Environmental Science and Policy 100 (2019) 74–83

Contents lists available at ScienceDirect

Environmental Science and Policy

journal homepage: www.elsevier.com/locate/envsci

Changes in risk of extreme weather events in Europe

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ARTICLE INFO

Keywords:
Extreme weather events
Disaster
Risk
Economy
Loss
Insurance
Management
Europe

ABSTRACT

Over the last decades, the damage caused by weather events has increased dramatically and ubiquitously. In Europe, weather catastrophes constitute a growing burden on national economies and insurance companies, not least because of the costs of precautionary measures. For a long time, the insurance sector has flagged that weather disasters are on the rise, both in terms of the number of occurrences and material damage caused. The main reasons for this are: increase in the number and area of settlements in exposed areas, the accumulation of ever more valuable and vulnerable assets in these areas, as well as the climate and environmental changes that have already taken place. This paper examines observed changes in risk of various categories of weather disasters in Europe, backed by statistical analyses of relevant, updated information originating from a valuable and quite unique source, Munich Re's NatCatSERVICE database, that is of considerable interest and value to the scientific community and beyond (e.g. in the reinsurance and insurance industries). The paper also calls for partnership in the reduction of risk of weather extremes and discusses the role of the insurance industry.

1. Introduction

There have been many weather disasters in Europe in the last two decades. They include numerous floods, such as those in northern Italy, France and Switzerland in 2000, in the upper Elbe and Danube catchments in 2002 and 2013, along the lower Danube in 2006, in the United Kingdom in 2007, in the Adriatic region in 2014, and in Germany and France in 2016. There have also been severe heat waves and droughts in the summers of 2003, 2010 and 2018; wildfires in southern and eastern Europe in 2007, 2010 and 2017; hailstorms in Germany (1984 and 2013); winter storms Kyrill (2007) and Xynthia (2010); as well as the extreme snowpack in the northern Alps in 2006 and at the beginning of 2019, just to mention a few examples.

Munich Re has been systematically collecting information on natural disasters since 1974. The NatCatSERVICE (NCS) database run by the company, covering losses caused by natural extreme events, is among the world's largest and contains more than 40,000 entries. The number of disastrous weather events included in the database is growing much faster than the number of geophysical events (earthquakes, volcanic eruptions) (Kundzewicz et al., 2014). This finding holds for several periods of analysis. This could have something to do with climate change, but also with non-climatic factors, such as land-use and land-cover change. Exposure has been growing with the intensification of human settlement of unsafe areas, such as flood plains.

Impacts from severe weather are not as devastating to European societies (in particular to the population of industrialised countries of the European Union and OECD) as to those in some other parts of the world, where whole countries are sometimes thrown back years in their development by the occurrence of disastrous weather extremes. On the whole, wealthy European Union countries make efforts to manage (and reduce) risk of weather extremes and to improve societal resilience (Hegger et al., 2016; Priest et al., 2016). But European states do have a significant burden not only from natural disasters themselves, but also from the costly measures that citizens demand from their governments to protect themselves and their properties, especially against the flood hazard. De Bruijn et al. (2017) examined resilience in practice, reviewing principles to enable societies to cope with extreme weather events.

There are several levels of disaster prevention and risk reduction. Since such categories of weather extremes as heat waves and floods are likely to become even more extreme and more frequent with climate warming, global reduction of greenhouse gas emissions (climate change mitigation) may curb the increasing hazard. However, the inertia of the process is high, so that today's emission reduction cannot reduce these hazards in the near future. Moreover, it is important that the global sum of emissions is reduced. Hence, if one country or region drastically curbs emissions and others do not follow suit, this is not sufficient to protect the global climate. Further, risk reduction embraces technical

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https://doi.org/10.1016/j.envsci.2019.06.007
Received 11 February 2019; Received in revised form 14 June 2019; Accepted 15 June 2019
Available online 25 June 2019
1462-9011/

control measures, forecasting and warning, as well as the individual's behaviour (of a person or of a company) and provisions to avoid being ruined by an extreme event. While there is a broad consensus that loss of life must be prevented by all means, the costs of efforts for reduction of monetary losses should be in reasonable proportion to the value of the items being protected.

The aim of this paper is to examine observed changes in risk of various categories of weather disasters in Europe (such as winter storms and storm surges; convective storms and flash floods; river and lake flooding as well as landslides; winter hazards; heat waves, droughts and wildfires). The paper offers statistical analyses of relevant, updated information originating from Munich Re's NatCatSERVICE database. It presents general statistics as well as time series of aggregated damage in three variants: nominal, inflation-adjusted and normalised. Finally, assessment and reduction of risk are tackled and the partnership for risk management is discussed, with particular focus on the insurance industry, which is an important innovation. We hope that our paper, and in particular the graphics, will be cited and used

2. Weather perils in Europe

Weather events in Europe are typically less intense than on other continents. This is illustrated for temperature and precipitation records in Table 1. Likewise, maximum wind velocities in Europe reach only some two-thirds of those achieved by hurricanes and typhoons. The highest recorded tornadic wind speed, according to WMO (https://wmo.asu.edu/content/world-meteorological-organization-global-weather-climate-extremes-archive), was 135 m/s (Bridge Creek, OK, USA).

As shown in Table 1, the European record of daily precipitation total (345 mm) constitutes only 19% of the world record (1,825 mm), while the European record of annual precipitation total (4,593 mm) constitutes only 17% of the world record (26,470 mm). Discharges of rivers such as the Amazon, the Mississippi and the Yangtze are by order of magnitude higher than in the Rhine and the Danube, and inundated areas are in the order of square kilometres rather than hectares. Nevertheless, nature's forces produce losses running into billions of euros each year in the densely settled and highly developed region of Europe. And heat waves have caused tens of thousands of additional deaths in recent years. The deadliest and costliest weather catastrophes in Europe since 1980 are listed in Tables 2a and 2b, separated according to category of weather events.

2.1. Winter storms and storm surges

Winter storms (gales) approach Europe from the Atlantic Ocean and threaten all countries from the western coast of the continent to a band stretching roughly across the Baltic states, Poland, Slovakia, and Hungary, and between southern Scandinavia in the north and northern Spain and the main ridge of the Alps in the south. Wind velocities in these large-scale storms can be as high as 250 km/h in gusts at prominent locations such as mountain peaks. They produce losses in excess of one billion dollars practically every year. The most expensive disasters since 1990 were gales Daria in January 1990, Lothar in December 1999, Kyrill in January 2007, and Xynthia in February 2010, with overall losses of US$ 7bn, 11.5bn, 9bn, and 6.1bn respectively (cf. Table 2a).

Winter storms are usually "dry", i.e. they do not bring significant amounts of precipitation, but sometimes they are accompanied by a storm surge – an unusual elevation of the sea water level along a coast due to wind set-up. Coasts and estuaries exposed to this threat are mainly those around the North and Baltic Seas, to a lesser extent those on the coasts of the Atlantic Ocean (UK, Ireland, France, Spain, Portugal), the Black and the Mediterranean Seas. The latter specification does not include the so-called "acqua alta", a high tide that frequently strikes Venice, most spectacularly in October 2017.

In Europe, catastrophic consequences from storm surges have not been experienced since the two devastating events of 1953 (the Netherlands and UK) and 1962 (German Bight, Hamburg). Efforts put into coastal protection, in particularly along the coasts of the North Sea, are enormous (multi-billion Delta Plan in the Netherlands), but, given the gigantic loss potential of an extreme event, this is entirely justified. For instance, in the Netherlands, 26% of the land is located in depressions and four million (Hut, 2015) people live below the mean sea level. There was a close call in December 1999 during winter storm Anatol: if this storm had taken a path 100 km further south, it could have produced a water level along Germany's Frisian coast much higher than the dyke crests, and would have inevitably resulted in a serious disaster. The 61 deaths during Xynthia (2010) resulted mostly from drownings in the storm surge.

2.2. Convective storms and flash floods

Severe convective storms (SCS), colloquially called thunderstorms, are intense meteorological events which usually occur in summer. They can bring high – often gusty – winds, plus hail, torrential rain and lightning. Sometimes they even spawn tornadoes. There are hundreds of tornadoes in Europe each year (Germany has about 60 on average). Several dozen of them cause significant damage (from hundreds of thousands to millions of euros), sometimes (like in Italy in 2002) even in the billion-euro range. While the area hit by an SCS is small compared to that of a winter storm, it is by no means always a local event. A single atmospheric disturbance can generate severe thunderstorms (squall line) over hundreds of kilometres. Also, destruction in the areas affected may be much more severe as wind velocities in thunderstorms tend to be higher than in winter storms.

A hailstorm, which is often part of an SCS, can be even more devastating. Even locally, huge damage in the order of many hundreds of millions of dollars and more can occur if such a storm hits a particularly vulnerable spot. For example, an event over a moderately populated

Table 1
Global and European records of indicators related to temperature and precipitation. Source of data: WMO (https://wmo.asu.edu/content/world-meteorological-organization-global-weather-climate-extremes-archive) except for the maximum 24 -h precipitation record in Czech Republic (Brázdil et al., 2005).

Indicator	Scale	Record value	Location of record
Minimum temperature [°C]	Global	−89.2	Vostok, Antarctica
	Continental Europe	−58.1	Ust'Schugor, Russia
	Europe, incl. polar region	−66.1	Northice, Greenland
Maximum temperature [°C]	Global	56.7	Furnace Creek Ranch (Death Valley), USA
	Europe	48.0	Athens and Elefsina, Greece
Maximum annual precipitation [mm]	Global	26,470	Cherrapunji, India
	Europe	4,593	Crkvice, Montenegro
Maximum 24 -h precipitation [mm]	Global	1,825	Foc-Foc, La Réunion
	Europe	345	Nova Louka, Czech Republic
Minimum annual precipitation [mm]	Global	0.76	Arica, Chile
	Europe	162.6	Astrakhan, Russia

Table 2a
Weather disasters in Europe (categories: flood, windstorm) since 1980 in which more than 100 people died and/or material losses exceeded US$ 5bn (in original values), listed chronologically. Data source: Munich Re NatCatSERVICE.

Year	Event type (name)	Regions/countries affected	Deaths	Overall losses (US$ bn, original values)	Overall losses (US$ bn, inflation-adjusted to 2018)	Insured portion (%)
1984	Tornado	Russia	400			
1987	Winter storm 87	W, N, E Europe	18	5.3	12.0	58
1990	Winter storm Daria	W, N, S Europe	85	7.0	13.9	77
1992	Flood	Ukraine	127			
1994	Flash flood	Southern Alps (I, CH)	68	9.3	16.0	1
1997	Flood (Odra/Oder)	E Europe (CZ, SK, PL, D)	118	6.0	9.5	13
1998	Flash flood	Italy	167			
1999	Winter storm Lothar	W Europe (F, B, D, A, CH)	113	11.5	17.6	54
2000	Flood	Southern Alps (CH, I, F)	38	8.5	12.7	6
2002	Flood	E Europe, Italy	193			
2002	Flood (Elbe, Danube)	W, E Europe	39	16.5	23.4	21
2005	Winter storm Erwin	W, N Europe	15	5.4	7.1	39
2007	Winter storm Kyrill	W, E Europe	49	9.0	11.2	58
2007	Flood	UK	5	8.0	9.9	75
2009	Winter storm Klaus	W, S Europe	26	5.1	6.1	59
2010	Winter storm Xynthia	W, S, N Europe	61	6.1	7.1	51
2012	Flash flood	Russia	172			
2013	Flood (Danube, Elbe)	C, E Europe	25	12.5	13.6	24
2016	Flood, Flash flood	France, Germany	22	7.0	7.4	45

Table 2b
Weather disasters in Europe (categories: heat wave, cold wave) since 1980 in which more than 500 people died, according to information from Munich Re's NatCatSERVICE database. The events are ordered by the number of fatalities.

Year	Event type (name)	Regions/countries affected	Deaths
2003	Heat wave	S, W, E, N Europe	70,000
2010	Heat wave	Russian Federation (Europe)	56,000
2015	Heat wave	W, S, E Europe	3,850
2006	Heat wave	W, E, S Europe	2,080
1987	Heat wave	Greece	2,000
2006	Cold wave	E, W, S Europe	790
2013	Heat wave	UK	760
2012	Cold wave	E, S, W Europe	540
2007	Heat wave	E, S, W Europe	500
1983	Heat wave	France	500

Characterisation of specific weather perils is presented in the sequel.

area south of Stuttgart (Baden-Württemberg, Germany) on 27/28 July 2013 caused an overall loss of almost US$ 3bn. This suggests that a hailstorm moving over a major city would have the potential to cause losses amounting to tens of billions of dollars.

Flash floods can happen anywhere. No place is safe. Flash flooding is due to high-intensity rainfall, during which the precipitation rate exceeds the infiltration and drainage capacities at the site where it occurs. Over largely sealed urban areas, where infiltration is strongly impeded, even moderate rainfall may cause significant flooding and lead to substantial damage (urban flash floods). In flat areas, water accumulates on the surface, but inundation can locally have considerable depths in depressions. On sloped terrain, the water gushes downwards with high velocity and destructive power. Transport of floating matter and sediment, erosion and undercutting of foundations increase the extent of damage. Flash floods are invariably surprising events. As a rule, they cannot be forecast sufficiently early – hence reacting and implementing protection measures are normally not an option. They also often kill people. Some 40 people died in September 2009 when a flash flood surprised them on a motorway in Istanbul, Turkey, while 172 Russians lost their lives in a single flash flood after heavy rain near the Black Sea coast in 2012. Southern Germany was hit by a sequence of flash floods in May and June 2016 that devastated several towns (e.g. Braunsbach, Simbach, Triftern, Polling); with losses adding up to US$ 2.2bn, of which US$ 1bn was insured.

2.3. River and lake flooding, landslides

River floods and overflowing of lakes are caused by long-lasting rainfall, covering large areas, sometimes entire basins, with a depth that far exceeds the soil's storage capacity, or by intense snowmelt or ice jam (see section on winter hazards below). The water is collected in the catchment's drainage systems and flood waves are generated in the main rivers and their tributaries and propagate downstream. The areas at risk of flooding are those adjacent to the watercourses. The flooding starts from the river; the sequence of areas being flooded is always the same, which means that it is possible to derive a relationship between flood magnitude (in terms of return period) and area affected, thus delineating flood-risk zones. In contrast to flash floods, river floods last much longer (days to weeks) and rise more slowly. The latter aspect is of crucial importance with regard to early-warning and precautionary measures. Flood risk depends on exposed assets. For instance, in largely natural drainage basins (e.g., such as the River Biebrza in northern Poland), abundance of water is more a blessing than a curse. Seasonal flooding of wide flood plains is a benefit to the riparian and wetland ecosystems.

Most landslides occur during wet periods, when the soil becomes soaked and loses internal stability. Wave erosion on coasts and retreating permafrost in alpine regions may be other causes for slides. Earthquakes and volcanic activity may also lead to landslides. As most such mass movements are local events, their economic consequences are usually small compared to those of other natural hazards. They may, however, gain greater importance when roads or railway tracks are blocked or carried away, imposing detours that can sometimes last for several months, or if they create dams and consequently back up rivers. Catastrophic flood waves following overtopping or the bursting of such a natural dam can only be prevented by substantial efforts that aim at achieving controlled drainage.

2.4. Winter hazards

Despite the warming climate, there are still winter hazards in Europe that bring death and destruction. Frost is a major killer on the continent. Snowmelt and ice-jam floods can bring high material damage.

For snow and snow/rock avalanches and icefalls, the same applies as for landslides regarding their perilous nature. However, while the actual damage is usually small, the costs of avalanche protection structures are very high as they aim at preventing fatalities. Even the extreme and very spectacular events in the Alps over several weeks in 1999 cost "only" around US$ 700 m. Human losses from avalanches occur mostly in remote areas and often hit people practising outdoor sports, in particular off-piste skiing and snowboarding.

High snowpack in populated areas can generate considerable damage, too: Germany, Austria and the Czech Republic suffered losses of US$ 850 m in the first quarter of 2006 due to collapsed buildings. In Katowice, Poland, on 28 January 2006, a roof of an exhibition hall at the International Katowice Fair, covered by a deep layer of snow and ice, collapsed, killing 65.

Frost and ice are potentially even more costly, deadly, and certainly an underrated hazard as regards the consequences of an extreme event occurrence. Besides the high correlation between cold temperatures and fatality rate, a large-scale, long-lasting interruption to the power supply due to iced power lines might create unimaginable consequences in our completely electrified world. In 2017, Europe's horticulture was severely hit by a late frost in May and June when the flowering season had already started. Losses ran into billions of euros.

Cold extremes continue to occur in Europe in a warming climate (Cattiaux et al., 2010). Frost and prolonged cold weather claim hundreds of lives in Europe each year. Table 2b lists two events that caused more than 500 fatalities each. The worst winters were 2006 with 790 deaths and 2012 with 540 deaths across Europe.

Even in a warming climate, freezing to death still remains a direct reason for many fatalities in some countries, such as Poland. In 2009 and 2010, 238 and 300 people froze to death (RCB, 2013) in the country. More recently, the numbers of fatalities due to freezing in Poland were lower, being 74, 107, and 111 in the winters of 2014/15, 2015/16 and 2016/17 respectively. Yet, in most winters, the number of direct low-temperature-related fatalities in Poland exceeds 100, likely more than in any other EU country. Persons that die in "non-NCS-events", i.e. on "normal" frost nights rather than during an extreme cold-spell (e.g. homeless people), are unlikely to be counted. They are not noted in the NatCatSERVICE and therefore not reflected in Table 2b.

2.5. Heat waves, droughts and wildfires

Heat waves contribute eight events in Table 2b (each causing more than 500 fatalities). The worst natural disaster in terms of lives lost in Europe in the past 100 years was the immense, widespread and long-lasting (June to mid-August), heat wave summer of 2003. In large parts of Europe, temperatures exceeded the average by 3–5 °C and annual precipitation levels were as much as 300 mm lower than normal, causing an estimated reduction of 30% over Europe in gross primary production of terrestrial ecosystems (Ciais et al., 2005). Christidis et al. (2015) noted a dramatically increasing chance of extremely hot summers since the 2003 European heat wave.

It is estimated that 70,000 people died across Europe as a consequence of sustained high temperatures over several weeks. This showed that even developed countries in Europe may not be adequately prepared to cope with extreme heat. The accompanying six-month drought affected agriculture, inland navigation, as well as industries that depend on cooling by water and processing of water, such as energy generation and drinking water supply. Many major rivers (e.g. in France, Germany and Italy) were at record low levels, resulting in disruption of irrigation and cooling of power plants.

Another intense heat wave caused 56,000 deaths in Russia in 2010. Ageing of the European population increases vulnerability as seniors are particularly sensitive to heat waves.

The list of heat wave fatalities in Europe presented in Table 2b cannot possibly cover all events. For example, Graczyk et al. (2018) reports the estimated number of additional deaths during heat waves in the ten largest towns in Poland in each of the four years of 1992, 1994, 2006 and 2010 as greater than 600. The European entries related to 2006 and 2010 include Poland. However, in two summers not included in Table 2b, namely 1992 and 1994, the estimated number of additional deaths during heat waves in the ten largest towns in Poland reached 790 and 1,186, respectively. Other EU countries may also have high numbers of heat wave-related fatalities, beyond the summers included in Table 2b.

In Europe, droughts do not kill nowadays, as they did in the remote past like the Middle Ages. While sustained heat kills people, it is mainly the associated drought that causes material losses. Climate change is expected to increase the probability of such summers dramatically.

Lack of rain provides conditions favouring wildfires that can destroy large areas and claim lives. High temperature and strong wind also enhance the wildfire danger. In 2003, the losses generated by wildfires reached US$ 1.2bn and 70 fatalities in southern Europe, in 2010, the fires around Moscow approached a US$ 2bn loss and claimed 130 lives. More recently, in the summer of 2017, 123 people died in several wildfire episodes, 110 of them in Portugal alone. In 2018, 100 people perished in wildfires in Greece.

3. Disaster statistics for Europe

3.1. Database

Munich Re has been systematically collecting information on natural disasters since 1974. The company's NatCatSERVICE (NCS) database, one of the world's most comprehensive databases covering information on losses caused by natural hazards, contains more than 40,000 entries (Munich Re, 2018a; (https://natcatservice.munichre.com/assets/pdf/180220_NCS_Methodology_en.pdf). The lead currency in the database is US dollars (US$). This means that all losses are converted from the local currency into US$, applying the exchange rate at the time the event occurred.

The most expensive weather-related disaster in Europe was the 2002 summer flood, which cost – as the sum of two events – a total of US$ 21.5bn (original values) across the continent. There were also 17 events in which at least 200 people were killed. The costliest disasters (> US$ 5bn) and the ones that claimed at least 100/500 lives since 1980 are listed in Tables 2a and 2b.

Table 2a suggests that there are distinct differences in the proportion of insured to overall losses depending on the type of event and the region hit. Indeed, a high insured proportion generally applies for windstorm events, almost independent of the countries affected. In temperature-related events (heat waves, frost) the insured share is low, but the death toll may be high. Floods range between these two extremes: in some countries (e.g. the UK, Switzerland, in certain cases France) private and state-run insurance cover assumes a large proportion of the losses, while in most western European countries the share is in the order of about 10–40%. In Eastern Europe this share is lower, while the death toll is higher.

Even with a relatively high number of weather events (4,890 have been recorded for Europe since 1980), one must exercise due care and caution when dealing with them, and certainly avoid thoughtless, fully automatic and purely statistical analyses. Despite the fact that Munich Re gives quality control utmost priority, checks every single entry as thoroughly as possible, and corrects entries whenever new information is available (sometimes even years after an event), numbers should not be crunched blindly by statistical methods but rather given due attention based on expert knowledge. Statistical analyses regarding natural disasters do require a large set of data, but this set must also be consistent and its components clearly understood. Nevertheless, Munich Re has made NCS partially accessible to the public, which allows them to conduct a variety of statistical analyses (http://natcatservice.munichre.com) on the basis of "relevant" events, i.e. those during which a loss occurred that was firmly measurable and not ignorable.

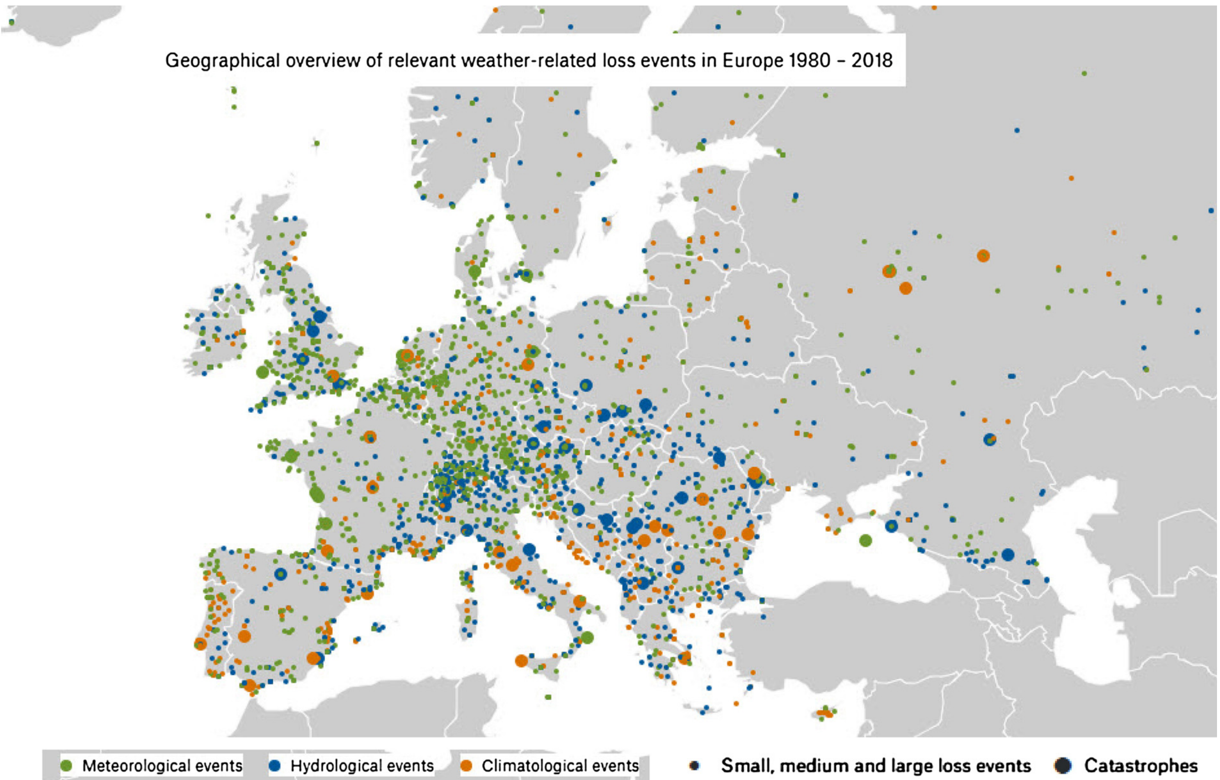

Fig. 1. Geographical overview of relevant weather-related loss events in Europe 1980–2018 (2,801 events). Source: Munich Re NatCatSERVICE (Munich Re, 2018a). (https://natcatservice.munichre.com/?filter=eyJ5ZWFyRnJvbSI6MTk4MCwieWVhclRvIjoyMDE3LCJhcmVhSWRzIjpbOV0sImV2ZW50RmFtaWx5SWRzIjpbNCw1LDddfQ%3D%3D&type=1).

3.2. General statistics

While losses due to natural hazards have increased dramatically all over the world, disasters caused by weather events have in particular put heavy burdens on societies and insurance companies in central and western Europe, including costs of measures needed to protect against them (Fig. 1).

A standard illustration comparing the relevant parameters, such as number of loss events, fatalities, overall losses and insured losses for different hazards, is presented in the form of pie charts in Fig. 2. They show that, for 1980–2018, 95% of loss events are weather-related, with storms (meteorological events) making up almost 50% of all events, and floods (hydrological events) almost another third. The so-called "climatological" events – mainly consisting of heat, drought, wildfire and frost – account for 16%. The remaining 5% refer to geophysical hazards: earthquakes, volcanic eruptions, tsunamis and subsidence. This pie chart has been pretty stable over time.

The sections of the "fatalities" pie chart, however, changed dramatically in 2003 and again in 2010. High numbers of fatalities in Europe, 70,000 and 56,000, caused by heat waves in these years, alone accounted for nine-tenths of the 91% segment of the pie related to climatological events. Disregarding these 126,000 deaths would reduce this category to only about 53%, whereas the hydrological, meteorological, and geophysical sectors would become much more pronounced (about 16% each). The stability of the “fatalities” pie chart is hence not high. Two single extreme events induced a dramatic change, while the picture without these events looks very different.

The average annual overall losses for 1980–2018 are equal to US$ 16.2bn. Dramatic changes brought by single events can be also noted in the chart of overall losses (Fig. 2). More than two-fifths of the 15% segment corresponding to geophysical losses (US$ 94bn) result from a single event – the 1980 Basilicata earthquake in Italy. While the original loss was only US$ 11.8bn, inflation adjustment to 2018 values boosted this figure to almost US$ 38.5bn, which is 6% of the US$ 631bn total. The relation between the three other sectors of the chart can be considered relatively stable over time. Losses from meteorological, hydrological, and – to a lesser extent – climatological events are accumulated from many occurrences, whereas the losses from earthquakes result from just a few costly events. Insured losses are clearly dominated by storms, simply because, in most countries, the take-up rate of storm insurance is much higher than that for other weather-related perils. This pie has not changed much over the past years, although more costly floods have occurred more recently and, at the same time, insurance for this peril has gained importance. For example, the penetration of flood insurance for private homes in Germany increased countrywide to about 41% in 2018, as compared to around 26% in 2009 and only less than 10% in the year 2002, when major flood events took place in the country in the basins of the Elbe and the Danube.

If we look more closely at the 1,719 events in Europe in which at least one person was killed, we see that storms and floods are leading by a long way (Fig. 3). However, the large numbers (> 200 deaths per event) were produced mainly by extreme temperatures (heat and cold) and geophysical events (earthquakes). In the range from 50 to 199 deaths, the picture becomes somewhat more balanced with cold/winter events and floods being the most significant hazards and earthquake falling back. In the next range (10–49 deaths), floods and storms clearly become the dominant types with roughly a third of the events each, and this dominance increases in the lowest category. Here, more than 50% of the events are storms.

3.3. Time series of overall and insured damages caused by weather events in Europe

Fig. 4 shows that the annual losses from weather events in Europe have somewhat increased, however, without exhibiting a clear upward trend. Results of trend detection may significantly depend on the

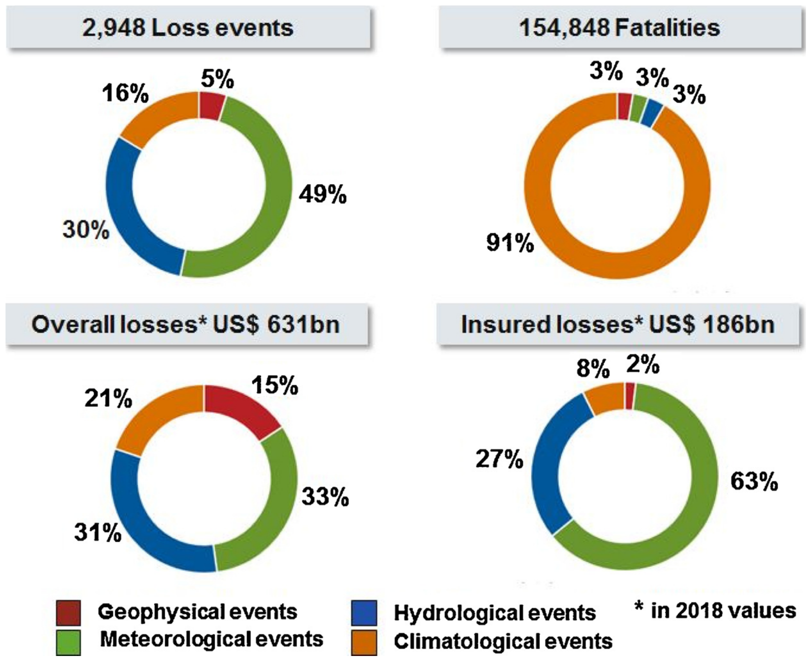

Fig. 2. Share of the four different categories of natural hazards in Europe in the period 1980–2018 with respect to number of loss events, number of fatalities, overall losses and insured losses (losses adjusted for inflation).

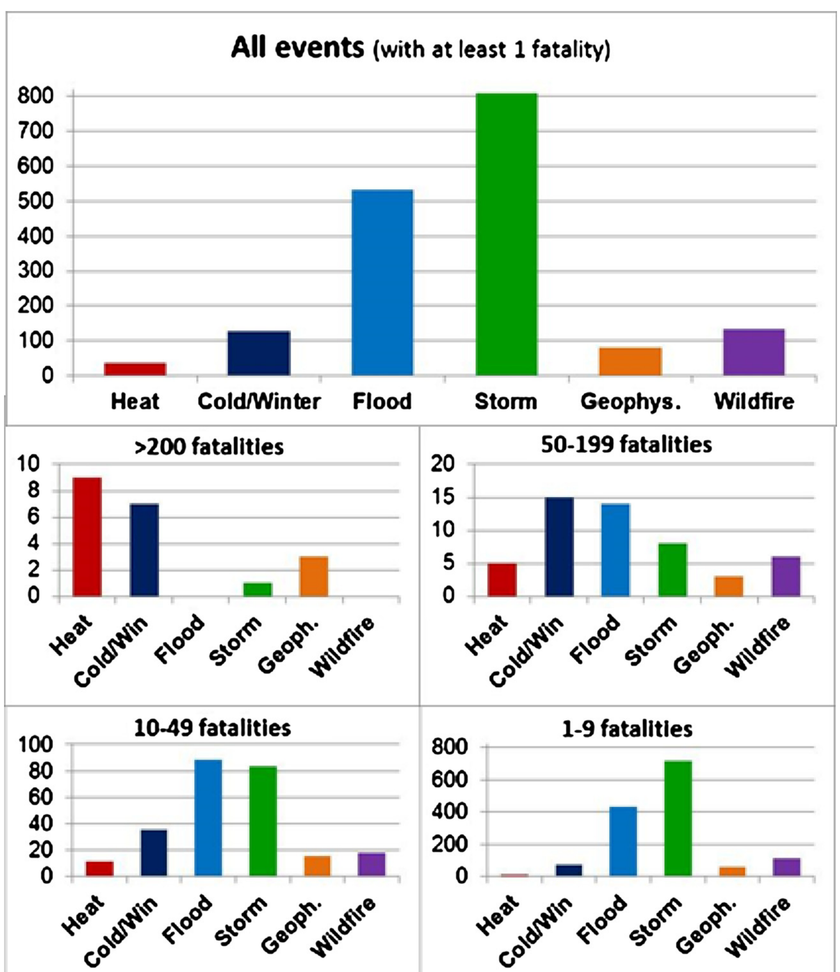

Fig. 3. Number of natural hazard events, ordered by range of the number of fatalities and event type, in each of which at least one person died, for the period from 1980 to 2018 (total: 1719 events).

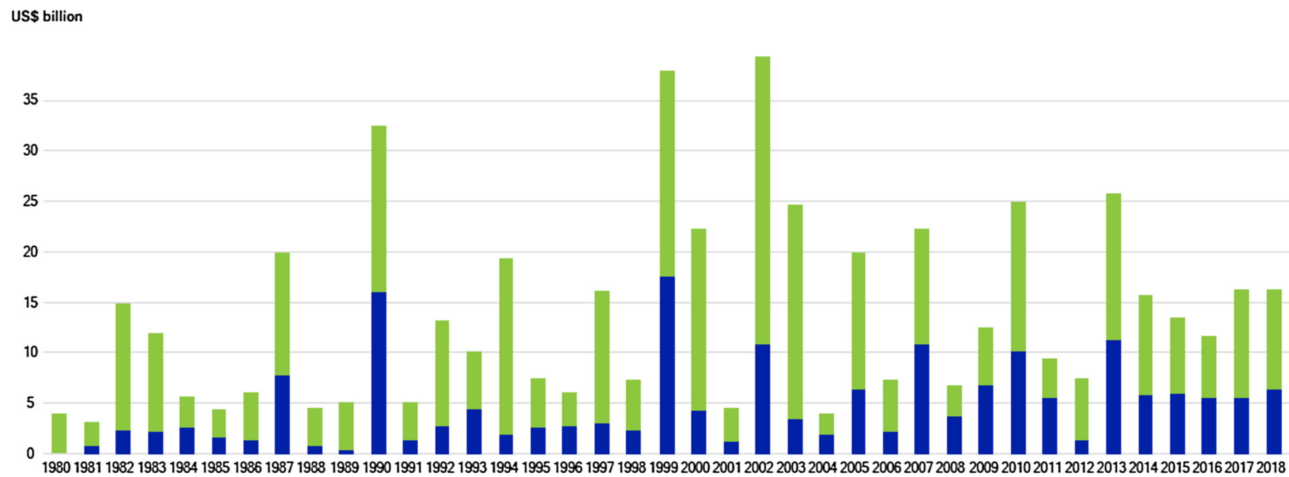

Fig. 4. Overall (■) and insured (■) annual losses from weather events in Europe in the period 1980 to 2018 (in 2018 values, losses adjusted for inflation). Shown are relevant loss events, i.e. those that exceed defined thresholds of normalised overall losses and/or fatalities. Threshold values are: Fatalities ≥ 1; Normalised overall loss ≥ US$ 100k, 300k, 1 m, or 3 m, depending on assigned World Bank income group of each affected country (see Eichner et al., 2016).

selection of the start-year and end-year of the data window examined. Nonetheless, the average annual overall loss in the second half of the period shown is distinctly higher than in the first. The trend in insured losses is clearly visible, which again points to an increase in insurance penetration. This increase is particularly driven by flood insurance.

3.4. Normalisation of losses

We would obtain a rather skewed picture if we simply compared estimates of absolute nominal damage (in original values) over time. Adjustment for inflation, as was conducted to produce Figs. 2 and 4, is typically carried out using the consumer price index (CPI) of each country and taking into account fluctuations in exchange rates. Normalisation takes into account local changes in GDP measured in US$. For details of how this is done, see Eichner et al. (2016).

There are considerable difficulties with inflation adjustment. It could be performed rather easily in the US$ area. However, applying the United States' inflation rate to loss figures of European countries, which sometimes had a completely different development of purchasing power parity (PPP), does not make much sense. Additionally, exchange rates come into play twice: at the time of the event and today. Even if today's inflation rate is not specified, as we give all figures in US$, it would implicitly become important if someone converts the inflation-adjusted figure to 2018 euros or national European currencies. The errors involved can be unacceptable. If we apply the specific countries' inflation rates, which would theoretically be possible, we run into the problem of multi-country events for which we cannot use the event losses. For multi-country (Europe-wide) statistics we could use US$ inflation. This is not an ideal solution. However, as many countries are involved (all in the same "block"), it can be considered acceptable and at least accounts for the general effect of rising prices (Fig. 5).

Adjustment for inflation is the minimum standardisation method that needs to be applied, but we also have to keep in mind such factors as changes in exposed assets, their susceptibility to wind and water, general wealth (expressed, for instance, by purchasing power parity), building-cost index, and others. This calls for normalisation.

Normalisation makes it possible to compare past events to today's situation. If both the former and the new conditions are known, this method represents a very accurate basis for comparison. However, comparing two stages in history in adequate detail becomes more and more difficult the larger an area becomes, and it is virtually impossible for a whole country. Therefore so-called proxy data must be used to assess an area's development. The most-used proxy – and actually the only one that is available globally – is gross domestic product (GDP), reported regionally. We have based our normalisation procedure on GDP at local level (Eichner et al., 2016), so that we can consider regional differences in development (e.g. coastal vs. inland areas).

Both nominal losses, that is original losses reported at the time an event occurred, and inflation-adjusted losses are not sufficient to identify the underlying causes for the temporal distribution of damage. Considering changes in consumer price indices (inflation) does not account for the increase in the number of objects at risk and their "value upgrades", but only for their change in price assuming they remain (physically) unaltered. However, flood plains and other open-space areas that were covered by water during extreme discharge situations decades ago without causing any noteworthy problems may accommodate new urban developments, commercial areas and industrial parks nowadays, hence the damage potential may have grown substantially.

4. Risk assessment and reduction

4.1. Definition of risk

The term "risk" is used in different ways in different situations. For scientific discussions, it should be defined in an unambiguous and consistent way. Here, risk is understood – in a qualitative way – as the product of a hazard (H), i.e. the average occurrence probability of a given natural event and its consequences (C):

$$R = H \times C \tag{1}$$

Consequences depend on the exposed values or values at risk, E, i.e. the objects that are present at the location involved, and vulnerability (V), i.e. the propensity to being adversely affected due to lack of resistance to damaging/destructive forces. Hence, in its simplest form, the risk can be calculated by multiplying the three components, H, E, and V (Kron, 2005):

$$R = H \times E \times V \tag{2}$$

According to Eq. (2), if there are no people or values that can be critically affected by a natural phenomenon, i.e. E = 0, there is no risk. Vulnerability can refer to human health and well-being (human vulnerability), structural integrity (physical vulnerability) or personal wealth (financial vulnerability). Insurance's contribution to risk control addresses the last of these factors. For an insurance or a reinsurance company, E is the portion of exposed values which is covered in the company's portfolio.

Hazard is the threatening natural event described in terms of its

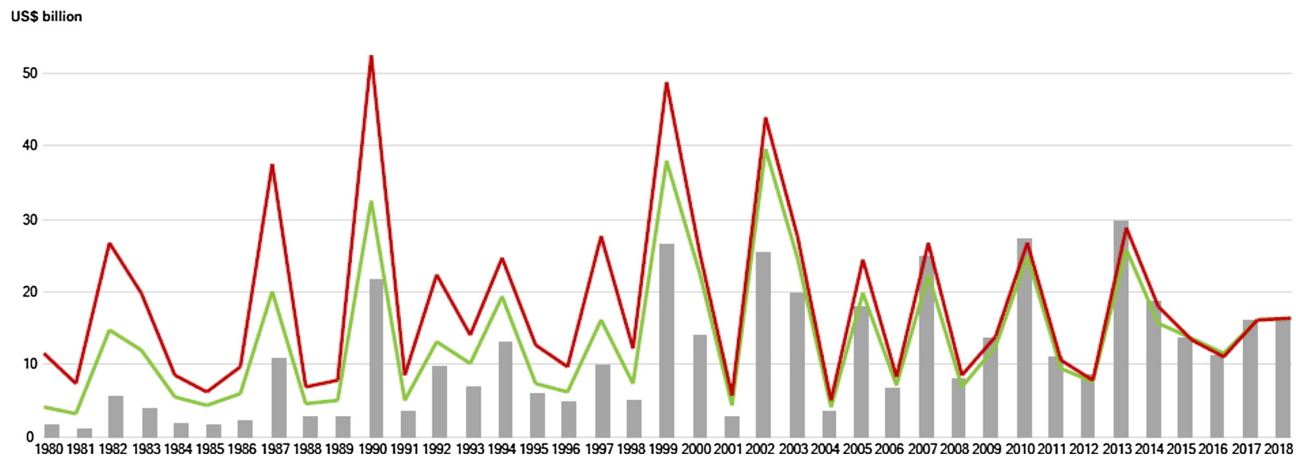

Fig. 5. Original (nominal) (■), inflation-adjusted (▬) and normalised (▬) overall annual losses from weather events in Europe in the period 1980 to 2018 (in 2018 values, losses adjusted for inflation). Shown are relevant loss events (c.f. Fig. 4).

magnitude and probability of occurrence. Exposure quantifies the values that are present at the site threatened/affected by the extreme event. Vulnerability is the hazard-specific lack (or loss) of resistance to damaging/destructive events. Vulnerability depends on the adaptive capacity of the system. The countries of Europe (and in particular EU member states) have – given their economic situation – much more capability to protect themselves against natural disasters than, for instance, less developed countries and countries with emerging economies. The material losses from extreme events in Europe are higher and the number of fatalities lower, except for the effects of heat waves and cold waves. The overall risk, determined by the hazard and the (possibly mushrooming) values of exposed assets, may increase.

Altogether, from 1980 to 2018, 4,890 destructive weather events (including 2,801 relevant events) are recorded in the NCS database for Europe. 837 of the events occurred in the 1980s, 1,239 in the 1990s, 1,345 in the first decade of the 21 st century and 1,469 since 2010 (i.e. in nine years; extrapolated to ten years this would yield (1,469/9 × 10) 1,632 entries. 525 of the 4,890 individual losses caused by adverse weather conditions exceeded US$ 100 m (in original values); 187 were above US$ 500 m, 92 above US$ 1bn, 45 above US$ 2bn, 13 above US$ 5bn, and four even topped US$ 10bn.

There exist several studies examining the risk of weather extremes (of one or several types) and their impacts in Europe. A few examples are given in the sequel.

Lugeri et al. (2010) assessed risk of river floods in Europe, by examining three components: hazard, exposure and vulnerability. They considered annual average damage and highlighted regions where the threat to the economy from river floods is of major concern, drawing the attention of policymakers to possible risk hotspots. Using a topography-based flood hazard map of Europe, they identified low-lying areas adjacent to rivers, as well as applying land-use data and damage-stage relationships for different land uses. Hazard classes were determined by the proximity to the river and the difference in elevation between the land and the closest river. The combination of hazard and the Corine Land Cover (CLC) map for Europe was used to estimate potential exposure of physical assets to floods. The vulnerability of the assets under threat was estimated by means of depth-damage functions for each land-use class of CLC.

Even if inter-annual variability in the number of large floods in Europe has been strong, Kundzewicz et al. (2018b) found an increasing trend in the number of floods with severity or magnitude greater than or equal to 1.5 and 5.0 respectively, in the time interval 1985–2016. The highest number (nine) of floods in this interval occurred in Romania.

The mortality risk related to heat waves has been on the rise. The load (frequency, duration, as well as intensity of heat waves) is increasing, while resistance is decreasing because European societies are ageing. Graczyk et al. (2018) found a disproportionate increase in additional mortality during heat waves among elderly people (aged 65 or more) in Poland.

Hanson et al. (2007) reviewed (observed and projected) impacts of weather extremes in Europe in selected sectors, based on modelling and expert judgment. Changes in weather extremes were found to cause decreasing wintertime and increasing summertime energy consumption. High temperatures and the negative characteristics that accompany the warming may reduce the attractiveness of Mediterranean summer holidays. Instead, the shoulder seasons, spring and autumn, can become more attractive. Warming of North European summers can render northern destinations more attractive to both North European tourists and those from the Mediterranean areas.

4.2. The partnership for risk reduction

Risk and loss minimisation calls for an integrated course of action. The risk must be carried on several shoulders: the state, the people and enterprises affected, and the financial sector, in particular the insurance industry. Only when they all cooperate with each other in a finely tuned relationship and in the spirit of a risk partnership is disaster risk reduction really effective.

The job of public authorities (i.e. the state or the government, be it national or regional) is primarily to reduce the underlying risk to society as a whole. Those directly affected (individuals, companies, communities) have great potential for loss reduction. The crucial point is whether they keep their risk awareness alive. Even those people who do not ignore the danger of natural hazards from the very beginning often quickly forget about it, especially if nothing happens for some time (short-memory syndrome). They must be informed and educated to build houses and use their land in an appropriate manner, control the exposure of their values, and be ready to take adequate action in an emergency. This includes preparing for catastrophic losses by taking financial precautions, e.g. buying insurance, a recommendation the European Court of Auditors gives in its November 2018 report dealing with the progress of the EU Floods Directive (ECA 2018).

The true task of insurance companies is to compensate financial losses that would have a substantial impact on the insured entities or even lead to their ruin. They carry the financial risk from events that have such a low probability that they cannot be considered foreseeable. Insurance redistributes the burden borne by individual entities among the entire community of all insured entities, which is composed in such a way that they all have a chance of being affected – even if the degrees of probability differ. Furthermore, insurers perform educational and public relations services, e.g. by publishing and disseminating easy-to-use material in which they draw attention to hazards and explain ways of dealing with them (e.g. Munich Re, 2008, 2012, 2013, 2018b).

In the same way as private individuals, insurance companies try to avoid volatility in their payments. Natural perils insurance is highly volatile. Large losses from a single event can be reduced by transferring part of the risk to the reinsurance sector, in which companies often do business worldwide. When catastrophic losses occur in one country, they are therefore covered from all over the world, thus relieving the local insurance market and possibly even preventing its collapse.

Only a relatively small proportion of buildings are exposed to river floods: the areas affected are always the same and flooding may occur there at almost regular intervals. People in these areas seek insurance, while those who live some distance from a river are not interested in buying cover. Hence, if an insurance company planned to sell individual policies as part of a voluntary insurance scheme, the premiums would have to be so high that prospective policyholders would normally find them prohibitive. This mechanism is called adverse selection or anti-selection.

Adverse selection can be avoided by offering multi-risk insurance packages. The portfolio is then composed of all kinds of clients: those who live close to a river (flood risk), those in a geologically active region (earthquake risk), those on a mountain slope (landslide and avalanche risk), and so on. Nevertheless, premiums for the various hazards should reflect the individual risk. In mass business – i.e. for private homes and small businesses and their contents – the effort required to assess the exposure of a certain building must be seen in the context of the annual premium income for one such object, which starts in Germany at the level of roughly 50 euros (equivalent to US$ 56, exchange rate of 1.13 euro/US$ as at June 2019) in low-risk areas. Since an individual assessment of the risk and the calculation of an individual premium for these objects are impossible, the premium must be fixed on the basis of a flat-rate assumption. For this, zones with a similar flood (earthquake, landslide) hazard must be identified and/or defined within which the premiums are constant.

Weather events (such as floods) constitute a hazard only when humans encroach on unsafe (e.g. flood-prone) areas. Hence, preventive measures aim to reduce the consequences of flooding by lowering the exposure of people and property, for example by prohibiting or discouraging development in areas at risk (Kundzewicz et al., 2018a). With spatial planning, zoning and bans on development in unsafe areas, it is possible to control new housing and infrastructure and to try to move the existing objects on flood plains out of harm's way. A success story in this respect was reported in the Netherlands, within the “Room for the River” programme that led to the relocation of farms from vulnerable areas.

There is no reasonable insurance solution that can possibly make insurance companies pay for all the losses that may be incurred. Instead, a certain amount has to be borne by the insured entities before the insurance becomes effective, i.e. deductibles must be introduced. Such a structure has advantages for both the insurer and the insured entities. The insurer does not have to settle masses of small losses and saves on both loss compensation payments and administrative costs. The client profits in the form of lower premiums. In a similar way, insurance contracts, especially in industrial business, often define a limit, i.e. a maximum payout sum.

An important consequence of deductibles is the motivation of policyholders "to do something" in order to reduce losses. If people themselves have to pay part of the loss, this should act as an incentive to take precautionary measures or to rescue items in the event of a natural disaster, such as a flood. With proper preparedness and freedom from the responsibility to pay for small losses (which may be very frequent), the insurance company only has to cover a reduced risk – so that the premium will be reduced, too. People whose exposure is so high that they cannot be granted standard insurance may only become eligible for cover by accepting a high deductible.

However, due to the low coverage, some European countries have seen the government forced to act as the insurer of last resort, paying for recovery after damage by natural disaster. This was the case after the destructive July 1997 flood in Poland. At the beginning of the flood, the then Prime Minister of Poland, Cimoszewicz, issued a sober statement that those who had not been insured could not expect compensation for their losses and that there were no significant central budget reserves to be used to this effect. However, as the deluge became extraordinarily damaging, the PM apologised for his statement, which was found to be undiplomatic in the context of the grimness of the unfolding situation. Nevertheless, the original statement of the PM and the unsatisfactory performance of the authorities in their flood management actions were violently criticised by the opposition. This criticism may have contributed to the defeat of the ruling coalition in the parliamentary elections, as surmised by many an international observer (see Kundzewicz et al., 1999).

At European Union (EU) level, there is a European Union Solidarity Fund (EUSF), http://ec.europa.eu/regional_policy/en/policy/what/glossary/e/eu-solidarity-fund, established after the summer 2002 floods that caused the highest-ever material damage by a flood in Europe. The Fund provides assistance to EU member states after major natural disasters, expressing European solidarity to disaster-stricken regions within the Union. It has already provided assistance to 24 EU member states that suffered natural disasters (such as floods, forest fires, earthquakes, storms and droughts). The total financial support from the fund thus far exceeds 5 billion euros. A list of all EUSF interventions can be found in: https://ec.europa.eu/regional_policy/sources/thefunds/doc/interventions_since_2002.pdf

5. Concluding remarks

Weather disasters have increased in number and intensity in recent decades and damage caused by extreme weather events has been on the rise in Europe. This finding results from the increase in the number and size of settlements in areas exposed to extreme weather events, the accumulation of increasingly valuable and vulnerable assets in these areas, as well as the climate and environmental changes that have already taken place. Weather catastrophes constitute a growing burden on national economies and insurance companies, not least because of the costs of precautionary measures.

The projections for the future look grim (e.g. Beniston et al., 2007). Forzieri et al. (2017) found that the percentage of the European population affected by weather-related disasters may increase by an order of magnitude in a hundred years: from 5% in 1981–2010 to two-thirds by about 2100. According to estimates by the European Commission in its climate-change adaptation strategy paper (EC, 2013), the average number of additional deaths caused by heat waves by 2050 may soar to 90,000 per year, i.e. more than in the record summer of 2003. Hence, what was once considered extreme may become the new norm. Results of Alfieri et al. (2017) indicate a correlation between warming and future flood risk, both at European and global levels.

This paper discussed weather perils in Europe, considering several categories of hazard. It also presented and interpreted the climate statistics for Europe, based on analyses of updated information on different categories of weather events, originating from Munich Re's unique NatCatSERVICE database. Statistics show that the risk of natural, weather-related disasters in Europe has been increasing, as have overall losses and insured losses. Yet, the volatility of losses is there for all to see. An individual extreme event may matter a lot. For instance, two major and widespread heat waves that occurred in Europe in 2003 and in 2010, responsible for 70,000 and 56,000 additional deaths respectively, have dominated the statistics, exceeding by orders of magnitude the number of fatalities caused by all the remaining natural disasters in Europe.

It is essential to reduce the risk of weather events. This is the objective of the EU Floods Directive (Directive 2007/60/EC on the assessment and management of flood risks) (EU, 2007). The Directive aims at the reduction and management of the risks that floods pose to human health, economic activity, the environment, and cultural heritage. Specifically, it requires all 28 EU member states to identify areas at risk from flooding, to map the extent of actual floods as well as assets and humans at risk in these areas and to take adequate measures to reduce this flood risk.

Risk reduction means reducing all three components of risk: hazard, exposure and vulnerability. While changes in hazard can be both natural and anthropogenic, changes in exposure and vulnerability are predominantly human-based, as people either move into harm's way or see potential harm move closer to them as a result of technological measures. The statement by Gilbert White: "Floods are acts of God, but flood losses are largely acts of man" (White, 1945), referring originally to floods, can indeed be extended to incorporate several other natural weather events, such as landslides or gale-force winds.

Transferring the residual risk to insurance is highly recommended. Insurance cover may not prevent the loss of homes and personal belongings, but it can prevent people from financial ruin.

Acknowledgments

Statistical data were taken from Munich Re NatCatSERVICE; ZWK wishes to acknowledge financial support from the project: "Interpretation of Change in Flood-related Indices based on Climate Variability" (FloVar) funded by the National Science Centre of Poland (project number 2017/27/B/ST10/00924).

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