Climate change adaptation and disaster risk reduction in Europe

Enhancing coherence of the knowledge base, policies and practices

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European Environment Agency

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European Environment Agency
Kongens Nytorv 6
1050 Copenhagen K
Denmark
Tel.: +45 33 36 71 00
Web: eea.europa.eu
Enquiries: eea.europa.eu/enquiries

Contents

Acknowledgements

Coordination

Sergio Castellari (European Environment Agency (EEA)) and Blaž Kurnik (EEA) with the support of André Jol (EEA), Paul McAleavey (EEA) and Jaroslav Mysiak (European Topic Centre on Climate Change Impacts, Vulnerability and adaptation (ETC/CCA), Euro-Mediterranean Centre on Climate Change (CMCC), Italy).

Executive summary

Lead authors:
Blaž Kurnik (EEA), Sergio Castellari (EEA), André Jol (EEA) and Jaroslav Mysiak (ETC/CCA, CMCC, Italy).

Contributing authors:
Rob Swart (ETC/CCA, Wageningen Environmental Research (WER), the Netherlands), Reimund Schwarze (ETC/CCA, Helmholtz Centre for Environmental Research (UFZ), Germany), Patrick Pringle (ETC/CCA, Environmental Change Institute, University of Oxford (OU), United Kingdom), Ad Jeuken (European Topic Centre on Inland, Coastal and Marine waters (ETC/ICM), Deltares, the Netherlands) and Henk Wolters (ETC/ICM, Deltares, the Netherlands).

Chapter 1

Lead Authors:
Sergio Castellari (EEA), Blaž Kurnik (EEA), and Jaroslav Mysiak (ETC/CCA, CMCC, Italy).

Contributing authors:
Patrick Pringle (ETC/CCA, OU, United Kingdom).

Chapter 2:

Lead authors:
Jaroslav Mysiak (ETC/CCA, CMCC, Italy), Sergio Castellari (EEA), Reimund Schwarze (ETC/CCA, UFZ, Germany) and Rob Swart (ETC/CCA, WER, the Netherlands).

Contributing authors:
Patrick Pringle (ETC/CCA, OU, United Kingdom), Ad Jeuken (ETC/ICM, Deltares, the Netherlands) and Henk Wolters (ETC/ICM, Deltares, the Netherlands).

Chapter 3:

Lead author:
Blaž Kurnik (EEA).

Contributing authors:
Paul van der Linden (ETC/CCA, Met Office, United Kingdom), Jaroslav Mysiak (ETC/CCA, CMCC, Italy), Rob Swart (ETC/CCA, WER, the Netherlands), Hans-Martin Füssel (EEA), Trine Christiansen (EEA), Leone Cavicchia (ETC/CCA, CMCC, Italy), Silvio Gualdi (ETC/CCA, CMCC, Italy), Paola Mercogliano (ETC/CCA, CMCC, Italy), Guido Rianna (ETC/CCA, CMCC, Italy), Koen Kramer (ETC/CCA, WER, the Netherlands), Melania Michetti (ETC/CCA, CMCC, Italy), Michele Salis (ETC/CCA, CMCC, Italy), Mart-Jan Schelhaas (ETC/CCA, WER, the Netherlands), Markus Leitner (ETC/CCA, Environment Agency Austria (EAA), Austria), Wouter Vanneuville (EEA), Ian Macadam (ETC/CCA, Met Office, United Kingdom).

Chapter 4:

Lead authors:
Tom De Groeve (Join Research Centre (JRC)), Blaž Kurnik (EEA), Jaroslav Mysiak (ETC/CCA, CMCC, Italy), Rob Swart (ETC/CCA, WER, the Netherlands), Jan C. Semenza (European Centre for Disease Prevention and Control), Vladimir Kendrovski (World Health Organisation, Regional Office for Europe).

Contributing authors:
Koen Kramer (ETC/CCA, WER, the Netherlands), Eva Ivits (EEA), Wouter Vanneuville (EEA), Lorenzo Carrera (ETC/CCA, CMCC, Italy), Veit Blauhut (University of Freiburg), Markus Erhard (EEA), Trine Christiansen (EEA).

Chapter 5:

Lead authors:
Ad Jeuken (ETC/ICM, Deltares, the Netherlands), Henk Wolters (ETC/ICM, Deltares, the Netherlands).

Contributing authors:
Jaroslav Mysiak (ETC/CCA, CMCC, Italy), Rob Swart (ETC/CCA, WER, the Netherlands), Sergio Castellari (EEA), Sebastian Hyzyk (European Investment Bank (EIB)), and Stefanie Lindenberg (EIB).

Chapter 6:

Lead authors:
Patrick Pringle (ETC/CCA, OU, United Kingdom), Jaroslav Mysiak (ETC/CCA, CMCC, Italy)

Contributing Authors:
Rob Swart (ETC/CCA, WER, the Netherlands), Reimund Schwarze (ETC/CCA, UFZ, Germany), Ad Jeuken (ETC/ICM, Deltares), Henk Wolters (ETC/ICM, Deltares), Sergio Castellari (EEA), Blaž Kurnik (EEA).

Members of the Advisory Group

Maddalena Dalí (DG Climate Action (DG CLIMA)), Laura Schmidt (DG Civil protection and humanitarian aid operations (DG ECHO)), Karmen Poljanšek (Joint Research Centre (JRC)), Luca Rossi (UN Office for Disaster Risk Reduction (UNISDR)).

Comments from the European Commission and international organisations

Maddalena Dalí (DG CLIMA), Claus Kondrup (DG CLIMA), Nicolas Faivre (DG for Research and Innovation (RTD)), Tiago Freitas (DG RTD), Marco Fritz (DG Environment (DG ENV)), Laura Schmidt (DG ECHO), Karmen Poljanšek (JRC), Lorenzo Alfieri (JRC), Catherine Gamper (Organisation for Economic Co-operation and Development (OECD)) and Luca Rossi (UNISDR).

Comments from Eionet National reference Centres (NRCs) and/or national representatives from EEA member countries

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Comments from expert reviewers

Carlo Cacciamani (Arpae Emilia-Romagna, Servizio Idro-Meteo-Clima, Italy), Francisco Espejo Gil (Consorcio de Compensación de Seguros, Spain, Clemente Fuggini and Carlo Strazza (D'Appolonia S.p.A., Italy), Jouni Paavola (School of Earth and Environment, University of Leeds, United Kingdom), Patrícia Pires (National Authority for Civil Protection, Portugal), Virginia Murray (Public Health England, United Kingdom), Nicanor Prendes and Mónica Gomez (Spanish Climate change office of Ministry for Fisheries, Agriculture and Environment, Spain), Ursula Schmedtje (ETC/ICM, UFZ, Germany), Hans Visser (Netherlands Environmental Assessment Agency, the Netherlands), Marc Zebisch (Eurac Research, Institute for Earth Observation, Italy).

Units, abbreviations and acronyms

AAAA	Addis Ababa Action Agenda
ADM	Adaptive Delta Management
AEMET	Spanish State Meteorological Agency
AMECO	Annual Macro-Economic Database of the European Commission
AR5	5th Assessment Report of IPCC
BAFU	Bundesamt für Umwelt (Federal Office for the Environment) (Switzerland)
BISE	Biodiversity Information System for Europe
CAP	Common Agricultural Policy
CAPE	Convective Available Potential Energy
CBD	Convention on Biological Diversity
CCA	Climate Change Adaptation
CCS	Consorcio de Compensación de Seguros (Extraordinary Risks Insurance Scheme) (Spain)
CF	Cohesion Fund
CFP	Common Fisheries Policy
Climate-ADAPT	European Climate Adaptation Platform
CMIP5	Coupled Model Intercomparison Project Phase 5
CR	Core Responsibilities
CRED	Centre for Research on the Epidemiology of Disasters
CSP	Climate Services Partnership
CV	Coefficient of Variation
C3S	Copernicus Climate Change Service
DFDE	Database on Forest Disturbances in Europe
DFO	Dartmouth Flood Observatory
DG	Directorate-General
DGA	General Directorate for Water (Spain)
DG CLIMA	Directorate-General for Climate Action
DG ECHO	Directorate-General for European Civil Protection and Humanitarian Aid Operations
DG ENV	Directorate-General for Environment
DRMKC	Disaster Risk Management Knowledge Centre
DRR	Disaster Risk Reduction
DRM	Disaster Risk Management
EAFRD	European Agricultural Fund for Rural Development
EAGF	European Agricultural Guarantee Fund
EAWS	European Avalanche Warning Services
EbA	Ecosystem-based Adaptation
EC	European Commission
ECA&D	European Climate Assessment and Datasets
Eco-DRR	Ecosystem-based Disaster Risk Reduction
ECMWF	European Centre for Medium-Range Weather Forecasts
EDO	European Drought Observatory
EEA	European Environment Agency
EFAS	European Flood Awareness System

EFDRR	European Forum for Disaster Risk Reduction
EFFIS	European Forest Fire Information System
EFID	European Flood Impact Database
EIA	Environmental Impact Assessment Directive
EIB	European Investment Bank
EIONET	European Environment Information and Observation Network
EM-DAT	Emergency Events Database (from the Centre for Research on the Epidemiology of Disasters)
EMFF	European Maritime and Fisheries Fund
EPFD	European Past Floods Database
ERA4CS	European Research Area for Climate Services
ERDF	European Rural Development Fund
ES	Ecosystem Service
ESA – CCI	European Space Agency's Climate Change Initiative
ESF	European Social Fund
ESIF	European Structural and Investment Funds
ESWD	European Severe Weather Database
ETC/CCA	European Topic Centre on Climate Change impacts, vulnerability and Adaptation
ETC/ICM	European Topic Centre on Inland, Coastal and Marine water
EU	European Union
EUSF	European Union Solidarity Fund
FWI	Fire Weather Index
FOCP	Federal Office for Civil Protection (Switzerland)
FOEN	Federal Office for the Environment (Switzerland)
FRMP	Flood Risk Management Plan
GAR	Global Assessment Report
GCF	Green Climate Fund
GCM	General Circulation Model
GDP	Gross Domestic Product
GFCS	Global Framework for Climate Services
GI	Green Infrastructure
GMES	Global Monitoring for Environment and Security
HFA	Hyogo Framework for Action
HWMI	Heat Wave Magnitude Index
IAM	Impact assessment model
ICG	International Centre for Geo-hazards
ICGC	Institut Cartogràfic i Geològic de Catalunya (Spain)
ICLEI	Local Governments for Sustainability (International Council for Local Environmental Initiatives)
IDA Climate	Interdepartmental Committee on Climate (Switzerland)
IMF	International Monetary Fund
IMILAST	Intercomparison of Mid Latitude Storm Diagnostics
IPCC	Intergovernmental Panel on Climate Change
IRDR	Integrated Research on Disaster Risk
ISO	International Organization for Standardization
IWRM	Integrated Water Resources Management
JRC	Joint Research Centre
LIFE	Financial Instrument for the Environment
MHRA	Multi-Hazard Risk Assessment
MIDAS	Met Office Integrated Data Archive System
MRE	Monitoring, reporting and evaluation
MS	Member State
NatCatSERVICE	Munich RE's natural catastrophe loss database

NBS	Nature Based Solution
NCFF	Natural Capital Financing Facility
NRA	National Risk Assessment
NWRM	Natural Water Retention Measures
ODA	Official Development Assistance
OECC	Spanish Bureau for Climate Change
OECD	Organisation for Economic Co-operation and Development
OIEWG	Open-Ended Intergovernmental Expert Working Group on Indicators and Terminology Relating to disaster Risk Reduction
PAPI	Prevention Program Against Floods (France)
PEDRR	Partnership for Environment and Disaster Risk Reduction
PHI	Potential Hail Index
PLANAT	Swiss National Platform for Natural Hazards
PoM	Programme of Measures
PPP	Public–Private Partnership
RBD	River Basin Districts
RBMP	River Basin Management Plan
RCP	Representative Concentration Pathways
RCM	Regional Climate Model
RDI	Reconnaissance Drought Index
RIDE	Research & Innovation for our Dynamic Environment (RIDE) Forum (United Kingdom)
Rx5d	Maximum five-day precipitation
SA	State Aid
SDG	Sustainable Development Goals
SFDRR	Sendai Framework for Disaster Risk Reduction
SIGMA	Swiss RE Institute's catastrophe loss database
SPEI	Standardised Precipitation-Evapotranspiration Index
SPEI-3	Standardised Precipitation-Evapotranspiration Index accumulated over 3-months periods
SPI	Standardised Precipitation Index
SSR	Seasonal Severity Rating index
TED	Total Economy Database
TEN-E	Trans-European Energy Network
TEN-T	Trans-European Transport Network
UN	United Nations
UCLG	United Cities and Local Governments
UNFCCC	United Nations Framework Convention on Climate Change
UNISDR	United Nations Office for Disaster Risk Reduction
XWS	eXtreme WindStorms
WEO	World Economic Outlook
WFD	Water Framework Directive
WHO	World Health Organization
WISE	Water Information System for Europe
WNV	West Nile Virus
WSDI	Warm Spell Duration Index

Executive summary

Scope and introduction

The impacts of weather- and climate-related hazards on the economy, human health and ecosystems are amplified by socio-economic changes and environmental changes (e.g. demographic development, land use change and climate change). Efforts to reduce disaster risk and at the same time adapt to a changing climate have become a global and European priority. Climate change adaptation (CCA) and disaster risk reduction (DRR) provide a range of complementary approaches for managing climate risks in order to build resilient societies. Both are cross-cutting and complex development issues with variations, e.g. CCA addresses mainly weather- and climate-related hazards and focuses on the future by addressing uncertainty and new risks, while DRR focuses on the present by addressing existing risks from all hazards. CCA and DRR face similar challenges, such as incomplete and uncertain knowledge bases, interplay of multiple actors and limited resources. Enhancing coherence between CCA and DRR policies and practices requires creating awareness, mobilising resources, and action by public and private stakeholders, preferably in partnership.

This report aims to contribute to better informed EU, national and subnational strategies, plans and multi-stakeholder processes for enhancing the coherence between CCA and DRR. It explores how public policies and risk management practices can foster coherence, and to what extent transfer of knowledge and experience from domain-specific methods and tools can drive mutually beneficial learning and capacity building. It builds upon a review of available documents, knowledge elicitation and interaction with a large number of experts and country representatives from both policy domains. A survey sent to the European Environment Agency (EEA) member countries in early 2016 and an expert workshop in April 2016 provided background information for preparing the report. The report also includes a review of past trends and future projections of selected weather- and climate-related hazards, including their economic, social and environmental impacts.

The report is structured as follows: Chapter 1 sets the scene, explains the scope and outline, and describes the methodological approach and key terms; Chapter 2 provides an overview of global and EU policies relevant to CCA-DRR linkages, describes key methods and tools, and presents European and national practices; Chapter 3 describes observational trends and projections of 10 selected natural hazards at the European scale, along with analysis of uncertainties, data gaps and information needs, and examples of past natural hazards; Chapter 4 summarises the DRR indicators developed at United Nations (UN) level and the indicators of progress of the Sendai Framework for Disaster Risk Reduction (SFDRR), then describes impacts of natural hazards and disasters on health and wellbeing, ecosystems, and economic wealth and cohesion; Chapter 5 provides an overview of 'good practices' for coherence between CCA and DRR practices in Europe; and finally, Chapter 6 presents findings from the previous chapters and identifies specific opportunities for further enhancing coherence between CCA and DRR in policy and practice.

Policies, methods and practices

CCA and DRR are among the main goals of the UN 2030 Agenda for Sustainable Development. The SFDRR identified climate change and variability as a driver of disaster risk, along with uncontrolled urbanisation and poor land management. Tackling these is expected to lead to a sizeable reduction of disaster risk. Consequently, the SFDRR aims for improved coherence between policy instruments for climate change, biodiversity, sustainable development, poverty eradication, environment, agriculture, health, and food and nutrition. The Paris Agreement on Climate Change of the United Nations Framework Convention on Climate Change (UNFCCC) is the first universal, legally binding global deal to combat climate change, mainly by reducing greenhouse gas emissions to keep the global temperature rise well below 2 °C and pursuing efforts to limit the temperature increase to 1.5 °C, compared with pre-industrial levels. Of equal importance, the agreement also requires major action to adapt to the adverse impacts of climate change and to enhance climate resilience, thus contributing to sustainable development.

The EU has various policies in place to address DRR and CCA. The EU Civil Protection Mechanism requires countries to conduct comprehensive multi-hazard risk assessments. The EU Action Plan on SFDRR 2015–2030 recognised the SFDRR as an opportunity to reinforce EU resilience to shocks and disruption in the context of sustainable development, and to boost innovation and growth. The EU strategy on adaptation to climate change, which is being evaluated in 2017–2018, aims to help EU Member States adapt to current and future impacts of climate change through enhancing national adaptation strategies, increasing and improving sharing of knowledge and mainstreaming adaptation in other policy areas. Both CCA and DRR are currently mainstreamed into key EU policies and strategies, including those for critical infrastructure protection, environmental protection, financial instruments of the Cohesion Policy and the EU Structural and Investment Funds (ESIF), agriculture, food and nutrition security, and integrated coastal management.

Comprehensive, multi-hazard risk and vulnerability assessment frameworks can support evidence-based and robust decision-making, and guide policies in DRR and CCA. The risks from current and future climate can cause immense impacts on societies and ecosystems. Climate risk assessments have improved as a result of high-performance computing, new generations of climate and disaster loss models, and increased availability of high-resolution exposure datasets, as well as through improved stakeholder engagement and knowledge synthesis processes. Quantitative impact assessment models are important tools to support decision-making on climate risks.

A selective review, conducted for this report, of the current practices in Europe revealed many innovative examples but also highlighted a need to foster coherence between DRR and CCA policies, practices and knowledge. This can be achieved by closer vertical and horizontal, cross-border and transnational coordination and cooperation. In some European countries policies for CCA and DRR are well connected. In some cases new institutions have been established to develop joint actions benefiting both policy areas. Responding to extreme events is the prime responsibility of local governments, but higher level governments have a role in supporting municipalities at the various stages of DRR. This entails effective coordination and collaboration between the national, provincial and municipal administrations (multi-level governance). EU Member States have found different solutions according to their national context. In those countries in which CCA and DRR are well coordinated, this coordination effort is not always made explicit. For example, flood risk prevention strategies often make use of assessments of long-term changes in flood intensity and frequency based on climate projections.

Weather- and climate-related natural hazards in Europe

Over the past decades, Europe has experienced many summer heat waves, droughts and forest fires characterised by lasting conditions of high temperatures and low precipitation, in particular in southern Europe. Since 2003, Europe has experienced extreme summer heat waves. Such extreme heat waves are projected to occur as often as every 2 years in the second half of the 21st century under the high-emission (RCP8.5) scenario ([1]). The most severe health risks are projected for urban areas in southern Europe and for Mediterranean coasts. The severity and frequency of droughts have increased in parts of Europe, in particular in southern and south-eastern Europe. Droughts are projected to increase in frequency, duration and severity in most of Europe, with the strongest increase projected for southern Europe. Forest fire risk depends on many factors, including climatic conditions, vegetation, forest management practices and other socio-economic factors. The burnt area in the Mediterranean region has varied since 1980. It is expected that, in a warmer climate, the fire-prone areas will expand northwards and longer fire seasons are projected in southern Europe.

Impacts related to changes in precipitation, notably heavy precipitation events leading to floods and landslides, have increased in Europe and are projected to increase further in the future. Heavy precipitation events have increased in northern and north-eastern Europe since the 1960s, whereas different indices show diverging trends for south-western and southern Europe. Heavy precipitation events are projected to become more frequent in most parts of Europe. The number of flood events causing large economic losses in Europe have increased since 1980, but with large interannual variability. The mountain environment is the most affected by landslides, and projected increases in temperature and heavy precipitation will affect rock slope stability conditions and favour increases in the frequency of shallow landslides in the future. Increased temperatures are expected to lead to decreases in Alpine snow amounts and duration, and hence to decreasing avalanche risks below

(1) In Representative Concentration Pathway (RCP) scenario the total radiative forcing reaches approximately 8.5 watts per square metre (W/m2) in 2100 and continues to increase afterwards.

1 500-2 000 m elevation, but increases in avalanche activities above 2 000 m elevation are expected.

Although studies suggest increasing risks of winter and autumn windstorms, uncertainties about the location, frequency and intensity of such storms, and related natural hazards such as hailstorms and storm surges, remain significant. Observations of windstorm location, frequency and intensity showed considerable variability across Europe during the 20th century. However, most studies agree that the risk of severe winter storms, and possibly of severe autumn storms, will increase in the future for the North Atlantic, as well as for northern, north-western and central Europe. For medicanes (Mediterranean tropical-like cyclones), decreased frequency but increased intensity is projected. Hailstorms damage crops, vehicles, buildings and other infrastructure, and despite improvements in data availability, trends and projections of hail events are still subject to significant uncertainties owing to a lack of direct observation and inadequate microphysical schemes in numerical weather prediction and climate models. Extreme high coastal water levels have increased at most locations along the European coastline. This increase appears to be predominantly due to increases in mean local sea level rather than to changes in storm activity. Projected changes in the frequency and intensity of storm surges are expected to cause significant ecological damage, economic loss and other societal problems along low-lying coastal areas across Europe, unless additional adaptation measures are implemented.

Impacts of natural hazards in Europe

The data on impacts of past disasters (economic, human and ecological) are fragmented and incomplete. The importance of a systematic collection of such data has been recognised as of key importance for better public policies on DRR and CCA. Under the SFDRR the signatory countries committed to reduce the impacts of disasters on economy and human health by 2030, and recognised the importance of monitoring in order to assess progress towards this goal, in line with the EU Civil Protection Mechanism. Spatially explicit, event-based, official disaster impact databases serve various purposes, including economic loss accounting, forensic analysis, risk modelling and risk financing. Economic loss accounting documents the evolution and helps to detect trends.

Climate change has caused noticeable effects on human health in Europe, mainly as a result of extreme events, an increase in climate-sensitive diseases, and deterioration of environmental and social conditions. Weather- and climate-related natural hazards threaten human health and affect social care services. The deadliest among the extreme weather- and climate-related events in Europe are heat waves. Health impacts of heat are manifested through fatigue, dehydration and stress, and can lead to worsening of respiratory and cardiovascular diseases, electrolyte disorders and kidney problems. These symptoms are aggravated by air pollution (in particular by fine particulates and ozone). Heavy precipitation events can result in flooding and run-off which can introduce faecal contamination into rivers and lakes. It can also potentially adversely affect water treatment and distribution systems, and overload the capacity of sewerage systems, causing discharge of untreated water.

Increase in frequency and intensity of extreme weather- and climate-related events may lead to greater impacts on ecosystems and their services. Natural hazards can affect and shape ecosystems and thus have an impact on the services that they provide. Weather- and climate-related natural hazards may affect an ecosystem to the point from which recovery is not possible, resulting in a loss of ecosystem services (e.g. water retention, food production, cooling, energy production, recreation and carbon sequestration). The intensity and spatial extent of such impacts of natural hazards depends both on the intensity and frequency of the events and on the state of the ecosystems affected. The vulnerabilities of ecosystems may already have been affected by other factors such as ecosystem fragmentation. Similar ecosystems in different bioclimatic zones in Europe may respond differently to climate change. An appropriate management of ecosystems can help to avoid or significantly reduce these, and provide additional benefits.

The total reported economic losses caused by weather- and climate-related extremes in the EEA member countries over the 1980–2015 period amounted to over EUR 433 billion. Weather- and climate-related, hydrological, and geophysical natural hazards cause sizeable and growing financial and economic losses. The financial losses consist of the value of capital lost and recovery and opportunity costs. Direct financial losses may set off supply and demand shocks that affect regional economies in and beyond the disaster-affected areas. The largest share of the economic impacts are caused by floods (38 %) followed by storms (25 %), droughts (9 %) and heat waves (6 %). The insurance coverage is largest for hailstorm-related loss which, however, represents only 4 % of the total loss, followed by windstorms. A large share of the total losses (70 %) has been caused by a small number of events (3 %).

Selected cases of enhanced coherence between climate change adaptation and disaster risk reduction

A better coherence between CCA and DRR can be fostered by development of a high-level strategic vision and local-level engagement of key actors, supported by adequate funding. The report presents selected cases from various European countries in which effective coherence between CCA and DRR has been achieved, in various ways and to various degrees. The selection is based on criteria that define 'good practice': coherence is deliberately planned rather than an accidental outcome; improved coherence pays off in both policy areas; and uncertainty and multiple possible futures are explicitly accounted for in risk prevention efforts, from both short- and long-term perspectives. Six examples are explored in terms of governance, financing, policies and measures, data and knowledge, methods and tools, and monitoring and evaluation. The six cases are (1) development of a long-term planning vision in the Netherlands; (2) insurance and risk financing based on public–private partnerships in Spain, France and the United Kingdom; (3) local risk governance in Switzerland; (4) national risk assessments serving both CCA and DRR purposes; (5) city networking for improved urban resilience; and (6) financing nature-based solutions for CCA and DRR.

In the Netherlands, the central government, water boards, provinces and municipalities work closely together to climate proof water management in the Delta Programme. The programme led to a new risk-based flood protection policy and standards based on three types of risk: individual, economic and societal. The Delta Programme promotes multi-layer safety policies and measures in which an optimal mix is proposed between prevention, sustainable spatial planning and crisis management. The shared risk knowledge base is used by both CCA and DRR communities, and is supported by open public data. The Delta Programme developed a new adaptive planning approach termed Adaptive Delta Management as 'a smart way of taking account of uncertainties and dependencies in decision-making on Delta Management with a view to reducing the risk of overspending or underinvestment'. This approach starts from short-term measures that are linked to long-term perspectives and it takes account of long-term uncertain impacts of climate change through the use of a range of scenarios, specification of critical thresholds and planning-ahead strategies as a series of subsequent measures, as well as economic evaluation frameworks assessing societal costs and benefits.

Insurers can contribute to enhancing societal resilience and coherence between CCA and DRR through incentivising risk prevention, helping to improve risk understanding and knowledge, and stimulating active engagement and investment. Economic costs of climate hazard risks can be reduced by well-designed ex ante financial management and protection instruments. Public–Private Partnerships (PPPs) provide services with joint bearing of responsibilities and efficient risk sharing. A number of PPPs exist in Europe, aiming at increasing insurance coverage and market penetration, and also ensuring strong financial backing for low-probability/high-impact risks. Examples of longstanding insurance-related PPPs include the risks insurance scheme of the Consorcio de Compensación de Seguros (Spanish Insurance Compensation Consortium) (CCS), the French Catastrophes Naturelles (CatNat) and more recently the Flood Reinsurance Scheme (Flood Re) in the United Kingdom.

The combination of national agenda setting and local implementation and integration can lead to effective CCA and DRR strategies. As a result of the decentralised system in Switzerland, operational responsibility for dealing with natural hazards and for civil protection lies, by law, first and foremost with the cantons and municipalities. The federal authorities define the strategy and principles, advise the cantons on sustainable protection measures, provide subsidies and adopt an overall control function. Formal arrangements have been put into place to secure cooperation between these actors, horizontally and vertically, and between federal organisations, the private sector and academic organisations. CCA has benefited from improved modelling of climate change, identification and modelling of known and emerging impacts of climate change, shared knowledge development, and formulating long-term visions and policy goals. DRR has benefited from improved risk maps, risk assessments and assessments of emerging risks, and from putting a monitoring system of 'threshold' phenomena in place. Exploitation of common ground between CCA and DRR is fostered, e.g. by sharing databases, models and information on hazards.

National risk assessments (NRAs) can serve as an effective base for CCA and DRR, as they contribute a broader understanding of risk and give hints on tolerance thresholds. This case is of a different nature than the three preceding ones, as it focuses on one specific arrangement. The added value of NRAs for CCA depends on the time horizon chosen in the NRAs. A short time horizon limits the value for CCA. The added value of NRAs for DRR is more obvious, as it provides the basis for DRR planning. The common ground that NRAs may help to exploit are understanding and use of risk metrics, tipping points and the timing of reaching these.

City networks are important mechanisms for motivating cities and for supporting capacity building for CCA and DRR policies and action in a sustained manner. Many networks of cities addressing CCA and DRR exist. Key networks are the Covenant of Mayors for Climate and Energy, C40 Cities, Making cities resilient campaign (United Nations Office for Disaster Risk Reduction, UNISDR), Resilient Cities annual conference (Local Governments for Sustainability, ICLEI), and 100 Resilient Cities (Rockefeller Foundation). A common feature of these networks is an absence of hierarchical authority and power (such as regulation and sanction). Instead their authority relies on strategies such as information and communication, project funding and co-operation, recognition, and benchmarking and certification. In a broader sense the role of city networks, and in particular their function in motivating cities and supporting capacity building in the area of climate change and disaster risk policy and action, is crucial. Ensuring and enhancing reliable funding of these networks will facilitate and strengthen continuation of their work.

Financing nature-based solutions (NBSs) is an effective approach to adapt to climate change and to reduce disaster risks. An instrument set up by European investment bank (EIB) finance projects which apply nature-based solutions such as re-naturalization of rivers to reduce the downstream flooding risk, agro-forestry projects and agricultural projects reducing soil erosion, green and blue infrastructure solutions in urban areas reducing climate change impacts such as heavy precipitation events or urban heat islands to mention only some.

Opportunities to enhance coherence between climate change adaptation and disaster risk reduction in policy and practice

Both CCA and DDR communities use the concept of 'resilience' and this provides common ground upon which more coherent policies and actions might be built. At a strategic level, CCA and DRR can be better integrated through the development of long-term national programmes and could be supported by more innovative risk financing instruments. For CCA as of 2017, 28 European countries (25 EU Member States and three EEA member countries) have adopted a national adaptation strategy (NAS) and 17 (15 EU Member States and two EEA member countries) have developed a national adaptation plan. For DRR, national and local multi-stakeholder platforms for DRR have been established in many countries in Europe. As with CCA, the DRR communities are seeking to build actions using an 'all-society' engagement process informed by multiple perspectives from both public and private sectors.

Policy instruments that incentivise more efficient use of natural resources contribute to reducing the impacts of climate change. A sound financial strategy that brings together different financial instruments to fund disaster response can lessen the impacts of climate change and variability, speed up recovery and reconstruction, and harness knowledge and incentives for reducing risk. A comprehensive financial strategy is conducive to better framed and better informed risk management and governance.

There are opportunities to communicate and share more consistent and complementary knowledge for CCA and DRR through web-based knowledge portals and multi-stakeholder coordination platforms. Improved and harmonised knowledge sharing and closely coordinated multi-stakeholder engagement can enhance coherence between CCA and DRR. Knowledge portals provide a platform for sharing information and thus can increase the understanding of vulnerabilities and risks, and risk mitigation and climate adaptation measures. The information and knowledge incorporated on knowledge portals typically includes guidance and decision support tools; the results of adaptation research; data and information; policies at transnational, national and subnational levels; and experiences and case studies from practice. Multi-stakeholder disaster risk management (DRM) coordination platforms have enhanced horizontal cooperation and partnerships across public and private spheres. The SFDRR encouraged development of similar platforms at local level, and these could be harnessed for the purpose of climate adaptation.

Monitoring, reporting and evaluation activities (MRE) are increasing in both policy areas but learning can be enhanced across both areas to improve coherence and quality. An increasing number of European countries are taking action on MRE for adaptation at the national level. This emphasis on MRE in CCA and DRR is partially driven by increased levels of investment in these areas, and thus a need to provide accountability, but also by a desire to understand 'what works well (or not)' and how to improve future practice. Thus MRE can help learning across cities, regions and countries. CCA and DRR share a number of characteristics that can make MRE challenging, such as long timescales, uncertainty and common baselines. MRE approaches that are specifically designed to address both CCA and DRR currently exist in only a few cases, but these are expected to increase in future.

Improved risk assessment methods and mutually beneficial approaches present opportunities to enhance coherence between the two policy areas.

Hazard mapping and risk assessment represent an area where integration of CCA and DRR is well advanced and recognised as a priority. There is an opportunity for mutual learning and advancing knowledge that will benefit both communities. Comprehensive climate change vulnerability and risk assessments have been performed by an increasing number of European countries. Furthermore, NRAs completed by EU Member States identify, assess and prioritise a number of security threats, of which climate change is only one. The experiences of some countries, such as France, the Netherlands and the United Kingdom, show that climate vulnerability and risk assessments need to build on strong institutional frameworks, clearly assigned responsibilities and authority, and close stakeholder engagement. A thorough understanding of risks including their cascade and spillover effects is therefore vital. Improved knowledge of the economic costs of natural hazards is also important for a better understanding of implicit and explicit government liabilities, and designing comprehensive risk financing strategies.

A well-functioning system of public and private, user-driven climate services can help catalyse economic and societal action, and transformation that reduces risks and improves societal resilience. The European Research and Innovation Roadmap for Climate Services gives primacy to a service perspective on climate services (i.e. away from supply to user-driven and science-informed) and is also underpinned by an approach to research and innovation based on co-design, co-development and co-evaluation of climate services. Improved alignment of demand-led CCA and DRR climate service products would require decision-makers from both communities to have stronger linkages with each other as well as with the providers of climate information and knowledge.

Nature-based solutions (NBSs) are a prime example of means to mitigate natural hazard risks and boost societal resilience that address both CCA and DRR. NBS approaches are often cost-effective, have multiple benefits, and can become increasingly valuable in the face of more frequent and/or severe extreme events. Adding CCA and DRR to the considerations used to motivate and design nature-/ecosystem-based solutions would add to the multipurpose nature of these solutions, help to leverage funding, and help to connect communities working on joint solutions. Usage or restoration of floodplains and upland areas to decrease flood risk in downstream areas, green infrastructure in urban areas to reduce run-off during high-intensity precipitation events and forest management aiming to reduce wild fires or landslides are just three of many examples. Such solutions can be promoted by better translating available scientific expertise and political support into practice. Initiatives such as the Biodiversity Information System for Europe (BISE) and Oppla (a new knowledge 'marketplace') can support learning and knowledge exchange on green infrastructural solutions. The European Climate Adaptation Platform (Climate-ADAPT) also contains a range of cases of nature-/ecosystem-based adaptation actions that have been implemented and that can provide inspiring examples for others to learn from.

Various funding and financing options for CCA and DRR are available at EU level. The EU agreed to spend 20 % of the resources under the Multiannual Financial Framework 2014–2020 on climate change-related action. Adaptation to likely impacts of climate change is integrated (mainstreamed) in major EU sectoral policies by means of the European Union Solidarity Fund (EUSF). Disaster resilience and risk prevention and management are also promoted under other priorities. Additional funds include Horizon 2020, LIFE and the European Solidarity Fund. Two urban adaptation-related reports (published in 2016 and 2017) describe a wide range of additional well-established and innovative financing instruments for nature-/ecosystem-based and other adaptation actions, such as crowd-funding and green bonds.

Improving the coordination of national-level indicators

There are growing demands for the establishment of national-level indicator sets for monitoring CCA and DRR actions in Europe. Progress in implementing the SFDRR will be monitored through an agreed set of indicators, while the UNFCCC is considering how best to track adaptation efforts at national level. The Sustainable Development Goals (SDGs) will also require countries to report on progress. The European Commission will prepare adaptation preparedness scoreboards for each EU Member State in 2017 as part of its evaluation of the EU adaptation strategy, to be finalised in 2018. There are opportunities to improve connectivity and coherence between these indicator requirements at EU level, to improve the efficiency of data collection at national level and to build up a more complete picture of CCA and DRR progress and priorities at national level.

1 Introduction

- At global, European and national level there is an emerging need to enhance coherence between climate change adaptation (CCA) and disaster risk reduction (DRR) by taking account of their similar objectives and differences.
- Successful coherence in knowledge base, policies and measures of CCA and DRR reduces both duplication of efforts and lack of coordination at the various levels of governance, contributing to better preparedness and response to disasters, and also to sustainable development.

1.1 Why do we need to enhance the coherence between climate change adaptation and disaster risk reduction?

Disaster risks and losses are of great concern for policymakers and citizens, since they have increased in recent decades and are expected to further increase as a result of a combination of projected demographic development and land use change, along with expansion of residential and economic activities in disaster-prone areas and projected climate change. There is evidence that climate change has increased the frequency and severity of certain extreme weather- and climate-related events, such as droughts, heat waves and heavy precipitation events, in some regions across Europe, and these trends are projected to continue, without climate change mitigation and adaptation (IPCC, 2012, 2014b; EEA, 2017).

At global and European levels it is becoming a high priority to implement a comprehensive, integrated risk approach by considering the full disaster management cycle ([2]) (prevention/mitigation, preparedness, response and recovery), which also takes account of the importance of climate change as a driver of risk (see Chapter 2). Climate change adaptation (CCA) and disaster risk reduction (DRR) provide a range of complementary approaches for managing the risks of extreme weather- and climate-related events (weather- and climate-related natural hazards) and disasters, and both are cross-cutting and complex development issues (see Box 1.1).

Scientific and policy attention on the issue of linking CCA and DRR has been recognised at international level (e.g. the Sendai Framework for Disaster Risk Reduction (SFDRR) of the United Nations Office for Disaster Risk Reduction (UNISDR) (UN, 2015), the Paris

Box 1.1 Key definitions of CCA and DRR used in this report

In this report we use the following key definitions for CCA and DRR:

- Climate change adaptation is the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm, or to exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects (IPCC, 2014b).
- Disaster risk reduction is aimed at preventing new and reducing existing disaster risk (exposure, hazard or vulnerability), and managing residual risk, all of which contributes to strengthening resilience and therefore to the achievement of sustainable development (IPCC, 2014a; UNISDR, 2017)

([2]) The 'traditional full disaster risk management cycle' includes the following elements: prevention/mitigation (minimising the effects of a disaster), preparedness (planning how to respond), response (efforts to minimise the hazards caused by a disaster) and recovery (returning to normal). In some studies response is merged with recovery and a new element (risk assessment) is included before prevention (see Section 2.2).

Agreement on Climate Change of the United Nations Framework Convention on Climate Change (UNFCCC) (UNFCCC, 2015)), European level (e.g. the EU Action Plan on SFDRR 2015-2030 (EC, 2016), the European Forum for Disaster Risk Reduction (EFDRR) Roadmap for the implementation of the Sendai Framework and the EU strategy on adaptation to climate change (EC, 2013)), and also at national level, with various initiatives already started in some European countries (see Chapters 2 and 5). Two publications published in 2017, namely the book 'The Routledge handbook of disaster risk reduction including climate change adaptation' (Kelman et al., 2017) and the report 'Science for disaster risk management 2017: knowing better and losing less' (Poljanšek et al., 2017) confirm the enhanced attention to DRR and the links to CCA. This attention at European scale is mainly due to the increasing frequency and intensity of certain extreme weather- and climate-related events, and to their significant socio-economic and human impacts (see Chapters 3 and 4). These extremes may be amplified in intensity and frequency due to further climate change, and can show strong regional differences across Europe (EEA, 2017). Bringing together policy and science experts and practitioners of CCA and DRR is needed at the European level (see Table 1.1).

Potential key benefits of enhancing coherence between CCA and DRR are, at both EU and national level:

- enhanced knowledge base, benefiting both policy areas;
- more effective and efficient policies and practises in both areas, due to exploitation of synergies;
- stronger collaboration between scientific and policy communities and networks;
- more efficient use of human and financial resources;
- better preparedness and response to disasters.

Table 1.1 Objective and main differences between climate change adaptation and disaster risk reduction

CCA	DRR
Common objective	
Both CCA and DRR address prevention and reduction of risks of disasters by reducing vulnerability and increasing resilience of societies.	
Main differences	
Focus mainly on future and addressing uncertainty and new risks — CCA addresses climate change and climate variability, including changes in climate extremes, and focuses on reducing risks of present and future climate change.	**Focus on present and addressing existing risks —** DRR focuses on reducing risks based on previous experience and knowledge of the past, considers as stationary the probability of occurrence of extremes, and does not systematically consider climate change as a driver of risk.
Addressing mainly weather- and climate-related hazards — CCA addresses weather-related hazards (e.g. storm, heavy precipitation), climate-related hazards (e.g. heat wave, drought), and hydrological hazards (e.g. flood), which are sub-sets of the hazards covered by DRR. In addition: **Longer time scale** — CCA also addresses impacts of slow onset changes (e.g. average temperature rise, sea level rise, drought, ice melting and loss of biodiversity).	**Addressing all hazard types** — DRR covers all hazard types including geophysical (e.g. earthquake, mass movement, volcanic activity, landslide, avalanche), hydro-meteorological (e.g. storm, extreme temperature, flood, wave action), climatological (e.g. drought, wildfire), biological (e.g. disease, insect infestation), and technological (e.g. oil and toxic spills, and industrial accidents).
Origin and culture in scientific theory — CCA has been developed as the progress of understanding the threat of climate change has increased.	**Origin and culture in humanitarian assistance and civil protection —** in general DRR has a longer history and originated from civil protection and humanitarian action following disaster events.
Mainly actors in environment ministries and agencies — CCA is developed and managed mainly from governmental departments, ministries, and scientific institutions responsible for environment and climate.	**Mainly actors in civil protection ministries and agencies —** DRR is developed and managed mainly from governmental departments, ministries and agencies responsible for civil protection, national security, emergency management and humanitarian assistance.

For example, an increased coherence between CCA and DRR can be relevant to better identification and assessment of risks of natural hazards, more coherent planning of risk reduction investments and improved elaboration of financing instruments. Furthermore, closer collaboration on these CCA and DRR issues is particularly relevant as most governments have ratified the UNFCCC Paris Agreement on Climate Change, in which climate change adaptation and disaster risk reduction are key components (see Chapters 2 and 5). In conclusion, efficient and effective CCA policies and measures must build on and expand existing DRR efforts, and sustainable DRR approaches must account for the impacts of climate change (see Chapter 6).

1.2 Scope and outline of the report

This report aims to contribute to a better awareness and further exchange of knowledge base, policy developments and implementation among decision-makers, policy and science experts, and practitioners in the CCA and DRR communities. The report also describes trends and projections of 10 selected weather- and climate-related natural hazards (including hydro-meteorological and geophysical natural hazards), and their related economic losses, in the past five decades. The geographical coverage of the report includes mainly the 33 European Environment Agency (EEA) member countries and the six cooperating countries (3). The report was prepared by a team of experts from the EEA, the Directorate-General Joint Research Centre (DG JRC) of the European Commission, the European Topic Centre on Climate Change Impacts, Vulnerability and Adaptation (ETC/CCA), the European Topic Centre on Inland, Coastal and Marine waters (ETC/ICM) and other institutions. An advisory group provided views on the scoping of the report. The advisory group included members of the EEA Scientific Committee; the European Commission's Directorate-General for Climate Action (DG CLIMA), Directorate-General for Environment (DG ENV) and Directorate-General for European Civil Protection and Humanitarian Aid Operations (DG ECHO); the UNISDR Regional Office for Europe; and the Organisation for Economic Co-operation and Development (OECD).

The report is based on a range of information sources (see Box 1.2). In addition, this report is also based on the information collected through a recent EEA survey. On 23 February 2016, the EEA sent a brief questionnaire (4) to all 33 member countries and the six cooperating countries. Responses were received from 22 countries (see Map 1.1).

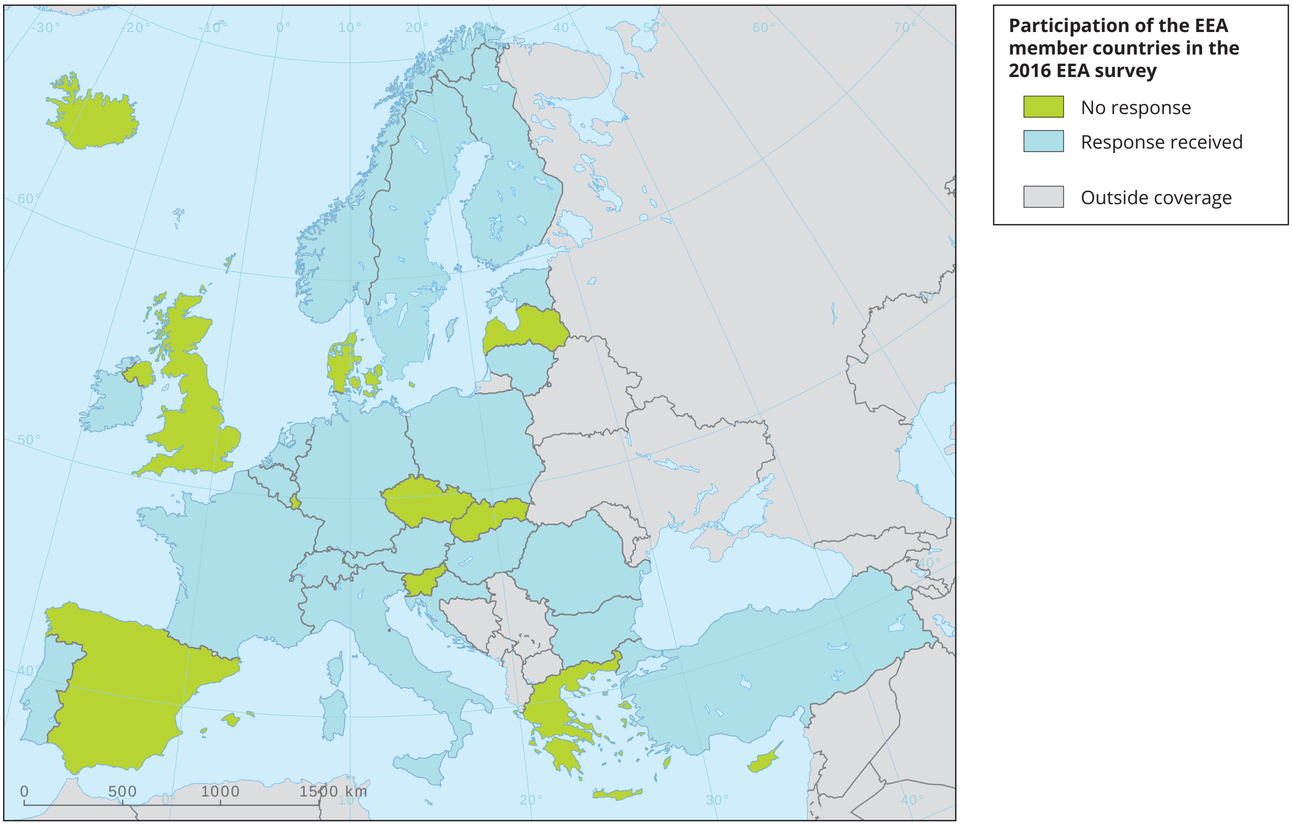
Furthermore the EEA organised the expert workshop 'Climate change adaptation and disaster risk reduction

Box 1.2 Country information on CCA and DRR used as input to the report

- 2015: according to the regulation on a mechanism for monitoring and reporting greenhouse gas emissions and for reporting other information relevant to climate change at national and EU level (5), the EU Member States reported to the European Commission information on their national adaptation planning and strategies, outlining their implemented or planned actions to facilitate adaptation to climate change. The information is accessible on the European Climate Adaptation Platform (Climate-ADAPT) country pages (6).
- 2015: according to the Hyogo Framework for Action (HFA, now SFDRR 2015–2030 — see Section 2.1), the relevant countries provided DRR progress reports including assessment of strategic priorities in the implementation of DRR actions and establishing baselines on levels of progress achieved in implementing the HFA's five priorities for action (7).
- 2012: the European Forum for Disaster Risk Reduction (EFDRR) working group on CCA and DRR carried out a survey (8) among European countries (HFA focal points and national platform coordinators) to obtain an overview of which member countries of the EFDRR link CCA and DRR, and how they do it (9).

(3) The 33 EEA member countries are the 28 EU Member States together with Iceland, Liechtenstein, Norway, Switzerland and Turkey. The six West Balkan countries are cooperating countries: Albania, Bosnia and Herzegovina, the Former Yugoslav Republic of Macedonia, Montenegro, Serbia and Kosovo under UN Security Council Resolution 1244/99.
(4) 'Information on the planned EEA 2017 report on CCA/DRR and a request for updated country information regarding national integration of CCA/DRR'.
(5) Regulation (EU) No 525/2013 of the European Parliament and of the Council of 21 May 2013 on a mechanism for monitoring and reporting greenhouse gas emissions and for reporting other information at national and Union level relevant to climate change and repealing Decision No 280/2004/EC, OJ L 165, 18.6.2013, p. 13.
(6) http://climate-adapt.eea.europa.eu/countries-regions/countries
(7) http://www.preventionweb.net/english/hyogo/progress/reports/index.php?o=pol_year&o2=DESC&ps=50&hid=2015&cid=rid3&x=9&y=5
(8) http://www.preventionweb.net/publications/view/35277
(9) http://www.preventionweb.net/files/27513_12efdrr3oct2012croatiawg1andreassen.pdf

Map 1.1 Participation of EEA member countries in the 2016 EEA survey



Note: The EEA survey was launched in early 2016 to gather updated information from countries regarding the status of integration of CCA/DRR at national or subnational levels.

Countries that responded to the survey: Austria, Belgium, Bulgaria, Croatia, Estonia, Finland, France, Germany, Hungary, Ireland, Italy, Lithuania, Malta, Netherlands, Poland, Portugal, Romania and Sweden (EU Member States), together with Liechtenstein, Norway, Switzerland and Turkey.

Countries that did not respond to the survey: Cyprus, Czech Republic, Denmark, Greece, Iceland, Latvia, Luxembourg, Slovakia, Slovenia, Spain and the United Kingdom.

Source: EEA.

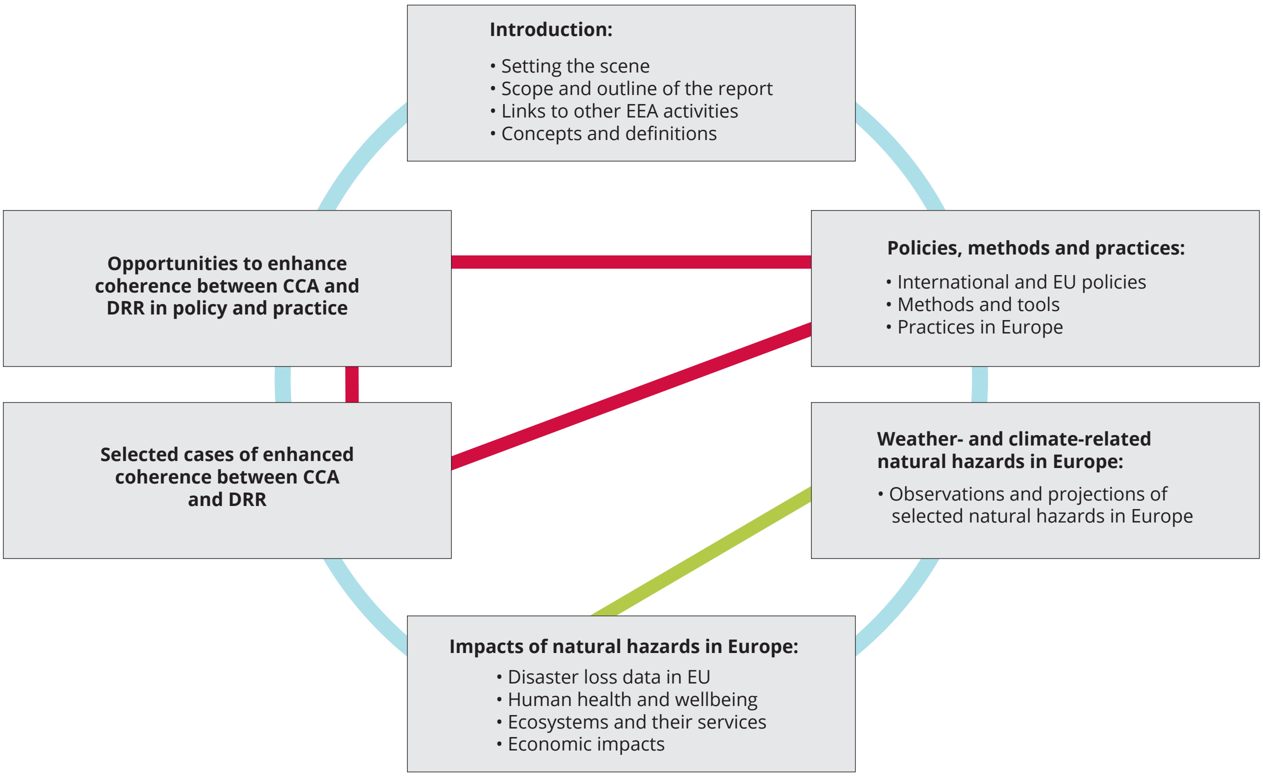
— policies and practice at European and national level' (11–13 April 2016), inviting experts from various EEA member countries, the European Commission (DG ECHO, DG CLIMA and DG JRC) and UNISDR to discuss the links between CCA and DRR policies and practices in Europe, and to explore lessons learned from national experiences.

The target audience of this report includes scientific/technical experts, policy advisers, and policymakers in EU institutions and EEA member countries who are involved in the development and implementation of CCA and/or DRR policies and measures. Moreover, the report may also provide useful input to the European Commission's evaluation of the EU strategy on adaptation to climate change in 2017–2018.

The report is structured as follows (see Figure 1.1). Chapter 1 explains the need to enhance coherence between the CCA and DRR communities (Section 1.1), the scope and outline of the report (Section 1.2) and the links to other EEA reports and activities (Section 1.3). Section 1.4 describes the methodological approach used.

Chapter 2 starts with a detailed overview of policies relevant to linkages between CCA and DRR at global, European and national levels (Section 2.1). It describes key methods and tools for planning CCA and DRR policies (Section 2.2) and presents how European policies on CCA and DRR are being put into practice at national and subnational level in various countries (Section 2.3).

Figure 1.1 Framework of the report



Note: Guidance to the user on how to read the report.

Source: EEA.

Chapter 3 describes observational trends in the past five decades and projections until the end of the current century, for 10 selected weather- and climate-related natural hazards at the European scale. These include heat waves, heavy precipitation events, river floods, windstorms (including medicanes), landslides, droughts (meteorological, soil moisture and hydrological droughts), forest fires, avalanches, hail and storm surges/extreme sea levels. This chapter also includes an analysis of uncertainties, data gaps and information needs for each natural hazard, and examples of past natural hazards. The chapter provides a useful summary of scientific knowledge on past and projected trends for key weather- and climate-related natural hazards. These hazards have been selected because of their relevancy for Europe: they already occur with regularity and/or intensity, causing significant socio-economic damage. Furthermore, most of them are projected to increase in severity, duration and/or extent under future climate change, and to show strong regional variations across Europe.

Chapter 4 summarises the indicators developed by the UN Open-Ended Intergovernmental Expert Working Group on Indicators and Terminology Relating to Disaster Risk Reduction (OIEWG), and the SFDRR indicators of progress (Section 4.1). Chapter 4 also complements analysis of the selected natural hazards presented in Chapter 3 by describing their impacts on health and wellbeing (Section 4.2), ecosystems (Section 4.3) and economic wealth and cohesion (Section 4.4).

Chapter 5 reviews the extent to which coherence between CCA and DRR practices in Europe can be effectively enhanced in areas where this would be beneficial, and in which cases. In comparison with the examples presented in Section 2.3 the cases in this chapter demonstrate a higher level of coherence and can be considered as 'good practices'. Here a good practice implies the following: (1) potentially duplicative and/or conflicting actions are avoided; (2) CCA is integrated into DRR practices and vice versa, with the aim of enhancing the knowledge base to the benefit of both policy areas; (3) more effective and efficient policies are conducted in both areas due to exploitation of synergies; (4) a stronger collaboration is achieved between scientific and policy communities and networks (see Chapter 6).

Finally Chapter 6 summarises findings from the previous chapters and identifies specific opportunities for further enhancing coherence between CCA and DRR in policy and practice. The opportunities identified and analysed in this chapter are the following:

- developing consistent and complementary knowledge and coordination platforms at EU, national and regional level;
- improved monitoring and risk assessment (outcomes and processes);
- enhancing coherence between CCA and DRR climate services;
- long-term national programmes;
- nature-based solutions to maximise co-benefits;
- risk and adaptation financing/from risk transfer to risk prevention financing;
- monitoring and evaluation to improve policy implementation and adaptive management.

1.3 Links to other EEA activities

During past years the EEA has published reports on themes related to impacts, vulnerability and adaptation to natural hazards.

The following EEA reports, published in the period 2014–2016, focus specifically on adaptation policies:

- National adaptation policy processes in European countries — 2014 (EEA, 2014b) builds on the results of a self-assessment survey conducted on national adaptation policy processes in Europe, and provides the most comprehensive overview of national adaptation policy processes in Europe to date.
- Adaptation of transport to climate change in Europe — Challenges and options across transport modes and stakeholders (EEA, 2014a) explores current climate change adaptation practices concerning transport across European countries.
- National monitoring, reporting and evaluation of climate change adaptation in Europe (EEA, 2015b) provides new insights into adaptation monitoring, reporting and evaluation systems at the national level in Europe and constitutes the first attempt to consolidate emerging information across European countries.
- Urban adaptation to climate change in Europe 2016 — Transforming cities in a changing climate (EEA, 2016c) presents the state and progress of adaptation in urban areas in Europe over the past decade and gives examples of practices and solutions for adapting to climate change.

So far two EEA reports have directly addressed impacts of a selected range of natural hazards in Europe:

- Mapping the impacts of recent natural disasters and technological accidents in Europe, published in 2004 (EEA, 2004);
- Mapping the impacts of natural hazards and technological accidents in Europe — An overview of the last decade, published in 2010 (EEA, 2011).

In particular, the latter (EEA, 2011) analyses the occurrence and impacts of disasters and underlying hazards in Europe for the period 1998–2009. It addresses the following hazards: storms, extreme temperature events, forest fires, water scarcity and droughts, floods, avalanches, landslides, earthquakes, volcanoes and technological accidents. The report highlights that comparable national data were not available for all EEA member countries. This issue still remains, although various initiatives have been put in place in recent years to address the problem. The main source of data for this report are global disaster databases such as the EM-DAT database of the Centre for Research on the Epidemiology of Disasters (CRED), the NatCatSERVICE of Munich RE and the European Forest Fire Information System (EFFIS) maintained by the JRC. This report shows the main issues relating to the selected hazards and, in some cases, reviews the impacts in different sectors, but it does not provide an assessment of how climate change affects the intensity and frequency of disasters.

In 2012, focusing specifically on droughts and water scarcity, the EEA published the report Water resources in Europe in the context of vulnerability (EEA, 2012b). At the beginning of 2016, the EEA published the report Flood risks and environmental vulnerability — Exploring the synergies between floodplain restoration, water policies and thematic policies (EEA, 2016a). This report presents the role of floodplains in flood prevention, including the impact of hydromorphological alterations on ecosystem services, and supports the implementation of the EU Floods Directive (EU, 2007), in particular with regard to environmental impacts and how these can be linked to CCA and DRR. Furthermore, this report looks at synergies between water management, nature conservation and economic developments, both in the field and at the policy level.

At the end of 2015 the EEA published a technical report, Exploring nature-based solutions — The role of green infrastructure in mitigating the impacts of weather- and climate change-related natural hazards (EEA, 2015a). This draws attention to certain types of extreme events and natural hazards at European scale that are very likely to be amplified by ongoing climate change, and to the role of 'green infrastructure' (GI) and ecosystem services in mitigating these related impacts.

Progress and challenges in European ecosystems have been addressed in an EEA reported entitled Mapping and assessing the conditions of Europe's ecosystems (EEA, 2016b). The report is an EEA contribution to the implementation of the EU Biodiversity Strategy to 2020 ([10]). The EU Biodiversity Strategy to 2020 uses mapping and assessment of ecosystems and their services to meet the Aichi targets of the Convention on Biological Diversity (CBD). The concept of the 'ecosystem-based approach' addresses the multi-functionality of ecosystems, with each providing a multitude of services. This allows a link to be established between the biodiversity-related targets and other policy lines, such as the Floods Directive, the common agricultural policy (CAP), the Forest Strategy, the Water Framework Directive, the Marine Strategy Framework Directive, territorial cohesion policies, etc., and to develop more integrated approaches. It necessitates exploring how changes in ecosystem management towards maintaining biodiversity can create mutual benefits, including flood and landslide protection, erosion risk reduction, climate change mitigation and adaptation, etc. To further develop the topic, in 2017 the EEA published a report entitled Green infrastructure and flood management — Promoting cost-efficient flood risk reduction via green infrastructure solutions (EEA, 2017b), which focuses on the possibility of implementing GI on European floodplains. This report will demonstrate the scope of GI and its potential for mitigating river floods in a cost-efficient way. It will further contribute to building the knowledge and evidence base on the benefits of applying GI, which can help awareness raising and serving strategic or policy directions in the future.

Furthermore, the EEA and ETC/CCA published a technical paper on extreme weather- and climate-related events in Europe, which includes the latest scientific knowledge available for the following categories of extreme events: temperature extremes (heat), heavy precipitation, drought and hail. The results of this work have been expanded and included in Chapter 3 of the current report (ETC/CCA and EEA, 2015).

Finally, in January 2017 the EEA published a comprehensive report, Climate change, impacts and vulnerability (EEA, 2017a). This is an update and revision of a report published in 2012 (EEA, 2012a). The new report presents trends and projections with 43 climate impact indicators and the vulnerability, risks and impacts of climate change in various socio-economic sectors, such as human health and ecosystems.

The EEA also regularly updates and publishes indicators online, including temperature extremes (CLIM 001) ([11]), heavy precipitation (CLIM 004) ([12]), windstorms (CLIM 005) ([13]), river floods (CLIM 017) ([14]), meteorological and hydrological droughts (CLIM 018) ([15]), forest fires (CLIM 035) ([16]) and economic losses from climate-related extremes (CLIM 039) ([17]).

The EEA also contributes to two European platforms related to impacts, vulnerability and adaptation to natural hazards. One is Climate-ADAPT ([18]), a partnership between the EEA and the European Commission (DG CLIMA, DG JRC and other DGs) launched in 2012, which is a web-portal entry to access and share data and information on CCA, in transnational regions, countries and urban areas, and on EU sector policies. Furthermore Climate-ADAPT provides some specific tools that support adaptation planning. The second platform relevant here is the Water Information System for Europe (WISE) ([19]), a partnership between the EEA, the European Commission (DG ENV, DG JRC and Eurostat) launched

([10]) http://ec.europa.eu/environment/nature/biodiversity/strategy/index_en.htm
([11]) http://www.eea.europa.eu/data-and-maps/indicators/global-and-european-temperature-3/assessment
([12]) http://www.eea.europa.eu/data-and-maps/indicators/precipitation-extremes-in-europe-3/assessment
([13]) http://www.eea.europa.eu/data-and-maps/indicators/storms-2/assessment
([14]) http://www.eea.europa.eu/data-and-maps/indicators/river-floods-2/assessment
([15]) http://www.eea.europa.eu/data-and-maps/indicators/river-flow-drought-2/assessment
([16]) http://www.eea.europa.eu/data-and-maps/indicators/forest-fire-danger-2/assessment
([17]) http://www.eea.europa.eu/data-and-maps/indicators/direct-losses-from-weather-disasters-3/assessment
([18]) http://climate-adapt.eea.europa.eu/
([19]) http://water.europa.eu/

in 2007, which provides a web-portal for water-related information ranging from inland waters to marine. In particular, WISE provides easy links to the European Flood Awareness System (EFAS) and the European Drought Observatory (EDO), which are managed by the JRC.

1.4 Concepts and definitions

The concepts and definitions presented in this report take into account a number of recent consolidated existing sources (IPCC, 2012, 2014b; UNISDR, 2017), but also reflect the fact that concepts and definitions evolve as knowledge, needs, perception and contexts change. CCA and DRR are dynamic fields, and will continue to evolve (see Box 1.3).

In past years the Intergovernmental Panel on Climate Change (IPCC) community pursued extensive efforts to establish a common terminology for dealing with climate change through CCA. The IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) (IPCC, 2012) identified links between climate change and extreme weather- and climate-related events, and considered DRR and CCA in the context of sustainable development. This approach was expanded further in the glossary of the IPCC Working Group II Fifth Assessment Report (AR5) (IPCC, 2014a). In 2015, furthermore, the SFDRR requested UNISDR, in close cooperation with its member countries and other stakeholders, to revise and update the terminology on DRR. This process was started by the OIEWG, and resulted at the beginning of 2017 in an updated DRR terminology (UNISDR, 2017) that was endorsed by the UN General Assembly on 2 February 2017. This revised terminology includes evolving practices and concepts related to DRR that have emerged in recent years, and has been translated into all official UN languages for dissemination.

In this section the core concepts used throughout the report are presented. Among the various climate change adaptation sub-terms, we consider the following concepts key: incremental adaptation, transformative adaptation, adaptation constraint, adaptation deficit and adaptation limit. Incremental adaptation includes adaptation actions that predominantly aim to maintain the essence and integrity of a system or process at a given scale. Transformative adaptation includes adaption actions that may change the fundamental attributes of a system in response to climate and its effects, and find different solutions (IPCC, 2014a). The aim of transformative adaptation is broader and systemic,

Box 1.3 The evolution of the concept of vulnerability in CCA and DRR

The concept of vulnerability has consistently changed over time. A recent study (Giupponi and Biscaro, 2015) reconstructs the evolution of the concept of vulnerability within the CCA and DRR research streams through an extensive bibliometric analysis and literature review. This study highlights the key role of UN institutions (UNISDR, IPCC) in providing contributions to the definition of vulnerability in CCA and DRR.

The recent IPCC reports (IPCC, 2012, 2014b) have been key in proposing solutions for converging on common definitions of vulnerability and related concepts for CCA and DRR.

On the DRR side, in 2009 UNISDR published a terminology booklet (UNISDR, 2009) in which vulnerability is defined with no specific focus on climate change ([20]) and in 2017 an updated terminology (UNISDR, 2017).

On the CCA side, IPCC efforts to converge on a unifying vulnerability concept started with the development of the SREX report (IPCC, 2012), which involved authors from both communities and aimed at a coordinated approach for CCA and DRR. This effort finalised a concise definition of vulnerability ([21]). The glossary provided in AR5 (IPCC, 2014a) built on the SREX effort and adopted a similar vulnerability concept ([22]) to that used in DRR, including two additional definitions (**contextual vulnerability/starting-point vulnerability** ([23]) **and outcome vulnerability/end-point vulnerability** ([24]). In the SREX report and in AR5, vulnerability was clearly established as one of the elements of the notion of risk.

([20]) 'The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard.'
([21]) 'The propensity or predisposition to be adversely affected.'
([22]) 'The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt. See also contextual vulnerability and outcome vulnerability.'
([23]) 'A present inability to cope with external pressures or changes, such as changing climate conditions. Contextual vulnerability is a characteristic of social and ecological systems generated by multiple factors and processes (O'Brien et al., 2007).'
([24]) 'Vulnerability as the end point of a sequence of analyses beginning with projections of future emission trends, moving on to the development of climate scenarios, and concluding with biophysical impact studies and the identification of adaptive options. Any residual consequences that remain after adaptation has taken place define the levels of vulnerability (Kelly and Adger, 2000; O'Brien et al., 2007).'

since it tries to address the root causes of climate change vulnerability. This integrative and long-term approach to addressing climate change impacts has the potential to transform cities into attractive, climate-resilient and sustainable places (EEA, 2016c). Adaptation constraint includes factors that make it more difficult to plan and implement adaptation actions, or that restrict options. Adaptation deficit is the gap between the current state of a system and a state that minimises adverse impacts from existing climate conditions and variability. Adaptation limit is the point at which an actor's objectives (or system needs) cannot be protected from intolerable risks through adaptive actions. Two kinds of adaptation limits can be identified: (1) hard adaptation limits where no adaptive actions to avoid intolerable risks are possible; (2) soft adaptation limits where options to avoid intolerable risks through adaptive action are currently unavailable (IPCC, 2014a).

In general, impacts represent the effects on natural systems (e.g. ecosystems, biodiversity) and human systems (e.g. lives, livelihoods, health, societies, services and infrastructures). In this report, the term impacts is used primarily to refer to the effects of extreme weather- and climate-related events, i.e. effects caused by the interaction of climate change or hazardous climate events occurring within a specific time period, and the vulnerability of an exposed society or system (IPCC, 2014a).

Vulnerability is defined in this report as the propensity or predisposition of an individual, a community, assets or systems to be adversely affected by the impacts of hazards. It includes a variety of concepts and elements such as sensitivity or susceptibility to harm, and lack of capacity to cope and adapt. Vulnerability is a result of diverse historical, social, economic, political, cultural, institutional, natural resource, and environmental conditions and processes (IPCC, 2014a; UNISDR, 2017).

Sensitivity is the degree to which a system or species is affected, either adversely or beneficially, by climate variability or change (IPCC, 2014a). On the other hand, coping capacity is the ability of people, organisations and systems, using available skills and resources, to manage adverse conditions, risk or disasters. The capacity to cope requires continuing awareness, resources and good management, in normal times and during times of crisis or adverse conditions. Coping capacities contribute to the reduction of disaster risks and strengthen resilience (UNISDR, 2017).

Exposure includes the people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas (UNISDR, 2017).

Exposure and vulnerability are distinct concepts, which are often confused by the general public. As clearly stated at page 69 in Chapter 2 of the SREX report (IPCC, 2012): 'Exposure is a necessary, but not sufficient, determinant of risk. It is possible to be exposed but not vulnerable (for example by living in a floodplain but having sufficient means to modify building structure and behaviour to mitigate potential loss). However, to be vulnerable to an extreme event, it is necessary to also be exposed.'

Hazard is defined as a process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation. Natural hazards are predominantly associated with natural processes and phenomena. Hazards may be single, sequential or combined in their origin and effects. Each hazard is characterised by its location, intensity, frequency and probability (UNISDR, 2017). Multi-hazard refers to (1) the range of multiple major hazards that a country faces, and (2) specific contexts where hazardous events may occur simultaneously, cascading or cumulatively over time, and taking into account the potential interrelated effects of these (UNISDR, 2017). Natural hazards are normally classified into various categories (see Box 1.4).

Hazardous event is defined as the manifestation of a hazard in a particular place during a particular period of time. Not every hazardous event may cause a disaster, but severe hazardous events may cause a disaster, as a result of the combination of hazard occurrence and other risk factors (UNISDR, 2017).

Disaster is a serious disruption of the functioning of a community or a society, at any scale, due to hazardous events interacting with conditions of exposure, vulnerability and capacity, and leading to one or more of the following: human, material, economic and environmental losses and impacts. The effect of the disaster can be immediate and localised, but is often widespread and could last for a long time. The effect may test or exceed the capacity of a community or society to cope using its own resources, and therefore may require assistance from external sources, which could include neighbouring jurisdictions, or national or international involvement (UNISDR, 2017). In general, disasters occur when hazards coincide with vulnerability, and the potential for a hazard to become a disaster depends mainly on a society's capacity to address the underlying risk factors, reduce the vulnerability of a community and to be ready to respond in case of emergency (EEA, 2011).

Risk is defined in this report as the potential for consequences where something of value is at stake and

Box 1.4 The selected natural hazards analysed in this report

The natural hazards analysed in this report are from the following broad categories (see Table 1.2):

- hydrological hazards caused by the occurrence, movement and distribution of surface and subsurface freshwater and saltwater;
- meteorological hazards caused by microscale ([25]) (e.g. tornadoes) to mesoscale ([26]) (e.g. storms) extreme weather and atmospheric conditions that last from minutes to days;
- climatological hazards caused by long-lived mesoscale to macroscale ([27]) atmospheric processes, ranging from intra-seasonal to multi-decadal climate variability.

Table 1.2 Classification of the 10 natural hazards selected for this report, taking into consideration that some natural hazards can be allocated to more than one category (e.g. heat waves are both meteorological and climatological)

Category of hazards	Specific natural hazard
Hydrological	River flood
	Landslide
	Avalanche
Meteorological	Heat wave
	Heavy precipitation
	Windstorm
	Storm surge
	Hail
Climatological	Drought
	Forest fire

Source: Based on Integrated Research on Disaster Risk classifications (IRDR, 2014).

where the outcome is uncertain, recognising the diversity of values. Risk is often represented as the combination of the probability of a hazardous event and its negative consequences (probability of occurrence of events or trends multiplied by the impacts if these events or trends occur). In this report, the term risk is used primarily to refer to the risks of impacts due to natural hazards from selected extreme hydrological, meteorological, climatological and geophysical events (IPCC, 2014a; UNISDR, 2017).

Disaster risk is the potential loss of life, injury, or destroyed or damaged assets to a system, society or community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability and capacity. Among the sub-terms of risk the most important are acceptable risk and residual risk. Acceptable risk, or tolerable risk, is the extent to which a risk is deemed acceptable or tolerable, and it depends on existing social, economic, political, cultural, technical and environmental conditions. Residual risk is the disaster risk that remains even when effective measures are in place, and for which emergency response and recovery capacities must be maintained. The presence of residual risk implies a continuing need to develop and support effective capacities for emergency services, preparedness, response and recovery, together with socio-economic policies such as safety nets and risk transfer mechanisms, as part of a holistic approach (UNISDR, 2017).

([25]) Microscale: short-lived atmospheric phenomena with horizontal scales of 1 km or less.
([26]) Mesoscale: atmospheric phenomena with horizontal scales ranging from a few kilometres to several hundred kilometres (e.g. sea breezes, thunderstorms).
([27]) Macroscale: atmospheric phenomena with horizontal scales ranging from several hundred kilometres to several thousand kilometres (e.g. extratropical cyclones, weather fronts).

Disaster risk management (DRM) is the application of DRR policies and strategies to prevent new disaster risk, reduce existing disaster risk and manage residual risk, contributing to the strengthening of resilience and reduction of disaster losses (UNISDR, 2017). DRM and DRR are interlinked: DRR is the policy objective of DRM, and the goals and objectives of the latter are defined in DRR strategies and plans.

Disaster risk assessment is defined as a qualitative or quantitative approach to determining the nature and extent of disaster risk by analysing potential hazards and evaluating existing conditions of exposure and vulnerability that together could harm people, property, services, livelihoods and the environment on which they depend (UNISDR, 2017).

Resilience is defined as the ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of essential basic structures and functions through risk management (UNISDR, 2017). Generally speaking, the resilience of a community with respect to any hazard or event is determined by the degree to which the community has the necessary resources and is capable of organising itself both prior to and during times of need. The uncertainties still inherent in the prediction of extreme events, amplified or driven by climate change, and in the estimation of related impacts, could require a change of paradigm in risk analysis and risk management. A new 'resilience management' is emerging as a better solution (Cutter et al., 2013; Linkov et al., 2014). Building resilience in society networks and infrastructures entails more focus on the first two elements (prevention and preparedness) of the DRM cycle, in order to prepare for and prevent the effects of extreme events and to build resilience, which will be needed to quickly cope and recover when these events occur (see Chapter 2). Resilience management requires new methods to define and measure resilience, new modelling and simulation techniques, and correct approaches to communicating with stakeholders. Resilience management may also require fundamental changes (transformative changes) in the social–ecological systems exposed to hazards (Lonsdale et al., 2015), which can make new systems more manageable under future hazards (Folke et al., 2010). The concept of resilience needs to complement the concepts of CCA and DRR (see Chapter 6).

Finally, an extreme weather- and climate-related event is defined as an event that is rare in time at a particular location. It would normally be as rare as or rarer than the 10th or 90th percentile of a probability density function estimated from observations. The rarity of extreme weather- and climate-related events makes them more difficult to understand scientifically, or to analyse and project, compared with 'average' weather. However, such events often have the highest impacts on and cause the greatest damages to human wellbeing, and to both natural and managed systems. By definition, the characteristics of what is called extreme weather may vary from place to place in an absolute sense. When a pattern of extreme weather persists for some time, such as for a whole season, it may be classified as an extreme climate event, especially if it yields an average or total that is itself extreme (e.g. drought or heavy rainfall over a season) (IPCC, 2014a). The terms extreme weather- and climate-related event or extreme natural event, natural hazard and disaster can be mistakenly misused among the general public; in simple terms, an extreme natural event is an abnormally severe natural event, a natural hazard is an extreme natural event that could threaten people and a disaster is an extreme natural event that does affect people.

This report presents 10 natural hazards (see Box 1.4). They were selected because they are of particular interest because of the impacts of recent European events and perceptions of their changing magnitude and frequency. The report does not address natural hazards such as earthquakes or tsunamis, since their frequency and magnitudes are largely independent of the changing climate. This report examines trends in time based on available observational data (i.e. physically measured with ground-based sensors or sensed remotely by radar or satellite instruments) and model reanalysis (the analysis of model data run historically in time). The report presents future projections of these natural hazards by using variables of proxies from climate models, data gaps, data needs and uncertainties, and describes selected recorded events with high socio-economic impacts.

2 Policies, methods and practices

- CCA and DRR are central to the sustainable development agenda in Europe and globally. Both policy areas pursue common objectives that include management of climate (variability and change) risks and building of climate-resilient societies.
- Comprehensive, multi-hazard risk and vulnerability assessment frameworks are needed to inform evidence-based and robust decision-making, and guide transformational changes in DRR and CCA.
- A review of the current practices suggests that, although innovative examples exist, the full potential of a better integration of DRR and CCA has yet to be exploited.

2.1 Overview of policies relevant to enhance coherence between climate change adaptation and disaster risk reduction

2.1.1 International policies

In 2015 the UN agreed on a renewed global partnership for sustainable development, the 2030 Agenda for Sustainable Development, building upon several complementary multilateral frameworks: the SFDRR, the Paris Agreement on Climate Change and the Addis Ababa Action Agenda on Financing for Development (AAAA). In 2016, the Agenda for Humanity and the New Urban Agenda extended the 2030 Sustainable Development Agenda (see Table 2.1). CCA and DDR are among the main goals of the 2030 Agenda for Sustainable Development, galvanised through these major UN conferences and summits held in 2015 and 2016.

Transforming Our World: The 2030 Agenda for Sustainable Development (UN, 2015b) embraces 17 Sustainable Development Goals (SDGs) with 169 policy targets and more than 300 indicators. The goals and targets are the core component of the new and ambitious global framework to achieve sustainable development and poverty eradication (EC, 2016b). It paves the way for a transition towards greener, fairer and more inclusive development, building upon international collaboration and partnership between states, non-state actors and civil society (EEB, 2015).

The SDGs recognise DRR and CCA as a way of achieving progress in other areas, in particular eradication of poverty, ending hunger and ensuring healthy lives (UNISDR, 2015).

The SFDRR (UN, 2015a) advocates multi-hazard, inclusive, science-based and risk-informed decision-making. It laid down priorities for action and policy targets, progress towards achieving which will be monitored by indicators that were developed by OIEWG and endorsed by the UN General Assembly on 2 February 2017. Understanding the hazards and risks, and measuring progress towards accomplishing the DRR targets, will only be possible if substantial efforts are put in to improving adequate risk assessments and comprehensive disaster impact records. The SFDRR identified climate change and variability as a driver of disaster risk, in conjunction with poverty and inequalities, uncontrolled urbanisation, and poor land management. Tackling these and other factors that contribute to intensification of risk is expected to lead to sizeable reduction of disaster risk. Consequently, the SFDRR pleaded for improved coherence between policy instruments for climate change, biodiversity, sustainable development, poverty eradication, environment, agriculture, health, and food and nutrition. Among others, this coherence will be promoted by adopting harmonised and nested sets of indicators capable of monitoring the progress made in different policy areas.

The AAAA defined a financial framework conducive to inclusive economic prosperity, and lined up financing

Table 2.1 Major UN global agreements with focus on climate change adaptation (CCA) and disaster risk reduction (DRR)

Major recent UN-led agreements	Contributions to harmonising the DRR and CCA agendas
Sendai Framework for Disaster Risk Reduction (SFDRR)	• Formulates priorities for actions and targets for DRR, coordinated with climate adaptation efforts where relevant • Acknowledges climate change as a driver of disaster risk • Addresses disaster preparedness for effective response and to 'build back better'
Addis Ababa Action Agenda (AAAA)	• Specifies financial means for reaching the SDGs and reiterates targets for solidarity financial flows
2030 Agenda for Sustainable Development	• Provides an overarching framework connecting the DRR and CCA targets and commitments with poverty reduction, economic growth, social inclusion and environmental protection • Explicitly addresses the challenge to combat climate change (SDG13), and directly and indirectly addresses DRR and adaptation in several other SDGs
Paris Agreement on Climate Change	• Limits human-induced global temperature rise to 2 °C (1.5 °C) compared with pre-industrial levels. • Addresses climate adaptation as a part of climate change policies (Article 7), and confirms Loss and Damage initiative as cornerstone of global policy architecture (Article 8)
World Humanitarian Summit	• Commits the UN Member countries to core responsibilities of humanitarian aid and disaster risk preparedness
Urban Habitat	• Focuses on urban environment as the major hotspots of vulnerabilities • Formulates New Urban Agenda as a vehicle for better integration of various policies contributing to sustainable development

Note: Agreements concluded in 2015–2016 that promote, directly or indirectly, climate and disaster resilience, and coherence between the CCA and DRR actions.

Sources: EEA, ETC/CCA.

resources with the priorities of the UN 2030 Agenda for Sustainable Development. The AAAA goes beyond Official Development Assistance (ODA), even though developed countries recommitted to meet the previously agreed targets on global solidarity and justice. It embraces trade, investments, cooperation, science and technology, capacity building, illicit financial flows, tax reform (including harmful tax practices and subsidies), role of the private sector and other areas, essentially redesigning global economic governance.

The Paris Agreement on Climate Change (UNFCCC, 2015) is the first universal, legally binding global deal to combat climate change and adapt to its effects. Having met the ratification threshold, it entered into force on 4 November 2016 and will be operative from 2020. The Paris Agreement embraced bold actions set to curb the global temperature rise well below 2 °C and pursuing efforts to limit the temperature increase to 1.5 °C, compared with pre-industrial levels. Put on equal footing, the adaptation goal focuses on ability to adapt to the adverse impacts of climate change and on climate resilience, so contributing to sustainable development (Articles 2 and 7). The Paris Agreement also comprises commitments on finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development. Beyond that, emphasis is placed on 'averting, minimising and addressing loss and damage associated with the adverse effects of climate change' (Article 8) and on the need to cooperate and enhance understanding, action and support in various areas such as early warning systems, emergency preparedness, comprehensive risk assessment and management, and risk insurance. The 2016 Conference of Parties held in Marrakech confirmed the commitment of countries and non-state actors to implement the Paris Agreement (UNFCCC, 2016). Procedures for its implementation will be finalised in 2017–2018.

The UN Secretary General's Agenda for Humanity (UN, 2016) includes five core responsibilities (CRs): CR1 prevent and end conflicts; CR2 respect rules of war; CR3 leave no one behind; CR4 change people's lives; CR5 invest in humanity. Of these at least three are related to natural hazard and climate risk: (1) CR3 addresses displacement and movements of refugees due to disasters; (2) CR4 entails emphasis on risk analysis and data investments; and (3) CR5 recalls the Sendai Framework's and the Paris Agreement's pledges for investment in risk (reduction) and adaptation. The 2016 Humanitarian Summit served as a backstage for launching a Global Partnership for Preparedness ([28]) to help most vulnerable countries to prepare for disasters.

The New Urban Agenda (UN, 2017), adopted at the UN Conference on Housing and Sustainable Urban Development (Habitat III), contains three transformative commitments: leaving no one behind and fighting against poverty; urban prosperity and opportunities for all; and ecological and resilient cities and human settlements. The latter places emphasis on a rapid and efficient recovery from natural hazard strikes. A resilient city is one whose population cares about the safety of individuals and the cohesion of communities, while actively transforming their habitat and taking advantage of reduced risk exposure to improve its essential functions.

The fifth session of the Global Platform for Disaster Risk Reduction was held in in Mexico (Cancún) from 22 till 27 May 2017. The Cancun High-Level Communiqué (UNISDR 2017a) reiterated the commitments made under the 2015/2016 UN conferences and summits. By emphasizing the close nexus between climate change and water-related hazards and disasters, the Communiqué pointed out to the Integrated Water Resources Management (IWRM) as an effective instrument for enhancing resilience and serving both, DRR and CCA goals. Moreover, the Communiqué restated the importance of outcome-oriented partnership between public and private sectors and civil society, and formulated 11 specific commitments among others 'building back better' and 'building better from the start'; conduct risk assessment for existing critical infrastructure (by 2019); and support the development of multi-stakeholder and socially-inclusive partnership initiatives.

2.1.2 EU policies

The EU framework on DRR was formed by a number of thematic legislations, central to which is the EU Civil Protection Mechanism. Concerted European action on adapting to climate change followed in the late 2000s ([29]). Both DRR and CCA are integrated in key EU policies and strategies, including civil and critical infrastructure protection, environmental protection, financial instruments of cohesion policy, ESIF, cross-border health concerns, agriculture, food and nutrition security, and integrated coastal management.

The EU has played an important role in devising the multilateral global frameworks, and lined up the European policies to their goals or even elaborated more ambitious ones (EC, 2014a, 2014c, 2014b). The EU and its Member States are among the largest contributors of public climate finance to developing countries, and firmly committed to scale up the support to developing countries to tackle climate change. In 2015, the total contributions for financing climate action in developing countries amounted to EUR 17.6 billion, which includes EUR 1.5 billion from the EU budget and EUR 2.2 billion from the European Investment Bank ([30]).

In November 2016 the European Commission published an action plan for sustainability (EC, 2016b). This outlines how the SDGs will be integrated into the European policy framework and made to conform with the priorities of the Commission.

The EU Action Plan on SFDRR 2015–2030 (EC, 2016a) recognised the SFDRR as an opportunity not only to advance the DRM agenda in Europe and to reinforce resilience to shocks and stresses, but also to boost innovation, growth and job creation. Annex 1 of the Action Plan ([31]) sums up the contribution of EU policies to fulfilling the SFDRR priorities and targets, especially in the fields of CCA, critical infrastructure protection, flood risk management, water and biodiversity protection, research and innovation, global health security, and food and nutrition security.

The European Union Civil Protection Mechanism (EU, 2013b) compels conducting comprehensive multi-hazard risk assessments at national or appropriate subnational level. Starting in 2015 and every three years subsequently, the key elements of the national risk assessments (NRAs) are to be reported to the European Commission.

In May 2017, the EC published a summary report and review of the collected NRAs (EC 2017). The report focusses on 11 main disaster risks among

([28]) The Global Partnership for Preparedness will strengthen preparedness capacities initially in 20 developing countries, helping them to attain a minimum level of readiness by 2020 for future disaster risks mainly caused by climate change.
([29]) The Green Paper 'Adaptation to climate change in Europe — Options for EU action' was the first milestone (2007), followed in 2009 by the EU White Paper on adaptation to climate change and in 2013 by the EU Climate Adaptation Strategy.
([30]) Council of the European Union http://www.consilium.europa.eu/en/press/press-releases/2016/10/25-climate-change-finance
([31]) Annex 1: Achieving the priorities of the Sendai Framework: a contribution of all EU existing policies and practices.

which floods, extreme weather, and forest fire. In the subsequent report, more emphasis will be placed on making the NRAs (more) comparable and uniform, and on conducting the risk assessment on regional level, within and across EU Member States. For the former purpose, the report identified good practices in NRA methodologies and processes. A still more comprehensive assessment and mapping of risk is mandated by the Floods Directive (EU, 2007), in which the likely impacts of climate change on flood frequency and intensity are to be taken into account, starting at the latest from the second planning cycle (2016–2021). Recently, the EEA published a report exploring the synergies between floodplain restoration and EU water and other thematic policies (EEA, 2016a).

The European Council's Directive on European critical infrastructures (EU, 2008) imposed assessment of risk for critical infrastructure ([32]) 'located in Member States the disruption or destruction of which would have a significant impact on at least two Member States'. Initially addressing only energy and transport sectors, the Commission anticipated a detailed review of additional assets and networks with a significant European dimension (Eurocontrol, Galileo, electricity transmission grids, and gas transmission networks) with respect to prevention, preparedness and response measures, interdependencies and potential cascading effects (EC, 2013a). The Decision on serious cross-border threats to health (EU, 2013a) covers all threats, including hazards related to climate change, to guarantee a coordinated approach to health security at the EU level.

The Disaster Risk Management Knowledge Centre (DRMKC) is the new European Commission initiative to improve and deepen communication between policymakers and scientists in the field of DRM, and is founded on three pillars: partnership, knowledge and innovation. The DRMKC has developed EU guidance for recording and sharing disaster damage and loss data (De Groeve et al., 2013, 2014; JRC, 2015).

The DRMKC produced first flagship science report 'Science for disaster risk management 2017: knowing better and losing less' (Poljanšek, et al., 2017) as an effort of more than two hundred academics and experts. The report was conceived to assist integration of science into evidence-based decision making, and to back-up science-policy and science-operation interface in both, DRR and CCA fields. The three main parts of the report attend to understanding, communicating and managing disaster risk, forming what has been labelled as a 'bridge concept' of the report (Poljanšek, et al., 2017). Respecting the three main action areas of the DRMKC, the report recaps the future challenges in terms of innovation, knowledge and partnership from three different perspectives: scientific experts, policy makers and practitioners. In doing so, the report contributes to the Science and Technology Roadmap to Support the Implementation of the Sendai Framework for Disaster Risk Reduction 2015-2030 from a European perspective (UNISDR 2016).

The EU Climate Adaptation Strategy (EC, 2013b) emphasised close coordination between national adaptation strategies and risk management plans, as well as synergies with DRR in cross-cutting areas such as sharing of data and knowledge, and assessment of risks and vulnerabilities. The Strategy called for 'climate-proofing' of non-climate policies, such as the CAP, the Cohesion Policy and the common fisheries policy (CFP). For example, technical guidance was published on integrating CCA in Cohesion Policy programmes and investments, and a set of principles and recommendations addresses the integration of CCA considerations under the 2014–2020 rural development programmes. Trans-European Transport Network (TEN-T) projects are expected to contribute to promoting transition to climate- and disaster-resilient infrastructure. The new guidelines for trans-European energy infrastructure — Trans-European Energy Network (TEN-E) — include 'climate resilience' as a parameter for energy system-wide cost–benefit analysis for projects of common interest in electricity transmission and storage, and in gas. The decades-old Environmental Impact Assessment Directive (EIA), having been amended a few times, was revised in 2014 and now more explicitly addresses climate change and disaster risks throughout the whole EIA process.

Released as a part of the EU Climate Adaptation package, the Green Paper on the insurance of natural and man-made disasters (EC, 2013b, 2013d) instigated a debate on what the role of the EU should be in the context of disaster insurance in Europe. The Green Paper raised concerns about the availability and affordability of insurance and explored various options, including mandatory insurance, product bundling, public reinsurance and disaster pools. Furthermore this Green Paper included a set of 21 questions, which was the basis for a consultation with stakeholders of public and private sectors launched to raise awareness and to assess the possibility of EU actions to improve the

([32]) Facilities, networks, services and assets which, if disrupted or destroyed, would have a serious impact on the health, safety, security or economic wellbeing of citizens, or the effective functioning of governments in the Member States (EC, 2004, 2006).

market for disaster insurance in the EU. The majority of respondents highlighted:

- that the penetration rate of disaster insurance varies across the EU Member States, due to the diversity of risks and differences in the regulatory environment;
- that mandatory product bundling is not an appropriate way to increase insurance penetration against disaster risks;
- more drawbacks than advantages for long-term disaster insurance contracts;
- a need for more adequate data for disaster mapping;
- that sharing data and cooperation across sectors can lead to improvements in data quality.

The OECD invited member countries to better prepare for catastrophic and critical risks (OECD, 2010, 2014a), including through better designed disaster insurance schemes. In 2014, the OECD Council adopted recommendations for dealing with critical risks (OECD, 2014b), which include collection and analysis of damage and losses from disasters, and development of 'location-based inventories of exposed populations, assets, and infrastructures' as a part of better appreciation of disaster risk. The recommendations also addressed the transparency of risk-related information that includes 'honest and realistic dialog' on risk among stakeholders, and public access to risk information (OECD, 2014b).

The 2013 Commission Communication defines Green Infrastructure (GI) as 'a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services' (EC, 2013c). Attention paid to GI is a part of the Biodiversity Strategy (EC, 2011a) and the Roadmap to a Resource Efficient Europe (EC, 2011b). Target 2 of the Biodiversity Strategy established that by 2020, 'ecosystems and their services are maintained and enhanced by establishing green infrastructure and restoring at least 15 % of degraded ecosystems'. The EEA has also analysed GI in a series of assessment reports (EEA, 2011, 2014b), including a recent report on the role of GI for DRR, in particular flood, storm surge, landslide and wind protection (EEA, 2016a). This EEA report confirmed that well-functioning GI (e.g. floodplains, riparian woodland, barrier beaches and coastal wetlands) can support DRR and CCA in such a way to lessen the impacts of natural hazards (e.g. floods and landslides). Furthermore, combining functional GI with disaster reduction infrastructure (e.g. flood protection works) can provide many benefits for innovative risk management approaches, adapting to climate change-related risks, maintaining sustainable livelihoods and fostering green growth.

Climate services ([33]) (Brooks, 2013; Lourenco et al., 2015; Brasseur and Gallardo, 2016) provide information that can help to reduce risks from extreme weather- and climate-related events, and improve societal resilience. Climate services have grown in numbers, quality and sophistication, stimulated by efforts under the World Meteorological Organisation's Global Framework for Climate Services (GFCS) and the Climate Services Partnership (CSP). The EU made large investments in systems enabling modern meteorological services under the Copernicus Earth observation programme (previously Global Monitoring for Environment and Security, GMES) (EC, 2014d), as a contribution to the Europe 2020 strategy for smart, sustainable and inclusive growth (EC, 2010b). Copernicus Climate Change Service (C3S) is one of six Copernicus service components, designed to deliver knowledge to support adaptation and mitigation policies. C3S is managed by the European Centre for Medium-Range Weather Forecasts (ECMWF) ([34]).

2.2 Methods and tools for risk assessment and policy planning in climate change adaptation and disaster risk reduction

DRM is a complex process that requires a range of methods and tools aligned with all possible components of the DRM cycle (including risk assessment): risk assessment, prevention, preparedness, response and recovery (see Figure 2.1). This section addresses methods and tools for risk assessment and policy planning in CCA and

([33]) The EU Roadmap (EC, 2015a) portrays climate services as 'transformation of climate-related data — together with other relevant information — into customised products such as projections, forecasts, information, trends, economic analysis, assessments (including technology assessment), counselling on best practices, development and evaluation of solutions and any other service in relation to climate that may be of use for the society at large' (p. 10).

([34]) http://www.ecmwf.int/

DRR. It draws on the International Organization for Standardization (ISO) standard risk management ([35]).

Risk assessment consists of three steps: risk identification ('finding, recognizing and describing risk'), risk analysis ('estimation of the probability of its occurrence and the severity of the potential impacts') and risk evaluation ('comparing the level of risk with risk criteria to determine whether the risk and/or its magnitude is tolerable'). In the context of climate risk assessment these steps need to consider all relevant climate and non-climate factors that generate a particular climate risk (Fenton and Neil, 2012).

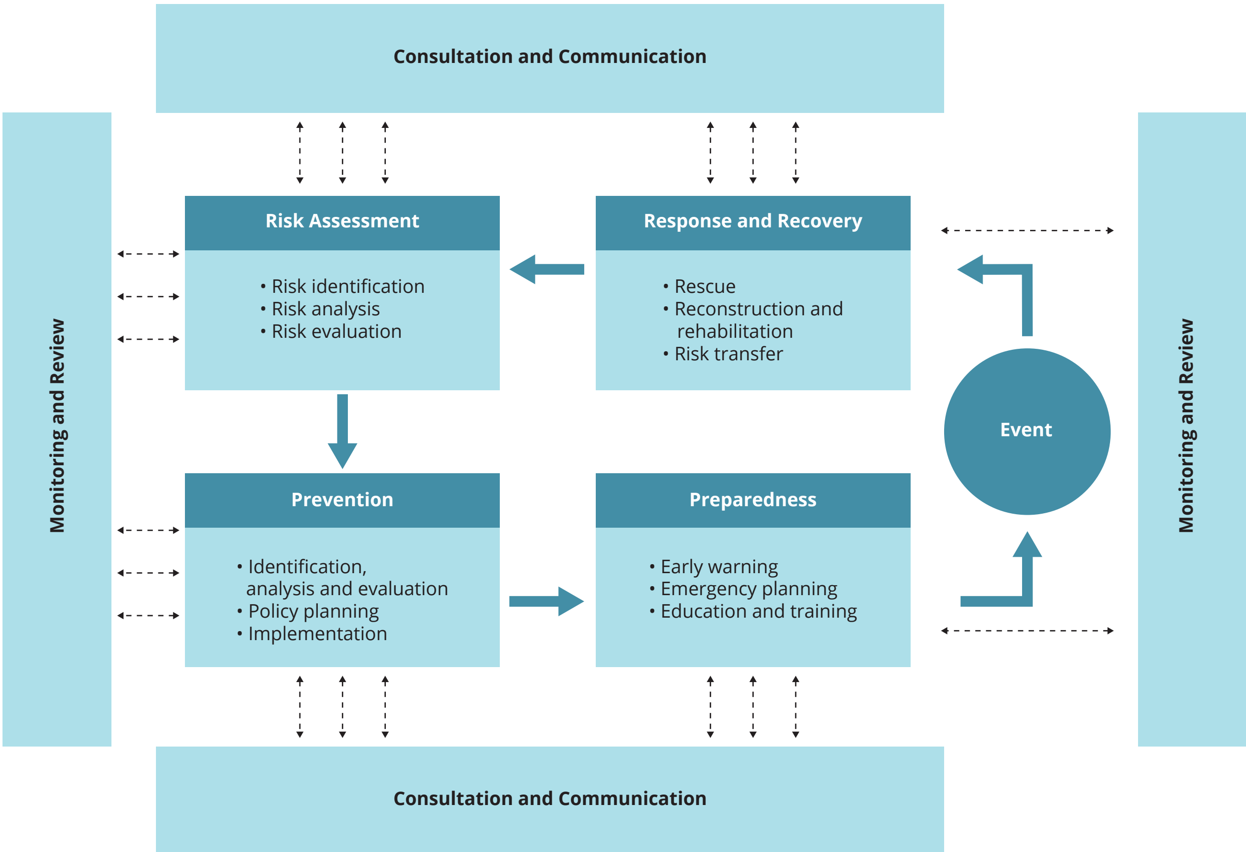
Risk assessment inherently relates to the available risk reduction options in terms of risk mitigation and adaptation planning (also termed 'prevention' in this report). Similar to the assessment of risk, the prevention options need to undergo an assessment procedure, consisting of identification, analysis and evaluation (of bundles) of risk mitigation, and adaptation options to effectively support policy planning and implementation of DRR.

Risk assessment and risk prevention are both systematically embedded into communication with, and consultation of, stakeholders. They are also iterative in nature, i.e. based on the monitoring and review of each and every component of DRM.

2.2.1 From risk assessment to integrated risk and vulnerability assessment

In the CCA community, vulnerability is more broadly defined as the relationship between all these components, i.e. hazard, susceptibility and exposure, taking account of the capacity of human and natural

Figure 2.1 Disaster risk management (DRM) cycle



Note: Based on ISO 31000, climate risk can be defined as the product of the likelihood of a climate-related event or trend and its consequences. In the climate adaptation community, the IPCC definition (IPCC, 2012) is more widely used and sees risk as the product of hazard ('potential occurrence of a climate-related physical event'), vulnerability/susceptibility ('propensity or predisposition to be adversely affected').

Sources: EEA, ETC/CCA (based on ISO 31000).

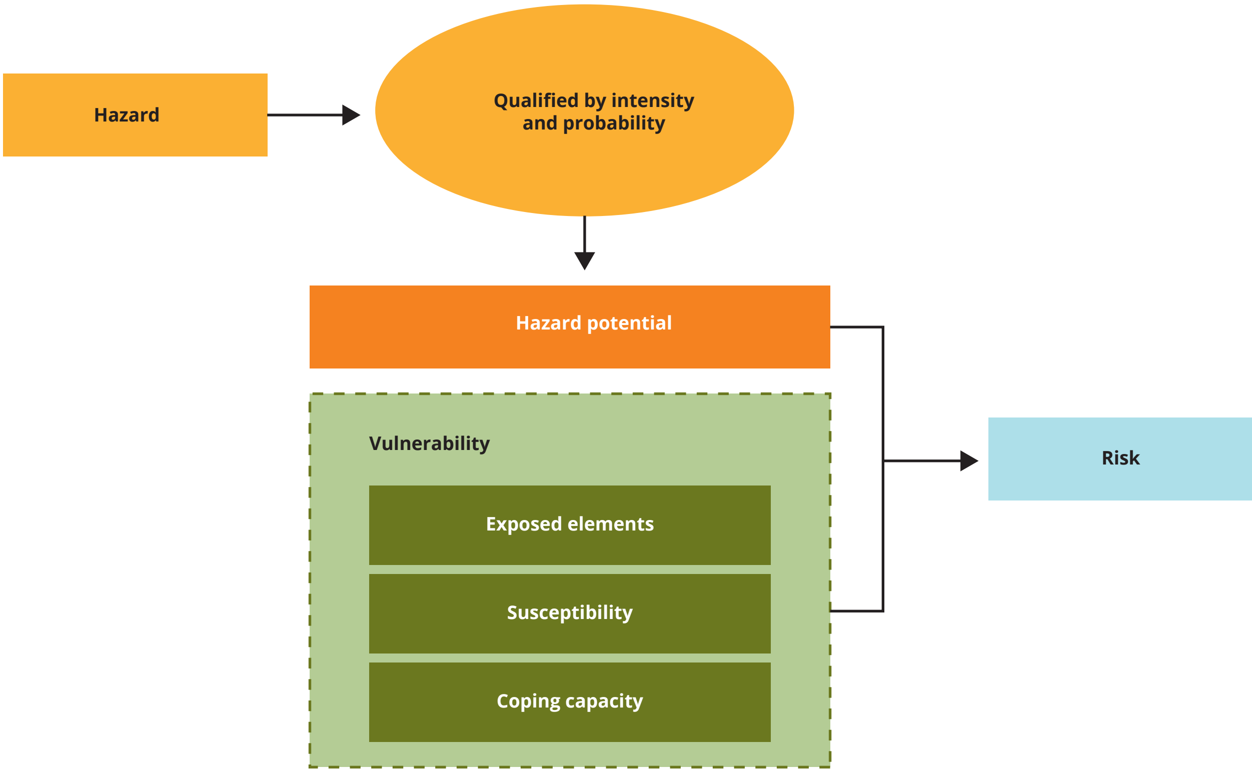
([35]) The risk management standard ISO 31000 of the ISO provides principles, framework and a process for managing risk in organisations of corporate governance. See http://www.iso.org/iso/home/standards/iso31000.htm systems to cope with and adapt to this risk (Figure 2.2). In its glossary, AR5, (IPCC, 2014) defines vulnerability as the propensity or predisposition of an individual, a community, assets or systems to be adversely affected by the impacts of hazards. Vulnerability encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt ([36]) (see Box 1.3).

Systems' vulnerability and adaptive capacity assessment has become the leading tool in adaptation planning in practice ([37]). A risk and systems' vulnerability framework for CCA was developed in the United Kingdom ('Adaptation Wizard') and has since been applied in PROVIA (2013) and many other international frameworks, such as the Urban Adaptation Support Tool of the Covenant of Mayors for Climate and Energy, and the Adaptation Support Tool, both included in Climate-ADAPT. The concept is also included in the EU guidelines on developing national adaptation strategies (EC, 2013e).

2.2.2 *Quantitative and qualitative risk assessment models*

In practice, the assessment of climate change-related risks or climate risk assessment is often conducted by means of science-based models ([38]), which aim to represent the causal relationships between the various climate and non-climate factors that generate risk. In the face of the complexity of these causal chains, and given the poor availability and/or accessibility of data, it is often impossible, however, to apply quantitative

Figure 2.2 The concepts of risk, hazard and vulnerability in the integrated risk hazard framework



Note: The exposure of various elements is shown here as part of the vulnerability of the group of elements, but exposure assessment may also be regarded as separate from vulnerability assessment.

Source: IPCC, 2012.

([36]) The IPCC (IPCC, 2001) had defined vulnerability as 'the degree to which a system is susceptible to, or unable to cope with adverse effects of climate change, including climate variability and extremes'. In this old concept, 'vulnerability' was the final outcome, essentially what we now call 'risk'. The new AR5 definition (IPCC, 2014) is in line with that of UNISDR (UNISDR, 2017c).

([37]) For an overview of national vulnerability and impact assessments to climate change in Europe, see for example http://climate-adapt.eea.europa.eu/countries-regions/countries, (SYKE, 2011) and (UBA 2015). Developing countries' national vulnerability and impact activities are summarised in (UNFCCC, 2014, 2015).

([38]) For an overview see the PROVIA/MEDIATION toolbox, available at: http://www.mediation-project.eu/platform/toolbox/toolbox.html numerical models of climate impacts. Qualitative — sometimes called descriptive — models, which are grounded in expert judgement and local people's knowledge, thus play a crucial role in climate risk assessment. This is not to be seen as a 'deficit' but as a necessary methodological ingredient when uncertainty and conflicting values and beliefs ('normative ambiguity') are involved (Klinke and Renn, 2002; Renn et al., 2011). Climate change is a problem in relation to both future climate developments and changing socio-economic systems (Groves and Lempert, 2007; Hallegatte et al., 2012). This requires systematic involvement of stakeholders, effective bi-directional discourse and iterative learning.

Nevertheless, quantitative numerical Impact Assessment Models (IAMs) are an important tool to support decision-making on climate risks. Their main advantage lies in the fact that they can be based on large ensembles of different climate models and risk scenarios and can thus identify model inputs that cause significant uncertainty in the output (perform 'sensitivity analyses') and help quantify uncertainty ([39]). In principle they can also be applied to choose robust risk treatment options (Lempert and Groves, 2010). To be 'useful and used', however, they have to leave their academic silos (Lemos and Rood, 2010). A decade of climate services experiences show that applied IAMs have to be salient (perceived to be relevant), credible (perceived to be of high technical quality) and legitimate (perceived to be based on non-discriminatory process) (Bowyer et al., 2014). Therefore, effective quantitative models need to be rooted in structural and sustained stakeholder dialogues. After all, 'if the local community is not involved in the development process, it will not trust (or use) the end product' (OECD, 2012).

Policy planning between optimisation and adaptation pathways

The assessment of climate risks is not only sequentially but also logically followed by a choice on risk reduction options. Whether conducted in economic terms or by any other societal evaluation criteria, they need to undergo a similar process of identification, analysis and evaluation, sometimes summarised as 'optimisation'. The methods and tools available to assess risk mitigation and climate adaptation strategies are similar to the ones applied in climate impact modelling, but are also to some extent specific to this task. They include cost–benefit analysis, cost-effectiveness analysis, multi-criteria analysis, robust decision-making, real options analysis and adaptive management ([40]). Along the continuum from cost–benefit analysis to adaptive management, these methods allow for a deeper consideration of normative ambiguity (conflicting values and beliefs) and uncertainty. Robust decision-making, for example, aims to support decisions in the absence of any probabilistic information on scenarios and outcomes, i.e. 'deep uncertainty' ([41]), while adaptive management allows for the updating of actions on the basis of incoming new information and therefore closely relates to risk management principles of monitoring and evaluation, and learning. The benefits of moving from traditional frameworks involving economic/engineering methods of assessment (such as cost–benefit analysis and cost-effectiveness analysis) are, firstly, to be able to consider pluralistic views on risk, and secondly to identify robust ([42]) (rather than economically optimal) strategies and measures of risk reduction. The further consideration of uncertainties in CCA policy planning has led to the development of the adaptation pathways concept (Haasnoot et al., 2013), which turns from mostly incremental risk mitigation policies for addressing proximate causes of risk to 'enabling environments' for a more radical societal transformation to address deeply uncertain future risk scenarios ([43]) (Walker et al., 2013; Wise et al., 2014).

From single-hazard to multi-hazard/multi-risk assessment

The European Commission has adopted an EU guideline 'Risk assessment and mapping for disaster management' (EC, 2010a) which, for the first time, assumes a multi-hazard and multi-risk perspective. It aims to assist Member States to further develop their NRAs, taking into account regions or classes of objects exposed to multiple hazards (e.g. storms and floods), with or without temporal coincidence. It also aims to consider 'cascading effects', in which one hazard triggers another in a cascading fashion (e.g. a flash

([39]) For more information see https://ec.europa.eu/jrc/en/samo
([40]) For an overview see the MEDIATION/PROVIA tool box, available at: http://www.mediation-project.eu/platform/toolbox/toolbox.html
([41]) Walker et al. (2013) have defined 'deep uncertainty' as the condition in which analysts do not know, or the parties to a decision cannot agree upon, (1) the appropriate models to describe interactions among a system's variables, (2) the probability distributions to represent uncertainty about key parameters in the models, and/or (3) how to value the desirability of alternative outcomes.
([42]) Robustness is defined as a decision-making attribute that gives a positive value to flexibility (in the sense of keeping options open) and allows a tradeoff of optimal performance for less sensitivity over a wide range of equally plausible scenarios
([43]) The recently concluded Know-4-DRR-project of the EU's 7th Framework Programme of Research goes even further in openness through its call for immediate, open-outcome social experiments, or 'living labs of DRR and CCA' (http://cordis.europa.eu/result/rcn/176819_en.html).

flood causing a breakdown of electricity supply and, as a result, leading to an industrial accident involving a hazardous materials spill). It is important to note that cascading effects may occur along the hazard chain (as in the case just mentioned) or along the vulnerability chain (e.g. the resilience of a street infrastructure exposed to an inundation event in summer is weakened during a subsequent winter frost). Sometimes those are called 'secondary effects' or, as in the case of a flash flood causing an industrial accident, 'secondary disasters' (Pescaroli and Alexander, 2015).

The methodological challenges of a multi-hazard risk assessment (MHRA) are numerous, especially when it comes to accounting for cascading effects (Kappes et al., 2012; Gallina et al., 2016). Quantifying the interactions of risks is also particularly difficult in the case of climate change, where probabilities of events are changing on different time paths (Liu et al., 2016). MHRA is very case sensitive (i.e. dependent on the set of hazards selected), even in less challenging settings (such as independent hazards), and demanding in terms of understanding inter-hazard physical relationships as well as input data (high-resolution data in space and time are needed), when it comes to cascading effects, as the following example (Box 2.1) demonstrates.

The OECD concludes in a major review of practices that multi-hazard and multi-risk assessments 'are still in their infancy' (OECD, 2012). It calls for greater attention to MRHA among scientists, research funders and policymakers. The Global Earthquake Modeling Initiative is given as a good example of how MHRA could be developed in the future, but it needs to be supported by policy frameworks of DRM ([44]). The recent series of EU-funded multi-projects (ESPON-HAZARD, ARMONIA and MATRIX) ([45]) and the above-mentioned EU guideline on MRHA represent good first steps in this direction.

2.3 Climate change adaptation and disaster risk reduction practices in Europe

2.3.1 Introduction

This section discusses how the various European policies described in Section 2.1 are being put into practice at national and subnational levels. Examples are drawn from a survey among EEA member countries between February and April 2016, and a workshop held at the EEA in Copenhagen on 11–13 April 2016. We distinguish between 'coordination and collaboration' (Section 2.3.2) and 'on-the-ground' examples of CCA and DRR practices (Section 2.3.3). In the context of this report, 'good practice' implies that at least potentially duplicative and/or conflicting actions are avoided. As noted in Chapter 1, a good practice enhances coherence with, or integrates CCA concerns into, DRR practices and vice versa, with the aim of enhancing the knowledge base and benefiting both policy areas. Good practice also realises more effective and efficient policies in both areas due to exploitation of synergies, and achieves a stronger collaboration between scientific and policy communities and networks. Successful examples of integrated adaptation and risk-mitigating measures have been explicitly designed to help both in coping with extreme events and in taking into account possible long-term climate-related

Box 2.1 'Natural disaster hotspots' in Europe under climate change

In a unique collaborative effort between various European modelling institutions, an assessment was attempted on how 'natural disaster hotspots', as defined by Forzieri et al. (2015), will evolve due to climate change in Europe. They find that regions in southern Europe (the Iberian Peninsula, southern France, northern Italy and the Balkan countries along the Danube) will see a 'progressive and strong increase in overall climate hazards' (Forzieri et al., 2016). The frequency of riverine floods will triple (with current 100-year events occurring roughly every 30 years in the 2080s in southern France and northern Italy, and perhaps subannually in the Danube region); and the frequency of heat waves, droughts and wildfires will increase more than 10-fold in the same period (mainly in southern Europe). The greatest accumulation of future risks, however, will occur in coastal regions bordering the North Sea such as the British Isles and the Netherlands, which are densely populated and economically pivotal for Europe. The overall exposure to multiple (independent) hazards shows a positive gradient that is 'even more pronounced than in single-hazard scenarios' (Forzieri et al., 2016). Hazard interactions and their 'secondary effects' could not be assessed in this study because of a lack of 'knowledge of the inter-hazard physical interactions' and a lack of hazards metrics with finer time resolution, where monthly data would be needed across hazards (Forzieri et al., 2016).

([44]) Overview of natural and man-made disaster risks in the EU: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52014SC0134&from=en
([45]) Natural and technological hazards and risks in European regions (ESPON-HAZARD); Applied multi Risk Mapping of Natural Hazards for Impact Assessment (ARMONIA); New Multi-Hazard and Multi-Risk Assessment Methods for Europe (MATRIX).

strategies and the EU sustainability agenda. As noted in Chapter 1, enhancing resilience is one concept that integrates DRR and CCA objectives.

A complicating factor in providing good practice cases of CCA and DRR is that many integrative good solutions are often described using other terms, or that integration may be implicit rather than explicit. Chapter 5 reviews the extent to which CCA and DRR practices in Europe are effectively integrated in areas where this would be beneficial, and how practices in both areas could be improved by taking into account CCA concerns in DRR practices and vice versa.

2.3.2 Coordination and collaboration

This section provides various examples of policies in the areas of CCA and DRR in EEA member countries. How are these implemented at the national and subnational level, and to what extent and how are they connected? Coordination and collaboration can be formal, i.e. with mandated roles and responsibilities, or it can be informal, e.g. information exchange or personal ties. Successful collaboration between CCA and DRR actors can be arranged between existing institutions, or new institutions can be established for this specific purpose. Below we discuss collaboration between various sectoral actors ('horizontal' coordination) and between different administrative levels ('vertical' coordination).

Horizontal coordination and collaboration

At the national level, in many European countries policy development for CCA and DRM are usually well connected. In some countries specific new institutions have been established to develop joint actions, such as the Climate Change Adaptation in Disaster Risk Management Working Group in the context of the Strategic Agency Cooperation on Risk Assessment and Management in Germany (see Box 2.2), which explores impacts of climate change on and adaptation needs for the population and the organisations themselves. Information on horizontal coordination and collaboration at state, provincial and municipal level is not easily available. Box 2.3 includes the example of the London Climate Change partnership. Integrating CCA and DRR for small organisations, such as municipalities with small populations, may be easier than for large organisations because of proximity of staff or shared responsibilities between CCA and DRR, but may also be hampered because of more limited human and financial resources at the local level. While most practice cases in this report relate to floods, heat waves can also have disastrous consequences and collaboration between DRR and CCA institutions can be beneficial in this context, as illustrated by the Austrian case in Box 2.4. At yet another scale, various regional collaborations demonstrate coordination between stakeholders in different sectors in different countries. One example is in the Baltic region, where the Baltadapt Strategy for adaptation to climate

Box 2.2 Strategic Agency Cooperation on Risk Assessment and Management in Germany

The working group 'Climate Change Adaptation in Disaster Risk Management', comprising the federal level of aid organisations, fire services, the Technical Relief Agency and the Federal Office of Civil Protection and Disaster Assistance, was formed in 2008 in order to discuss possible impacts of climate change and resulting adaptation needs. One insight of their work is that not only the population, but also the organisations themselves, can be affected by climate change. Against this background, the working group identified needs for improvements in, for example, warning, operation coordination, human and material resources, and to strengthen the individual's capacity for self-help in the light of climate change. Continuous exchange within the group ensures that both further impacts and needs can be detected.

Since 2007, the Strategic Government Climate Change Adaptation Alliance has led cooperation between the German Meteorological Service, the Federal Office of Civil and Disaster Assistance, the Technical Relief Agency, the Federal Office for Building and Regional Planning and the Federal Environment Agency, to deal with topics of disaster management in terms of CCA. Besides general information exchange between the authorities involved, the work concentrates on joint research projects focusing on extreme events, especially heavy precipitation, under changing climate conditions. The cooperation thereby aims to expand the knowledge base on extreme weather events as a major cause of damage to people and goods, in order to improve coping with climate change from short-term, operational actions to long-term planning measures.

Sources: EEA expert workshop/survey; http://www.bbk.bund.de/DE/AufgabenundAusstattung/KritischeInfrastrukturen/Projekte/Klimawandel/klimawandel_node.html; http://www.umweltbundesamt.de/die-strategische-behoerdenallianz-anpassung-an-den.

Box 2.3 Horizontal coordination of climate change adaptation and disaster risk reduction in the United Kingdom — adaptation and resilience

In 2011, the UK National Hazard Partnership was established at the national level as a consortium of 17 public bodies (mainly government departments and agencies, trading funds and public sector research establishments). This aims to build on partners' existing natural hazard science, expertise and services to deliver fully coordinated impact-based natural hazard advice for civil contingencies, and responder communities and governments, across the UK. This partnership provides input for an NRA which is performed every year. This is a confidential assessment that draws on expertise from a wide range of departments and agencies of government, and is accompanied by the National Risk Register, the public version of the assessment. The government aims to ensure that all organisations have clear and effective risk assessment processes in place. Working at all levels, the risk from emergencies facing the country as a whole is assessed and mitigated. The assessment focuses on single events, but longer term vulnerabilities such climate change are considered as part of the assessment of existing risks.

At the local level, the London Climate Change Partnership is the centre for expertise on CCA and resilience to extreme weather. The partnership comprises public, private and community sector organisations that have a role to play in preparing London for extreme weather today, and climate change in the future. The London Climate Change Partnership is part of the Climate UK network, which consists of a number of organisations and individuals throughout England, Scotland, Wales and Northern Ireland that work to support local action on climate change.

Source: Cabinet Office, 2015.

Box 2.4 A comprehensive heat protection plan for Styria, Austria

Heat waves are a major threat for large parts of Styria at present, and will be even more so in the future. A province of Austria, Styria has approximately 1.2 million inhabitants, and its capital Graz is home to about 280 000 people. In 2011 the first version of the heat protection plan was presented, and this was updated in 2015. The Public Health Department of the Provincial Government of Styria is responsible for the plan, which contains all relevant information about the scientific background of climate change and more specifically heat waves. The impacts of environmental pollution on humans and threats posed to vulnerable groups are described in detail. Additionally the plan contains information about measures to reduce the short- and long-term negative impacts of heat. Cooperation between the Government of Styria and the Austrian Central Institute for Meteorology and Geodynamics is an important element of the plan. Based on meteorological models, the institute issues an alert to responsible stakeholders in the event of a forecast predicting three consecutive days of heat. As a consequence the heat protection plan is activated.

Source: Feenstra, 2016.

change also pays attention to DRR. A large number of collaborative public and private networks are to implement this strategy. The adaptation strategies of transnational river basins like the Strategy on Adaptation to Climate Change for the Danube (ICPDR, 2013) or the Strategy for International River Basin District Rhine for adapting to climate change (ICPR, 2015) are other examples of horizontal collaboration.

Vertical coordination and collaboration

Responding to extreme events is the responsibility primarily of local governments, but higher level governments have a role to support municipalities in the various stages of DRR (prevention, preparedness, response and recover; see Box 2.5). An extreme event can turn into a disaster if it exceeds the ability of the affected community to cope using its own resources (UNISDR, 2017b). This requires effective coordination and collaboration between the national, state, provincial and municipal administrations, and different EU Member States have different solutions according to national context. From the perspective of national policy development, the EEA (2014a) stresses the importance of vertical coordination for CCA and provides examples from 18 out of 29 countries in a survey, but does not specifically consider integration or coherence with DRR. Another report (EEA, 2016b) confirms this importance and provides some examples from an urban point of view, but again does not explicitly address integration or coherence between CCA and DRR.

Box 2.5 Coordination between national government and municipalities, Norway

Norway has organised cooperation across levels, from the national level (laws and regulations) to county governors (audits and supervision) and municipalities (implementation). In 2015, a government-appointed commission presented a Green Paper on management of urban flooding, suggesting changes in the legislation to enhance 'blue–green' solutions for management of surface water. In 2016, the government issued a White Paper on societal safety, which highlights the SFDRR as an instrument for preventing disasters, including natural hazards and impacts of climate change. It emphasises a holistic approach that includes various risk drivers and interdependencies at all levels of planning, and the cross-sectoral coordinating role of the municipalities and the county governors in the management of disaster risks. The Natural Hazard Forum is a cooperative forum for the relevant national authorities for preventive work relating to natural hazards. The 2015 national survey of municipalities by the Directorate for Civil Protection (answered by 90 % of the municipalities) shows that 85 % have carried out comprehensive risk and vulnerability assessments, and that 93 % have an emergency plan. Even if some assessments do not meet the requirements of the Civil Protection Act, there is a positive trend. In general, larger municipalities (cities, towns) are well on track. Their risk and vulnerability assessments are cross-sectoral, and cover both existing and future risks, as 86 % of them have included climate change impacts. These assessments provide a knowledge base for societal planning at local level — the aim is that societal planning should enhance disaster prevention.

Furthermore, several authorities are responsible for various regulations regarding urban flooding and the municipal management of such issues. The Norwegian Environment Agency is responsible for having an overview of the regulations regarding urban flooding, and makes this information publicly available on its website. In addition, the Environment Agency is responsible for administration of a climate adaptation grant scheme, to which municipalities may apply. One important task for the Environment Agency is, together with the Directorate for Civil Protection and the Norwegian Water Resources and Energy Directorate, and in dialogue with many other relevant directorates, to draft a version of central planning guidelines. These guidelines will describe how the municipalities and counties can incorporate CCA into their planning activities according to the Planning and Building Act.

Source: EEA expert workshop/survey; http://www.dsb.no/; www.miljøkommune.no

In Norway, this link is explicitly made and clear roles have been assigned to the national, county and local administrations, with the national administration providing guidance and financial support (see Box 2.5). In Austria, the provincial and municipal levels have specific legislative and implementation authority, while protection is funded jointly by the various governmental levels (see Box 2.6). The Italian National Civil Protection Service has a well-functioning vertical coordination mechanism in which volunteers play a significant role (Box 2.7). Other countries could learn from Italy regarding its highly mobile force of volunteer organisations. Tens of thousands of volunteers could be mobilised, within just a few days, to support professionals in emergency response, relief and recovery activities. The OECD review also points to a number of challenges, such as the need to increase damage reduction efforts and better implement prevention policies, enhance public awareness and the capacity for emergency management in some municipalities, improve insurance coverage for natural disaster losses and reinforce incentives to invest in mitigation measures. While vertical coordination may be well established, integration of CCA concerns may help address some of these challenges.

Box 2.6 Legislative competence of municipalities in Austria

Regarding natural hazard management, the provincial governments have legislation competence in (1) development planning, (2) building affairs and (3) catastrophe/disaster measures and execution competence in flood control and supra-local disaster management. On community/municipality level they have execution competence in (1) land-use planning and building (also by considering hazard and risk maps), (2) local disaster management and (3) avalanche commission (where appropriate). Both levels (province, community) contribute financially to protection measures, together with the federal state. The communities have — in most cases — responsibility to maintain protection structures. Adaptation activities at the local level (regions, municipalities) were initiated mainly through research projects, where collaboration with local authorities took place.

Source: EEA expert workshop/survey; http://www.klimawandelanpassung.at/

Box 2.7 National Civil Protection Service in Italy

The Italian national civil protection system was evaluated by the OECD as having effective governance mechanisms, with a clear line of command and control, including at the operational level. Public safety and security services from central, regional, provincial and municipal levels of government are well coordinated, along with critical infrastructure operators, the military, volunteer organisations and scientific research institutes. Furthermore, the civil protection system is able to scale-up operations to a level appropriate to the event in question, as it integrates human resources and equipment from different organisations into coherent and concerted emergency management operations. The civil protection system quickly and accurately evaluates the severity of events as they transpire, thanks to strong situation awareness and collaborations with the scientific community. Central and regional authorities have developed a network of real-time information sharing between monitoring stations, which provides capacity to anticipate and model events.

Source: OECD, 2010.

2.3.3 Implementation of climate change adaptation and disaster risk reduction in practice

The previous section discussed how EEA member countries coordinate the development of CCA and DRR practices through various governance arrangements. This section addresses examples of how this is turned into practice 'on the ground' through measures to address both problems. As noted in the introduction, in many cases CCA and DRR are dealt with jointly but are not labelled as such. For example, in many countries flood risk prevention policies have started to take into account long-term changes in flood intensity and frequency because of climate change, but do not explicitly call this CCA. Examples are programmes such as Room for the River in the Netherlands and the United Kingdom, the Noordwaard Polder in the Netherlands, and the Calle 30 and Madrid Rio projects which are noted in *Towards an EU research and innovation policy agenda for nature-based solutions & re-naturing cities*, the final report of the Horizon 2020 expert group on nature-based solutions and re-naturing cities (EC, 2015b). Practices to increase drought resilience also sometimes take into account climate change (see Box 2.8), but the EEA survey in support of the current report suggests that droughts are seldom addressed as 'disasters' in the context of the SFDRR, which usually focuses on short-term high-impact extreme weather events like floods or storms.

Below some examples of practices are presented according to the disaster response cycle (see Figure 2.1). It can be noted that in many cases measures relate to more than one of the steps. Capacity building, for example, can cover prevention or preparedness, and a typical preparedness measure such as emergency planning can also include preventive aspects.

The extent to which current practices already effectively integrate CCA and DRR will be discussed in the lessons learned in Chapter 5, where opportunities for adapting current practices, to more effectively apply the knowledge developed in one of these areas to the other, will also be presented.

While some level of integration between CCA and DRR may be relevant in all phases of this cycle, the relevance, level and characteristics of integration vary

Box 2.8 Drought planning in water resource systems, Júcar river basin district, Spain

The Júcar river basin is one of the most vulnerable areas of the western Mediterranean region, due to high water exploitation indices, and to environmental and water quality problems when droughts occur. In the future the situation will worsen if human pressures increase and variability of precipitation and air temperatures are also higher. In the Júcar river basin, water scarcity and hydrological variability produce frequent and long hydrological droughts. Preparation for droughts is achieved through (1) integrated river basin planning, including proactive measures that minimise the risk of operative droughts (i.e. failure of the system to provide water services); (2) special drought plans, including continuous monitoring of drought indices in order to detect the risk in medium- to short-term management, and sets of proactive and reactive measures for different scenarios (i.e. normal, pre-alert, alert and emergency); and (3) participatory drought management by means of a special drought committee, to mitigate the impact of droughts and find suitable compromise solutions to provide an equilibrium between economic needs and environmental protection. Up-to-date integrative decision support systems are used to enhance and facilitate the ability to address drought. The emphasis of the plans is on enhancing the resilience to drought of the water resources systems.

Sources: Andreu et al., 2013; Andreu, 2015.

between phases. For example, CCA is not relevant for the stage of immediate emergency response to an extreme event (defined by UNISDR as 'the provision of emergency services and public assistance during or immediately after a disaster in order to save lives, reduce health impacts, ensure public safety and meet the basic subsistence needs of the people affected'), although it may be relevant in the subsequent recovery stage. Three categories of preventive or preparedness practices can be considered (EEA, 2013): 'grey' measures (physical infrastructure), 'green' measures (nature- or ecosystem-based solutions) and 'soft' measures (enhancing adaptive capacity, information platforms, climate adaptation and risk services, and insurance schemes). Below, examples are discussed of practices for those phases of the DRR cycle for which integration with CCA is most relevant: prevention, preparedness, and response and recovery.

Prevention

Risk reduction, or prevention, is the 'outright avoidance of adverse impacts of hazards and related disasters' (UNISDR) ([46]). This DRR phase may offer most opportunities for integration of CCA and DRR in two directions. First, climate change considerations should take into account a longer time perspective and where relevant a larger spatial scale than traditionally is the case for DRM. Conversely, CCA action can benefit from considering short-term issues related to extreme weather events (future weather rather than future climate). The sector for which integration between CCA and DRR appears to have advanced most is water management, mostly in flood management but also in addressing drought and water scarcity. An example of 'grey' measures to reduce vulnerability to floods is the building of upstream reservoirs to protect downstream population and economic assets, such as in the case of the Tisza basin in Hungary (see Box 2.9) or the Isar basin protecting the city of Munich in Germany.

The impacts of extreme weather- and climate-related events on human society and the environment can often be reduced using GI solutions, and often have higher benefits than 'grey' solutions (EEA, 2015). In the EU, green and nature- or ecosystem-based solutions are increasingly encouraged, mainly because they often serve multiple purposes (e.g. CCA, DRM, promotion of human wellbeing and biodiversity conservation) which broadens support and facilitates funding. They provide a multitude of ecosystem services, including DRR and CCA, and can be integrated into various sectoral policies (EEA, 2011). The role of spatial planning should be emphasised in facilitating and delivering GI (EEA, 2014b). Nature-based solutions can be developed in larger rural areas, such as the Danube Delta (see Box 2.10), but are also relevant in an urban context (EEA, 2016b).

Many 'soft' measures are possible to increase resilience to climate change and extreme weather events. Enhancing adaptive capacity through awareness raising and capacity building is discussed below under 'preparedness'. Sometimes, practices that have been conceived primarily from a DRR perspective can be adapted to take into account longer term climate change concerns. For droughts and water scarcity, examples are incentives for water saving and increased water efficiency. The various types of grey, green and soft measures can also be combined into integrated

Box 2.9 Temporary floodwater storage in agricultural areas in the middle Tisza river basin. Hungary

Increasing exposure to floods is a consequence of river regulation and land reclamation works that have shaped the landscape of the Tisza floodplain. During the past 150 years, an extensive flood defence and water management infrastructure has been constructed. Climate and land use change in the basin are increasing the frequency and magnitude of floods. The Hungarian Government has been pursuing a new flood defence strategy for the Tisza, based on temporary reservoirs where peak floodwater can be released. A plan to build six reservoirs was adopted, with the option of building an additional five. This case study is based on the analysis of operational scenarios of the reservoir schemes, while some of the detailed assessment took place specifically in one of the polders, the Hanyi-Tiszasülyi reservoir.

Source: Climate-ADAPT; http://climate-adapt.eea.europa.eu/metadata/case-studies/temporary-flood-water-storage-in-agricultural-areas-in-the-middle-tisza-river-basin-hungary

([46]) https://www.unisdr.org/we/inform/terminology measures. Examples are the infrastructure and economic incentives to reduce vulnerability to drought in the Segura and Tagus basins in Spain (see Box 2.11).

Preparedness

Preparedness is defined as 'the knowledge and capacities developed by governments, professional response and recovery organizations, communities and individuals to effectively anticipate, respond to, and recover from, the impacts of likely, imminent or current hazard events or conditions' (UNISDR, 2017c). Enhancing resilience is a common objective of preparedness measures, which integrate DRR and CCA.

Important categories are the early warning systems and emergency plans, developed in Europe and many Member States at national, regional and local levels for various types of hazard, in particular floods, but also avalanches, storm surges and landslides (e.g. the Multi-Hazard Approach to Early Warning System in Norway; see Box 2.12).

Such early warning systems and emergency plans are not necessarily good practice examples of integration between CCA and DRR, but can provide such examples if they are used to raise awareness and build capacity, emphasising the increases of risks with climatic change.

Box 2.10 Ecosystem-based floodplain restoration in the Danube Delta for flood reduction

Over the past century, the floodplains of the Danube and its tributaries have been subject to major human interventions which caused significant changes in the hydromorphology of the river–floodplain ecosystem, and losses of natural values and processes. During this time, an estimated 68 % of floodplains were lost. However, political changes in central and eastern Europe, and respective EU policies, as well as the Ramsar Convention on Wetlands, are fostering efforts to re-establish the lateral connectivity of floodplains along the Danube and its major tributaries through restoration projects. In the past two decades, thousands of floodplain restoration projects have been planned and implemented, of various sizes and with different purposes and levels of success. WWF International has recently inventoried existing projects and prioritised remaining areas for restoration.

Source: Sudmeier-Rieux, 2013.

Box 2.11 Infrastructure and economic incentives to reduce vulnerability to drought in the Segura and Tagus basins, Spain

The Segura river basin in the south-east of Spain suffers from a structural condition of water scarcity and drought occurrence. For decades, the focus for dealing with this condition has been placed on instrumental objectives such as increasing water transfer facilities (i.e. the Tagus–Segura Water Transfer, a major diversion project), developing alternative sources (i.e. desalination and reuse), or making use of water in a more technically efficient way (i.e. irrigation modernisation). So far, the highly disputed water resources transferred from the Tagus basin have mainly satisfied demand. The changing climate is increasing drought frequency in both basins, requiring the implementation of additional strategies to adapt. A recent strategy, currently under implementation, is introducing a set of economic policy instruments aimed at addressing structural modifications of long-term water demand in the Segura basin to achieve efficient use of the limited water resources available.

Source: Climate-ADAPT; http://climate-adapt.eea.europa.eu/metadata/case-studies/infrastructure-and-economic-incentives-to-reduce-vulnerability-to-drought-in-segura-and-tagus-basins

Box 2.12 Multi-Hazard Approach to Early Warning System in Sogn og Fjordane, Norway

The county of Sogn og Fjordane frequently experiences avalanches and landslides, storm surges and flooding. Due to climate change and related impacts on extreme weather events, these hazards are expected to be exacerbated; more extensive adaptation strategies and measures are therefore needed. This demonstration project (part of the EU-funded Clim-ATIC project) explored the potential for an effective, reliable and cost-efficient early warning system that has a multi-hazard approach and makes use of location and population-based communication technologies, such as mobile phones, as well as social media such as Facebook and Twitter. The system was tested with a sample warning followed by a survey and data analysis to judge its efficacy. Early warning systems as an example of CCA and DRR make sense only if they are also used to increase awareness on climate change.

Source: Climate-ADAPT; http://climate-adapt.eea.europa.eu/metadata/case-studies/multi-hazard-approach-to-early-warning-system-in-sogn-og-fjordane-norway

Examples of such capacity-building programmes can be found in Portugal (Box 2.13) and Poland (Box 2.14).

Because they are relatively low cost and have the potential to reach many people, web-based information systems are a popular way to attempt to increase awareness and preparedness among vulnerable actors in society. Such portals are developed both by the CCA community (see EEA, 2016a for an overview of climate change information portals) and the disaster risk community (e.g. UNISDR's Preventionweb or the European Commission's DRMKC, operated by the JRC). In many cases the integration between them is limited to mutual links, but in some cases, they are integrated more fully, as in Norway (see Box 2.15). Going beyond preparedness, in Malmö, Sweden, resilience is being improved through a systematic, holistic approach with stakeholder participation that addresses DRR and CCA in a much wider context, aiming at maintaining business continuity and improving quality of urban life (Box 2.16).

Response and recovery

Recovery is defined by UNISDR ([48]) as 'the restoration, and improvement where appropriate, of facilities, livelihoods and living conditions of disaster-affected communities, including efforts to reduce disaster risk factors'. CCA considerations are raised when considering improvements that in a developing-country context are often called 'building back better'. In that context, the practices mentioned under 'prevention' and 'preparedness' can be taken into account, with the main difference being that they are motivated by an actual disaster. A good example is the Prevention Program Against Floods (PAPI, see Box 2.17) in

Box 2.13 Portugal — Awareness raising at municipal level and training programmes to improve resilience

Portugal has emergency plans at national, district and local levels. Exercises and drills have been done regularly at these three levels and include items related to DRR and CAA. Municipalities are very active in public education campaigns to enhance awareness of risk and protective measures, developing campaigns to improve resilience. Major risks considered are forest fires, floods and heat waves. Tools include sessions for children and schools, leaflets, and social media, to provide information on weather forecasts, warnings and self-protection measures. Mobilisation of several stakeholders is important, including civil protection agents, municipality services, parish councils and citizen groups. The Autoridade Nacional Proteção Civil developed a nationwide educational programme for children which is implemented in more than 300 schools, and which includes CCA examples. The ClimAdaPT.Local project, under the European Economic Area (14) AdaPT grants programme, was responsible for a significant increase of the municipalities' capacity to assess and reduce vulnerability to climate change. It provided training and guidance for 26 municipalities to elaborate their own local adaptation strategies and for the creation of a network for sharing knowledge and best practices on implementing adaptation measures. This pilot project is presently being replicated on a larger scale for other municipalities under the Cohesion Fund National Programme (POSEUR)

Source: EEA expert workshop/survey; http://www.prociv.pt/clube/

Box 2.14 Poland — Education and training for dealing with natural hazards

In Poland the attitude towards hazard problems has changed in recent years. Now it is characterised by an integrated and unanimous approach towards natural disaster problems:

- The integrated approach means that research, legislation, control and measurement of economic, technical, educational, social and insurance problems relating to hazards are developed in parallel and treated equally.
- The unanimous approach to natural disasters takes account of the inextricable links between the causes of extreme events, which may be both natural and anthropogenic.

For the people affected or environment degraded by extreme events, it makes no difference whether it was formally classified as an extreme event caused by natural powers, or the result of a technical catastrophe. In both cases assistance is essential. Floods, which are considered the main hazard, need special and comprehensive measures to be taken. Over recent years floods have occurred every year and in increasing strength. The Institute of Meteorology and Water Management — National Research Institute systematically tries to improve knowledge about extreme events, and their mechanisms (origins), protection and recovery (relief) methods. Various initiatives and many activities are undertaken.

Source: EFDRR; https://www.unisdr.org/files/35277_ddrccafinal.pdf

([48]) http://www.preventionweb.net/english/professional/terminology/

Box 2.15 Troms, Northern Norway: Use of climate services — what data at which level?

A pilot project in Troms County (2015) aimed to guide municipalities in how to integrate CCA efforts in social and spatial planning. The project partners were the County Governor in Troms, the Directorate for Civil Protection, the Norwegian Meteorological Office, the Norwegian Water Resources and Energy Directorate and four municipalities in Troms. The objective of the project was to obtain an overview of the existing knowledge base for Troms county — i.e. existing knowledge, the legal basis (relevant legal acts and sections), existing guidelines and directives, and tools and resources useful and relevant to the municipalities in their CCA efforts. This resulted in guidance called Klimahjelperen ('Climate Helper') which can be used for other counties. The project was also a pilot for the Norwegian Climate Service Centre, providing input to what kind of data the municipalities need and how to present the data in a way that is useful to them. As a result the Troms project developed a climate change county profile. The Norwegian Climate Service Centre is making similar profiles for every county in Norway.

Source: EEA expert workshop/survey and EFDRR; https://klimaservicesenter.no/faces/desktop/article.xhtml?uri=klimaservicesenteret/klimaprofiler, http://www.klimatilpasning.no/veiledere/klimahjelperen/

Box 2.16 Nationally promoted municipality work with CCA and DRR in Sweden

The Swedish Civil Contingency Agency promotes UNISDR's Making Cities Resilient Campaign and cooperation between municipalities for CCA and DRR. The Swedish cities that participate in this DRR campaign have started a national network where they can discuss their CCA and DRR challenges with colleagues from the other cities. Two network meetings are held per year. During these meetings the host demonstrates various prevention and mitigation measures in the field so that all can learn from the relevant city's experiences and solutions. Interviews with municipalities and other stakeholders, and publication of 'good examples' of CCA and DRR, are an inspiring way of sharing good practices. This has resulted in the publication of Making cities resilient in Sweden: Six inspiring examples of disaster risk reduction action (MSB, 2015). The cities of Arvika, Gothenburg, Jokkmokk, Karlstad, Vellinge and Ängelholm contributed to this publication, which was published for the World Conference on Disaster Risk Reduction held in Sendai, Japan, in 2015.

The Swedish city of Malmö has been selected as a role model of the ICLEI Resilient Cities programme. In its Environment Programme of 2009, Malmö declared an ambition to become 'the Best City in the World for Sustainable Urban Development by 2020'. One component of this is that the city must prepare for risks such as changes in temperature, sea level rise and increased precipitation to avoid unacceptable ecological, economic and social consequences of natural events such as floods, storms and heat waves. The plans are recorded in an action plan for climate change adaptation and the comprehensive plan for city development.

Integrating DRR and CCA and combining them with an ambition to improve quality of urban life, Malmö plans to build resilience through holistic sustainable development as well as continuity planning for risk reduction. Malmö believes that a resilient city can be achieved through the development of holistic sustainability where ecological, economic and social perspectives are combined. Malmö's goal is to further develop the city's adaptive organisational ability to react to unforeseen events. Malmö's approach to DRR is that by achieving a resilient city in general, resilience against natural disasters is also anticipated. This will be achieved and maintained by consolidating and raising the level of education, strengthened integration and cooperation between city departments, enterprises, universities and organisations. This kind of comprehensive view also permeates the ongoing work on climate adaptation and well-organised planning. The aim is to use the ecological development as a driving force for economic growth and social innovation. Malmö has chosen to realise its sustainability ambitions (including CCA) by focussing on co-creation with private developers through the organisation of 'stakeholder partnership processes'. This allows for an effective mix of private and public funding. The approach entails the initiation of dialogues with private developers from the very start of an urban development process.

Source: EEA expert workshop/survey

Resilient Cities campaign: https://www.unisdr.org/campaign/resilientcities/home/cityprofile/City%20Profile%20Of%20Malm%C3%B6/?id=293

Climate-ADAPT case study 'Optimization of the mix of private and public funding to realise climate adaptation measures in Malmö'; http://climate-adapt.eea.europa.eu/metadata/case-studies/optimization-of-the-mix-of-private-and-public-funding-to-realise-climate-adaptation-measures-in-malmo

France, for coastal flooding, which was developed as a response to the violent windstorm Xynthia which hit parts of western Europe in general and France in particular in 2010. PAPI includes both preventive and preparedness aspects (e.g. seawalls and improved emergency warning systems, respectively). In Germany, after serious flooding in the Elbe basin in 2002, a study identified lessons learned and formulated recommendations on future risk prevention that already at that time referred to climate protection (see Box 2.18). A final example are the Italian funds to reduce hydro-geological risks that were present at an earlier date but after being dormant for a number of years were stepped up recently in response to a number of serious flood and landslide events (see Box 2.19). These recent natural hazards in Italy drove the government to create a specific centralised structure under the Italian Prime Minister's Office, which is in charge of managing these funds, and monitoring and evaluating their expenditure.

Insurance is a typical example of an option for the recovery phase. A link with CCA can be made if longer-term prevention is considered in developing the insurance scheme, such as in the Extraordinary Risks Insurance Scheme in Spain (see Chapter 5).

Box 2.17 France — PAPI: A prevention programme against floods, taking climate change into account

Between 27 February and 1 March 2010, the violent windstorm Xynthia crossed western Europe and hit the Atlantic coast of France, mostly the coasts of Vendée and Charente Maritime, including La Rochelle and its vicinity. The area around the city of La Rochelle is subject to storm surges that may cause coastal flooding. The most recent and still remembered events are those of 1953 in the North Sea, 1999 (Storm Martin) and 2010 (Storm Xynthia) on the Atlantic coast. While the 1953 event remains the most grave in Europe, historical studies show that the French Atlantic coast has suffered more events of that type than the shores of the North Sea. In the most recent, four people died close to La Rochelle and 750 ha were flooded, including the historic harbour of the city. This led to the identification of three particularly vulnerable areas in which houses had to be relocated. Following this tragic event and given the economic importance of the territory, a Prevention Program Against Floods (PAPI) for coastal flooding was set up by the local authorities, and was recently approved by the National Commission responsible for evaluating these plans. PAPI is part of a national plan formulated after Xynthia and dedicated to preventing the consequences of rapid submersions due to storm surges and flash floods. The main challenge of PAPI was to develop a new strategy of flood management, involving all relevant stakeholders in the territory. This strategy is built on a holistic approach and consists of the delimitation of a risk area, the design of protection measures and the functioning of early warning systems, etc. All stakeholders were involved at the various stages of the process, through a governance structure, and all the measures adopted within the prevention plan were evaluated through a cost–benefit analysis.

PAPI is expected to last from 2013 until 2017, and takes as its starting assumption a sea level 20 cm higher than the one observed during the Xynthia flooding, also taking into account the sea level rise due to climate change. This higher level would triple the surface of the flooded area and would increase dramatically the number of people and goods affected. The new strategy was developed on two main axes. The first is the risk culture and its integration into the planning and development of back-up plans based on early warning systems. The second is the protection of human, economic and urban-related issues, with a particular focus on tourism (the region is highly touristic in summer). PAPI includes population resettlement and reinforcement of physical protection on the coast (seawalls). The various protection measures are adapted according to the exposure and the strategic challenge of the sector's activities. Typically, the sizing of the protection works has been the main element debated and finally resolved by the cost–benefit analysis.

Source: EFDRR, 2013.

Box 2.18 Risk reduction after the event: Lessons learned from the Elbe floods in 2002

In the summer of 2002, heavy rainfall lead to strong flood waves, e.g. on the Müglitz, Weißeritz and Mulde rivers in the Erz Mountains, and also to large flooded areas along the Elbe river. This flood ruined lives and destroyed substantial parts of the infrastructure in Saxony, Saxony-Anhalt, Brandenburg and Mecklenburg-Western Pomerania. The estimated loss amounted to about EUR 12 billion in Germany alone. Particularly unfortunate were the 36 fatalities (21 in Germany, 15 in the Czech Republic). The German Committee for Disaster Reduction initiated an interdisciplinary study to identify lessons learned that could be applied everywhere in Germany to reduce flood risks. A key recommendation was that the previously prevalent separate view of precaution and response must be overcome, and that flood risk management should include all aspects of flood risk reduction and disaster response.

Recommendations included: (1) risk reduction through spatial planning has to be strengthened; (2) measures for evaluating effectiveness must be worked out and weighted in accordance with their importance for flood risk management; (3) limits to natural retention must be recognised and accepted, addressing demands for 'climate protection' in connection with flood risk reduction; (4) technical flood protection equipment is essential for reducing extreme flooding, making limitations and risks transparent; (5) warning systems for specific dangers and regions, ranging from gathering data and forecasts right through to the reaction of affected persons, should be expanded; (6) for successfully implementing protection concepts, a discussion process must be introduced that involves the whole of society and involves the whole population; (7) flood risk reduction and flood response are cross-sectoral tasks and require a great deal of communication, cooperation and management; (8) private precautions, and constructional, behavioural and insurance-aided risk reduction, should be systematically developed and stimulated; (9) the interests of a broad range of political areas must be integrated in the drawing up of flood risk reduction concepts at an early stage; (10) action covering whole river catchment areas and extending across borders is essential for 'preventative flood protection' and for preventative flood risk reduction; and (11) solidarity with subsequent generations requires decisions on flood risk reduction concepts despite great uncertainties. The notion that 'everything should get better, but nothing should change' does not achieve the objective in the case of flood protection.

Source: German Committee for Disaster Reduction, 2004.

Box 2.19 Effective management of old and new funds to reduce hydro-geological risks in Italy

Italy is notoriously prone to natural hazards and disaster risk. Among the 28 EU Member States, Italy has experienced the largest economic damage from natural hazards over the period 1980–2015, according to a recent analysis by the EEA via the CLIM 39 indicator. The flood hazard and risk mapping conducted in the context of the Floods Directive (EU, 2007) has shown that around 4.0 %, 8.1 % and 10.6 % of Italian territory was prone to high (return period 1: 20–50 years), medium (return period 1: 100–200 years) and low risk (return period 1: 300–500 years), respectively (Trigila et al., 2015). In May 2014 the Italian Government established a coordination unit ('Struttura di missione contro il dissesto Idrogeologico e per lo sviluppo delle infrastrutture idriche - Italia Sicura'), under the Prime Minister's Office and working in a close collaboration with the Minister for Environment, Land and Sea and the Minister for Infrastructures and Transport. The Italia Sicura initiated and monitors progress in implementing the national plan to prevent and combat hydrological risk and the Metropolitan Flood Protection Plan. The former entails some 7 120 structural protection projects, with total costs amounting to approximately EUR 9 billion. The Metropolitan Cities Plan involves 157 structural interventions worth EUR 1.2 billion. The progress of implementation can be monitored via a user-friendly web interface.

Source: http://italiasicura.governo.it/site/home/italiasicura.html;

Trigila et al., 2015; https://www.eea.europa.eu/data-and-maps/indicators/direct-losses-from-weather-disasters-3/assessment

3 Weather- and climate-related natural hazards in Europe

- Since 2003, Europe has experienced several extreme summer heat waves. Such heat waves are projected to occur as often as every 2 years in the second half of the 21st century, under a high emissions scenario (RCP8.5). The impacts will be particularly strong in southern Europe.
- Heavy precipitation events have increased in northern and north-eastern Europe since the 1960s, whereas different indices show diverging trends for south-western and southern Europe. Heavy precipitation events are projected to become more frequent in most parts of Europe.
- The number of very severe flood events in Europe has varied since 1980, but the economic losses have increased. It is not currently possible to quantify the contribution due to increased heavy precipitation in parts of Europe compared with better reporting and land use changes.
- Observations of windstorm location, frequency and intensity have showed considerable variability across Europe during the 20th century. Models project an eastward extension of the North Atlantic storm track towards central Europe, with an increase in the number of cyclones in central Europe and a decreased number in the Norwegian and Mediterranean Seas. For medicanes (also termed Mediterranean Sea hurricanes), a decreased frequency but increased intensity of medicanes is projected in the Mediterranean area.
- Landslides are a natural hazard that cause fatalities and significant economic losses in various parts of Europe. Projected increases in temperature and changes in precipitation patterns will affect rock slope stability conditions and favour increases in the frequency of shallow landslides, especially in European mountains.
- The severity and frequency of droughts appear to have increased in parts of Europe, in particular in southern and south-eastern Europe. Droughts are projected to increase in frequency, duration, and severity in most of Europe, with the strongest increase projected for southern Europe.
- Forest fire risk depends on many factors, including climatic conditions, vegetation, forest management practices and other socio-economic factors. The burnt area in the Mediterranean region increased from 1980 to 2000; it has decreased thereafter. Projected increases in heat waves together with an expansion of the fire-prone area will increase the duration of fire seasons across Europe, in particular in southern Europe.
- Observational data between 1970 and 2015 show that alpine avalanches cause on average 100 fatalities every winter in the Alps. Increased temperatures are expected to lead to decreases in alpine snow cover and duration, and in turn to decreased avalanche activity below about 1 500-2 000 m elevation in spring, but increased avalanche activity above 2 000 m elevation, especially in winter.
- Hail is responsible for significant damage to crops, vehicles, buildings and other infrastructure. Despite improvements in data availability, trends and projections of hail events are still subject to large uncertainties owing to a lack of direct observation and inadequate microphysical schemes in numerical weather prediction and climate models.
- Extreme high coastal water levels have increased at most locations along the European coastline. This increase appears to be predominantly due to increases in mean local sea level rather than to changes in storm activity. Projected changes in the frequency and intensity of storm surges are expected to cause significant ecological damage, economic loss and other societal problems along low-lying coastal areas in northern and western Europe, unless additional adaptation measures are implemented.

3.1 Introduction

Weather- and climate-related natural hazards such as heat waves and heavy precipitation have become more frequent and/or intense in Europe and, along with socio-economic changes and hazard exposure, an increase in damage and economic losses has also taken place (IPCC, 2012; Donat et al., 2013a; EEA, 2017). It is therefore considered important by European society and policymakers to understand the role of climate change in driving extreme weather, and also the interactions and interdependencies of extreme weather and climate events with other natural phenomena and human activities (Donat et al., 2013b; EEA, 2017).

Climate change is expected to lead to changes in the frequency and strength of many types of extreme weather- and climate-related events (IPCC, 2012). Extreme events are rare by definition, which means that there are fewer data available to analyse past changes in their frequency or intensity. This makes extreme weather more difficult to analyse, understand, project and verify. Rare extreme events tend to have the highest impact and cause the greatest damage to natural and managed systems, and to human wellbeing (see Chapter 4).

The natural hazards included in this section of the report (i.e. heat waves, heavy precipitation, river floods, windstorms (including medicanes) ([49]), landslides, droughts, forest fires, avalanches, hail and storm surges) were selected on the basis that they occur in Europe with sufficient regularity and/or intensity to cause substantial economic damage, and loss of life at a significant level.

A further reason for selection is that research indicates that, under future climate change in Europe, these events are nearly all projected to increase in severity, duration and/or extent, e.g. heat waves are projected to become more intense and to last longer, and extreme precipitation events will increase in both frequency and intensity. Another reason behind the interest in these events is that their future projected changes are not distributed equally across Europe — for example, patterns of projected changes to river flooding and heat waves both show strong regional differences between northern and southern Europe (e.g. Russo et al., 2014; Alfieri et al., 2015b).

Selected natural hazards are features of the Earth system (including components such as the water cycle, sedimentary cycle, and the weather and climate systems) and are frequently linked to, or dependent on, each other. Examples include:

- Meteorological drought (rain deficiency) can cause soil moisture (agricultural) drought affecting plant growth, which may then deepen into hydrological drought affecting watercourses, water resources and natural ecosystems.
- Soil moisture droughts can act as a precursor for forest fires and also landslides.
- Saturated soil (high soil moisture) may lead to flooding when subject to heavy or persistent precipitation.
- Heavy or persistent rainfall is a major trigger for landslides, either through facilitating soil movement or by surface water run-off initiating soil erosion.
- A rapid increase in mean temperature can lead to snow melt and surface thawing, resulting in landslides, rock falls and debris flows.
- Heat waves can be amplified by low levels of soil moisture that restrict cooling from evapotranspiration.

Natural variability in the climate system still plays a key role in extreme weather, as climate change makes some extremes more frequent and/or intense. Long-term climate change, or trends, will also affect some natural hazards, for example projected changes in air temperature and snowfall in mountain areas will lead to reduced snow cover in lower altitudes, reducing avalanche activities below about 1 500-2 000 m elevation.

To assess past changes in variability of natural hazards a dense network of stations providing regular monitoring of key atmospheric climate variables, using standardised measurements, quality control and homogeneity procedures at European level, is essential. However, even where sufficient data are available, several problems can limit their use for analysis. These problems are mainly connected with (1) limitations of distributing data in high spatial and temporal resolution in many countries, (2) unavailability of data in easy-to-use digital format, and (3) lack of data homogeneity.

Projected extreme weather- and climate-related events are based on a range of studies published in

([49]) Also termed Mediterranean Sea hurricanes. See Cavicchia et al., 2013, 2014 for more details.

peer-reviewed academic papers and reports and using different global emissions scenarios (SRES) (Nakicenovic and Swart, 2000) or representative concentration pathways (RCPs) (van Vuuren et al., 2011). The projections presented in this report do not show the effects of limiting global temperature increase to well below 2 °C on the changes in frequency and magnitude of the extremes in Europe, partly due to the lack of available scientific literature.

3.2 Heat waves

3.2.1 Relevance

The increase in the global surface temperature is expected to affect the frequency and intensity of extreme events, such as heat extremes (Fischer and Schär, 2010; Donat et al., 2013b; Russo et al., 2014). The severity of a heat wave depends on a number of factors, including duration, relative intensity (how much hotter than normal — e.g. in the period 1961–1990) and absolute intensity.

Heat extremes have been shown to be induced by soil moisture droughts, because dry soil reduces evaporative cooling and increases the severity of heat waves (Mueller and Seneviratne, 2012). On the other hand, heat extremes can increase the frequency and intensity of heavy precipitation events (including hailstorms), because warmer air can hold a greater quantity of water (Berg et al., 2013; Kendon et al., 2014; Groenemeijer et al., 2016) and therefore increases the probability of development of convective (hail) storms (see Section 3.10).

Heat extremes also have strong direct impacts on human health and wellbeing, and society (e.g. through decreased labour productivity), ecosystems (e.g. through forest fires), and agriculture (through decreased crop and livestock productivity). In particular, heat waves exacerbated by the urban heat island effect and air pollution can have devastating impacts on human health in urban areas, including impacts such as heat stress (see Section 4.2).

3.2.2 Past trends

Observational data show a continued increase in heat extremes over land in the period 1997-2012 (Seneviratne et al., 2014), but this increase also depends on how heat extremes are defined.

At the global scale, warm days and nights, as well as heat waves, have become more frequent in recent decades (Zwiers et al., 2013; Seneviratne et al., 2014). The increase in maximum daily temperatures has generally been faster than the increase in annual average temperature (IPCC, 2013). In Europe, since the 1950s, large areas have experienced intense and long heat waves, with notable impacts on human health and socio-economic systems (García-Herrera et al., 2010; Russo et al., 2015). As a result, 500-year-old temperature records were broken over 65 % of Europe in the period 2003-2010 alone (Barriopedro et al., 2011).

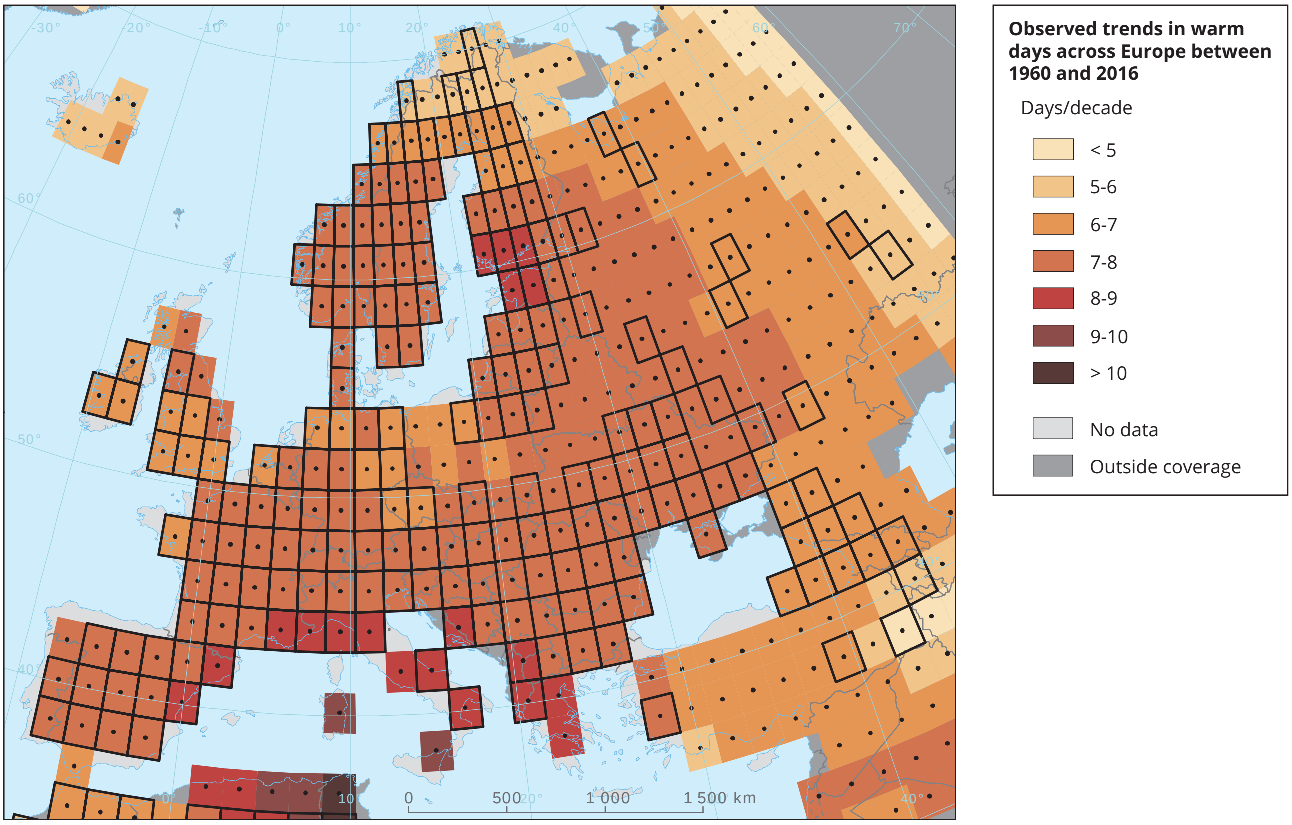
Indices for extreme temperatures, including the annual maximum value of daily maximum temperature, have shown significant upwards trends across Europe since the 1950s (Donat et al., 2013a). The number of unusually warm days has increased by up to 10 days per decade between 1960 and 2016 in most of southern Europe and Scandinavia (Map 3.1). Based on the daily heat wave magnitude index (HWMI), Europe experienced 11 intense and long heat waves between 1950 and 2016, most of which occurred after 2000 (in 2003, 2006, 2007, 2010, 2014 and 2015) (Russo et al., 2015). The most severe heat waves have been characterised by the persistence of extremely high night-time temperatures (Russo et al., 2015). A substantial fraction of the probability of recent extreme events can be attributed to human-induced climate change, and it is likely that, for temperature extremes occurring over previous decades, a fraction of their probability was attributable to anthropogenic influences (King et al., 2016).

3.2.3 Projections

Periods with extreme high temperatures are projected to become more frequent and to last longer across Europe during this century. Different projections based on different sets of multi-model ensembles agree on increases in heat wave frequency and severity for most European regions during the 21st century under all RCP scenarios (e.g. Fischer and Schär, 2010; Schoetter et al., 2014; Russo et al., 2014, 2015). Extreme summer heat waves such as the ones experienced in parts of Europe in 2003 and 2010 will become much more common in the future. Under the RCP8.5 high emission scenario, very extreme heat waves ([50]) (which are much stronger

([50]) To assess changes in heat waves the heat wave magnitude index (HWMI) has been used. The HWMI is defined based on the magnitude and length of heat waves in a year, where heat waves are periods of at least 3 consecutive days with maximum temperature above the threshold for the reference period 1981-2010. For details, including the definition of very extreme heat waves, see Russo et al., 2014.

Map 3.1 Observed trends in warm days across Europe between 1960 and 2016



Note: Warm days are defined as being above the 90th percentile of the daily maximum temperature centred on a 5-day window for a reference period. Grid boxes outlined with solid black lines contain at least three stations and thus trends are more robust. High confidence in the long-term trend (at the 5 % level) is shown by a black dot (which is the case for all grid boxes in this map). The reference period is 1971-2000.

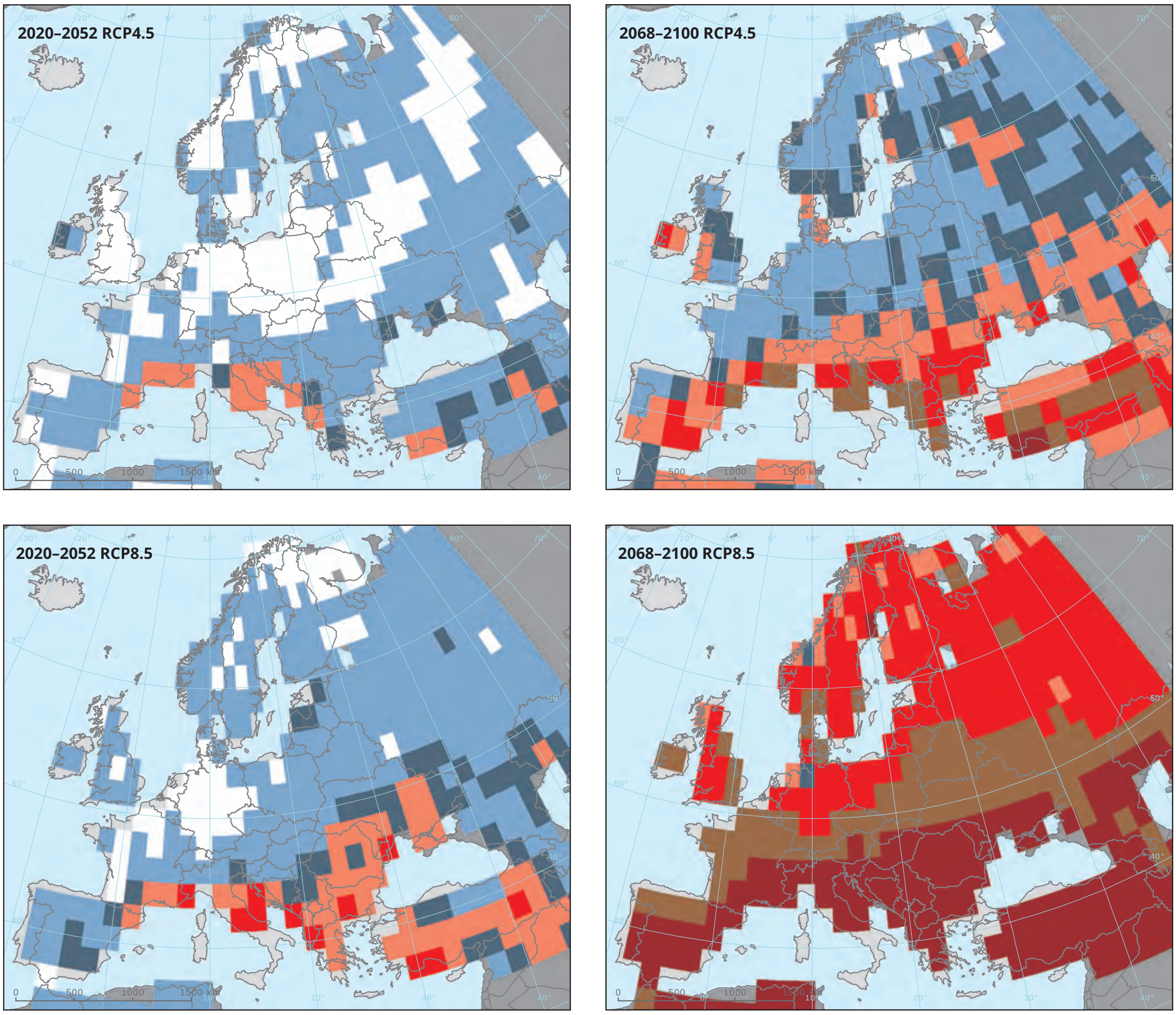
Sources: EEA and UK Met Office, based on HadEX2 (updated from Donat et al., 2013b).

than those of either 2003 or 2010), are projected to occur as often as every 2 years in the second half of the 21st century (Map 3.2). The projected frequency of heat waves is strongest in southern and south-eastern Europe (Russo et al., 2014). According to a different analysis, at the end of the 21st century 90 % of the summers in southern, central and north-western Europe will be warmer than any summer in the period 1920-2014 under the RCP8.5 high emission scenario (Lehner et al., 2016). The most severe health risks are projected for low-altitude river basins in southern Europe and for the Mediterranean coasts, where many densely populated urban centres are located (Lehner et al., 2016).

3.2.4 Uncertainties, data gaps and information needs

To capture the severity of a heat wave there are a number of factors that can be accounted for, including duration, intensity (how much hotter than during the reference period — e.g.1961–1990) and when the event occurred during the year. A variety of heat wave metrics could be determined from temperature measurements alone. The most common indices use the threshold of the 90th or 95th percentile of the maximum and/or minimum temperature respectively to find the onset of the heat wave, which must last at least 3 consecutive days. Using heat wave indices one can derive yearly number of heat waves, the length

Map 3.2 Number of very extreme heat waves in future climates under two different emissions scenarios



Heat wave frequency

Number in 33 years

0–1 | 1–2 | 2–3 | 3–6 | 6–12 | 12–15 | 15–33 | No data | Outside coverage

Note: Very extreme heat waves are defined as having a heat wave magnitude index (HWMI) above 8. For comparison, the 2003 western European heat wave had an average HWMI of around 3, and the 2010 eastern European heat wave had an average HWMI of around 5. The top maps show the median of the number of very extreme heat waves in a multi-model ensemble of general circulation models (GCMs) of the near future (2020-2052) and the latter half of the century (2068-2100) under a mitigation emissions scenario (RCP4.5). The lower maps are for the same time periods but under a high emissions scenario (RCP8.5).

Source: Adapted from Russo et al., 2014.

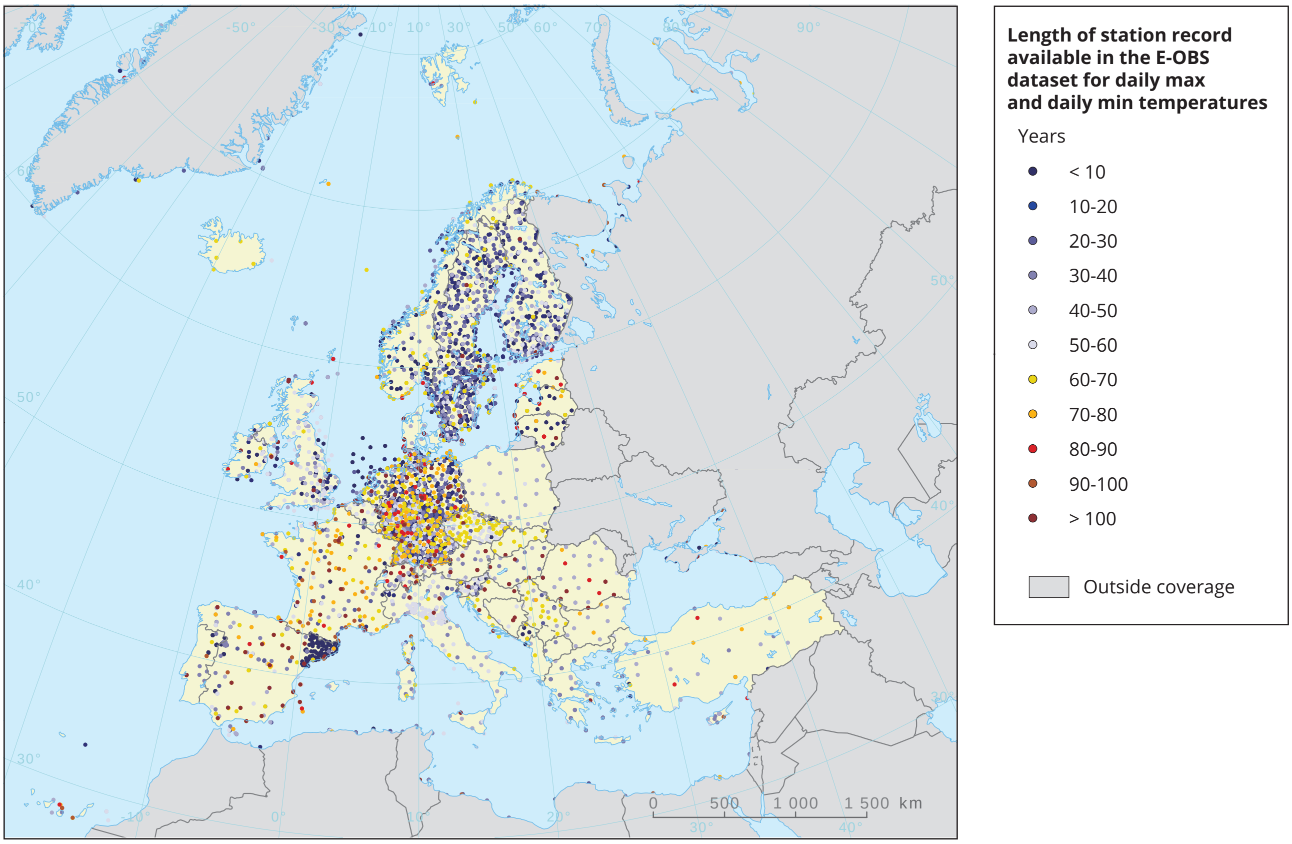
of the longest heat wave event, the yearly sum of heat wave days, the hottest day of the hottest event and the average magnitude of all the heat waves within a given year in order to study the multiple elements of a heat wave.

However, other indices have also been developed that could be used for analysing heat wave studies (Zwiers et al., 2013; Perkins, 2015). The most commonly used are:

- number of days with maximum temperature above 25 °C — summer days (SU);
- number of days with minimum temperature above 20 °C — tropical nights (TR);
- numbers of days with maximum (TX90p) and minimum temperatures over the 90th percentile (TN90p);
- highest maximum (TXx) and minimum temperatures (TNx);
- warm spell duration index (WSDI).

To calculate heat wave indices over Europe, long-term records of standardised and quality-controlled meteorological data are needed. Raw data are usually archived with no or limited quality controls applied. National meteorological or climate services then perform various quality assurance techniques, but the final data products are not always shared. There are areas in Europe that have no or very sparse measurements, and also some regions that have much shorter data records than others, which limits what can be inferred regarding any long-term trends (Map 3.3). Also, although some station data are shared freely, not all countries provide or share data from similar numbers of stations. In Germany, where many stations with long records are provided and made available to all users, more detailed analysis would be possible than in other countries within Europe. This problem increases when attempting to study climatological extreme events across the globe, with large data gaps even in interpolated products (Donat et al., 2013a; Zwiers et al., 2013). Regional reanalysis and satellite-based observations can improve the coverage and homogeneity of temperature data.

Map 3.3 Length of station record available in the E-OBS dataset for daily maximum and daily minimum temperatures



Note: Stations available in the European Climate Assessment and Datasets (ECA&D) (with different lengths of records) for daily maximum and minimum temperatures.

Source: van der Schrier et al., 2013.

3.2.5 *Selected event*

An extreme summer heat wave occurred across Europe in June and July 2015. On 1 July, in London the temperature record was 36.7 °C and Paris recorded its second hottest day ever on 2 July, with a high temperature of 39.7 °C. On 4 July Berlin's highest temperature on record, 37.9 °C, was measured and on 5 July a weather station in Kitzingen recorded 40.3 °C, breaking the previous record for the hottest temperature ever recorded in Germany (Dong et al., 2016). Averaged over central Europe the seasonal mean (June-August) surface air temperature anomaly was 2.40 °C above the 1961–1990 mean and it reached up to 7 °C in some parts during the period between 28 June and 4 July 2015 (Map 3.4).

The magnitude of warming is comparable with previous hot summers in Europe, such as 2003 (e.g. Christidis et al., 2015) and 2010 (Barriopedro et al., 2011; Otto et al., 2012). The summer of 2015 was also the driest and the second hottest summer in recent decades. These temperature anomalies are associated with an anomalous anticyclonic circulation, reduced precipitation over central Europe and a weak increase over northern Europe (Dong et al., 2016).

3.3 Heavy precipitation

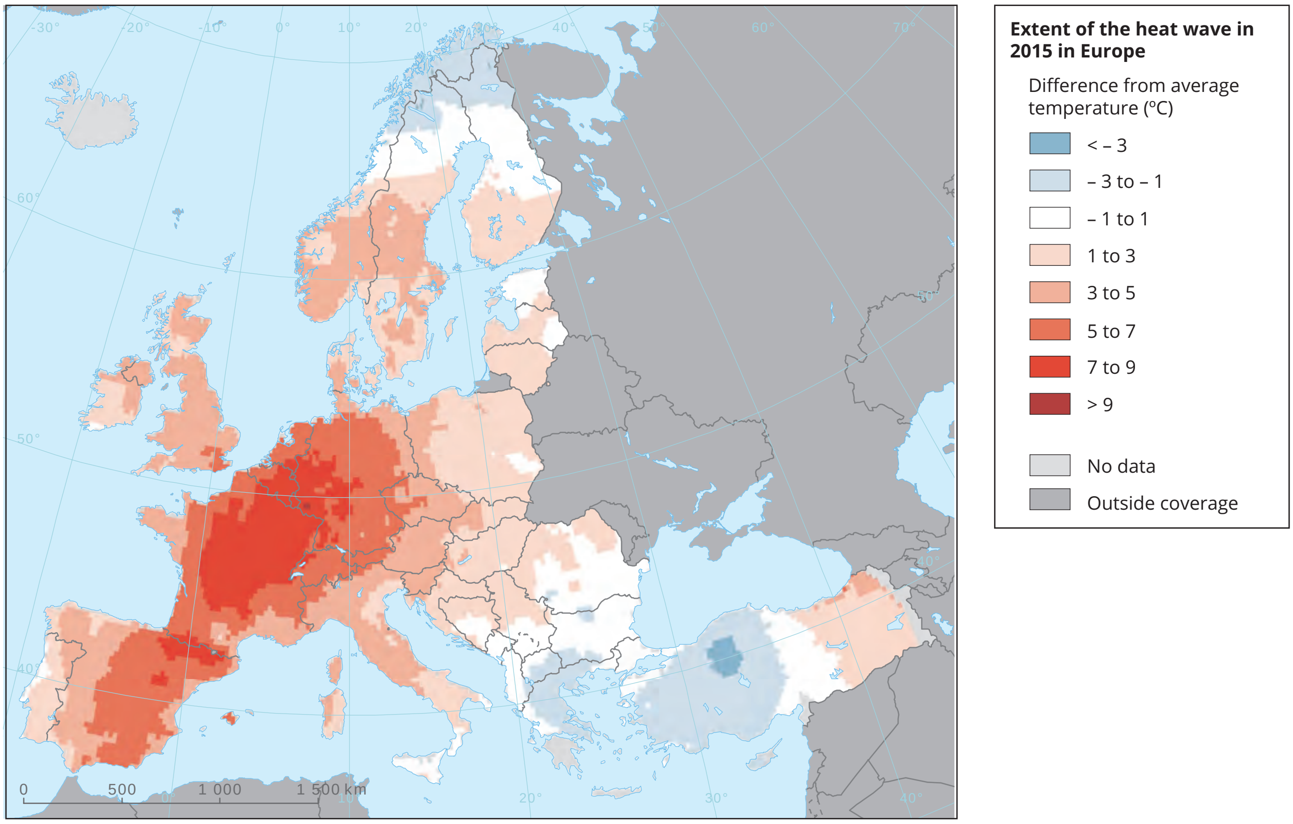
3.3.1 *Relevance*

Changes in the frequency and magnitude of heavy precipitation events can have considerable impacts on society, including agriculture, industry and ecosystem services.

An assessment of past trends and future projections of heavy precipitation is therefore essential for advising policy decisions on mitigation, and on CCA and DRR. The risks posed by heavy precipitation hazards, such as flooding events (including cloud burst and flash floods) are also influenced by non-climatic factors, such as population density, floodplain development and land use changes. Hence, estimates of future changes in such risks need to consider changes in both climatic and non-climatic factors.

Heavy precipitation events comprise high-intensity short-duration events and extended-duration low-intensity events (wet spells), which may lead to flooding with related impacts (see Section 3.4). Extreme precipitation on short observational timescales

Map 3.4 Extent of the heat wave in 2015 in Europe



Note: Average temperature anomalies (°C) for Europe between 28 June and 4 July 2015. Baseline period is 1961-1990.

Source: EEA based on the E-OBS dataset (updated from Haylock et al., 2008).

generally increases with temperature (Utsumi et al., 2011; Berg et al., 2013).

3.3.2 Past trends

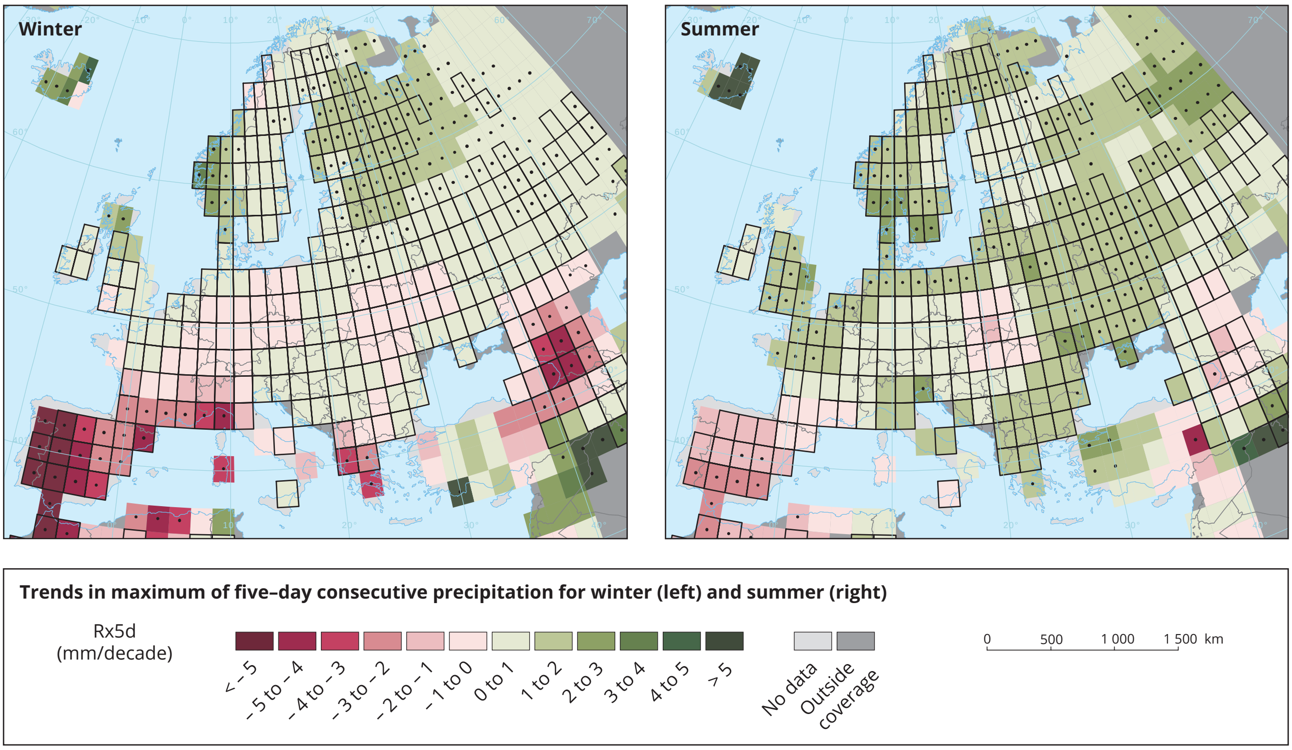
On average, heavy precipitation events have become more intense and more frequent in Europe but there are important variations across regions and indices used (Berg et al., 2013; Gallant et al., 2013; Trenberth et al., 2014; Scherrer et al., 2015). Clear trends for large-scale heavy precipitation events are difficult to detect because the number of events is small and they take place at irregular intervals and with irregular intensity. However, in the absence of internal variability, climate models agree that heavy precipitation is becoming more intense and more frequent in Europe, especially in central and eastern Europe in winter (Fischer et al., 2014).

There are now more areas in Europe seeing increasing extreme precipitation than those seeing a decrease, with increases in heavy precipitation over northern Europe and decreases over southern Europe seen in the 20th century (Hov et al., 2013a). There is also evidence of longer wet spells at the expense of dry spells in some areas (in the north of Europe in winter) and an increasing proportion of total rainfall occurs on heavy rainfall days (Zolina et al., 2009). In Europe the number of most extreme precipitation events is increasing at a faster rate compared with the mean than more moderate events (Berg et al., 2013; Hov et al., 2013a).

The length of wet spells and the intensity of heavy precipitation events have decreased in south-western Europe but increased in northern and north-eastern Europe (van den Besselaar et al., 2011). The latter increase is a consequence of the observed poleward shift of the North Atlantic storm track and the weakening of Mediterranean storms (Hov et al., 2013a).

The majority of observation-based studies that investigate trends in extreme rainfall intensity are based on data recorded at the daily timescale. An index for maximum 5-day precipitation (Rx5d) shows significant increases up to 4 mm per decade over northern and north-western Europe, and decreases of 4 to 5 mm per decade in south-western Europe in winter (Map 3.5, left), while summer trends are smaller, decreasing between 1 and 3 mm per decade (Map 3.5,

Map 3.5 Trends in maximum 5-day consecutive precipitation for winter (left) and summer (right)



Note: Maps show observed trends in 5-day consecutive precipitation in millimetres per decade.

Grid boxes outlined with solid black lines contain at least three stations and thus trends are more robust. High confidence in the long-term trend (at the 5 % level) is shown by a black dot (which is the case for all grid boxes in this map). The reference period is 1971-2000.

Sources: EEA. UK Met Office.

right). The smaller trends in central and south-eastern Europe for both seasons are not statistically significant.

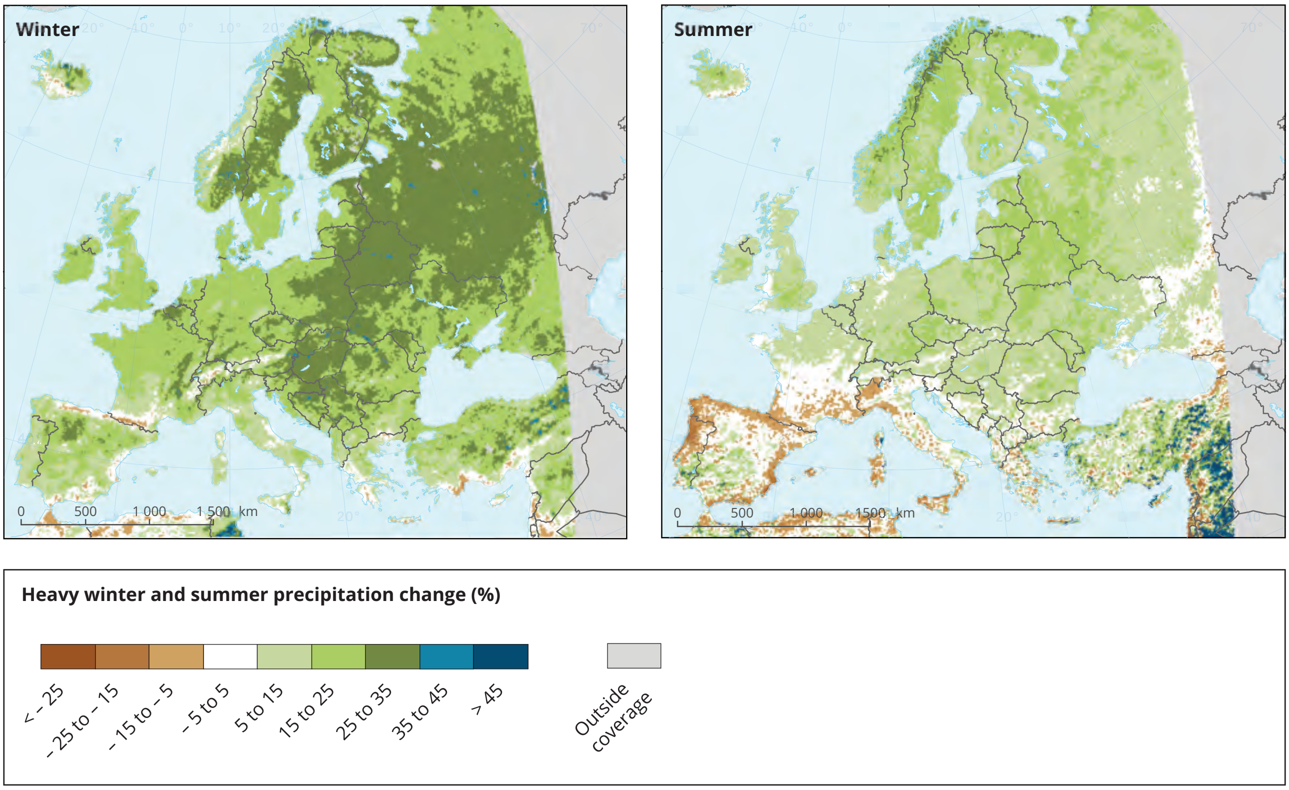
Records of daily mean precipitation are often insufficient to study trends and changes in heavy precipitation. Damage associated with heavy precipitation often originates from subdaily localised heavy precipitation events, which can lead to costly flash floods. Due to limited data availability only a limited number of studies have focused on large regional-scale assessments of subdaily precipitation (Hartmann et al., 2013). A recent review study concludes that extreme subdaily precipitation events have generally increased in Europe, even in regions with decreases in mean rainfall, but there is large variability across regions, seasons, and in event duration (Westra et al., 2014).

3.3.3 Projections

Global warming is projected to lead to higher intensity of precipitation as well as longer dry periods in Europe (Seneviratne et al., 2012; Hov et al., 2013a). Modelling studies show that globally a warming atmosphere has an intensifying effect, with dry regions getting drier and wet regions getting wetter, and extremes of precipitation increasing in both the wettest and driest regions. Modelled projections of extreme precipitation events indicate an increase in the frequency, intensity and/or amount under future climate in Europe, and events currently considered extreme are expected to occur more frequently in the future. Globally, a 1-in-20-year annual maximum daily precipitation amount is likely to become a 1-in-5- to 1-in-15-year event by the end of the 21st century (IPCC, 2013).

Projections show an increase in heavy daily precipitation (here defined as the intensity of the heavy precipitation events defined as the 95th percentile of daily precipitation) in most parts of Europe in winter, by up to 35 % during the 21st century (Map 3.6 left). In summer the increase is also projected in most parts of Europe but decreases are projected for some regions in southern and south-western Europe (Map 3.6, right) (Jacob et al., 2014). Similar patterns were found for other heavy precipitation indices (Rajczak et al., 2013; Sillmann et al., 2013; Giorgi et al., 2014).

Map 3.6 Projected changes in heavy precipitation in winter (left) and summer (right)



Note: Projected changes in heavy daily precipitation (%) in winter and summer 2071-2100, compared with the baseline period 1971–2000 for the RCP8.5 scenario based on the ensemble mean of different regional climate models (RCMs) nested in different general circulation models (GCMs). Heavy precipitation is defined as the intensity of the heavy precipitation events defined as the 95th percentile of daily precipitation (only days with precipitation > 1 mm/day are considered).

Source: EURO-CORDEX (Jacob et al., 2014).

3.3.4 Uncertainties, data gaps and information needs

In order to accurately assess trends in heavy precipitation at local scales, high-resolution datasets are required. Globally and within Europe, some regions have shorter data records than others, and even within Europe, not all data from weather stations are shared freely. As a result, there are large data gaps even in interpolated products (Donat et al., 2013a; Zwiers et al., 2013). In regions where many stations with long records are available to all users, more detailed assessments are possible than in regions with a small number of stations or with short records. Limited data availability is particularly detrimental for the detection of long-term climate trends in extreme events. Increased data sharing by meteorological services would improve the accuracy of regional climate change assessments, including understanding of past and future climate and weather extremes.

Rain gauge data are available over land only, and availability is low in southern and eastern Europe. Gauge records are of variable length and quality, and there may be discontinuities at country borders. Satellite and radar data provide greater coverage and resolution in certain areas but are subject to uncertainties in measurement and processing, and have shorter records. Merged rain gauge, radar and satellite data combine their sources of uncertainty.

For historic trend analysis, data are required at a resolution sufficient to quantify the intensity and location of heavy and extreme precipitation, which can have limited temporal and spatial extent. Uncertainties in trends are overall larger in southern Europe and the Mediterranean region, where there is also low confidence in trends (Seneviratne et al., 2012).

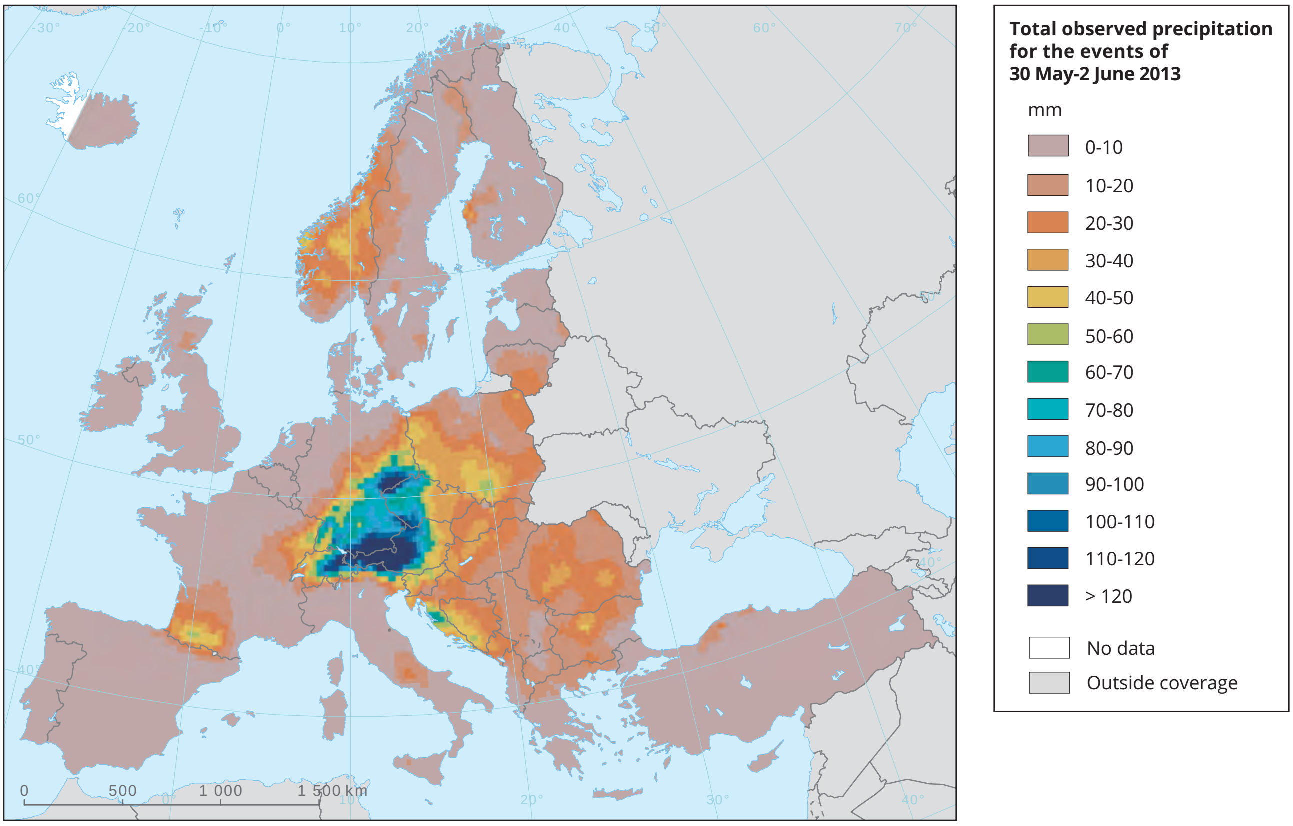
Models generally underestimate extreme precipitation intensity, and are better at locating extreme rainfall than estimating its intensity, but model accuracy improves with resolution. RCMs capture the basic features of European climate, including spatial and temporal variability, but do not represent features such as a cold/wet bias, or isolated convection. The increase in model spatial resolution from 50 km to 12.5 km captures more detailed features, but can be limited in the representation of seasonal means over large subdomain regions. One deficiency in the EURO-CORDEX ensemble is that the 'very wet' general circulation models (GCMs) from Coupled Model Intercomparison Project Phase 5 (CMIP5) are have not yet been downscaled, although the temperature spread is well covered (Jacob et al., 2014). Precipitation statistics are dominated by interannual to interdecadal variability and are less spatially coherent compared with temperature change. Finally, there is a lack of a clear large-scale pattern associated with extremes because the number of events is small and they take place at irregular intervals and with varying intensity.

The increase in the spatial and temporal resolutions of global and regional climate models has generally improved the representation of heavy precipitation and increased confidence in model-based projections (Kopparla et al., 2013; Giorgi et al., 2014; Montesarchio et al., 2014). However, regional climate models with spatial resolutions of between 10 and 30 km typically used in climate change studies are still too coarse to explicitly represent subdaily localised heavy precipitation events (Chan et al., 2014; Ban et al., 2015). Evidence from high-resolution climate models suggests that the intensity of subdaily extreme rainfall is likely to increase in the future, whereby an increase of (theoretically estimated) ~ 7 % per degree Celsius appears most likely in many regions (Westra et al., 2014). A very high-resolution model (typically 1–5 km) used for weather forecasts with explicit convection has recently been used for a climate change experiment for a region in the United Kingdom. This study projects intensification of short-duration heavy rain in summer, with significantly more events exceeding the high thresholds indicative of serious flash flooding (Kendon et al., 2014; Ban et al., 2015; Lehmann et al., 2015).

3.3.5 Selected event

Heavy precipitation can cause different types of flooding; the most common are fluvial (river floods) and pluvial (surface floods). A heavy precipitation event occurred in central Europe from 30 May to 2 June 2013, and caused large-scale river floods (Map 3.7) (EURO4M-CIB, 2013). Parts of central Europe received more than 100 mm in a 72-hour period in June 2013, while precipitation exceeded 100 mm in total during this event over a large area of, Austria, the Czech Republic, Germany and Switzerland. Some stations recorded over 200 mm, close to the average monthly precipitation level based on historic datasets for 1951–2012 (van Engelen et al., 2008). The resultant flooding affected south and east Germany, Austria and western parts of the Czech Republic, with severe flooding in the Elbe and Danube catchments. Belarus, Poland, Hungary, Serbia, Slovakia and Switzerland were affected but to a lesser extent.

Map 3.7 Total observed precipitation for the events of 30 May to 2 June 2013



Note: Map shows cumulative precipitation amount over the period between 30 May and 2 June 2013

Source: ECA&D (van Engelen et al., 2008; EURO4M-CIB, 2013).

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3.4 River floods

3.4.1 Relevance

There are many different types of floods. They can be distinguished based on the source of flooding (e.g. rivers and lakes, urban storm water and combined sewage overflow, or seawater), the mechanism of flooding (e.g. natural exceedance, defence or infrastructure failure, or blockage) and other characteristics (e.g. flash flooding, snowmelt flooding or debris flow) (EC, 2013).

River floods are a naturally occurring phenomenon that have contributed to shaping the riparian zone and floodplains over time. Prolonged precipitation, heavy precipitation, and snowmelt events can on their own or in combination generate river floods where water level rises many metres above the normal level to inundate adjoining areas. Today, river systems in Europe, as in many other parts of the world, are heavily altered from their natural state. Over the past thousand years, and most significantly in the 20th century, riparian zones and floodplains have been increasingly developed by human activity. River channels have been excavated and straightened to ease navigation, altering the river's natural hydromorphology, riparian zones have been drained and floodplains built over. Such development increases the risk of economic damage and floods are becoming one of the most costly natural disasters in Europe (Chorynski et al., 2012; Donat et al., 2013a; EEA, 2016a). Water from river floods damages infrastructure, industrial plants, property and agricultural land, and may indirectly generate production losses caused by damaged transport or energy infrastructure. Floods can also lead to loss of life, displacement of people and damage to cultural heritage. Pollution levels are often high during floods and can have adverse effects on human health, e.g. through contamination of agricultural products and bathing waters, or pollution of drinking water supply.

3.4.2 Past trends

Trends in river floods can be assessed either by analysing number of river floods or by analysing economic losses. Detections of significant trends in number of river floods in Europe is often difficult because of natural large variability of river floods (Lugeri et al., 2010; Donat et al., 2013a; Kundzewicz et al., 2017). Reliable determination of changing flood frequency requires long-term observations of river flows. Often, time series are not long enough to detect trends and hydrological networks have typically been shrinking, for budget reasons. Based on information from the Dartmouth Flood Observatory (DFO) archive, the number of large flood events increased during the period 1985-2009. Also the timing of the European floods has changed. Warmer temperatures have led to earlier spring snowmelt floods throughout northeastern Europe and earlier soil moisture maxima have led to earlier winter floods in western Europe (Blöschl, et al., 2017).

Less extreme events or events with small spatial extent can influence trends due to reporting biases; the selection of 'larger' floods is expected to reduce the reporting bias (Kundzewicz et al., 2013).

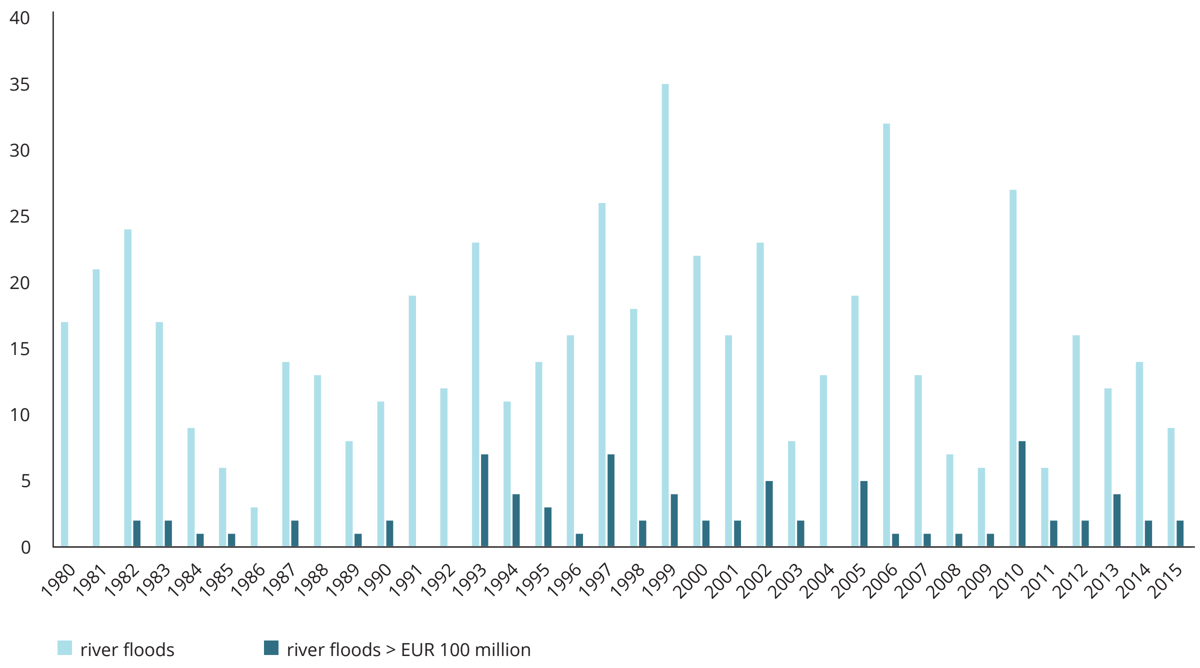
On the other hand, however, data on economic losses can be another source for analysing trends in the impact of floods, but trends can be strongly influenced by reporting biases. Such information, for example, is available from NatCatSERVICE maintained by the Munich RE loss database. The database contains almost 1 500 recorded flood events in the period 1980–2015 in 33 EEA member countries; however, only 120 can be classified as severe flood events (here defined with a threshold of economic loss exceeding EUR 100 million) (Figure 3.1).

Economic losses from flooding in Europe have increased substantially since the 1970s (Barredo, 2009). The increasing trend in economic damages from river floods is primarily attributable to socio-economic factors, such as increasing wealth located in flood zones, but river channel management and changes in climate also play a role. In terms of regional gross domestic product (GDP), flood risks are highest in large parts of eastern Europe, Scandinavia, Austria, the United Kingdom and parts of France and Italy (Lugeri et al., 2010).

3.4.3 Projections

Atmospheric warming and associated hydrological changes have significant implications for regional flood intensity and frequency. To investigate climate change impacts on the hydrological cycle, research employed a combination of climate and hydrological models that

Figure 3.1 Number of river flood events between 1980 and 2015 in EEA member countries



Note: Light blue bars show all recorded river floods and dark blue bars show only flood events exceeding EUR 100 million in economic losses.

Source: Munich RE, 2016, provided to EEA under institutional agreement.

have the ability to integrate various contributing factors and assess potential changes to hydrology at global to local scales through the century (Andersen and Marshall Shepherd, 2013).

Future changes in the risk of river floods in Europe have been simulated using a hydrological model driven by an ensemble of climate simulations (Rojas et al., 2012; Alfieri et al., 2015a, 2015b; Kundzewicz et al., 2017). Of particular interest is the frequency analysis of flood peaks above the 100-year flood level, which is the average protection level of the European river network, albeit with significant regional differences (Rojas et al., 2013; Jongman et al., 2014) and simulated flood risk assessment in Europe based on high-level greenhouse gas concentrations in the atmosphere (RCP8.5) (Alfieri et al., 2015a).

Using three different future periods based on the hydrological model LISFLOOD and an ensemble of seven climate models the level of change in 100-year (Q100) floods shows large regional differences in Europe (Map 3.8). Blue rivers indicate an increase in flood level and red rivers indicate a decrease (Alfieri et al., 2015a).

For the end of the 21st century, the greatest increase in Q100 floods is projected for the British Isles, north-west and south-east France, northern Italy and some regions in south-east Spain, the Balkans and the Carpathians. Mild increases are projected for central Europe, the upper section of the Danube and its main tributaries. In contrast, decreased Q100 floods are projected in large parts of north-eastern Europe owing to a reduction in snow accumulation, and hence melt-associated floods, under milder winter temperatures. These results are consistent with earlier studies (Dankers and Feyen, 2009; Ciscar et al., 2011; Rojas et al., 2012). Map 3.8 shows an average of several models which provides the best assessment of the seven model simulations. However, individual model results can vary substantially and all results are subject to uncertainty, stemming from several factors. There are uncertainties linked to the climate scenarios that are used as a basis for the projections. The LISFLOOD analysis is restricted to the larger rivers in Europe, which may not be representative of a whole country or region. For example, in northern Europe, rainfall-dominated floods in smaller rivers may increase because of projected increases in precipitation amounts, even where snowmelt-dominated floods in large rivers are projected to decrease (Vormoor et al., 2016). Scarcity of ground data of adequate quality and quantity is also a reason for uncertainty in projections, because the material for calibration and validation is not satisfactory (Kundzewicz et al., 2017).

Changes in flood frequencies below the protection level are expected to have less significant economic effects and affect fewer people than small changes in frequencies in the largest events (e.g. with a return period of 500 years) (Alfieri et al., 2015a).

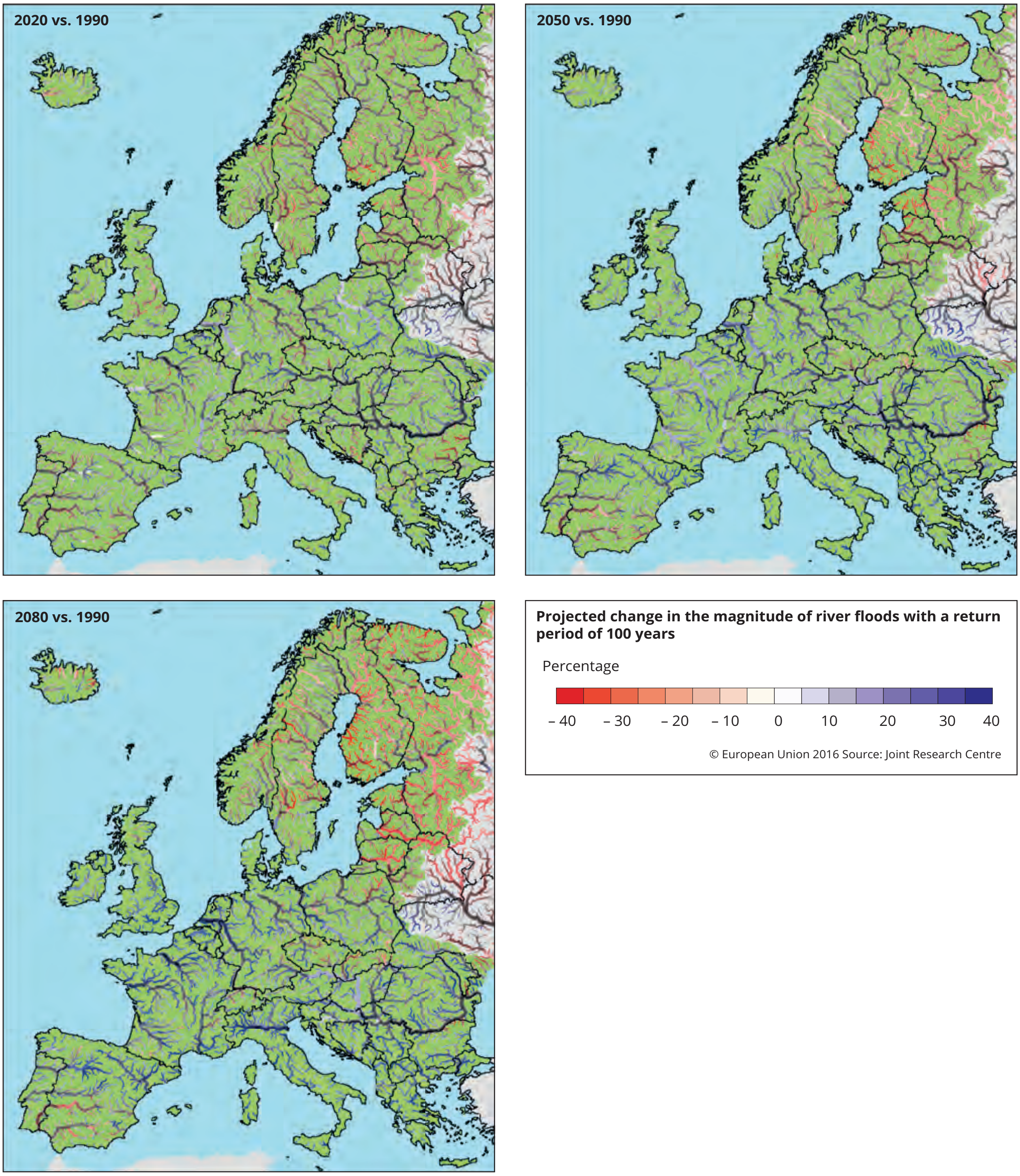
A follow-up study combined the results of a flood hazard assessment with detailed exposure maps to estimate the economic and health risks from river floods in Europe (Alfieri et al., 2016). The results suggest that a high climate change scenario could increase the socio-economic impact of floods in Europe more than three-fold by the end of the 21st century. The strongest increase in flood risk based on expected annual population affected is projected for Austria, Hungary, Slovakia and Slovenia (Alfieri et al., 2015b). Adaptation measures have been estimated to reduce economic damage from (fluvial and coastal) floods substantially (Mokrech et al., 2014; Alfieri et al., 2016).

3.4.4 Uncertainties, data gaps and information needs

Trends in river flood frequency and intensity are uncertain due to low temporal and spatial occurrence of floods and inconsistencies in the historical record, and also because of changes in river morphology, stemming from straightening of rivers, dams, diversions, natural changes in channel volume as well as changes in land use and climate change. Civil authorities, infrastructure managers and private companies are able to use the available information and apply it in a risk context. Floods impact data can be obtained from databases such as the DFO ([51]) of the University of Colorado, the Emergency Events Database (EM-DAT) ([52]) of the Centre for Research on the Epidemiology of Disasters and the NatCatSERVICE by Munich RE ([53]). Information on river flood hazard and risk maps for Europe has been available under the European Floods Directive (EU, 2007) since 2013 and is revised every six years. As many rivers cross borders, the directive supports international collaboration, requiring the development of flood risk management plans within each of the approximately 180 river basin districts in Europe.

([51]) http://floodobservatory.colorado.edu/
([52]) http://www.emdat.be
([53]) http://www.munichre.com/natcatservice

Map 3.8 **Projected change in river floods (peak flow events) with a return period of 100 years, in the early (left), mid (centre) and late (right) 21st century**



Note: Projected change in the level of a 100-year daily peak river flow (Q100). Relative change for the time slices 2006–2035 (2020), 2036–2065 (2050) and 2066–2095 (2080) compared with the ensemble mean of the baseline (1976-2005). Based on an ensemble of seven EURO-CORDEX simulations forced by the RCP8.5 scenario and the LISFLOOD hydrological model. The consistency of the model projections is evaluated through the use of the coefficient of variation (CV) of the relative change. Smaller CVs indicate better model agreement on the projected mean change. Rivers with larger CVs (greater than 1) are shown in grey.

Source: Adapted from Alfieri et al., 2015a.

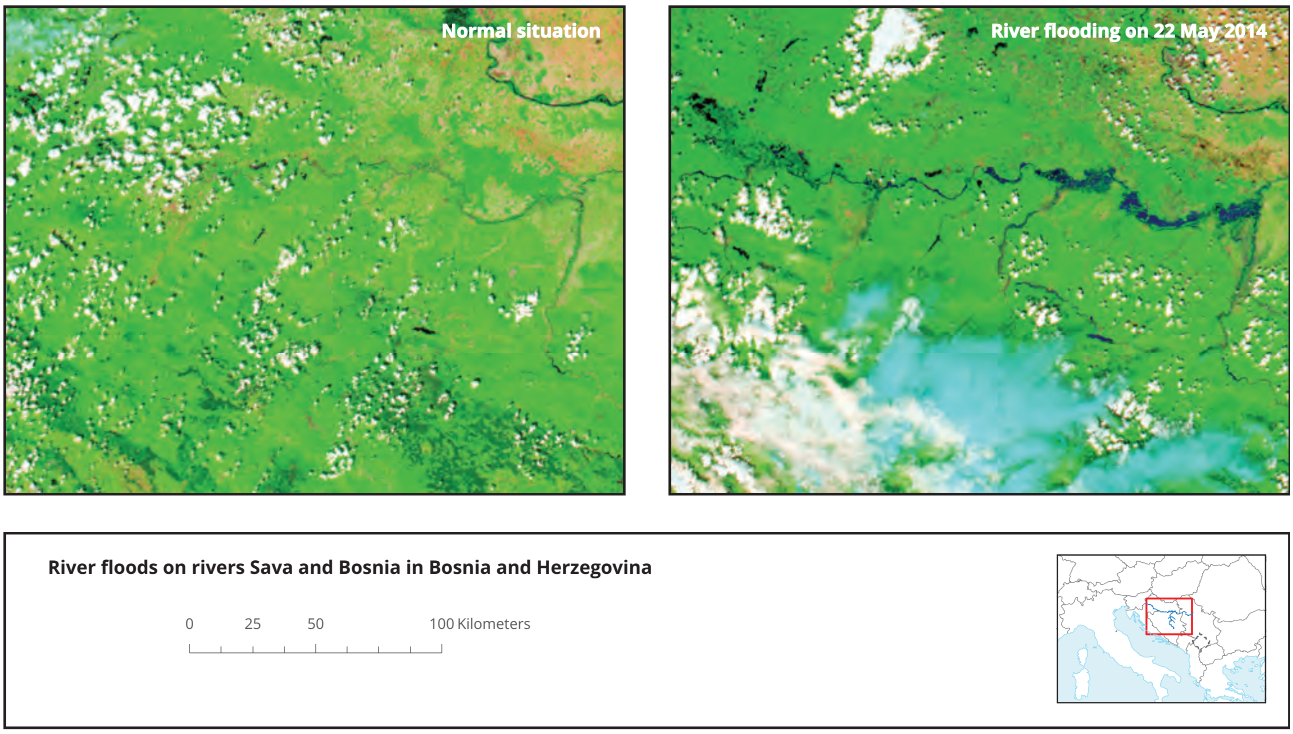
Information that can reduce disasters due to river flooding in Europe is focused on clarifying flood hazard and flood risk, and developing early warning systems and knowledge on prevention and protection measures. Flood hazard is mapped as the area impacted by, for example, a 100-year flood, and flood risk mapping combines the hazard area with assets at risk of adverse impacts. An early warning system is a model that, based on inputs of flood hazard and risk maps, conditions in the river and its surrounding catchment, rainfall duration and intensity, can predict water level height along the river corridor at short notice and issue risk warnings. This is for emergency operations.

Although flood extent is identified by most EU Member States, different countries use different approaches and a European flood hazard map is not currently available. Consequently, an assessment of flood risk based on a uniform methodology is also unavailable on a European scale. A European assessment of flood hazard and flood risk is, however, a highly relevant tool needed to obtain a holistic perspective on management needs. As flood risk reduction measures, such as building new dikes or dams, are costly and may both exacerbate flood risk and be environmentally unfriendly, there is an increased interest in addition to technical solutions in using so-called nature-based solutions (NBSs) to manage flood risks. These are solutions based on re-establishing the natural water retention properties of parts of a river. For example, this can be achieved by allowing flooding along certain parts of a river with the objective of reducing overall flood height, or by moving dikes away from the direct vicinity of the river channel to allow more space for water during floods. At present, there is limited information available about the use of such measures at European level, for example an overview of green measures related to the policy objective 'to take adequate and coordinated measures to reduce flood risk' ([54]).

3.4.5 Selected event

In May 2014, the heaviest rain in over 100 years was recorded in the Balkans, especially across, Bosnia-Herzegovina and Serbia. As a result the River Bosnia in Maglaj experienced a 1-in-500-year flood event, and in other parts of the river the measured discharge reached levels of almost a 1-in-1 000-year

Map 3.9 River floods on Sava and Bosnia rivers in Bosnia and Herzegovina



Note: Left figure shows normal situation in the region and right figure shows extent of river flooding on 22 May 2014.

Source: TC Vode (www.tcvode.si) and data © Landsat.

([54]) Natural Water Retention Measures — http://nwrm.eu/

event (Kastelic et al., 2014; Vidmar et al., 2016) (Map 3.9). The resulting river floods affected 2 million people, including the loss of 82 lives, and over 3 000 landsides were recorded across the Balkan region (Kastelic et al., 2014; Blunden and Arndt, 2015). Economic losses were estimated at EUR 1.55 billion, and it took a year for the coal mines at Tamnava and Veliki Crljeni in Serbia to be recommissioned.

Many valley towns in Serbia were also hit by the floods and subsequent land- and mudslides, including the heavily affected and damaged small town of Krupanj in western Serbia. In Krupanj, at least 20 houses were fully destroyed, and infrastructure and more than 500 houses were seriously damaged. The town was without electricity and cut off from its surroundings for 3 days (Figure 3.2).

3.5 Windstorms

3.5.1 Relevance

Windstorms are atmospheric disturbances that are defined by strong sustained wind. They can range from relatively small and localised events to large features covering a substantial part of the continent. Large storms in Europe are extratropical cyclones; from wave disturbances over the Atlantic Ocean, they develop as low-pressure weather systems that capture their energy from the temperature contrast between the subtropical and polar air masses that meet in the Atlantic Ocean. In northern and north-western Europe, severe cyclones can occur all year. In central Europe, severe cyclones occur mainly between November and February, but they can also occur in other seasons.

In the southernmost part of the European continent, tropical-like cyclones are known to occur over the Mediterranean Sea. These cyclones are called medicanes ([55]) and they share several features with tropical cyclones, including a spiral cloud structure with a cloud-free eye, winds up to hurricane force and heavy precipitation. Due to the topography of the Mediterranean basin, surrounded by land, these storms usually do not reach the intensity of the strongest extratropical cyclones.

Windstorms can lead to structural damage, flooding and storm surges, which may be caused either by the wind itself, in particular short gusts, or by accompanying heavy precipitation. These events can have large impacts on human health and on vulnerable systems, such as forests, as well as transport and energy infrastructures. According to Munich RE's natural catastrophe loss database

Figure 3.2 Flood and mudslide damage to houses in the town of Krupanj, Serbia, 2014

Photo: © By Zoran Dobrin - Permission by email, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=32886545

([55]) Sometimes also termed Mediterranean Sea hurricanes. See Cavicchia et al., 2013, 2014 for more details.

(NatCatSERVICE), storms were the costliest natural hazard (in terms of insured losses) in Europe between 1980 and 2015; they ranked second for overall losses and fourth in terms of the number of human casualties. The European regions most strongly affected were north-western, western and northern Europe, in particular regions close to the coast (Outten and Esau, 2013; Osinski et al., 2015).

3.5.2 Past trends

Studies of past changes in extratropical storms have used a variety of methods, making it difficult to compare the results of different studies or to assess if there is any underlying climate change signal (Stott, 2015). Storm location and intensity in Europe have shown considerable variation over the past century, but tracks of intense windstorms in the Northern Hemisphere have likely shifted northwards since at least 1970 (Ulbrich et al., 2009; Hov et al., 2013a).

Wind data at the local or regional levels can show a series of decreases and increases continuing over several decades. Available studies of storm activities (i.e. storminess) in north-western Europe indicate relatively high levels during the 1880s, followed by below average conditions between the 1930s and 1960s, a pronounced increase in storminess until the mid-1990s, and average or below average activity afterwards. Somewhat similar patterns were observed in other parts of Europe (Matulla et al., 2007; Feser et al., 2014; Dawkins et al., 2016). There is low confidence in the robustness of reanalysis results for extreme wind speeds before the middle of the 20th century (Hartmann et al., 2013; Feser et al., 2014).

A single study for the period 1871 to 2008 using global reanalysis data suggests an increasing trend in storminess (defined as above 95th annual percentiles of daily maximum wind speeds) across western, central and northern Europe, with storminess in the North Sea and the Baltic Sea region reaching its highest values towards the end of the 20th century (Donat et al., 2011b). Other available studies have produced evidence that both conflicts and agrees with this result (Wang et al., 2011, 2014; Brönnimann et al., 2012; Krueger et al., 2013).

In the period 1979–2014, based on 6 103 high-resolution model-generated historical footprints, a decline of windstorm damage has been found (Roberts et al., 2014; Dawkins et al., 2016). Such a decrease, however, could be linked to climate variations on interannual and decadal scales (Dawkins et al., 2016). Much of the change in windstorms is explained by the North Atlantic Oscillation (NAO) (Scaife et al., 2014; Dawkins et al., 2016). Analysis of longer time series is needed in order to draw robust conclusions.

Studies on medicanes using global climate models or reanalysis data agree that medicanes are a rare event, with an average occurrence of 1 to 2 events per year (e.g. Cavicchia et al., 2013). The low frequency is related to various concurrent factors, such as a lower than average wind shear and large vertical temperature gradients in the atmosphere, which are favourable for the formation and intensification of medicanes. No significant past trend in medicanes has been detected in the analysed period (Cavicchia et al., 2013, 2014).

3.5.3 Projections

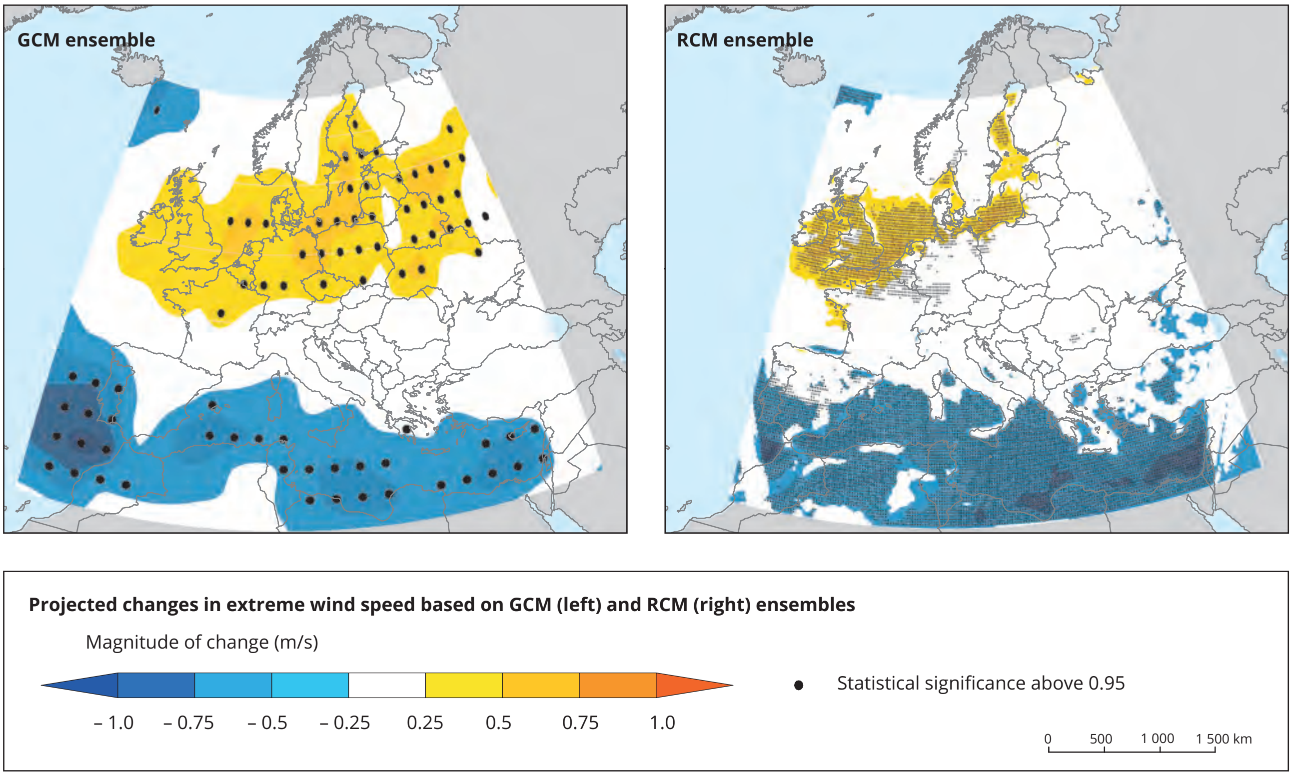
The simulation of extratropical cyclones in climate models remains a scientific challenge in spite of significant recent progress in modelling techniques. Earlier model studies showed both poleward (Gastineau and Soden, 2009) and equatorward (McDonald, 2011; Scaife et al., 2011) shifts in the Atlantic storm track.

Recent simulations based on CMIP5 data project an eastward extension of the North Atlantic storm track towards central Europe, with an increase in the number of cyclones in central Europe and a decreased number in the Norwegian and Mediterranean Seas. During summer a reduction in the number of North Atlantic cyclones along the southern flank of the storm track was projected (Zappa et al., 2013).

A study using two multi-model ensembles (one based on 9 GCMs and another based on 11 RCMs) projects a small increase in the wind speed of the strongest winter storms over northern parts of central and western Europe, and a decrease in southern Europe (Map 3.10) (Donat et al., 2011a). The associated projected change in mean potential economic loss varied between – 7 % in the Iberian Peninsula and + 25 % in Germany for the last three decades of the 21st century, considering the A1B emissions scenario (Nakicenovic and Swart, 2000).

A comprehensive review study covering the North Atlantic as well as northern, north-western and central Europe shows large agreement among models that the intensity of winter storms will increase in all these regions over the 21st century (Feser et al., 2014). Intensity of storms is here defined with the proxy (e.g. when mean sea level pressure measured in a single station is 35 hPa below the mean annual sea-level pressure) derived from the models. Another recent study, focusing on central Europe, concluded that models consistently projected an increased

Map 3.10 Multi-model ensemble projections of winter storms



Note: Ensemble mean of changes in extreme wind speed (defined as the 98th percentile of daily maximum wind speed) for A1B (2071-2100) relative to 1961-2000. Left: based on 9 GCM runs. Right: based on 11 RCM runs. Coloured areas indicate the magnitude of change (unit: m/s), statistical significance above 0.95 is shown by black dots.

Source: Donat et al., 2011a.

frequency and intensity of severe storms over central Europe. Under A1B conditions, changes in frequency towards the end of the 21st century range between – 11 % and + 44 %, with an ensemble mean change of 21 % (Pardowitz, 2015). The intensity of storms affecting central Europe once a year was found to increase by about + 30 %, with individual models projecting changes between – 28 % and up to + 96 %. These results are largely consistent with those of a recent study based on the GCM projections underlying the IPCC's AR5 (Zappa et al., 2013). One recent study with a single very-high resolution (~ 25 km) GCM indicates that the frequency, intensity and area affected in Europe by severe autumn storms originating in the tropical Atlantic will increase in a warmer future climate (Baatsen et al., 2015). However, this result cannot be considered robust, as it has not yet been confirmed by other studies.

For medicanes, a decreased frequency but a tendency to an increased intensity of the most violent storms is projected. This result is likely to be robust due to the agreement between studies employing different techniques, such as dynamical downscaling, analysis of high-resolution GCMs or generation of synthetic storm tracks (Romero and Emanuel, 2013; Tous and Romero, 2013; Cavicchia et al., 2014).

3.5.4 Uncertainties, data gaps and information needs

Various factors affect the ability to robustly assess European windstorm activity. In spite of recent progress, there is still a lack of long-term homogeneous observational data in some parts of the continent. On the other hand, the horizontal resolution of reanalysis and model data might not be yet high enough to fully represent the physical processes responsible for regional storm activity. The use of high-resolution downscaling and increasing resolution of the next generation of global models are expected to improve the representation of small-scale storms in the coming years.

The XWS (eXtreme WindStorms) (Roberts et al., 2014) catalogue is aimed at filling the gap in the availability of data for past European windstorms, by providing open-access datasets of the most intense storms from the period 1979–2014. This dataset combines the use of high-resolution modelling data and station observations to provide recalibrated information on storm intensity in a format directly usable to assess windstorm impact.

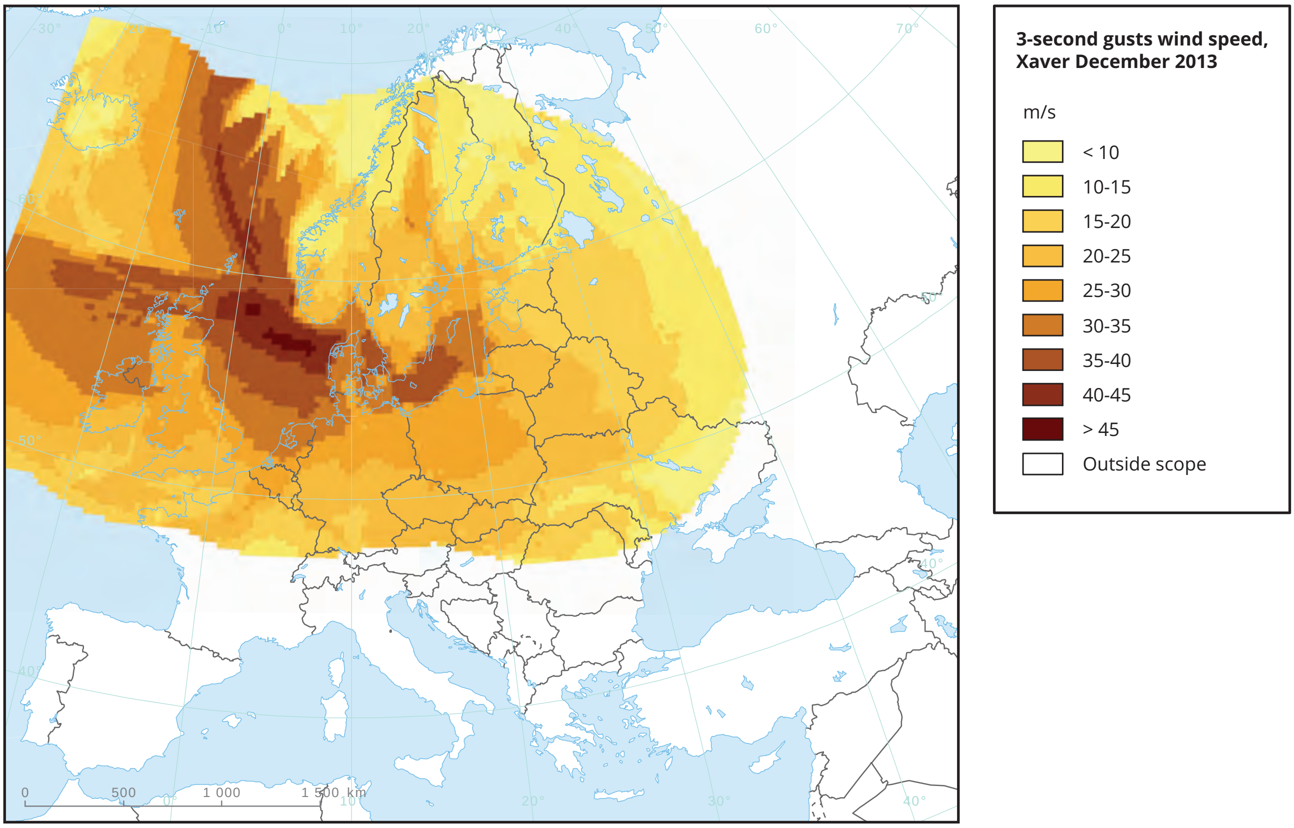
Concerning the other source of uncertainty, i.e. differences arising from different analysis techniques, efforts are under way to quantify the uncertainties and find a consensus, including the Intercomparison of Mid Latitude Storm Diagnostics (IMILAST) initiative (Roberts et al., 2014). The IMILAST initiative is aimed at assessing what aspects of cyclone climatology are robust and what aspects are still affected by uncertainties related to the detection method.

3.5.5 Selected events

Storm Xaver, hitting northern Europe in December 2013 and causing EUR 800 million of insured loss, was one of the most damaging windstorms of the recent years, and ranks as the 13th most intense storm (based on wind speed data) of the past 25 years (Roberts et al., 2014). The storm footprint, based on the analysis of 3-second wind gusts, shows values of up to 55 m/s (Map 3.11).

Among the most recent cases of medicanes, an event occurring in January 2014 has been extensively studied using available observations and high-resolution models (e.g. Cioni et al., 2016). The storm crossed the whole Tyrrhenian Sea, crossed the Italian peninsula, and then increased again its intensity in the Adriatic Sea (Map 3.12). Two distinct tropical phases were detected, over the Tyrrhenian Sea and Adriatic Sea respectively (red circles in Map 3.12). During the first tropical-like phase, the storm reached hurricane strength with wind speeds of 33 m/s.

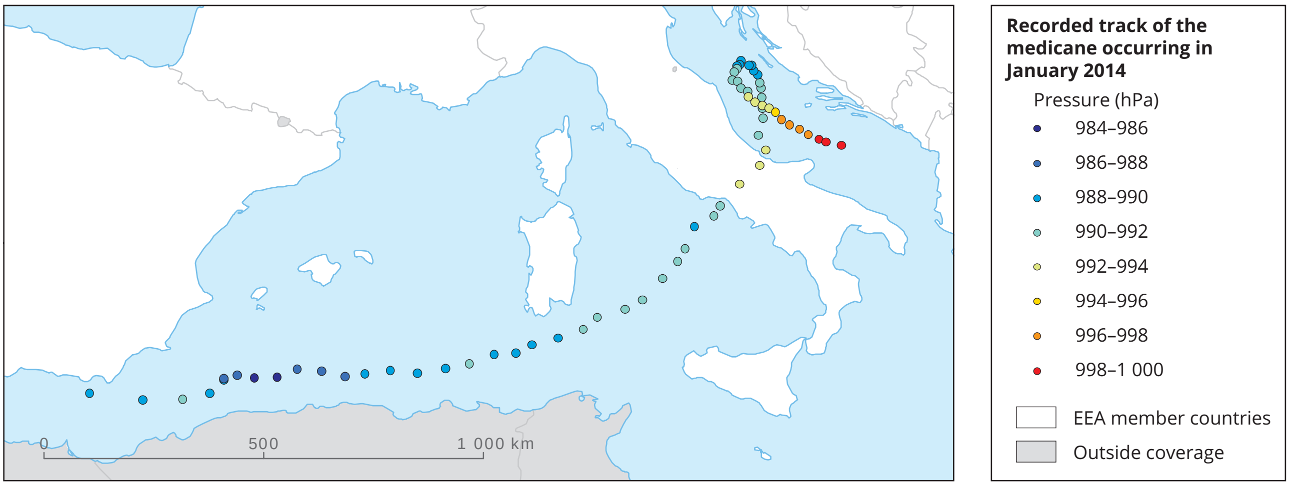
Map 3.11 Footprint of Storm Xaver in December 2013



Note: The storm footprint is defined by considering the highest 3-second wind gust during a 72-hour period. Data are obtained from the Met Office Integrated Data Archive System (MIDAS).

Source: XWS database (Roberts et al., 2014).

Map 3.12 Recorded track of medicane occurring in January 2014



Note: Medicane track from a high-resolution simulation of January 2014. Red circles indicate tropical-like dynamic structure.

Source: Adapted from Cioni et al., 2016.

3.6 Landslides

3.6.1 Relevance

Landslides are natural hazards which in Europe cause fatalities and significant economic losses (Haque et al., 2016). Landslides occur as a combination of meteorological, geological, morphological, physical and human factors. Extreme weather- and climate-related events (such as heat waves, droughts and heavy precipitation) are the most common trigger of landslides in Europe. Shallow landslides are mostly triggered by heavy and/or persistent precipitation events, while deep-seated landslides are only weakly related to extreme weather or climate events.

Surface water run-off caused by heavy precipitation can induce some types of landslide, such as hyper-concentrated, debris flows or mudslides. An abrupt increase in the mean temperature can lead to more evident changes in mountain environment (i.e. evapotranspiration, snow melting, oscillations in snow-line elevation and snowfall/rainfall rates, etc.), with significant effects on landslides, mainly rock falls and debris flows.

The IPPC's AR5 (IPCC, 2013) only assessed the likelihood of changes in the main climate drivers which can cause landslides. Beyond efforts within the scientific community to improve knowledge on landslides and their sensitivity to climate change, the SFDRR 2015–2030 (UNISDR, 2015) focuses on reducing risk and losses by promoting specific actions that aim to encourage a science–policy interface for effective decision-making, within the context of landslide risk management.

Nevertheless, significant past trends and robust signals for future projections in landslides occurrence and magnitude are not easy to detect, partly due to the poor availability (and often reliability) of the historical record (both for landslide events and the triggering weather patterns), and partly due to the complexity of the local physical processes involved: climate anomalies, weather patterns that trigger landslides, non-linear slope hydrological response and related geomechanics.

3.6.2 Past trends

Comprehensive assessments of changes in frequency and magnitude of landslides at the European scale must also account for changes in demography, spatial planning, land use and land cover. It is therefore difficult to reanalyse events based on climate data only (Petley, 2012). Studies of landslide activities in Europe therefore assess changes in the susceptibility of an area to landslides rather than changes in landslide frequency and magnitude. This susceptibility represents, in a given area, the degree of proneness to landslides, defined with reference to geological properties, morphology, soil types, vegetation and land use. These factors statically define susceptibility, but do not provide any estimate of the intensity and frequency of an event (i.e. hazard). Two European landslide susceptibility maps were separately developed at the International Centre for Geo-hazards (ICG) (Nadim et al., 2006) and at the JRC using the same available datasets (Van Den Eeckhaut and Hervás, 2012). The ICG model considered all landslide types, while the JRC model considered only slide- and flow-type landslides. The resulting maps represent the situation in Europe well overall, identifying the main susceptibility/hazard hotspots (e.g. the Pyrenees, the Alps and their foothills, the Apennines, and coastal areas of the United Kingdom and Scandinavian Peninsula) (Map 3.13).

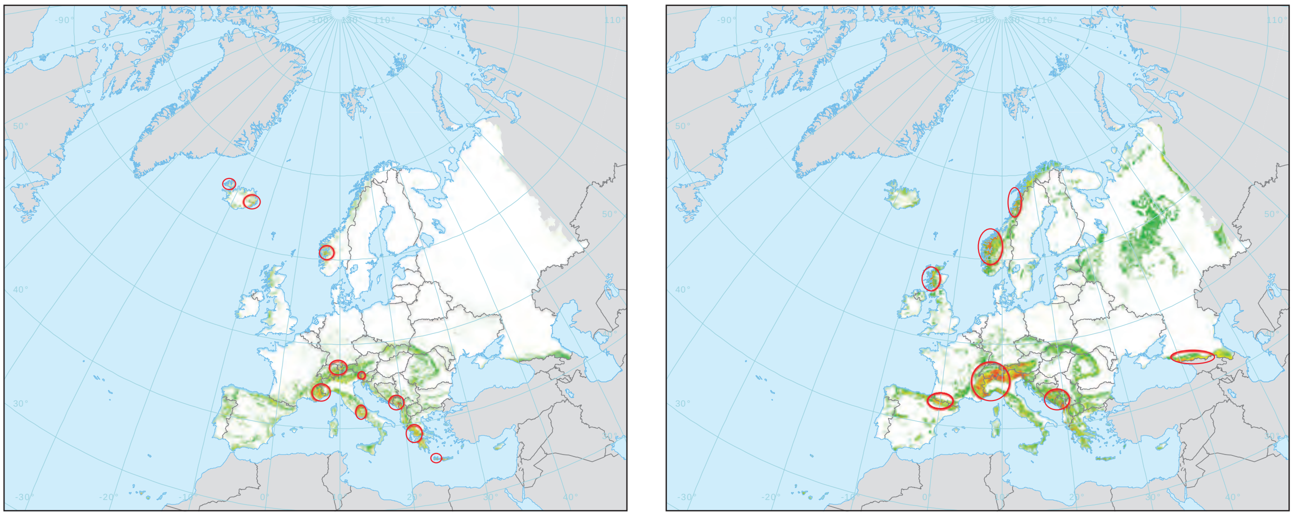
Several studies have focused on identifying the relationship between frequency in landslides and heavy precipitation (Polemio and Petrucci, 2010; Polemio and Lonigro, 2014; Gariano et al., 2015). For the Italian Alps of the Piedmont region, change in landslide activity and in the seasonal distribution of precipitation in the period 1960–2011 has been analysed by Stoffel et al. (2014), who found that landslide activities increased during spring, which is related to increased winter precipitation, and in summer, related mainly to dry conditions in spring and summer.

Most of the assessments based on past-events analysis draw attention to a broad range of possible impacts of climate change on landslide activity, but relationships are still weak and links uncertain (Flageollet et al., 1999; Stoffel and Beniston, 2006; Stoffel and Huggel, 2012; Jomelli et al., 2016).

3.6.3 *Projections*

The projected increase in surface temperature is expected to result in more intense and frequent rainfall events. In particular, 'extreme precipitation events over most of the mid-latitude land masses and over wet tropical regions will very likely become more intense and more frequent' (IPCC, 2013). In addition, there is a 'high confidence that changes in heavy precipitation will affect landslides in some regions' (IPCC, 2012). Where the frequency and/or the intensity

Map 3.13 Landslide susceptibility for weather-induced landslides: International Centre for Geo-hazards (ICG) (left) and Joint Research Centre (JRC) (right) models



Landslide susceptibility for weather induced landslides: ICG (left) and JRC models (right)

Low Medium High No data Outside coverage

0 500 1 000 1 500 km

Note: A distinct difference can be observed between the two models, where the JRC model has larger areas classified as being exposed to landslides than the ICG model. This shows that classification of landslide zonation maps is subjective and depends on decisions made by the experts. The classified hazard map of the JRC is more conservative, although it does incorporate hotspots of known hazard such as north-west Scotland, which the ICG model does not. Red circles show possible hotspots. White represents regions without landslide hazard.

Source: Adapted from Jaedicke et al., 2014.

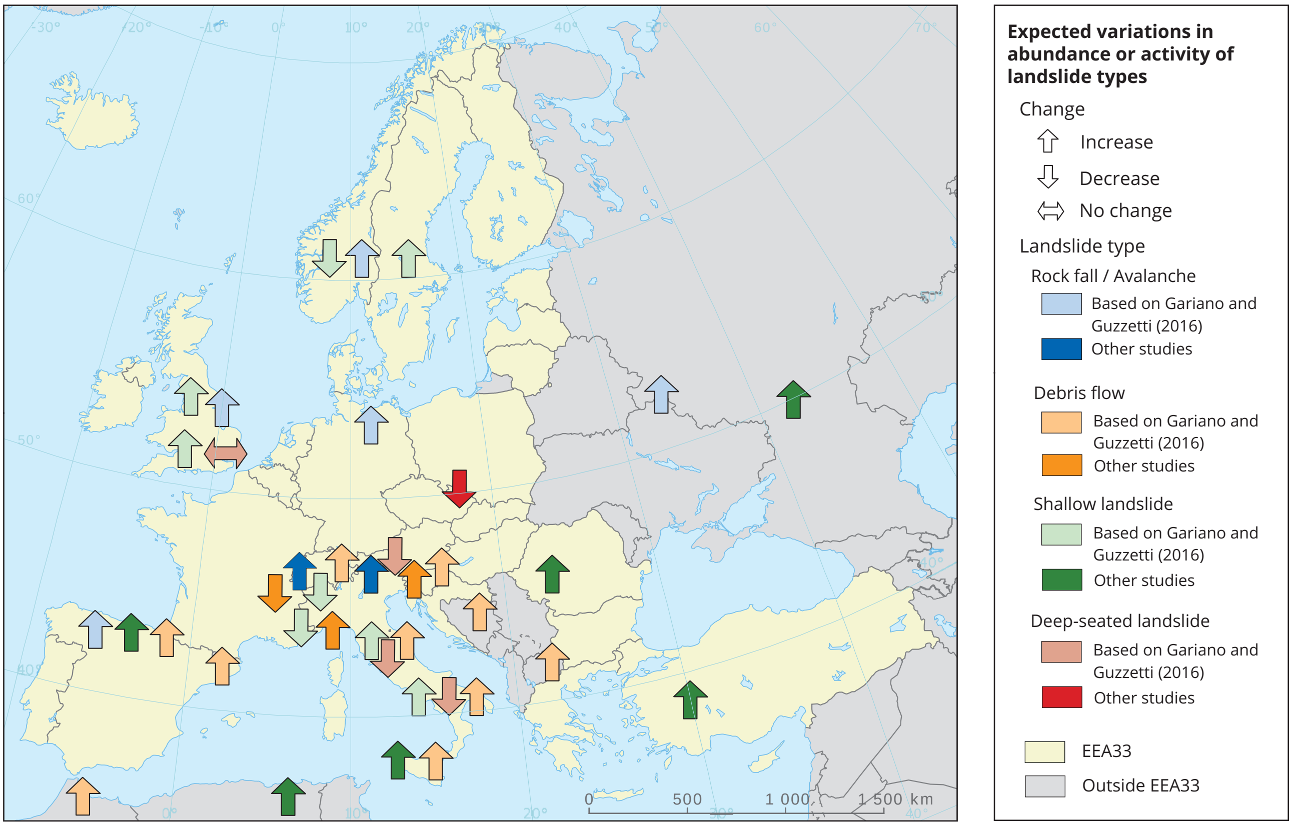
of rainstorms will increase, shallow landslides, including rock falls, debris flows and debris avalanches, and also ice falls and snow avalanches in high mountain areas, are also expected to increase (Stoffel et al., 2014)

Mountain environments, especially those in northern Europe, will be the most affected by projected increases in heat waves and changes in precipitation patterns (Donat et al., 2013a; IPCC, 2014; Jacob et al., 2014). An expected increase in temperature and changes in precipitation patterns will affect rock slope stability conditions and favour higher infiltration amounts within fine/coarse terrains and likely to favour the inception of debris flows or, more generally, shallow landslides.

Most of the assessments of global climate change impact on landslides have been carried out at local scales. One study, focused on a region in the United Kingdom, applied climate change projections to a statistics-based model in order to investigate future slope stability. It showed that the return period of winter land movements is projected to decrease from 4.0 to 3.5 years by the 2080s, based on the medium and high-end scenarios (Dixon and Brook, 2007).

Map 3.14 shows variations in frequency or activity of four landslide types based on an ensemble of GCMs driven by different climate scenarios (see Gariano and Guzzetti, 2016 for an overview). The greatest evidence consists of a general decrease in abundance/activity of deep-seated landslides and of an increase in rock falls, debris flows and more generally in shallow landslides. It should not be overlooked that in the past decade there has been increasing wildfire-induced change on the natural surface, especially in Mediterranean areas, making the topsoil more prone to erosion; this has reduced the amount of rainfall required to initiate shallow landslides (such as debris flows and mudslides) and associated surface erosion processes (Moody et al., 2013; Santi et al., 2013).

Map 3.14 Expected variations in abundance or activity of four landslide types, driven by projected climate change



Note: Dark colours are projections from the literature based on different climate scenarios and light colours are projections from a study for the end of the 21st century, based on the RCP8.5 scenario (Gariano and Guzzetti, 2016).

Source: Adapted from Gariano and Guzzetti, 2016.

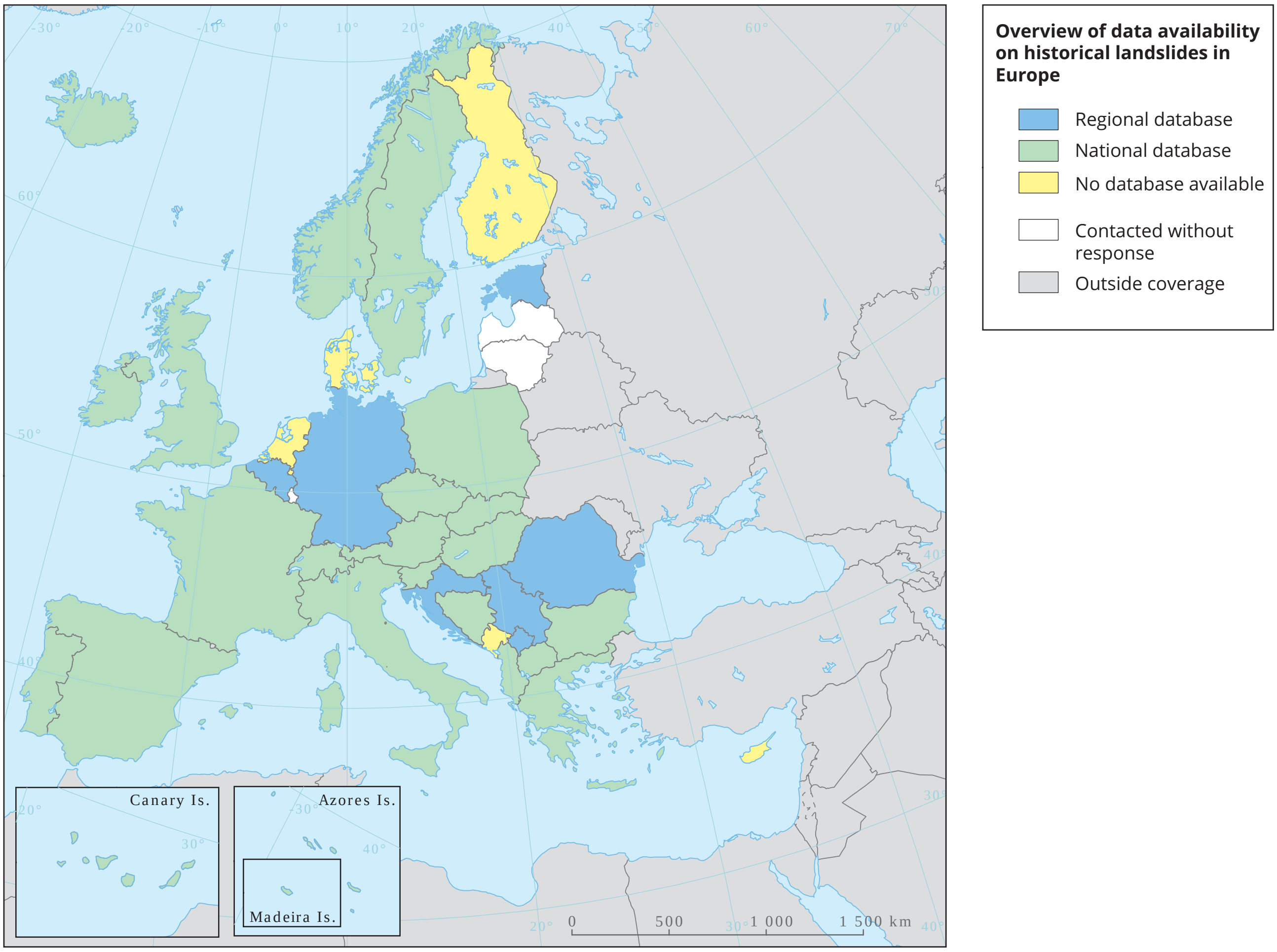
3.6.4 Data gaps, information needs and uncertainties

In order to identify European hotspots of landslide occurrences, two tools can be used: (1) data catalogues and (2) susceptibility maps. Detailed databases/inventories of observed data (e.g. weather forcing and landslide events) would constitute the most useful source/tool for quantifying changes in past landslide occurrence and for defining relationships for the future. Unfortunately, detailed historical records are often unavailable, or the information stored can be unreliable and often inconsistent with other catalogues (Map 3.15).

Detailed databases of observed characteristics of past landslides should constitute the most useful source/tool for quantifying susceptibility, hazard and landslide risk. Many European countries have been creating national and/or regional landslide databases (Van Den Eeckhaut and Hervás, 2012), but the scarcity of detailed information can distort trends. Several scientific papers (Günther et al., 2012) have identified significant variations in the level of detail provided, the completeness of the databases and the accuracy of the language used in national/regional landslides inventories.

In Europe, although a marked improvement in climate models has been recognised, the modelling chain of landslides still suffers limitations in the predictability of heavy precipitation at the local scale. Coarse time resolution data may fail to represent peak rainfall intensities, so that significant variations in pore water pressure and water content may drastically affect mechanical terrain behaviour under the influence of precipitation lasting a span of hours (Ciervo et al., 2016).

Map 3.15 Overview of national datasets at European level



Note: The figure shows an overview of data availability on historical landslides in Europe. Data are available for most European countries, either from national databases (green) or regional databases (blue).

Source: Adapted from Van Den Eeckhaut and Hervás, 2012.

3.6.5 *Selected events*

A large landslide formed at Maierato (Vibo Valentia District), southern Italy, on 15 February 2010, at 14.30 local time, when rapid failure occurred after several days of preliminary movements. The landslide had an area of 0.3 km^2, a runout distance of 1.2 km and an estimated volume of about 10 million m^3. The landslide caused nearly 2 300 inhabitants to be evacuated, with high economic losses. The most probable trigger of the landslide was cumulative precipitation over the preceding 20 days (with a return period of more than 100 years), which followed a long period of 4-5 months of heavy rainfall (about 150 % of the average rainfall of that period) (Gattinoni et al., 2012).

3.7 Droughts

3.7.1 *Relevance*

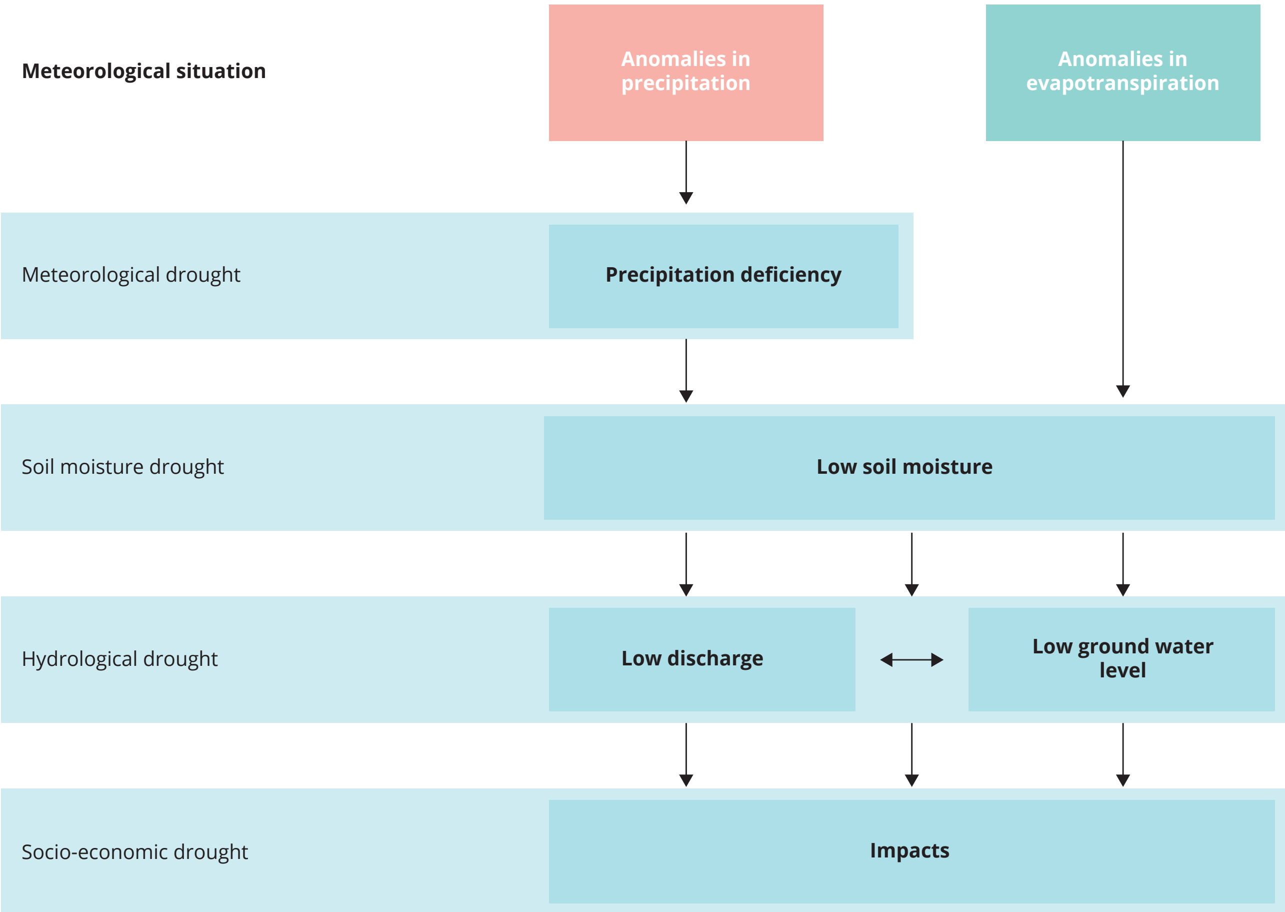
Droughts have severe consequences for Europe's citizens and most economic sectors, including agriculture, energy production, industry and public water supply (Blauhut et al., 2015). However, the term 'drought' is used in various contexts, which may cause confusion when terminology is not carefully used.

A persistent meteorological drought (rain deficiency) can turn into to a soil moisture (agricultural) drought, affecting plant and crop growth, which in turn may deepen into a hydrological drought affecting watercourses, water resources and groundwater-influenced natural ecosystems. Furthermore, hydrological droughts detrimentally affect freshwater ecosystems including vegetation, fish, invertebrates and riparian bird life (EEA, 2012, 2015, 2016b, 2016a). Hydrological droughts also strongly affect navigation on rivers, cooling of power plants and water quality, by reducing the ability of a river to dilute pollution (Figure 3.3).

3.7.2 *Past trends*

Drought has been a recurrent feature of the European climate in recent times. From 2006 to 2010, on average

Figure 3.3 Droughts types and causes



Source: Adapted from Van Loon, 2015.

15 % of the EU territory and 17 % of the EU population have been affected by meteorological droughts each year. In the 1990s and 2000s the drought hotspots were the Mediterranean area and the Carpathian region (Sepulcre-Canto et al., 2012; Spinoni et al., 2016). Significant European droughts occurred in 2010, 2011 and 2015. The 2011 drought was especially severe and affected many countries in Europe.

Meteorological droughts

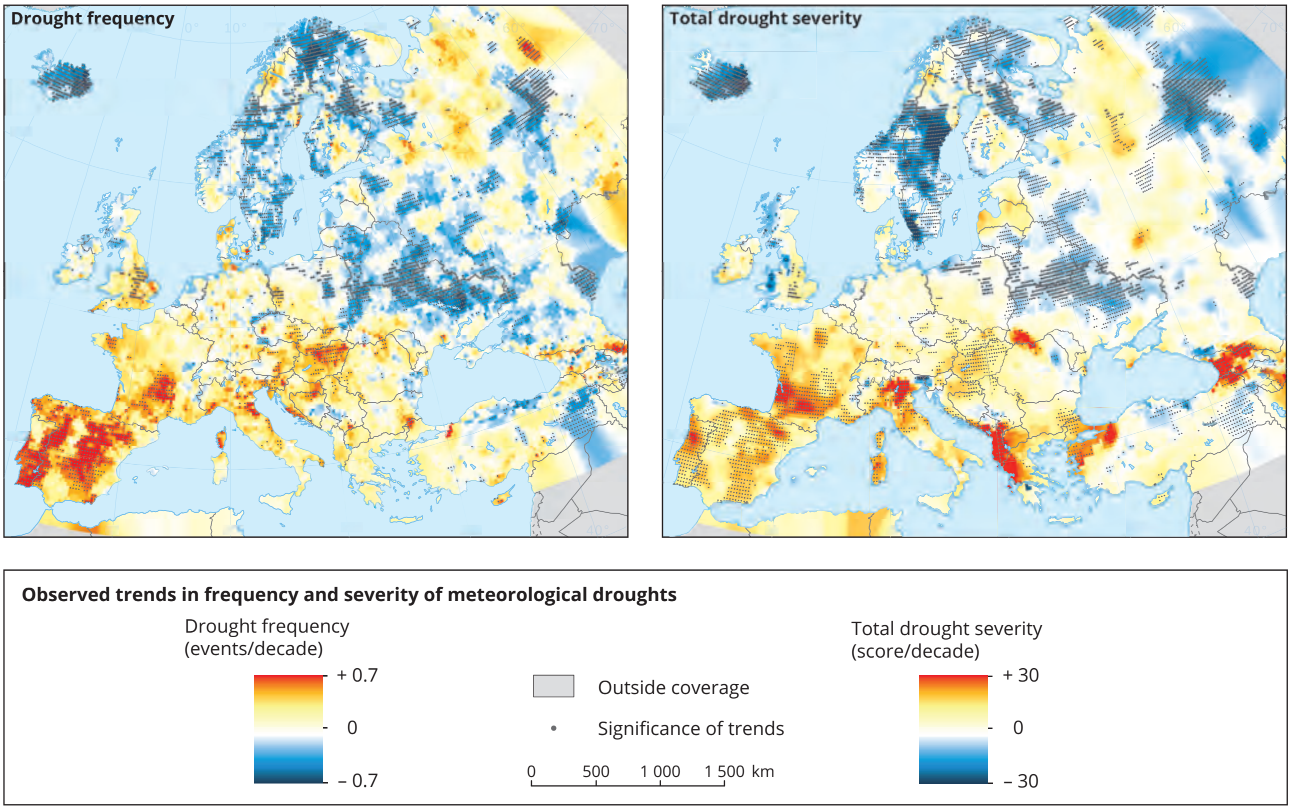
Meteorological droughts are usually characterised using statistical indices, such as the standardised precipitation index (SPI) (McKee et al., 1995), standardised precipitation evapotranspiration index (SPEI) (Vicente-Serrano et al., 2009) and reconnaissance drought index (RDI) (Tsakiris et al., 2007).

Since 1950, the frequency of meteorological droughts in Europe has increased, mostly in southern and central Europe, but droughts have become less frequent in northern Europe and parts of eastern Europe (Map 3.16, left). Trends in drought severity (based on a combination of three drought indices — SPI, SPEI and RDI) also show significant increases in the Mediterranean region (in particular the Iberian Peninsula, France, Italy and Albania), as well as in parts of central and south-eastern Europe; and decreases in northern Europe and parts of eastern Europe (Map 3.16, right) (Gudmundsson and Seneviratne, 2015; Spinoni et al., 2015).

Soil moisture droughts

As a spatially and temporally comprehensive set of harmonised soil moisture data over a sufficient soil depth is not available, assessments of past trends in soil moisture rely on hydrological models driven by data on climate, soil characteristics, land cover and phenological phases. These simulations take account of changes in available energy, humidity and wind speed, but disregard artificial drainage and irrigation practices. Modelling of soil moisture content over the past 60 years suggests that there has been little change at the

Map 3.16 Observed trends in frequency (left) and severity (right) of meteorological droughts

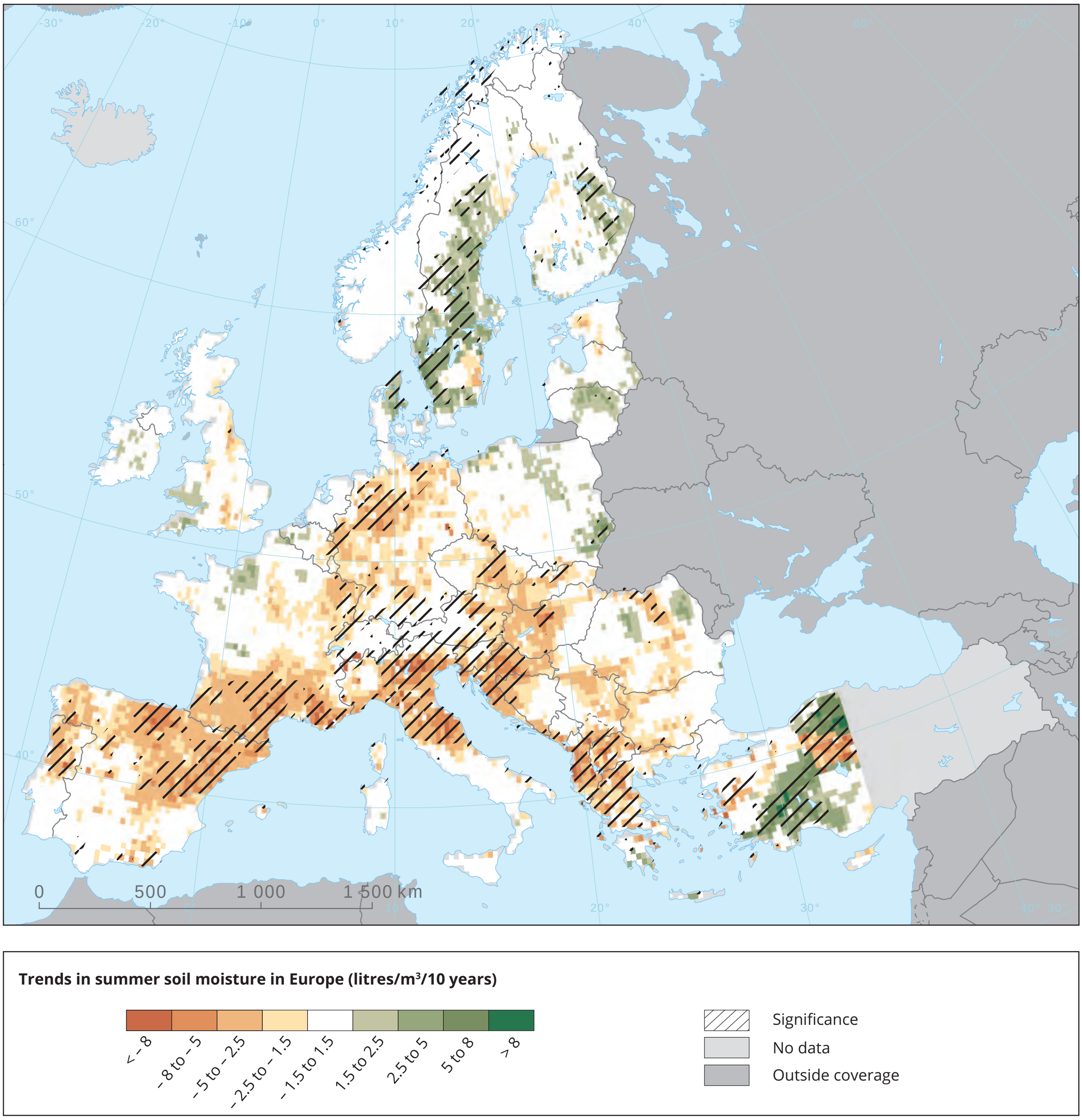


Note: This map shows the trends in drought frequency (number of events per decade; left) and severity (score per decade; right) of meteorological droughts between 1950 and 2012. The severity score is the sum of absolute values of three drought indices (SPI, SPEI and RDI) accumulated over 12-month periods. Dots show trends significant at the 5 % level.

Source: Adapted from Spinoni et al., 2015.

global and pan-European levels (Sheffield et al., 2012; Kurnik et al., 2015). At the subcontinental scale, however, significant trends in summer soil moisture content can be observed. Soil moisture content has increased in parts of northern Europe, probably because of increases in precipitation amounts. In contrast, soil moisture has decreased in most of the Mediterranean region, particularly in south-eastern Europe, south-western Europe and southern France. Apparent substantial increases in soil moisture content modelled over western Turkey should be treated with caution because of the limited availability of climate and soil data in the region, which affects the accuracy of the modelled trends (Kurnik et al., 2015) (Map 3.17).

Map 3.17 Past trends in summer soil moisture content



Note: Trends refer to the period 1951-2012; soil moisture content was modelled using a soil water balance model in the upper soil horizons; summer means June to August.

Source: Adapted from Kurnik et al., 2015.

Hydrological droughts

Most stream gauges in Europe show a decrease in summer low flows over the second half of the 20th century (Map 3.18). However, the current data availability is insufficient for attributing this trend to global climate change (Stahl et al., 2010, 2012).

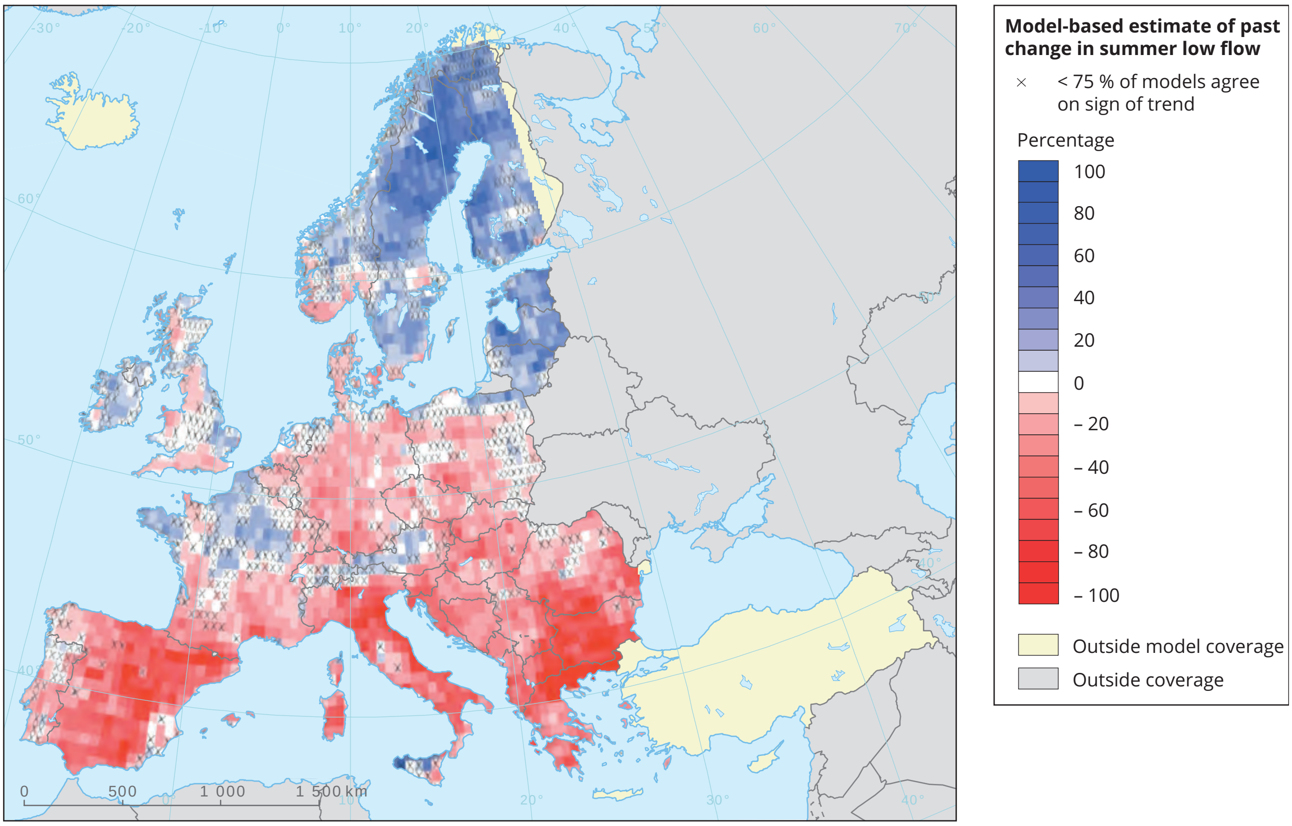
3.7.3 Projections

An assessment of European meteorological droughts based on different drought indices and an ensemble of RCMs has projected drier conditions for southern Europe for the mid-21st century, with increases in the length, magnitude and area of drought events (van der Linden and Mitchell, 2009b). In contrast, drought occurrence was projected to decrease in northern Europe (Henrich and Gobiet, 2012). Similar results were obtained in later studies based on different indices and climate projections (Orlowsky and Seneviratne, 2013; Giorgi et al., 2014; Touma et al., 2015; Spinoni et al., 2015).

Meteorological droughts

A models ensemble from the EURO-CORDEX (Jacob et al., 2014) community projects that the frequency and duration of extreme meteorological droughts (defined as having a value below – 2 on the standardised precipitation index, SPI-6) will significantly increase in the future (Stagge et al., 2015). These projections showed the largest increases in frequency for extreme droughts in parts of the Iberian Peninsula, southern

Map 3.18 Model-based estimate of past change in summer low flows



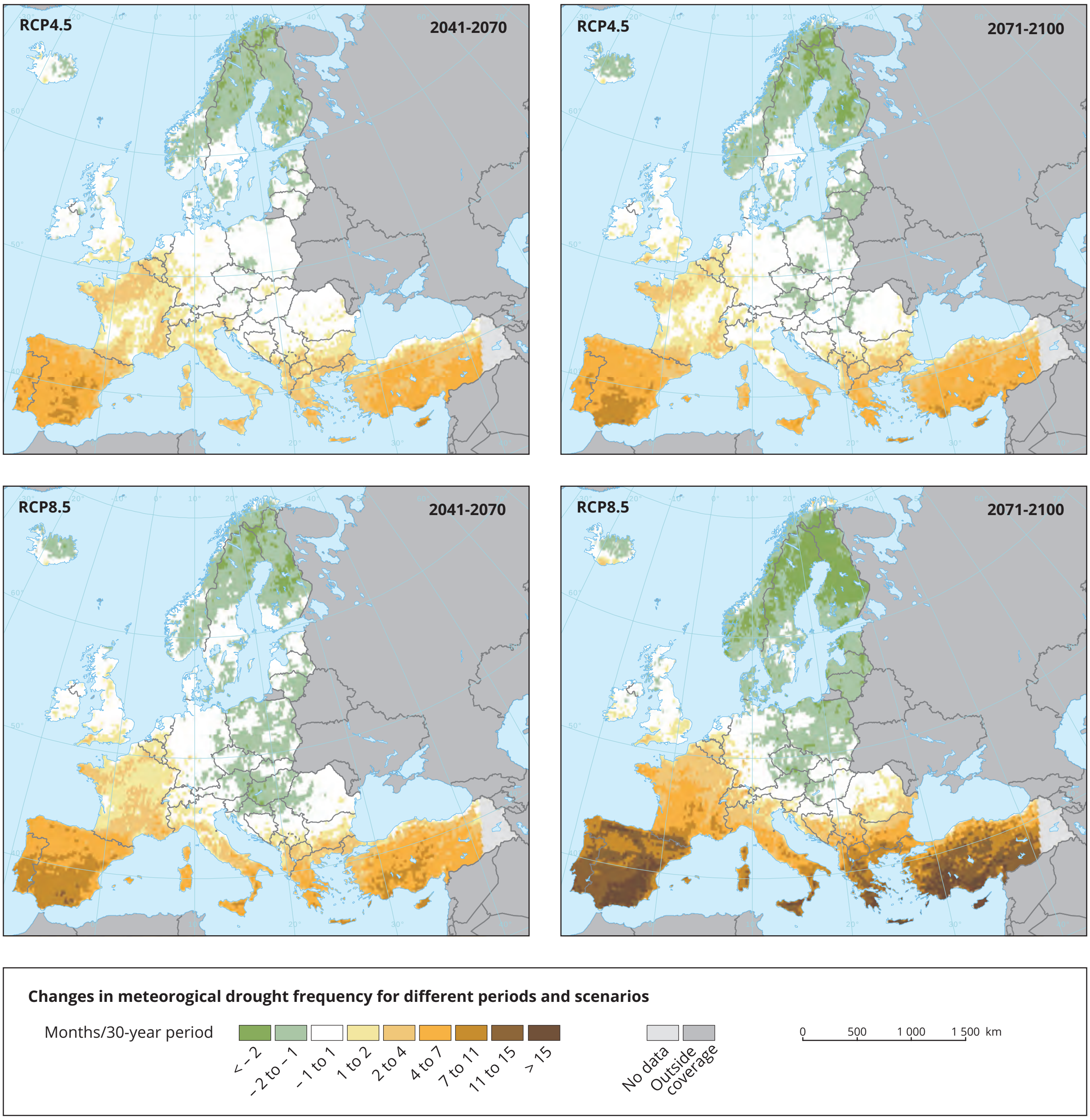
Note: This map shows the ensemble mean trend in summer low flow from 1963 to 2000. '×' denotes grid cells where less than three quarters of the hydrological models agree on the direction of the trend.

Source: Adapted from Stahl et al., 2012.

Italy and the eastern Mediterranean, especially at the end of the century, with respect to the baseline period 1971–2000 (Map 3.19). The changes are most pronounced for the RCP8.5 high emissions scenario and slightly less extreme for the moderate (RCP4.5) scenario.

Drought projections that also consider potential evapotranspiration (e.g. SPEI) showed substantially more severe increases in the areas affected by drought than those based on the precipitation-based SPI alone. For example, the fraction of the Mediterranean region under drought was projected to increase by 10 % by

Map 3.19 Projected change in frequency of meteorological droughts



Note: This map shows the projected change in the frequency of extreme meteorological droughts (number of months in a 30-year period where the SPI accumulated over 6-month periods (the SPI-6) is below – 2) between the baseline period 1971-2000 and future periods 2041-2070 (left) and 2071-2100 (right) for the RCP4.5 (top row) and RCP8.5 (bottom row) scenarios.

Source: Adapted from Stagge et al., 2015.

the end of the 21st century based on RCP8.5 using the SPI, whereas an increase of 60 % was projected using the SPEI (Touma et al., 2015).

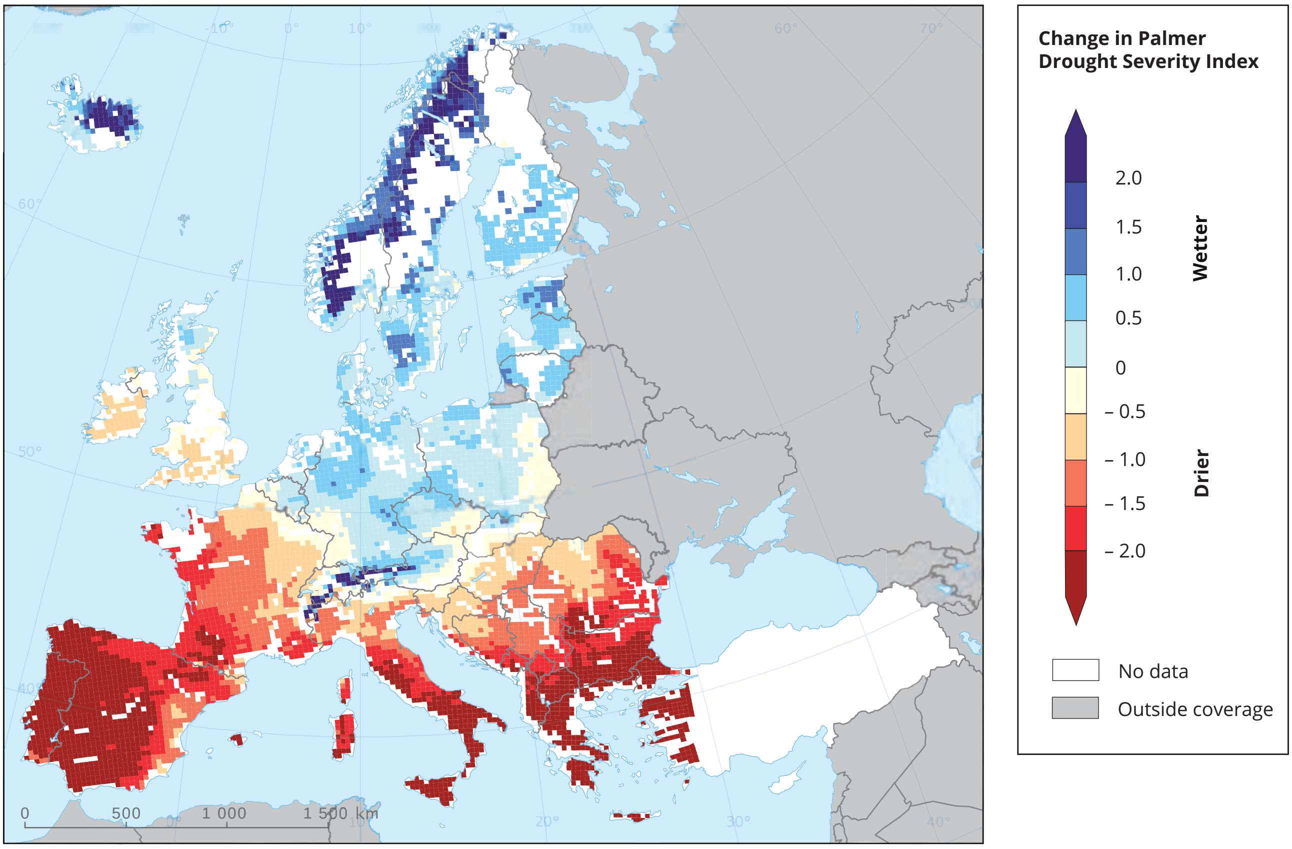
Soil moisture droughts

Based on the results of 12 RCMs, projected changes in soil moisture anomaly (Palmer drought severity index) show a strong latitudinal gradient, from pronounced drier conditions in southern Europe to wetter conditions in northern European regions in all seasons (Map 3.20). The largest changes in the soil moisture index between 2021–2050 and the baseline period (1961–1990) are projected for the summer period in the Mediterranean, especially in north-eastern Spain, and in south-eastern Europe (Henrich and Gobiet, 2012).

Hydrological droughts

The top row of Map 3.21 depicts the projected impact of climate change on the 20-year return level minimum river flow (left) and deficit volumes (right). Increasing severity of river flow droughts is projected for most European regions, except for northern and north-eastern Europe. The strongest increase in drought risk is projected for southern Europe, but

Map 3.20 Projected changes in summer soil moisture

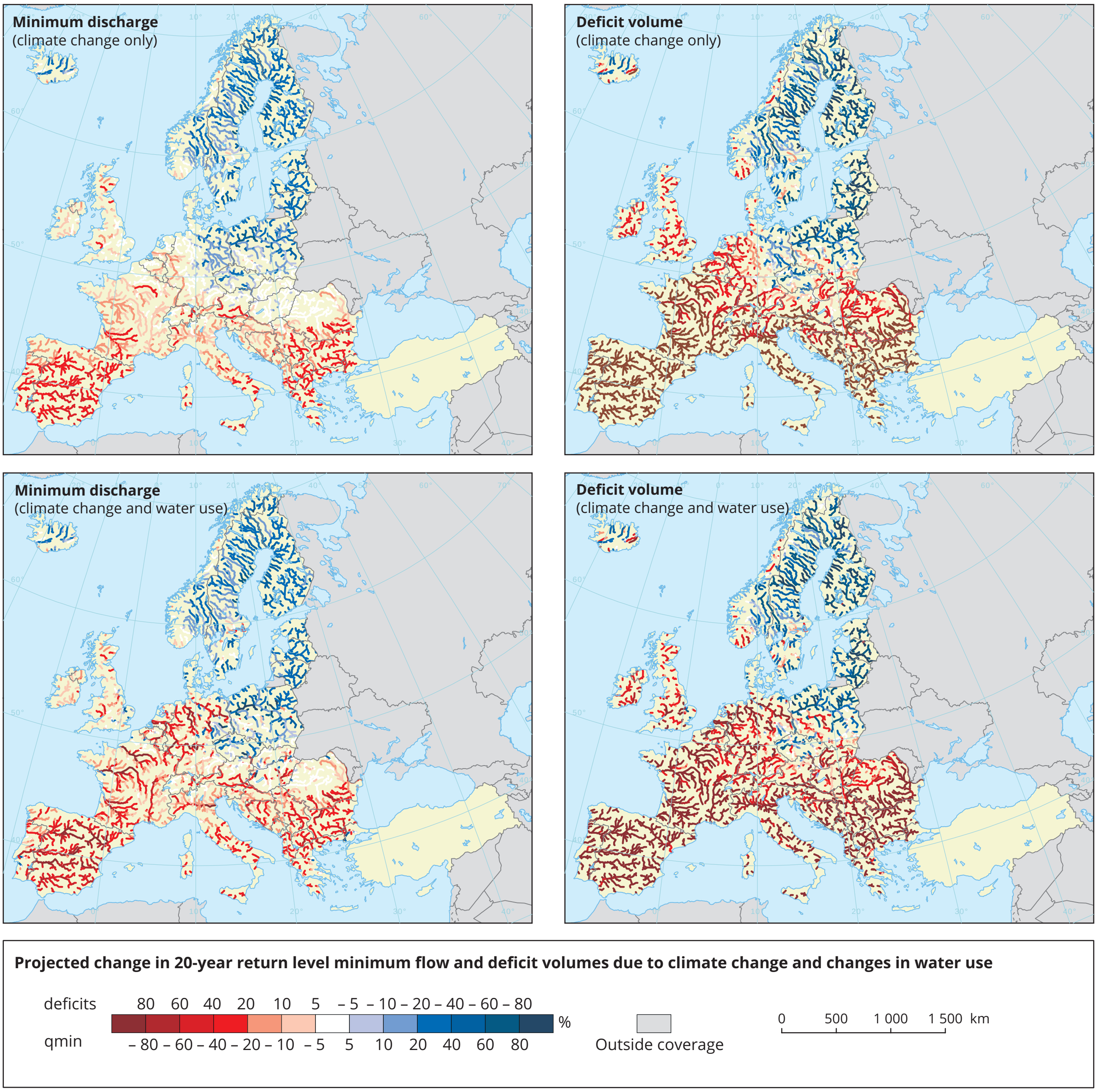


Note: Changes are based on the self-calibrated Palmer drought severity index and presented as mean multi-model change between 1961-1990 and 2021-2050, using the SRES A1B emissions scenario and 12 RCMs; red indicates drier and blue indicates wetter conditions.

Source: Adapted from Henrich and Gobiet, 2012.

mean increases are also projected for large parts of central and north-western Europe. However, these increases show large seasonal variations and also depend on how the models represent the evapotranspiration and soil moisture (Wong et al., 2011). The bottom row of Map 3.21 shows the combined impact of climate change and changes in water consumption (based on the 'Economy First' water use scenario) on the same drought indices. In most regions, projected increases in water consumption further aggravate river flow droughts (Forzieri et al., 2014, 2016). Water use and abstraction will exacerbate minimum low flows in many parts of the Mediterranean region, leading to increased probabilities of water deficits when maximum water demand overlaps with minimum or low availability (EEA, 2012).

Map 3.21 Projected change in 20-year return level minimum flow and deficit volumes due to climate change and changes in water use



Note: Differences between the end of the 21st century (SRES A1B scenario) and the control period (1961–1990) for minimum discharges (left) and change in deficit volume (right), for climate change only (top row) and a combination of climate change and water use (bottom row).

Source: Adapted from Forzieri et al., 2014.

3.7.4 Uncertainties, data gaps and information needs

Meteorological, hydrological and soil moisture droughts are subject to uncertainty related to the number, accuracy and spatial and temporal distribution of observations. Direct drought metrics such as soil moisture can be quantified by measurements taken in situ, and also by satellite remote sensing. In situ measurements represent mostly local conditions, while satellite measurements only assess top layers of the soil. Drought studies therefore rely on reanalysis of model data to establish trends, which introduces a level of uncertainty. Another source of uncertainty is the choice of drought index, although this is less significant than the choice of threshold for impact assessment (Parry et al., 2012).

Sources of uncertainty in modelled projections include the representation of interrelated physical processes, but the use of multi-models (both climate and hydrological) helps to reduce uncertainty and improve robustness of outputs (van Huijgevoort et al., 2014). However, some aspects of the climate/hydrological system such as streamflow trend analysis may not be representative over long timescales due to interdecadal variability (Hannaford et al., 2013). In the near future, internal climate variability is the dominant source of uncertainty in meteorological and soil moisture drought projections (Orlowsky and Seneviratne, 2011, 2013), and for the distant future (end of the 21st century) the difference between emissions scenarios becomes dominant. The move to probability-based ensemble modelling methods helps to better characterise uncertainty.

3.7.5 Selected event

The European drought of 2011 affected most of Europe. The Czech Republic, Germany, the Netherlands and Slovakia reported their lowest winter rainfall. River levels were below average in large parts of central and eastern Europe, affecting navigability on the Rivers Rhine and Danube. Low reservoir levels affected electricity production in Serbia, drinking water supply in Bosnia and winter crop production in Bulgaria, Hungary, Romania and Ukraine, where winter grain yields were estimated to be 30 % below average. Unusually dry conditions also gave rise to forest fires in several countries including Germany, Moldova, Slovakia and Ukraine (Map 3.22).

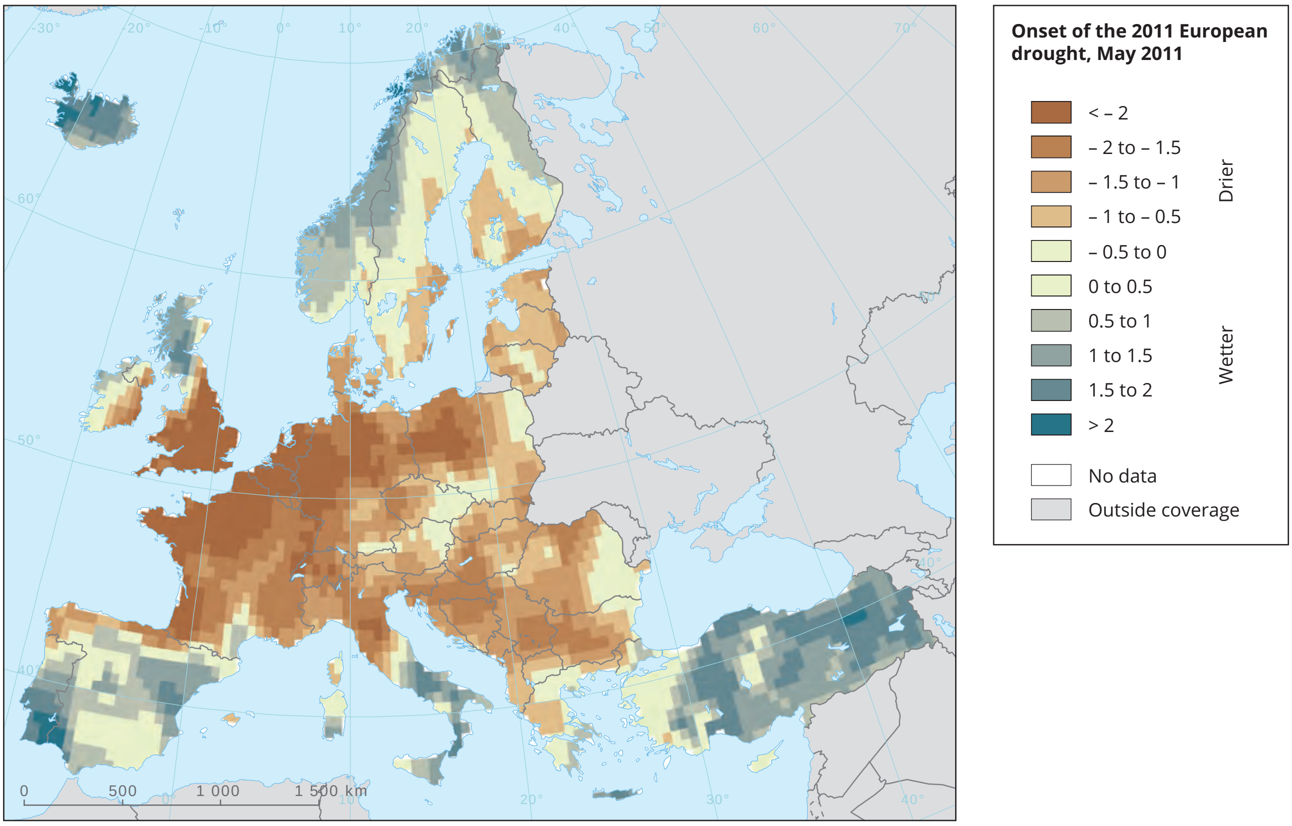
An analysis of European drought using ECA&D station data (van Engelen et al., 2008) showed that November 2011 was the driest November since 1920 (Spinoni et al., 2015). The year 2011 was the mid-point of a significant multi-year drought in regions of western Europe. The winter drought between 2010 and 2012 was one of the 10 most significant drought events of the past 100 years in the south-eastern United Kingdom (Kendon et al., 2013). During the drought, reduced spring rainfall severely affected water resources, stream flows and agriculture, before ending abruptly with a change in the jet stream in April 2012 (Marsh et al., 2013).

3.8 Forest Fires

3.8.1 Relevance

Forest fires are an integral part of forest dynamics in many ecosystems, where they are an essential element of forest renewal. They help control insect and disease damage, and eliminate litter accumulated on forest floors. At the same time, forest fires also disturb forest landscapes. Fire regime and risk are the result of complex interrelationships between several factors, including climate and weather conditions, vegetation (e.g. fuel load), topography, land, forest and fire management, and cultural and socio-economic context (Moreira et al., 2011; Moreno, 2014; Rego and Silva, 2014; Salis et al., 2014). Although over 95 % of fire ignitions are caused by humans (either accidently or intentionally), it is well documented that the major determinants of fire spread and intensity are weather and fuel accumulation (Pereira et al., 2005; Koutsias et al., 2012; Pausas and Fernández-Muñoz, 2012; Pausas and Paula, 2012). The risk posed by forest fires typically involves a combination of extreme weather conditions (e.g. prolonged drought, high temperatures, low relative humidity, strong winds), and fire suppression capabilities (Camia and Amatulli, 2009). Climate change is expected to influence forest fire regimes and risk in Europe, and elsewhere. Indeed, there is evidence that, in a warmer climate, more severe fire weather conditions, expansion of the fire-prone areas, and longer fire seasons are likely to occur in Europe, even if relevant spatial variations are projected. Moreover, the impacts of forest fires are expected to be more significant in southern European countries and fire-prone ecosystems (Kovats et al., 2014). However, forest fires may become problematic in other regions of Europe as well.

Map 3.22 Onset of the 2011 European drought: situation for May 2011



Note: The drought situation is described with Standardised Precipitation-Evapotranspiration Index accumulated over 3-months periods (SPEI-3). The baseline period is 1971-2000.

Source: EEA. Data from Vicente-Serrano et al., 2009.

3.8.2 Past trends

The past trends of fire frequencies and area burned are difficult to analyse because fire data are strongly affected by significant changes in past years in the statistical reporting systems of the EU Member States.

According to the JRC's European Forest Fire Information System (EFFIS) ([56]) fire data, the number and extent of forest fires vary considerably from one year to another depending on seasonal meteorological conditions. Some multiannual periodicity in the burned area trend can also be partially attributed to the dead biomass burning/accumulation cycle, typical of fire-prone regions. The average area burned per year between 1980 and 2014, in the five southern European countries, varied considerably both spatially and temporally (Figure 3.4).

Fire occurrence in Europe is commonly high in three periods (i.e. winter fires in mountainous areas, spring fires in northern and central Europe, and summer fires

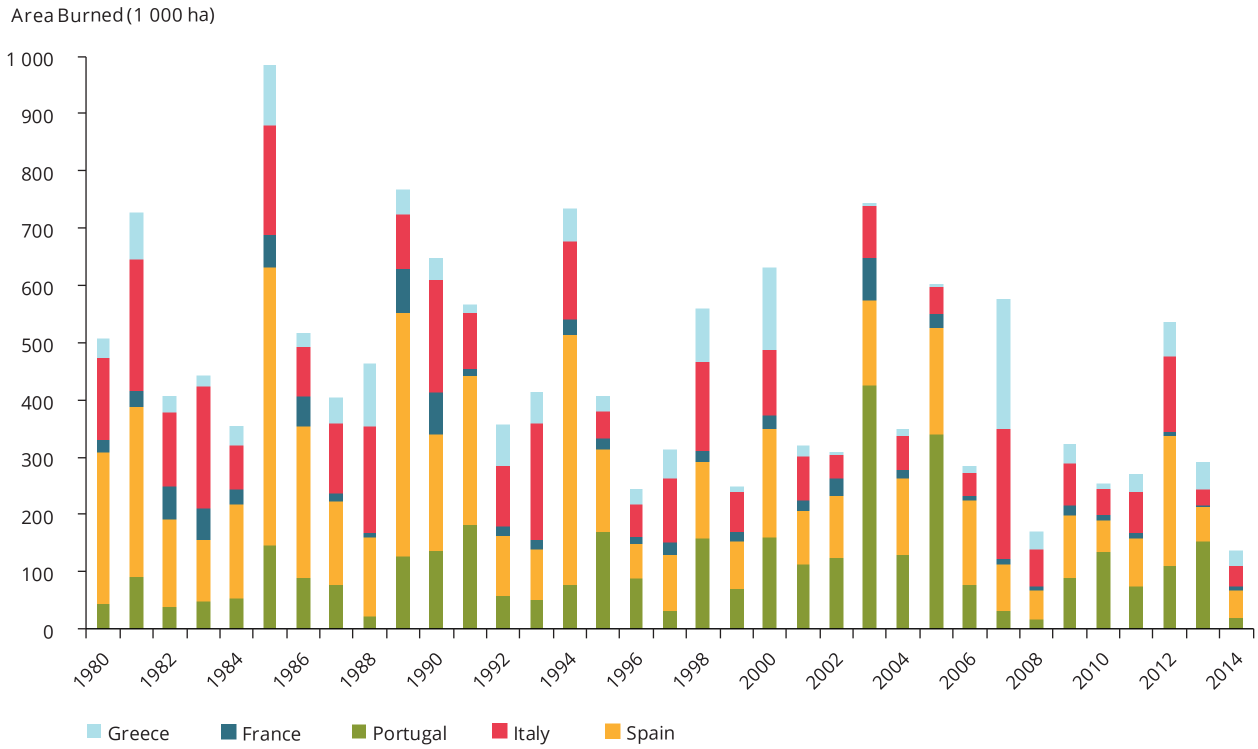
([56]) http://forest.jrc.ec.europa.eu/effis/

associated with summer droughts). The majority of forest fires occur in the summer, and the areas most affected are concentrated in Mediterranean Europe (San-Miguel-Ayanz et al., 2013; Schmuck et al., 2015)

Past trends of fire danger have also been analysed by processing time series of meteorological fire danger indices, which are routinely used to rate the fire potential due to weather conditions. The Canadian fire weather index (FWI) is used in EFFIS to rate daily fire danger conditions in Europe (Van Wagner, 1987). Daily severity values can be averaged over the fire season to obtain a seasonal severity rating (SSR) index. The index is dimensionless and allows objective comparison of fire danger across regions and years; SSR values above 6 are considered in the extreme range.

Map 3.23, left shows annual SSR values averaged over the fire season in the period 1981–2010. SSR was computed based on daily weather data including air temperature, relative humidity, wind and precipitation from ECMWF. Other factors driving the fire regime, such as land use changes or fuel dynamics, are not taken into account by the SSR. The SSR trends from 1981 to 2010 indicate significant increase in forest fire danger in several regions in Europe (Map 3.23, right).

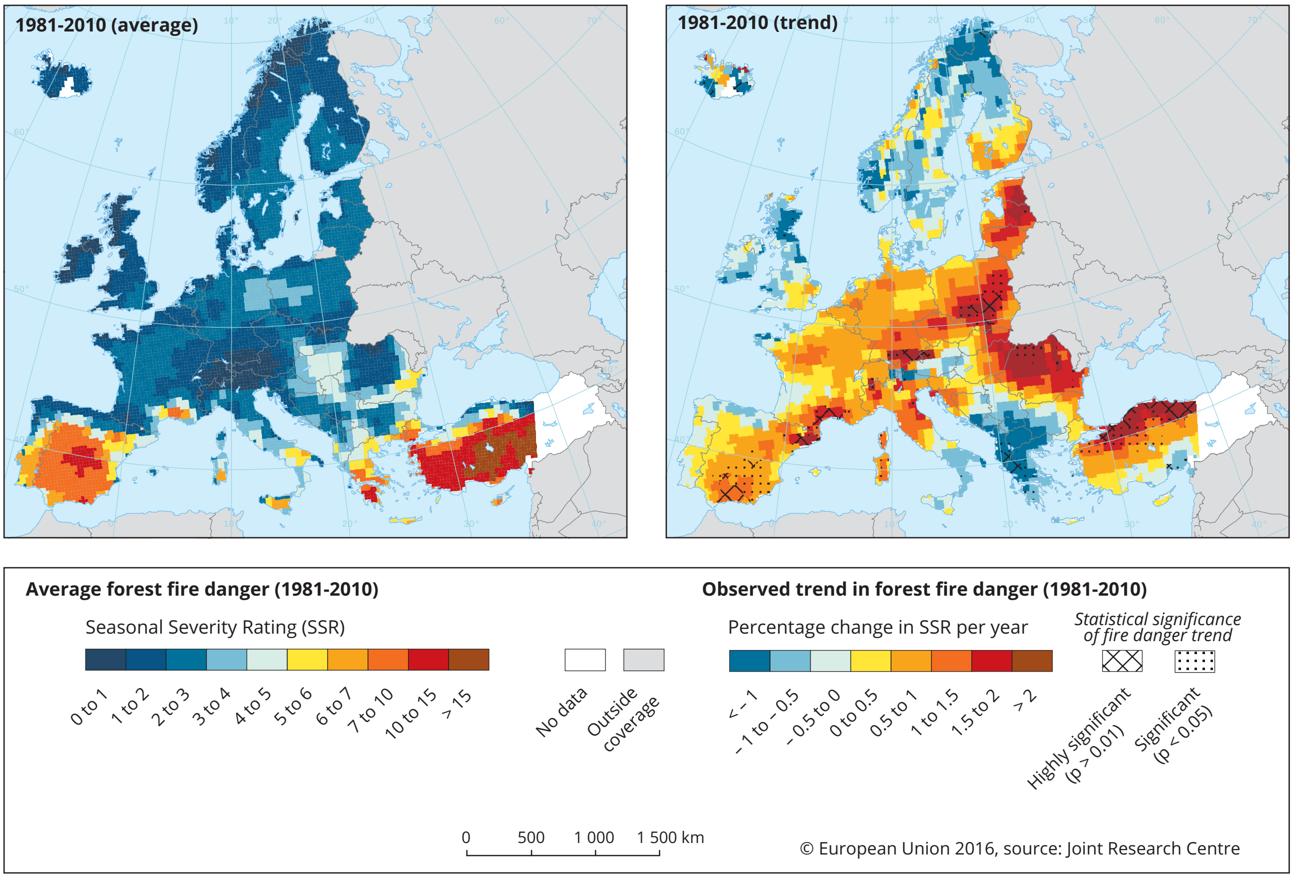
Figure 3.4 Area burned (thousand hectares) in the five southern European countries



Note: Total burned area per year based on recorded events.

Sources: Adapted from San-Miguel-Ayanz et al., 2013 and Schmuck et al., 2015.

Map 3.23 State and trend of fire danger for the period 1981-2010



Note: Fire danger is expressed by the seasonal severity rating (SSR). Daily severity values can be averaged over the fire season using the SSR index, which allows objective comparison of fire danger across time and space. The coarse scale of the map does not allow accounting for specific conditions of given sites, as for example in the Alpine region, where the complex topography may strongly affect local fire danger. The left panel shows the average SSR values during the period 1981 to 2010, whereas the right panel shows the linear trend in the same period.

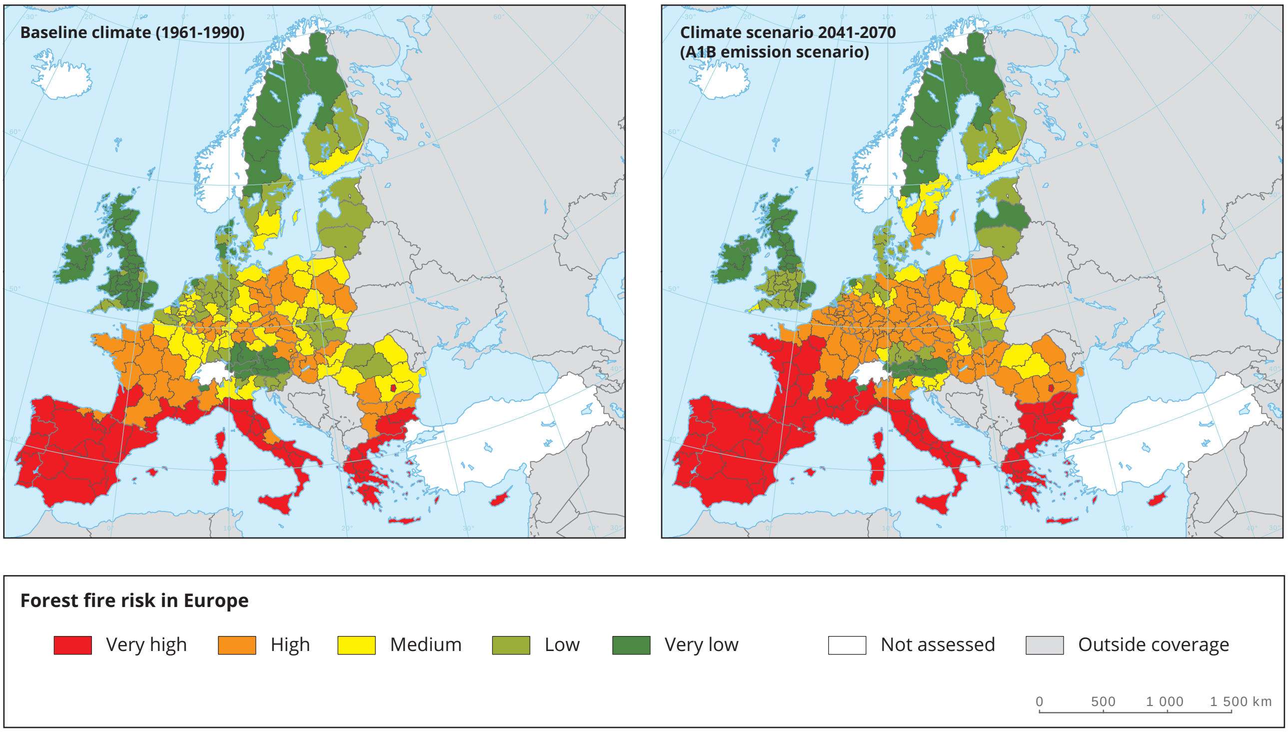
Source: Camia, 2012 (personal communication, based on Camia et al., 2008).

3.8.3 Projections

Climate change projections suggest substantial warming and increases in the number of droughts, heat waves and dry spells across most of the Mediterranean area and more generally in southern Europe (Kovats et al., 2014). These projected changes would increase the length and severity of the fire season, the area at risk and the probability of large fires, possibly enhancing desertification, particularly in southern Europe (Lindner et al., 2010; Carvalho et al., 2011; Dury et al., 2011; Vilén and Fernandes, 2011; Arca et al., 2012; Moreno, 2014). As a result, the annual area burned, the probability of large fire events and the greenhouse gas emissions from forest fires are projected to grow with respect to the actual conditions. In central and northern latitudes, the increase in temperatures and fire danger conditions could favour fire occurrence and spread, thus expanding northward the areas prone to forest fires.

Based on a set of regional climate models driven by the A1B scenario (Nakicenovic and Swart, 2000) the potential forest fire risk will increase in several European areas, notably in Mediterranean and central Europe, in the period 2041–2070 compared with the baseline period (Lung et al., 2013; Bedia et al., 2014) (Map 3.24).

Map 3.24 Forest fire risk in Europe



Note: Forest fire risk calculated for baseline period (1961–1990) and 2041–2070 (A1B emission scenario).

Source: Lung et al., 2013.

The PESETA II study ([57]) has estimated that the burnt area in southern Europe would more than double during the 21st century for a reference climate scenario and increase by nearly 50 % for a 2 °C rise scenario (Ciscar et al., 2014). Another study has estimated a potential increase in burnt areas in Europe of about 200 % during the 21st century under a high emissions scenario (A2) (Nakicenovic and Swart, 2000), assuming no adaptation. The forest fire risk could be substantially reduced by additional adaptation measures, such as prescribed burning, fire breaks and behavioural changes (Khabarov et al., 2016). The forest fire projection based on the Earth system models (ESMs) and radiative concentration pathways (RCP8.5 and RCP2.6 (van Vuuren et al., 2011)) show that eastern Europe is projected to become a new fire-prone area in future years. However, changes in future burned area for Mediterranean and northern Europe are less robust due to the uncertainty in fire–vegetation interaction (Wu et al., 2015).

3.8.4 Uncertainties, data gaps and information needs

The JRC's EFFIS collects fire data for the European region based on reports from EU Member States. Data availability differs across countries, and time series longer than 25 years are available for only a few countries. Other data sources, such as the Database on Forest Disturbances in Europe (DFDE) ([58]), are less harmonised and standardised, and suffer from inconsistencies among data sources. The availability of accurate data on fire ignition locations, size and causes represents a key point for fire monitoring and management, and is crucial to design prevention and adaptation strategies and post-fire and restoration interventions.

A better understanding of forest fire drivers would be also supported by an enhancement of current spatial and temporal details of data. Additional information needs relate to the socio-economic impact of forest fires and the improvement of fire emissions estimates,

([57]) Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis, see https://ec.europa.eu/jrc/
([58]) http://www.efi.int/portal/virtual_library/databases/en/peseta