TOPICS GEO

Natural catastrophes 2015
Analyses, assessments, positions
2016 issue

The earth's "hotting up"

The warmest year since records began saw El Niño have a major impact on many weather-related losses. **PAGE** 20

Climate change
Year of decisions

Nepal
A country reduced to rubble

Analysis techniques
Reassessing the data

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Dear Reader,

2015 was another year in which losses from natural catastrophes remained fairly low. In fact, overall losses and insured losses were even below the 30-year average. The natural “climate oscillation” El Niño had a marked influence on the patterns of weather-related events, and was partly responsible for the low level of hurricane activity in the North Atlantic.

Even though the financial losses were limited, because countries with high insurance penetration were largely spared, the number of registered loss events was again extremely high. Emerging and developing countries in particular struggled to deal with severe flooding and heatwaves. But the most devastating event of the year occurred at the top of the world in Nepal, where more than 9,000 lives were lost in earthquakes.

2015, the second year in succession to set a record for the global annual mean temperature, was also strongly influenced on a political level by climate change: the breakthrough at the climate conference in Paris gives us reason to hope that climate change can still be slowed to a level where the risks in most regions of the world remain manageable.

The current issue of Topics Geo provides the facts and figures behind the year’s events and analyses the processes that caused them. I hope you find the articles both interesting and informative.

Munich, February 2016

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

NOT IF, BUT HOW

In focus: 2015 was very much a climate year. While new temperature records were being set and a strong El Niño was developing, there was finally movement in global climate politics. A new course was set at the G7 summit in July and the climate conference in Paris in December.

4

In focus

Contents

Catastrophe portraits: Nepal has always been known as a high-risk country for earthquakes. In April 2015, the Himalaya region was hit by a devastating catastrophe.

28

Catastrophe portraits

NatCatSERVICE/Research

NatCatSERVICE/Research: Satellite images from space promise to open up new opportunities for risk management. It is vital that we take advantage of these developments.

52

Standards


ERDINGER
ALKOHOLFREI
21
HOCHFILZEN
BMW xDrive
WÜRTH

Climate facts 2015

Eberhard Faust

The earth is hotting up: 2015 saw the highest global mean temperatures ever recorded. Despite the fluctuations in individual years, it is clear that the long-term upward trend is continuing and climate change is not expected to let up any time soon.

2014 had already been the warmest year since the time series began in 1880, but it only narrowly exceeded 2005 and 2010 according to data from the NOAA. Yet substantially higher figures were recorded in 2015. According to the NOAA data published in mid-January 2016, it was by far the warmest year from a global perspective. The mean global temperature over land and ocean surfaces exceeded the 20th century mean of 13.9°C by 0.90°C, surpassing the 2014 record (0.74°C) by 0.16°C. In 2015, the mean global temperature climbed for the first time to 1°C above the mean for the period from 1850 to 1900, which corresponds to the pre-industrial temperature level. This means that half of the 2°C limit – or two thirds of the 1.5°C limit stipulated in the Paris Agreement (COP21) – was already reached in a single year.

One of the reasons for the high temperatures in 2015 was a very pronounced El Niño phase in the tropical Pacific that developed from March 2015; this released a large amount of thermal energy into the atmosphere, and circulation systems changed due to teleconnection patterns. It was also excessively warm in the northeast Pacific region, including the western half of North America. Eurasia and the African-Indian Ocean region likewise exhibited positive thermal anomalies.

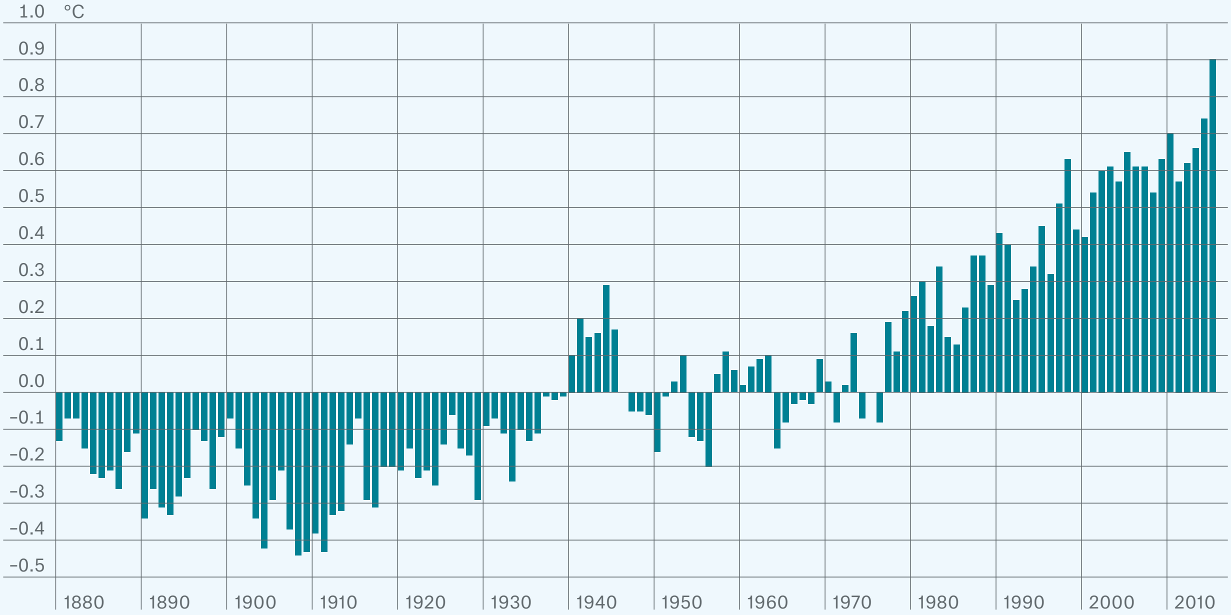
As regards rainfall, many regions reflected the typical influence of El Niño over the course of the year (more on this subject in the article “A strong El Niño”, pages 22 to 26). This included the drought in northeastern Brazil, northern parts of South America, the Caribbean, northwestern North America, and broad swathes of southern Africa; the reduced summer monsoon in some parts of India, and the drought in parts of Southeast Asia, Indonesia, and some southern and eastern regions of Australia. Similarly, the excessive rainfall in southern and southeastern regions of North America, southern Brazil, northeastern Argentina, southern India and the British Isles corresponds to the typical El Niño pattern.

The fact that the influence of El Niño is clearly recognisable in the temperature and rainfall signal shows that the long-term climate change signal is always superimposed by the natural variability of climate on different time scales. In this way, the very strong El Niño event has not only contributed to a high mean annual temperature in 2015, but may also produce a similar effect in 2016. However, the superimposition by natural climate variability also means that there will be years in the future with a somewhat lower mean global temperature. Accordingly, a substantial portion of the temperature fluctuation in the time series for global mean annual temperatures in the past can be explained by the climate variation between El Niño and La Niña events.

Nevertheless, the recent record years for mean annual temperature show that the latest data do not allow identification of an interruption in the increase in mean global temperature any more – in other words, the long-term upward trend is continuing.

Deviation of the global mean temperature from the 1901–2000 average

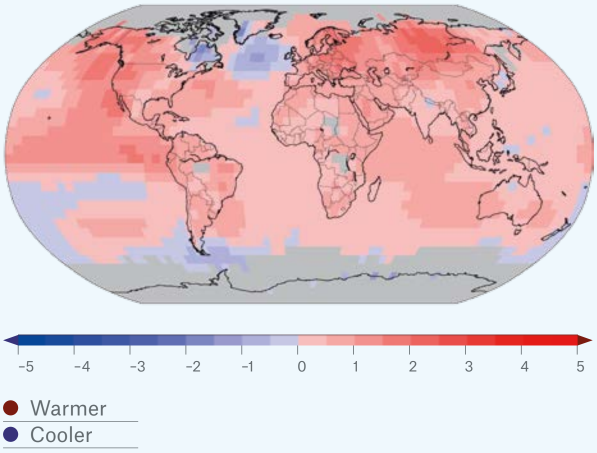
15 of the 16 warmest years on record fall in the period 2001 to 2015.



Source: Munich Re, based on NCDC/NOAA

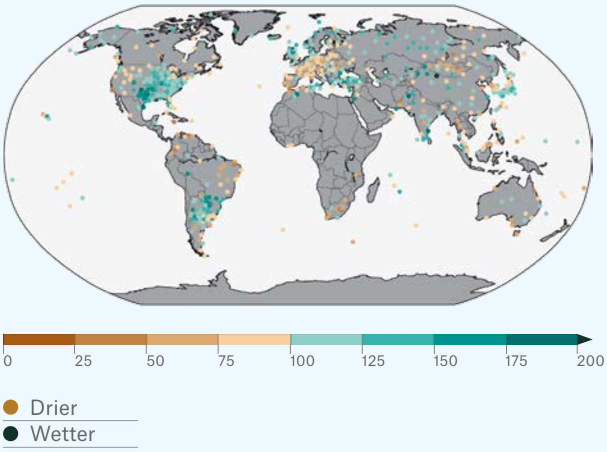
Regional anomalies of the 2015 mean annual temperature compared with 1981–2010

With the exception of eastern Canada, the temperatures over almost all of the world's land surface and over most of the ocean regions contributed to the strong deviation of the mean annual temperature from the 1981–2010 mean. Ten months in the year 2015 broke the record for the respective global mean monthly temperatures.

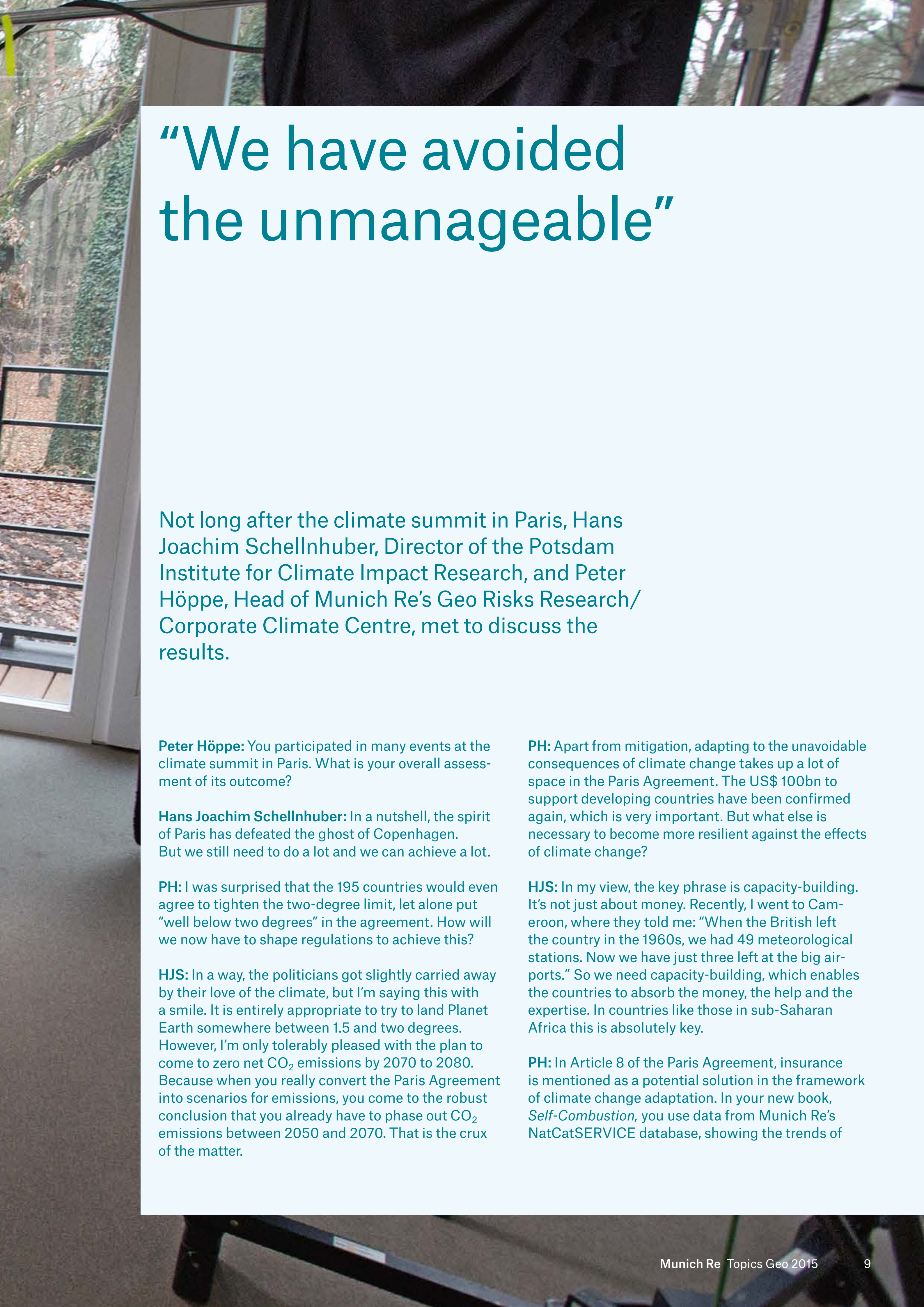


Regional anomalies of annual precipitation in 2015 compared with the 1961–1990 mean

Annual precipitation over land areas for 2015 recorded at the weather stations included here was about 23 millimetres below the 1,033 millimetre mean for the 1961–1990 reference period.



Source: NCDC/NESDIS/NOAA



“We have avoided the unmanageable”

Not long after the climate summit in Paris, Hans Joachim Schellnhuber, Director of the Potsdam Institute for Climate Impact Research, and Peter Höppe, Head of Munich Re’s Geo Risks Research/ Corporate Climate Centre, met to discuss the results.

Peter Höppe: You participated in many events at the climate summit in Paris. What is your overall assessment of its outcome?

Hans Joachim Schellnhuber: In a nutshell, the spirit of Paris has defeated the ghost of Copenhagen. But we still need to do a lot and we can achieve a lot.

PH: I was surprised that the 195 countries would even agree to tighten the two-degree limit, let alone put “well below two degrees” in the agreement. How will we now have to shape regulations to achieve this?

HJS: In a way, the politicians got slightly carried away by their love of the climate, but I’m saying this with a smile. It is entirely appropriate to try to land Planet Earth somewhere between 1.5 and two degrees. However, I’m only tolerably pleased with the plan to come to zero net CO_2 emissions by 2070 to 2080. Because when you really convert the Paris Agreement into scenarios for emissions, you come to the robust conclusion that you already have to phase out CO_2 emissions between 2050 and 2070. That is the crux of the matter.

PH: Apart from mitigation, adapting to the unavoidable consequences of climate change takes up a lot of space in the Paris Agreement. The US$ 100bn to support developing countries have been confirmed again, which is very important. But what else is necessary to become more resilient against the effects of climate change?

HJS: In my view, the key phrase is capacity-building. It’s not just about money. Recently, I went to Cameroon, where they told me: “When the British left the country in the 1960s, we had 49 meteorological stations. Now we have just three left at the big airports.” So we need capacity-building, which enables the countries to absorb the money, the help and the expertise. In countries like those in sub-Saharan Africa this is absolutely key.

PH: In Article 8 of the Paris Agreement, insurance is mentioned as a potential solution in the framework of climate change adaptation. In your new book, *Self-Combustion,* you use data from Munich Re’s NatCatSERVICE database, showing the trends of natural disasters and the losses they have caused. What role do you see for insurance now, after Paris, in terms of adaptation?

HJS: If we are moving into a new regime of extreme events – and a world two degrees warmer will be a new regime – and if we want to provide the most vulnerable people with a shock-absorbing system, then that can only be done with insurance. The problem is that those people who are most vulnerable will not be able to afford the premiums, so it has to be set up as a global system of solidarity. I wonder whether we could take a more detailed look at who is really affected by extreme events. Can we show from data that the poor are hit hardest?

PH: Yes, we can. We have broken down our data in the NatCatSERVICE database into different income groups. So we have the very poor countries, the middle-income countries and the rich ones. Here we can clearly see that the poorest people are affected most, especially if you relate losses to the GDP of the country, to what they have, to what they can afford.

HJS: In terms of income?

PH: Right. The rich countries can afford disasters. They have insurance, they have quick access to money to stabilise or even boost their economy. But the poor countries fall into a poverty trap if there is nothing available – like insurance – which can help them get back into business. The other reason why poor countries are more affected by climate change is that most of them are situated in extreme climate zones. Being aware of that, we established the Munich Climate Insurance Initiative about ten years ago. And just before Paris, we saw that the G7 countries – parallel to the climate negotiation process – have decided to initiate a large project on climate risk insurance. Do you see this as a valuable contribution to the whole negotiation process?

HJS: I am really enthusiastic about it actually. And I am so glad it happened just before Paris. It sent the right signal. But let me also refer to something else that we may have to consider: if you talk about adaptation as a global strategy, then I guess the most important adaptation of all is migration. But not everyone has the means to migrate. A lot of people are trapped in risk zones – they have no money, not even information. But I guess if we have two degrees warming, we will have to move people around the planet.

PH: Especially from the small island states.

HJS: The Maldives are doomed, even with well below two degrees, let's face it. But also other people in other regions are affected by changes in weather patterns or precipitation. So yes, if we want to provide support for people, if we want to absorb shocks, we might have to think about new forms of insurance to make people more mobile, even if this might be going beyond the classic format of insurance.

PH: Munich Re is certainly one of the first movers in this respect. We have provided data on losses and shown that weather-related loss events have already changed, thus creating an awareness of the problem. We are providing new solutions, microinsurance for example. But is there anything else that you would expect in the coming years from the insurance industry?

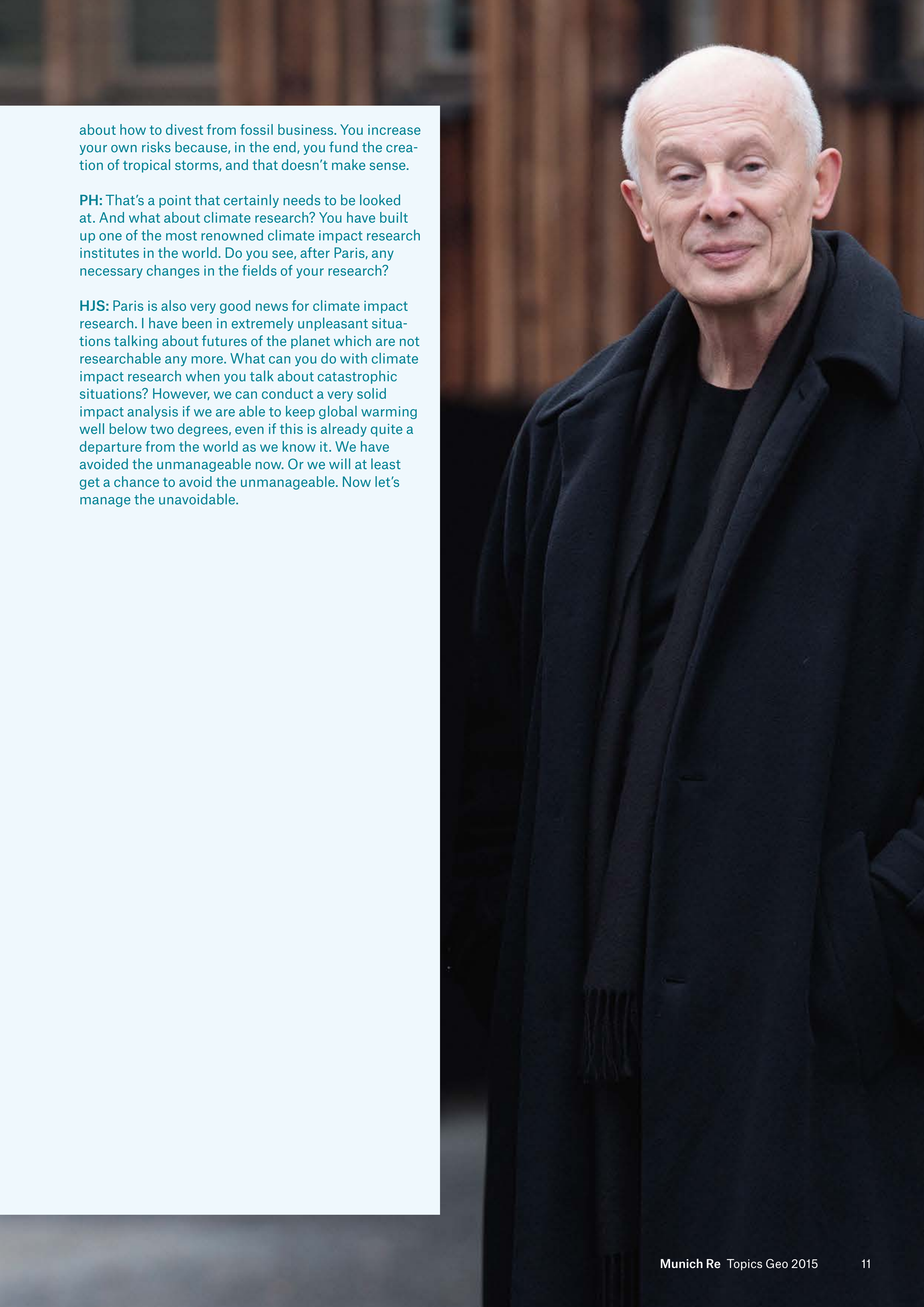
HJS: First of all, let me re-emphasise that you are a double hero in this game, so to speak. You have indeed provided some of the best data in the world on the development of extreme events and losses, and everyone looks at the tables and charts compiled by Munich Re. You have the climate change unit, and you were among the first to consider new formats and schemes for insuring those who have no chance to be insured under normal conditions. But I think you would complete your mission if you would also think

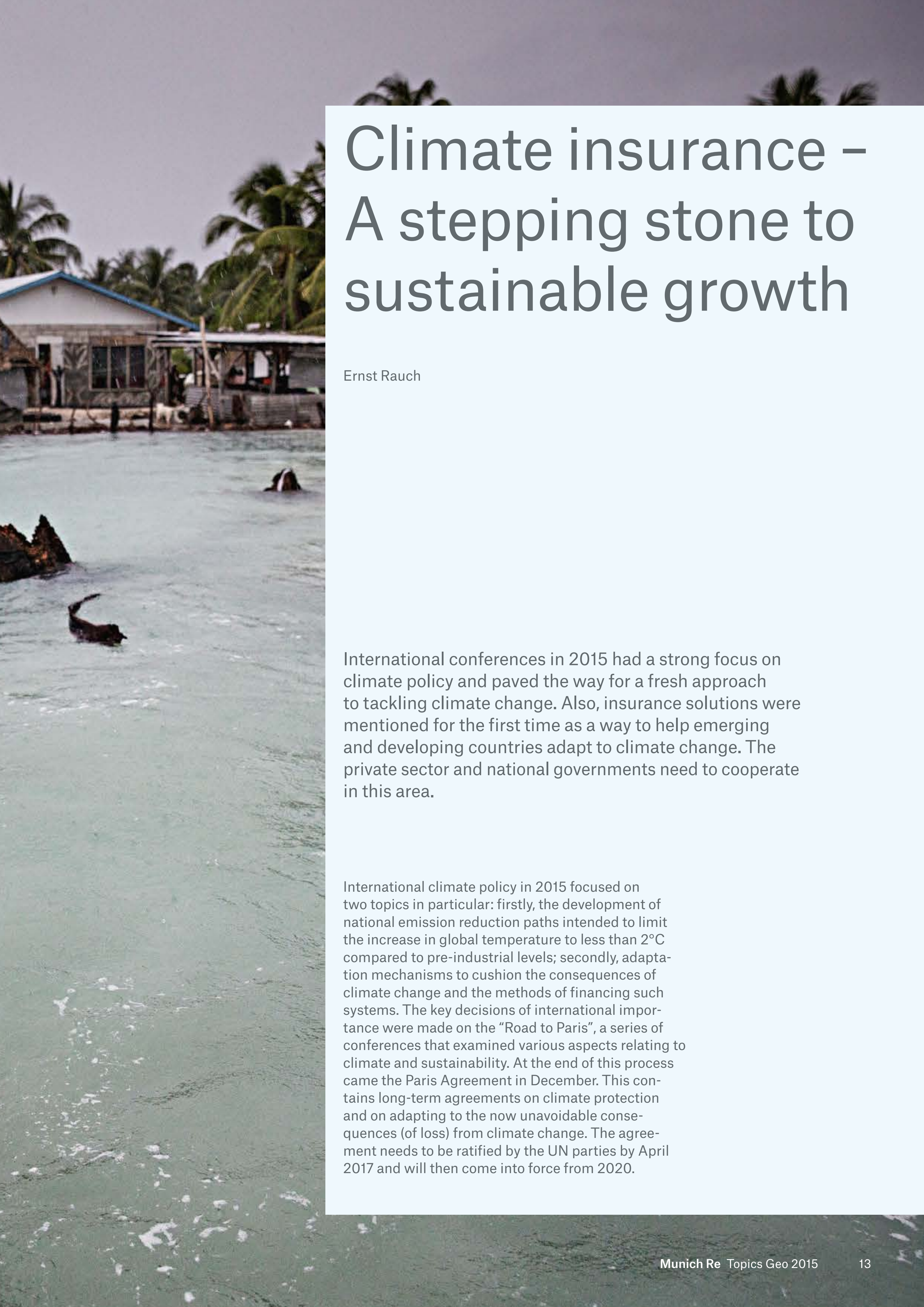
>> You can watch a video recording of the discussion between Peter Höppe and Hans Joachim Schellnhuber at: www.munichre.com/topicsgeo2015

about how to divest from fossil business. You increase your own risks because, in the end, you fund the creation of tropical storms, and that doesn't make sense.

PH: That's a point that certainly needs to be looked at. And what about climate research? You have built up one of the most renowned climate impact research institutes in the world. Do you see, after Paris, any necessary changes in the fields of your research?

HJS: Paris is also very good news for climate impact research. I have been in extremely unpleasant situations talking about futures of the planet which are not researchable any more. What can you do with climate impact research when you talk about catastrophic situations? However, we can conduct a very solid impact analysis if we are able to keep global warming well below two degrees, even if this is already quite a departure from the world as we know it. We have avoided the unmanageable now. Or we will at least get a chance to avoid the unmanageable. Now let's manage the unavoidable.





Climate insurance – A stepping stone to sustainable growth

Ernst Rauch

International conferences in 2015 had a strong focus on climate policy and paved the way for a fresh approach to tackling climate change. Also, insurance solutions were mentioned for the first time as a way to help emerging and developing countries adapt to climate change. The private sector and national governments need to cooperate in this area.

International climate policy in 2015 focused on two topics in particular: firstly, the development of national emission reduction paths intended to limit the increase in global temperature to less than 2°C compared to pre-industrial levels; secondly, adaptation mechanisms to cushion the consequences of climate change and the methods of financing such systems. The key decisions of international importance were made on the “Road to Paris”, a series of conferences that examined various aspects relating to climate and sustainability. At the end of this process came the Paris Agreement in December. This contains long-term agreements on climate protection and on adapting to the now unavoidable consequences (of loss) from climate change. The agreement needs to be ratified by the UN parties by April 2017 and will then come into force from 2020.

But even if the global community follows the path of decarbonisation (abandoning fossil fuels), the risks from weather-related natural hazards will, in all probability, continue to increase. This is because CO_2 has a mean residence time in the atmosphere of approximately 100 years and contributes to global warming throughout this period. The frequency and intensity of severe weather events – torrential rainfall and heatwaves in particular – have already increased in many regions over the past few decades.

Developing countries most at risk

Low-income countries are particularly vulnerable. More poor than rich lives are lost, both in absolute terms and as a percentage of population. Moreover, material losses that cannot be repaired or replaced because of insufficient funds lead to a lasting loss of prosperity.

According to Munich Re's NatCatSERVICE, approximately 850,000 people lost their lives between 1980 and 2014 as a result of weather-related natural catastrophes worldwide. Of these, 62% (527,000) lived on less than US$ 3 per day (income groups in accordance with the World Bank definition, see diagram on the right), and are therefore counted among the world's poorest people. As a proportion of the world population, however, this group represented only around 12% in 2014. If you consider the next-highest income group (daily income of up to approx. US$ 11), the rate drops considerably but still shows a disproportionately high mortality rate from weather catastrophes among low-income sections of the population. In our assessment, the reasons for this are clear: what pushes up the numbers of victims is a lack of information on preventive measures and a lack of financial resources to adapt to natural hazards.

Adaptation options vary depending on the region and hazards involved, but there are two main categories:

1. Ex-ante preventive measures taken ahead of a catastrophe in order to mitigate losses. These include early warning systems, but also structural precautions and land-use regulations.

2. Ex-post measures to deal with the consequences of loss, including humanitarian aid and financing schemes. These help to overcome the economic impact of a disaster and pave the way for repair and reconstruction efforts, thereby developing resilience.

Climate insurance – A crucial adaptation instrument

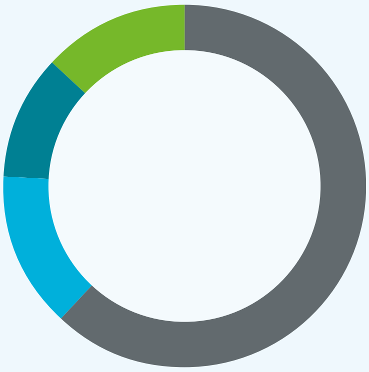
For the first time ever, the final document of a UN Climate Conference of the Parties (COP) mentions insurance solutions as a way to facilitate adaptation to climate change. At the G7 summit in Elmau in June 2015, the member states agreed to launch a climate insurance initiative (InsuResilience), highlighting the importance of financial risk transfer concepts, particularly for emerging and developing countries.

Milestones on the "Road to Paris"

In 2015, a series of conferences paved the way for a climate protection agreement under the auspices of the United Nations. You can find more information on this process on our internet site at: www.munichre.com/en/group/focus/climate-change/viewpoints.

World Economic Forum	**Davos**	21–24 January
UN World Conference on Disaster Reduction	**Sendai**	16–17 March
G7 Climate Insurance Conference	**Berlin**	7 May
UN Sustainable Energy for All Forum	**New York**	17–22 May
G7 Summit	**Elmau**	7–8 June
Climate Change Conference	**Bonn**	1–11 June
UN Sustainable Development Summit	**New York**	25–27 September
UNFCCC's COP21	**Paris**	30 November–11 December

Fatalities* from severe weather events worldwide 1980–2014: 850,000

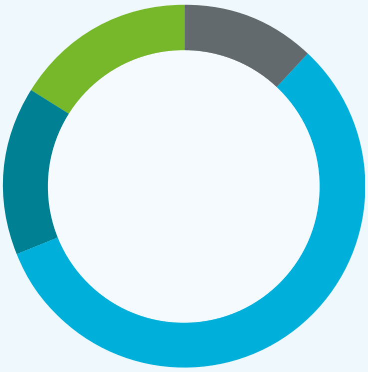


Income groups according to the World Bank definition

● 62%	countries with low annual incomes (≤US$ 1,005)
● 14%	countries with lower-middle annual incomes (US$ 1,006–3,975)
● 11%	countries with upper-middle annual incomes (US$ 3,976–12,275)
● 13%	countries with high annual incomes (≥US$ 12,276)

*Not including famine victims

World population in 2014 7.2 billion



- ● 12%
- ● 57%
- ● 15%
- ● 16%

Sources: Munich Re NatCatSERVICE, World Bank

The objective of InsuResilience is to give an additional 400 million people in emerging and developing countries access to insurance by the year 2020 to protect themselves against weather-related catastrophes. This will either be organised on a macro level with insurance cover for entire countries (indirect insurance of the population), or on a micro level with insurance policies for individual persons (direct insurance of the population).

Claims payments are linked to clearly defined weather parameters such as amounts of rainfall or wind speed. Such products are known as parametric or trigger-based covers. In this way, people can insure themselves against drought, windstorm or heavy rainfall, each of which is recorded using objective measurement methods. This mechanism makes terms and conditions transparent, reduces the administrative cost of calculating claims amounts, and thus enables payouts to be made promptly. It should be remembered, however, that besides the above-mentioned advantages of parametric triggers, there is also a basis risk to be taken into account (occurrence of a loss before the defined trigger level has been reached). However, the simplicity of the payout principle on a parametric basis means that micro and macro solutions already exist in a number of developing countries and, in line with the G7 declaration, should be further built upon.

Sustainable growth remains a vain hope in the absence of hedging instruments against the economic shocks from natural catastrophes.

If structured well, insurance solutions not only create incentives to take preventive measures (by way of knowledge transfer and/or deductibles), but also represent an effective tool to finance claims burdens. If the public and private sectors are to overcome the immense financial impact of such disasters, it is imperative to soften their long-term impact on the economy. To this end, the introduction of climate insurance solutions promotes the construction of robust social and economic structures, thereby developing resilience.

Public-private partnerships are required

If the G7 target is to be attained, the affected countries will have to adopt the necessary regulatory measures and participate financially in the project. The additional provision of international aid or ramp-up support from climate funds, such as the Green Climate Fund (GCF), also constitutes a promising solution.

This is the only way to develop lasting (i.e. sustainably financed) insurance schemes in developing countries and emerging markets that enable people to better adapt to the new risks resulting from climate change.

Climate insurance solutions could become a textbook example for cooperation between the public and private sectors. The roles of the individual cooperation partners are clearly defined based on the competences and resources of each:

- The public sector defines the legal and regulatory framework and the socio-political aims. The establishment of weather databases, the development of publicly accessible risk information systems, and knowledge building among the population can also be supported at both national and international levels.

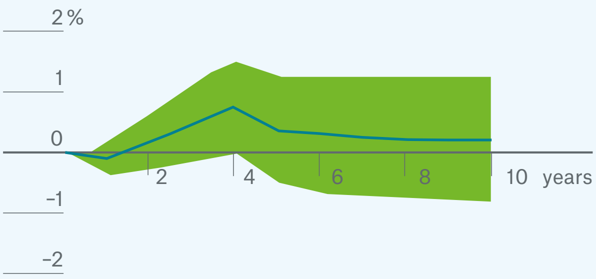
- The insurance industry is responsible for the development and implementation of climate insurance solutions. To this end, it provides expertise, risk models, best practices from other countries and, most importantly, risk capital. Risk-commensurate premiums need to be charged for the mechanism to function in a lasting and stable manner. Only then will pricing adequately reflect the loss potential and create an incentive for people to take measures that reduce the risk.

In the past, diverging views between the private and public sectors often presented insurmountable obstacles in the realm of risk financing that made it impossible to develop insurance schemes in less developed countries. But there is a growing awareness that it is precisely these countries that have the most urgent need to adapt to the consequences of climate change.

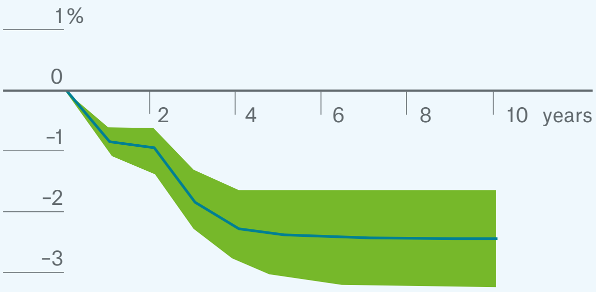
Cumulative development of a country's gross domestic product following a major loss

In the years following a natural catastrophe, GDP deviates from the trend it would have taken without the event. It can be clearly seen that the performance of countries with a comprehensive insurance system is much better, and that the duration of the slump is much shorter. The diagrams show the development of GDP with and without insurance.

a) Countries with a comprehensive natural catastrophe insurance system



b) Countries without a natural catastrophe insurance system



Source: Munich Re, based on von Peter et al., Bank for International Settlements, 2012 (schematic presentation)

Energy issues

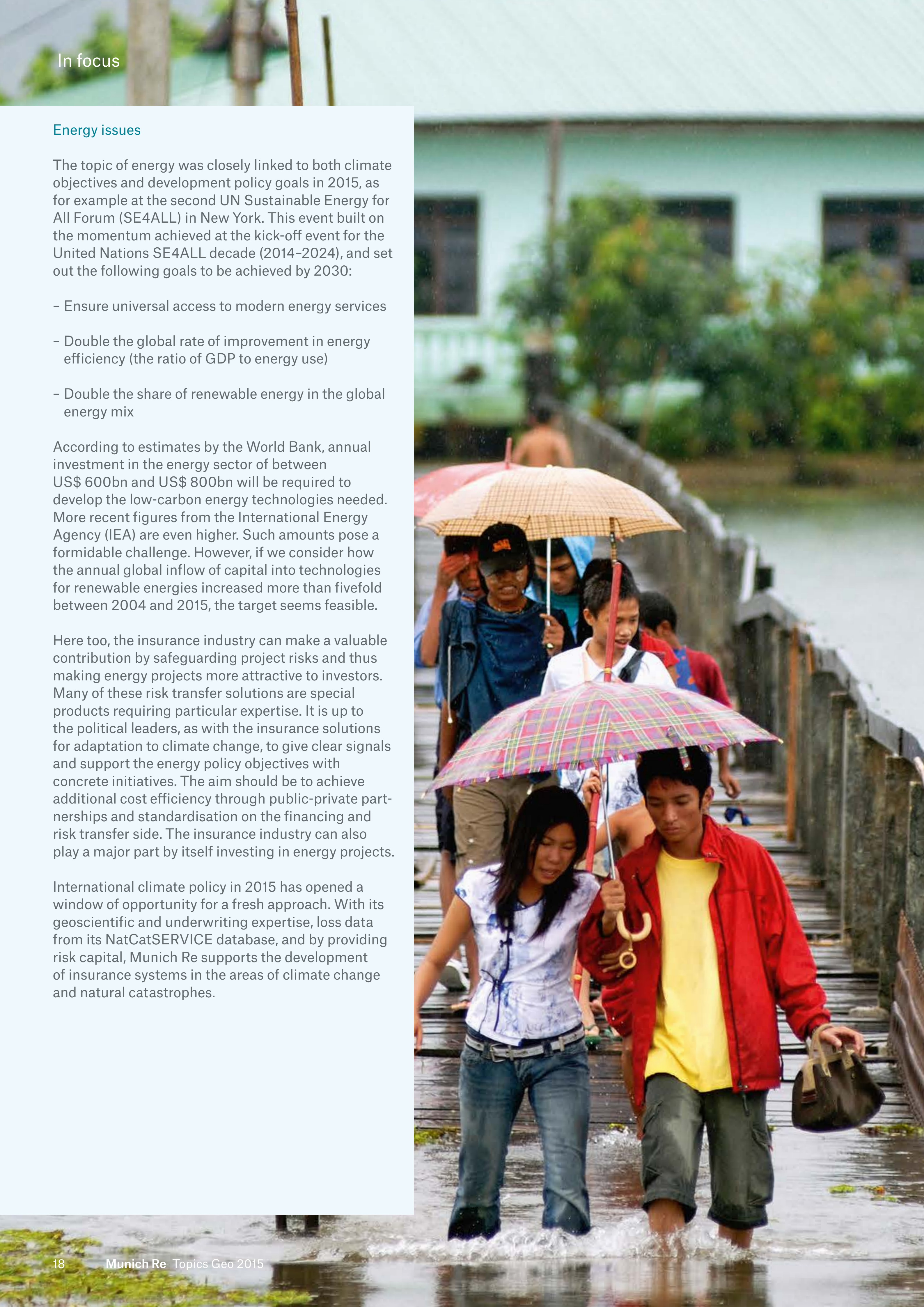
The topic of energy was closely linked to both climate objectives and development policy goals in 2015, as for example at the second UN Sustainable Energy for All Forum (SE4ALL) in New York. This event built on the momentum achieved at the kick-off event for the United Nations SE4ALL decade (2014–2024), and set out the following goals to be achieved by 2030:

- Ensure universal access to modern energy services
- Double the global rate of improvement in energy efficiency (the ratio of GDP to energy use)
- Double the share of renewable energy in the global energy mix

According to estimates by the World Bank, annual investment in the energy sector of between US$ 600bn and US$ 800bn will be required to develop the low-carbon energy technologies needed. More recent figures from the International Energy Agency (IEA) are even higher. Such amounts pose a formidable challenge. However, if we consider how the annual global inflow of capital into technologies for renewable energies increased more than fivefold between 2004 and 2015, the target seems feasible.

Here too, the insurance industry can make a valuable contribution by safeguarding project risks and thus making energy projects more attractive to investors. Many of these risk transfer solutions are special products requiring particular expertise. It is up to the political leaders, as with the insurance solutions for adaptation to climate change, to give clear signals and support the energy policy objectives with concrete initiatives. The aim should be to achieve additional cost efficiency through public-private partnerships and standardisation on the financing and risk transfer side. The insurance industry can also play a major part by itself investing in energy projects.

International climate policy in 2015 has opened a window of opportunity for a fresh approach. With its geoscientific and underwriting expertise, loss data from its NatCatSERVICE database, and by providing risk capital, Munich Re supports the development of insurance systems in the areas of climate change and natural catastrophes.



COP21 – Let's make the most of the new opportunities

In many respects, 2015 was very much a climate year. It gave us a new global temperature record fuelled by a strong El Niño, significantly exceeding the previous record of 2014. It was almost as if a further compelling argument was being presented for the climate negotiations. Throughout the year, suspense built up, accompanied by some extremely ambitious expectations, as we moved towards the climate summit in Paris. It was clear to everyone that a failure like that of 2009 in Copenhagen would signal the end of the UN-led negotiation process – and this had to be avoided at all costs.

Back in June in Elmau, the G7 countries had laid solid foundations by reaffirming their commitment to restrict global warming and make support payments to developing countries. However, a new feature was agreement on a five-year project that will enable an additional 400 million people in developing countries to protect themselves against increasing losses from extreme weather events in the form of insurance solutions. This initiative sent out a clear signal: that we take the problems faced by people in developing countries very seriously and are prepared to take responsibility for emissions. In my opinion, this gesture had a positive effect on the atmosphere at the negotiations, which have frequently been affected by the conflicting interests of the countries responsible for climate change and those that suffer most from it.

Further enabling factors included the superb organisation of the conference by the French hosts, and the excellent management of the negotiations by the French Foreign Minister, Laurent Fabius. A breakthrough was finally reached, not least thanks to the positive mood that prevailed, which inspired goodwill in many countries that would otherwise have tended to block proposals. I believe that the result of the climate summit is the best possible outcome that could be achieved at the present time. What's more, with the target of holding global warming to "well below two degrees Celsius", an even stricter limit was set than originally planned. Yet certain risks remain from the Paris Agreement: the individual countries still have to ratify the agreement; there are no sanctions if the voluntary reduction targets are not met; countries can opt out of the agreement.

And we also need to be very clear about one thing: even if all the promises are kept, and the reduction targets are tightened after five-year review periods, climate change cannot be stopped. Yet Paris represents a breakthrough. It has considerably improved the opportunities to limit climate change within a framework that is still manageable for most countries. The effects, however, which have become already detectable with the current global warming of just under one degree Celsius, will intensify, so more vigorous adaptation efforts are required.

From our perspective, a further aspect that must be seen in a very positive light is the fact that Article 8 of the Paris Agreement now officially recognises insurance solutions as an important part of the adaptation process. For example, the already operational pool solutions to cover losses from extreme weather events in poorer countries – such as the African Risk Capacity (ARC), the Caribbean Catastrophe Risk Insurance Facility (CCRIF), and the Pacific Catastrophe Risk Assessment and Financing Initiative (PCRAFI) – are seen as useful and extendible approaches.

It is now up to us insurers to breathe life into the new opportunities that have emerged. As a globally operating reinsurer, we understand better than anyone the very different regional hazard situations, how they are changing and the vulnerabilities involved. Managing risks – including those posed by climate change – is part of our core business. After Paris, the door is now open for us to contribute our expertise and help to achieve a meaningful increase in people's resilience to the unavoidable consequences of climate change.
Let us make the most of this opportunity!

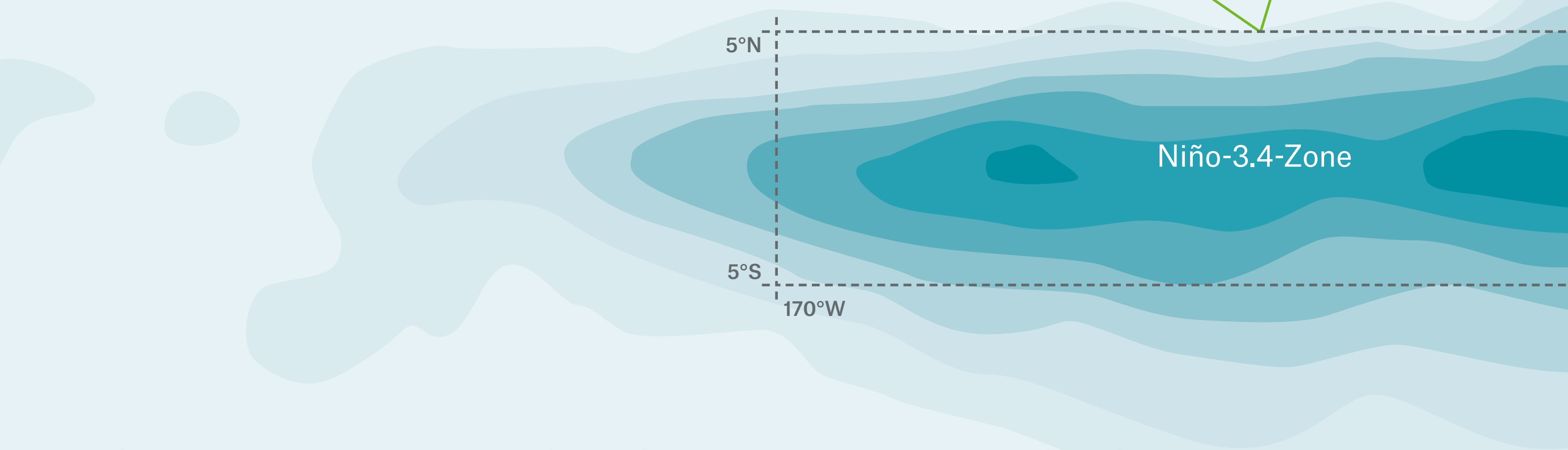
Prof. Peter Höppe,
Head of Munich Re's Geo
Risks Research/Corporate
Climate Centre
phoeppe@munichre.com

1997/1998: +2.8°C

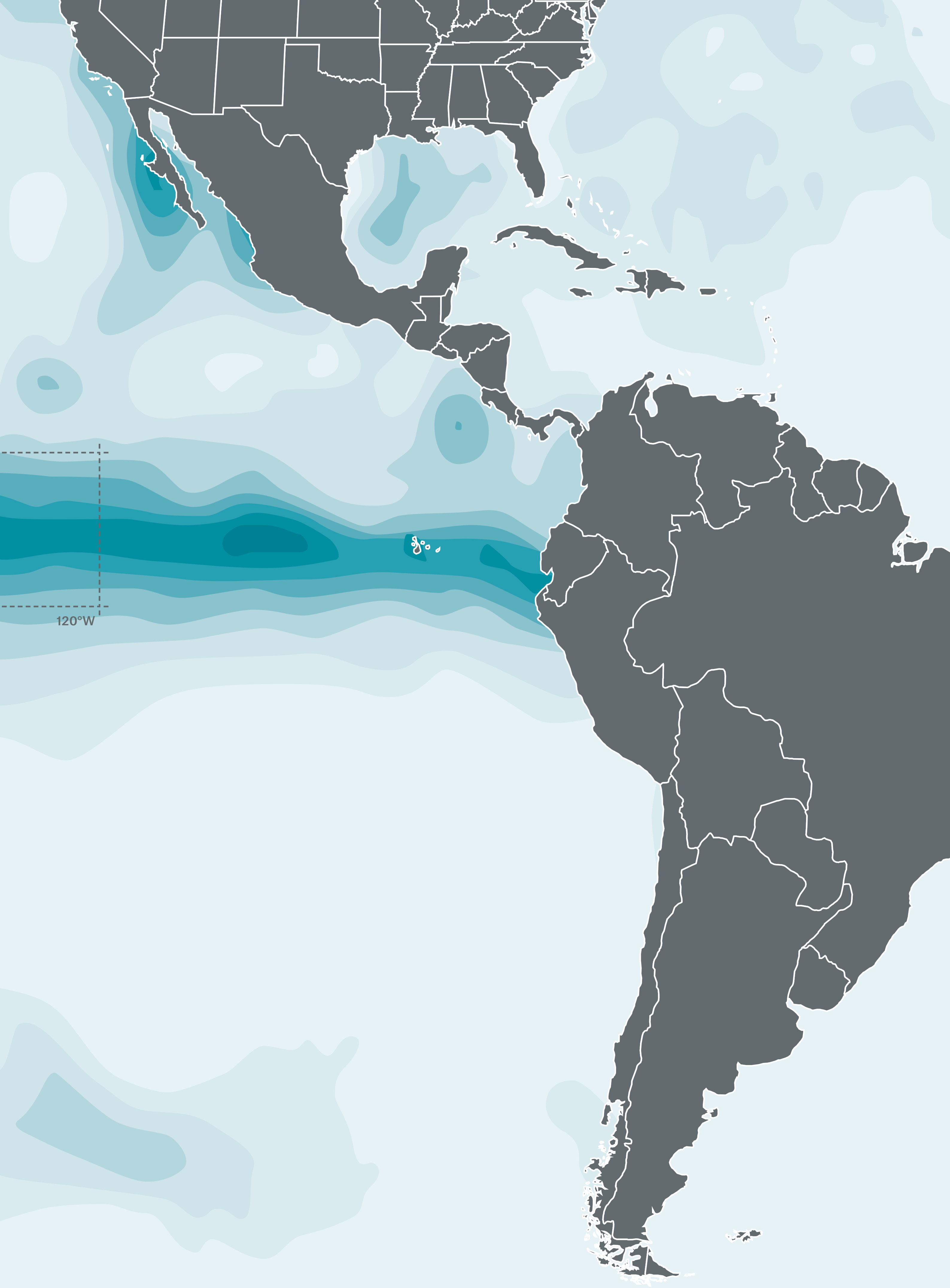
In 1997/1998, in the strongest El Niño event ever recorded, the maximum index for the Niño 3.4 zone was 2.8 (weekly average), representing a deviation of 2.8°C above the long-term average.

2015/16: +3.1°C

Up to the end of December 2015, the maximum weekly index (15–21 November) for the Niño 3.4 zone was already 3.1.



The natural oscillation that characterises El Niño (and its counterpart La Niña) is one of the most important in the earth's climate system. It has far-reaching effects for certain regions of the world. The third strongest El Niño event since 1950 was recorded in 2015.


120°W

A strong El Niño

Eberhard Faust

2015 brought us a very strong El Niño event. Its impact was felt in many places and such strong events could occur more frequently in future.

From March 2015, the climate phenomenon first nicknamed “the Christ child” – El Niño – by Peruvian fishermen developed into one of the strongest events registered since records began in 1950. If we measure the ocean portion of this phenomenon, following the weekly mean sea surface temperature across what is known as the Niño 3.4 region (see pages 20/21), the largest deviation from the mean value in the climate reference period (1981–2010) up to the end of 2015 was 3.1°C. That is even greater than the deviation in the 1997/98 event, which was considered the “El Niño of the century” (Fig. 1).

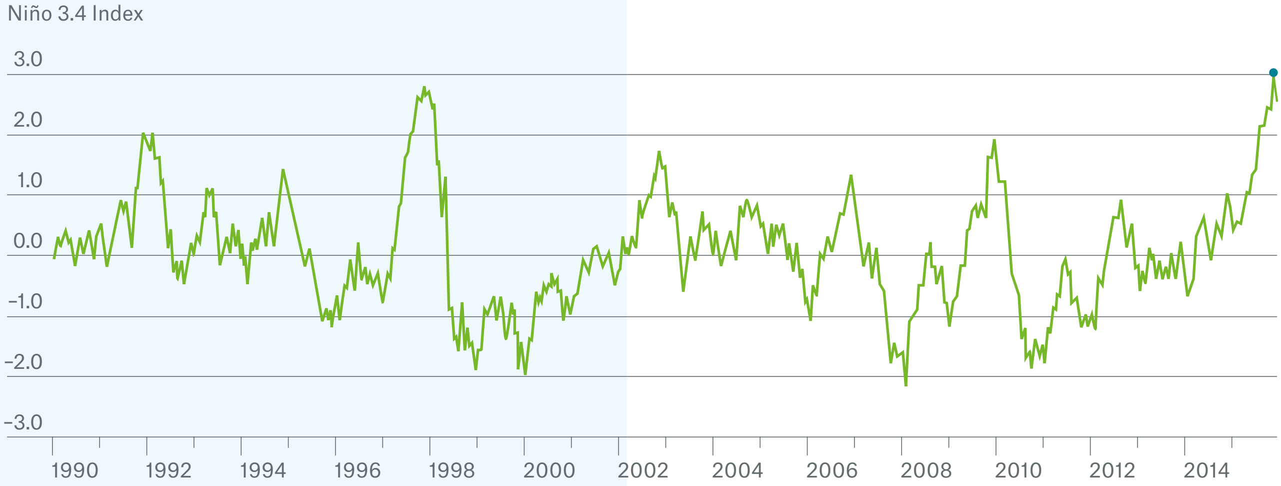
However, the changes in atmospheric circulation that accompanied the ocean changes in the strong events of 1982/83 and 1997/98 were more intense than in the current episode.

El Niño is a climate phenomenon that couples ocean and atmosphere. For a comprehensive record of the intensity of the event, the most practical approach is therefore to summarise the various ocean and atmospheric variables in a single index. This was attempted with the Multivariate ENSO Index (MEI) defined by Wolter and Timlin, which incorporates sea-level air pressure, the north to south and west to east wind components, sea surface temperature, air surface temperature, and cloud cover in the tropical Pacific region. This analysis shows that the 2015 El Niño event, up to and including December, is the third strongest event since 1950 (Fig. 2).

Typically in El Niño events, a trend of warmer sea surface temperatures is registered in the eastern equatorial area of the Pacific, with the development peaking around the end of the year. As a result, towering rain clouds associated with warm sea surface temperatures are displaced into the central and eastern regions of the equatorial Pacific. This means that it becomes unusually dry in the west of the tropical Pacific, in other words along the coast of (north)east Australia as far as Southeast Asia, while central and eastern areas, close to Ecuador and northern Peru tend to experience unusually high rainfall. We already described other typical effects in the Topics Geo 2014 issue, which you can download from our client portal connect.munichre.com.

Weekly Niño 3.4 Index

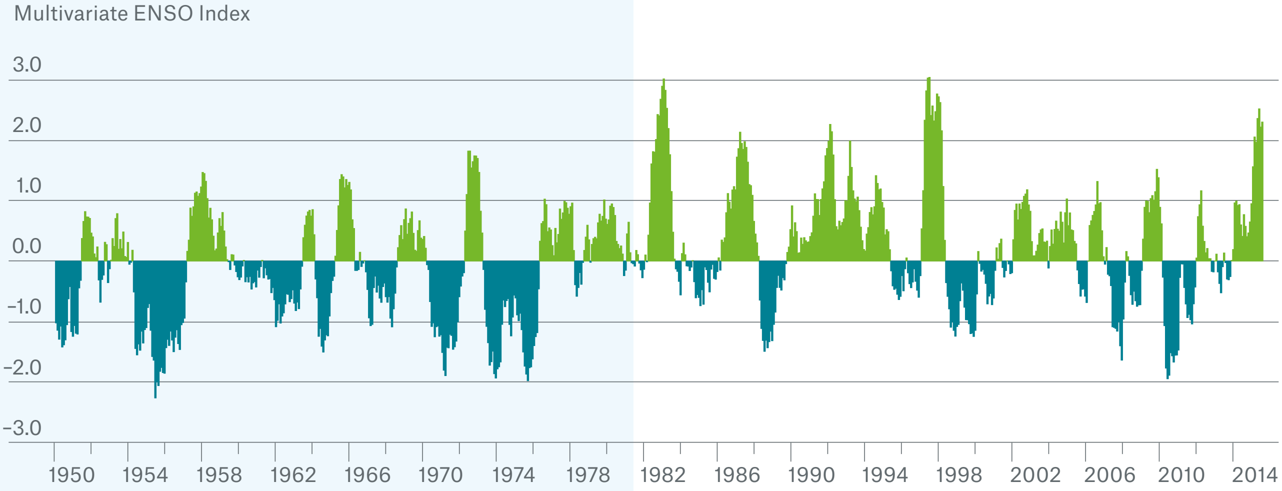
Fig. 1: The intensity of the ocean component of El Niño and La Niña events can be measured using the weekly deviation in sea surface temperature in what is known as the Niño 3.4 region in the tropical Pacific (5°N–5°S, 170–120°W), according to which the 2015/2016 event has already exceeded that of 1997/1998.



Source: Munich Re, based on the Climate Prediction Center, NOAA

Multivariate ENSO Index 1950–2015

Fig. 2: Using the Multivariate ENSO Index, we can measure the coupled ocean-atmosphere intensity of an overall El Niño or La Niña event. It shows that the 2015/16 event is the third strongest after 1997/1998 and 1982/1983.



Source: Munich Re, based on Earth System Research Laboratory, Physical Sciences Division, NOAA

After the start of the New Year, the run-up phase to the peak (onset year) is typically followed by a regression to neutral conditions (decay year). In most cases, significant El Niño events in the context of this sequence reach their peak around the end of the year, and in many cases, then switch sign in the decay year; in other words, in the second half of the year, they transition into La Niña events, the cold sister of El Niño. Here, the effects are, to a degree, the opposite of El Niño: the trade wind drives warm water to the coastlines of the western tropical Pacific, bringing increased rainfall to the region – in other words, to northeastern Australia, Indonesia and Southeast Asia. Conversely, it tends to be dry in the eastern part of the tropical Pacific and along the equatorial coasts of South America, while the ocean cools significantly. While it is still unknown at the start of 2016 whether this will develop into a La Niña phase, there is at least an increased likelihood of that happening.

Change in cyclone activity

One of the most prominent teleconnection events from strong El Niño episodes, and one that was once again in evidence in 2015, is a change in tropical cyclone activity in each of the ocean basins. In the North Atlantic, hurricane activity typically declines, because the atmospheric conditions are less favourable for the formation and development of tropical cyclones, especially in the tropical west. One reason for this is the more powerful wind shear resulting from a stronger easterly airflow at high altitude in conjunction with slightly stronger trade winds from easterly directions close to the sea surface. Air also descends from high altitude, leading to localised warming and drier conditions, thus inhibiting convection, a fundamental process in the physics of tropical cyclones. Primarily because of these effects, the Accumulated Cyclone Energy (ACE) in this season was only 60% of the mean value over the climate reference period 1981–2010 (Klotzbach, 2015).

In contrast, the level of activity of severe cyclones in the eastern North Pacific is exceptionally high – likewise a typical effect of El Niño. The ACE there was 219% of the mean value for the normal period. The reason for this increase is that, during substantial El Niño episodes, wind shear tends to be below average, while sea surface temperatures are above average. Both these factors promote the development of severe storms.

The El Niño conditions also produced a similar result in the western part of the North Pacific: an unusual number of severe storms developed there, because their locations of formation were shifted east towards the warmer water, and closer to the equator. Consequently, the storms moved over relatively warm sea surfaces for longer periods, where they were able to reach high intensities under light wind shear. The Accumulated Cyclone Energy (ACE) in 2015 was 161% of the mean value of the climate reference period 1981–2010.

Notable effects in 2015

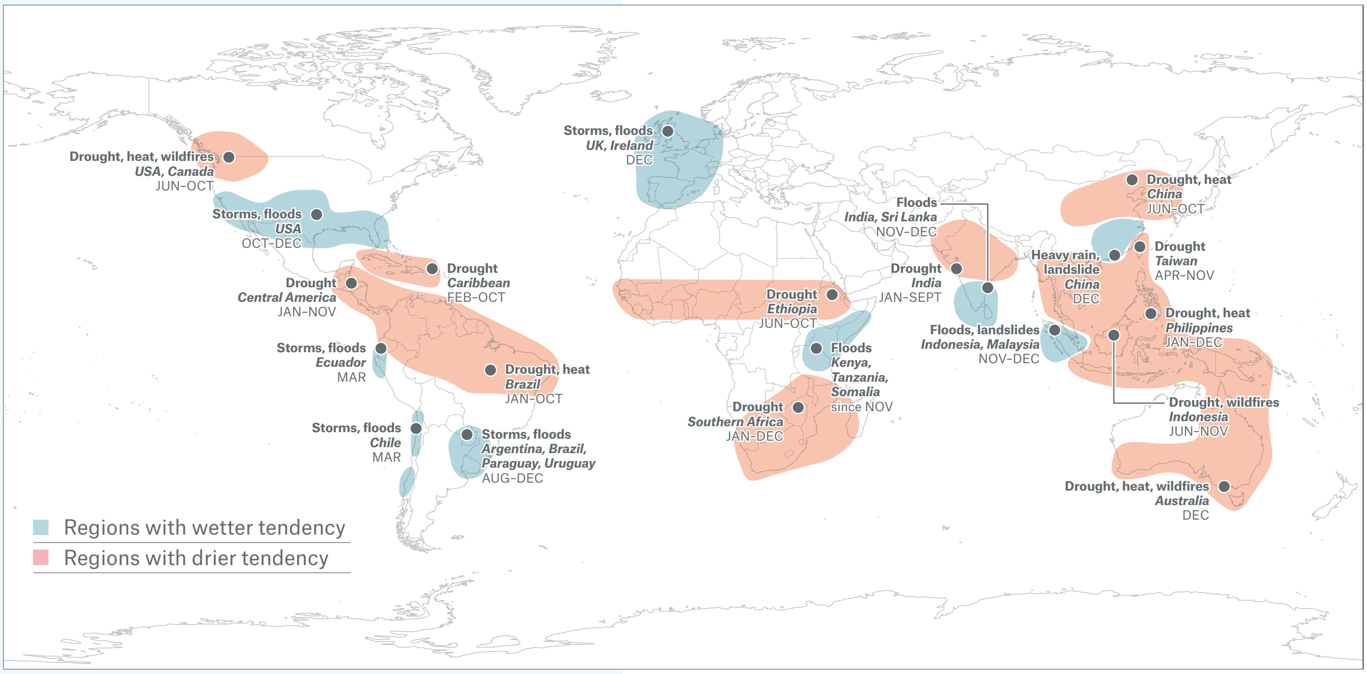
The map on page 25 (Fig. 3) shows the regional precipitation-related teleconnection events which occur with a typical high-intensity El Niño. Loss events are also noted that correspond to these categories and were recorded up to the end of 2015. It should, however, be remembered that El Niño teleconnection events can overlap with other climate phenomena, such as the phases of the Indian Ocean Dipole. Because of these individual conditions, each El Niño event has its own characteristics. The losses can only be aggregated after the event has come to an end in 2016.

In what way does a strong El Niño impact the macroeconomy? Some countries may suffer a short-term reduction in real GDP growth, as has been observed in Indonesia, South Africa and Australia, for example. This is partly due to reduced agricultural yields as heat and drought take their toll. Indonesia, for example, has experienced reduced yields for coffee, cocoa and palm oil. The production and export of nickel (used in steel production) can also suffer as low water levels have a major impact on hydropower facilities and river transportation. This can push up the global price of foodstuffs and metals in particular. However, there are also countries that enjoy a brief boost to GDP growth during El Niño events, for example the US. This is because there are fewer hurricanes, and changes in temperature or rainfall can increase the output of certain agricultural products such as soybeans. US neighbours Canada and Mexico also benefit (Cashin et al., 2015).

As well as the loss effects illustrated in Fig. 3, there were other noticeable repercussions. One of the most important is that the El Niño event contributed to the high global mean temperature in 2015, the warmest year since records began. On the environmental front, according to the US weather service NOAA, the excessive warming of the seas triggered the third registered global episode of coral bleaching after 1998 and 2010. Under environmental stress caused by

Loss events in 2015 influenced by El Niño

Fig. 3: Zones typically affected by rainfall deviation from the long-term mean caused by El Niño. Depending on the time of the year, the deviations in parts of these zones can vary greatly or in some cases even swing in the opposite direction entirely. The diagram also shows clusters of typical loss events per region that occurred in 2015.



Loss event(s)	Region(s)	Period
Drought, heat, wildfires	NW USA, SW Canada	Jun–Oct 2015
Storms, floods	Southern USA	Oct–Dec 2015
Drought	Central America	Jan–Nov 2015
Drought	Caribbean	Feb–Oct 2015
Storms, floods	Ecuador	Mar 2015
Storms, floods	N Chile	Mar 2015
Drought, heat	NE Brazil	Jan–Oct 2015
Storms, floods	NE Argentina, S Brazil, Paraguay, Uruguay	Aug–Dec 2015
Floods, windstorms	UK, Ireland	Dec 2015
Drought	Ethiopia	Jun–Oct 2015
Floods	Kenya, Tanzania, Somalia	since Nov 2015
Drought	Southern Africa	Jan–Dec 2015
Drought	India	Jan–Sep 2015
Floods	India, Sri Lanka	Nov–Dec 2015
Drought, heat	NE China	Jun–Oct 2015
Heavy rain, landslide	S China	Dec 2015
Drought	Taiwan	Apr–Nov 2015
Drought, heat	Philippines	Jan–Dec 2015
Floods, landslides	W Indonesia, W Malaysia	Nov–Dec 2015
Drought, wildfires	Indonesia	Jun–Nov 2015
Drought, heat, wildfires	SE Australia	Dec 2015

Source: Munich Re, NatCatSERVICE; Zones based on Davey et al, Climate Risk Management 1 (2014); International Research Institute for Climate and Society, Columbia University.

increased temperatures, coral sheds algae that normally live symbiotically in its tissues, with the result that it takes on a bleached appearance. In addition, in losing the algae, it also loses its main source of food and becomes susceptible to disease. If this condition persists over a period of months, the coral then dies. The reef structures then degrade rapidly, their coastal protective function against storms quickly declines, the habitat for fish and other environmentally and economically important species disappears, and local tourism loses visitors. The event began in mid-2014 in the North Pacific and then began to have an effect on the South Pacific and the Indian Ocean. Hawaii has now been badly affected, and the islands of the Caribbean are also at risk. Researchers expect this event to continue in 2016.

Strong El Niño events will become more frequent

Strong El Niño events like that in 2015/16 may occur much more frequently this century than they did in the 20th century if the observed pace of climate change continues (business-as-usual scenario). This is the conclusion of a study conducted by leading ENSO researchers (Cai et al., 2014). According to its projections, intensive El Niño events that occurred every 20 years, or less often, in the period 1891–1990, will be experienced twice as frequently in the period 1991–2090.

The main reason for this is the relatively strong warming of the eastern equatorial Pacific that would occur with continued climate change. This would mean that the level of warming required there for the formation of a strong El Niño phase would become increasingly easy to achieve.

The criterion used here for an extreme El Niño event is not the extent of the anomaly in sea surface temperature, but rather the consequent anomaly in precipitation of at least 5 mm/day in the Niño 3 zone. This effect in the atmosphere also takes into account the long-range atmospheric teleconnection patterns associated with extreme events.

If, following the COP21 resolutions in Paris, emissions rise by less than the business-as-usual scenario, this would mean that the increase in extreme El Niño events will reduce accordingly.

Qualified predictability

It is important for risk management purposes that a variability in climate such as El Niño can be predicted, within limits, roughly six to eight months in advance (see Topics Geo 2014). At the same time, the origins of these events are dependent on processes in much shorter time scales that are in some cases difficult to predict. The models are therefore imprecise in terms of temporal dynamics or the maximum intensity achieved by an event. Since roughly the end of April 2015, the ensemble average from the international prediction models listed by the International Research Institute for Climate and Society indicated a maximum expected intensity close to the upper end of the moderate range (Niño 3.4 index ≈1.5), and a strong event was then finally forecast from May 2015, although with a much lower amplitude than actually developed.

References:

Cai, W., S. Borlace, M. Lengaigne, P. van Rensch, M. Collins, G. Vecchi, A. Timmermann, A. Santoso, M.J. McPhaden, L. Wu, M.H. England, G. Wang, E. Guilyardi, and F-F. Jin, 2014: Increasing frequency of extreme El Niño events due to greenhouse warming. Nature Climate Change, DOI: 10.1038/NCLIMATE2100

Cashin, P., K. Mohaddes, and M. Raissi, 2015: Fair Weather or Foul? The Macroeconomic Effects of El Niño. International Monetary Fund, Working Paper WP/15/89, 29 pages

Klotzbach, P., 2015 (personal communication)

2015 – 7.8

Fatalities: 9,000; buildings destroyed: 60,000; buildings damaged: 280,000

1833 – 7.6

Fatalities: 500; buildings destroyed: 4,000; buildings damaged: Unknown

1934 – 8.0

Fatalities: 10,700; buildings destroyed: 80,000; buildings damaged: 120,000

Once again, the world's rooftop has been rocked by devastating earthquakes. Although lessons were learned from previous catastrophes, the consequences of the latest earthquakes in the spring of 2015 were devastating for Nepal. Despite huge international aid efforts, reconstruction has been severely hampered by a combination of poor risk management and inadequate organisation.

1988 – 6.9

Fatalities: 1,450; buildings destroyed: 23,000; buildings damaged: 80,000

Earthquake at the top of the world

In the spring of 2015, Nepal and the neighbouring states of India, China and Bangladesh were rocked by a series of powerful earthquakes. The consequences were devastating, especially in the rural district to the northwest of the Nepalese capital, Kathmandu.

Martin Käser and
Wilhelm Morales Avilés

Nepal
Earthquake losses 2015: **US$ 5.1bn**
GDP 2014: **US$ 19.7bn**
Losses as a percentage of GDP: **26%**

The largest mountain range in the world, the Himalayas, is also home to the highest mountains on the planet. They were formed by the collision between the Indian and the Eurasian continental plates, which began around 65 million years ago. Today, the Indian plate is moving at the rate of around 4 to 5 cm per year in a northerly direction, in the process lifting the Himalayas by roughly one centimetre per year. The forces that occur during this collision sometimes exceed the shear strength of the rocks deep beneath the Himalayas. This produces the sudden displacement of enormous rock masses, which scrape past one another in a matter of seconds, triggering powerful earthquakes in the process.

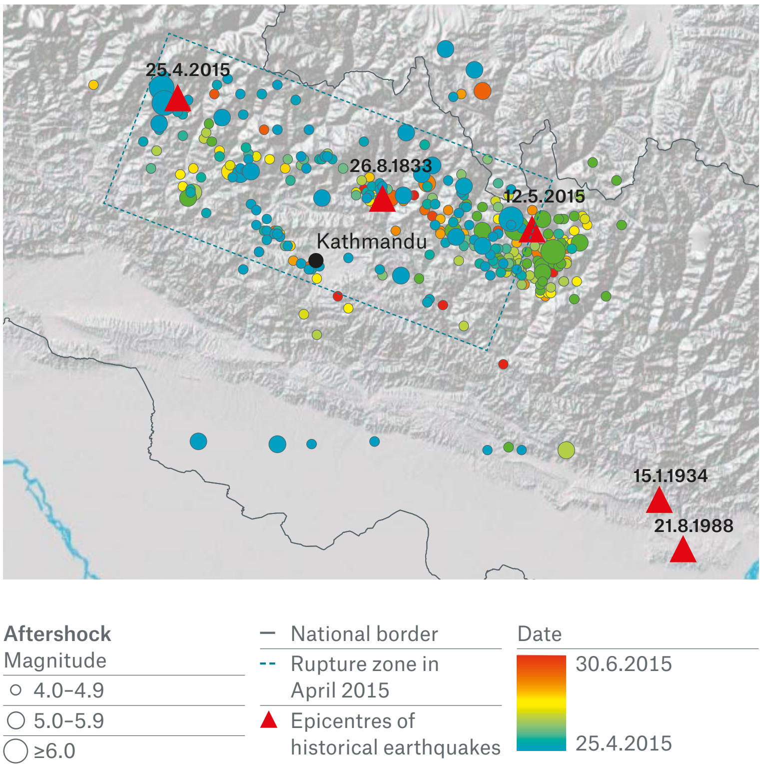
Displacement of up to four metres

It was such an earthquake that struck Nepal just before noon on 25 April 2015. It occurred on one of the known major fault lines along the Himalayas, and its magnitude was measured at 7.8, with the epicentre close to the town of Gorkha. Its force was especially strong in the rural district to the northwest of the capital, Kathmandu. Here, displacement of up to 4 metres occurred at a depth of between 10 and 25 kilometres on a rupture face angled to the north. Overall, the rupture face was approximately 100 kilometres long and 80 kilometres wide. In the epicentral area, ground motion was observed up to level IX (of a maximum of XII) on the Mercalli Intensity Scale. In the high mountain regions further north, the quake triggered landslides and avalanches over a wide area, which buried entire villages in the steep valleys that have been carved out of the mountains.

Over the following days, there were hundreds of major and minor aftershocks (Fig. 1). The largest, with a magnitude of 7.3, occurred on 12 May, again around lunchtime, approximately 80 kilometres east of Kathmandu. Further damage was caused, and rescue teams from international aid organisations were also caught up in events.

No respite for Nepal

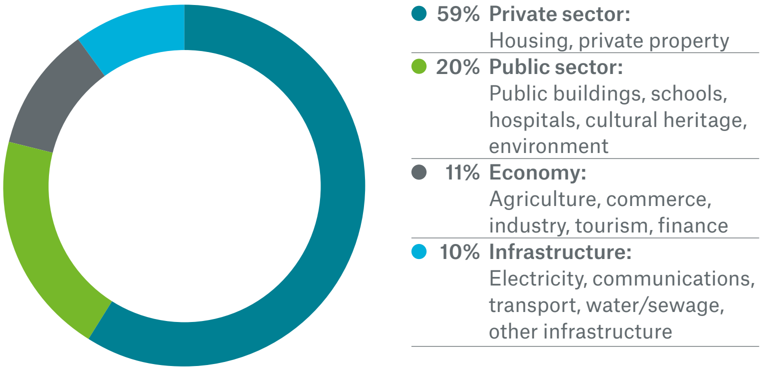
Fig. 1: Aftershocks continued for two months in northern Nepal after the first quake on 25 April.



Source: Munich Re, based on data from the Nepal Seismological Centre: Esri

Losses in different sectors

Fig. 2: The lion's share of economic losses were to private housing



Source: Munich Re, based on data from the National Planning Commission (Government of Nepal)

Many schools destroyed

The earthquakes claimed over 9,000 lives in Nepal, India, China and Bangladesh. There were over 23,000 injured, and more than half a million were left homeless. Despite the fact that Nepal has had a National Building Code since 1994, buildings seldom comply with this construction standard. Building materials (clay, brick, bamboo and wood) are often of poor quality, and the method of construction typically leaves structural weaknesses. Bracing elements are either left out entirely, or the reinforcement measures used are inadequate.

There was an alarming number of school buildings affected. A total of 6,000 were significantly damaged or completely destroyed. If the quake had struck on a school day instead of on a Saturday, there would have been many more children among the victims.

Gorkha not a worst-case scenario

Nepal is considered one of the most exposed earthquake regions in the world. Yet even stronger tremors and more violent ground motion than in the Gorkha quake are perfectly possible. The massive deposits of sediment in the southern foothills of the Himalayas (e.g. in the Kathmandu Valley) can even significantly intensify earthquakes at a local level. Seen from this perspective, the Gorkha quake was by no means a worst-case scenario.

Historical earthquake catastrophes in the region around Kathmandu are known from the years 1833 (magnitude 7.6), 1934 (magnitude 8.0) and 1988 with a magnitude of 6.9 (see graph on pages 28/29). A total of 10,700 people died in 1934, with around 80,000 buildings destroyed and more than 120,000 damaged.

Over 50 years later, the 1988 earthquake claimed the lives of 1,450 people and, despite its relatively low magnitude, again damaged more than 80,000 buildings. Railways, bridges and roads were also seriously affected.

Many mountain villages were flattened as their simple clay houses offer no resistance to powerful earthquakes. Landslides then brought further devastation.

Very few losses insured

Economic losses from the quakes of 25 April and 12 May are estimated at US$ 5.6bn (90% of these in Nepal), of which roughly US$ 210m was insured. Life insurers estimate that they have to pay out less than a million US dollars for local people, as only around 4% of the victims were insured. Sectors such as housing, education, cultural heritage and healthcare were the worst affected (Fig. 2). Most private residential buildings had no insurance cover. Only damage to newer buildings, whose construction had been financed by banks, was generally covered.

Tourism is of key importance to Nepal's economy, with over half a million visitors from abroad each year, and it is estimated that there were 20,000 visitors in the country in April at the time of the earthquake. Many world-famous monuments were badly damaged, a number of which were on the UNESCO list of world heritage sites. They included 700 historical, mostly Buddhist, structures with the typical pagodas and stupas, and it is unlikely that they can all be rebuilt.

Given the importance of tourism, the Nepalese government was anxious to reopen some of the most important sites as quickly as possible (e.g. Bhaktapur Durbar Square, Hanuman Dhoka Durbar Square, Bodnath Stupa, Patan Durbar Square, the Pashupatinath Temple). In early June then, the local Ministry for Culture and Tourism declared that Nepal was again a safe travel destination. However, reconstruction work on the most important cultural sites is likely to take at least another five years.

Mountain tourism affected

The mountains are a further tourist attraction. In particular, Mount Everest, rising to an altitude of 8,848 metres, and which the earthquake pushed roughly four centimetres to the southwest, is a prime destination for many people. An avalanche of snow and ice on Pumori, a neighbouring seven-thousand metre peak, claimed a number of victims. At least 19 mountaineers and Sherpas were killed at Everest Base Camp, while others were injured.

Two weeks after the quake, under pressure from international expeditions, the government initially permitted preliminary activities to reopen the traditional route through the Khumbu Icefall. (Nepal Tourism Association: "… climbing will continue, there is no reason for anyone to quit their expedition"). However, shortly afterwards, the Nepalese and Chinese authorities decided to prohibit all further expeditions. As a consequence, 2015 was the first time in 41 years that no one climbed Mount Everest.

Hold-ups in distributing billions in aid

The international community and charity organisations had promised Nepal billions in aid by the end of June. However, due to protests against the new constitution, very little government aid reached those affected. The authorities came under fire immediately after the earthquake because complicated customs procedures were stopping relief supplies getting into the country. In the absence of official assistance, people have been helping themselves as best they can. They have turned to friends and family abroad, or are trying to earn the money needed to rebuild their homes by working in Qatar or Saudi Arabia.

Need to heighten risk awareness

Prompted by the Global Earthquake Model (GEM) community initiative, supported by Munich Re, a study appeared in August 2015 on the seismic hazard and risk situation in Nepal. The findings from this study provide an important basis for making political decisions on land use, building codes, structure of the insurance industry, and catastrophe planning. With adequate risk assessment, it is possible to reduce the social and economic consequences of earthquakes.

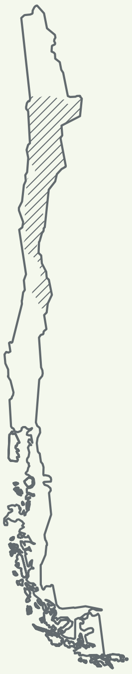
The Kathmandu Valley Earthquake Risk Management Project, also supported by Munich Re, was launched back in 1995. Its objective is to make school buildings more sturdy by giving due consideration to earthquake-resistant construction methods and effective structural reinforcing elements. A total of 300 schools have already benefited from the project, 270 of which were in the recently affected earthquake area. None of these buildings sustained significant damage, whereas 80% of the other schools were badly damaged or even destroyed.

A further positive knock-on effect from the project is that earthquake-resistant construction methods have also been used in many villages for newly built housing. Nepal intends to replace all the schools that collapsed with new, reinforced buildings within the ambitious period of five years. The cost for this is likely to be in the region of US$ 400m. However, international organisations believe the schedule is unrealistic, since it would involve the construction of over 1,200 new buildings a year.

Floods in the Atacama Desert

It is not every day that you have a billion-dollar loss in the desert, especially one caused by water. The people in northern Chile now know from painful experience that it can indeed happen.

Wolfgang Kron



Chile
Atacama flood losses 2015:
US$ 1.5bn
(US$ 0.5bn insured)
Flood losses in Chile 1995–2014:
US$ 0.6bn (0.06)
Nat cat losses in Chile 1995–2014:
US$ 34.7bn (9.0)
(in 2015 values)

Flash floods are among the most dangerous natural events, and very few locations are safe from them. Last year, people living in Chile's Atacama Desert, one of the driest regions on earth, learned this lesson the hard way. The apparently paradoxical claim that more people drown in the desert than die of thirst was proven to be true.

Northern Chile's Atacama Desert only gets a few millimetres of rain each year. In fact, some places there may go many years without a drop falling at all. Part of the reason for this is the region's location between coastal mountains over 2,000 metres in altitude and the Andes, which in places tower over 6,000 metres: the two mountain ranges form a double rain shadow.

5 mm precipitation – The annual average

In addition, the region's location between the 20th and 30th parallels south, where air masses subside and dry out, promotes the extremely dry climate. And finally, the cold Humboldt Current along the coast hinders evaporation and thus the formation of rain clouds.

Very special atmospheric conditions are required for it to eventually rain. As, for example, at the end of March 2015, when after almost ten years of drought, and at the end of an extremely hot summer, a cold front moving in from the southwest channelled moist air into this desert region. For three days, there was intensive rainfall compared to normal levels.

60 mm precipitation – In a single day

On 25 March, over 60 millimetres was measured in some places, a quantity that the dry desert soil was unable to absorb. The courses of rivers like the Copiapó, which had been dry for 17 years, were suddenly transformed into raging torrents. Flash floods formed, which quickly developed into destructive mudflows due to the barren and therefore erosion-prone terrain. The situation was exacerbated by enormous boulders that were swept from the hillsides by the water. The flash floods tore a path of destruction through the towns of Copiapó and Antofagasta, something that had not happened for 80 years. Quillagua, the driest place on earth, where there had been no rain since 1919, experienced four millimetres of precipitation. Even this small quantity was enough to damage some houses.

Copper mines brought to a standstill

At first sight, the estimated US$ 1.5bn in overall losses and US$ 500m in insured losses seem astonishing in view of the sparse population of the Atacama Desert. But it must be remembered that one third of the world's copper production comes from widespread deposits in Chile. Several mines had to close down temporarily. Transport to and from the mining sites is largely handled by private railway lines, most of which are insured. Damage to infrastructure was the main reason for the enormous costs.

But the consequences for populated regions were also severe, with many localities left under water. There were a total of 31 confirmed deaths, with others still unaccounted for. Over 2,000 houses were completely destroyed, and more than 6,250 badly damaged. There were also losses in the agricultural sector, as there is intensive cultivation of table grapes and olives along the Copiapó. Even though most of the 2015 grapes had already been harvested, substantial losses may be expected over the next few years because of the large number of plants that were left buried under hardened mud.

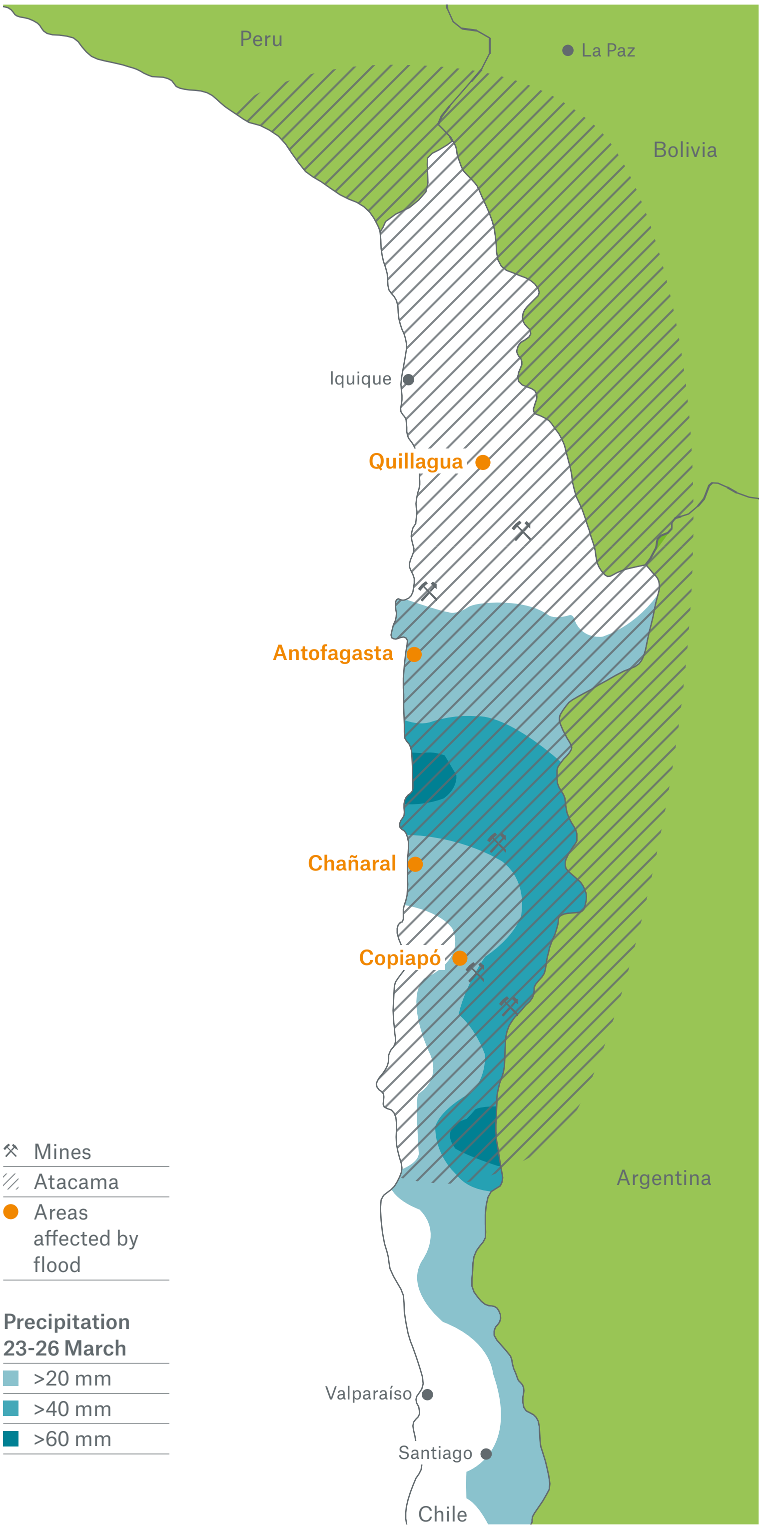
Insurers face challenges

Chile is a country exposed to a variety of natural hazards. Besides the Atacama floods, it experienced two volcanic eruptions last year, and a severe earthquake followed by a five-metre tsunami, as well as droughts and bushfires. While the average insurance penetration for private urban households and commercial businesses is quite high, rural districts such as those affected in March lag some way behind.

However, the Chilean insurance industry is on a firm footing. Its underwriting standards are high and there is generally adequate reinsurance cover for major catastrophes.

When the desert floods

Even as one of the driest places on earth, Chile's resource-rich Atacama Desert still suffered flood losses in 2015.



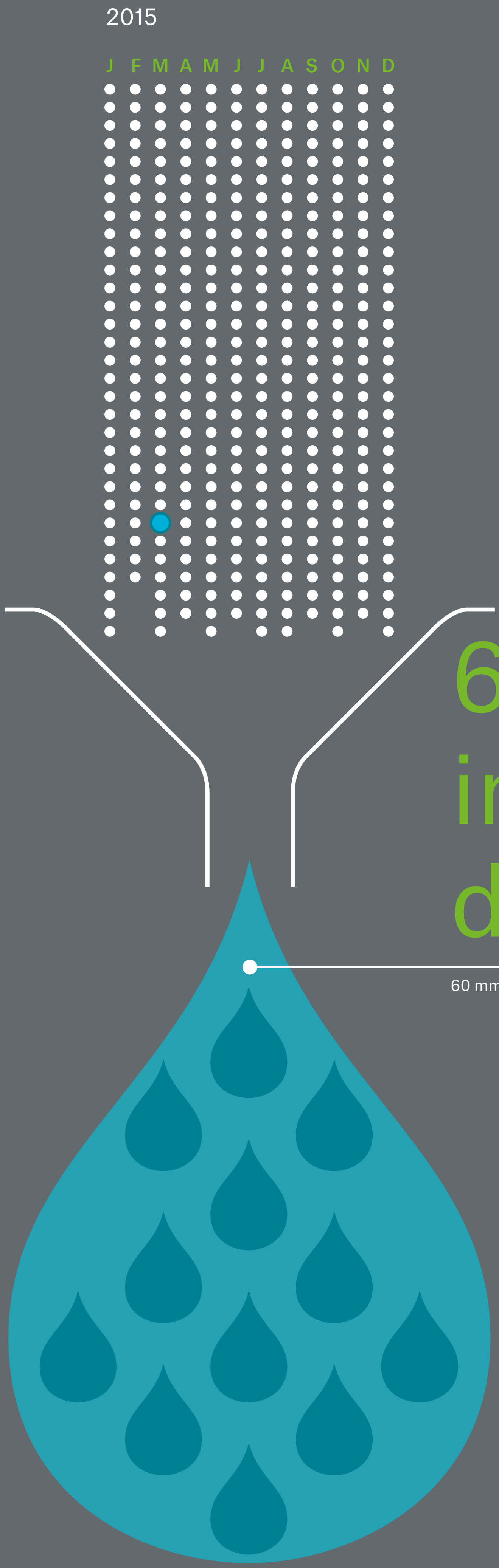
Source: Munich Re, based on DMC, Sección Meteorología Agricola

Riverbeds which have been dry for many years are quickly transformed into almost impenetrable obstacles. Even knee-high water can be deadly at high speeds.

On 25 March 2015 it rained in the Atacama Desert, with up to 60 mm falling in some places. While 60 mm of rainfall would not merit a second glance in most places, in the Atacama Desert that is equivalent to twelve years’ rainfall. Consequently, the land and its people are simply not prepared for such conditions.

Annual average of 5 mm

5 mm of rain is equivalent to 5 litres of water per square metre.
This would fill a small bucket.



60 mm in a single day

60 mm of rain (60 l/m^2) would half fill a bathtub.

Major earthquake events in recent years, for example, were shouldered without any great difficulty.

The bulk of the half a billion dollars in insured losses comes from the mining industry, and private infrastructure, such as roads, bridges and water supply facilities. Over half of the region's irrigation channels, and almost 30% of plantation areas were badly damaged by accumulation of silt and mud.

Virtually impossible to protect against flash floods

Flash floods are one of the most dangerous natural events – in part because they still tend to be underestimated. Worldwide, there were 105 flash flood events last year in which at least five people lost their lives – and many of these fatalities could have been avoided. While it may be understandable to want to save your car from an underground garage, it is also an extremely risky undertaking. The water often arrives extremely suddenly, brooks no obstacles, and develops incredible force. Since most vehicles are in any case insured, their loss is generally compensated for.

Taking precautions against extreme flash floods is far from easy. They normally occur directly where rain is falling, but often move at great speed and sometimes outside natural watercourses. Their rarity (in terms of a particular location), in conjunction with their great destructive force, virtually precludes structural precautions. The only form of precaution is to build as far away as possible from depth lines in a valley or on a hillside – the potential routes for flash floods. It is also useful to place doors and other openings, through which water can enter, at some decimetres above ground level. While this offers no protection in extreme events, structures at least remain free from damage in moderate flash floods.

The fact that flash floods can occur virtually anywhere and protective structures are simply not economically feasible in many cases makes them an ideal subject for insurance. No other prevention measure against this natural hazard is as cost-efficient as an insurance policy.

While unusual events can catch people unawares and cause untold damage, nature very often just gets on with things. After years without rainfall in the Atacama, flowers that only bloom every five to seven years suddenly burst into life and transformed the desert into a sea of colour.

Fortunate outcome of a monster storm

Category 5 hurricanes that make landfall usually result in catastrophes. Not Hurricane Patricia: a powerful but small storm on the Pacific coast.

Doris Anwender

Mexico

Hurricane Patricia 2015:
US$ 550m

Average annual losses from tropical cyclones (2000–2014):
US$ 1.8bn

Insured losses 2015:
US$ 25m

Average annual insured losses from tropical cyclones (2000–2014): **US$ 410m**

(in 2015 values)

The North Pacific experienced an unusually active hurricane season in 2015, with Hurricane Patricia setting new records on 23 October. When it made landfall, it was the most powerful hurricane in the eastern Pacific since records began, and one of the strongest hurricanes ever registered worldwide. However, thanks to a combination of fortunate circumstances, damage was moderate.

Patricia was able to draw its energy from the waters off the coast of Mexico, which had warmed significantly due to the prevailing El Niño conditions. Small differences in wind speed between sea level and higher levels in the atmosphere also favoured the development of tropical hurricanes in the region. As a result, the ten category 3, 4 and 5 hurricanes that developed in the eastern Pacific in 2015 easily exceeded the long-term annual average of 4.1 between 1981 and 2010. Prior to Patricia, the last time that a category 5 hurricane formed in this ocean basin and made landfall was back in 1959.

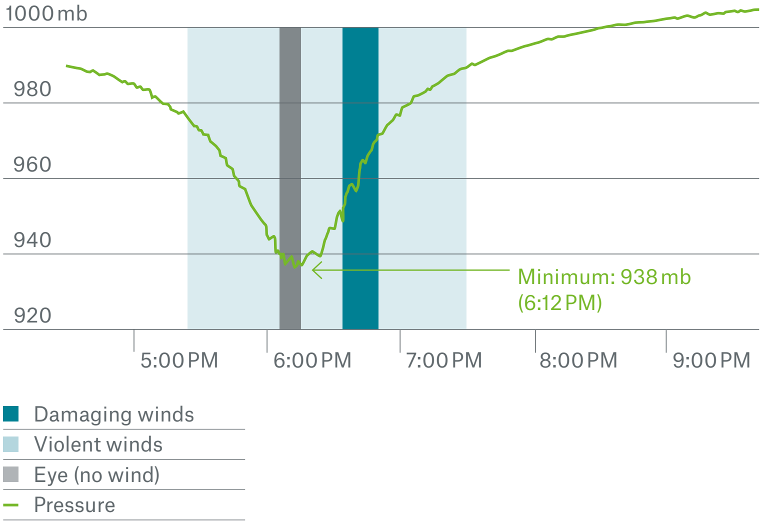
Peak gusts of 400 km/h

Patricia originated on 20 October 2015 with the development of a tropical depression roughly 300 km south of the Gulf of Tehuantepec in southern Mexico. The low pressure area moved in a west-northwesterly direction parallel to the coast, and by 22 October had already intensified to a category 1 hurricane. Over the next 15 hours, Patricia underwent an explosive intensification, and in the night of 23 October wind speeds for a category 5 hurricane (the highest category) were recorded.

Because of the exceptionally warm ocean temperatures of 31°C and the weak wind shear, the storm quickly gathered strength over the next twelve hours, to the extent that peak gusts of around 400 km/h are likely to have been reached during this period. The maximum one-minute sustained wind speed was estimated at a record 325 km/h. Approximately 24 hours later, a slightly weakened Patricia made landfall close to Cuixmala in the Mexican state of Jalisco. The US National Hurricane Center estimated the hurricane's peak wind speed at 270 km/h (one-minute sus-

In the eye of the storm

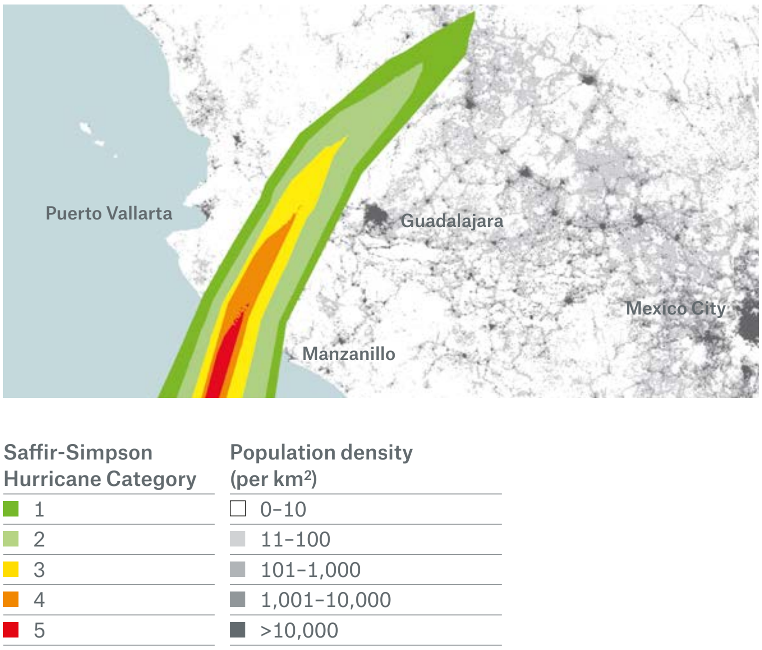
Fig. 1: Pressure (green line) and wind speed of Patricia as it passed through the community of Emiliano Zapata (close to the point of landfall)



Source: Munich Re, based on J. Morgermann & E. Sereno: iCylone chase report

Patricia makes landfall

Fig. 2: The area hit by Patricia's storm field was sparsely populated, as it missed the busier towns of Puerto Vallarta, Manzanillo and Guadalajara.



Source: Munich Re; Population density: LandScan (2009)TM, UT BATTELLE, LLC on behalf of the U.S. Department of Energy

tained), with gusts of up to 340 km/h in the Chamela-Cuixmala Biosphere Reserve.

The hurricane quickly weakened due to the influence of the near-coastal mountains, and dissipated within 24 hours over the mountains of central Mexico. The remnants of the storm briefly intensified a rain system over the south of the USA, but without any major impact.

Little damage despite category 5

The reason Patricia caused so little damage in Mexico despite its record wind speeds is primarily because it was relatively small in size. It may even be the least damaging category 5 tropical storm ever to make landfall in the western hemisphere. The diameter of the total wind field with at least hurricane wind speed was only around 200 km. Similarly, the diameter of Patricia's eye, on whose wall the strongest winds and therefore the greatest damage occurred, was extremely small at less than 20 km.

There was also the fact that Patricia moved at approximately 23 km/h, an advance speed that is above the average for these latitudes. This reduced the time in which the hurricane could develop its maximum destructive potential. The peak wind speeds that were found in Patricia's rear eyewall lasted for only 17 minutes (Fig. 1). The precipitation field also passed rapidly by, so that there was very little flooding. Despite this, the Mexican National Water Commission did record daily rainfall of 300 mm in some places.

Patricia's narrow wind field passed over an area that was relatively sparsely populated, sparing almost entirely the tourist city of Puerto Vallarta to the north, and the port of Manzanillo to the south (Fig. 2). Another reason the feared catastrophe did not materialise was because the government had ordered evacuations at an early stage and residents had been brought to safety.

Wind power meets fossil fuels: Patricia was an enormously powerful hurricane. Fortunately, it hit a relatively small and sparsely populated area.

In the regions affected, for example in the community of Emiliano Zapata, there was the usual pattern of severe wind damage: houses collapsed, roofs were torn off, concrete power poles snapped, and trees were uprooted or split in two. The insured loss was US$ 25m with an overall loss of US$ 550m.

Storm size often more important than intensity

Patricia is a good example to illustrate that it is not just the maximum wind speed or the category that is important when assessing a hurricane. If factors like the size of the storm and the dimensions of the eye are ignored, a false picture of the actual risk situation can quickly result. Wide-area storms, such as Ike, for example, which struck Texas in 2008 as a category 2 hurricane, and Sandy, which was only just at hurricane force as it passed over New York in 2012, caused many times the amount of damage that Patricia left behind.

The influence of coastal topography is another aspect that should not be forgotten. In the cases of Ike, Sandy, and also with Katrina (2005), a large part of the damage came from the storm surge that formed as a result of the hurricane. Along the coast of Mexico, on the other hand, the ocean floor falls away sharply, preventing the development of a high storm surge, and the enormous waves that resulted from Patricia's extreme wind speed smashed harmlessly against the steeply rising coastline.

It could have been much worse

The small and relatively sparsely populated area, the rapid passage of the storm, and the unfavourable conditions for a storm surge clearly prevented much higher losses occurring. This is illustrated by a comparison with Hurricane Odile, which made landfall in 2014 in Baja California. Odile was only category 3, but struck a region with a large number of luxury resorts, causing insured losses of over US$ 1.2bn. From this, we can only imagine what destruction a hurricane of Patricia's strength could have wreaked in Puerto Vallarta, one of Mexico's leading tourist centres. In short, we can say that Mexico had a lucky escape with Hurricane Patricia.

Golden State aflame

Drought conditions in California over the past four years – the warmest and driest period in its recorded history – have elevated the wildfire hazard to extreme levels. The dry conditions fuelled several large wildfires in the state during this period, but all occurred in remote, sparsely populated areas with little human habitation or property exposure. Unfortunately, this pattern would change in September 2015, when two large conflagrations – the Valley Fire and the Butte Fire – broke out near populated areas of northern California. By the time they were extinguished, the fires had become two of the most damaging on record in the state.

Mark Bove

California
Area burned 2015:
364,000 ha
Average area burned in the period 2003–2014: **234,000 ha/year**

No end to the rain deficit

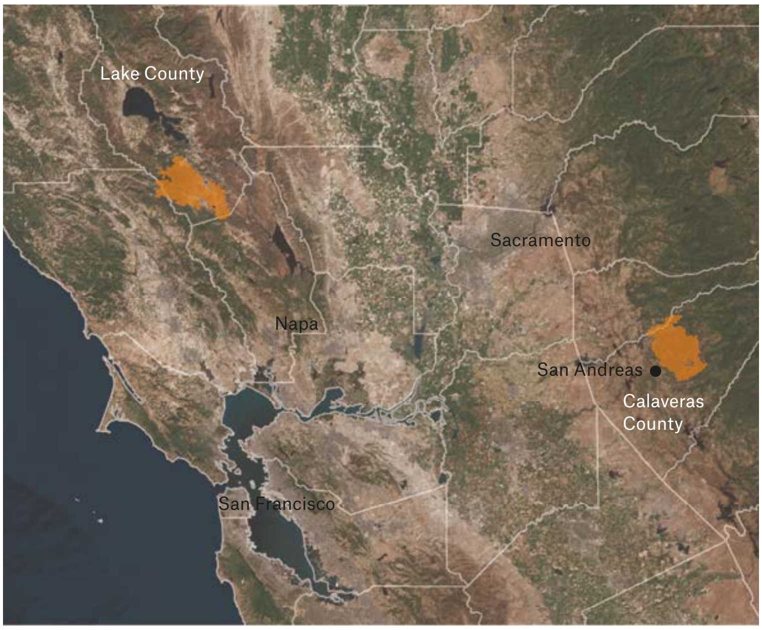
Drought conditions in California continued to worsen during the first half of 2015. Los Angeles only received about 100 mm of rainfall over this period, about 170mm below normal. Further north, the cities of Sacramento and Fresno, in the heavily agricultural central valley, saw half-year rainfall deficits of 170 mm and 120 mm respectively. And after four years of similarly below-average rainfall across the state, some indices of drought intensity indicate that the current drought in California was the worst since the 1840s.

One of the most dire effects of the continuing drought is its impact on the Sierra Nevada snow pack, the source of most of the state's fresh water during the dry summer season. The water content of the snow pack was decimated by another year of drought, dropping to just 5% of its normal amount, eclipsing the previous record low of 25% set in 2014. The lack of snow pack, combined with significant depletion of available ground and surface water, led to the first state-wide water restrictions in California's history.

Droughts increase wildfire hazard

Large wildland fires typically require two meteorological ingredients: dry conditions and high winds. Years of extreme drought conditions in California created exceptionally hot and dry conditions, turning brush, chaparral and forests across the state into tinder boxes. The second ingredient, high winds, can arise from several different meteorological sources. Most large historical wildfires in California have been associated with so-called "Santa Ana" wind events. These occur when high pressure over the western United States causes dry, easterly winds from inland deserts to be funnelled through mountain passes, causing an increase in velocity. Furthermore, air temperatures rise considerably as Santa Ana winds descend towards the coast due to adiabatic heating, resulting in hot, dry conditions and the potential for wind speeds in excess of 140 km/h. Although Santa Ana wind events are more commonly associated with wildfires in southern California, similar downsloping wind events can occur in northern California as well.

"Wild fires"



■ Fire area
▨ County boundaries

Source: Munich Re, based on data from the California Department of Forestry and Fire Protection, and Esri, World Imagery (satellite image)

However, Santa Ana wind conditions were not present during the Valley and Butte fires. Instead, the fires took advantage of both terrain and copious amounts of fuel to create their own wind. As wildfires heat the air around them, the air expands and begins to rise, creating a localised area of low pressure. The low pressure forces air to be sucked in, providing more oxygen for the fire to grow. This, combined with very low humidity and large amounts of dry fuel available, caused the fires to grow quickly, lowering the pressure further and ultimately generating winds that exceeded gale force. Terrain can help exacerbate this phenomenon as well, as fires tend to race quickly uphill, and hills can funnel winds into a narrow area, increasing velocities.

Large fires in northern California

The larger of the two fires, the Valley Fire, was ignited on 12 September north of the Napa Valley winemaking region. The fire rapidly spread out of control, and grew to 40 km^2 in size in less than six hours and 200 km^2 by the following day. Over 10,000 residents of the county were ordered to evacuate the rapidly growing fire area. But several small towns in the path of the fire were largely destroyed by the advancing flames.

Comparison of major US fires

The two 2015 fires are among the largest and most destructive in US history. The table below shows the ten most destructive fires based on the number of buildings damaged or destroyed (losses in original values).

Name	Month/ year	State counties affected	Area burned (ha)	No. of buildings burned*	Economic losses in US$ m	Insured losses in US$ m	Fatalities
Oakland Hills	10/1991	Alameda, CA	647	2,900	2,500	1,700	25
Cedar	10/2003	San Diego, CA	110,579	2,820	2,000	1,060	15
Valley	09/2015	Lake, Napa, Sonoma, CA	30,783	1,910	1,400	960	4
Bastrop	09/2011	Bastrop, TX	13,903	1,673	750	530	4
Witch	10/2007	San Diego, CA	80,124	1,650	1,700	1,300	2
Old	10/2003	San Bernadino, CA	36,940	1,003	1,500	980	6
Jones	10/1999	Shasta, CA	10,603	954	>50	n/a	1
Butte	09/2015	Amador, Calaveras, CA	28,679	818	400	260	2
Paint	06/1990	Santa Barbara, CA	1,983	641	400	265	1
Fountain	08/1992	Shasta, CA	25,884	636	>160	n/a	0

*Includes all structures: houses, barns, cabins, etc.

Source: Munich Re NatCatSERVICE, Cal Fire, PCS

Forest fires and wildfires can destroy vast areas of land in next to no time. Hillsides present no problem, as the fires usually travel even faster uphill.

By the time the Valley Fire was contained on 6 October, over 1,900 structures had been destroyed, including approximately 1,300 homes and 70 businesses, making the Valley Fire the third most destructive wildfire in California history, in terms of total structures burned.

The Butte Fire, which burned in the foothills of the Sierra Nevada mountains east of Sacramento, began three days earlier on 9 September. Similar to the Valley Fire, the conflagration grew rapidly, covering an area of 60 km^2 in just a few hours and 130 km^2 by the next day. The local terrain hampered firefighting efforts against the blaze, and for a period of time the town of San Andreas, the county seat of Calaveras county, was evacuated due to the fire threat. Although the town of San Andreas remained unscathed, the Butte Fire destroyed 475 homes and 343 outbuildings before being contained on 1 October.

Insurance impacts and underwriting lessons

It is estimated that the Valley and Butte fires collectively caused US$ 1.8bn in overall losses, of which US$ 1.2bn was insured, with the Valley Fire making up about 80% of the above totals. The fires were the most damaging in California since the 2007 Witch Fire in San Diego (US$ 1.5bn insured loss, all values in 2015 dollars), and the worst in northern California since the Oakland Hills firestorm in 1991 (US$ 3bn insured loss). As with most wildfires, the majority of insured losses from the Valley and Butte fires were from residential buildings and automobiles. Although there can be exceptions, large commercial losses due to wildfire tend to be limited, as the majority of large commercial properties are located in urbanised areas, not along the wildland interface. Some exceptions to this rule are small, “main street” type businesses, “big box” retail stores that follow residential development into wilderness areas, and vacation resorts in forested regions.

Major wildfires that cause significant amounts of property damage are much less common in northern California than in southern California. Several factors drive this difference in wildfire frequency. Northern California, in particular the densely populated San Francisco Bay region, typically receives more precipitation than Los Angeles or San Diego, reducing the hazard. Nor does northern California see as many Santa Ana wind events as southern parts of the state. From a socio-economic perspective, rugged terrain around San Francisco bay limits developed areas to narrow strips along its perimeter. Comparatively, the terrain in coastal southern California is more conducive to suburban and exurban sprawl, and has more areas of dense exposures near the wildland-urban interface.

Due to the rapid speed and size of major wildfires, losses tend to be binary in nature: either a building survives with only minor damage or is completely destroyed. This occurs because the fires are fought with limited resources on rugged terrain that makes firefighting difficult. Many locations become impossible to reach or protect during the fire, and ultimately decisions must be made to triage the situation and prevent the fire from spreading to additional populated areas. But even within the burned area, not all buildings are destroyed. Many structures survive intact, but typically have some level of smoke damage.

A continued dry future for California

A strong El Niño event brought above-average precipitation to California during the winter of 2015–2016, bringing short-term relief to the drought and fire-stricken state. However, it is unclear whether the precipitation will completely alleviate drought conditions or only reduce the drought’s severity. Furthermore, excessive amounts of rainfall in a short period of time may act to destabilise hillsides recently affected by the fires, increasing the landslide and mudslide hazard within the burn area.

Looking further into the future, insured losses from large wildfires in the American West are expected to continue to increase in frequency and severity. This increase is primarily being driven by the continued construction of new homes and businesses within the wildland-urban interface and increasing values of both real and personal property. Federal and state budgets for fighting wildfires also tend to be underfunded, limiting the ability of firefighters to protect as much property as possible.

However, environmental conditions are also contributing to the increased wildfire risk. Warming temperatures, in part due to anthropogenic influences, are extending the wildfire season, as well as causing earlier snowmelts that reduce the amount of groundwater and soil moisture available to plants and increase the amount of fuels during peak wildfire season. The heat and recent drought conditions have also stressed trees, making them more vulnerable to disease and insects, such as the invasive pine bark beetle that has killed off over an estimated 12.5 million trees in the state. And more wildfires are likely in the future as California’s climate continues to become drier over time.

Expect the unexpected:
Natural disasters in Australia and New Zealand

Australia and New Zealand are exposed to all kinds of natural hazards: floods, cyclones, hailstorms, bushfires, earthquakes and volcanic eruptions.

The scientific facts and economic impacts of the different natural hazard events in this part of the world are summarised in our brochure “Expect the unexpected” and presented in detail on our website:
www.munichre.com/auznz-natcat

NOT IF, BUT HOW

Munich RE

Catastrophes that made history

1815

2015 was the anniversary year of a number of major natural catastrophes that all have a special place in history for one reason or another.

200 years ago
1815
In the largest volcanic eruption ever recorded in human history, Mount Tambora on the Indonesian island of Sumbawa ejected 140 gigatonnes of lava and claimed the lives of 71,000 people. The following year went down in history as the "year without a summer", and was accompanied by famine throughout Europe.

100 years ago
1915
On 13 January, an earthquake in the Abruzzo mountains in central Italy virtually wiped the town of Avezzano from the map. A single building was left standing and over 11,000 (85%) of the town's 13,000 inhabitants lost their lives. Following the disaster, discussions began for the first time on prevention measures and civil defence.

50 years ago
1965
At the start of September, Hurricane Betsy swept across the Gulf of Mexico and the southern states of the USA. It was the first weather event to cause insurance losses of over US$ 500m.

1915

1965

1975

1995

40 years ago
1975
Torrential rain over the Henan lowlands in China led to the failure of more than 60 dams and resulted in a rain-related flood catastrophe on a scale that had never been seen before. A total of 26,000 people drowned, and a further 145,000 died from disease and starvation.

30 years ago
1985
Even though the epicentre of the quake on 19 September was over 350 kilometres away on the Pacific coast, the worst damage occurred in Mexico City, where the death toll was 9,500. The soft soil under the city amplified ground motion up to 20-fold, a phenomenon that has since been known as the Mexico City effect.

20 years ago
1995
The Kobe earthquake on 17 January was the first event in history to produce overall losses of US$ 100bn. It had repercussions around the world as it revealed the vulnerability of the global economy to major catastrophes.

10 years ago
2005
At the end of August, Hurricane Katrina devastated large parts of the US Gulf Coast and left New Orleans under water. With US$ 125bn in overall losses, Katrina was the costliest weather event ever, while the insured losses of US$ 60.5bn made it the most expensive event ever for the insurance industry.

1985

2005

Satellites Supercomputers Statistics

Petra Löw

Munich Re's Geo Risks Research unit engages in a wide range of activities. Thinking outside the box is one of the most important attributes for a globally active reinsurer. Innovation, creativity and a wealth of ideas, in combination with detailed expert knowledge, ensure progress and development in the markets.

High-resolution satellite data have been used for many years to assess loss events in the post-event appraisal process. New satellite and analysis techniques can greatly enhance practical application and provide prompt, high-quality loss estimates, while at the same time eliminating the need to dispatch an army of loss adjusters to the scene. But the processes used here have to be adapted to the needs of the insurance industry. Our experts are ideally placed to assist with this task, having both the technical background and experience working with these systems.

Being able to model earthquake events and represent them in three-dimensional form opens up new possibilities to gain a better understanding of the extreme forces that are at work in massive earthquakes. Munich Re has launched a cooperation initiative in this fascinating area with the Polytechnic University of Milan.

The intensity of severe thunderstorms has increased in both the USA and Europe over the last few years. Hail, in particular, costs the insurance industry billions each year.

How have loss events worldwide developed over the last few decades, and what are the reasons for this trend? These are topics that Munich Re has been investigating in detail for a very long time. The methods used for this are being constantly refined, adjusted and improved to the state of the art. Any trends and the reasons for them can only be identified and analysed in the context of socio-economic changes in values.

Munich Re's NatCatSERVICE provides a detailed overview of loss events, and concentrates on the analysis of time series. For the first time, all our statistics and analyses from this publication are available in the form of online graphics.

>> Visit our website at: www.munichre.com/topicsgeo2015

The year in figures – Global

Following the record-breaking year of 2011, the figures for 2015 marked the fourth year in a row with low losses from natural catastrophes. Despite the moderate claims burden, thanks largely to the absence of extreme catastrophes, overall losses in 2015 came to US$ 100bn, of which US$ 30bn was insured. Overall losses were below the average of US$ 180bn for the last ten years, and also below the long-term average for the last 30 years of US$ 130bn. Insured losses, on the other hand, were not far short of the loss burden from 2014 (US$ 31bn) and also the long-term average for the last 30 years (US$ 34bn). Some 23,000 people lost their lives in natural catastrophes last year. The figure was three times that of the previous year, which, with around 7,700 fatalities, remains one of the lowest years on record for the number of victims. In terms of the number of events, the trend towards greater and more detailed reporting continued, with the total number further increasing to 1,060 events. The biggest increase was seen in minor loss events, although the figures for these are subject to some uncertainty. On this subject, see the article on page 62, which looks in detail at the question of the comparability of past and current events.

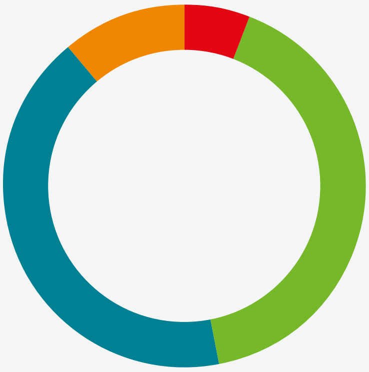
Number of events

Loss events are divided into four main groups: last year, 6% resulted from geophysical events (earthquake, tsunami, volcanic eruption), representing the biggest deviation from the long-term average of 12%. Some 94% were weather-related catastrophes, 41% attributable to storms and 42% floods. 11% were droughts, heatwaves and forest fires, which are designated as climatological events. The distribution of weather events to the different perils is in line with the long-term average.

Fatalities

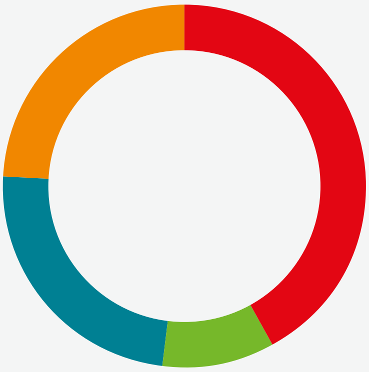
With 23,000 fatalities, 2015 was below the 10-year and 30-year averages. This notwithstanding, there were some extremely serious events. 80% affected the continent of Asia, a substantially higher figure than the long-term average of approximately 70%. The deadliest catastrophe by far was the series of earthquakes that struck Nepal and the neighbouring states of India, China and Bangladesh at the end of April, claiming the lives of some 9,000 people. This places the event among the fifteen deadliest earthquakes since 1980. A heatwave in May and June took the lives of almost 3,700 people in India and Pakistan. In Europe as well, hot, dry weather produced extreme heat stress, from which more than 1,200 people died.

Events: 1,060
Percentage distribution



● Geophysical events	6%
● Meteorological events	41%
● Hydrological events	42%
● Climatological events	11%

Fatalities*: 23,000
Percentage distribution



● Geophysical events	42%
● Meteorological events	10%
● Hydrological events	24%
● Climatological events	24%

*Not including those missing

Source: Munich Re NatCatSERVICE

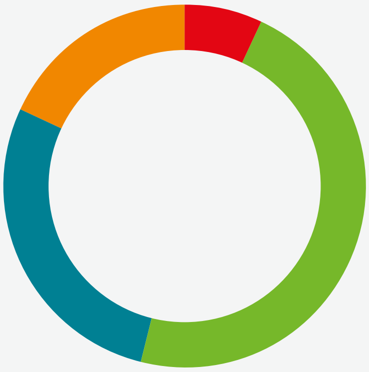
Losses

The aggregate losses from natural catastrophes over the last year amounted to US$ 100bn. 31 events exceeded the billion-dollar threshold. These included events like the earthquake in Nepal, winter storms in the USA, Canada and Europe, typhoons in China, Japan and the Philippines, extensive flooding in the United Kingdom, and droughts on virtually every continent. In a long-term comparison, the claims burden from geophysical events fell from 22% to 7%, while the figure for storms increased from an average of 40% to 47%. Hydrological events, at around 28%, have remained at roughly the same level. Climatological events rose from an average of 13% to 18%. Droughts play a particular role in this context, seriously affecting the agricultural sectors in the USA, Canada, Europe and China.

The Munich Re NatCatSERVICE estimates the claims burden for the global insurance industry in 2015 at approximately US$ 30bn. As with the overall loss amount, this represents the fourth year in succession with a reduction in insured losses, and is the lowest value since 2009. North America accounted for 58% of all insured losses, Europe 19%, Australia and Asia 8% and 12% respectively, and South America 3%. Among the costliest events was a series of winter storms in the USA and Canada that caused insured losses of US$ 2.1bn. Storms in the USA in April and May resulted in insured losses of US$ 1.2bn and US$ 1.4bn respectively. As the year came to an end, Winter storm Goliath notched up insured losses of around US$ 550m, with violent storms, tornadoes, heavy rain and snowstorms in the southwest of the USA. The storm system claimed 45 lives.

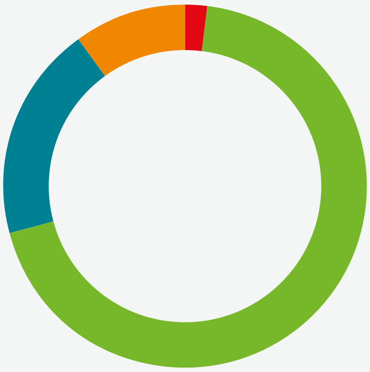
Outside North America, it was Europe and Asia that were the main regions affected. Winter storm Niklas swept through Europe in March/April, and at the end of the year, Winter storms Desmond and Eva also brought widespread flooding to the United Kingdom. Overall, the losses in Europe for the insurance industry amounted to almost US$ 5bn. In August, Typhoon Goni struck Japan, Korea and the Philippines, causing insured losses of US$ 1.4bn. The Australian insurance market was also affected by several large events in 2015, including a major storm with hail and flash floods, and a winter storm in April. Overall losses for 2015 in the continent amounted to approximately US$ 2bn.

Overall losses: US$ 100bn
Percentage distribution



●	Geophysical events	7%
●	Meteorological events	47%
●	Hydrological events	28%
●	Climatological events	18%

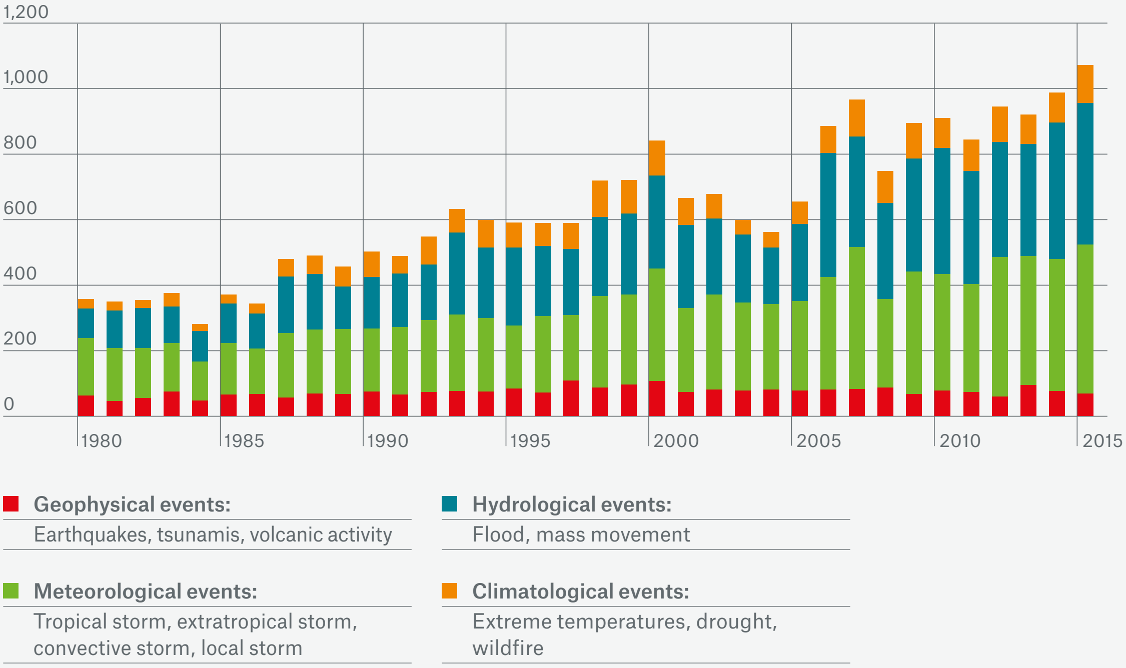
Insured losses: US$ 30bn
Percentage distribution



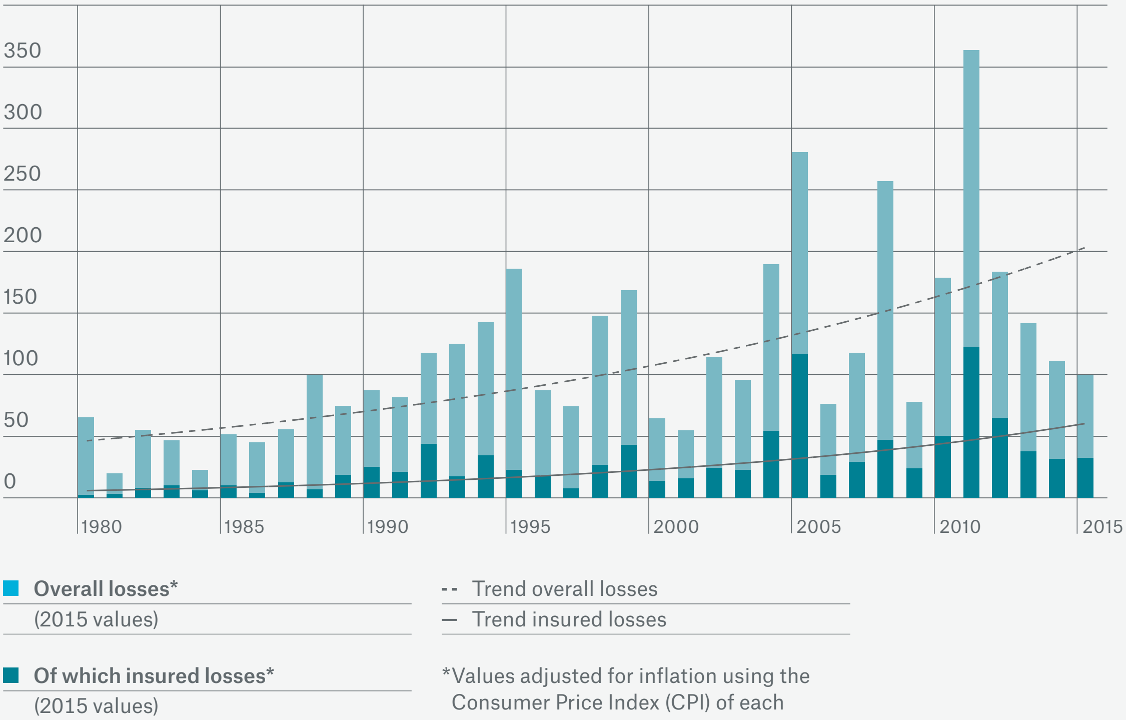
●	Geophysical events	2%
●	Meteorological events	69%
●	Hydrological events	19%
●	Climatological events	10%

Source: Munich Re NatCatSERVICE

Number of loss events 1980–2015



Overall and insured losses 1980 to 2015 (in US$ bn)



*Values adjusted for inflation using the Consumer Price Index (CPI) of each country and taking into account fluctuations in exchange rates

Source: Munich Re NatCatSERVICE

The year in figures – Regional

North America

Around 22% of all global loss events in 2015 were recorded in North America (including Central America and the Caribbean). They caused the deaths of around 800 people. Of the direct overall losses of US$ 30bn, more than half – US$ 17bn – were insured losses. Ten events exceeded the billion-dollar threshold for overall losses, with three of these exceeding US$ 1bn in insured losses. These events included winter storms, severe storms and floods in both the USA and Canada. The total burden from loss events for the USA alone came to US$ 24bn, of which US$ 14bn was insured. Some regions of both the USA and Canada were affected by extreme drought in 2015, which mainly impacted agricultural production and caused overall losses of more than US$ 2bn. The 2015 hurricane season was moderate. Aggregate losses from tropical storms in the Atlantic were only US$ 1.5bn, well below the average figures of recent years.

South America

Approximately 100 loss events were recorded in South America in 2015. Flooding, flash floods and severe storms claimed the lives of 370 people and caused direct overall losses of just under US$ 2bn. There was also a series of smaller earthquakes, and a powerful earthquake in Chile that triggered tsunami waves. The magnitude of the strongest quake measured M_w 8.3, with the epicentre in the province of Araucania. Aggregate losses were US$ 800m, of which US$ 350m was insured.

Europe

Europe accounted for 13% of all loss events worldwide in 2015. Almost 1,600 people were killed, with the heatwaves in the summer months claiming the most lives. The overall loss from all events came to just under US$ 13bn. The insured loss totalled US$ 5.6bn. At the end of March and beginning of April, Winter Storm Niklas caused widespread damage, primarily in Germany but also in other parts of Europe. At the end of the year, Winter Storms Desmond and Eva brought wide-scale flooding to the United Kingdom, causing overall losses of almost US$ 3bn, roughly US$ 2bn of which was insured. There were also small-scale regional events with high losses in 2015. Storms involving heavy rain bring the additional risk of flash floods. Just such a flood occurred at the end of September on the French Riviera, where 20 people were killed. The storm front also passed over Spain and Italy. The insured loss came to a total of US$ 700m. In contrast, eastern Europe and parts of central Europe experienced a very dry year in 2015, with high temperatures and a serious shortage of rainfall. In Romania in particular, but also in Poland and the Czech Republic, a drought seriously affected agricultural production. The overall loss is estimated to be around US$ 1.5bn.

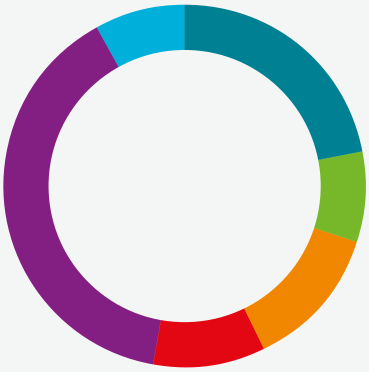
Africa

The African continent was affected almost exclusively by weather-related events in 2015. The most significant of these were droughts,

Loss events 2015

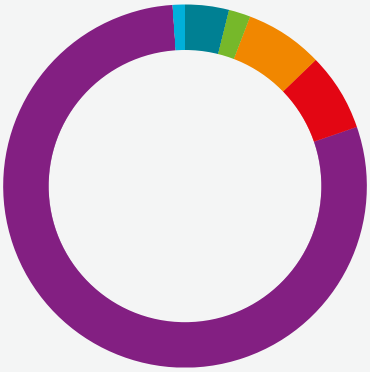
Percentage distribution by continents

Events: 1,060



● North, Central America, Caribbean	22%
● South America	8%
● Europe	13%
● Africa	10%
● Asia	39%
● Australia/Oceania	8%

Fatalities*: 23,000



● North, Central America, Caribbean	4%
● South America	2%
● Europe	7%
● Africa	7%
● Asia	80%
● Australia/Oceania	<1%

*Fatalities do not include famine victims and people missing

Source: Munich Re NatCatSERVICE

floods, severe storms and two tropical cyclones. A total of around 100 loss events were recorded. Overall losses amounted to US$ 3bn, of which only a small portion was insured. Around 1,700 people died, mainly in flooding and flash floods. The costliest events in 2015 were two periods of drought – one in southern Africa and the other in Ethiopia. The overall loss for these two events came to US$ 2bn.

Asia

Asia accounted for 39% of all loss events recorded worldwide, for 80% of global fatalities, and 44% of overall losses, but only 12% of insured losses. 13 events reached or exceeded overall losses of US$ 1bn. At the end of April, a series of earthquakes rocked parts of South Asia, causing devastation above all in Nepal, where over 500,000 houses and public buildings were destroyed. The overall loss came to approximately US$ 4.8bn and the death toll was 9,000. Bangladesh, China and India were also affected, with an overall loss of almost US$ 500m. From July to November, India was repeatedly afflicted by serious floods. As a result of heavy monsoon rains, many rivers burst their banks. Overall losses were divided between two main events, and came to a total of US$ 5bn. The cost for the insurance industry was approximately US$ 800m. The extremely active typhoon season resulted in losses of US$ 11.5bn. Extensive areas of Asia were also afflicted by droughts and forest fires. Special mention should be made in this context to the forest fires in Indonesia which, exacerbated by the extremely dry conditions and deliberate slash and burn practices, left the region shrouded in smog for months.

Australia/Oceania

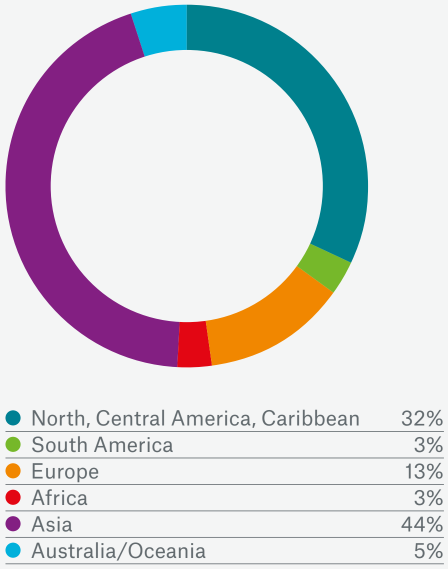
2015 in this region was dominated by weather events, with a total of 80 recorded. The costliest event for the economy as a whole, and for the insurance industry, was a winter storm that struck New South Wales in April, causing losses of US$ 1.3bn. Of this, US$ 730m was insured. Cyclone Marcia made landfall in Queensland. The overall loss burden from natural catastrophes in Australia was US$ 3.9bn, of which US$ 2.1bn was insured. Cyclone Pam swept over Vanuatu, the Fiji Islands and Kiribati. Economic losses from Marcia and Pam came to US$ 1.3bn, while the insured loss was US$ 550m. New Zealand was largely spared major events in 2015, with approximately US$ 200m from minor flash floods and local flooding.

Our latest analyses, charts and interactive maps are available as free downloads from the Touch Natural Hazards section of our website:

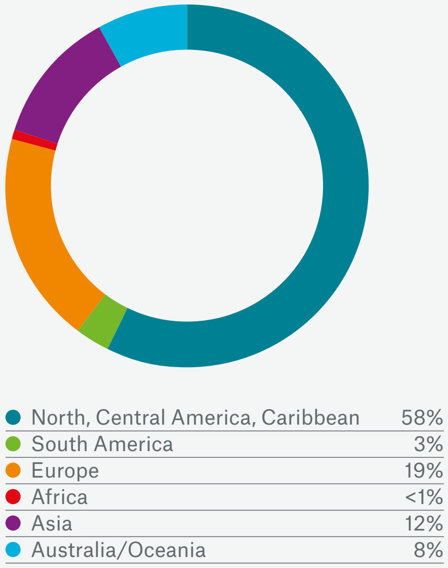
>> www.munichre.com/touch

Loss events 2015
Percentage distribution by continents

Overall losses: US$ 100bn



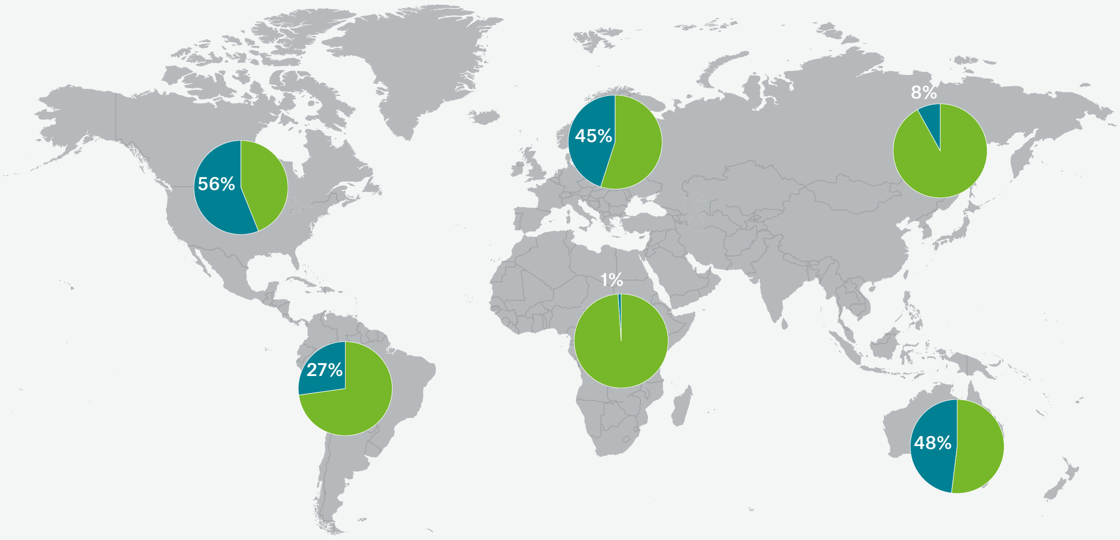
Insured losses: US$ 30bn



Source: Munich Re NatCatSERVICE

Loss events 2015

Insured losses as a percentage of overall losses for each continent

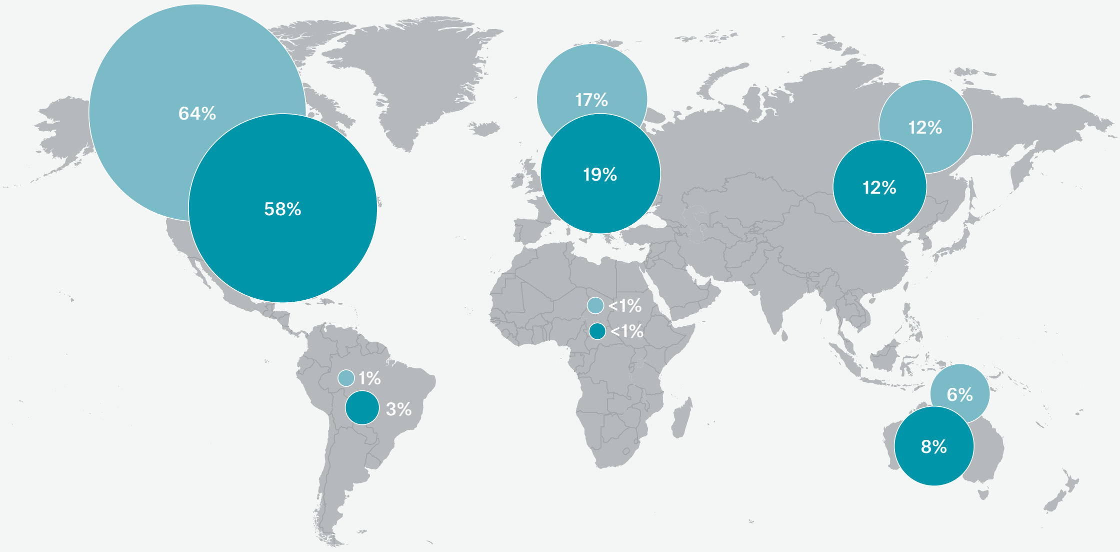


● Uninsured losses

● Insured losses

Loss events 2015 compared to 1980–2014

Breakdown of global insured losses by continent



● Insured losses 2015

● Insured losses 1980–2014*

*Values adjusted for inflation using the Consumer Price Index (CPI) of each country and taking into account fluctuations in exchange rates

Source: Munich Re NatCatSERVICE

The year in pictures

January to March
Floods: Southern Africa
Overall losses: US$ 480m
Insured losses: very minor
Fatalities: 288

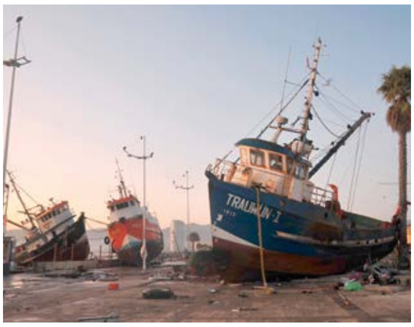
16–25 February
Winter storm: USA, Canada
Overall losses: US$ 2,800m
Insured losses: US$ 2,100m
Fatalities: 40

18–21 February
Cyclone Marcia: Australia
Overall losses: US$ 800m
Insured losses: US$ 400m
Fatalities: 1

25 April
Earthquake: Nepal, China, India
Overall losses: US$ 4,800m
Insured losses: US$ 210m
Fatalities: 9,000

23–28 May
Severe storms, flash floods: USA
Overall losses: US$ 2,700m
Insured losses: US$ 1,500m
Fatalities: 32

May to June
Heatwave: Pakistan, India
Overall losses: minor
Insured losses: very minor
Fatalities: 3,670



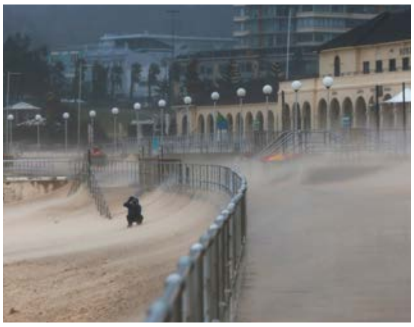
16 September
Earthquake: Chile
Overall losses: US$ 800m
Insured losses: US$ 350m
Fatalities: 15

30 September–6 October
Flash floods: France, Italy, Spain
Overall losses: US$ 950m
Insured losses: US$ 700m
Fatalities: 20

1–5 October
Typhoon Mujigae: China, Philippines
Overall losses: US$ 3,500m
Insured losses: minor
Fatalities: 22

23–26 March
Flash floods: Chile
Overall losses: US$ 1,500m
Insured losses: US$ 500m
Fatalities: 31

30 March–1 April
Winter storm Niklas: Europe
Overall losses: US$ 1,400m
Insured losses: US$ 1,000m
Fatalities: 11



19–24 April
Winter storm: Australia
Overall losses: US$ 1,300m
Insured losses: US$ 730m
Fatalities: 7

June to November
Wildfires: Indonesia
Overall losses: US$ 1,000m
Insured losses: very minor
Fatalities: 19

6–11 September
Floods: Japan
Overall losses: US$ 1,400m
Insured losses: US$ 650m
Fatalities: 8

12 September–8 October
Wildfires: USA
Overall losses: US$ 1,400m
Insured losses: US$ 960m
Fatalities: 4

2–6 October
Floods: USA
Overall losses: US$ 1,700m
Insured losses: US$ 400m
Fatalities: 21

17–27 November
Wildfires: Australia
Overall losses: US$ 200m
Insured losses: US$ 120m
Fatalities: 2

December
Floods: British Isles
Overall losses: US$ 3,000m
Insured losses: US$ 2,000m
Fatalities: 5

Source: Munich Re NatCatSERVICE

Innovative new ways of analysing historical loss events

Jan Eichner, Petra Löw,
Markus Steuer

Past natural catastrophes offer valuable information for present-day risk assessment, provided the loss data can be accurately transferred to the present. The trends in these data are subject to a range of influences that vary according to time and place. These influences need to be filtered out.

Socio-economic developments in values and changes in natural hazards, for example as a result of climate variability and climate change, have a fundamental impact on these trends. Economic factors on the exposure side generally play a greater role in this context. A further component affecting the trend is the increase in the recording of very small loss events due to the steady improvement in reporting, especially in industrialised and emerging countries. In order to assess the different factors, loss data need to be made comparable in terms of place and time on the basis of a global economic assessment.

Inflation adjustment and normalisation

Two similar, but fundamentally different, questions can be asked to assess past loss events according to today's standards: (a) What would event X cost in today's money? (b) What damage would event X cause today?

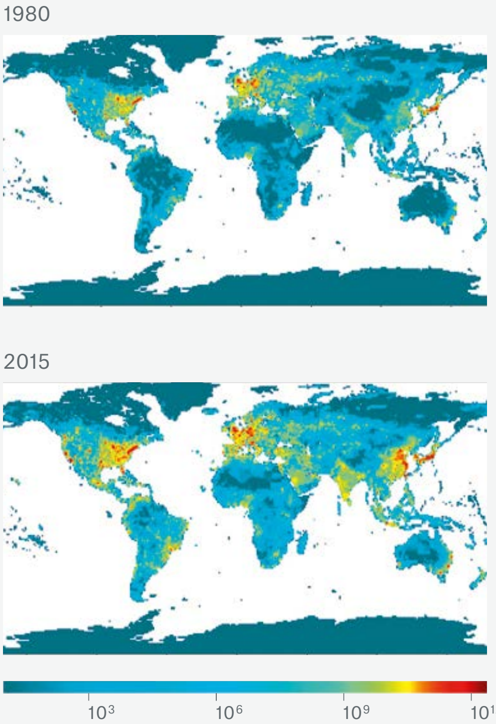
To answer the first question, we simply consider the extent of the damage and look at the development of the monetary value of the loss amount. However, in order to answer (b), the loss must be re-evaluated under present-day conditions, in other words, taking into account any changes in the exposed assets and vulnerability.

In the first case, it is enough to apply inflation to the historically determined loss data with the help of an established price index. It is important to ensure that the index represents the actual development of prices in the region in question and is based on the currency of the country concerned.

To investigate the second question regarding the scale of economic loss that a historical event could achieve today, an additional adjustment has to be made regarding the development of values in the area affected. Such an adjustment is known as normalisation. Indexing is the term used if insured losses are being examined and the changes in insurance penetration are taken into account. Macroeconomic data such as gross domestic product (GDP) have become the established economic reference values for the normalisation of loss data (see Topics Geo 2012).

Tracing economic hotspots

Fig. 1: Gross domestic product (GDP) as a proxy for the changes in values, distributed on a 1°x1° grid for the years 1980 and 2015. The darker the shade of red in a cell, the greater its contribution to a country's GDP (measured in nominal US$).



Source: Munich Re, based on the World Bank

Income determines catastrophe class

The classification of a natural catastrophe depends on where it occurs. If the World Bank attributes a country to a low-income class (IC), the highest catastrophe level is already reached with losses of US$ 100 million or more. In the case of rich countries, the value needs to be 30 times greater. The number of victims also plays a decisive role.

Cat class (CC):	0	1	2	3	4
IC high	≥0	≥3	≥30	≥300	≥3,000
IC upper-middle	≥0	≥1	≥10	≥100	≥1,000
IC lower-middle	≥0	≥0.3	≥3	≥30	≥300
IC low	≥0	≥0.1	≥1	≥10	≥100
Fatalities	0	≥1	≥10	≥100	≥1,000

Loss thresholds in US$ m

Source: Munich Re

These data are available in high quality and are easy to access. The historical loss amount is multiplied by a normalisation factor that is equal to the ratio of current GDP to the GDP at the time of the historical event. Assuming that this GDP ratio accurately reflects the local changes in values, we can calculate the anticipated loss amount that would result if the event were to occur again today. Influences resulting from a change in vulnerability are not factored in.

New approach: Hazard-specific cell-based normalisation

If the GDP data relate to an entire country or a region that is significantly larger than the area affected by the natural catastrophe, one cannot automatically assume a proportional correlation between national GDP and changes in value in the area affected. To smooth this distortion, we have developed a method that we call hazard-specific regionalised normalisation. A global 1°x1° grid forms the centrepiece of this normalisation version. The annual proportion of the country's GDP is calculated for each cell, beginning with the year 1980. A weighting is performed using the population trend in the cell, in some cases interpolated or extrapolated (Fig. 1). The special feature of this approach is that each individual cell contains a time series with the GDP share attributable to it since 1980. Cells that cross national borders are recorded several times, along with their corresponding share.

NatCatSERVICE, Munich Re's global loss database, includes the geographic coordinates for the locations and regions that are worst affected in a loss event. These form the basis for what is known as the loss footprint for an event. In addition, each natural hazard – whether thunderstorm, flash flood or winter storm – has its individual geographic extent, which is known as the hazard footprint.

Footprints

A winter storm normally covers an area many times bigger than that of a thunderstorm. In turn, the geographical extent of a thunderstorm is typically much bigger than that of flash floods following torrential rain. The aim is to achieve a kind of geometric compromise between the hazard footprint and the loss footprint on the 1°x1° grid.

An individual normalisation footprint is obtained for each event from the geocoded loss-location information and the hazard-specific selection pattern derived from it. This specifies which cells should be used to calculate the normalisation factor. Munich Re's NatCatSERVICE has calculated the typical footprints for five basic types of loss event. When sorted according to extent, these are:

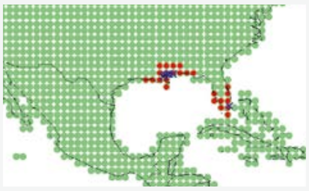
1. Small-scale events (including flash floods, landslides and lightning strikes)
2. Local events (including severe thunderstorms, earthquakes, bushfires and forest fires)
3. Flood events (riverine floods)
4. Coastal events (tropical cyclones, storm surges, tsunamis)
5. Large-scale events (including winter storms, droughts and heatwaves)

Some of these hazard-specific cell-selection patterns can be seen in Fig. 2. These graphs are available for the 28,000 or so country-based events since 1980 that are included in the NatCatSERVICE.

Footprints of different natural catastrophes

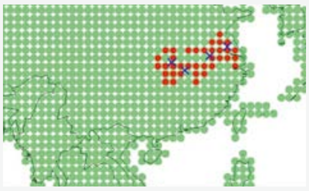
Fig. 2: Each natural catastrophe has its own loss pattern, known as the loss footprint. Needless to say, this is larger for storms like Hurricane Katrina in 2005 or winter storm Martin in 1999 than it is for local thunderstorms.

Hurricane Katrina in the USA – 2005



Winter storm Martin in France and Spain – 1999

Floods in China – 1991



Severe thunderstorms in Europe – 2001

Source: Munich Re

To determine the particular normalisation factor, we take the sum of the cell values of the whole footprint for the year in which the event occurred, and compare this value with the sum of the cell values of the footprint for the current year.

Fig. 4 (page 66, right-hand column) shows the development in global annual totals for nat cat losses for the nominal, inflation-adjusted, and cell-based normalised losses over the period 1980–2015 for all types of natural hazards. A distinct flattening can be seen in the development of the normalised loss amounts compared with the increases in nominal and inflation-adjusted values. However, this flattening needs to be interpreted with caution, since quite different trends can emerge on a regional and hazard-specific level, which are then lost in the global analysis.

Two examples of loss amount trends for severe thunderstorm losses in North America and flood losses in Europe are displayed in Fig. 3. The increase in severe thunderstorm losses in normalised application is in line with meteorological observations made in the USA during the same period: an increase in intensity of severe – and consequently costly – thunderstorms with tornado outbreaks and severe hail. When assessing the diminishing trend in normalised flood losses in Europe, it must be remembered that a lot of money was invested in improving protection measures immediately after the devastating floods of 2002. These measures have borne fruit: despite the similar hydrological scale, the loss from the 2013 flooding was significantly below the normalised value for the 2002 event.

Number of events has a negligible impact

The normalisation method described here allows us to establish how the risk for any region has changed over time in terms of the loss amounts. As well as economic development, a further criterion for the risk assessment is that the recording of loss events must have remained constant over the period under consideration. However, this is not the case for most regions. For example, the internet has made a substantial contribution to ensuring that smaller events in particular are better recorded today than they were 30 years ago. This effect accounts for a substantial portion of the trend in increasing numbers of loss events, as shown in Fig. 4 (left-hand column, top row). However, this reporting trend has no notable impact on the loss amount trend, since annual loss amounts across all types of natural hazard depend on just a few major loss events which have always been recorded.

Improved comparability thanks to differentiated classification

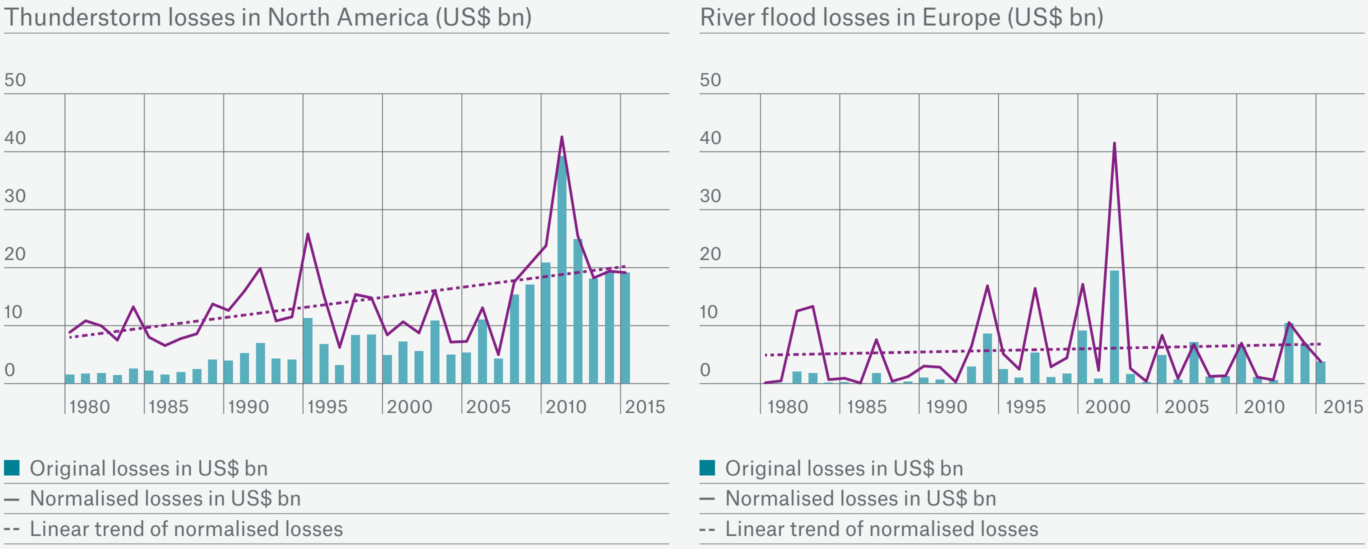
It is important to have sensible graduations between the loss events in order to analyse the influence of small and major loss events on the loss statistics. One way would be simply to apply three globally applicable thresholds to the normalised loss data (such as 10, 100 and 1,000 million US dollars), in order to organise the events according to the degree of economic severity. But such a global distribution fails to take account of the fact that a loss of US$ 100m is of quite different significance for countries like Haiti or Bangladesh than it is, say, for the USA or Germany. Allowance can be made for these geographic and economic differences by spreading out the thresholds. The four income classes used each year by the World Bank to define every country can be adopted for this purpose. With each income class, the per capita gross national income increases by a factor of between 3 and 4. The metric proposed for classifying catastrophes in the table on page 62 uses this distribution, whereby the degree of severity of an event, as measured by the loss amount, depends on the particular income group. The number of victims is also incorporated into the measurement of the degree of severity.

The normalised loss amount and income category for a country in the current year, in conjunction with the number of victims, provide the catastrophe class. This procedure represents the most robust method of making the economic influences of natural catastrophes comparable in terms of time and location.
When this catastrophe class metric is applied to all loss events in the NatCatSERVICE database, it becomes clear that only the severe events in a particular year are of significance for the development of loss amount statistics (Fig. 4, bottom row, right). The growing number of small loss events resulting from improved reporting, particularly in recent years, has a negligible influence on loss amount statistics (in contrast to the frequency statistics). Even if the number of small loss events recorded is many times higher, the influence on the total loss amount remains insignificant.

After normalisation and filtering using the catastrophe classes, what remains are residual trends and fluctuations. Attributing these then shifts the focus to changes in vulnerability (for example improved flood protection, stricter building codes or more efficient early warning systems), as well as to changes on the natural hazards side (decreases and increases in the intensity and frequency of natural hazard events). To make a further distinction here, we need to analyse regionalised and hazard-specific statistics. The method presented here is a suitable basis for this kind of further analysis.

Examples of regional loss amount trends

Fig. 3: Nominal and normalised annual losses from severe thunderstorms in North America (left) and flood losses in Europe (right). Whereas there are meteorological reasons for the increase in the normalised losses from severe thunderstorms, protection measures that have been implemented must also be taken into account in explaining the trend in flood losses.



Thunderstorm losses in North America (US$ bn)

River flood losses in Europe (US$ bn)

Source: Munich Re NatCatSERVICE

A comparison between original losses and normalised losses from the most significant events since 1980

The table shows the most destructive events since 1980 after normalisation, and permits a direct comparison between the original loss and the normalised loss. The table reveals two notable effects. In Japan, the normalised losses from the two major earthquakes are less than the original losses, a feature that, apart from Japan's economic stagnation, is largely due to the long-term depreciation of the yen against the US dollar. Another extreme example is China. Some of the largest normalisation effects can be seen here. The extremely strong economic development along China's main waterways and coasts results, as in the case of the eastern China floods in 1991, in a normalisation factor of 24. These examples demonstrate the losses that historical nat cat events would cause today.

Year	Event	Region affected	Nominal original loss (US$ bn)	Normalised loss (US$ bn)
2011	Tohoku earthquake and tsunami	Japan	210	174
2005	Hurricane Katrina	USA	125	167
1991	Eastern China floods	China	6.8	165
2008	Sichuan earthquake	China	85	156
1998	Yangtze floods	China	16	130
1994	Northridge earthquake	USA	44	91
1995	Kobe earthquake	Japan	100	90
1992	Hurricane Andrew	USA and Bahamas	27	82
1988	Spitak earthquake	Armenia and Turkey	14	71
2012	Hurricane Sandy	USA, Carib. and Bahamas	68.5	70

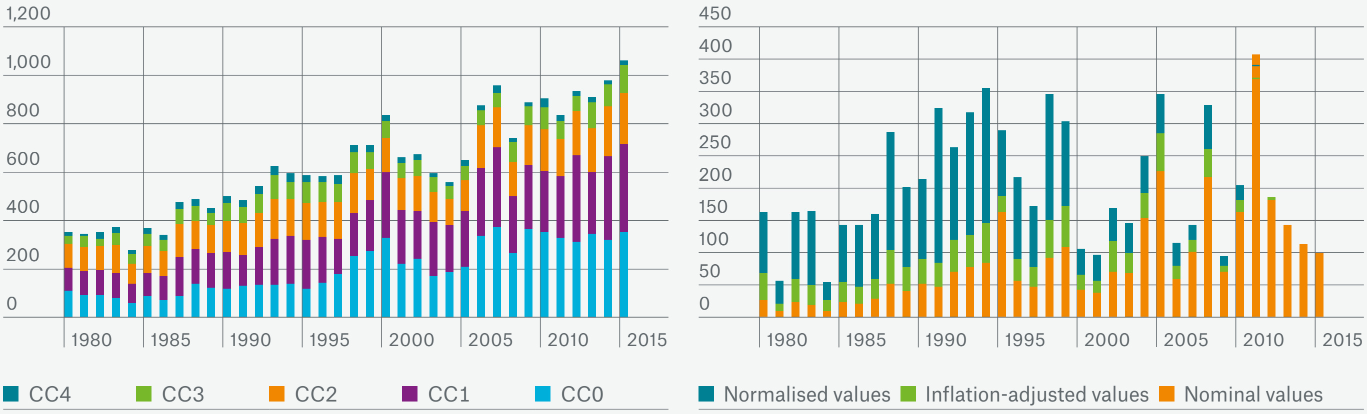
Source: Munich Re NatCatSERVICE

Historical loss events reassessed

Fig. 4: Frequency statistics following catastrophe classification (left) and the accompanying annual amounts for direct overall losses from all loss events (right). This figure's key message: the CC0 events contribute virtually nothing to the overall loss. The amount of overall losses is essentially determined solely by the largest and severest loss events (CC4).

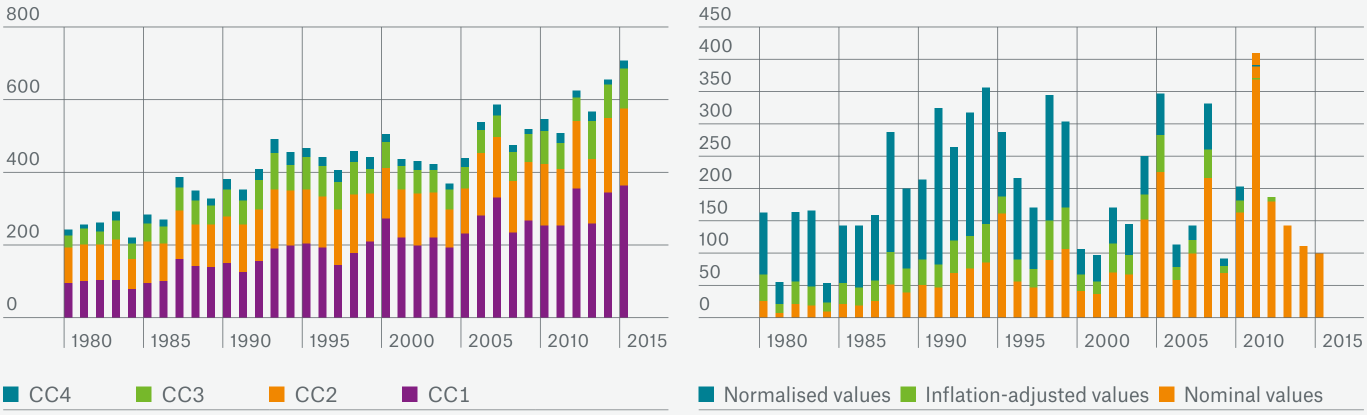
Number of loss events by cat classes CC0–CC4

Annual global overall losses in US$ bn (CC0–CC4)



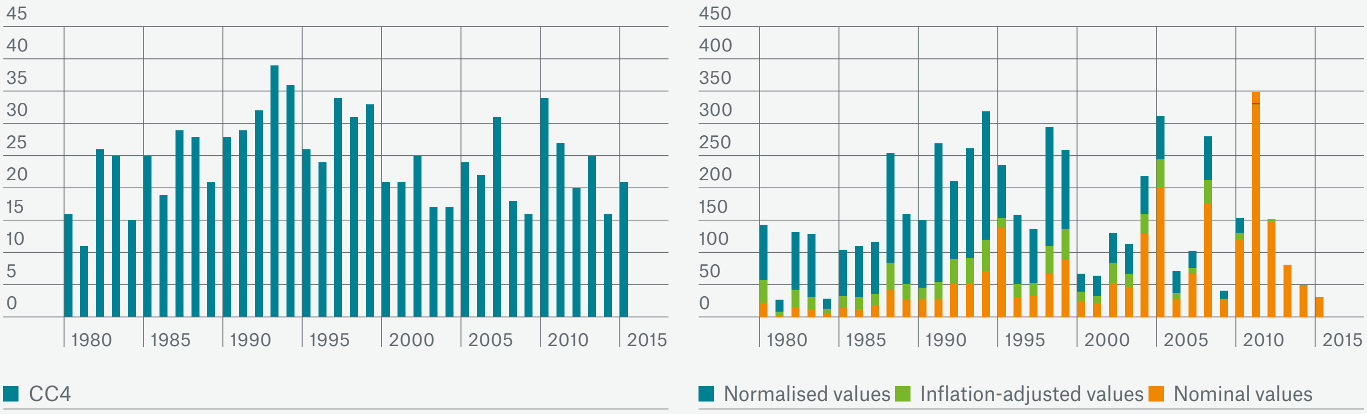
Number of loss events by cat classes CC1–CC4

Annual global overall losses in US$ bn (CC1–CC4)



Number of loss events by cat class CC4

Annual global overall losses in US$ bn (CC4)



Source: Munich Re NatCatSERVICE

Remote sensing with satellites – A new era for risk management

Andreas Siebert

Although satellite images have been available for decades, insurers have been reluctant to introduce them into their risk management. To leverage the full potential of this source of data and information, providers and users need to work together more closely.

The American Landsat programme and the French SPOT series have been providing images from orbit for civil applications since the 1980s. Thanks to the growing number of national and commercial providers in the remote sensing market, interested parties today can call on a variety of satellite systems, for example the European Union's Copernicus project. Seven specially developed satellite missions, the Copernicus Sentinels, form the centrepiece of the project's space component. These generate radar and spectral images for earth observation purposes, and to monitor the oceans and atmosphere.

Besides satellite pictures, images of the surface of the earth are also provided by aircraft and drones at a lower altitude. Whereas satellites are suitable for observing large areas, such as flood areas, the advantages with drones lie in studying smaller sites and industrial complexes.

Resolution – The magic word in the industry

A major benefit of having such a variety of data providers is that temporal resolution has improved significantly in recent years. In the past, a weekly fly-by cycle was the rule. Nowadays, many regions of the earth are overflown on an almost daily basis by at least one system, which then supplies the relevant images. The challenge is to pick out the suitable data from a highly fragmented jungle of providers.

Spatial resolution, in other words the ability to show details, is a key criterion with digital satellite images. The greater the number of grid cells (pixels) that are available to cover the area of interest, the more clearly defined the image will be. Whereas in the past, spatial resolutions in the tens of metres were standard, objects today can be identified in the decimetre range. This is known as VHR (Very High Resolution). With this level of detail, buildings and infrastructure, and even individual vehicles, can be clearly identified. The downside of this is that it involves a significantly larger volume of data, although this should pose no problem, at least for the analysis of smaller areas.

As well as temporal and spatial resolution, spectral resolution plays a key role in remote sensors. This depends on the electromagnetic radiation wavelengths (e.g. visible light, near or far infrared) that are covered by the sensors. Satellites usually take pictures on different spectral channels. If they cover the visible light spectrum, the resulting image is similar to the view from an airplane. In contrast, infrared channels can provide information on the state of vegetation or plant vitality. This can be very useful for agricultural insurance and

Earth observation data (satellites, aerial images, drones): Some examples of added value for the insurance industry

Earth observation raw data

→

Risk-related image processing

- Event footprints
- Settlement areas
- Agricultural areas
- Digital elevation models
- Building classes
- Vegetation index
- Drought areas
- Forest fire detection
- Thermal leaks
- Monitoring (before/afterwards)
- 3D modelling

→

Combination with insurance data

- Exposure (market/client)
- Vulnerability
- Scenarios
- Risk locations
- Accumulation zones
- Hotspots
- Losses
- Industrial complexes
- Insurance penetration

→

Added value for risk management

- Visualisation
- Risk modelling
- Risk assessment
- Loss estimation
- Accumulation control
- Fraud detection
- Market potential
- Innovative product development

Sources for satellite images: GAF AG, © Antrix, GAF, Airbus, DigitalGlobe for estimating harvests. Thermal images show differences in temperature and are used to study climate-related issues or to monitor thermal leaks at power plants, for example.

The various spectral channels also include radar images using the SAR principle (Synthetic Aperture Radar). The key advantage with these is that they are independent of weather conditions, since they allow images to be taken under the cloud cover.

Bridging gaps

Satellite data form part of what is called spatial data, because they include georeferencing. For this reason, they are a prime source of data for the analysis of natural hazards, and for short-term weather and long-term climate monitoring. Satellite data are also used in the Munich Re client and service tools, primarily as a visualisation and orientation background, such as those from Google Earth. This program has been available since 2005 and is an integral part of many map applications today. NATHAN (Natural Hazards Assessment Network), the Munich Re hazard assessment tool, also relies on such visualisation techniques. Somewhat less “visible” is the satellite information contained in complex data analysis, as for example in the NATHAN global natural hazard maps. This is also true of our hailstorm zones, wildfire map, and detailed flood zones, among others. The latter use high-resolution digital terrain models derived from satellite images.

Satellite data first found their way into underwriting or risk management through post-event or post-disaster applications. They make use of up-to-date images to determine the area affected, and ideally even the loss intensity. Using geoanalytical procedures, these footprints can then be compared with a company’s own exposure. This facilitates prompt and realistic loss estimates in property and agricultural insurance.

Today’s improved temporal resolution also helps provide imaging technology support for monitoring tasks. Applications are also conceivable in the engineering sector, for example to observe the progress of construction projects or the development and status of infrastructure installations.

Formulate requirements precisely

In the past, the dialogue between risk managers and the data or service providers has not always been entirely successful. Part of the reason for this was that each side had little understanding of the other, and insufficient attention was paid to the requirements of the risk managers on the one hand, or to the technical limitations of the providers on the other. With the advance of big data and data analytics in an increasing number of business sectors, many new providers and start-ups are knocking on doors, offering solutions for the insurance industry.

To ensure successful cooperation, the technical options on the provider side to meet the requirements of the risk managers must first be sounded out. Demands are also placed on the risk experts. They must give clear specifications to the data suppliers in order to make the most of the potential for technical innovation. Requests such as “we need better claims data” are clearly too imprecise in this context, and will invariably lead to disappointment on both sides. Nor should the difficulty be underestimated of the process between receiving the image raw data and ending up with usable underwriting information. In many instances, complex image processing and interpretation methods are involved.

You can contact our team of geodata and satellite experts if you would like to find out more about this subject.

Severe thunderstorms in Europe

Eberhard Faust

In certain regions of Europe, the intensity of thunderstorms has increased over recent years. Prevention is key to keep losses at low levels.

Severe thunderstorms can occur almost everywhere in Europe. A particularly high level of severe thunderstorm activity has been observed in regions of southwestern, central, southern and southeastern regions of the continent. The strongest activity has been recorded in northern Italy's Po Valley directly south of the Alps. There is also a high level of activity directly north of the Alps along an arc stretching from the northern half of Switzerland over southern Germany and into parts of Austria. Further high-incidence regions are at the foot of the Pyrenees, in southeastern Spain, in the area close to the Massif Central in France, and in southeastern Europe in the vicinity of the mountain ranges there.

Severe thunderstorm activity reduces directly above the high mountain regions because, on average, there is less convection due to lower surface temperatures and moisture. Thunderstorm activity progressively declines towards the coastlines in the northern and northwestern regions of Europe. It is true that autumnal flooding losses on the French Mediterranean coast or in northern Italy in the course of a northward atmospheric flow from the Mediterranean are often conditioned by a low pressure system in the western Mediterranean, but these are triggered locally under the influence of thunderstorm cells.

The key loss drivers

Over the last few years, severe thunderstorms in Europe have frequently resulted in insured losses of more than a billion euros, mainly from hail and strong gusts, but also in connection with flash flood events. For example, the severe thunderstorms on 27/28 July 2013 in the north and southwest of Germany cost the insurance industry as much as US$ 3.8bn. In many cases, building losses are sustained because the fall direction of hailstones is pushed away from the vertical by wind, so that they impact on building walls with external thermal insulation, with the result that the thin plaster finish is chipped off down to the reinforcement fabric. Other vertical surfaces, such as façade elements, illuminated advertising and external sun protection systems on the windows, are also damaged in this way. As a general rule, it has been found that roofs and walls, or façade elements in buildings, usually dominate hailstorm loss patterns. Losses to the roof and interior can increase dramatically if rain then penetrates the building through broken roof tiles, invariably in older building stock.

The ten largest normalised insured losses from severe thunderstorms in Europe since 1980

Using the country-specific evolution of GDP as a proxy, past losses were converted as if they had been sustained from the destructible assets existing today (2015 values). Of the ten largest events, seven already feature an insured loss of more than US$ 1bn. Seven of the ten biggest losses have occurred during the last eight years. The annual normalised losses from severe thunderstorms in Europe since 1980 are shown in the online section www.munichre.com/topicsgeo2015.

Date	Event	Affected area	Overall losses in US$ m (2015 values)	Insured losses in US$ m (2015 values)	Fatalities
27–28.7.2013	Hailstorms, severe storms	Germany	5,000	3,800	
7–10.6.2014	Severe storm (Ela), hailstorms	France, Belgium, Germany	3,800	3,000	6
12.7.1984	Hailstorms	Germany (Munich)	5,400	2,700	
28.5–2.6.2008	Severe storm (Hilal), flash floods	Germany	1,800	1,300	3
23–24.7.2009	Severe storms, hailstorms	Austria, Czech Rep., Germany, Poland, Switzerland	2,200	1,300	11
15.6.2010	Flash floods, floods	Southern France	1,600	1,100	27
4–9.11.2011	Floods, flash floods	France, Italy, Spain	2,100	1,100	15
2–3.7.2011	Flash floods, severe storm	Denmark (Copenhagen)	1,500	900	
3–4.10.1988	Flash floods	Southern France	1,400	870	11
3–9.11.1987	Flash floods, landslide	Southeastern Spain	4,400	820	16

Source: Munich Re NatCatSERVICE

Needless to say, as well as damage to commercial and residential buildings, losses in marine and motor insurance are also major contributors to the overall loss, especially where these involve car storage yards or traffic on the roads during busy periods. It is clear that the use of more expensive construction materials and rising repair costs are a major factor in the increasing losses in Europe from severe thunderstorms, and in particular from hailstorms and storm gusts.

The hazard situation is changing

The latest scientific studies suggest that the increase in destructible assets and repair costs are not the only reasons for the shift in loss potential from hailstorm events in Europe: the trends for the frequency and intensity of thunderstorms are also changing. The energetic potential for convective processes is described by the potential thunderstorm energy (CAPE = Convective Available Potential Energy): the thermodynamic properties of the atmosphere and of its lower portion provide information about whether sufficient energy is available for convective processes. The soundings of the atmosphere required for this are carried out at regular intervals at specially established weather stations. A recent study (Mohr and Kunz, 2013) found widespread significant rising trends at these stations for the available potential thunderstorm energy in Europe over the period 1978 to 2009, with particularly pronounced trends in central and eastern Europe, but also in southern France and northern Italy.

Rising moisture content in the lower atmosphere is viewed as the key driver of these increases – a necessary physical consequence of long-term warming: warmer sea surfaces lead to higher evaporation, and for each degree of increase in temperature, the atmosphere in a vapour-saturated environment can have a mass of water vapour that is approximately 7% higher. Vapour-laden air rises in the convective processes that lead to the formation of thunderstorms, as it has a lower specific weight than drier ambient air. In addition, during the water's different phase transitions (gaseous – liquid – frozen), additional thermal energy is released, which in turn accelerates convection. Increased water vapour therefore acts as an energetic propellant for convection. The trends from other convection indices also correspond to these station-based trends for the available thunderstorm energy. At the same time, such variables only provide information on the thunderstorm potential, and not on whether or how frequently this potential actually leads to thunderstorms from trigger mechanisms, such as wide-area lifting processes or fronts.

Increases in kinetic energy of hail

Insurance data, such as the number of days with hail damage and loss figures in excess of specific thresholds, actually show increases in the number of events for the southwest of Germany, on top of the increase in available thunderstorm energy in the region, and other thunderstorm-related variables (Kunz et al., 2009). Observations in France (Atlantic/Pyrenees) using hail pads, which can measure the kinetic energy of hailstones, found substantial increases in the region of 70% in the annual mean value for kinetic energy per hailstorm during the period 1989 to 2009 (Berthet et al., 2011), although there was no trend for the annual frequency of the hail events. Similarly, in northern Italy in the period 1975 to 2009, significant increases of almost 60% were observed in kinetic energy for severe events, i.e. the top 10% (Eccel et al., 2012).

An interesting observation in this context is that the height of the freezing level above ground plays a significant role in the distribution of hailstone size in a hailstorm event, and thus also influences the kinetic energy: the height of the freezing level rises as the temperature increases. Under these conditions, smaller hailstones (approx. <1 cm in diameter) in a storm would melt faster during their descent; for this reason, evaluations of the hail pads for a higher freezing level show corresponding decreases. On the other hand, because of the thicker layer beneath the freezing level in warmer conditions, a pronounced updraught region results in which larger hailstones can form.

Consequently, in this scenario a greater number of large hailstones (approx. >1 cm in diameter) reach the ground. The fact that the average height of the freezing level has increased over the last few years suggests that this process has already contributed to the observed increases in the kinetic energy of hailstorm events and will continue to contribute in the future (Dessens et al., 2015).

Hailstorm events becoming more frequent

On the question of future changes in thunderstorm activity due to climate change, the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, published in 2013, stated the following: "Overall, for all parts of the world studied, the results are suggestive of a trend toward environments favouring more severe thunderstorms, but the small number of analyses precludes any likelihood estimate of this change." (IPCC, 2013, WG I, p. 1087). Reference is made to two studies on the estimation of insured losses: for agricultural insurance in the Netherlands, hail claims covered under outdoor farming insurance are projected to increase by between 25% and 29%, and claims under greenhouse horticulture insurance by between 116% and 134%, assuming a temperature increase of +1°C (Botzen et al., 2010).

According to a joint project undertaken by the German Insurance Association (GDV) and climate research institutions, a 15% increase in the annual claims rate of homeowners' comprehensive insurance due to hail-dominated summer storms has been projected for the period 2011 to 2040, compared with the reference period 1984 to 2008, and an increase of as much as 47% for the period 2041 to 2070. The assumed emission scenario (SRES A1B) and the global warming resulting from it will remain roughly consistent until the 2040s with the path to meet the two-degree limit (Gerstengarbe et al., 2013).

The statement on the sign of the change is more important than the actual percentage figures, which are subject to many uncertainties relating to the models and the greenhouse gas concentration scenarios. Even if humankind manages to meet the two-degree limit, substantial increases should be expected over the next few decades.

Loss prevention is key

For risk carriers, this means that ever greater importance must be attached to efforts to ensure construction materials are more resistant to hailstones, and to promote the use of hail nets and loss prevention efforts across the board. This is because the volume of destructible assets will also increase further along with the potential changes in the hazard.

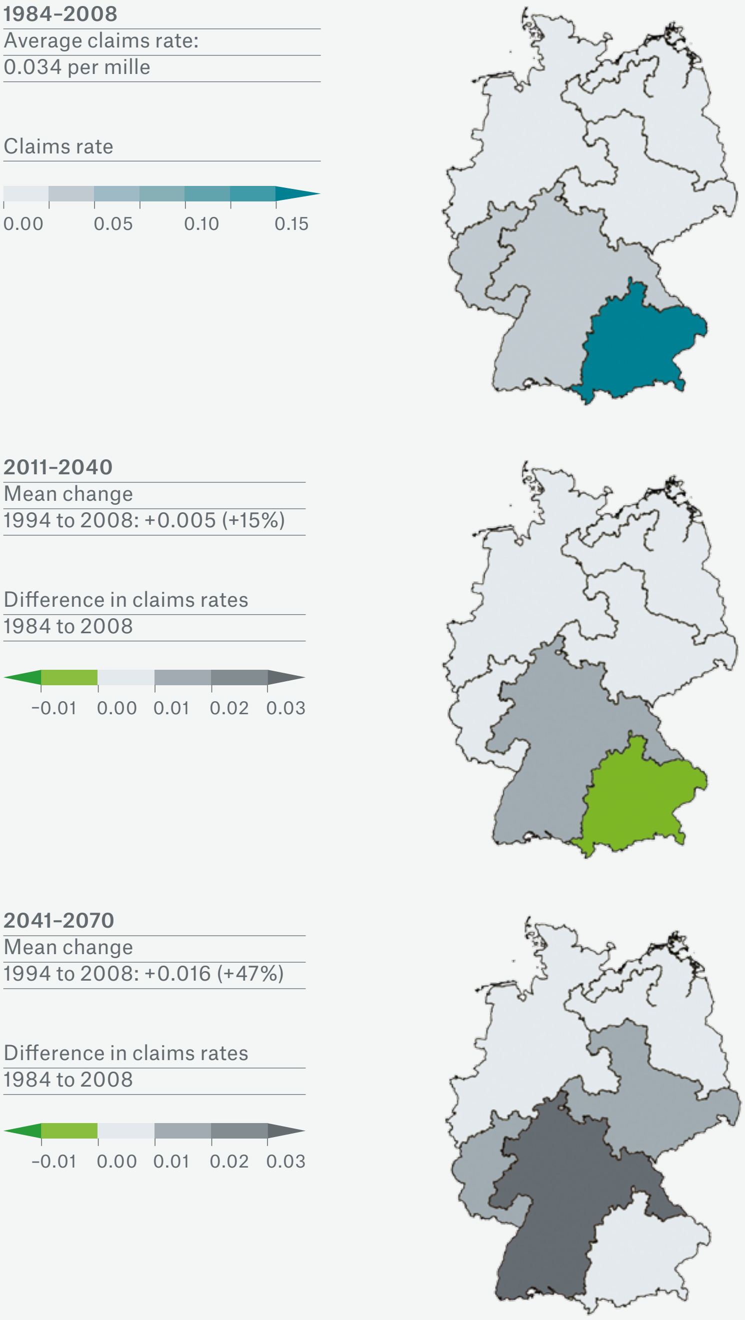
With this in mind, the insurance industry fully supports efforts to improve the strength and resistance of buildings. The Swiss Cantonal Fire Insurance Association runs the "Elementary Safety Register Hailstorm", which establishes the hail resistance of various materials used in building exteriors. Companies can have their products tested by means of a hail impacter, which fires hailstones of defined properties at the surfaces used on buildings. Products that pass this test are then listed in the hail register. Initiatives of this kind can help make loss prevention an integral part of competition among the manufacturers of such materials. In this way, the aspect of loss prevention can be incorporated in the building planning phase and help to ensure that costly repairs become less likely.

The references for this article can be found on our website at www.munichre.com/topicsgeo2015

Projection of losses due to summer storms/hail

Projected change in summer claims rates for storm/hail (homeowners' comprehensive insurance) for the periods 2011 to 2040 and 2041 to 2070 as compared to the reference period 1984 to 2008. The geographical sub-units are defined through similar loss characteristics and do not correspond to any administrative reports or common insurance regions.

Projected change in the mean annual loss ratio storm/hail in summer, based on the reference period 1984 to 2008



1984–2008
Average claims rate:
0.034 per mille

Claims rate

2011–2040
Mean change
1994 to 2008: +0.005 (+15%)

Difference in claims rates
1984 to 2008

2041–2070
Mean change
1994 to 2008: +0.016 (+47%)

Difference in claims rates
1984 to 2008

Source: Final report on the GDV project "Impact of climate change on the loss situation in the German insurance industry", December 2011

Virtual earthquakes in 3D

Marco Stupazzini

Thanks to supercomputers, it is now possible to simulate earthquakes and their devastating effects. Although such analyses are a valuable risk management tool, the scope of application is still limited.

On 17 January 1995, a major earthquake devastated the city of Kobe, killing almost 6,500 people and leaving tens of thousands homeless. After this event, the Japanese government approved the construction of the world's largest shaking table, nicknamed "E-Defense" (www.bosai.go.jp/hyogo). This impressive facility was designed to be capable of full-scale 3D earthquake testing on buildings. It opened up a new set of opportunities and challenges for scientists and engineers, and boosted their goal of large physical testing of structures subjected to strong motion shaking.

Does the same apply to earthquakes themselves? Would it be possible to reproduce an earthquake by way of a large physical experiment? On the one hand, it would be extremely difficult because even for a small earthquake of M_w 5.0, the energy released is comparable to the 1945 Hiroshima atomic explosion. The other problem is that it could also be extremely dangerous. Fortunately, there is an alternative: high-performance computing (HPC) has provided the chance of creating a virtual laboratory, where rare and unpredictable, albeit realistic, natural events like earthquakes can be simulated and studied from a physical point of view.

In fact, we sometimes tend to forget that an earthquake is a complex dynamic phenomenon in which the propagation of waves plays a crucial role. This is probably because after a significant event we usually look at a map, a static map, showing the maximum observed (or modelled) ground motion amplitudes as a tool to estimate the impact of this event. In most cases it is a sound procedure. Nonetheless, it is worth bearing in mind some caveats regarding this state of affairs:

- The map has usually been computed using a ground motion prediction equation (GMPE), a simplistic, empirical model essentially based on the statistical regression of previous ground motion recordings observed elsewhere, and aimed at predicting a selection of ground motion parameters (e.g. Peak Ground Acceleration) as a function of a few key parameters, such as the distance from the fault, the magnitude of the earthquake itself, the focal mechanism, and finally the soil effect (e.g. amplification or deamplification).

- It has been improved by observed data (recorded during the event under investigation), but only if those data were available.

- It therefore might be not capable of taking into account certain effects related to the intrinsic nature of an earthquake.

An earthquake releases a large amount of energy in a short time, primarily by means of motion and secondarily by way of sound and heat. It therefore essentially produces permanent displacement and seismic waves, propagating in the soil. Indeed, if we had a sufficient number of seismometers (instruments designed to record the ground motion as a function of time) deployed in the right place, we would be able to construct a film presenting the propagation of this elastodynamic wave. Unfortunately, this is not really feasible as only few countries in the world deploy dense networks of such instruments and because of the long time intervals between seismic events.

By using a GMPE, it is usually possible to determine the ground motion of an earthquake on the basis of its magnitude, the source-to-site distance and subsoil conditions. Usually, but not always. If the area in question is characterised by complex geology and is located close to the seismic source (i.e. the fault itself), more physical modelling might be required to properly take into account the complex ground shaking occurring under these circumstances.

A simple analogy might help to explain this more clearly: you pick up your luggage from the baggage carousel at the airport. You try to open the suitcase with the combination lock and realise you have taken the wrong bag. You have selected the suitcase on the basis of certain characteristics (colour, size, weight, brand), which it unfortunately shares with many other bags. You have correctly identified the "average suitcase". However, you are not interested in the average suitcase. You want your bag.

San Francisco, Los Angeles and Tokyo are three examples where risk management should not rely on the prediction of the average ground motion. If the spatial correlation is not taken into account, there may be great errors in the loss estimates.

The so called, "physics-based simulation" (PBS) approach takes into account these additional factors, providing a more realistic picture of the specific earthquake scenario. The PBS approach differs substantially from the one based on GMPE: the latter aims at vastly simplifying the modelling of the maximum ground motion by means of very few input parameters and relies mainly on observed data. The former takes into account a distinctly more realistic description of the earthquake physics and is therefore suited to reproducing complex seismic wave propagation phenomena, such as "near-field" effects occurring in the proximity of the seismic source, resonance inside a soft "alluvial basin" or complex constitutive behaviour of the earth's crust.

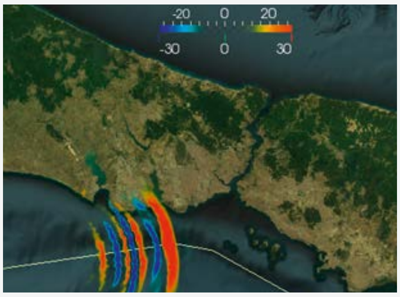
An example of the capabilities of this method is provided by the PBS for the Christchurch quake of 22 February 2011. The observed time histories (not only the peak values) were compared against the modelled seismograms and proved that this state-of-the-art methodology is now mature enough, within a certain frequency band, to help us in providing further insights into the ground motion occurring close to a fault and in a very complex 3D geotechnical and geological environment.

Given that PBS has proved its reliability, seismologists and engineers are now recreating seismic motion of past earthquakes and simulating the ground shaking induced by the rupture occurring along well-known faults. Besides earthquake-prone areas such as San Francisco, Los Angeles and Tokyo, PBS have also been conducted for Istanbul, Wellington and Santiago de Chile.

At the moment, PBS remains confined to specific areas of the world owing, on the one hand, to the level of geotechnical/geological information required to model the target area and, on the other hand, to the high computational cost involved. Nonetheless, it is clearly one of the most promising approaches to better understanding the consequences of this infrequent but potentially destructive natural event. Munich Re works together with the Polytechnic University of Milan in order to exploit the benefits that PBS offers and to incorporate 3D scenarios into our probabilistic earthquake models (http://speed.mox.polimi.it).

Seismic wave propagation

Examples of a physics-based simulation: The first three images show the modelled horizontal ground velocity (in centimetres per second) orthogonal to the fault, for a scenario with a magnitude of 7.0 in the area of Istanbul. You can see the snapshots at 15, 25 and 35 seconds after the beginning of the rupture. The bottom picture shows the modelled horizontal peak ground velocity in the examined area.



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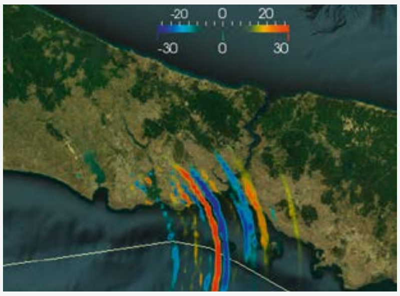

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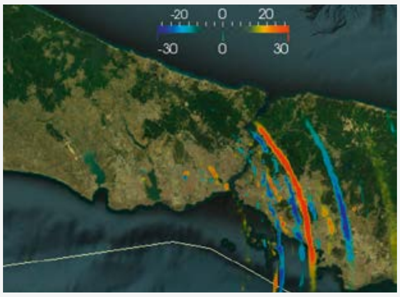

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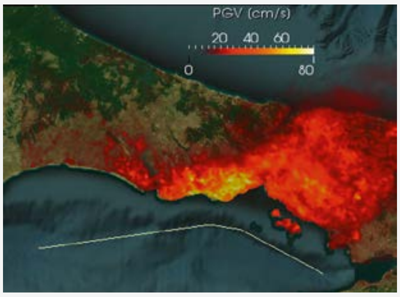

Peak horizontal ground velocity

Sources: Munich Re, Politecnico di Milano

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Topics Geo – 50 major loss events 2015

No.	Date	Loss event	Country/ Region	Deaths	Overall losses US$ m	Insured losses US$ m	Explanations, descriptions
1	January–March	Floods	Malawi, Mozambique	288	480		Heavy seasonal rain, thunderstorms, flash floods. >1 million houses damaged/destroyed. Severe losses to agriculture. Outbreak of epidemical disease. Displaced: >720,000, affected: >1.4 million.
2	January–December	Drought	USA		1,800		Extreme drought. Lack of rain, lakes dry up, high temperatures. >12 million trees affected. Water supply affected. >2,000 km^2 of crops affected.
3	January–December	Drought	India		1,500		Dry conditions due to delayed and inadequate monsoon, >70% deficiency in rainfall. 37,000 km^2 of crops damaged, >30% of crops lost. Affected: 6 million farmers.
4	January–December	Drought	Southern Africa	98	1,500		Dry conditions, lack of rain. Water supply affected. Power outages. Business interruption. Losses to agriculture, famine. 5.4 million tons of crops (maize) destroyed, livestock killed. Affected: >3.7 million.
5	8–11.1.	Winter storms Elon, Felix	Germany, Scandinavia, UK	3	560	380	Two low pressure systems, high wind speeds, thunderstorms, hail, heavy rain, snowfall. Thousands of buildings, schools, houses damaged. Weather-related accidents, air and rail traffic affected. Airport (Helgoland) damaged. Power failures.
6	1–16.2.	Floods, severe storms	Bulgaria, Greece	14	740		Thunderstorms, high wind speeds, heavy rain (93 mm/24 h), storm surge. >2,300 houses damaged. Roads flooded. 70 km^2 of farmland flooded. Livestock killed.
7	16–25.2.	Winter storm	USA, Canada	40	2,800	2,100	High wind speeds, ice storm, heavy snowfall, freezing rain, snow and ice accumulation, flash floods. Houses damaged. Pipes burst. Air and road traffic, public transport affected. Business interruption. Schools closed.
8	18–21.2.	Cyclone Marcia	Australia	1	800	400	Cat 5 cyclone. Thunderstorms, gusts up to 285 km/h, heavy rain (300 mm/24 h), flash floods. >55,000 houses damaged/destroyed. Vehicles damaged. Air and road traffic affected, ports closed, coal exports affected.
9	February–March	Avalanches, winter damage	Afghanistan	291	10		Series of avalanches, snowstorms, heavy snow and rain, flash floods. >9,000 houses, 2 schools, mosque damaged/destroyed. Roads blocked. Trees downed. Losses to agriculture. Injured: 96, affected: >28,000.
10	9–16.3.	Cyclone Pam, storm surge	Vanuatu	11	520	150	Cat 5 cyclone. Gusts up to 290 km/h, heavy rain, high waves (up to 8 m). >14,000 houses damaged/destroyed. Crops (>90%) destroyed, livestock killed. Injured: 150, affected: >160,000.
11	23–26.3.	Flash floods	Chile	31	1,500	500	Thunderstorms, torrential rain, landslides. Rivers burst their banks. >20,000 houses damaged/destroyed. Several hospitals damaged. Bridges washed away. Mining operations suspended. Affected: >29,000.
12	30.3–1.4.	Winter storm Niklas	Germany, Netherlands	11	1,400	1,000	High wind speeds, up to 115 km/h, heavy rain. Vehicles damaged. Widespread damage to overhead cables, trains damaged, rail traffic disrupted. Air traffic affected. Container ship ran aground.
13	7–10.4.	Severe storms	USA	3	1,600	1,200	Thunderstorms, tornadoes, high wind speeds, gusts up to 320 km/h. >100 houses damaged/destroyed. Bridges damaged. Trees, power lines downed. Air traffic affected. Zoo animals killed. Injured: >20.
14	18–21.4.	Severe storms	USA		1,300	940	Thunderstorms, tornadoes, wind speeds up to 112 km/h, hail, heavy rain, flash floods. Numerous homes, commercial buildings, shopping centre damaged. Vehicles, trains damaged. Trees, power lines downed.
15	19–24.4.	Winter storm, flash floods	Australia	7	1,300	730	High wind speeds, heavy rain (300 mm/24 h). >100 houses damaged/destroyed. Cars, boats damaged. Bridges damaged/destroyed. Air traffic affected. Port closed, coal exports affected. Livestock killed.
16	25.4.	Earthquake	Nepal	9,000	4,800	210	M$_w$ 7.8. Heavy rain, avalanches, landslides. >920,000 houses damaged/destroyed. Cultural heritage destroyed/damaged. Injured: >21,000, evacuated: >65,000, displaced: 52,000, affected: 8.3 million.
17	25.4.	Hailstorm	Australia		400	330	Thunderstorms, high wind speeds, heavy rain, large hailstones, flash floods. Factory buildings, warehouses destroyed, numerous homes damaged. Metro damaged. Roads flooded.
18	30.4–4.5.	Flash floods, severe storms	Australia	6	500	280	Thunderstorms, strong gusts, heavy rain (>350 mm/24 h), lightning. Numerous houses flooded. Plantations, crops esp. banana, macadamia, strawberry, sugar cane damaged/destroyed, harvest affected.
19	April–August	Drought	Romania, Poland		1,500		Dry conditions, lack of rain. Water supply affected. Losses to agriculture, >16,600 km^2 of farmland and fisheries affected, tourism hit.
20	April–September	Drought	Canada		1,300	600	Dry conditions due to lack of rain (40% of normal precipitation). 30% less crop production (grain), population of insects increased, reduction of livestock. 80% of farmers affected.
21	12.5.	Earthquake	Nepal, India	228	800		Aftershock M$_w$ 7.3, further tremors up to M$_w$ 6.3. Landslides, rockfall. >760 houses damaged/destroyed. Injured: >3,600, displaced: >3,900, affected: 7,800.
22	18–22.5.	Floods, landslides	China	35	1,000		Heavy seasonal rains, mudslides. Nine-storey building collapsed, >84,000 houses damaged/destroyed. Losses to agriculture, >300 km^2 of farmland affected. Evacuated/displaced: >290,000, affected: >3.7 million.
23	23–28.5.	Severe storms, flash floods, floods	USA	32	2,700	1,400	Thunderstorms, tornadoes, high wind speeds, hail, torrential rain. Rivers burst their banks, dam overflowed. >5,000 houses damaged/destroyed. 10,000 vehicles damaged. Bridges destroyed.
24	May–June	Heatwave	India, Pakistan	3,670			High temperatures (48°C), dry conditions. Heat-related deaths.
25	1.6.	Tornado	China	444	20	15	Thunderstorm, high wind speeds, heavy rain. Cruise ship on Yangtze River sank.
26	2–5.6.	Flash floods	Ghana	263	100		Heavy rain. >180 houses damaged/destroyed, schools flooded. Drainage systems flooded. Water supply affected. Power outages. Injured: >400, displaced: >14,000, affected: >51,000.
27	23.6–7.7.	Floods	China	27	1,400		Heavy seasonal rains, flash floods, landslides. >170,000 houses damaged/destroyed. Losses to agriculture, >900 km^2 of farmland affected. Evacuated: >290,000, displaced: >300,000, affected: 9.6 million.
28	June–August	Heatwave	Europe	1,250			Temperatures up to 45°C. Highways, roads damaged (blow-ups). Electricity supply affected, factories closed due to power shortages. High fish mortality in rivers. Heat-related deaths.
29	June–August	Floods	Myanmar	132	300		Heavy seasonal rains, flash floods, landslides. >520,000 homes damaged/destroyed. Health centres, monasteries, schools damaged. Extensive losses to agriculture. Displaced: >1 million, affected: >1.8 million.
30	June–Dec.	Drought	Ethiopia		500		Severe drought conditions, lack of rain. Food shortages. Affected: >7.1 million.
31	June–November	Wildfires	Indonesia	19	1,000		Forest, brush and agricultural fires, >21,000 km^2 burnt. Widespread smoke, smog, air pollution, dry conditions. Airports closed, air traffic affected. 6,000 schools closed. Affected: 40 million.
32	2–14.7.	Typhoon Chan-hom	China	1	1,400		Cat 4 typhoon. Wind speeds up to 190 km/h, heavy rain, flash floods, landslides, storm surge. >3,700 houses damaged/destroyed. Losses to agriculture. Evacuated: >1.4 million, affected: >3.5 million.
33	4–5.7.	Severe storms, hailstorms	Germany, Belgium	2	450	350	Low pressure system, thunderstorms, hail (9 cm in diameter), heavy rain, flash floods. Numerous houses, church damaged. Hundreds of vehicles damaged. Damage to photovoltaic installations and greenhouses.
34	19–27.7.	Severe storms, flash floods	China	19	450		High wind speeds, hail, heavy rain (250 mm/24 h). >27,000 homes damaged/destroyed. Hydropower stations destroyed. Vehicles washed away. Evacuated: >160,000, displaced: >9,000, affected: >4.1 million.
35	28.7–30.8.	Floods, landslides	India	125	1,500		Heavy seasonal rains, flash floods, landslides. >13,000 villages flooded. >820,000 houses damaged/destroyed. Extensive losses to agriculture. Evacuated: >500,000, affected: >106 million.
36	July–August	Floods	Pakistan	238	180		Heavy seasonal rains, snow melt, glacial lake outburst. >33,000 houses damaged/destroyed. Losses to agriculture, livestock killed. Evacuated: >1.2 million, displaced: >160,000, affected: >1.5 million.
37	2–13.8.	Typhoon Soudelor, floods	China, Taiwan	39	2,800	120	Cat 5 typhoon. Torrential rain (>600 mm/24 h), high waves (>9 m). >72,000 houses damaged/destroyed. Power outages, >6.8 million people without electricity. Evacuated: >720,000, affected: >3.1 million.
38	18–25.8.	Typhoon Goni (Ineng), floods	Japan, Philippines, PRK	73	2,000	1,400	Cat 4 typhoon. Gusts up to 250 km/h, heavy rain (250 mm/24 h). Flooding. >8,800 houses damaged/destroyed. Infrastructure damaged. Air, railway traffic affected. Losses to agriculture. 500,000 households without power.
39	25–31.8.	Tropical Storm Erika, flash floods	Caribbean	36	450		Tropical storm. Heavy rain (320 mm/12 h), landslides, flash floods, high waves. Rivers burst their banks. Airport facilities. Losses to agriculture. Displaced: >7,900, affected: >20,000.
40	6–11.9.	Floods	Japan	8	1,400	650	Torrential rain (540 mm/24 h), flash floods, >450 landslides. Dykes breached, >60 rivers burst their banks, 40 km^2 flooded. Business interruption.
41	9.9.–8.10.	Wildfires (Valley Fire, Butte Fire)	USA	4	1,600	1,200	Forest, brush, grassfires, >600 km^2 burnt. High wind speeds, dry conditions. > 2,000 houses damaged/destroyed. Livestock killed. Evacuated: >10,000, displaced: >23,000.
42	16.9.	Earthquakes, tsunami	Chile	15	800	350	M$_w$ 8.3. Tsunami, landslides, rockfall. Air traffic affected. Mining activity interrupted. Losses to livestock and aquaculture (90% of oyster cultures). Injured: >6,000, evacuated: >1 million, displaced: 9,000.
43	30.9.–6.10.	Flash floods, severe storms	France	20	950	700	Severe storms, tornadoes, torrential rainfall (196 mm/24 h), flash floods, high waves. Several houses damaged. Thousands of vehicles damaged. Roads flooded. Rail traffic affected. Campsites evacuated.
44	1–5.10.	Typhoon Mujigae, floods	China	22	3,500		Cat 4 typhoon. Tornadoes, gusts up to 240 km/h, heavy rain (250 mm/24 h), landslides, high waves. >19,000 houses destroyed. >2,800 km^2 of crops affected. Injured: >220, evacuated: >210,000.
45	2–6.10.	Floods, flash floods	USA	21	1,700	400	Thunderstorms, torrential rain (>500 mm/12 h), coastal flooding. Rivers, creeks burst their banks, dams breached. 1,800 vehicles flooded, boats damaged. Highways, interstates, bridges damaged.
46	26.10.	Earthquake	Pakistan, Afghanistan	401	300		M$_w$ 7.5, depth: 213 km. Landslides. >150,000 houses damaged/destroyed, >1,400 schools damaged. Roads blocked. Injured: >2,200, affected: >78,000.
47	17–27.11.	Wildfires (Pinery Fire)	Australia	2	200	90	Bushfires, high wind speeds, high temperatures (>39°C). 830 km^2 burnt. 77 homes damaged/destroyed. >380 farm buildings destroyed. 600 km^2 of farmland destroyed, livestock (500 pigs, 51,000 chickens) killed.
48	November–December	Floods	India	597	3,500	700	Two flood waves. Torrential seasonal rains. >81,000 houses damaged/destroyed. Airport, 8 airplanes damaged. Factories temporarily shut down. Displaced: 1.8 million, affected: 3 million.
49	December	Floods, winter storms	UK, Ireland	5	3,000	2,000	Winter storms Desmond and Eva. High wind speeds, heayy rain, coastal flooding. Rivers, canals burst their banks. >7,000 houses damaged. Container ship damaged. Bridges damaged, roads blocked. Tens of thousands of houses without electricity.
50	24.12.15–2.1.16	Severe storms, Tornadoes, floods	USA	45	1,200	550	Thunderstorms, several tornadoes, flash floods. >2,900 houses damaged/destroyed. Vehicles damaged. >160,000 people without electricity. Air traffic affected. Livestock (30,000 head of cattle) killed.

Topics Geo – World map of natural catastrophes 2015

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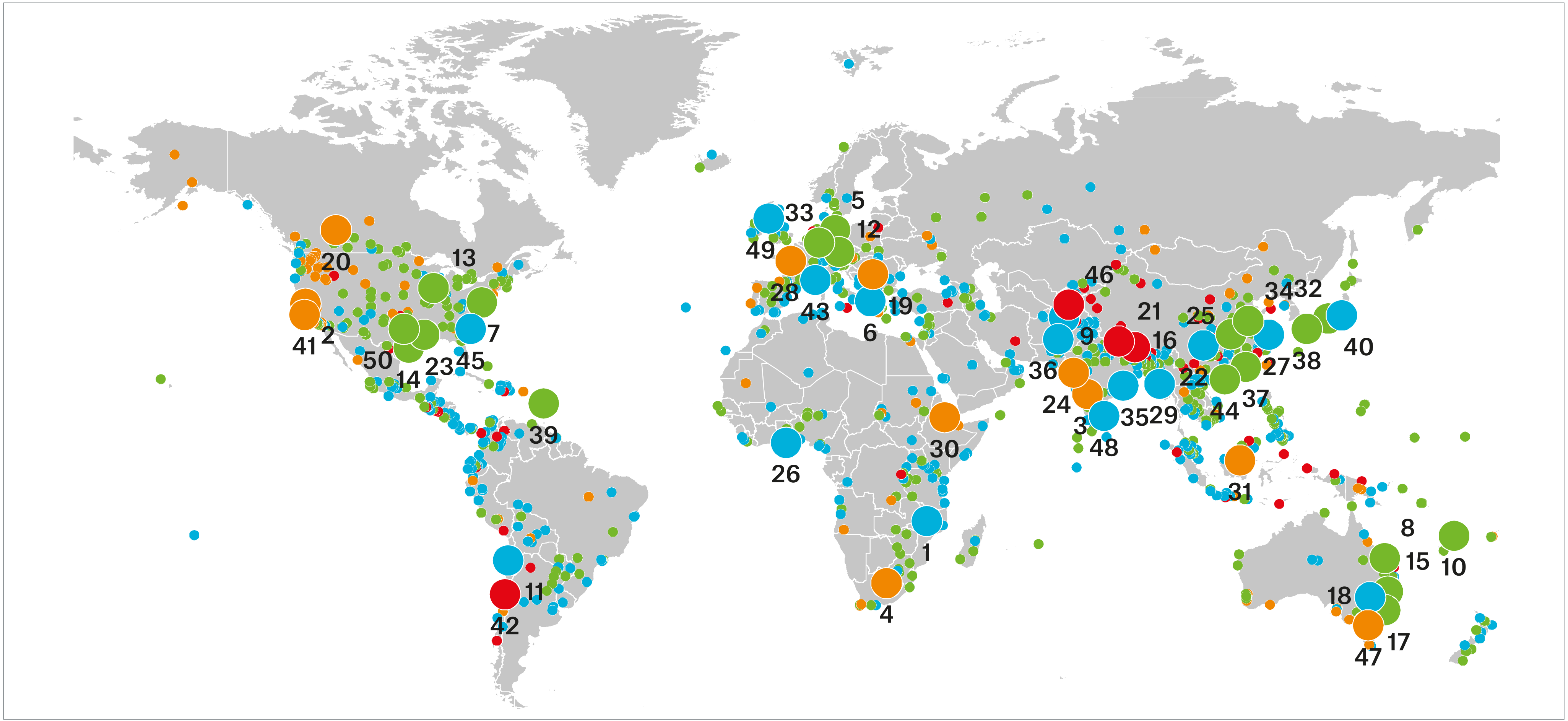

1,060 natural hazard events, thereof

○ 50 major events (details overleaf)

- ● **Geophysical events:** Earthquake, tsunami, volcanic activity
- ● **Meteorological events:** Tropical storm, extratropical storm, convective storm, local storm
- ● **Hydrological events:** Flooding, mass movement
- ● **Climatological events:** Extreme temperatures, drought, wildfire

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NOT IF, BUT HOW