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Trends in extreme weather events in Europe: implications for national and European Union adaptation strategies

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building science into EU policy

EASAC

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Its mission reflects the view of academies that science is central to many aspects of modern life and that an appreciation of the scientific dimension is a pre-requisite to wise policy-making. This view already underpins the work of many academies at national level. With the growing importance of the European Union as an arena for policy, academies recognise that the scope of their advisory functions needs to extend beyond the national to cover also the European level. Here it is often the case that a trans-European grouping can be more effective than a body from a single country. The academies of Europe have therefore formed EASAC so that they can speak with a common voice with the goal of building science into policy at EU level.

Through EASAC, the academies work together to provide independent, expert, evidence-based advice about the scientific aspects of public policy to those who make or influence policy within the European institutions. Drawing on the memberships and networks of the academies, EASAC accesses the best of European science in carrying out its work. Its views are vigorously independent of commercial or political bias, and it is open and transparent in its processes. EASAC aims to deliver advice that is comprehensible, relevant and timely.

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Foreword

During the past 50 years the global mean temperature at the Earth's surface has increased by about 0.7 degrees Celsius, very probably contributed to by increased emissions of greenhouse gases. The associated economic and societal risks, the product of probability and consequence, are increasing. As the releases of greenhouse gases and particulate matter related to human activities continue to increase, the demand for action, despite uncertainty, is growing. It is not primarily the change in the mean of climate variables such as temperature, precipitation or wind, or in derived variables like storm surge or water runoff, but rather the changes in the extremes of these variables that pose serious risks. Future extremes could become the most potent drivers of economic and social impacts.

Having said that, the reduction of the factors driving climate change (mitigation) has the benefit of reducing the cost of adaptation. But mitigation and adaptation measures must go hand in hand. Investments must be targeted so that risks are reduced, optimising the cost–benefit relationships between them.

This EASAC report summarises an assessment headed up by the Norwegian Academy of Science and Letters and the Norwegian Meteorological Institute in collaboration with EASAC of historic and possible future changes in extreme weather over Europe. It deals with impacts that include heat waves, floods, droughts and storms. The work, which was completed before the release of the 'Summary for Policy Makers' of the 5th Assessment Report from Working Group 1 of the Intergovernmental Panel on Climate Change, provides expert confirmation from a European perspective. Highlights refer to the nature of the evidence for climate-driven changes in extreme weather in the past, the potential impact of further climate change in altering the pattern of these extremes, and possible adaptation strategies for dealing with extreme weather impacts.

Changes in extreme weather events will, in some cases, present the European Union and its Member States with significant challenges. For example, increases in drought, linked to increases in wind storms, are expected to impact agricultural productivity. Agriculture has considerable adaptive capability, but investment will be needed which will add to the costs of agricultural production. Such investment demands careful planning and the best possible understanding of the future conditions to ensure that plant-breeding programmes, for example, are well targeted.

The EASAC Working Group has taken care to differentiate between what is known to a high level of confidence and what experts are less certain about, and to give information about the degree of precision that we can attribute to the advice for adaptation to extreme weather and climate change. The target group of this report is policy-makers and politicians in European institutions who are committed to the construction and implementation of evidence-based policies. EASAC intends that this report will contribute to the debate about the impacts of future extreme weather on the peoples and economies of Europe and reinforce many of the messages broadcast by the Intergovernmental Panel on Climate Change.

We thank the EASAC working group chaired by Professor Øystein Hov for its expert deliberations and for its detailed full report, Professor Lars Walløe for stimulating this work in the first place, the Norwegian Academy of Sciences for leading this EASAC activity and contributing to the costs of the work, and Professor Michael Norton for assembling the EASAC document. We are indebted to EASAC member academies for all their input and to the peer reviewers and assistants who worked to ensure that this report is as accurate, complete and accessible as possible.

Professor Sir Brian Heap
EASAC President

1 Background

Extreme weather can have a severe impact on society. Europe and areas of Russia experienced unprecedented heat waves during the summers of 2003 and 2010. In 2013, record-breaking floods affected Germany, Hungary and other countries. During summer 2007, the United Kingdom experienced a series of destructive floods across the country such that defences were overwhelmed. These brief examples illustrate that extreme weather may affect lives and livelihoods, agriculture, ecosystems and cause large-scale damage to property and loss of life. Independently of the existence of any trends, these examples also reveal the need for adaptation to today's climate variability; extreme weather events are seen as a part of normal life where societies have learnt to some extent to deal and adapt. However, whether there are trends in such extreme events along with a warming planet is a critical question.

Popular images of global warming are often based on a mental model of a uniformly distributed gradual change. However, potential outcomes for a given location and time may range from hardly any warming to very rapid temperature increases, as we are currently observing in the increase in Arctic temperatures. Thus, adaptation has to address impacts of climate change at local to regional levels. Adapting to climate change is not just a matter of average changes but much more of potential changes in the occurrence of extremes and their frequency, intensity and duration. In particular, policy making at the European Union (EU) level covers 28 countries with a combined population of over 500 million. The EU countries are spread over several very different climate zones from the Mediterranean sub-tropical to the Arctic. Changes in the frequency or intensity of extreme events have considerable implications for vulnerable communities across the continent. Given the inertia in the climate system whereby effects of emissions so far have not yet exerted their full effect, and the absence of effective measures to reduce future emissions of the greenhouse gases that contribute to forcing global warming, adaptation to the consequences becomes necessary and unavoidable.

The Norwegian Academy of Science and Letters and the Norwegian Meteorological Institute, with the support of an EASAC working group, recently published a substantial analysis of the scientific literature on extreme weather events in Europe and the implications for European policy on possible adaptation strategies (NAS and NMI, 2013). This was completed before the release of the Summary for Policy Makers of the 5th Assessment report from the Working Group 1 of the Intergovernmental Panel on Climate Change (IPCC, 2013) and thus cites the earlier work of IPCC (2007) and the IPCC special report on extreme weather (IPCC/SREX, 2012).

EASAC has produced this overview of the Norwegian analysis (NAS and NMI 2013) for European and National Policy makers, as well as European media and public at large. The first part provides information on extreme weather events and trends in recent decades as well as related impacts upon society. It is followed by an introduction to the scientific background on global warming and weather extremes, and the projections of future trends of meteorological extreme events that emerge from climate models under various scenarios of future greenhouse gas emissions. Finally, approaches to adaptation are introduced and recommendations provided. Readers wishing to obtain full source details for the figures, tables and references are recommended to consult the full report, which also includes more detailed analyses of the climatic conditions in various sub-regions of the EU (NAS and NMI, 2013).

2 Extreme weather and trends in Europe

Extreme weather-related events may have great humanitarian impacts entailing loss of lives, in addition to the economic and partly insured losses. Data collected since 1980 by the insurance industry provide one indicator of trends in extreme events. Although these are not direct measures of extreme weather events *per se* and may not have recorded all perils in the earlier record, they show weather-related catastrophes recorded worldwide to have increased from an annual average of 335 events from 1980 to 1989, to 545 events in the 1990s and to 716 events for 2002–2011. Floods and the 'climatological' perils like heat waves, droughts and wild fires show the most pronounced upward trend, followed by storms (Figure 2.1). The analysis presents a clear distinction between all weather-related perils and geophysical hazard events like earthquakes, volcano eruptions and tsunamis, with the latter group showing only a slight and statistically non-significant increase.

Compared with other continents, the increase in loss-relevant natural extreme events in Europe has been moderate (Figure 2.2), with an increase of about 60% over the past three decades. The highest increases have occurred in North America, Asia and Australia/Oceania with today about 3.5 times as many events as at the beginning of the 1980s.

The humanitarian effects are exemplified by the record-breaking heat waves over Central and Western Europe during the summer of 2003 and over Russia during the summer of 2010 (Figure 2.3), which led to tens of thousands of heat-related deaths across Europe, crop shortfalls, extensive forest fires and record high prices on the energy market among many other effects. In the winters of 2005/2006 and 2009/2010 (also Figure 2.3), parts of Europe experienced unusually cold temperatures that caused travel disruption, cold-related mortality and high energy consumption.

Flood damage has strongly increased owing to a wide range of factors, and floods are an increasingly urgent problem (Figure 2.4). Flood risk and society's vulnerability increase because of a range of climatic and non-climatic factors, with a high dependence on site-specific conditions and a combination of these different factors[1]. Losses caused by floods have increased and the death toll continues to be high, as illustrated in Table 2.1.

The economic loss burden of extreme weather events has been considerable, estimated to be €405 billion since 1980 (in 2011 values). The most costly hazards have been storms and floods, amounting to a combined total loss of more than €308 billion. The most affected countries were Germany (455 events), France (425), United Kingdom (415), Switzerland (360), Italy (355) and Spain (317).

In agriculture, the 2003 and 2010 heat waves and associated dry conditions resulted in major regional crop shortfalls. The drought conditions and associated fires in the 2010 heat wave also caused a 25–30% drop in the forecast of Russia's annual grain crop production, compared with 2009.

Figure 2.1 Trends in different types of natural catastrophe worldwide, 1980–2012 (1980 levels set at 100%; Munich Re NatCatSERVICE).

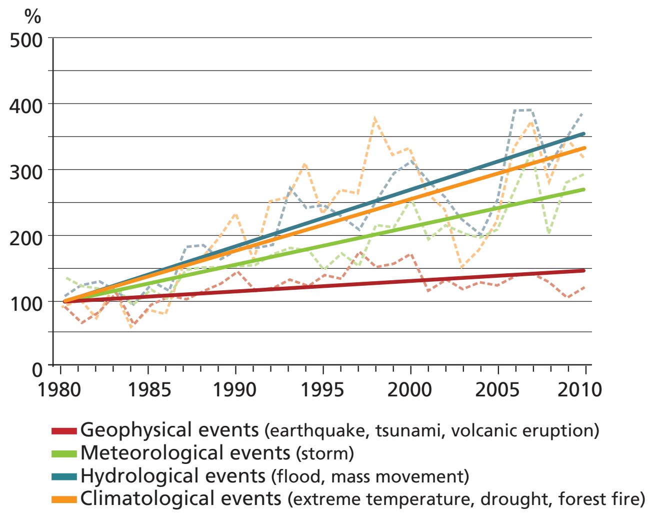
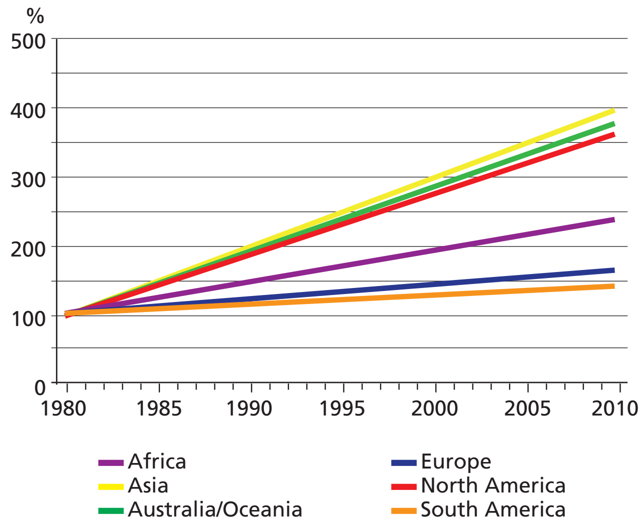


Figure 2.2 Relative trends of loss-relevant natural extreme events in different parts of the world (1980 levels set at 100%; data from Munich Re NatCatSERVICE).



[1] Changes in flood risk have been caused by socio-economic, terrestrial and climatic factors. Changes unrelated to climate change include deforestation, urbanisation and reduction of wetlands, which tend to diminish the available water storage capacity and increase runoff. In addition, economic growth may place more assets under exposure to risks of flooding.

Figure 2.3 Extreme events of cold over Russia (11–18 December 2009, left) and heat (20–27 July 2010, right) compared with the 2000-2008 average (Figure 3.1 on page 28 of NAS and NMI, 2013).

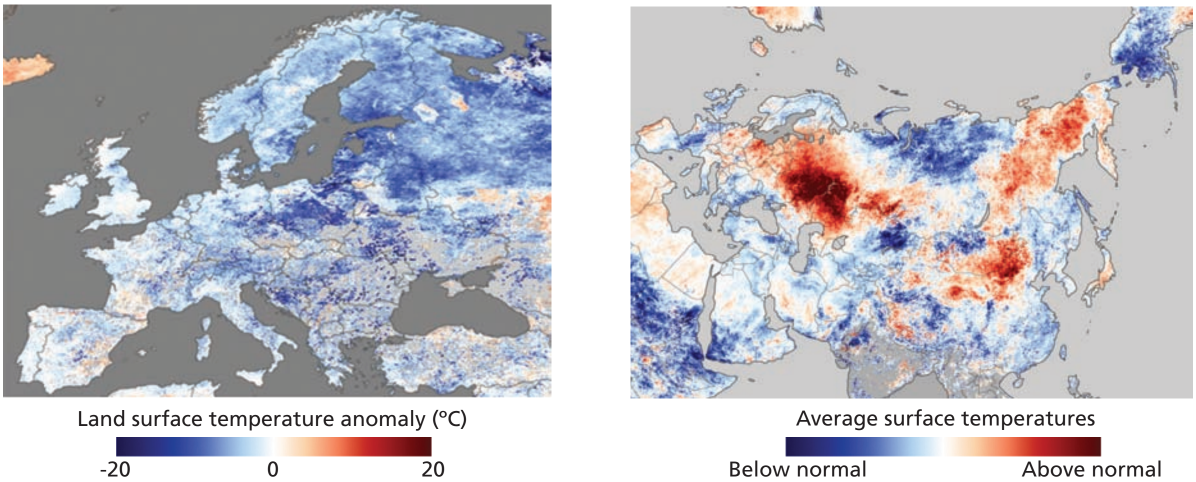
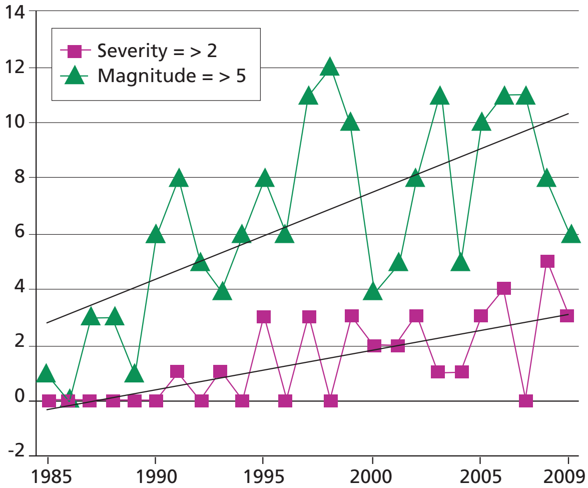


Table 2.1 Floods in Europe with the highest (inflation-adjusted) losses

Flood date	Country	Inflation-adjusted damage (€)	Number of fatalities
November 1966	Italy	10 billion	70–116
August 1983	Spain	2–6 billion	40–45
November 1994	Italy	4.5–10 billion	64–83
July 1997	Poland, Czech Republic, Germany	2–6 billion	100–115
October 2000	Italy, France, Switzerland	7.5 billion	13–37
August 2002	Germany, Czech Republic, Austria	15 billion	47–54
August 2005	Romania, Bulgaria, Switzerland, Austria, Germany	1.1 billion	53
May/June 2013	Central Europe	13 billion	25

Source: see Table 4.1 on page 61 of the full report (NAS and NMI, 2013), where the sources of information are listed; additional data are from Dartmouth Flood Observatory.

Figure 2.4 Large floods in Europe with severity 2 (return period of 100 years or more) and magnitude (index of duration, severity and area) equal to or above 5 (NAS and NMI, 2013, page 61).



Other damage factors related to extreme weather conditions that might need to be considered include the following:

- damage to and destruction of infrastructure:
- irreversible changes in the environment;
- effects on biodiversity;
- inefficient use of land resources;
- population migrations that are environmentally displaced;
- competition for scarce resources;
- decrease in water quality;
- spread of diseases.

In summary, based on insurance industry data (not peer reviewed), the number of loss-relevant weather extremes has increased significantly globally and, to a smaller but still relevant degree, in Europe. There is increasing evidence that at least part of these increases is associated with global warming. The number of large floods in Europe has increased as well as the associated damage, but evidence linking this to climate changes is weak, partly because of a lack of data and partly because of changes in risk management and land use.

3 Connections between global warming and weather extremes

The basic science and trends in global warming and associated climate change have been reviewed in detail by the IPCC (IPCC, 2007; IPCC, 2013) and will not be repeated here. The robust warming signal projected by global climate models is already acknowledged in global risk reports such as those of the World Economic Forum (2013) and the International Risk Governance Council (Renn, 2006). An IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (IPCC/SREX, 2012) also provides a global overview of current knowledge about extreme weather events and changing climate, and their implications for society.

The recent 5th Assessment of Climate Change (IPCC, 2013) concluded that '*warming of the climate system is unequivocal*' and that '*it is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century*'. The statistics described in section 2 above indicate that the frequency of climatological events overall and the resulting damage are increasing. Recent studies have also been able to attach probabilities to the extent to which inherent natural variability is involved and the extent to which climate change associated with global warming is exacerbating this (Box 3.1).

One central message from these analyses summarised in Box 1 is that although no single event is caused by climate change associated with global warming, all weather events include a manifestation of climate change because the environment in which they occur is warmer and, in many areas, with higher moisture content than it used to be.

In the basic consideration of extreme events, there is a need to recognise the effects of a change in the average value for a weather event (temperature or precipitation) on the future frequency and intensity of that event. This is illustrated in Figure 3.1 for the example of temperature; the figure illustrates that increasing the mean temperature (the solid curve shifts to the dashed curve on the right) results in an increase of the frequency of hitherto record hot days, but also leads to days hotter than have ever been experienced before.

Another critical factor is that potential nonlinear effects associated with extremes may be triggered by the nature of regional climate regimes. For Europe, these are the North Atlantic Oscillation and its association with the position of the Polar Jet Stream in the atmosphere, and the wind-driven North Atlantic surface currents (Gulf Stream) associated with the Atlantic Meridional Overturning Circulation. For instance, a shift in storm

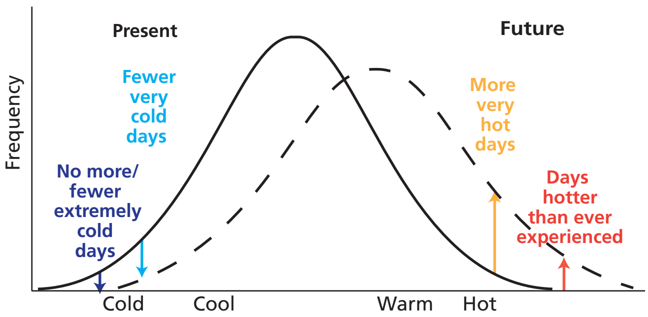
Box 3.1 Assessing the contribution of climate change and natural variability to extreme events

The NAS and NMI (2013) report reviews recent studies that allow us to assess the contribution of climate change associated with global warming to the probability of extreme events. These analyses do not seek to relate any event only to climate change and global warming, but allow the probability that such events would have occurred in a non-warming world to be assessed and compared with events under current global warming conditions. The main insights include the following.

- Warming increases the water vapour in the lower ~10 km of the atmosphere; this feeds storm systems with additional energy which, when released as precipitation, amplifies the intensity of heavy rainfall events.
- Heavy and extreme rain events have been associated with high sea-surface temperatures.
- Human influence on climate has increased the probability that persistent anticyclones may cause heat waves in Europe such as in 2003 by around a factor of four compared with the scenario without recent climate warming.
- Extreme summertime temperatures are being experienced that are more than three standard deviations* warmer than would be expected from the climatological record. These high temperature extremes typically covered areas less than 1% of Earth's land surface between 1951 and 1980, but under the current situation these events may affect areas of about 10% of the Earth's land surface. Some of the hot anomalies during 2006–2011, including in Europe, exceeded three, four and five standard deviations of the 1951–1980 observations.
- The relative influence on these extreme heat waves of natural internal fluctuations is still under investigation. One model indicates that it is unlikely that the extreme hot summers in Western and Central Europe in 2003 and in Russia in 2010 would have occurred in the absence of global warming and, for a future global warming of at least 1 °C, anomalies exceeding three standard deviations would be the norm and five standard deviations should be occasionally expected. However, another study suggests that, at least for Russia in 2010, natural internal fluctuations may have been mainly responsible.

*The standard deviation measures how far the data are spread around the overall average.

Figure 3.1 Effects of shifting the mean temperature value on frequency and intensity of temperature extremes (Figure 3.2 of NAS and NMI, 2013).



tracks may in principle entail higher storminess in some regions, less in others, with no net change globally. The polar amplification in recent warming trends (whereby the temperature rise is larger in the Arctic than at middle and low latitudes) has, among other things, manifested itself as a long-term negative trend in sea-ice cover, snow cover, and the average position and strength of westerly wind system at mid-latitudes. Furthermore, as pointed out in the IPCC 5th Assessment (IPCC/SPM, 2013), the Atlantic Meridional Overturning Circulation is projected to weaken over this century in response to scenarios of future greenhouse gas emissions. Even though the strength of this projected weakening is uncertain, such reductions may reduce the transfer of heat to the North-East Atlantic and the Euro-Atlantic sector of the Arctic, with potential for local cooling and disruption of weather patterns.

When we start assessing future trends and risks, we must also recognise that in a complex system such as the Earth's climate, extreme events recur in an irregular mode: the timing is unpredictable, and extreme events may essentially be regarded as stochastic (non-deterministic and sporadic). The discipline of statistical modelling is therefore suited to describing extreme events. The emerging framework is essentially risk analytic, relying on information about extreme weather phenomena and related consequences. The NAS and NMI (2013) report details the way in which statistics are used to assess the probability of events, and how it is possible through risk analysis to understand the nature of unwanted, negative consequences to human life, health, property or the environment, as a first step in reducing and/or preparing for them.

The full report considers the risks of different extreme events, and examines the following in detail:

- extreme temperatures;
- intense precipitation and floods;
- wind storms;
- convection-related events, thunderstorms and hail;
- droughts.

4 Specific climate extremes

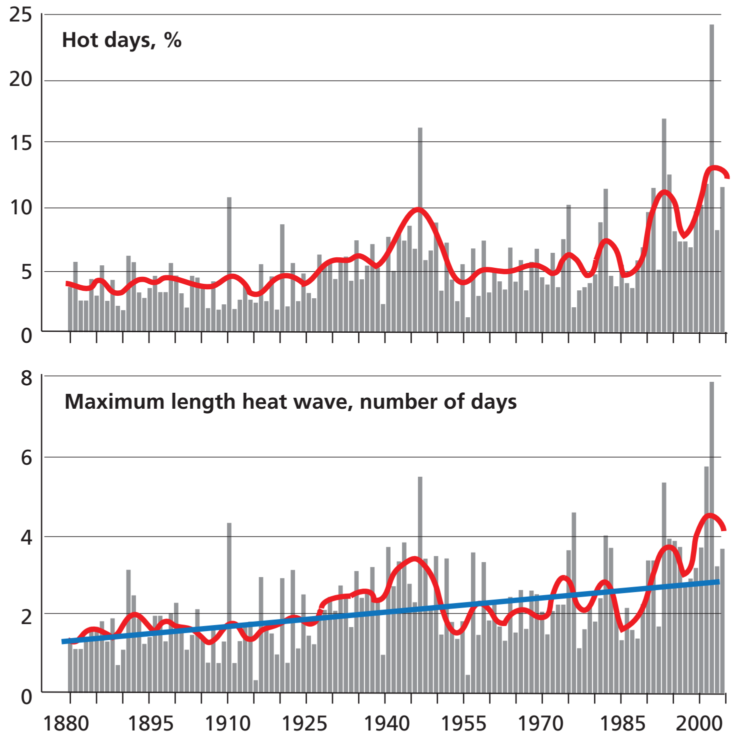
4.1 Extreme heat and cold

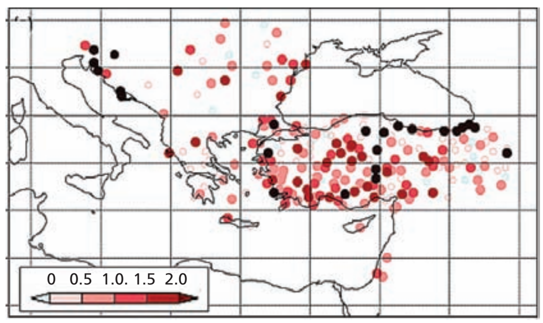
Since adaptation to extremes of heat and cold is particularly difficult, changes in their frequency, duration or spatial extent, and extreme intensities never experienced before would place these phenomena among the most serious challenges to society. The IPCC Special Report on Extreme Events (IPCC/SREX, 2012) concludes that there have been major increases in the frequency of warm temperature extremes in Europe, with high confidence in this conclusion for the Mediterranean region. Over North and Central Europe, there is medium confidence in an increase in heat-wave intensity and frequency. Furthermore, there has been a clustering of exceptionally warm European summers, and recent spring and autumn temperatures were also exceptionally warm. Based on homogenised long-term temperature series at 54 European stations, on average, the length of heat waves has doubled and the frequency of hot days has almost tripled since 1880 (Figure 4.1).

The high-temperature summer extremes have been contrasted with extreme cold winters in some years in parts of Europe. However, such cold spells are often associated with the same type of long-lasting high-pressure systems as summer heat waves. Such anticyclones can 'block' the otherwise natural eastward propagation of air and weather systems, sometimes for many weeks, with huge contrasts between longitudinal sectors. Blocking anticyclones over continents in summer will be dominated by cloud-free air with strong solar heating of the ground and exhaustion of soil moisture. Sectors on each side will often be dominated by persistent cyclones with cool air and convective rain. In between, air will efficiently flow northwards on the western and southwards on the eastern flanks of the blocking anticyclone. This enhanced meridional flow is the key to understanding why the same type of regional weather patterns that cause heat waves in summer may cause extreme cold weather in some sectors in winter. Persistent northerly flows may efficiently bring Arctic air masses far south while, at the same time, sectors to the west may often experience mild air from the south.[2]

Recent studies suggest that retreating sea-ice in the Arctic may have an impact on the occurrence of such

Figure 4.1 Percentage of summer days when maximum temperature exceeded long-term daily 95th centile (top left) and maximum heat-wave duration in days, 1880–2005 over Western Europe (bottom left). Right: linear trends in heat-wave intensity in Southeastern Europe, 1960–2006.





Trend 1960–2006 (° C/decade)

[2] For example, the cold winter of northern and western parts of the European continent in 2013 under the influence of persistent cold air from Northern Russia and the Arctic was accompanied by mild weather over the northern North Atlantic with relatively high temperatures as far north as Spitzbergen.

Figure 4.2 Degrees of warming projected to occur between 2000 and 2100 (June–August) by climate models (see page 35 of the full report for details).

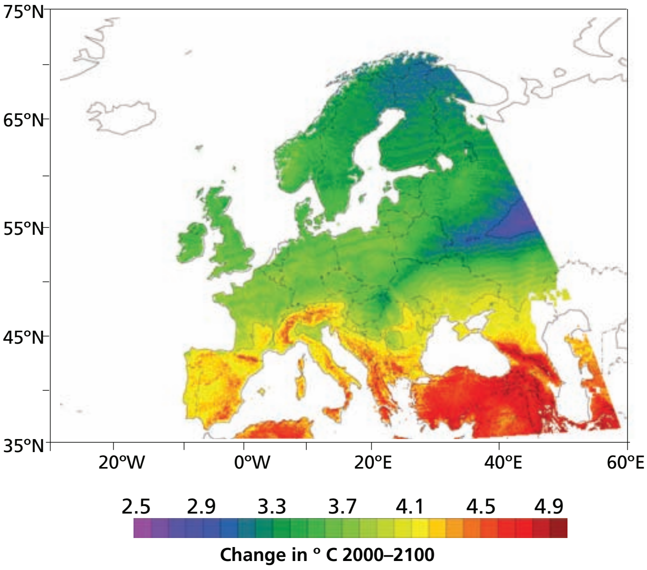
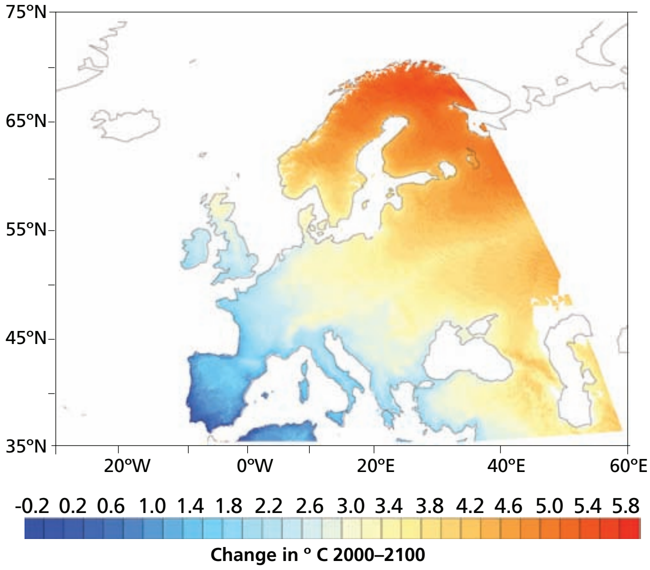


Figure 4.3 Degrees of warming projected to occur between 2000 and 2100 (December–February) by climate models (see page 35 of the full report for details).



weather patterns. Further research is needed to test these hypotheses, but even in the absence of such mechanisms, Europe will continue to experience cold spells even when mean temperatures increase further in the long term.

Turning to the future, based on scenarios for changes in energy use, emissions of greenhouse gases, aerosols and land use, climate models project (Figure 4.2) the following.

- More frequent warm days and nights: the greatest increase in Southern and Central Europe and least in Northern Europe;
- Decreasing frequency of cold days and nights across all Europe.
- Heat waves in Europe are very likely to become more frequent, intense and longer-lasting, mainly following an increase in seasonal mean temperatures. As a result, the probability of occurrence of recent events such as the 2010 Russian heat wave would increase substantially by a factor of 5–10 by mid-century. Extremely hot summer temperatures, as seen in 2003, are projected to be exceeded every second to third summer by the end of the 21st century.
- Temperatures during the hottest days are expected to increase substantially more than the corresponding mean local temperatures in Central and Southern Europe: temperature extremes may rise by more than 6 °C.
- Winter cold extremes are expected to become rarer on average (Figure 4.3).

4.2 Extremes of precipitation

Extreme precipitation can be short term (from a fraction of an hour to a few hours and, in very rare cases, one day), which results from a strong convergence of atmospheric water vapour with local dynamic processes triggering precipitation over confined areas. However, extreme precipitation may also be associated with large amounts of precipitation occurring over longer periods (weeks to seasons) when the short-term intensity need not be particularly extreme, but the duration causes precipitation amounts sufficient to impact nature and society.

The NAS and NMI (2013) report suggests increases in precipitation over land north of 30° N (1901–2005), and decreases over land between 10° S and 30° N, after the 1970s. Intense precipitation in Europe exhibits complex variability and a lack of a robust spatial pattern, but there are more regions that exhibit a positive rather than negative trend in heavy precipitation, as has also been observed globally. In addition, short and isolated rain events have been regrouped into prolonged wet spells so that precipitation totals in longer wet spells have increased (Figure 4.4).

For future trends, the capacity of the atmosphere to hold water vapour increases by about 7% per degree Celsius of temperature increase, increasing with higher temperatures. This increased atmospheric moisture feeds storms on all spatial scales with more water vapour, and if other factors remain unchanged, precipitation should increase. In addition, extra precipitation releases more latent heat of condensation in the rising air associated with the convergence of moisture into the storm. This causes enhanced convergence of more moisture, and a positive feedback, increasing the precipitation rate

Figure 4.4 Observed trends (percentage per decade) in the contribution to total precipitation of very wet days.

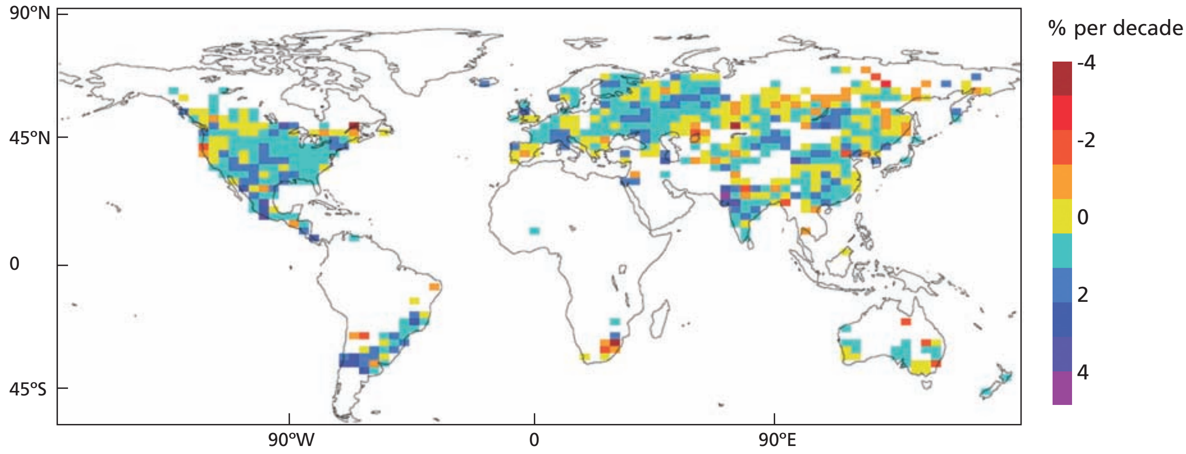
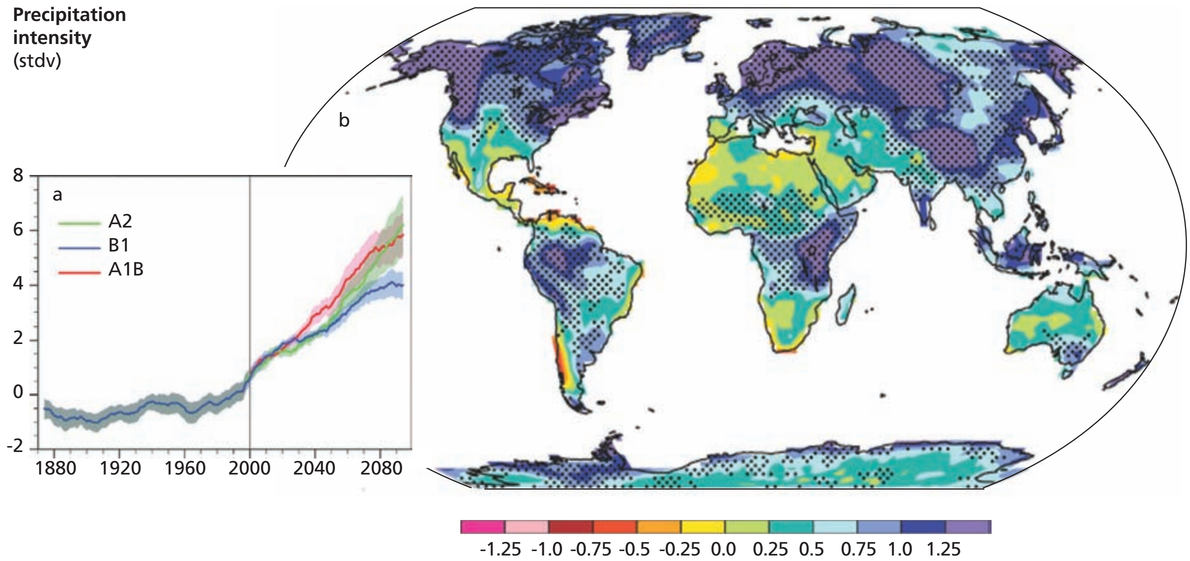


Figure 4.5 Changes in spatial patterns of precipitation intensity (defined as the annual total precipitation divided by the number of wet days) over land, based on multi-model simulations from nine global coupled climate models.



further. Consequently, events with light and moderate precipitation amounts must on average decrease, while the heavy precipitation events become more frequent (even in regions with decreasing total precipitation).

Precipitation in Northern Europe depends to a considerably larger extent on moisture transported from North Atlantic storm tracks than in Southern Europe, where precipitation relies more on regional evaporation. Regional climate model results for Northern Europe imply that high intensity and extreme precipitation become more frequent; the increased frequency is estimated to be larger for more extreme events. However, a considerable variation exists within the sub-regions (see NAS and NMI, 2013). With the exception of the Mediterranean region, wetter winters are expected throughout the continent, but less snow and more rain. In summer, a strong difference in the change in precipitation intensity between Northern Europe (getting wetter) and Southern Europe (getting drier) is projected (Figure 4.5). As pointed out in IPCC (2013), changes in the water cycle will not be uniform, and the contrast in precipitation between wet and dry regions will increase.

In summary, it is thus expected that

- in general, across Europe there will be more frequent events of high precipitation and fewer events of moderate or low precipitation in future;
- over most areas, winters will in general be wetter (outside the Mediterranean) and summers drier;
- there will be differences in change across Europe, with drier conditions in Southern Europe and wetter conditions in Northern Europe.

4.3 Storms, winds and surges

European wind storms are intense and related to travelling cyclones associated with larger areas of low atmospheric pressure. They occur most frequently during winter. Data analyses indicate in the past 60 years an increase of storminess in Europe, with a strong rise from the 1960s to the 1990s and some moderation thereafter. The extent to which this is part of natural variability or is related to anthropogenic climate change is not known and needs further investigation. Observed long-term variations in European storminess are not yet well understood.

Climate models examined in NAS and NMI (2013) estimate an overall decrease in cyclone numbers in the Northern Hemisphere mid-latitudes, but an increase in the number and intensity of severe storms in Northwestern and Central Europe. An increase in extreme wind speed is expected for an area stretching from the United Kingdom to Poland (Figure 4.6).

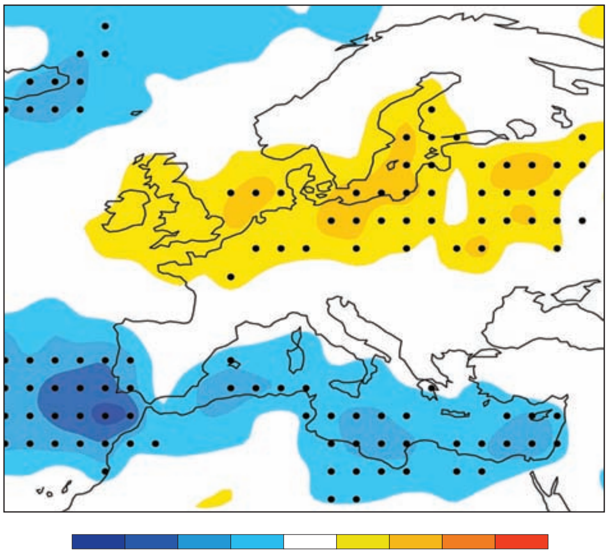
Severe convective storms may produce heavy rain, which can also be accompanied by large hail and by hazardous wind phenomena such as tornadoes or downbursts. These storms are extreme manifestations of moist atmospheric convection, and are generally referred to as thunderstorms, owing to the lightning and thunder often accompanying storm development. The convective storms can form organised storm ensembles called meso-scale convective systems. For instance, a rare windstorm called a *derecho* involving a strongly organised line of thunderstorms was observed in Europe (10 July 2002 in Germany). Currently, the data available for such summer storms are not sufficiently reliable to assess recent trends in the frequency of local hazardous phenomena. Yet, model scenarios suggest that in future there can be more occasions when conditions are favourable for the development of these storms.

Regarding storm surges, areas of particularly high probability of occurrence are the North Sea coast, some areas of the Baltic coastal zone, parts of the Iberian west coast, the Gulf of Lyon and areas of the northern shores of the Adriatic. Climate change may affect storm surges both through the continuing rise in average sea level and through changes in the number, path and strength of cyclonic storms. Global mean sea level rose by an average of 1.7 mm per year over the 20th century, and since the 1980s it has risen at an average rate of 3.4 mm per year. Estimates of future sea level rise range from 0.26 to 0.55 m under the lowest future-emissions scenario, to between 0.52 and 0.98 m under the highest, until the end of the 21st century (IPCC, 2013). Some recent studies project more than a 1 m rise by the end of the century. There are significant regional differences in sea level rise due to changes in ocean circulation and atmospheric pressure. The extremes of sea level associated with storm surges pose threats to coastal cities, with millions of people and assets valued at many trillions of Euros exposed.

4.4 Drought

Drought is one of the most damaging types of natural hazard over long periods, with severe potential impacts on agriculture, food production and the water supply. In Europe, droughts and prolonged dry spells comprising an abnormal deficit of precipitation are relatively rare events. Examples of prolonged European droughts include the 2005–2006 drought over the Iberian Peninsula, the dry conditions associated with the 2003 heat wave, and the 1975–1976 drought over the southern British Isles and northern France. Currently available records suggest that, although increasing summer dryness has been observed in Central and Southern Europe since the 1950s, no consistent trends can be seen over the rest of Europe. The IPCC/SREX (2012) report concludes that there is medium confidence that anthropogenic influence has contributed to some changes in drought patterns since the 1950s, in particular trends towards more intense and longer droughts in Southern Europe.

Figure 4.6 Ensemble mean of the 98th percentile of the maximum wind speed in the climate model simulations. Changes are shown for the IPCC/SREX scenario A1B for 2071–2100 relative to 1961–2000. Coloured areas indicate the magnitude of change (in metres per second); statistical significance above 0.95 is shown by black dots.



The NAS and NMI (2013) report explains the various definitions and indices of drought, and that projections based on knowledge of physical processes expect increasing atmospheric greenhouse-gas concentrations to lead to enhanced evaporation, earlier snow melt and vegetation onset: three factors contributing to enhanced summer drying. Thus, a long-standing result from global-coupled models has been a projected increase in summer drying in the mid-latitudes in a future, warmer climate, with an associated increased likelihood of drought. Summer dryness is expected to increase in the Mediterranean, Central and Southern Europe during the 21st century, leading to enhanced risk of drought, longer dry spells and stronger soil-moisture deficits. In Northern Europe, however, no major changes in dryness are expected until the end of this century.

5 Future risks and adaptation

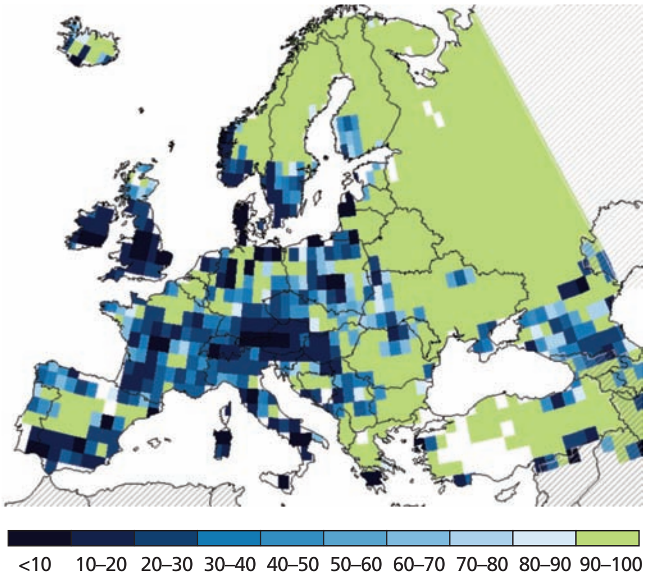
In the previous chapters, the increase in natural catastrophes has been introduced with evidence on past trends and projections of future trends. To characterise extreme weather in future projections is difficult because of the spatial and temporal variability of such rare events. For some areas of Europe, a greater or reduced probability in certain categories of extreme weather is expected. For instance, floods corresponding to a return period of 100 years are expected to become considerably more frequent in wide areas of Poland, Germany, Austria, Switzerland, France and Italy (Figure 5.1). In contrast, over wide areas of Russia and Scandinavia, such 100-year events may occur less frequently.

The NAS and NMI (2013) report reviews extreme weather potential impacts on specific sectors, particularly those of agriculture, energy and health, but also transport infrastructure, water supply, snow melt, flooding, air pollution, forest and wildfires, destabilisation of infrastructure in mountainous regions, vulnerability of wind-power generators and transmission lines, finance through the insurance sector and other aspects. In different sectors of the economy, adaptation strategies to extreme weather events have been part of planning processes for many years. Current energy and transport infrastructure, for example, have improved their resilience to extreme precipitation and consequent flooding. In part this has been a commercial or operational response to the experience of past extreme events and in part the need to plan infrastructure to improving resilience standards.

The concept of adaptation to extreme climatic events has roots going back centuries; however, when the climate changes, the conditions to which societies have historically adapted are no longer the norm, and there is a need to adapt further. Assumptions about future operating conditions are a normal part of planning, with definition of the future climate being crucial to the design process. It is clearly desirable in future investment to build in a degree of resilience, but there is a trade-off between the degree of resilience and affordability, and a project assessment may need to set the level of acceptable risk.

The critical factor in planning is the frequency of extreme events and their severity. For planning purposes it is necessary to understand whether such instances will occur as in the past or whether there is a trend towards greater frequency and/or severity. Weather and climate data are thus fundamental inputs to the planning processes. The NAS and NMI (2013) report outlines the European research underway to improve the understanding of impacts of extreme weather on different sectors of the European economy at European and regional scales. Out of 28, only 13 of the European Economic Area countries

Figure 5.1 Recurrence interval (return period) of today's (1961–1990) 100-year flood at the end of the 21st century (2071–2100).



(the EU countries plus Iceland, Liechtenstein and Norway) have national adaptation strategies.

The role of climate variability in disaster risk management was examined in the IPCC/SREX (2012) report. Such risk management includes immediate response and relief associated with disasters in addition to long-term planning, although response planning is part of long-term risk management. The role of climate sciences is to provide information about the range of plausible scenarios and likelihoods that should be taken into account, and inform the modification and expansion of local disaster risk-management principles and experience. The geographic pooling of risks through reinsurance related to food security, trade and energy production and delivery is one approach for adapting to climate change on a global scale.

The NAS and NMI (2013) report also reviews adaptation to and experience of climate change, but points out that relevant case studies remain in short supply. An overview on climate-change adaptation (also termed climate-proofing) both for existing and new infrastructure can be found in IPCC/SREX (2012); for example, upgrading of ports to account for future sea level rise and changes in storm surges.

Climate-proofing can also include investment in education, ensuring that the impacts of extreme weather and action to counter them become better known. The IPCC/SREX (2012) report also estimated that global costs of climate-proofing with a 2030 time horizon could be in the range US$48–171 billion per year. However, these figures are quite uncertain, and the inclusion of such elements and sectors as ecosystem services, energy, manufacturing, retailing and tourism could add further costs. The NAS and NMI (2013) report reviews some of the few analyses available on the cost of local risk management and its cost–benefit; for example, in defending Copenhagen against risks of sea level rise and storm surges.

In the absence of protection, future extremes of sea level associated with storm surges coupled with a global sea-level rise will significantly increase storm flood risks in coastal zones of Europe. Although there is considerable uncertainty on future sea-level rise, it is important to start implementing long-term adaptation in the coastal cities located in the most vulnerable areas. Planning and new coastal infrastructure investments should take into account the risk over the entire lifetime of the infrastructures and allow for flexibility, making it possible to upgrade them if sea-level rise turns out to be larger than expected. Furthermore, it is necessary to improve flood emergency plans, early-warning systems and evacuation schemes. Long-term strategies of protection versus accommodation (living with floods) versus retreat are also covered in NAS and NMI (2013).

Traditionally, drought management has been reactive, relying largely on crisis management. However, this approach has been ineffective because of its untimely response, poor coordination and poor reach in drought-affected groups or areas. NAS and NMI (2013) indicates a need for sophisticated and reliable drought monitoring tools and early-warning systems that integrate seasonal forecasts with drought projections, with improved communication involving advisory and extension services.

Adaptation to temperature extremes includes the following:

- early-warning systems that reach particularly vulnerable groups, such as the elderly and children (and related medical staff);
- vulnerability mapping and corresponding measures;
- public information on what to do during heat waves, including advice on behaviour;
- use of social-care networks to reach vulnerable groups.

The increased future variability in precipitation, in terms of time, space and intensity, will increase the uncertainty in the productivity in agriculture, with high losses if extreme events occur. Additionally, these events and changing climatic conditions introduce new challenges for farmers in decision making and planning what crops should be planted. A general improvement in resilience would be desirable through, for example,

- development of soil-protecting farming systems and water-saving technologies (including improved irrigation efficiency);
- breeding and cultivation of plant varieties capable of adapting to changing conditions;
- development of new technologies to exploit the relative advantages of climate change;
- development of a satisfactory insurance system for farmers.

Further climate-proofing strategies are discussed in IPCC/SREX (2012).

6 Conclusions

1. Scientific information about temporal changes in the probability of extreme weather events, their magnitude and scale, is important for informed social and political decision-making leading to adequate climate-change adaptation strategies in Europe. It is thus important that such information should continue to develop in detail and reliability to improve their value to planning and the adaptation-policy process.

2. Insurance industry data (not peer reviewed) clearly show that the number of loss-relevant weather extremes has significantly increased on a global scale and, to a smaller but still relevant degree, in Europe. Weather events, particularly heat waves have also been responsible for considerable loss of life, estimated at around 140,000 fatalities in Europe since 1980. There is increasing evidence that global warming drives at least part of these trends.

3. Trends to more and longer heat waves and fewer extremely cold days and nights have been observed. It is expected that the trends towards longer and more intense heat waves will continue with further warming.

4. Winter rainfall has decreased over Southern Europe and has increased further north. Recent decades have experienced large floods and associated damages, although consistent trends in annual flood maxima are not currently evident. Future projections suggest increases in flood risk over a wide area of Europe owing to increases in the frequency and intensity of heavy rainfall.

5. Increasing summer dryness, which is associated with drought, has been observed in Central and Southern Europe since the 1950s but no consistent trend is evident over the rest of Europe. Climate models suggest more frequent droughts in the future throughout Europe, although flash and urban floods triggered by local, intense precipitation events are also likely to be more frequent.

6. Projections of future climate suggest an increase in windstorm-related risks for Western and Central Europe.

7. Low-lying coastal zones are considered particularly vulnerable to climate change, especially through sea level rise, and storm surges.

8. For the production of many crops in European agriculture, weather extremes are the most significant factor in the impact of climate change. An increased frequency of extreme weather events would probably be damaging to crop production, horticulture and forestry. Measures are needed to protect against these effects and to ensure the future production of food and raw materials.

9. Adaptation is a critical part of societal responses to the threats of global warming and climate change. Such strategies are already implemented to improve the resilience of specific sectors, such as in the health and transport sectors. However, adaptation needs to be considered across a wider range of sectors, taking into account the latest scientific information on the probabilities of extreme weather events.

10. Most required adaptation actions will need to be performed by a greater number of individual Member States, but there is an important role for the European Commission and its institutions to support Member States in the development of National Climate Change Adaptation Plans. In addition, some adaptation measures will require action at a European level, such as where there are shared resources or geographic features that cross national borders. There will also be a requirement for EU action where sectors or resources have strong EU integration (for example agriculture and fisheries, water, biodiversity, and transport and energy networks). The EU also has a critical role in strengthening European climate-research communities and building networks across borders and disciplines.

7 Recommendations

Based on the NAS and NMI (2013) report, EASAC makes the following recommendations on strengthening EU capabilities to respond to the threats posed by climate change.

1. **Information.** Effective, cost-efficient adaptation depends critically on information about how future global warming will affect extremes of all weather phenomena. Further research is therefore required, in particular on the development of regional models for predicting possible changes to patterns of extreme weather. Meeting needs for data and information requires the development of climate service networks[3] at European and national levels.

2. **Heat-waves**. Given that impacts of heat waves are highly variable across Europe, further studies of the factors affecting health outcomes during heat waves are required.

3. **Flood defence and early warning.** Good practice in flood preparedness and zoning for flood defence across Europe should be shared, including information about different responses to flood preparedness and flood warnings.

4. **Agriculture.** To improve the resilience of European agriculture, urgent action is required to establish plans after the approval of national or regional adaptation strategies. Guidance on vulnerability to extreme weather and possible measures to increase resilience should be produced.

5. **Strengthen the basis for informed action and our knowledge about climate.** Climate-change adaptation has to become a continuous process that relies on continued monitoring of the state of the climate and the environment. Hence, sustained observations, analysis and climate modelling about the Earth are integral parts of a robust and flexible climate-change adaptation strategy. Knowledge dissemination and innovation are crucial in helping to confront the challenges associated with climate change. It is necessary to continue strengthening European climate-research communities and to build networks across borders and disciplines. It is important that society has free and ready access to the information on which to base its decisions. Research management also should ensure adequate resources for the cross-disciplinary research needed to provide a more complete account of climate change and its impacts. Climate models have proved of immense value in providing the basis for understanding climate and its future. However, there is an urgent need to improve regional climate representation in global climate models to reduce uncertainties and improve projections, for example for extreme precipitations or hail storms and other local climatic phenomena that remain imperfectly understood.

6. **Recommendations for society, scientific communities and science policy makers.** There may be many barriers to adaptation, including those that are physical, technical, psychological, financial, institutional and knowledge. For climate-change adaptation, it is important to consider the range of different factors that affect vulnerability, including human factors, and to use the best possible information about the extreme weather conditions that will challenge this vulnerability. Although current climate models[4] have limitations in predicting future changes in extreme weather, it is important to make the best use of the information available, and to act now, because the stakes are high and adaptation investments are more beneficial now than later. The risks associated with future climate change can however only be reduced by mitigation measures. These require governmental decisions.

[3] The concept of climate services is in Box 5.2 in NAS and NMI (2013).
[4] New generations of climate simulations are designed to provide more accurate and geographically differentiated information.

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