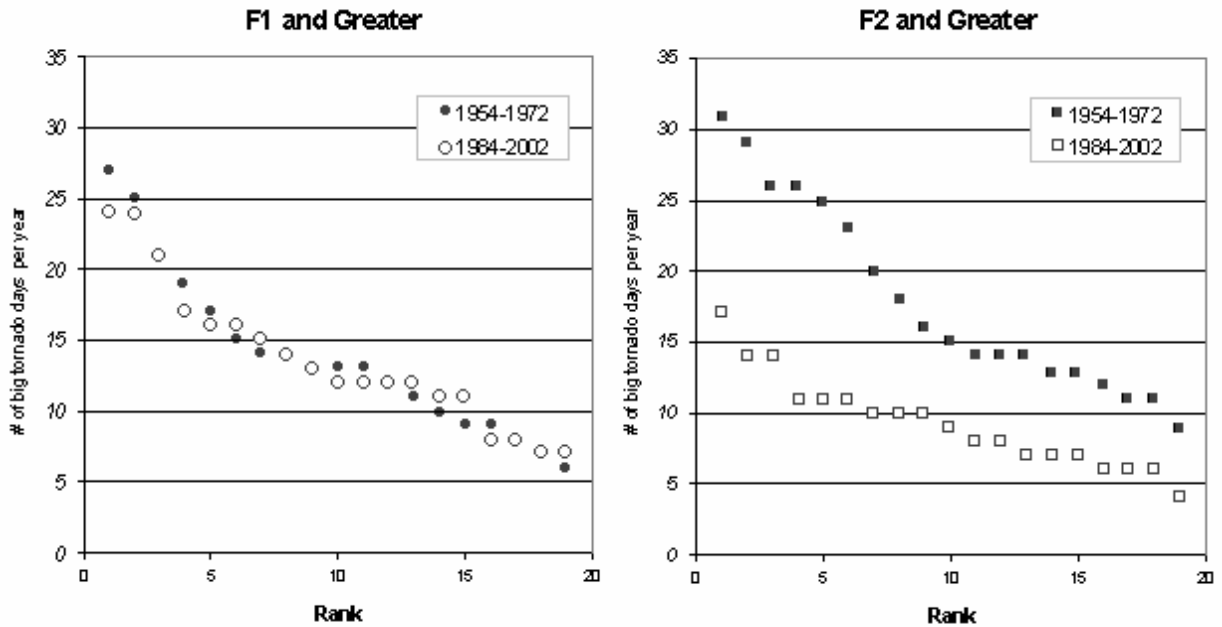


Fig. 2: The ranked distribution of number of days per year exceeding threshold for “big tornado days,” as defined by Verbout et al. (2006). F1 and greater series (left) and the F2 and greater series (right). The early portion of the dataset (1954-1972) is denoted by black points; the later portion of the dataset (1984-2002) is represented by open points. The leftmost point in each series is the greatest value and decreases to the right. (From Verbout et al. 2006).

The number of tornadoes reported per year has increased by about 13 per year, or roughly 1% of the current number of reports. Fundamentally, it is effectively impossible to determine whether any changes have occurred in the actual meteorological events from the official observed records in the US. Relatively large physical changes (say, 20% in the period of record) *could* have happened, but would be difficult to detect in the background of reporting issues. There is a profound break in the reported number of strong tornadoes (at least F2 on the Fujita scale, going from F0 to F5) in the mid-1970s, as shown in Fig. 2. Brooks (2004) also showed that the reported path length and width information has undergone large changes, seemingly independent of official policy alterations. It is possible to smooth the report data to produce a distribution of tornado occurrence that may be a reasonable estimate of “truth” (Brooks et al. 2003a), but that smoothing is likely to make the estimate sufficiently resistant so that real changes would be masked. In related work, Dotzek et al. (2003, 2005) and Feuerstein et al. (2005) have shown that the distribution of tornadoes by intensity is similar over much of the world by fitting statistical distributions to reports. Although different environmental regimes can be distinguished (e.g., the US vs. the United Kingdom), the quality of the fit at the most intense end of the spectrum, which represents the rarest events, means that detecting changes in the distribution by intensity of the strongest tornadoes will be difficult at best, unless those distributions are very different.

ENVIRONMENTAL CHANGES

An alternative approach to the question of changes in meteorological events is to look for possible changes in environmental parameters favorable for severe thunderstorms. Brooks et al. (2003b) followed techniques from forecasting research and developed relationships between large-scale environmental conditions and severe thunderstorms and tornadoes, using global reanalysis data. Recently, the work has been expanded to look at a longer period of record around the globe. Interannual variability on a global scale in the frequency of favorable severe thunderstorm environments has been large, with no discernable trend. Regionally, there have been changes, although the question of the quality of the reanalysis representation requires caution to be applied to the interpretation. The eastern US showed a decrease from the late 1950s to the early 1970s, followed by a slow increase through the 1990s

(Fig. 3a). For the same size region including the high-frequency severe thunderstorm areas of southern Brazil and northern Argentina, there has been a decrease though the period of record (Fig. 3b).

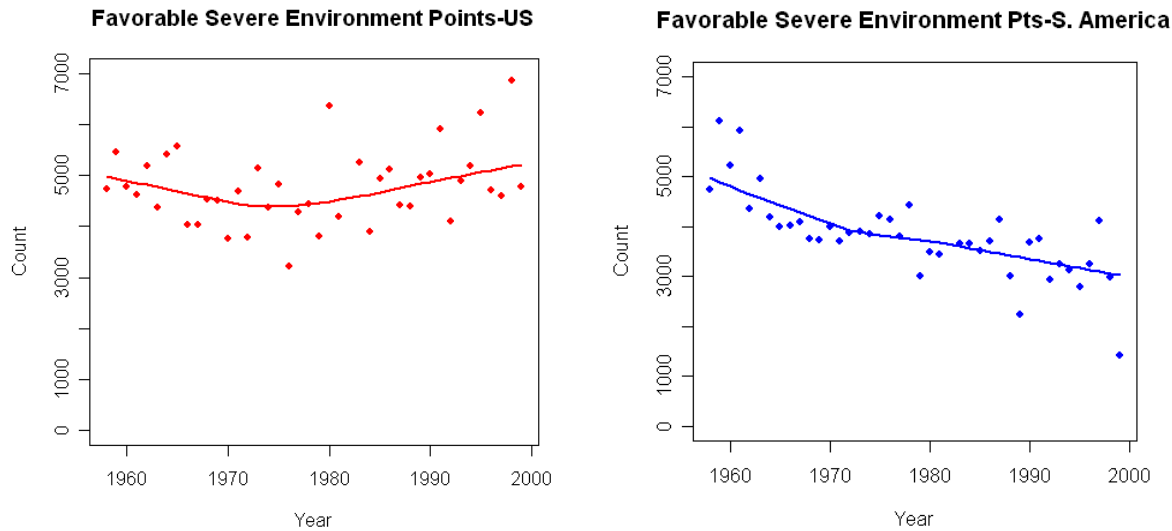


Fig. 3: Counts of 6-hourly periods at individual gridpoints with favorable environments for severe thunderstorms in the US, east of the Rockies (left) and South America (right).

The inflection point in 1973 in the US record is consistent with an inflection point in the number of reports of 3-inch (7.5 cm) diameter and larger hail per year. The reanalysis suggests an increase of 0.8% per year in the number of favorable environments in the region, whereas the reports have increased by 6%. If we take the reanalysis as an estimate of the real changes, a step to be taken with a grain of salt, it implies that the environmental changes have accounted for about 13% of the total changes in reports. It is interesting to note, perhaps, that the reanalysis trend in the US qualitatively resembles the US surface temperature record. Observations of events in South America are insufficient to corroborate the trend seen in the reanalysis.

DAMAGE AMOUNTS

The question of changes in the property damage caused by severe thunderstorms is a separate issue. The difficulties encountered in the report databases seem minor compared to those in the damage databases. Again, the systematic collection of data is a serious issue. Looking at historical descriptions of damage in national meteorological services, it is not always apparent whether damages that are reported are insured losses or total losses. Also, for some storms, no monetary estimate may be given. In other cases, the estimates that get recorded may be preliminary. For example, in some sources, the 1975 Omaha, Nebraska tornado is listed as the biggest-damage tornado, in inflation-adjusted dollars, in US history, based on a statement made the next day by the mayor of the city that there might be \$750 billion in damage, an estimate that turned out to be high by a factor of three. Nevertheless, the original estimate made it into some “official” records and still appears in some lists of the damage.

Another issue is that severe thunderstorm damage tends to be relatively isolated (in space), but occurs relatively frequently. Where and when storms occur can dramatically affect the amount of damage, even for the exact same meteorological event. An urban area may suffer little property damage from a widespread fall of 1 cm diameter hail, while a vineyard or grain crop at certain times of the year might be devastated. Hail of 5 cm diameter might cause vast amounts of damage in an urban environment, especially to vehicles, while, if it occurs before crops have emerged from the ground in spring, it might have little impact in a rural location.

Brooks and Doswell (2001a) looked at the record of property losses from the most damaging tornadoes in the US from

1890-1999 and adjusted the losses for inflation and national wealth.¹ They found that, by including the wealth adjustment, there was no tendency for changes in the most damaging tornadoes in recent years, with a return period of about 10 years for a billion dollar tornado. As possible support for the notion of using wealth adjustment, Beatty (2002) took the most damaging tornado from the Brooks and Doswell study, the Saint Louis tornado from 1896 and put its damage path on the current area to estimate property damage. His estimate was about 10% smaller than the approximately \$3 billion estimate from Brooks and Doswell based on national wealth adjustment.

As part of preparing for this workshop, I've built a simple model of the damage process. The model consists of two parts-tornado description and damage associated with the tornado. For the first part, I start with the mean number and standard deviation of annual reported tornadoes based on the linear regression from Verbout et al. (2006), roughly 1200 and 150, respectively. For each simulated year, a count of tornadoes is drawn from the distribution. Each tornado is then assigned a Fujita scale rating, drawing randomly from the empirical distribution of tornadoes by intensity for 1995-2004. A damage amount is assigned to each tornado. The damage amount for each F-scale is assumed to be exponential and has an absolute lower bound. The maximum damage is capped at \$6 billion, in order to avoid rare, but extremely large values that might bias the results. As a first guess, the lower bound of F5's damage was \$100 million, with a 10% probability of exceeding \$1 billion. The lower bound for each successively smaller F-scale was an order of magnitude smaller. The 10% probability was taken as an order of magnitude above the lower bound. (I've done some exploration with the various shapes of the distributions and bounds, but the results of the study are qualitatively similar.)

The distribution of annual damage from this model is log-normal, roughly similar to the observed annual reported damage. The mean of the distribution is roughly \$400 million per year and the return period for a single billion-dollar tornado is approximately a decade, in keeping with the observed record. The annual damage is, in effect, controlled by the damage associated with a small number of tornadoes, almost exclusively from the F3 and stronger tornadoes.

I explored the effects of changing the annual number of tornadoes and the distribution of intensity, looking for statistically significant differences in the distribution of annual damage. Increasing the mean number of tornadoes by less than 30% (more than two standard deviations) failed to produce statistically significant differences from the control simulation. Similarly, increasing the number of the most damaging tornadoes (F4 and F5) by 50% was necessary to get significant differences or to make the return period for billion-dollar tornadoes much shorter than a decade. These results aren't surprising, given that the damage is concentrated in a small number of rare events. Thus, large changes are needed to give a high probability of generating damaging tornadoes. As a result, it seems unlikely that damage amounts will provide a clear indication of changes, even with reasonably large physical changes.

CONCLUDING THOUGHTS

Problems in the reporting databases mean that it is extremely unlikely that climate change will be detectable in severe thunderstorm and tornado reports, even if there is a physical effect. Estimation of changes in the frequency of favorable environments may be more useful. There is no evidence to date to suggest that changes in damage are related to anything other than changes in wealth in the US. Given inflation on the order of 3% per year and a real GDP growth rate of 3.5%, reflecting the trends of the last half century, we would expect unadjusted damages to double every 10-11 years. From the adjusted damage work of Brooks and Doswell (2001a), there has been one year (1953) with 5 of the 30 most damaging tornadoes in US history. Thus, even a year with multiple events would not be evidence of changes.

It is of fundamental importance for future work to develop systems that collect data on the events and their effects in a systematic, consistent way. In the absence of databases of at least reasonable quality, it is extremely difficult to say much of substance.

¹ As of the middle of April 2006, no tornadoes have occurred that would have been included in the top 30 in terms of adjusted-damage in the US.

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THE PROXIMATE AND ULTIMATE FACTORS ACCOUNTING FOR THE INCREASED COSTS OF DISASTERS: DIAGNOSIS AND PRESCRIPTION

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1. Proximate Versus Ultimate Causes.

For the purposes of this paper the word “causes” is preferred over “factors”. It is assumed that “factors” and “causes” both mean “explanations for”, and can be taken as synonyms. It is more usual to separate causes into proximate and ultimate, and to consider factors as a set without initial differentiation as to relative importance or “proximity” to the presumed effect.

The proximate causes of the increase in disaster losses have been well rehearsed. They include generic factors such as the growth in human populations, and increases in wealth and real property. These factors lie beyond the reach or domain of the disaster mitigation community (DMC). The size and growth rate of human populations are the business of demographers and experts in human health and fertility, and the governments and agencies that they advise; increases in wealth and real property are similarly the domain of economists and the financial and investment worlds. It has not been considered the business of the disaster mitigation community (DMC) to advocate the reduction of human population growth or the reduction of economic growth and increases in wealth and real property. Perhaps this should be questioned. The DMC might make common cause with those who want to curb the growth in human populations, (and rejoice when growth is low or negative as in some countries?) and those who question the headlong rush to growth at any price and make common cause with the supporters of sustainable development or those who eschew high mass consumption and opt for lives of voluntary simplicity.

Beyond these generic causes of population growth and increases in wealth there are other proximate causes of the growing disaster losses which are clearly within the domain of the DMC. These include the disproportionate occupation of hazardous zones and the invasion of such lands either among the wealthy for amenity value (coastal areas, good views) or among the poor for lack of choice or opportunity (favelas on steep slopes, occupation of flood plains). The proximate causes also include the poor quality of construction, or when a minimal standard of construction is mandated by governmental authorities, the systematic avoidance or evasion of such regulations, usually for short term benefit.

2. Ultimate Causes.

The ultimate or more “upstream” causes of disaster losses have to do with the reasons why these proximate causes persist and have not been subject to serious attention from the disaster prevention community. Four factors or causes of this kind have been suggested. (White, Kates, and Burton. 2001). The text which follows draws heavily on this paper with some updates and new interpretations. The four factors are:

- **To some extent knowledge is lacking and disaster management continues to be flawed by significant areas of ignorance.**

This is no doubt the case in some places. Hazard zones have not everywhere been well mapped or identified, and the probabilities of extreme events are not well understood and considerable uncertainty remains. A good case can be made for more research on the “natural” causes of disasters. At the same time it has to be recognized that the physical science understanding of the process generating natural extremes has advanced considerably in recent decades and that in many cases of atmospheric hazards forecasting and warning abilities have improved

dramatically. While lack of knowledge might be offered as a partial explanation for growing losses in developing countries such an excuse is much less valid in developed countries, but losses continue to grow in developed countries.

- **To some extent knowledge is available and not used.**

Clearly the knowledge that exists could be more effectively used. There is probably more reason to attribute rising losses to the failure to act appropriately, than to the lack of knowledge. Yet there is evidence that in both developed and developing countries disasters continue to take people by surprise and that insufficient preparations have been made to deal with emergencies, even though this has been a major thrust of international activities. In developing countries this likely reflects the lack of resources, and the lack of adaptive capacity. There has been a rhetorical shift to arguing for more than emergency disaster relief and rehabilitation towards the long-term strengthening of the capacity to design and execute mitigation and vulnerability reduction efforts. As the climate changes and as the need for adaptation becomes more evident and recognized, there is clear opportunity for synergies between climate change adaptation and disaster prevention - mitigation.

- **To some extent knowledge is used ineffectively.**

Whereas in developing countries available knowledge may not be used due to lack of resources and capacity, in developed countries there are often major programmes designed to use knowledge that do not work effectively. At times this almost can be described as a pretence at using knowledge. Even where the knowledge is considerable, and the resources and capacity are available the administrative functions fall short of what might be expected. Land use planning and building regulations exist but have often been applied with a lack of conviction or are subject to frequent variances obtained by political means. Earthquake and other building codes have similarly not been properly enforced. Insurance, even when coupled to land use regulation has probably increased and not reduced losses for similar reasons. Conflicting interest and lack of political will seems to be at the base of many failures to apply knowledge effectively.

- **To some extent it may be a time-lag problem.**

The notion is that knowledge is increasing and becoming more widely available and used, and that with trial and error and a slow learning process the underlying situation is improving and it is only a matter of time before the positive results become manifest. While it would be reassuring to attribute rising disaster losses to a time-lag effect in the effective use and application of knowledge there is little room for complacency on this score. While the record of attempts to manage disasters is at best a slow success story proceeding in very small increments, there is little reason to expect fundamental change in the near term. Beyond these ultimate causes there are more profound and intractable factors at work.

3. Beyond the Ultimate Causes.

The above list of ultimate causes assumes that natural science and rationality can and will prevail. Or they are based on the hope that this will prove to be the case. The International Decade for Disaster Reduction in the 1990s was based on this sort of belief, and the work of the Kobe Disaster Conference (January 2005) and the Hyogo Declaration which it produced seems to have been similarly inspired. It is appropriate therefore to step back and ask if there are other factors that lie behind the persistent and evidently growing failure to manage disaster losses. This question has been asked before and the answer seems to fall into three parts – the nature of the problem; the deficiencies of human society or human nature; and the lack of measures to offset the situation.

Disaster events by definition occur infrequently in any one place. Human society has proved to be remarkably effective in adapting to variations in the natural environment. It is one of the distinguishing traits of our species. Humans have

effectively spread and occupied virtually all the environments on the planet from sub-arctic to semi-desert, to mountains and coasts. That successful livelihoods have been achieved in all these environments is testimony to adaptability and adaptive capacity. Throughout history there have been sudden losses and setbacks and perhaps even collapse due to environmental extremes to which people were not adapted. The fact that this obtains today is therefore not new. It is the scale of human development and the globalization of communications which makes the failure to adapt to extremes more visible and many times greater in consequences. But the phenomenon itself is not new. It stems from the nature of rare events in concert with the nature of human society. There probably has always been some level of adaptation deficit – greater exposure to extreme events and greater vulnerability due to the failure to adopt the right kind and enough mitigation measures. Due to the proximate causes identified the adaptation deficit is now growing at an apparently exponential rate. (Burton. 2004).

People have and always have had, as noted by economists among others, a short term time preference. Not withstanding our knowledge of the future and our capacity to anticipate, we tend to have a strong preference for the immediate and the short term. Discount rates as applied in most economic analysis used to make decisions take little account of the future beyond three or four decades. The present value of an asset that can only be obtained in fifty years time is practically zero. This is of course reflected in the behaviour of our political institutions.

What is to be done? We can throw up our hands and say – that is the nature of the human condition and it cannot be changed. Or we can turn our attention to finding the antidote, at least as far as disasters are concerned.

4. Policy and Research Implications.

The policy and research implications of the foregoing diagnosis can be summed up in terms of the old fable – we must be both hedgehog and fox. The hedgehog you will recall knows one thing, one big thing, and the fox knows many things.

- i) The first the big thing. Some sort of cultural transformation is needed that permits us to incorporate the rare and the long term into the everyday. Ken Hewitt (Hewitt 1997) was among the first in the disaster field to argue that disasters are not just rare events but that they are built into our everyday decisions. Dennis Milette (Milette 1999) has echoed this in his call for a “redesigned national culture” and a “cultural shift”. In recent years many other voices have repeated this message, but it is one thing to identify a need and a direction and quite another to know how to get there. The need and the direction involve moving to sustainable development; to greater respect for and harmony with the environment; to much greater social equity on a global scale; to a world managed by the rule of law and to an expansion and strengthening of international law. The case for such changes would be more easily understood if people could come to adopt a longer term view and the willingness to reduce the demand for instant gratification.

Such hopes and expectations it will be argued are well beyond the scope or capacity or even the interest of the disaster mitigation community. On the other hand if any such transformation is to be achieved it will require the combined efforts of many communities of interest. The disaster community is one such community and we can most help by making common cause with like-minded groups. One of the foremost to be considered is surely the climate change community. While probably only a very small part of the increase in disaster losses over the past few decades can be attributed to climate change, there is now strong evidence that climate change is affecting the intensity and frequency of some weather extremes and this trend is projected to continue and accelerate.

Beyond working with the climate change community to encourage and promote the development of longer term considerations into current decision making, the disaster mitigation community can design its own work to the same end. This requires not one big thing but many smaller and clever things.

i) **Smaller and Smarter.**

Clearly there is much to be done in further advancing knowledge and scientific understanding of the causes of the increased costs of disasters in recent decades, and more needs to be done to ensure that the knowledge is disseminated and available and that the capacity to use it is strengthened. More and better is also needed to ensure that knowledge is used effectively and in a timely way, and that the political will to act accordingly is generated and supported.

The creation of the political will is perhaps the most crucial element and since there are many obstacles this cannot be achieved without the growth of public awareness. Many of the efforts of the recent past have been directly or indirectly aimed at creating public awareness including the UN Decade on Disaster Reduction, the work of the International Strategy for Disaster Reduction (ISDR), and the Kobe Conference and the Hyogo Declaration. Similarly the work of the Red Cross/Red Crescent in promoting grass roots attention to natural hazards and community based risk and vulnerability assessment contributes from a bottom-up perspective.

Beyond these efforts some new and additional ideas might be advocated and adopted. These involve institutional change. If a culture shift is to be brought about the aspirations of scientists; those at risk, and those with social concern should be supported by institutional change.

It has been suggested that an Intergovernmental Panel on Natural Disasters (IPND) (Burton 2001) would be a helpful way of periodically updating scientific knowledge and bringing it to the attention of the public and decision makers. This is modeled on the Intergovernmental Panel on Climate Change which has been so effective in assessing and articulating the science of climate change. It could also work together with the Planning Group on Natural and Human-Induced Environmental Hazards and Disasters now being established by the International Council of Scientific Unions. An Intergovernmental Panel could also be augmented by a more popular institution such as an annual or periodic international forum on disasters similar to those that now exist for water resources (World Water Forum) and forests. These fora have been effective in calling attention to their respective issues and to the need for policy shifts that are in line with what is required to curb the growth in disaster losses.

Other institutional innovations could include the specific incorporation of natural weather-related disasters into the post-2012 regime of the UN Framework Convention on Climate Change, including a new legal instrument for adaptation. The use of insurance as a social policy instrument has received little serious consideration, and the work of the Munich Climate Insurance Initiative (MCII) could be further developed and widely promoted.

5. Conclusion and Summary.

There are many factors, proximate, ultimate and beyond, that can account for the increased costs of disasters in recent decades. The implications for research and policy that stem from the diagnosis made in this white paper are that the efforts directed at the proximate causes should be redoubled without delay, and that the more basic or fundamental causes must also be addressed through the generation of public awareness and the strengthening of political will. Recognizing that this is a slow process some immediate attention could be focused on institutional changes at the international level.

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NATURAL DISASTER LOSSES AND CLIMATE CHANGE: AN AUSTRALIAN PERSPECTIVE

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Summary

Ninety-five percent of the total building losses in Australia over the last century are due to natural hazards of a meteorological nature – tropical cyclones, floods, thunderstorms (especially hailstorms) and bushfires. This study reviews a recent analysis of insured property losses due to natural hazards over the last four decades that found no obvious remaining trend due to factors including global climate change after these losses had been indexed correctly for changes in population, wealth and inflation. Such trends are also noticeably absent from changes in a frequency-severity potential destructiveness index developed for land-crossing tropical cyclones on the east coast of Australia. This is also the case for the probability of national losses from bushfire, which has remained remarkably stable over the last century. We can say little about flood, which although important, is not uniformly insured in Australia. We conclude that to date, at least, societal changes – wealth and population - are the principle reasons for the increasing inflation-adjusted cost of natural disasters in this country.

We can cite few examples of legislative changes that might encourage communities to adapt more aggressively to mitigate anticipated changes in global climate. We suspect that this is in part due to the very large uncertainty associated with climate change predictions at a local level. Nonetheless improved building codes introduced after the destruction of Darwin in 1974 by Tropical Cyclone Tracy show what can be done where there is a demonstrated need. We argue that in addition to more scientific studies on improving climate projections under different emission scenarios, more quantitative effort be invested in detailing the vulnerability of communities to climate change. The recent study by Chen and McAneney (2006) looking at fine resolution estimates of the global coastal population as a function of distance from the shoreline and elevation is one example of this type of work.

Background

Meteorological hazards dominate building losses in Australia's short-recorded history of natural disasters. In terms of the total number of building losses (insured and uninsured) between 1900 and 2003, tropical cyclones (hurricanes and typhoons) have been most destructive, accounting for almost one third of losses with floods and bushfires each contributing about another 20%, as do thunderstorms if hail, gust and tornado are combined. Earthquake only accounts for 7%, a proportion that is heavily dependent upon a single event - the 1989 Newcastle earthquake¹ (Figure 1). This breakdown of cumulative losses by hazard suggests that Australia should be more sensitive than many other jurisdictions to changes in global climate, but by itself tells us nothing about how things are changing over time. The bulk of this paper will address this question.

We begin with an examination of a recent indexation of the Australian Insurance Disaster Response Organisation's (IDRO) database of insured losses since 1967. Our interest is to see whether any observable signal remains after we have adjusted the original losses for changes in inflation, population and wealth, in much the same way as has already been done for the US hurricane record (Pielke and Landsea 1998). The effort has been to estimate event losses in today's dollars; in short, what this event would cost the insurance industry if it were to reoccur today. Any residual trend might then be ascribed to other factors including global climate change.

¹ For long return period events such as damaging earthquakes, the historical record in Australia is an inadequate sample on which to judge the future.

In attempting to probe more deeply, we then look at two particular hazards: tropical cyclones and bushfires. We will have less to say about flood, which despite being important in an Australian context (Blong, 2004) has not been universally insured.

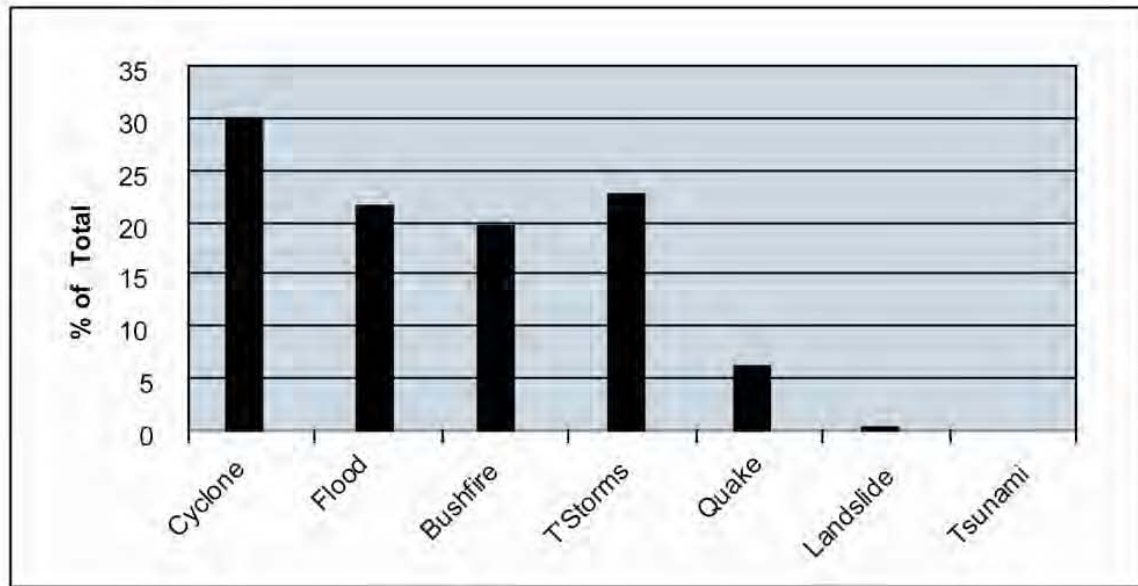


Figure 1: Percentage of the accumulated building damage between 1900 and 2003 attributed to different perils. T'storms refers to the combined losses from thunderstorms – hail, gust and tornadoes. Damaged buildings (including commercial premises) have been normalized to *residential house equivalents* destroyed using relative floor areas and building costs, where one *house equivalent* could equal two homes each 50% destroyed or 10 homes each of which experienced damage amounting to 10% of their replacement value. During bushfires, as compared with some other perils such as hailstorms, say, homes are more often than not completely destroyed (Source: PerilAUS database, Risk Frontiers.)

Insured losses – what would they cost today?

The above discussion considered total building losses – insured and uninsured. We now turn to an examination of insured losses, in particular the IDRO Natural Disaster Event List, which has recorded losses since 1967. The Disaster List is a record of natural hazard events in Australia that have caused significant insured losses. The list contains details of each event including date; areas affected; total insured (industry) cost in “original” dollars; and total industry loss in “equivalent current” dollars. Although the threshold loss for inclusion in the database has been varied over time, most refer to events with insured losses in excess of \$A10 million.

To estimate these losses in today’s terms, Crompton (2005) explored a number of different indexation methodologies. Each of the indexation methodologies incorporated a range of surrogate factors to account for changes in population, inflation, and wealth across regions. The preferred approach (Appendix A) is based on changes in dwelling numbers and value. It possesses important attributes of simplicity; easy accessibility of the underpinning information; and, by adjusting only for changes in building value, is *independent* of land value. Both this approach and that of Pielke and Landsea (1998) produce very comparable adjustments. Since damage to dwellings often makes up a major component of most catastrophe losses, our approach assures reasonable alignment to total insured losses.

Figures 2a and b below present the results of this analysis. Annual losses have been calculated for years ending 30 June to take account of the southern hemisphere seasonality of the main meteorological hazards. The Disaster List contains only five non-weather-related events – four earthquakes and one tsunami – out of a total number of 157 and so there is no bias towards these events in the annual losses.

When correctly indexed, the time series of insured losses exhibit no obvious trend over the last four decades. Tropical cyclones and hailstorms have the highest average losses per year, although tropical cyclone losses in Figure 2b have not been adjusted for improved building codes in cyclone-prone areas. To allow for this effect, the indexed tropical cyclone losses would need to be reduced. Figure 2b reveals that the increasing trend in unadjusted losses (Figure 2a) is largely attributable to changes in the number and value of dwellings.

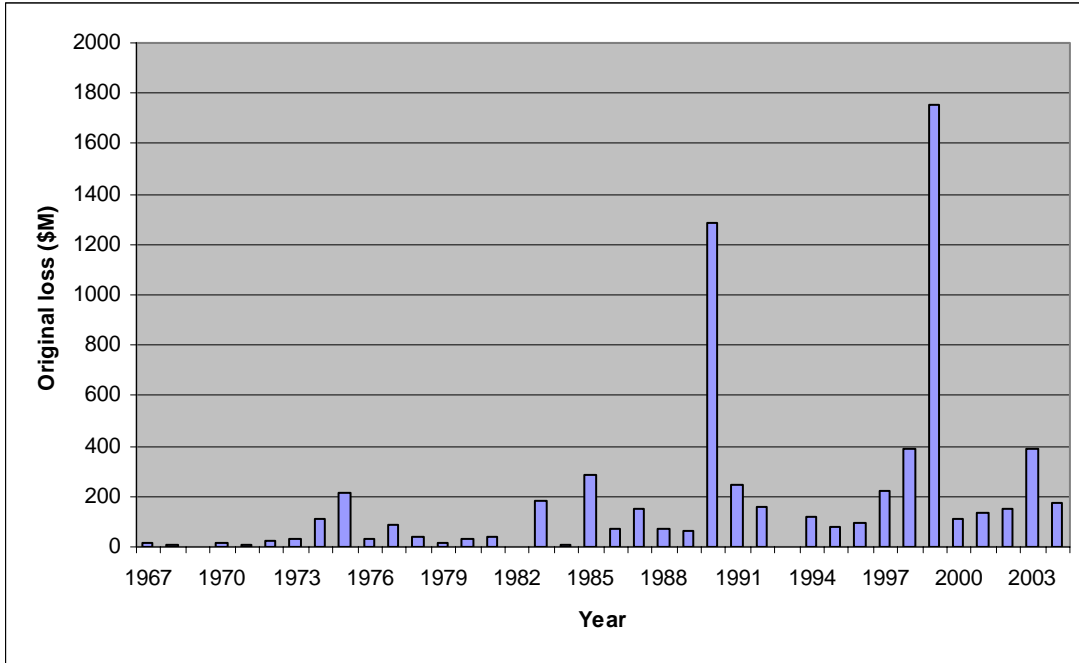


Figure 2a: Original annual aggregate insured losses (\$M) for all events in the IDRO database for 12-month periods ending 30 June.

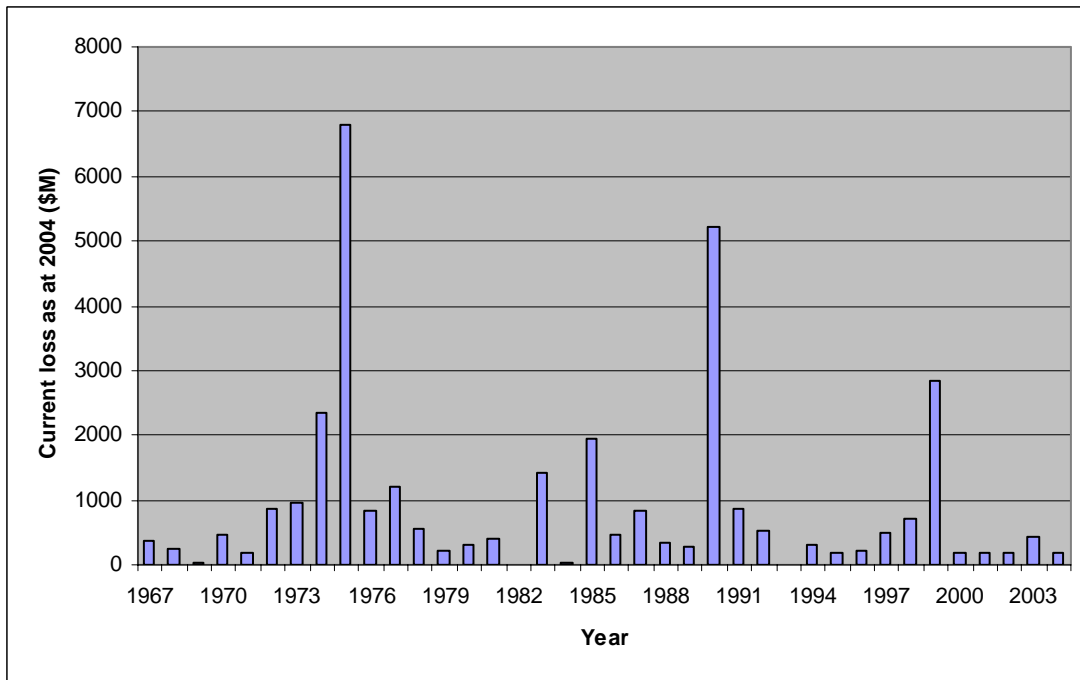


Figure 2b: As for (a) above but losses have been indexed to 2004 dollars.

Figures 3a and b show the breakdown by frequency and contribution to insured losses by hazard type after eliminating losses due to non-meteorological events – earthquake and tsunamis. In Figure 3b tropical cyclone losses have been reduced by 50% in a notional effort to account for improved building standards introduced after Tropical Cyclone Althea devastated Townsville in 1971 and Tropical Cyclone Tracy destroyed Darwin in 1974. In fact the actual reduction will be unique for each tropical cyclone path. The breakdown in insured losses by peril is somewhat different to that of the total number of buildings lost over the last century as displayed in Figure 1 and shows hail being the most destructive over this shorter time period. We remind the reader that flood risk is unrepresented here since it is not uniformly insured.

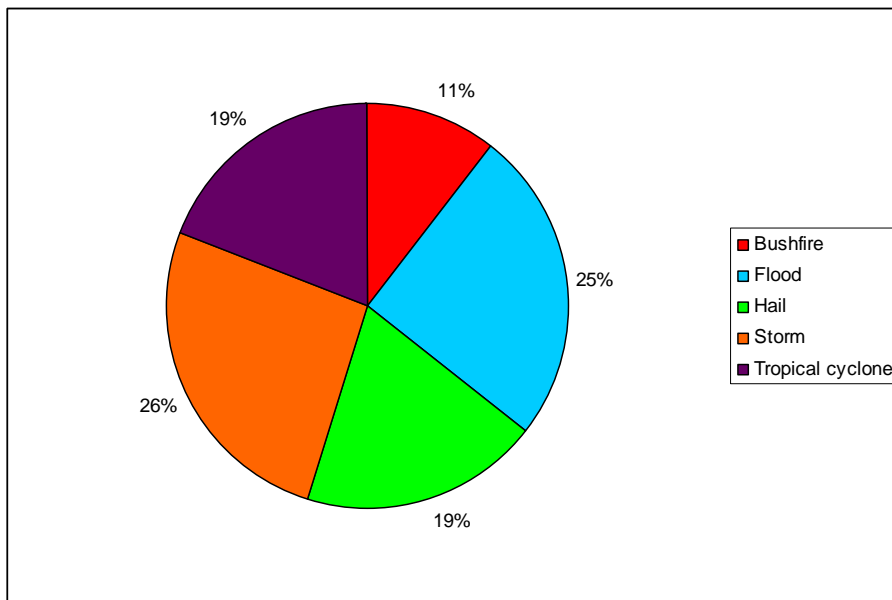


Figure 3a: Percentage of the number of weather-related events classified by hazard type in the IDRO database. Here event losses from hailstorms have been separated from other forms of severe weather – tornados and high winds.

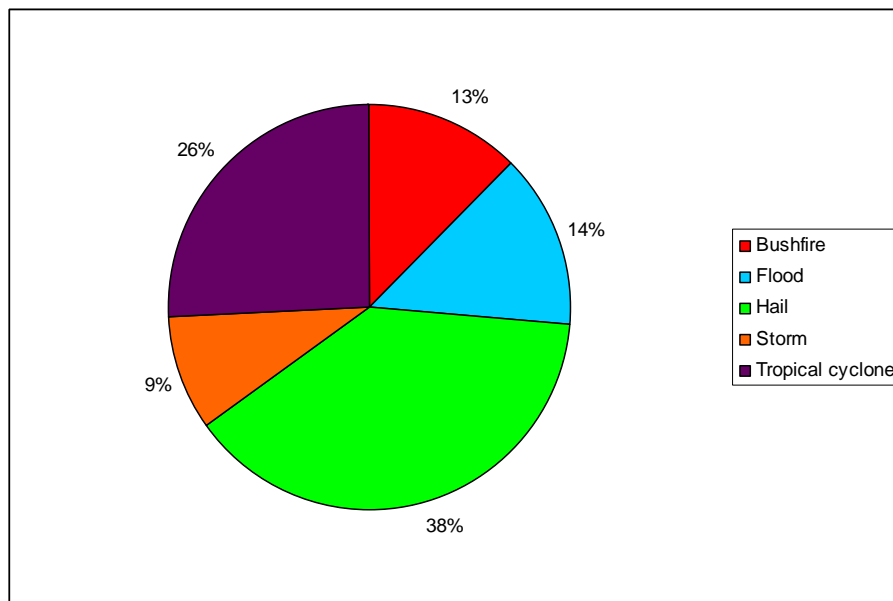


Figure 3b: Percentage of the total current loss as at 2004 (\$M) of weather-related events classified by hazard type. Tropical cyclone losses have been reduced by 50% in a notional attempt to account for post-1980 improvements in building codes in cyclone-prone areas. In fact, the true adjustment should vary for each tropical cyclone path and the proportion of post-1980 construction.

Frequency and severity of tropical cyclones that made landfall on the Australian east coast

We now briefly consider the time series of tropical cyclones that have crossed the east coast of mainland Australia during the last 45 years. Only events having a central pressure less than or equal to 995hPa were included. The analysis begins from the 1961 season and ends at the current 2005 season.

Cyclone activity in the South-western Pacific region is strongly related to the El Niño - Southern Oscillation (ENSO). Cooler ocean temperatures exist in the western Pacific and Coral Sea during El Niño episodes and ocean temperatures near the Queensland coast are typically above average during La Niña phases. Consequently, cyclone activity tends to shift further away from the east coast of Queensland and further north resulting in fewer than normal landfalling cyclones during the El Niño phase than during the La Niña phase.

Figure 4 shows successive five-season period frequencies of tropical cyclones that have crossed the east coast. Within each of the five-season periods there are different numbers of El Niño, La Niña, and neutral events. With the exception of 1971-75, there have been between two and four tropical cyclones for each period. It comes as no surprise that La Niña episodes dominated during this period.

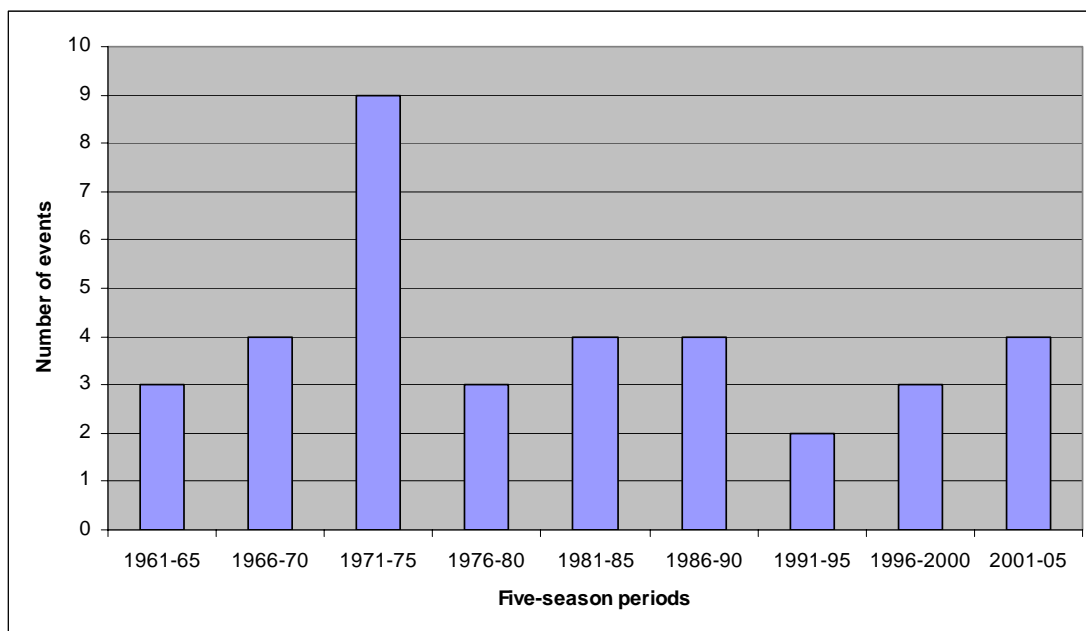


Figure 4: Number of tropical cyclones to cross the east coast during five-year periods.

Figure 4 only tells part of the story. Of more interest is the combination of frequency and intensity. According to Gray (2003), when normalised for coastal population, inflation, and wealth per capita, tropical cyclone-spawned damage in the US rises by a factor of four for each successive increase in Saffir-Simpson intensity category. Thus a landfalling Category-3 hurricane typically causes about four times the normalised damage of a Category-2 hurricane and so forth. Assuming that this same ratio between cyclone categories holds true for Australian conditions, Figure 5 takes this weighting into account. In calculating these figures, Category-5 and -4 events have each been assigned an equal weighting of 1/4; Category-3 a weighting of 1/16; Category-2 a value of 1/64 and Category-1 events 1/256. These are then summed for each 5-year period to obtain a relative potential destructiveness index.

By concentrating on the damage potential of the hazard alone, Figure 5 assumes a uniform portfolio of assets at risk. It also allows for Australia's low population density and the large physical distances between population centres on the exposed east coast. Actual damage arising from individual tropical cyclones will vary widely as a result of differences in population, terrain, topography, proportions of construction conforming to improved (wind loading) building codes, wealth per capita, direction and forward speed, storm surge, and rainfall.

Again we see no obvious change (increase or decrease) in the potential destructiveness over the time periods represented in Figure 5. Figures 4 and 5 focus on the east coast because this is where most of the insured exposure is located; however, very similar results hold for the western and north coasts of Australia or for the entire coastline. Nonetheless we do acknowledge that the small number of cyclones per five-year time interval makes it difficult to draw very robust conclusions. Moreover while the increase in surface air temperatures has accelerated since the 1980's, ocean temperatures have been slower to respond due to thermal inertia and thus it may well be too early for these to have yet played a significant role in increasing cyclone frequency or other attributes in this region.

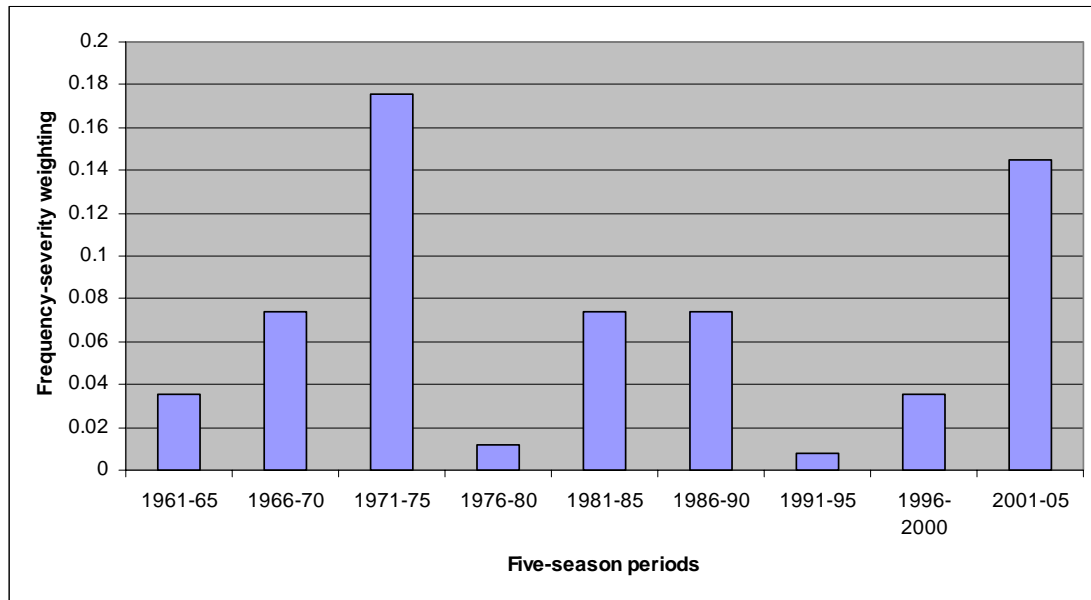


Figure 5: Combined frequency-severity of tropical cyclones that have crossed the east coast of Australia during five-year periods.

Annual probability of bushfire losses

Many papers on bushfire risk in Australia have concluded that the bushfire hazard will increase under high carbon dioxide emission scenarios (e.g. Pitman et al., 2006 and papers cited therein). With this in mind, it is interesting to look at the statistics of event losses over the last century. Table 1, drawn from Risk Frontiers PerilAUS database of building losses, lists two relevant statistics and illustrates how these change when calculated between a given start year and 2003. The first row indicates that at least some home destruction can be expected in approximately 60% of years, a statistic that has remained remarkably constant despite large increases in population, improvements in fire fighting technology and better understanding of bushfire physics. The corollary is that in 40% of years, bushfires cause no home losses. On reflection, this stability is perhaps not too surprising given that the propensity for fires to escalate once started is largely a function of the surface water budget, ambient temperatures, windspeed, and fuel load. Of these variables, only the latter is subject to human intervention through controlled burnoff practices. Moreover, once a fire exceeds a certain scale, there is very little that can be done to stop it until it runs out of fuel.

The second row of Table 1 lists the average annual frequency of having more than 25 homes destroyed within a single week, in other words, the annual probability of having a significant event loss as opposed to a large annual loss. This statistic has similarly remained remarkably constant at around 40%. At current average asset values (AU\$375,000 for average home and contents), an event loss of 25 homes would come close to AU\$10 million, the lower limit for consideration in the IDRO database. The 7-day time window has some relevance for reinsurance contracts but is introduced here merely to confirm that the stability of the annual probability of any loss mentioned already also holds true for larger events.

Although we concede that bushfire losses are the result of a complicated mix of social and climatic phenomena, the inference is again clear. We have little signal that can be unequivocally assigned to a changing climate. To argue that global increases in temperature and an increasingly lengthy urban-forest interface (Chen and McAneney 2005) have been exactly compensated by improved fire management techniques would stretch credulity.

Table 1: Statistics of bushfire loss probabilities (Source: *PerilAUS*, Risk Frontiers) calculated between the start year and 2003. The top row lists the frequency of any (non-zero) loss, while the second includes only those that resulted in more than 25 homes destroyed within a single week. Data in the first column (1900) has been adjusted to account for missing data (McAneney 2005).

Start Year	1900	1926	1939	1967	1983	1990
Annual probability of a loss	57%	54%	49%	59%	62%	64%
Annual Probability of a major event	40%	43%	41%	38%	38%	36%

Implications for research and policy

The evidence reviewed above suggests that, in Australia, population, inflation and wealth are the predominant reasons for increased insurance losses *to this point*. The role of monotonic changes in the frequency and intensity of natural hazard events, attributable to global climate change or otherwise, appears minor and is not detectable at this time. This conclusion is similar to that drawn by Pielke and Landsea (1998) and Changnon *et al.* (2000) for the US losses.

Given the above conclusion, it seems reasonable that research on climate change science should go hand in hand in a holistic manner with disaster management and mitigation research. As in other parts of the world, there is not a strong formal connection between researchers in the two communities in Australia. An important area of common interest between the disciplines should be quantifying and reducing vulnerability to coastal inundation, storms, bushfires and floods.

An encouraging example of what is possible is work undertaken at Risk Frontiers on identifying Australian addresses vulnerable to a wide range of ocean-related natural catastrophes such as storm surge, tsunami and significant sea-level rise under global warming (Chen and McAneney, 2006). Using the most recent, fine resolution global databases, this work quantifies the number of addresses in Australia located within 3 kilometres of the coast and having an elevation less than 6 metres above mean sea level. In extending this analysis globally, this paper provides plausible lower bound global estimates on the numbers of people at risk in coastal areas for the first time ever.

When it comes to developing and implementing climate change adaptation policy to, for example, reduce vulnerability in a particular locality or constituency, there is a problematic disconnect. On the one hand, confidence in global climate models is highest for global average temperature, wind, pressure, etc. Rainfall is more challenging and sea level rise has to be derived separately (McAvaney *et al.* 2001). Policy implications have naturally centred on reducing global emissions at a global level, e.g. Kyoto protocol. Meanwhile, disaster management or mitigation requires projections at a local level and for small-scale event-based phenomena such as floods, hailstorms and tropical cyclones. Global climate models cannot currently provide these projections with any skill.

There are very few examples of policies or legislation in Australia that were developed to help communities adapt to possible future climate change. An often-cited reason is the lack of reliable information at the local scale noted above. Given the truth of the oft quoted “all politics is local” attributed to Tip O’Neil, the Speaker of the House of Representative in the US, it is difficult to see significant changes occurring in the near future in this country.

The only positive Australian example we can point to are improved wind loading codes introduced in the 1980's as part of a *National Building Code of Australia*. These were introduced and enforced for all new construction following the destruction of Darwin by Tropical Cyclone Tracy in 1974. As a result, dramatic reductions in cyclone-induced losses were observed following Tropical Cyclones Winifred (1986) and Aivu (1989) (Walker, 1999) and more recently, Larry (2006). While, in reality, these improvements were introduced in response to existing natural variability in the occurrence of natural hazards, they are a perfect example of steps that should be taken to start to adapt to any future impacts of climate change.

It is not unknown for insurance companies to adjust their risk profile in response to perceived changes in climate variability or extreme events. After Samoa suffered three major cyclones within four years in the late 1980s and 1990s, the country's only insurer refused to renew insurance policies for cyclone damage and clients could only get new policies at a higher premium and with a structural engineer's certificate. Similarly Fiji was hit by a succession of cyclones in the mid 1980s. Half the insurance companies operating in the country withdrew and those that remained raised premiums and insisted on engineering reports for commercial buildings (Leigh *et al.* 1998). More recently Allstate in the USA stopped offering policies in coastal parts of New York City and Nassau, Suffolk and Westchester counties because the risk of hurricanes was perceived to be too high (as reported in the New York Times, 11 March 2006).

The 12-month cycle of insurance and reinsurance means that such reactive responses by the industry can take effect very quickly. They can also have important social and economic consequences. On a positive note the withholding of insurance or inclusion of conditions relating to building construction can prompt policy and legislative changes that reduce overall vulnerability to current natural hazards regimes and to the effect of climate change. To date, this is leverage that Australian companies have been loath to use.

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Appendix A

Indexation Methodology

$$CL_{04} = L_a \times N_{a,b} \times D_{a,s}$$

CL_{04} - event loss converted to 2004 value (current loss);

a - year the event occurred;

L_a - event loss in year 'a' (original loss);

b - Urban Centre / Locality (UC/L) impacted by the event. The UC/L Structure groups Census Collection Districts (CCDs) together to form defined areas according to population size criteria (<http://www.abs.gov.au>);

$N_{a,b}$ - dwelling number factor, determined by the ratio of the number of dwellings as at 2004 in the UC/L originally impacted by the event to the number in year 'a'. This information is derived from the 1966 and 2001 Census of Population and Housing;

s - State/Territory that contains the UC/L impacted by the event;

$D_{a,s}$ - dwelling value factor, determined by the ratio of the State/Territory average *nominal* value of new dwellings in 2004 to that of year 'a'. The dwelling value factor is calculated for the State/Territory that contains the UC/L impacted by the event. State/Territory average *nominal* values of new dwelling units are calculated by dividing the value of building work completed within a year by the number of completions within the same year. The relevant values are taken from the ABS *Building Activity* reports (<http://www.abs.gov.au>).

Note that the increase in average dwelling value is in part due to increasing average dwelling size and marked improvements in the quality of the housing stock (<http://www.abs.gov.au>).

While it has been shown the most important factors have been quantified and combined in the above indexation methodology, it is important to recognise factors not accounted for in the adjustment process. These include but aren't necessarily limited to the following:

- building code changes;
- changes in insurance penetration;
- changes in the quality of insurance issued over time i.e. companies ceasing to offer policies in high risk areas;
- changes in the impact of post-event inflation (demand surge);
- possibility of no change in population or exposure for particular events even though it is automatically assumed in the adjustment - imagine a hailstorm whose footprint extended across an already densely populated area where there have been no material changes in population or dwelling numbers since the time of the event;
- the impact of loss mitigation measures, e.g. improved bushfire prevention and fighting measures or new levees constructed near or around rivers in the case of flood;
- possibility that some recent events in the Disaster List not registering a loss had the same event occurred years ago, i.e. demographic changes mean that it's now possible for an event to register a loss in an area where there may not have been any people living in the past. This is particularly a problem for hazards such as hailstorms where there is no record of the event unless it impacted a populated area;
- frequency and magnitude of some of the hazards in the Disaster List are affected by meteorological and atmospheric cycles.

Note that not all of these adjustments increase the original loss.

When applied to the Disaster List, the preferred approach and that of Pielke and Landsea (1998) produce comparable current loss values. This is no coincidence, as dwelling assets comprise the main driver of the Australian wealth factor (63% for the 12-month period ending in June 2004) while the preferred methodology uses dwelling number and dwelling value factors directly. A disadvantage of the Australian wealth factor is that the dwelling assets also include land value. Moreover, an indexation methodology based on dwellings rather than population has advantages in that the housing stock increased at almost double the rate of population during the period 1911 to 1996. The outcome has been a marked decline in the average number of occupants of each dwelling in Australia from around 4.5 in 1911 to around 2.5 by 1996 (<http://www.abs.gov.au>).

THOUGHTS ABOUT THE IMPACT OF CLIMATE CHANGE ON INSURANCE CLAIMS

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Summary

This paper focuses on the type of extreme event that is important to property insurers, and considers evidence on how those risks have been changing, and how they might change in future with climate change. Some evidence is drawn from UK, which has wide insurance coverage for weather perils and also much familiarity with international catastrophe insurance. The author believes there is good ground to argue that climate change is already affecting the risks, though it is not the only factor that has caused change. Further, the risks of extremes may be changing very rapidly.

1. Introduction

Potentially, the insurance industry is exposed to climate change in a number of ways, although the effects may vary greatly between jurisdictions, due to industry structure and practice, as well as climatic and geographical differences. The insurance industry is already encountering aggravated claims for insured property damage in extreme events, particularly flood, storm, and drought. As yet, the main causes of the rising trend in property claims in recent decades are socio-economic rather than climatic, but the contribution of climatic change will likely rise quickly, due to the strongly non-linear relationship between climatic variables and damage, and the fact that a small shift in mean conditions can create a large change in extremes. The pace of change regarding weather extremes is fast. The underlying rate of change can be 12% per year for very rare events, and in the range 2 to 4 % for extreme, but "insurable" events. This means that underwriting strategies are inadequate to the real risks. Already target regions are evident, on coasts and particularly on deltas. Likewise some sectors could be strongly affected, with greatly increased risks.

A key source of evidence is UK, because of its wide insurance cover and good statistical database, as well as its familiarity with overseas markets, through its subsidiaries and also reinsurance of external markets. Next we look at global trends using data from Munich Re. Then we shall consider the literature as revealed by IPCC. Finally we look at European storm, from two studies not in the current IPCC draft.

2. UK Evidence

2.1 The Climate Idea

The UK has the longest series of scientific weather records in the world (1659 for monthly temperature, and 1766 for precipitation - see Hadley Centre website. This gives us the ability to calculate long-term weather patterns with confidence. For insurers, it is the extremes that matter, since those are what cause property damage.

Any month in which the monthly temperature or rainfall fell in the top or bottom ten percent of the historical range will have experienced some rather extreme days, so this decile threshold can be used to identify the extreme-weather months (hot, cold, wet, and dry). Since we are using the decile level to pick the months, there ought to be twelve such months in every decade (10 % of 120 months).

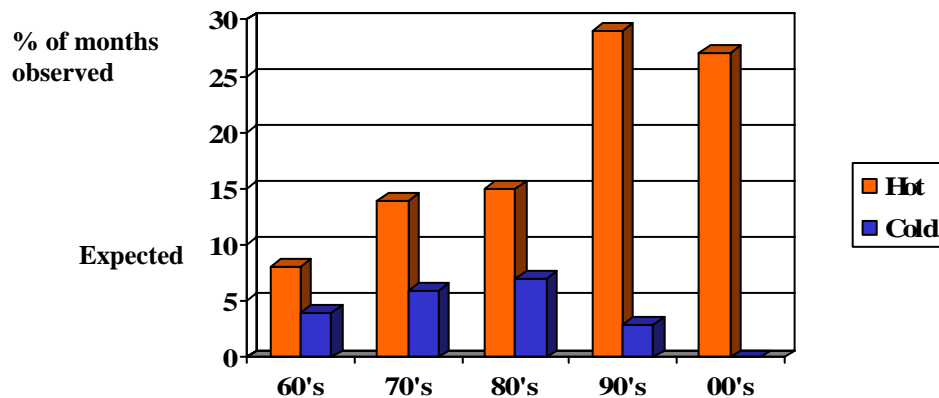
The table shows the pattern of extreme months in recent decades in the UK (bold for high value, italic for low value, as values outside the range 7 to 17 are statistically significant at the 5% confidence level).

Table 2.1 Recent UK weather: extreme months since 1960 (see Also Figure 2.1 below)

Number per decade (12 expected)	1960's	1970's	1980's	1990's	2000's (pro-rated to March 2004)
Hot	10	17	18	34	33
Cold	5	7	8	3	0
Wet	14	11	19	15	26
Dry	10	15	10	15	2

Note to Table 2.1. The figures for the 2000's decade are estimated by scaling up the observed occurrence of extreme months to March 2004, by the factor 120/51 to allow for the remaining months of the decade.

- For hot months, the 1960's were just below average, with only 10 hot months. Since then the frequency has risen dramatically, and it has been running at nearly 3 times the expected rate since 1989 in fact. This is the highest level since records began.
- Cold months however have been running well below the expected level since 1960, and have now disappeared. Again, this is unprecedented.
- Wet months have become steadily more frequent, now running at double the customary rate. This is particularly a winter phenomenon.
- Dry months seem to have receded for the moment. However, it is worth noting that what matters here from an insurance point of view is a succession of below-average months, rather than simply isolated very dry months. A prolonged dry period leads to shrinkage of clay soil, with consequent damage to the foundations of buildings and claims for subsidence.



Statistical significance of the recent observations

To test whether the data is generally consistent with the long-term average of 12 extremes per decade, we can use the standard χ^2 test, with 4 degrees of freedom. The test results are:

$$\text{Hot } \chi^2 = 61.3 \quad \text{Cold } \chi^2 = 15.6 \quad \text{Wet } \chi^2 = 12.1 \quad \text{Cold } \chi^2 = 5.5$$

Since the significance levels at 98% = 11.7, and at 99% = 13.3, the test results confirm that, apart from cold months, the observed weather since 1960 has been abnormal.

Applying the standard normal distribution approximation test to the deviations from expected: $z = \frac{\text{observed} - \text{expected}}{\sqrt{\text{expected} \times \text{probability of not occurring}}}$ for temperature after 1990 gives:

Hot $z=7.75$ Cold $z=3.47$

These values would be seen by chance 1 in a million and 1 in 4000 times respectively, confirming how very abnormal this weather is by historical standards.

Implications

This change to warmer winters is associated with more storms (the number of winter storms crossing the UK has doubled over the last 50 years), more rain, fewer frosts, and faster thaws. Warmer, drier summers mean more clay-soil subsidence. Significant weather events affecting the UK during this period include:

- The extended drought and heatwave of 1975/6
- The “hurricane” of October 1987
- The severe windstorms of January and February 1990
- Numerous severe local floods eg at Perth in January 1993 (see Annex 2 for more detail)
- The Shetland storm of 1993, probably the deepest ever depression in NW Europe, which wrecked the tanker Braer
- The drought and heatwave of 1995
- The Easter floods of 1998
- A close call - three storms devastated mainland Europe (December 1999).
- The Autumn floods of 2000
- The drought and heatwave of 2003
- Looming drought in 2006

2.2 Insurance Data (see Annex A1 for statistical data)

However, it has to be borne in mind that the impacts develop unevenly when looked at on an annual basis, because of catastrophes. Figure 2.1 shows this for weather claims in constant values, which demonstrates the true scale of the 1990 peak. The massive spike in 1990 was due to a four-week period of storms commencing on Burns’ Day. The fact that individual years have been lower since then does not mean the risk is diminishing, because of the random occurrence pattern. There was another great storm in 1987, a near-miss in 1993 and three near-misses in 1999!

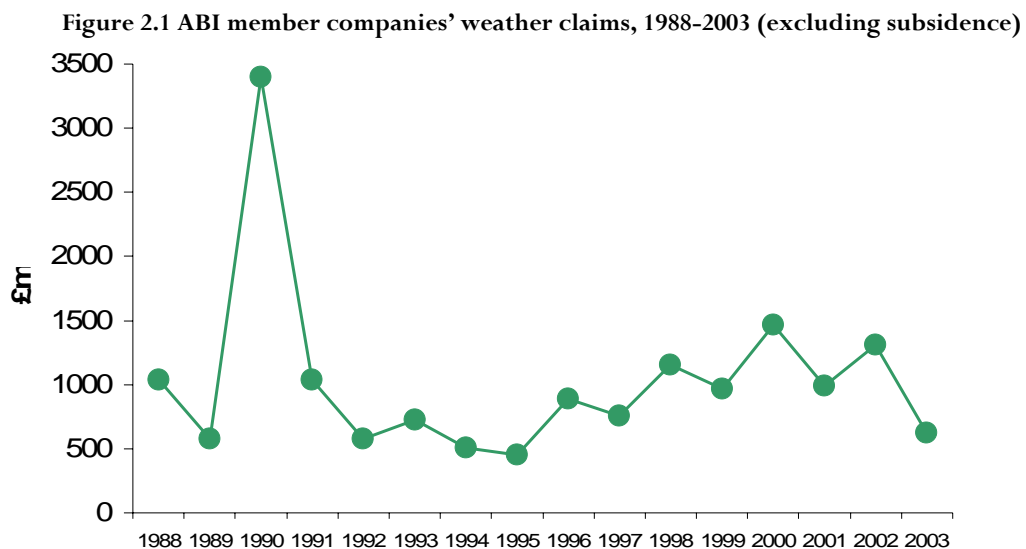
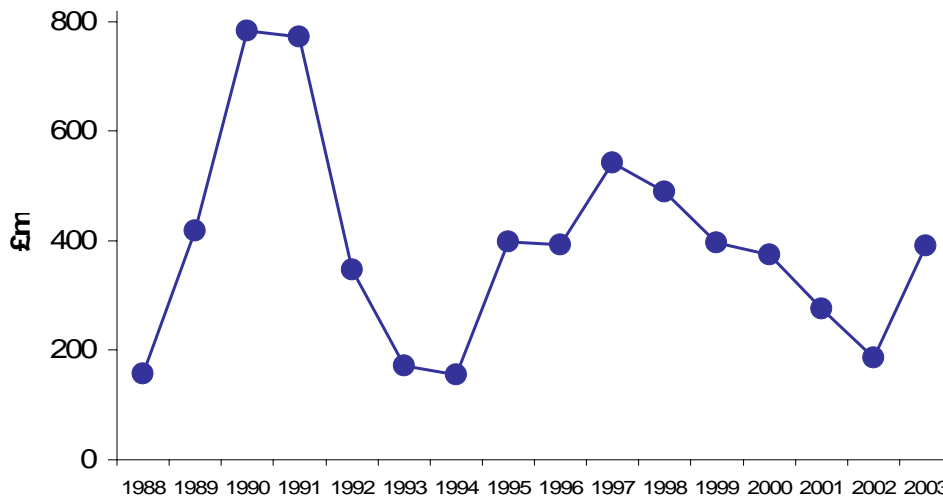


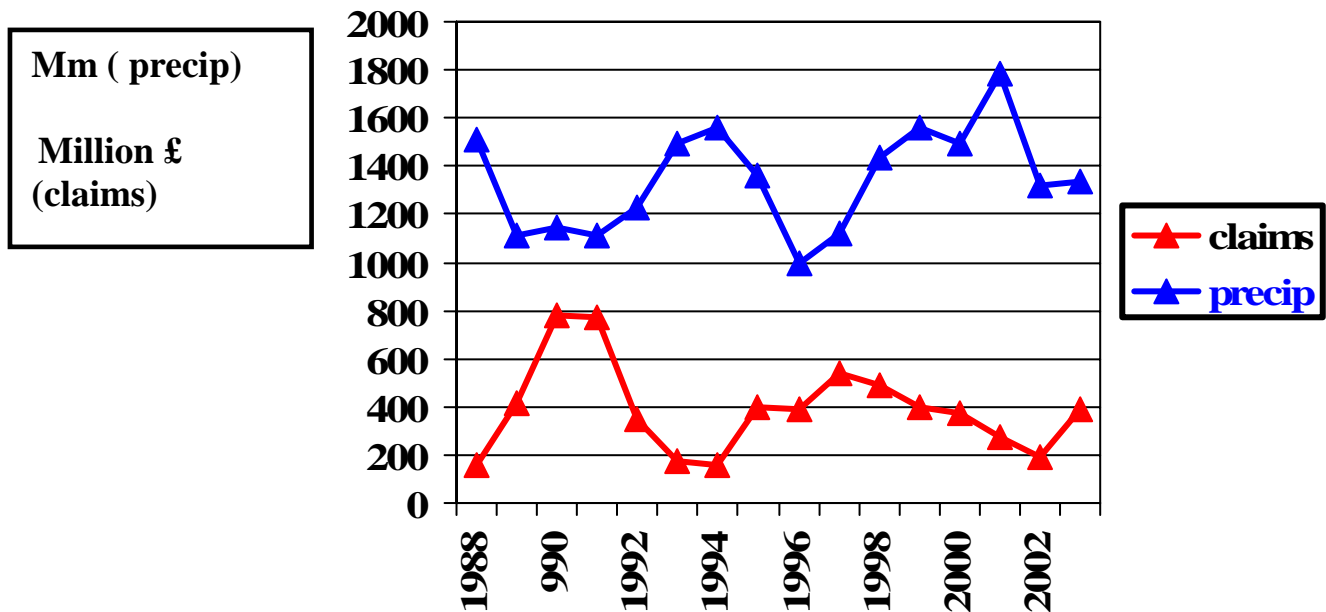
Figure 2.2 ABI member companies' subsidence claims 1988-2003.



Subsidence appears to be a cyclical problem (see Figure 2.2); there is no clear evidence of a trend, rather the cost oscillates depending partly on weather and partly on the housing market (sellers wish their house to look perfect). Twice in the last 40 years there have been great droughts in storm years (1976 and 1990), and this combination of events should therefore be borne in mind as a possibility when carrying out risk assessment and financial planning. The cost of climate claims of £4.2 billion in 1990 was 127% greater than the next highest year, 2000.

In fact subsidence is highly influenced by precipitation, as shown crudely by Figure 2.3. There are of course other factors, such as the state of the housing market, and the detailed location of rainfall (most problems arise in the clay belt of mid and SE England).

**UK household buildings – subsidence damage (insurance claims) in 2003
constant £**
versus
18 month accumulated precipitation to September of year (in mm)



2.3 Weather Risk Trends

The UK insurance industry has been willing to underwrite the broadest range of weather perils. However, the prospective increase in UK weather damage may make such risks unacceptable for insurers. Two approaches indicate that the risk is already rising quickly, so that this could soon become a significant issue for the industry and its customers. The first method is based on projections by the Foresight Programme¹ in their recent work on flooding while the second looks at the issue with an illustrative example for a reinsurer. It is important to remember that without reinsurance many risks would not be insured at all. This became evident when reinsurers withdrew from the market for terrorism risk in 1993. The government had to step in with the creation of Pool Re to provide a backstop for the primary insurers, who were about to withdraw in the absence of reinsurance.

The Foresight Programme's view of flooding in the 2080's

Table 2.2 shows the basic estimates of flood risk now and in the 2080's, as provided by the Foresight Programme (Part II, Tables 9.1 and 9.2). x

Basis	Present day	World markets	National Enterprise	Local Stewardship	Global Sustainability
Annual expected damage (£billion)	1.3	28.4	20.7	2.2	6.7

Table 2.2 Annual Expected Flood Damage, present day and 2080's

The costs in the 2080's are based on four scenarios of how society might develop, using a classic two-dimensional approach (scale and sustainability). It should be emphasised that these scenarios are non-interventionist ie they assume that no action is taken on account of climate change in flood defence or planning policy. Thus they give a true view of how the underlying risk will behave. Of course society will be able to take precautionary measures (at a cost) to control the future damage, but the inherent risk will still exist.

The increase in flood damage for "local stewardship" is 69% over the 80-year period, but this scenario seems almost utopian in that it requires a reversal of current trends in consumption and globalisation, and the estimated damage lies well away from the other three projections. It has been ignored for the purposes of these calculations.

The increase in flood damage between now and the "global sustainability" scenario is an increase of 415%. If the underlying process is uniformly continuous this implies an annual change of 2.1%, compounded for 80 years.

The increase in damage between now and the "world markets" scenario is an increase of over twenty times the amount. To generate this would require an annual increase of just over 3.9%.

The calculation for the "national enterprise" scenario is an annual increase of just over 3.5%.

Thus on the basis of the Foresight Programme view of future flood risk, the risk of flood damage is already increasing by between 2.1% and 3.9% per annum, or in round terms a range of two to four percent per year. As Annex 3 indicates, not all of this is due to climate change, but a very substantial part is.

Illustrative Reinsurance Example

Reinsurers tend to work on very focussed risk portfolios, because they are dealing with those risks which are unacceptable to primary insurers. The example below illustrates how this could escalate in future and become unacceptable.

Suppose that in 2000 the reinsurer assessed there were three possible event outcomes, normality, an extreme event (defined as a 1-in-100 year probability), and a catastrophe (defined as having a 1000 year return period). Swiss Re's current estimates for inland flood and windstorm in the UK are shown in Table 2.3 below.

¹ *Future Flooding*, Foresight Programme, Office of Science and Technology, April 2004

Table 2.3 Estimated event costs

Event type	Normal	Extreme	Catastrophe
Return period (years)	Annual	100 yrs	1000 yrs
UK river flood	-	£1.7 bn	£3.9 bn
UK Storm	-	£10 bn	£24 bn

If the reinsurer ignores the possibility of other events (ie slightly smaller than the 100 year flood, or between the 100- and 1000-year flood, or greater than the 1000 year event) then it would assess the annual expected claim cost, or risk premium due to inland flood as £20.9 million (1% of £1,700 million, and 0.1% of £3,900 million).

Of course a reinsurer would not be presented with the risk for the entire UK, but would receive presentations from individual insurers for their share of the UK market. Thus for a fictional insurer Quint with a 5% market share the exposure for river flood is £85 million in the 100 year event, and £195 million in the 1000 year event.

However, the balance of these events will be disturbed by climate change. Judging what the change will be is problematic, because the current generation of climate models is not well-suited to dealing with extreme weather events like storms, which are, in climate-science terms, rather small-scale even though their impacts are large. However, for heatwaves and intense rainfall floods, there is a growing body of evidence that indicates that the frequency of today's extremes will be much higher in future, perhaps 4 times greater². Furthermore, this escalation factor rises rapidly as one raises the definition of "extreme" due to the shape of the tail in statistical distributions.

This might lead the reinsurer to assess that the typical distribution of events in 2050 will shift to 4% and 1%. (ie four times more frequent extremes, and ten times more frequent catastrophes, on today's definitions). This is the scale of change which UKCIP is suggesting for future flood risk³. On that basis the annual risk level rises to £107 million (4% of £1,700 million, and 1% of £3,900 million) , an increase of 412% over a 45 year period, or roughly 3% per year, which is in the middle of the 2-4 % range based on the Foresight projections.

Potential Range of Increase in Risk Premium

The approaches above support a range of 2 % to 4% as an annual increase in risk premium, based on consideration of the potential weather hazard, and potential changes in exposure. However, experience has shown that riskiness increases for other reasons also, such as vulnerability of materials and behaviour. There are no reliable measurements of this factor, but it is significant that the cost of natural disasters had been rising rapidly for several decades (see Section 4) before the influence of climate change began to appear. Clearly therefore this factor is significantly greater than zero. We can therefore conclude that a conservative estimate of the underlying increase in risk premium is **two to four percent per annum**.

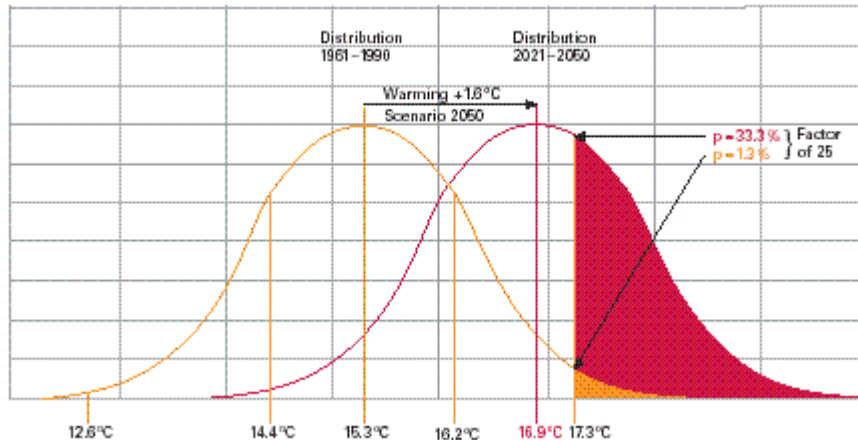
An attitude which comes up repeatedly among underwriters is that recent extreme events are simply a feature of normal climatic variability. This is reinforced by the view that since property insurance policies are annually renewable, it would be easy to extricate oneself from a deteriorating risk situation before permanent damage was done to the balance sheet. But, we are in a dynamic situation, which produces very rapid change in the likelihood of extreme events. The diagram below shows the expected change in temperature distribution for UK summers due to climate change. A hot summer, like that of 1995, with a temperature of 17.3 °C was likely to occur about once in 75 years or

² *Regional climate-model predictions of extreme rainfall for a changing climate*, Huntingford C et al, Quarterly Journal of Royal Meteorological Society, vol 129 pp1607-1621, 2003

³ *Climate Change Scenarios for the United Kingdom: the UKCIP02 Scientific Report*, Hulme M et al, Tyndall Centre for Climate Change Research, April 2002

1.3% of the time on the climatic pattern of the period 1961-90, where the average was 15.3 °C. For the period 2021-2050, centred on 2036, the average temperature will be 16.9 °C. On that basis the chance of exceeding a temperature like 1995 will be 33.3% ie one year in three! This implies a change in return period of 25 times, and the rate of change will be faster still for less frequent events. Clearly this process is already under way, and it is reasonable to suppose that the rate of change is constant. It might be objected that temperature is not a critical variable for insurers- in fact recent evidence on hurricanes (see CERES report,2005) shows that rapid increases of intensity have been occurring there.

Figure 1 Change in distribution of UK summer temperatures: disjoint effect on extremes
(source Climate Change Impacts Review Group, 1991)



Taking the midpoint of the two periods as representative, gives a time span of 60 years between the two patterns. To produce a 25-fold change within 60 years implies an annual rate of change of about 4.5% per year. Such a rapid change, if ignored, soon accumulates into a significant error. In five years, it means that return period calculations for the event would be 25% too low. The only reason it is not noticed soon is that the probability of the event is still quite low for the initial part of the transition time.

Nevertheless, what it means is that one can expect "surprises" to start occurring: there are many potential low probability events, so that some of them do start to occur "too often". (Of course the reverse happens at the other end of the distribution, where events do not happen as often as they should- a phenomenon that is harder to notice obviously. Usually, we can assume that damage only happens at one side of the distribution.)

However, the position is really even more extreme, because we are dealing with a multi-dimensional, nonlinear system. The shifts can compound across more than one factor to produce very unexpected costs - for example inland and marine flooding at the same time eg Hurricane Katrina. Other factors which could raise costs are pressure to make ex gratia payments, repair price inflation due to scarcity of supplies, close repetition (eg Lothar and Martin 1999, or the 1990 European storms, or the 2004 hurricane and typhoon season), and denial of access or failure of utilities, as in New Orleans 2005. If events become more frequent, that will also increase the chance of coinciding with an uncorrelated event eg an earthquake, or an economic catastrophe, as happened in UK on October 17th 1987, when the 87J storm coincided with a global stockmarket crash.

Conclusions

- Risk assessment will be wrong, and prices consequently will also be wrong. If historical data is used to set prices, the error might be in the region of 25% for “average” weather risks, much more for catastrophic risks.
- Exposure accumulations will be too large.
- Reinsurance plans may be inaccurate, and reinsurers themselves may be taking on too much risk.
- Estimates of risk-based capital will be incorrect- eg the risk of .0007% failure for an AA rating will be too generous.

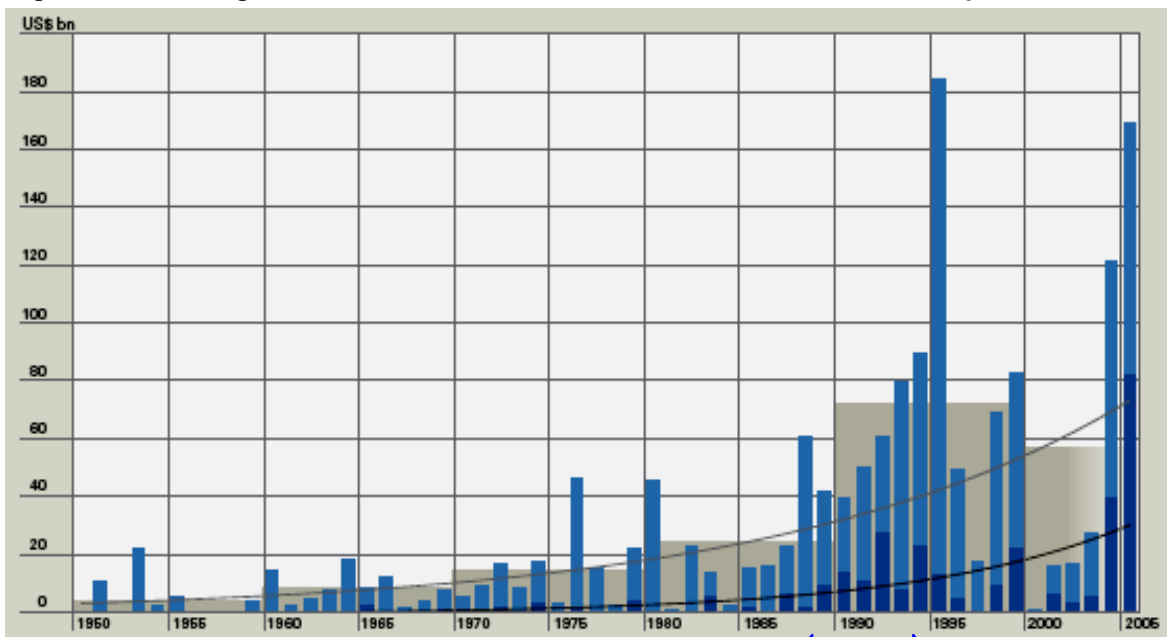
2. 2005 in perspective

The 2005 hurricane season can be seen as an indicator of climate change, in the same way that the European heatwave of 2003 is now recognised to have been. Before Katrina, the statistical evidence was accumulating rapidly that global warming causes more intense hurricanes, and the records broken in 2005 confirm this: most storms (27), most hurricanes (13), most strong US-landfalling hurricanes (4), costliest in total (\$200 billion+), single most expensive (Katrina), and strongest ever (Wilma). The season also had three of the six strongest hurricanes recorded (Wilma, Rita, Katrina) and continued a very active phase (most storms, hurricanes, and strong hurricanes ever in a two-year or three-year period). The hurricane season of 2005 may cost insurers \$60 billion, more than double any previous year. The true cost is much greater – possibly \$250 billion direct economic loss including uninsured losses and property blight, and even greater globally when higher oil prices and lost economic production is included- not to mention the over 1,300 dead and thousands of people traumatised. Post- Katrina issues include coverage disputes with Mississippi State, the cost and quality of the new levees, land zoning, business interruption, and long-term relief payments.

In terms of relevance to insurers, climate change will make tropical storms more intense (ie stronger winds, heavier rain, and higher sea-surges). In USA this will possibly be reinforced by natural cyclicality over the next two decades. This author is sceptical of this argument on cycles for two reasons. Firstly, the data required to estimate a cycle length is roughly ten times the cycle, and we don't have such a long timeseries for hurricanes. Secondly, there is a tendency to view climate change simplistically as a monotonic increase in temperatures. In fact we know that in the third quarter of 20th century, a cooling effect occurred due to the large amount of eg sulphur dioxide being emitted, which suppressed the longterm warming. This cooling therefore put a brake on various extreme events eg hurricanes, winter storms for some decades. Regarding other hazards- Flooding events will become more frequent. Droughts will become more severe in some regions.

It could be argued that we have been here before. The insurance market reacted strongly to a series of great storms between 1987 and 1992. However, the magnitude and number of events this time is on a new level- see the accompanying figures.

Figure 2.1 Cost of great natural disasters (Munich Re *Dark colour is uninsured cost, light colour is insured*).



The time of the first insurance alarm at global warming

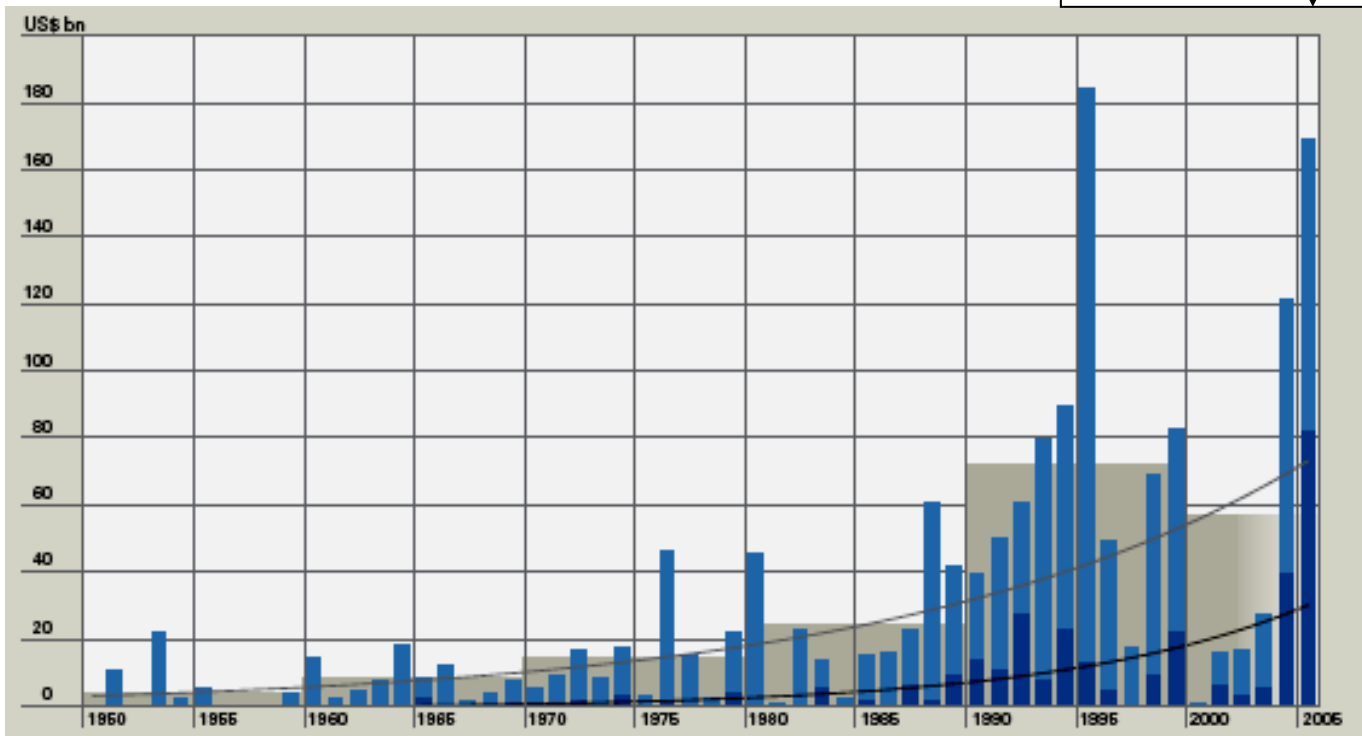
In fact, we shall focus on the economic losses, rather than insurance claims, because the latter are a rather variable proportion of the total, depending on the state of the insurance market and its interaction with other stakeholders. It can be argued that even without climate change or variability the total damage varies depending on such factors as risk awareness, preventive measures, and an efficiently prepared crisis management (Munich Re, 2006)

Also, Figure 2.1 presents a misleading impression, because it includes earthquakes and tsunamis as well as climatic disasters. Also, this author believes that the costs attributed to 2005 are too low, because Katrina and Rita caused massive disruption on global energy markets with harmful effects to many nations around the world. Figure 2.2 attempts to rectify these points by removing the largest earthquakes (1994, 1995, and 2004) and adding a speculative amount for global disruption to energy markets (see below). It is worth noting, that the effect of the hurricanes lingers on locally. New Orleans may never recover, (as happened to Galveston in 1900), and the defences will be weaker in 2006 than in 2005.

Figure 2.2 Adjusted cost of great natural disasters

Source Munich Re *Dark colour is uninsured cost, light colour is insured. Supernormal cost of Katrina and Rita is shown by black arrow . white bars eliminate costs of earthquakes in 1994, 1995 and 2004.*

Likely total cost up to \$300 billion owing to energy market disruption ↓



While Munich Re has a more conservative view regarding the economic costs, it does believe there is a watershed regarding insurable costs, following the 2004 and 2005 hurricane seasons. Figure 2.3 indicates that Munich Re now believes that the damage curves have shifted by almost a factor of two, for a number of reasons. These views are shared by many expert commentators (eg Tillinghast, RMS)

Figure 2.3 Shift in return period after 2005 season (Munich Re)

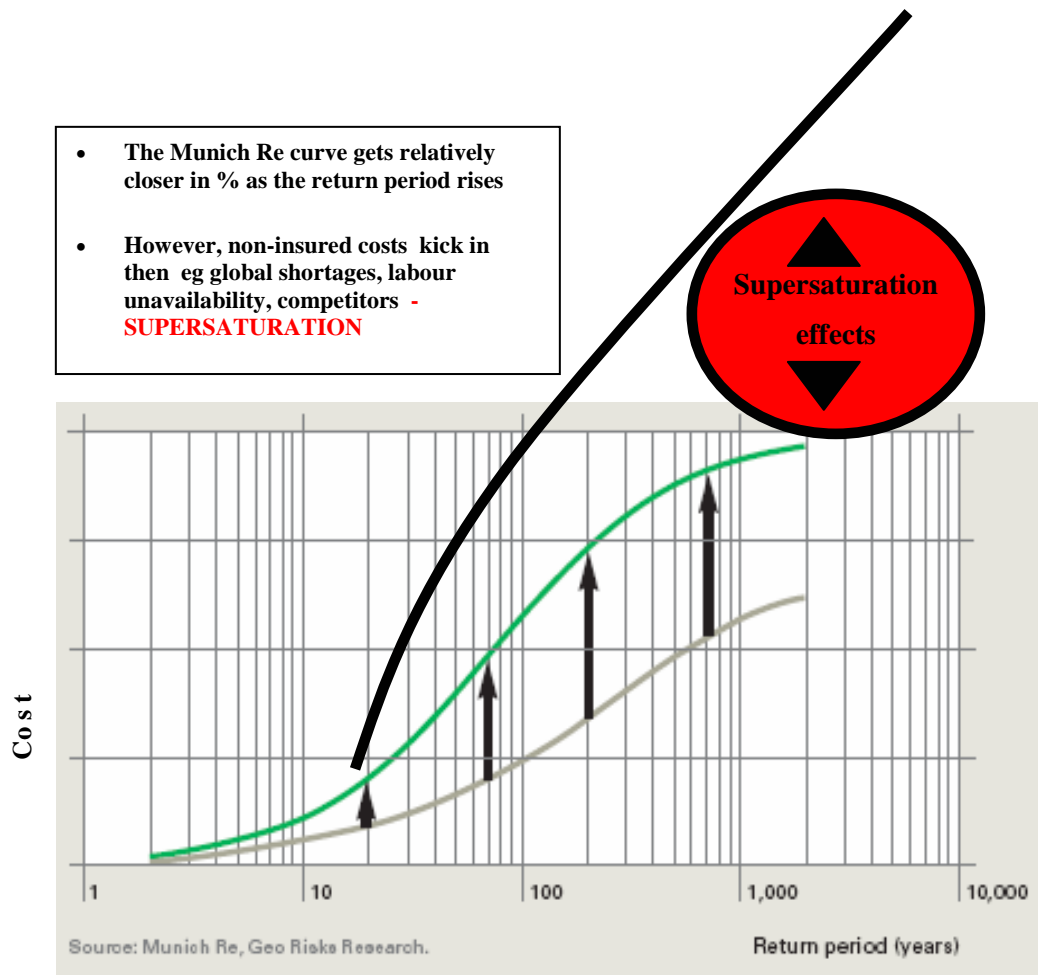
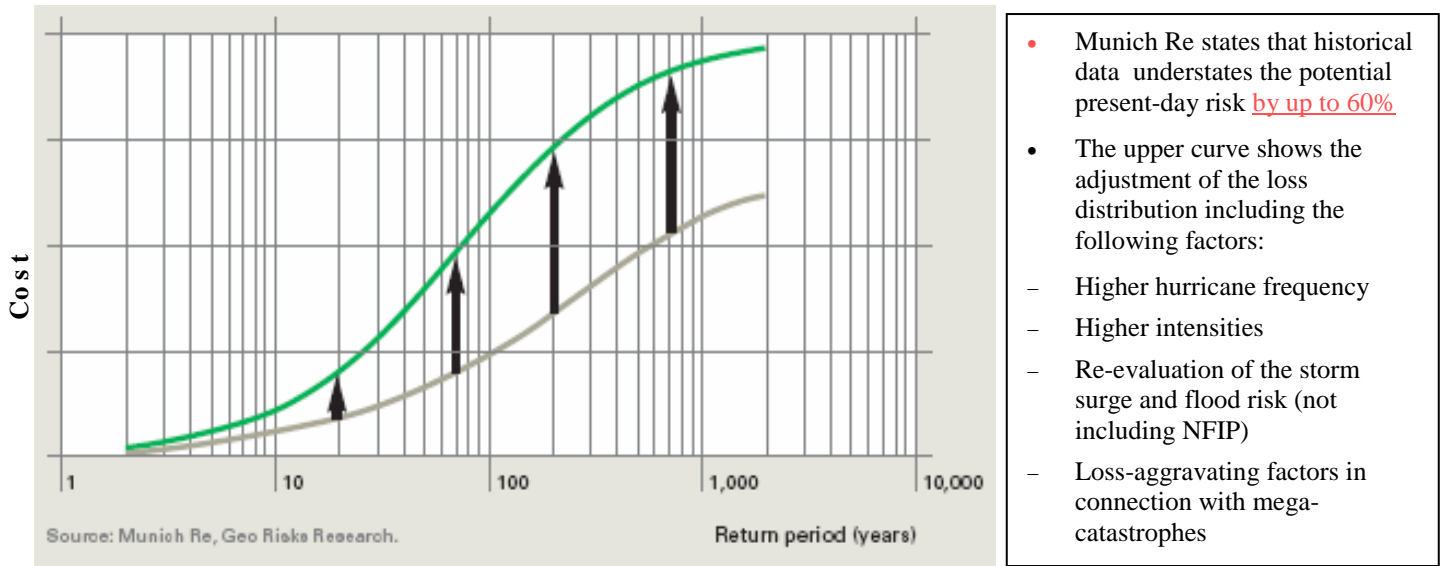


Figure 2.4 Supersaturation and damage curves

This author believes that once damage reaches a certain level, the effects escalate dramatically, due to firstly their longevity- the recovery is more extended, with consequent vulnerability and greater on-costs, while the geographic extent is much greater through effects like migration and global market disruption. We saw this happen in 2005. Some economists have dismissed the likely costs of climate impacts as acceptable, around 0.2 % or less of GDP by mid-century. In fact Katrina may have cost 2% of US GDP in 2005 already. For New Orleans it was a turning point; tens of thousands may never return, and new defences may cost \$32 billion + for which there is no budget.

In Super Catastrophes like Katrina, losses become nonlinear, i.e., the scale of the event itself causes losses to increase further, through a variety of processes (see eg RMS, 2005). Indeed costs might have been even greater if Katrina had not weakened before landfall, or Rita and Wilma had not veered away. After Hugo in 1989, roughly a dozen insurers were financially overwhelmed. Generally, these were smaller regional insurers that had not purchased sufficient reinsurance. After Andrew, nine insurers failed. Even some very large carriers were stressed to the limit. There have been no reports of insurance company failures as a result of Katrina (Tower Perrins, 2005), though ironically two airlines have filed for bankruptcy due to high fuel prices (RMS, 2005).

It was an accident waiting to happen. A classic deltaic city in the literature, (see IPCC, 2007) slowly subsiding and threatened by sealevel rise and storm surge, it grew during the hurricane pause (1965-95). **Did climate change play a part in the cost of Katrina? The answer must be yes, but we cannot quantify the share precisely.** Sealevel rise contributed to the storm surge obviously. In addition, the sea was unusually warm, which is a classic symptom of climate change. Finally, there is strong statistical evidence (Emanuel, Webster, Munich Re) that once a storm starts it is now likely to become stronger. Some commentators put a range of 10 to 60% on the contribution of climate change.

3. Munich Re Climate-Related Losses

Munich Re has been compiling statistics of natural disasters for many years because they illustrate the need for risk management. Their definition of what are "major natural catastrophes" follows the criteria laid down by the United Nations

- the affected region's ability to help itself is distinctly overtaxed, in that interregional or international assistance is necessary, thousands are killed, hundreds of thousands are made homeless, and there are substantial economic losses and/or considerable insured losses. In this section we exclude those disasters like earthquakes and volcanoes which are not weather-related.

Table 3.1 Great weather-related disasters 1950-2003 : Munich Re, monetary data in constant 2003 values.

	1950's	1960's	1970's	1980's	1990's	1994-03
Number	13	16	29	44	74	47
Economic loss (\$ bn)	41.8	54.8	82.8	130.5	439.1	288.8
Insured loss (\$ bn)	-	6.1	12.1	23.9	101.2	58.8

Table 3.1 shows great weather-related disasters for the period 1950-2003. Clearly there has been a global increase in numbers and costs of weather disasters, paralleling the UK picture. Of course, there are many reasons for this trend, including increased volumes of assets located in more hazardous areas. It will be noted that the 1990's were the most costly decade, and that the moving 10-year figure figures have fallen since then. This partly reflects the fact that the early 90's witnessed major incidents in the USA (1992 Hurricane Andrew, 1993 Mississippi flood) where the concentration of assets is much greater than elsewhere. A more reliable indicator is the number of incidents which shows a strong upward trend.

Table 3.2 Great flood disasters 1950–2003 : Munich Re, monetary data in constant 2003 values.

	1950's	1960's	1970's	1980's	1990's	1994-03
Number	6	6	8	18	26	16
Economic loss (\$ bn)	31	22	20	28	234	163
Insured loss (\$bn)	-	0.24	0.41	1.52	8.39	8.02

The number of flood events has stabilised at a level well above the mid-twentieth century level, but the costs have risen enormously, both in pure economic terms and in insured value, reflecting the incidence of flooding in wealthier countries like UK and Germany.

On the New Orleans flood of 2006, Munich Re notes that the levees were built in the 1960s and were designed to withstand Saffir-Simpson Category 3 hurricanes. They were also supposed to stand up to storm surges with wind speeds of up to 209 km/h. Why then did this catastrophe occur when Katrina only hit New Orleans with wind speeds of a Category 1 and 2 hurricane? Most of the levees are made of swamp peat with a high concentration of organic substances. They stand on a relatively thin layer of clay which lies on a natural layer of peat. In the centre of the levee is an impervious concrete wall which extends into the peat layer. Initial studies suggested that the impervious wall was not deep enough. Water probably flowed under the wall and saturated the subsoil, thus reducing its stability (Munich Re 2006)

New Orleans is by no means an isolated case. Munich Re has identified a number of other flood scenarios in the USA:

- Storm surge in Texas (Galveston/Houston)
- Storm surge in Florida (Miami)
- Storm surge in the northeast (New York)
- Mississippi-Missouri flood (St. Louis)
- Levee breach in the Central Valley, California (Sacramento)
- Flash floods in the west (Las Vegas, Denver)

Table 3.3 Great windstorm disasters 1950–2003: Munich Re, monetary data in constant 2003 values.

	1950's	1960's	1970's	1980's	1990's	1994-03
Number	7	10	19	21	42	26
Economic loss (\$bn)	11.1	32.9	51.7	54.1	189.9	97.4
Insured loss (\$ bn)	0	5.9	11.7	21.0	82.9	43.3

The number of windstorm events has trended strongly upward, with a peak in the early 90's. The costs have not risen quite as fast as for flood, but are still double the levels encountered in the 1980's for insured and total damage.

Parallels with UK

The increase in global economic losses from weather recorded by Munich Re is broadly consistent with the ABI data for UK only. (It is better to take the economic cost, rather than insured cost, for the global losses, because practice varies so widely in the use of insurance as a compensation vehicle). Between the 1980's and the ten-year period 1994-2003, the cost in constant currency rose from \$130 billion to \$289 billion, an annual rate of increase of 6% over fourteen years. During the same period in UK the annual increase was about 6.5% in the constant-value cost of climate-related claims.

It is interesting too that the global figures have recently exhibited a strong uplift in flood damage, as has happened in the UK. This indicates that the UK experience is part of a general pattern.

4. Loss trends and projections

Pielke and Boissonnade argue that the upward trend in losses shown by Munich Re is just due to socioeconomic factors, not increases in climatic extremes. Recently RMS has been examining global loss trends. Preliminary results seem to show that climatic factors are important. The 1990's were much worse than previous decades, and this pattern has resumed again after a short lull in the early 2000's. This is not conclusive, since there are various factors that cloud the issue, such as the effectiveness of disaster preparations and the wealth of the affected regions (USA has a disproportionate effect on the total losses due to its wealth), but it does mean that one of the standard objections to using loss statistics as an indicator of climate change is weakening.

One example of a positive finding is that after correcting for wealth, population and location, **at the national level, a 1% increase in precipitation results in about a 2.8% increase in US catastrophic losses.**

Studies of the potential net losses to USA from climate change have produced estimated in the region of 0.1 to 0.2 % of GDP. **This seems much too low now- the 2005 hurricane season may cost two percent of US GDP, with international repercussions beyond that eg high winter fuel costs in UK.** Recent works by Mills in USA have not provided robust figures for future loss potential, but merely indicated that on the basis of current trends, the losses demand a coherent response from government and the private sector.

Results for 3 out of 4 climate scenarios for the UK imply an annual increase of 2 to 4% in the cost of flood damage, which will have a large impact on the medium and long-term planning of infrastructure. A preliminary study by this author for Association of British Insurers (ABI) indicated that future climate-related insurance claims in UK might be two to three times higher than current levels by 2050 assuming no change in government policy on climate adaptation. (ABI, 2004). One of the main uncertainties in this calculation is the future frequency and severity of extreme climate events because climate models do not yet provide a consistent estimation of future storm tracks and intensity. This is a key weakness: in the UK, the cost of a 1000-year extreme climate event is roughly two-and-a-half times larger than the cost of a 100-year event. In Germany, insurance claims increase as the cube of maximum wind speed, or even a power relation of the fourth or fifth degree according to Munich Re, because of collateral damage from debris. A recent study of German storm losses estimated a 60% increase in insured losses in Germany by 2080 without adaptation.

ABI estimated the increased insurance cost of hurricanes (US), typhoons (Japan) and European winter storms due to climate change as around two-thirds by the 2080's, keeping other factors constant, to a new annual average of \$27 billion. The extreme seasons would be worse, around 75% higher than currently due to the nonlinear damage curve as windspeeds increase. These calculations may now be regarded as on the low side, especially for USA, as they came before some of the more recent papers on observed increases in hurricane intensity. ABI also made a cursory estimate of future European flood costs, but it should be disregarded as it simply assumed they would parallel the UK trend (ABI, 2005).

ABI went on: 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. 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.

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.

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.

5. Science of climate change (IPCC WG II, in draft)

The next IPCC report in 2007 will stress the vulnerability of certain key areas with insurable infrastructure- particularly deltas, but most coastlines are sensitive to damaging events. Global figures are not relevant to local underwriting: the sea is not flat (!), and the rate of SLR (sea-level rise) is accelerated by subsidence in deltas, while storm surges become more damaging in the absence of sea-ice in northern latitudes, or because of the trend to more intense hurricanes (see later). The rates of change in risk are significant: for example in Los Angeles area, the return period for severe flooding is decreasing at **between 2.5 and 4 % per year**.

At first sight trends on river flooding are contradictory, with the risk increasing in some regions, but decreasing in others. However, this reflects clear underlying trends in precipitation and warming. High-latitude regions are getting wetter, while low-latitude continents are experiencing droughts in the interior. At the same time, warmer weather is advancing the thaw dates for arctic regions. Thus most of USA, Russia and northern Europe are experiencing greater floods. This was reported by Milly in a study of mega-rivers which noted that the probability of such floods occurring at random was well below 5% ie there is a new factor- climate change. It has been argued that land-use and other human factors are intensifying the problem, but there is no doubt that the underlying risk has changed already. In some areas of Europe, the risk of severe flood is changing at over 3% per year (a current 100 year return period will be just 10 years for the Mosel by 2070 for example). Naturally, the higher the greenhouse gases, the stronger the risk will be. The effect will be seasonal- with much wetter winters in Northern Europe (20% more rain on average), and drier summers (as much as one-third less rain). Monsoons in Asia are also expected to be much wetter. (In fact the 2005 monsoon saw a record 994 mm of rain fall in 24 hours at Bombay).

Drought will be a major issue for the Mediterranean/ Maghrib regions. (Portugal currently has a rainfall deficit of 77% below normal, which would occur just once in 400 years randomly). The risk of severe heatwaves in Europe is rising rapidly- possibly at 12% per year, so that the 2003 drought will be the normal pattern of summer in 60 years.

Large-scale circulation changes like ENSO (El Nino Southern Oscillation) and NAO (North Atlantic Oscillation) are important for extreme events. Currently climate models (GCM's) cannot say what the future pattern of ENSO will be (one side benefit of more ENSO's would be a likely reduction in hurricane frequency, but there is no reason to plan for this). On the other hand, modellers do expect NAO to remain positive until mid-century, which means higher sea-levels for northwest Europe, stronger onshore winds, and more rain.

Regarding European storms, the most important feature is the steady intensification of the wind pattern "CP11" (previously called Wz), which means stronger, possibly clustered storms for northwest Europe, and heavy rain for southwest Europe. There is still disagreement among modellers, but a weak consensus for somewhat stronger European storms by late 21st century (an 8% increase in windspeed).

One of the most striking recent results is that intense tropical hurricanes have almost doubled in frequency in recent decades, at the same time that SST (sea surface temperature) has risen by about 0.5C. This is an unexpectedly strong relationship, indicating that the potential damage is rising at around 2% per year, according to Emanuel's Power Dispersion Index (PDI). Some sceptics have argued that the trend is exaggerated because older records are incomplete, or they have argued that there are natural cycles of regional activity. These points can be dismissed- the records have been well-validated, and the trends are global, not localised. Future results confirm this trend to more intense events. Some researchers believe that return periods could reduce by two-thirds or more in 50 years or so, due to warmer oceans. Even the sceptics believe that we are in for a

period of up to 30 years of more active hurricanes, so there is a consensus for the planning horizon! Most of the work has focussed on Atlantic hurricanes, but similar views have been expressed for typhoons also.

While attention is drawn to the catastrophic events, attritional losses can also be expected to rise. A wide range of indicators of temperature and precipitation (known as Frich indices) are expected to become more extreme. Particular issues are heatwaves in northwest and northeast America, and regions adjoining the Mediterranean.

Finally, though it is not immediately relevant to current operations, it is useful to review the outlook for extreme climate change. Recent research indicates that this possibility is higher than previously expected. There are several "choke points" which could trigger rapid change due to major shifts in natural processes like ocean currents or plant life. (The Gulf Stream appears to have weakened by 30% over recent decades). Also, computer modelling has been restricted by the amount of available runtime for GCM's. Recent research that capitalised on spare capacity in decentralised PC's indicated that the climate may be far more sensitive than we believed, and temperatures could start to accelerate. Even a conservative view indicates that we may have only 20 years now before "dangerous climate change" becomes inevitable.

6. European Storm

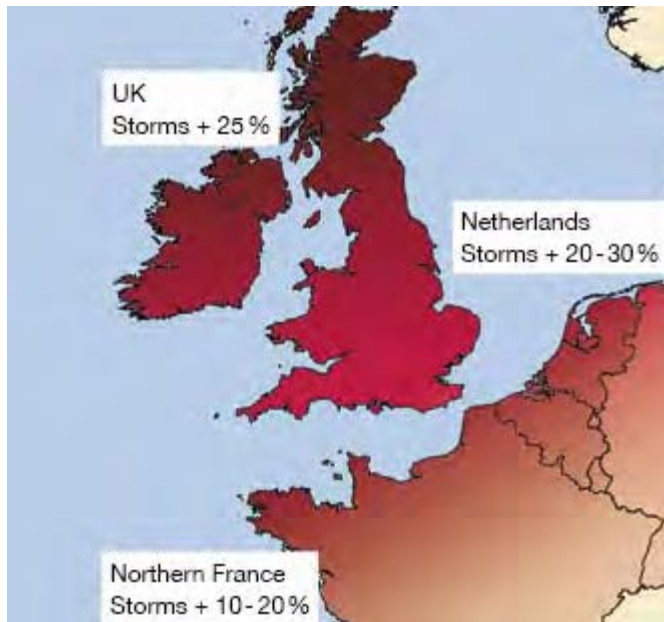
Two studies are considered here, historical storms, and future climatology.

The author reported a striking correlation between winter temperature and the occurrence and strength of great European storms, using the CET as a proxy for temperature, and Lamb's record of great storms (Dlugolecki et al. 1994). This has been dismissed by some meteorologists as unscientific, since it relies on a subjective catalogue, rather than instrumental observations of storm strength. However, it is currently the only long time series, and the findings seem quite robust. Indeed, Lamb himself did not notice this correlation, but did note that 1990 (which fell after his record formally ended) produced great storms, and that was a very warm winter indeed. Therefore, it seems that this may be worthy of further investigation as a pointer to the future.

Type of winter month	Storm frequency	Storm intensity
Warm	15%	2,568
Medium	7%	2,544
Cool	6%	1,075

**Source: temperatures from CET series, storms data from Lamb
Since then.. 1990(Burns Day++), 1993 (Braer), 1999(Europe December)
andlug@hotmail.com**

WWF has recently carried out a scientific assessment of future storminess, with the results indicated below.



The map indicates that strong increase in storm frequency are expected by 2090.

Additionally, maximum windspeed would increase in range 8 to 16% .

The joint effect would be an increase of about 75% in storm costs, other things being equal, in a range 50% to 100% increase.

If we then allow a margin for “saturation” effects eg lack of recovery capacity, the costs there could be well over 100% increase- making no allowance for economic growth in the meantime.

Future storm activity in Europe- Source “Stormy Europe” WWF 2006

6. Other issues

Other property/casualty classes may be affected by shifts in extremes also e.g. business interruption, automobile, travel, but this author does not believe that the industry faces the prospect of a wave of climate-change –related liability claims.

Automobile In the USA, 16% of automobile accidents are attributed to adverse weather conditions as are one-third of the accidents in Canada. Vehicles also sustain insurance losses during natural disasters, amounting to \$3.4 billion between 1996 and 2000 and averaging 10% of all disaster-related property losses. In some events, such as hailstorm, damage to automobiles can exceed 50% of total catastrophe losses (Mills, Roth and Lecomte, 2005). In Hurricane Katrina, one estimate reckoned that about half a million vehicles had been damaged, mainly by flood-water, with about half of them insured. The insured costs alone fell in the band \$1.2 to 2.3 billion, or between three and four percent of the total insured losses (Towers Perrin, 2005). While this is normally a major loss, it was so dwarfed by the concurrent buildings damage that another estimate ignored automobile entirely (RMS, 2005).

In less severe climates, such as UK, automobile claims are correlated with meteorological conditions, with dry / warm weather seeing less accidents reported, and cold/wet being the opposite. The exception to this is that in very severe winters motorcycle claims diminish owing to their drivers’ greater awareness of the dangerous conditions. However, the type of accidents also change, with many more minor “shunts” in icy conditions, so historically the UK is not exposed to major catastrophes in this class.

Agriculture another obvious impact area is agriculture, particularly crops, but the private market avoids this area , so it is hard to comment on trends.

Health/life The effects could extend into life and health and pensions also, albeit probably less strongly, for the private insurance industry since privately insured people are wealthier than average and generally have better health and access to medical care. The latest estimate of excess deaths in the European heatwave of 2003 is around 50,000, but with minimal effect on insurance emarkets. Similarly, the 1300 deaths in Katrina had little effect on US insurers. In the USA there has been a major programme of research into climate change and human health. Five areas were examined: heat stress, extreme events, air pollution, water-borne/food-borne disease, and vector-borne/rodent-borne disease. Among the findings were that heavy precipitation is strongly linked to outbreaks of water-borne disease: 58% of outbreaks were preceded by a rainfall event in the top decile, and 68% of outbreaks by events in the top two deciles. Water contamination was also linked to extreme precipitation, but with a greater lag effect.

Insurance products have very low penetration in less developed countries, where the impacts of climate change are expected to be most acute, due to the greater vulnerability of those regions to extreme events. Consider Asia. Glaciers in the Himalaya are receding faster than in any other part of the world and many disappear by the year 2035, with catastrophic results for rivers in India, China, etc. Six mega cities in Asian deltaic regions will have population exceeding 10 millions by 2010. These deltas are shrinking due to sediment starvation eg the Changjiang sediment discharge will fall by 50% after construction of the Three-Gorges Dam. For a 1 m rise in sea level, half a million square hectares of Red river delta and up to 2 million square hectares of Mekong river delta is projected to be flooded. The deltas are also usually economically more developed. The GDP of the three metropolises located in the Zhujiang delta, Changjiang delta and Huanghe delta will represent 80% of China's total GDP in 2050. The current rate of sea level rise in coastal areas of Asia is reported to be between 1 to 3 mm per year – marginally greater than the global average, and is accelerating gradually. Clearly, refugees from such regions would disrupt neighbouring regions also, besides placing a burden on global society. (Source – IPCC 2007 in draft)

Insurers will also be touched by climate change by government mitigation policy which will alter the economics of energy consumption, with effects on technologies offered for insurance, and on investment returns in a wide range of industries (beside being underwriters, insurers are also major investors⁰, but that is beyond the remit of this paper.

7. REFERENCES

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Annex 1 - ABI Climate-Related Claims

Year	Original values (£ million)			Constant values (2003 £ million)		
	Subsidence	Weather	Climate	Subsidence	Weather	Climate
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1988	91	605*	696*	157	1037*	1194*
1989	255	351	606	418	577	995
1990	506	2194	2700	784	3401	4185
1991	540	723	1263	772	1038	1810
1992	259	427	686	347	573	920
1993	134	566	700	172	727	899
1994	125	404	529	156	504	660
1995	326	373	699	398	455	853
1996	333	752	1085	393	891	1284
1997	472	656	1128	542	753	1295
1998	437	1030	1467	489	1153	1642
1999	364	885	1249	397	964	1361
2000	350	1377	1727	375	1467	1842
2001	265	945	1210	276	987	1263
2002	183	1285	1468	187	1312	1499
2003	390	621	1011	390	621	1011
1992-1997	1649	3178	4827	2008	3903	5911
1998-2003	1989	6143	8132	2114	6504	8618
Six-year increase	21%	93%	68%	5%	67%	46%

Table A.1 ABI climate-related claims costs

Notes to table A.1

*The 1988 figures have been calculated by estimating the cost of commercial weather claims, missing in the original data, from the ratio of such claims to domestic claims in other years.

- 1) motor and other non-property classes other than business interruption are excluded from these figures.
- 2) The constant value figures adjust for the effect of inflation, by scaling the figures using the government RPIX index of prices.

Table A.1 shows the total amount reported annually by ABI member companies in respect of weather-related (burst pipe, storm, flood) and subsidence claims for commercial and household property accounts, including the related business interruption figures for commercial business.

As can be seen, over the period 1998-2003, the claims for weather alone came to nearly £6.2 billion, which was an increase of 93% over the comparable six year period 1992-97, virtually double in original values. This is indicative of the underlying increase in “attritional” weather events, whereas most attention is caught by the spectacular events ie great storms or floods.

Preliminary Assessment of Future Costs

This section presents the current scale of insurance industry costs from climate-related incidents, based on ABI data, together with projections of the top-range potential costs under the UKCIP climate change scenarios. Table A.2 gives the historical data, in 2003 values, relating to claims paid by ABI member companies. They relate to the period from 1998 only, since figures split by cause are not available before then. In making the adjustments in the table as described in the footnotes, the author used quarterly data also (available back to 1991), and applied judgement based on extensive experience with insurance industry claims statistics.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Commercial of which flood	Business Interrup. of which flood	Domestic Pipes of which flood	Domestic Storm of which flood	Domestic Flood	Revised storm	Revised Flood
1998	286 188	32 21	239 0	457 317	139	249	665
1999	269 171	26 15	278 0	333 193	58	249	437*
2000	467 369	85 74	238 0	420 280	258	249	981
2001	178 80	14 3	354 102	278 138	163	249	486*
2002	270 172	27 16	420 168	479 339	117	249	812
2003	98 0	11 0	310 58	140 0	61	249	119*
Average						250	350

Table A.2 Base calculations of present-day weather claim costs (£million at 2003 values)

Column (1) Left-hand figures from ABI. Right-hand figure derived by assuming steady figure of around 2003 level is due to storm, nil for burst pipe claims, and that the residue is from flood.

Column (2) Same procedure as for column (1).

Column(3) Left-hand figure from ABI. Right-hand figure derived by assuming the true cause of these claims is mainly burst pipes (non-weather or frost) rather than flood and that this applied to all claims in 1998,1999, and 2000. This is based on the author's experience, and the remarkable stability of the quarterly loss figures for those years, all lying in the range £48m to £62m, apart from Q3 1999 at £79m, The average amount in these years came to £252 million, and this is subtracted from the left-hand figures for 2001-03 to derive hidden flood claims in those years.

Column (4) Left-hand figure from ABI. Right-hand figure by assuming 2003 figure was entirely storm, in the absence of any major events, applying the same correction to previous years.

Column (5) From ABI, with no adjustment.

Column (6) This is the sum of the residual amounts from columns (1), (2), and (4) after removing the amounts assumed to be flood. Effectively, it assumes that the 2003 figures in those columns were entirely due to storm, since 2003 was a very dry year, and that those figures were typical of earlier years, in the absence of any major reported incidents.

Column (7) Column (5) plus flood allocations in Columns (1)-(4). Since the years 1998, 2000, and 2002 were affected by major flood incidents, the cost of a "typical" year is taken buy averaging the values for 1999, 2001 and 2003, marked *.

Subsidence

Current levels

Subsidence claims have been fairly static in recent years, with a running 5-year total of around £1.6bn, or about £300m per year. The peak years were 1990 and 1991, with over £750m each in 2003 values (see Figure 3.2), but since then the worst year has been 1997 at £542m, suggesting that the current peak may lie around £600m.

Future levels

An unpublished study by a leading scientific agency for ABI derived a relationship between meteorological conditions and claims costs historically, based on insurance company data. The study then considered the implications of future climate scenarios up to the 2080s. The findings suggested a doubling of cost, i.e. £3.2bn over five years, or £600m per year. The peak might be £1.2bn in a year (double the average cost). This is less than twice the cost of the peak years 1990 and 1991. Although the general tendency is for climate change to exacerbate the peak costs, this is unlikely for subsidence, because wetter winters will prevent lengthy droughts like that in 1990/91. This is true even for the south-east with its drought-sensitive clay soils, where the above-average trend towards drier summers, could be largely offset by a contrary trend towards wetter winters.

Storm

Current levels

From above the background level is around £250m per year currently, since there were no major storms in the period 1998-2003. The cost of a major storm is around £1,500m on the basis of the 1987 storm and industry data on the individual 1990 events. Allowing for a return period of ten years, this would generate a further allowance of £150m per year for major storms, giving £400m annually for storm risk currently (background and major elements combined).

An extreme year in the UK might be seen as around £2,500m currently, taking 1990 as a base. The total weather cost in 1990 was 3,400M, while the average annual cost during the period 1988-2003 ran at 990m. Subtracting the "average" gives $3,400 - 990 = 2,410$, or £2,500m rounded up. Note that this is considerably less than the 100-year storm estimate of £10bn in Table 5.1 from Swiss Re for UK. This is due primarily to the fact that we are looking at a shorter return period, of roughly ten years.

Future levels

Going by the UKCIP outlook, we should allow +50% for frequency in the more populated regions of UK. At the same time, it seems that there could be a 6% increase in wind strength. Figure A.1 shows a clear non-linear relationship between windspeed and damage, with a gearing of approximately 1:5 i.e. a 6% increase in windspeed would produce a 30% rise in damage. The compound effect on claims costs of the increases in frequency and windspeed are $1.5 \times 1.3 = 1.95$ i.e. about double. Therefore the future annual smoothed cost could be $2 \times £400m = £800m$ pa.

The peak loss in future might be equivalent to three major storms in one year. There were four major storms inside four weeks in northwest Europe in 1990, and three within three weeks in 1999. Since we are anticipating a general increase in winter depressions frequency of 50%, a figure of three in a severe year may even be on the low side. The cost of a major storm could rise by perhaps 30% due to faster windspeeds (as explained above). Additionally, future storms will be wetter, (on the basis that by 2050 winters will be about 15% wetter, with more intensive events), and so cause more damage, particularly in a multiple-event scenario, where damage cannot be repaired before the next storm arrives. Based on the author's unpublished analyses of company claims data, an allowance of 30% for these elements is required. This gives a peak year cost of $£7.6bn = £1.5bn \times 3 \times 1.3 \times 1.3$, or £7.5bn rounded.

Inland Flood

Current levels

The background level for flood claims including commercial lies at around £350m per year. High years cost about £800m (i.e. an additional cost of £450m), so allowing for one every five years gives an additional £90m pa. This amounts to about $£350m + £90m = £440m$ pa, or £400m rounded.

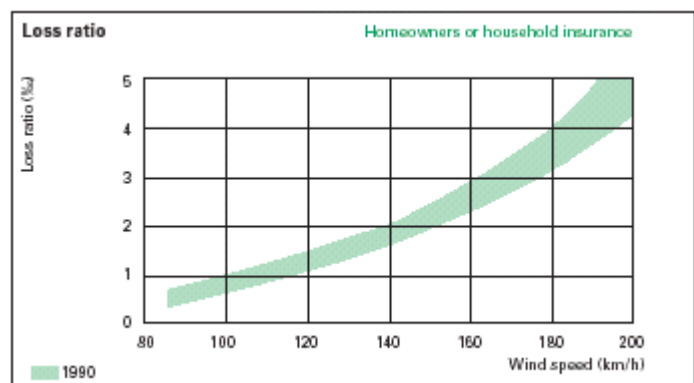


Figure A.1 Great Britain Household Insurance: damage versus windspeed, 1990 storms [Source Munich Re: Winter storms in Europe (II), 2002]

A recent ABI study of flood potential provided an estimate of about £1,500m as the likely worst case exposure. This compares closely with the estimate of £1,700m given by Swiss Re for a 100-year flood event.

Future levels

The Foresight study provides a very wide range, depending on the climate change scenario and response strategies. If responses are implemented, the range is much narrower, with a topside of double today's costs. Therefore, even with a substantial amount of action on flood risk management, the background level of flooding would rise from £400m to £800m.

Peak cost could be three times the current level. This reflects the trend towards heavier and more intense rainfall patterns (conservatively a doubling effect- Huntingford, 2003 estimates that return periods for extreme monthly rainfall could reduce by a factor of between four and seven times by late 21st century), and also the nonlinear nature of the damage response curve, whereby higher flood levels and longer flood durations produce disproportionate increases in damage (roughly a 50% effect). This gives an extreme-year cost of $3 \times £1.5\text{bn} = £4.5\text{bn}$ in a year.

Coastal flood

Current levels

Coastal flood is negligible in terms of insurance claims currently, largely thanks to the high quality of defences. The last significant incursion was in February 1990 at Towyn in North Wales, and cost under £100M. Therefore the background level has been set at nil. Since the Thames Barrier defence complex currently provides a very high level of security for London, the extreme cost would occur elsewhere e.g. East Anglia, and informal industry estimates indicate a potential value for such an event of around £5bn.

Future levels

For background levels, it is assumed that the Foresight recommendations are adopted, so that the risk of coastal flooding continues to be well-managed, with an absence of any significant incursions, and an annual cost of nil.

For the peak cost, it is assumed that the Thames Barrier defence complex fails, and that the event is compounded by other factors, for example up-river flooding due to heavy winter rains, and generally stormy conditions affecting the efficiency of the recovery process. Based on information from the Environment Agency, the London Climate Change Partnership puts £80bn assets at risk, and £30bn estimated economic loss from a major flood. Perhaps two-thirds of this would be insured because much of the infrastructure damage and business interruption costs would not be covered due to public policy and customer choice, giving a current exposure of £20bn insured damage. Allowing for the greater depth of water in future, and the compounding effect, an increased cost of two to four times can be envisaged, resulting in a cost of, conservatively, £40bn.

All the above estimates ignore the effects of socio-economic changes, such as the location and value of assets, and any substantial changes in Government policy.

Annex 2 Floods in Perth, Scotland

The UK has been hit almost annually since the early 1990's by severe local floods. The first significant one of these occurred in 1993 in Central Scotland, at the town of Perth, where the author lived and worked for the international insurer, General Accident, which had its world headquarters there. In January 1993, 45 cm equivalent rain fell in 18 days, but the effect was made worse by the accumulation of snow which then rapidly thawed (see Table below). 42 square kilometres were flooded and the total cost to insurers was £125 million, a very substantial figure considering that the town had only 40,000 inhabitants.

January 1993	Weather	Temperature (oC)	Comments
11th	Gales, snow	1	Blizzard, roads cut
12th	Gales, snow	2	Food runs out
13th	Snow showers	2	Rescue convoys
14th	Heavy rain	5	Local floods
15th	Thaw, rain	5	Head waters flood
16th	Heavy rain	7	Rivers rise
17th	Showers	4	Record flow on

Table A.3 Chronology of the Perth 1993 flood

The situation was extraordinary, because initially the problem was a surfeit of snow which resulted in Perth being cut off by road, rail and air. The Army was called out to attempt to break through with emergency supplies, either by special vehicles, or by helicopter if the weather cleared. Just as this started, a fast thaw arrived, with continuous rain. Soon the River Tay began to rise, reaching record flows on 17th January, and bursting through the flood defences in several places. Hundreds were evacuated, and some remained in temporary accommodation for nine months. Many of the losses were borne by insurers, though often under-insurance complicated matters.

The area was known as a flood hazard (as far back as 1210, when King William the Lion had to escape by boat from Perth Castle, which was built of wood and was destroyed utterly, and never rebuilt). The local flood defences were constructed in 1974 to a standard that could cope with any "normal" flood of the previous 200 years ie up to about 6.2 metres. (There had been one in 1814 which was 7 metres, but that was due to ice-blockages). The town deliberately permitted a major housing development in this floodplain, believing that the wall made it safe. In fact the 1993 flood reached 6.5 metres, and the wall broke, resulting in 1500 houses being flooded. This flood came on top of previous storms, so there were many other claims from houses which were not flooded, due to power cuts causing food spoilage, and also for damage to property stored at low-lying golf-courses.

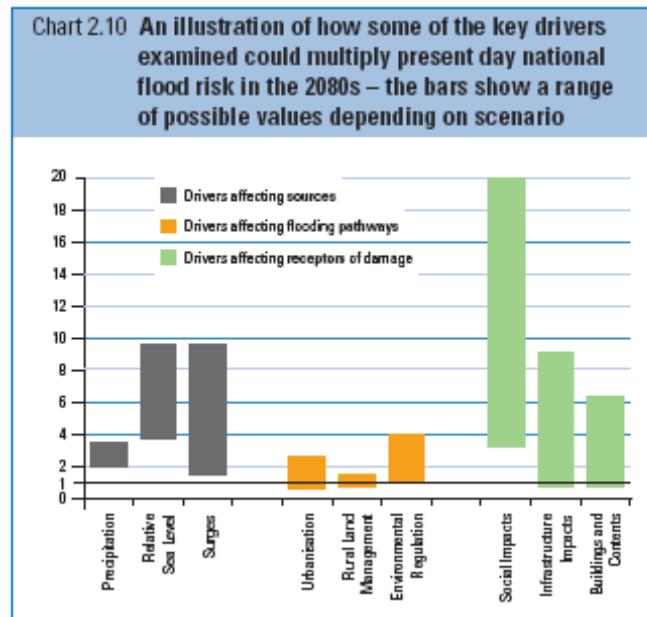
Following the incident, insurers continued to provide flood cover to former clients, but naturally they adjusted their premium levels and deductibles. A key factor in this was the intentions of the public authorities. Perth was fortunate, in that it was the first major flood in Scotland for many years, and attracted great sympathy and political support for new defences. As a result, magnificent new flood defences including holding tanks, were commissioned and completed in 2001. However, that did not solve all the problems.

In 2002, wet weather in the spring filled the holding tanks. Unfortunately, a severe thunderstorm latched on to the town in July, and the ensuing cloudburst could not be contained. Localised flooding ensued, exacerbated by the flood walls. For the first time in its 100-year history, the two-day Perth Agricultural Show had to be cancelled and the central park was closed to visitors for the entire summer due to health fears from sewage. The Show had a lucky escape in 2004, when just after it ended torrential rain fell for three days from a decaying hurricane, causing the cancellation of the Perth Highland Games for the second time in three years.

The floods of 1993 and 2002 are both events that are typical of climate change: a prolonged wet winter period with rapid thawing, and a violent summer thunderstorm. The 2004 flood was maybe bad luck- we do not know yet.

Annex 3 - Foresight -Executive Summary

Foresight evaluated the influence of 19 drivers on future flood risk for each of the four future scenarios (see Chart 2.10).



- **Climate change** – has a high impact in every scenario. Risks at the coast will be particularly affected: relative sea-level rise could increase the risk of coastal flooding by 4 to 10 times. Precipitation will increase risks across the country by 2 to 4 times, although specific locations could experience changes well outside of this range.
- **Urbanisation** – particularly in flood-prone areas, could increase rainwater runoff, increasing flooding risk by up to 3 times. At the same time, new developments and weak planning controls on the types, densities and numbers of new buildings could also increase risk. There is a clear message here regarding the importance of urban development to future flood risk.
- **Environmental regulations** – could be risk-neutral or could affect flood pathways by constraining maintenance and flood-risk management along rivers, estuaries and coasts, thereby raising risk. This argues for an integrated approach to decisions on flood management and environmental regulation in order to achieve multiple benefits for people and nature.
- **Rural land management** – a recent major study showed that there is substantial evidence that current land-management practices have led to increased surface runoff at the local scale. However, there is a general absence or uncertainty of evidence of the impacts at the catchment scale. There is also a lack of knowledge of how small-scale impacts combine at larger scales. Further research has been recommended to explore the possible impacts of land-management practices at both local and catchment scales.
- **Increasing national wealth** – will increase the value of the buildings and assets at risk and is therefore a strong driver of economic impacts. However, increases in flood damage as a proportion of national wealth will be much smaller and may even reduce in certain scenarios.
- **Social impacts** – these are difficult to quantify, but the analysis showed a large increase in social risks in all scenarios, by 3 to 20 times. Unless these risks are managed, significant sections of the population could be blighted. Many of the drivers that could have the most impact are also the most uncertain. Some of this uncertainty relates to scientific understanding – for example, uncertainties in how to model the climate. However, other sources of uncertainty are inescapable – such as the extent to which the international community will succeed in reducing greenhouse-gas emissions. It is therefore important to develop policies that can cope with a wide range of possible futures, and which can respond flexibly to an evolving world.

HURRICANES AND CLIMATE CHANGE: WHAT IS THE LINK?

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Summary

Storms and storm damage are increasing in severity and in related economic damages, at a time when climate is changing. This is a prospectus to hold a workshop to explore the links between storms (primarily tropical cyclones and windstorms) and climate change. It is intended to bring together climatologists who work with large data sets, modelers from research institutions and the insurance sector, and insurers and reinsurers to explore the issues of statistical correlations, plausible underlying mechanisms, prediction and attribution.

Background

Storm intensity has increased significantly since the 1980s and damages from storms have also escalated. Rising real estate values, increases in coastal populations, and greater insurance penetration have all played significant roles. *And* more and more intense storms are also contributing, with new research finding a strong association between the increasing severity of storms and warming of the oceans (Emanuel 2005; Webster et al. 2005; Hoyos et al. 2006). In addition, novel events are occurring: e.g., hurricanes in the southern hemisphere, hurricanes hitting Spain, and Atlantic windstorms penetrating deep into Europe.

On February 2, 2006, the following article appeared on the front page of the Wall Street Journal:

Cold Front: Hurricane Debate Shatters Civility Of Weather Science; Worsened by Global Warming? Spats Are So Tempestuous, Sides Are Barely Talking; Charge of 'Brain Fossilization' Valerie Bauerlein. Wall Street Journal (Eastern Edition). New York, N.Y.: Feb 2, 2006. p. A.1

Abstract: In October 2004, Dr. [William Gray]'s views faced a head-on challenge from Kevin Trenberth, head of climate analysis at the National Center for Atmospheric Research, a prominent institute in Boulder, Colo., where Dr. [Greg Holland] also works. At a news conference convened by Harvard Medical School's Center for Health and the Global Environment, Dr. Trenberth outlined his position that the spate of hurricanes that slammed the U.S. in 2004 might be linked to global warming caused by humans. He said rising temperatures weren't necessarily triggering more hurricanes but might be causing stronger ones, because as oceans warm they create more water vapor, the fuel for hurricanes.

Dr. Holland, the scientist who was supposed to appear with Dr. Gray Tuesday night, once was a student under Dr. Gray. At the Atlanta meteorological conference, he said seasonal forecasts, especially Dr. Gray's, are rarely correct. An ally of Dr. Gray, Chris Landsea, of the National Hurricane Center, presented a critique of the global-warming hurricane theories, but the two scientists weren't in a forum that allowed debate.

Dr. Gray says his forecasts are accurate and improving each year. As for his resistance to the new challenges, it is based on experience and solid science, not his age, he said. "I don't feel I'm fossilized. If half my ex-Ph.D. students say I'm senile, then I'll quit. They have not."

Climate change has profound implications for all industries, including public utilities, timber, automotive, electrical appliances, the energy sector and for finance (insurers, banks, pension funds, raters, and brokers). The financial sector is especially sensitive to emerging trends. The dramatic (50-fold) rise in catastrophe-related damages from \$4 billion

per annum in the 1960s-80s, to \$123-145 in 2004 and \$200-225 billion in 2005 in three decades has stunned financial leaders. Insured losses have also tripled: from 10% in the 1980s to an average of 30% in the past two years, as more extreme weather events affect Europe, the US and Japan.

Leading reinsurers have asserted that a third year of losses on the level of those in 2004 and 2005 could bankrupt many insurance companies. And all four hurricane prediction centers – NOAA's National Hurricane Center (NHC); Tropical Storm Risk (TSR, Benfield, London); Accurate Environmental Forecasting (AEF); and Colorado State University (Wm. Gray) -- are predicting a severe fall storm season. In addition to the baseline shift created by deep ocean warming and the warm tropical Atlantic and Caribbean sea surfaces, long-term cycles (driven by a 20-30 year Pacific Decadal Oscillation, which began around 1998, and a warm tropical Multidecadal Oscillation that began about 1995, and the probable La Nina we have just entered (that reduces the strength of westerlies) are reinforcing factors leading to the predictions for a high number of intense storms this fall.

The studies of Emanuel (2006) and Webster et al. (2005) demonstrate that hurricanes have increased in intensity and destructiveness in the past three decades. The assessment of the increasing Accumulated Cyclone Energy (ACE) Index used by the three Cat Modeling Groups -- Risk Management Services (RMS), AIR World Corporation (AIR) and EQECAT – are consistent with these studies. The underlying reason for the miscalculations of the past two seasons can most probably be traced to the warming of the deep ocean. This warming was first detected in 1994 (Parilla et al., reported in *Nature*), was confirmed by Syd Levitus and colleagues of NOAA (2000) and reinforced by Tim Barnett and colleagues of Scripps in 2005 (2005). Barnett et al. found that 84% of the heat of global warming and that the pattern of the heat is unmistakably attributable to the buildup of greenhouse gases. In 2005 Syd Levitus recalculated the heat accumulation and concluded that the deep ocean is holding 22 times the heat that has built up in the atmosphere.

NB. Tim Barnett and Kerry Emanuel were both skeptical on the issue of climate change until new data and analysis convinced them that it was necessary to include the contributions of greenhouse gas-induced warming to explain the observed changes.

This may account for the sequences of extremes we are experiencing, such as the KRW (Katrina, Rita, Wilma) mega-event that has insurance companies so concerned. Warm water at depths replaces that which evaporates in one storm to fuel the subsequent storms. John Coomber, former CEO of Swiss Re confided: a third consecutive year of losses on the magnitude of the past two will put a lot of insurance companies out of business. Many long-term implications of the biological damages – including mold in New Orleans and extensive coral bleaching and coral disease in the Caribbean in 2005 – have not yet entered into the calculations.

Conclusion

Warming of the deep oceans is the central driver of more intense storms and sequences of intense storms. Changes in Atlantic Ocean circulation, attributable in large part to warmer, saltier tropical seas, and melting of Greenland and more rain falling at high altitudes, is also contributing to more intense Atlantic hurricanes, wind storms penetrating deep into Europe, and to novel events, such as the hurricane hitting Brazil in 2004 and those hitting Spain and Portugal in 2005. Continued warming of the ocean, melting of ice and increased water vapor in the atmosphere all suggest that more intense storms are to be expected, compounding the impacts of 20-30 year natural cycles in the Pacific and Atlantic Oceans.

Global warming has raised the probability of more intense storm and anomalous weather patterns, and, along with rising coastal populations, increasing real estate prices and greater insurance penetration, the sequences of extremes of multiple types, shorter return times between extremes, wide swings in weather, and weather anomalies and major outliers that also contribute to enhanced vulnerability to damages from storms.

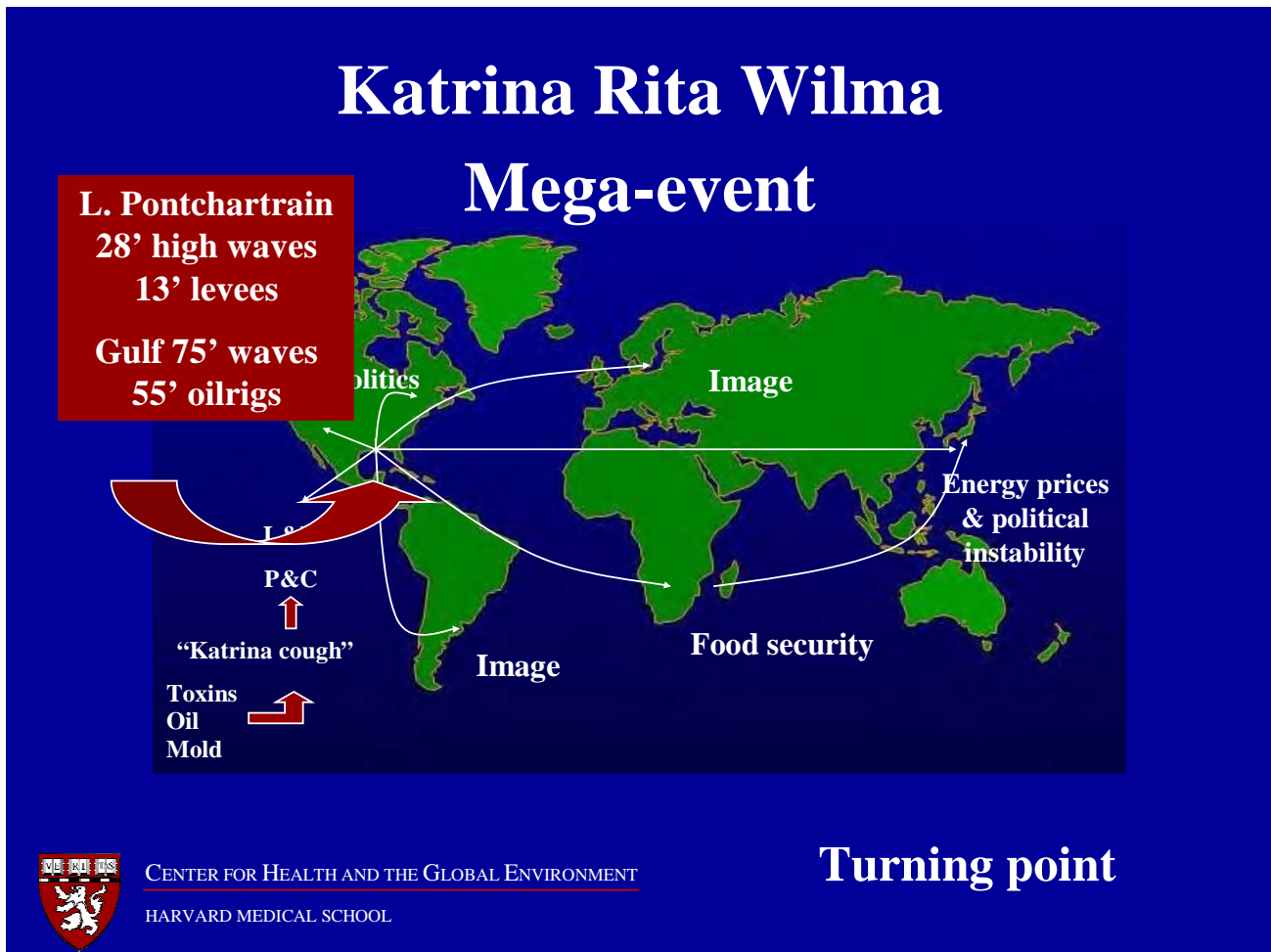


Figure 1. The cascading consequences of Katrina

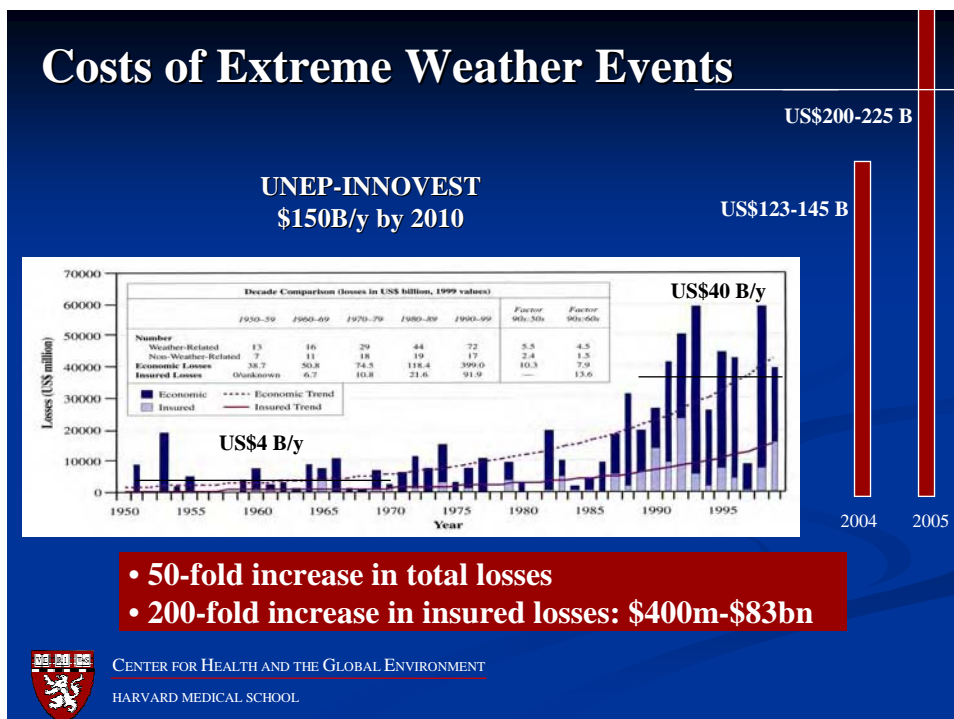


Figure 2. Calculating the costs of natural catastrophes

Changing Nature and Structure of Events

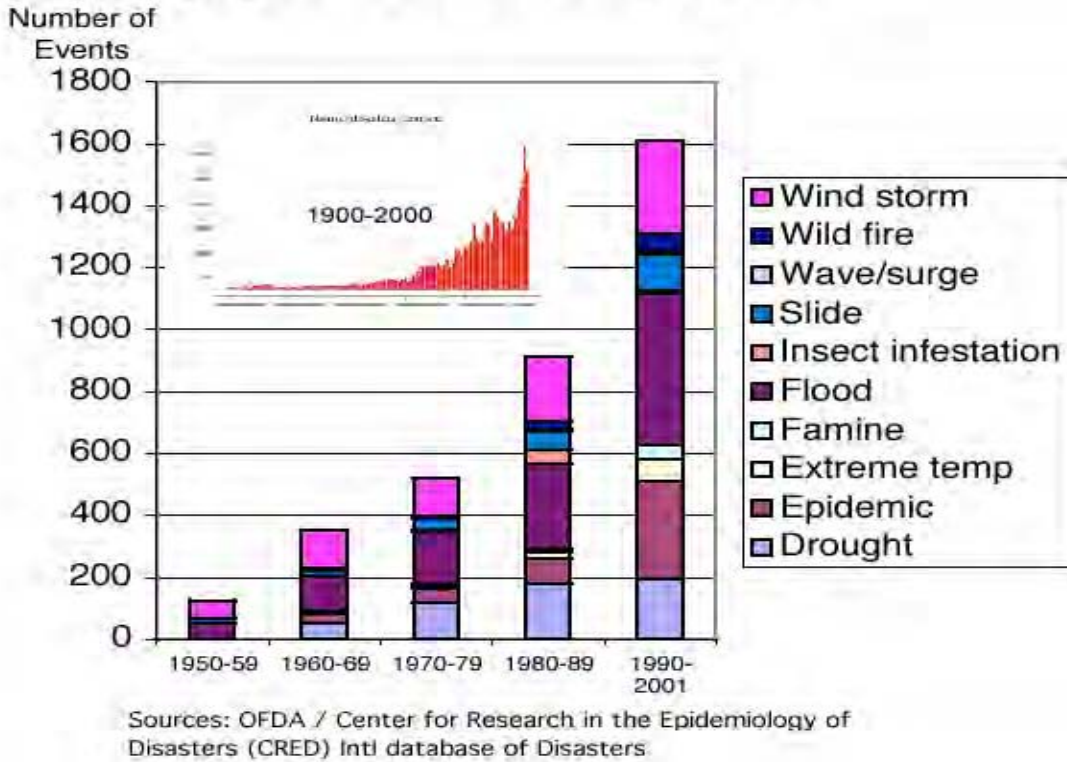


Figure 3. Trends in extreme weather events

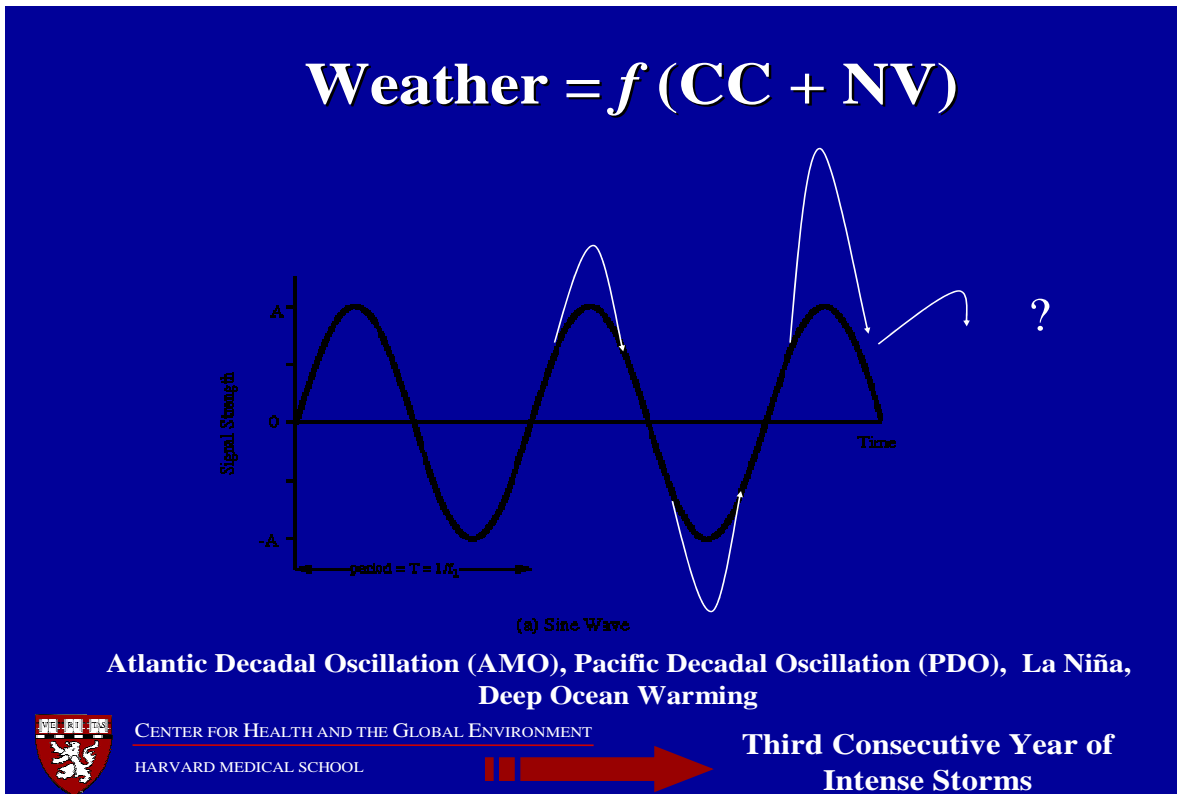


Figure 4. A visualization of how climate change may be viewed as exaggerating natural cycles, and -- for this coming fall of 2006 -- how the Atlantic, Pacific, evolving La Niña event, along with deep ocean warming, are all lined up to increase the probability of a severe fall storm season.

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1. Barnett, T. P., Pierce, D. W., AchutaRao, K. M., Gleckler, P. J., Santer, B. D., Gregory, J. M. & Washington, W. M. Penetration of human-induced warming into the world's oceans. *Science* 309, 284-287 (2005).
2. Bryden, H.L., Longworth, H.R., Cunningham, S.A. Slowing of the Atlantic meridional overturning circulation at 25° N. *Nature* 438, 655-657 (2005).
3. Curry, R. & Mauritzen, C. Dilution of the northern North Atlantic Ocean in recent decades. *Science* 308, 1772-1774 (2005).
4. Emanuel, K. The dependence of hurricane intensity on climate. *Nature* 326, 483-485 (1987).
5. Emanuel, K. Increasing destructiveness of tropical cyclones over the past 30 years. *Nature* 436, 686-688 (2005).
6. Epstein, P. R. Climate change and human health. *New England Journal of Medicine* (6 October 2005).
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8. Hansen, J., L. Nazarenko, R. Ruedy, Mki. Sato, J. Willis, A. Del Genio, D. Koch, A. Lacis, K. Lo, S. Menon, T. Tsvakov, Ju. Perlwitz, G. Russell, G.A. Schmidt, and N. Tausnev 2005. Earth's energy imbalance: Confirmation and implications. *Science* 308, 1431-1435, doi:10.1126/science.1110252.
9. Hansen, J. E. A slippery slope: How much global warming constitutes dangerous anthropogenic interference? *Climatic Change* 68, 269-279 (2005).
10. Houghton, J. T., Ding, Y. & Griggs, D.J. et al. (eds.) *Climate change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change.* (Cambridge University Press, Cambridge, UK, New York, USA, 2001).
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13. Levitus, S., Antonov, J.I., Boyer, T.P., & Stephens, C. 2000: Warming of the world ocean. *Science* 2287: 2225-2229.
14. Levitus, S., Antonov, I., Wang, J., et al. Anthropogenic warming of the earth's climate system. *Science* 292, 267-270 (2001).
15. McCarthy, J. J., Canziani, O. F., Leary, N. A., Dokken, D. J. & White, K. S. (eds.) *Climate change 2001: Impacts, adaptation, & vulnerability contribution of working group ii to the third assessment report of the intergovernmental panel on climate change* (Cambridge University Press, 2001).
16. Mills, E. Insurers in a climate of change. *Science* 308, 1040-1044 (2005).
17. Rignot, E., and P. Kanagaratnam, Changes in the velocity structure of the Greenland Ice Sheet. *Science* 2006 311: 986-990.
18. Thompson, L.G., Mosley-Thompson, E., Davis, M.E., et al. Kilimanjaro Ice Core Records: Evidence of Holocene Climate Change in Tropical Africa. *Science* 298, 589 – 593.
19. Trenberth, K. Uncertainty in hurricanes and global warming. *Science* 308, 1753-1754 (2005).
20. Webster, P. J., Holland, G. J., Curry, J. A., and H.-R. Chang, Changes in tropical cyclone number, duration, and intensity in a warming environment. *Science* 2005 309: 1844-1846.

DEATH AND DEATH RATES DUE TO EXTREME WEATHER EVENTS: GLOBAL AND U.S. TRENDS, 1900-2004

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Abstract

Despite the recent spate of deadly extreme weather events such as the 2003 European heat wave and the hurricanes of 2004 and 2005, aggregate mortality and mortality rates due to extreme weather events are generally lower today than they used to be. Globally, mortality and mortality rates have declined by 95 percent or more since the 1920s. The largest improvements came from declines in mortality due to droughts and floods, which apparently were responsible for 95 percent of all deaths caused by extreme events during the 20th century. For windstorms, which contributed most of the remaining 5 percent of fatalities, mortality rates are also lower today but there are no clear trends for mortality. Cumulatively, the declines more than compensated for increases due to the 2003 heat wave. With regard to the U.S., current mortality and mortality rates due to extreme temperatures, tornados, lightning, floods and hurricanes are also below their peak levels of a few decades ago. The declines for the last four categories range from 55 to 95 percent. If extreme weather has indeed become more extreme, global and U.S. declines in mortality and mortality rates are perhaps due to increases in societies' collective adaptive capacities owing to a variety of interrelated factors — greater wealth, increases in technological options, and greater access to and availability of human and social capital — although luck may have played a role. Because of these developments, nowadays extreme weather events contribute less than 0.06 percent to the global mortality burden in an average year, and, by and large, seem to be declining. In summary, there is no signal in the mortality data to indicate increases in the overall frequencies or severities of extreme weather events, despite large increases in the population at risk.

Introduction

Even prior to Hurricanes Katrina and Rita striking the U.S. coast, there was speculation in medical and scientific journals, the popular press and elsewhere that climate change would exacerbate extreme weather events through, among other things, intensification of the hydrological cycle, hurricanes and other storms, and, thereby, raise deaths and death rates globally as well as in the United States (see, e.g., IPCC 2001: Table SPM-1; Patz 2004; MacMichael and Woodruff 2004; Schiermeier 2003, 2005; Trenberth and Taylor, no date). Since then, this speculation — fueled by recent, somewhat controversial studies suggesting that hurricane intensities might be stronger because of climate change (e.g., Webster et al. 2005; Emmanuel 2005a, 2005b; Pielke, Jr., 2005; Landsea 2005) as well as the occurrence of recent weather related disasters ranging from the Central European floods of 2002, the 2003 European heat wave, and the back-to-back disastrous Atlantic hurricane seasons of 2004 and 2005 — has only intensified as epitomized by the recent *Time* magazine cover story warning all to worry more about global warming (Kluger 2006; see also, for example, Anderson and Bausch 2006).

This note examines whether losses due to weather-related extreme events (as measured by aggregate deaths and death rates) have increased globally and for the United States in recent decades, as they should have if — all else being equal

¹ Views expressed in this article are the author's, and not of any unit of the U.S. government.

— climate change has indeed increased the frequencies or severities of such events, as some have claimed might occur (see, e.g., IPCC 2001; Patz 2004; MacMichael and Woodruff 2004). It will also try to put these deaths and death rates into perspective by comparing them with the overall mortality burden, and briefly discuss what trends in these measures imply about human adaptive capacity.

Trends in Mortality and Mortality Rates

GLOBAL TRENDS, 1900-2004

In general, climate change could change the frequencies, intensities and/or durations of extreme weather events such as floods, droughts, windstorms and extreme temperatures — increasing them at some locations and for some periods while decreasing them at other locations and other periods. Some of the effects of these changes will tend to offset each other and/or be redistributed over space and time. For instance, an increase in deaths due to heat waves at one location might be compensated for by a decline in deaths due to fewer or less intense cold waves at the same or another location. Alternatively, climate change might redistribute the temporal and spatial pattern of rainfall, droughts and other such events. Accordingly, to estimate the net impact, if any, of climate change on mortality, it is probably best to examine cumulative deaths at the global level aggregated over all types of extreme events. Because of the episodic nature of extreme events, such an examination should ideally be based on several decades, if not centuries, worth of data. Any such examination should, of course, be cognizant that adaptive capacity and exposure of human populations to risk also change over time.

In particular, one should examine mortality rates so as to filter out the effect of population growth on the population at risk. However, it may be argued that the use of mortality rate may be inadequate to eliminate the effect of increases in populations at risk since, as the population becomes larger, people will migrate to riskier and more vulnerable locations as the less vulnerable locations are occupied. In addition, inappropriate state policies and the availability of insurance, which allows individuals to bear less than their full burden of risk, may place even wealthier populations at greater physical risk (in addition to increasing financial risk; Goklany 2000).

Figure 1, based on data from EM-DAT, the International Disaster Database maintained by the Office of Foreign Disaster Aid and Center for Research on the Epidemiology of Disasters at the Université Catholique de Louvain, Brussels, Belgium, displays data on aggregate global mortality and mortality rates between 1900 and 2004 for the following weather-related extreme events: droughts, extreme temperatures (both extreme heat and extreme cold), floods, slides, waves and surges, wild fires and windstorms of different types (e.g., hurricanes, cyclones, tornados, typhoons, etc.).^{2,3} It indicates that both death and death rates have declined at least since the 1920s. Specifically, comparing the 1920s to the 2000-2004 period, the annual number of deaths declined from 485,200 to 19,400, a 96 percent decline, while the death rate per million dropped from 241.8 to 3.1, a decline of 98.7 percent.

²Figure 1 is constructed using data the following sources: (1) For deaths, EM-DAT (2005). (2) For population from 1900-1925, McEvedy & Jones (1978). (3) For population from 1950-2004, World Resources Institute (2005). (4) For population from 1926-1949, estimates were based on interpolation for each year using the 1925 estimate from McEvedy and Jones and the 1950 WRI estimate, assuming exponential population growth. For 2004, I excluded the deaths due to the Boxing Day Tsunami disaster (which, according to EM-DAT killed 226,435 people). Death estimates, in particular, are approximate and, possibly, more prone to error as we go further into the past. As is evident from the following footnote, EM-DAT is not quite complete. While events in the earlier years might have been missed, EM-DAT should have captured the major natural disasters, particularly in recent years. This suggests that mortality and mortality rates might have been higher in the early decades of the 20th century than is indicated in Figure 1, and subsequent figures and tables.

³EM-DAT contains data on the occurrence and effects of over 12,800 mass disasters in the world from 1900 to present. The data are compiled from various sources, including UN agencies, non-governmental organizations, insurance companies, research institutes and press agencies. For a disaster to be entered into the database one or more of the following criteria must be met: (a) at least 10 people must have been reported killed, (b) at least 100 people must have been reported as affected, (c) a state of emergency must have been declared, or (d) there should have been a call for international assistance.

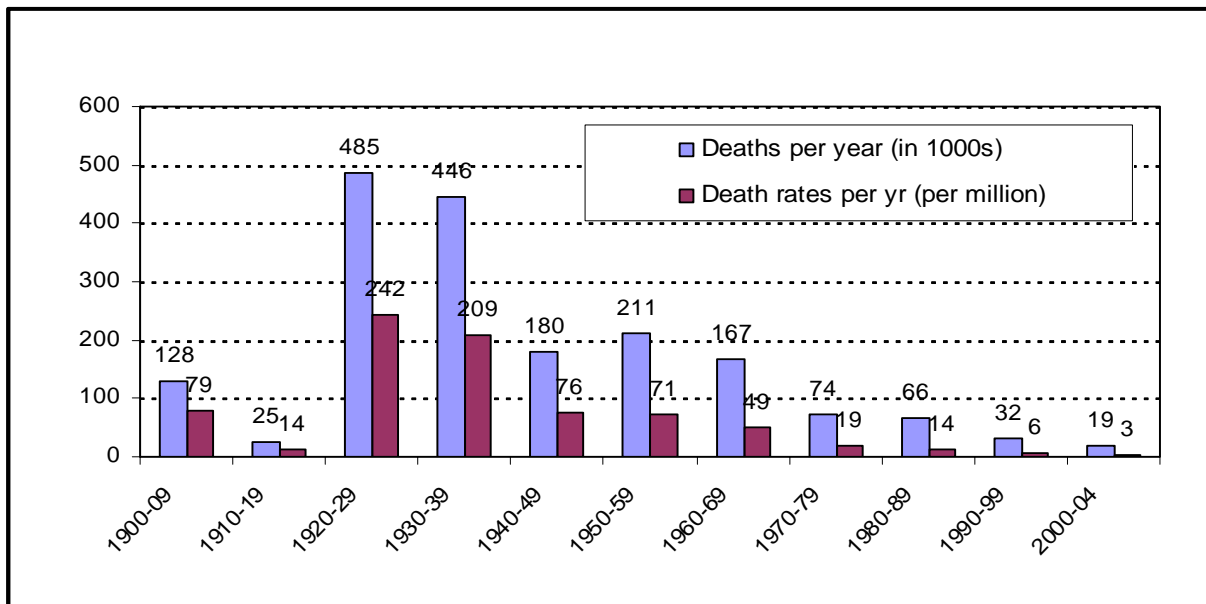


Figure 1: Global Death and Death Rates Due to Extreme Events, 1900-2004. Note that data for the last period are averaged over five years worth of data. Sources; EM-DAT (2005); McEvedy and Jones (1978); WRI (2005).

Table 1 provides a breakdown of the average annual global deaths and death rates for the various categories of extreme events for 1900–1989 and 1990–2004. The columns are arranged in order of declining mortality ascribed to the various events (highest to lowest) for the former period. This shows that:

- During much of the 20th century, the deadliest extreme events were droughts, followed by floods and windstorms. Over the 105 year record, droughts and floods were responsible for 55 and 38 percent of all fatalities worldwide due to all extreme weather events, while windstorms contributed an additional 7 percent. Thus, these three categories together accounted for over 99 percent of the fatalities due to extreme events.
- Aggregate annual mortality for the seven categories of extreme events declined by 86 percent between the 1900-1989 and 1990-2004 periods, while the annual mortality rate dropped by 94 percent.
- Mortality declines between the two periods were mainly due to declines in annual fatalities owing to droughts and floods (see also Figures 2 and 3). The remarkable 99.9 percent drop in annual drought fatalities indicates that, for whatever reason, available food supplies per capita have increased in marginal areas, possibly due to greater food production at the global level and an enhanced ability to move food from food surpluses areas to deficit areas through institutions such as international trade and governmental and nongovernmental aid agencies and philanthropies (e.g., through the World Food Program or the International Red Cross) facilitated by better transportation and communication networks, and irrigation facilities (Goklany 1998). The 89.5 percent decline in flood fatalities between the two periods possibly reflects better control, prevention and management of floods through construction of dams and other infrastructure, supplemented by better emergency response measures facilitated by improvements in transportation systems, flood forecasting, and management of water facilities, among other things.
- While average annual fatalities due to windstorms increased from around 11,000 to 15,000 per year between the two periods, the annual mortality rates declined by about a third (see also Figure 4).
- Annual mortality rates dropped for virtually every category except extreme temperatures. However, the spike in deaths and death rates owing to extreme temperatures during the 2000-2004 period, which occurred because of the 2003 European heat wave, were more than compensated for by declines in flood and drought fatalities.⁴

⁴ EM-DAT (2005) ascribes over 45,700 deaths to the 2003 European heat wave.

	Deaths per year		Death Rates per yr (per million people)	
	1900-1989	1990-2004	1900-1989	1990-2004
	<i>Droughts</i>	111,185	126	49.77
<i>Floods</i>	75,216	7,872	31.96	1.34
<i>Windstorms</i>	10,858	14,780	3.96	2.68
<i>Slides</i>	457	839	0.15	0.14
<i>Waves/Surges</i>	126	181	0.06	0.03
<i>Extreme Temperatures</i>	99	4,253	0.03	0.69
<i>Wild Fires</i>	21	49	0.01	0.01
TOTAL	197,963	28,099	85.94	4.92

Table 1. Global deaths and death rates for various types of events, 1900-1989 and 1990-2004. Sources: EM-DAT (2005); McEvedy and Jones (1978); WRI (2005).

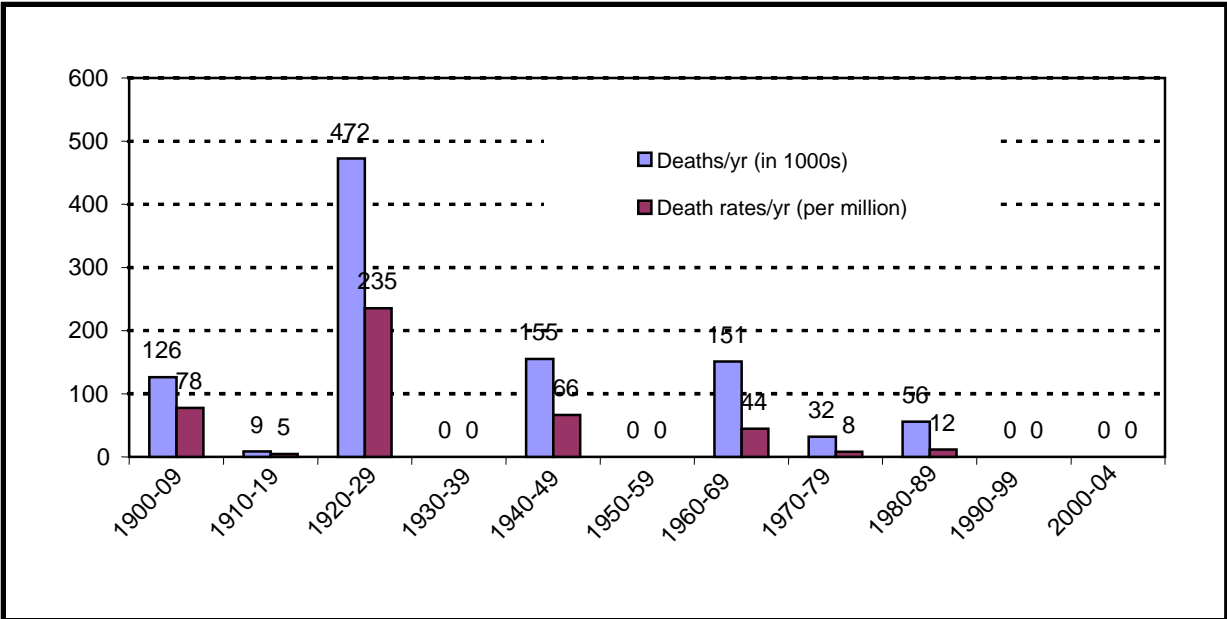


Figure 2: Droughts - Global Deaths & Death Rates, 1900-2004. Sources: EM-DAT (2005); McEvedy and Jones (1978); WRI (2005).

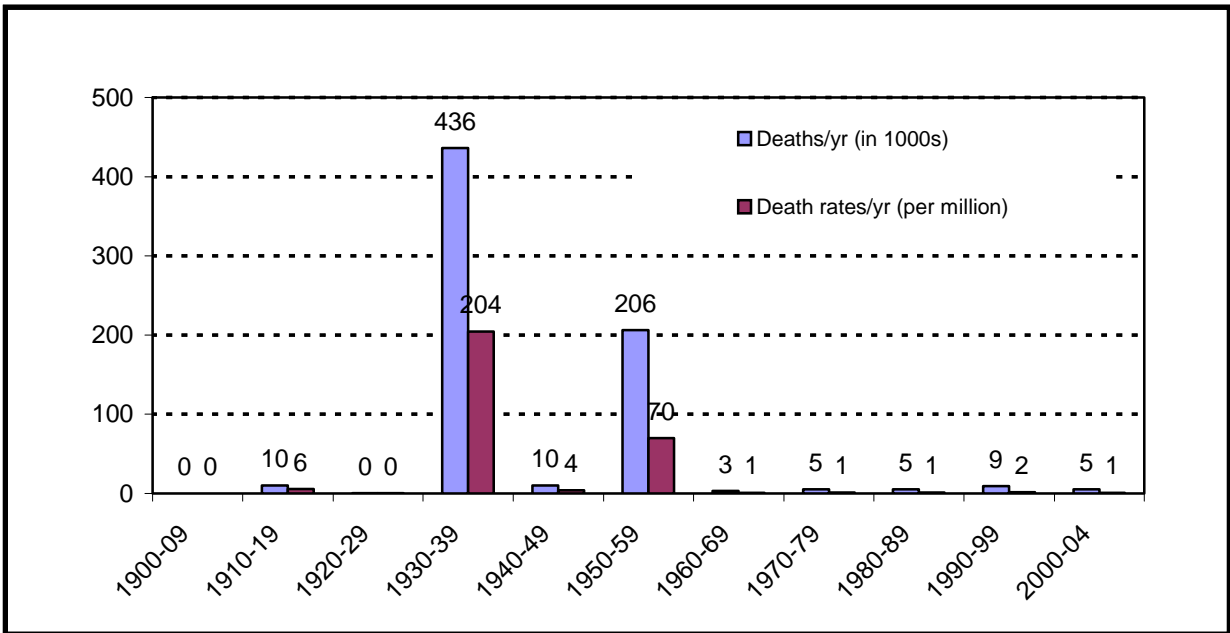


Figure 3: Floods: Global Deaths and Death rates, 1900-2004. Sources: EM-DAT (2005); McEvedy and Jones (1978); WRI (2005).

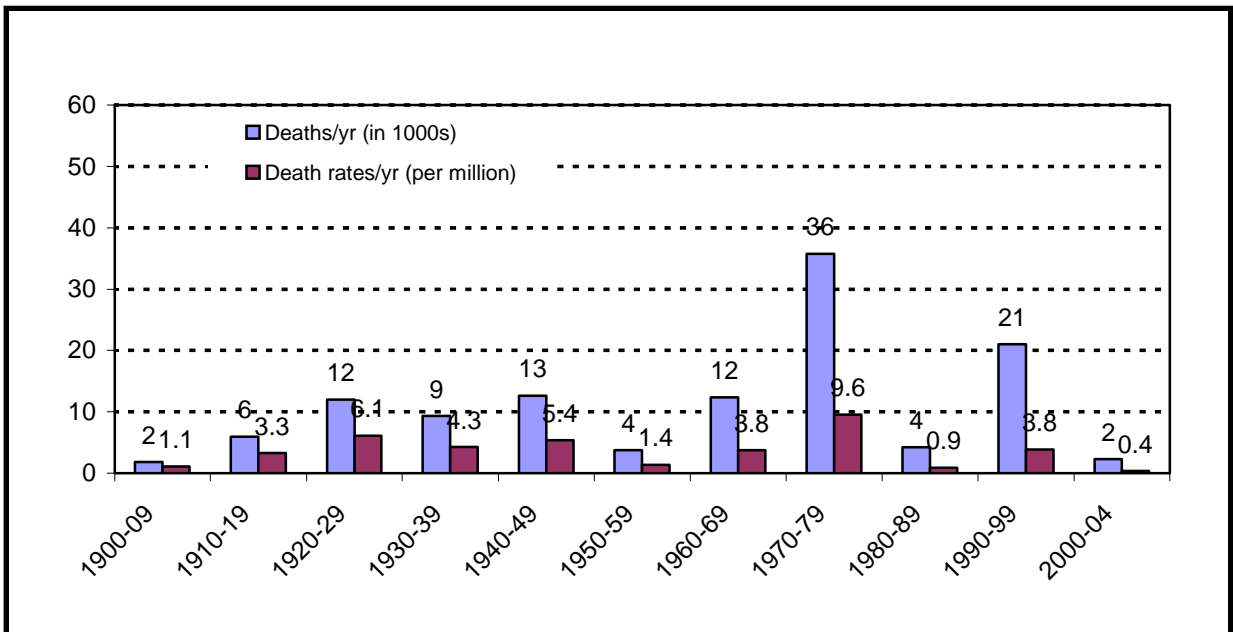


Figure 4: Windstorms: Global Deaths and Death Rates, 1900-2004. Sources: EM-DAT (2005); McEvedy and Jones (1978); WRI (2005).

Cause of Death	No. of Deaths	Percent of Total Deaths
I. Communicable Diseases	18,324,000	32.13%
<i>Tuberculosis</i>	<i>1,566,000</i>	<i>2.75%</i>
<i>HIV/AIDS</i>	<i>2,777,000</i>	<i>4.87%</i>
<i>Diarrhoeal diseases</i>	<i>1,798,000</i>	<i>3.15%</i>
<i>Malaria</i>	<i>1,272,000</i>	<i>2.23%</i>
<i>Other tropical diseases</i>	<i>129,000</i>	<i>0.23%</i>
<i>Other infectious & parasitic diseases</i>	<i>3,362,000</i>	<i>5.90%</i>
<i>Subtotal -- Infectious and parasitic diseases</i>	<i>10,904,000</i>	<i>19.12%</i>
<i>Respiratory infections</i>	<i>3,963,000</i>	<i>6.95%</i>
<i>Nutritional deficiencies</i>	<i>485,000</i>	<i>0.85%</i>
<i>Maternal and perinatal conditions</i>	<i>2,972,000</i>	<i>5.21%</i>
II. Noncommunicable Conditions	33,537,000	58.81%
<i>Malignant neoplasms</i>	<i>7,121,000</i>	<i>12.49%</i>
<i>Cardiovascular diseases</i>	<i>16,733,000</i>	<i>29.34%</i>
<i>Respiratory diseases</i>	<i>3,702,000</i>	<i>6.49%</i>
<i>Other noncommunicable conditions</i>	<i>5,981,000</i>	<i>10.49%</i>
III. Injuries	5,168,000	9.06%
<i>Road traffic accidents</i>	<i>1,192,000</i>	<i>2.09%</i>
<i>Violence</i>	<i>559,000</i>	<i>0.98%</i>
<i>War</i>	<i>172,000</i>	<i>0.30%</i>
Extreme weather events	19,400	0.03%
<i>All other injuries</i>	<i>3,225,600</i>	<i>5.66%</i>

Table 2: Global deaths per year due to various causes, early 2000s. NOTE: All data are for 2002, except for deaths due to extreme weather events, which are based on the annual average from 2000-2004. Sources: WHO (2004), EM-DAT (2005).

THE GLOBAL MORTALITY BURDEN FROM EXTREME EVENTS

To place the current death toll due to all extreme weather events in a wider context, consider that the average annual death toll for 2000-2004 due to all weather-related extreme events according to EM-DAT (2005) was 19,400. By contrast, the World Health Organization (2004) estimates that in 2002 a total of 57.0 million people died worldwide from all causes, including 5.2 million from other kinds of accidents. Out of these, road traffic was responsible for 1.2 million deaths, violence (other than war) for 0.6 million, and war for 0.2 million (see Table 2). Thus, while extreme weather-related events, because of their episodic nature, garnish plenty of attention worldwide, their contribution to the global mortality burden is, at 0.03 percent of global deaths, relatively minor. Their contribution to the global burden of disease should be similarly small.

Notably, the contribution of extreme events to the mortality burden for accidental causes of death is also small (at 0.4 percent). Also, over the last fifty years at least, the general decline in annual mortality due to extreme weather events (see Figure 1) has occurred despite an increase in all-cause mortality (WRI 2005).

A recent review paper in *Nature* (Patz et al. 2005) estimates that climate change may have been responsible for over 150,000 deaths worldwide in 2000. This estimate is largely based on an analysis put out under the auspices of the World Health Organization (McMichael et al. 2004). The latter study arrived at its estimate by ascribing to climate change (a) 77,000 out of about 250,000 deaths due to protein malnutrition, 47,000 out of about 2 million deaths due to diarrheal disease, and (c) and 27,000 out of over 1 million deaths due to malaria (see WHO 2002). It also ascribed 2,000 deaths to floods in 2000, based on the EM-DAT data base. Although this study's estimates for non-flood-related deaths are problematic,⁵ if one accepts them as valid, that means that climate change currently accounts for less than 0.3 percent of all global deaths. Accordingly, based on current contributions to the global mortality burden, other public health issues outrank climate change.

U.S. TRENDS IN MORTALITY AND MORTALITY RATES, 1900-2004

Among the problems in developing a long time series for U.S. deaths due to all (or most) extreme weather phenomena is that the length of the U.S. (data) record varies according to the type of event. The *Annual Summaries* (e.g., NOAA 2004, 2005) published by National Oceanic and Atmospheric Administration (NOAA) provides time series data on fatalities due to hurricanes, floods, tornadoes and lightning, respectively, from 1900, 1903, 1916 and 1959 onward. Each year's summary also gives that year's death toll due to a variety of other weather related phenomena such as extreme cold, extreme heat, drought, mudslides, winter storms, avalanches, etc., but it does not provide any time series data for these other categories of natural disasters. Another problem is that the data for several phenomena from these summaries are at variance with other data sources. Specifically, there are discrepancies between mortality data from these *Annual Summaries* and (a) the Hydrologic Information Center's (HIC 2005) estimates for floods, (b) the National Hurricane Center's data for hurricanes (Blake et al. 2005), and (c) CDC's WONDER database for extreme

⁵ The authors themselves note that among the challenges in developing estimates of the health impacts of climate change is that "climate change occurs against a background of substantial natural climate variability, and its health effects are confounded by simultaneous changes in many other influences on population health... Empirical observation of the health consequences of long-term climate change, followed by formulation, testing and then modification of hypotheses would therefore require long timeseries (probably several decades) of careful monitoring. While this process may accord with the canons of empirical science, it would not provide the timely information needed to inform current policy decisions on GHG emission abatement, so as to offset possible health consequences in the future. Nor would it allow early implementation of policies for adaptation to climate changes." Hence the estimates were based on modeling studies, with quantification based on anecdotal information. The temperature-disease relationship used to develop the estimate for diarrhea, for example, was based on 6 years worth of data from Lima, Peru, and 20 years of data from Fiji. In addition, the amount of climate change estimated for 2000 was based on the results of a general circulation model at resolution of 3.75o longitude and 2.5o latitude. The results of such models, which are inexact at best at the global level, tend to greater uncertainty as the resolution gets finer.

cold and extreme heat. Based on previous conversations with personnel from the various agencies (Goklany 2000), it was decided to use HIC data for floods, and Blake et al. (2005) for hurricanes through 2004. The Center for Disease Control’s WONDER database was used for extreme heat and cold, because it is based on actual death certificate records, which, in turn, are based on medical opinion as opposed to the National Weather Service’s expert opinion. To date (April 2005), these data are readily available only from 1979 to 2002.⁶

Figure 5 shows the trend in cumulative deaths and death rates for a subset of extreme weather events, specifically, hurricanes, floods, tornados, lightning, and extreme heat and cold from 1979-2002.⁷ It shows that despite any warming that may have occurred, both deaths and death rates have not increased over this period. If anything, they might have declined over this period, during which all-cause mortality increased by 28 percent (USCB 2004).

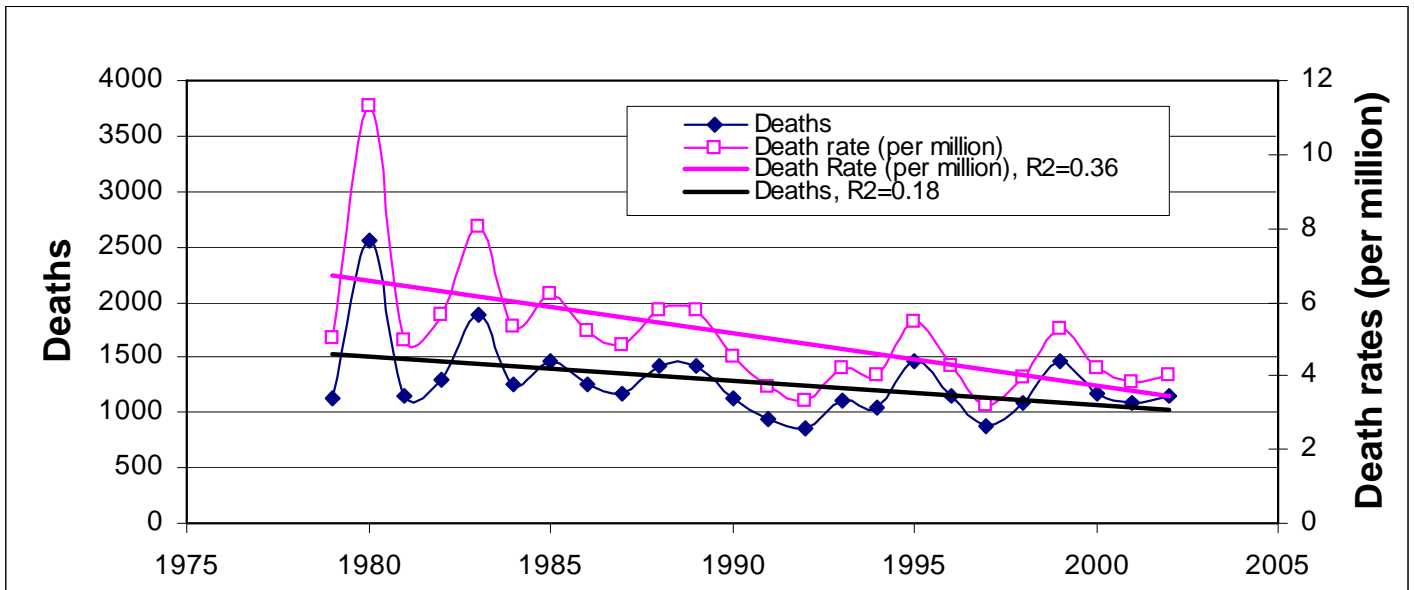


Figure 5: Cumulative U.S. Deaths and Death Rates, 1979-2002, for Hurricanes, Floods, Lightning, Tornados, Extreme Heat and Extreme Cold. Sources: for hurricanes, Blake et al. (2005); for lightning and tornados, NWS (2004, 2005) and Hinson (2005); for floods, HIC (2005); for extreme heat and cold, CDC (2005).

The linear trend lines plotted in Figure 5 (and any subsequent figures) were automatically generated by EXCEL, which uses ordinary least squares analysis. Notably, the bulk of the weather-related deaths (53 percent) during this period were caused by extreme cold. In importance, these were followed by extreme heat, floods, lightning, tornados, and hurricanes, which contributed 28, 8, 5, 4 and 2 percent, respectively. See Table 3.

⁶ To further complicate matters, the NOAA website provides a “65-Year List of Severe Weather Fatalities” (from 1940-2005). Unfortunately, the data in this list for lightning is inconsistent with the data from its *Annual Summaries*. Enquiries to NOAA, so far, have not resolved these discrepancies satisfactorily.

⁷ In the WONDER database, mortality data for 1979-1998 are coded using the International Classification of Disease, version 9 (i.e., ICD-9) for 1979-1998, and ICD-10 for 1999 onward. To identify deaths due to extreme heat, I used codes E900.0 and E900.9 for ICD-9 (per Goklany and Straja 2000), and X30 for ICD-10. The corresponding codes used for extreme cold were E901.0 and E901.9, and X31, respectively.

	Cumulative deaths	Deaths per year	Percent of annual all-cause deaths
Extreme cold (XC)	16,313	680	0.031%
Extreme heat (XH)	8,589	358	0.016%
Flood (F)	2,395	100	0.005%
Lightning (L)	1,512	63	0.003%
Tornado (T)	1,321	55	0.003%
Hurricane (Hu)	460	19	0.001%
Sum	30,590	1,275	0.058%
Total deaths, all causes, 1979-2002 average		2,189,000	100.000%

Table 3. US deaths due to weather-related events, 1979-2002. Sources: for extreme events, see text; for total all-cause mortality, USCB (2004).

Figures 6 (and 7) show the 10-year moving averages for deaths (and death rates) due to hurricanes from 1900-2005, floods from 1903-2004, tornados from 1916-2004, and lightning from 1959-2004, as well as for cumulative deaths (and death rates) from these four individual categories of events (from 1959 to 2004). Death rates in Figure 7 are calculated using national population estimates from the US Census Bureau (USCB).⁸

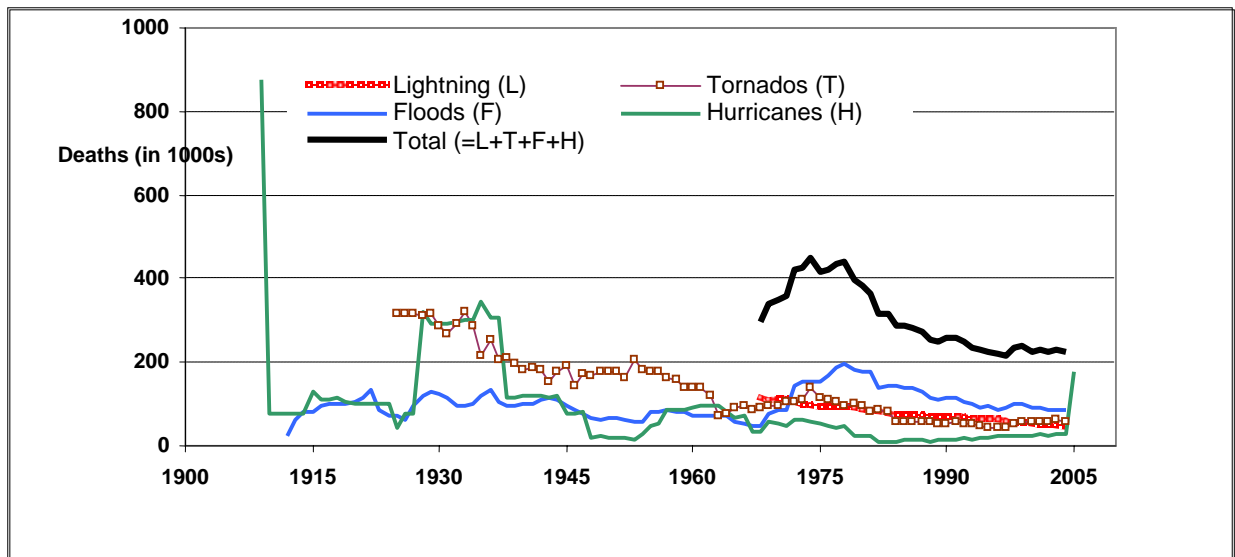


Figure 6: U.S. Deaths due to Hurricanes (1900-2005), Floods (1903-2004), Tornados (1916-2004), Lightning, (1959-2004) and Total (1959-2004); 10-year moving averages. Sources: for hurricanes, Blake et al. (2005), and NHC (2006); for lightning and tornados, NWS (2004, 2005) and Hinson (2005); for floods, HIC (2005) and Goklany (2000).

⁸ For hurricanes it might have been more appropriate to use annual estimates of the coastal population to estimate death rates, but that would have complicated calculations of cumulative death rates.

Figure 6 shows that for the most recent 10-year period for which data are available or estimated (i.e., from 1996-2005 for hurricanes and 1995-2004 for the other types of events), deaths declined below their earlier peaks in the 10-year moving averages by 56 percent for floods, 58 percent for lightning, 82 percent for tornados and, despite Hurricane Katrina, 80 percent for hurricanes. Such declines are consistent with results of earlier analyses (Goklany 2000). Similarly, Figure 7 indicates that the corresponding declines for death rates (comparing their peaks with the most recent 10-year period) were 76 percent for floods, 72 percent for lightning, 95 percent for hurricanes and 93 percent for tornados.

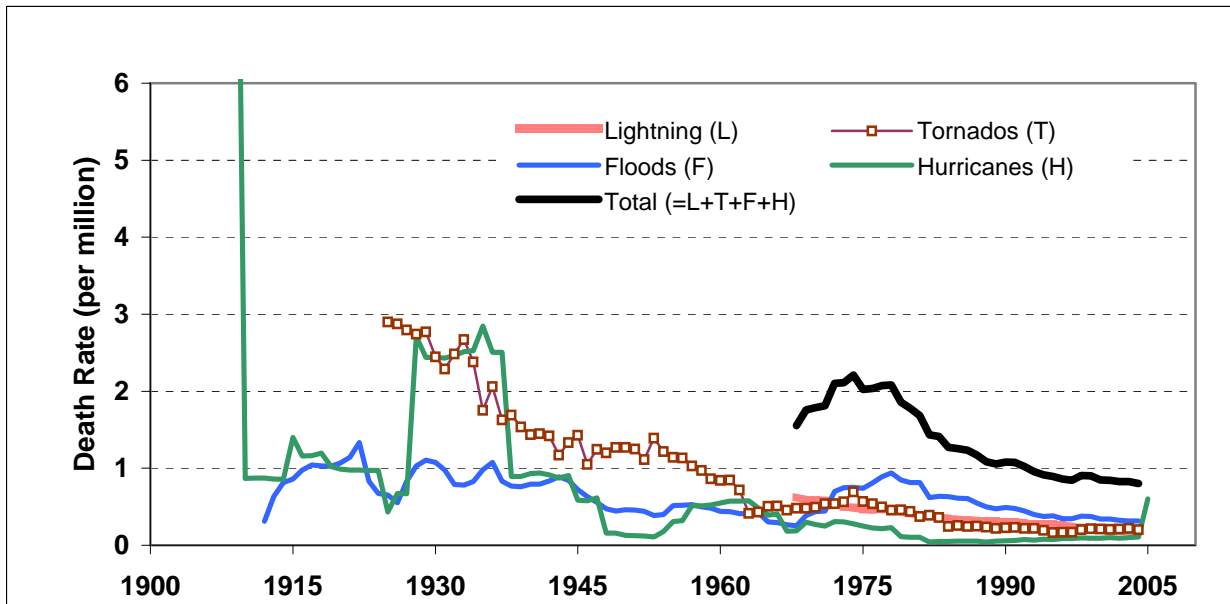


Figure 7: U.S. Deaths Rates due to Hurricanes (1900-2005), Floods (1903-2004), Tornados (1916-2004), Lightning, (1959-2004) and Total (1959-2004); 10-year moving averages. Sources: for hurricanes, Blake et al. (2005) and NHC (2006); for lightning and tornados, NWS (2004, 2005) and Hinson (2005); for floods, HIC (2005) and Goklany (2000); for population, USCB (2006).

Both figures show:

- A large spike for hurricanes at the very beginning of the record due to the Galveston Hurricane of 1900, and a smaller spike due to Hurricane Katrina at the very end punctuated by a relatively high plateau in the late 1920s which extended into the late 1930s, and troughs extending from the late 1940s to the early 1950s and, again, in the 1980s and 1990s.⁹ This is also illustrated in Figure 8.¹⁰
- Mortality and mortality rates dropped more or less steadily for lightning and tornados over the period for which records are available.
- Mortality from floods exhibit no particular trend from 1903 to 2004, although mortality rates might have declined somewhat (see also Figure 9).¹¹ Note that the mortality due to floods in 2005 is expected to be higher than in previous years because of floods related to hurricanes that year.

⁹ These figures assume 1,500 deaths in 2005. As of 10 April 2006, according to the National Hurricane Center (2005) there were 1,409 confirmed deaths due to hurricanes during 2005. However, I rounded this number up because the Katrina count is not yet complete. The figures also assume a death toll of 8,000 for the 1900 Galveston Hurricane (Blake et al. 2005).

¹⁰ Note that in Figure 8 the data for the last period is based on a six year average, while that for other periods are based on ten year averages.

¹¹ In Figure 9 the data for the last period is based on a five year average, while that for other periods are based on six year averages.

- Cumulative annual mortality and mortality rates for the above four categories of extreme weather events have declined since the mid-1970s. Figure 10 indicates that both deaths and death rates for these four categories declined 24 and 52 percent, respectively, from 1959-64 to 2001-04.¹²

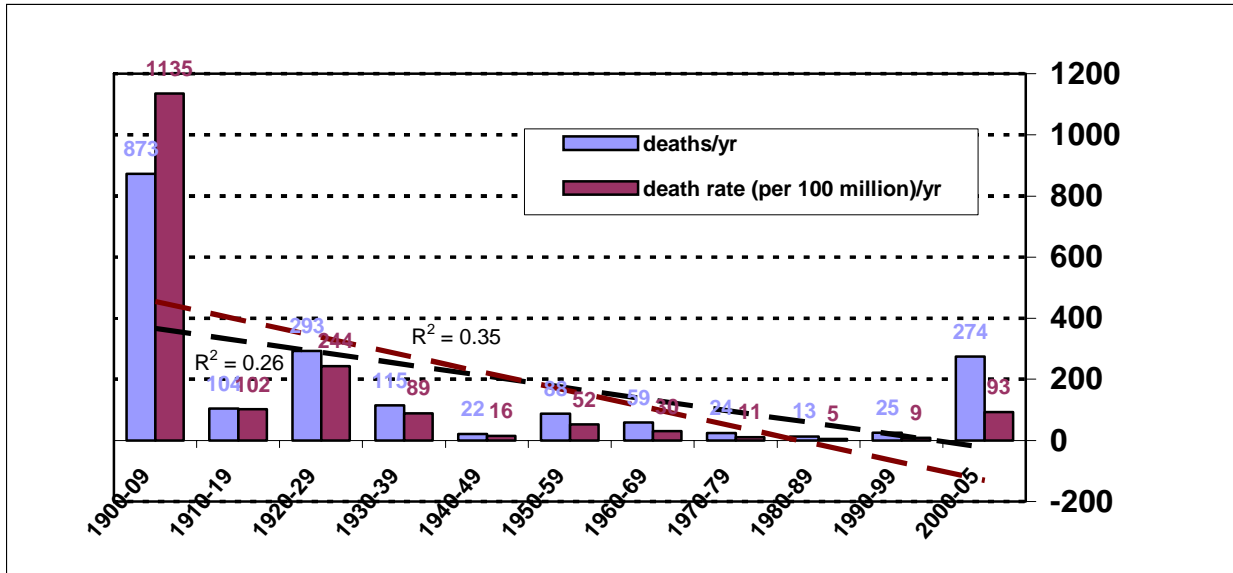


Figure 8: Annual U.S. Deaths and Death Rates due to Hurricanes, 1900-2005. Sources: Blake et al. (2005); NHC (2006); USCB (2006).

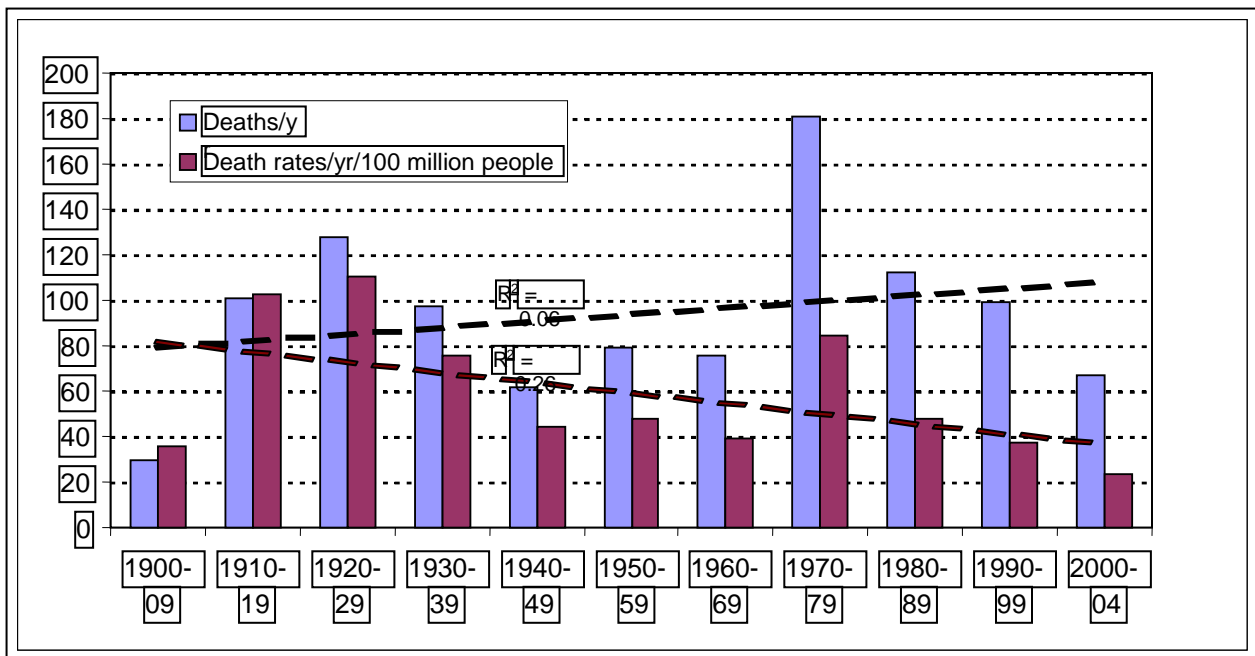


Figure 9: Annual U.S. Deaths and Death Rates due to Floods, 1903-2004. The data for 1900-1909 are based on the seven-year average from 1903 through 1909 because the HIC's series starts in 1903. Sources: HIC (2005); USCB (2006).

¹² Note that the last period spans four years, while the other periods span six years. Also, the decline between 1971-76 to 2001-04 ranges from 56 percent for mortality and 68 percent for the mortality rate.

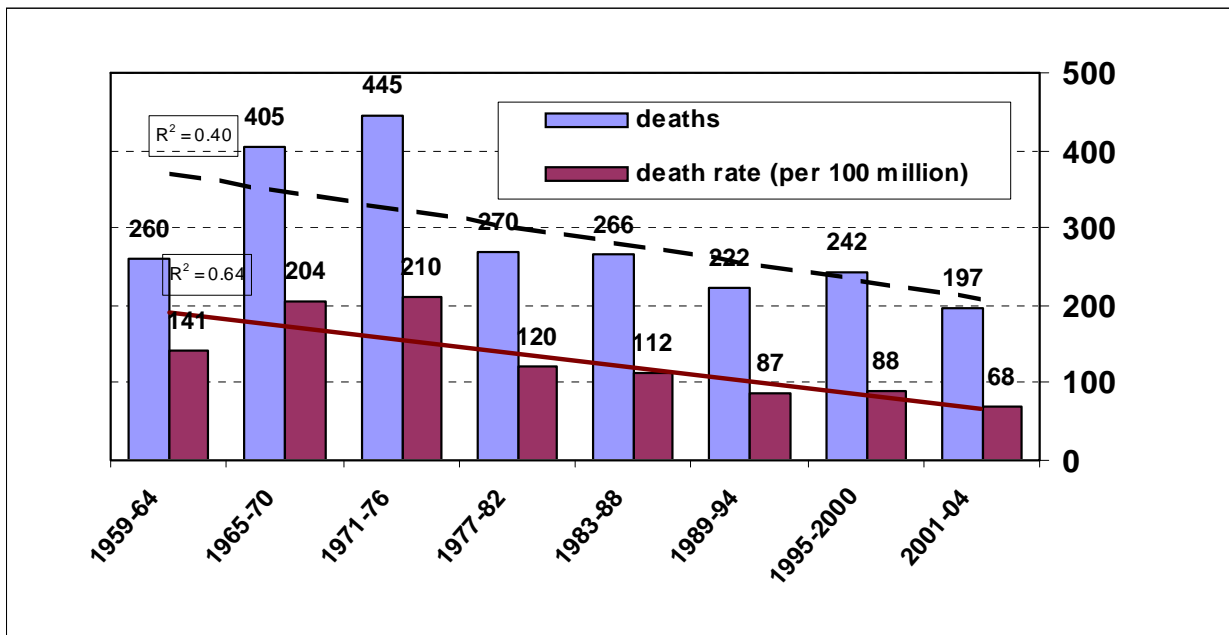


Figure 10: Cumulative Annual U.S. Deaths and Death Rates from Hurricanes, Floods, Lightning, and Tornadoes, 1959-2004. Sources: For hurricanes, Blake et al. (2005); for lightning and tornadoes, NWS (2004, 2005); for floods, HIC (2005); for population USCB (2006).

The previous figures (6 through 10) show that currently deaths and death rates are, in general, lower than they used to be in the past. Predictably, death rates have declined more rapidly than deaths per year, confirming results from previous studies (Goklany 2000). If the frequency, intensity and duration of extreme weather events has increased in recent decades — all empirical issues best left to climatologists — there is no signal of that in the data on either mortality rates or, more importantly, mortality despite an increase in populations at risk.

Discussion and Conclusions

The information presented above indicates that globally as well as for the United States, the aggregate contribution of extreme weather events to the mortality burden is currently relatively minor, ranging from 0.03 to 0.06 percent.

At the global level, the data, while incomplete, indicate:

- Aggregate annual mortality and mortality rates owing to extreme weather events have declined between 95 and 99 percent, respectively, since the 1920s regardless of whether the frequencies, intensities and/or durations of extreme weather events have increased (or not) due to human-induced or natural climate change.
- Much of the above improvement is due to a substantial decline in mortality due to droughts and floods, which apparently caused 95 percent of the fatalities due to extreme events between 1900 and 2004.
- Death rates for the different categories of extreme events were generally lower in the 1990s and early-2000s than in previous decades, with the notable exception of extreme temperatures, which were higher because of the 2003 European heat wave.
- Regarding windstorms, both mortality and mortality rates peaked in the 1970s. The average annual mortality due to windstorms over the past 15 years exceeded the average over the rest of the 20th century but the mortality rate was a third lower.

With respect to the United States:

- In an average year, more lives are lost to extreme temperatures — both extreme heat and extreme cold — than to more heavily publicized events such as tornadoes, hurricanes and floods. According to data from the

Centers for Disease Control, extreme cold, on average, claims more lives than tornados, floods, lightning, hurricanes and extreme heat, combined.

- In general, mortality and mortality rates from the various categories of extreme events examined here (tornados, hurricanes, floods, lightning and extreme temperatures) are lower today that they have been in the past. Based on 10-year moving averages, for the most recent 10-year period for which data are available (or for which data can be approximated), mortality declined by 55-80 percent for floods, lightning, tornados and hurricanes while mortality rates declined by 70-95 percent. However, there are no consistent trends for mortality due to floods, and both mortality and mortality rates for hurricanes spiked in 2005. However, these spikes are lower than levels that had been reached in previous periods.

Thus, mortality rates and, more significantly, mortality for the most deadly and destructive forms of extreme weather events have apparently declined substantially over the past several decades. This suggests that if climate change has exacerbated extreme events then either mankind has been extremely lucky in terms of where and when these events have struck or — a more likely explanation — society's ability to cope with extreme events has not only improved, it has for the most part put its increased adaptive capacity to good effect.

Several interrelated factors have contributed to this increase in adaptive capacity. First, today's societies have available to them a wider range of technological options to finesse the consequences of extreme events before they strike and to cope with their aftermath after they have struck. Such options range from early warning systems, building codes, and better meteorological forecasts to better construction, communications and transportation systems which increased the ability to transport men and materiel (including food, medical and other essential supplies) in and out of disaster zones. Second, many of these options were learnt through experience and were enabled through the ability of wealthier societies to research and develop new technologies and practices. Greater wealth also allowed them to obtain and implement more effective technologies. Once developed, it is possible for poorer societies to learn from and adapt technologies developed in wealthier, more technologically sophisticated nations. Third, societies have greater access to human and social capital to protect themselves from, and cope with, adversity in general and extreme weather events in particular (IPCC 1991; Goklany 1995, 2000, 2006; Goklany and Straja 2000).

However, as indicated by the European experience with the 2003 heat wave and the U.S. experience with Hurricane Katrina, the importance of human and social capital cannot be overemphasized. They are just as important as wealth and increased access to technology. Moreover, greater adaptive capacity is necessary but not sufficient to effectively cope with extreme events. Such capacity must be deployed more rapidly and used more fully.

Nevertheless, the decline in deaths and death rates from extreme events indicates that if extreme events have become deadlier then adaptive capacity has evolved even faster, and thus far wealth, technology, and human and social capital have, despite notable exceptions, have for the most part apparently trumped natural climatic variability and human-induced climatic change.

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CLIMATE CHANGE AND DISASTER LOSSES: UNDERSTANDING AND ATTRIBUTING LOSSES AND PROJECTIONS

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Question 1: What factors account for the dramatically increasing costs of weather-related disasters (specifically, floods and storms) in recent decades?²

Losses (adjusted for inflation) caused by natural catastrophes, as defined by the US property insurance industry, have risen by a factor close to 100 between the 1950s and the past decade (Changnon et al. 2000). For a storm to create significant economic losses, two conditions have to be met: storm occurrence at a sufficiently high intensity, and exposition of vulnerable assets to this hazard. Losses increases have to be driven by one of these two factors, or recent appearance of new loss drivers.

Could part of these losses increases be driven by greenhouse induced global warming? Over the tropical North-Atlantic, the tropical cyclone record extends back to 1900. The North-Atlantic is the basin where data is considered to be the most complete. But reconnaissance aircrafts fly since only 1944 and satellite data is available since 1970. Prior to that date, storms may have been missed. Post-1970 hurricane wind speed records indicate a clear increase in hurricane activity over the past decades (Emanuel 2005, Webster et al. 2005) which is well correlated with North-Atlantic Sea Surface Temperatures (SST) trend. However, even for this modern era record, there is some controversy in the wind speed estimates (Landsea, 2005). Added to the short duration of the record, this makes Landsea (2005) question whether the observed increase in hurricane activity is forced by anthropogenic activities. Longer records over the US continent show that in the past, hurricane activity did fluctuate at multi-decadal time scales (Landsea 2005), and that these fluctuations correlate very well with the principal modes of multi-decadal tropical cyclone variability (Bell and Chelliah 2006). This low-frequency tropical cyclone variability is evidenced through coherent behaviour of the entire circulation in the Tropics (Bell and Chelliah, 2006) and affects mostly the annual rate of occurrence of major events (Goldenberg et al. 2001). It is therefore not quite clear whether the recent increase in hurricane dissipation power (Emanuel 2005) is a manifestation of global warming (through SST increase) or whether it reflects natural climate variability.

Modelling studies regarding the intensification of hurricanes as a result of warmer SSTs can help resolve this issue. Kouchi et al (2005) report results obtained with a very high horizontal resolution climate model (20 km grid resolution) that show an increase in maximum wind speed as a result of anthropogenic activities, but a significant decrease in cyclone frequency (except over the North-Atlantic). These results obtained with a model that explicitly resolves tropical cyclone circulations, are in line (in terms of intensity) with those reported by Knutson and Tuleya (2004) and with theoretical considerations (Emanuel 1987). However, it is worth noting that up to now, no trends in maximum hurricane wind speed have been detected from the data (Webster et al. 2005). One reason for this may be that hurricane maximum intensity has a short tail distribution and therefore an upper bound, obtained from theoretical considerations (Bister and Emanuel 1998, Emanuel 1999) or from modelling the data with extreme value distributions.

¹ The views expressed are those of the author and do not necessarily reflect the views of the AXA group

² Answer is provided in the context of the tropical cyclone discussion

Because storms only occasionally reach this theoretical upper limit, and because this particular moment in the storm life cycle may not be properly reported in 6-hourly records, it may be a while before trends in hurricane maximum intensity are actually detected from observational data.

Hurricane losses records properly normalized reflect the multi-decadal variability of hurricane activity over the North-Atlantic and the US coast, but do not reflect any long-term trend (Pielke and Landsea, 1998, Pielke 2005). For eleven years, the activity has been intense if not extreme across the North-Atlantic and losses are very significant over the past two years, but *normalized per-storm loss* does not show evidence of a trend over the 20th century (Pielke 2005). Over a sufficient amount of time, trends in hazard should manifest in trends in per-storm loss (after proper normalization, a manifestation of increasing severity), and/or trends in annualized cumulative losses (after normalization, a manifestation of increasing annual rate of occurrence). As none can be detected today, it seems premature to attribute recent hurricane losses to trends in hazards resulting from global warming, although following Trenberth (2005) we note that non-detecting does not enable to conclude regarding the existence.

Corrected for inflation, the cause of increasing disaster losses over the past century is for a very large fraction a result of increasing asset exposure to natural hazards (Changnon et al. 2000, Pielke 2005). In the past (centennial time scales) variability of natural geophysical hazards (including possible trends) has been orders of magnitude smaller than trend implied by economic or population growth: Hurricane Andrew loss estimate doubled in just 10 years because of migration and rise in assets values.

Recently, new loss drivers have contributed to record loss amounts. We specifically refer to demand surge, generally understood as the temporary increase in repair prices (building materials and labour costs) resulting from the surge of demand for rebuilding homes and services, following major events. Industry surveys, professional sources and CAT models vendor's communications indicate that in 2004 and 2005, demand surge was a very significant, non-linear component of the overall reported loss. Demand surge is a complex phenomenon, difficult to quantify and model, as it depends on micro- and macro-economical aspects, but also behavioural, environmental and political drivers. It is probably becoming an increasingly important component of the overall loss as the economy tends to operate in a particularly tense demand and supply environment. Another potential current and future loss driver is inflation of legal costs.

Considering future loss projections, they rely upon combined expected rise in wealth and population. Over the US, the Association of British Reinsurers (ABI 2005) estimate it will correspond to a 700 % increase in assets over a 100 year time frame. But shall we therefore consider that disaster losses will raise by a factor 7 over the century? We return to this point when discussing appropriate metrics for natural catastrophes cost estimate, but first, we compare this factor 7 to what can be expected from climate variability alone. To obtain a 700% increase in hurricane destructiveness by wind speed changes only, would require a doubling in mean hurricane wind speeds (as loss varies as the cube of the wind speed). This is clearly not realistic, neither on observational, theoretical or modelling grounds. By combining wind speed projections and frequency projections, 700% increase in destructiveness would be obtained by a tripling in major hurricane frequency and a 32% increase in damaging wind speed over a 100 year time frame. The latter figure is quite unrealistic too and no climate scenarios support such shifts in hurricane wind speed distribution. Consider for example than in the ABI 21st century projections, an upper-end stress scenario was defined as a 9% increase in damaging wind speed, while Kouchi et al. (2005) report a 7% increase in maximum wind speed following anthropogenic activities.

Question 2: What are the implications of these understandings, for both research and policy?

We provide an answer to this question in the context of assessing the economical cost of natural disasters for the society. Consequently, the metric needed for this assessment shall reflect the cost, for the society, of a given disaster economic loss. As the society – irrespective of the hazard occurring or even existing – evolves, the evolution of the

cost for the society of a given natural hazard shall not reflect the overall society gradual move (economical growth, demography) but shall solely reflect the changes, in either the natural hazard itself or the society specific exposure and vulnerability to the natural hazard. A proper yearly metric reaching this goal can be defined as the yearly loss normalized by annually defined *cumulative nationwide asset*. This strongly relates to the GNP (Gross National Product). As stated above, this metric, the loss per asset value, or loss per GNP provides a time-varying view of the cost incurred by the society, undistorted by its overall evolution which occurs irrespective of the hazard, but which exemplifies specific factors affecting the loss itself. These specific factors are either geophysical, either societal:

- trends in natural hazard
- specific migration towards hazard-prone regions (meaning differential in coastal population growth versus overall nationwide population growth)
- modifications in exposure or vulnerability of assets exposed to the hazard (where, how, how vulnerable are assets).
- Sensitivity of the society to disaster losses (demand surge effects, claims litigation cost surge, ...)
- different growth rate of the hazard-prone region compared to national growth rate

It is likely that only the first four factors are significant players in long-term variations of loss per asset value. It is interesting to note that if for example we were to address the question of future disaster losses incurred, not by the society, but for example by the US insurance industry, the metric used would be different. It should only reflect changes in natural hazards, and changes in exposure and vulnerability of the insured assets (points 1 and 3 above).

This metric is also appropriate to consider when discussing virtues of climate mitigation policy versus society adaptation for natural disaster assessment. This debate can be phrased as, for the Society (in the future), which policy should be promoted now in order to reduce the cost for the Society of future natural hazards. Clearly, what matters is the cost incurred by the Society and therefore loss per GNP is a proper measure of cost. The debate should therefore focus on comparing the benefit of society adaptation in reducing this loss per GNP, versus the benefit of reducing greenhouse gases emission in preventing any rise in this loss per asset value (taking as a possible scenario that loss per asset value could raise either by increasing storm frequency or severity). It is clear that taking society adaptation measures to protect against natural catastrophes should be promoted as it provides valuable benefits to the society and the people, irrespective of increasing hazard. The same argument holds however for climate mitigation: it provides benefits by reducing impacts of climate change on the environment and the society, irrespective of whether climate change is responsible for more severe extreme events. Benefits of one policy versus the other is not straightforward to assess because of the complexity of societal behaviour affecting losses. In the future, loss per asset value could be reduced if enforcement of stronger construction codes results in reduced vulnerability, reliable warnings were issued in advance to the exposed population and protection measures of homes were taken, construction was promoted further inland in less vulnerable areas than right on the coast, flood defences be erected, better awareness of people through education and media communication that ends up in a reduction of the migration flow towards exposed areas, etc ...

How to measure the sensitivity of the loss per asset value to specific measures? Risk models, because they incorporate all aspects of the risk (hazard, exposure, vulnerability, cost surge and loss estimate) are very good candidates to address these issues. Sensitivity experiments can be specifically designed to quantify for example, the reduction in cost the society can expect from certain adaptation measures (as well as from mitigation measures, see for example the ABI 2005 report). The insurance industry, the scientific and the private sector modelling community, policymakers and local communities would benefit mutually from using these risk models to assess the sensitivity of the loss to varying assumptions.

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OVEREXPLOITATION OF ECOSYSTEM RESOURCES VS. THE COSTS OF STORMS AND FLOODING RISK MANAGEMENT

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Introduction

Historically, human settlements followed land terraces and banks close to water courses, but avoided main riverbeds because of flood risks. Especially during recent decades, enlarging human settlements like cities broke this habit and extended themselves within riverbeds, with the help of grand works of river regularization. In the same period, intense local and regional deforestation changed the flow regimes of large river basins, in the sense that rivers increased basic and flood volumes of waters. By the time human settlements and agglomerations already went a long way in incorporating riverbeds, changes in hydrological regimes determined that river systems found their old natural course and flooded the primary river beds (Plate, 2002).

A highly typical way of overexploitation of natural resources that leads to high water-related risks is deforestation. Forests regulate directly the surface water circuits through their physiological and ecologic functions. In addition, forests have indirect influences on natural water circulation as their biomass traps atmospheric carbon dioxide – the gas most responsible for the "greenhouse effect", thus acting as sinks. On the other hand, new findings (e.g. Keppler et al., 2006) states that methane (an important greenhouse gas) is readily formed in situ in terrestrial plants under "oxic conditions" by a hitherto unrecognized process, thus acting as a source. Nevertheless, the extensive loss of Earth's forests may contribute to increasing global warming (e.g. Arrow et al., 2000; Andreassian, 2004; The Economist, 2005), and eventually contributing to changes in weather and climate.

Dealing with climate-driven and weather-related risks requires fair understanding of three fundamental aspects. First, climatic changes (in temperatures and precipitations) are not equally distributed across the Earth. Second, socio-economic and techno-infrastructure capacity to deal with environmental hazards is also not equally distributed among regions and countries. Third, detailed mechanisms of interactions and influences of human and natural factors are rarely clear, and need highly complex analysis, because of a) co-variation of anthropogenic and natural gradients in the landscape, b) scale dependence of mechanisms, c) nonlinear behaviour of natural systems, and d) complex history of natural influences and land-uses (e.g. Doorkamp, 1998; Simonovic, 2000; Allan, 2004). Given these limitations, we make an attempt in this background paper to address the following two questions in context of the overexploitation of ecosystem resources versus the costs of storms and flooding risk management:

Question 1: What factors account for the dramatically increasing costs of weather-related disasters (specifically, floods and storms) in recent decades?

Question 2: What are the implications of these understandings, for both research and policy?

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A brief analysis of factors (e.g. overexploitation of ecosystem resources) accounting for increasing costs of climatic/weather-related disasters, their implications, and insights followed by a summary is presented hereinafter.

Contributing Factors

The weather-related disaster losses have increased dramatically in recent decades, as shown in a figure (http://www.grida.no/climate/ipcc_tar/wg2/fig8-1.htm) published in 2001 by the IPCC (Pielke, Jr., 2005). Moreover, the magnitude, frequency and impacts of storms and floods appear to have increased in the last decade apparently as a consequence of global climatic changes – but also because of higher human pressures over environment viz. deforestation, urbanization and river regularization (e.g. Kundzewicz and Kaczmarek, 2000; Muzik, 2002; WWDR1, 2003). In 2002, for example, approximately 47 percent of the Brazilian Amazon was under some type of human pressure including deforested areas, urban zones, agrarian reform settlements, areas allocated for mining and mining exploration as well as areas under pressure as indicated by incidence of fire in Fig. 1 (Barreto et al., 2006).

The mechanism through which forests control the surface water circuits is complex and not completely understood, but the basic processes are mainly related to mechanical reception of precipitations, respiration and biomass production,

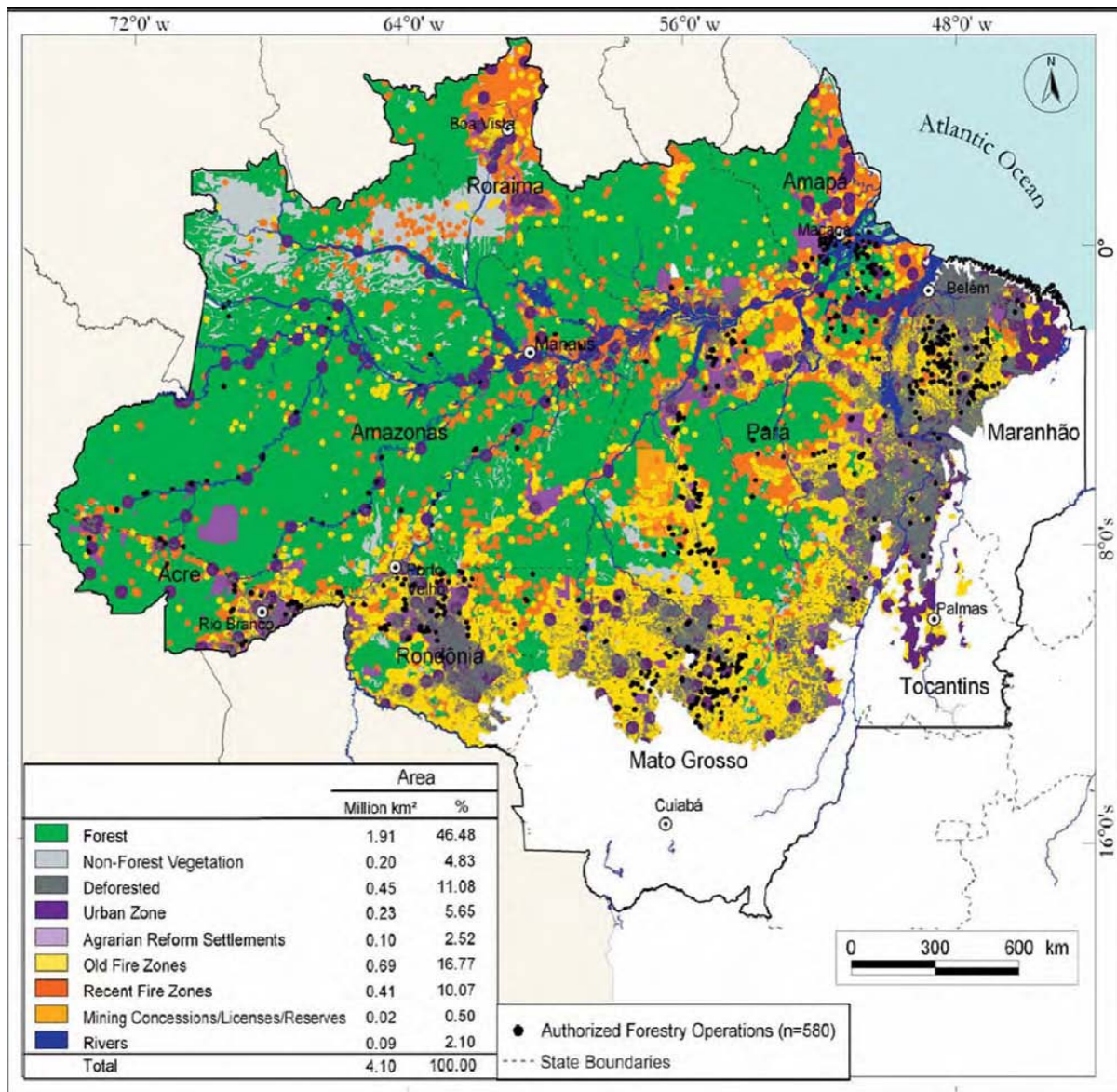


Fig.1: Human Pressure in the Brazilian Amazon - All Indicators (Source: Barreto et al., 2006).

variation of soil hydrological and hydro-chemical properties (e.g. Naef et al., 2002). The runoff of meteoric water on surface slopes is dependent of the hydraulic properties of soils, notably soil infiltration capacity, the later being influenced by changes and memory effects associated with land-uses (Naef et al., 2002; Zimmermann et al., 2006). Agricultural expansion against forest cover can lead to constant degradation of land, albeit without significant increase in agricultural yields, especially in steep slope areas, for example like in Central Himalaya, India, during the 1967-1997 period (Wakeel et al., 2005).

It has been observed that the timber harvest and forest cover reduction usually results in increases of the stream flow. Just to give a short example, studies from southern Appalachian catchments showed that commercial clear-cutting resulted in 28% increase of the stream flow; water discharges diminished in the subsequent years as the wood vegetation started to recover (Swank et al., 2001). The extent of forest reduction needed to result in observable changes in water yield varies with geographical and biological properties of the river catchments (e.g. Stednick, 1996; Sun et al., 2005). Forest composition in a river collection basin directly influences how much effects forest have on low flows and peak flows in rivers (Robinson et al., 2003). Moreover, rapid urbanization of forested watersheds may cause higher peak flows and lower low flows, especially in areas with frequent heavy rains and steep slopes, one such representative example being Taiwan (e.g. Cheng et al., 2002).

Extreme storms and floods in the last decades happened mostly in Asia, but also in America and Europe. At present, about 40% of human population live in areas vulnerable to floods and rising sea levels, among nations most at risk being Bangladesh, China, India, Netherlands, Pakistan, Philippines, USA, and small island developing countries (Doornkamp, 1998; WWDR2, 2006). Tropical countries with monsoon climates (e.g. Bangladesh and India) are more prone to floods. Nevertheless, floods in the relatively small Red river in Canada and the USA in April-May 1997 have shown that developed temperate zone countries are not immune from them (Singh, 1997). In wealthy countries, however, while the number of fatalities from storms and floods go down, the material losses and economic risks keep rising, due to a increasing economic vulnerability in the general context of present policies (e.g., Kundzewicz and Kaczmarek, 2000; Hall et al., 2005). For example, costly ice storms in the US have been increasing dramatically in recent years – as shown in Fig.2 (Changnon, 2003).

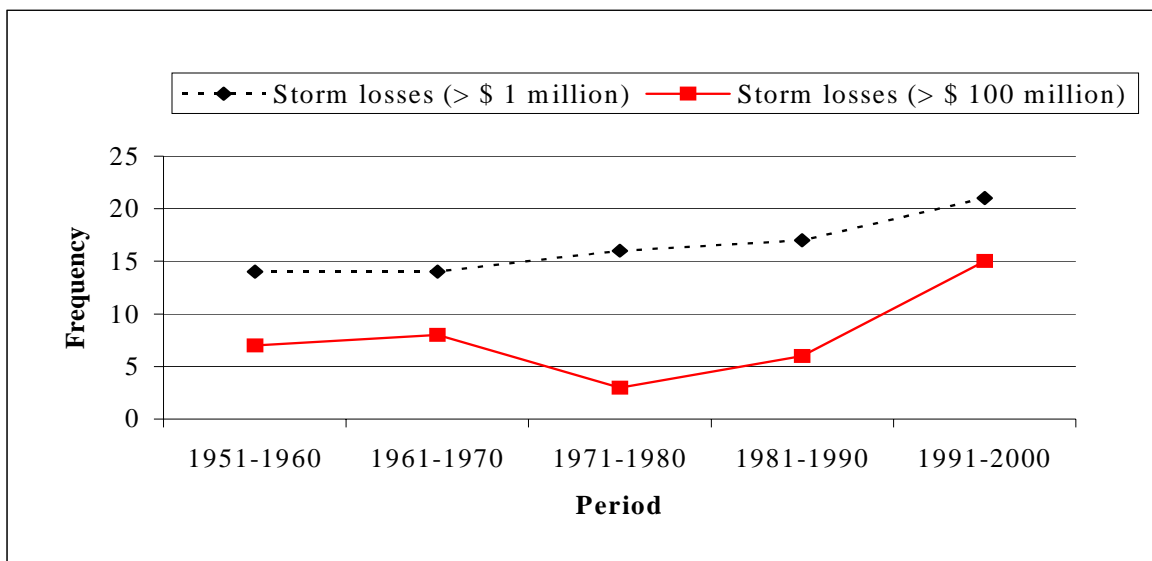


Fig. 2: The frequency of damaging ice storms during 1951-2000 in the US (as defined at two levels of losses – 1998 US \$) (Data source: Changnon, S.A., 2003)

There are evidences that engineering measures such as storage, marginal embankments, improvement of waterways, etc. can and do reduce flood intensity and flood damage (Ojha and Singh, 2004). In contrast, Kundzewicz and Kaczmarek (2000) argue that higher cost of flood events is not only a policy issue, but a result of present practices e.g. over-reliance on engineering solutions such as dikes. The fact is that failure of physical solutions like dykes is usually, and inadvertently, considered as highly improbable. As a result, no significant preparation is carried out for such a possibility. One such example is the flooding of the New Orleans city in 2005, following dike failures during the level 5 hurricane Katrina. But this is not an isolated case. As a rule in the coastal areas, engineering works removed the danger from most (and low intensity) floods, so that what remain are only two situations: no flood or catastrophic floods (Doornkamp, 1998). Also, it is not uncommon that floods repeatedly visit the same country/area in short intervals, like it occurred in the Rhine River in Germany during 1993 and 1995 and in South Korea in 1995 and 1996. In both cases, the later floods were less costly than the earlier ones, showing that some lessons were learned and appropriate actions were taken in time (Kundzewicz and Kaczmarek, 2000).

Case Study

Recently, Romania was the European country most hit by water related events, i.e. heavy storms and floods. In 2005, the yearly amount of rainfall in Romania was with 34% higher than the normal average (866.5 mm, instead of 647.0 mm), and with monthly distribution more uneven than usually, with several local highest recordings ever for rainfalls and river flows. The mean annual temperature was with 0.1°C lower than the reference period 1961-1990, with monthly average also with significant variations from the normal. Storms with heavy precipitations were concentrated in certain months, including winter snow covers. In almost every month it occurred that the flood defence levels were exceeded on rivers across the country, and a series of large floods affected the whole country mainly between April and September. The 2005 floods affected all 41 counties, and resulted in 76 human casualties and ca 2.0 billions US dollars (ca 1.7 billions Euros) (REIFMP2005, 2005). The extensive damages, notably on agriculture and infrastructures is thought to have strongly impacted on the national GDP annual growth, which dropped to ca. 4.3 in 2005, from 8.3 in 2004.

The recognized cause for such events and damages are: melting of snow (locally over 1 m thick) and heavy rainfalls (locally over 200 litres/m²) or the two combined; deforestation; dikes failures due to higher, repeated and longer periods of high flow (up to 20 days); insufficient maintenance of flow-control system of reservoirs and channels; unauthorized and/or inappropriate constructions in high risk areas; under-equipped and inefficient institutions responsible for prevention and mitigation of disaster effects.

Putting aside the unusually extreme climate events and the unavoidable limits of any physical river regularization and the financial means, the big floods during 2003-2005 in Romania were most disastrous in areas that have undergone extensive deforestations following legal changes from state to private ownerships (law 400/2002), particularly on the slopes of the Carpathians Mountains. After flooding, new rules have being adopted in 2005, stipulating that, irrespective of ownership type, reforestation is compulsory within two years after deforestation. In case of reforestation failure with private owner, reforestation will automatically be realized by the National Forest Administration – RNP, at the cost of the owner. As reforestation is not very cheap, owners are expected to tend to avoid clear-cutting in the first place.

In addition, a detailed national map of flood risk is currently being worked by Romanian and German specialists, and due to be finished by 2008. Such measures are part of the National Strategy for Climatic Changes (SNSC) in Romania, developed by the National Commission on Climate Changes, within the authority of the Romanian Ministry for Environment and Waters, and in collaboration with other ministries, in order to comply with the United Nation Convention on Climatic Changes (law 24/1994) and the Kyoto Protocol (law 3/2001), and with the environment requirements of the European Union (SNSC, 2005), as well as the National Strategy for the Flood Risk Management

(SNMRI, 2005), which also includes special first version of manuals like the Prefect's Manual for the Management of Flood Emergencies (MprefMSUCI, 2005) and the Mayor's Manual for the Management of Flood Emergencies (MprimMSUCI, 2005). Moreover, as a consequence of the floods in the spring of 2006 in all countries along Danube River, talks have began for building a joint international systems of early flood warning and associated management in the Danube's catchment. All such initiatives and management practices currently have a purely national character.

So far it seems that, with the support of the European Union to which it is planned to adhere most probably in 2007, Romania did learn the right lessons. However, now experts look at how efficiently applied these plans are: a matter of governance effectiveness. This was a point on which experts insisted during the negotiation of the treaty of EU – Romania association, namely Chapter 22 – Environment. New large floods are expected during 2006 and the next years, but casualties and material losses are due to decrease. A cost analysis of this evolution will be highly instructive for future measures of reduction in the costs caused by storms and floods.

Implications

In the past, once countries attained a certain level of economic development, they could deal better with issues of environmental protection and management. However, in the present era, developing countries appear to be stuck in a vicious cycle of poverty and deficient nature management. For example, economic development in lower income economies is accompanied by extensive overuse and/or natural resource conversion (Barbier, 2005).

In the context of a country's national strategy for sustainable development, holistic actions are a prerequisite to address climate and water-related crises in a cost-effective manner (Duda and El-Ashry, 2000). However, adoption and implementation of such action plans are a most difficult problem in developing countries in Asia, South America, Africa and Central-Eastern Europe, due to lack of financial and institutional resources (Loucks, 2000) and also due to the conflict in interests of different stakeholders. For example, a highly ambitious and massive water project that would integrate most of India's major waterways primarily aimed to mitigate problems of floods and droughts in different regions of the country has become a topic of intense debate in the scientific and policy-making communities (Gurjar, 2003).

The costs of facing natural hazards like storms and floods reflect the fact that prevention of and recovery from such extreme events is positively correlated with how sustainable society use natural resources. The rising costs of facing and recovering from storms and floods indicate *unsustainable* patterns of development, meaning human-caused climate and sea level changes, urban land claiming into flood plains and other wetlands, poor land use management like undiscerning deforestation, and short-sighted governance based on destroying the self-regenerating capacity of the natural life-support systems.

According to recommendations adopted by International Union for the Conservation of Nature (IUCN) in 2004, the *Precautionary Principle* should prevail in environmental decision making and management. This appeal was followed by a resolution titled *Protecting the Earth's waters for public and ecological benefit*, and stating that the ecosystem approach to water resources management need to be central in any water governance policy (IUCN Congress Bulletin, 2004). The sustainable management of water resources involve anticipation and acceptance of change (as opposed to inflexibility in the face of new information and new objectives), clear goals, and adaptability in finding multi-objective tradeoffs in a multi-participatory decision making process involving all stakeholders (e.g., Peterson et al., 1994; Loucks, 2000; Simonovic, 2000; Plate, 2002).

In short, both investors and local authorities and populations must become fully aware that forests help catch and retain meteoric water where it falls (source control), with many advantages, most notably conservation of water resources (including recharges of groundwaters), and buffering natural systems and ecosystem resources from possible climate change impacts on local investments and economic and social activities. For example, even in currently highly centralized countries like China local people were recently involved in extensive works of reforestations aiming at

mitigating destructive effect of floods (Wan, 2003). This might be due to the fact that in this country that pioneered grand work of engineering to regularize the streams of rivers, water containment by dikes proved to be inappropriate for the present days, and reduction of water runoffs are to be preferred (Plate, 2002).

Consequently, if they want to have a long-term perspective, investors should assist responsible institutions in updating knowledge and mechanisms of integrated local environmental management in areas with high risk of storms and flooding. Particularly developing countries should demand investors proceed to long term planning, and they should develop incentives for investors to make such long term investments. One such solution is forest plantations for commercial logging, as alternatives to natural forest cutting; but also, such plantations should be knowledge-based, e.g. located in areas with best suited topography and hydrology.

Insights

As nature recognizes no political border and the World is now acknowledging the benefits and the challenges brought by globalization, the considerate part of the human society is in process of merging economic, social and ecological perspectives into one paradigm; *sustainable development* (WCED, 1987; Giddings et al., 2002). This concept and theory developed around the idea of mitigating long-term risks in human activities i.e. present developments should not compromise future developments.

In a narrow sense, flood risk management is the process of managing an existing flood risk situation, by being prepared for the storm and/or flood, and to mitigate the disaster. This includes performing (and continuously updating) risk and vulnerability analysis (which includes maps produced with the help of Geographical Information Systems – GIS) as a basis for long term management decisions. In a wider sense, it includes planning of a disaster protection system (Todini, 1999; Plate, 2002).

An important aspect of flood risk management is that the flood-insurance when subsidized by governments may encourage settlements of hazardous areas, and increase material losses due to flooding. Without such incentives, settlers may consider leaving – permanent evacuation from high risk areas should actually be encouraged, as it is safer and cheaper. Absolute safety against water-related risks is impossible. However, a disaster conscious society should combine prevention of, preparedness to, and mitigation of disaster effects (e.g. Kundzevich and Kaczmarek, 2000; Plate, 2002; Priest et al., 2005.). However, sharing risk management between insurers and the state might be an option for sustainable development in high risk areas (e.g. Dahlstrom et al., 2003). In addition, investors might find incentives and mechanisms to contribute flood recoveries, especially in poor countries which do not afford paying for protection prior to disasters (Kunreuther and Linnerooth-Bayer, 2003).

The above viewpoints indicate that risk management plans at national levels are essential but not sufficient – involvement of local people is needed. Particularly in countries with a history of centralized administration (e.g. in the former Soviet Union and its satellite countries), people tend to look for help from government rather than to help themselves (e.g. Nunes Correia et al., 1998; McDaniels, 1999; Vari, A., 2002). It is to be expected that integration of these countries into the European Union, will help improve local attitudes in governance, via the implementation of the "subsidiarity principle" of the EU, which states that what the lesser entity can do adequately should not be done by the greater entity unless it can do it better. In short, this means that any measure that can be taken locally should be taken locally (Duda and El-Ashry, 2000). The contrary would only impede upon operability, efficiency and costs of the storm and flood risk management.

Valuable toolkits, such as revealed-preference (RP) techniques, stated-preference (SP) techniques, and conjoint analysis (CJ), required for estimating individual and group preferences and options in valuations of complex (multi-attribute) natural resources (including in watersheds), and between alternatives of environmental management, are being already

developed by economists. But they need further refinement, especially towards applicability to real-world management (e.g. Farber and Griner, 2000). Several researchers (e.g. Duda and El-Ashry, 2000; Allan, 2004; Reynolds and Hessburg, 2005) have a viewpoint that although it is hard to ascribe precise limits to most certain landscapes, management decisions (evaluation, restoration, and so on) should follow an integrated landscape perspective at the most natural landscape unit which is the river collection basin. As an illustration, instead of extending into riverbeds, the development of human settlements should be planned by giving priority consideration to river's natural course of flow. And further, regularization work all along river streams should be more relaxed, i.e. allowing more space for rivers; river flows should be regularized at the collection basin level by measures of adapted land uses (scenarios) and ecosystem management (Niehoff et al., 2002). As a result of such policy measures, with the floods along Danube River in Romania, in the spring of 2006, many previous agricultural fields have undergone controlled flooding, and some of them are planned to be left and restored as flood wet lands.

Forestry practices influence water yield and quality. Locally, forest management must integrate several basic water goals, at the level of each river catchment basin: quantitative and qualitative stream flow regularization in the target river basin, including limiting peak flows (Twery and Hornbeck, 2001). In this respect, management should be based on paired-catchment studies: similar river basins, one untreated (acting as reference) and one treated (deforestation or reforestation) (e.g. Watson et al., 2001). Lack of uncoordinated exploitation of forest and water resources can only result in reciprocally excluding measures and investments in forestry and hydrology, hence higher costs for the local community, including the costs of living with natural risks. This requires that the cost-benefits analyses of natural resources management must include details on the best type of forest (and other vegetation) cover (Sahin and Hall, 1996) for given local needs. For example, if the flood risk is high, the goal of diminishing the costs of environmental changes associated with floods should be aimed at by favouring forest types that insure low water yields and low peak flows. Agricultural and urbanization plans must take into account the effect of changing land uses implied by urban expansions within peri-urban ecosystems, in the context of current climate changes (e.g. Hartig et al., 1996; Nunes Correia et al. 1999; Niehoff et al., 2002; Naef et al., 2002; Pivot et al., 2002). Scientific research should support such planning, by investigating the climatic and ecological mechanisms that influence the water circuits and the weather-related risks. For example, the few studies on the effect of reforestation (most studies deal with deforestation) upon stream flows lead sometime to contradictory results (Andreassian, 2004). More knowledge is needed upon how ecosystems can regulate water circuits at river basin landscape. Long-term studies (with permanent stations) on both deforestation and reforestation are largely missing and should be promoted and supported.

During the 2003-2005, while the wood demand was basically stabilized, the demand for environmental services of forests, related to the protective roles of forests has soared (Leslie 2005; FAO, 2006). Thus, the relationships between the economic concept of value and the bio-physical dimensions of forests (especially uplands) need be further tackled by extensive research (e.g. Kramer et al., 1997). Similarly, flood (alluvial) plains have various functions which are not taken into consideration when river regularizations are planned, but which need economic valuation (e.g. Gren et al., 1995). In addition, combined natural risk effects must be studied and managed. For example, the Shanghai area is strongly exposed to and affected by typhoons. Beside wind-caused damages, storm-induced floods sometimes combine with high spring tides to produce highly destructive floods (Zhong and Chen, 1999). Similar effects are also well accounted in Europe, in the North Sea area; the situation can be further complicated, for example by coastal subsidence following gas extractions (e.g. Doornkamp, 1998).

In island and coastal countries, such as in the Pacific area that is particularly hit by cyclones, or in countries hit by monsoon and El Niño storms and floods, it is important not only to try to mitigate but also adapt to climate changes. Starting with the Pacific Islands Climate Change Assistance Programme and the Pacific Islands Framework for Action on Climate Change, Climate Variability and Sea Level Rise (2000), the region has seen a renewed interest in climate

change adaptation over the past few years (Bettencourt et al., 2006). The broad solution at hand appears to be the promotion of research and global policy for carbon trapping (mainly by forests) to diminish the concentration of carbon dioxide in the atmosphere. But adaptation to climate change, and risk management of natural hazards have emerged as core development issues particularly for Pacific Island countries. In this area the protective role of coastal forests (mangrove) is required to be further studied and employed in measures of risk attenuation and in general sustainable coastal development. Among the most important properties of mangrove forests are: reduction of severity of storms and coastal flooding, high regeneration capacity and productivity, key roles in the stability and productivity of coastal marine ecosystems – including for the regeneration of the fish populations (e.g., Arrow et al. 2000; Benfield et al., 2005). The 2004 Indian Ocean tsunami showed the importance of maintaining natural wave breakers, by managing coral reefs, mangroves, and sand banks (Bettencourt et al., 2006).

In addition to the necessity of appropriate economic incentives and mitigation/adaptation related efforts, the general fundamental insight pertaining to risk costs and risk management is that nothing can be done on long term (i.e. in a sustainable fashion) without the involvement of the local people in a fair and inclusive manner. The concept of sustainable management of natural resources is (unfortunately) only recent, and it challenges most old cultural habits. It is, therefore, clear that no sustainable management can be carried out successfully without first achieving basic ecological education through all age groups, education levels, and professions. Otherwise, management efforts not including the local people (including owners, beneficiaries, etc) in a proper manner would simply be ineffective.

In this respect, particular international actions worth mentioning, like the conference "Education and public awareness for sustainable development", held in November 1995, in Pruhonice, Czech Republic, and the European "Convention on Access to Information, Public Participation in Decision-Making, and Access to Justice in Environmental Matters", from 25 June, 1998, Aarhus, Denmark (<http://europa.eu.int/comm/environment/aarhus/>). Also, in order to raise efforts in the field of environmental education and public awareness pertaining to environmental issues, the United Nations declared the period 2005-2014 the Decade of Education for Sustainable Development. Further information about educational and public awareness actions taken by United Nations, including those towards disaster reduction, are available at http://portal.unesco.org/education/en/ev.php-URL_ID=27234&URL_DO=DO_TOPIC&URL_SECTION=201.html.

To put it differently, old habits die hard. As a consequence, costs of water-related risks will probably go lower only on medium and long-term, and only on the condition that environmental education (including education for sustainable development) will be properly resourced and planned. Thus, economic agents have an interest in financing such education, desirably in a coordinated fashion with state authorities, because ecological education is the first step for any national environmental policy. Further, eco-efficiency of economic activities (e.g. Pickett et al., 2001; Huppel and Ishikawa, 2005; Wall-Markowski et al., 2005) should be a central issue in ecological education at levels of specialists in industrial planning and production.

Summary

Increasing environmental stresses associated with global climate change and less employment opportunities in rural areas force people to migrate towards burgeoning cities (Gurjar and Lelieveld, 2005) leading to significant changes in the regional landscape and anthropogenic emissions. A recent research report states that land-use conversion in the Brazilian Amazon is triggering forest loss and degradation and rapidly changing the regional landscape. According to the Food and Agriculture Organization (FAO) of the United Nations, Brazil accounted for approximately 42 percent of global net forest loss from 2000 to 2005; most of this deforestation occurred in the Brazilian Amazon (Barreto et al., 2006). The global water cycle is influenced by both global climate changes and Earth's ecosystems, and both undergo transformations caused by anthropogenic activities, e.g. release of greenhouse gases into the atmosphere and landscape modifications. As reported by the Intergovernmental Panel on Climate Change (IPCC), the average Global temperature

increased by 0.6 ± 0.2 °C during the 20th century, and it has been estimated to rise further with 1.4 – 5.8 °C until 2100. This may lead to changes in frequency, intensity, and duration of extreme events, e.g. more hot days, heat waves and heavy precipitation events. It is argued that many of these projected changes would cause increased risks of floods and droughts in many regions, and predominantly adverse impacts on ecological systems and socio-economic sectors (IPCC, 2001).

Ecosystems and the functions they render to individuals and society (such as – providing food, fiber, medicines and energy; processing carbon and other nutrients; and purifying and regulating water resources) are sensitive to variation and change in climate (Brenkert and Malone, 2005). As natural systems are subject to considerable stochastic variations, sensitivity analysis is needed to investigate the uncertainty associated key parameters (e.g. storms intensity, rainfall amounts) and thus estimate floods risks and necessary management strategies and actions (Kramer et al., 1997; Doornkamp, 1998; Arrow et al., 2000). Insights from such analyses might help policy makers and managers identify appropriate trade-offs between the costs and the benefits of protecting forests in sensitive river catchments. From an economic and financial perspective, the idea is that ecosystems (notably forests) must actually be counted as water infrastructure, and valued using cost-benefits balance (Emerton and Bos, 2004). Also, because the price of timber usually does not include the removal of other forest benefits, the price of timber is naturally underestimated, particularly with clear-cutting. Correct estimation should not only include the costs of wood extraction and transport, but also the costs of removing the other functions of the forest (especially the protective effects), for example the costs of reconstruction after floods that are expected thereafter. In economic terms, this would mean bringing the so-called "shadow prices" (which account for all values that a product has to society) into the light (Freeman, 1993; Gardiner et al., 1995; Farber and Griner, 2000).

Economic welfare of human societies across the Earth depends on capital flows, but investments are very sensitive to perceived as well as actual risks. Therefore, natural events like climate-born phenomena qualify as most serious, long-term menaces to local, national and global economies. In this context, all socio-economic actors are deemed to corroborate efforts for achieving coherent action and effective risk management. The real-life success of any risk management program is key-conditioned by finding case-by-case answers to a pervasive problem – *the conflict of usages of natural resources*. Such unsolved conflicts can only result in the destruction of natural resources, due to overexploitation, and subsequent price escalations. For example, according to FAO of the United Nations, Indonesia is losing each year almost two millions hectares of forest (i.e. about the size of Wales), while South America loosed between 2000-2005 ca 4.3 hectares per year.

Since the world's rainforests, a global asset, are owned by the mainly poor and developing countries, cutting them down for profit or livelihood is a tempting source of income for their owners. On the other hand, the forests are sinks for atmospheric CO₂ and hence help in mitigating the problem of man-made global warming and climate change. They are also rich storehouses of biodiversity – another global resource. In such situations, in order to stop illegal exploitations of forests in developing countries, economic incentives and use of advanced science and technology for controlled and sustainable logging are a promising solution – provided a good governance equipped with efficient socio-political institutions and effective policy instruments are there in place to ensure constructive co-operation between local community, government, industry and environmentalists. Fortunately, today science and technology is developed enough to help conserve the forests. For example, there could be a possibility that genetically engineered trees are used to make plantations faster growing and more viable, and consequently lessen the pressure to hack down wilderness forest (The Economist, Mar 23rd, 2006). Hence, with an aim to make markets work for the welfare of forest based communities, imparting education and giving control to the local people (including property rights) could probably result in the cost-effective and sustainable ways to avoiding overexploitation of ecosystem resources and reducing costs involved in storms and flooding risk management.

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**FINNISH LOCAL VIEW ON THE FACTORS ACCOUNTING
FOR THE COSTS OF WEATHER-RELATED DISASTERS
(SPECIFICALLY, FLOODS AND STORMS)
IN RECENT DECADES AND IMPLICATIONS OF UNDERSTANDING
THESE FOR BOTH RESEARCH AND POLICY**

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1. Introduction

As the factors accounting for the costs of weather-related disasters (specifically, floods and storms) in recent decades and the implications of understanding these for both research and policy are considered from the Finnish point of view the climatology of the pertinent weather phenomena are discussed also with some outlook to the scenarios. With regard to storm there are both some semantic differences between English and Finnish and challenges in interpretation of what phenomena of the Finnish climate to include in this category in the context of insurances. In addition some policy issues are discussed as this seems to be another important point.

2. Factors in weather-related disasters

2.1 Floods

Since 1960 (Puupponen, 2006) in terms of house damage costs the three most severe flood episodes in Finland have occurred as follows.

Spring 1966 – Southern Finland: This spring flood has been since 1969 the highest flood in the rivers of Southern Finland. The water equivalent of the snow at the beginning of April was still widely 200 – 250 mm which was roughly double compared with the normal value and in fact a record value. The melting of the snow was postponed to a late time point around 1 May. Consequently the recurrence value of the observed flood flows exceeded in several drainage basins 100 years in terms of a Gumbel distribution estimate. No exact damage data are available, but in relation to later damage inventories the probable cost level has been of the order of 10 million euros.

Summer 2004 – Southern and Central Finland: The heavy rains end of July 2004 around the line Helsinki – Jyväskylä – Kajaani were exceptional both in their extent and heaviness. The five-day precipitation at the end of July exceeded 100 mm over a very wide area. As the July precipitation in these areas was of the order of 200 mm, the soil was saturated already prior to the heavy rain episode. Consequently flood damages on houses took place especially in Riihimäki, some 60 km north of Helsinki, and in Voyri and Oravainen close to the central west coast. The damage costs were some 8 million euros excluded any harvest losses or damages to enterprises and public communities.

Spring 2005 – Lapland: At the beginning of May there was a lot of snow in Lapland and its water equivalent increased still slightly during early May. The water equivalent exceeded at places 180 mm in Northwestern Lapland and the head areas of the Kemijoki river and the Ivalonjoki river drainage basins around 10th May. This value was approximately double compared with the normal value. The snow melted very fast after the middle of May, at its fastest by some 20 mm per day. This caused a record flood in the Ounasjoki river and the Ivalonjoki river with highest water levels in 50 years and with an approximate recurrence time of 50 years. The flood caused mainly house damages at most in Ivalo and Kittila (cf. Fig. 1). The damage costs were some 5 million euros excluding any harvest losses or damages to enterprises and public communities.

Extreme spring floods occur when large snow amounts under rainy conditions which prevent the more typical conditions of fair weather and consequent large evaporation of snow. In this sense the spring flood can be seen as a combined, accumulative phenomenon which can be foreseen by appropriate early warning systems. Also in case of summer floods their formation is to some extent accumulative in terms of prior saturated wetness of the soil.

Although also summer floods can cover wide areas, in Finland these episodes have been mostly fairly restricted and caused mainly by local heavy showers.

Even if two of the floods of large costs in terms of damages have occurred quite recently it should be emphasized that the type of these floods was quite different and that these do not necessarily reflect any climate changes in Finland. Rather they are outcomes of the large natural variability of the Finnish climate and quite possible extreme values even under the latest WMO standard normal period 1961-1990.

Regarding the potential of large spring floods it should be pointed out that the snow water equivalent studies of Hyvarinen (2003) revealed that in the Kemijoki river drainage basin the snow water equivalent on 1 April 1947 – 2001 had an increasing trend (cf. fig. 2). As Hyvarinen (2003) points out the short time series might have exaggerated the slope of this increasing trend. In addition the melting of the snow takes often place under clear



Figure 1: Spring 2005 flood in Kittila, Lapland

sunny weather and a consequent relatively large evaporation. Hence even an increasing snow water equivalent in Lapland does not necessarily imply risk for increasing spring floods. In more southern parts of Finland the results of Hyvarinen (2003) indicated no or a decreasing trend in snow water equivalent.

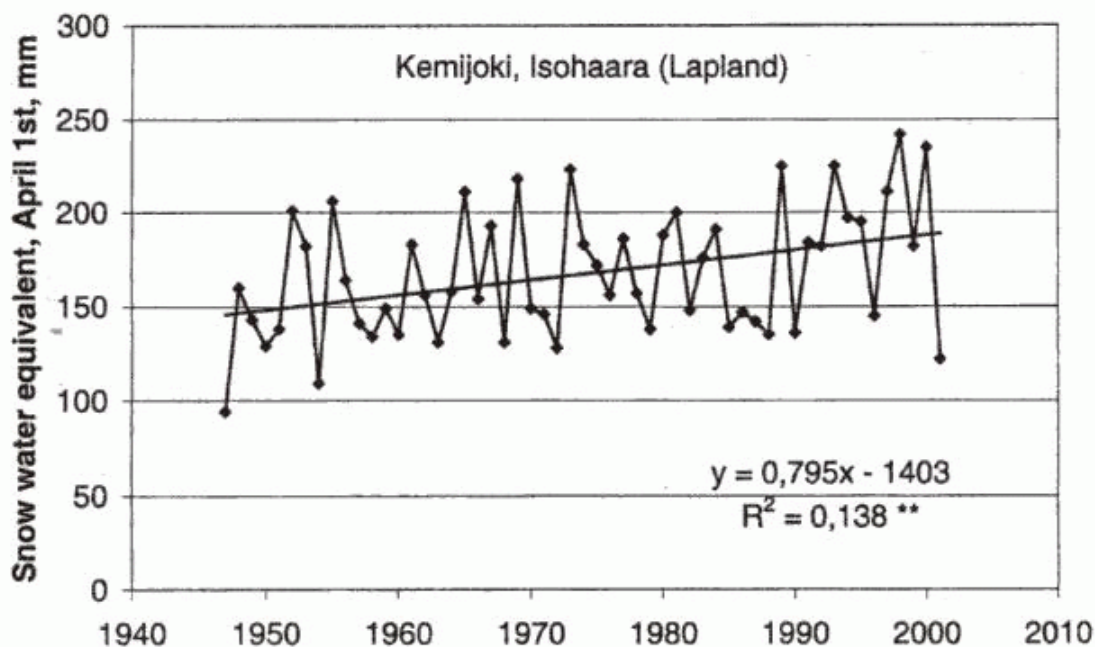


Figure 2: Water equivalent of snow in Kemijoki river drainage basin in Lapland on 1 April 1947 – 2001 (Hyvarinen, 2003)

Beside the floods in inland drainage basins it is possible to have floods due to high water levels on the coasts of the Baltic Sea basin. On the Finnish coast the most severe situation of this type was experienced in the context of storm Gudrun 8-9 Jan, 2005 (cf. fig. 3), when the sea level in the central and eastern parts of the Gulf of Finland reached new record values. In Helsinki the situation was quite critical as the pumping stations could barely survive from the extra load. Fig. 4 shows estimated recurrence values of high sea level at Loviisa (some 100 km east of Helsinki) adjusted by parameterization for the expected climate in 2030 (Johansson et al., 2004).

The exceptionally high sea level can be understood as a coincident combination of several factors. First, we have the natural oscillation or seiche of the water mass in the Baltic Sea basin. Just at the occurrence of the storm Gudrun the phase of the seiche was such that the sea level in the area of the Gulf of Finland was high. Second, the prevailing surface wind direction during Gudrun was such that the strong wind piled water to the Gulf of Finland and kept it there causing record high sea level values in the whole area with the highest values in the easternmost parts of the gulf. This kind of a combination is rare but possible as observed during the passage of the storm Gudrun. The consequent high sea level rise can be foreseen with an appropriate early warning model.

In Helsinki the peak value of the sea level was 1.51 m above the normal level and the situation was quite critical with the pumping stations managing just barely the incident.

2.2 Storms

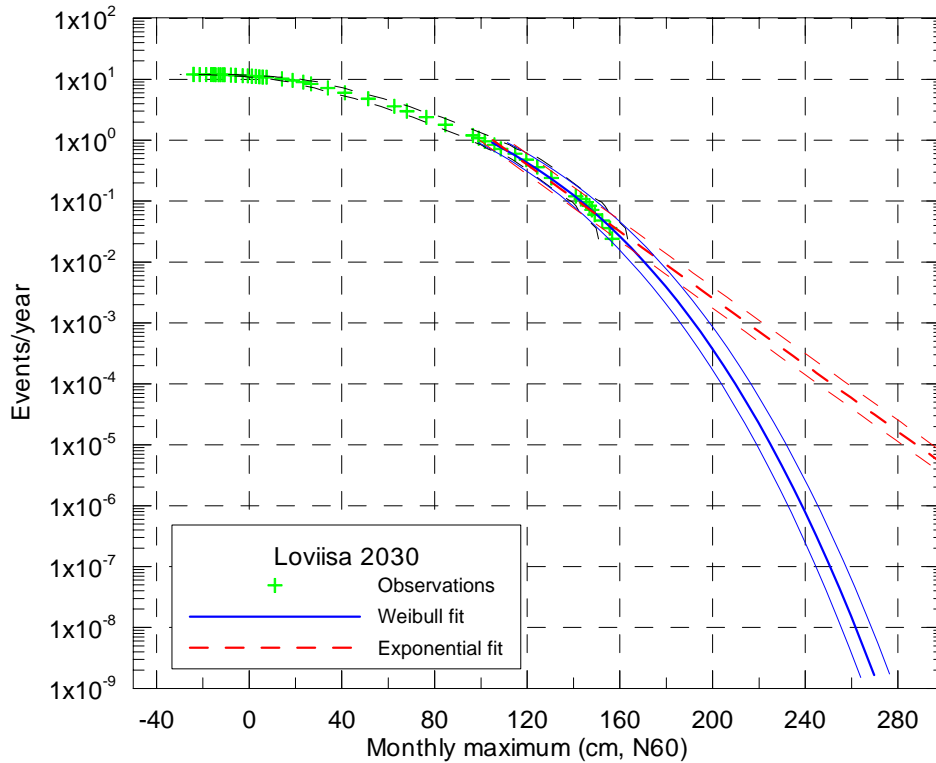
Regarding storms there is a semantic difference between the English word storm and its equivalent in Finnish as the Finnish equivalent is restricted exclusively to wind storms. In addition already the strong gale with a wind speed of at least 21 m/s is classified as wind storm in the Finnish coastal areas. In inland locations the wind is considered dangerously strong as the wind speed is 14 m/s or higher. Both of the adapted definitions are supported by both acceptable climatological risk levels and observed impacts in practice.

Gudrun 8 – 9 January 2005



Figure 3: The track and affected regions of the storm Gudrun 8 – 9 January 2005

Probability distribution of sea level maxima, Loviisa 2030



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Figure 4: Extreme value distribution fits to observed maximum sea level values at Loviisa with adjustments to the expected climate in 2030 (Johansson et al., 2004).

In addition to the wind storms and severe storms some other phenomena, like freezing rain/slipperiness and heavy snow loads/clinging snow are considered from the point of view of damages.

The annual numbers of wind storm days for the Finnish maritime areas is given in fig. 5. The corresponding numbers of dangerously strong wind days for the Finnish inland areas are presented in fig. 6. Both of these figures show that there is at least no indication of an increasing trend after 1990.

Annual number of wind storm days in the Finnish maritime areas 1990 - 2005

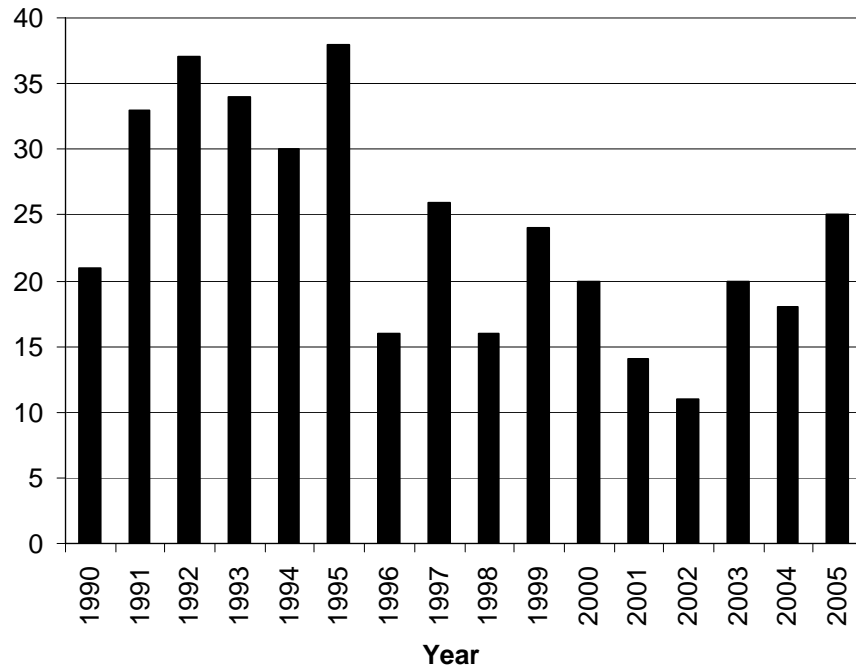


Figure 5: The annual number of wind storm days in the Finnish maritime areas 1990 – 2005

Annual long-term deviations in the number of days with dangerously strong winds in the Finnish inland areas 1961 - 2000

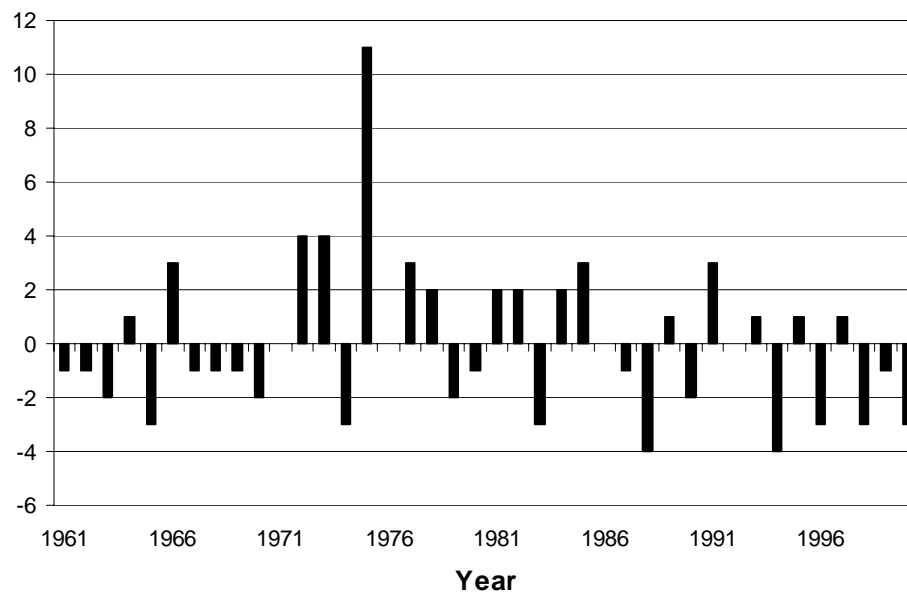


Figure 6: The annual deviations from 1961 – 1990 normal values of the number of days with dangerously strong winds in the Finnish inland areas in 1961 – 2000.

Another study (Myllys, 2006) indicates that the number of deep low pressure systems crossing Finland has remained relatively constant, whereas the number of disturbances moving from southwest to Finland in the context and along the eastern rim of a so-called central low located typically west of Scandinavia is increasing. All this is in line with figs. 5 and 6 as the Finnish wind storms and dangerously strong wind situations are associated with the deep lows which have a different and more northerly path than those causing the largest damages in Southern Sweden and the Baltic countries. Although the storm Gudrun was a close call for some coastal areas of Southern Finland, all the major damages caused by it took place south of Finland.

In the context of these large-scale storms probabilities of their forecasted hit are given 48 hours in advance, whereas the warnings with quantitative wind speed values are given 24 hours in advance.

With the recently installed modern Doppler weather radar network in Finland and encouraged reporting by public on local storms, like trombs and downbursts, the former synoptic manual observations are not comparable in their sparse regional resolution. Despite of the increased public awareness and publicity of these phenomena it is too early to give any estimates of the recent trends in the occurrence of severe local storms in various parts of Finland. With the increasing number of free-time houses in many parts of the country it is possible that there is the statistical chance of getting increases in damages of this kind (cf. fig. 7) (Teittinen, 2006). However, one should be cautious to conclude that this would mean an increase in the number of severe storm events in Finland.

One recently well documented severe storm (storm Unto) event took place in Finland on 5 July 2002 (cf. fig. 8) (Teittinen, 2006). The wind damage area of this storm was 450 km in its length and some 100 km in its breath. In the damage areas the gust speeds exceeded at many places 33 m/s. In some areas of Eastern Finland the gust speeds exceeded 50 m/s. Widely extended thunderstorm related wind damages alike have been documented formerly mainly in North America and only once in Europe. It should be emphasized, however, that there is no reason to



Figure 7: Damage caused by the F2 class (wind speed 50 – 69 m/s) tromb in Kontiolahti (north of Joensuu), Eastern Finland on 20 August 2004

believe that severe storms like storm Unto would not have occurred earlier in Finland. In fact there is one description in Finnish of an intense tromb family, which has swept through Southern and Central Finland on 4 August 1932 (Angervo and Leiviska, 1944).

General probabilistic forecasts of the occurrence of thunderstorms are given 24 hours in advance, but more detailed warnings pose a challenge to the nowcasting and at most some hours ahead.

Freezing rain events, per se, are known to cause problems on power lines and in power supply although such events are rather rare in Finland. The trend in the number of freezing rain events is slightly or modestly increasing both in Helsinki (0.7 events/decade) and Rovaniemi (at the polar circle; 2.4 events/decade). It must be remembered though that Rovaniemi observation station upon a nearby hill is known to encounter freezing rain events more than its surroundings. On the other hand the slight increase in the freezing rain events is in concert with the warming winters and reflects well in general the mild winters since the 1990's in Finland.

Storm Unto 5 July 2002

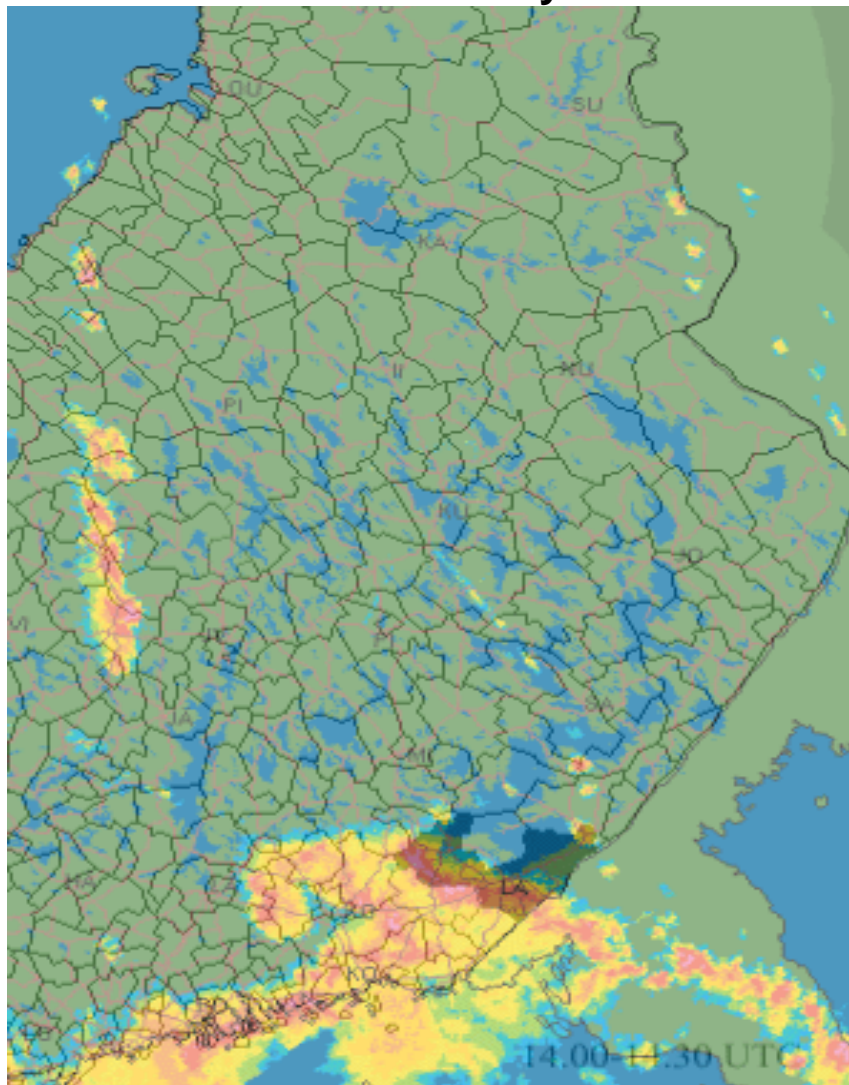


Figure 8: Compositing radar observation of storm Unto on 5 July 2002 14:00 – 14:30 UTC

The formation of slipperiness on roads and pavements is a phenomenon connected not only with freezing rain but in fact in many cases with sublimation taking place right at the road or pavement surface. Therefore the prevention of

the road and pavement slipperiness is still a challenge both for the weather service and the service providers, as the slipperiness causes annually severe problems both for traffic and pedestrians. Measured in the number of slipperiness prevention tasks per winter season the largest values are encountered in Southwestern Finland with large values in southern, central and western parts of the country. With the relatively short records on traffic accidents and injuries of pedestrians it is still a challenge to relate the slipperiness to its consequences in terms of costs.

According to fig. 2 the snow water equivalent had an increasing trend in Lapland. Even if it per se does not necessarily mean increasing risks for large spring floods another risk is more obvious and that is the increasing snow load on the roofs of buildings. Lately incidents of broken roofs have been experienced even in more southern parts of Finland under circumstances where the design loads based on climatological snow water equivalent recurrence values have not been exceeded. Hence the climatic change is not to be blamed on all these damages. In addition the Finnish Environment Institute gives timely regional warnings and recommendations to shovel the snow down from the roofs. This can be considered as an appropriate early warning service.

Clinging snow is another mechanism by which snow can cause excessive loads. In practice this needs specific rain, thawing and snowfall conditions around zero degrees centigrade. As a consequence of such incident trees can get heavy snow load on them which forces them to bend. This can cause local power lines to be broken especially, if a wind storm gets the chance to blow on the preloaded trees. Fig. 9 gives recent 10-year mean numbers on heavy snow load (in excess of 20 kg/m²) events in various parts of Finland. The map indicates the regional distribution of this risk. Recently two rather consecutive wind storms (storm Pyry, 1 Nov 2001 and storm Janika 15-16 Nov 2001) after a heavy clinging snow incident on 31 Oct 2001 caused large losses of cut trees and broken power lines in Southern and Central Finland.

2.3 Climate scenarios

Climate scenarios for the 21st century in Finland have been published elsewhere by Jylha et al. (2004) in the context of the FINADAPT project and will not be discussed here.

Regarding the floods the shortening snow season is anticipated to decrease the peak values of spring flood flows by 2021 – 2050 (Tammelin et al., 2002).

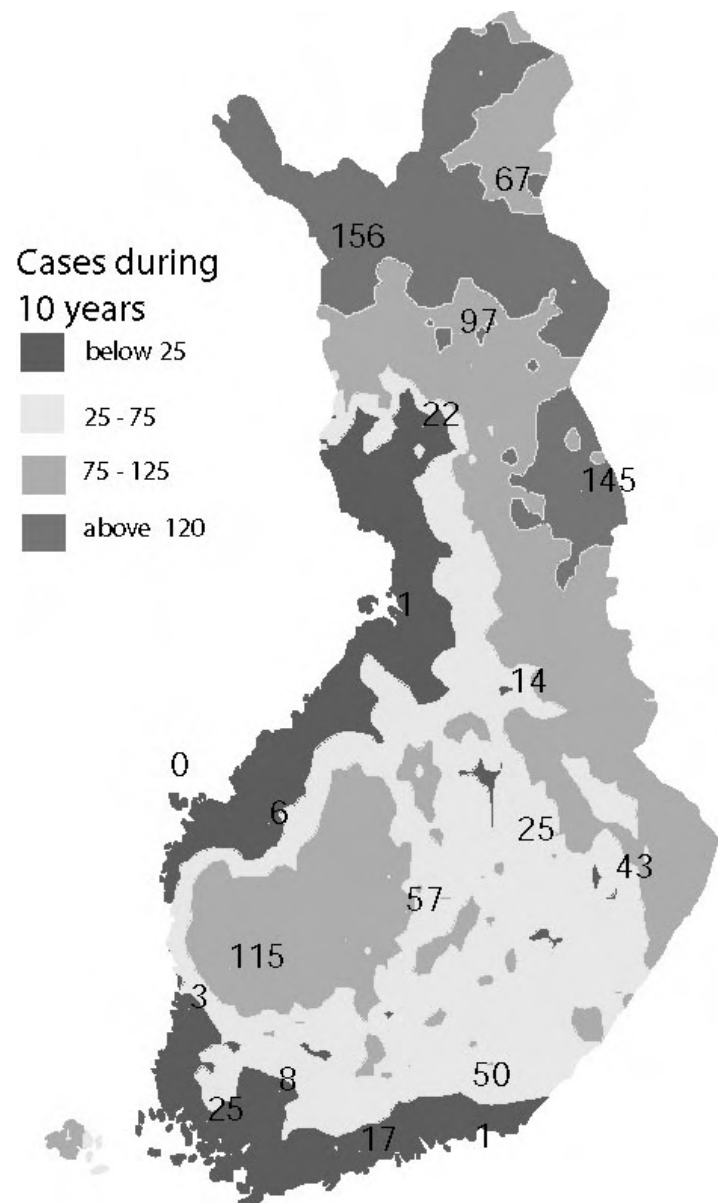


Figure 9: Number of cases in which the snow load on the average during ten years exceeds 20 kg/m²

3. Implications

3.1 Floods

As pointed out by Hyvarinen (2003) the improvement of drainage basin flood forecasts depends primarily on improvements in estimating areal precipitation. This in turn poses challenges to the development of various remote sensing techniques, primarily on weather radar networks, and dense enough rain gauge networks as references. In Finland this challenge is focused both on reliable estimates of snowfall precipitation and on area precipitation estimates in the context of showers. All these improvements would give us a better basis to dimension properly the needed infrastructure, like dams and reservoirs, of various drainage basins in order to avoid excessive floods.

Another important topic is the estimation of recurrence values in the context of short intense showers. With the traditional 24 hour or at its best 12 hour rain gauge measurements it is almost impossible to get any meaningful estimates for the intensities of short showers, although this is important also for the dimensioning of local sewerages and the estimation of local flood risks. Many of the current dimensioning estimates of shower intensities are quite uncertain and need to be improved.

In order to hedge against intense local showers and thunderstorms we need to improve our knowledge of the mesoscale climatology where we have a common interest with the development of the nowcasting.

Parallel to the efforts mentioned above we should also develop appropriate early warning models cooperatively with the various users and stakeholders. From the meteorological point of view the use of ensemble forecasts would be a natural choice to bring in the probabilistic view needed.

3.2 Storms

When we widen our view to the hedging against wind storms and the prevention of slipperiness and excessive snow loads as well, we face the fact that with the advanced technology and the post-modern trend to maximize the profit of various services we have exposed us to increased insecurity. This should be kept in mind as we consider the possible trends in weather-related risks and damages. Are we ignoring the impacts of the current natural variability of our climate, when we are trying to blame the damages on the more popular concept of climate change? So far this seems to be the case to a considerable extent in Finland as there seems not to be almost any convincing increasing trends in the weather related phenomena of concern.

The storm category as understood here in the Finnish context consists mainly of short-term phenomena, but also of some accumulative or combined phenomena of longer time span. Most of them relate to typical time scales of the weather service and some even to nowcasting, although the related macro- and mesoscale climatology must not be ignored. Here one important research area is the development of limited area forecasting models and their verification. The use of ensemble forecasts would give a good starting point to develop appropriate early warning models.

3.3 Policies

As far as policies are concerned the view in this paper has been to emphasize the role of the early warning services of the meteorologists, hydrologists and oceanographers where appropriate. In addition it has been pointed out that in Finland its climate of the extremes has so far been relatively stable and indicated predominantly no increasing trends.

On the other hand the Finnish society and business environment have undergone recently quite remarkable changes which should be taken into account in the efforts to build the future on a reasonable balance between the security

and the uncertainties and risks to be managed as well as possible with the available resources, the insurance sector included. The example on broken roofs due to more or less regular late winter snow load indicates rather problems in the assembly phases of the roof construction and the liability chain.

4. Summary

Both the weather-related disaster types and the presented implications reflect the related issues of the Finnish climate with respect to insurance. As pointed out, so far it is quite hard to assign any of the weather-related disasters to the recent climate monitored changes of some 1 °C increase in the monthly mean temperature of December – March. In case of increased costs of weather-related disasters in Finland the current adapted policies should be considered as one important factor as steps to improve the management of risks for the Finnish climate are taken.

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Ever since the beginning of human history, natural disasters have been closely associated with human beings. According to the statistics, economic losses caused by meteorological disasters in China account for over 70% of the total losses by all natural disasters. Each year the stricken crop areas damaged by various meteorological disasters reach 50 million hectares, the stricken population amount to over 400 million and the total economic loss equals 3%-5% of GDP in China. Moreover, the losses of meteorological disasters increase rapidly, according to the German insurance company Munich Re, the costs of major disasters raised more than tenfold in the second half of the twentieth century, from an average of about \$4 billion per year in the 1950s to more than \$40 billion in the 1990s, in inflation-adjusted dollars. Many factors account for the dramatically increasing costs of weather-related disasters in recent decades.

Population growth. Population growth may result in the increase of disaster losses. Natural phenomena are likely to affect more people because earth's population has increased. According to the United Nations Population Fund, this stands at about 6.5 billion people and is projected to reach 9.1 billion people in 2050. Compared with densely populated area, disaster with the same magnitude hit sparsely populated areas will therefore cause less damage. High population density means more deaths in a disaster, at the same time, growing population pressures have led many people to settle on vulnerable flood plains and hillsides. Satellite photographs taken of the China's Yangtze River over the past decade show increasing numbers of people moving into the most flood-prone areas, so in a flood in 1998 resulted in 3700 deaths, dislocated 223 million people, inundated 25 million hectares of cropland, and cost \$30 billion. In China, The flood prone area accounting for 8% of national territory is inhabited by nearly 50% of the total population, where the gross industrial and agricultural product is estimated to be 2/3 of the national total. This is a very important problem.

Ecological degradation. Ecological degradation exacerbates flooding and landslides. Human activities, like deforestation, excessive land reclamation, large scale road construction, mining in mountainous and hilly areas and wetlands destruction, will inevitably degrade the soil and water, which will further result in floods or landslides. The soil erosion rate along the Yangtze River has doubled since the 1950s. Devastating landslides and floods have been exacerbated in recent years by deforestation and dikes that have hemmed in the Yangtze River and eliminated wetlands. Excessive logging of hillsides is partly to blame for the worst floods on the Yangtze River in China in 1998, and in that flood, over 550 people died as a result of mud slides.

The destruction of forests also results in natural water storage loss and silting of rivers and lakes and has raised the level of the rivers more and more. The Yangtze River flow rates in the summer of 1998 were below the historic highs but water levels are setting records because of the silting of river beds. Dongting Lake, a major regulator of the Yangtze floods, shrunk from 6,000 km² in 1700 to 4,350 km² in 1949 and by another third to just 2,820 km² by 1980. When tropical storms hit the Caribbean in September 2004, there was nothing to stop storm waters gathering and wreaking devastation in Haiti because of deforestation.

Urbanization and industrialization. Disasters are also a consequence of development and industrialization. In

Europe, experts believe that countries such as France and Germany are more adversely affected by floods today because major rivers, such as the Rhine, have been straightened to ease commercial traffic. Urbanization increases runoff two to six times over what would occur on natural terrain. The rapid urbanization will result in bigger and more frequent floods on the one hand and more economic losses on the other. More importantly the damage of the system/network of communication, water supply, electricity supply, oil and gas supply, information net work in one place will affect the system in other places of the same city or other cities, which may paralyze the whole system of a region. The Chinese rush toward industrialization and economic modernization has indirectly contributed to the severity of the flooding. The government of Hunan Province in China in May 1992 tore down one kilometre of dikes in the name of opening up new agricultural land. The result was that 80,000 hectares of farmland and 700,000 people lost their protection from flooding.

Irrational land use and plan. Land reclamation for agriculture in flood-prone areas and accompanying human settlements increase flood vulnerability and losses by floods. Man-made irrational production activities, such as the filling in of lakes and rivers, have reduced their ability to regulate the floodwaters. The most densely populated 10% of Chinese territory which produces 70% of its agricultural and industrial product lies below the flood level of China's rivers, so China has been frequently hit by big floods and suffered from flood disasters. Owing to the reclamation of the flood plain and detention lakes, the detention area for the lower Yangtze has been reduced to about a half of that in 1954. The Jingjiang detention area and other man-made detention areas not been employed for flood storage as in 1954's flood event.

Poor and bad dwelling conditions. Poor and bad dwelling conditions also lead to the increase of disaster losses. There's a huge relationship between the damage and poverty, and disasters disproportionately harm poor people in poor countries. In several countries, poor people are looking for spaces that are not already used to build their houses or their communities, and those spaces are usually at higher risk for natural disaster. Those countries typically have densely populated regions, shoddily constructed buildings, sparse infrastructure, and grossly inadequate public health capabilities. Moreover, there are increasing numbers of people living in areas such as coastlines, and they have the potential for more devastating disasters. Thus, while the world's poorest 35 countries make up only about 10 percent of the world's population, they suffered more than half of the disaster-related deaths between 1992 and 2001.

Inadequate prevention capacity and preparation. One reason for the Yangtze River flood of 1998 is that the dikes and reservoirs are only built to counter floods that might come once every 10 to 20 years. That is a far lower standard than in the US or Japan. More silt and less water storage capacity in the Yangtze River basin will mean that even with less water, floods will become more serious than ever before. Hurricane Katrina in the United States is also a good example, The storm struck a city whose levees had not been maintained or strengthened for years, and government agencies' response to the emergency was at first inadequate. Early warning systems and education are essential to prevent and militate against the effects of natural disasters. In its World disasters report 2005, the International Federation of Red Cross and Red Crescent Societies notes that a simple phone call saved thousands of lives when the giant tsunami waves hit India in 2004.

Climate change. Climate change-whether helped by human behavior or not-is playing a role. Hurricane experts say the world is in the midst of a routine, cyclical climate change that causes the Caribbean to heat up, increasing the frequency of powerful storms. The seasonal floods afflicting China every summer are caused by the Asian monsoon winds, which sweep rain clouds from the oceans toward China in the spring and summer, in 1998, however, the rains began earlier and were heavier than usual, and the Chinese dikes were not prepared nor properly fortified to withstand the tremendous downpour.

There are significance for research, policy and action if we understand these factors that lead to the increasing losses of

disasters. Disasters stem from a complex mix of factors, including climate change, socioeconomic factors, and inadequate disaster preparedness and education on the part of governments as well as the general population. The escalating costs of disasters could be attributed in part to climate change, but in most cases, the effect of human activities was greater than that of global warming. So some disaster experts reject the term “natural disasters”, arguing that there is almost always a man-made element. In the Yangtze River flood in 1998, government officials initially denied that were anything but natural, but at last recognized the human factor in worsening "natural" disasters.

Both natural climate change and human factors should be considered in disaster research and decision-making. But if we only consider disaster losses, much more attention should be given to human activities and corresponding ever-growing societal vulnerabilities to disaster. Compared with the long-term climate change control, we could improve disaster vulnerability more directly and the function is immediate, though this is complicated and difficult because of the limited land resources and increasing population pressure. There is a need to reach a common understanding and agreement from all concerned of this solution.

Natural disasters would not have such a devastating effect on people's lives if they were not exposed to such risks in the first place. Today many countries are working to improve their disaster preparedness. Some experts also believe the most practical approach to preparedness of disaster may be to focus on reducing the risks rather than factors behind the risks, so preparation should focus on making people less vulnerable to disasters.

Most tools needed to reduce disaster vulnerability already exist, such as risk assessment techniques, better building codes and code enforcement, land-use standards, and emergency-preparedness plans. PAHO has expanded its programmes to focus not only on preparedness but also on mitigation. This involves reducing secondary deaths and destruction that can occur in the aftermath of a disaster, and implementing building codes that require hospitals, schools, military bases other vital structures to be built to withstand such disasters. Many effective actions are possible to reduce disaster losses even in the face of poverty and dense population.

Application of the insurance and fund is no doubt a feasible way to reduce disaster effectively, It has been demonstrated by the past several years of practices that the insurance can play a very important role in reconstruction of afflicted regions and in rearrangement of victims and that the use of a large amount of insurance money accelerated greatly the economic rebuilding in disaster areas. Microfinancing is another avenue, giving poor people the means to improve their economic situation so that a disaster does not hit them as hard as it would otherwise, and also by lending them money to use in recovering from it.

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COST OF INACTION AND COSTS OF ACTION IN CLIMATE PROTECTION

ASSESSMENT OF COSTS OF INACTION OR DELAYED ACTION OF CLIMATE PROTECTION AND CLIMATE CHANGE

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Summary

The ultimate objective of the climate convention and of related instruments like the Kyoto protocol is to reduce greenhouse gas emissions to a level that avoids dangerous climate change. In order to considerably reduce risks of climate change, the European Union already decided a climate protection target: to prevent global surface temperature to increase more than 2°C (Celsius) compared to pre industrial levels. The number and intensity of extreme weather events, such as flooding caused by heavy precipitation, heat waves and big storms has considerably increased in the past. With a temperature increase of over 2°C the probability of even more frequent heavy climate events could rise substantially. Big re-insurance companies, such as the MunichRe, figured out that extreme weather events have risen by a factor 3.1 since 1960. This has led to drastic growth in both economic and insured losses. For example, the flooding in Europe in the year 2003 caused losses of 9.3 billion Euros only in Germany.

This study aims at calculating the costs of inaction, i.e. when no climate policy takes place, contrasted with the costs of action, i.e. the costs of climate policy. We intend to shed some light on what might happen if concrete climate policy started today or started at a later point of time. In particular, we are interested in the costs of inaction, and thus the potential economic damages from climate change. For this, we apply a world economic model that includes damage functions and economic interrelations from climate impacts. We assess the potential impacts of climate change and provide some sensitivity analyses with respect to the assumptions on the reaction of the climate system.

The main difficulties with such quantitative impact studies lie in the monetary valuation of damages from climate change and in regional as well as in temporal differences of action and impact. Mitigation costs and ancillary benefits as well as adaptation costs and benefits typically accrue in the same region. However, this is not true for mitigation benefits: local or regional emissions reduction efforts result in globally and temporally dispersed benefits. Benefits of avoided climate change impacts amass much later than the costs of mitigation (OECD 2004). Impact assessment studies most often only evaluate responses to changes in mean climate and not those associated with abrupt changes or extreme events. Furthermore, monetising damages of goods like biodiversity or health is very problematic as the uncertainties are very large and inherent value judgements cannot objectively be made.

This paper assesses and compares the costs and benefits of climate protection, i.e. the „costs of inaction“, which include climate damages, adaptation costs on the one hand with the “costs of action”, i.e. mitigation costs on the other hand. We apply a scenario approach with which we compare different emissions stabilisation scenarios to a reference case. The assessment of the “costs of inaction” is based on a globally very aggregated and simplified damage approach, which crucially depends on the parameter values taken into account.

The scenarios aim at avoiding a global surface temperature increase of more than 2°Celsius (C) compared to pre-industrial levels. Especially we assess a reference scenario where no climate protection or emission mitigation actions take place and two mitigation scenarios: scenario one “early Action” (ScenA) intends not to overshoot the 2°C limit, scenario two “delayed Action” (ScenB) starts with drastic emission reduction effects at a later time period (2030).

It turns out that only with early emission reduction warming beyond the limit of 2°C can be avoided. Even drastic emissions reduction efforts starting at a later point of time (2030) will not be sufficient to stay within the 2°C limit. Damages from climate change are lower if the limit is met. The costs of action are substantial. However, the avoided damage costs are even higher than the costs of action. This is particularly the case when emission reduction efforts are postponed to later time periods. Both policy scenarios provide benefits in terms of avoided damages. ScenA leads to higher positive effects than ScenB in terms of gross world product (GWP) because the avoided damages are higher and overcompensate the mitigation costs.

Introduction

The number and intensity of extreme weather events, such as flooding caused by heavy precipitation, heat waves and big storms has considerably increased in the past. With a temperature increase of over 2°C the probability of even more frequent heavy climate events could rise substantially. Big re-insurance companies, such as the MunichRe, figured out that extreme weather events have risen by a factor 3.1 since 1960. This has led to drastic growth in both economic and insured losses. For example, the flooding in Europe in the year 2003 caused losses of 9.3 billion Euros only in Germany.

The ultimate objective of the climate convention (Art. 2) and related instruments like the Kyoto protocol is to reduce greenhouse gas emissions to a level that avoid dangerous climate change. In order to reduce risks of climate change considerably, the European Union already decided a climate protection target: to avoid global surface temperature increase of more than 2°C compared to pre-industrial levels. The temperature target has been repeatedly reiterated by the Environmental Council since 1996, and, in March 2005, also by the Heads of Government of the EU. However, even an increase of the global temperature by 2 C compared to the pre- industrial level leads to substantial climate impacts, such as on ecosystems and water scarcity. In order to stay within the temperature limit of 2°C with high likelihood, a stabilisation of greenhouse gas concentrations of 400 ppm would be necessary (Hare and Meinshausen 2004). Greenhouse gas emissions need to be reduced drastically, globally by at least 50% up to 2050.

After the Russian ratification of the Kyoto protocol, the Kyoto protocol entered into force on 16 February 2005. This also means that in 2005 international negotiations for further emissions reduction targets need to begin. The German government is aiming for an EU greenhouse gas emission reduction target of 30% by 2020 compared to 1990 emissions level and similarly ambitious targets for other industrialised countries. Germany would then be prepared to accept an emissions reductions target of 40% by 2020.

The European spring council (March 2005) reaffirmed that the overall global annual mean surface temperature should not exceed 2°C above pre-industrial levels. Furthermore, the Council notes that there is increasing scientific evidence that the benefits of limiting overall global annual mean surface temperature increase to 2°C above pre industrial level outweigh the costs of abatement policies. The Council encourages considering mid- to long-term strategies and targets (2020: 15-30 %) and therefore asked the Commission to continue to work on a cost benefit analysis of emissions reductions strategies. The costs of climate protection need to be compared with avoided damages, avoided adaptation costs and ancillary benefits (as for example avoided air pollution). There are only a few quantitative assessment studies that evaluate the cost of inaction, i.e. the costs of climate change (e.g. Tol et al. 2004, Nordhaus and Boyer 2000, Fankhauser 1994, Hope 2004. For an overview see for example Pittini and Rahman 2004 and Schellnhuber et al. 2004). The main difficulties with such quantitative impact studies lie both in regional as well as timely differences. Mitigation

costs, adaptation costs and ancillary benefits typically accrue in the same region. However, this is not true for mitigation benefits: local or regional emissions reduction efforts result in globally and timely dispersed benefits. Benefits of avoided climate change impacts amass much later than the costs of mitigation (OECD 2004). Impact assessment studies most often only evaluate responses to changes in mean climate and not those associated with abrupt changes or extreme events. Furthermore, quantitative impacts are difficult to assess, as both the evaluation of non-market impacts as well as the aggregation of regional impacts is very problematic. In particular, monetising damages of goods like biodiversity or health is very problematic as the uncertainties (as for example the chosen discount rate) and impreciseness are extraordinary large. Because of these difficulties cost benefit analyses alone are not an appropriate tool for the assessment and determination of strategies and targets for climate protection.

This paper assesses and compares the costs and benefits of climate protection, by quantifying so called „costs of inaction“, i.e. climate damages and adaptation costs, on the one hand and the “costs of action”, i.e. mitigation costs on the other hand. We compare the benefits of mitigation (that means the avoided damages of climate change, avoided adaptation costs and ancillary benefits), with the costs of action, i.e. the costs of meeting concrete emissions reductions targets to stay within the limit of 2°C global warming above pre-industrial levels. In particular, we assess a reference scenario where no climate protection or emissions mitigation activities take place and compare it with two mitigation scenarios: scenario A (“early action”) intends to avoid average global warming of more than 2°C, scenario B starts with are economically feasible at a later time period (2030) (“delayed action”).

Overview of Impact – Integrated Assessment- Studies

The majority of studies in climate policy have focussed on the costs of climate policy, i.e. the costs of action. To date, detailed information is available on the regional and global costs of various climate policies. Policy makers want to compare these costs to the benefits that arise due to the climate policies they initiate. Not many studies so far, however, have tackled the challenge of evaluating the costs of inaction or the benefits of climate policies. Many problems occur that make a simple cost benefit analysis challenging. Those problems relate to the dispersion of costs and benefits over time and space, to uncertainties and the synthesis of quantitative and qualitative information. This section thus gives a detailed overview of current research activities in this area. Among the initiatives, the most comprehensive one is the recently published OECD book on ‘the benefits of climate change policies’ (2004).¹

The OECD book presents a selection of review papers each focussing on different aspects of the benefits of mitigation policy. The study points out that problems with coherent benefits research arise for two reasons, partly due to lack of research and partly due to lack of synthesis of research into some coherent measure or set of measures for policymakers and the public to understand and weigh the benefits. The goal, thus, is to provide a survey of available information and to set out a framework and priorities for future research work. The overall aim of the OECD initiative is to improve the information on the benefits of climate policies for policymakers. Several interesting studies exist that focus on the quantitative assessment of the costs and benefits of mitigating climate change with the help of integrated assessment models (e.g. Tol et al. 2004, Nordhaus and Boyer 2000, Fankhauser 1994, Hope 2004, etc.). The models differ in their regional, sectoral and time coverage and need to be seen in light of the model structure, assumptions and uncertainties as pointed out below. For a survey and discussion of studies using an integrated assessment approach see also Pittini and Rahman (2004) and Schellnhuber et al. (2004).

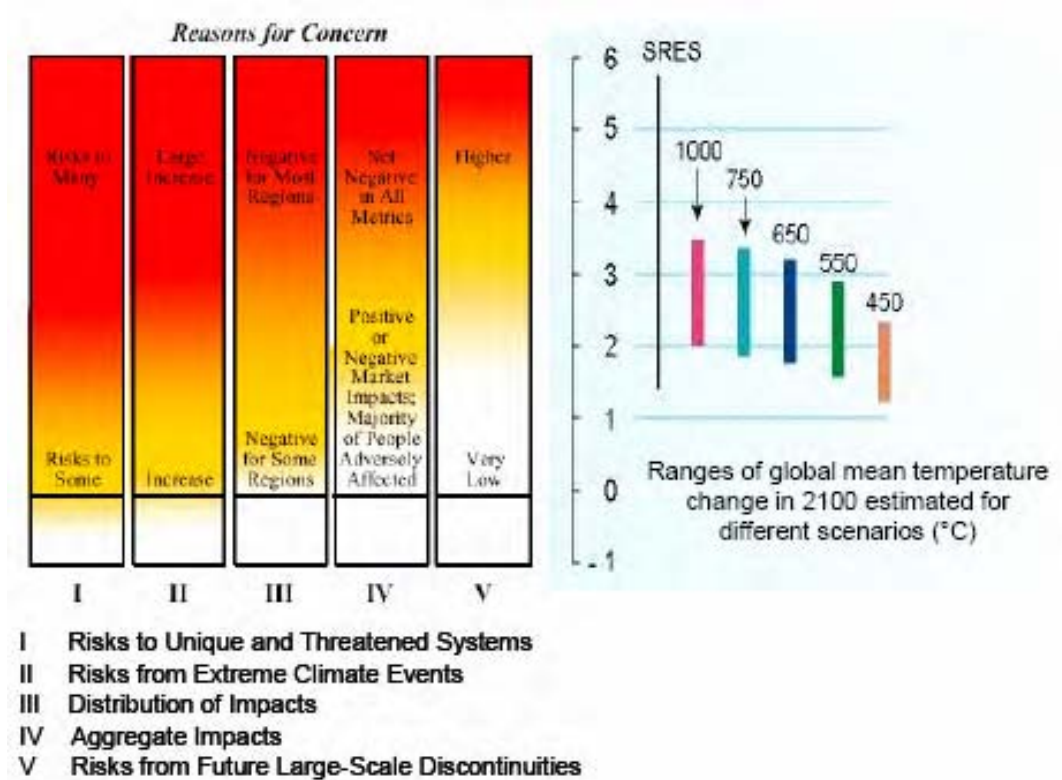
Climate change: Why bother?

The Intergovernmental Panel on Climate Change (IPCC) in its Third Assessment Report sets out five reasons for concern relating to I) the risks to unique and threatened systems, II) the risks from extreme climate events, III) the distribution of impacts, IV) to aggregate impacts and V) to risks from future large-scale discontinuities, and assessed the

¹ That is the benefits of avoiding climatic change and reducing the likelihood of any resulting net adverse impact.

links between those concerns (or impacts) and global mean temperature change in 2100 (see Figure 1). These can then be linked again to different emissions pathways or concentration levels as for example provided by the IPCC's Special Report on Emissions Scenarios (SRES). (IPCC 2000) and stabilisation scenarios based on these SRES scenarios. It shows that even a CO₂-concentration of 450ppm which is well known to be associated with high costs is likely to lead to an increase in global mean temperature above 2°C compared to 1990 (0.6°C have to be added to get the warming above pre-industrial levels) (see also Hare and Meinshausen, 2004) and to substantial impacts related to the reasons of concern I and II and also some for III and IV. The IPCC assessment clearly reveals the high and multidimensional uncertainties that exist regarding any impact analysis.

Impacts of climate change occur not only due to a change in mean climate (warmer mean temperature, melting of glaciers and pole caps), but also in due to changes in climate variability and frequency and severity of extreme events (such as the magnitude and quantity of droughts, storms and floods) and due to irreversible abrupt non-linear changes. It would mean that the system - due to external forces - is pushed from one equilibrium to the other, thus crossing a threshold that can lead to unpredictable and/or irreversible changes. Examples for such events are a change in the thermohaline circulation in the North Atlantic Ocean or the die-back of the Amazon forest, leading to a release of the stored carbon thus enhancing global warming.



Source: IPCC (2001), Synthesis Report.

Figure 1. Relating global mean temperature change to reasons for concern

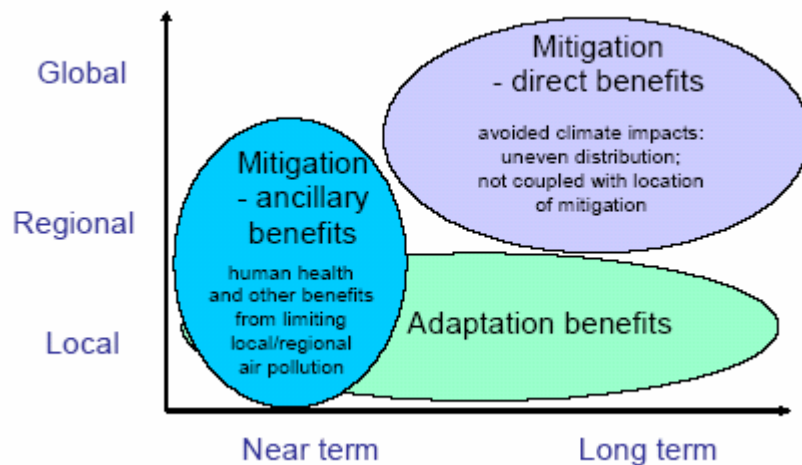
Impact studies so far most often focus on changes in mean climate only. However, a number of studies, among others by Schneider and Lane (2004), Narain and Fisher (2000), Baranzini et al. (2003), suggest that accounting for variability in climate and abrupt non-linear change is likely to shift the 'optimal' level of abatement. Moreover, Schneider and Lane (2004) argue that a reduction of the likelihood of high consequence events could be among the main benefits of early and stringent GHG mitigation.

Benefits – What? Where? When?

For the assessment of global mitigation policy benefits it is important to note the various dimensions of benefits. Firstly, a common understanding is needed what kind of benefits may occur. There are direct benefits of mitigation in the form of avoided damages in, for, example agricultural production, coastal and water resources, terrestrial ecosystems productivity, biodiversity etc. In addition, there are adaptation benefits, in form of avoided adaptation costs, and indirect or ancillary benefits. Ancillary benefits of GHG mitigation exist in the form of a reduction of harmful air pollutants such as sulphur dioxide (SO₂), nitrogen dioxide (NO_x), volatile organic compounds (VOC) and primary particulate matter (PM₁₀). (Schellnhuber et al. 2004) Carbon sequestration technologies often also remove other pollutants from the waste gas stream. A policy that reduces the use of fossil fuels has beneficial effects in terms of mitigating both climate change and regional scale/large scale air pollution. In addition, considerable costs of fossil fuel transports including damage costs from accidents such as oil spills would be mitigated., Climate policy may also lead to a diversification of energy sources, which would decrease the economic and societal sensitivity to disruption of supply.

The other dimensions of benefits relate to the distribution over space and time. Mitigation efforts undertaken now or at any point in time will lead to benefits that partly arise at a much later point of time. This requires a normative judgement of the value of future generations when comparing the costs and benefits in present time values. For economic analyses an appropriate discount rate needs to be chosen. Apart from the distribution of costs and benefits over time, the long-term horizon of climate change presents another major research challenge. Greenhouse gases, in particular carbon, stay in the atmosphere for very long time periods, thus contributing to climate change on a long-term scale. Thus emissions mitigated today produce benefits that reach far into and beyond the 21st century. Any such long-term analysis suffers from very high uncertainties.

Similarly to the time dimension or intergenerational aspects, intragenerational or regional equity of the distribution of costs and benefits plays a major role. Mitigation costs and ancillary benefits typically occur in the same location (or region) where mitigation efforts are taken. Similarly, adaptation costs and benefits accrue in the very same location. However, mitigation costs and direct benefits from mitigation are not immediately linked. Mitigation efforts may take place anywhere in the world and reduce global GHG concentrations. The benefits from the reduction in terms of avoided climate change impacts, however, may show at a very different location from where mitigation originated. The challenge for policy makers thus is to weigh the benefits of climate policy on a global scale rather than a regional one. In this context, equity issues become of importance as the vast majority of GHG emissions stem from industrialized countries while the impacts of climate change are expected to hit less developed countries the hardest. Figure 2 provides an overview of how those different dimensions of mitigation and adaptation policy benefits are linked.



Source: Morlot and Agrawala (2004)

Figure 2. Mitigation and adaptation policy benefits over space and time

Another distributional aspect relates to the sectoral allocation of climate change mitigation benefits. As the IPCC's five reasons of concern show some sectors or systems will be affected harder at lower temperature increases than others.

Hitz and Smith (2004) survey the existing literature on global impact from climate change by sector. The sectors cover agricultural production, coastal resources, water resources, human health, energy, terrestrial ecosystems productivity, forestry, biodiversity, and marine ecosystems productivity. The survey reveals that some sectors, such as coastal resources, health, marine ecosystems, and biodiversity exhibit increasing adverse impacts. Increasing adverse impacts means there are still adverse impacts with very small increases in global mean temperature. These adverse impacts increase with higher global mean temperatures. The authors (Hitz and Smith 2004) were unable, however, to determine whether the adverse impacts increase linearly or exponentially with global mean temperature. Other sectors, such as agriculture, terrestrial ecosystems productivity and forestry exhibit parabolic relationships between temperature increase and impact. This means that a small increase in temperature may exhibit positive impacts while the impact turns adverse for larger increases in temperature. At which temperature increase the inflection point occurs differs by sector as well as by region and is difficult to determine due to uncertainties concerning adaptation (agriculture) and the lack of studies especially for the lower range of temperature change to compare with (forestry). For the other sectors, the authors could not establish a consistent pattern between temperature and impact from the existing data. An overview of their findings together with their assessment of a level of confidence for the deciphered relationships is given in Table 1.

Sector	Increasing adverse impacts ^a	Parabolic	Unknown	Confidence
Agriculture		X ^b		Medium/Low
Coastal	X			High
Water			X	
Health	X ^c			Medium/Low
Terrestrial ecosystem productivity		X		Medium
Forestry		X ^d		Low
Marine ecosystems	X ^e			Low
Biodiversity	X			Medium/High
Energy			X	
Aggregate			X	

Notes:

a. Increasing adverse impacts means there are adverse impacts with small increases in GMT, and the adverse impacts increase with higher GMTs. We are unable to determine whether the adverse impacts increase linearly or exponentially with GMT.

b. We believe this is parabolic, but predicting at what temperature the inflection point occurs is difficult due to uncertainty concerning adaptation and the development of new cultivars.

c. There is some uncertainty associated with this characterisation, as the results for the studies we examine are inconsistent. On balance, we believe the literature shows increasing damages for this sector.

d. We believe this is parabolic, but with only one study it is difficult to ascertain temperature relationship, so there is uncertainty about this relationship.

e. This relationship is uncertain because there is only one study on this topic.

Source: Hitz and Smith (2004)

Table 1. Summary of sectoral damage relationships with increasing temperature

Though positive impacts appear at lower levels of temperature change in some sectors and regions, research suggests negative impacts as global mean temperatures increase beyond certain levels. Across all sectors one consistent pattern among all studies is an increasingly adverse impact beyond an approximate increase in global mean temperature of 3 to

4°C. At lower levels of temperature increase, however, a number of studies show negative impacts for some sectors. These conclusions need to be seen in light of the existing uncertainties, including a lack of impact studies for the lower temperature range and problems of estimating existing impact studies, which prevent them from identifying a precise critical temperature beyond which damages are adverse and increasing. Hitz and Smith (2004) do not attempt to aggregate impacts across sectors. This is because the results vary widely within studies, from scenario to scenario and between studies. The studies do not analyse the same scenarios or use the same baselines and are most often based on different units. Also, there are important linkages between sectors (such as agriculture and water resources), which cannot be accounted for in individual sector studies. Many studies do not take into consideration extreme events or the possibility of abrupt non-linear disruption. Also, the assumptions on the speed and nature of economic and technological development differ by study and influence how vulnerable systems will react to climate change. In addition to these concerns, all of the above mentioned aspects and uncertainties apply (regional and timely impacts, long term aspects, kind of benefits etc.).

From sectoral to global, from physical to economical: Aggregation and monetization of impacts

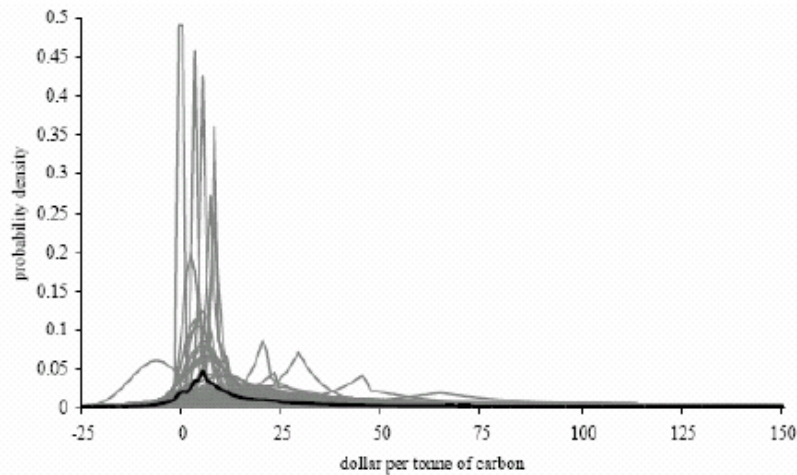
As climate change is a global problem and the costs of climate policies (costs of action) can relatively easily and meaningfully be expressed in economic units (e.g. price per ton of carbon), policymakers seek to compare these costs with the associated global benefits of climate policies (costs of inaction). However, while it is difficult to aggregate impacts across sectors, giving impacts an economic value is seen to be even more challenging. In addition to all the uncertainties mentioned, an economic valuation of climate change impacts inevitably implies value judgements with respect to which non-market impacts² to include and how to value them, with respect to predicting how relative and absolute impacts will develop into the future and with respect to aggregating the costs of climate change across regions and countries (equity weighting) and aggregating across generations (discount rate).

Pittini and Rahman (2004) provide an overview of findings with respect to marginal costs of climate change impacts (i.e. the social cost of carbon). The estimates mainly result from analyses with integrated assessment models (IAM). IAMs combine scientific and economic aspects of climate change into a single dynamic modelling framework. They produce estimates for the social costs of carbon either as shadow prices of carbon in comparing marginal abatement costs to marginal damage costs or as average incremental costs of a small perturbation in emissions from a business as usual baseline. Pittini and Rahman point out that results from IAMs are driven by inherent value judgements, which renders it difficult to compare carbon price estimates. In addition, the IAMs surveyed differ in their regional aggregation, in their complexity of climate and/or economic components, in their level of including non-market impacts, and in the assumptions on their business as usual baseline. Tol (2004) stresses that IAMs - in order to assess absolute damage costs - need to establish the future size of the population and the economic, natural, social and human capital stocks at risk. With a timeframe as long as global warming damages, no prediction of future developments can be done with any confidence. Scenarios are thus used to describe possible futures. They do not claim to describe the most likely future. Because of the use of these scenarios, global warming damage assessments have a contingent nature: they are contingent upon the assumptions embedded in socioeconomic scenarios, whether explicit or not. In addition, Pittini and Rahman point out that there are severe limitations in the coverage of some key climate change issues, such as the impacts of low-probability high-risk impacts, extreme weather events, social contingent impacts and impacts in the areas of biodiversity, ecosystems. Thus, the social costs of carbon presented in the following need to be seen in light of the shortcomings. They will not represent any true value of the marginal damage costs until these issues are better understood and supplementary probabilistic sensitivity analyses are undertaken and incorporated into the estimates to account for uncertainties.

²Non-market impacts are impacts for which a market price does not exist, such as biodiversity, ecosystems, health, tourism, recreation.

Findings from several review studies provide a range of a possible carbon damage costs. In particular, Pittini and Rahman (2004) refer to estimates from the following studies:

- Pearce et al. (1996) review existing studies for the IPCC 2nd assessment report and report a range of **5-125 US\$/tC** (tons of carbon) in 1990 prices (or 6-160 US\$/tC in 2000 prices) relating to carbon emissions from 1991-2000. For the period 2001-2010, the estimates range from **7-154 US\$/tC** 1990 prices (and 9-197 US\$/tC in 2000 prices). Social cost estimate increase over time, as marginal damage costs tend to increase with higher greenhouse gas concentrations.
- 8 major studies are reviewed by Clarkson and Deyes (2002) and reveal an estimated range of **50-200 US\$/tC** for the global damage costs of carbon emissions. In real terms these number should be increased by approximately 1.5 US\$/tC per year because the costs of climate change are likely to increase over time.
- 24 estimates from 12 studies are reviewed in Pearce (2003) and lead to a range of **6-39 \$/tC** for the social price of carbon.
- Tol (2003b) conducts a meta-analysis of 88 estimates from 22 published studies for the marginal social costs of carbon dioxide. He finds a very wide and right skewed distribution of costs (see Figure 3), with a mean at **104 US\$/tC**. Weighing these estimates, Tol concludes that the marginal costs may not exceed **50 US\$/tC** and are likely to be even lower than that. The weights are based on Tol's normative value judgement. They are applied to reflect different quality levels of the estimates and to account for the fact that there are groups of results in the database that originate from the same modelling exercise and thus incorporate an inherent bias. Thus, the results need to be seen in light of the method and normative assumptions chosen by Tol.



Source: Tol (2003b).

Note:

Tol (2003b) collects 88 estimates of marginal social cost of carbon dioxide figures, from 22 studies. As Tol notes, one would expect the reported estimates to vary considerably, with high to low end marginal social cost estimates ranging from USD 1666/tC through to USD 7/tC. The probability density function in grey highlights the full range of the 88 estimates. The combined probability density function appears in black.

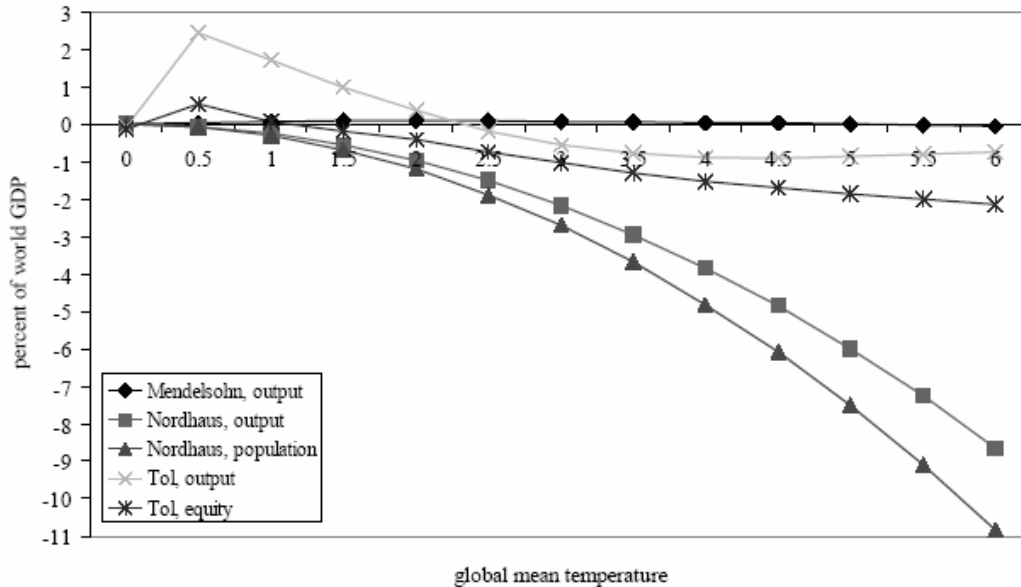
Figure 3. Meta-analysis of 88 estimates of the marginal social costs of carbon

The range of impacts of changes in global mean temperature (up to 6°C) on global GDP is illustrated in Figure 4.³ Four scenarios from three studies with different approaches to aggregating costs show a broad range of possible damage costs.

³ The global GDP loss for a specific time period or point in time can be deduced for each GHG concentration scenario in multiplying the social costs of carbon (in \$/tC) with the amount of global emissions (C) and comparing the resulting global total costs with global GDP to yield the percentage global loss.

It needs to be pointed out that any such quantitative assessment and its interpretation needs to be seen in light of the underlying problems and caveats as discussed above (such as differing model structures, approaches, and assumptions taken as well as differing time horizon, regions, sectors, and kind of damages covered). They do, however, serve as an illustration of the range of results from such efforts. Depending on the weighting factor used for aggregating costs across sectors and regions, some studies imply initial aggregate benefits from small changes in mean temperature while others show substantial damages even at low level of temperature changes.

However, all four scenarios consistently show increasing damages (in terms of GDP losses) for higher magnitudes of climate change.



Source: Tol et al. 2004.

Note:

Mendelsohn et al. (1997) aggregate impacts across different regions weighted by regional output. Nordhaus and Boyer (2000) aggregate either weighted by regional output or weighted by regional population. Tol (2002) aggregates either by regional output or by equity, that is, by the ratio of world per capita income to regional per capita income.

Figure 4. Impact of climate change as a function of the change in global mean temperature

Conclusions: What to draw from the existing and where to go from here?

Despite these challenges, the OECD study (2004) points out some general patterns that can be detected in the literature

1. Some sectors, such as agriculture, may experience net positive impacts globally of a small amount of climate change
2. Some sectors show adverse impacts even for low levels of global warming (such as biodiversity, health, marine ecosystems)
3. No research indicates any positive impact from climate change as temperatures increase beyond certain levels.
4. Marginal adverse impacts emerges across all sectors for a temperature increase beyond 3-4°C in global mean temperature
5. Number of studies indicates that the economically ‘optimal’ level of mitigation is increased when accounting for the risks of irreversible, abrupt climate change. Thus, calling for more investment in abatement in the near-term.

A broad conclusion is that sound summary estimates of benefits in a single (monetary) measure to compare with aggregate costs may not be adequate on their own to inform policy decisions. Cost benefit methods alone may be inadequate and should be complemented with risk-based methods (such as probabilistic approaches). The OECD study

calls for a presentation of benefits in two different forms: monetised estimates and physical impact estimates. They point out that a coherent set of indicators and research strategy is needed. Such a strategy would involve the following steps: Firstly, global physical variables for impacts should be researched and identified. Thereafter, regional physical variables should be tackled. These should be followed by an economic valuation leading to a set of regional monetary variables. Finally, an attempt of monetised aggregate benefits assessment can be undertaken. A modest and preliminary research goal thereby should be to have consistent and comparable regional information so that impacts associated with levels of global mitigation can be assessed.

Climate Change- Extreme Weather Events

The number and intensity of extreme weather events, such as flooding caused by heavy precipitation, heat waves and big storms has increased considerably. Table 2 illustrates extreme climate events, the probability of occurrence and potential impacts. Not only the number of extreme climate events is expected to increase but also the intensity,

Extreme Climate Event	Probability	Impacts
Higher max. Temperature. More Hot Days and Heat Waves over nearly all land areas	Very likely	Increased Incidence of Deaths and serious diseases in older age groups and urban poor. Increase of Heat Stress in livestock and wildlife Shift of Tourist Areas Increase of risks of damages to a number of crops Reduction of Energie Supply Reliability Increase of Energy Demand for Cooling
Higher minimum Temperatures, fewer cold days, frost days and cold waves over nearly all land areas	Very Likely	Decreased cold- related human Morbidity and Mortality Decreased Risks of Damages to a number of Crops, and increased Risks to Others Extrended Range and Activity of some pest and Disease Vectors Reduced Heating Energy Demand
More Intense Precipitation Events	Very Likely	Increased Flood, Landslide, Avalanche and Mudslide Damage Increased Soil Erosion Increased Flood Runoff could Increase Recharge of some Floodplain Aquifers Increased Pressure on Government and Private Flood Insurance Systems
Increased Summer Drying over most Mid-Latitude Contiental Interiors and associated Risks of Drought	Likely	Decreased Crop Yields Increased Damage to Building Foundations caused by groud Shrinkage Decreased Water Resource Quantity and Quality Increased Risk of Forest Fire
Increase in Tropical Cyclone Peak Wind Intensities, mean and peak precipitation intensities	Likely	Increased Risk to Human Life, Risk of Infection Disease Epidemics and many other Risks. Anstieg der Risiken für Krankheiten und Epidemien Increased Coastal Erosions and Damage to Coastal Buildings and Infrastructure. Increased Damage to Coastal Ecosystems such as Coral Reefs and Mongroves.
Intensified Droughts and Floods associated with El Nino events in many different Regions	Likely	Decreased Agricultural and Rangeland Productivity in Grought- and Flood Prone Regions. Decreased Hydro- Power Potentials in Drought prone Regions
Increased Asian Monsoon Precipitation Variability	Likely	Increase in Flood and Drought Magnitude and Damages in Temperature and Tropical Asia
Increased Intensity of mid- latitude storms	Low	Increased Risk to Human Life and Health Increased Property and Infrastructure Losses Increased Damage to Coastal Ecosystems

Source: IPCC (2001).

Table 2 Projected Changes during the 21st century in extreme climate phenomena and their likelihood

especially of extreme precipitation events. Some regions (particularly poor regions) will and already have been more strongly affected than other regions. It is expected that in the region of North America more storms, hurricanes and tornados with extreme wind intensities will occur. In Asia floods are more likely to happen. In Europe, however, not only extreme heat waves or floods are more likely but also storms, such as tornados (MunichRe 2002).

Table 3 shows the number of extreme weather events and their economic and insured losses from 1950 until today. As the figure shows, the number of extreme weather events went up drastically. From the 1960s to the 1980s the number of such events went up by a factor of 2.8. Moreover, within the last ten years

Great Weather Disasters 1950 - 2004								
Decade comparision								
Decade	1950-1959	1960-1969	1970-1979	1980-1989	1990-1999	last 10 1995-2004	Factor 80s : 60s	Factor last 10: 1960s
Number	13	16	29	44	74	49	2,8	3,1
Economic losses	43,9	57,6	86,9	136,9	460,8	331,1	2,4	5,8
Insured losses	unknown	6,4	12,7	25,1	106,2	87,6	3,9	13,6

Losses in US\$ bn (2004 values)

MRNatCatSERVICER

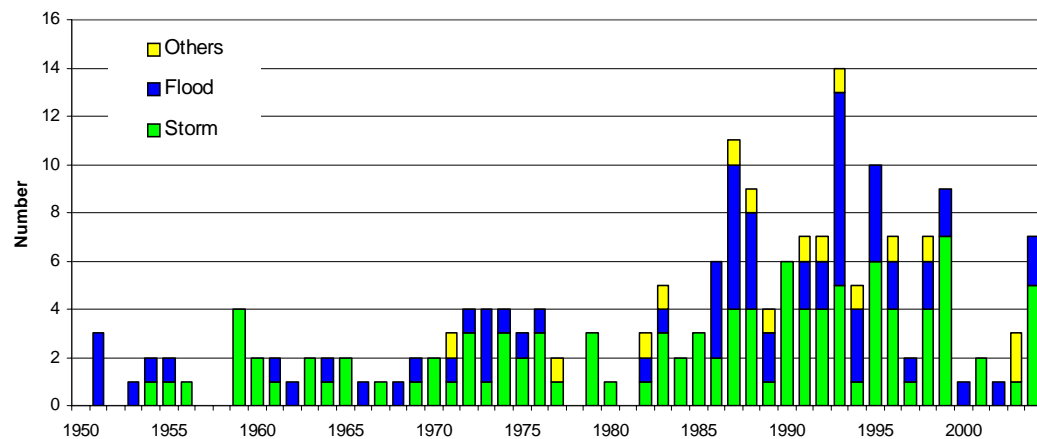
Table 3 Great weather disasters 1950- 2004

Source:2004 Geo Risks Research Dept., Munich Re

the number of extreme events was as much as 3.1 times higher than in the 1960s. This led to drastic increases for both economic and insured losses (Table 3 and Figure 5).

Extreme heat phenomena and precipitation events also happened in Europe (including Germany): in the summer of 2002 Middle and Eastern Europe were infested by a flood catastrophe, caused by heavy rainfalls. This extreme weather event affected the Eastern and Southern part of Germany, the South West of the Czech Republic and Austria and Hungary caused by the strong flooding of the main rivers, Danube, Elbe, Moldau, Inn and Salzach. The flood hit Germany, Austria and the Czech Republic the hardest. Economic damages amounted to up to 9.2 billion Euros in Germany only.⁴

Great Weather Disasters 1950 - 2004
Number of events

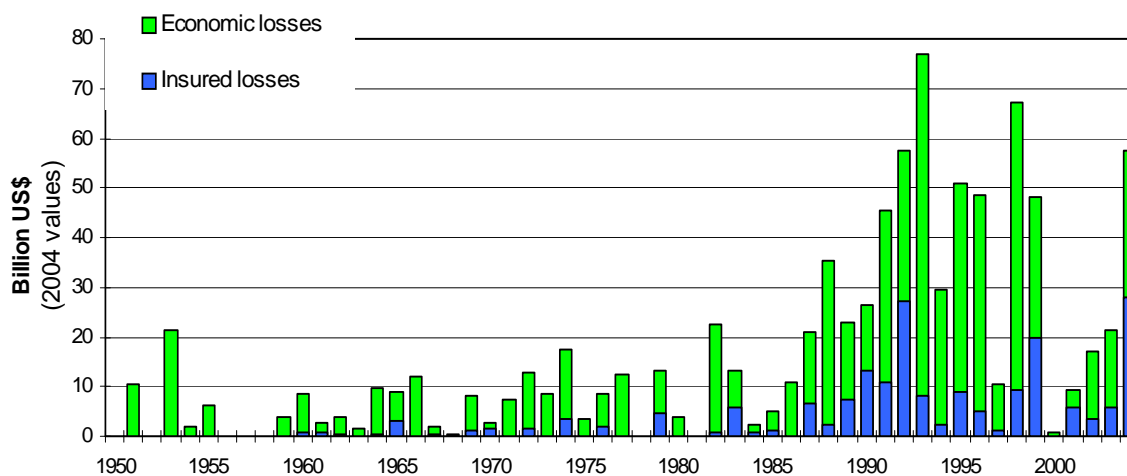


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Figure 5: Great weather disasters 1950-2004

⁴ One of the largest re-insurance companies, the Munich Re assessed the damages associated with the flood, see Münchner Rück: Jahresrückblick Naturkatastrophen 2002, München 2002

Great Weather Disasters 1950 - 2004 - Economic and insured losses



Source: 2004 Geo Risks Research Dept., Munich Re

Figure 6: Economic and insured losses of great weather disasters 1950-2004

In the summer of 2003, only one year after the big flood, Europe suffered from an extreme heat wave. The economic damages included increased diseases (such as cardiovascular problems or, for example, malaria that can occur also in the European country area) and an increased number of heat related deaths. Especially in France, the mortality rate of elderly people increased considerably in this period. Furthermore, damages of crop gains, disruption of energy supply and an increase of forest fires, especially in Southern Europe, took place.⁵ In total, economic damages related to the European heat wave can be assessed at 10 to 17 billion Euros.⁶

Costs of Action versus Cost of Inaction of Climate Protection- A Quantitative Assessment

We assess the costs of action, i.e. the costs of emissions reduction, and the costs of inaction, i.e. the impacts of human induced climate change, with the help of a quantitative modelling tool (WIAGEM - World Integrated Assessment General Equilibrium Model). We compare three scenarios: The reference scenario, which does not include any climate protection measures. Scenario A (ScenA, "early action") limits the increase in global surface temperature to 2°C, while Scenario B (ScenB, "delayed action") defers the introduction of emissions reductions to a later point of time (2030). Here, we assume that concrete emissions mitigation policies that intend to reach specific emissions reduction targets start after 2030. No climate policy takes place before 2030.

Our analysis is performed using the multi-regional WIAGEM model. WIAGEM is an integrated economy-energy-climate model that incorporates economic, energy and climatic modules in an integrated assessment approach (Kemfert 2002a and 2002b). To evaluate market and non-market costs and benefits of climate change, WIAGEM combines an economic model - with special focus on the international energy market - with a climate model that accounts for temperature changes and sea level variations. The design of the model focuses on multilateral trade flows. The representation of economic activities is based on an intertemporal general equilibrium approach and contains the international markets for oil, coal and gas. The climatic model is based on general interrelations between energy and

⁵ High water temperatures of rivers due to high outside temperatures cause risks of inadequate cooling of nuclear reactors. In 2003, this initiated a shut down of nuclear power plants in Germany and France.

⁶ Tony Blair assessed the economic damages at about 13.5 billion US\$ and 26.000 fatalities, see speech of the British Prime Minister on the occasion of the 10th anniversary of the "Price of Wales Business & the Environment Programme", London 14. September 2004.

non-energy related emissions, temperature changes and sea level variations, all inducing substantial market and non-market damage cost economic impacts. WIAGEM accounts for all six greenhouse gases (GHG) that potentially influence global temperature, sea level variation and the assessed probable impacts in terms of costs and benefits of climate change. Additionally, the model includes net changes in GHG emissions from sources and removals by sinks resulting from land use change and forestry activities.

Market and non-market damages are evaluated according to the damage costs approaches of Tol (2002, 2003 and 2004) who calculates different damages of regional climate change. To assess impacts by climate change, we follow Tol's approach (2003) to cover impacts on forestry, agriculture, water resources and ecosystem changes as an approximation of a linear relationship between temperature changes, per capita income or GDP and adaptation costs due to climate change. This means, increased emissions lead to an increase of the global surface temperature which causes global economic impacts. Regional economic impacts depend on the countries economic performance and population development, i.e. per capita income. Tol (2003) estimates climate change impacts covering a variety of climate change impacts. Along with sectoral impacts on agriculture, forestry, water resources and energy consumption, he covers impacts on ecosystems and mortality due to vector borne diseases and cardiovascular and respiratory disorders. In addition to the damage cost assessments of Tol, we implement adaptation costs and additional costs to the economy lowering other investments (crowding out effect).

We include the same regional damage functions in our model. However, the damage functions are disaggregated according to the specific sort of damage (impacts on forestry, water, mortality). We assume that there is a functional relationship between overall temperature change and regional economic income (see Annex). The model results differ substantially from the findings of Tol (2004). This is because of two main reasons. First; we apply a fundamentally different global economic approach than Tol (2002) applies in his cost assessment study. We use a global general equilibrium approach that covers interregional and intersectoral trade effects, he uses a much simpler approach that neglects the interregional trade effects. The model applies a recursive dynamic approach so that we cover feedback effects from damages or other shocks. This means, in each time period (the model covers 5 year time intervals), impacts occur due to temperature change and regional per capita productivity change. This affects the dynamic impacts in the model: if impacts of climate change occur countries face higher expenditures. These expenditures cannot be spent as initially planned (thus crowding out investment). The main difference in the modelling framework here in comparison to Tol is that we apply a recursive dynamic approach where countries face impacts of climate change. Second, we include a detailed climate model that assesses the temperature changes from emission profiles (Kemfert 2002). Both reasons cause the fact that the dynamic feedback effects from the climate and the economic system yield much higher damage costs as earlier studies. In addition to the pure economic income effects we cover economic shocks due to adaptation. Countries spend a certain amount on adaptation when climate change occurs.⁷ These expenditures are crowding out investments that cannot be spent as previously intended in a growth model. Adaptation (or protection costs) in WIAGEM mean costs that occur to adapt to damages. They do not prevent future damages. Future damage costs are only reduced in the following way: with less climate change by, for example reduced emissions, countries spend less protection costs. Ancillary benefits are related to the level of emissions. A reduction in emissions implies higher ancillary benefits. We find that these effects cause reactions on economic development.

Figure 7 graphically illustrates the modelling structure and the interaction of economic activities, energy consumption, climate and ecological impacts in WIAGEM. Uncertainty about the correct determination of the model, data and key parameters distorts the understanding of the social, economic and ecologic impacts of climate change. Uncertainties could justify postponing significant mitigation efforts. However, uncertainty also includes the risk of significant climate

⁷ If climate change is reduced (by for example reduced emissions), countries spend less percentage of investments for adaptation.

changes that induce considerable impacts. The uncertainty about data quality is reduced because the model is based on a detailed economic database representing a well-known and scientifically accepted economic database. Model and parameter uncertainties are covered by choosing an innovative modelling approach and by including parameter sensitivity analysis.

WIAGEM is a multi-sector, multi-region dynamic intertemporal integrated assessment model. The model covers a time horizon of 100 years and solves in five-year time increments.⁸ The basic idea behind this modelling approach is the evaluation of market and non-market impacts induced by climate change. The economy is represented by 25 world regions, which are further aggregated into 11 trading regions for this study (see Table 4).

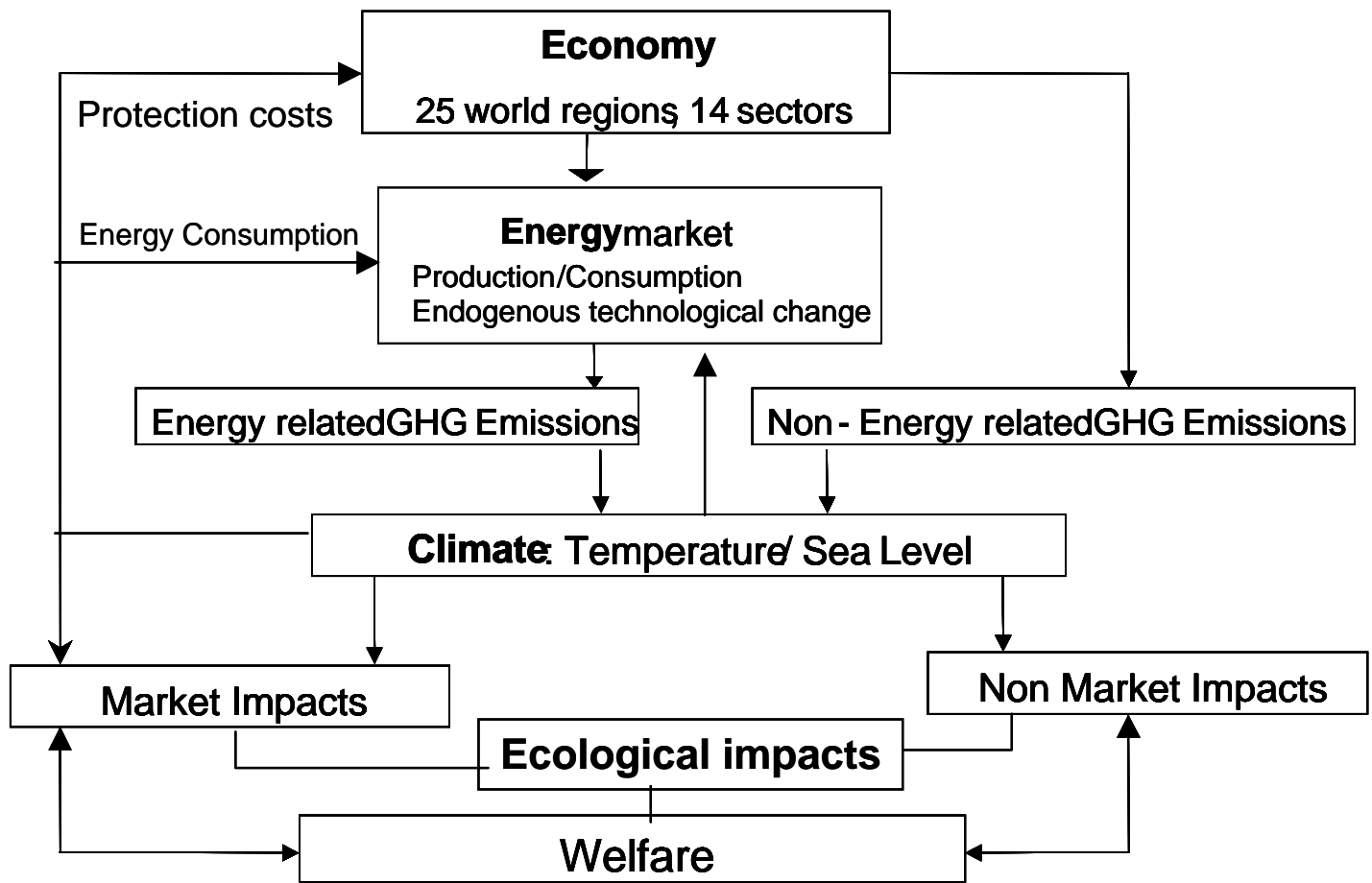


Figure 7 Modelling structure in WIAGEM

The economy of each region is disaggregated into 14 sectors, including five energy sectors: coal, natural gas, crude oil, petroleum and coal products, and electricity. Goods are produced for the domestic and export markets. The output of the non-energy sectors is aggregated into a non-energy macro good. WIAGEM covers a production function that allows for (imperfect) substitution between the input goods, labour, energy (i.e. coal, oil and gas) and capital (so called constant elasticity of substitution CES production function). The substitution elasticities are crucial parameters of the model: if we allow for a very good substitution option between the individual energy inputs, mitigation costs may be reduced as countries simply substitute coal with gas. Vice versa, if we allow for low substitution options, countries face higher mitigation costs, as it is more difficult to substitute for example coal with gas.

⁸ See Kemfert (2002b) for a detailed model description.

Integrated Assessment Model

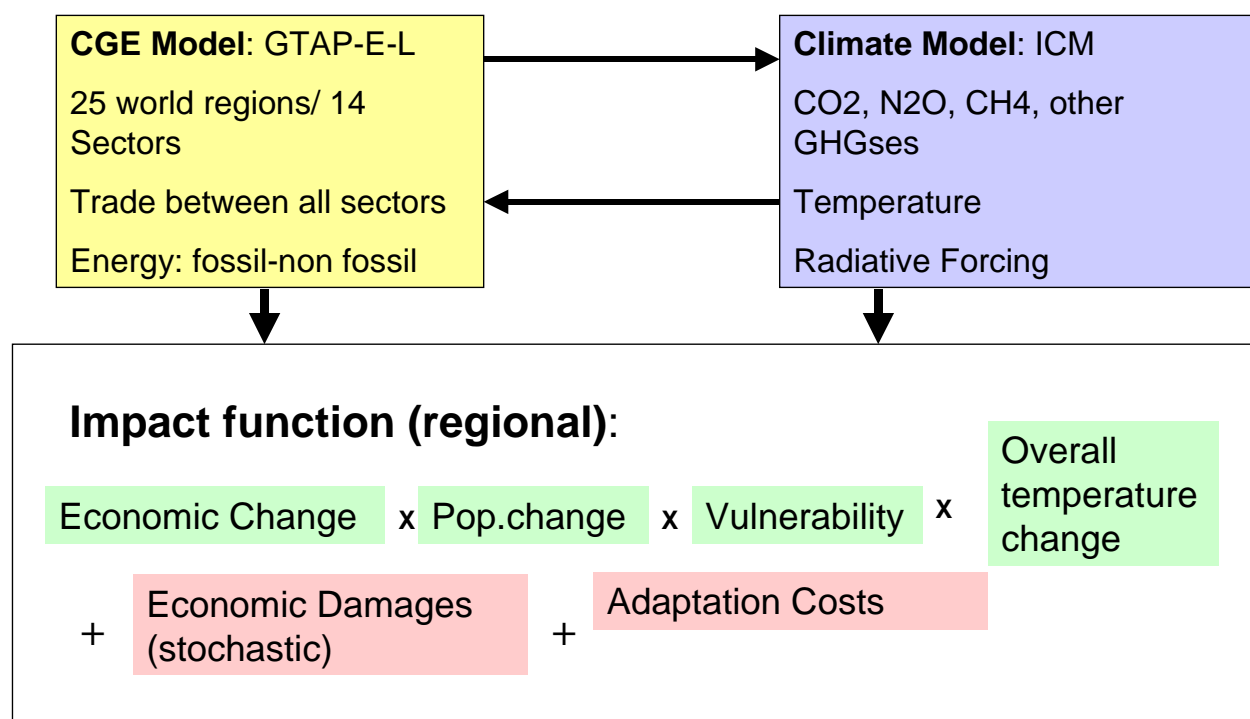


Figure 8: Integrated Assessment Model- Impact Assessment

The same functional form (CES) is assumed for the household's utilities: they can choose between current consumption or savings, under the constraint of individual incomes. Also here the substitution elasticity is a crucial parameter, as with high savings and low current consumption economic growth can be lower. The basic assumptions for the elasticity values are shown in Table 5.

Regions	
ASIA	India and other Asia (Republic of Korea, Indonesia, Malaysia, Philippines, Singapore, Thailand, China, Hong Kong, Taiwan)
CHN	China
CNA	Canada, New Zealand and Australia
EU15	European Union
JPN	Japan
LSA	Latin America (Mexico, Argentina, Brazil, Chile, Rest of Latin America)
MIDE	Middle East and North Africa
REC	Russia, Eastern and Central European Countries
ROW	Other Countries
SSA	Sub Saharan Africa
USA	United States of America

Table 4 Definitions of countries and regions in WIAGEM

WIAGEM covers the option to increase low carbon technologies which lowers mitigation costs. Countries invest in R&D expenditures that brings low carbon technologies with reduced costs. Even those countries can benefit by technological changes that do not increase their expenditures in R&D by so called spillover effects: if, for example, Europe invents a new low carbon technology, it will be exported also to other countries (e.g. China).

Type of elasticity	Value
Armington elasticity of substitution	1
Armington elasticity of transformation	2
Elasticity of fossil fuel supply	1 (coal), 4 (gas, oil)
World interest rate	2
Elasticity of substitution between non-energy and energy composite in production and final demand	0.25-0.5 (Annex B), 0.20-0.4 (non-Annex B)
Interfuel elasticity of substitution	0.5 (final demand)

Table 5 Key parameter of model WIAGEM

In addition to the non-energy macro good, oil, coal and natural gas are traded internationally. The global oil market is characterized by imperfect competition to reflect the ability of the OPEC regions to use their market power to influence market prices. Coal is traded in a competitive global market, while natural gas is traded in competitive regional markets with prices determined by global or regional supply and demand.

Energy-related greenhouse gas emissions occur as a result of energy consumption and production activities. WIAGEM includes all six greenhouse gases covered under the Kyoto Protocol: carbon dioxide (CO₂), methane (CH₄), nitrous dioxide (N₂O), and the fluorinated gases HFC, PFC and SF₆. Thereof the first three are considered to have the greatest impact on climate change over the 100-year period covered by the model. Key assumptions about the gases are shown in Table 6. WIAGEM also covers non-energy related emissions, we assume a constant growth rate over time, see Table 6.

Trace Gas	CO ₂	CH ₄	N ₂ O
Atmospheric Concentration			
Pre- Industrial (ppmv)	278	0.789	0.275
1992 (ppmv)	353	1.72	0.310
Energy related Emissions			
1992 (billion tons)	6.0	0.08	0.0001
Growth rate, post 1992			
Non-energy related Emissions			
1992 (billion tons)	0.2	0.454	0.0139
Growth rate, post 1992	0	0.8	0.2

Table 6: Summary key assumptions greenhouse gases ⁹

Impacts of climate change cover market and non-market damages; the former comprise all sectoral damages, production impacts, loss of welfare etc., while the latter contain ecological effects such as biodiversity losses, migration, and natural disasters. To assess impacts by climate change, we follow Tol's approach (2002) to cover impacts on forestry, agriculture, water resources and ecosystem changes as an approximation of a linear relationship between global temperature changes, per capita income or GDP and adaptation costs due to climate change. We estimate climate change vulnerability covering a comprehensive evaluation of diverse climate change impacts. Along with sectoral impacts on *agriculture, forestry, water resources and energy consumption*, he covers impacts on ecosystems and mortality due to vector borne diseases and cardiovascular and respiratory disorders (see Appendix I for more details). We assume that there is a functional relationship between global

⁹ Source: IPCC (1990) and IPCC (1992)

temperature change, regional population change and economic income change that affects the impacts on ecosystems, forestry, health and water. We furthermore assume that energy consumption, here space heating and cooling, depends on the economic income, energy productivity and overall temperature change (see Annex for detailed mathematical description and parameters): That means, with increasing global temperature impacts of climate change increase, depending on the regional economic performance of a country (per capita income) and the population development. We assume a linear relationship between temperature change and climate change impact on forestry and water. Energy consumption for heating and cooling depends on the temperature development, population and income change, and technological progress within the energy sector. The loss of ecosystems depends on the per-capita income change and population change. We furthermore assume a non-linear relationship between health¹⁰ (mortality) and regional temperature change and income. The main shortcoming of this approach (from Tol covered in this study) is the assumption of a global surface temperature that leads to regional impacts, and not a regional temperature development. Only for the impact assessment of health and mortality we account for regional temperature weights.

We apply the same functional relationships as Tol (2004) who assesses economic impacts of climate change on ecosystems, forestry, water and health. He applies damage functions that relate on the global temperature change (not regional temperature change) and the per capita economic performance of a region. However, as we apply a fundamentally different economic model, our model results show that damage assessments are much higher than earlier studies. Most of the previous Integrated Assessment studies (Nordhaus 1991, Cline 1992) assume one damage function for the global assessment of damages. Tol (2002) firstly assessed regional damages in relation with global surface temperature and regional per capita performance. We apply the same functional relationship for the sectors ecosystem, forestry, water and mortality (parameters see Appendix). However, we cover detailed and disaggregated dynamic economic and climate feedback effects. Two main reasons lead to different damage effects than previous studies: First, we cover a detailed CGE model that incorporates interregional and intersectoral trade effects and dynamic investment decisions. Second, most integrated assessment models so far include one aggregate damage function for the world and do not disaggregate regional impacts. In this model approach, we assume that regional impacts of climate change are caused by the overall (global) temperature changes, income changes of a country and regional population. We then sum up all impacts. However, regional differences in climate change are not accounted for.

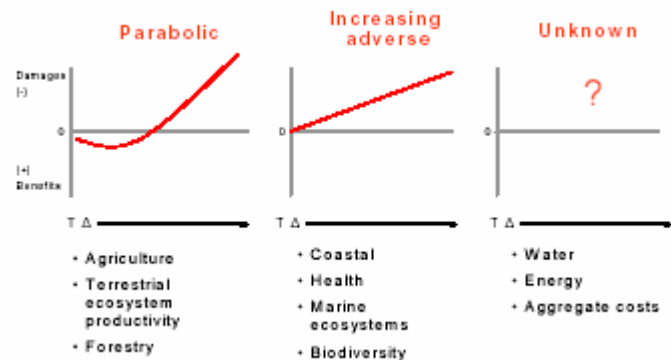
Model Results

This chapter presents our model results on the costs and benefits of climate policy. The first section highlights previous estimates from comparable studies. Our results are then presented in light of those estimates.

Results from Comparable Studies

Quantitative modelling studies crucially depend on the assumptions about economic development, the incorporation of dynamic interrelations, the aggregation level, time and the climate threshold. Furthermore, the assumptions about damages of climate change significantly affect the quantitative impact assessment.

Within the terrestrial ecosystem productivity area, a parabolic damage function is seen to be most realistic, as especially in the short term time horizon benefits from climate change might be most likely (Morlot and Agrawala, 2004). Most studies assume a linear relationship between temperature change in time and impacts on health, biodiversities, marine ecosystems and



Source: Morlot and Agrawala (2004), Chapter 1 OECD study

Figure 9 Damage functions

¹⁰ Although there exist more recent studies that estimate an economic growth reduction of malaria disease alone by 1 % per year, we still stick to the chosen relationship with less drastic impact assumptions, see Malaney et al (2004)

coasts. Still highly uncertain are impacts on water and energy. As some model studies only incorporate few aspects, a comparison of impact assessment studies becomes very challenging.

The range of uncertainties related to impact assessment studies is very high. Market and non-market impacts estimates vary widely between individual studies (OECD 2004).

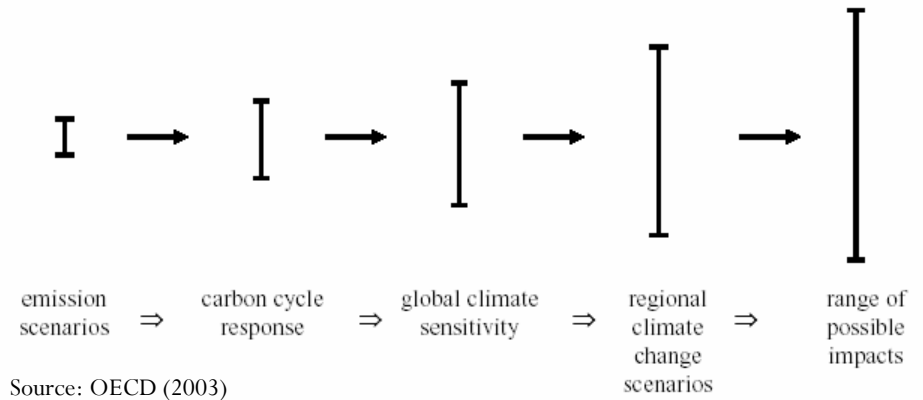
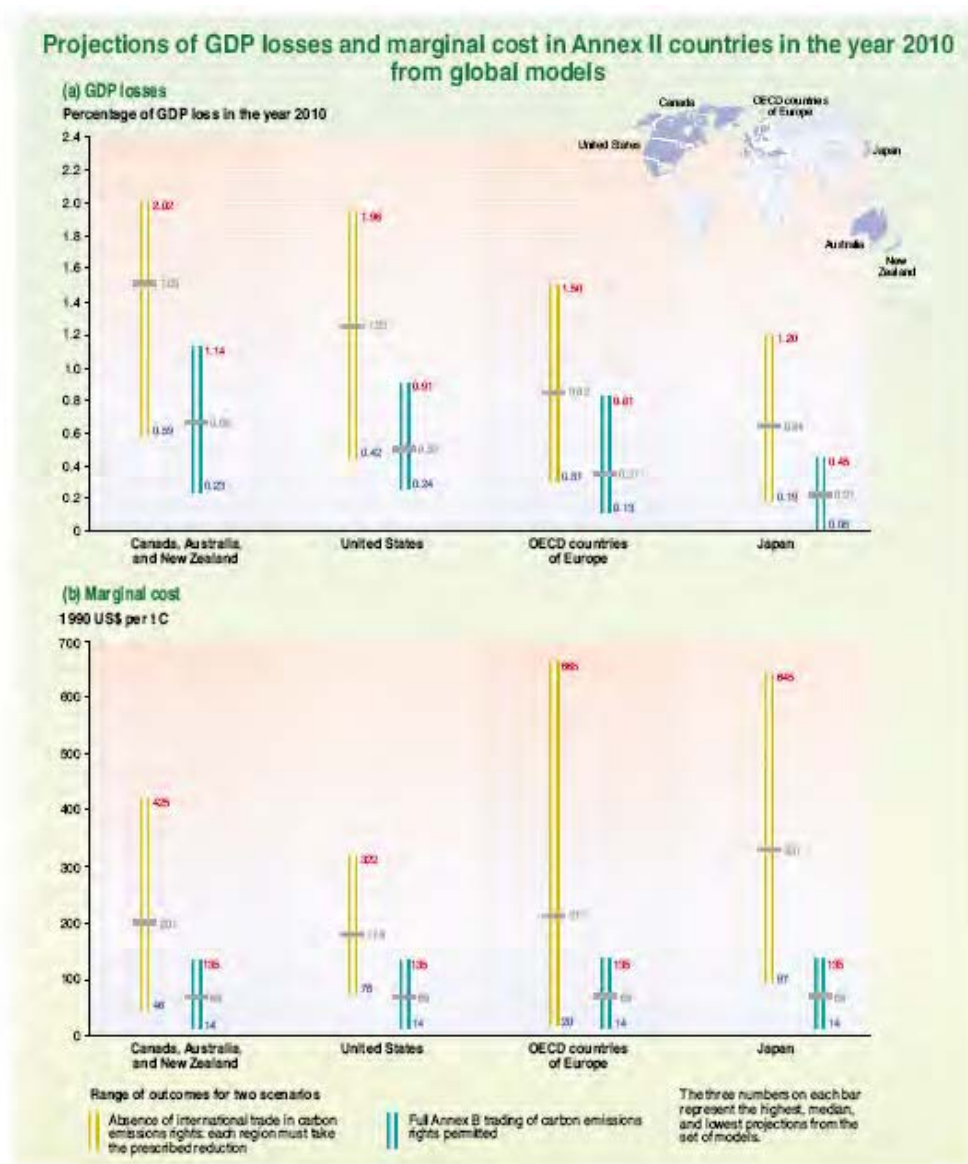


Figure 10. Range of major uncertainties in impact assessments

In this study, we incorporate both market and non-market impacts. Market impacts are reflected in a very detailed way as we apply a disaggregated CGE model that cover the main economic regions of the world that are linked via bilateral trade flows.



Source: IPCC (2001) and Weyant (1999)

Figure 11. Global Mitigation Costs as GDP losses and marginal costs of different global models

Non-market impacts are included by a very aggregated functional relationship, that certainly crucially depends on the key assumptions and parameters. Also, impacts from damages are covered based on sectoral and regional damage functions that depend on global temperature and regional economic income and population changes. As regional climate change is not taken into account, and damage functions are very aggregated and stylised, this is still a very rough global estimate of impacts.

Global mitigation costs assessments differ widely, as model constructions, assumptions and parameterization diverge substantially. IPCC (2001) summarised abatement costs as percentage of GDP of different regions. An emissions trading system reduces costs considerably.

Model Calculations

This section presents our model calculations. We compare the benefits and costs of climate protection, that is, on the one hand the avoided climate damages and adaptation costs as well as the ancillary benefits, on the other hand i.e. the costs of emissions mitigation related to avoiding global mean warming by more than 2°C. Especially, we assess a reference scenario where no climate protection or emission mitigation actions take place and two mitigation scenarios: Scenario one “early Action” (ScenA) aim at avoiding a global surface temperature increase of more than 2°C compared to pre-industrial levels, while scenario two “delayed action” (ScenB) starts with drastic emission reduction policies at a later time period (2030) resulting in much higher levels of emissions and temperature increase throughout the entire time horizon of 100 years. Furthermore, we assume in ScenA and ScenB a climate sensitivity of 2.8°C (see Appendix I). In an additional sensitivity analysis, we compare the results with those for a high climate sensitivity (HCS-4.2°C) and a low climate sensitivity (LCS-1.5°C).

Scenario Description	Emission Start	Mitigation	Climate sensitivity
Scenario A (ScenA)	Now		middle (2.8°C)
Scenario B (ScenB)	2030		middle (2.8°C)
Scenario B with faster technological change (Scen-B-ITC)	2030		middle (2.8°C)
Scenario A- high climate sensitivity (ScenA-HCS)	Now		high (4.2°C)
Scenario A- low climate sensitivity (ScenA-LCS)	2030		low (1.5°C)
Scenario B- high climate sensitivity (ScenB-HCS)	2030		high (4.2°C)
Scenario B- low climate sensitivity (ScenB-LCS)	2030		low (1.5°C)

Table 7. Scenario description

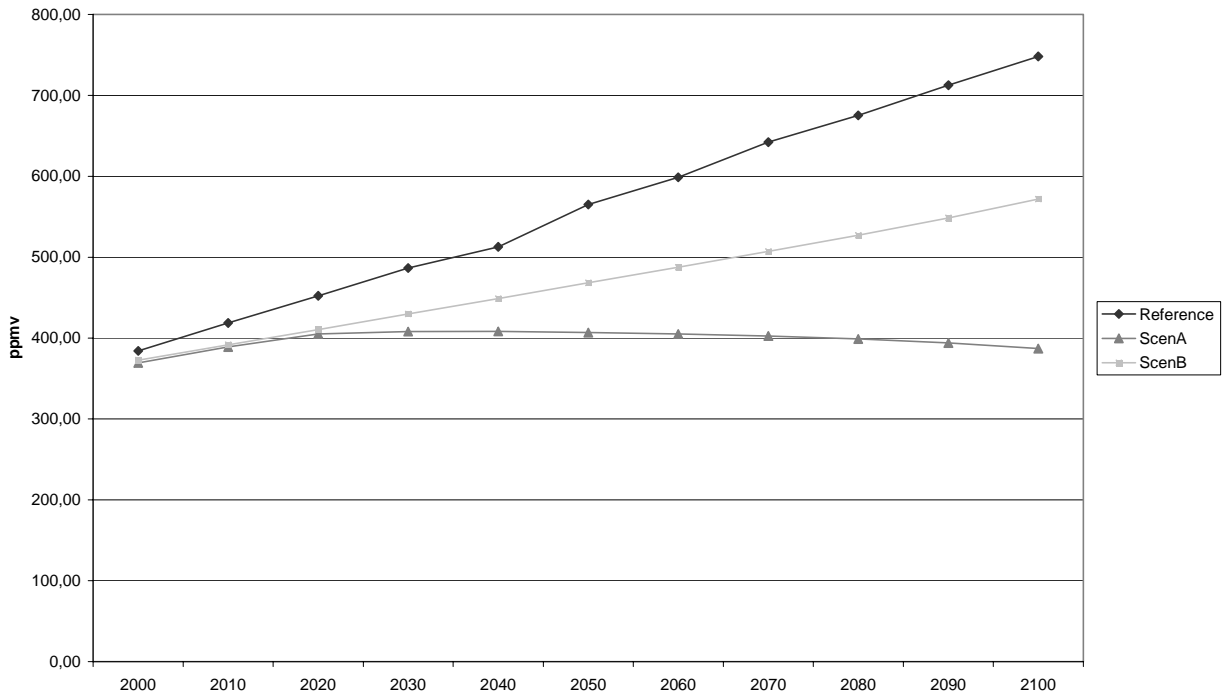


Figure 12. Greenhouse gas concentrations of different scenarios (in ppm CO2)

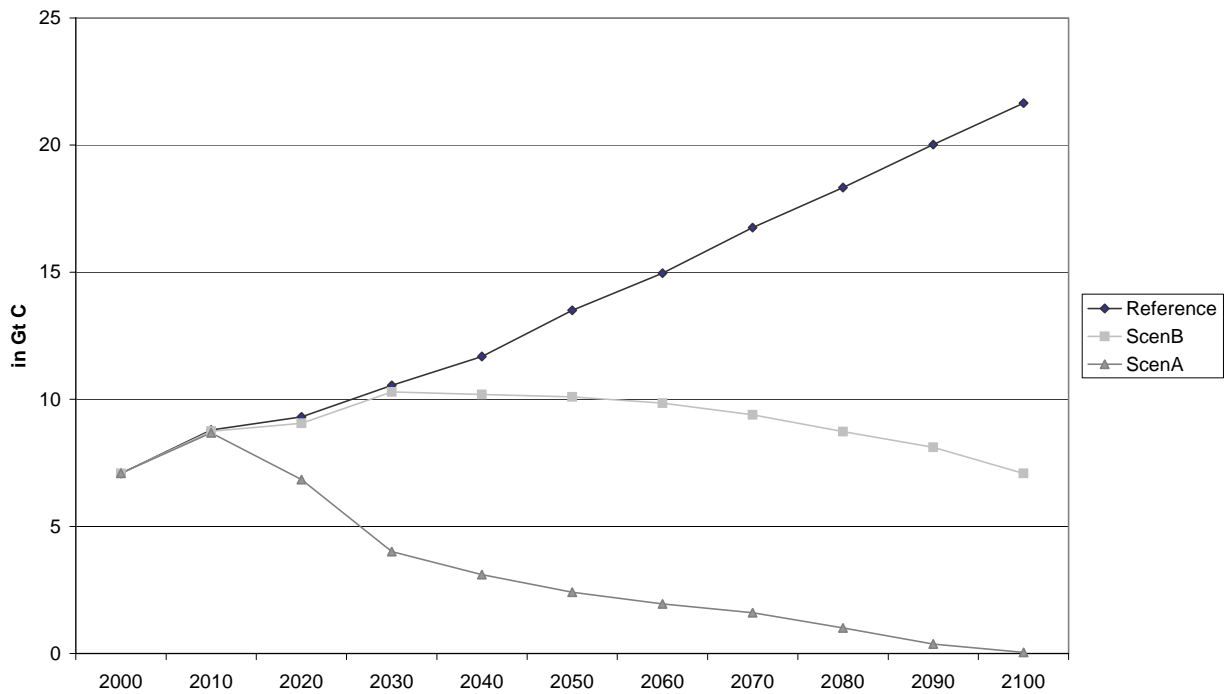


Figure 13: Carbon dioxide emissions development in Gt

In ScenA, we assume that a temperature limit of 2°C is met (assuming a climate sensitivity of 2.8°C). This implies that emissions need to be reduced considerably in comparison to the reference scenario. In the reference scenario, emissions reach a concentration of about 750 ppm (CO2 equiv.), which is transformed into a temperature increase of 4.3 °C in 2100 (Figure 11 and Figure 13). In order to avoid a temperature increase of more than 2°C, emission concentration need to be reduced by about 45 percent to a level of slightly over 400 ppm in 2100 (CO2). Assuming lower climate

sensitivity, a higher emissions concentration (slightly less than 600 ppm) is possible in accordance with the 2°C target). Reversely, with higher climate sensitivity more severe emissions cuts are necessary to reach the 2°C target. The CO2 concentration would need to come down to less than 400 ppm compared to 750 ppm in the baseline.

It turns out that in ScenB avoiding global warming of more than 2°C cannot be fulfilled at all as climate protection in form of concrete emission reduction starts too late (2030). In order to avoid a temperature increase of more than 2°C, we have to incorporate induced technological developments. This means that we implement a scenario where we explicitly allow technological innovations, i.e. energy efficient and cheap technologies. In the other scenarios, we also include technological innovations (exogenous and endogenous) but not in that large extend. But even with the inclusion of induced technological development, warming exceeds the temperature limit of 2°C if climate policy starts in 2030. Even with the assumption of low climate sensitivity in ScenB, the temperature target of 2°C cannot be met.

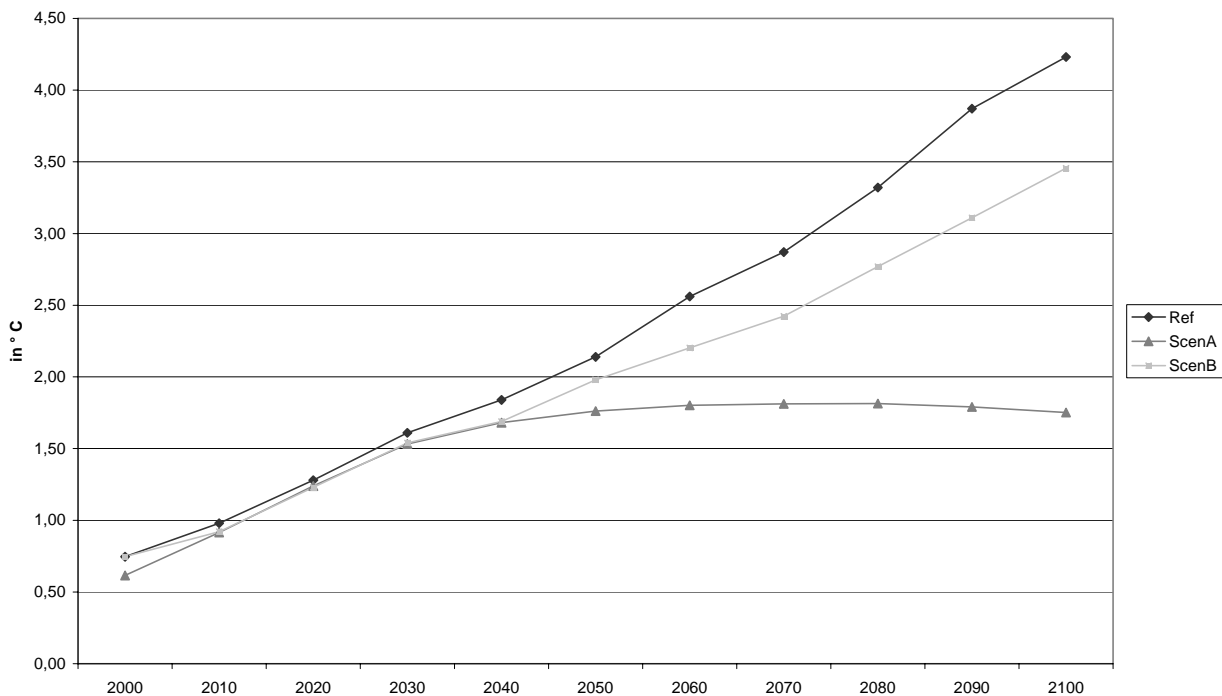


Figure 14 Temperature development of different scenarios (in °C)¹¹

We report the total costs as the sum of mitigation costs (as a result of a climate policy) and the damage costs (Figure 14). The damage costs, or costs of inaction, refer to the damages that occur as a result of the temperature increase (Figure 13) and the corresponding emissions concentration (that is, including ancillary costs e.g. due to air-pollution). It shall be noted that even the target of limiting the temperature increase to 2°C above pre-industrial levels (ScenA) will still result in damage costs i.e. in costs related to damages that occur at a temperature increase of 2°C. In the reference scenario where no mitigation action is taken costs solely relate to damage costs.

Total costs, i.e. the sum of mitigation costs and damages costs¹², are substantially lower in ScenA than in ScenB. Because climate policies start early, mitigation costs are initially higher in ScenA than in ScenB. Interestingly, however, despite a much later start of climate mitigation policies in ScenB, the costs of action are almost identical in terms of

¹¹ In scenario A, the temperature target is 2°C in 2100, some decline below 2°C is because of terminal conditions of the model in 2100.

¹² Mitigation costs assess all economic costs to reach the emissions targets, i.e. production declines or substitution costs towards another technology. We compute these costs as shadow costs of emissions reduction measured in percentage of GDP. Damage costs cover all impacts due to climate change.

percentage GDP losses in the two time periods 2050 and 2100. This is because, in ScenB, more drastic measures need to take place after 2030, which overcompensate reduced mitigation costs in the time before 2030. As in ScenB emission mitigation starts late and the temperature target of 2°C cannot be reached by 2100, damages are much higher than in ScenA, especially in later time periods (2100). This results in higher total costs for ScenB.

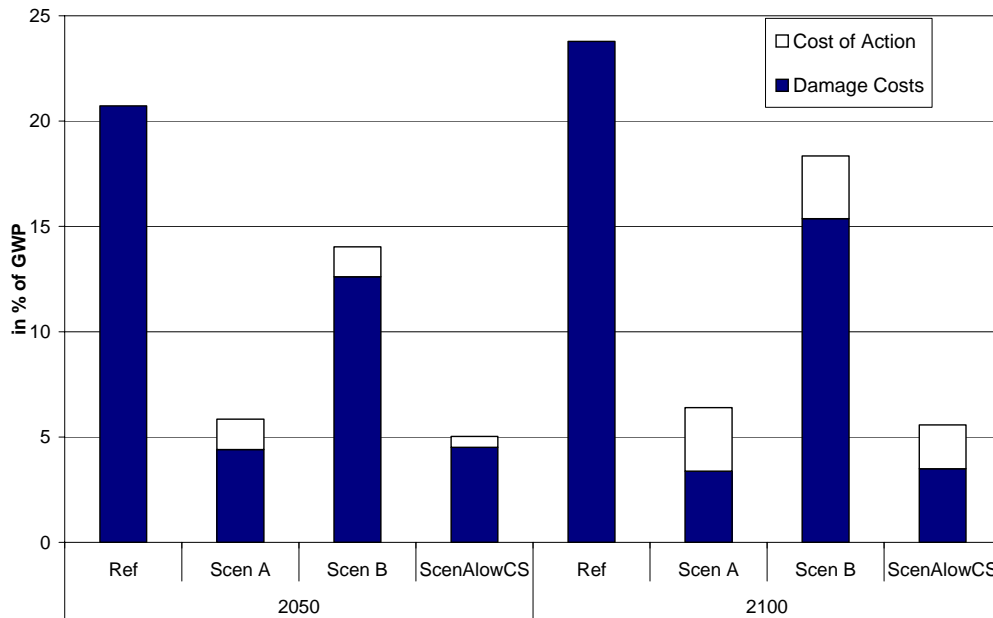


Figure 15. Total costs as sum of costs of action (mitigation costs) and damage costs in 2050 and in 2100

Figure 15 shows the damages avoided in ScenA and ScenB compared to the reference scenario. Both ScenA and ScenB result in lower emissions concentration and temperature increase than the reference scenario. Thus, both policy scenarios provide benefits in terms of avoided damages. As the temperature target of 2°C is met in ScenA and the corresponding emissions concentration is substantially lower, the avoided damages are much higher in ScenA than in ScenB.

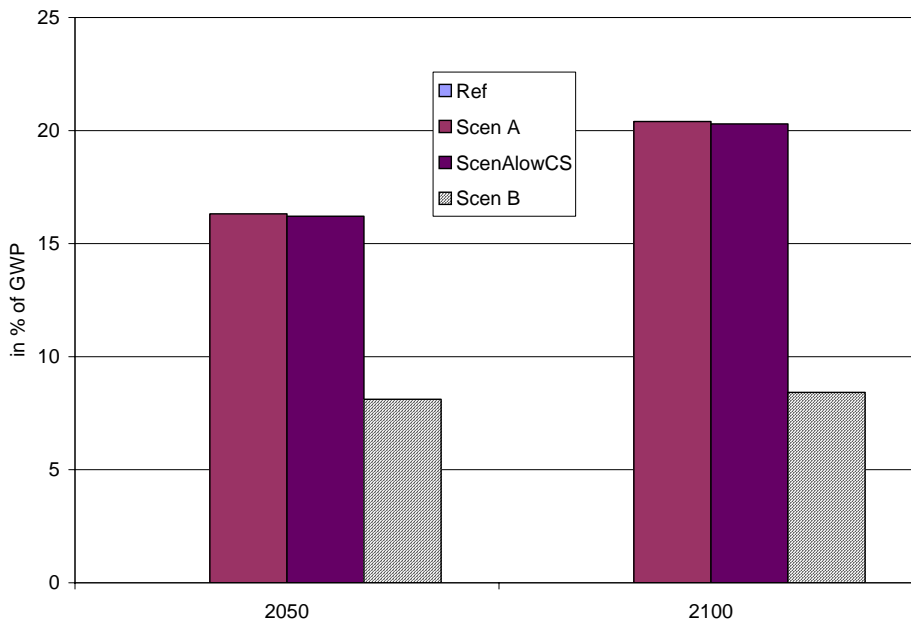


Figure 16. Avoided damages compared to the reference scenario

The net effects compared to the reference scenario, i.e. the difference of avoided damages (compared to the reference case) and mitigation costs are shown in terms of percentage changes of gross world product (GWP) in Figure 16. We see the net gain the policy scenarios induce compared to the reference scenario. ScenA leads to higher positive effects in terms of gross world product (GWP) than Scen B, compared to the reference scenario because the avoided damages are higher and mitigation costs are almost identical.

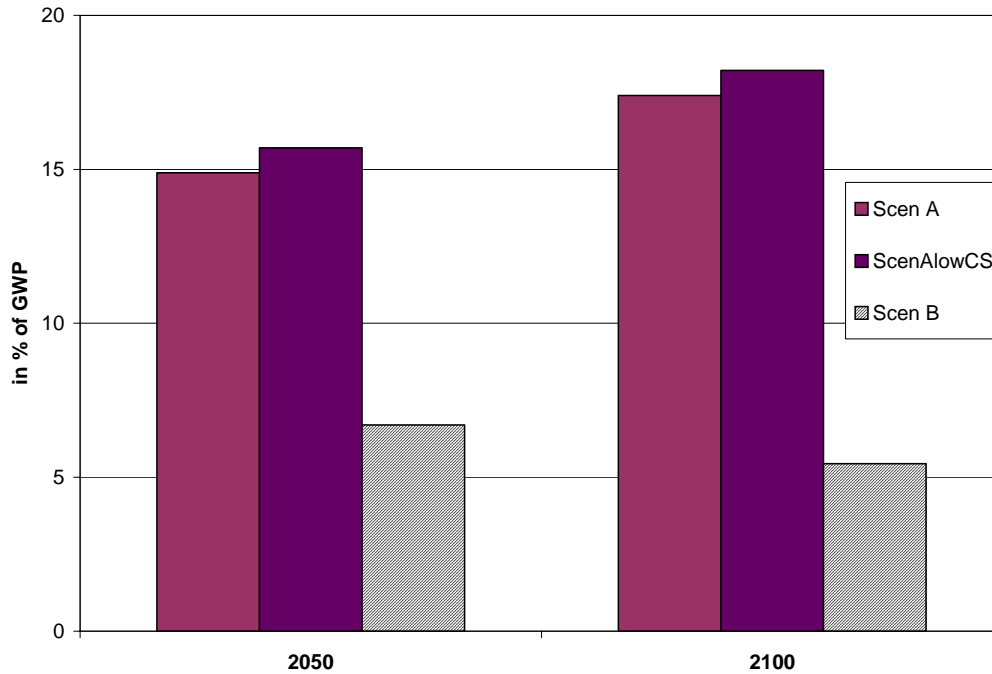


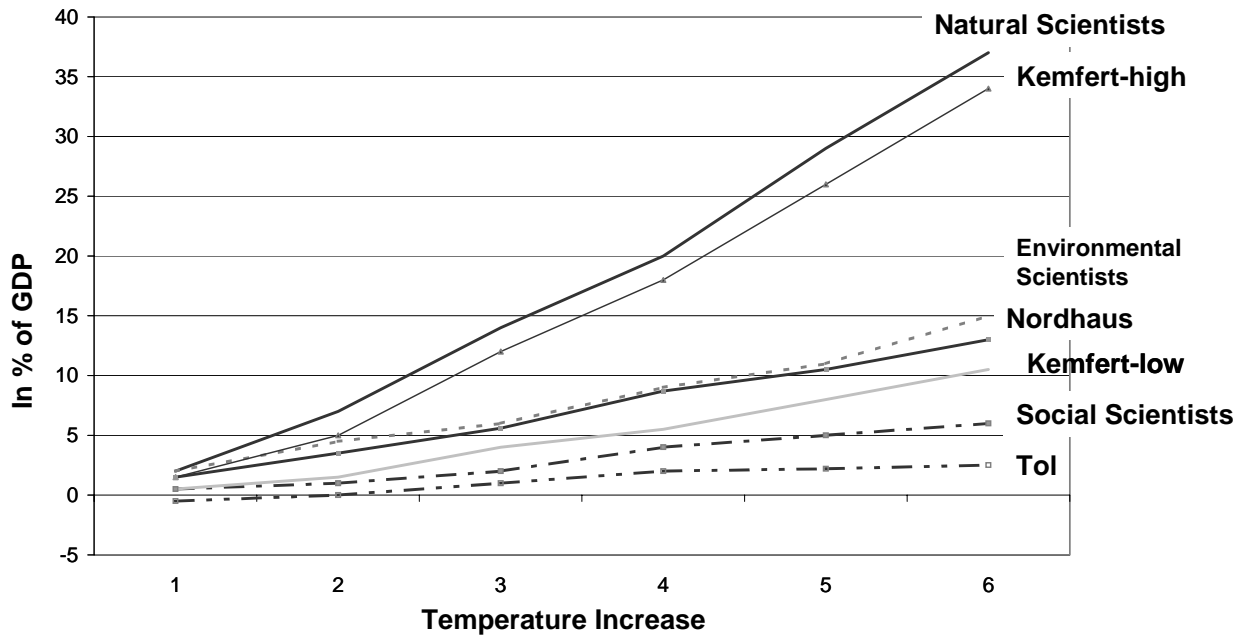
Figure 17. Net effects compared to reference case as difference of avoided damages and mitigation costs

If we assume a lower climate sensitivity (ScenA lowCS), a higher greenhouse gas concentration, and thus higher emissions, would be possible in order to meet the 2°C temperature target. This would lead to lower mitigation costs and, thus, lower total costs. At the same time, avoided damages would be slightly lower than in ScenA as the same temperature target is reached at a higher corresponding level of greenhouse gas emissions and thus damages are higher with the lower climate sensitivity.¹³ The net effect, i.e. the difference between avoided damages and mitigation costs, would be higher than for higher climate sensitivity, as the reduction in mitigation costs overcompensates the slight reduction of benefits (i.e. avoided damages).

Global damages in the reference case reach 20 to 23 percentage of global GWP in 2050 and 2100, respectively. In the spectrum of previous results (Figure 17) these results lie within the area of environmental and natural scientists. In comparison to previous studies (i.e. IPCC 2001 and Weyant 1999), we estimate higher damages than other economic studies. In this study we cover a full economic CGE model linked with a climate model that is able to assess dynamic impacts (economic growth, trade) but also monetise damages of climate change. The costs of action (mitigation costs) estimations lie well within the range of earlier studies (Weyant 1999).

Our damage assessment differs substantially from previous findings (Nordhaus (1991), Cline (1992) or Tol (2002, 2004)). This is because of two main reasons. First; we apply a fundamentally different global economic approach than

¹³ Higher damages occur because ancillary benefits are lower. Ancillary benefits are related to the emissions level and not to the change in temperature. Thus, with a lower climate sensitivity and correspondingly higher emissions ancillary benefits decrease even though temperature related damages remain the same.



Source: OECD (2003) with own additions

Figure 18 Damage assessments of different science perspectives ¹⁴

Tol (2002) applies in his cost assessment study. We use a global general equilibrium approach that covers interregional and intersectoral trade effects, he uses much simpler approach that neglects the interregional trade effects. The model applies a recursive dynamic approach so that we cover feedback effects from damages or other shocks. Second, we include a much more detailed climate model that assesses the temperature changes from emissions development (Kemfert 2002). We find that the dynamic feedback effects from the climate and the economic system cause much higher damage costs as earlier studies. In addition to the pure economic income effects we cover economic shocks due to adaptation. Countries spend a certain amount on adaptation when climate change occurs.¹⁵ These expenditures are crowding out investments that cannot be spent as previously intended in a growth model. We find that these effects have an additional major impacts on economic development.

In contrast to Nordhaus and Cline we apply regionally different damages function that are based, however, on the global temperature change. Damages occur basically because of three main issues: First, the global temperature change which is caused by energy related and non-energy related emissions, second, the regional population change and third the economic performance, the economic income change of a region. So, not only regions with a high economic performance but also with high population growth are affected by climate change if the global temperature changes. In comparison to other studies, higher economic damages have three reasons: the dynamic modelling approach with interregional and intersectoral feedback effects, the detailed climate system that is affected by the emissions coming from the economic performances and sectoral disaggregation of damage functions instead of adding one damage function into the model. The total effects differ from many economic studies but not from earlier studies of natural scientists. Figure 18 illustrates the individual damages in percentage of GDP: ecological impacts have the highest impact

¹⁴ RICE-99 is an Integrated Assessment model that combines a simplified economy-growth model with a climate model and assumes a global damage function for the world developed by William Nordhaus. The model has been modified over time, RICE-99 refers to the version of 1999 (Nordhaus und Boyer 2000)

¹⁵ If climate change is reduced (by for example reduced emissions), countries spend less percentage of investments for adaptation.

as well as health and mortality. In this study, this is especially the case because of the relationship between income changes and population (health) and temperature and population (mortality). With increasing temperature energy demand for cooling increases.

Tol (2002) finds total world damages within the range of 6-9 % of world GDP (sum of all regions). These damages differ widely between regions. The regional disparities of damages occur because of population development and economic performances. Our model approach takes the same assumptions about the relationship between global surface temperature, population development and economic performances. However, as we cover dynamic feedback effects the total impacts are higher, here in the range up to 20 % of global GDP. For example, high-developed nations such as Europe, USA and Japan heavily depend on international trade.¹⁶ If these nations have to divert expenditures to climate impacts and adaptation, these investments are not available to be spent in other sectors. As the model covers the dynamic growth effects and trade effects, economic losses are higher. Especially fast growing nations such as China have to accept welfare losses if climate change occurs.

Conclusion

Increased greenhouse gas emission cause climate change. The share of human induced climate change increase in the future. Past economic damages can hardly be purely attributed to increased greenhouse gas emissions. Primary factors for increased economic damages are increased population, wealth and migration to vulnerable regions. However, especially the extreme climate events of the past years give an indication of first impacts through man made climate change. As increase of future greenhouse gas emissions significantly increase the number and intensity of extreme climate events. If no emissions reduction take place, economic damages increase by factor 10. Because of that, we need concrete climate policy strategies to reduce greenhouse gas emissions and an increase of expenditures in research and development for alternative energies.

We conclude with the following two statements:

1. Only with early emission reduction warming beyond the limit of 2°C can be avoided. Even drastic emissions reduction efforts starting at a later point of time (2030) will not be sufficient to stay within the 2°C limit.
2. Damages from climate change are lower if the 2°C temperature limit is met. The costs of action are substantial. However, the avoided damage costs are even higher than the costs of action.

¹⁶Trade in goods account for more than 35 % of GDP (PPP)

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Appendix I: Detailed Description of WIAGEM

By coupling the economic and climate impact part of WIAGEM with the detailed climate module ICM, we consider the relationship between man-made emissions and atmospheric concentrations and their resulting impact on temperature and sea level. We cover classes of atmospheric greenhouse gas stocks with different atmospheric lifetimes (modelled by the impulse response function) and reduced forms of the carbon cycle model developed by Maier-Reimer and Hasselmann (1987) and applied by Hooss (2001). Energy and non-energy related emissions of CO₂, CH₄ and N₂O as well as those of halocarbons and SF₆ alter the concentrations of these substances which in turn influence radioactive forcing.

As a result, the multi-gas climate model ICM was obtained that takes into account all important greenhouse gases (carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, sulphur hexafluoride, tropospheric and stratospheric ozone, and stratospheric water vapour) and aerosols by modelling their dynamic atmospheric behaviour as well as the radiative forcing originating from changes in the concentration of the respective substances.

ICM is driven by time-dependent paths of the anthropogenic emissions of CO₂, CH₄, N₂O, halocarbons, SF₆ and SO₂. In WIAGEM total anthropogenic emissions are determined by:

$$TOTEM_{r,t} = E_{r,t} + NonE_{r,t} - S_{r,t}$$

with TOTEM indicating the total anthropogenic emissions per region and time period, E_{r,t} as regional emissions per time period. Non-energy related emissions are countered for each greenhouse gas, regional and time period. Sinks (S_{r,t}) reduce total emissions.¹⁷

The atmospheric concentration of greenhouse gases may be altered due to direct emissions, exchange with reservoirs (e.g., ocean, biosphere, pedosphere) and chemical reactions (destruction or formation). The biogeochemical submodules of ICM take into account these different processes in a greenhouse gas-specific manner. In general, the modules are reduced-form models of complex two- or three- dimensional greenhouse gas cycles or atmospheric chemistry models and are calibrated with respect to historical concentration records.

The carbon cycle module (see Appendix I) developed at the Max-Planck Institute for Meteorology in Hamburg consists of (a) a differential impulse-response representation of the 3 dimensional Hamburg Model of the Ocean Carbon Cycle (HAMOCC), extended into the non-linear high-CO₂ domain by explicit treatment of the chemistry governing the CO₂ uptake through the ocean surface, and (b) a simple non-linear impulse response model of the terrestrial biosphere's CO₂ fertilization. Applying an inverse calibration technique, the quantitatively unknown CO₂-fertilization factor has been adjusted in order to give a balanced 1980s mean budget as advised by the IPCC inter- model comparison exercise.

Various components of the MAGICC model (Wigley, 1988; Wigley and Raper, 1992; Wigley, 1994; Osborn and Wigley, 1994; Wigley et al., 1996, Harvey et al., 1997) were adopted in order to simulate the atmospheric chemistry of major non-CO₂ greenhouse gases.

Changes in the concentration of non-CO₂ greenhouse gases (CH₄, N₂O, halocarbons, and SF₆) are calculated by a simple one-box model approach according to

$$\frac{dC(t)}{dt} = \frac{1}{b} \sum_r TOTEM_r - \frac{1}{\tau} (C - C_{pre-industrial})$$

¹⁷ This means also that the emissions reductions targets are reduced.

where b is a concentration-to-mass conversion factor and τ is the lifetime of the greenhouse gas. For N_2O , halocarbons and SF_6 , the lifetime is assumed to be constant (IPCC, 1996; Harvey et al., 1997). CH_4 is removed from the atmosphere by soil uptake and chemical reactions with OH. The lifetime of CH_4 takes into account both processes and as the OH concentration itself is influenced by CH_4 , the lifetime attributed to chemical processes is modelled to be dependent on the CH_4 concentration according to Osborn and Wigley, 1994).

The atmospheric concentration of different greenhouse gases has the following impact on radiative forcing (IPCC, 1990):

$$\Delta F_{CO_2} = 6.3 \ln\left(\frac{CO_2}{CO_{2_0}}\right)$$

$$\Delta F_{CH_4} = 0.036(CH_4^{0.5} - CH_{4_0}^{0.5}) - f(CH_4, N_2O) + f(CH_{4_0}, N_{2O_0})$$

$$\Delta F_{N_2O} = 0.14(N_2O^{0.5} - N_{2O_0}^{0.5}) - f(CH_4, N_2O) + f(CH_{4_0}, N_{2O_0})$$

with ΔF measured in Wm^{-2} , concentrations for CH_4 and N_2O given in ppbv and the subscript 0 used to indicate pre-industrial concentrations. . The CH_4 - N_2O interaction term (expressed in Wm^{-2}) is determined by:

$$f(CH_4, N_2O) = 0.47 \ln\left[1 + 2.01 \cdot 10^{-5} \cdot (CH_4 \cdot N_2O)^{0.75} + 5.31 \cdot 10^{-15} \cdot CH_4 \cdot (CH_4 \cdot N_2O)^{1.52}\right]$$

where CH_4 and N_2O have to be replaced by actual CH_4 and N_2O concentrations or alternatively by their respective pre-industrial levels as expressed in equations 3 and 4.

Total radiative forcing F can be approximated (IPCC, 2001, p. 355) by adding each greenhouse gas radiative forcing effect. In addition to the components just described, the radiative forcing description in ICM takes into account the contributions from SF_6 , tropospheric ozone and stratospheric water vapour (both dependent on CH_4 concentrations), aerosols, and halocarbons including indirect effects according to stratospheric ozone depletion.

The time evolution of the global annual mean surface air temperature is calculated according to the impulse response function approach used in NICCS. A detailed description of this component can be found in Hooss (2001), Hooss et al. (2001), Bruckner et al. (2003), Joos et al. (2001), and Meyer et al. (1999). In order to include the radiative forcing of non CO_2 -greenhouse gases, the carbon dioxide concentration used in NICCS is to be replaced by the equivalent carbon dioxide concentration (measured in ppm) defined by IPCC (1996a, p.320):

$$C_{Equiv} = 278 ppm \cdot \exp\left(-\frac{\Delta F}{6.3 \frac{W}{m^2}}\right)$$

Aggregated impacts of climate change are evaluated by:

We follow the approach of Tol (2001) for economic impact assessment of ecosystem changes:

$$E_{t,r} = \alpha \frac{y_{t,r}}{y_{1990,r}} P_{t,r} \frac{y_{t,r}/y_b}{1 + y_{t,r}/y_b} \quad (3.9)$$

with E as the value of the loss of ecosystems and y the per capita income and P as population size. α and y_b are parameter ($\alpha = 0.5$, $y_b = \$20.000$).

Impact assessment of vector borne diseases are determined by:

$$m_{r,t} = \alpha_r T_t^\beta \left(\frac{y_c - y_{t,r}}{y_c - y_{base,r}} \right)^\gamma \quad (3.10)$$

$$\perp y_{t,r} \geq y_c$$

with m representing mortality, and α , γ and y_c denoting parameter ($\alpha= 1$ (0.5-1.5), $\gamma= 1$ (0.5-1.5), $y_c= \$3100$ (2100-4100)).

Furthermore, mortality due to changes in global warming are measured:

$$\Delta M = \alpha + \beta T_b \quad (3.11)$$

Where ΔM denotes the change in mortality due to a one degree increase in global warming, T_b as current temperature and α and β are parameter.

Furthermore, we take into account Tol's approach to determine demand for space heating (SH) and space cooling energy (SC):

$$SH_{t,r} = a_r T_t^\beta \left(\frac{y_{t,r}}{y_{t,1990}} \right)^\epsilon \left(\frac{P_{t,r}}{P_{t,1990}} \right) \prod_{s=1990}^t EP_{s,r} \quad (3.12)$$

$$SC_{t,r} = a_r T_t^\beta \left(\frac{y_{t,r}}{y_{t,1990}} \right)^\epsilon \left(\frac{P_{t,r}}{P_{t,1990}} \right) \prod_{s=1990}^t EP_{s,r} \quad (3.13)$$

Total damages are assessed by the following relation:

$$\Delta DAM_t^r = \alpha_t^r \cdot (\Delta P T_t^\beta \cdot \frac{y_t^r}{y_0^r}) + PC_t^r \quad (3.14)$$

ICM estimates the climatic changes due to greenhouse gas emissions and the impact modules estimates the corresponding impacts. Market and non-market damages associated with these impacts, are assessed by coupling the climate module of ICM with WIAGEM. We express impacts as changes to regional and global welfare and GDP.

Mathematically the carbon cycle model containing all differential equations can be described as follows:

$$c_1 = D(c_1) \cdot \left\{ e - \frac{n_2}{h_s} c_s(c_1) + \frac{n_2}{h_2} c_2 - (b_3 + b_4) B(c_1) + \frac{1}{\tau_{B3}} c_{B3} + \frac{1}{\tau_{B4}} c_{B4} \right\}$$

$$c_2 = \frac{\eta_2}{h_s} c_s(c_1) - \frac{\eta_2 + \eta_3}{h_2} c_2 + \frac{\eta_3}{h_3} c_3$$

$$c_3 = \frac{\eta_3}{h_2} c_2 - \frac{\eta_3 + \eta_4}{h_3} c_3 + \frac{\eta_4}{h_4} c_4$$

$$c_4 = \frac{\eta^4}{h_3} c_3 - \frac{\eta^4}{h_4} c_4$$

$$c_{Bc} = A(c_1) \cdot c_1$$

$$c_{B3} = b_3 \cdot B(c_1) - \frac{CB3}{\tau_{B3}}$$

$$c_{B4} = b_4 \cdot B(c_1) - \frac{CB4}{\tau_{B4}}$$

with:

t	Simulation time
x	Spatial coordinates
s	Season index
e	Anthropogenic CO ₂ emissions
C_{CO2}	Atmospheric CO ₂ concentration (by volume)
$C_{CO2, equiv}$	Atmospheric equivalent CO ₂ concentration
$C_{CO2, pre}$	Pre-industrial CO ₂ concentration
c_a	Anthropogenic carbon in the atmosphere (in GtC)
c_s	Anthropogenic carbon in the oceanic mixed layer
c_j	Anthropogenic carbon in the j th oceanic layer
c_l	Anthropogenic carbon in the composite layer
q_j	Carbon flux from layer $j - 1$ into layer j
c_B	Anthropogenic carbon allocated by the land vegetation
c_{Bi}	Anthropogenic carbon in land biosphere reservoir i
c_{Bc}	Short-term anthropogenic carbon in land biosphere
$B(c_l)$	Nonlinear auxiliary function (= additional NPP)
$A(c_l), D(c_l)$	Nonlinear auxiliary functions
T	Near-surface temperature change (relative to pre-industrial level)
CC	Cloud-cover change (relative to pre-industrial level)
P	Precipitation change (relative to pre-industrial level)
H	Humidity change (relative to pre-industrial level)
SLR	Sea-level rise (relative to pre-industrial level)
PC	Principal component
EOF	Empirical orthogonal function

**PERSPECTIVES ON FOCUSED WORKSHOP QUESTIONS
REGARDING PAST ECONOMIC IMPACTS OF STORMS OR FLOODS**

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1. According to research currently available, what factors account for the increased costs of disasters in recent decades?

a. Hurricanes

For the case of U.S. landfalling hurricanes, Pielke and Landsea (1998) make a strong case that societal factors such as increasing population in coastal areas affected by hurricanes, increases in value of structures in those areas, and inflation are the key drivers of increased economic damages from hurricanes in recent decades. In contrast, changes in U.S. landfalling hurricane climate appear to play a more minor role. A recent key analysis on the latter influence is Landsea's (2005) U.S. Power Dissipation Index (PDI) for landfalling tropical cyclones (TCs) since 1900, updated through 2005 (Fig. 1). This TC climate metric shows no strong evidence for an upward trend during the 20th century, although 2004 and 2005 appear as strong outliers at the end of the series. Landsea (2005) comments that 1886, although not shown on the figure, is estimated to be comparable to 2004 and 2005, again emphasizing the limited evidence for a long-term trend in this metric at this time.

The absence of a strong trend is noteworthy given indications of a century-scale SST warming trend in the tropical Atlantic Main Development Region (e.g., Fig. 2, see also Knutson et al., 2006), and of possible SST-correlated upward trends in Atlantic *basin-wide* TC counts and storm maximum PDI (Figs. 3 and 4, Emanuel 2006). Interestingly, the U.S. landfalling PDI also does not clearly show the pronounced multi-decadal modulation seen in the basin-wide Atlantic PDI (Fig. 5) and major hurricane counts (not shown) since the late 1940s. Although the current "active era" of Atlantic hurricane activity apparently began in 1995, only during 2004 and 2005 did the U.S. landfalling PDI reach or exceed the strong levels that occurred several times in the first half of the 20th century (Fig. 1).

Thus, while there is debate about whether there is a century-scale trend in various Atlantic basin-wide TC measures (e.g., Emanuel 2006; Landsea, personal communication 2006), there does not appear to be any real debate about the lack of trend to date in U.S. landfalling PDI statistics. A key question to resolve is why this is the case. Emanuel (2005b) raises a fair point that U.S. landfalling storms are only a small fraction of all Atlantic hurricanes so that a basin wide index is based on about 100 times more data than the U.S. landfalling PDI. This means that the failure to see a trend in the U.S. landfalling PDI may be a signal to noise issue, with a possible underlying trend masked by the high noise levels and limited sample size for U.S. PDI. On the other hand, the sensitivity of hurricane intensity to sea surface warming implied in the Emanuel (2005a) results exceeds by a factor of 6 the sensitivity inferred from the Knutson and Tuleya's (2004) idealized hurricane modeling study, which found a sensitivity of about 4% per degree Celsius SST increase. In a recent examination of Atlantic potential intensity data since about 1980, the discrepancy with our modeling work appears to be about a factor of 4, and that discrepancy might be partly attributable to a general reduction of surface wind speeds in the basin over time (Emanuel 2006).

In summary, in attributing the sharp rise in U.S. hurricane damages to various factors, the U.S. landfalling PDI results do not support a clear role for century-scale climate change in the observed damage trend.

b. Floods

Concerning possible trends in damaging floods, Milly et al. (2002) tentatively detected an upward trend (Fig. 6) in the global frequency of "great floods" (100-year floods on river basins larger than 200,000 km²). In their climate-model-based estimates of sensitivity of great-flood rates to an idealized quadrupling of atmospheric CO₂, the most sensitive regions were in the high latitudes and the tropics (Fig. 7). Milly et al. (2005) presented evidence that the global pattern of 20th-century trends in mean annual streamflow was partially controlled by forced climate change, although trends in any single region generally could be explained by internal variability. The latter study lends some credibility to climate models' retrospective and prospective estimates of flood risk.

Groisman et al. (2005) present evidence for increasing occurrence of intense precipitation events (upper 0.3%) for many extratropical regions, but they note that it is difficult to relate the changes in very heavy precipitation directly to changes in flooding. Knutson and Tuleya's (2004) simulations of hurricanes under CO₂-warmed climate conditions, with a 20% increase in storm core rainfall for a 1.75°C SST warming, suggests the possibility of a future trend in hurricane-related precipitation rates. Groisman et al. (2004) report that no change can be detected at this time in hurricane-related precipitation along the southeast coast of the U.S. However, they did not assess whether the *per storm* precipitation has changed. Local precipitation totals from hurricanes are strongly influenced by the storm translation speed as well as storm-relative precipitation rates.

Pielke and Downton (2000) find that both precipitation increases and societal factors (population and wealth) have contributed to the increase in U.S. flood damages in recent decades. They found that 2-day heavy rainfall events and the number of wet days were two climate statistics that were more closely linked to flood damage than other measures they examined. They noted a trend, correlated to the increase in these precipitation measures, in damage per capita, but not in damage per unit wealth.

In summary, the analyses by Milly et al. and Pielke and Downton suggest that climate factors may be at least partially responsible for the observed increase in flood occurrence and flood damages in recent decades, although societal factors appear important.

2. What are the implications of these understandings, both for research and policy?

Societal factors (coastal population growth, increased development of more expensive infrastructure at the coast, etc.) have almost certainly been the key drivers of the strong, systematic rise in total U.S. hurricane damages over the past several decades. One implication of this is that research to understand these drivers and how to best reduce vulnerability to hurricane damage is a worthwhile undertaking. There is probably much "low-hanging fruit" to be harvested in this regard, if the goal is to reduce the aggregate amount of hurricane damage in the future, relative to a "business as usual" scenario. Consumers, businesses (e.g., insurers) and policymakers could benefit from such studies, particularly since wide-spread adoption of damage-reducing preventative measures will likely require proactive measures from these stakeholders.

The possibility of substantial long-term increases in historical PDI in several basins, including the Atlantic, and the possibility of even greater increases in the future imply that this topic also deserves considerable attention from the hurricane and climate research communities at this time. The lack of a long-term trend in U.S. landfalling TC statistics could reflect a signal-to-noise issue, as Emanuel (2005b) suggests, or could be indicative of greater data problems in the basin-wide statistics as compared to the U.S. landfalling TC statistics. In general, the causes of the differing behavior between all-basin and landfalling TCs need to be resolved.

Despite the evidence that societal factors have almost certainly been the key drivers of the sharp rise in total hurricane damages in the U.S. in recent decades, there is some ambiguity arising regarding the interpretation of the past two very damaging seasons. In addition, the (highly uncertain) future projections of increases in hurricane intensities and perhaps

other TC metrics imply that climate change could lead to additional damage potential for whatever coastal infrastructure exists at a given point in the future. For example, Emanuel (2005a) reports roughly a doubling of PDI accumulated over the Atlantic and Northwest Pacific basins in the last 30 years, associated with roughly an 0.5°C SST increase. If future PDI changes were to scale with future SST changes in that manner, it seems likely that a climate change signal in landfalling PDI will eventually emerge, even for the U.S. landfalling hurricanes, unless there is a strong mitigating effect from changes in storm tracks, or other factors. It is important to note that SST increases in the Atlantic during the 21st century are likely to be much more substantial, perhaps by a factor of four (e.g., Knutson and Tuleya 2004), than the warming that occurred in the 20th century. Future sea level rise, a process which apparently has a very long equilibration time scale (e.g. centuries to millennia) will almost certainly further exacerbate coastal flooding problems from a given hurricane to some degree, unless substantial damage mitigation steps are undertaken.

From a research perspective, the implications include the need for improved climate-quality monitoring and for improved historical and “paleoclimate-proxy” tropical cyclone data bases. These will provide better information for assessing future changes, and more reliable statistical assessments of past changes in hurricane activity, including land fall, in all basins. Specific examples include the need to reanalyze tropical cyclone data bases in all basins, and not just the Atlantic. Greater efforts should be made to provide researchers with access to original “raw” historical observations rather than derived quantities, concerning past tropical cyclones (Emanuel, personal communication). Aircraft reconnaissance of hurricanes in basins outside the Atlantic should be initiated or resumed. For example, aircraft reconnaissance was conducted in the NW Pacific basin beginning in the 1940s, but was discontinued in 1987. Aircraft reconnaissance would provide more reliable intensity estimates than are now possible using satellite-only methods. Another example is paleotempestology research, which attempts to use information in the geological record, such as overwash deposits in near coastal lakes, to infer pre-historic hurricane activity.

In general, hurricane-climate research is expected to progress most rapidly when a combination of theory, modeling, and observations are brought to bear on the problem.

Concerning policy implications, I’ll pass on the question, since giving recommendations on policy matters lies outside the realm of my responsibilities as a NOAA scientist.

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Figures

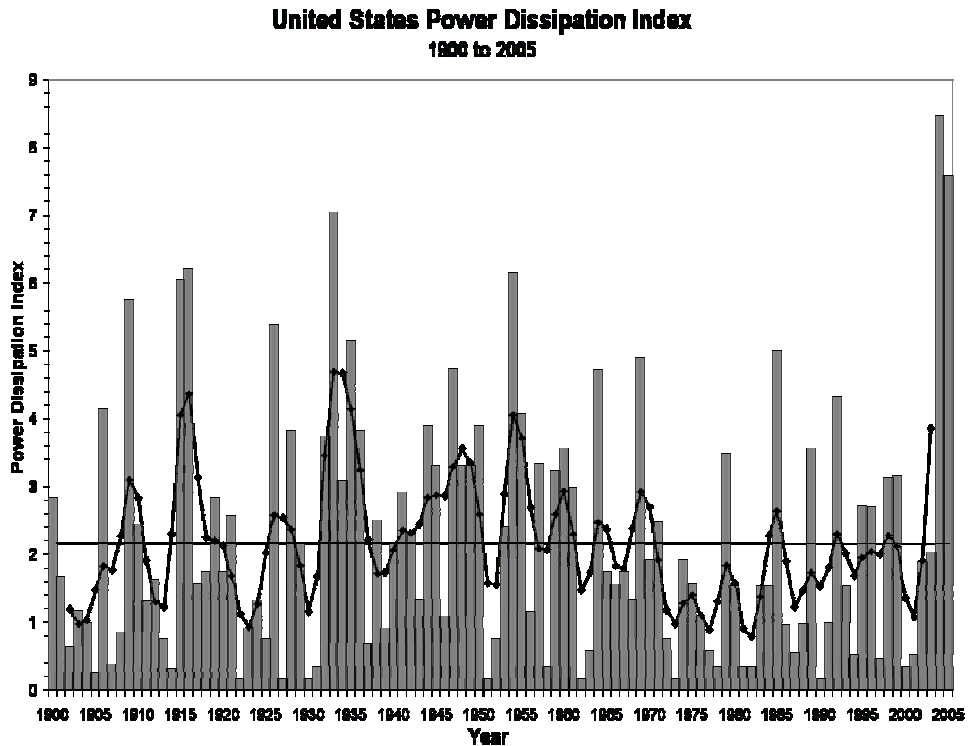


Fig. 1. Power Dissipation Index (PDI) for continental United States, 1900-2005 in units of m^3s^{-3} , multiplied by 10^{-5} . Based on all tropical storms, subtropical storms, and hurricanes at time of impact. Black curve smoothed with two passes of 1-2-1 filter. From Landsea (2005).

Atlantic Main Development Region (MDR) vs Global Temperature

10-yr running means; HadCRUT2; 80W-20W, 10N-20N; Ref to 1881-1920 mean

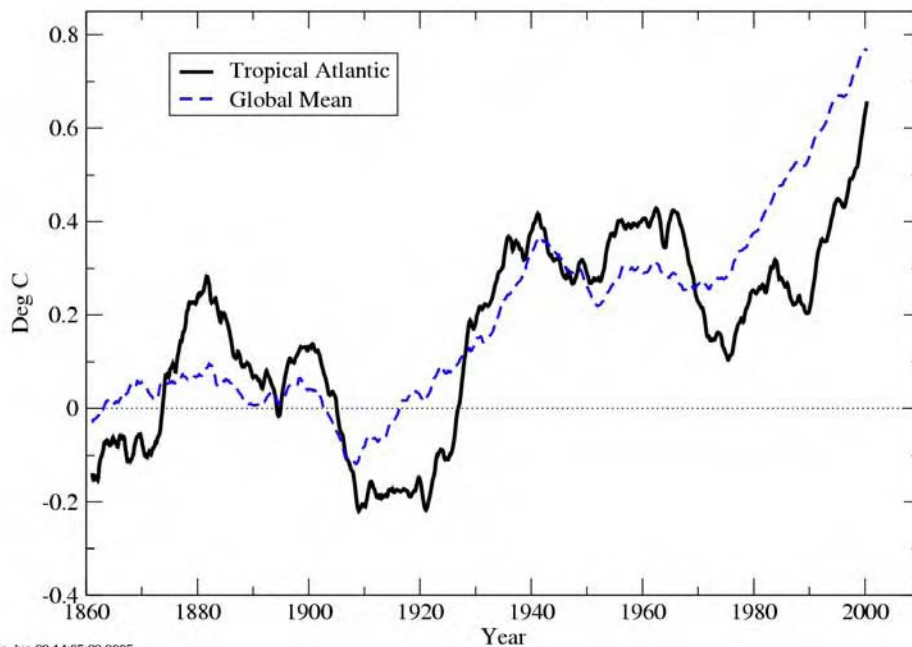


Fig. 2. Atlantic Main Development Region (MDR) surface temperature vs global mean surface temperature. MDR region defined as 80W-20W, 10N-20N. 10-yr running annual means, referenced to 1881-1920 are plotted.

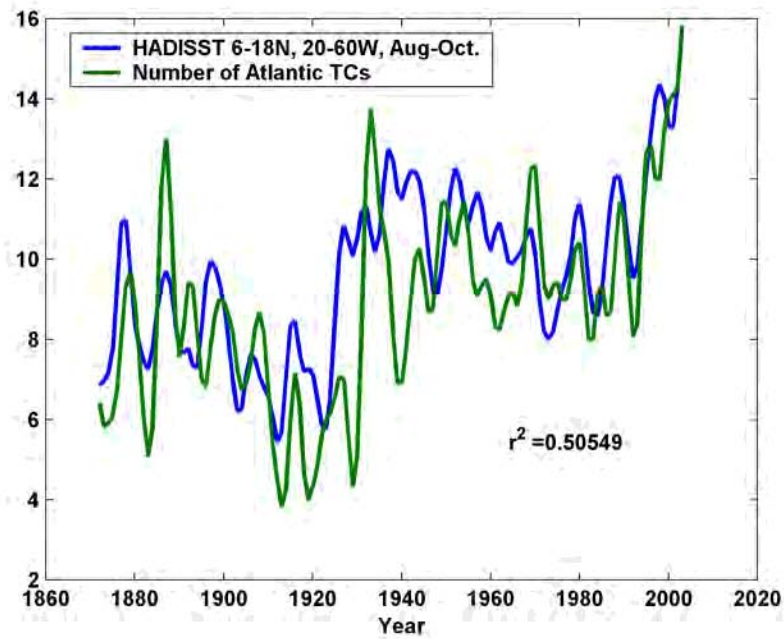


Fig. 3. Annual number of Atlantic tropical cyclones (smoothed) versus sea surface temperature (Aug. – Oct.) in the tropical Atlantic (6-18N, 20-60W). Source: Emanuel 2006.

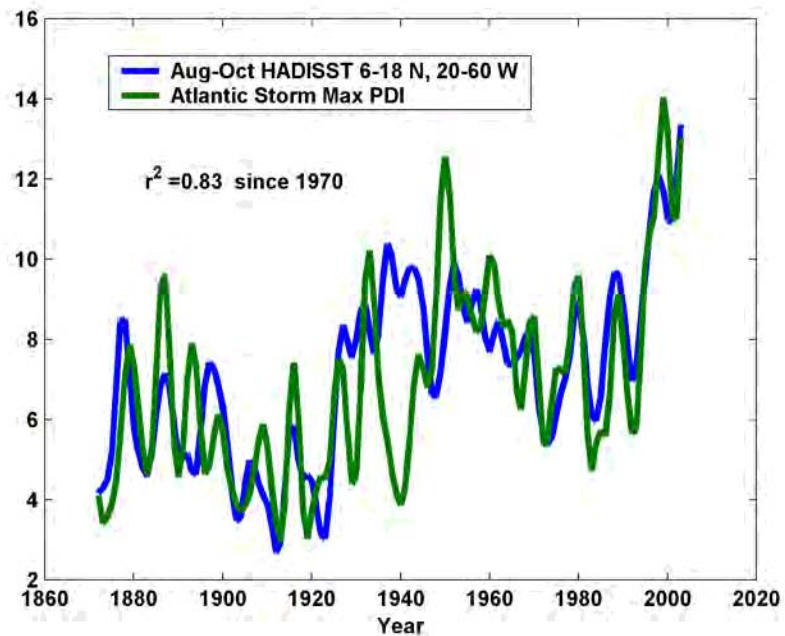


Fig. 4. Storm maximum power dissipation index (one value per storm) for the Atlantic basin versus sea surface temperature (Aug. – Oct.) in the tropical Atlantic (6-18N, 20-60W). Values scaled by arbitrary constants to show correlation of curves. Source: Emanuel 2006).

Atlantic Power Dissipation Index Original Data - 1949 to 2005

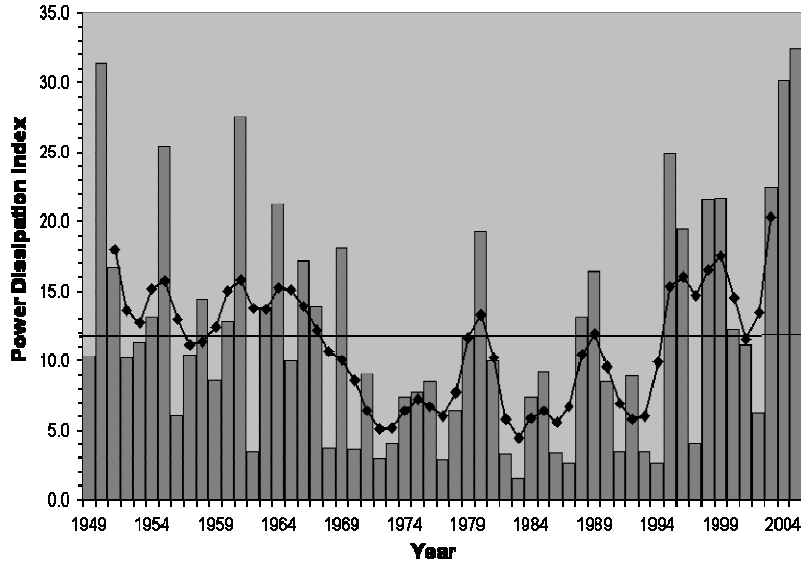


Fig. 5. Atlantic Power Dissipation Index (PDI) from Landsea (2005) using no correction of early period wind intensities, in contrast to Emanuel (2005). Values multiplied by 10^{-6} , in units of $\text{m}^3\text{sec}^{-3}$.

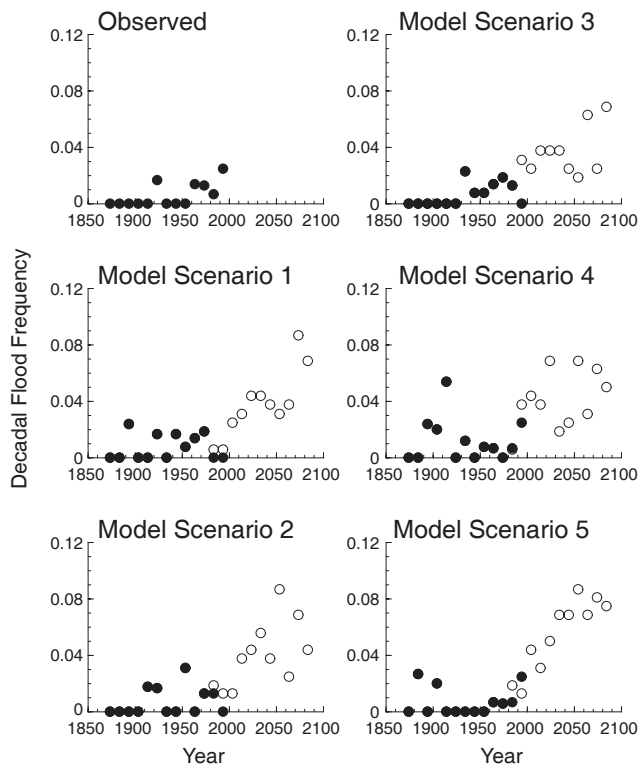


Fig. 6. Decadal extratropical flood frequencies for observations (upper left) and a series of climate model experiments with the GFDL R30 coupled climate model forced by historical estimates of greenhouse gases and direct effect of sulfate aerosols, with $+1\%/yr$ CO_2 forcing for post-2000. The flood frequency is defined as the number of events exceeding the 100-yr discharge divided by the number of station years of observations. In modeled output, filled circles are obtained with station starting and ending dates as in observations, while open circles are obtained with all stations continuing operation once begun. Source: Milly et al. 2002.

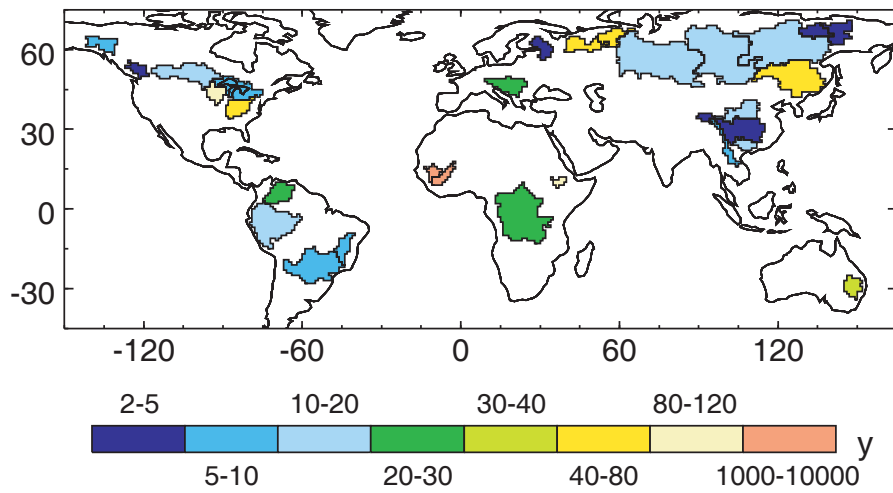


Fig. 7. Map showing gauged drainage areas and flood-risk sensitivities. Color indicates the modeled return period, under idealized CO₂ quadrupling, of the flood magnitude associated with a 100-year flood before the CO₂ increase. Source: Milly et al. 2002).

THE SEARCH FOR TRENDS IN A GLOBAL CATALOGUE OF NORMALIZED WEATHER-RELATED CATASTROPHE LOSSES

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Abstract

In order to evaluate potential trends in global natural catastrophe losses it is important to compensate for changes in asset values and exposures over time. A study has been undertaken to create a Global Normalized Catastrophe Catalogue covering weather-related catastrophe losses in the principal developed (Australia, Canada, Europe, Japan, South Korea, US) and developing (Caribbean, Central America, China, India, the Philippines) regions of the world. We have attempted to survey losses from 1950 to 2005 although data availability means that for many regions even for the largest events the record is incomplete before the 1970s. After 1970 when the global record becomes more comprehensive we find evidence of an annual upward trend for normalized losses of 2% per year) that corresponds with a period of rising global temperatures. However over this same period, in some regions, including Australia, India and the Philippines normalized losses have declined. The significance of the trend in global normalized losses is dominated by the affect of the 2004 and 2005 Atlantic hurricane seasons as well as by the bias in US wealth relative to other developing regions. What is presented here provides a short summary of the global results of this study. Full results are in course of publication also covering individual peril regions and the exploration of correlations with global temperatures.

Introduction

Economic losses attributed to natural disasters have increased from US \$75.5 billion in the 1960s to \$659.9 billion in the 1990s (a compound annual growth rate of 8%). Private sector data also shows rising insured losses over a similar period. Both reinsurers and some climate scientists have argued that these increases demonstrate a link between anthropogenically induced global warming and catastrophe losses. However, failing to adjust for time-variant economic factors yields loss amounts that are not directly comparable and a pronounced upward trend through time for purely economic reasons.

To allow for a comparison of losses over time many previous studies have adjusted past catastrophe losses to account for changes in monetary value in the form of inflation. However in most countries far larger changes have resulted from variations in wealth and the numbers and values of properties located in the path of the catastrophes. A full normalization of losses, which has been undertaken for the United States hurricane and flood, also includes the affect of changes in wealth and population to express losses in constant dollars. These previous national US assessments, as well as those for normalized Cuban hurricane losses, have failed to show an upward trend in losses over time, but this was before the remarkable hurricane losses of 2004 and 2005.

In order to assess global trends over time we set out to compile a database of normalized economic losses attributed to weather-related catastrophes from 1950 to 2005 from a large and representative sample of geographic regions. Regions were selected which had a reasonable centralization of catastrophe loss information as well as a broad range of peril types: tropical cyclone, extratropical cyclone, thunderstorm, hailstorm, wildfire and flood. The surveyed regions also span high and low latitude areas.

Although global in scope, this study does not cover all regions. We have, for example, not included losses from Africa

or South America; first because these continents are more affected by persistent climatological catastrophes (in particular drought) than sudden-onset weather-related catastrophes. Also the core economic loss data, in particular for much of Africa, is simply unavailable. However, the surveyed area includes the large majority of the world's asset exposure (and the majority of the population).

Methodology

We normalize losses to 2005 USD by adjusting for changes in wealth (GDP per capita in USD), inflation and population. This methodology is consistent with that used by Pielke and Landsea (1998) and is given below:

$$NL_{2005} = L_y * (W_{2005}/W_y) * (I_{2005}/I_y) * (P_{2005}/P_y),$$

where normalized losses in 2005 USD (NL2005) equal the product of losses in year y and the change ratios in wealth (W), inflation (I) and population (P). Where GDP per capita is expressed in nominal terms we omit the inflation multiplier.

Data

We researched and compiled the best available economic loss data from international agencies, national databases, insurance trade associations and reinsurers as well as RMS internal figures. Data quality varies by region. Table 1 indicates coverage by region and hazard type. The final column indicates our assessment of the reliability of the estimates. In cases where the quality of insured loss data exceeds that of economic losses we have estimated economic losses based upon insurance coverage ratios for the affected region and hazard type from contemporary insurance penetration rates.

Table 1: Survey Coverage and Data Confidence

Region	Hazards	Data Confidence Level
Australia	Hail, Typhoon, Wildfire	H
Canada	Hail, Ice	M* - H
Caribbean	Hurricane	M
Central America	Hurricane	M
China	Flood, Typhoon	L* - M
Europe	Flood, Wind	H
India	Flood, Cyclone	L* - M
Japan	Flood, Typhoon	L* - M
Korea	Typhoon	L-M
Philippines	Typhoon	M
United States	Flood, Hurricane, Ice, Wildfire	H

* Data incomplete

Data sets from a number of territories are clearly incomplete through the 1950s and 1960s as shown in Figure 1 which presents relative data completeness by decade. For this reason any assessment of global trends prior to the 1970s has to omit a number of important contributory regions.

Figure 1. Data Completeness by Decade

Regional Peril	1950s	1960s	1970s	1980s	1990s	2000s
Australia Cyclone	Relatively Incomplete	Relatively Incomplete	Relatively Incomplete	Relatively Complete	Relatively Complete	Relatively Complete
Australia Hail	Relatively Incomplete	Relatively Incomplete	Relatively Incomplete	Relatively Complete	Relatively Complete	Relatively Complete
Australia Wildfire	Relatively Incomplete	Relatively Incomplete	Relatively Incomplete	Relatively Complete	Relatively Complete	Relatively Complete
Canada Hail	Relatively Incomplete	Relatively Incomplete	Relatively Incomplete	Relatively Complete	Relatively Complete	Relatively Complete
Caribbean Hurricane	Relatively Incomplete	Relatively Incomplete	Relatively Incomplete	Relatively Complete	Relatively Complete	Relatively Complete
Central America Hurricane	Relatively Incomplete	Relatively Incomplete	Relatively Incomplete	Relatively Complete	Relatively Complete	Relatively Complete
China Flood	Relatively Incomplete	Relatively Incomplete	Relatively Incomplete	Relatively Complete	Relatively Complete	Relatively Complete
China Typhoon	Relatively Incomplete	Relatively Incomplete	Relatively Incomplete	Relatively Complete	Relatively Complete	Relatively Complete
Europe Flood	Relatively Incomplete	Relatively Incomplete	Relatively Incomplete	Relatively Complete	Relatively Complete	Relatively Complete
Europe Wind	Relatively Incomplete	Relatively Incomplete	Relatively Incomplete	Relatively Complete	Relatively Complete	Relatively Complete
India Cyclone	Relatively Incomplete	Relatively Incomplete	Relatively Incomplete	Relatively Complete	Relatively Complete	Relatively Complete
India Flood	Relatively Incomplete	Relatively Incomplete	Relatively Incomplete	Relatively Complete	Relatively Complete	Relatively Complete
Japan Flood	Relatively Incomplete	Relatively Incomplete	Relatively Incomplete	Relatively Complete	Relatively Complete	Relatively Complete
Japan Typhoon	Relatively Incomplete	Relatively Incomplete	Relatively Incomplete	Relatively Complete	Relatively Complete	Relatively Complete
Korea Typhoon	Relatively Incomplete	Relatively Incomplete	Relatively Incomplete	Relatively Complete	Relatively Complete	Relatively Complete
Philippines Typhoon	Relatively Incomplete	Relatively Incomplete	Relatively Incomplete	Relatively Complete	Relatively Complete	Relatively Complete
US Flood	Relatively Incomplete	Relatively Incomplete	Relatively Incomplete	Relatively Complete	Relatively Complete	Relatively Complete
US Hurricane	Relatively Incomplete	Relatively Incomplete	Relatively Incomplete	Relatively Complete	Relatively Complete	Relatively Complete
US Wildfire	Relatively Incomplete	Relatively Incomplete	Relatively Incomplete	Relatively Complete	Relatively Complete	Relatively Complete
Legend	Relatively Incomplete		Moderately Complete		Relatively Complete	

The cumulative normalized losses for each year since 1950 are shown as a graph in Fig 1.

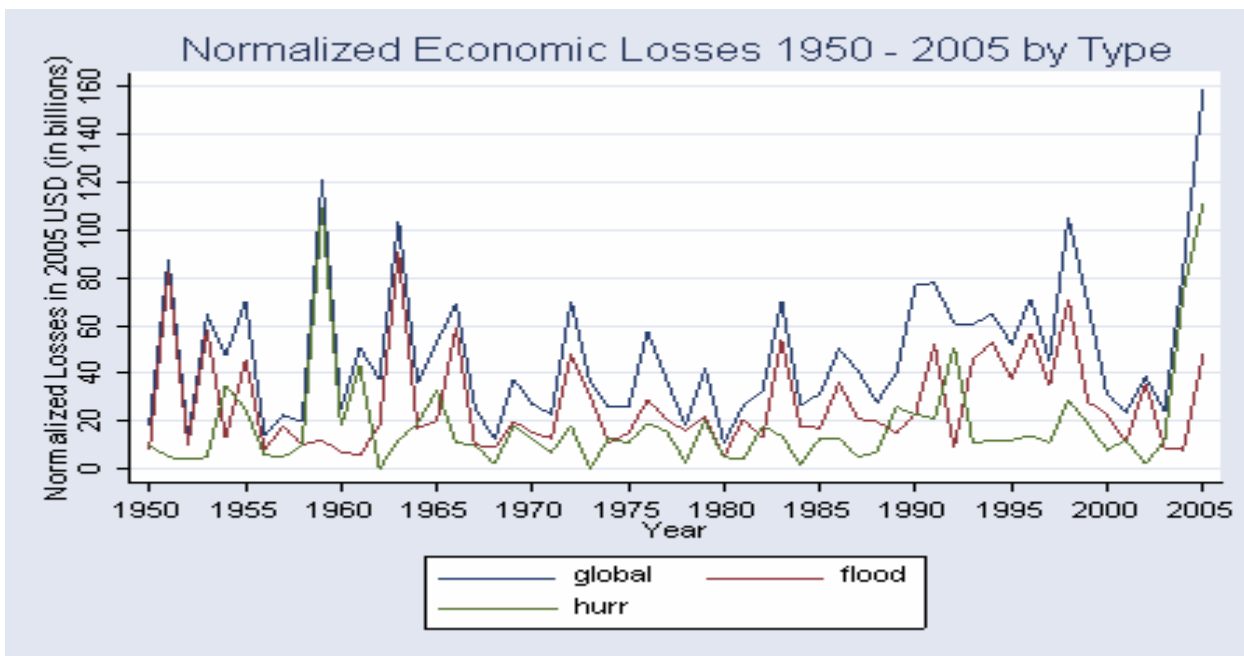


Fig 1 – Normalized economic losses for tropical cyclone, flood (storm surge and inland) and across all weather related perils, 1950-2005.

Caveats

There are four issues which merit discussion before proceeding to the results:

- i) The term ‘economic loss’ defies precise definition and is likely to have become broader over time. Today’s estimates include direct damages such as physical damage to infrastructure, crops, housing, etc. and indirect damages such as loss of revenue, unemployment and market destabilization. For example, Indonesia’s losses from the 2004 tsunami include an estimated \$1.53 billion USD for initial reduction in economic activity. As there is no systematic way to standardize loss estimates over time we proceed with the caveat that recent loss estimates may report a more comprehensive and therefore higher economic loss.

- ii) The reporting of economic loss estimates tends to improve with the size of the event and over time. Recent losses are almost everywhere better recorded due to improvements in communications, literacy, news coverage and insurance penetration. Failing to account for the summation of small to mid-size event losses below a certain monetary threshold (e.g. \$1 billion USD) will certainly affect aggregated loss estimates for most countries in earlier decades, which is why the focus here has been the largest losses.
- iii) The method of normalization employed here assumes a constant vulnerability through time. For wind and hail, vulnerability reflects the susceptibility of buildings to direct damage, while for flood and wildfire it is the degree to which communities have been protected from risk (with flood defenses and fire breaks). The bias of assuming constant vulnerability is strongest where substantial adaptation (mitigation) has occurred, as for normalizing 1950s and 1960s storm surge losses in northern Europe, 1950s and 1960s storm surge and river flood events in Japan or 1970s wind loss events in Australia. However for most perils and regions, such as US hurricane, real reductions in vulnerability have been modest. The question of testing the degree to which the affects of adaptation can be demonstrated from the normalized losses is considered further in the Discussion section.
- iv) The normalization methodology employed uses national statistics to compute the multipliers. Previous US normalizations use State and County level data to normalize losses. With the benefit of county level resolution in the US we can see that the population growth rate between certain coastal, hazard-prone regions such as Florida is understated by using the national average. However, we consider the large-scale migration to hazardous coastal areas seen in the US to be the exception. In the developing countries we survey, industrialization has led to migration to urban areas, which generally have lower risk profiles than rural areas. In other countries there has been a greater balance between urban and coastal migration patterns.

Trend Analysis

To test for a trend in normalized losses over time we perform a linear regression of normalized economic losses on the year. The model is given below in equation 1.

$$(1) \quad NL_y = \alpha + \beta_1 YEAR_y + \epsilon_y$$

Normalized losses (NL) in year y are determined by the loss year (YEAR) y , where ϵ is the error term. If time is a significant determinant of loss level we would expect the year to be statistically significant. The coefficient sign will indicate the direction of the trend.

We fit the regression twice using global normalized loss estimates as well as hazard type and regional subsets, first with data from 1950 – 2005 and then with data from 1970 - 2005.

Due to the large impact of Katrina, 2005 losses are nearly four standard deviations from the mean and exert an upward pull on the overall trend. To separate out the affect of Katrina on the overall results we ran the regression separately with Katrina losses removed.

Table 1: OLS Regression of Normalized Losses on Year

Survey Group	Time Period	
	1950 – 2005	1970 – 2005
Global Losses	379.26 (241.9)	1251.08*** (423.45)
Global Losses (Katrina Removed)	220.24 (210.62)	855.22** (330.28)

** Significant at 5%, ***Significant at 1% ^ at 0.055

When analyzed over the full survey period (1950 – 2005) the year is not statistically significant for global normalized losses. However, it is significant with a positive coefficient for normalized losses for specific regions such as Canada at 10%, Korea at 5%, and China at 1% (in all of which the earlier record is known to be incomplete). The coefficient is negative (but not significant) for Australia, Europe, India, Japan and the Philippines.

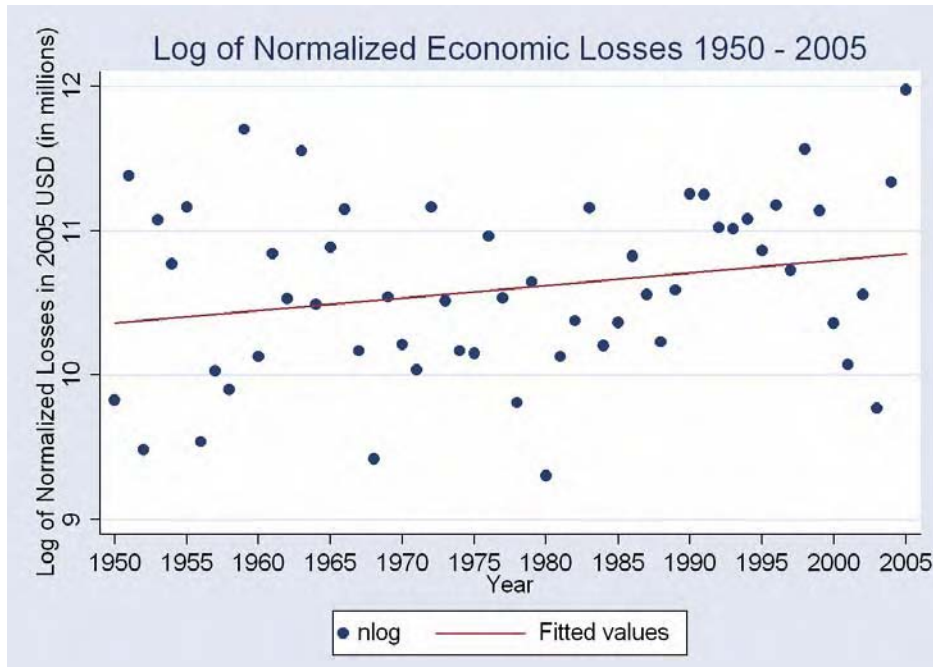


Fig 2: Trend line of Log of Normalized Economic ‘Global’ Losses relative to year since 1950

For the more complete 1970-2005 survey period, the year is significant with a positive coefficient for (i.e. increase in) global losses at 1% with an R2 value of 0.20 (5% with Katrina excluded), China at 1% (although again the early part of the record is likely to be incomplete), global tropical cyclones at 5% (both with and without Katrina losses) and for Caribbean losses at 10%. However, there is a decreasing trend in normalized losses for Australia at 10%, the Philippines at 5% and India at 1% (all located around the eastern Indian Ocean).

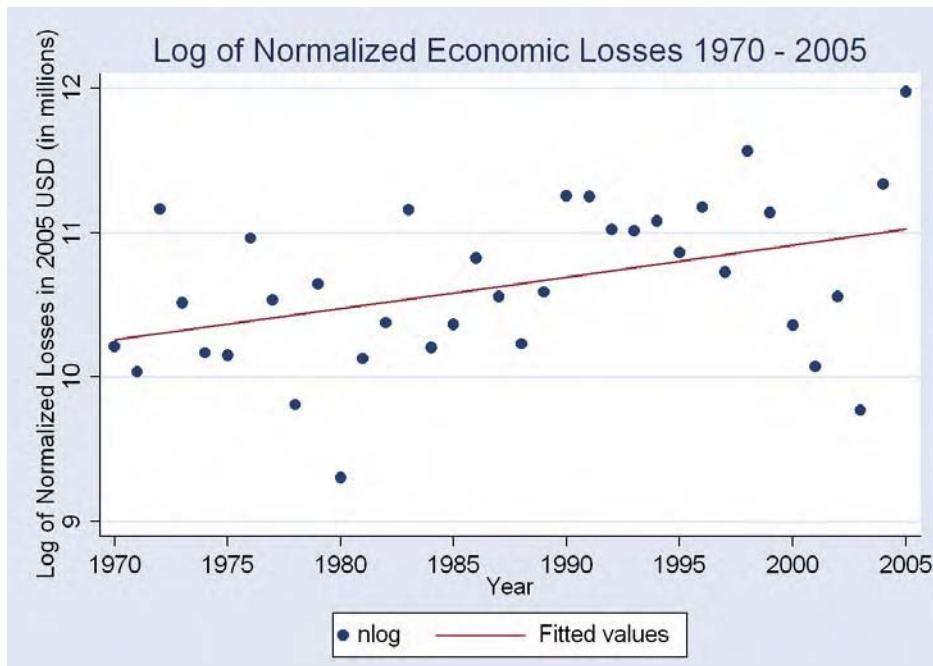


Fig 3: Trend line of Log of Normalized Economic ‘Global’ Losses relative to year since 1970

Discussion

Before attempting to consider the implications of these findings we should first explore potential reasons for trends within the dataset. As already noted our methodology does not normalize for changes in the vulnerability of buildings nor does our regression control for improved mitigation, as around reducing flood risk. However, there are several clear regional examples of declining loss trends since 1950 which merit comment. In Europe and Japan extensive investments in coastal flood defenses, in particular during the 1960s, have been well documented and the actual losses from events such as Typhoon Vera or the 1953 and 1962 North Sea storm surges would in consequence be significantly reduced below the normalized values if they recurred today. For flood in Europe the top three loss years all occur by 1966 and recent flood years have reached less than half the value of the high loss years in the first 20 years of the record.

While improved flood mitigation can help explain some part of the reduction of catastrophic flood losses since the 1950s other causes must be sought in explaining the upward trend in global losses seen since the 1970s.

Before concluding that these loss results demonstrate a strong rising trend in normalized catastrophe losses, we performed some simple tests to explore the sensitivity of this result.

The first test involved exploring whether such a trend could have been identified before the 2004 and 2005 loss years, with their heavy contribution from hurricanes in the US. The results of excluding these loss years show a reduction in the significance of the trend. Had we executed this study in 2003 we would have found no evidence to suggest an upward loss trend from 1950 and weaker evidence (at 10%) from 1970 onwards.

The second test involved removing the record of flood losses in China, in particular because it is likely to be incomplete prior to the 1980s. This also has the impact of the reducing the significance for a post 1970 trend in worldwide normalized losses - but which is still significant at 10%.

The importance of the contribution of the 2004 and 2005 US hurricane highlights the difficulty inherent in compounding global losses from nations with very different asset levels as wealthier nations will inevitably have higher nominal loss totals. Record years for hazard losses in a developing region would not have exerted such a strong pull on trend significance. For illustrative purposes we re-normalized each region's normalized losses by multiplying by the ratio of US GDP per capita to regional GDP per capita. This crude modification approximates a homogenous distribution of wealth. This adjustment yields results which are significant at 5% from 1950 onwards, but not significant when isolated from 1970 – 2005.

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TRENDS IN NATURAL CATASTROPHES – POTENTIAL ROLE OF CLIMATE CHANGE

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Introduction

For more than 30 years now, Munich Re scientists have been analysing natural hazards throughout the world. The Geo Risks Research department today has a staff of 27 out of which are 20 with a degree in natural science.

Over the past few years, there have been growing indications that the frequency and intensity of natural catastrophes is being influenced more and more by the unfolding process of climate change. Recent years have been marked by a particular accumulation of weather related extreme events:

- In the summer of 2002, the hundred-year flood in the Elbe and Danube region (Germany and eastern Europe), caused by a large-scale circulation pattern, which was also behind the extreme summertime precipitation events of 1997 (Odra), 2001 (Vistula) and 2005 (alpine region)
- In 2003, the 450-year hot summer with an excess mortality due to heat affecting more than 35,000 in Europe
- In 2004, a new record of losses caused by hurricanes in one season
- In 2004, the record typhoon season in Japan (ten landfalls)
- In March 2004, the first appearance of a tropical cyclone in the South Atlantic leading to losses in South America (Brazil)
- On 26 July 2005, India's largest precipitation volume in 24 hours: 944 mm in Mumbai
- In 2005, the largest number of tropical cyclones (27 and 15 hurricanes) in one season in the North Atlantic since recordings began in 1851
- Three of the ten strongest Atlantic hurricanes ever recorded occurred in 2005: the strongest hurricane of all times (Wilma – core pressure: 882 hPa), the fourth strongest hurricane (Rita), and the sixth-strongest (Katrina) since recordings began
- In 2005, Hurricane Katrina, the costliest single event of all time in absolute terms with over US\$ 125bn in economic losses and approx. US\$ 60bn in insured losses
- In October 2005, the most northerly and easterly hurricane (Vince), which formed off Madeira
- In November 2005, the first tropical storm to reach the Canary Islands (Delta)
- The 2005 hurricane season in the North Atlantic was marked by an early high activity record and an exceptionally long duration. By the end of July, seven tropical cyclones had already developed thus topping the previous record of five cyclones by that time. Further on, we saw four cyclones during November and December, the last one being active until 6 January 2006. The extraordinary length of the 2005 hurricane season accords with the long-term observation of an increasing trend in terms of the length of the hurricane season in the North Atlantic (linear trend of 4.8 days/decade since 1915 – Webster and Curry, 2006b).

Munich Re's NatCatSERVICE® database

Munich Re's GEO experts have been researching loss events due to natural hazards around the globe for over 30 years. These losses are documented in the NatCatSERVICE® database, which documents all natural catastrophes since 1970

(19,000 events). Retrospectively major historical events (3,000 events since eruption of Mt. Vesuvio 79 AD) and all great natural catastrophes back to 1950 have been included.

The reports of events are based on a large number of very different sources and are only entered in the database after thorough review and verification. The possibilities for researching information on natural phenomena throughout the world have improved constantly (Table 1 and Figure 1). Good descriptions and analyses of major loss events in the past can still be found today, for instance in historical reports. The earliest natural catastrophe recorded in the NatCatSERVICE® database is the eruption of Vesuvius in Italy in 79 AD, which was described in precise detail by Pliny the Younger.

Scientific reports

- Annali di geofisica
- BSSA (Seism. Soc. of America)
- Climatic Perspectives
- Disasters in China
- Earthquake and Volcanoes
- Earthquake Spectra
- EERI (EQ Engineering Res. Inst.)
- Hong Kong Observatory
- International Seismological Centre
- Journal of Meteorology
- National Hurricane Center
- Natural Hazard Observer
- Natural Hazards
- NOAA
- PIK (Potsdam Inst. of Climate Impact
- University of Hawaii
- Research
- Swiss Earthquake Service
- Transactions Am. Geophys. Union
- USGS (United States Geological Survey)
- World Meteorological Organisation
- Various newsletters and periodicals (e.g. Technisches Hilfswerk)

NGOs and GOs

- ECLAC
- International Federation of Red Cross and Red Crescent
- OCHA/DHA
- United Nations
- USAID/OFDA
- Others

Weather services

- Fiji Meteorological Service
- German Weather Service
- Monthly Weather Report
- United States Weather Service
- Weekly Climate Bulletin
- etc.

Insurance industry and news agencies

- 10+ insurance related (WIR, PCS)
- 5+ News agencies (Dow Jones)
- Worldwide network of contacts in science, economy etc.
- Proceedings
- Munich Re Branches, 50+ countries
- Claims/Loss Reports from clients
- Reports insurance companies
- Insurance Associations worldwide

Tab. 1 Main sources of Munich Re’s NatCatSERVICE® database

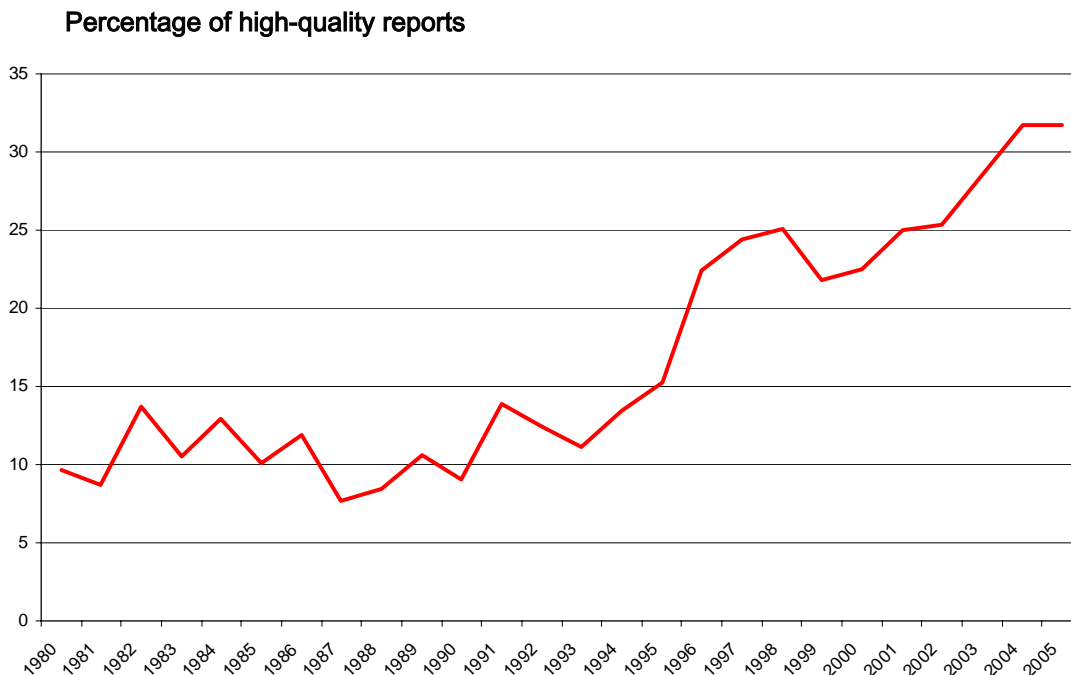


Fig. 1 Percentage of high-quality reporting in relation to all available records over time

The quality of data on natural catastrophe losses is dependent mainly on the following factors (Figure 2 and Table 2):

- Availability of high-quality information (source quality: insurers' figures v. press figures).
- Public perception of catastrophes is strongly influenced by reports in the media. As reports on climate change have become more frequent, people have become more aware of weather-related natural catastrophes, and reporting of them has increased. However, this has not affected data input at the NatCatSERVICE®, since most of the information used comes from claims reports from insurance companies and insurance associations and is not influenced by reports in the media.
- Information on natural hazard events distorted by vested interests, for example in China – the rise in natural catastrophes coincides with the political opening up of the country since 1980. Nevertheless, it has had no effect on the NatCatSERVICE®'s long-term statistics, as only so-called major natural catastrophes, on which reporting has been consistent, are used (e.g. number of major natural catastrophes in China in the 1950s: 4; 1960s: 0; 1970s: 2; 1980s: 4; 1990s: 7; from 2000: none). The problem of distorted information on natural hazard events is currently (2006) being examined in detail.

In our database every data record is given a quality class (1–6, 1 being the highest quality, 6 the lowest) according to the source used for loss figures (insured and economic losses) (Figure 2 and Table 2). Information on all of the largest and most devastating natural catastrophes has a quality class of 1 or 2.

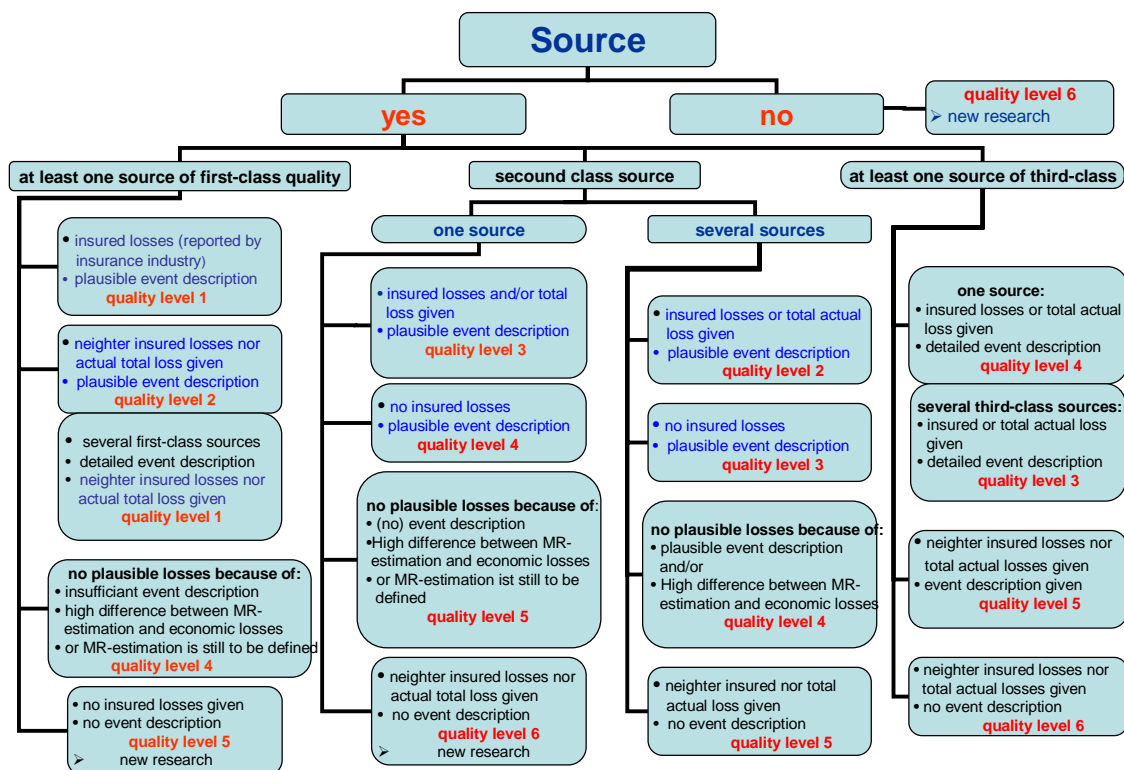


Fig. 2 Decision tree to characterise the data quality level

Quality level 1	Loss assessment with very good reporting
Quality level 2	Loss assessment with good reporting
Quality level 3	Loss assessment with satisfactory, middle-sized reporting
Quality level 4	Loss assessment with sufficient, small-sized reporting (loss amount without clear plausibility)
Quality level 5	Loss assessment with fault, poor reporting (loss amount without plausibility) ➤ Dataset (loss assessment) cannot be used for statistics
Quality level 6	Loss assessment with inadequate or missing reporting ➤ Dataset (loss assessment) cannot be used for statistics

Tab. 2 Quality levels of data

In order to be able to perform trend analyses and avoid any distortions of information, all events are categorised into seven categories according to their financial and/or humanitarian effects – from pure natural events with a very modest or virtually no economic effect to major natural catastrophes. Our evaluations and statistics do not take into account pure natural events (Table 3).

0	Natural event	No property damage (e.g. forest fire with no damage to buildings)			
1	Small-scale loss event	1-9 fatalities and/or hardly any damage			
2	Moderate loss event	10-19 deaths and/or damage to buildings and other property			
			2000-2005	1990s	1980s
3	Severe catastrophe	20+ fatalities and/or overall losses	US\$ > 50m	>40m	>25m
4	Major catastrophe	100+ fatalities and/or overall losses	US\$ > 200m	>160m	>85m
5	Devastating catastrophe	500+ fatalities and/or overall losses	US\$ > 500m	>400m	>275m
6	Great natural catastrophe „ <i>GREAT disaster</i> “	Thousands of fatalities, economy severely affected, extreme insured losses (UN definition)			

Tab. 3 Classification of catastrophe strength into seven catastrophe categories

Trend analyses of the data show very clearly that natural catastrophes have increased dramatically throughout the world in numbers and are causing more and more damage. The trend curve of great natural catastrophes (category 6 - thousands of fatalities, billion-dollar losses) worldwide per year reveals an increase from about two at the beginning of the 1950s to a current figure of about seven (Figure 3).

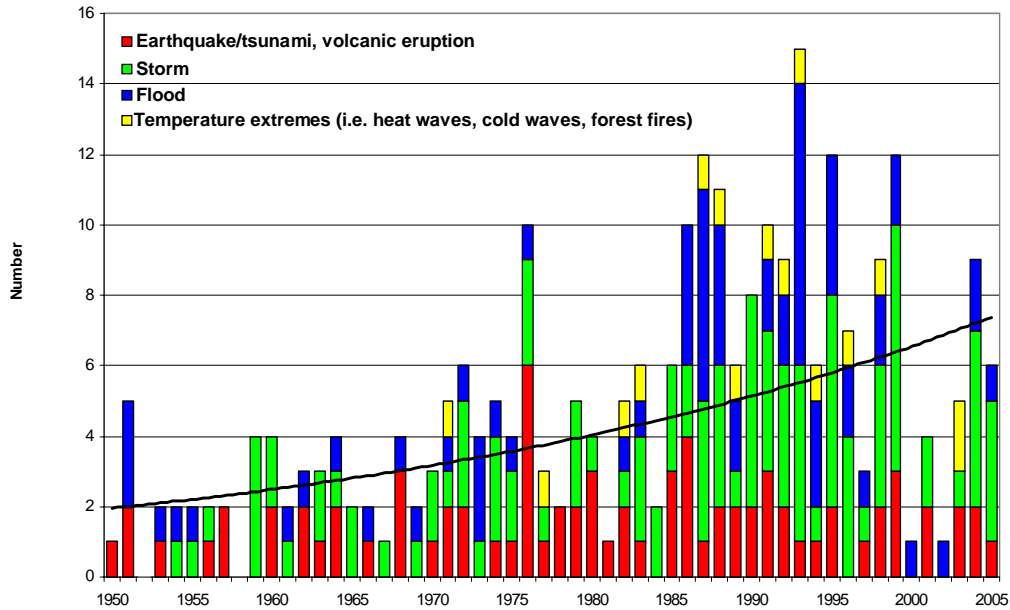


Fig. 3 Great natural disasters 1950 – 2005, number of events

In material terms, economic and insured losses from these great natural catastrophes rose even more steeply – to US\$ 173bn in economic losses and US\$ 83bn in insured losses – in the record year of 2005 (Figure 4). The original economic losses in the year 1995 (Kobe earthquake) were lower compared to 2005 – due to inflation adjustment they exceed the 2005 level by a small amount.

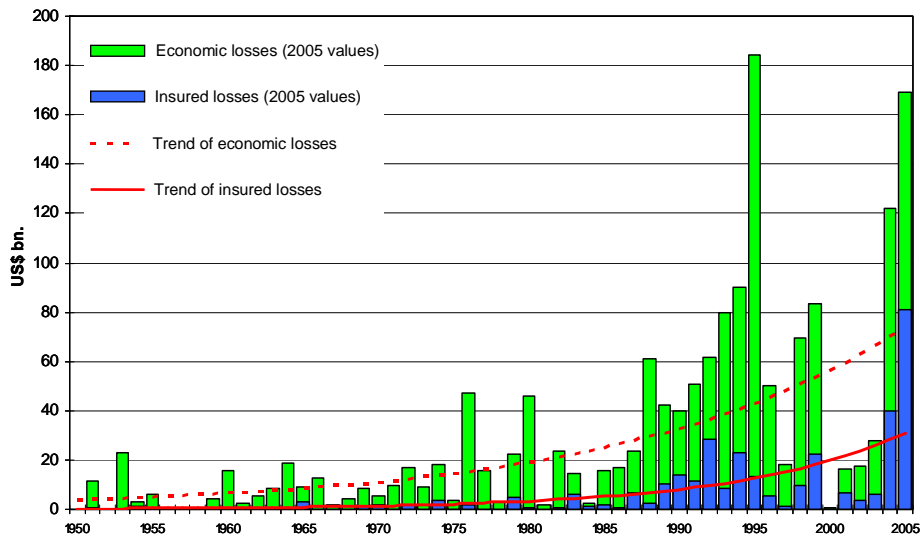


Fig. 4 Great natural disasters 1950 – 2005, economic and insured losses

This trend is apparent not only in the events classified as “major natural catastrophes”, but also when we analyse all loss events worldwide in catastrophe categories 1 to 6 (Figures 5 and 6). Similar to the preceding years major natural catastrophes contribute 78 % to the overall economic and 88 % to the insured losses.

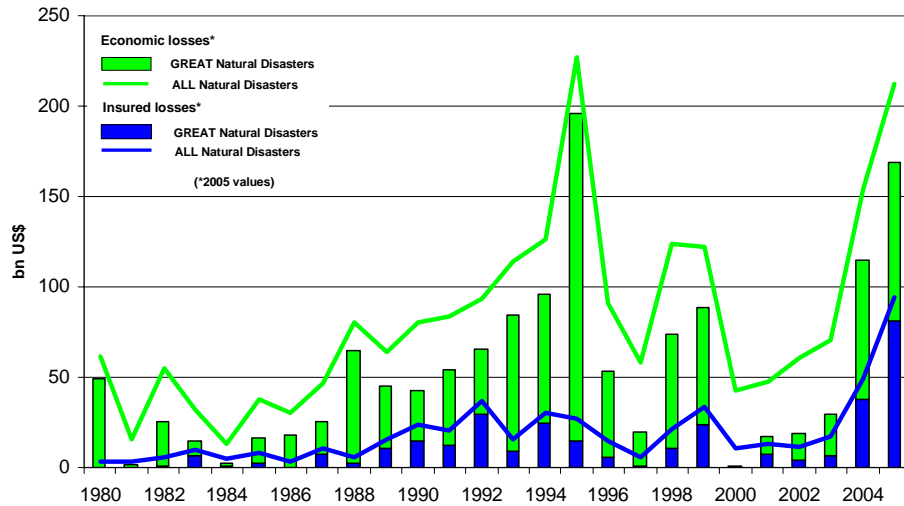


Fig. 5 Natural disasters 1980 – 2005, comparison of great natural disasters with all global natural disasters 1980 - 2005

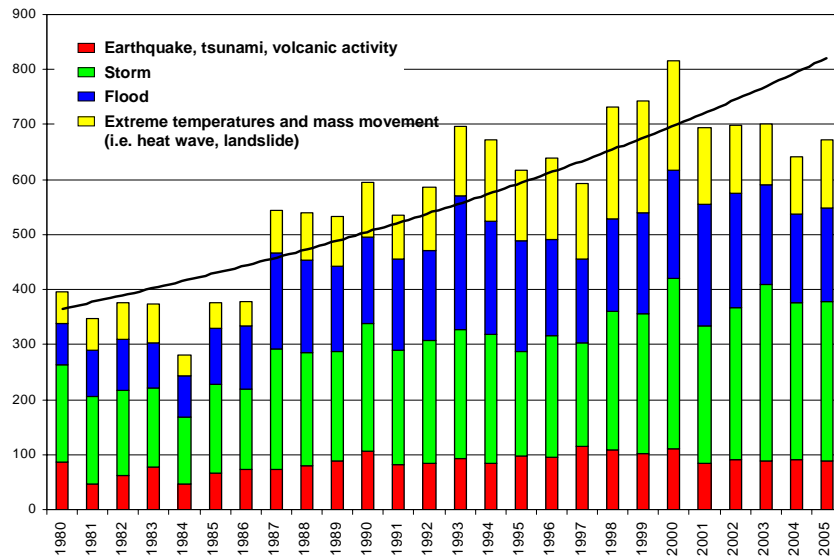


Fig. 6 All global natural disasters 1980 – 2005, number of events

The comparison of temporal trends of the numbers of all and major natural catastrophes reveals a much steeper increase of the costly major ones.

The strong rise of losses over time is influenced by population growth, development and industrialisation of highly-exposed regions, elevated vulnerability of modern technologies and increased insurance cover. As the positive trend in the number of natural catastrophes is mainly due to weather-related events like windstorms and floods and is not apparent in the same way in the case of events with geophysical causes like earthquakes, tsunamis, and volcanic eruptions, there is some justification for assuming that it is not the result of a reporting bias but of changes in the atmosphere and particularly climate change.

Climate Change and changing frequencies/intensities of natural catastrophes

The past few years have provided mounting support for the hypothesis that a changing climate contributes to the positive trend in natural catastrophes over time.

- Analyses of air bubbles trapped in Antarctic ice cores suggest that throughout the past 750,000 years the concentration of carbon dioxide – the most important of the greenhouse gases – has never before been anywhere near the level it has reached today (EPICA community, 2004):
- The last five years (including 2005) rank second to sixth in the table of the warmest years worldwide since 1861. The warmest year to date globally was 1998, in the northern hemisphere 2005 (World Meteorological Organization, 2005).

The third status report of the Intergovernmental Panel on Climate Change (IPCC, 2001) regards the link between global warming and the frequency and intensification of extreme weather events as highly significant. The expected increase in global average temperatures by the end of the century – of between 1.4 and 5.8°C, depending on the emission and climate models used – increases the probability of record temperatures enormously. Global warming raises the air's capacity to absorb water vapour and thus the precipitation potentials. Together with stronger convection processes, this leads to more frequent and more extreme intense precipitation events, which are today responsible for the majority of flood losses. The milder winters that are now typical in central Europe also reduce the snow areas over which stable cold high-pressure systems used to act as a barrier to the low-pressure systems coming in from the Atlantic. Therefore, the barrier is often weak or driven eastwards so that devastating series of winter storms like those in 1990 and 1999 can no longer be considered exceptions. The wind readings at representative German weather stations reveal a clear increase in the number of storm days in the past three decades (at Düsseldorf Airport, for example, this figure has risen from about 20 to 35 a year; Otte, 2000). Although not scientifically confirmed, a trend towards more frequent and more extreme low-pressure systems, i.e. an increase in windstorm activity as such, has been observed in the North Atlantic over the past few decades.

It has been indicated in an increasing number of scientific publications in recent years that there is a connection between climate change and the frequency and intensity of natural catastrophes.

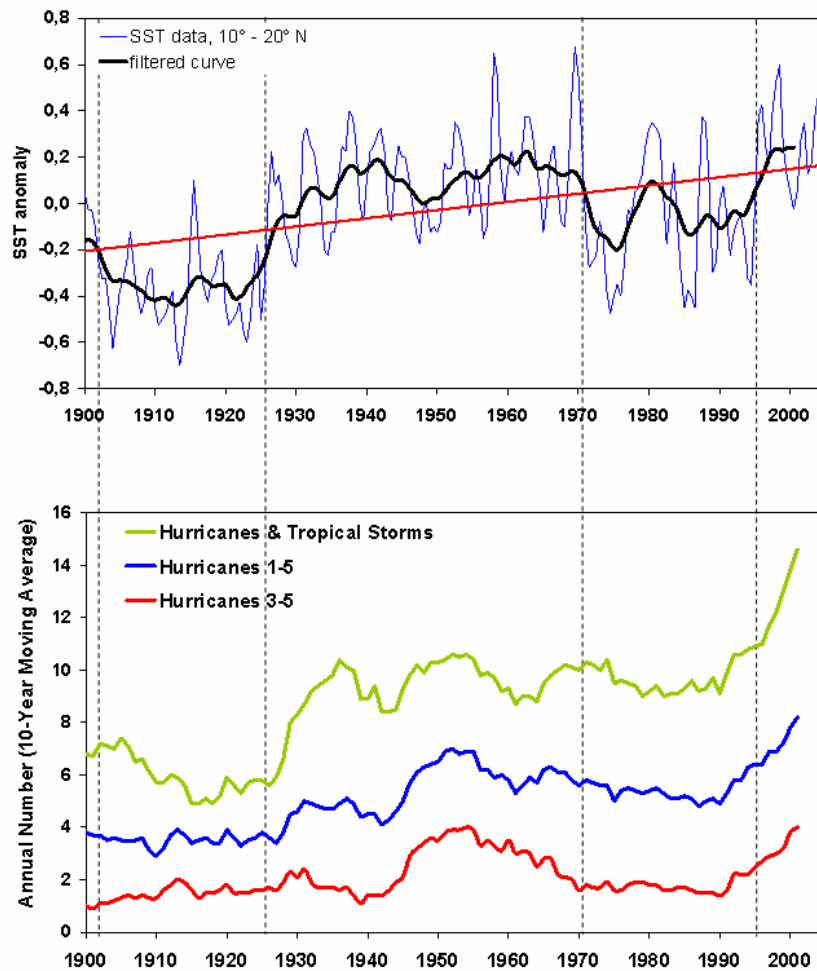
- According to British scientists, it is highly probable (>90%) that the influence of human activity has at least doubled the risk of a heat wave like the one that hit Europe in 2003 (Stott et al., 2004).
- Simulation models of future hurricane activity which factor in climate change show that by 2050 the maximum wind speed of hurricanes will have increased by 0.5 on the Saffir-Simpson Scale and that the associated precipitation volume will have increased by 18% (Knutson and Tuleya, 2004).
- The signal of anthropogenic warming has clearly been detected in a global warming of the world's oceans. The temperature of the uppermost layers of the world's oceans has increased substantially over the past four decades (Barnett et al., 2005).
- We have strong indications, for instance, that one of the consequences of the increasing sea surface temperature in the tropical Indian Ocean is the ever increasing drying up of Southern Africa due to a zonal circulation (similar to the Walker Circulation). This trend has been observed over the second half of the 20th century and has recently been shown as closely connected to the Indian Ocean warmer trend which is most probably caused by global warming (Hoerling et al., 2006). Increasing drought and famine risks will be among the consequences for the countries affected in southern Africa.

At this point we will go into some detail regarding the tropical cyclone issue in the North Atlantic.

As shown by a study of Barnett et al. 2005, the temperature of the uppermost layers of the world's oceans has increased substantially over the past four decades. Especially the sea surface temperature of the tropical ocean regions – one of the major factors for development and intensity of tropical cyclones – has risen globally by about 0.5°C since 1970 (Agudelo and Curry, 2004). One might question the relative importance of SSTs and the warmth of the uppermost water layers – as the primary source of energy and moisture – in comparison with other decisive preconditions for TC

development such as, for instance, low vertical wind shear in the troposphere or the change of zonal winds with longitude. A new paper studying the period 1970 to 2004 gives strong indications that the clear increasing global trend in category 4 and 5 hurricanes is directly linked to the long-term trend in tropical SSTs, while the other aspects of the tropical environment, though responsible for short-term variations in hurricane intensity, do not contribute significantly to the global trend of increasing hurricane intensity over time (Hoyos et al., 2006; see also Webster et al., 2006a). Although there is no distinctive trend in the global number of cyclones occurring every year, the percentage of category 4 and 5 hurricanes has been increasing since 1970 and indeed has more than doubled since then. There has been a steep increase in absolute terms too, from about eight per year at the beginning of the 1970s to eighteen per year in the period 2000 to 2004 (Webster et al., 2005). These findings are corroborated by the tight correlation found by Emanuel between the intensity of TCs in the North Atlantic and West Pacific – as measured by the annual aggregate of wind power release – and SSTs (Emanuel, 2005a; Emanuel, 2005b; cf. Kerr, 2006).

Especially for the North Atlantic, scientific findings over the past few years indicate two factors affecting sea surface temperature and hence hurricane activity variations over time: firstly, there is a multidecadal SST oscillation (Atlantic Multidecadal Oscillation – AMO) caused by a natural sea current fluctuation and secondly a superimposed long term warming process most probably caused by climate change - the resulting clear linear warming trend since 1870 amounts to $0.036^{\circ}\text{C}/\text{decade}$ for the tropical North Atlantic (Figure 7).



Figures 7A and 7B Upper panel (7A): Sea surface temperatures 1900 to 2004 in the tropical North Atlantic 10° - 20° N (excluding the area west of 80° W). Anomalies relative to 1961 to 1990. Data taken from Trenberth, 2005. Red line: linear trend; heavy black line: filtered curve.

Lower panel (7B): ten-year running mean curves for annual cyclone numbers of major hurricanes (red), all hurricanes (blue) and all named tropical cyclones (green) in the North Atlantic basin. Data from NOAA and UNISYS.

Independent of human-induced changes, **natural cycles make** the SST of ocean basins oscillate. In the North Atlantic this phenomenon is described by the “Atlantic Multidecadal Oscillation (AMO)” which in the 20th century showed a periodicity of about 65 years (Knight et al., 2005). The associated cold and warm phases are characterised by a margin of deviation of around 0.5°C in SST, which is about the same range as the presumed climate-change effect. The natural climatic fluctuation is most probably driven by the ocean’s large-scale currents (Thermohaline Circulation THC - Knight et al., 2005; Vellinga and Wu, 2004). The current warm AMO phase started in 1995 and is expected to last for another ten to twenty years.

Warm phases produce a distinct increase in hurricane frequency and also more intense storms, whereas cold phases have the opposite effect. In the current warm phase, 4.1 major hurricanes (Saffir-Simpson categories 3 – 5) have already occurred per year on average whilst in the previous cold phase this figure was only 1.5 (which means an increase of approx. 170%). Of course, a definite value for the average annual level of activity for the whole warm phase can only be given when this phase has ended and the 11 years of data since 1995 are not that much in comparison with the 45 years of data for the 1926–1970 warm phase. However, these 11 years are all we have at present and there is no reason to believe that they are far from being representative for the whole phase.

A comparison of corresponding AMO phases since 1900 indicates that the natural fluctuation is superimposed by a long-term warming process. This is to be expected from the above-mentioned global SST warming over time. Hence the level of tropical cyclone activity increases from one warm phase to another (Figure 7B). The increase in the number of major hurricanes per year from 2.6 to 4.1 on average from the previous warm phase to the current one means an increase of approx. 60%.

The changes observed for the North Atlantic basin are also reflected in US landfalls (Figure 8). In the case of major hurricanes, the annual average number of landfalls in the US has increased by about 230% from 0.3 to 1.0 compared with the last cold phase (approx. 1971 – 1994) and by about 70% from 0.6 to 1.0 compared with the last warm phase (approx. 1926 – 1970).

Equally, in terms of losses the cold phase – warm phase swing is reflected in the data (presented at the workshop). There is no doubt that climate conditions exert a strong influence on loss data.

The insurance industry is affected by climate change in a number of ways:

- The greater number and severity of extreme events are increasing the frequency and dimensions of the losses incurred.
- The volatility of losses is growing.
- New types of exposure are developing (e.g. hurricanes in the South and Northeast Atlantic).
- Unprecedented extreme values are being registered (in 2005, the strongest hurricane ever recorded).
- Premium adjustments often are lagging behind claims developments.

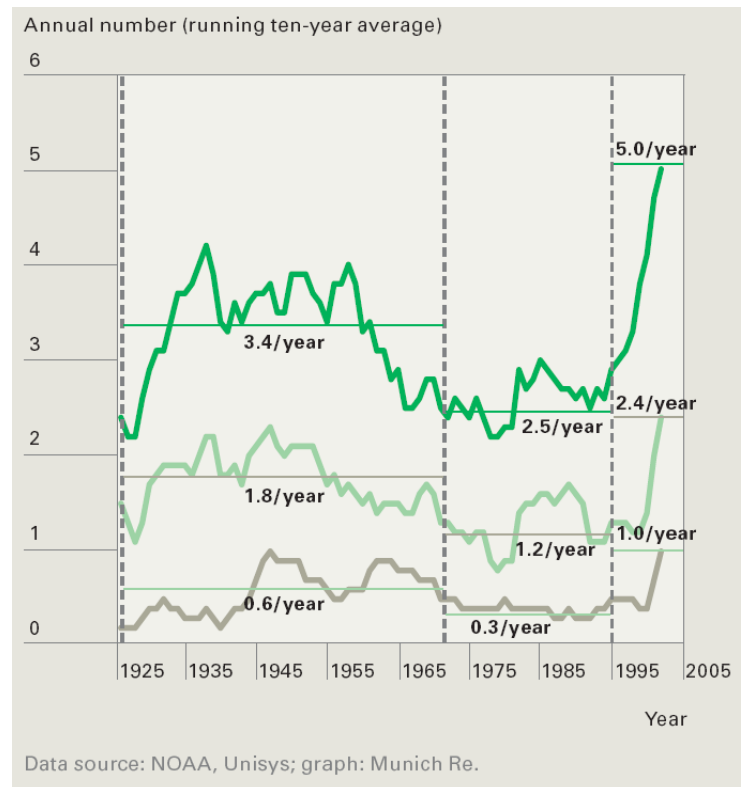


Fig. 8 Annual number of tropical cyclone US landfalls (ten-year running mean) and annual means over climatic phases for major hurricanes (grey curve), all hurricanes (light green curve) and all named tropical cyclones (green curve). Data source: NOAA/Unisys.

In spite of the unfavourable loss trends, the insurance industry still offers a wide range of covers for natural hazard losses. At the same time, it is endeavouring to encourage loss prevention on the part of its clients. Furthermore, it is making great efforts to control its own loss potentials through the application of modern geo-scientific methods. A quantitative forecast of future climate change's impact on the frequency and intensity of extreme weather events is still a problem.

The insurance industry has great potential for promoting climate protection and thus exerting a positive influence on future losses – by considering climate protection aspects in its products, investments, sponsoring activities, and its communications. Munich Re will continue to play a leading role in these areas.

Conclusions

The data in Munich Re NatCat*SERVICE*® clearly show significant trends of ever greater numbers of extreme weather events and losses caused by such events during the last decades. There is convincing evidence that climate change is occurring already, not only affecting air temperatures but also sea surface temperatures. A growing number of serious scientific studies provide pieces of evidence for causal links between climate change and a rise in natural catastrophe hazards, such as tropical storms, floods, droughts or heat waves. Taken together, these facts form the basis of our conviction that part of the increasing losses caused by natural catastrophes are a consequence of global warming.

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Is global warming contributing to an increase in tropical cyclone activity? (Presentation prepared for the Workshop “Climate Change and Disaster losses”, 25-26 May 2006, Hohenkammer, Germany)

**WHITE PAPER PREPARED FOR
WORKSHOP ON CLIMATE CHANGE AND DISASTER LOSSES:
UNDERSTANDING AND ATTRIBUTION TRENDS AND PROJECTIONS**

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Summary

- Climate change is real, and has a significant human component related to greenhouse gases, as summarized by the IPCC's Working Group I. Nothing in this white paper contradicts this work.
- Global disaster losses have increased.
- The increase in disaster losses is primarily due to floods and storms.
- Scientists have not yet attributed changes in floods and storms to human causes. However, there is evidence for the detection of trends in some phenomena, especially tropical cyclones.
- Some long-term disaster loss records are of suitable quality for research purposes.
- Long-term records of disaster losses indicate that the overwhelming factors responsible for increasing disaster losses are a result of societal change and development.
- Looking to the future, societal change will continue to be the dominant factor in increasing disaster losses. This conclusion is robust to a wide range of climate change scenarios. Identifying the signal of human-caused climate change in disaster loss trends will remain difficult for decades to come.

Global disaster losses have increased.

A

wide range of datasets from around the world paint a consistent picture: Disaster losses have been increases rapidly in recent decades. Figure 1 below was produced by Munich Re and is illustrative of the more general conclusions (Munich Re, 2005).

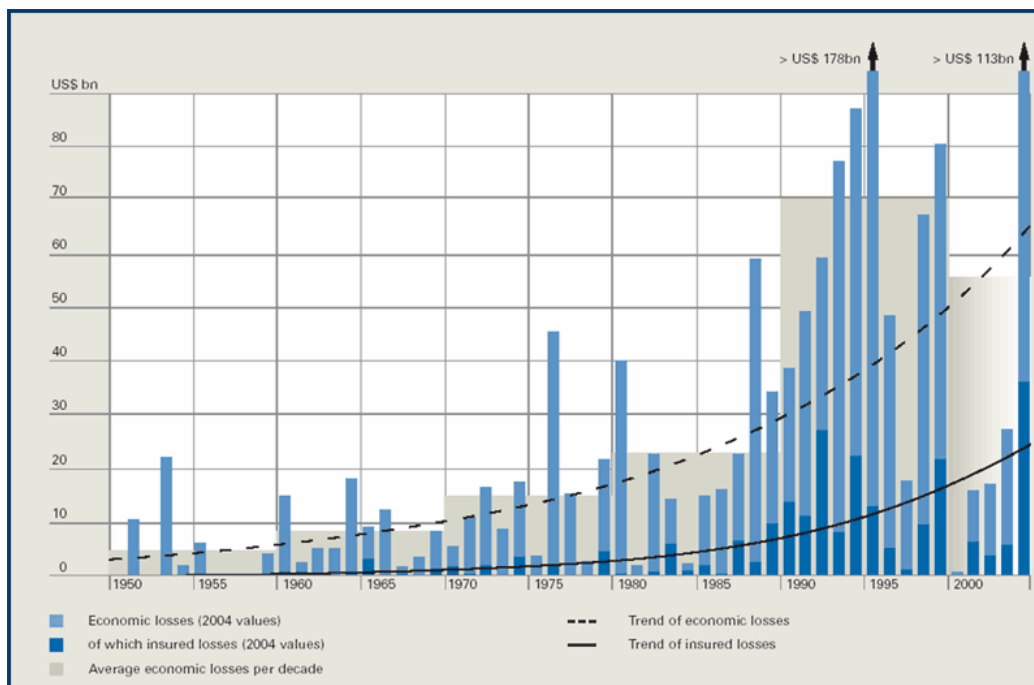


Figure 1. Global trend in disaster losses.

It is important to recognize that disaster losses do not increase in every region at a constant rate. Some regions may see decreasing trends. Disaster losses typically come in discrete, large values and the trend record is driven by the increase in the costs of the largest disasters, such as hurricanes in the United States.

The increase in disaster losses is primarily due to floods and storms.

The trend of increasing disaster losses has been driven largely by damage associated with floods and storms. Figure 2 (right) indicates that the vast majority of insured losses are the result of floods and storms (Association of British Insurers, 2005).

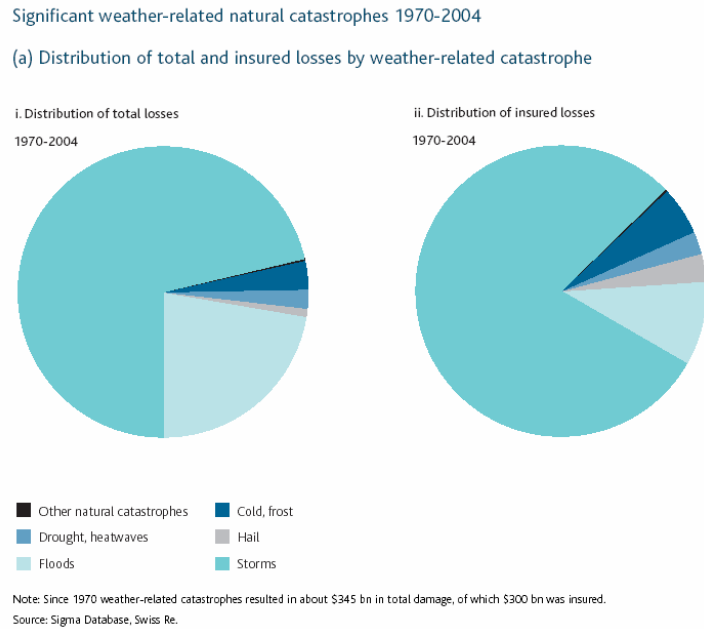


Figure 2. Distribution of insured losses 1970-2004, ABI, 2005.

The three figures below (3a, b, 3c) show for the decades of the 1990s the distribution of disasters by phenomena in terms of the number of disasters, total damage, an loss of life.¹ A consistent picture emerges from this data for atmospheric-related disasters – floods and wind storms are the primary phenomena responsible for disasters around the world according to each of these metrics.

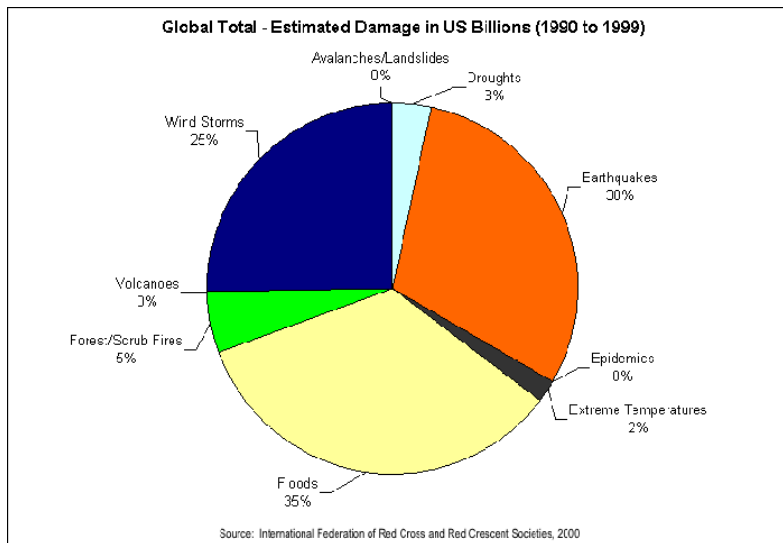
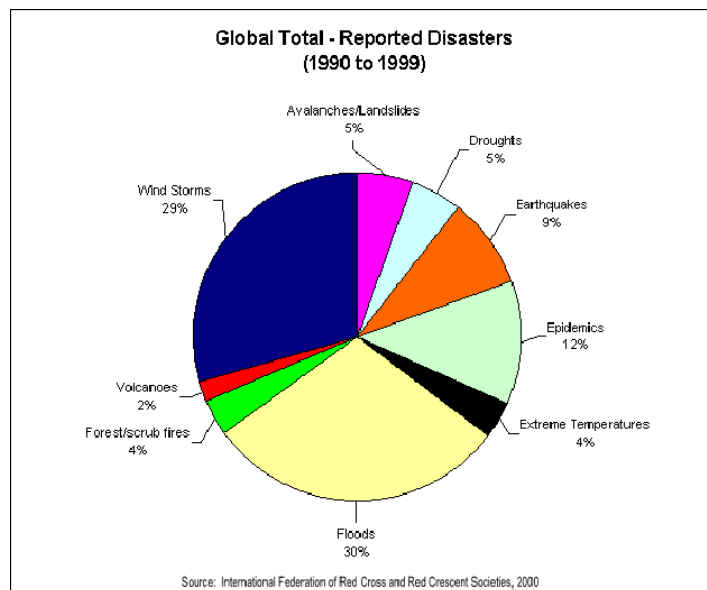
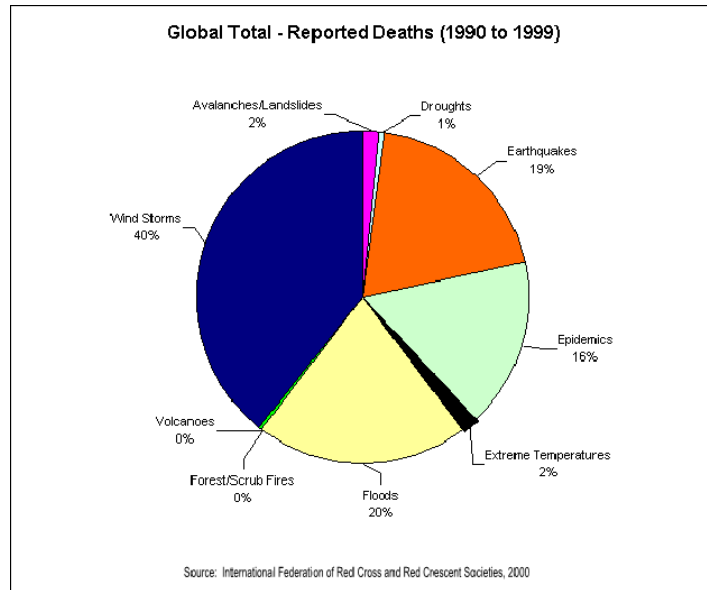


Figure 3a. IFRC, 2000. Total disaster losses in the 1990s by cause.

¹ Data from the Red Cross World Disasters Report (International Federation of Red Cross and Red Crescent Societies, 2000).



Figures 3b and 3c. Total deaths and number of disasters by cause during the 1990s. IFRC, 2000.

Scientists have not yet attributed changes in floods and storms to human causes. However, there is evidence for the detection of trends in some phenomena, especially tropical cyclones.

The most recent IPCC report took a close look at research on extreme weather events and found little evidence for changes over time (IPCC, 2001). Consider that over recent decades, the IPCC found no long-term global trends in extra-tropical cyclones (i.e., winter storms), in “droughts or wet spells,” or in “tornados, hail, and other severe weather.” No research (that I am aware of) has been published that would overturn these conclusions. In the absence of global trends in these weather events, they cannot be identified as being responsible for any part of the growing global economic toll. Regional trends may paint a different picture, however, in this context as well detection of trends and attribution to human causes remains incomplete.

Tropical Cyclones

Research on tropical cyclones has advanced rapidly since the last IPCC. In 2005 Massachusetts Institute of Technology’s Kerry Emanuel published a study in the journal *Nature* that described an increase in the intensity of

hurricanes in the North Atlantic and North Pacific (Emanuel, 2005). Another prominent study by Webster et al. has found an increase in the proportion of the strongest storms since 1970 (Webster et al., 2005). These two papers, published in the midst of a record Atlantic hurricane season in terms of both activity and damages have prompted much discussion about trends in tropical cyclone behavior.

However, it is important to recognize that neither of these papers focused on attribution. Emanuel (2005) expressed some uncertainty as to the factors responsible for the trends presented in that paper, stating “*Whatever the cause*, the near doubling of power dissipation over the period of record should be a matter of some concern” (emphasis added). Webster et al. (2005) even go so far as to observe that “attribution of the 30-year trends to global warming would require a longer global data record and, especially, a deeper understanding of the role of hurricanes in the general circulation of the atmosphere and ocean, even in the present climate state.” And both the Emanuel and Webster et al. papers have prompted a vigorous discussion with responses to each subsequently published by Landsea (2005) and Chan (2006), respectively.

A vigorous debate continues within the community about the trends themselves. These studies are complemented by a new paper forthcoming in *Geophysical Research Letters* in May, 2006 which find no trends in global tropical cyclone intensity from 1986-2005, with the exception of a dramatic increase in intense storms in the Atlantic Basin (Klotzbach, 2006a). Its author concludes,

These findings indicate that there has been very little trend in global tropical cyclone activity over the past twenty years, and therefore, that a large portion of the dramatic increasing trend found by Webster et al. [2005] and Emanuel [2005] is likely due to the diminished quality of the datasets before the middle 1980s. One would expect that if the results of Webster et al. and Emanuel were accurate reflections of what is going on in the climate system, than a similar trend would be found over the past twenty years, especially since SSTs have warmed considerably (about 0.2°C – 0.4°C) during this time period (Klotzbach, 2006b).

Given these various results, a position paper by the World Meteorological Organization’s Commission on Atmospheric Sciences, its Tropical Meteorology Research Program Panel (whose authorship included Emanuel, Holland, Knutson, Landsea, among other prominent scientists) concluded:

The research issues discussed here are in a fluid state and are the subject of much current investigation. Given time the problem of causes and attribution of the events of 2004-2005 will be discussed and argued in the refereed scientific literature. Prior to this happening it is not possible to make any authoritative comment (WMO/CAS, 2006).

Disaster losses related to tropical cyclones are discussed in some detail below. However, it seems reasonable to conclude that, at the present time, while detection of trends in tropical cyclone behavior may yet achieve a scientific consensus, attribution of such trends to human causes remains to be settled in the scientific literature. This area of science is undergoing rapid change as new research results are published, so it may be that detection and attribution will soon be unambiguously achieved. But until that occurs claims of definitive detection and attribution are premature, and thus so too would be any definitive link between trends in damage and human effects on tropical cyclones. In any case, this issue is largely moot as will be shown below, there are no long term trends in damages related to tropical cyclones – in the U.S., Caribbean, or India.

Floods

The IPCC did find “a widespread increase in heavy and extreme precipitation events in regions where total precipitation has increased, e.g., the mid- and high latitudes of the Northern Hemisphere”. (IPCC, 2001) But, at the same time, the IPCC warned that “an increase (or decrease) in heavy precipitation events may not necessarily translate into annual peak

(or low) river levels”. Indeed, while the IPCC found some changes in streamflow, it did not identify changes in streamflow extremes (i.e., floods), and concluded on a regional basis that, “Even if a trend is identified, it may be difficult to attribute it to global warming because of other changes that are continuing in a catchment.”

Since the IPCC was published it does not appear that uncertainties have been resolved one way or another. For example, a recent (2005) study by the International Ad Hoc Detection and Attribution Group, published in the Journal of Climate, was unable to detect a greenhouse gas signal in global precipitation (International Ad Hoc Detection and Attribution Group, 2005). And research on trends in precipitation appears to have mixed results, e.g., with one recent study finding no global trends: “Increased precipitation in some regions is balanced by decreased precipitation in other regions, and the global average change is near zero;” (Smith et al., 2006) Yet another recent study reaches a different conclusion, “Data are often incomplete in spatial and temporal domains and regional analyses are variable and sometimes contradictory; however, the weight of evidence indicates an ongoing intensification of the water cycle.” (Huntington, 2006)

But in this case, like that in the case of tropical cyclones, a close look at the damage data does not indicate that climate trends play anything more than a very minor role (if any) in the global increase in disaster losses related to floods.

Some long-term disaster loss records are of suitable quality for research purposes.

We have intensively studied disaster loss data in the United States (Downton et al., 2005; Downton and Pielke, 2005). In particular we have reconstructed the record of flood losses kept by the U.S. National Weather Service and compared the updated loss figures with those collected independently by states. We found very large disagreements on loss totals for small events, but much lower disagreement for losses which totaled more than \$500 million. We also found no reason to believe that errors in these estimates of disaster losses contain systematic biases over time. Thus, it is appropriate to conclude:

- Disaster loss data collected by the U.S. NWS is appropriate for seeking to identify climate trends.
- Estimates for large events may contain errors of, on average, 40% when compared to independently collected estimates for the same event.
- However, these errors tend to even out over time and space. There is no reason to believe that a longitudinal bias exists in the errors.
- Extreme caution should be applied when aggregating loss datasets collected in different places for different purposes.
- If loss datasets are combined for purposes of discerning climate trends, we recommend that it is absolutely essential to at the same time study each loss database independently for purposes of quality control and bias, and to conduct analyses of the role of climate trends in the region where the losses occurred.

Long-term records of disaster losses indicate that the overwhelming factors responsible for increasing disaster losses are a result of societal change and development.

Floods

Using the dataset described in the previous section, Figure 4a from our research shows how flood damage has increased dramatically in the United States, but Figure 4b shows that it has stayed almost constant when growing national wealth is considered.

This analysis indicates that the entire trend in losses is removed once one accounts for the growth in wealth. However, there are some indications that increasing precipitation is related to increasing damages. In a 2000 study, using an earlier version of the NWS flood loss dataset, we found a relationship between precipitation trends and damages (Pielke and Downton, 2000). The relationships were strongest when we focused at the regional scale and identified metrics of

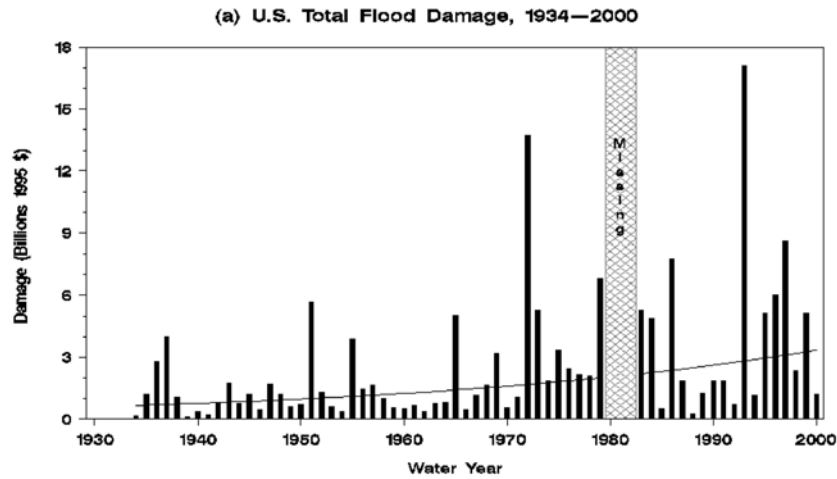


Figure 4a. Trends in U.S. flood damage, 1934-2000, adjusted for inflation.
<http://www.flooddamagedata.org>.

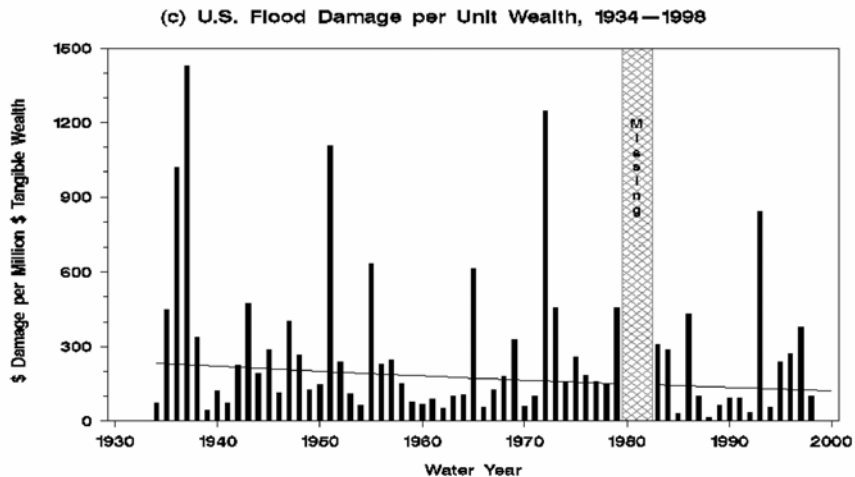


Figure 4b. Trends in U.S. flood damage per unit of wealth, 1934-1998.
<http://www.flooddamagedata.org>.

precipitation most closely related to the regional hydrologic and societal characteristics associated with flood damage. As the scale increases from the regional to the national, the relationship between various metrics of precipitation and damage becomes weaker. I would hypothesize that this relationship would change similarly when one goes from the national to global scale. In any case, the relationship of precipitation trends to damage is dwarfed by the overwhelming influence of societal changes as drivers of increasing flood losses.²

Tropical Cyclones

The case of hurricane impacts in the United States is similarly instructive. Consider economic damage (adjusted for inflation) related to hurricane landfalls in the United States, 1900–2005, as shown in Figure 5. Although damage is growing in both frequency and intensity, this trend does not reflect increased frequency or strength of hurricanes. In fact, while hurricane frequencies have varied a great deal over the past 100+ years, they have not increased in recent decades in parallel with increasing damages. To the contrary, although damage increased during the 1970s and 1980s, hurricane activity was considerably lower than in previous decades.

² The UK Foresight project on flooding came to similar conclusions,
http://www.foresight.gov.uk/Previous_Projects/Flood_and_Coastal_Defence/index.html

Total Losses per Year from Atlantic Tropical Cyclones in 2005 Dollars

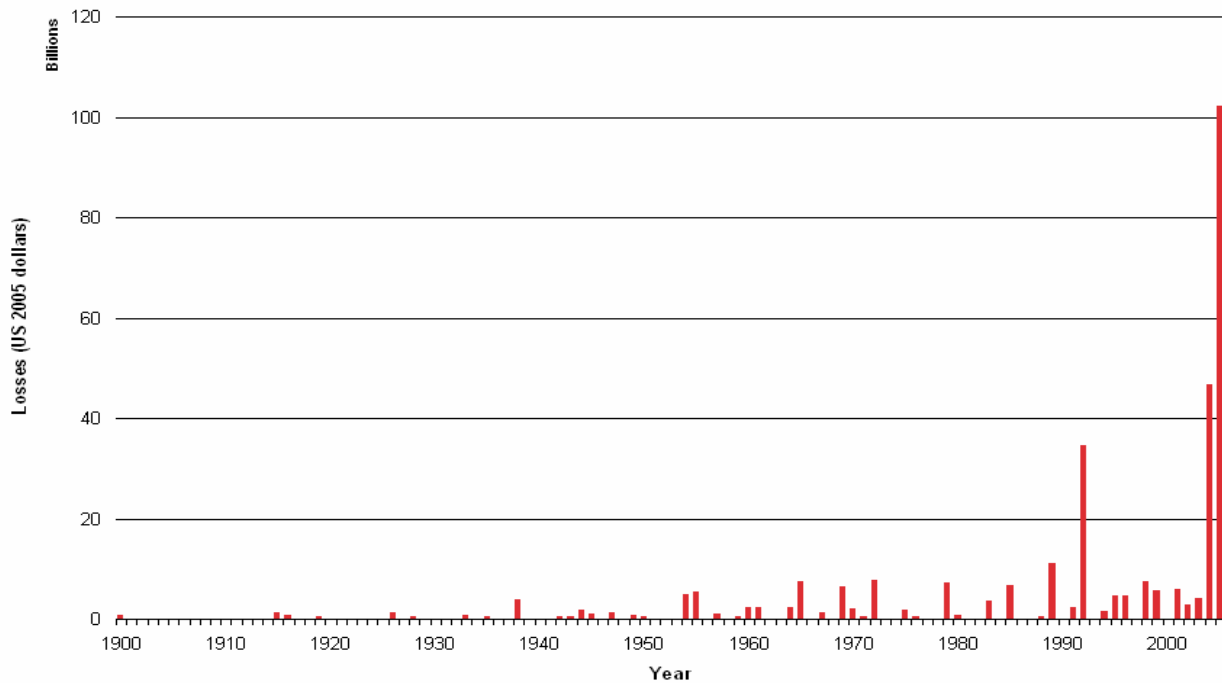


Figure 5. Trend in U.S. hurricane damage, 1900-2005. Source: NOAA/NHC

To explain the increase in damage, it is therefore necessary to consider factors other than variability or change in climate. Society has changed enormously during the past century and coastal development has taken pace at an incredible pace.

Given the significance of societal change in trends of hurricane damage, one way to present a more accurate perspective on such trends is to consider how past storms would affect present society. We developed a methodology for ‘normalizing’ past hurricane damage to present day values (using wealth, population, and inflation). (Pielke and Landsea, 1998) Figure 6 shows the historical losses of Figure 5 normalized to 2005 values. The normalized record shows that the impacts of Hurricane Andrew, at close to \$53 billion (2005 values) (unpublished analysis by author, updated from Pielke and Landsea, 1998), would have been far surpassed by the Great Miami Hurricane of 1926, which would have caused an estimated \$137 billion damage had it occurred in 2005, exceeding similarly accounted costs of Katrina. We can have some confidence that the normalized loss record accounts for societal changes because, unlike the unadjusted data, the adjusted damage data accurately reflect well-understood patterns of climate variability, such as the signal of El Niño and La Niña in hurricane frequencies (Katz, 2002).

Figure 6 shows no longitudinal trend in losses related to tropical cyclones, even with the extreme losses of 2004 and 2005. Kerry Emanuel, who has documented an increase in hurricane intensities in the Atlantic Basin accepts this conclusion. He writes on his website, “There is a huge upward trend in hurricane damage in the U.S., but all or almost all of this is due to increasing coastal population and building in hurricane-prone areas. When this increase in population and wealth is accounted for, there is no discernible trend left in the hurricane damage data.” (Emanuel, 2006) A comment that I wrote in response to Emanuel’s paper (2005), also published in *Nature*, provided evidence that indicated that once U.S. hurricane damage was adjusted to reflect societal changes, there was no trend of increasing damages over the twentieth century or an increase in damages per storm (Pielke, 2005).

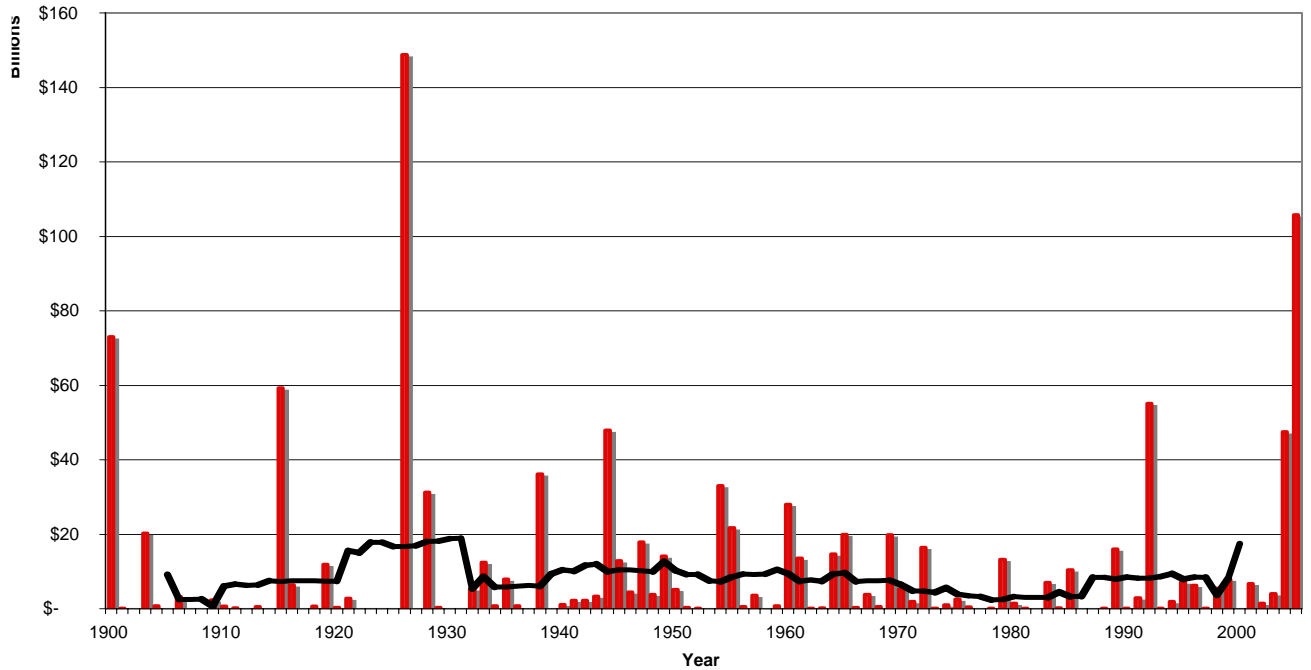


Figure 6. Estimated hurricane damages 1900-2005 if storms of the past made landfall with coastal development of 2005.
Source: Roger A. Pielke, Jr., work in progress

Similar conclusions have been reached in studies that looked at Latin America and the Caribbean (Pielke et al., 2003), and well as in an India case study (Raghavan and Rajesh, 2003).

Of course, the case studies discussed above focus only on the United States and do not provide a global perspective. However, a very large portion of the trend in global losses is from the United States, and in particular from hurricane losses. A focus on death or other human impacts would necessarily result in a different focus, perhaps with different conclusions. As an operating hypothesis, the results from the case studies discussed above provide suggest that research in Europe and Asia, in particular, might focus on identifying disaster datasets of suitable quality for such research and efforts to quantitatively disaggregate the role of population growth and wealth in regional trends in disaster losses.

What About the Conclusion of the IPCC 2001 WG II?

One important reason for some confusion among scientists stems from a claim made by the IPCC Working Group II attributing some part of the trend of increasing disaster losses to changes in climate. (IPCC, 2001) However, upon closer look, the claim seems unfounded. The IPCC relied on a report published in 2000 by Munich Re that found that global disasters resulted in \$636 billion in losses in the 1990s compared with \$315 billion in the 1970s, after adjusting for changes in population and wealth. (Munich Re, 2000) The Munich Re report concludes that disaster costs have increased by a factor of two (i.e., 636/315), independent of societal changes, and the IPCC suggests that climate change is responsible for the difference.

Methodologically, the calculation is suspect for a number of reasons. First, Munich Re provides neither their methods nor data. Second, Munich Re admits that data on changes in wealth are not available around the world and changes in GDP are not always a good proxy for data on wealth. Third, Munich Re's data apparently includes weather and non-weather events (e.g., it appears to also include earthquake damages).

But assuming that all of the issues raised above can be overcome, and in the end there remains a 2-to-1 ratio. The fact is that the large decadal variability in disaster losses makes it quite dodgy to assert a trend by comparing two different ten-year periods over a period of 30 years. This can be illustrated with an example from our database of hurricane losses. If

we adjust the hurricane loss data, accounting for trends in population, wealth, and inflation, to 2005 values and then compare decades (data can be seen in Figure 6), we see some interesting things.

First, the ratio of the 1990s to the 1970s is quite similar to the Munich Re analysis, 2.1 (\$87B/\$41B). But if we look at other decadal comparisons, the picture looks quite different, the 1990s to the 1940s = 0.8 (\$87B/\$110B) compared to the 1990s to the 1920s = 0.5 (\$87B/\$184B). The bottom line is that the 2000 Munich Re analysis, which provided some valuable insights on disasters to be sure, tells us nothing about the attribution of the causes for increasing disasters, yet its results were used by the IPCC to suggest otherwise.

Looking to the future, societal change will continue to be the dominant factor in increasing disaster losses. This conclusion is robust to a wide range of climate change scenarios.

It goes beyond the scope of the present workshop to focus on the future. However, it should be simply noted that societal change will continue, of course, with dramatic implications for continued increases in disaster losses. In this context, identifying the signal of human-caused climate change will require that two conditions be met:

1. Scientific evidence of both the detection and attribution of trends in extreme events (i.e., storms and floods) to human-caused climate change.
2. A signal of such changes evident in the disaster loss record that is significant in the context of societal change, and importantly, in the context of the inherently noisy data of disaster losses.

Until that time occurs, it is premature to suggest that the observed large increase in disaster losses is related to anything other than increasing population at risk possessing ever-greater amounts of wealth at risk of loss. The bottom line is that identifying the signal of human-caused climate change in disaster loss trends will remain difficult for decades to come.

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1. What factors account for the dramatically increasing costs of weather-related disasters (specifically, floods and storms) in recent decades?

While the socio-economic Impact of weather-related hazards has undeniably increased tremendously in the past few decades, the reasons are to be looked for in social, political and economic factors rather than in the meteorological phenomena themselves.

2. What are the implications of these understandings, for both research and policy?

The following are needed:

- 1) Continued research for understanding the meteorological phenomena and the mechanisms of damage including the likely effects of climate change.
- 2) Pro-active preparedness for disaster mitigation which will include engineering, social and legal measures.

I attach a background paper setting out the basis for these answers.

.....

First question: What factors account for the dramatically increasing costs of weather-related disasters (specifically, floods and storms) in recent decades?

While the socio-economic Impact of weather-related hazards has undeniably increased tremendously in the past few decades, the reasons for the increase are to be looked for in social, political and economic factors rather than in the meteorological phenomena themselves. I shall confine myself to tropical cyclones, which are the most hazardous weather phenomena and floods which are the most disastrous weather-related events. I am illustrating with two recent examples from India.

Tropical Cyclones

Andhra Pradesh (location shown in Fig. 1) is one of the most cyclone-prone states in India with a coastline of about 1030 km. Reliable meteorological as well as economic data are available since about 1970. From a study of the tropical cyclones hitting the state in the period 1971-2000 it was shown by Raghavan and Rajesh (2003) that there was no trend of increase of frequency or intensity of tropical cyclones (actually there was a negative trend within these three decades) but the estimated damage was increasing over the period. Normalisation of the damage for inflation, increase in population and economic activity in the region showed that there was no trend in the normalised damage figures. This agrees with similar studies in the USA (Pielke and Landsea, 1998). The study could not be extended to other coastal states in India because of difficulties in getting reliable damage data although reliable meteorological data are available. There is however no reason to expect a very different result in those states. Actual damage in future cyclones is expected to increase further.

I have also examined the attention given by administrators to *preparedness* for disastrous events and for *post-disaster relief*. The figures for Andhra Pradesh (source: Government of Andhra Pradesh) are as below.

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<i>EXPENDITURE</i> ²	Indian Rupees Crore (Crore means 10 ⁷)
Relief expenditure after the event (including cyclones, floods and droughts), from 1979-80 to 1999-2000.	2781
Damage estimated to have occurred in one single tropical cyclone in 1996	6129
expenditure on preparedness before each event	Not available
World Bank-aided Project in the nineties mostly on infrastructure development	801

The fact that data on expenditure incurred on preparedness were not even available except for the World Bank project outlay, shows that much more importance is attached to relief after the event rather than proactive preparedness *before* it. This attitude is understandable in the sociopolitical context and is not confined to Andhra Pradesh. One has only to draw a parallel to the state of preparedness in New Orleans, USA, before Hurricane Katrina, despite elaborate plans being available.

Although in recent decades, awareness on cyclone preparedness has improved in this region, there is a “Fading Memory Syndrome”, which results in slackness in disaster preparedness if there is no cyclone affecting an area for a few years (Raghavan and Sen Sarma, 2000). The phenomenal damage and deaths in the “super cyclone” (defined as one with maximum sustained surface wind of 62 m s⁻¹ or more; in this case 72 m s⁻¹) which struck the Indian State of Orissa in October 1999, may be largely attributed to want of preparedness.

Floods

Floods occur every year in several parts of India especially during the monsoon months (June to September). In the southernmost state of Tamil Nadu (see Fig. 1) the major part of the rainfall occurs in the October to December season which is locally called the “northeast monsoon” season. In the period October to December 2005 there was a total rainfall of 774 mm which is about two standard deviations above the normal of 429 mm. The rain resulted from several low pressure systems moving in from the Bay of Bengal, some of which attained cyclonic storm intensity (wind speed greater than 17 m s⁻¹) while at sea but weakened before landfall. Hence the damage due to these events was entirely by flooding and not wind or storm surge. According to media and official reports the entire state had unprecedented floods affecting various districts. The rainfall however, was *not* unprecedented. The year 1946 had higher rainfall and five other years in the 20th century had comparable rainfall, but the floods were not serious in those years.

Unlike in the case of tropical cyclones, floods in India have been increasing over the years in severity and area affected, but the causes are not meteorological.

It was found in this case that the floods were largely man-made and attributable to the following causes.

1. Drainages were blocked over the years in the name of development.

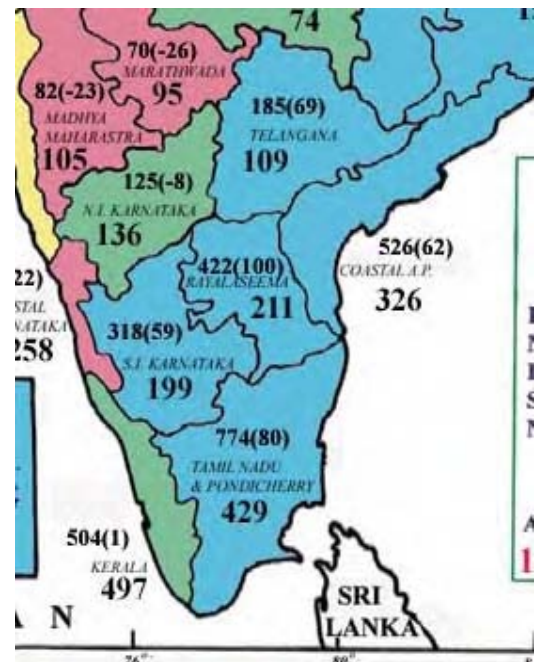


Fig. 1 Map of peninsular India showing location of “coastal Andhra Pradesh” and “Tamil Nadu and Pondicherry” on the east coast. The rainfall figures for the latter are 774 mm from October to December, 2005 which is 80% above the normal figure of 429 mm. – figure courtesy India Meteorological Department.

² At present 45 Indian Rupees are equal to a US Dollar but the exchange rate has varied considerably over the years. Hence conversion of the above figures to US Dollars may be misleading.

2. Large numbers of water storage ponds built in previous centuries for storing rain water for irrigation, were allowed to be silted up or even destroyed by building over them or encroaching on them.
3. Rivers and canals which were navigable even 50 years ago were encroached upon or filled with sewage and garbage. There were even “university” and “government” buildings built over some river beds.
4. Destruction of wetlands e.g. coastal mangrove swamps³.
5. Encroachments were encouraged or subsidised by governments over the years, to meet real or contrived demands from various sections of society⁴.

It is true that for an accurate assessment of floods, complete information on intensity and duration of each spell of rainfall should be examined (e.g. Trenberth et al., 2003), but it is clearly established in this case that the above human-made causes were dominant.

Other Phenomena

There may be other adverse weather phenomena which may themselves be increasing because of “climate change” but even in these cases human activities may often be major contributors. Examples are large-scale deforestation, depletion of ground water, widespread mining and other land use changes.

Causes

Scientific opinion on whether tropical cyclones are increasing in frequency or intensity and whether such increase is due to “global warming” is inconclusive. The work of Emanuel (2005) and Webster et al. (2005) is often cited (in many cases, out of context), in support of the contention that cyclones are increasing due to global warming. According to Emanuel, the “potential destructiveness” of hurricanes increased markedly since the mid-1970s. He concluded that future warming may lead to an upward trend in tropical cyclone *destructive potential*, and—taking into account an increasing coastal population—a substantial increase in hurricane-related losses in the twenty-first century. He did *not* find any increase in number of cyclones. Note that the increase in losses is attributed not just to the intensity of the cyclones but also to societal factors such as increase in coastal population. Also note that most cyclones do not reach the maximum potential intensity given by theory. Emanuel has also said that it is absurd to think that the Katrina disaster is due to global warming. <http://wind.mit.edu/~emanuel/anthro2.htm>) But this part is conveniently forgotten.

Webster et al. (2005) examined data of the past 35 years and found that the number of cyclones and cyclone days have increased in the North Atlantic during the past decade but this is not the case in all other ocean basins. A large increase was seen in the number and proportion of intense hurricanes (categories 4 and 5) in all basins but the maximum intensity remained unchanged over 35 years. These increases are attributed by them to increasing sea surface temperature. But (and this part often goes unnoticed) the authors say “*attribution of the 30-year trends to global warming would require a longer global data record and, especially, a deeper understanding of the role of hurricanes in the general circulation of the atmosphere and ocean, even in the present climate state*”.

It has been pointed out by Patrick Michaels (of the University of Virginia) <http://www.tcsdaily.com/article.aspx?id=091605F> that in the Atlantic where good data are available for earlier years also, just the opposite occurred in the period 1945 to 1970 i.e. there was a greater number of intense hurricanes than in the period 1970 to 1994. Gray (2006) is of the view that “the large increase in Atlantic hurricane frequency and strength of intensity since 1995 is natural and is a result of the large increase in the Atlantic thermohaline circulation (THC)”. Pielke et al. (2005) also state that the claims of linkage with global warming are premature.

³ It was found that damage due to the tsunami of 26 December 2004 was minimal in those coastal areas where mangroves were intact compared to severe impact in other areas where they had been destroyed—Swaminathan (2005).

⁴ Some of the encroaching structures were demolished after the floods.

The Association of British Insurers (2005) report on “Financial Risks of Climate Change” states “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”.

The projections for the future (based on assumptions of climate change) are sensitive to the model used and vary widely. Therefore, they do not necessarily reflect reality. For example, Knutson and Tuleya (2004) estimate a 6% increase in hurricane wind speeds by 2080. This is disputed by others (e.g. Michaels et al, 2005). According to Pielke et al., (2005), even if this increase is there, the increase by now would have been 0.5 to 1 m s⁻¹, which is smaller than the error in satellite techniques of estimating wind speed and it is also small in comparison with inter-decadal changes.

In the absence of clarity about whether observed increase in incidence of events is due to climate change or periodical oscillations of meteorological and oceanographic parameters the assumptions in the model projections can be counter-productive. An example is the widespread assumption that drought in Asia and Africa would be the consequence of the 1997 El Niño in many regions including India and southern Africa. That did not happen. In southern Africa, people made decisions based on the likelihood of drought, such as not planting, that ultimately hurt them (Dilley 2002).

Answer to the first Question:

*Hence it is my submission that the observed increase in **impact** of severe weather events is attributable largely to human-made social, political and economic causes and not due to any increase in the events themselves.*

Second Question: What are the implications of these understandings, for both research and policy?

Are we doing enough to minimize the impact of severe weather phenomena?

Attribution of the increases to global warming or to natural causes is often used as an excuse for inaction by branding the events as “acts of God” (see e.g. Kennedy, 2006). Instead of worrying about whether the events will increase due to climate change the more appropriate and immediate question to ask ourselves is “*Are we doing enough to minimise the **impact** of severe weather phenomena?*”. It is amply evident that we are not.

Relief vs Preparedness:

Palliative “relief” measures after each severe weather event are undertaken at great cost. Pro-active preparedness measures, though less expensive, and more durable, are given less importance and are often totally neglected. Relief measures in the limelight are politically rewarding while preparedness involves hard work behind the scenes. While better preparedness cannot totally avoid damage or relief expenditure, it can mitigate human suffering as well as economic damage. By preparedness we mean the various aspects which may have different relative priorities in different parts of the world.

Preparedness may consist of:

1. Improvement of physical infrastructure e.g. better construction, better roads, drainage, water storage facilities, reliable communication networks⁵.
2. Creation of awareness of risks.
3. Discouragement or prevention of unwise land use, preservation of coastal wetlands and shelter belts⁶.

⁵ A recent development in India is a scheme to disseminate disaster warnings automatically through mobile phone networks which have a large penetration in rural areas.

⁶ In India the Government had banned all construction within 500 meters of the shoreline. This ban was violated almost all over the country. Based on the recommendations of a committee which went into this (Swaminathan, 2005), it is now proposed to define areas available for development near the coast on “scientific principles”.

These aspects have been studied extensively and there are no technical difficulties in implementing preparedness schemes. The impediments are socio-political e.g. how to overcome conflicting interests, population pressures and so on.

Insurance:

Insurance is one area which needs development in many parts of the world. For example in India, government property is not insured (as a policy) and insurance of private property in rural areas especially agricultural crops is almost non-existent. In the absence of insurance, the Governments step in and provide ad hoc relief after each event. This results in uneven and wasteful deployment of funds and blame games between various agencies and affected people. It also makes the assessment of losses difficult. An insurance policy linked to regulations of land use is desirable.

Answer to the second question:

The following are needed:

- (1) *Continued research for understanding the meteorological phenomena and the mechanisms of damage including the likely effects of climate change.*
- (2) *Pro-active preparedness for disaster mitigation which will include engineering, social and legal measures.*

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Germany*

1. What accounts for the dramatically increasing costs of weather-related disasters (specifically floods and storms) in recent decades?

Weather and damage changes are implied to be of global character. Weather systems and their changes occur regionally and often are different from region to region, these differences not smoothing out when going to a global scale. The same is true for damage. Economic and social systems show even higher degrees of regional and temporal differentiation. Whether the spatial patterns of weather patterns match the ones of the economic ones within any given time interval could be investigated with enough high quality data being available.

Moving back and forth in time in steps of decades means to assure the quality of the data used for any comparison purposes. The quality of weather data is rather well known. However, weather damage comes with rare weather events, with limited accuracy of the occurrence frequency data. Most societies have regulations that ensure the existence of protective systems to reduce damage. In principle that would mean damage only to occur if threshold values are exceeded. In practice damage occurs gradually and already at values far below design thresholds because of error, negligence, or ageing. The threshold values and their enforcement strongly influences the relation between size of a weather event and damage. Future data solely rely on climate model results with error estimates of modest accuracies. Economic analyses are usually confined to one particular country. To produce long time series is not simple (Maddison 2003). The results available show quite some variety in the economic structure and their changes, being different also from country to country. When a retrospective analysis for Germany is extended over 100 years or longer it means to go through 5 major political and economic systems, and quite substantial changes in the country's size and population. This becomes evident when looking at economic indicators such as national wealth, natural capital, fixed assets, human resources, gross domestic product, capital productivity, capital intensity, interest rates, and inflation rates. These parameters show country-specific and parameter-specific different and specific changes. This makes the formulation of the relation between the size of a rare weather event and the economic damage complicated and inaccurate, and there are few concrete analyses available in this field, and in there no systematic error estimates are given.

The methods that different nations apply to combine and employ their assets to generate well-being after a weather event are multifold, each one itself complex. Unquestionably, human resources is the major contributor to national wealth and usually left almost unharmed after a weather event. Damage caused by weather events is inflicted to a major proportion on fixed assets (Kunte et al. 1998). It is however plausible that the use of economic damage or cost as a proxy for rare weather event data is possible only with very limited reliability, in the end probably not allowing to draw any globally and century-long valid conclusions on a quantitative relation between rare weather events and damage.

2. What are the implications of these understandings, for both research and policy?

Although it might be difficult to make use of national economic data as proxy for weather data, there remains the challenge to anticipate future changes for each nation separately. Whether global indicators of the past allow extrapolations into the national future seems to be doubtful. Research needs to develop methods to quantify errors of past and future national weather and national economic changes, both separately and together. It may be that scenario

techniques are closest to allow results.

Policies –on a national basis- need to acknowledge that the whole spectrum of future changes needs a variety of adaptation strategies, integrating projected weather changes into them.

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GLOBAL WARMING AND / OR CLIMATE CATASTROPHE: CULTURAL DIMENSIONS OF AN ENVIRONMENTAL PROBLEM.¹

Hans von Storch and Werner Krauss

von Storch, H., and W. Krauss 2005: Culture Contributes to Perceptions of Climate Change. A comparison between the United States and Germany reveals insights about why journalists in each country report about this issue in different ways. Niemann Reports, winter 2005, 99-102.

When we talk about the weather, we also establish our social relations and construct the world we live in. This commonplace becomes relevant today when we talk about extreme weather events and climate change. There is a cultural dimension inherent in these discourses: people perceive and connect these phenomena differently in the United States and in Germany. Reactions to the Kyoto treaty made this obvious, and climate change again was hotly contested when the recent catastrophic hurricanes had to be explained. How to cope with these different perceptions? Time, history and media representations are often neglected factors in the scholarly discussions of climate change, but - as we shall show in the following – knowledge about cultural factors is indispensable not only for understanding differences between national perspectives, but also for adequate planning for catastrophe management.

Recent hurricane seasons have been extreme from the more recent United States' perspective. This year, the devastation was particularly severe when New Orleans was almost directly hit by hurricane Katrina. In comparing the 2005 hurricane season to previous ones, what surprised was not so much by the severity and frequency of the storms that made landfall, but the degree to which civil defence was obviously overwhelmed at a site historically known for its extreme vulnerability.

The basic events of the Katrina disaster unfolded much as did similar disastrous European storm surges in 1953 in the Netherlands and 1962 in Northern Germany. In all cases, the storms came as surprises after a long period of lull; underestimating the danger, thousands of people in the Netherlands and hundreds in Hamburg drowned. When police ordered evacuations in Hamburg, many people refused to leave the threatened zone – as did many people in New Orleans in 2005.

The difference among these situations was however evident from the societal response. In Hamburg, the then-unknown state minister Helmut Schmidt took the initiative. In spite of uncertain legality for the orders he issued, he called for the military, which turned out to be a key factor in catastrophe management, and it was the mythical beginning of Schmidt's political career, who later became chancellor of Germany. Shortly after the event, a new large-scale coastal defence program was instituted. When, 14 years later, a much more severe storm surge formed in 1976, Hamburg's coastal defence proved sufficient, and no serious damage occurred. In a reverse of this image-making, the Netherlands became famous for its coastal defence politics in the aftermath of the disastrous 1953 flooding, which became part of national identity.

What happened in New Orleans? To begin with, just as in Hamburg 1962, people underrated the site's (known) vulnerability and the potential damage. But then, little aid on the ground and insufficient catastrophe management led to four days of agony with close TV coverage. It became obvious that specific social factors made the meteorological extreme event a social catastrophe: a link emerged between race, poverty and vulnerability. There were rumours of massive looting and crime before the armed forces arrived. President Bush took the initiative too late, and only after widespread protests in the media and emerging social unrest.

¹ We are indebted to Katherine Arens for de-Germanizing our English and helpful thoughts.

But there is another crucial difference to be considered: the perception and interpretation of such extreme weather events have changed dramatically in the last 50 years. “Global warming” and “Klimakatastrophe” (climate catastrophe) anthropogenic climate change have entered the stage of public attention; extreme weather events are interpreted no longer as natural, but as man-made. Moreover, even though public opinion (and political practice) on climate change is differing in the US and in Germany, the media in both societies use the same discursive framework of vulnerability, even if it is constructed in culturally different ways.

The scientific construct of anthropogenic climate change

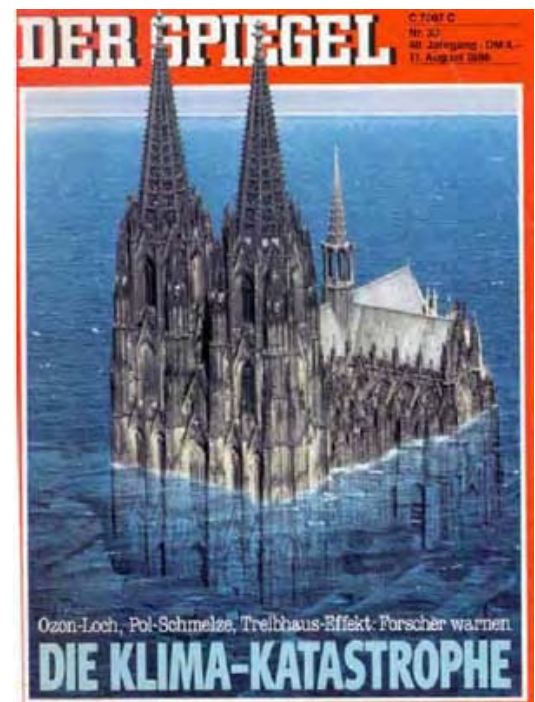
In scientific quarters where the dynamics and sensitivities of past and ongoing climate developments are studied, there is little doubt that today climate is changing significantly faster than in the historical past. As a consequence of this detection, one concludes that there must be non-natural factors at work. When different external factors are considered as possible causes, the most consistent explanation of this change attributes two-thirds of twentieth-century warming to the accumulation of greenhouse gases in the atmosphere, while another third is related to the sun's changing output. While a broad consensus in the scientific community asserts that rising temperatures are an effect of human emissions, a similar conclusion has not been drawn about anthropogenic changes in other weather phenomena such as windstorms in the tropics or at mid latitudes. Recently, a number of claims about hurricane intensity have been made. However, the hurricane statistics vary on time scales of a few decades; the data describing the significant upward trend cover just the last 30 to 40 years, with a lull commencing in the 1970s after an active period in the 1940s and 50s. Thus, the conclusion of an anthropogenic signal is methodologically premature.

However, climate change is not only a topic in the inner circles of climate researchers, but also in the public domain. The interplay between climate research and the public sphere, i.e. the public demand for orientation and options for strategies is one of the key constraints on current climate research. Given prevailing uncertainty about the scientific facts on the one side, and the high stakes for the public in general on the other, climate science has become a field contested for discursive reasons, not just factual ones, and so emerges as exemplary for what some social scientists call post-normal science.

The media representation of climate change in Germany....

While in the US public opinion, “global warming” is used to refer to a tendency towards warmer conditions, climate change in Germany is often framed more broadly, equated foremost with “Klimakatastrophe” (climate catastrophe). All disastrous weather events are interpreted as a result of climate change. The severe Elbe river flooding in August 2002 is exemplary in this regard²: the result was a national state of emergency, which at the

same time became a national symbol in the media: German reunification was symbolised in the nation's unified effort to collect donations in support of the victims and took on visible form as embodied in sweaty bodies piling up sandbags to prevent eastern Germany from further flooding. While media reports on flood mitigation and repair work dominated the first days after the events, the search for underlying explanations soon attracted even greater attention. Aside from presumably minor sins such as manipulating rivers beds and flood plains, the main culprit was quickly identified –



² For a detailed discussion of the media coverage, refer to Krauss, W., 2005 Beyond Facts and Fiction: The Elbe River Flood 2002 in the Media. In: Döring, Martin (ed.) Cultural Dimensions in River Management. The Case of the Netherlands and Germany. Hamburg: Hamburg University Press (in press)

climate change, brought upon us by ourselves. This explanation was not explicitly supported by scientists, but it was assumed by many commentators and read between the lines of many reports. The commentary in a regional newspaper in the flooded area is exemplary:

*"Now the flood finally reached our backyard. This flood confronts us with the "why," with the sins we have committed, with the search for its origins. Even without scientific certainty we know that the flood is a consequence not only of cosmic changes, but of our own way of living."*³

This is only one impressive example of an explanatory strategy which Germany's legendary weekly Der Spiegel had already dubbed Klimakatastrophe in 1986. Its cover became an icon for the German attitude towards climate change: Cologne cathedral, half submerged in a flood. The cover article's argument was based on plausible scientific knowledge claims: rising temperatures increase the volume of the ocean, melt ice sheets and fuel an accelerated atmospheric energy cycle, which together lead to higher water levels and more water vapour and thus to more extreme rainfall. A tendency in the eighties towards more violent North Atlantic and North Sea storms helped to support these claims empirically. Reference to such exceptionally vigorous and erratic weather events helped to implant the concept of Klimakatastrophe firmly in the public's mind because the theory was consistent with older culturally constructed views that the weather is getting worse and less predictable, as a result of nature's response to human misconduct.⁴

Yet since the mid-1990s, the severe wind-storms in Northern Europe again became less violent, a trend scarcely noticed by the media or the public. Also, it was found that the number and violence of storms increased starting around 1960 after a long period of weakening storm activity – and many analyses began just in about 1960, when good meteorological data became available for the region. Both in terms of the actual data available and public perception of it, this situation is congruent with more contemporary discussions on the increasing intensity of hurricanes in the Atlantic – an assumption that is also based on scarce data covering a too short time span of thirty years that indeed showed increasing storm intensity.

In Germany, the concept of Klimakatastrophe took on a new life and became a valuable asset in the public shift towards a more environmentally "conscious" political attitude, often with moral undertones: humanity in general is blamed for destroying the fundamental balance between nature and humans. Following in the tradition of romantic and protestant ethics, many symbols and stereotypes became correlated with German "Klima-Angst": the rise of the Green Party, the fall of nuclear industry, the collective task of waste separation and recycling in private households or the moralistic call to bike instead of driving. Closely connected and in reciprocal relationship with this public perception shift was the rise of German climate research – scientists used these cultural symbols to communicate with the public via the media, as popular figures in public discourse.

Interestingly, German climate scientists form a rather uniform phalanx of supporters of the concept of anthropogenic climate change. Only a few dissenters exist. They are not climate scientists and are hardly noticed by the public. In contrast, a handful of publicly identifiable individuals have emerged to dominate media discourse on climate change. They do not explicitly claim causal relationships between increased greenhouse gas levels and extreme events, but rather allude to the cautionary principle and point out that the extreme events would be "consistent" with future expectations. The public understands such weak causal explanations as overly cautious rhetoric about what they see as an established "fact": that such recent violent climate events as the Elbe or the New Orleans flooding are not natural but man-made and thus, by implication, avoidable (!). Consistently, then, the federal minister for the environment from Germany's Green Party more than alluded to the "fact" that the New Orleans disaster was self-inflicted by a stubborn

³ Sächsische Zeitung, 11. August 2002

⁴ For an account of historical western beliefs in extreme weather and adverse climate conditions, refer to von Storch, H., and N. Stehr, 2000: Climate change in perspective. Our concerns about global warming have an age-old resonance. *nature* 405, 615

US administration.

...and in the U.S.

In the U.S., the household term referring to anthropogenic climate change is not "catastrophe," but "Global Warming." Thus, the future will be warmer but not more variable or extreme -- a very different implicit projection than in the German metaphor for the situation. Not surprisingly, therefore, cold spells in the US are associated with jokes about scientists talking about global warming, while German scientists can use such events as further evidence for an evolving man-made disaster.



As in Germany, an interplay between science and the public is constitutive for the overall perception of weather events and climate change. From the beginning, public opinion (and research directions) was heavily influenced by long-standing disputes (rhetorical and real) between powerful social groups such as industry, environmentalists, scientists, and religious groups (with the creationists in science serving as a symbol for the blurring of boundaries among these parties). The term "sceptic" is in this context a completely respectable label for the opposition, and not a dirty word, as it is in Germany. Politics, the public sphere and science are engaged in the midst of a fierce debate on how to interpret scientific data and models - at least the parties "who care" are. The media thus in most cases present the problem of anthropogenic climate change as a conflict between two opposing schools of thought – and give both school similar space for advocating their views. Within the scientific community, in contrast, one finds the sceptics isolated and equipped often with poor arguments; nonetheless, their arguments are eagerly fostered by political and religiously motivated power groups who can command significant media attention. Despite such differences, however, a recent survey among European and North American climate scientists has revealed that these two scientific communities actually hold very similar views on the assessment and projections of future climate change.

In the past, US media stories about Global Warming were – and different from the case in Germany – rarely pegged explicitly to extreme weather events. And so, consistently, in the beginning of the Katrina-disaster, the Times-Picayune in Louisiana showcased local attitudes towards the hurricane in a characteristic caricature:



However, the talk about Katrina later changed. There was now no time for jokes, but a lot of talk about the “National Shame” in the American media. President Bush picked up on this public perception when he tried to “repair” American self-understanding and confidence in his almost biblical address to the nation:

“In the life of this nation, we have often been reminded that nature is an awesome force, and that all life is fragile. We're the heirs of men and women who lived through those first terrible winters at Jamestown and Plymouth, who rebuilt Chicago after a great fire, and San Francisco after a great earthquake, who reclaimed the prairie from the Dust Bowl of the 1930s. Every time, the people of this land have come back from fire, flood, and storm to build anew -- and to build better than what we had before. Americans have never left our destiny to the whims of nature -- and we will not start now.”

Contrary to the German attitude sketched above, the American construction of identity in relation to nature revealed in speeches like this is optimistic and far from self-criticism. President Bush never mentioned climate change or the industrial nations' role in causing it. He spoke about saving energy, but that reference was related to the potential damage to Texan oil refineries, not to a global ethical imperative. While in Germany, climate change became an issue for the media from the first day of the Elbe river floods in 2002 (and while the German media immediately covered New Orleans' catastrophe in headlines), the climate change discussion took more than three weeks to make it to cover stories about Katrina's aftermath in the leading journals in the U.S. – it will be interesting to see how long the interest in the issue will remain, given that infrastructure and social welfare concerns have predominated in public discussion.

Yet climate change has not been absent from US public discourse. In fact, using weather extremes as evidence for the need for reduction of greenhouse gas emissions into the atmosphere was promoted heavily by parts of the US elite in the late 1980s and early 1990s. After the Mississippi flooding and the 1988 drought, for example, a famous claim was made during a US Senate hearing: that the heat conditions in that summer were due to Global Warming. That argument was also used regularly to appeal for support for environmental policy, with then-Vice-president Al Gore as its most prominent public proponent. However, over the longer term, that campaign could not sustain its impetus, and so the link between extreme events and human actions lost its persuasiveness among the US media and for the US public. It had been oversold, and the political climate had changed, to assume the shapes it did in the Katrina disaster.

Conclusion

Media representations of extreme weather events and their embedding in overarching frameworks fluctuate, as do symbols over time, and the story of differing perceptions and resulting actions has not, and will not, come to an end. The boundaries between science, politics and public sphere are blurring, and climate research is one of the most prominent examples for this ongoing “post normal science” process. Bringing into this debate social science analysis, in particular with respect to different time horizons and media discourses, is not just adding a further element to the end of an analysis, but it is indispensable for understanding public dynamics and for designing appropriate catastrophe management in a world, which was, is and will remain to be vulnerable.

People react not only according to abstract concepts and scientific data, but to traditions, to experience and shared values – and, as we have shown, the scientific construction of facts is cultural, as well. If most Germans understand weather extremes as scripture written on the wall of impending, self-inflicted disaster, and if most American are willing to submit to climate extremes as given risks, these different attitudes have little to do with superior morale, responsibility, or rationality, but with deeply different culture value frameworks.

The German approach may have the advantage that it helps to institute a meaningful policy of sustainability with respect to environment and resources. The advantage of the US approach may be that it helps individuals adapting better to crises, with less fear. The disadvantage of the US approach is that people are also shielded from thinking about

sustainable energy and resource usage, while the Germans are lead to assume a missionary attitude, telling the world what is environmentally right and what is wrong. Some Germans seem to even believe that improved protection against extreme events is not really needed as soon as appropriate Klimaschutz (climate protection) measures will be implemented.

In either case, it becomes critical to examine how public and scientific rhetorics intersect to help create climate politics and research, not as ancillary to "real science," but as critical epistemological determinants of scientific attitudes and explanations.

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CLIMATE CHANGE IN PERSPECTIVE

Our concerns about global warming have an age-old resonance.

Hans von Storch and Nico Stehr

von Storch, H., and N. Stehr, 2000: Climate change in perspective. Our concerns about global warming have an age-old resonance. nature 405, 615.

Many people think that the threat of ‘global warming’ arose only towards the end of the twentieth century. But the idea of human (anthropogenic) interference with climate has an important — although often overlooked — historical dimension. Climate change, either natural or anthropogenic, has been discussed from the classical age onwards, evolving from the expected benefits of climate engineering to today’s fear of global disaster.

People have always been aware of climatic variation — in the freezing of rivers or success of harvests, for instance¹. Whether these changes were interpreted as natural or manmade depended mainly on the philosophy of the time. In the Middle Ages, change was seen as a natural process, the systematic deterioration of a living, and thus ageing, world. Anthropogenic changes were thought of as man’s attempt to fulfil God’s task of completing creation, whereas negative events were seen as a heavenly riposte to bad behaviour, such as punishment for tolerance towards witches².

By the eighteenth and nineteenth centuries, interest focused on the effects of deforestation and other forms of land use. The colonies of North America, for example, were thought to have become more temperate as a result of deforestation during colonization³. By 1890, climate change was discussed in modern terms: “Deforestation, as a part of agricultural expansion everywhere, must necessarily result in less rainfall and more frequent droughts. This view is most poignantly expressed by the saying: man walks the earth and desert follows his steps! ... The Italian government has been paying special attention to reforestation and its expected improvement of the climate ... The alternation of periods of heavy rainfall with droughts must be prevented ... In the United States, deforestation is seen as the cause of a reduction in rainfall ... The committee chairman of the AAAS has demanded decisive steps to extend woodland to counteract the increasing drought. In Vienna in 1873, the Congress for Agriculture and Forestry discussed the problem in detail. When the Prussian house of representatives ordered a special commission to examine a proposed law concerning the preservation and planting of forests, it pointed out that the falling water levels of Prussian rivers was one of the most serious consequences of deforestation, and could only be reversed by reforestation. The same concerns were raised in Russia.”^{4,5}

More exotic ideas about human influence on climate mirrored technological developments. Lightning conductors (in 1816 in Switzerland), nuclear explosions in the 1950s, supersonic transport in the 1970s, and space traffic have all been blamed for climatic deterioration⁶. In the first half of the twentieth century, optimism about the potential of science and technology was reflected in plans to improve climate on an almost hemispheric scale by redirecting the Gulf Stream or

¹ Lamb, H. H. *Climate, History and the Modern World* (Methuen, London, 1982).

² Glacken, C. J. *Traces on the Rhodian Shore* (Univ. California Press, Berkeley, 1967).

³ Williamson, H. *Trans Am. Phil. Soc.* 1 (1771).

⁴ Brückner, E. *Klimaschwankungen seit 1700 nebst Bemerkungen über die Klimaschwankungen der Diluvialzeit: Geographische Abhandlungen herausgegeben von Prof. Dr Albrecht Penck in Wien (Hölzel, Vienna and Olmütz, 1890).*

⁵ Stehr, N. & von Storch, H. (eds) *The Sources and Consequences of Climate Change and Climate Variability in Historical Times* (Kluwer, Dordrecht, 2000).

⁶ Kempton, W., Boster, J. S. & Hartley, J. A. *Environmental Values in American Culture* (MIT Press, Cambridge, MA, 1995).

Siberian rivers, or blocking the Bering Strait. Later, this optimism was replaced by concern that adversaries might develop 'climate weapons' — perhaps for modifying the global ocean circulation — and an international agreement banning them was prepared⁷. The possibility of a nuclear winter following from military action was discussed in the 1980s, as was the effect of burning oil wells in Kuwait at the beginning of the 1990s.

The modern concern about carbon dioxide as an agent of anthropogenic climate change can be traced back to the end of the nineteenth century and the Swedish chemist Svante Arrhenius. In 1933, a paper in *Monthly Weather Review* identified a significant warming trend, which in 1938 was related to the human greenhouse effect. This warming was followed by a global cooling, thought to be the first indication of a new ice age, accelerated by aerosols from industrial pollution blocking out sunlight. Eventually, Arrhenius's theory was revived, supported by the strong warming in the 1980s and 1990s, palaeoclimate findings and sophisticated modelling studies. As in the nineteenth century, the concept of anthropogenic climate change became news, advocated by scientists. Government bodies were established to advise on suitable action.

Although most of the historical concerns over climate turned out to be exaggerated, we are not claiming that the present concept of global warming is flawed. We are convinced that greenhouse gases are accumulating in the air, and strongly believe that near-surface temperatures are rising in response. But we are not convinced that present and future climate change will have a significant impact on society and global ecosystems.

Today, as in the past, the claim that anthropogenic climate change is associated with a serious impact on human society is still a hypothesis, often based on simplistic methodology. An important contrast with many of the earlier cases is that climate change is now perceived as negative. Of course, this view is not limited to climate change. Until the 1950s, it was thought that science would improve living conditions. Nowadays, it is often seen as a threat. When modern science scribbles on the wall, it is no longer about emancipation from nature but about possible disaster — nuclear war, genetic manipulation, climate change.

Many scientists realize that our knowledge of the climate system will always suffer from significant uncertainty because of its open, complex and heterogeneous character and the long timescales involved. Thus, studies of climate change are bound to be characterized by high uncertainty and high stakes, with public, antagonistic debates not only between scientists but also activists and other non-specialists^{8,9}. However, age-old concerns about extremes of climate are part of the cultural background², for scientists as well as the public. This subjectively genuine concern, nourished by the mass media, underlies the activist scientists, who wield the same apocalyptic scenario of drought, delugial floods and devastating storms as their historical counterparts.

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⁷ Ponte, L. *The Cooling* (Prentice–Hall, Englewood Cliffs, 1976).

⁸ Funtowicz, S. O. & Ravetz, J. R. in *Risk Analysis in the Private Sector* (eds Whipple, C. & Covello, V. T.) 217–231 (Plenum, New York, 1985).

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SHORT STATEMENT: ANITA WREFORD

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We are beginning research which aims to develop a method for assessing the economic impacts of extreme events associated with climate change, using forecasting of observed social costs of present day extreme events. The rationale is that present and previous events have documented costs, which we can use to inform future costs.

We are interested in determining the factors accounting for the increased costs of disasters in recent decades in order to project costs into the future. We would like to see whether we can represent 'learning' from previous disasters as an adaptation process that reduces costs in the future.

FACTOR ANALYSIS OF DISASTER LOSSES: CHINA CASE STUDY

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1. Introduction

As reported by the Ministry of Civil Affairs, China, the central government agency responsible for disaster management and mitigation (Jia, 2005) for the past 15 years, about 370 million people annually have been affected by various kinds of natural hazards, and thousands have lost their lives in China. Moreover, over the same period of time, about 4 million buildings and 500 million hectares of crops were destroyed, with direct economic losses of more than 120 billion US dollars each year on average (Figure 1). In the 1990s, disaster losses increased by 40% compared with the 1980s. Among all kinds of natural hazards that occurred, losses caused by floods, droughts and earthquakes were 80 to 90% of the losses, which was about 3 to 6% of GDP.

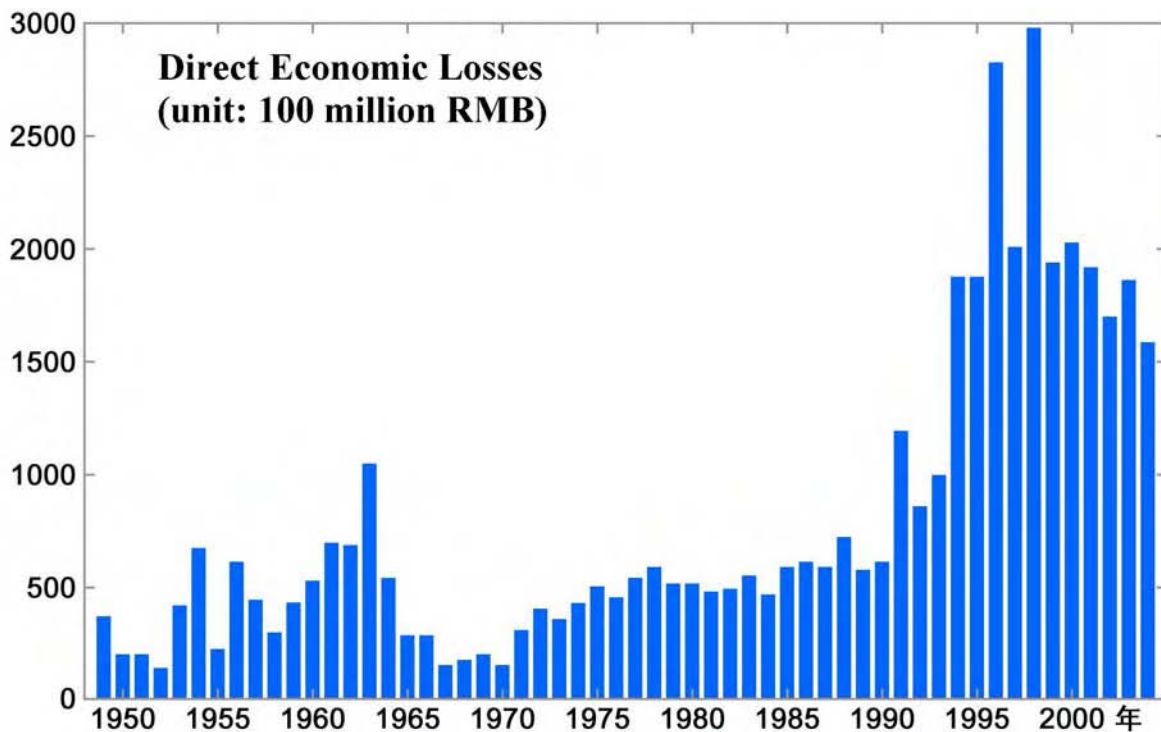


Figure 1. Direct Economic Losses Due to All Natural Hazards in China (Source: China National Disaster Research Group, 2000; China National Climate Center, 2005)

Floods and storms have been recognized as major hazards in China for more than 3,000 years, since agriculture always plays a dominant role in China's economy and society. For example, as historical records show, the Yellow river in northern China has flooded more than 1,500 times during the past 2,000 years and affected more than 250,000 square kilometers. Figures 2a, 2b, 2c and 2d show the time series of direct economic losses, populations affected, the area of affected crops, and the buildings that were destroyed by major floods and storms in China from 1990 to 2005.

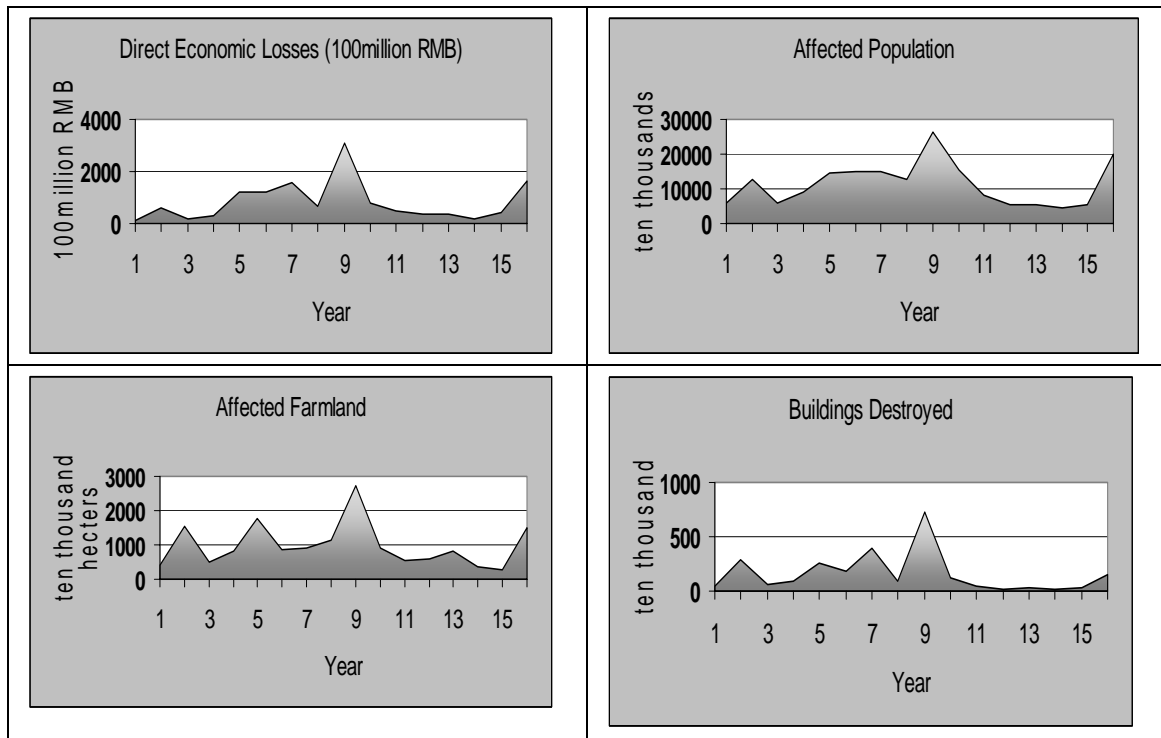


Figure 2. Time series of a) direct economic losses; b) affected population; c) affected farmland; d) number of buildings destroyed. (Source: Guo et al., 2005 and Ministry of Water Resources, 2006)

China’s complex geological topography and various climatic conditions render the country extremely vulnerable to hydrological hazards, including floods and storms. In general, the topography of China can be divided into three distinct steps: from the high mountains in the west, to many hills and flat valleys in the middle of the country, and ending in fertile deltas and vast flat alluvial plains in the east (Figure 3a). Most major rivers which originate from the high mountains in the west flow eastward, accelerating from the first step to the second step. The water then suddenly slows down when it enters the third step before flowing into the ocean.

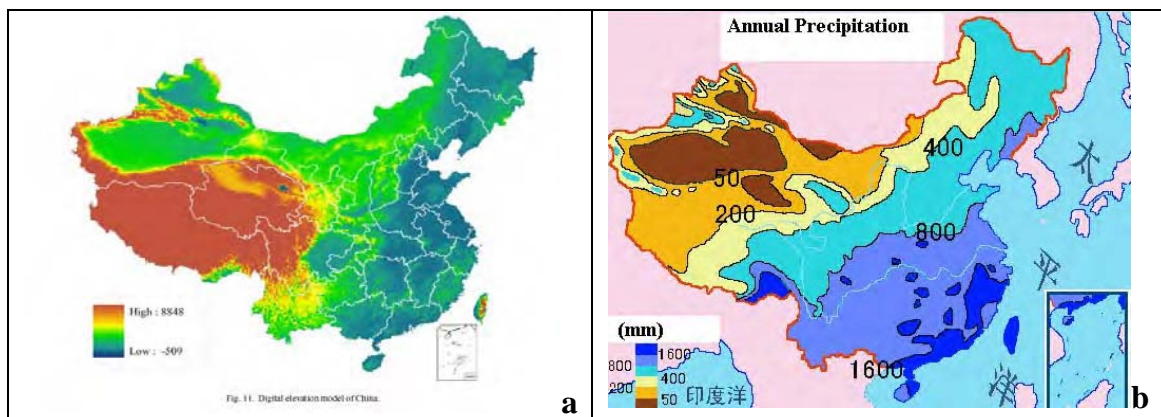


Figure 3 a) Topography of China; **b)** Annual Precipitation Distribution in China

Although China’s territory covers many different climate zones defined as torrid, subtropical, warm-temperate and temperate, most portions of the east and middle regions in China are governed by the monsoon climate, which brings significant spatial and temporal variations in rainfall patterns which peak in summer and are concentrated along the Yangtze river basin (Figure 3b).

2. Factors causing increased losses due to floods and storms

China has had the largest population and the fastest economic growth rate in the world for the past twenty-five years. It is not surprising that the major factors related to increased losses caused by floods and storms, as in other developed and developing countries around the world, can be traced to the increase in both population and wealth, as pointed out by Pielke Jr. and Landsea (1998) and others (e.g., Loster, 1999).

a. Population Increase

The population of mainland China surpassed 1.3 billion on Jan. 6, 2005, according to China's National Statistics Bureau (NSB) (Xinhua News, 2005). The increase in population, as shown in Figure 4, is not evenly distributed around the country. Most of the increase has occurred in eastern China partly due to migration from rural to urban areas, which also has experienced the fastest economic development

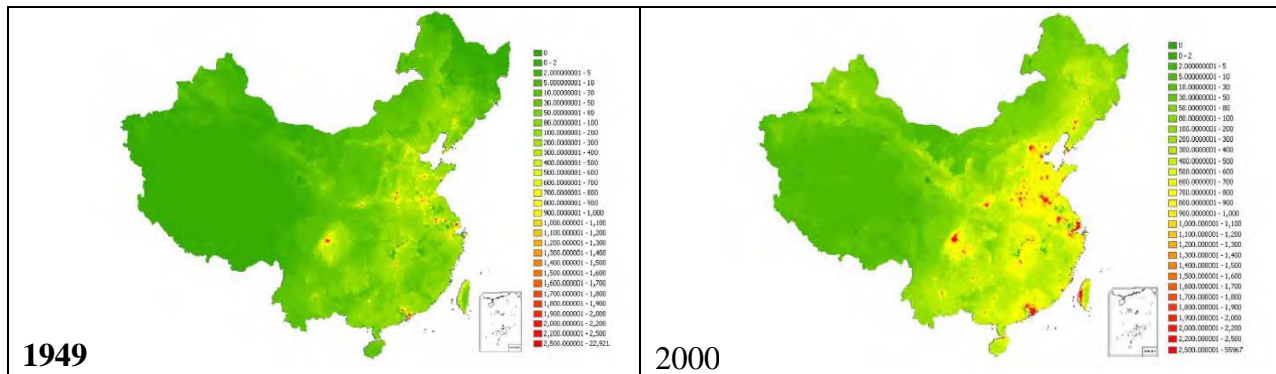


Figure 4. The population distribution of China in 1949 (left) and 2000 (right) in unit of persons per square kilometer. (Source: Tian et.al., 2004)

b. Wealth Increase

China has achieved remarkable progress in economic development since its reform and opening policy adapted in 1979. According to the statistics, the average growth rate of Chinese GDP was as high as 8.2% from 1979-2005 (National Statistic Bureau, 2005). China has become the world's fifth-largest economy in terms of GDP and has moved to the rank of a middle-income country, according to GDP per capita measures (exceeding \$1,000 US dollars in 2003). It is a miracle that China has kept a high economic record for such a long time. With such high growth in the economy, the Chinese people have also become richer. For example, the number of wealthy people, each with more than \$1 million US dollars in assets, has increased more than 12% every year (Merrylin Group, 2004). Meanwhile, a sizeable middle class is starting to emerge. The income increase in urban areas has kept a similar tempo with the growth of the national economy, with an increase in average employee salary of 16-33% in the past five years.

Although further studies need to be carried out in order to determine a reliable trend in China's flood and storm damage, based on a normalization of the damages that takes inflation into account, as well as changes in population and wealth, the increase of population and wealth obviously plays an important role in the increasing trend of losses. The other factors which have been considered in China, however, are highly dependent on the differing interests of numerous government agencies.

Factor 1: Weak Capacity in Hydrological Management (emphasized by Ministry of Water Resources)

For more than 50 years, China has built and reinforced over 270,000 km dikes of various standards, constructed more than 10,000 km of sea dikes, built 85,000 reservoirs of large, medium and small size with the total storage of 518.4 billion m³, and developed 97 flood detention and storage zones for major rivers, including the Yangtze river, Yellow river, Huai river and Hai river with a total area of 30,000 km² and total volume of 107.8 billion m³.

However, not only most projects along the major rivers were constructed with only a standard of withstanding the worst flood that might be expected over a ten to twenty year period but also after many years of mismanagement and overuse, it is estimated that at least 40% of these hydrological engineering projects are presently in various degrees of malfunction. As pointed out by the Ministry of Water Resources,

“The changes of flood control situation in China are mainly indicated as (a) the decline of the flood carrying capacities in river courses and flood detention capacities in wetlands which caused the flood stages higher and higher at the same discharge; (b) Flood-protected areas rely more on dikes for their safety that aggravate hardships in flood fighting; (c) inundated areas caused by river outflows have decreased, but that caused by local rainstorms increased; (d) the densities of inhabitants and properties in flood prone areas increased sharply, which have aggrandized flood damages and emerged the scarcity of flood-protected level in urban areas; (e) casualties in flood plains decreased, but the rate of casualties caused by torrents and mud-rock flows in gullies and valleys, and storm surges along coastlands increased; (f) the conflicts among different regions during flood control operations aggravated and hardness in harmonizing enlarged; (g) the management and maintenance of the flood control engineering system becomes more important, and demands on information system and decision-support system increased, and so on.” (Cheng Xiaotao, Ministry of Water Resources, 2005)

Since more than 70% of total national fixed assets, 44% of the total population, one-third of the farmland, several hundred cities, and a huge number of heavy industrial facilities and infrastructures are downstream of many rivers, the potential for increased losses caused by floods and storms is very high without appropriate prevention and mitigation management plans.

Factor 2 Environmental Degradation (emphasized by National Environmental Protection Bureau)

During the past 25 years, with increasing economic development but protection of the natural environment lagging behind, 70% of the rivers in China are now polluted. The major pollution sources come from municipal and industrial waste water and overuse of pesticides in agriculture. For example, in 2004, among a total of 661 cities, only 55% of them have waste water processing facilities and among these facilities, the efficient treatment rate is only 45.7%. As a result, when even small-scale floods and storms occur, polluted water from upstream flows downstream and can cause considerable damage to the agriculture and tourism businesses, as well as short-term and long-term impacts on the health of human beings and ecosystems.

The areas of land degradation, which leads to soil erosion in many river basins, are also increasing. Currently, more than 37% of the total land surface in mainland China suffers various kinds of land degradation problems, of which about 50% is directly caused by floods and storms (National Environmental Protection Bureau, 2005). Moreover, with the national policy of speeding up urbanization, many wetlands and lakes which used to be buffer zones for floods have been transferred to industrial use or replaced by apartment buildings. For example, in Shanghai more than 25% of water surface has been lost due to urban development (People’s Daily, 2003). As a result, in combination with increasing sediment deposition due to the soil erosion and land reclamation, many lakes and reservoirs have lost their capacities to hold floodwaters (Shankman and Liang, 2003).

Factor 3 Climate Change (emphasized by China Meteorological Administration)

Although northern China is still suffering from a long-lasting period of droughts starting in the 1980s, there is a trend toward an increase in annual precipitation in southern China, as shown in Figure 5 (Zhai and Wang, China National Climate Center, 2003). For the future, an increase of precipitation in China is also predicted by the IPCC based on different scenarios (IPCC, 2003). More precipitation in China usually means more floods and more frequent storms.

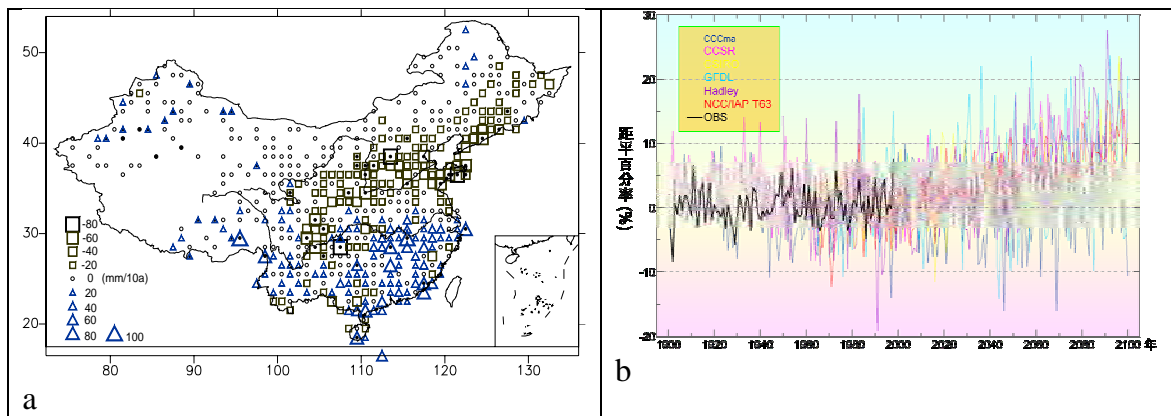


Figure 5. a) The trend of annual precipitation over China in the last 50 years (Zhai and Wang, China National Climate Center, 2003); **b)** IPCC prediction based on different scenarios (IPCC, 2003)

Factor 4 Political Game (stated by overseas scholars)

“A man who wishes to run the country well should give priority to flood control” is a saying handed down from generation to generation in the Chinese nation. Leaders, on the other hand, have often used flood disasters as an opportunity to show the people how powerful they are and to test how much control they can gain by moving resources around. As pointed out by overseas Chinese scholars, a large amount of the losses during the Great Yangtze River Floods in 1998 was mainly due to wrong decisions made by the leaders from the central government, who wanted to use the opportunity to test both the loyalty of the military and the strength of their power (Wang, 2005).

3. Implications for Research and Policy

For researchers:

First, many floods and storms should not only be categorized based on physical characteristics, such as wind speed and pressure as in the case of typhoons, but the social and economic impacts should also be considered. For example, in the Korean cases of Super-typhoons Rusa and Maemi, we found that “the significant differences in their physical characteristics led to different damages to the society” (Ye, 2005).

Second, a reliable, up-to-date monitoring, early warning and assessment system is needed. Again, in our Korea super-typhoon case study, it was found that the government agencies used either averaged data or out-of-date information when they dealt with these extreme events.

Third, since it is impossible for scientists to single out factors responsible for increases in flood and storm losses, future research on these issues should not only include the scientific community in different disciplines but also, and even more importantly, government decision makers, city managers, community organizations, planners, and insurance companies.

For policy makers:

First, as we discussed above, it is clear that different government agencies have their own needs and different working priorities when dealing with flood and storm disasters. Therefore, improving capacity of communication and sharing information among these government agencies is a must, at least in China’s case.

Second, a third party, for example, insurance companies, should play an important role in government assessments when decisions on hydro-meteorological issues are being made, such as major river diversions and other mega-scale hydrological engineering projects.

Third, floods and storms are repeating natural events. Humans dealt with these natural hazards even before the dawn of

civilization. Looking back into the history of other countries, one can easily find many similar lessons that have been learned and so many social, economic and political solutions that have been identified. The question is, as Glantz asked in his UN 16-country study on the impacts of El Nino, "Why are many of those solutions known by governments, researchers, and individuals learned but not yet applied?" (Glantz, 2001)

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DISASTER'S IMPACT: UNDERSTANDING AND ATTRIBUTING TRENDS AND PROJECTIONS OF DAMAGE AND LOSSES: THE ECLAC PERSPECTIVE

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Are there lessons to be learned from the recent disasters at the global scale? Are the numbers of disasters increasing and is their impact more severe? Is there a difference to be established among hazard exposure and the resilience, fragility and brittleness of human-made vulnerabilities? How do countries and societies manage risk, transfer it or disperse it. ECLAC has observed an increase in disasters' costs in recent decades. Not only has the replacement value gone upwards, given the global increase in a number of inputs' prices and materials.

1. Factors account for the increased costs of disasters in recent decades according to the research to ECLAC's experience

On the basis of recent years' analysis of disasters in Latin America and the Caribbean, particularly the 2004 and 2005 hurricane seasons (in the Caribbean and in Mexico and Central America) and ECLAC's involvement in supporting the World Bank's damage and needs assessment in the Indian Ocean countries after the tsunami, some trends are discernible in this increase that bear stressing:

- a) Demographic growth and the increased localization of human settlements near coastlines and river basins,
- b) Faster growth in the number of disasters associated with hydrometeorological phenomena rather than derived from volcanic or seismic activity (the 2004 Indian Ocean tsunami being a very severe and very long return period phenomenon).
- c) Increased sophistication and cost of infrastructure in vulnerable areas without appropriate risk reduction measures (for example increased agricultural production in floodplains and slopes without appropriate risk reduction techniques)
- d) Increase environmental degradation leading to increased exposure with insufficient defense mechanisms and natural environmental barriers to mitigate the impact of natural phenomena (hydro or geomorphologic)
- e) Climate variability cycles, larger variations of climate variables (rainfall, seasonal extremes, etc.), and climate change measured in such variables as seawater temperature, rainfall, drought and air temperature means as well as wind speed of extreme events are associated with impacts on non-adapted infrastructures.
- f) Development of new sectoral activities –such as tourism—that are located in highly exposed areas (particularly in beaches and coastlines of islands and territories prone to recurrent phenomena such as cyclones, hurricanes and tropical storms)
- g) Increased value added of economic activities that do not incorporate risk reduction financing as part of their financial, social and environmental viability and sustainability analysis.
- h) Differentiated social and economic impact in terms of asset losses, income and livelihoods in rural and urban areas, primary (agriculture, commodities, extraction industries such as mining, etc.), secondary (industrial production, industrial processing, manufacture, etc.) and tertiary (services, such as transport, communications and telecom., tourism, financial sector, commerce and trade, e-commerce and information technology), as well as income strata, age groups and gender.
- i) In spite of higher insured claims, in developing countries insured damage and losses are still a small percentage of total impact

- j) Globalization of information and improved assessment techniques also explain a more visible quantified impact and the inclusion of such previously non considered costs such as environmental, gender and cultural damage and losses

There is a growing literature that covers research on possible scenarios of climate change in the next 10 to 50 years, which would have severe consequences on human life and human activity.¹ ECLAC has a cumulative experience in disaster's impact assessment that started in Central America in the mid nineteen seventies. Given the nature of the developing countries of Central America and the Caribbean: the hazards faced, the high levels of vulnerability, the extreme exposure associated with both their geographic location and patterns of production and levels of development, major catastrophes overwhelm their capacity to respond. The fact that disasters surpass their response mechanisms is particularly acute not only in the emergency and immediate response phase but mostly in their resilience and need for external resources to undertake their reconstruction processes. This latter consideration led to the affected countries' governments to request ECLAC –as an intergovernmental technical cooperation part of the United Nations—to assist them in assessing the damages, losses and needs generated by disasters in order to validate or support their request for international assistance. Since the first assessment in 1973 to the latter ones in 2005, ECLAC has developed a methodology to assess in a systematic way damages (as impacts on assets and capital) and losses (as impacts on flows in terms of income, expenditures and value added that reflects on economic variables) that has increasingly being recognised, now being a part of the PROVENTION and World Bank's toolkit.

In response to several countries and institutions both in the Latin American, Caribbean and Southeast Asian regions, ECLAC carried out in 2004 and 2005 such assessments. In 2004, in association with other national, regional and international institutions, comprehensive assessments in six countries (Bahamas, Cayman Islands, Dominican Republic, Grenada and Jamaica). In 2005 participated –at the request of the World Bank—in the assessment of the Indian Ocean Tsunami, and with regional and international institutions in Central America and the Caribbean floods in Guyana and the impacts of hurricanes Emily, Stan and Wilma over a number of countries –namely Guatemala, El Salvador and Mexico. Additionally the ECLAC's assessment methodology is becoming a tool to assess the impact of climate change and potential adaptation measures and policies.²

The partial figure of damage and losses –in terms of assets lost, destroyed or harmed and of economic flows interrupted, increased or altered due to the damage—reaches an amount of more than US\$ 6,000 million dollars. If the reported damage in Cuba (US\$ 1,500 million) and in the state of Florida due to the four hurricanes is combined, the figure climbs to US\$ 37,600 million.

In summary, the cases analyzed by ECLAC this year show that 76% of the total impact was constituted by actual physical damage to assets (houses, businesses, roads and bridges, utilities, schools, hospitals and clinics, etc.), which imply losses in terms of flows of more that US\$ 1,454 million.

By sector, most of the damage affected the social sectors (47.5%) and productive activities (both goods and services,

¹ The author is one of numerous researchers involved in the fourth IPCC assessment. For a possible scenario of climate change see http://www.ems.org/climate/pentagon_climate_change.html.

² These studies may be downloaded at: <http://www.eclac.cl/mexico>, under recent documents. They are the following:

- Bahamas, "Hurricanes Frances and Jeanne in 2004: Their Impact in The Commonwealth of the Bahamas" (LC/MEX/L.642/Rev.2, LC/CAR/L.23/Rev.2), 8 December 2004
- Cayman Islands, "The Impact of Hurricane Ivan in the Cayman Islands" (LC/MEX/L.645/Rev.1, LC/CAR/L.25/Rev.1) 8 December 2004
- Dominican Republic, "Los efectos socioeconómicos del huracán Jeanne en la República Dominicana" (LC/MEX/L.638), 3 November 2004
- Grenada : "Macro-Socio-Economic Assessment of the Damages Caused by Hurricane Ivan" (as part of a OECS led mission), September 7th, 2004
- Haiti : « Le cyclone Jeanne en Haïti: dégâts et effets sur les Départements du Nord-Ouest et de l'Artibonite : approfondissement de la vulnérabilité » (LC/MEX/L648, LC/CAR/L27), March 2005
- Jamaica: "Assessment of the socioeconomic and environmental impact of Hurricane Ivan on Jamaica" (LC/MEX/L.636, LC/CAR/L.22), 20 October 2004

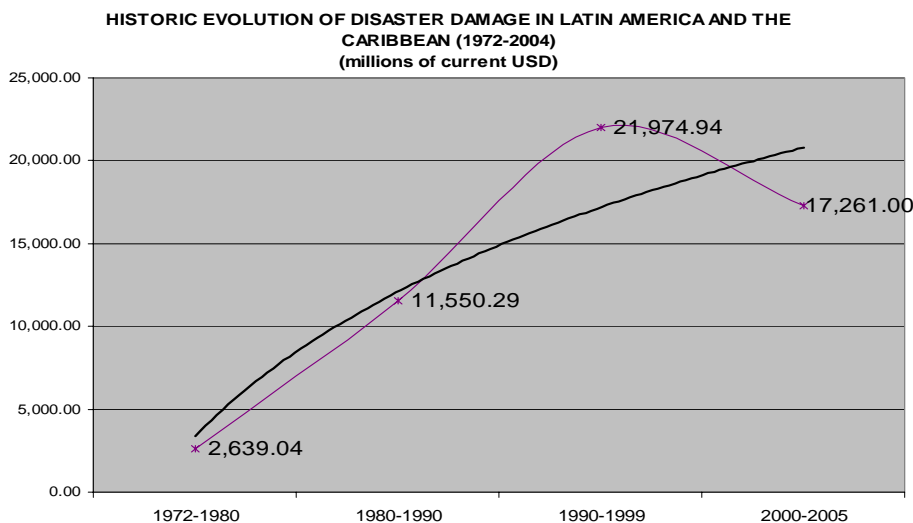
35.2%, namely tourism). Damage and losses to infrastructure and utilities such as electricity, water and sanitation, and transport represent 15.6%, and the direct environmental impact, since most of natural resources are expected to recuperate, is 1.3%. This, nevertheless, does not imply that environmental action in terms of clean up, restoration and preservation of habitats and better environmental management is of lesser importance. In reality the amount of accountable damage pointedly signals that environmental assets and their services do not receive adequate valuation. The impact in terms of GDP is quite severe in most cases: 212% in Grenada and 138% in the Cayman Islands.

If the impact suffered by other territories and countries not appraised such as the Netherlands Antilles, parts of Mexico or the State of Florida, is added, damage would certainly exceed the total figure indicated of US\$ 37,600 million, once the impact in the overall economic performance of these economies is taken into account. As pointed out and is well known, in the more developed territories and countries insurance coverage and national response capabilities will compensate for the losses in the short to medium term but will, nevertheless, mark this season as one where the issue of sustainability of the present patterns of physical and spatial settlements will have to be reassessed in order to prepare these territories to move from prevention of unexpected events to adaptation to ever increasing damage if no appropriate measures are taken.

However, from a social point of view the most severe socioeconomic and human toll, was concentrated in the least developed, smaller countries affected, whose capability to rebuild and return to the path of growth and development is limited given the lack of appropriate insurance coverage, institutional response and preventive policies. This is particularly the case of Haiti and Grenada, but other economies with fragile environment and indebted or weakly performing economies were burdened by the severity of the events. In Grenada the total impact was estimated to be almost US\$ 889 million, which is equivalent to more than twice (2.12 times) the current value of last year's GDP.

An additional relevant conclusion is that even though most damage occurs in the private sector, it falls on Governments to take care of and assist those segments of the population with lower income, which are highly dependent on basic agricultural or fishing activities that are affected. Productive activities rank high in the amount of damage and losses and in some cases the ensuing losses (economic flows affected) will persist for a long period of time, in some instance years. Infrastructure vulnerability is enhanced by poor environmental management and environmental degradation, leading to high productive risks and huge human suffering.

Some figures that come out of recent assessments done by ECLAC:



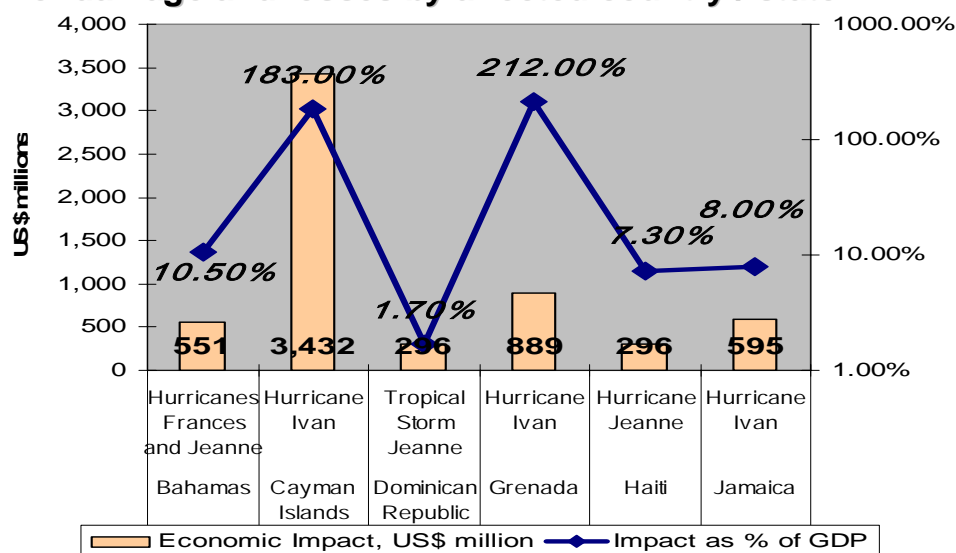
IMPACT OF DISASTERS IN LATIN AMERICA AND THE CARIBBEAN – 1972-2005 (based on ECLAC assessments)						
PERIOD	AFFECTED POPULATION		TOTAL IMPACT (CONSTANT 2004 VALUE)			
	Deaths	Directly affected population	TOTAL	DAMAGE (to assets)	LOSSES (in flows)	External impact
1972-2005	115,176	35,463,890	232,259.40	150,335.00	80,424.30	77,221.00
YEARLY AVERAGE (on the basis of ECLAC assessed disasters in Latin America and the Caribbean)	3,490	1,074,663	7,038.20	4,555.60	2,437.10	2,340.00

The Caribbean 2004 hurricane season exemplifies different experiences in terms of damage, losses and response that are relevant to the sustainability and capacity to mitigate and adapt to extreme events, even more so than the tsunami.

Economic impact of 2004 Hurricane Season (based on assessments made by ECLAC)		
Island / State	Economic Impact, US\$ million	Natural Event
Total of ECLAC assessed damage and losses	6,059	Ivan, Frances and Jeanne a/
Bahamas	551	Hurricanes Frances and Jeanne
Cayman Islands	3,432	Hurricane Ivan
Dominican Republic	296	Tropical Storm Jeanne
Grenada	889	Hurricane Ivan
Haiti	296	Hurricane JeannE
Jamaica	595	Hurricane Ivan
Florida	30,000	Jeanne, Charley and Frances
Cuba	1,500	Hurricanes Ivan and Charley
Total (including Cuba and Florida)	37,559	

Source: ECLAC

2004 Atlantic Hurricanes: Relative and absolute impact of damage and losses by affected country / state



The 2004 and 2005 hurricane season further show that built vulnerability is not necessarily development related but more closely associated with inappropriate risk appropriation and valuation and with costlier infrastructure, more value added related infrastructure and negative externalities being not assumed by the industrial and commercial sectors. Additionally it shows that the government's assessment of risk and their preparedness to face its consequences and reduce risk is also not necessarily related to levels of industrialization.

2005 Atlantic Hurricane season			Deaths	Directly affected population	Total impact (millions of USD)	Damage (to assets)	Losses (in flows)	Per capita impact on affected population	
Date	Location	Type of event	Population	Total impact (millions of USD)					
January	Guyana	Flood due to intense rainfall in December/January period in coastal floodplains in Georgetown and Albion	34	274,774	465.1	418.3	46.8	1,692.70	
October	Guatemala	Torrential rains, tropical storm Stan	1,583	474,821	988.3	421.1	567.2	2,081.40	
October	El Salvador	Torrential rains, tropical storm Stan, and Ilamatepec (Santa Ana) volcano eruption	69	72,141	355.7	196.2	159.5	4,930.60	
July-September	United States b/	Dennis, Katrina, Rita	1,698	900,000	200,000.00	65,000.00	135,000.00	222,222.20	
July-September	Mexico b/	Emily, Wilma, etc.	64	2,680,571	2,200.00	1,250.00	950	820.7	
August	Cuba b/	Emily	4	63,300	413.2	322.8	90.4	6,527.50	
Other events a/		Dennis	16	2,500,000	1,400.00	950	450	560	
			1,134	3,474,389	150	100	50	43.2	
TOTAL	Assessed by ECLAC		1,690	885,036	2,222	1,358	864	2,511.00	
TOTAL	(not including United States)		2,900	6,002,307	5,559	3,236	2,174	926.2	
TOTAL	(INCLUDING UNITED STATES)		4,598	6,902,307	205,559	68,236	137,174	29,781.20	

Source: ECLAC estimates

Nota: Data for Mexico and United States are partial and reflect preliminary estimates. In the case of Mexico the complete assessment is in process by the official technical entities.

a/ Includes volcanic eruptions, earthquakes and floods in other countries and are an estimate on the basis of partial data.

b/ Based on diverse sources, not official estimates.

Just as accountability in public spending is linked to transparency, risk transfer must be linked to risk appropriation. It is still dramatically true that risk transfer tends to be made on false premises: instead of having a larger number of financial instruments of risk transfer, society tends to transfer its losses and disaster related damage to the state.

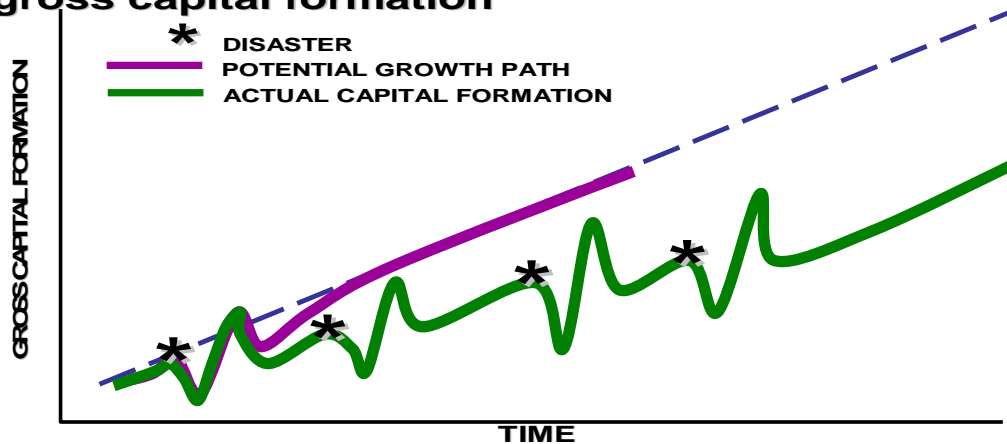
Some comments are also possible in the context of the type of disasters that are being faced and the type of damage they cause.

Geomorphologic events (seismic, volcanic, etc.) or non climate related have larger damage than losses –affect more severely infrastructure but cause relatively less losses than climatic ones. Nevertheless the number and impact of meteorological or climate related ones –including drought—seems to be growing, according to recently assessed disasters. The table summarizes the composition of disasters assessed by ECLAC over the years.

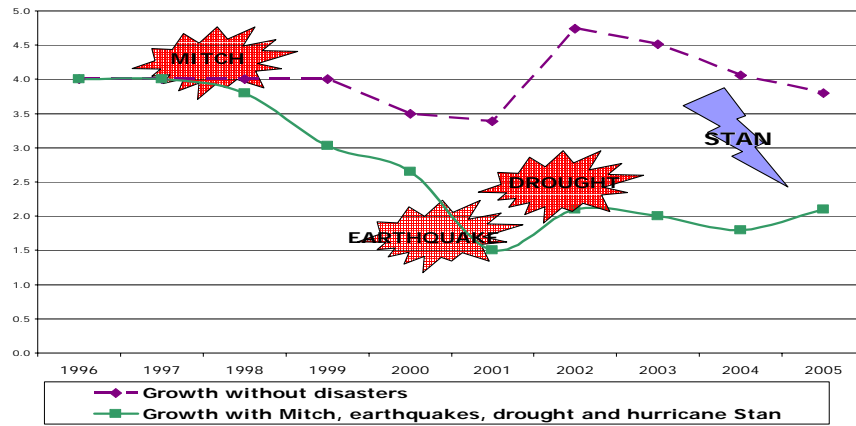
DIFFERENT IMPACTS OF DIFFERENT EVENTS (as observed in ECLAC assessments, 1972-2005)						
	AFFECTED POPULATION		TOTAL IMPACT (constant 2004 prices)			
	Deaths	Directly affected population	TOTAL	DAMAGE (to assets)	LOSSES (in flows)	External sector impact
METEOROLOGICAL (CLIMATIC) EVENTS	50,424	24,945,145	118,926	73,382	43,304	35,600
GEOMORPHOLOGICAL (SISMIC, VOLCANIC) EVENTS	64,752	10,518,745	113,334	76,953	37,120	41,621
Droughts	35	2,200,000	10,599	5,888	4,712	3,141
TOTAL ASSESSED EVENTS	115,176	35,463,890	232,259.40	150,335.00	80,424.30	77,221.00
Meteorological as % of total	44%	70%	51%	49%	54%	46%
Droughts as % of total	0.07%	8.82%	8.91%	8.02%	10.88%	8.82%
Damage composition						
Total				64.70%	34.60%	33.20%
Meteorological or climatic				61.70%	36.40%	29.90%
Non-climatic				67.90%	32.80%	36.70%
Droughts				55.50%	44.50%	29.60%

Trends of disaster’s recurrence and impact and their implication for the economic dynamism of a country and its development path are illustrated in recent cases such as El Salvador and others. The following graphs correlate disasters relative damage and its implication for development over time.

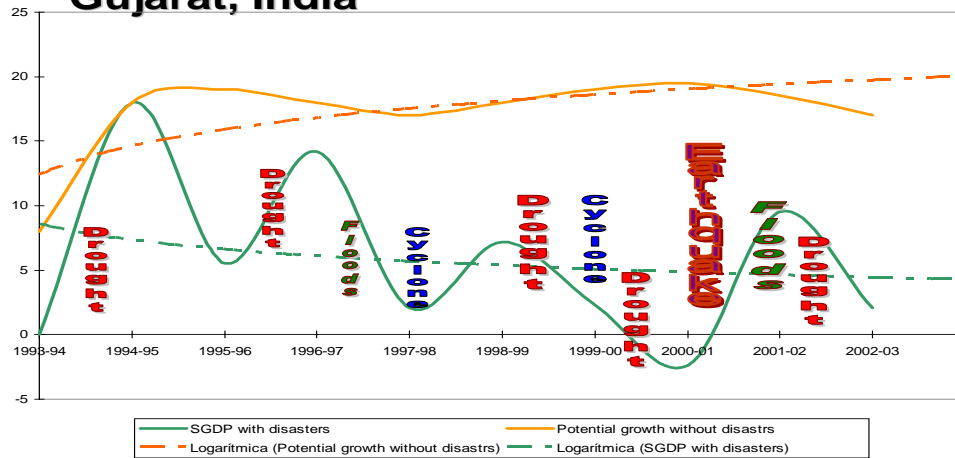
CUMULATIVE IMPACT of successive disasters on gross capital formation



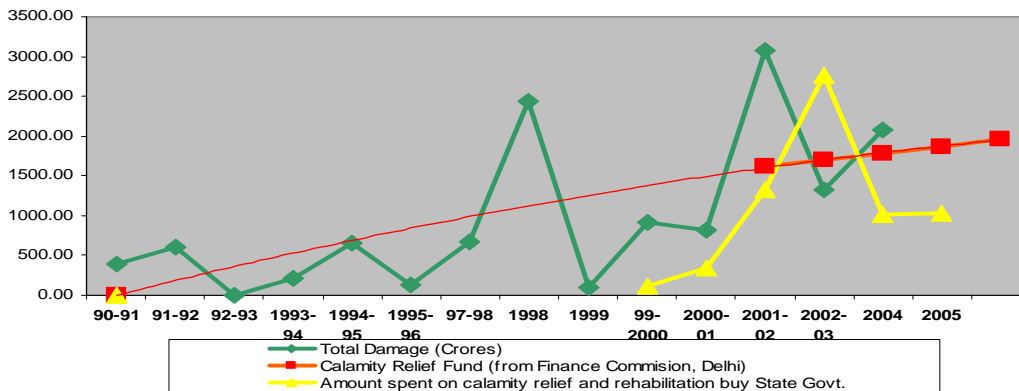
Disasters Impact on El Salvador's GDP



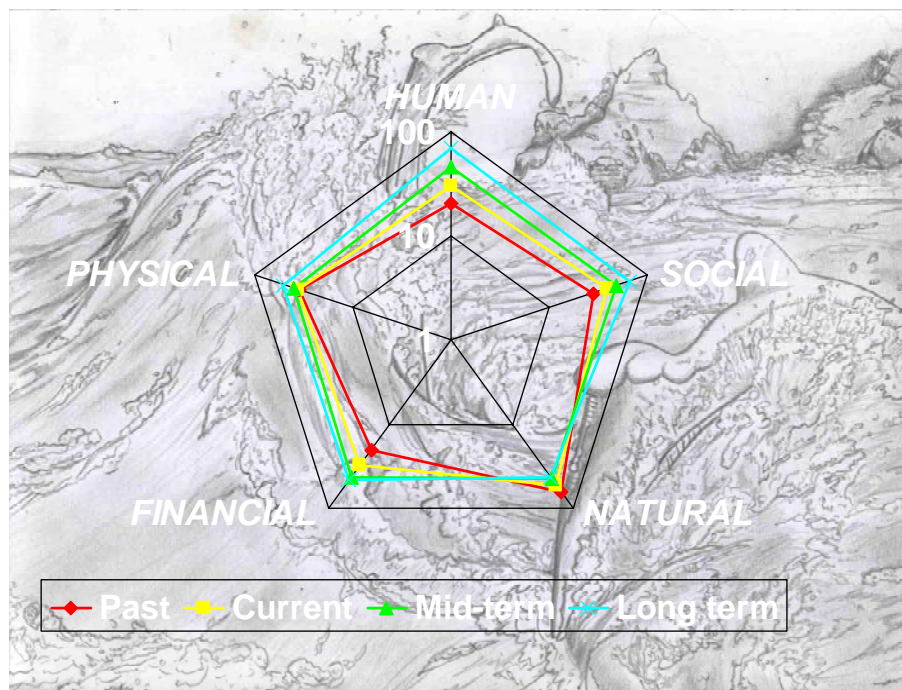
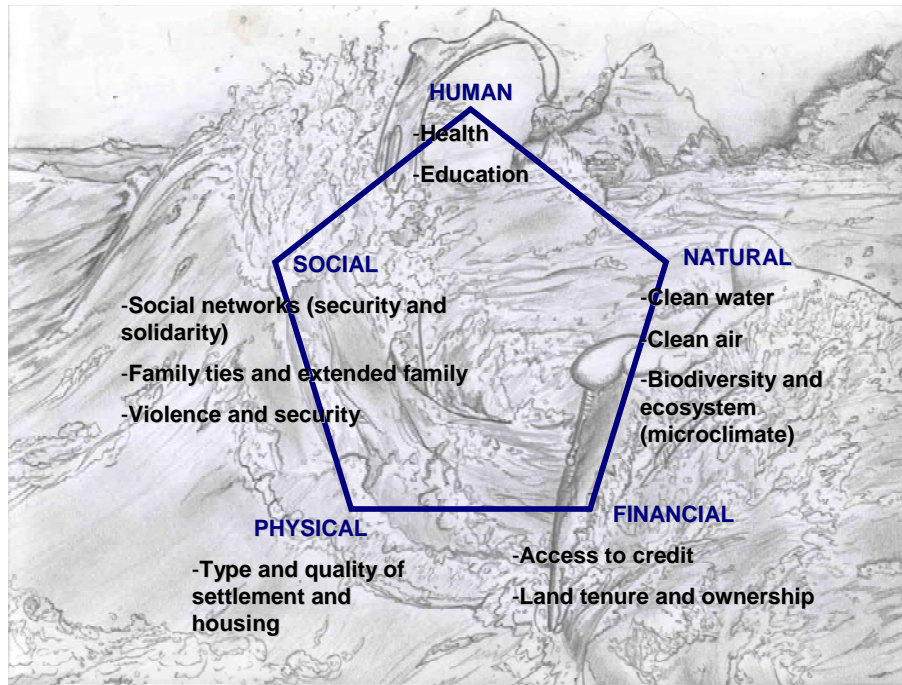
Impact of disasters on GDP: State of Gujarat, India



Gujarat (INDIA): Total Damage from disasters and Calamity fund budgeted resources (Crores of Rupees)



The effect, of a cumulative nature, that disasters have distorts, transforms and changes the development pattern of a society. If natural, human, physical and political factors are considered, their evolution will be affected by disasters in such a way that is not appropriate to consider such events as merely external shocks: they become –due to their recurrence and lingering effects—an intrinsic element of the process that has to be tackled. That is to say that in modeling a disaster’s impact, as could be done by the use of econometric models be they general or of partial equilibrium, the disaster becomes over time an endogenous variable.



Post-disaster needs must be seen in a wider context: extreme events may be drivers for change. In brief the experience of re-insurers is a good example of financial adaptation to change. I seems a lot more difficult to promote the social adaptation to changing vulnerabilities and exposure. In that sense both the Asian tsunami and the “Katrina effect” seem relevant: extreme events for which society had not adapted. In the first instance due

Risk transfer becomes a crucial element in disaster reduction. Traditionally it has been made in what may be categorized as a spurious way, by not internalizing risk as part of the viability (economic, financial, social, environmental) and having private investment externalize risk to society at large, placing demands on government. Similarly, countries, particularly developing countries with high vulnerability and insufficient resources to sustain their development process, transfer risk to the international community. Thus the balance of resources from the international community and governments concentrates heavily in response and reconstruction investment, rather than on risk reduction, prevention, mitigation and adaptation. On the other hand, the “virtuous” alternatives to risk transfer imply recognizing risk and accepting responsibility in facing it, at both the individual and institutional levels.

Thus disaster reduction requires, first, appropriation and responsibility which come from appropriate regulatory and institutional frameworks and, second, economic and financial instruments that provide leverage to attain the risk reduction goals. Such instruments are relevant as part of macroeconomic policies of compensation and development. In a concrete sense, appropriate investment in risk management and transfer will generate pre-disaster leverage and reduce damage (in a manner similar to anti-cyclical policies such as price compensation funds for commodities). But that is only part of the risk management equation. The other is more at the microlevel, focusing on having investors internalize risk (invest in its reduction on the basis of the profitability of not losing such investment in the face of disasters) instead of externalizing it to the rest of society. Also at the micro level, governments – as part of appropriate social policy – should generate resources and community based resilience. It seems fair to say that state-assisted responsibility and solidarity are needed instead of irresponsible charitable and paternalistic responses. The use of community-based institutions and instruments such as microcredit associations, self-help groups, community women groups has been successful in some instances, namely in some countries in Asia and is worth pursuing.

2. Some implications of these understandings, for both research and policy

Recent ECLACs experience points out to information requirements and technical and analytical gaps that require further research and attention. On the basis of this observation, some of the most pressing research priorities are listed.

- a) Risk appropriation and risk transfer,
- b) The state’s responsibility vs. the individual and social responsibility to reduce risk.
- c) Better assessment of risk as the complex result of hazards, recurrence, vulnerability and exposure.
- d) The correlation of built risk with demographic, economic and social variables.
- e) Moral hazard assumed by states and inappropriate protection.
- f) Development goals, such as poverty reduction or the United Nations Millennium
- g) Development Goals or the World Bank’s Poverty Reduction initiatives and the negative impact that disasters have on them. While it is still true that the composition of damage shows that in developing countries human costs are higher than economic ones, it is also true that development related investment is lost at higher rates and in relative terms economic losses are also higher in those countries. That is to say that even though in absolute terms economic losses are larger in industrialized countries, once they are measured relatively to GDP or the overall economic assets of countries, it is the developing ones that suffer most while they are also the least covered by insurance, contingency funds or other such risk bearing and risk transfer instruments.

Recent literature and studies produced by ECLAC

The list includes not only recently completed studies but new or forthcoming work.

- ECLAC updated (2003/4 Handbook, <http://www.eclac.cl/mexico>)
- Valuation of cultural assets (K. Vespars, ECLAC, draft, 2005)
- The 2004 hurricanes in the Caribbean and the Tsunami in the Indian Ocean. Lessons and policy challenges for

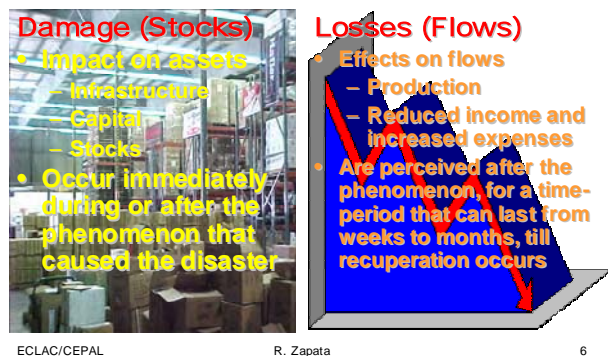
development and disaster reduction (Ricardo Zapata Martí, LC/MEX/L.672, August 2005, Estudios y perspectivas series

- No. 35
- Economic impact of the 26 December 2004 Indian Ocean disaster (Asian Disaster Preparedness Center (ADPC), prepared by Roberto Jovel, 2005, non-published)
- Efectos en Guatemala de las lluvias torrenciales y la tormenta tropical Stan, octubre del 2005 y Perfiles de proyecto, LC/MEX/R.895, Noviembre de 2005
- Efectos en El Salvador de las lluvias torrenciales, tormenta tropical Stan y erupción del volcán Ilamatepec (Santa Ana) octubre del 2005 y Perfiles de proyecto. LC/MEX/R.892, November 2005
- Características e impacto socioeconómico del huracán "Emily" en Quintana Roo, Yucatán, Tamaulipas y Nuevo León en Julio de 2005, LC/MEX/L.693, December 2005
- See also 2004 Assessments in the Caribbean (Grenada, Bahamas, Cayman, Dominican Republic, Gonaives/Haiti, Jamaica and in Guyana (both 2005 and 2006) (<http://www.eclac.cl/mexico>)
- Drought in Belize in 2004-2005an assessment of its economic impact, A report prepared by International Consultant Roberto Jovel, for use in a training seminar on the assessment of disaster impact, held in Belmopan, January 2006.
- Natural Disaster Assessments case studies in Southeast Asia, presented to the REGIONAL WORKSHOP ON METHODOLOGIES TO ASSESS SOCIO-ECONOMIC IMPACTS OF NATURAL DISASTERS, 19 - 21 October 2005
- United Nations Conference Centre, Bangkok, undertaken under an ESCAP/BCPR/ECLAC project.
- Methodological proposal of country studies for IDB project on indicators of disaster management and risk indicators, and First reports on national case studies on disaster's impact and risk management infrastructure for Mexico, Chile, Colombia, Nicaragua and Jamaica (<http://www3.cepal.org.mx/iadb-eclac-project>)

What is the methodology?

The socioeconomic and environmental impact evaluation methodology has been developed in Latin America by ECLAC³ since the mid 1970s (the first requirement made by a government to have an assessment was the case of the 1972 earthquake in Managua, Nicaragua).

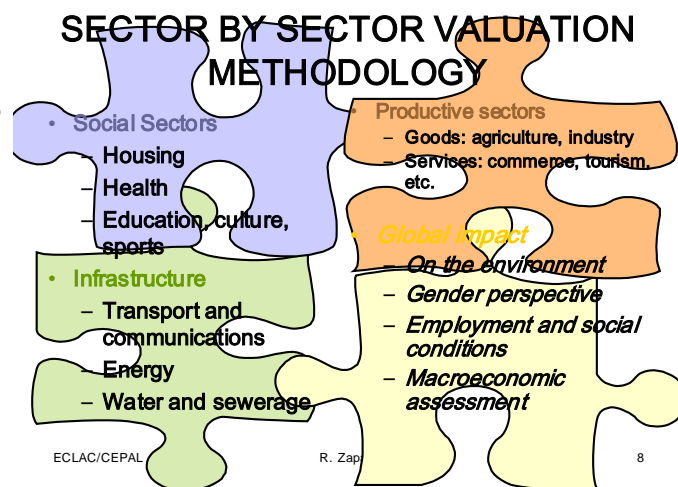
Main Concepts



The main concepts used in a systemic sectoral approach are of a stock flow analysis. This entails first assessing the damage (partial or total) in assets, i.e. quantifying firstly the physical damage as miles or km. of road, miles or meters of bridges, number, type and size of buildings (i.e. houses, schools, hospitals, factories, warehouses, churches, museums, etc.); machinery, stocks of production, land for agricultural use, forest and natural reserves, beaches and ecological systems such as coral reefs; number of classrooms, hospital beds, etc. The valuation of these may be calculated in terms of present actuarial or book value (for insurance purposes, for example); at replacement value (current market

value of construction of similar structures), real estate value, proxy prices in the case of environmental assets in terms of services rendered by asset damaged or lost. Valuation may also be attempted in terms of reconstruction that introduces hazard mitigation, vulnerability reduction or risk management measures.

Once damage and its value are established, the economic consequences of that damage are assessed in terms of flows affected, sector by sector. These refer to the current value of production lost, reduced or deferred; additional production, distribution and marketing of production, trade in goods and services, increased government expenditures, and public service utilities (either provided privately or by the state); and reduced income both at the personal and entrepreneurial level as well as in terms of public finances. Reduced income to the state will be associated with reduced economic activities, special tax holidays given due to the disaster which can be of a general nature (reduction or elimination of import duties for example) or location specific to favour the disaster area. Other potential flow impacts could occur in the external sector, such a reduced exports or increased imports, and on the financial side, transfers received (be it private as remittances from nationals abroad or public as charitable contributions), new donations and grants as well as reconstruction credits. On the plus side



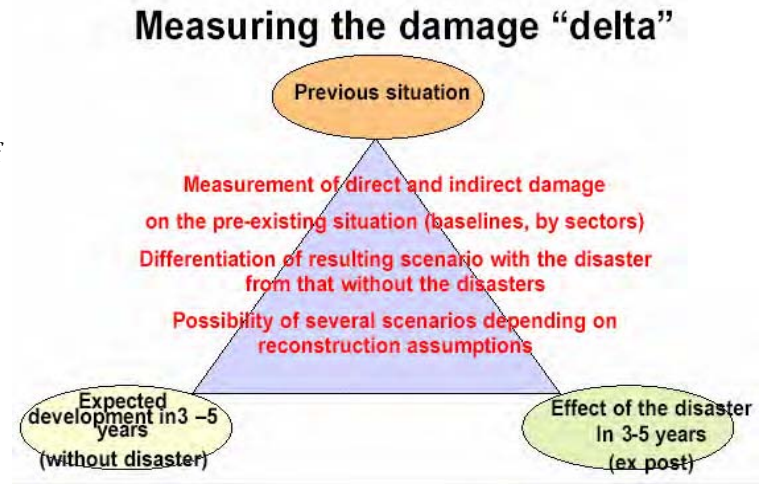
Damage (direct impact) refers to the impact on assets, stock, and property, valued at agreed replacement (as opposed to reconstruction) unit prices. The assessment should consider the level of damage, i.e., whether an asset can be rehabilitated/repared, or has completely destroyed.

Losses (indirect impact) refer to flows that will be affected, such as reduced income, increased expenditure, etc. over the time period until the assets are recovered. These will be quantified at present value of such flows.

³ See <http://www.eclac/mexico>, under “desastres”. Handbook for the evaluation of the socioeconomic and environmental impact of disasters (LC/MEX/G.5, July 2003) available at the following web pages: <http://www.eclac.cl/mexico>, (“desastres”), http://www.worldbank.org/hazards/knowledge/other_res.htm, and <http://www.proventionconsortium.org/toolkit.htm>.

also should be considered insurance and reinsurance payments from overseas. The sum of damage and losses, sector by sector, constitute the total impact of a disaster.

These impacts, assessed sector by sector, as flows variations resulting from the disaster, are then used—in their value added component—to estimate the macroeconomic impact of the disaster. The purpose of such an exercise is to establish the gap—or delta—that the economy as a whole and its components will experience. In fact three alternate situations are analyzed: the pre-disaster situation and trend (baseline situation), the non-disaster expected performance, and the post-disaster impact. This impact, in its entirety, without any potential reconstruction or response, constitutes the base scenario. To consider the



reconstruction needs (as distinct and different from damage and losses) several possible scenarios may be considered on the basis of the system’s absorptive capacity, that is, the resources available for reconstruction (from insurance and reinsurance, contingency or emergency funds, or credit available). Alternatively the base scenario serves to establish the financial gap to be filled, considering the reconstruction strategy (and its cost) that is put forward by the relevant stakeholders.

What is the use or purpose of the evaluation?

The general purpose of the evaluations is to provide a preliminary assessment of the damage and losses after a disaster in order to identify immediate recovery and longer-term reconstruction needs, and to determine the economic and financial implications of the event. The assessment’s conceptual basis is a stock/flow analysis that evaluates effects (i) on physical assets that will have to be repaired, restored, replaced or discounted in the future and (ii) on flows that that will not be produced until certain assets are repaired or rebuilt.

The end product will be a consolidated summary of damage and losses that provide the extent and breadth of a disaster’s impact, in quantitative, sector by sector, geographically specific terms that are stratified by affected groups, stemming from information compiled immediately after the event. It should not be considered a definitive assessment, but rather a preliminary understanding, compiled in a timely manner, to inform urgent recovery efforts. This quantification offers two further results: a determination of the relative size of impacts on relevant economic variables (by use of macroeconomic analysis and scenario modelling under different assumptions for the reconstruction potential and needs); and an analysis of the resource gap that these reconstruction scenarios pose to the government and to the affected population.

Use of Assessment Report

The evaluation’s most important function is to provide decision-makers and stakeholders with a quantitative basis to request recovery funding assistance, and to design a reconstruction strategy. The quantification, given its sector by sector nature, allows for concrete, specific proposals for action in sector or geographic terms. It is a tool for determining priorities (importance vs. urgency) and sequencing (timeline for reconstruction process), i.e. to restore livelihood through income and employment while physical reconstruction of housing, production, and infrastructure proceed.

How to proceed: when and how the methodology is applied

Past experience indicates several needs. First, a team must be established to collect, organize, and analyze the necessary sector by sector information, from profiling existing baseline to superimposing damage and losses with a unified and

comparable approach. The team should be multidisciplinary and inter-institutional, with clearly designated focal points to compile and present the data in a comparable manner –so that they can be summarized and factored into a macroeconomic scenario exercise. Each focal point should have common terms of reference. The global analysts (e.g. macroeconomists, environmental economists, gender experts) will proceed to use the emerging data of damage and losses to: contrast the disaster scenarios to the non-disaster trend; make environmentally related damage and losses visible; and differentiate men and women’s impact and roles in the post-disaster process.

Second, a deadline must be established to submit the final report deadlines for submission of sector data (quantification in standardized format with agreed common criteria) and accompanying descriptive text must be set depending on the final deadline. The description will include not only narratives of the event’s impact on the sector but also the criteria and assumptions made to establish damage and loss figures.

Third, a deadline must be set for completion of a global analysis, and this deadline must be discussed and made compatible with a strategic reconstruction proposal. Caveats as to accuracy of available data, methodological considerations and assumptions made must be specifically addressed. The timing for the assessment should be such that, without losing its timeliness, it does not interfere with the ongoing emergency, particularly the search and rescue, although thinking of the future in terms of the needs for the reconstruction process is an immediate task to be pursued since some actions are required to be undertaken promptly, especially those related to providing housing solutions, health and education services, and recovery strategy. Additionally, discussion of the future serves as a therapeutic measure to overcome trauma. The main concern is that it does not interfere with immediate life-saving activities and emergency relief operations.

Each sector team should consult and exchange information with each other to avoid duplication, share data of common interest or of interest in more than one sector, and identify information gaps or lack of information. The sector specialist will not only gather information on baselines and the disaster’s impact on them (i.e. damage and losses), but on reconstruction needs in the form of sectoral strategic responses. These can be used as input to develop an overall reconstruction strategy and possibly project proposals.

The strategic proposal will include a framework for action, based on pre-existing policies or development strategies, focusing on adaptation of the latter to the needs for the reconstruction, prioritize and sequence the process, define resource gaps to be filled from government, private and external sources, and profile execution processes in which affected populations and other stakeholders can play key roles in reconstruction.

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Ryan Crompton obtained both his BSc (Advanced Mathematics) (2001) and Postgraduate Diploma in Accounting (2003) from Macquarie University. He joined Risk Frontiers at the completion of his studies and is responsible for the research and development work associated with Risk Frontiers' tropical cyclone loss estimation model (CyclAUS).

Other recent work includes a report prepared for the Insurance Council of Australia in which various indexation methods were explored and applied to their historical list of insured natural disaster losses. Other interests include the pricing and structure of catastrophe bonds, and he has previous experience in numerical ocean modelling and the analysis of mining risk.



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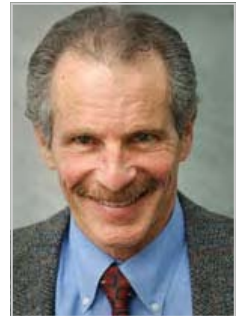
Andrew worked for 27 years in Aviva insurance group, in a number of senior technical and operational posts, starting with General Accident in 1973, and retiring from the position of Director of General Insurance Development in December 2000. He served as the chief author on Financial Services and later reviewer for the Intergovernmental Panel on Climate Change in its Second, Third and Fourth (due 2007) Assessment Reports in Working Group 2, and carried out similar duties for official UK and EU reviews of climate change. He also chaired two studies of climate change by the Chartered Insurance Institute (1994 and 2001), and is currently recruiting the writing team for a third report due in 2007.

Andrew obtained BSc (Hons) in Pure Mathematics at Edinburgh (1970), MA in Operational Research at Lancaster (1971), and PhD in Technological Economics at Stirling (1978), and is Fellow of Chartered Insurance Institute (1990), and Fellow of Royal Meteorological Society (1992).

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In the weather derivatives department of AXA Re, he was originally responsible for providing expertise regarding the underwriting of weather derivatives, and developing tools to efficiently manage the exposure. He is now mostly involved in the risk modelling department of the company, in charge of studying climate hazards variability and providing guidance for the management of the property book of business.

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He is co-author/co-editor of five books, and has a number of research papers to his credit. He has received several awards and fellowships including the prestigious Advanced Postdoctoral Research Fellowship of the Max Planck Society (Germany), which was awarded to him to work at the Max Planck Institute for Chemistry (MPIC) in Mainz, Germany, for three years. Based on his outstanding research work at the MPIC – Mainz, the Scientific Steering Committee of the global change SysTEM for Analysis, Research and Training (START), Washington, D.C., U.S.A., honored him with the 2004 START Young Scientist Award. To learn more about Dr. Gurjar see: <http://www.iitr.ernet.in/departments/CE/people/faculty/facthtml/bholafce.htm>.

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Richard has fourteen years of experience as a researcher and senior researcher on societal vulnerability and adaptation to climate variability and change. He has been a principal investigator in a number of collaborative projects, including WISE, DINAS-COAST (which he co-ordinated), ATEAM, Security Diagrams, cCASHh, NeWater and ADAM. In addition, he has provided research and consultancy services to UNDP, UNEP, UNFCCC, GEF, World Bank, OECD, WHO, IUCN, Germanwatch, the European Commission and the governments of the Netherlands, Germany, Norway and the United Arab Emirates. He has been a lead author in the IPCC Second and Third Assessment Reports and the Millennium Ecosystem Assessment, and a co-ordinating lead author in the IPCC Special Report on Technology Transfer and the Fourth Assessment Report. He co-organised the seminal IPCC Workshop on Adaptation in 1998 and the Potsdam Workshop on Adaptive Capacity and Development in 2001.

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Emma Tompkins is a research fellow at University of Oxford's Centre for the Environment and Tyndall Centre for Climate Change. Emma's previous experience has been in multi-disciplinary projects. Her specialisation is in institutional adaptation to environmental change, environmental management, participatory approaches, integrated and inclusive coastal zone management, multi-criteria analysis (MCA), contingent valuation methods, stakeholder analysis and conflict management. Her research interest lies in developing a theory of adaptive capacity to climate change. This area of research includes understanding the determinants of adaptive capacity; what motivates individuals and societies to respond to natural hazards; and identifying the linkages between adaptive and mitigative capacity.



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Hans von Storch is director of Institute of Coastal Research of the GKSS Research Centre and professor at the Meteorological Institute of the University of Hamburg. From 1987 - 1995, he was Senior Scientist and leader of the "Statistical Analysis and Modelling" group at the Max Planck-Institut für Meteorologie (Hasselmann division). In 1996, Hans von Storch became director of the Institute of Hydrophysics at the GKSS Research Centre and professor at the Meteorological Department of the University of Hamburg. In 2001, the Institute of Hydrophysics became part of the Institute of Coastal Research. Within that institute, he is director of the division "Systems Analysis and Modelling".



His research interests are climate diagnostics and statistical climatology, specifically detection and attribution of anthropogenic climate change, variability and change in storminess and related marine variables (storm surges, ocean waves), regional climate change; use of paleo proxy data to study climate variability and change, transdisciplinary context.

Hans has published eleven books, and numerous articles and is in charge of a number of projects. He is member of the advisory boards of *Journal of Climate* and *Meteorologische Zeitschrift*, *Annals of Geophysics*,

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Hans studied mathematics, physics and Danish at the University of Hamburg, and received a diploma in mathematics in 1976. While a student he also worked as a programmer at the Department of Oceanography. He went on to receive his Ph.D. from the Meteorological Department of the University of Hamburg in 1979, and his "Habilitation" in 1985.

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Qian Ye, after obtained his Ph.D. degree in Satellite Climatology from Oregon State University in 1993 and worked with NOAA and Chinese Academy of Sciences for seven years, is now working in Center for Capacity Building, National Center for Atmospheric Research in the field of weather and climate related impacts on society. He has worked with Dr. Michael Glantz, CCB director, to promote an education and training program so called Climate Affairs Program around the world, especially in Asia including China, Great Central Asia and Southeast Asia. He has worked with China Meteorological Administration and universities as well as local and national government agencies to develop social and economic impact research programs around China. He is also working with China National IHDP committee as deputy general secretary and with Chinese Academy of Meteorological Sciences as President assistant. Currently, he is leading an international research team to conduct a social and economic impact assessment project for WMO/WCRP Beijing 2008 Olympics Forecasting Demonstration Program. As a special advisor for the newly established China Weather TV, he is helping CWTV to develop a research program on better disseminating natural hazard information based on different technologies including traditional media such as TV, radio and newspapers as well as new media such as internet, cell phones and satellite radios.



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Professionally Ricardo has worked for the UN/ECLAC since 1975. Previously he was editor and researcher at the Special Projects Department of the Mexico office of the a major international editorial house (1968-1969); Assistant researcher, Economics Department, Universidad Católica del Perú (1972-73); Assistant professor, Economics Department, same institution (1972-73); Lecturer on Macroeconomic Theory and International Trade, Universidad Católica de Guayaquil (Ecuador) (1974-75); Columnist and editor, "El Comercio" daily newspaper, Quito (Ecuador) (1973-1975); contributor and executive editor, "Vistazo" weekly newsmagazine, Guayaquil (Ecuador) (1974-1975).

His areas of expertise are in economic matters, international trade, and economic and social impact of natural disasters.

In the United Nations Economic Commission for Latin America and the Caribbean, he worked at the Joint ECLAC/FAO Agricultural Division (Santiago, Chile), 1976-81; was Trade Officer, Subregional Office for the Caribbean (Trinidad y Tabago), 1981-83; Economic Affairs Officer, Joint ECLAC/FAO Agriculture Unit, subregional Headquarters in Mexico 1983-1987, Chief, International Trade Unit at the same office, 1987-2005, and since 1989 to date has been the Focal Point for Disaster Evaluation of ECLAC. In those capacities he has represented ECLAC at numerous events, conferences and intergovernmental meetings. Has been responsible for several interdisciplinary research projects at the Subregional Headquarters, and conducted numerous expert-group meetings on issues such as trade, competitiveness, integration, tourism, small and medium size enterprises. Has taken part in numerous training activities in Central America and the Caribbean, among them five regional courses on integration for Central American officials, jointly with SELA (Latin American Economic System), in the framework of a co-operation project of the G3 countries, funded by the Mexican government.

Ricardo has participated in a number of conferences, symposia, seminars, on trade issues and on the valuation and socio-economic impact of natural disasters. Among the latter he attended the United Nations World Conference on Natural Disaster Reduction, held in Yokohama, Japan, in 1994, International Forum that took place at the end of the International Decade for the Reduction of Natural Disasters (Geneva, July 1999), and the Second World Conference on Natural Disasters, held in Kobe, Hyogo, Japan, in 2005.

In the field of disasters he has led numerous assessment missions in the Latin American and Caribbean region, coordinated the current edition of the ECLAC methodology for disaster evaluation (published in 2004), provided technical assistance to the World Bank's Hazard Risk Management Team (including the assessments of the 2004 Tsunami in Indonesia and India), and coordinated technical cooperation projects between ECLAC and the Interamerican Development Bank and the United Nations Development Programme Among the latter he attended the United Nations World Conference on Natural Disaster Reduction, held in Yokohama, Japan, in 1994, and the International Forum that took place at the end of the International Decade for the Reduction of Natural Disasters (Geneva, July 1999).