

Earthquake, flood, nuclear accident

The triple disaster of Tohoku in Japan stunned society, the scientific and economic community.
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Floods
Severe floods in Australia, the USA and Thailand

Climate summit
Decisions postponed

Risk management
Three-dimensional modelling increases transparency

EDITORIAL

Dear Reader,

The disaster in Japan on 11 March 2011 has made clear how vulnerable society and the economy are in the face of geophysical events, which have been receiving less attention in recent years due to the all-pervading discussion on climate change. The Tohoku quake was also possibly the first natural disaster leading to long-term energy policy changes (nuclear phase-out in Germany and Switzerland, cancellation of the introduction of nuclear power in Italy) in numerous countries far away from the affected region. Our column on page 56 sheds light on background factors of the hazard posed by geophysical risks.

“This is totally different from anything we have ever experienced”, observed Japanese earthquake researcher Professor Norio Okada, referring to the catastrophe in his home country. He was one of the participants in an international panel of experts invited by Munich Re to examine this dominant 2011 topic from different perspectives so as to improve understanding of it. The ramifications of the event pose new challenges for the scientific community and the insurance industry regarding issues such as the complex economic interactions involved and the quality of hazard maps, earthquake models, early warning systems and disaster response organisation. What lessons can politicians, scientists and insurance industry learn from this event – not only for Japan but also in the global context? Answers to this question can be found in an article on page 12.

With economic losses amounting to some US\$ 380bn, 2011 has been the most expensive natural disaster year to date, far surpassing the previous record (US\$ 220bn) set in 2005. At US\$ 105bn, insured losses also reached a new high. The loss figures were dominated by 2011's earthquakes – in addition to Japan, above all the devastating event in New Zealand. The year also saw disastrous floods in Australia, Thailand, France and Italy and the tornado outbreak in the USA. Weather-related risks in the USA and Canada are constantly altering as a result of anthropogenic climate change and natural climate cycles like La Niña. We report on such phenomena and other topics in the chapter entitled “Facts, figures, background” on page 40. A special publication on “Weather risks in North America”, our in-depth analysis of the natural hazard situation in this region, is due to appear in May 2012.

And, now, I would like to wish you an interesting read of our latest edition of Topics Geo.

Munich, February 2012



Torsten Jeworrek
Member of the Munich Re Board of Management and
Chairman of the Reinsurance Committee



NOT IF, BUT HOW

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STUDY
**“The Limits to Growth”:
 40 years on**

In 1972, researchers from the Massachusetts Institute of Technology (MIT) published “The Limits to Growth”, a report commissioned by the Club of Rome. It explored the global effects of industrialisation, population growth, food shortages, the depletion of natural resources and the destruction of habitats. The impact of greenhouse gases on our climate was also an issue, even at that time. Forty years on, the study, which made headlines when it first came out, is as topical as ever, with the ongoing debate on what we can do about the world’s rising population, our consumption of natural resources and the effects of climate change.

>> Information on the Club of Rome at www.clubofrome.org



MUNICH RE FOUNDATION
 DIALOGUE FORUMS
**Who controls the world’s
 destiny?**

Upheaval in the Arab world, the nuclear phase-out in Germany, Europe’s debt crises: What political, economic and social forces are behind these events? What part is played by natural resources and new media forms – who determines the power structures of tomorrow? These are just some of the issues that will be in the spotlight at the 2012 dialogue forums.

>> Further information is available at www.munichre-foundation.org



DISASTER RESEARCH
New IRDR working group

The International Council for Science (ICSU) has established the DATA (Disaster Loss Data and Impact Assessment) working group as part of its Integrated Research on Disaster Risk (IRDR) programme. The tasks to be carried out by the working group include identifying the loss data required for effective disaster risk management, defining binding standards and methods for loss-data collection and management and exploiting synergies between organisations dealing with loss data. The working group is chaired by Munich Re’s Geo Risks Research.

>> Further information can be found at www.irdrinternational.org



NEWS IN BRIEF

Pole position for Munich Re in Green Rankings: Munich Re came first in US “Newsweek” magazine’s global Green Rankings. With a score of 83.6 points (out of 100), Munich Re beat last year’s winner IBM (82.5) into second place and was well clear of other companies from the insurance sector.

Munich Re’s new scholarship programme Munich Re’s scholarship programme has been revamped. As of 2013, the two existing, long-standing scholarships will be replaced by the Munich Re Scholarship Programme. The Horst K. Jannott Scholarship will be held for the last time in 2012, but the Alois Alzheimer Scholarship has now been discontinued.

The three-month curriculum of the new Munich Re Scholarship Programme is aimed at high potentials in client companies throughout the world, and is designed to equip them to address the challenges of today’s globalised insurance industry.

Princeton’s solar energy campaign heats up in 2012: Munich Re Reinsurance America, Inc. has concluded a contract with SunPower Corp. – a leading solar energy equipment provider – for the design and installation of a carport solar generation system. Thanks to the 2.5-megawatt system, Princeton office will be able to cut its electricity bill by some US\$ 500,000 per annum.



NATHAN Risk Suite award finalist

The Commission of Geo-Information Business (GIW) of the German Federal Ministry of Economics and Technology presents its annual GeoBusiness Award in recognition of innovative ideas in the field of geoinformation. In 2011, Munich Re's NATHAN Risk Suite was one of the three finalists.

Modern integrated risk management requires a detailed knowledge of geographical environment. Munich Re's NATHAN (Natural Hazards Assessment Network) Risk Suite optimises your assessment of natural hazard risks, from entire portfolios down to individual risks at address level – worldwide. Clients can select the most suitable product or module according to the number of risk locations to be analysed and the level of accuracy and depth of integration required within their work processes. NATHAN clarifies complex interrelationships and provides more accurate pricing, faster processing times and portfolio management support.

NATHAN Risk Suite works with high-resolution maps and satellite imagery from Microsoft's Bing Maps. Individual risks can be pinpointed and the surrounding area reviewed. The natural hazards exposures of complete portfolios can also be analysed – a real-time web service is available on request, which is directly linked to our clients' workflows.

In addition to online services, NATHAN Risk Suite is also available on DVD. Over 50,000 copies have been distributed, making it Munich Re's most popular product. Needless to say, as in the past, the World Map of Natural Hazards print product is included in our NATHAN Risk Suite package.

>> For further information go to:
www.munichre.com/touch/naturalhazards/en



Earthquake, tsunami, nuclear accident – The triple disaster of Tohoku

On 11 March 2011, the largest earthquake ever recorded in Japan shook the northeast of the country. The tsunami triggered by the quake not only devastated several hundred kilometres of coastline but also led to the nuclear disaster at Fukushima.

Alexander Allmann

The magnitude M_w 9.0 earthquake occurred at 2.26 p.m. local time at a depth of 30 km along the subduction zone off the east coast of Honshu Island. The epicentre was 130 km to the east of the coastal town of Sendai and approximately 370 km north of Tokyo. It was the fourth-strongest event worldwide over the past 100 years and triggered a 10-m high tsunami. In some bays the run-up was even higher than 40 m. Two days previously, there had been a magnitude M_w 7.2 foreshock. The strongest aftershock (M_w 7.9) occurred 40 minutes after the main shock.

Although the earthquake hazard is generally considered very high in Japan, the location and strength of the event were surprising. According to the official Japanese earthquake model HERP (Headquarters for Earthquake Research Promotion), which also forms the basis of all commercial earthquake models, a maximum magnitude of M_w 8.3 had been assumed for this region. Whereas the northern part of the area affected has been devastated several times already in its history by powerful tsunamis (as in 1611, 1896 and 1933, for example), a similarly high tsunami probably only occurred in the southern region (Sendai) in 869.

The massive tsunami caused by the earthquake on 11 March devastated several hundred kilometres of coastline.

Based on scientific analyses of such historic tsunamis and using GPS measurements, the average recurrence periods now expected for a magnitude M_w 9.0 mega-quake range from 440 to 1,500 years in this region of Japan.

In view of the strength of the earthquake, the length of the rupture surface responsible for the quake (450 km) is very small, but the maximum displacement of up to 50 m at the rupture surface is extremely large. The fact that such relatively small rupture surfaces can cause quakes of such a magnitude also raises questions about maximum magnitudes in other subduction zones around the world.

Stress field change across much of Japan

The strong ground motion continued for several minutes and reached a peak value of 2.7 g (g = gravitational acceleration). Due to its size, and thanks to the numerous seismic monitoring stations, no other earthquake in the world has ever been so well recorded. According to an initial analysis of the values measured, the high-frequency peak ground accelerations (PGA) extending up to a distance of some 100 km from the rupture surface were significantly higher than expected; at greater distances they were considerably lower. The percentage of long-period ground motion at all distances from the epicentre was distinctly lower than had been predicted by current models.

The quake altered the regional stress field below much of Japan. In addition to the anticipated aftershock activity in the area of the rupture surface, this also led to a detectable increase in seismic activity in regions at greater distances. The result was several quakes with magnitudes in the range of M_w 6.0 at a distance of up to 300 km from the original aftershock zone. An increased activity rate over a time period of several years can be expected after megaquakes of this magnitude.

The earthquake claimed more than 15,800 lives, over 3,400 people are still missing and almost 6,000 were injured. More than 300,000 houses were destroyed or severely damaged and over 600,000 buildings were slightly damaged.

Overall losses of over US\$ 200bn

Fortunately, the damage in Greater Tokyo was comparatively low. Most of the damage was concentrated in the prefectures of Iwate, Miyagi, Fukushima and Ibaraki. Of the over US\$ 200bn economic losses caused by the quake, US\$ 35bn to US\$ 40bn were insured (including the state-subsidised Japan Earthquake Reinsurance). This makes it the most expensive natural disaster in the world, and the event with the largest number of fatalities in Japan since the great Tokyo earthquake in 1923, with 143,000 fatalities.

Devastating tsunami damage was wreaked along the entire northeast coastline of Honshu. Small and medium-sized settlements in narrow bays were most severely affected. In these localities, even four or five-storey buildings were completely inundated and whole towns were razed to the ground. The infrastructure of roads, bridges and railway tracks was completely washed away in some places, and many fishing ports with thousands of boats were destroyed. Even the efficient early warning system with an advance warning time of 15 to 20 minutes and, probably globally unique, extremely massive protection walls could not prevent the thousands of tsunami victims; however, without these measures, the victim statistics would have been much higher. The only possibility of preventing such catastrophes in the future is a general prohibition on construction in particularly vulnerable coastal areas.

The ten most expensive earthquake catastrophes for the insurance industry

| Month/ Year | Event | Magnitude M_w | Country | Overall losses US\$ m (in original values) | Insured losses US\$ m (in original values) | Fatalities |
|----------------|---------------------|--------------------|--------------------------|--|--|------------|
| 3/2011 | Earthquake, tsunami | 9.0 | Japan | 210,000 | 35-40,000 | 15,840 |
| 1/1994 | Earthquake | 6.8 | USA | 44,000 | 15,300 | 61 |
| 2/2011 | Earthquake | 6.1 | New Zealand | 16,000 | 13,000 | 181 |
| 2/2010 | Earthquake, tsunami | 8.8 | Chile | 30,000 | 8,000 | 520 |
| 9/2010 | Earthquake | 7.0 | New Zealand | 6,500 | 5,000 | |
| 1/1995 | Earthquake | 6.9 | Japan | 100,000 | 3,000 | 6,430 |
| 12/2004 | Earthquake, tsunami | 9.0 | South and Southeast Asia | 10,000 | 1,000 | 220,000 |
| 10/1989 | Earthquake | 6.2 | USA | 10,000 | 960 | 68 |
| 6/2011 | Earthquake | 5.9 | New Zealand | 2,000 | 800 | 1 |
| 10/2004 | Earthquake | 6.6 | Japan | 28,000 | 760 | 46 |

In contrast to the almost complete destruction in the tsunami areas, losses in the other areas hit by the earthquake were moderate. Even in areas in which the ground motion had been very strong, only minor structural damage was caused and very few buildings collapsed, although this was spread over a much larger area than that hit by the tsunami. The stringent building regulations were one of the main reasons why the damage, in particular to houses built after 1981, was much lower than expected. Although Tokyo's skyscrapers swayed strongly for many minutes, there was no significant damage there.

In some areas of Greater Tokyo built on reclaimed land, there was widespread, heavy subsidence. Many residential buildings in these areas became uninhabitable. However, most of the large apartment buildings and industrial facilities have deep-reaching foundations that protected them against substantial losses. Damage was caused, above all, to supply lines and external facilities. The over 300 fires and a number of spectacular major industrial fires, for example in the Chiba refinery, did not contribute significantly to the total damage.

Despite the less extensive damage to buildings outside the tsunami region, some industrial facilities were affected by business interruption as a result of significant damage to goods and production facilities.

In the nuclear power station of Fukushima, which was also hit by the tsunami, the entire power supply and local emergency back-up systems failed. Failure of the cooling system led to reactor overheating and ultimately to a meltdown, probably in three reactors. The consequences of the largest nuclear disaster since Chernobyl: widespread radiated areas within a radius of 30 km around the power station were evacuated; electricity was rationed in Japan for months; in Germany and Switzerland, the decision was taken to accelerate the phase-out of nuclear power.

Major uncertainty regarding loss estimates

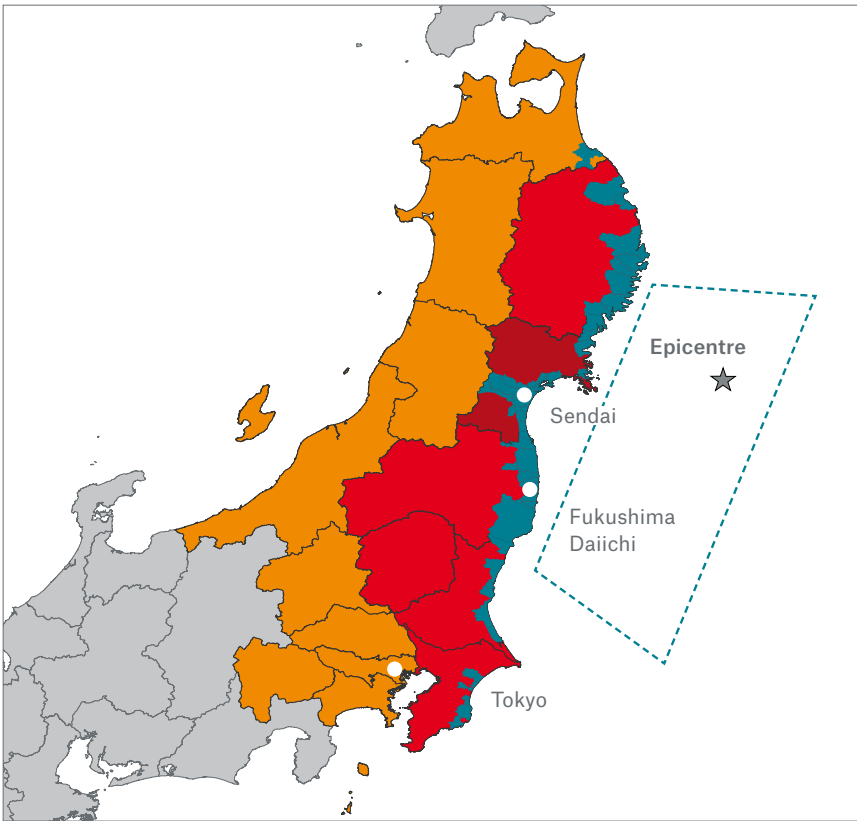
The Japanese insurance market is divided up into three sectors. Most of the insurance companies only offer earthquake coverage for commercial risks with the focus on industrial policies subject to stringent limits. Residential buildings are covered by cooperatives and a state-run reinsurance pool (JER – Japan Earthquake Reinsurance).

Earthquakes with the highest death tolls since 1900

| Month/ Year | Event | Magnitude M _w | Country | Overall losses US\$ m (in original values) | Insured losses US\$ m (in original values) | Fatalities |
|----------------|---------------------|-----------------------------|--------------------------|--|--|------------|
| 12/1920 | Earthquake | 8.5 | China | 25 | | 273,400 |
| 7/1976 | Earthquake | 7.8 | China | 5,600 | | 242,800 |
| 1/2010 | Earthquake | 7.0 | Haiti | 8,000 | 200 | 222,570 |
| 12/2004 | Earthquake, tsunami | 9.0 | South and Southeast Asia | 10,000 | 1,000 | 220,000 |
| 9/1923 | Earthquake | 7.9 | Japan | 2,800 | 590 | 142,800 |
| 10/2005 | Earthquake | 7.6 | South Asia | 5,200 | 5 | 88,000 |
| 12/1908 | Earthquake, tsunami | 7.2 | Italy | 116 | | 86,000 |
| 5/2008 | Earthquake | 8.0 | China | 85,000 | 300 | 84,000 |
| 12/1932 | Earthquake | 7.6 | China | | | 77,000 |
| 5/1970 | Earthquake | 7.9 | Peru | 550 | 14 | 67,000 |

Earthquakes with a magnitude of 9.0 or more since 1900

| Month/ Year | Event | Magnitude M _w | Country | Overall losses US\$ m (in original values) | Insured losses US\$ m (in original values) | Fatalities |
|----------------|---------------------|-----------------------------|--------------------------|--|--|------------|
| 5/1960 | Earthquake, tsunami | 9.5 | Chile | 550 | | 1,500 |
| 3/1964 | Earthquake, tsunami | 9.2 | USA | 540 | 45 | 131 |
| 11/1952 | Earthquake, tsunami | 9.0 | USSR (Asia) | | | 1,300 |
| 12/2004 | Earthquake, tsunami | 9.0 | South and Southeast Asia | 10,000 | 1,000 | 220,000 |
| 3/2011 | Earthquake, tsunami | 9.0 | Japan | 210,000 | 35-40,000 | 15,840 |



While magnitude refers to the energy released by an earthquake, intensity indicates the effect of the earthquake, (i.e. the extent of damage). The map shows the degree to which individual Japanese prefectures were affected

Earthquake intensity

- Extremely high
- Very high
- High
- Moderate or minor
- Areas with tsunami losses

--- Approximate outline of fracture face

Source: Munich Re, based on data from USAID, <http://japan-guide.com>



Many boats capsized as a result of the tsunami, causing oil spills.

The losses for JER, which covers approximately 25% of all residential buildings in Japan, amount to some ¥1,200bn (approximately US\$ 15bn); more than 800,000 policies are affected. Although practically no damage is visible in the centre of Tokyo, some 200,000 policies are affected in Greater Tokyo and the average loss per policy is only around 50% lower than in the particularly heavily hit and tsunami-devastated prefectures in the northeast.

Payment for large industrial policies is limited to only a few per cent of the sum insured. In some cases, limits have been significantly exceeded, in particular due to major tsunami losses, so that a number of major industrial clients must pay a high percentage of the losses themselves. As predominantly large-scale industrial risks are insured, it can happen that the entire losses of a number of insurance companies involve only a few policies. This, together with inadequately detailed exposure information, can lead to substantial uncertainties with regard to loss estimates. For the assessment of tsunami losses, precise details of the location of the insured risks are required in particular, as inaccuracies of just one kilometre can mean the difference between no damage and complete destruction. More specific exposure information in Japan is the most important condition for achieving more reliable modelling and loss estimates.

Business interruption coverage in the Japanese market is either extremely limited or unavailable. Although the main region affected accounts for only about 8% of the Japanese economy, losses at major automotive and high-tech industry suppliers caused production downtimes all around the world and focused attention on international CBI policies. Speculation on losses in the billions for some companies and their impact on the insurance industry highlighted the complex global production network and the enormous difficulties encountered in estimating the losses. Transparency in respect of the main supplier companies and strict limits are essential if major losses are to be avoided in this area.

With additional losses in marine insurance (particularly in ports) as well as in accident and life insurance, the Tohoku quake is a multi-line event. In the case of motor insurance, earthquake damage is usually excluded in Japan, otherwise there would have been significant claim payments. Japan is also a special case with regard to life insurance, although here the opposite applies: a potentially high number of victims with an equally high insurance density.

The Tohoku earthquake occurred during the main phase of reinsurance renewals in Japan, which was concluded in a well-ordered manner despite the high level of uncertainty due to strong aftershocks and, consequently, possible further damage. As the probability of medium-size events particularly has risen strongly due to the earthquake, an increased level of losses must be taken into consideration, above all in proportional contracts. The size of the area impacted by such megaquakes and the large number of losses involved make it more difficult to separate the losses caused by the main earthquake from those caused by subsequent strong aftershocks.



Conclusion

The Tohoku earthquake is not only the most expensive natural disaster on record worldwide to date, it also shows that the enormous efforts undertaken in the areas of earthquake research, earthquake-resistant construction methods and early warning systems, even in countries such as Japan, cannot prevent such major disasters. Although an earthquake of this magnitude had not been expected in the region, the overall risk in Japan is adequately reflected in the available models. The level of the ground motions and the resulting losses lie within the range of expectations. Model results are always associated with significant uncertainties. However, major uncertainties in loss and risk assessment are due to a lack of sufficiently high-resolution exposure information – and this too has been demonstrated once again by the Japanese earthquake.



OUR EXPERT

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“This is totally different from anything we have ever experienced”

Following the devastating earthquake in Japan on 11 March 2011, industry, the scientific community and the politicians need to change their approach – nationally and on a global level. In October 2011, Munich Re hosted a forum of international experts who discussed this catastrophic event from a scientific, political, socio-economic and insurance perspective.



Prof. Dr. Norio Okada
Disaster Prevention Research Institute (DPRI), University of Kyoto, Japan.



Prof. Dr. Jochen Zschau
Helmholtz Centre Potsdam
German Research Centre for
Geosciences (GFZ).



Dr. Charles Scawthorn
Partner, SPA Risk LLC, a consultancy
firm specialising in natural disaster risk
reduction.

To see the film summarising the event that dominated the natural catastrophe year 2011, the Japanese earthquake, and explaining the experts' views, please visit our website:
www.munichre.com

Dr. Smolka: First of all, I would like to thank you all for taking part in this round-table discussion on the Tohoku earthquake. It's my particular pleasure also to greet Dr. Arnoldussen from the Board of Management of Munich Re.

The Tohoku earthquake was a truly remarkable event. In terms of the overall losses, it was the biggest earthquake and natural disaster of recent decades. What were your first reactions when you heard the news about this earthquake?

Prof. Okada: Well, I was chairing the faculty meeting at Kyoto University. And when the disaster took place it took us about ten minutes to figure out what was happening. So the first job I had to do was to send people around to check out what was happening.

Smolka: So, you felt the earthquake's energy?

Okada: Yes, we certainly felt it. But we didn't at first think it was an earthquake. All the professors there thought that it was only something we'd imagined. Fifteen minutes later, I cancelled the faculty meeting and had them go and check around. We quickly learned that a disaster on an unprecedented scale was taking place in Fukushima. I immediately also sensed that this was really different – totally different from anything we had ever experienced. I also felt that it would take on global proportions.

Smolka: Dr. Scawthorn, you have lived in Japan for quite some time and have seen a lot of earthquake damage all over the world. What was your first assessment when you heard about the earthquake?

Dr. Scawthorn: Well, I actually happened to be in Morocco on a project when the earthquake occurred, but we live in Kyoto, and my wife was in Japan, and I called her. In Kyoto, she had felt the earthquake. And then, within an hour or two, we started to see TV footage of the tsunami's destruction and to learn about Fukushima.



Dr. Anselm Smolka
Head of Geo Risks in Corporate Underwriting/Accumulation Risks Management, Munich Re.

I returned to Japan as quickly as I could – it took several days. Let me say that I have seen a fair amount of earthquake damage over the years including major tsunamis in the Indian Ocean and Japan, but I had never seen destruction such as this. It was shocking. I believe it has some major implications for Japan, and globally.

Smolka: Dr. Arnoldussen, you are in charge of the Japan and Australasian regions, and they've also had a sequence of disasters before. So, what was your responsibility?

Dr. Arnoldussen: Well, when I learned about the earthquake I was on a skiing holiday in Switzerland. Then I got a call from the department head, and our first concern was: "Are our staff secure in Tokyo?" So we made contact with everybody, and then we had to decide – faced with the nuclear accident in Fukushima and the reinsurance renewals, in the weeks running up to 1 April. Over the course of the weekend, we decided to move most of our people from the Tokyo office, first to a hotel in Osaka and then to our branch in Singapore,



Dr. Ludger Arnoldussen
Member of Munich Re's Board of Management.

where we have a full working environment. And that was very difficult for our Japanese staff because they were very reluctant to leave their country in a situation like that.

Smolka: Prof. Zschau, you had experience from the Indonesian earthquake in 2004, also a giant tsunami, and then this Tohoku earthquake happened.

Prof. Zschau: Yes, I was caught by the news early in the morning at home by the press. And I had made an agreement with the press that they would only call me in a very severe case. The first time was the Sumatra earthquake. I didn't expect it to be similar to Sumatra. Japan is a different situation. It's a highly industrialised country with the best seismic early warning system and also with a very good tsunami early warning system. So I thought at the beginning, it couldn't be a disaster of the extent which one saw later. But then the magnitude was revised upwards, and the other consequences also became

clear. It clearly showed how the earthquake risk has become globalised. It showed that we have to turn our attention to chain interactions, not only in the natural system, but also in the man-made system.

Smolka: Referring to this lack of scientific understanding, after the event there was a big debate in the community about the official Japanese hazard map. It includes time dependency, which may have been somewhat misleading because there was so much focus on the Tokai gap and maybe another earthquake in Tokyo.

Okada: Some say our specialists and regulators need to do better on how to communicate these kinds of issues to people. Because the way the event actually happens is not what the hazard map tells you. And so I think this is the kind of area where we need to be more sophisticated, more refined and better trained in our approach. Also the question of evacuation, which seems to be an essential issue, is something we need to address.

Smolka: Hazard mapping is usually a national undertaking and there is always the danger that outlier or unorthodox opinions will be suppressed. I think that's a general problem with science.

Zschau: This, I think, is a very general experience, not only for Japan but worldwide. If I take, for instance, the earthquake in Haiti in 2010, there had been a publication two years before it saying that an earthquake of 7.2 could happen at any time. And it did. I think there is a general problem in bridging the gap between practice and scientific theory. And if I look to the large European projects that are funded at the moment by the European Commission, their major component is the interaction between



theory and practice, together with disaster management and civil protection, because it's been realised that there is a general weakness in these areas.

“The earthquake risk has become globalised.”

Prof. Dr. Jochen Zschau

Scawthorn: I think you've touched on a good point. One of my first observations after this event was that there are limits to the probabilistic approach. First of all there are the technical limitations on our data and our ability to properly use that data. The second point is: in some cases, we can calculate rare events with probabilities of one in 5,000 years, let us say. But, all too often, these things are simply dismissed as too low a probability. And, in some cases as being impossible, or too expensive to deal with. But these are events that threaten the existence of a society or an organisation. The 11 March event was an existential threat for Japan because of the nuclear dimension. If that nuclear radiation release had been somewhat worse and gone in the wrong direction, we could have lost Tokyo, which in many ways is an existential threat for Japan. So, that should have been considered.

Smolka: What does this mean for risk communication?

Scawthorn: The issue of risk communication is really important. And while, within the community, we do need discussion – we can sometimes consider and then reject the outlier – the public does not want to be involved in the debate. They don't have the time, the interest, or the vocabulary. They simply want the bottom line. So, the community has to come together and speak with one voice. And when they do that, they should not be prosecuted for manslaughter if they're wrong, which is what we're seeing in Italy right now in the case of the Italian seismologists accused of failing to warn of the L'Aquila earthquake.

Zschau: Our hazard maps do not reflect more than the seismicity rate. High seismicity means high hazard, low activity low hazard. And this does not take into account at what stage of the earthquake cycle we are. So the earthquake hazard in Cologne, Germany, for instance, may be higher at the moment than the hazard in central Italy, because we don't know when the last earthquake occurred in Cologne, and we don't know where we are in the cycle. A time-dependent hazard assessment is very important.

Smolka: I think we can agree on the message that the probabilistic approach has to be supplemented by taking a deterministic view of worst-case scenarios. And now the models will become available to do so, although we will have to use some imagination of course. Dr. Arnoldussen, maybe this would also be an interesting argument for you?

Arnoldussen: It is. And I am more and more concerned about whether we can use the models as we do right now for determining an adequate risk premium. I think for us what is very important is whether you have three 6.0 magnitude events, maybe with two or three months' time difference, or whether they happen within seconds. And also the very long timescales we're talking about: 500 years, 1,000 years; and the lack of data for the older events – that makes it very difficult. You get a probable maximum loss from the models, but then the individual circumstances can involve a huge loss cost for insurers.

Smolka: If you take the Tohoku earthquake, we believe that there's an increased likelihood of a mid-size quake for the Tokyo Bay area.

Arnoldussen: That has implications for our negotiations with clients about the right level of risk premium. What should you do as somebody trying to make a business out of this? Adequate rates and conditions are indispensable. Then Munich Re will continue to provide capacity.

“We need to be more and more creative and imaginative.”

Prof. Dr. Norio Okada

Scawthorn: There are two fundamental questions here. First – will I or my organisation survive an event? And second – will I make a profit? The first one is the existential-threat event, and as an insurer you have to reserve against that. And the second



one is where the probabilistic models come in, because you can then use those in dynamic financial analysis or benefit-cost analysis to properly set your rates. Now, let's come back to this point: “Will I survive an event?” Solvency II is requiring reserving for a 1-in-200-years loss, I believe. Well, if you take a hundred large insurance companies, you can interpret that as implying that one will fail every two years. And, while this is a very simplistic calculation, it is not so absurd.

Smolka: ... that's right, although in terms of a specific event scenario, a 500-year or 1,000-year loss would also be sustainable. And with regard to nuclear power plants?

Scawthorn: We have about 500 nuclear power plants in the world. They are each designed for one-in-a-million-year events: 10^{-6} probability per year of a core melt, which sounds like an acceptably low risk. But, this actually translates to 1/2,000 probability per year of a core melt somewhere in the world. Well now, these plants have lifetimes of 20 years, which are typically being extended for another 20, so take 40 years. Referring to the lifetime, we therefore have a loss, we have a core melt, with probability of 1/50 during the lifetime of the plants – by the way, about 1/25 during a healthy person's lifetime – not one in a million. Actually, I'm oversimplifying these calculations – the reality is more complex.

But what have we had in the last 32 years? We've had three of these events – Three Mile Island in 1979, Chernobyl in 1986 and now Fukushima Daiichi in 2011. So, this whole probabilistic approach, 10^{-6} , it sounds fantastic, but it's ...

Smolka: ... in the global context a different story.

Scawthorn: To me it was immediately obvious that nuclear power is doomed in Japan as soon as this happened, because Japan cannot afford that risk. I think the Japanese public has already seen this, although some other people in Japan still need to learn that lesson. And several European countries have also heeded that message.

Okada: We need to be more and more creative and imaginative about the serious consequences. When it comes to the case where society is going to almost collapse in terms of population and communities, everyone has to be there as a participant. It is extremely important to involve scientists from different fields, politicians, regulators, and insurance companies.

“The insurance and reinsurance industry could play a bigger role.”

Dr. Ludger Arnoldussen

One more thing I'd like to bring up is the issue of business sector stakeholders: business continuity is really necessary. Even companies located in Kyoto suffered a lot from what happened in eastern Japan. So maybe they can strategically change their way of management regarding where to locate further supply chains. I mean, in what other ways can you communicate and coordinate with companies outside of Japan, in terms of production, marketing, transportation and logistical systems? But this requires more and more integrated disaster risk management, something I fully advocate.

Arnoldussen: I fully agree. We noticed that industry in Japan, but also around the world, is reconsidering the matter following the experience of the Tohoku earthquake. I believe that many companies are now diversifying their supply chain. Another point: You mentioned that the country could collapse following an extreme event. I think, nowadays, in these times of sovereign debt crisis, this could happen even earlier, because a lot of risk is carried by government: the residual risk. Take Japan: we estimate that only 15% of the economic losses in Japan were insured. Much of the rest is borne by the Japanese government. And, with the debt ratios that you have in many countries, the limit for a country's economic collapse might not be that far away. So that we think that the insurance and reinsurance industry could play a bigger role.



Scawthorn: You mentioned that the insurance industry can do more. I have a question for you: How can it do more? Because we see that, in many countries, the private sector insurance companies are not filling the gap and the government has to step in with things like the California Earthquake Authority or EQC in New Zealand, or TCIP in Turkey and so on. So, in what way can the insurance industry do more as part of this integrated approach?

Arnoldussen: Well, I think at the heart of the problem lies the risk awareness of the public and also of governments. And why do you have such government institutions in California and in New Zealand? To do things in an efficient way you need large-scale coverage of the risks, and that is where compulsory insurance or government institutions can sometimes help. Often, reinsurers then cover the risks of those authorities. I think we have to find ways of increasing the amount of coverage either by incentivising the public or making them more aware of the risks. If I take the example of Munich Re, and this is true of some of the other large players, we did not use our maximum capacity for Japan. So, I think we would have had the ability to cover a larger amount of risk, but this did not happen, because at the price level that we required there was not enough demand.

Okada: This might not be relevant to what's now being discussed, but from the viewpoint of integrated disaster risk management it requires a mutual aligning among all stakeholders involved. Another thing I'd like to add is the question of adaptive management. It is something like: you make this room smoke-free and if that works you apply it to the entire floor, and then to the entire building or to Munich. I venture to promote this approach to some community-based disaster reduction practices to establish whether a method is working well or not in actual cases. If not, we need to check out why not, and how can we come up with viable solutions? My question: Is the insurance/reinsurance industry also interested in promoting this kind of social experiment? If this kind of approach were of interest to reinsurers like Munich Re, there are a lot of academics who are now interested in integrated risk management, and eager to work in partnership.

Arnoldussen: I think this would be an interesting way of addressing the problem and moving it forward.

Smolka: One question I asked myself after the Tohoku earthquake was: What lessons can I draw for a Tokyo scenario out of this event?

Scawthorn: Just as we saw the North Anatolian fault zone where the segments have unzipped all the way to Istanbul, and we're now waiting for a mega disaster in Istanbul, this event has unzipped three big segments simultaneously, and stopped just short of Tokyo. So, we have a much greater potential for a Tokyo earthquake right now. Whether it's a repeat of the 1923 magnitude 8 earthquake or even a magnitude, say 7, if it's underneath Tokyo, it doesn't make too much difference. It's going to be catastrophic. Everybody knows this.

Smolka: What about the quality of building construction?

Scawthorn: Buildings turn over – in other words older houses are torn down and newer houses replace them – in Japan at a greater frequency than in most other countries. This accelerated after the Kobe earthquake when the Japanese saw that their older, traditional Japanese houses were very weak. Many people have now replaced their houses. But still there are older buildings in Tokyo and there's going to be building damage.

Smolka: ... Liquefaction damage ...

Scawthorn: ... especially in eastern Tokyo, in what's called the Sumidagawa River area. This will break the water mains, the gas mains. I would expect many refinery fires all around Tokyo bay, and conflagrations in Tokyo, despite Tokyo's fire department being the largest fire department in the world and extremely capable. But I expect them to be overwhelmed. It does depend, however, on the wind and meteorological conditions. The night of 1 September 1923 was hot and dry, with strong winds. If it's a cold, rainy day versus a hot windy day, that can make all the difference in the world.



Zschau: Coming back to what Prof. Okada said about an integrated approach: What would have changed, if perfect knowledge had been there? I mean, this is difficult to estimate.

“380,000 people were saved. I mean, that's excellent.”

Dr. Charles Scawthorn

Scawthorn: If someone had said. “I guarantee that at 2 o'clock tomorrow afternoon this event is going to occur with this wave height”, and so on, what would have changed? How would the damage have changed? Presumably, they would have been able to evacuate some of the 20,000 people who did die. Actually, the warning and evacuation worked very well. There may have been of the order of 400,000 people at risk; 380,000 of them were saved. I mean, that's excellent. But they couldn't have moved the buildings. They couldn't have built the sea walls overnight. So, the property damage would not have changed very much at all. The integrated approach is a long-term approach that needs to integrate land-use planning. It needs to integrate structural, locational, operational, and risk transfer methods.

Zschau: Take the early warning system which was in place. The seismic early warning system gave, as far as I heard, the first information eight seconds after the first p-wave arrival was detected, which was 31 seconds after the earthquake – this was the first public information. Much too low in terms of reported magnitude, but it was the first public information. And it was estimated that this warning saved many lives. But some of the people that got the warning did not go up to high enough ground, because they were not expecting such a large tsunami. So, that was the misleading aspect and things could have been better if the right magnitude determination had been announced at least a few minutes earlier ...

“We also need to be more dynamic in developing worst-case scenarios.”

Prof. Dr. Norio Okada

Scawthorn: Early warning is fantastic and, to the extent that we can implement it, it is one of the great contributions of science towards resisting this hazard.

Okada: I'd like to mention that, in a way, there have been lots of successes. In some areas, the early warning worked, and disaster education worked. We quite often say: "Well, we have this case that's actually happened, so we should learn from it" but we also need to be more dynamic in developing worst-case scenarios which are not necessarily identical to what has actually happened.

Scawthorn: The Japanese government is very diligent on this problem. There are only a few countries in the world that are really tackling the problem and Japan is a leader in that field. There are lots of lessons to be learned and, I think, first and foremost they are trying to learn these lessons themselves.

Okada: Yes. Well, there'd be two ways to put it. How we evaluate what happened in terms of the way the government worked, but also: In what way could we do better? One thing which worked very well, for instance, is the civil defence force, which was immediately mobilised. They also worked very well in the case of the Fukushima issue. And this is the best example of the lessons we learned from the Kobe earthquake. NGO groups also worked very well. They set up a kind of federation this time. And the federation started to organise integrated emergency management and effectively shared information and mutual reporting. This kind of new development is very much based on the lessons we learned from Kobe.

Smolka: ... and with regard to Fukushima?

Okada: Well, the nuclear accident made it clear that our country is very weak in quick centralised decision-making. Some authority should be in

place aside from the person who is in charge of the country. I think we still lack this kind of practice or political culture, as well as an emergency management culture. Things have been rather free-handed, with a lot of time spent getting people involved in discussing and organising, which is very confusing at times. Also, this time we were forced to work together with other countries. And we are thankful to other international sectors for coming in and helping us organise things. One more thing I'd like to add: our country is still very much reluctant to introduce what I would call adaptive management. We are very slow to change the laws. Once a law is fixed, then we don't like to change it. And one further aspect: the recovery and restoration process is an extraordinarily big job now ...

Smolka: ... and requires a participatory approach ...

Okada: ... which we have lacked so far. This is one of the reasons why things didn't work out. We have had several earthquakes and tsunamis in that area, and there are always those who then say: "Let's move people to high ground". A start was made and, in cases of previous tsunami disasters in Tohoku, for some areas it worked, but for many areas it didn't. How to make people maintain a course of action really needs adaptive management. Things should move forward step by step, and ordinary people should always be involved. I don't know whether we will succeed in this or not, but if we do, it would be a huge success in terms of recovery and restoration.

Smolka: I think that's an issue everywhere – not just in Japan. After a disaster, many decisions are taken, but the people, those who are affected, are just left out.

Scawthorn: Comparing to Kobe, I think in 1995 there was a Self-Defence Force division in Nishinomiya – that is, military forces were very close to Kobe – and yet did not move because the central government did not dispatch them. So, the Japanese learned from this. Ten days ago, I was with Lt. General

Watanabe, the commander of the North East Army, and also with the Regional Director of the Ministry of Transport for Tohoku. And General Watanabe and his officers made it very clear that Japanese law had changed, the Self-Defence Force's policy had been changed, and they self-dispatched after this latest event. They moved immediately. And the Ministry of Transport very quickly adapted to this.

Smolka: This challenge of the unforeseen event is very hard to plan for, however polished the plan. I mean, you could have foreseen, with more knowledge, a magnitude 9 followed by a tsunami, even maybe damaging Fukushima. But if you think about a Tokyo scenario, it could be a completely different story.

Scawthorn: You can characterise events as unforeseen, as foreseeable, as foreseen, as foretold, or as predicted. Well, I realise, this is a little bit of semantics in the English language, but each of those implies narrowing parameters of time and space. Now, in the Tohoku event, this was actually foretold in the literature. Another example of something that was foretold was Katrina. It was the cover story of National Geographic six months before the event. The cover story! And San Francisco: five months before the 1906 earthquake, the National Board of Fire Underwriters in San Francisco said that this event will occur and cannot be – the fire – cannot be held off. The real crux is, how do we identify – to paraphrase somebody else – the unknown unknowns? How do we foresee the unforeseeable, so to speak? How do we make the unforeseeable foreseen? We have to use our imagination. And, actually, the literature of fiction is full of novels and stories that later come true. Take the novel "The Lion's Game" (by Nelson DeMille) which completely foresees the 9/11 attacks. In that case it's a 747 attack on the Capitol building, but it's completely foreseen.

Zschau: I agree with imagination, which is usually at the beginning of scientific work. But with imagination alone you cannot convince others. For that we need evidence.

Scawthorn: We do have evidence ...

Zschau: Paleoseismology is becoming very important. This would be the evidence needed in addition to imagination to get more information on these very rare large events.

Smolka: To focus all the aspects we discussed, what are the most important lessons, the most important points you will all take from this event?

Arnoldussen: As came out in the discussion, I think for me one lesson was: What credibility can I attach to models? How should they be used in the business sense? They may give the best possible estimate, but reality is always quite different, and so I think that has put things in a different perspective for me. Another issue is the question of the interconnectedness of the global economy, and how the supply chains are connected to the financial markets. The third point is that we are reaching the limits of governments being the last resort for damage compensation. I think, there are economic limits to that, and we are trying to investigate how reinsurance and insurance can extend those economic limits by supporting government or settling losses from an event.

“What credibility do models have? How should they be used in the business sense?”

Dr. Ludger Arnoldussen

Okada: The first of the lessons is: Some lessons will be “unlearned” again. This applies everywhere, every time. Lessons are unlearned, or lessons are bound to be unlearned again and again, and so failures tend to be repeated. But it also requires new knowledge. What I mentioned here, for instance: in the eastern part of Japan, they had already suffered several times, but still they suffered again. And so, in that way the lessons were not learned well. Why are lessons not learned? There are lots of social implementation gaps. Like, you know, liability issues, which need to be managed, otherwise those in charge tend to do just as much as the law requires and no more to increase safety. You can’t change such attitudes so easily. By the way, if Tokyo is hit, even on the lower scale, 7, there’ll be a tremendous impact. Tokyo could be paralysed in a very unforeseen way; but maybe it is foreseeable.

Scawthorn: The first lesson is that there are limits to the probabilistic approach. And the limits are that existential threats need to be treated differently. And to illustrate that, if we take risk as the consequence tied to probability, no matter how small the probability, if the consequence is infinite, then the risk is infinite. And in that regard nuclear power is a semi-infinite risk for many locations. And Japan, I think, will find its way to conclude that it cannot afford nuclear power. And I think other countries are finding that also. A second lesson is that disaster risk reduction is a long-term undertaking requiring an integrated approach that combines structural, land-use, operational and financial mitigation measures.

Zschau: The first lesson, I think, is that the disaster risk chain is a very complex phenomenon, building many interactions not only with the natural system, but also propagating into the man-made system, and this requires first a new focus of interdisciplinary research, and second, the building up of a new, more effective partnership, public-private partnership, for managing the risk. The second one is similar to what was said before that, although geoscientists

had made a lot of progress after the Sumatra earthquake, this earthquake in Tohoku showed us the limitations of our knowledge, and I agree with Dr. Scawthorn that we need to think about better ways of hazard assessment, and probabilistic hazard assessment alone is probably not enough. And third is that this earthquake has clearly shown the global component and shows that the earthquake risk is globalising. This, I think, requires, in the long term, better and stronger international cooperation.

Smolka: The Tohoku earthquake, as you have summarised, is a testament to our limitations and has shown our shortcomings, but also has shown ways to cope with such a situation, which we will hopefully use in further instances. Thank you!



Earthquakes in Christchurch, New Zealand

Just months after the 2010 Darfield earthquake, another catastrophe struck the Canterbury Plains in 2011. On 22 February, a magnitude 6.1 quake struck the Christchurch region, causing 181 fatalities and heavy damage in the city centre and suburbs. This again poses fundamental questions on the reliability of the building codes and how well prepared people are.

Marco Stupazzini

The series of earthquakes that started in September 2010 is termed the Canterbury earthquake sequence. It began on 4 September 2010 with a powerful magnitude 7.0 earthquake (the Darfield earthquake), which was followed by several thousand aftershocks. At 12.51 p.m. (local time) on 22 February 2011, over five months after the main Darfield shock, a magnitude M_w 6.1 event (the Lyttelton earthquake) struck the city and suburbs of Christchurch – the largest city on the South Island of New Zealand, with about 400,000 inhabitants. On 13 June 2011, a magnitude M_w 5.9 earthquake occurred near the suburb of Sumner, producing one fatality and yet more damage in Christchurch and Lyttelton. Four more earthquakes with magnitudes between M_w 5.0 and 6.0 shook the east coast near New Brighton on 23 December. As with the other quakes, local ground liquefaction and coastal rockfalls occurred.

The 22 February earthquake is one of the greatest natural disasters ever recorded in New Zealand. The death toll was 181, with around 2,000 people injured. Tens of thousands of structures, already weakened by the Darfield event and its aftershocks, suffered heavy damage.

Scenes of wide-scale destruction met the eye in central Christchurch.



The earthquake was generated by an oblique thrust fault located between the Australian and Pacific plates, only 6 km from the city centre. The Canterbury sequence occurred along a previously unknown fault system buried under the sediments of the Canterbury Plains without surface evidence.

During the last ten years, a set of seismic surveys was carried out here but there was no clear indication that a major earthquake was imminent in this particular region. Regarding the effects and the consequences of the quake, the attention was drawn to two aspects that had a primary role in the interpretation of the damage pattern: the extremely severe, strong ground shaking observed, both on the horizontal and vertical component and the widespread liquefaction across the city.

Many effects contributed to the high level of shaking observed:

- The distance from the source: The top edge of the fault that ruptured in the Lyttelton earthquake was located at a shallow depth and 6 km from the central business district (CBD); the Darfield rupture stopped about 20 km from the CBD.
- The directivity effect: Seismic waves tend to get stacked on top of each other in the direction in which the fault ruptures propagate, which can lead to substantial amplification.
- Soft subsoil and effect of the basin: Deep thickness of sediments beneath Christchurch (600-1,200 m to the basement rocks).

In order to examine the performance of buildings and infrastructures, we have to place the 2010-2011 earthquake sequence in the context of the present seismic design philosophy.



As buildings collapsed, a thick cloud of dust rose over the city.



Left: Seismic waves can shake the ground to such an extent that it loses its stability, assuming liquid-type properties. Vehicles sink and buildings subside.

Right: Many houses were damaged as a result of sand boils, a typical manifestation of liquefaction.

Simplifying, we can distinguish between two different performance levels: serviceability and ultimate limit state. The former is associated with relatively frequent events and prescribes that the building must remain in full service and occupancy. The latter is associated with longer return periods (e.g. 475 years), therefore some losses are expected but not to a degree that may lead to a failure. With this background in mind, we can comment that the ground motions experienced in the February earthquake were as severe as the ones predicted according to the seismic building code for a 2,500-year return period, therefore definitely above the ground motion used to design the buildings in Christchurch. In addition, the Christchurch building stock is comparatively old. Historical and pre-code buildings, especially in the city centre, had little earthquake resistance.

Exceptional level of destruction

The Lyttelton earthquake was particularly devastating. Many unreinforced masonry structures suffered severe damage or collapsed. Two multi-storey reinforced concrete buildings, Canterbury Television (CTV) and the Pyne Gould Corporation building also collapsed and there was significant failure of building components including stairs, columns and walls in reinforced concrete buildings (the Forsyth Barr building and Hotel Grand Chancellor).

There was widespread liquefaction in the suburbs to the east of the central business district and within that district itself. This resulted in lateral movement of foundations, ground failures or tilting affecting many multi-storey buildings.

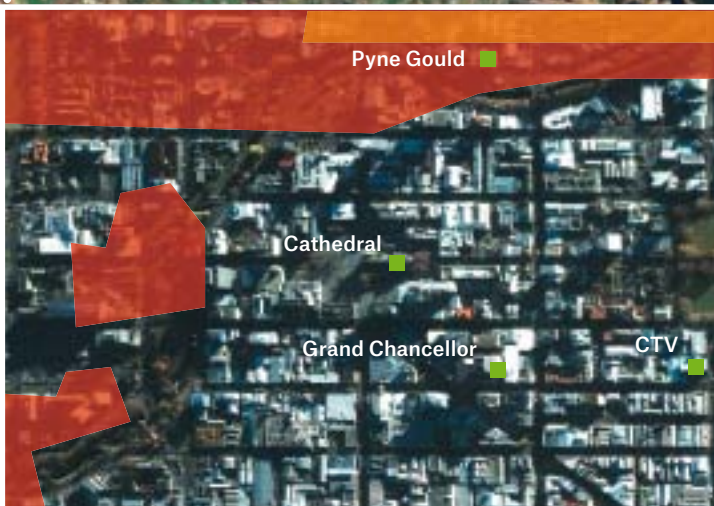


The Canterbury earthquake sequence raised many questions in respect of hazard and risk assessment, and risk perception in general. Some of the salient features are discussed below:

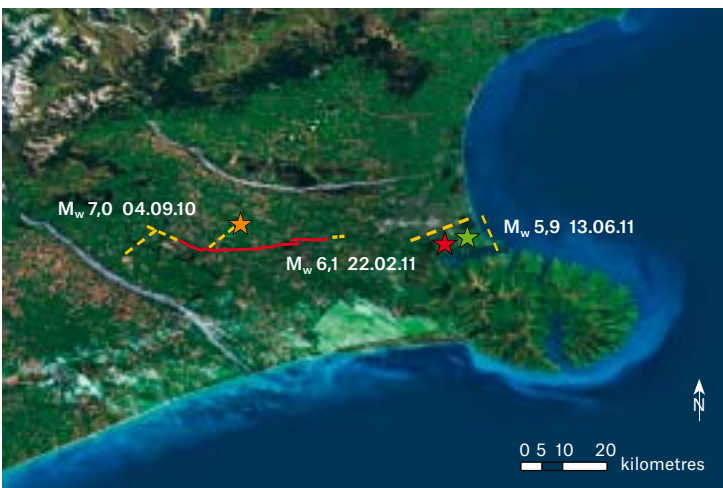
- Earthquake clustering and aftershocks: The Canterbury earthquake sequence represents one of the rare cases worldwide where an aftershock or triggered event (the Lyttelton event of 2011) caused a higher loss than the preceding main shock (the Darfield event in September 2010). How stress transfer/trig-gering and aftershock activity can find their way into probabilistic risk modelling will have to be investigated, as will how probable such event con-stellations are in a worldwide context. December 2011/January 2012 marked the bicentennial of the New Madrid earthquake sequence of 1811-1812. A repeat of the earlier event could produce insured market losses in the two- to three-digit billion dollar range.
- Clustering represents a challenge not only for mod-elling, but also in terms of recovery and reconstruc-tion, which necessarily take place in an acutely unsafe environment.
- The whole sequence, and particularly the Lyttelton earthquake, represents a series of extremely rare events. Geological research has shown that the fault system re-activated in this sequence last moved more than 10,000 years ago. Whilst the probability of such earthquakes has been captured correctly in the New Zealand earthquake model, this is not true of the serious damaging consequences. How to make allowance for such extremely rare events is a challenge for planners and risk managers
- Ground deformation and liquefaction: The lique-faction hazard in the Canterbury Plains was well known. But the extent to which it materialised, especially in the Lyttelton earthquake where several square kilometres were affected, nevertheless came as a surprise. What potential is there for similar earth- quakes elsewhere in the world?
- Vulnerability: When drawing conclusions about other earthquake scenarios in New Zealand, and the Wellington region in particular, it must be kept in mind that the earthquake resilience of the capital region is distinctly higher than that of Christchurch thanks to a rigorous rehabilitation programme. Begun in the late 1980s, this involves replacing old buildings with new and reinforcing existing construc-tions. On the other hand, the possible maximum magnitude is higher in Wellington, and the Wellingt-on fault runs right along the edge of the city centre.



Areas in Christchurch (central business district enlarged) in which soil liquefaction was observed during the earthquakes on 4 September 2010, 22 February 2011 and 13 June 2011.



- Liquefaction on 4 September 2010
- Liquefaction on 22 February 2011
- Liquefaction on 13 June 2011
- Fault (concealed)



The map shows the main shock on 4 September 2010 and the two strongest aftershocks up to June 2011.

- ★ Epicentres
- Fault (concealed)
- Greendale Fault

Source: Munich Re based on data from GNS Science and Misko Cubrinovski, University of Canterbury, Christchurch

Lump-sum indemnities

As in science, engineering and risk evaluation, the Canterbury earthquake sequence also taught new underwriting lessons and raised questions.

- Number of claims and event attribution: With more than 600,000 claims, there were unavoidably delays in the loss settlement process, despite the enormous efforts undertaken by the Earthquake Commission (EQC) and the private insurance sector, and even though a contingency plan had been in place before the event. Assigning individual losses to specific events in the event sequence proved difficult in the numerous cases where buildings had been damaged twice or more.
- The high number of claims led unavoidably to lump-sum indemnification of smaller losses.
- Another issue hindering loss settlement was the long-term inaccessibility of the central business district.
- The widespread ground deformation/liquefaction resulted in an unusually high proportion of total losses, which exceeded the first loss limit under the EQC policies and thus spilt over into excess policies offered by the private market.
- The situation was further exacerbated by the fact that the Canterbury Earthquake Recovery Authority (CERA) declared vast areas as uninhabitable, and they include buildings that were not a total loss. Property in these areas was bought by CERA, and the insurance rights transferred to CERA, which will try to obtain as much insurance compensation as possible to reimburse expropriated building owners.
- One of the principles of insurance - unforeseeability of the loss - does not apply in the present situation. Nobody can predict when the ongoing seismic crisis will come to an end. There is potential for further magnitude M_w 6.0 events in the region, which could also damage areas less affected hitherto. This will have to be reflected in pricing.

Losses from the earthquake on 22 February 2011

| | |
|----------------|-----------|
| Fatalities | 181 |
| Injured | 2,000 |
| Overall losses | US\$ 16bn |
| Insured losses | US\$ 13bn |
| Homes | 10,000 |



Conclusions

The magnitude M_w 6.1 earthquake of 22 February 2011, which affected the city of Christchurch, increased risk awareness and the demand for engineers to provide economically efficient structural systems that involve minimum economic loss while helping to preserve lives during large earthquakes. A programme is needed to improve resistance to such events in the areas concerned. This will have to be included in the next generation of earthquake building codes.

Beyond the engineering considerations the Canterbury earthquake sequence, and especially the February quake, raised many questions relating to hazard and risk assessment and their application in risk management and insurance. The length of the ongoing seismic crisis presents a particular problem where recovery and reconstruction are concerned, on the one hand, and underwriting practice, on the other. The seismic crisis highlighted the necessity of drafting efficient contingency plans for events involving several hundred thousand claims, and the need for clear, transparent coverage conditions and settlement practices in a situation where responsibilities of the private insurance sector, government insurance schemes and the government as such are closely interlinked. It may be that an event like the shock on 22 February, which combined several adverse features leading to an extreme loss, is to be considered a very rare occurrence. Isolating the features of general relevance out of such a singular event is a formidable challenge in terms of risk assessment, risk management and insurance.



OUR EXPERT

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Severe floods in Australia, the USA and Thailand

Major earthquake disasters obscured somewhat the fact that 2011 was also a year of severe flood disasters. Well-above-average rainfall, lasting for several months in some places, brought floods on a scale not seen for decades.

Wolfgang Kron

Queensland, Australia: The country had already suffered heavy precipitation in December 2010. Shortly before the end of the year, a new series of torrential rains began that lasted until mid-January. Flash floods occurred, the worst on 10 January in the town of Toowoomba, where 22 people died. Reservoirs filled up in no time and rivers became swollen. A flood wave on a scale last seen in 1974 swept through the two-million metropolis of Brisbane. The entire city centre commercial district was flooded metre-deep. For almost two weeks, disaster management teams, residents and business owners fought against the waters.

In the end, overall losses from all the December and January events were in the order of US\$ 7.3bn, of which a third (US\$ 2.4bn) was insured. No sooner was the worst over than a Category 4 cyclone (Yasi) began moving in the direction of Queensland. This time people were lucky however: the storm made landfall several hundred kilometres north of Brisbane and the rain fell over largely unpopulated areas. It nevertheless inflicted damage in the amount of US\$ 2.5bn, of which US\$ 1.3bn was insured.

Although reports that “floodwaters covered an area the size of France and Germany combined” were not correct (in fact the floods spanned a total area of this size), it was nevertheless true that the magnitude of the floods was unexpected. By contrast, unusually heavy precipitation lasting several weeks came as no surprise. Due to the La Niña weather phenomenon, an exceptional rainy season was to be anticipated in Australia. In addition, the western Pacific off the coast of Australia had never before been as warm as at the turn of 2010/2011 – ideal conditions for high evaporation rates and a high water content in the air masses flowing towards the mainland.

USA: In May and June 2011, the worst floods in decades occurred along the Mississippi and some of its main tributaries. Although losses were heavy, they were comparatively moderate considering the scale of the event, and stayed within the single-digit billion US-dollar range, to a large extent because the flood management system in the USA is much more efficient than in most other countries. In the early summer of 2011, large areas of land were not at the whim of uncontrolled flooding, as is often the case in other regions, since the flood waters were diverted through designated spillways into areas with a lower density of assets. A detailed description of the Mississippi flood can be found in our “Schadenspiegel” issue no. 2/2011 (www.munichre.com/publications/302-07075_en.pdf).



When the Brisbane River burst its banks many parts of the city of Brisbane were inundated.

Thailand

The broad flat plain of the Chao Phraya river that crosses Thailand from north to south is not just the country's most productive agricultural area but also its heartland. Shortly before the river empties into the Gulf of Thailand, it flows through the seven-million megacity of Bangkok, whose surrounding area is home to a further five million people. This plain, in which 40% of Thailand's gross national product is generated, was worst hit by the 2011 disaster, although other parts of the country together with Cambodia, Laos and Vietnam also experienced heavy floods.

Months of rain

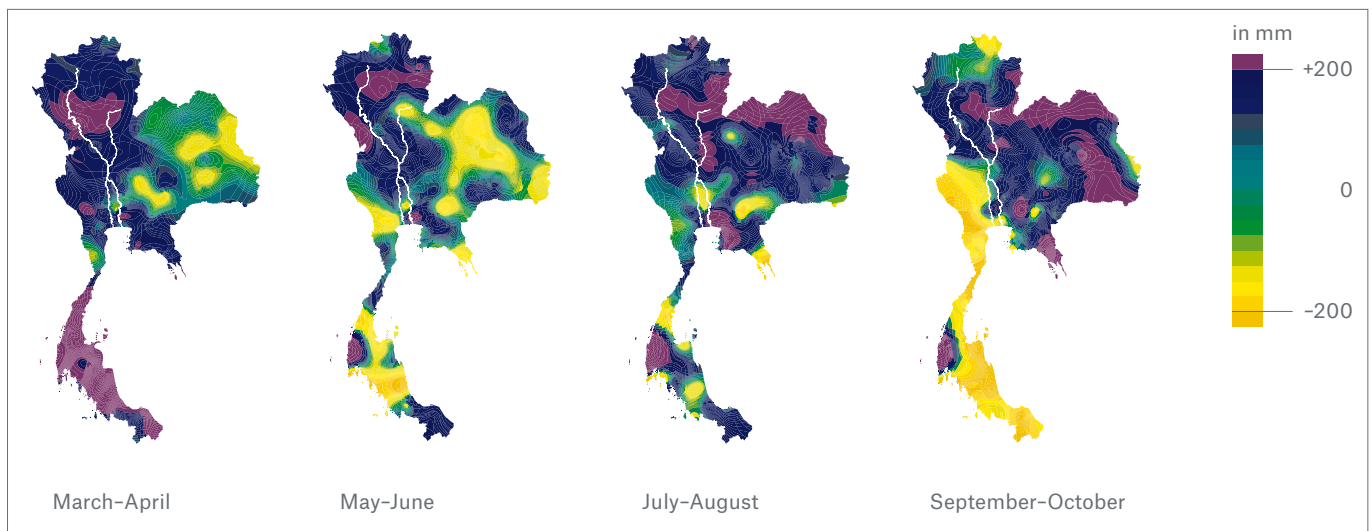
Central Thailand's rainy season lasts from mid-May to October. The southwest monsoon brings moist, warm air that generates rainfall over the plain or, ultimately, on reaching the mountains. This season accounts, in an average year, for some 1,000 to 1,300 mm of rain – a good 80% of the region's annual precipitation. In 2011, La Niña probably played a key role here too; during this phase, the monsoon is particularly intense. Increased precipitation occurred in South and Southeast Asia.

In the north of Thailand, 3.5 times the normal amount of rainfall in March led to numerous flash floods in the mountains and virtually filled the Bhumipol and Sirikit reservoirs. The summer monsoon began in May, bringing well-above-average precipitation over a period of several months.

The first major floods occurred when, at the end of July, Typhoon Nock-ten made landfall in northern Vietnam, pouring veritable torrents of rain over the entire region all the way to northern Thailand. Again flash floods occurred in many places. The floods spread from the north to the south in the subsequent two months, particularly as the two major dams had to be increasingly opened to avoid overspill, largely losing their flood-control function. Vast amounts of water from the north of Thailand converged in the Chao Phraya. By mid-September, practically all low-lying areas in central Thailand as far as the northern outskirts of Bangkok were inundated. Floodgates at the entrances to irrigation channels were opened or broke. The water masses poured into paddy fields, villages and towns. The town of Nakhon Sawan at the confluence of the Ping and Nan, the two rivers that meet to form the Chao Phraya, was submerged in no time. The historic capital of Ayutthaya with its wonderful temples was also flooded, as were numerous large industrial parks. However, this overflowing benefited Bangkok by attenuating the approaching flood wave.

At the beginning of October, all the reservoirs were so full that the operators had to discharge large quantities of water to protect the dams. This exacerbated the flooding situation downstream and increased the hazard for Bangkok and the industrial parks on the Chao Phraya plain. Sandbag barriers were feverishly erected, repaired and heightened. Nevertheless, 32 of the city's 50 districts were submerged and two million people were ordered to leave their homes. Fortunately, Bangkok's city centre business district escaped flooding.

Excess precipitation



During each two-month period from March to October, rainfall in the north of Thailand was significantly above the relevant two-month long-term average, in some places by as much as 1,000 mm.

Source: Munich Re, based on data supplied by the Thai Meteorological Department and analysed by Mr. Saman Prakarnrat

In early November, the waters slowly began to recede, starting in the north of the country. In the Chao Phraya valley gradients are shallow, and in some areas the water even had to be pumped away. Not until the end of the year had the water drained off completely.

The floods did not affect the Chao Phraya region alone. People battled against the flood waters – often in vain – in 64 of Thailand’s 76 provinces, including the east of the country, on the Khorat Plateau where, however, monetary losses were much lower in the absence of major values. The consequences in humanitarian terms were nonetheless at least as bad there as in central Thailand.

Overall losses approximately US\$ 40bn

The floods were the worst Thailand had experienced in 50 years but the extent of the areas flooded was less shocking than the scale of the overall losses in the US\$ 40bn region caused by the flood waters. Over the past 30 years, Thailand has experienced rapid development. With its burgeoning population (1980: 46.5 million; 2010: 68 million) and economic growth, there has been a proliferation of huge new settlements, particularly commercial and industrial parks, with assets valued in the tens of billions. The traffic and supply infrastructures have also been significantly extended, especially in Greater Bangkok. With the economy booming, the flood hazard became a side issue and was generally underestimated. However, the hazard was even increasing, as widespread tracts of land that had previously served as a buffer for flood waters were swallowed up by development.

The large industrial parks were the principal loss drivers. Seven such parks, with 1,000 production halls in which almost half a million people worked, were metre-deep in water. Massive damage was caused to property, production was halted, supplies and deliveries were interrupted, sometimes for weeks on end, ultimately with global repercussions. The worst hit sectors were the electrical, computer and automotive industries, manufacturers of medical equipment and the food industry. Nine Japanese car producers were forced to cease operations, resulting in a production loss of 6,000 cars a day. Global players were among those companies most affected, as supplies from Thailand were disrupted. The closure of a hard drive plant had a worldwide impact. One quarter of all hard disk drives are manufactured in Thailand. The sector was hit by shortages and prices rose.

Away from the industrial parks too, many factories were affected; estimates ranged from 10,000 to 15,000 businesses in 20 provinces. At least 900 of the 2,150 factories in the region of Ayutthaya alone were affected. Some 300,000 people are likely to have lost their jobs permanently and a further 700,000 to have been temporarily unemployed.



Hundreds of thousands of homes were flooded as well as utility companies, supply lines, schools and universities, including the renowned Asian Institute of Technology (AIT) and Thammasat University – one of the main evacuation centres, which itself then had to be evacuated. Several hospitals were also cleared. Roads and railway lines were rendered impassable by the floods, and additionally many bridges and flyovers were blocked by vehicles parked there by their owners to save them from being damaged. The damage to roads and motorways was in the order of half a billion US dollars. However, things could have been far worse in Bangkok: two of its main transport systems, the Skytrain and the underground, were left virtually unscathed. The international airport was also operating more or less normally, while the airport used for domestic flights was completely inundated and had to close. Nevertheless, Bangkok had to contend with substantial traffic problems, with flood waters at least 80 cm deep in more than 30 districts, home to some 800,000 people.

Throughout the period of flooding from July to November, over 13 million people were affected, two million being forced to leave their homes.

Thailand's agricultural and livestock sectors were also badly hit. A total of 1.6 million hectares of agricultural land (more than 10% of the total) were flooded and destroyed or damaged, including 1.35 million hectares of paddy fields. A quarter of the harvest was lost. Some ten million farm animals were at risk or had to be evacuated and many of them died.

According to the Tourism Authority's estimates, the industry suffered losses of at least US\$ 2bn, as some 300,000 guests stayed away.

Low insurance density – Heavy losses

Never before during an inland flood had such high insured losses been incurred (previous record: United Kingdom in 2007 at US\$ 6bn) despite Thailand's being a country where the insurance density is generally not high. Estimates (as at February 2012) stand at US\$ 10bn.

Approximately 90% of all insured losses were incurred by industrial business, largely relating to seven industrial parks with assets valued at nearly US\$ 20bn that had been completely inundated. Loss ratios were in the 50% range, which is very high for river floods. The floods also resulted in business interruption losses (manufacturing coming to a halt due to flooded production lines) and contingent business interruption losses (caused by disruptions to supply chains and transport links) which are proving very hard to quantify, especially as they affected companies worldwide.

Following the Tohoku earthquake in Japan, the floods in Thailand once more demonstrated the problems associated with far-reaching business interruption policies. Four-fifths of the insured industrial losses were incurred by Japanese companies hit by the Tohoku quake which had relocated their production facilities to Thailand.

Left: A number of historic sites, such as this temple to the north of Bangkok, were completely cut off by the waters.

Right: Many drivers parked their vehicles on flyovers, impeding traffic.



In the private sector, the insurance density in Thailand is only 1%, according to the General Insurance Agency. Homeowners who obtain a loan are only obliged by their bank to insure against fire but not flood. Only 10% take out flood insurance, for which an additional 25% is levied on top of the standard fire premium. Consequently, Thailand's Office of Insurance Commission reported that the insured losses resulting from the loss of or damage to one million homes (150,000 in Greater Bangkok) amounted "merely" to half a billion US dollars.

In view of the heavy insured losses in Thailand the insurance industry will have to react. This will mean looking at the accumulation of insured values, and checking the conditions for insurability and the adequacy of the rates. What was special about this event was that the losses involved such high insured values in a country where the overall level of development is relatively low. Particularly evident in this respect were the effects of global interconnections and the contingent business interruption losses this caused, affecting many different parts of the world.

In spite of the heavy losses, the reinsurance sector will continue to cover industrial risks in Thailand provided the government and the operators of industrial parks make a rigorous and sustained effort to ensure the sites are better protected in the future.

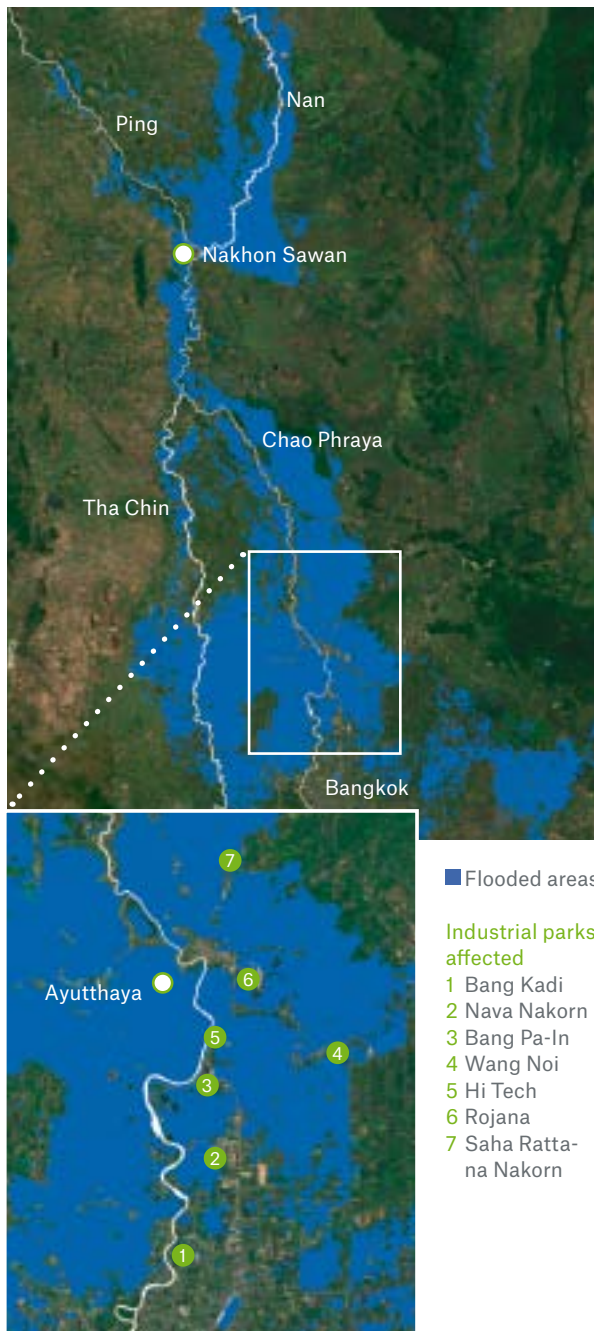
Foreign investors rely on the adequate and affordable insurance of industrial risks in Thailand. At the same time it is essential for Thailand that multinational corporations do not withdraw their production facilities from the country. Therefore, the government has to see to it that more far-reaching flood control and mitigation measures are implemented to prevent similar losses in the future. One idea, for example, is to channel the Chao Phraya flood waters to the west and east, past centres located along the lower reaches of the river where there is a high concentration of values, by developing the existing network of waterways and canals. Protecting the industrial parks against flooding will be expensive; for the Rojana industrial park in Ayutthaya alone it would cost US\$ 400m.

Loss figures

| | |
|-----------------------------------|---------------|
| Deaths | 813 |
| No. of people evacuated | 2,000,000 |
| Overall losses | US\$ 40bn |
| Insured losses | US\$ 10bn |
| Number of homes destroyed/damaged | 1,000,000 |
| Flooded arable land | 1.6m hectares |

The Rojana industrial park near Ayutthaya was completely flooded and production was at a standstill for weeks on end.





Vast areas of land along the Chao Phraya were submerged. Seven industrial parks were affected and this is where most of the insured losses were sustained.

Source: Munich Re, based on data from NASA NRT Experimental Flood Maps



Conclusion

Water – in the form of tsunamis, floods or flash floods – was the cause of death of approximately 95% of the 27,000 people who lost their lives in natural disasters in 2011. Just days before the end of the year, over a thousand people in Mindanao in the Philippines were killed by mudslides that occurred while they were asleep.

Thailand was shaken to the core by its worst flood disaster in recent decades, which may impede the rapid growth rates of the recent past. Many companies will have lost substantial sums of money in this ostensibly “secure” producer country, despite payouts under insurance policies. It would be very much to Thailand’s detriment if such companies were to withdraw. The country has invested significant amounts in flood control – mainly in Bangkok. This tendency to focus on the capital must be reviewed in the light of the urgent need to invest in flood control measures elsewhere.

It is also necessary to tighten up the land-use regulations and ensure they are strictly observed. Implementing such measures would help rather than hinder development because planning certainty is a key criterion for investors. The flooding hit many companies’ profits. Thailand must ensure it is better prepared to avoid such losses if it is to continue to provide attractive business sites for multinationals, either by strengthening its flood defences or by applying the more effective and efficient means of prudent land-use planning.

Another key factor will be higher insurance density in the private and commercial sectors. With this goal in mind, the establishment of a 500 billion baht (US\$ 17bn) insurance pool has now been proposed. This would benefit the population, the economy and the insurance industry because higher insurance density means more reliable risk assessment and a better spread of the risks.



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Spring 2011: Severe thunderstorms in the USA

An extremely active spring thunderstorm season caused damage on an unprecedented scale across the eastern United States. Numerous tornado outbreaks devastated entire cities, causing a record US\$ 25.9bn in insured losses and over 600 thunderstorm-related fatalities, the highest loss of life from the peril since 1925.

Mark Bove

Although many climatological and meteorological factors contributed to the severe thunderstorm and tornado outbreaks of 2011, strong La Niña conditions were among the most significant (see also Eberhard Faust's article on page 40). La Niña, an anomalous cooling of sea surface temperatures in the eastern equatorial Pacific Ocean, has been shown to create atmospheric patterns over the eastern half of the United States that are conducive to severe thunderstorms and tornadic activity. This occurs because La Niña enhances the polar front jet stream over North America, which in turn provides more energy to extratropical cyclones moving into the United States from the Pacific Ocean and Canada. This increased energy, combined with the strong temperature gradients and wind patterns associated with these types of frontal systems, can increase the potential of severe thunderstorms and their associated perils.

Record spring tornado activity

The influence of La Niña on severe thunderstorms occurs during late winter and spring and is most pronounced over the Deep South and Midwestern states, extending from Louisiana and Mississippi northward to Ohio and Michigan. In this broad region, the potential for large tornadic outbreaks is elevated, including an increase in the number of long-tracked, violent tornadoes. The 1974 Super Outbreak occurred in this region during a La Niña year, as well as several major outbreaks in 2011. Other areas of the United States, including the Plains states commonly referred to as "tornado alley", typically do not see a significant increase in tornadic activity during a La Niña year.

Several records were set by the 2011 thunderstorm season. Though it appears likely that the total tornado count for 2011 will be below the 2004 record of 1,817, it is probably the most active spring tornado season on record, as several hundred of 2004's tornadoes were spawned by landfalling hurricanes during the summer season. April 2011 saw a record 748 confirmed tornadoes, and April 27 also set a record for being the most active tornado day in US history, with 226 tornadoes. There were six EF5 tornadoes in 2011, tying the record set in 1974. It was also the deadliest tornado season in the United States in over 85 years, with 551 fatalities due to tornadoes alone, of which 318 occurred on 27 April.

Thousands of hailstorms and thunderstorms

Two severe thunderstorm outbreaks generated over half of the insured losses observed in 2011. The first event, dubbed the 2011 Super Outbreak, was the result of a powerful extratropical cyclone that developed over the southern plains and moved eastward across the Ohio River Valley from 25 to 27 April. During those three days the system spawned hundreds of tornadic thunderstorms, extending from the Deep South to the US eastern seaboard. In total, the event triggered 353 tornadoes across 22 states, as well as thousands of hail and straight-line wind events.

Particularly hard hit by the outbreak was northern Alabama, where three EF5 tornadoes decimated the small towns of Hackleburg, Shottsville, and Rainsville, effectively wiping them off the map and killing 120 people. The city of Tuscaloosa and several suburbs of Birmingham, Alabama's largest city, were also devastated by a long-tracked EF4 tornado that stayed on the ground for 110 km (70 miles) and had a maximum

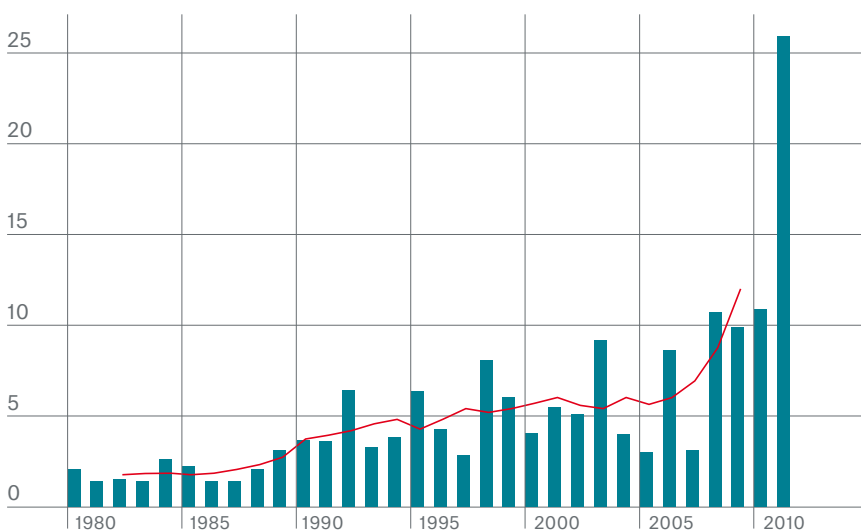


Parts of Pratt City Alabama were left in ruins in the Super Outbreak on 27 April.

width of 2.4 km (1.5 miles). Over 60 people perished during the tornado, which was the largest single cause of insured loss from the entire outbreak. Ultimately, the 2011 Super Outbreak caused an estimated US\$ 7.3bn in insured damage, the largest insured loss ever caused by a thunderstorm outbreak (in terms of original dollars).

After three weeks of relative quiet following the 2011 Super Outbreak, the second major thunderstorm loss of 2011 occurred in late May, as a series of low-pressure systems triggered several waves of severe thunderstorms that stretched from Texas to the Mid-Atlantic states. This outbreak triggered at least 180 tornadoes, including two EF5 tornadoes. The storms caused US\$ 6.9bn in insured losses and claimed at least 178 lives.

Insured thunderstorm property losses in the USA (US\$ bn) 1980-2011



■ Thunderstorm losses (2011 values)

— Five-year moving average

Since 1980, insured thunderstorm losses have been rising in the USA, reaching unprecedented levels in 2011.

A large proportion of insured and human loss from this outbreak came from a single event: the Joplin, Missouri, tornado. The tornado, which originated near the Kansas-Missouri state line, intensified rapidly as it moved eastward over the densely populated southern half of Joplin, ultimately reaching a maximum width of 1.6 km (one mile) at its widest point and EF5 intensity. Although the city’s downtown district was spared, an estimated 2,000 buildings were destroyed by the tornado, about 15% of the city’s building stock. Homes and businesses were completely destroyed, and the St. John’s Regional Medical Center, a major healthcare provider for the city and southwestern Missouri, was also heavily damaged and ultimately determined unsafe for use and scheduled to be demolished. Due to its severity and path over a major city, the Joplin tornado has become one of the costliest and deadliest tornadoes in US history, with estimated overall losses exceeding US\$ 3bn and a human toll of 158 direct casualties.

Thunderstorm loss trends

Insured losses in the United States due to the thunderstorm events of 2011 are currently estimated at US\$ 25.9bn. This amount is more than double the previous record, set in 2010. Although it is likely that 2011’s loss total is a bit of an outlier, due to the severity of the outbreaks and two major cities suffering heavy damage, they dramatically illustrate that the trend of increasing insured thunderstorm losses over the past 30 years is continuing. The current five-year average thunderstorm loss (2007–2011) now stands at a record US\$ 12.1bn per year, an increase of US\$ 3bn over the previous five-year period. The current average is almost US\$ 6bn higher than a decade ago and almost ten times higher than the 1980–1984 average. The top six largest annual insured thunderstorm losses totals, all exceeding US\$ 8bn, have occurred in the past nine years. The frequency of billion-dollar thunder-

storm losses has also continued to rise, and 2011 was the second successive year with three such outbreaks. There have now been 24 billion-dollar thunderstorm events since 1994; only one thunderstorm event before then caused a loss of that magnitude.

The primary factor for the rise in thunderstorm losses in the United States continues to be socio-economic in nature. The United States population has shifted southward over the past 50 years, to regions that have a greater frequency of severe thunderstorms. The shift in population has led to sprawling cities and rapid suburban and exurban growth, which have created more areas of dense exposure accumulations that severe thunderstorms hazards can hit. The value and amount of real and personal property, including electronic devices that are extremely vulnerable to lightning, have also risen dramatically over this time period, further increasing thunderstorm loss potentials. Finally, building codes in many thunderstorm-prone states are not sufficient to ensure buildings withstand high winds (tornadic or otherwise) and hail damage, leading to increased vulnerability of buildings to these perils.

Though currently not a major driver of insured loss trends, there is some evidence that climate change could become a larger component of thunderstorm loss trends in the coming decades. This is because warmer surface temperatures could lead to greater convective potential in thunderstorms, as well an increase in available moisture for these storms. Scientific studies have indicated that, in a warmer climate, the number of days per year on which atmospheric conditions are conducive to severe weather may increase across the eastern United States. There are also some indications that this is already occurring to some extent, as an increase in the frequency of large hail events has been observed over the past 35 years and more frequent weather conditions with high thunderstorm potential east of the Rocky Mountains.

The ten most expensive natural catastrophes for the insurance industry in the USA

| Rank | Year | Date | Event | Insured losses (US\$ m in original values) |
|------|------|-------------|--|--|
| 1 | 2005 | 25–30 Aug. | Hurricane Katrina | 62,200 |
| 2 | 2008 | 12–14 Sep. | Hurricane Ike | 18,500 |
| 3 | 1992 | 23–27 Aug. | Hurricane Andrew | 17,000 |
| 4 | 1994 | 17 Jan. | Northridge earthquake | 15,300 |
| 5 | 2005 | 20–24. Sep. | Hurricane Rita | 12,100 |
| 6 | 2004 | 12–21 Sep. | Hurricane Ivan | 12,000 |
| 7 | 2005 | 24 Oct. | Hurricane Wilma | 10,700 |
| 8 | 2004 | 13–14 Aug. | Hurricane Charley | 7,600 |
| 9 | 2011 | 22–28 April | 2011 Super Outbreak (severe storms, tornadoes) | 7,300 |
| 10 | 2011 | 20–27 May | Severe storms, tornadoes | 6,900 |

Small steps, big effect

From a single risk perspective, proper construction techniques are critical in reducing thunderstorm losses. Buildings should be constructed with continuous load paths in the walls and proper roof-to-wall and wall-to-foundation connections. Exterior doors should open outwards, windows should be impact-resistant and garage doors reinforced. All these steps can greatly reduce the potential of wind damage, particularly for straight-line wind events and weak tornadoes. Additional wind mitigation techniques, such as hurricane straps, can further fortify a building against wind damage. Hail damage, a much more common type of thunderstorm loss, can easily be mitigated through use of proper building materials, such as hail-resistant roofing and siding. All of these techniques, if implemented universally, could provide substantial reductions in thunderstorm loss from future events.

From a portfolio perspective, capping exposure accumulations within small geographic areas and insuring a variety of property construction types can be used to limit potential losses from a severe thunderstorm outbreak. The area impacted by an individual tornado or hail swath is very small, so limiting the amount of exposure written in a given development or community can help prevent an accumulation of large losses from a single, severe event. This type of geographic control, if uniformly implemented across an entire portfolio, could also help to reduce the accumulation of losses from larger outbreaks that impact hundreds of discontinuous areas. Further, diversifying or limiting certain types of construction in a given geographic region can also reduce losses, as some classes of construction are less vulnerable to wind and hail than others.



Conclusion

Never have thunderstorm losses been as high as in 2011 – a maximum not expected, even after the previous record years of 2008 and 2010. Despite probably being an outlier loss year, the trend of increasing thunderstorm losses does not show any signs of slowing, primarily due to increasing exposures but climate change may also play a role in this.

The heavy losses of 2011 highlight the importance of managing thunderstorm risk, from an individual occurrence and aggregate loss standpoint. Individual events involve less risk in the case of thunderstorms than hurricanes and earthquakes because they do not produce comparably high insured losses. But, due to their frequency, annual aggregated thunderstorm losses are often higher than hurricane losses, and account to a large extent for increasing natural catastrophe losses in the USA. In 2008 and 2009, insured thunderstorm losses were US\$ 20bn, more than hurricane losses for the same period (including Ike).

Since 1980, only six hurricanes and one earthquake have had insured loss totals, in terms of original dollars, that exceeded those from the 2011 Super Outbreak and the Joplin outbreak. In the same period, annual hurricane losses have only exceeded annual thunderstorm losses in five cases. Thunderstorm losses are now comparable with the losses from a moderate to severe hurricane season. Insurers must take steps to address this in their risk management.



OUR EXPERT

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Climate protection further postponed

The climate summit, held this year in Durban, was again dominated by sweeping declarations of intent, binding decisions being postponed, as in the past. The key to efficient climate protection lies in achieving a small-scale consensus between the main emitters.

Peter Höppe

Never before had pre-summit expectations been as low as in the run-up to the 17th Conference of the Parties (COP17) in Durban. The effects of the massive disappointments of the 2009 climate summit in Copenhagen and the relatively limited progress made in Cancún the year before lingered on. Other problems such as the national debt crises in Europe and the USA and the threat of a global recession also attracted a lot of attention, so that less priority was given to finding rapid solutions to the climate change issue.

The starting point of the negotiations was the target already set in Copenhagen and consolidated in Cancún of limiting global warming to a maximum of 2°C. The goal of the negotiations on adaptation to unavoidable climate change impacts was the establishment of a Green Climate Fund (GCF) to support developing countries. By 2020, the fund's coffers are to be filled with a substantial proportion of the annual US\$ 100bn pledged by the industrial nations.

Steps agreed to help developing countries

Concrete decisions already taken at the end of the first week of negotiations went largely unnoticed by the general public. These related to the Loss and Damage programme that had been adopted in Cancún, according to which a detailed submission is to be drafted by

Climate change is bringing not just more floods but increasing droughts, causing considerable problems for sectors dependent on water such as shipping and energy.

the December 2012 climate summit in Qatar (COP18) on how to address losses linked to climate change in developing countries. The climate risk index presented by Germanwatch in Durban and based on data from Munich Re's NatCatSERVICE shows that the ten countries worst affected by climate change are in the developing world, with Pakistan heading the list in 2010. A work programme agreed on in Durban sets out the steps to be taken in 2012 to address the Loss and Damage issue. One contentious item concerned the setting up of an international mechanism such as the global pool for losses caused by extreme weather events proposed by the Munich Climate Insurance Initiative (MCII). The USA, in particular, is opposed to initiatives of this nature over which it has no direct influence. Three thematic areas are to be addressed in 2012:

A technical paper will be drawn up to evaluate the risk situation in the developing countries in the light of the anticipated impacts of climate change, taking into account inputs from all the major stakeholders. The paper will be presented to experts and used to draft a recommendation for COP18.

Four expert meetings are scheduled (three regional, one for the small island developing states) on potential risk management tools, including insurance programmes. At these meetings, risk prevention and insurance options will be discussed and the requisite resources quantified.

By 17 September 2012, the negotiating delegations and relevant organisations are to submit proposals on the role to be played by the United Nations Framework Convention on Climate Change (UNFCCC) in the risk management of loss and damage caused by climate change. These proposals will also be included in the recommendation for COP18.

No consensus was reached in Durban on how the resources needed for the Green Climate Fund (GCF), which is to finance the adaptation measures, are to be raised by 2020 and how those resources will be managed. Some countries, among them the USA, are opposed to centralised administration of the fund but most delegations are in favour. German Environment Minister Norbert Röttgen proposed locating the fund's administrative centre in Germany. Similar offers were also put forward by Switzerland and South Korea. A decision is expected by the end of next year, pending which the GCF secretariat will be located in Bonn.

Nevertheless, how the fund is to be financed after 2013 remains unclear. For the period from 2010 to 2012, the industrialised countries had collectively pledged some US\$ 10bn annually. No firm commitments have as yet been forthcoming for the period following 2013.



This baobab tree symbolised the 17th climate summit in Durban. In keeping with the idea of protecting the climate, the tree was lit up by people pedalling the cycles.

Another subject discussed in Durban was whether a tax could be levied on the shipping industry, which currently accounts for approximately 3% of global emissions, and the proceeds used to bolster the GCF. A levy of US\$ 25 per tonne of CO₂ could generate US\$ 25bn in tax revenues, part of which could be channelled into the GCF. However, no agreement was reached, some delegations being categorically opposed to such a measure.

Reluctance to commit to fast-track, binding emissions cuts

The negotiations on reducing greenhouse gas emissions and on climate change adaptation measures failed to produce firm commitments. The paradox remains that, while there is a general consensus on the need to limit global warming to 2°C (some delegations even called for this target to be reduced to 1.5°C), there is a general reluctance to commit to legally binding reduction targets. As in previous climate summits, declarations of intent only were made and concrete measures postponed.

A decision was taken to negotiate a global agreement under international law by 2015 that will include all the relevant emitter countries. However, the agreement will not take effect until 2020. The voluntary, non-binding commitments on greenhouse gas reduction entered into in Copenhagen will nowhere near suffice if the 2°C goal is to be achieved. The fact that it even proved possible to reach an agreement on the drafting of a binding agreement to apply from 2020 was probably due to the ambitious negotiations conducted by a coalition made up of the EU delegation, the small island states and the developing countries, and to China's change of attitude on a binding solution. When the negotiations reached a stalemate China, for the first time, stated that it would be willing to consider binding post-2020 reduction targets provided certain conditions were met, including an extension of the Kyoto Protocol and the taking into account of prior reduction commitments. Negotiations were impeded by the USA's rigid stance on binding commitments and India's refusal to make concessions.

The resulting decision to negotiate an international, legally binding agreement by 2015 on emission reductions, although more than had been expected ahead of Durban, nonetheless amounts at present to no more than a declaration of intent.

Consensus within small group – Key to effective climate protection

Nevertheless, whether the relevant emitter countries are really prepared to make effective cuts is questionable. Although agreement was reached to extend the Kyoto Protocol beyond 2012, the CO₂ emissions covered by the agreement make up only 15% of global emissions. On top of this, Canada announced its withdrawal from the current Kyoto Protocol just days after the Durban summit. Thus Canada, which failed to meet its targets by a huge margin, will avoid having to pay a substantial penalty for non-compliance. Japan and Russia – the fourth and fifth highest emitters – had already stated ahead of Durban that they would not participate in a second commitment period of the Kyoto Protocol.

Negotiations have been hampered by the fact that the UNFCCC climate summits are becoming increasingly complex. The summits undoubtedly provide the best forum for concluding internationally binding agreements and taking the needs of the countries worst affected by climate change into consideration. However, as part of this process, it would be expedient for talks to be held initially between a smaller group consisting of the main emitter nations.

The key to efficient climate protection lies in a consensus between the six primary emitters: China, the USA, the EU, India, Russia and Japan, which account for 75% of global CO₂ emissions. In this way, concrete proposals can be drafted and tabled for discussion at the climate summits.

The current negotiation results are not equal to the task of tackling the human risk climate change involves because climate protection will not allow any postponement of decisions. Anyone who recognises the 2°C target must, consequently, accept specific emission-reduction targets. Regrettably, this consequence has not yet been drawn.

Glimmer of hope on the summit sidelines

Ahead of Durban, Munich Re advocated a climate protection Plan B alongside the international negotiations. The aim of the plan is to develop climate-friendly renewable energy sources able to compete financially with fossil energy sources in the medium term. Some regions could take the lead in this area. A very positive step in this direction was taken on the summit sidelines when the governments of South Africa, Germany, the UK, Norway and Switzerland and the European Investment Bank signed a partnership agreement under the South African Renewables Initiative. The next few years will see the onset of massive growth in South Africa's renewable energy sector.



OUR EXPERT

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Facts, figures, background

The influence of La Niña from January to May and August to December was a major cause of many of the extreme weather losses in 2011.

Eberhard Faust

According to provisional data from the World Meteorological Organization (WMO), 2011 will probably be the tenth warmest year since recording began in 1850. The WMO data indicate that the temperature was $+0.41^{\circ}\text{C}$ ($\pm 0.11^{\circ}\text{C}$) higher than the 14°C average for the reference period 1961–1990. Last year was marked above all by a strong La Niña phase which started to develop in mid-2010 and reached a climax at the turn of 2010/11. A brief neutral phase in mid-2011 was followed in August 2011 by a return to weak La Niña conditions that lasted until the end of the year. The La Niña influence, shown in the US National Climatic Data Center's temperature anomaly map in the form of a typical widespread drop in temperature in the eastern half of the Pacific basin, is largely responsible for the lower global mean annual temperature in 2011 compared with 2010. However, the long-term time series of global mean annual temperatures shows that, although the La Niña years occurring during this time were approximately $0.1\text{--}0.2^{\circ}\text{C}$ cooler on average than the years immediately before and after, an overall upward trend is evident throughout the La Niña years. The WMO also reported that 2011 was the warmest La Niña year on record.

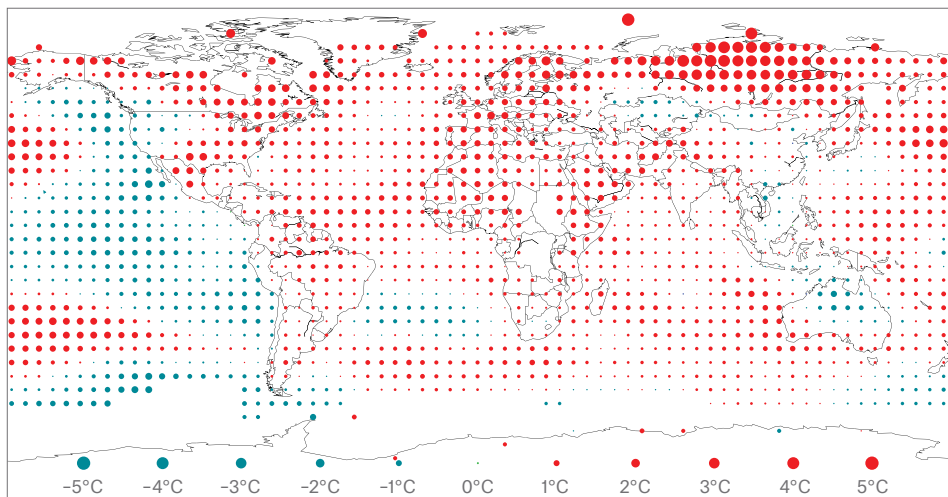
Marked positive warm anomalies in the annual figures for 2011 were observed primarily in Siberia, the high Arctic latitudes, southern and eastern North America, northern Europe, East and West Africa and Southwest Asia.

Dramatic changes in the Arctic

Already in 2010, as a consequence of the warm Arctic, the sea ice extent, typically at a minimum in September, was the third lowest since the start of satellite measurements in 1979. On 9 September 2011, the area of the Arctic ice cap was the second lowest (4.33 million km^2) of the measurement series. The loss trend amounts to -12% of the 1970–2000 mean per decade.

The September sea ice extents of the past five years have been the five lowest of the time series. In terms of Arctic sea ice volume, which indicates both the area of the ice and its thickness, the model-based calculation conducted by Washington University's Polar Science Center for September 2011 even showed an absolute minimum volume since calculations began in 1979.

Regional mean annual temperature anomalies for 2011 with respect to a 1971–2000 base period

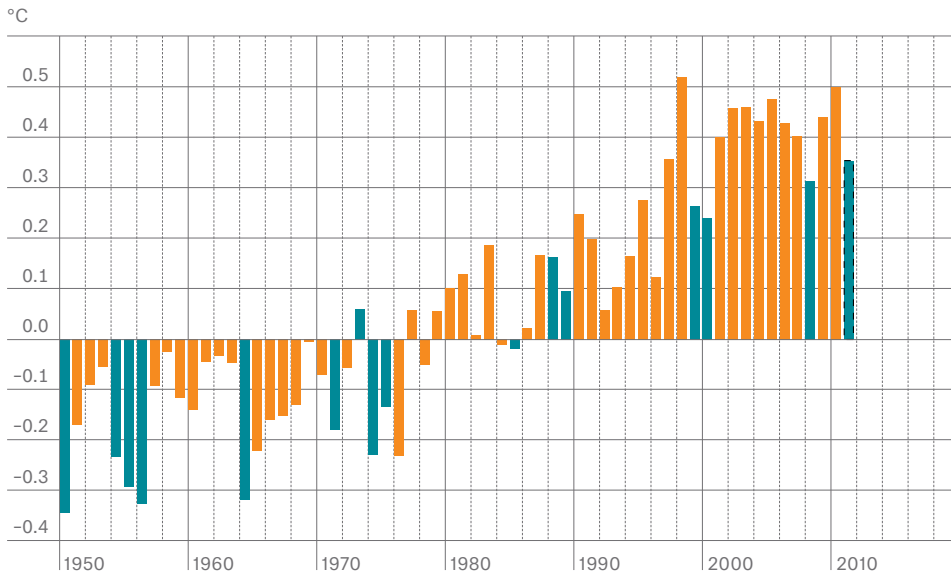


In most regions, 2011 temperatures were above the 1971–2000 average. Lower temperatures were recorded primarily in the eastern Pacific.

● Warmer
● Cooler
than the long-term average (1971–2000). The larger the dots, the greater the deviation from the average temperature.

Source: National Climatic Data Center/NESDIS/NOAA

Time series of mean global annual temperature anomalies with respect to a 1961-1990 base period for the period 1950-2011

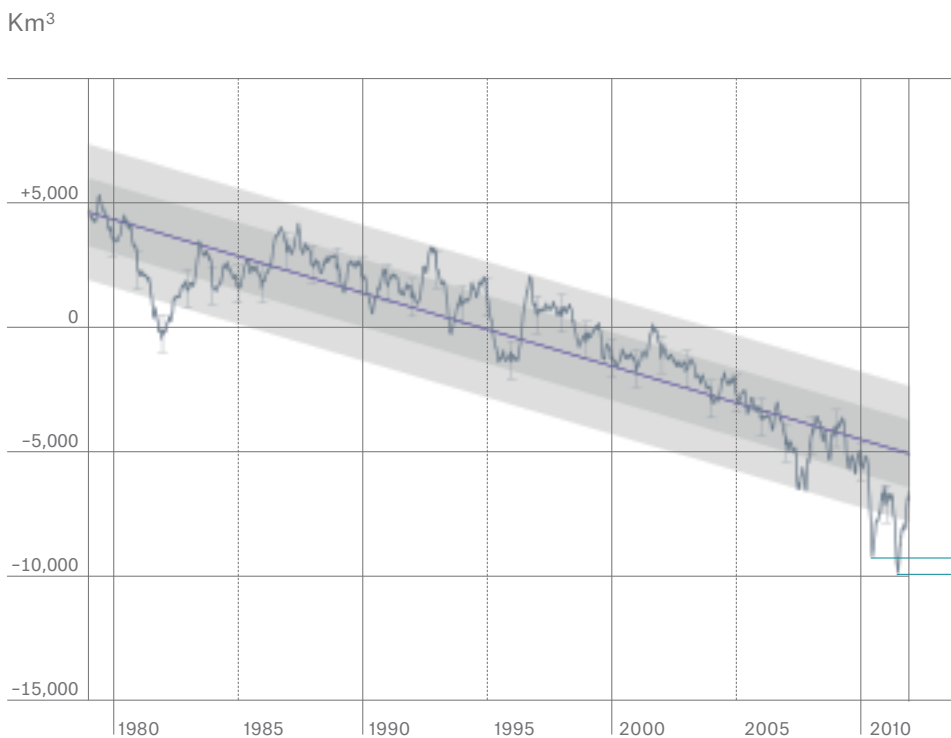


The La Niña years in the time series of the Met Office/University of East Anglia show a rise in global mean annual temperature over time, as does the entire series. Of all the La Niña years, preliminary analyses indicate that 2011 has been the warmest to date. Years in which the average Oceanic Niño Index (NOAA/CPC) is not more than -0.5 are termed La Niña years.

- Neutral and El Niño years
- La Niña years
- Preliminary estimate, based on January–October 2011

Data sources: Met Office/Climate Research Unit of the University of East Anglia; NOAA/Climate Prediction Center

Arctic sea ice volume anomalies for 1979-2011 with respect to the 1979-2010 mean



In September 2011, the Arctic sea ice volume modelled on the basis of observations by the Polar Science Center of the University of Washington was some 380 km³ less than in 2010, the previous record year. However, this difference lies within the range of model uncertainty.

Data source: Polar Science Center, Applied Physics Laboratory, University of Washington

As a consequence of the dramatic changes in the Arctic, the Northwest and Northeast Passage were opened to shipping for several weeks in summer in 2011, as in preceding years. Work is currently under way to develop service and infrastructure systems for the passage north of the Canadian coastline, especially for tanker traffic; Canada is considering the construction of a deep-water port in Resolute Bay. Compared with the Rotterdam-Tokyo route via the Suez Canal, the Northwest Passage option is over 5,000 km shorter and avoids the areas around the Horn of Africa and in Indonesia where piracy is prevalent.

La Niña persisting for many months

The influence of La Niña from January to May and from August to December 2011 was a major cause of many of the year’s extreme weather losses. During La Niña conditions, temperatures in the Central and Eastern Equatorial Pacific and much of the Eastern Pacific Basin are considerably lower, while the trade winds from the east increase in strength, driving the warm tropical surface waters towards the basin’s western perimeter off the coasts of Southeast Asia and Australia. These oceanic and atmospheric processes alter pressure and precipitation patterns not only in the Pacific Basin and along its perimeters but also elsewhere due to the long-range effects they have on the climate system. The first La Niña event in 2011, which lasted from mid-2010 to May 2011, was one of the strongest ever registered according to the Southern Oscillation Index/SOI (which describes the difference in surface air pressure between Tahiti and Darwin).

La Niña I - Drought and heat

One dramatic effect of La Niña was a severe drought on the Horn of Africa that spread throughout a region encompassing large areas of Kenya, Somalia and Ethiopia. It began in October 2010 and lasted until September 2011, causing widespread famine and large-scale migratory movements, particularly in Somalia and Kenya. Around 80% of the livestock of the nomadic populations in Somalia alone died, and some 13 million people required humanitarian aid.

The 2010/11 La Niña event was also closely linked with extreme drought and – in the summer – heat in the southern USA and northern Mexico. In Texas, precipitation levels (273 litres per square metre in the period from January to October) were well under half the long-term average, while the average June–August temperature was 3°C above the long-term average. Further effects were extensive wildfires and dust storms. The Bastrop County Fire in Texas in September destroyed approximately 1,500 houses. Direct drought losses to crops, livestock and forests in the southern USA were in the order of US\$ 8bn, of which US\$ 1bn were insured.

In July, a heatwave extended northwards from Texas and Oklahoma across the central states of the USA and into much of the eastern half of the country. Meteorological stations recorded 78 new daily maximum records.

Drought-hit areas in the USA



In particular, New Mexico, Texas, Oklahoma, Louisiana and Georgia in the USA and northern Mexico suffered from a lack of rainfall. The map shows the situation in July 2011.

- Abnormally dry
- Moderate drought
- Severe drought
- Extreme drought
- Exceptional drought

Source: NOAA

La Niña II – Heavy rainfall and flooding

Between December 2010 and January 2011, under typical La Niña influence, heavy flooding occurred in northern and eastern Australia, resulting in major losses. In Southeast Asia, probably due to La Niña, the more active monsoon triggered widespread extreme precipitation, notably in the Mekong and Chao Phraya basins. This led to severe floods with enormous losses (see Wolfgang Kron’s article on page 26).

Heavy rainfall between January and March in southern Africa which caused a number of floods in the north of South Africa and in Namibia, Botswana, Zimbabwe and Angola, is as much a long-range effect of the La Niña phase as the heavy precipitation accompanied by mudslides, landslides and floods that hit Colombia and Bolivia in the first third of the year. There was a recurrence of such events in Colombia from November, during the year’s second La Niña phase. Hundreds lost their lives in this region, while houses bridges and roads were destroyed.

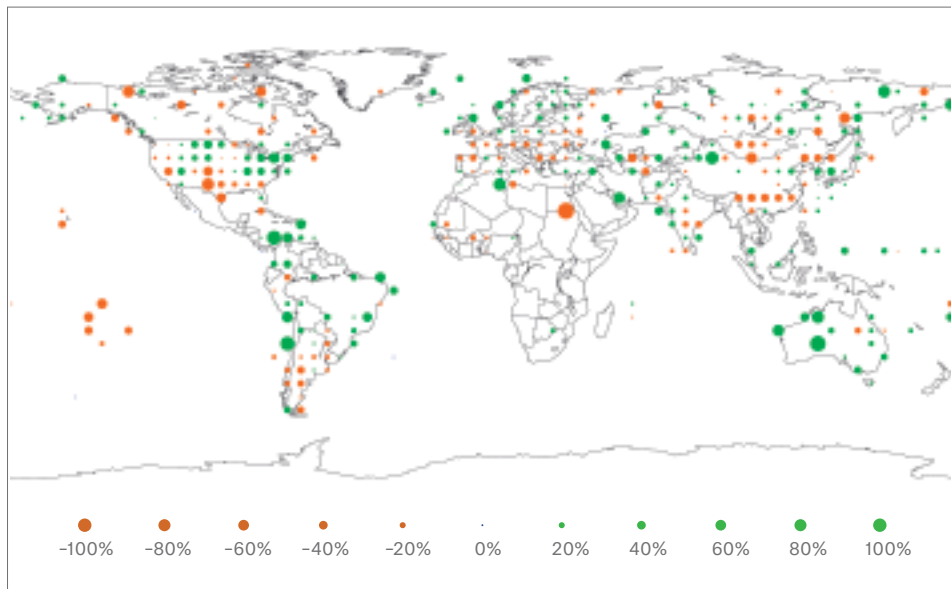
La Niña III – Severe storms and tropical cyclones

The severe storm outbreaks with numerous tornadoes, torrential rain, hail and gale force winds that hit the USA in April and May were among the events with the highest death tolls and resulted in the highest annual storm losses on record. They are primarily caused by increased polar-front activity during La Niña years; disturbances can move into North America from the northwest, unleashing severe thunderstorms in more southerly regions (see Mark Bove’s article on page 32). However, it is also evident from

long-term observations that, as well as rising normalised thunderstorm losses (adjusted to take account of the effects of higher exposure over time), meteorologically measured storm potential is also on the increase. Although long-term climatic changes are the cause, the main factor underlying 2011’s extremes is a natural climate swing linked to La Niña.

A highly active Atlantic hurricane season had been forecast following the change to a weak La Niña phase in August and warm tropical Atlantic temperatures. It was, in fact, the third-strongest season since records began, with 19 named storms in the Atlantic basin compared with a 1995–2010 warm phase average of 15. However, relatively few attained hurricane force (seven out of 19 compared with the warm-phase average of eight out of 15) or severe (category 3 and more) levels (three out of 19 compared with the warm-phase average of four out of 15).

Regional anomalies in annual precipitation in 2011 (%) with respect to a 1961–1990 base period



It was on average an exceptionally dry year in the southern USA and across much of Europe and Asia.

- Drier
 - Wetter
- than the 1961–1990 mean

Source: National Climatic Data Center/NESDIS/NOAA

As in the five preceding years from 2006, no 2011 hurricane reaching the USA was classified as a major hurricane (minimum category 3) at landfall, whereas in 2004 and 2005 there were in total seven such hurricanes. Several factors probably accounted for the relatively benign storm developments in this basin:

- Despite abnormally high sea surface temperatures, particularly in the Caribbean, central and eastern parts of the tropical corridor were relatively cooler than in 2010. Strong trade winds caused the upper and lower water layers to mix, which led to lower temperatures in the main tropical breeding ground up to the season's climax.
- In spite of weak La Niña conditions, the average difference between surface-level winds and winds at 6 km altitude in the corridor between latitudes 20° and 30° north over the Atlantic and the Gulf of Mexico between August and October did not diminish; in other words, wind shear remained high. Most of the storms moved into this corridor and, here too, the high wind shear accounted for the fact that the storms did not become stronger. In the Caribbean, vertical wind shear was weaker but there were few storms.

- A very prolonged so-called atmospheric trough formed at high levels over the east coast of the USA, i.e. the air flow was directed away from the land towards the northeast, so that most of the hurricanes veered northwards and then northeastwards over the Atlantic before they could make landfall. The trough also helped prevent storms from the east penetrating into the Caribbean, where they would have strengthened in the prevailing conditions. The high-pressure trough has prevented a number of hurricanes from making landfall in the USA in the past six years - in notable contrast to 2004 and 2005.

There were three US landfalls in 2011: Hurricane Irene in North Carolina and New Jersey on 27 August following its landfall in the Caribbean, and Tropical Storm Lee in Louisiana on 4 September. Hurricane Irene, in particular, which moved up the northeast coast of the USA across the New York City area, was a timely reminder of the enormous damage that large hurricanes could inflict on this region. Fortunately, by the time it made landfall in New Jersey, Irene had weakened to a category 1 tropical storm. Losses in the region were largely caused by torrential rain and the ensuing flash floods. In all, Irene caused insured losses of US\$ 5.6bn, overall losses amounting to US\$ 7.4bn.

In the USA, firefighters battled with the flames for weeks on end.



The Northwest Pacific typhoon season, with 20 named storms, ten of which became typhoons and seven severe typhoons (category 3 minimum), was comparatively weak. Between 1965 and 2010, the average was 16 typhoons and nine severe typhoons per year. This, together with the fact that most of the storms began relatively far to the west of the basin, is a typical effect of a La Niña phase. Despite a comparatively weak typhoon season, we should not forget that Washi/Sendong, the last tropical storm in 2011, caused some 1,300 fatalities in the Philippines.

Flash floods, floods, landslides

In January, about 900 people died in flash floods and landslides triggered by extremely heavy rainfall in southeast Brazil, making it the natural disaster with the highest death toll in Brazil's history. In April, there were more flash floods and landslides in southern Brazil. In June, heavy rainfall and flooding in central and southern China led to severe inundations and landslides and 1.6 million people had to be evacuated. Following the devastating flooding in 2010, southern Pakistan was again hit by severe floods in August and September 2011.

The Horn of Africa region, particularly Kenya, which had been plagued by drought until September, suffered torrential rains from October, which again destroyed many crops.

Conclusion

Many of 2011's weather disasters were influenced by the year's La Niña conditions. The impact on circulation and precipitation patterns that starts in the Equatorial Pacific area changes the probability of extreme weather occurrences in many parts of the world, as illustrated by the floods in northern and eastern Australia, particularly in the Brisbane area, the severe storm season in the USA and increased monsoon activity in Southeast Asia, all three of which resulted in enormous losses. The conclusion drawn from the data for the year as a whole is that scientifically based prognoses and analyses relating to natural climate oscillations like El Niño and La Niña and the change in risk they cause will be further monitored and, where insurers are concerned, appropriate risk management steps taken.

La Niña's impacts appear in some cases to have already been modified by the long-term effect of climate change that has caused higher sea surface temperatures in recent decades. In the case of the floods in northeast Australia, for example, an important factor was exceptionally warm sea temperatures off the east coast, which increased evaporation rates. A warmer atmosphere can also absorb more moisture and generate more severe precipitation events. Whereas a single strong La Niña year always causes a relative fall in the mean global temperature time series, it is also clear that La Niña years have been growing increasingly warm throughout the time series. There is no reason to doubt that global warming will continue.

Hurricane Irene, whose path crossed the densely populated region between Boston and Washington as well as New York, was a reminder of the enormous losses a strong hurricane could cause if it made landfall in this region. Insurers and local authorities would be well advised to factor this into their risk management and take the far from improbable case of a major hurricane disaster in the northeast USA into consideration in the relevant scenarios.



OUR EXPERT

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NatCatSERVICE: The most comprehensive natural catastrophe database

With rising concentrations of values, new growth regions, increasing risk complexity and, not least, the effects of climate change, natural hazard analysis is an essential part of risk management. Based on decades of experience in analysing and evaluating natural hazard events, Munich Re's NatCatSERVICE is among the world's leading sources of information on natural catastrophes. Occurrence and loss data from around the world have been documented and analysed by Munich Re's Geo Risks Research unit since 1974. This unique archive of natural hazard events has resulted in the most comprehensive natural catastrophe loss database in the world, which goes back to the eruption of Mount Vesuvius in 79 A.D. Approximately 1,000 such events are added to it each year. The database is the foundation that underlies a broad spectrum of risk management and risk research information, tools and services. Originally developed for the insurance industry, NatCatSERVICE is now used in addition by scientific institutes, non-governmental organisations and the media, and in the political decision-making process.

The latest analyses, charts, and statistics are available as free downloads from the Touch Natural Hazards section of our website www.munichre.com/touch

On 23 October 2011, eastern Turkey was shaken by a magnitude $M_w 7.2$ earthquake, which killed over 600 people in Van province.

The year in pictures



10 to 14 January

Floods: Australia
Overall losses: US\$ 2,800m
Insured losses: US\$ 1,875m
Fatalities: 22



12 to 16 January

Flash floods, landslides: Brazil
Overall losses: US\$ 460m
Insured losses: US\$ 50m
Fatalities: 900



31 January to 6 February

Winter storms: USA
Overall losses: US\$ 1,900m
Insured losses: US\$ 1,425m
Fatalities: 39



2 to 7 February

Cyclone Yasi: Australia
Overall losses: US\$ 2,500m
Insured losses: US\$ 1,300m
Fatalities: 1



22 February

Earthquake: New Zealand
Overall losses: US\$ 16,000m
Insured losses: US\$ 13,000m
Fatalities: 181



11 March

Earthquake, tsunami: Japan
Overall losses: US\$ 210,000m
Insured losses: US\$ 35,000-40,000m
Fatalities: 15,840



April to May

Severe storms, tornadoes: USA
Overall losses: US\$ 39,000m
Insured losses: US\$ 20,500m
Fatalities: 585



18 April to 23 May

Floods: USA
Overall losses: US\$ 4,600m
Insured losses: US\$ 500m
Fatalities: 9



April to May

Floods: Colombia
Fatalities: 90



11 May
 Earthquake: Spain
 Overall losses: US\$ 200m
 Insured losses: US\$ 100m
 Fatalities: 10



May to July
 Wildfires: Canada
 Overall losses: US\$ 1,500m
 Insured losses: US\$ 720m
 Fatalities: 1



June to July
 Floods: China
 Overall losses: US\$ 2,000m
 Fatalities: 355



October 2010 to September 2011
 Drought: East Africa
 Fatalities: >50,000



22 August to 2 September
 Hurricane Irene: Caribbean, USA
 Overall losses: US\$ 7,400m
 Insured losses: US\$ 5,600m
 Fatalities: 55



August to November
 Floods: Thailand
 Overall losses: US\$ 40,000m
 Insured losses: US\$ 10,000m
 Fatalities: 813



23 October
 Earthquake: Turkey
 Overall losses: US\$ 550m
 Insured losses: US\$ 40m
 Fatalities: 604



4 to 9 November
 Flash floods: Italy, France, Spain
 Overall losses: US\$ 2,100m
 Insured losses: US\$ 1,100m
 Fatalities: 14



16 to 18 December
 Tropical Storm Washi: Philippines
 Overall losses: US\$ 40m
 Fatalities: 1,268

The year in figures

Petra Löw, Angelika Wirtz

The year 2011 was the most expensive natural catastrophe year ever in national economic terms. At US\$ 380bn, it far exceeded 2005, previously the costliest year on record. Insured losses also came to a record US\$ 105bn. Munich Re's Geo Risks Research recorded 820 loss-related events, which corresponds to the average for the past ten years. Hurricanes in the North Atlantic accounted for the bulk of the enormous claims expenditure in 2005 but last year's severe earthquake disasters in Japan and New Zealand alone accounted for overall losses of US\$ 228bn and insured losses of US\$ 50bn.

Nearly 90% of 2011's events were weather-related. Overall and insured losses from weather-related natural catastrophes were the second-highest on record since 1980 (taking inflation into account). Consequently, 2011 also goes down as a year of extreme weather-related catastrophes.

Number of events

NatCatSERVICE's database records all natural hazard events that give rise to property damage or personal injury. Depending on the monetary and humanitarian impact of these events, we divide them into six categories, ranging from minor losses to great natural catastrophes.

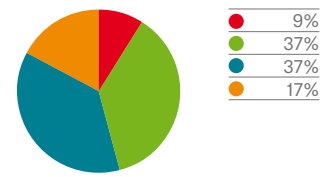
The following five events from last year fall into loss category 6 (great natural catastrophes, with thousands of fatalities and/or hundreds of thousands left homeless and/or substantial economic/insured losses).

- 22 February: Earthquake, New Zealand
- 11 March: Earthquake, tsunami, Japan
- April to May: Tornado outbreaks, USA
- August to November: Floods, Thailand
- October 2010 to September 2011: Drought: East Africa

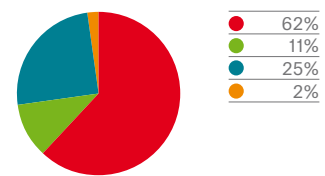
The breakdown of loss-relevant events between the main geophysical, meteorological, hydrological and climatological hazards is more or less in line with the average over the past 30 years. In 2011, 91% of the world's natural catastrophes were weather-related: 300 storms, 310 floods, storm surges and mass movements caused by torrential rain. The climatological events category - wildfires, droughts, heatwaves and cold waves - comprised 140 events, including 117 wildfire events. Geophysical natural hazards made up 9% - namely 54 earthquakes and 16 volcanic eruptions that caused personal injury and/or property damage.

The percentage breakdown by continent is also in line with the long-term average, most catastrophes occurring in Asia (240) and America (290); in Europe there were 150, in Africa 80 and in Australia 60.

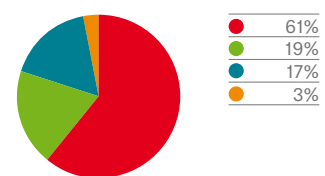
820 events
Percentage distribution worldwide



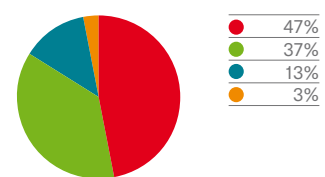
Fatalities: 27,000
Percentage distribution worldwide



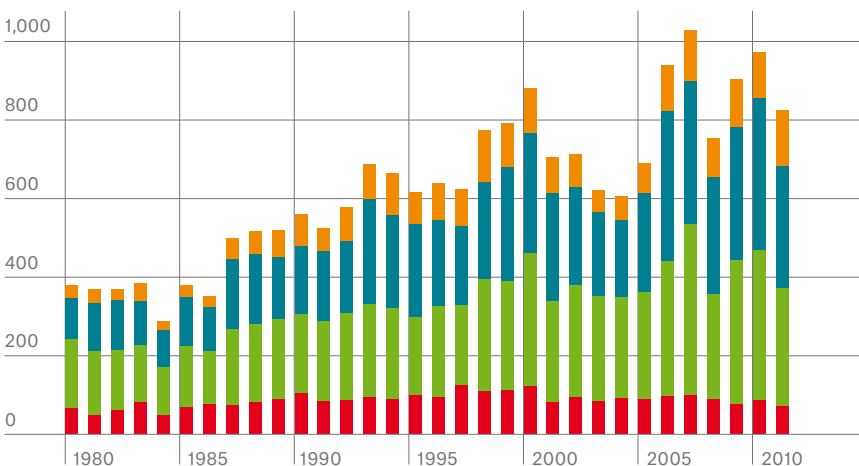
Overall losses: US\$ 380bn
Percentage distribution worldwide



Insured losses: US\$ 105bn
Percentage distribution worldwide



Number of natural catastrophes 1980-2011



- Geophysical events: Earthquake, volcanic eruption
- Meteorological events: Tropical storm, winter storm, severe weather, hail, tornado, local storm
- Hydrological events: Storm surge, river flood, flash flood, mass movement (landslide)
- Climatological events: Heatwave, cold wave, wildfire, drought

Fatalities

In 2011, 27,000 died in natural disasters, which was well below the long-term average; since 1980, the average has been 73,000 fatalities per year. The severe earthquake and tsunami in Japan caused 15,840 fatalities. In Brazil, 900 people were killed by landslides. Devastating floods caused thousands of deaths: in Pakistan (520), Thailand (813) and the Philippines (1,268). The storms in the USA in April and May 2011 resulted in 585 fatalities. The number of deaths reported for 2011 does not yet take account of the catastrophic drought and subsequent famine on the Horn of Africa, one of the year's worst humanitarian catastrophes.

Losses

The year's overall losses (US\$ 380bn) are the highest ever recorded in Munich Re's loss database. Insured losses also reached the record high of US\$ 105bn. The 2011 figures differ significantly from the overall loss pattern since 1980:

- 61% of overall losses and 47% of insured losses were caused by earthquakes - the long-term average is 22% for overall losses and 10% for insured losses.
- Overall earthquake losses were around US\$ 230bn, 22% of which were insured losses - around US\$ 50bn; the average for insured losses is approx. 10%.

- Globally, only 37% of insured losses were caused by windstorm events, the average being 76%. One reason for this was the very active but relatively benign hurricane season, with only three US landfalls and insured losses of some US\$ 5bn; over the past ten years, annual US hurricane losses have been close to the US\$ 17bn mark on average. Devastating tornadoes in the USA caused record insurance industry losses in 2011. The total came to around US\$ 25bn, which is more than 50% of all insured windstorm losses in 2011.
- The US\$ 15bn in insured flood losses made up 13% of insured losses. The floods in Australia (in January) and Thailand (August to November) were the most expensive events.



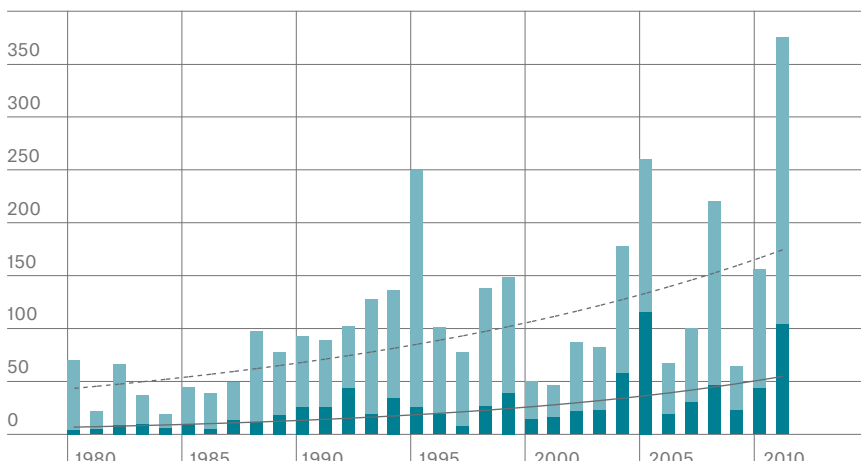
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Overall losses and insured losses 1980-2011 (US\$ bn)



- Overall losses (in 2011 values)
- Of which insured losses (in 2011 values)
- - - Trend: overall losses
- Trend: insured losses

Three-dimensional modelling increases transparency

Although three-dimensional building models are not yet in widespread use, this will doubtless change in the near future, thanks to the advantages their high-density information can offer, for instance, to the insurance industry in areas such as risk identification, risk assessment and loss modelling.

Andreas Siebert, Martin Simon

As part of a cooperation project between the Ludwig Maximilian University of Munich, the Bavarian State Office for Surveying and Geoinformation and Munich Re, investigations are currently under way to test the suitability of three-dimensional building models, so-called "building block models", for use in modelling natural hazards.

The hypothesis is that, particularly in the case of regional natural events such as floods, a detailed analysis using three-dimensional building information can improve the quality of property insurance models.

The project investigated how suitable the data are for defining flood areas and whether the findings on the expected extent of building losses can be improved. The accuracy of the underlying digital terrain model (DTM) plays a decisive role in this respect.

Choice of terrain model is crucial

One important aspect of flood modelling is choosing suitable terrain models for calculating inundation areas and depths and so the survey office prepared a number of models with different resolutions. To strike the right balance between level of detail, volume of data and run times, tests were conducted to identify the most suitable grid intervals for flood models. Compared with models having a 10-m grid interval (DTM 10), the height information in the high-resolution terrain models (resolutions of up to 2 m) is very precise, but run times are much longer due to the greater volume of data involved and more detailed terrain models do not necessarily yield significantly improved results. A review of the quality of flood models, based on the city of Regensburg in Bavaria, Germany, used six digital terrain models of different resolutions (1 m, 2 m, 5 m, 10 m, 50 m and 90 m). The results vary considerably. The 90 m and 50 m results are, as expected, very imprecise. The results between 10 m and 1 m differ from each other only slightly with respect to the number of buildings affected. Similarly, in determining the water depths, which are also crucial for calculating the extent of the losses, the differences between the two resolutions were a virtually negligible 5 to 10 cm. In our view,

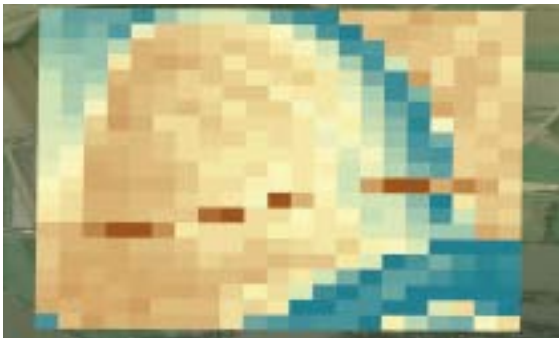
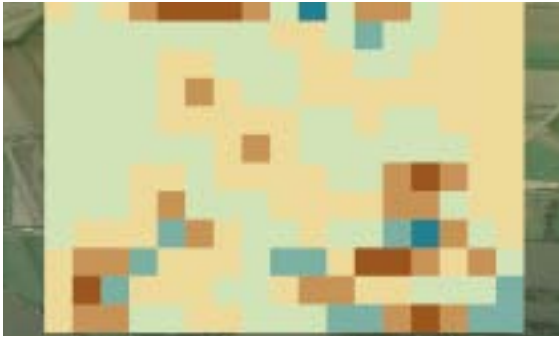
the most suitable basis for flood modelling is the DTM 10 model, given that a smaller quantity of data has to be processed.

Three-dimensional modelling shows inundation depths

To model floods on the Danube between Regensburg and Passau, the historic water levels of the August 2002 floods and different flooding scenarios were used. One of the scenarios applied was a 100-year flood, i.e. a flood that, statistically, occurs once in a 100 years. In addition to this, a process has been developed for deriving flood scenarios from the German insurance industry's official flood zones (ZÜRS). The precise area inundated was calculated for all these flood scenarios. As well as showing the overall extent of the areas flooded, using the three-dimensional building model, it was also possible to identify the individual buildings affected by the floods and determine the building inundation depths. These are important findings with regard to the implementation of flood protection measures, such as mobile flood barriers, and the efficient management of commercial and industrial risks.

Analysis of different loss aspects

The relative loss figures can be simulated using flood modelling and the various water-level loss functions. Factors affecting the losses include the depth and duration of flooding. The type of building (single family home, apartment block, building with or without basement), building materials (brick, wood) and year of construction also influence the vulnerability of and extent of damage to the building. The losses can be analysed into two separate categories: losses to buildings and losses to contents. Combined with occupancy data, also provided by the survey office, it is now also possible to differentiate between the various forms of building function. This division into different categories along with the various loss functions enables the losses to residential properties, industrial and public buildings to be determined.



— Dam line depicted in digital terrain models with different resolutions. Grid intervals shown here (from top to bottom): 90 m, 50 m, 10 m, 1 m.

Being able to clearly assess risk exposure at industrial sites with large sums insured (notably in the case of the floods in Thailand) based on precise location data is a huge advantage. This is because substantial contingent business interruption losses can result if commercial activity ceases at industrial and logistics sites with complex supply-chain relationships. The floods in Thailand affected several industrial parks with huge concentrations of values, causing production losses and shipment problems, as a result of which a number of key electronics manufacturers sustained contingent business interruption losses. This in turn led to supply shortages in the computer and automotive industries. Three-dimensional models can be used to facilitate the assessment of location risks of this type and clarify the extent of global interconnection involved.

Additional information improves risk transparency

In addition to flood and loss models of affected buildings, information such as the ZÜRS zoning system or building utilisation can also be applied to individual buildings. The LoD1 building model used for such models in the Danube region offers not only address information but also height and area details and descriptions of building and roof types, which can provide additional loss-interpretation pointers.

To improve risk transparency and communication, three-dimensional building data can also be linked to other information or values (for example, building heights in order to depict exposures or loss amounts). Moreover, three-dimensional map displays are an excellent means of visualising exposure concentrations and principal loss areas.

On the other hand, we should not forget that discharge and water level are natural factors, and subject to a considerable degree of uncertainty. This cannot be reduced by loss models.



Conclusion

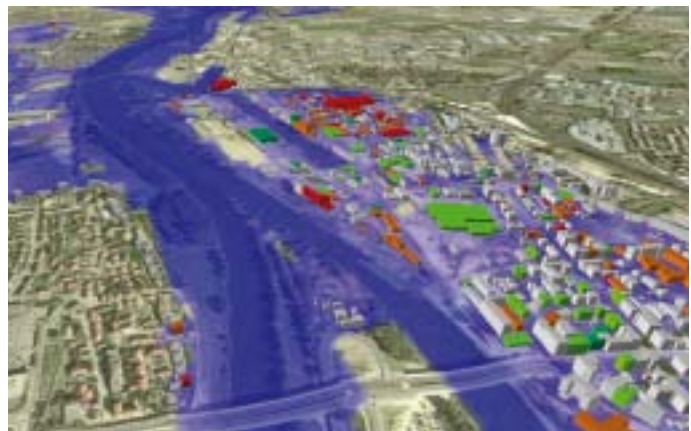
Three-dimensional building models have only been in use for a short time (predominantly for scientific investigations) and, unfortunately, such datasets are not yet available for the country as a whole. Moreover, there are still licensing and costs issues to be resolved. However, precisely because of the density of building information they offer, such models will be in great demand in the coming years and will play a major role in risk identification, risk evaluation and loss modelling in the insurance industry.

The next-generation building model, the LoD2, which the Bavarian State Office for Surveying and Geoinformation plans to introduce in 2015, will offer the insurance industry an even wider range of applications. Storm and severe-weather modelling also stand to benefit because the enhanced model will give precise information on the roofs of buildings, facilitating the analysis of storm and hail losses to buildings and fixtures (such as photovoltaic systems).

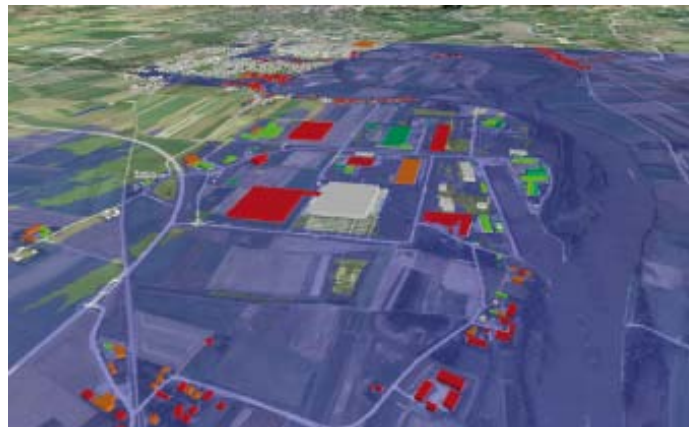
As well as offering advantages in terms of integrated risk management, the modelling results pinpoint buildings requiring better protection against floods in the form of technical facilities – an important factor in risk prevention.



Three-dimensional building model (LoD1) of the city of Regensburg on the Danube.



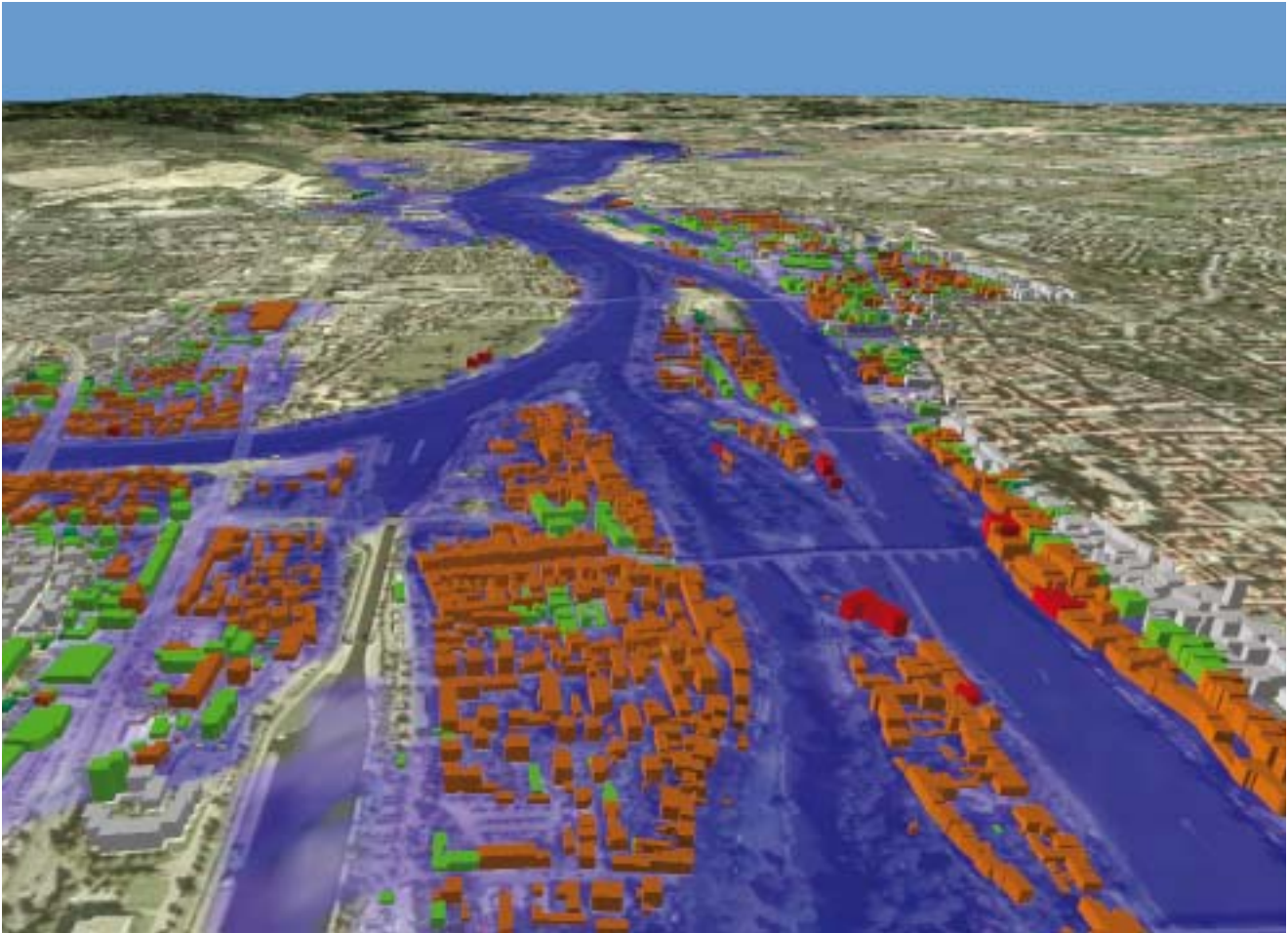
Individual building inundation depths in Regensburg for a 100-year-flood model.



Individual building inundation depths at an industrial location for a 200-year-flood model.

Building inundation depths

- No inundation
- Up to 20 cm
- Up to 50 cm
- Up to 100 cm
- Over 100 cm



Example illustrating losses from a 100-year flood in Regensburg.

Extent of losses

- Nil
- Up to 10%
- Up to 25%
- Up to 50%
- Over 50%

Source: Bavarian State Office for Surveying and Geoinformation



OUR EXPERTS

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Geophysical hazards

Spotlight on earth



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The natural catastrophe year of 2011, was the most expensive on record. While, in 2005, it was primarily Hurricanes Rita, Wilma and Katrina that led to record losses, in 2011 earthquakes, especially the ones in Japan and New Zealand, caused immense devastation. Only due to the fact that insurance density for earthquake losses is substantially lower than that for storm damage were the insured losses of some US\$ 100bn in 2011 "no higher than" in 2005, the most expensive year to date for the insurance industry.

After 15 years during which weather-related catastrophes have been the main driving force behind the damage and losses, the year 2011 reminded us how unstable the earth is on which we live. Already in 2010, the earthquakes in Haiti and Chile and the eruption of Eyjafjallajökull in Iceland had drawn attention to geophysical hazards. The material losses incurred were, however, only approximately half as high as those caused by extreme weather events. Over the past 31 years, the losses caused on average by geophysical events accounted for 22% of the economic losses but only 10% of the insured natural disaster losses.

Not forgetting the earthquake risk despite climate change

In recent years, the headlines have often featured the increase in extreme weather events, which most probably is caused by climate change. The fact that human activities (greenhouse gas emissions) are leading to an increase in natural catastrophe hazard is new in the history of the human race. However, in the face of this realisation it was quickly forgotten that immense

threats are also still posed by purely natural hazards, such as earthquakes, tsunamis or volcanic eruptions. With the exception of smaller earthquakes triggered by mining or reservoirs for instance, these natural hazards, as far as we know, are not influenced by human activities but are actually subject to natural laws, and for this reason do not exhibit a long-term trend (over a period of several centuries).

Increased global networking also leads to higher losses

The fact that successive years of increased activity occur from time to time is statistically plausible. Geophysicists are discussing whether physical processes could be the reason for such clustering, but even then, they would still remain natural processes, which does not change the hazard posed by them in the long term. The fact that the losses caused by geophysical events are assuming ever greater dimensions is due, on the one hand, to people and values becoming increasingly exposed and, therefore, being more at risk. On the other hand, increased global networking, for example, has led to higher losses due to supply failures, such as after the earthquake in Japan.

Insurers cannot prevent catastrophes - But they can mitigate the consequences

Three years ago, Munich Re decided to support the world's largest disaster risk modelling project, the "Global Earthquake Model" (GEM) financially and technically as the main sponsor. I believe the events in 2011 and 2010 have made it more than clear that this decision was absolutely right.

This project ensures that earthquake risk transparency is created even for countries which would not be catered for by commercial modelling organisations because of the low insurance density, so that the basis for insurability and prevention measures can also be provided. Because only those who are aware of the hazard situation will ultimately ensure that preventative measures are taken and that the economic conditions for recovery and reconstruction and aid for the victims are available in the event of a catastrophe.

2011 has shown us quite clearly that despite the discussion about increasing weather risks, important as it is, we should not forget the other natural hazards. Although they do not demonstrate long-term trends they still have enormous damage potential. Insurers cannot prevent such catastrophes. But they can help mitigate their consequences.

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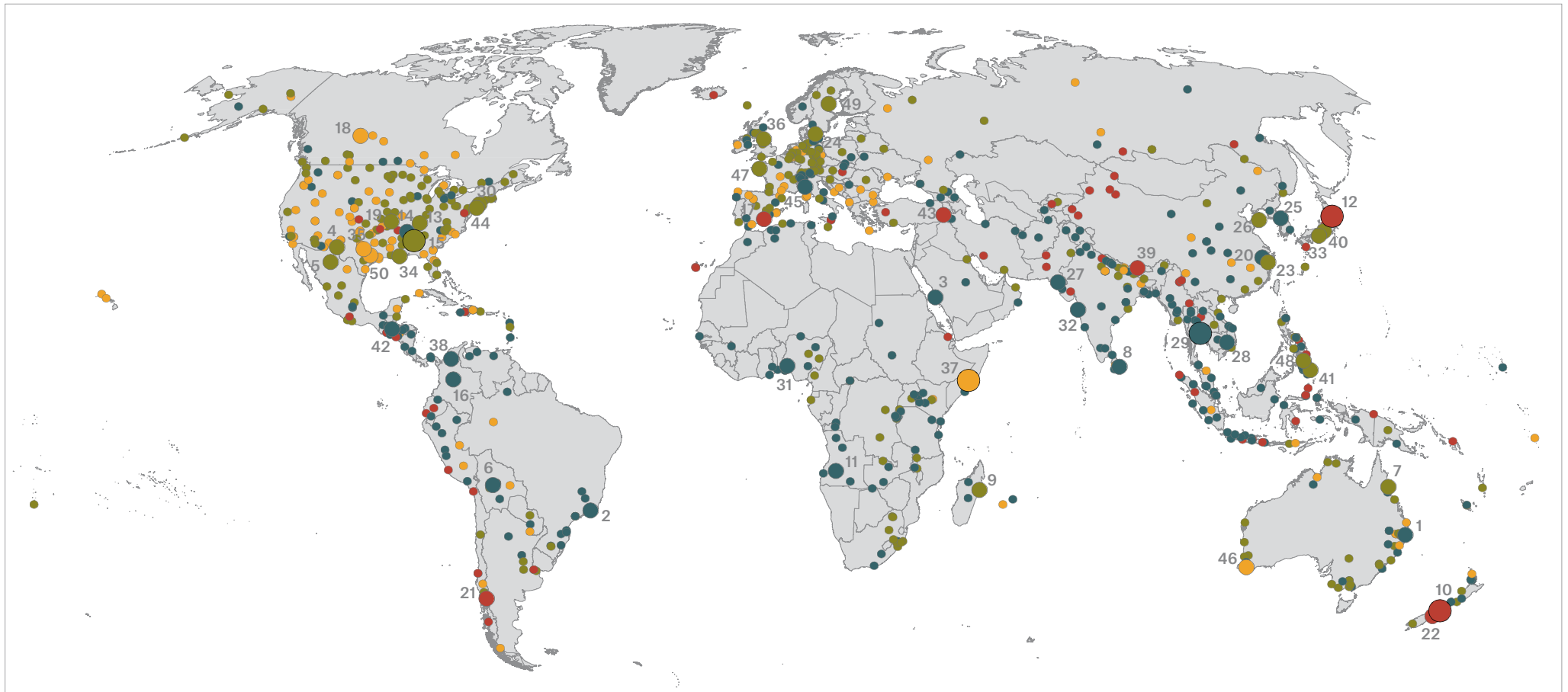
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Topics Geo – 50 major events in 2011

| No. | Date | Loss event | Region | Deaths | Overall losses US\$ m | Insured losses US\$ m | Explanations, descriptions |
|-----|------------------|--------------------------------------|------------------------------------|---------|-----------------------|-----------------------|--|
| 1 | 10.-14.1. | Floods | Australia | 22 | 2,800 | 1,875 | Brisbane River burst its banks. Tens of thousands of buildings flooded. Losses in agriculture and mining sector |
| 2 | 12.-16.1. | Landslides, flash floods | Brazil | 900 | 460 | 50 | Torrential rain. Rivers burst their banks. Thousands of houses destroyed, 185 bridges and roads damaged. |
| 3 | 26.-28.1. | Floods, flash floods | Saudi Arabia | 11 | 300 | 80 | Dam breached. Historical buildings destroyed, warehouses flooded. 11,000 vehicles damaged. |
| 4 | 31.1.-6.2. | Winter storms, blizzards | USA | 39 | 1,900 | 1,425 | "Groundhog Day Blizzard". Production halted at >30 automotive manufacturers' plants. |
| 5 | 1.-8.2. | Winter damage, frost | Mexico | 3 | 500 | 200 | Temperatures as low as -15°C, snowstorms. Severe damage to agriculture. |
| 6 | Feb.-April | Floods, landslides | Bolivia | 52 | | | Rivers burst their banks. Hilltop collapsed. Hundreds of houses destroyed. Towns, bridges, highways damaged. Homeless: 10,000. |
| 7 | 2.-7.2. | Cyclone Yasi | Australia | 1 | 2,500 | 1,300 | Category 4 cyclone. Buildings and vehicles damaged/destroyed. Ports closed, rail services suspended. Losses to agriculture. 180,000 homes without electricity. |
| 8 | 3.-14.2. | Floods | Sri Lanka | 18 | 300 | | Heavy monsoon rains. 45,000 houses damaged/destroyed. Losses to agriculture, livestock and fisheries. |
| 9 | 14.-19.2. | Cyclone Bingiza | Madagascar | 34 | | | >6,000 homes and many schools damaged. 80% of infrastructure destroyed. Agricultural losses. 77,000 homeless |
| 10 | 22.2. | Earthquake | New Zealand | 181 | 16,000 | 13,000 | M _w 6.3, widespread liquefaction. Ten multi-storey buildings, 10,000 buildings damaged/destroyed. |
| 11 | 5.-16.3. | Floods | Angola | 113 | | | 5,000 homes destroyed. Roads, bridges damaged. Losses to agriculture. Displaced: 35,000. |
| 12 | 11.3. | Earthquake, tsunami | Japan | 15,840 | 210,000 | 35,000-40,000 | M _w 9.0, tsunami 5 km inland. Many coastal areas totally destroyed. Severe losses to industry and economy Fukushima Dai-ichi plant: nuclear reactor damaged, radioactivity released. 6,000 injured and 500,000 displaced. |
| 13 | 3.-5.4. | Severe storms, tornadoes | USA | 9 | 3,500 | 2,000 | >20 tornadoes, severe hail. Buildings and vehicles damaged/destroyed. |
| 14 | 18.4.-23.5. | Floods, landslides | USA | 9 | 4,600 | 500 | Torrential rain, severe storms, snowmelt. Rivers burst their banks, esp. Mississippi, Ohio. Towns flooded. |
| 15 | 22.-28.4. | Severe storms, tornadoes | USA | 350 | 15,000 | 7,300 | >160 tornadoes up to EF5, severe storms, hail, towns, cities (esp. Tuscaloosa), loss/damage to thousands of homes, vehicles and an airport destroyed. Losses to industry and agriculture. 269,000 homes without electricity. |
| 16 | April-May | Floods, landslides | Colombia | 90 | | | >7,400 homes destroyed. Major losses to infrastructure. |
| 17 | 11.5. | Earthquake | Spain | 10 | 200 | 100 | M _w 5.1. 20,000 buildings, roads and vehicles damaged. >300 injured. |
| 18 | 14.-16.5. | Wildfires | Canada | 1 | 1,500 | 720 | Wind speeds up to 100 km/h. Hundreds of buildings damaged/destroyed. Power outages. 10,000 evacuated. |
| 19 | 20.-27.5. | Severe storms, tornadoes | USA | 176 | 14,000 | 6,900 | >100 tornadoes up to EF5, torrential rain, hail, airport hangar, >10,000 buildings damaged/destroyed. EF5 tornado hit Joplin, Missouri (158 deaths). 75% of Joplin destroyed. Roads closed. |
| 20 | 1.6.-17.7. | Floods, landslides | China | 355 | 2,000 | | Torrential rain. 130,000 buildings damaged/destroyed. Hundreds of bridges, roads and several hydropower plants damaged/destroyed. Heavy losses to agriculture. 2.3 million evacuated. |
| 21 | 4.6.-21.7. | Volcanic eruption, Puyehue | Chile, Argentina, Uruguay | | 30 | | Gas and ash ejected. Airport closures, hundreds of flights cancelled. Agriculture, livestock and fisheries affected. |
| 22 | 13.6. | Earthquake | New Zealand | 1 | 2,000 | 800 | M _w 5.9. Liquefaction. >100 buildings damaged. Bridges collapsed. Port facilities, wharves damaged. |
| 23 | 25.-28.6. | Tropical Storm Meari, floods | China, Philippines, Korea | 17 | 50 | | Wind speeds up to 135 km/h, flash floods and mudslides. Thousands of homes damaged/destroyed. Roads and bridges damaged. Air traffic disrupted. Losses to agriculture. |
| 24 | 2.-3.7. | Severe storms, tornadoes | Denmark | | 300 | 200 | Thunderstorms and hailstorms, torrential rain >1,000 buildings damaged. Communications disrupted. |
| 25 | 26.7.-2.8. | Floods, landslides | North and South Korea | 88 | 255 | 76 | Dykes breached, rivers burst their banks. Villages cut off. >15,000 homes and thousands of vehicles damaged. Losses to agriculture and infrastructure. |
| 26 | 28.7.-9.8. | Typhoon Muifa (Kabayan), floods | Korea, China, Japan, Philippines | 22 | 800 | 100 | Category 5 typhoon. Thousands of homes and port installations destroyed. Fishing boats capsized. Losses to infrastructure and agriculture. 1.35 million evacuated. |
| 27 | Aug.-Oct. | Floods | Pakistan | 520 | 2,500 | | Dykes breached, 6,000 villages inundated. Bridges washed away. Heavy losses to agriculture and livestock sector. |
| 28 | Aug.-Nov. | Floods | Cambodia Vietnam | 355 | 400 | 20 | Mekong floods. Dykes and bridges washed away. Roads blocked. Hundreds of homes damaged/destroyed. Losses to agriculture. |
| 29 | Aug.-Nov. | Floods, landslides | Thailand | 813 | 40,000 | 10,000 | Torrential rains. One million buildings flooded/damaged. Seven industrial parks inundated. Heavy losses to infrastructure, agriculture, aquaculture and livestock sectors. |
| 30 | 22.8.-2.9. | Hurricane Irene, storm surge, floods | Caribbean North America | 55 | 7,400 | 5,600 | Category 3 hurricane. Hundreds of thousands of buildings and vehicles damaged/destroyed. Agricultural sector and telecommunications affected. |
| 31 | 26.-29.8. | Flash floods | Nigeria | 102 | | | Torrential rain, Eleye dam breached. Homes, vehicles and bridges damaged/destroyed. |
| 32 | Sept.-Oct. | Floods | India | 90 | 930 | | Severe monsoon rains. Rivers burst their banks. Villages cut off. 130,000 homes damaged/destroyed. Heavy losses to infrastructure, agriculture and livestock sector. |
| 33 | 3.-5.9. | Typhoon Talas | Japan | 68 | 650 | 430 | Torrential rain, mudslides, thousands of homes and vehicles damaged/destroyed. |
| 34 | 3.-10.9. | Tropical Storm Lee | USA | 15 | 750 | 560 | Villages cut off. Thousands of homes and vehicles damaged/destroyed. Infrastructure losses. |
| 35 | 4.-19.9. | Wildfires | USA: esp. Texas | 2 | 1,000 | 530 | Area of 11,000 km ² destroyed by fire. Worst wildfire in Texas for more than ten years. 1,600 homes destroyed. |
| 36 | 12.9. | Severe storms, tornadoes | Northern Europe | 1 | 300 | 150 | Remains of Hurricane Katia. Wind speeds of up to 130 km/h, torrential rain, flash floods, homes damaged. |
| 37 | Okt. 2010-Sep 11 | Drought | Somalia, Djibouti, Kenya, Ethiopia | >50,000 | | | Two years of below-average precipitation, extreme shortage of water. Severe losses to agriculture and livestock sector. Famine, food shortages and disease. Affecting 13.3 million |
| 38 | Sept.-Dec. | Floods | Colombia | 187 | | | 150,000 buildings damaged/destroyed. 11,000 km ² arable land flooded, 160,000 head of livestock killed. |
| 39 | 18. Sep | Earthquake | South and east Asia | 134 | 1,500 | | M _w 6.9, hundreds of landslides. Tens of thousands of buildings destroyed/damaged. Roads and bridges damaged. Power and communication lines destroyed. Over 100,000 left homeless. |
| 40 | 20.-22.9. | Typhoon Roke | Japan | 13 | 1,700 | 1,200 | Category 4 typhoon. Wind speeds up to 215 km/h, torrential rain, losses to infrastructure, public transport hit. Automotive production halted (Toyota, Mitsubishi, Nissan) for a time. |
| 41 | 26.9.-4.10. | Typhoon Nesat, floods | Philippines, China, Vietnam | 89 | 1,500 | | Wind speeds of up to 150 km/h, heavy rain, landslides. Thousands of homes flooded. Losses to agriculture and fisheries. |
| 42 | 11.-19.10. | Floods, landslides | Central America | 124 | 1,500 | | Rivers burst their banks, dykes breached. Tens of thousands of buildings damaged/destroyed. Hundreds of bridges washed away. Losses to agriculture and livestock sector. |
| 43 | 23.10. | Earthquake | Turkey | 604 | 550 | 40 | M _w 7.2, 65,000 homes damaged/destroyed. Power outages, water and gas supplies affected. >4,200 injured. |
| 44 | 28.-31.10. | Winter storm | USA, Canada | 29 | 900 | 665 | Heavy snowfalls. Communications disrupted. Power lines and trees brought down. |
| 45 | 4.-9.11. | Flash floods | France, Italy | 14 | 2,100 | 1,100 | Severe weather, mudslides. Thousands of buildings and vehicles damaged/destroyed. Heavy losses to infrastructure. |
| 46 | 23.-24.11. | Wildfires | Australia | | 50 | 30 | Wildfires. Area of >155 km ² destroyed by fire. >30 homes destroyed and 16 damaged. Roads closed. 200 evacuated. |
| 47 | 15.-17.12. | Winter Storm Joachim | Western Europe | | 650 | 390 | Heavy snowfalls, torrential rain, flash floods, road and rail traffic disrupted. |
| 48 | 16.-18.12. | Tropical Storm Washi | Philippines | 1,268 | 40 | | Flash floods, landslides. Rivers burst their banks. >6,800 homes damaged/destroyed. |
| 49 | 25.-26.12. | Winter Storm Patrick (Dagmar) | Northern Europe, Baltic | 1 | 200 | | Wind speeds of over 160 km/h, torrential rain, coast lashed by exceptionally high waves, landslides. Towns/cities flooded. Buildings, homes and vehicles damaged. Road and rail traffic blocked. Telecommunication infrastructure damaged. |
| 50 | Jan.-Dec. | Drought | USA | | 8,000 | 1,000 | Lack of rain and low water tables. Severe losses to agriculture and livestock sector. |

Topics Geo – World map of natural catastrophes 2011



820 natural hazard events, thereof

○ 50 major events (selection)

○ In 2011, five events fulfilled the criteria applicable to a great natural catastrophe.

- **Geophysical events:** Earthquake, volcanic eruption
- **Meteorological events:** Tropical storm, winter storm, severe weather, hail, tornado, local storm
- **Hydrological events:** River flood, flash flood, storm surge, mass movement (landslide)
- **Climatological events:** Heatwave, cold wave, wildfire, drought

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