GIS-Based Infrastructure Management System for Optimized Response to Extreme Events of Terrestrial Transport Networks

European critical hazards (natural)

Interim Deliverable InD2.1

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SAFEWAY

GIS-BASED INFRASTRUCTURE MANAGEMENT SYSTEM FOR OPTIMIZED RESPONSE TO EXTREME EVENTS OF TERRESTRIAL TRANSPORT NETWORKS

Grant Agreement No. 769255

European Critical Hazards (natural) Interim Deliverable InD2.1

WP 2 Risk Factors and Risks Analysis

Deliverable ID	**D 2.1**
Deliverable name	**GIS Map and identification of hot spots of sudden extreme natural hazard events, including database with impact and return periods**
Interim Del. ID	**InD 2.1**
Interim Del. name	**European critical hazards (natural)**
Lead partner	**NGI**
Contributors	UMINHO, Ferrovial, TØI, IMC, IP, NR

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SAFEWAY Project Synopsis

According to European TEN-T guidelines, due consideration must be given to the risk assessments and adaptation measures during infrastructure planning, in order to improve resilience to disasters. SAFEWAY's aim is to design, validate and implement holistic methods, strategies, tools and technical interventions to significantly increase the resilience of inland transport infrastructure. SAFEWAY leads to significantly improved resilience of transport infrastructures, developing a holistic toolset with transversal application to anticipate and mitigate the effects extreme events at all modes of disaster cycle:

1. **"Preparation":** substantial improvement of risk prediction, monitoring and decision tools contributing to anticipate, prevent and prepare critical assets for the damage impacts;
2. **"Response and Recovery":** the incorporation of SAFEWAY IT solutions into emergency plans, and real-time optimal communication with operators and end users (via crowdsourcing and social media);
3. **"Mitigation":** improving precision in the adoption of mitigation actions (by impact analysis of different scenarios) together with new construction systems and materials, contributing to the resistance & absorption of the damage impact.

SAFEWAY consortium has 15 partners that cover multidisciplinary and multi-sectorial business fields associated with resilience of transport infrastructure in Europe: national transport infrastructure managers & operators, a main global infrastructure operator, partners able to provide various data sources with large coverage in real time, comprehensive ITC solutions, and leading experts in resilience, risk databases, remote sensing-based inspection, and decision systems based on predictive modelling.

SAFEWAY will carry-out 4 real case studies distributed through 4 countries, linked to 5 corridors of the TEN-T Core Network. SAFEWAY has as main expected impacts:

1. at least 20% improvement in mobility; and
2. at least 20% lower cost of infrastructure maintenance.

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Executive Summary

The main Objective of this deliverable is to identify risk factors, mainly with regard to natural hazards. The identification encompasses identification of critical natural hazard (Section 2), review of natural hazard maps at European level (Section 3) and review of natural hazard maps at National or regional level for the Pilot areas (Section 4).

The first step was to identify the critical natural hazards, i.e. sudden natural extreme events leading to malfunctioning of terrestrial transport networks in Europe. Further, modes of malfunctioning of the infrastructure caused by each one of these events were described. The identification of critical hazards and failure modes was performed from a generic point of view, as well as specific for the Pilot areas. The generic approach considered all plausible failure modes with a natural extreme event trigger for roads and railways, and is based on a literature review and a review of results from previous EU projects, and considers the vulnerability and resilience of terrestrial transport systems. The specific approach for Pilot areas has considered the most important triggers and failure modes for Pilot areas. This assessment was performed by the infrastructure owners (Ferrovial, Infrastructure Portugal and Network Rail):

- **Portugal:** Natural weather related events with the greatest impact on road and rail transportation in the case study area of Portugal are forest fires and floods.
- **Spain:** Natural hazards that have had the greatest impacts in the Spanish case studies of the Mediterranean corridor (case study 2a in Murcia Region and case study 2b in Malaga region) are flooding, landslides, earthquakes, heavy rain and hot/cold waves.
- **UK:** Compensation payments for the London North-West (LNW) Route clearly shows that wind, flooding and snow-related events have had the most significant impact.

The next step was to assess the likelihood of natural events. This is done by providing an overview of available inventories, databases and GIS maps of natural hazards at European level and at National level for the Pilot areas. Downloadable data at European level includes:

- Flood hazard maps and catalogues
- Wild fire catalogues
- Hazard maps related to wind and temperature (heat)
- Landslide hazard maps
- Earthquake hazard maps and catalogues

In addition, other available information on European maps of weather related hazards for current and future climate has been reviewed and summarised. Further, a brief overview of European dynamic hazard maps used for monitoring and forecasting has been provided.

For countries with Pilot areas, information about the following hazard types has been reviewed and described:

- **Portugal:** Wild fires and flood
- **Spain:** Flood, heatwaves (and wild fires)
- **UK:** Flood and wind

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1. Introduction

Transportation is an important component of a society to maintain its functions and its economic and social development. Many different types of adverse weather conditions challenge transportation networks, such as

e.g. storms, intense precipitation, extreme temperatures, as well as weather related hazards like floods, erosion, landslides, and forest fires. Negative impacts include accidents, damage to infrastructure or to components of

the infrastructure, delays and malfunctioning of the transportation network, resulting in economic consequences. Climate change is anticipated to lead to an escalation of such negative impacts if no counter-measures are taken.

1.1 Framework for risk assessment

The IS0 31000:2009 represent a globally accepted standard for risk management. The principles of effective risk management in ISO 31000 are that it should (Purdy; 2010):

1. Create and protect value;
2. Be an integral part of all organizational processes;
3. Be part of decision making;
4. Explicitly address uncertainty;
5. Be systematic, structured, and timely;
6. Be based on the best available information;
7. Be tailored;
8. Take into account human and cultural factors;
9. Be transparent and inclusive;
10. Be dynamic, iterative, and responsive to change;
11. Facilitate continual improvement of the organization.

In the risk management framework established by ISO 31000, risk assessment includes risk identification, risk analysis and risk evaluation, and is followed by risk treatment (decision making and execution of regarding risk reduction). In the following, each element in the risk management process is presented in more detail.

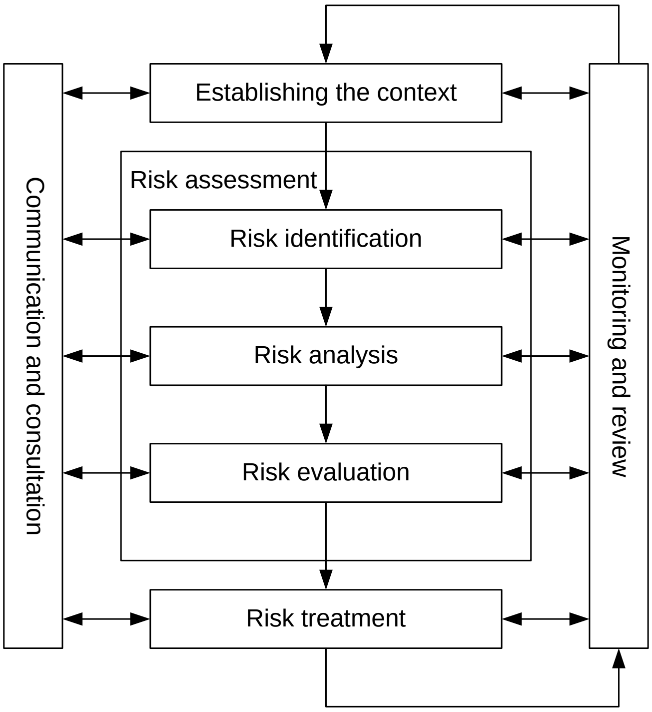

Figure 1: Risk management process. Source: ISO-31000: 2009

1.1.1 Establishing the context

According to ISO 31010, establishing the context defines the basic parameters for managing risk and sets the scope and criteria for the rest of the process. It considers background studies to the particular risks being assessed. In this phase, the risk assessment objectives, risk criteria, and risk assessment programme should be determined and agreed. For a specific risk assessment, establishing the context should include:

a) Establishing the external context (e.g. cultural, political or financial factors, perceptions and values of external stakeholders).
b) Establishing the internal context (e.g. internal information flow, decision process, internal stakeholders, standards and internal processes).
c) Establishing the context of the risk management process (e.g. responsibilities, extent of project, defining risk assessment methodologies, risk criteria, identification of decision and action processes, identifying required resources, evaluation of risk assessment and management process).
d) Defining risk criteria (e.g. use and character of probabilities, type of consequences, risk treatment decision process)

1.1.2 Risk assessment

Risk assessment includes risk identification, risk analysis and risk evaluation. Risk assessment provides an understanding of risks, their causes, consequences and their probabilities, which provides an input to decisions about:

- whether an activity should be undertaken;
- how to maximize opportunities;
- whether risks need to be treated;
- choosing between options with different risks;
- prioritizing risk treatment options;
- the most appropriate selection of risk treatment strategies that will bring adverse risks to a tolerable level.

1.1.3 Risk treatment

Risk treatment is a part of risk management performed in parallel with or after the risk assessment study. It involves the decision making process of how to mitigate the risk (if needed) and the actual execution of mitigation work, which can be physical means and/or non-physical means for example of an organisational character. It involves selecting and agreeing on one or more relevant options for either (a) reduce the probability of occurrence of the hazard phenomena or (b) reduce the consequence once the hazard phenomena occurs, or both. Once the mitigation program is decided, it should be implemented. This is part of a cyclical process of assessing and reassessing the level of risk, with a view to determining its tolerability against the criteria previously set, in order to decide whether further treatment is required.

1.1.4 Risk communication and perception

Risk communication is an essential part of risk management, both internally in the risk management project group itself, and with various types of external stakeholders. Establishing a communication plan, and involving external stakeholders early in the project phase is a key success factor for the project, and can contribute to:

- defining the context appropriately;
- ensuring that the interests of stakeholders are understood and considered;
- bringing together different areas of expertise for identifying and analysing risk;
- ensuring that different views are appropriately considered in evaluating risks;
- ensuring that risks are adequately identified;
- securing endorsement and support for a treatment plan.

1.1.5 Monitoring and review

Risk management is a continuous process. All risk projects at some point needs verification of the correctness of the premises for, and findings from, the project. It is therefore recommended to carry out monitoring and review actions on a regular basis in order to verify that:

- assumptions about risks remain valid;
- assumptions on which the risk assessment is based, including the external and internal context, remain valid;
- expected results are being achieved;
- results of risk assessment are in line with actual experience;
- risk assessment techniques are being properly applied;
- risk treatments are effective.

1.2 Scope of report

Following steps to be accomplished in WP 2:

- Establishing context: Which type of impact? (To be defined in accordance with WP 5). Suggestion: Reduction of mobility (reduction of capacity/loss of service for the transportation line or speed reductions due to difficult driving conditions) and deterioration of infrastructure components caused by natural events.
- Risk identification: Identify failure modes, including identification of trigger, Section 2
- Risk assessment: Hazard maps for the most critical triggers: review and collection of European hazard maps both static, considering long term and short-term changes (long-term: climate change; short term: dependent on current weather conditions and meteorological parameters) (Input to WP 7)
- Purpose of the work, connection with other Tasks and deliverables.
- Impact assessment: direct material impact. Direct impacts on mobility (D2.3)
- Input to models for optimisation of maintenance and resilience. Input to decision support systems. Help decisions regarding maintenance and operation (Input to WP 5 and further to WP 6)

2. Risk identification

2.1 Identification of plausible weather-triggered failure modes for terrestrial transportation lines

The risk identification comprise a review of all plausible failure modes with natural extreme event trigger for road and rail. The review has considered papers and projects considering vulnerability and resilience of terrestrial transport systems towards natural events. The failure modes are summarised in Table 1. The table is based on summaries from EEA(2017), VTT(2011) and Snelder and Calvert(2016).

Table 1: Description of failure modes for transportation lines triggered by extreme weather events or related hazards

Extreme weather event or related hazard	**Impacts on transport with classification:** **S:Relevance for service, i.e. affecting mobility M:Material degradation, affecting for maintenance need**			
	Road		**Rail**	
Heat waves	Damage to pavements	M,S	Rail buckling	M,S
	Vehicle failure (tyres)	S	Material fatigue	M,S
	Fatigue of drivers	S	Increased instability of embankments	M
			Overheating of equipment	M
			Thermal expansion on bridge expansion joints and paved surfaces	M
Forest fires	Reduced visibility Dangerous driving conditions	S	Dangerous conditions and damage to infrastructure assets	M,S
Heavy precipitation	Reduced visibility and surface friction	S		
	Mass transport by surface water in or along the embankment	M	Mass transport by surface water in or along the embankment	M

Extreme weather event or related hazard	**Impacts on transport with classification:** **S:Relevance for service, i.e. affecting mobility M:Material degradation, affecting for maintenance need**			
	Road		**Rail**	
Flooding (urban, river, flash floods, storm surge)	Water on road and in underground transport system	S	Water on line and in underground transport system	S
	Erosion and destruction of embankment	S,M	Erosion and destruction of embankment	S,M
	Erosion (scouring) and damage to bridge supports	S,M	Erosion (scouring) and damage to bridge supports	S,M
Landslides	Blocking of transportation line	S	Blocking of transportation line	S
	Destruction of transportation line	S,M	Destruction of transportation line	S,M
Wind	Difficult driving conditions; exposed parts of roads (e.g. bridges) closed due to strong wind gusts	S	Exposed parts of line (e.g. bridges) closed due to strong wind gusts	S
	Obstacles on the road owing to fallen trees and other objects	S	Obstacles on the road owing to fallen trees and other objects	S
			Damage to infrastructure such as signals, catenary, etc. (e.g. owing to falling trees)	S,M
Fog	Reduced visibility	S	Reduced visibility	S
Storms (thunderstorms, hail, blizzards, i.e. strong wind gusts, intense snowfall)	Reduced visibility and surface friction	S	Reduced visibility and surface friction	S
	Obstacles on road	S	Obstacles on rail line	S
	Failures in transport control system	S,M	Failures in transport control system	S,M
Cold spells	Reduced surface friction	S		S

Extreme weather event or related hazard	**Impacts on transport with classification:** **S:Relevance for service, i.e. affecting mobility M:Material degradation, affecting for maintenance need**			
	Road		**Rail**	
	Technical failure of vehicles	S	Deterioration of infrastructure	
	Deterioration of infrastructure	M		
Snowfall	Reduced visibility and surface friction	S	Obstacles on rail line owing to snowdrift, broken branches etc.	
	Obstacles on roads owing to snowdrift and broken branches	S,M		

2.2 Risk identification for case study areas

The pilot and demonstration activities are small-scale, short-term projects that test and validate the innovative methodologies and technologies which were being developed in WPs 2-4 for future replication or scaling up.

For the weather-related events, the focus is on:

- Case 1: Portugal, region of Santarem/Leiria.
- Case 2a and 2b: Spain, Murcia and Malaga regions.
- Case 3: United Kingdom, rail infrastructure between Manchester and London

Case 1 corresponding to the Atlantic corridor, particularly in the hot spot surrounding Leiría including 73.37 railway km, and 5 European roads with 22,822 daily users.

Case Study 2 in Spain: The Cases 2a (Murcia region) and 2b (Malaga region) both correspond to the Mediterranean corridor. They include High-Speed railway network (154 km and 4 stations), conventional network (1,600 km and 97 stations), 11 tunnels and 32 bridges. Only the high-speed section has around 10 million passengers a year.

Case Study 3 in the UK, the North Sea - Mediterranean corridor, will be carried-out in the London-Manchester rail network including 337.3 railway km, 1,235 bridges, 13 tunnels, 846 retaining walls and 28 stations.

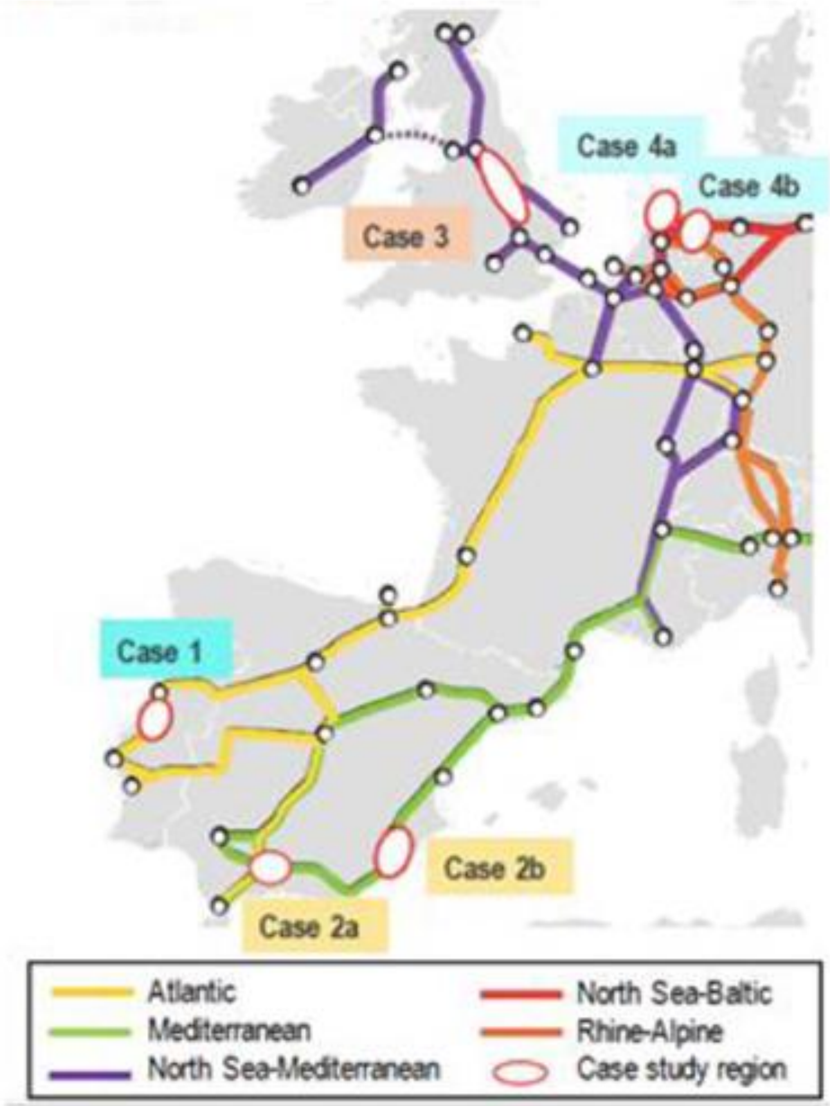

Figure 2: Map of case study areas

2.2.1 Risk identification/failure modes Portugal, natural events

The natural weather related events with greatest impact on road and rail transportation in the case study area in Portugal are forestfires and floods.

The severity of forestfires may, in addition to the climatic conditions, be explained that the adjacent areas of the transportation infrastructures are occupied with forest species that burn really fast.

Portugal has various floodplain areas, near the main rivers, namely Tejo and Mondego River, with high population and several important infrastructures, that during the rainy season suffer floods.

2.2.2 Risk identification/failure modes Spain, natural events

The natural hazards that have had the greatest impacts in the Spanish case studies in the Mediterranean corridor (case study 2a in Murcia Region and case study 2b in Malaga region) are flooding, landslides, earthquakes, heavy rain and hot/cold waves (Ferrovial; 2018). Overall failure modes situations in which the whole transportation system is placed in danger include:

- **Heavy rain** can cause rivers to **flood**. When such situation happens close to a railway line, the flow might drag every possible material and the infrastructure might end up working as a dam.
- **Sudden increase of lateral wind** might also be the reason of derailment of a train**.**

Further failure modes were identified at asset level. Ferrovial (2018) link each critical asset belonging to the case studies in the Mediterranean corridor with the possible events, natural or man-made, that lead the asset to malfunctioning. Table 2 summarise the failure modes triggered by natural, weather-related events in the Spanish case study.

Table 2: Failure modes at component level; weather related natural hazards, in the Spanish case study.

Meteorological trigger or related hazard	**Components**	**Failure mode description** **Relevance for loss of service (S), affecting transportation line health and need for long-term maintenance (M).**	
Flood	Viaduct	The terrain under the footing of the viaducts washed away	S,M
Flood	Cut slope and embankment	Increased slope erosion affecting service life and potentially causing landslides or embankment failure	S, M
Flood	Drains, culverts	Blocking of culverts by debris (branches, leaves etc.), preventing drainage. Water accumulate in the upslope ditch, potentially causing landslide or embankment failure.	S, M
Flood	Fencing and protection elements	Damage, movement or removal of protection elements by flood	M
Flood	Vegetation	Damage, movement or removal of vegetation, worsening slope stability	M

Meteorological trigger or related hazard	**Components**	**Failure mode description** **Relevance for loss of service (S), affecting transportation line health and need for long-term maintenance (M).**	
Flood	Rail track	Mechanical failure of tracks, ultimately leading to derailment	M
Flood	Ballast	Destabilization of the ballast bed, modifying track stability	M
Heavy rain	Ballast	Saturation of surrounding areas of the track to full capacity Water reaching the ballast level, leading to materials drag, modifying the safety of the track.	M
Heavy rain leading to flood	Same as for floods.		
Landslide	Overpass and underpass	Differential strains in underpasses and overpasses in the transition to the cut slope	M
Landslide	Viaduct	Differential strains in viaducts in the transition to the cut slope	S,M
Landslide	Fencing and protection elements	Damage, movement or removal of protection elements by landslide	M
Landslide	Vegetation	Damage, movement or removal of vegetation, worsening slope stability	M
Landslide	Rail track	Mechanical failure of tracks, ultimately leading to derailment	M
Landslide	Ballast	Destabilization of the ballast bed, modifying track stability	M
Hot/cold waves	Cut slope and embankment	Change of the terrain properties, potentially causing **landslides**	M
Hot/cold waves	Drains, culverts	Pipe outlet blocked with ice, preventing drainage. Water accumulate in the upslope ditch, potentially causing landslide or embankment failure.	M,S

Meteorological trigger or related hazard	Components	Failure mode description **Relevance for loss of service (S), affecting transportation line health and need for long-term maintenance (M).**	
Hot/cold waves	Vegetation	Vegetation surrounding the track killed during heatwave, worsening slope stability.	M
Hot/cold waves	Rail track	Ambient **temperature gradient** increase might cause unexpected rail fatigue. Railway steel contracts at low temperatures and expands at high temperatures. An increase of the temperature gradient might cause a premature rail wear. No information available yet about how the temperature gradient might reduce the rail life cycle.	M
Hot/cold waves	Fish plate joint	Hot/cold waves might lead to mechanical failure of fish plate joints. If several contiguous fish plate joints are for example fractured, the rail could overlap and consequently provoking derailment of trains	M,S
Hot/cold waves	Expansion joint	If the expansion joint expands too much because of the temperature, the tracks might overlap, potentially derailing trains.	M,S

2.2.3 Risk identification/failure modes UK, natural events

Two approaches for identification of most critical weather-related impact:

- Based om costs for disruption.
- Based on failure modes at asset level

NetworkRail (2014) present analysis of the compensation payments to train and freight operators for network disruption (Schedule 8 performance costs) during the period 2006/07 to 2013/14. The analysis clearly shows that wind, flooding and snow-related events have had the most significant impact on the Route. Vegetation incursion on the overhead line equipment and track as a result of high wind speeds has been the most significant factor on the London North West (LNW) Route.

Table 3: Most severe weather-related impact based on compensation payment for network disruption (Schedule 8 costs) (NetworkRail; 2014)

Weather-related impact	Schedule 8 costs[1]	Projected future impacts	Prioritisation
Wind	£2.2m	Wind changes difficult to project, however, generally projected to increase	High
Flooding	£1.2m	Up to17% increase in February mean daily precipitation[2]	High
Snow	£1.75m	Up to 2.6°C increase in January mean daily minimum temperature[2]	Medium
Adhesion	£0.8m	Complex relationship between adhesion issues and future climate change.	Medium
Heat	£0.5m	Up to 3°C increase in July mean daily maximum temperature[2]	Medium
Earthslips	£0.4m	Up to17% increase in February mean daily precipitation[2]	Medium
Cold	£0.4m	Up to 2.6°C increase in January mean daily minimum temperature[2]	Low
Sea level rise	Not recorded	0.2m increase in sea level rise[3]	Low
Lightning	£0.3m	Storm changes difficult to project, however, generally projected to increase	Low
Fog	£3k	Complex relationship, however, research suggests fog events may decrease	Low

1 Annual average 2006/07 to 2013/14
2 UKCP09 projection, 2050s High emissions scenario, 50th percentile, against 1970s baseline
3 UKCP09 projection, 2050s High emissions scenario, 50th percentile, against 1990 baseline.

Table 4: Failure modes at component level for weather related natural hazards in the UK case study.

Meteorological trigger or related hazard	**Components**	**Failure mode description** **Relevance for loss of service (S), affecting transportation line health and need for long-term maintenance (M).**	
Floods	Under bridges	Scour of bridge foundations. Three assets are over canal	S, M
Flood	Culvert	Culvert capacity exceeded during flood or reduced after flood due to mass transport	S,M
Heavy rainfall	Retaining wall	Landslides/geotechnical movement	S,M

3. Hazard maps and data bases at European level

3.1 Overview

The continuous urbanization in areas often exposed to natural hazards have dramatically increased the number of natural disasters and the economic damage in the last two decades (figure 3 a,b; EMDAT, 2017).

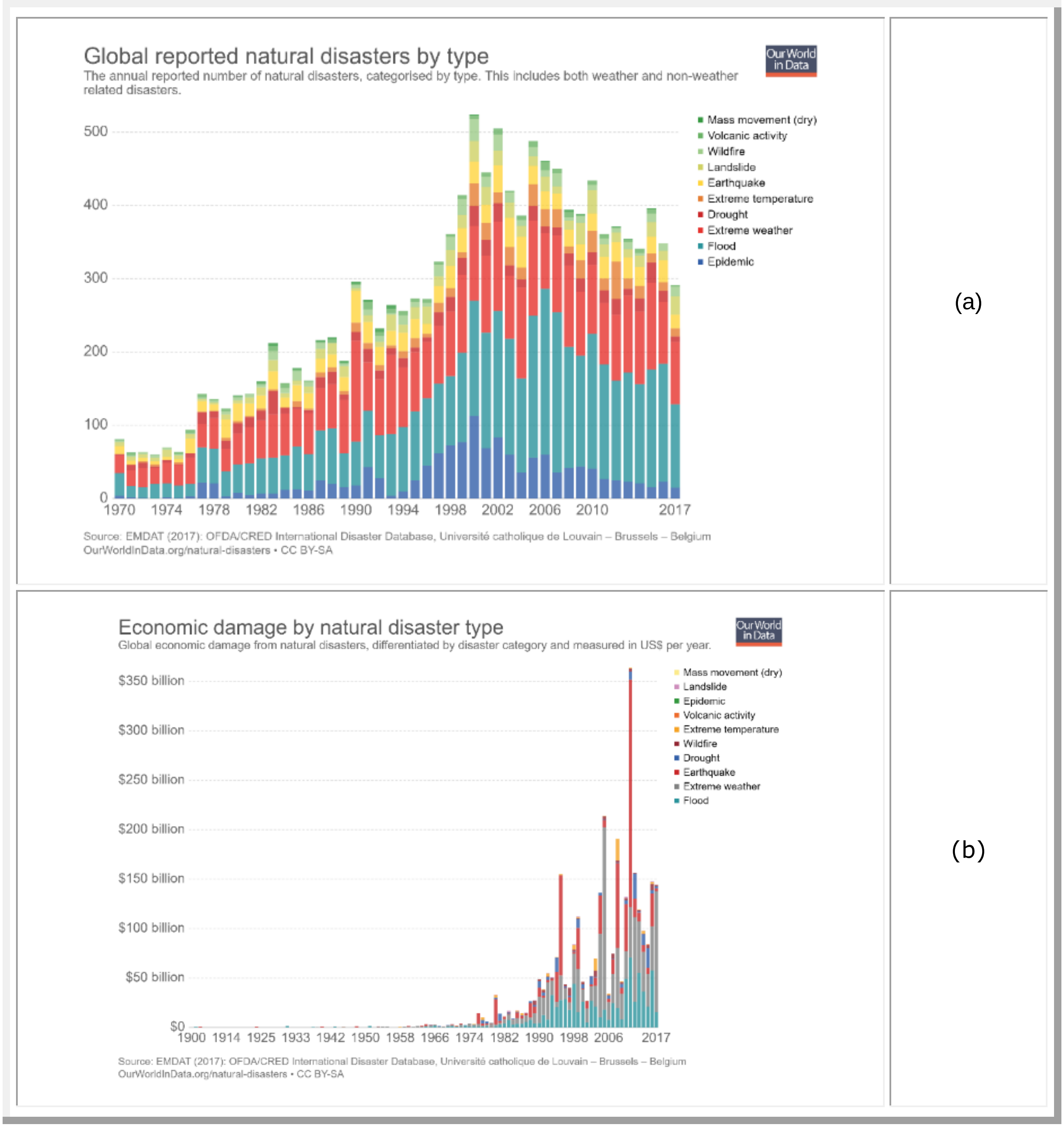

Figure 3: (a) global reported natural disasters by type for the period 1970-2017; (b) economic damage by natural disaster type for the period 1900-2017

An increased number of governmental and research institutions are involved, or have been involved in the last decade, with natural hazards analysis and mapping. The aim often focused on the definition of hazard maps and/or on the monitoring and forecasting of extreme natural events. Detailed hazard maps, as well as reliable forecasts of such events, can lead to the reduction of both fatalities and economic damages to buildings and infrastructures. The aim of this section is to provide maps that allows the visualization of extreme weather conditions and natural hazard risk 'hot spots'. The most relevant data will be integrated into the SAFEWAY IMS. The identification is conducted by review and evaluation of existing Global and European databases on weather and natural hazards. A list of databases produced for mapping natural hazards is reported in the tables Table 6-Table 11. The name of the database, the detail on the type of data available and the link for downloading the dataset are some of the information gathered. Furthermore, the tables are divided as a function of the natural hazards treated: flood, wildfire, wind, heat, landslide, earthquake. There are some databases gathering datasets for different natural hazards, such as the Global Risk Data Platform (GRDP), the Global Risk Data Platform and the Socioeconomic Data and Applications Centre (SEDAC). Overview of data sources are given in Table 5.

Table 5: List of available data sets from various EU projects and official data sources in Europe (to be completed)

Map theme	**Project**
Landslides	LAMPRE
Meteorology	ANYWHERE
Floods, flash floods, debris flow, landslides	ANYWHERE
Storm surges	ANYWHERE
Heatwaves	ANYWHERE
Forest fire	ANYWHERE
Drought	ANYWHERE
Storms, severe winds	ANYWHERE
Snowfall	ANYWHERE
EWE indicators	INTACT
Flooding, Ireland	INTACT
Flooding, Netherlands	INTACT
Landslides, Italy	INTACT

Map theme	Project
Droughts, Spain	INTACT
Extreme winter conditions, Finland	INTACT
Natural hazards: floods, earthquakes, landslides, forest fires, meteorological extreme events due to climate change	Improver
Landslides	Safeland
Extreme weather event	EWENT
EWE probability	RAIN
Landslides and more	Infrarisk
Natural hazards	Matrix
Climate changes	European Environment Agency
Flooding	Floodsite
Various data sets	EU Joint research centre
Databank of all occurred gravitational hazards in Switzerland	StorMe - databank
Canton Bern database of gravitational events (also available for all Swiss cantons)	Geoportal des Kantons Bern
Hazard Map for canton Bern (also available for all Swiss cantons)	Geoportal des Kantons Bern
Monitoring and forecasting floods	Copernicus EFAS
Flood early warning	I-REACT
Forest fire	EFFIS
Forest fire and flood projection (ArcGIS)	EEA

The main databases and their origins have been described in detail in the next section. The most relevant data will be integrated into SAFEWAY IMS (WP7).

Table 6: Flood

a) Hazard maps

Name	Description	Scale	Type of file	Variable	Descriptor	Database	Web-site
Joint Research Centre Data Catalogue (JRC)	flood hazard maps	Europe	Geotiff	water depth	(m)	10, 20, 50, 100, 200, 500 years	http://data.jrc.ec.europa.eu/collection/floods
Global Risk Data Platform	Physical exposure to floods	World	Geotiff	annual physical exposition	(people/ year)		https://preview.grid.unep.ch/index.php?preview=data&events=floods&evcat=3&lang=eng
Global Risk Data Platform	Economical exposition to flood	World	Geotiff	economical exposure	($/year)		https://preview.grid.unep.ch/index.php?preview=data&events=floods&evcat=4&lang=eng
Global Risk Data Platform	risk index for flood hazard	World	Geotiff	risk index	(from 1 to 5)		https://preview.grid.unep.ch/index.php?preview=data&events=floods&evcat=5&lang=eng
Global Assessment Report on Disaster Risk Reduction 2017	flood hazard maps	World	Grid file	frequency	5 classes	25, 50, 100, 200, 500, 1000 years	https://risk.preventionweb.net/capraviewer/download.jsp?tab=9&mapcenter=0,1123252.6982849&mapzoom=2; http://unisdr.envcomp.eu/browse/Hazard/Earthquake_Hazard_maps
Socioeconomic Data and Applications Center (SEDAC)	Global Flood Hazard Frequency and Distribution	World	asc.grid	decile	decile		http://sedac.ciesin.columbia.edu/data/set/ndh-flood-hazard-frequency-distribution/data-download
Socioeconomic Data and Applications Center (SEDAC)	Global Flood Proportional Economic Loss Risk	World	asc.grid	decile	decile		http://sedac.ciesin.columbia.edu/data/set/ndh-flood-proportional-economic-loss-risk-deciles/data-download

a) Catalogues

Name	Description	Time interval data	Method	Scale	Type of file	Variable	Descriptor	Web-site
Global Risk Data Platform	flood events	1999-2007		World	shape	flood events		https://preview.grid.unep.ch/index.php?preview=data&events=floods&evcat=1&lang=eng, http://floodobservatory.colorado.edu/Archives/index.htm

Table 7: Wildfire Catalogues

Name	Description	Time interval data	Method	Scale	Type of file	Variable	Descriptor	Web-site
Global Risk Data Platform	Fires events	1995-2011	t is based on the modified algorithm 1 product of World Fire atlas (WFA, ESA-ESRIN) dataset	world	gif, ASCII	Fire events		*https://preview.grid.unep.ch/index.php?preview=data&events=fires&evcat=1&lang=eng*
Global Risk Data Platform	Fires density	1997-2010	t is based on the modified algorithm 1 product of World Fire atlas (WFA, ESA-ESRIN) dataset		Geotiff	Fire events	(event/pixel)	https://preview.grid.unep.ch/index.php?preview=data&events=fires&evcat=3&lang=eng
NASA earth observations	Fires density	2000-2018	Up to date information and satellite images on fires, storms, floods, volcanoes, earthquakes, and droughts	world	Geotiff, CSV	Fire pixels	(event/pixel)	https://neo.sci.gsfc.nasa.gov/view.php?datasetId=MOD14A1_M_FIRE
Socioeconomic Data and Applications Center (SEDAC)	Global Fire Emissions Indicators	1997-2015	Satellite-Derived Environmental Indicators.		CSV	Area burned	(sqkm)	http://sedac.ciesin.columbia.edu/data/set/sdei-global-fire-emissions-indicators-country-level-1997-2015/data-download#close

Table 8: Wind

Name	Description	Time interval data	Method	Scale	Type of file	Variable	Descriptor	Database	Web-site
INTACT project	wind prediction	short (2011-2040), medium (2040-2070), long (2070-2100)		World	ascii grid	http://scm.ulster.ac.uk/~scmresearch/intactnew/index.php/Extreme_weather#Extreme_indicators_based_on_wind	m/s	Absolute, trend or Delta	http://scm.ulster.ac.uk/~scmresearch/intactnew/index.php/Extreme_weather_maps
The Global Wind Atlas	wind speed		from mesoscale to microscale (250 m)	World	tiff	velocity	m/s		https://globalwindatlas.info/area/Norway/Hordaland
European Monthly wind speed (MAPPE model)	wind speed	2002-2006	aggregated station indices data for all stations within ECA&D.	Europe	adf	velocity	m/s		http://data.jrc.ec.europa.eu/dataset/jrc-mappe-europe-setup-d-11-wind-speed
European Climate Assessment (ECAD)	Maximum value of daily maximum wind gust (FXx)		aggregated station indices data for all stations within ECA&D.	aggregated station indices data for all stations within ECA&D.	txt			yearly/daily	https://eca.knmi.nl//download/millennium/millennium.php
European Climate Assessment (ECAD)	Days with FG <= 2 m/s (calm days) (FGcalm)		aggregated station indices data for all stations within ECA&D.	aggregated station indices data for all stations within ECA&D.	txt			yearly/daily	https://eca.knmi.nl//download/millennium/millennium.php

Name	Description	Time interval data	Method	Scale	Type of file	Variable	Descriptor	Database	Web-site
European Climate Assessment (ECAD)	Days with southerly winds (DDsouth)		aggregated station indices data for all stations within ECA&D.	World	txt			yearly/ daily	https://eca.knmi.nl//download/millennium/millennium.php
European Climate Assessment (ECAD)	Days with easterly winds (DDeast)		aggregated station indices data for all stations within ECA&D.	World	txt			yearly/ daily	https://eca.knmi.nl//download/millennium/millennium.php
European Climate Assessment (ECAD)	Days with FG >= 6 Bft (10.8 m/s) (FG6Bft)		aggregated station indices data for all stations within ECA&D.	World	txt			yearly/ daily	https://eca.knmi.nl//download/millennium/millennium.php
European Climate Assessment (ECAD)	Days with northerly winds (DDnorth)		aggregated station indices data for all stations within ECA&D.	World	txt			yearly/ daily	https://eca.knmi.nl//download/millennium/millennium.php
European Climate Assessment (ECAD)	Days with westerly winds (DDwest)		aggregated station indices data for all stations within ECA&D.	World	txt			yearly/ daily	https://eca.knmi.nl//download/millennium/millennium.php
European Climate Assessment (ECAD)	Mean of daily mean wind speed (FG)		aggregated station indices data for all stations within ECA&D.	World	txt			yearly/ daily	https://eca.knmi.nl//download/millennium/millennium.php

Table 9: Heat

Catalogues

Name	Description	Time interval data	Method	Scale	Type of file	Variable	Descriptor	Database	Web-site
INTACT project	temperature prediction	short (2011-2040), medium (2040-2070), long (2070-2100)		world	ascii grid	http://scm.ulster.ac.uk/~scmresearch/intactnew/index.php/Extreme_weather#Extreme_indicators_based_on_wind	°C, day	Absolute,Trend or Delta	http://scm.ulster.ac.uk/~scmresearch/intactnew/index.php/Extreme_weather_maps
NASA EARTH OBSERVATIONS	Temperature anomaly	2000-2018	Up to date information and satellite images on fires, storms, floods, volcanoes, earthquakes, and droughts	world	Geotiff, CSV	°C	°C/pixel	monthly	https://neo.sci.gsfc.nasa.gov/view.php?datasetId=MOD_LSTAD_M
NASA EARTH OBSERVATIONS	global temperature anomaly	1880-2018			Geotiff, CSV		°C/pixel	monthly, yaerly	https://neo.sci.gsfc.nasa.gov/view.php?datasetId=GISS_TA_Y&date=2018-02-01
NASA EARTH OBSERVATIONS	Land Surface Temperature	2000-2018	Up to date information and satellite images on fires, storms, floods, volcanoes, earthquakes, and droughts	world	Geotiff, CSV	°C	°C/pixel	monthly	https://neo.sci.gsfc.nasa.gov/view.php?datasetId=MOD_LSTD_M
European Climate Assessment (ECAD)	Heating degree days	1936-1990	aggregated station indices data for all stations within ECA&D.	world	txt	°C	°C/year	yearly/daily	https://eca.knmi.nl//download/millennium/millennium.php

Name	Description	Time interval data	Method	Scale	Type of file	Variable	Descriptor	Database	Web-site
European Climate Assessment (ECAD)	Minimum value of daily maximum temperature	1931-2004	aggregated station indices data for all stations within ECA&D.	world	txt	°C	°C/year	yearly/daily	https://eca.knmi.nl//download/millennium/millennium.php
European Climate Assessment (ECAD)	Summer days>25C		aggregated station indices data for all stations within ECA&D.	world	txt	days		yearly/daily	https://eca.knmi.nl//download/millennium/millennium.php
European Climate Assessment (ECAD)	No. of summer days (SU)*		aggregated station indices data for all stations within ECA&D.	world	txt	days		yearly/daily	https://eca.knmi.nl//download/millennium/millennium.php
European Climate Assessment (ECAD)	Warm spell duration index (WSDI)*		aggregated station indices data for all stations within ECA&D.	world	txt	WSDI		yearly/daily	https://eca.knmi.nl//download/millennium/millennium.php
European Climate Assessment (ECAD)	No. of warm nights (TN90p)*		aggregated station indices data for all stations within ECA&D.	world	txt	days		yearly/daily	https://eca.knmi.nl//download/millennium/millennium.php
European Climate Assessment (ECAD)	Maximum of daily maximum temperature (TXx)*		aggregated station indices data for all stations within ECA&D.	world	txt	°C		yearly/daily	https://eca.knmi.nl//download/millennium/millennium.php
European Climate Assessment (ECAD)	Consecutive summer days (CSU)		aggregated station indices data for all stations within ECA&D.	world	txt	days		yearly/daily	https://eca.knmi.nl//download/millennium/millennium.php
European Climate Assessment (ECAD)	No. tropical nights (TR)*		aggregated station indices data for all stations within ECA&D.	world	txt	days		yearly/daily	https://eca.knmi.nl//download/millennium/millennium.php

Name	Description	Time interval data	Method	Scale	Type of file	Variable	Descriptor	Database	Web-site
European Climate Assessment (ECAD)	No. of warm days (TG90p)		aggregated station indices data for all stations within ECA&D.	world	txt	days		yearly/daily	https://eca.knmi.nl//download/millennium/millennium.php
European Climate Assessment (ECAD)	No. of warm day-times (TX90p)*		aggregated station indices data for all stations within ECA&D.	world	txt	days		yearly/daily	https://eca.knmi.nl//download/millennium/millennium.php
European Climate Assessment (ECAD)	Maximum of daily minimum temperature (TNx)*		aggregated station indices data for all stations within ECA&D.	world	txt	°C		yearly/daily	https://eca.knmi.nl//download/millennium/millennium.php
E-OBS data access	daily mean temperature TG, daily minimum temperature TN, daily maximum temperature TX, daily precipitation sum RR and daily averaged sea level pressure PP	1950-2018			grid				http://c3surf.knmi.nl/dataaccess/access_eobs.php

Table 10: Landslide

Name	Description	Method	Scale	Type of file	Descriptor	Database	Web-site
Global Risk Data Platform	Frequency of landslides triggered by earthquakes	combination of trigger and susceptibility defined by six parameters: slope factor, lithological (or geological) conditions, soil moisture condition, vegetation cover, precipitation and seismic conditions.	world	Geotiff	4 classes	earthquake-induced	https://preview.grid.unep.ch/index.php?preview=data&events=landslides&evcat=1&lang=eng
Global Risk Data Platform	Frequency of landslides triggered by precipitations	combination of trigger and susceptibility defined by six parameters: slope factor, lithological (or geological) conditions, soil moisture condition, vegetation cover, precipitation and seismic conditions.	world	Geotiff	4 classes	rainfall-induced	https://preview.grid.unep.ch/index.php?preview=data&events=landslides&evcat=2&lang=eng
Global Risk Data Platform	Physical exposition to landslides triggered by earthquakes	population grid for the year 2010, provided by LandScanTM Global Population Database (Oak Ridge, TN: Oak Ridge National Laboratory)	world	Geotiff		earthquake-induced	https://preview.grid.unep.ch/index.php?preview=data&events=landslides&evcat=3&lang=eng
Global Risk Data Platform	Physical exposition to landslides triggered by precipitations	population grid for the year 2010, provided by LandScanTM Global Population Database (Oak Ridge, TN: Oak Ridge National Laboratory)	world	Geotiff	(people/year)	rainfall-induced	https://preview.grid.unep.ch/index.php?preview=data&events=landslides&evcat=4&lang=eng
Global Risk Data Platform	Economical exposition to landslides triggered by earthquakes	A Global Domestic Product grid for the year 2010, provided by the World Bank,	world	Geotiff		earthquake-induced	https://preview.grid.unep.ch/index.php?preview=data&events=landslides&evcat=5&lang=eng
Global Risk Data Platform	Economical exposition to landslides triggered by earthquakes	A Global Domestic Product grid for the year 2010, provided by the World Bank,	world	Geotiff	(1000$/year)	rainfall-induced	https://preview.grid.unep.ch/index.php?preview=data&events=landslides&evcat=6&lang=eng
Global Risk Data Platform	risk index for landslide hazard triggered by precipitations	designed by UNEP/GRID-Europe for the Global Assessment Report on Risk Reduction (GAR). It was modeled using global data. Credit: UNEP/GRID-Europe.	world	Geotiff	from 1 (low) to 5 (extreme)	rainfall-induced	https://preview.grid.unep.ch/index.php?preview=data&events=landslides&evcat=7&lang=eng

Table 11: Earthquake

a) Hazard maps

Name	Description	Method	Scale	Type of file	Variable	Descriptor	Database	Web-site
Global Assessment Report on Disaster Risk Reduction 2017	Hazard map	set of parameters that describe the future seismic activity on each of them based on historical records together with relationships to obtain hazard intensities as a function of magnitude and distance	world	Grid file	peak ground acceleration	PGA	250, 475, 975, 1500, 2475	https://risk.preventionweb.net/capraviewer/download.jsp?tab=9&mapcenter=0,1123252.6982849&mapzoom=2; http://unisdr.envcomp.eu/browse/Hazard/Earthquake_Hazard_maps, https://risk.preventionweb.net/capraviewer/download.jsp?tab=9
Socioeconomic Data and Applications Center (SEDAC)	Global Earthquake Hazard Frequency and Distribution	2.5 minute grid utilizing Advanced National Seismic System (ANSS) Earthquake Catalog data of actual earthquake events exceeding 4.5 on the Richter scale during the time period 1976 through 2002	world	asc	earthquake hazard frequency	decile		http://sedac.ciesin.columbia.edu/data/set/ndh-earthquake-frequency-distribution
Socioeconomic Data and Applications Center (SEDAC)	Global Earthquake Hazard Frequency and Distribution	2.5-minute grid of global earthquake hazards developed using Global Seismic Hazard Program (GSHAP) data that incorporate expert opinion in predicting localities where there exists a 10 percent chance of exceeding a peak ground acceleration (pga) of 2 meters per second per second (approximately one-fifth of surface gravitational acceleration) in a 50 year time span	world	asc	peak ground acceleration	4 calsses		http://sedac.ciesin.columbia.edu/data/set/ndh-earthquake-distribution-peak-ground-acceleration/data-download

b) Catalogues

Name	Description	Method	Scale	Type of file	Variable described	Web-site
SHARE	European Earthquake catalogue	1900-2006	Patial excerpt of "The European-Mediterranean Earthquake Catalogue" (EMEC)	europe	excel file	https://www.emidius.eu/SHEEC/
International seismological centre	catalogue of earthquakes	1904-2018			csv, kmz	http://www.isc.ac.uk/iscgem/download.php

3.2 Description of downloadable European hazard maps/data bases

3.2.1 Joint Research Centre Data Catalogue

The Joint Research Centre (JRC) is the European Commission's science and knowledge service. The headquarters are in Brussels but there are research sites in five Member States: Geel (Belgium), Ispra (Italy), Karlsruhe (Germany), Petten (the Netherlands) and Seville (Spain). The work is largely funded by the EU's budget for Research and Innovation. The aim of the JRC is to support EU policies with independent scientific research as well as to contribute to a healthy and safe environment.

The JRC data catalogue contains 94 collections about several topics: environment, energy supplies, sustainable mobility and consumer health and safety. The Floods collection consists in 13 datasets about flood hazard maps at European and global scale.

Flood Hazard Maps at European and Global Scale

This collection contains pan-European flood hazard maps at 100 meter resolution for several return periods, from 10 to 500 years. A combination of distributed hydrological and hydraulic models was set up for the European domain (Alfieri et al., 2014) to realize the maps. Then, an observed meteorological data set is used to derive a long-term streamflow simulation and subsequently coherent design flood hydrographs for different return periods along the pan-European river network.

The maps are provided in GeoTIFF file and can be opened with a GIS software. They depict flood prone areas in Europe for flood events with different return periods. The cell values indicate water depth in meter (Figure 4).

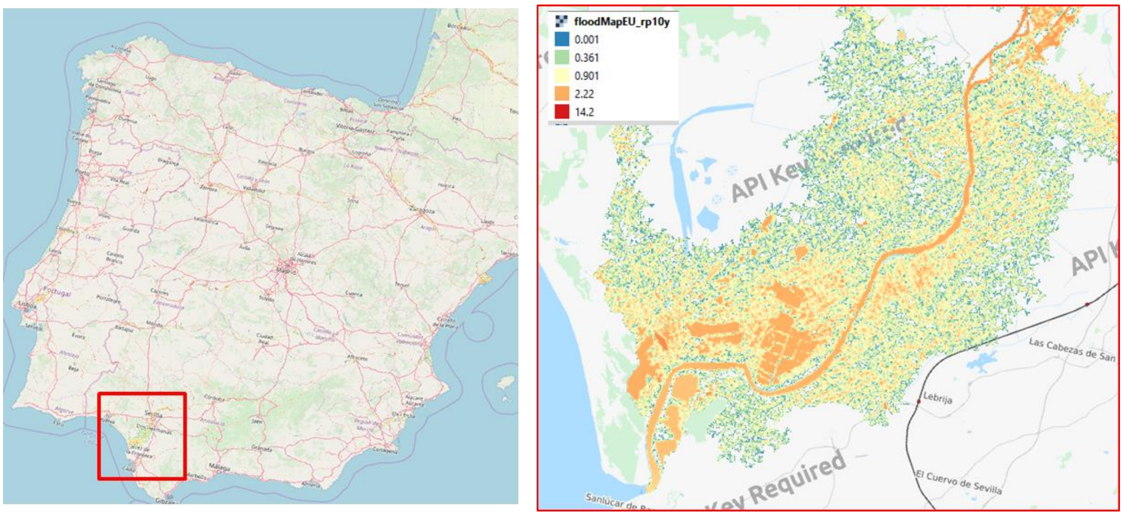

Figure 4: Map of the flood prone areas in Spain for flood events with 10-year return period. Cell values indicate water depth (in m). Source: JRC data catalogue on Floods

3.2.2 Global risk data platform

The Global Risk Data Platform replaces the previous PREVIEW initiative launched in 1999 by UNEP/GRID-Geneva to share spatial data information on global risk from natural hazards. Currently, the collection of data is made via a wide range of partners. The Global Risk Data Platform has been developed as a support to the Global Assessment Report on Disaster Risk Reduction (GAR). Many improvements were made on the data and on the application. At present the Global Risk Data Platform allows to visualise, download or extract data on past hazardous events, human & economical hazard exposure and risk from natural hazards. It covers tropical cyclones and related storm surges, drought, earthquakes, biomass fires, floods, landslides, tsunamis and volcanic eruptions. In the following the indicators important for SAFEWAY project are briefly described.

Flooding

The Global risk data platform provides different maps and datasets regarding floods: events; physical exposure; economical exposure; risk. A catalogue of the past flood events in the period 1999-2007 is available in a shape file format. The observed floods are obtained from the Dartmouth Flood Observatory (DFO). The physical exposition dataset is provided in a GeoTIFF format and it estimates the expected average annual population (2007 as the year of reference) exposed (inhabitants) to flood. The economical exposition dataset provides an estimate of the annual economical exposition to flood in a GeoTIFF format. A Global Domestic Product grid for the year 2010, provided by the World Bank, has been used to realize this dataset. It describes the expected average annual GDP (2010 as the year of reference) exposed in US $. Finally, a global estimated risk index for flood hazard has been defined combining together the information of the other maps. The dataset is provided through a GeoTIFF format and it represents the risk index in 5 classes (from low, 1, to extreme, 5; figure 5).

Fire events

The Global risk data platform provides two maps regarding fire events: events; density. The fire events dataset is a catalogue over the period November 1995 - March 2011. The data are presented in monthly global fire maps, in GeoTIFF, obtained by satellite images (Gregoire et al., 2001) from the European Space Agency (ESA-ESRIN) World Fires Atlas Program (ATSR). The fire density map includes an average of fires density over the period 1997-2010. The variable described is the expected average number of event per 0.1 decimal degree pixel per year multiplied by 100 (e.g. 64 value means 0.64 events per year). The dataset is provided in a GeoTIFF format.

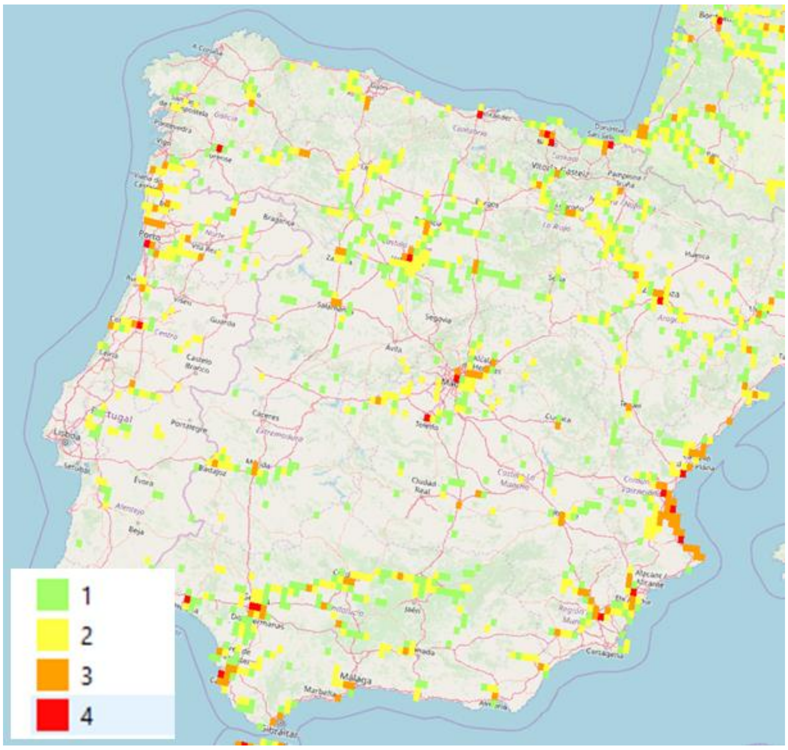

Figure 5: Estimated risk index for flood hazard. Unit is estimated risk index from 1 (low) to 5 (extreme). Source: Global risk data platform

Earthquakes

The database on earthquakes includes several maps: catalogue of events; earthquakes modified Mercalli intensity; physical exposure; economical exposure. The earthquakes catalogue gathers events with magnitude higher than 5.0 as reported by the Advanced National Seismic System (ANSS) Catalogue over the period January 1970 - June 2015. The ANSS Composite Catalogue is a world-wide earthquake catalogue created by merging the master earthquake catalogues from contributing ANSS institutions and then removing duplicate solutions for the same event. The global estimate of the Modified Mercalli Intensity dataset is based on Global Seismic Hazard Assessment Program (GSHAP) dataset, converted to Modified Mercalli Intensity (MMI) using the methodology developed by Wald et al. (1999). The dataset on the annual physical exposition to earthquakes includes MMI categories higher than a given value (5,7,8,9) over the period 1973-2007. It is based on two data sources: 1) Modified Mercalli Intensity map available in the Shakemap Atlas from USGS; 2) A population grid for the year 2010, provided by LandScanTM Global Population Database. The map shows the average annual population (2010 as the year of reference) exposed (inhabitants). The economical exposure to earthquakes is like the previous one. The difference is that a Global Domestic Product grid for the year 2010, provided by the World Bank, has been used to carry-out the analysis. The variable described is the expected average annual GDP (2010 as the year of reference) exposed in US $ (year 2000 equivalent).

3.2.3 Socioeconomic Data and Applications Center (SEDAC)

SEDAC is one of the Distributed Active Archive Centers (DAACs) in the Earth Observing System Data and Information System (EOSDIS) of NASA. SEDAC focuses on human interactions in the environment. Its mission is to develop and operate applications that support the integration of socioeconomic and earth science data and to serve as an "Information Gateway" between earth sciences and social sciences (http://sedac.ciesin.columbia.edu/about). The SEDAC provides maps and information on different natural hazards: floods, droughts, wildfires, landslides, earthquakes and multi-hazards.

Flooding

The SEDAC provides two maps concerning floods: the Global Flood Hazard Frequency and Distribution; and the Global Flood Proportional Economic Loss Risk. The maps are both structured as a 2.5-minute grid. The first represents the relative frequency of flood occurrence (Dilley et al., 2005). The greater the grid cell value in the final data set, the higher the frequency (figure 6). The map has been derived from a global catalogue of extreme flood events between 1985 and 2003 compiled by Dartmouth Flood Observatory. The second map (figure 7) depicts the flood proportional economic loss by weighting the value of the Gross Domestic Product (GDP) exposure to flood for each grid cell by a vulnerability coefficient (Sachs et al., 2001; Dilley et al., 2005).

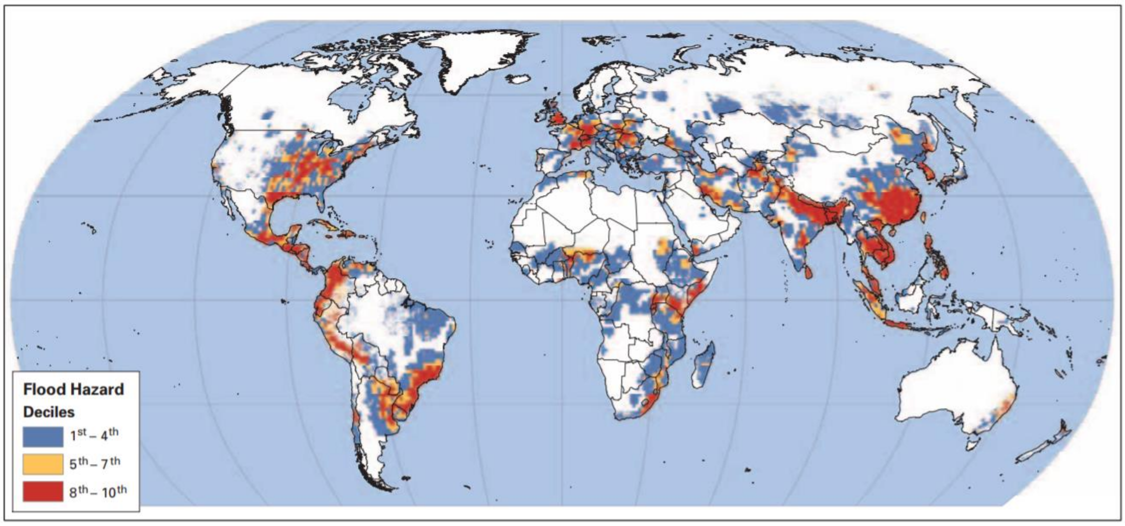

Figure 6: Distribution of flood hazard. (Dilley et al., 2005)

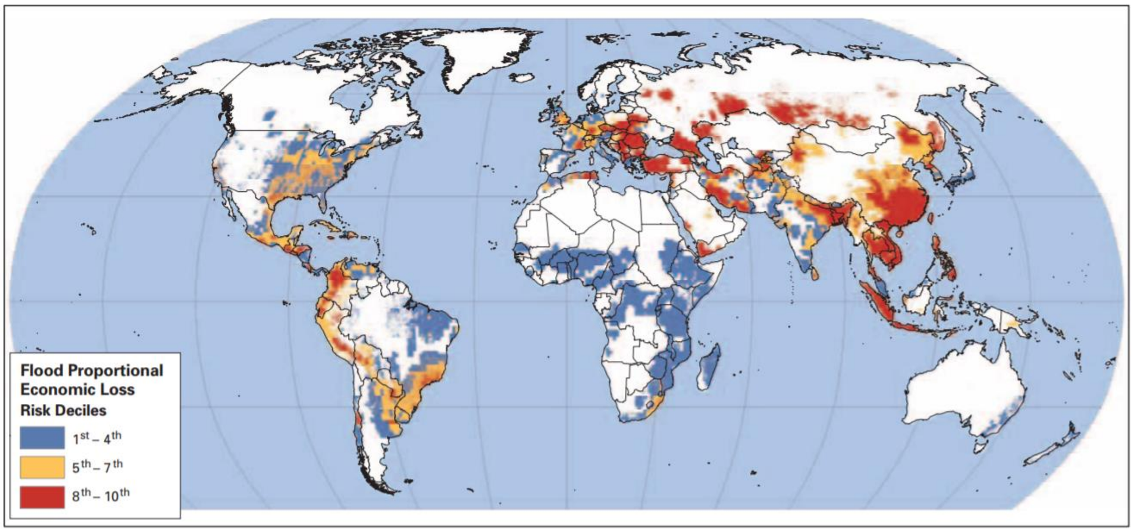

Figure 7: Economic loss due to flood as a function of the GDP density (*Dilley et al., 2005)*

Earthquakes

The two maps available for assessing earthquake hazards have been generated considering two different data sets. The first based on the Global Seismic Hazard Program (GSHAP) data that incorporate expert opinion in predicting localities where there exists a 10 percent chance of exceeding a peak ground acceleration (pga) of 2 meters per second in a 50-year time span (Dilley et al., 2005). The latter dataset uses the Advanced National Seismic System (ANSS) Earthquake Catalogue data of actual earthquake events exceeding 4.5 on the Richter scale during the period 1976-2002.

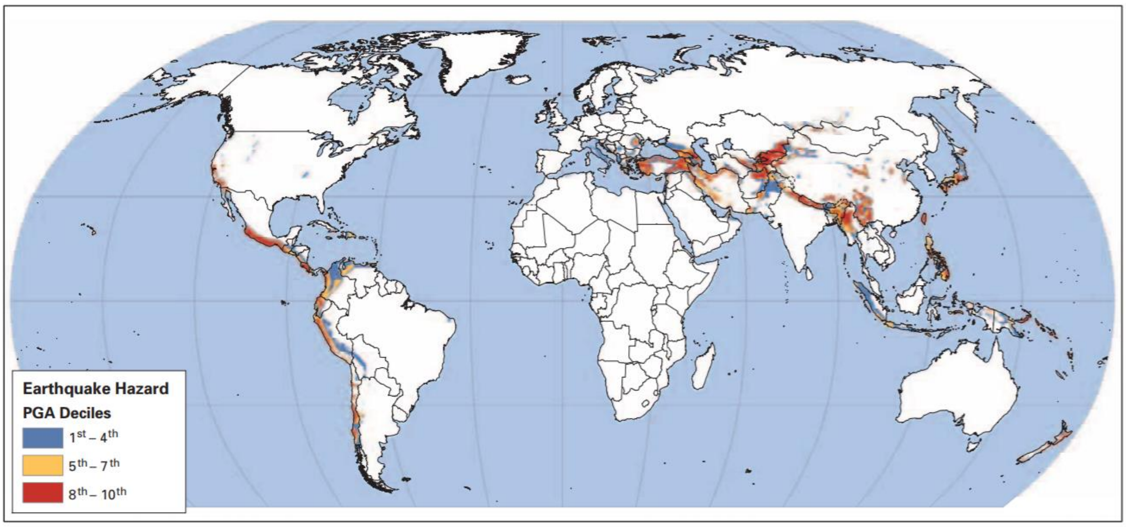

Figure 8: Global Earthquake Hazard Distribution - Peak Ground Acceleration (Dilley et al., 2005)

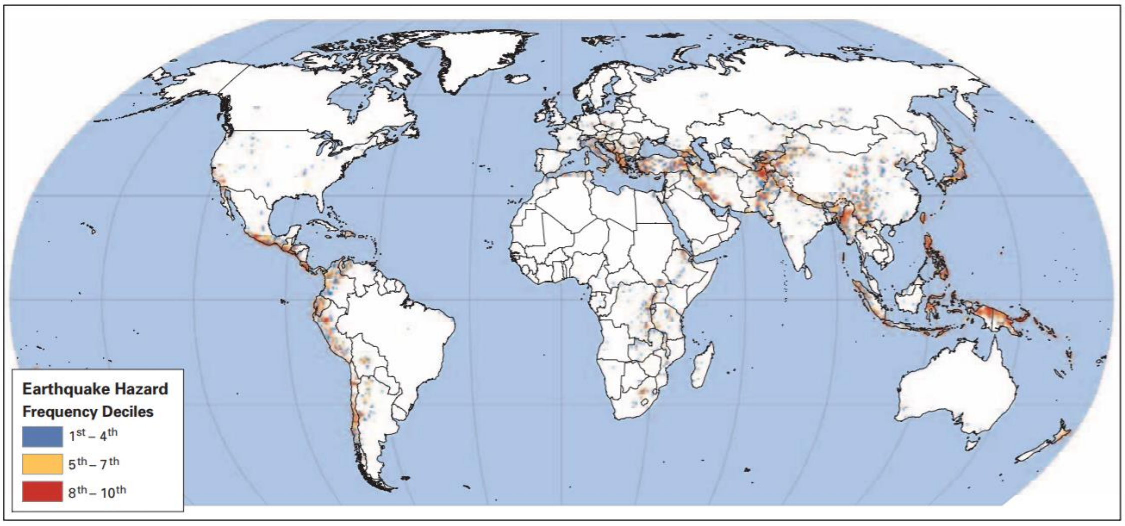

Figure 9: Global Earthquake Hazard Frequency and Distribution (Dilley et al., 2005)

3.2.4 NASA Earth Observations (NEO)

NEO is part of the EOS Project Science Office located at NASA Goddard Space Flight Center. The mission is to collect information about Earth's ocean, atmosphere, and land surfaces through satellite images, in order to depict climate and environmental changes as they occur on the planet. The images in NEO are freely available for public use without further permission in both CSV (comma separated values) and floating point GEOTiff files. The database gathers information on different branches: atmosphere, energy, land, life, ocean; and are continuously updated.

Fire events

The Moderate Resolution Imaging Spectroradiometer (MODIS) Fire Product provides information on the location of a fire, its emitted energy, the flaming and smoldering ratio, and an estimate of area burned. The red, orange, and yellow pixels on these maps show the locations where the MODIS instrument detects actively burning fires (figure 10).

Indicators for extreme weather conditions

The NEO database provides several interesting indicators for describing the climate change. The global temperature anomaly, the land surface temperature anomaly and the land surface temperature, seem to be the most useful database for the purposes of SAFEWAY project. The global temperature anomaly analysis specifies the temperature anomaly at a given location as the weighted average of the anomalies for all stations located within 1,200 kilometres of that point, with the weight decreasing linearly with distance (figure 11). Shades of red and orange indicate areas where the average annual temperatures are warmer than they were in that area during the base period from 1951-1980. The dataset contains information for the period 1880-2018.

The land surface temperature anomaly and the land surface temperature are datasets representing temperature patterns of the top millimetre (or "skin"), for both day-and night-time, of the land surface — including bare land, snow or ice cover, urban areas, and cropland or forest canopy — as observed by MODIS in clear-sky conditions for the period 2000-2018. The land surface temperature anomaly dataset shows land surface temperature anomalies for a given day, week, or month compared to the average conditions during the period 2001-2010. Figure 12 compares the temperature patterns of the top millimetre (or "skin") of the land surface in Celsius degrees and the land surface temperature anomalies for July 2018.

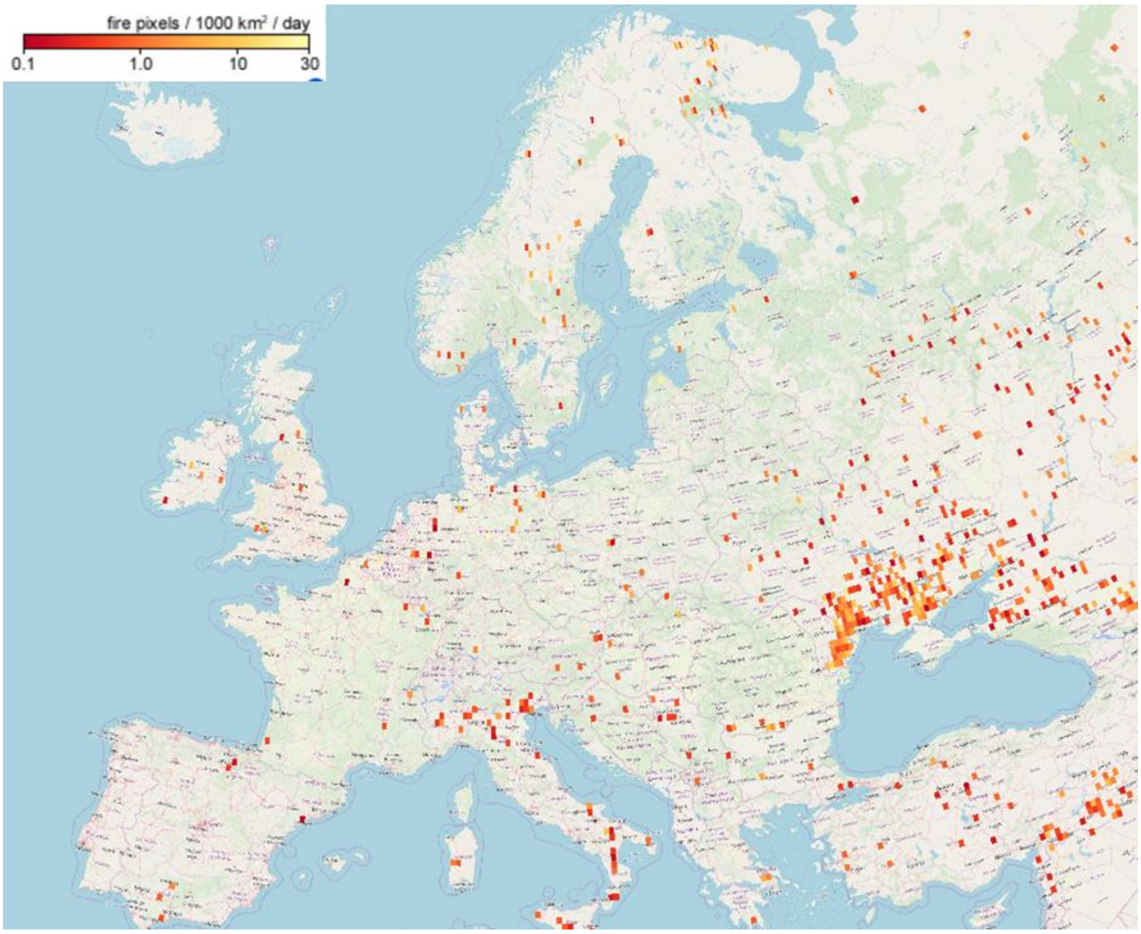

Figure 10: Locations where the MODIS instrument detects actively burning fires. The colours represent a count of the number of fires observed within a 1,000-square-kilometer area for July 2018

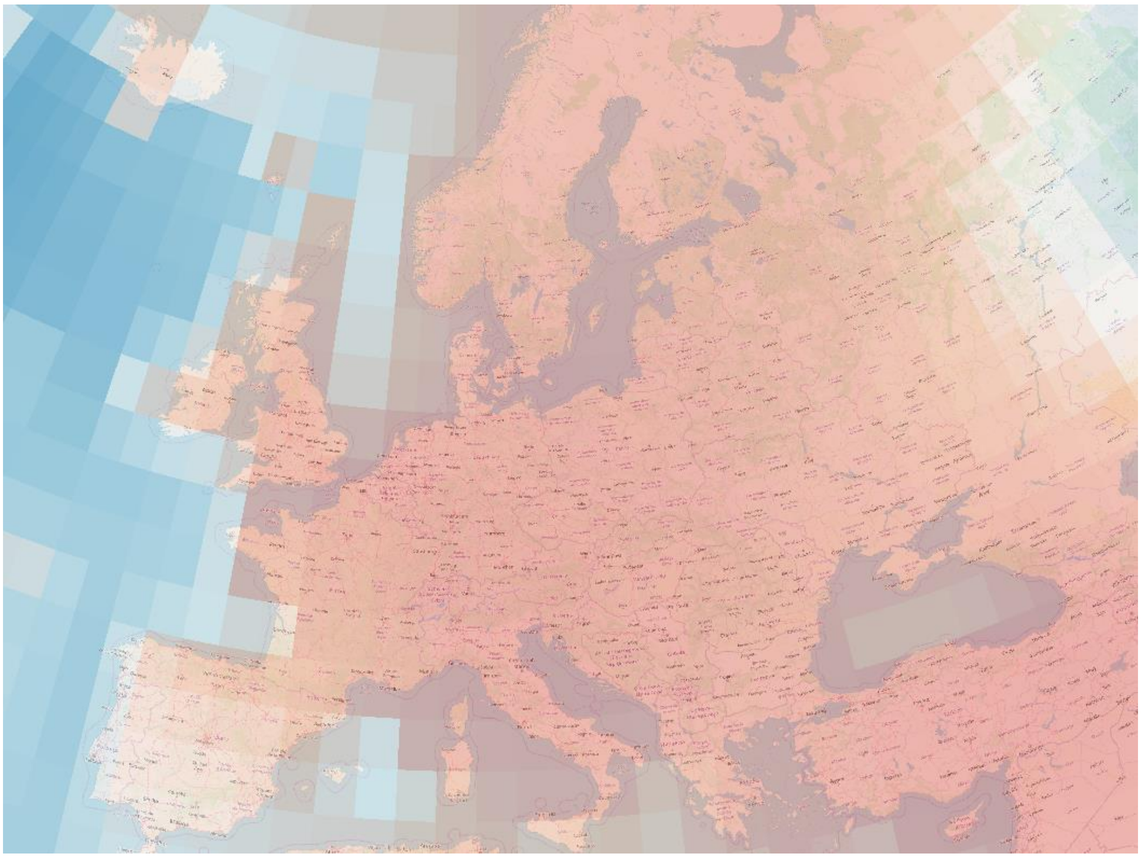

Figure 11: Global temperature anomaly in Europe for the year 2017. Shades of red and orange indicate areas where the average annual temperatures (in Celsius degree) are warmer than they were in that area during the base period from 1951-1980

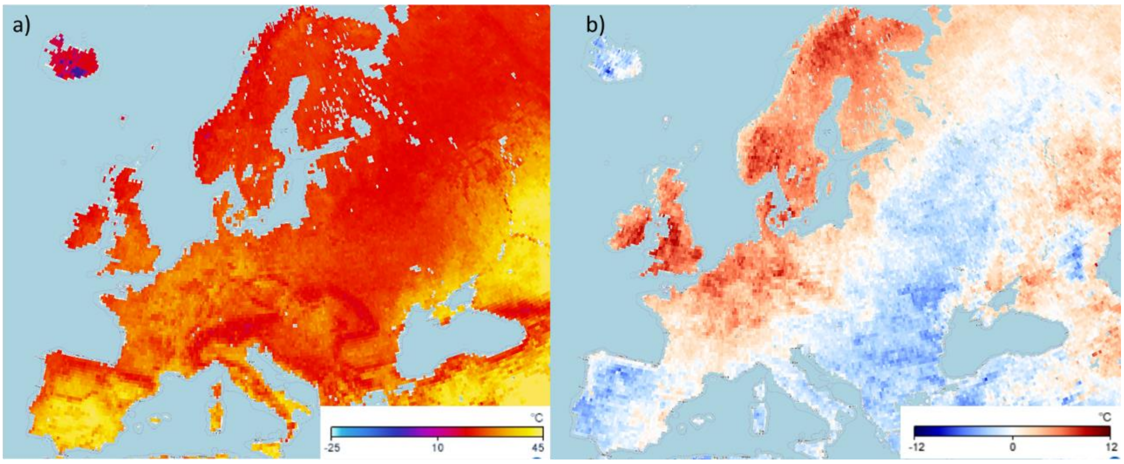

Figure 12: a) The temperature patterns of the top millimetre (or "skin") of the land surface in Celsius degrees for July 2018; b) Land surface temperature anomalies for July 2018 compared to the average conditions during that period between 2001-2010

3.2.5 Global Assessment Report on disaster risk reduction (GAR)

The Global Assessment Report on Disaster Risk Reduction (GAR) is a biennial global assessment of disaster risk reduction and comprehensive review and analysis of the natural hazards that are affecting humanity. The GAR contributed to achieving the aims of the Hyogo Framework for Action through monitoring risk patterns and trends and progress in disaster risk reduction while providing strategic policy guidance to countries and the international community. The GAR is produced in collaboration and consultation with a wide range of stakeholders, including various UN agencies, governments, academic and research institutions, donors and technical organizations and specialists.

The GAR Atlas presents the output of a Global Risk Model (GRM) that can estimate the disaster risk associated with different kinds of hazard (earthquakes, tsunamis, flooding, cyclonic winds and storm surge) faced by national economies throughout the world. This model has been developed by a consortium of leading scientific and technical organisations, under the coordination of UNISDR. The main purpose of the GAR Atlas is to broadly identify high risk areas at global level and identifying areas where more detailed data should be collected and where detailed risk assessments are to be performed.

Earthquakes and seismic hazard

For the GAR Atlas, a fully probabilistic seismic hazard analysis at global level was developed by CIMNE and INGENIAR Ltda. This hazard model is a continuation and improvement of the one developed in the framework of GAR13 where a set of tectonic provinces were identified and characterized by means of a set of parameters that describe the future seismic activity on each of them based on historical records together with relationships to obtain hazard intensities as a function of magnitude and distance. The hazard analysis was performed using the program CRISIS2014, a state-of-the-art tool for these kinds of tasks and widely known and acknowledged by experts in the field across the world. More details about the probabilistic seismic hazard analysis can be found in Cardona et al. (2015). The chosen variables for hazard intensity measure were the spectral acceleration and the peak ground acceleration. Hazard maps considering different return periods for both variables have been considered. In particular, 5 hazard maps considering 250, 475, 975, 1500, 2475 years as return periods have been realized. For the same return periods, different hazard maps for the spectral acceleration, respectively of 0,2; 0,5; 1 seconds, have been derived (see figure 13).

Figure 13: Seismic hazard considering spectral acceleration of 1 second for a 250 year return period

3.2.6 European Climate Assessment & Dataset project (ECA&D)

The European Climate Assessment & Dataset project (ECA&D) was initiated in 1998 and has received financial support from EUMETNET and the European commission. Between 2003 and 2008 the project has been partially funded by European Meteorological Network (EUMETNET). From 2009 onwards, the Royal Netherlands Meteorological Institute (KNMI) has committed itself to fund ECA&D. ECA&D has now obtained the status of Regional Climate Centre (RCC) for high resolution observation data in WMO Region VI (Europe and the Middle East). Currently, there are 69 National Meteorological and Hydrological Services, observatories and universities from Europe and the Mediterranean sharing long-term daily resolution climatic time series from meteorological stations. The objective of ECA&D is to analyse, aggregate and validate the meteorological data collected by the stations in the WMO region VI. For each station 72 indices are calculated monthly, describing changes in the mean or extremes of climate. The indices are grouped in different categories describing weather characteristics: cloudiness, cold, compound, drought, heat, humidity, pressure, rain, snow, sunshine, temperature. The full dataset covers the period 1950-2018. It has originally been developed and updated as parts of the ENSEMBLES (EU-FP6) and EURO4M (EU-FP7) projects. Currently it is maintained and elaborated as part of the UERRA project (EU-FP7).

3.2.7 Extreme weather event hazard maps from the INTACT project

Simple extremes are characterized by the occurrence of an extreme value for a single variable (such as temperature), whereas complex extremes involve a critical combination of variables associated with a weather or climate phenomenon, such as a cyclone (rainfall and wind) or drought and many others. The INTACT project was focusing specifically on four types of extreme weather:

- Temperature extreme
- Precipitation extreme (also including snowfall)
- Wind extreme
- Complex extreme (including 2 different parameters among temperature, precipitation and wind)
    - Combined temperature and precipitation extreme
    - Combined temperature and humidity extreme

Most of the indices considered in INTACT have been defined following the recommendations of the CCl/CLIVAR/JCOMM Expert Team on Climate Change Detection and Indices (ETCCDI)

Extreme indicators based on temperature

Different climate indices are available to address the different aspects (frequency, amplitude and persistence) of the extreme temperature events. The INTACT project considers only some of them. In particular, there are indices calculating the number of days exceeding a specific threshold, which can be a fixed value or based on the percentile of the different (minimum, maximum or mean) temperature distribution (percentile-based indices could be more useful to express anomalies relative to local climate). Other indices evaluate the number of consecutive days in which a specific threshold is exceeded (or not), while others evaluate the absolute extreme value reached. Usually, temperature indices include indices to classify both high and low temperature extreme events. At the same time, depending on the features of the extreme event to be classified, the distribution of the mean, maximum or minimum daily temperature is considered.

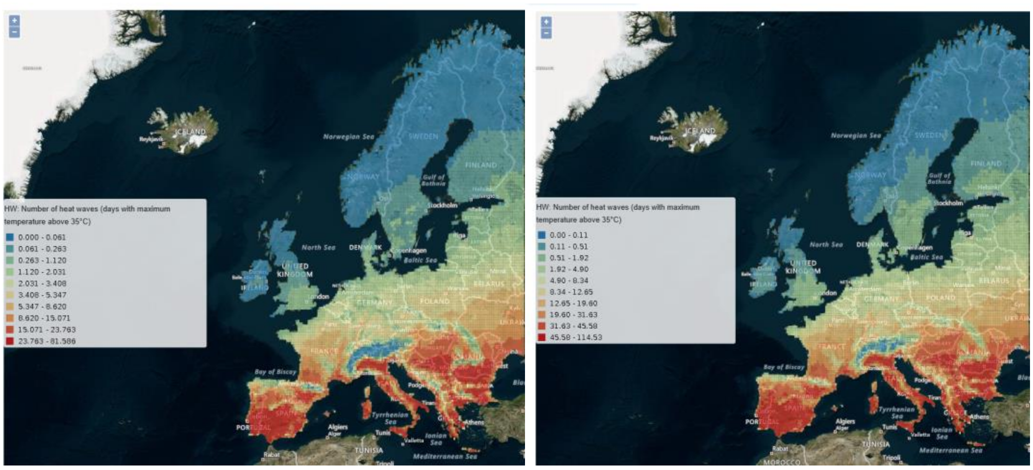

Figure 14: Predictions of number of heatwaves(days with a maximum temperature above 35°C) per year for time periods 2011 - 2041 (left) and 2071-2100(right)

Extreme indicators based on precipitation

Concerning precipitation EWI, they are quite similar to the temperature ones, including frequency, amplitude and persistence of extreme precipitation events. Precipitation extreme indicators can characterize events with high precipitation, but also extremely dry conditions. Most indicators are based on the number of days or consecutive days overcoming a fixed daily precipitation threshold, while others are derived from the number of days exceeding (high precipitation events) or not (low precipitation events) a specific percentile of daily precipitation distribution. There are also others concerning the absolute extreme value of cumulated precipitation on a selected time span (1 day, 2 days or 5 days, typically).

Extreme indicators based on snow

Regarding snow, five different indices have been selected: the first based on the frequency of the snow days (snow precipitation higher than 1 mm); the second and the third are related to the frequency of days exceeding an assigned threshold for the snowfall. The fourth is related to the amount of maximum yearly snowfall. The last index provides information about the contribution of the four seasons to the yearly snowfall.

Extreme indicators based on wind

Two basic typologies of indicators have been selected to characterize extreme wind events: indices based on the frequency of daily wind intensity (considering different threshold values); indices based on the maximum daily value reached by the mean wind intensity and by gusts. Gusts are sudden, rapid and brief changes in the wind speed. Wind extreme values have a significant importance for engineering application. Unfortunately, due to the difficulty to obtain homogeneous high-frequency wind data, these indices have been barely considered in literature.

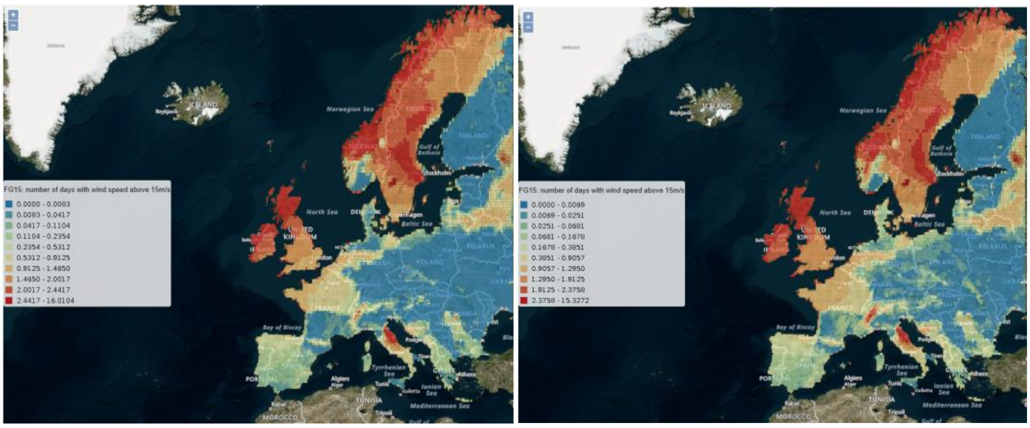

Figure 15: Number of days with wind speed above 15m/s per year for time periods 2011 - 2041 (left) and 2071-2100(right)

3.2.8 Other datasets

For the Multimedia Assessment of Pollutant Pathways in the Environment (MAPPE) project several datasets were developed. A set of 12 maps of monthly mean wind speed is available. The maps describe the average wind per month for the period 2002-2006.

The SHARE European Earthquake Catalogue, compiled in the frame of the SHARE project 2006 by GFZ Potsdam, is an earthquake catalogue for the period 1900-2016.

Another earthquake catalogue is compiled by the International Seismological Centre for the period 1904-2018.

3.3 European maps of weather related hazards in current and future climate

Climate change is increasingly affecting Europe. Most impacts of climate change have been adverse, although some might be beneficial. Increases in sea and land temperatures vary between southern and northern regions, being more harmful in southern than in norther areas. Changes in precipitation pattern make wet regions of Europe wetter, particularly in winter, and dry regions drier particularly in summer. Yet, rises in sea level, more frequent high winds, and storm surges can be directly dangerous for natural and built environments and human health.

Projections of climate change are supported by changes in European ground temperatures, precipitation levels, occurrences of windstorms, and rise in seal-levels in northern regions. Rationale for review of the above meteo-and-climatic parameters rests on the fact that their variability has short, medium and long-term implications for functionality, serviceability and safety of overland transport (road and rail) infrastructures.

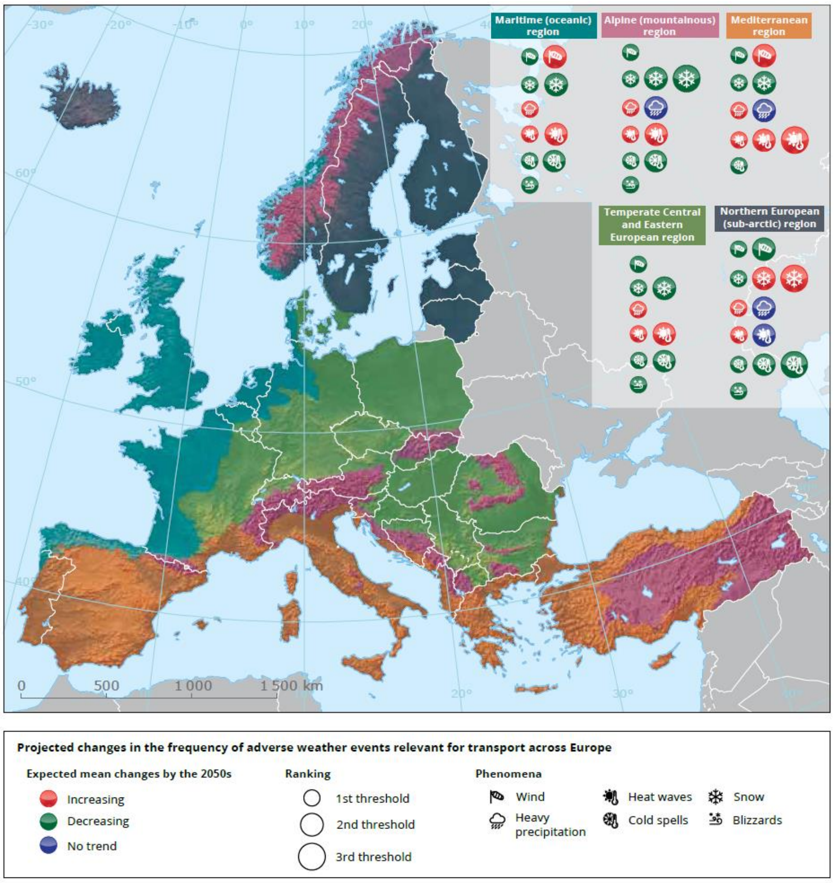

Figure 16: Projected changes in the frequency of adverse weather events relevant for transport across Europe. Source: EEA (2017); adapted from Leviäkangas and Saarikivi (2012)

3.3.1 European Temperatures

Temperatures across Europe are expected to continue increasing throughout the 21-century. Projections from the EURO-CORDEX initiative suggest that European land will warm faster than global land areas (Jacob et al., 2014). According to the mean from multi-modal ensemble runs, European land areas are projected to warm in the range of 1 to 4.5°C for the RCP4.5 scenario and in the range of 2.5 to 5.5°C for RCP8.5 over the 21-century (2017-2100 as compared to 1971-2000). The strongest warming is projected in north-eastern Europe and Scandinavia during winter and in southern Europe during summer (EEA, 2017).

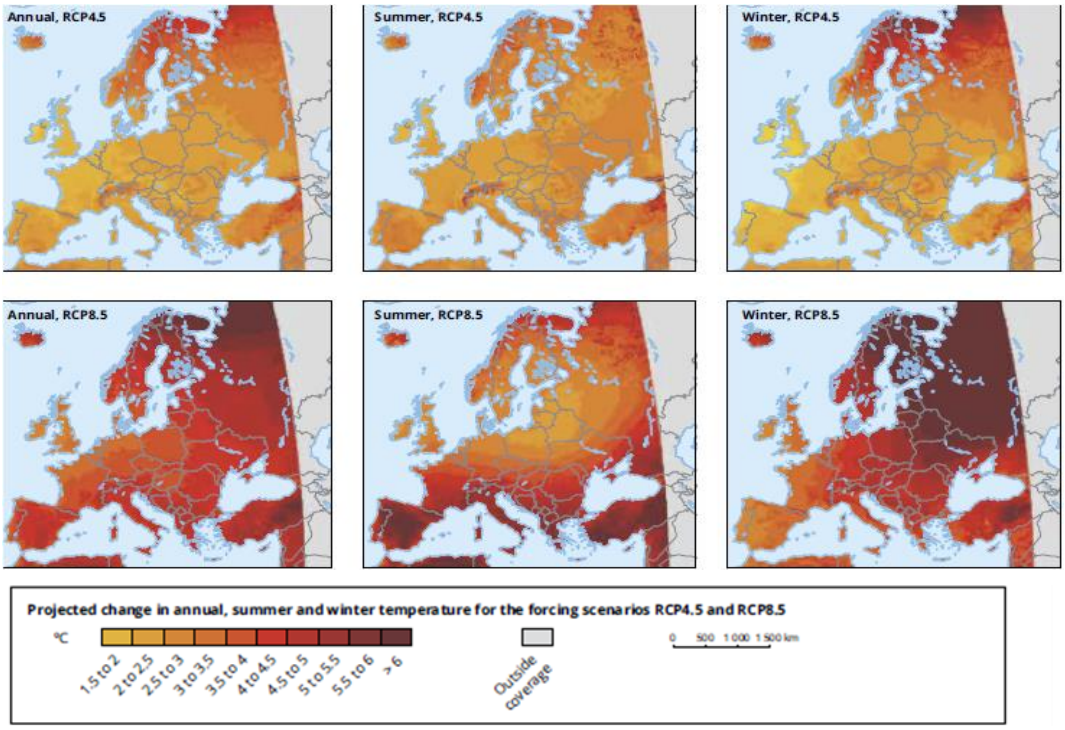

Figure 17: Projected Changes in Mean Annual Summer and Winter Temperature under Two Radiative Forcing Scenarios RCP4.5 and RCP8.5[1]

Periods with extreme high temperature are projected to become more frequent and to last longer across Europe during the 21-century (Fischer and Schär, 2010; Russo et al., 2014; Schoetter et al., 2014). Projections based on multi-model ensemble agree on increases in heat wave frequency and magnitude for most European regions during the 21-century under RCP scenarios[2]. Extreme summer heat waves, such as the ones experienced in different parts of Europe in 2003 and 2010, will become much more common in the future. Under the RCP8.5 scenario,

[1] *Note: This map shows mean annual (left) summer and winter (right) near surface temperature (°C) over the period 2017-2100 compared with the baseline period 1971-2000 for the radiative forcing scenarios RCP4.5 (top) and RCP8.5 (bottom). Model simulations are based on the multi-model ensemble average of many different combined GCM-RCM simulations from the EURO-CORDEX initiative.*

[2] *The RCP (Representative Concentration Pathway) scenarios are projecting the radiative forcing which is determined not only by direct anthropogenic greenhouse emissions, but also by the future development of the global carbon cycle and other processes. Moreover, the process of RCP development has been separated from the socio-economic storyline development, which means that the different RCPs are not directly associated with a specific socio-economic scenario (EEA, 2017 p.38).*

very extreme heat waves[3] are projected to occur as often as every two years in the second half of 21-century (see maps in the following). The projected frequency of heat waves is greatest in southern and south-eastern Europe (Russo et al., 2014). According to a different analysis, at the end of the 21-century, 90% of summers in southern, central and north-eastern Europe will be warmer than any summers in the period 1920-2014 under RCP8.5 scenario (Lehner et al., 2016). The most severe risks are projected for low altitude river basins in southern Europe, and for the Mediterranean costs where many densely populated urban centres are located (Fischer and Schär, 2010).

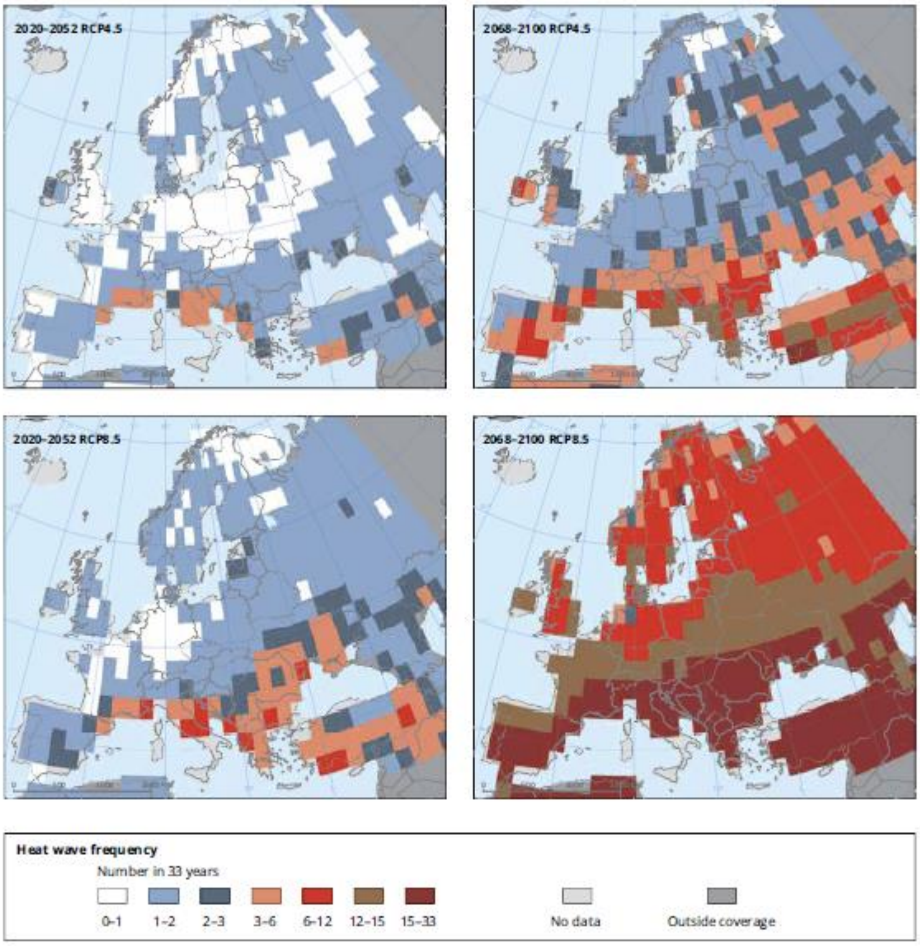

Figure 18: Number of Very Extreme Heat Waves in Europe's Future Climates under Two Different Emissions Scenarios[4]. Source: Adopted from Russo et al., 2014 and reproduced from EEA, 2017 p.79

[3] To assess changes in heat waves, HWMI (Heat Wave Magnitude Index) has been used. The HWMI is defined based on the magnitude and length of heat waves in a year where the heat waves are periods of three consecutive days with a maximum temperature above the threshold of the reference period 1981-2010 (EEA, 2017, p.77).
[4] Note: Very extreme heat waves are defined as having HWMI (Heat Wave Magnitude Index) above 8. For comparison, the 2003 western European heat wave had an average of around 3, and the 2010 western European heat wave had an average HWMI of around 5. The upper maps show the median number of very extreme heat wave that derives from a multi-modal ensemble of GCMs of the near future (2020-2052) and later half of the century (2068-2100) under RCP4.5 scenario. The lower maps reflect the same time-period projections but under RPC8.5 scenario.

3.3.2 Mean Precipitation

For a high emissions scenario, RCP8.5, the models (ensemble mean) do project a statistically significant increase in annual precipitation in large parts of central and northern Europe (up to about 30%), and a decrease in southern Europe (of up to 40 %) from 1971-2000 to 2071-2100 (see maps in the following). In summer, though, the precipitation decrease extends northwards (Jacob et al., 2014). A zone with small change that are not significant (but are however, partially robust in the direction of change), shows where the precipitation pattern (as presented in the ensemble mean) changes the direction of the change. For a medium emission scenario (RCP4.5) the magnitude of change is smaller, but the pattern is very similar to the pattern for the RCP8.5 scenario. The range of projected changes in precipitation from the multi-model ensemble are generally the same between RCP4.5 and RCP8.5, or larger in RCP8.5, especially at the end of 21-century (Jacob et al., 2014)[5] .

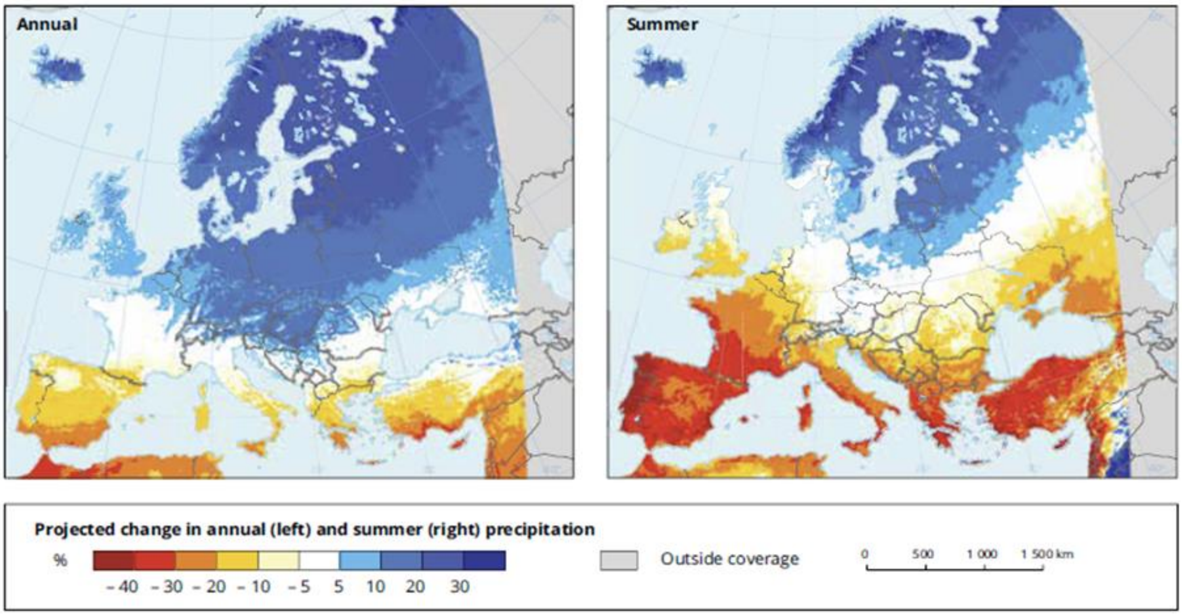

Figure 19: Figure 19 Projected Change in Annual and Summer Precipitation in Europe (EEA; 2017)[6]. Source: EURO-CORDEX (Jacob et al., 2014), and reproduced from EEA, 2017, p.81

[5] Despite that daily precipitation records have been systematically collected since 1950s, still acclimate change signal cannot be detected with certainty in all European regions owing to the high spatial and temporal variability in precipitation. Difficulties in detecting trends can also arise from the small sampling area of rain gauges, calibration errors in instrumentation and erroneous measurement during snow and gales (e.g. Hofstra et al.., 2009 quoted in EEA, 2017 p.81.

[6] Note: The maps show projected changes in annual (left) and summer (right) precipitation (%) in the period 2071-2100 compared with the baseline period 1971-2000 for the radiative forcing scenario RCP8.5. Model simulations are based on a multi-model ensemble average of many different RCM simulations from the EURO-CORDEX initiative.

3.3.3 Heavy Precipitation

Global warming is projected to lead to higher intensity of precipitation and longer dry periods in Europe (IPCC, 2012; Hov et al., 2013). Projections show an increase in heavy daily precipitation in most parts of Europe in winter, by up to 35% during the 21-century. Heavy precipitation in winter is projected to increase over most of Europe with increases up to 30 % in north-eastern Europe (see left map below). In summer, an increase is also projected in most parts of Europe, but decreases are projected for some regions in southern and south-western Europe (see right map below) (Jacob et al., 2014). Similar pattern was found for other heavy precipitation indices (Rajczak et al., 2013, Sillmann et al, 2013: Giorgi, Coppola and Raffaele, 2014).

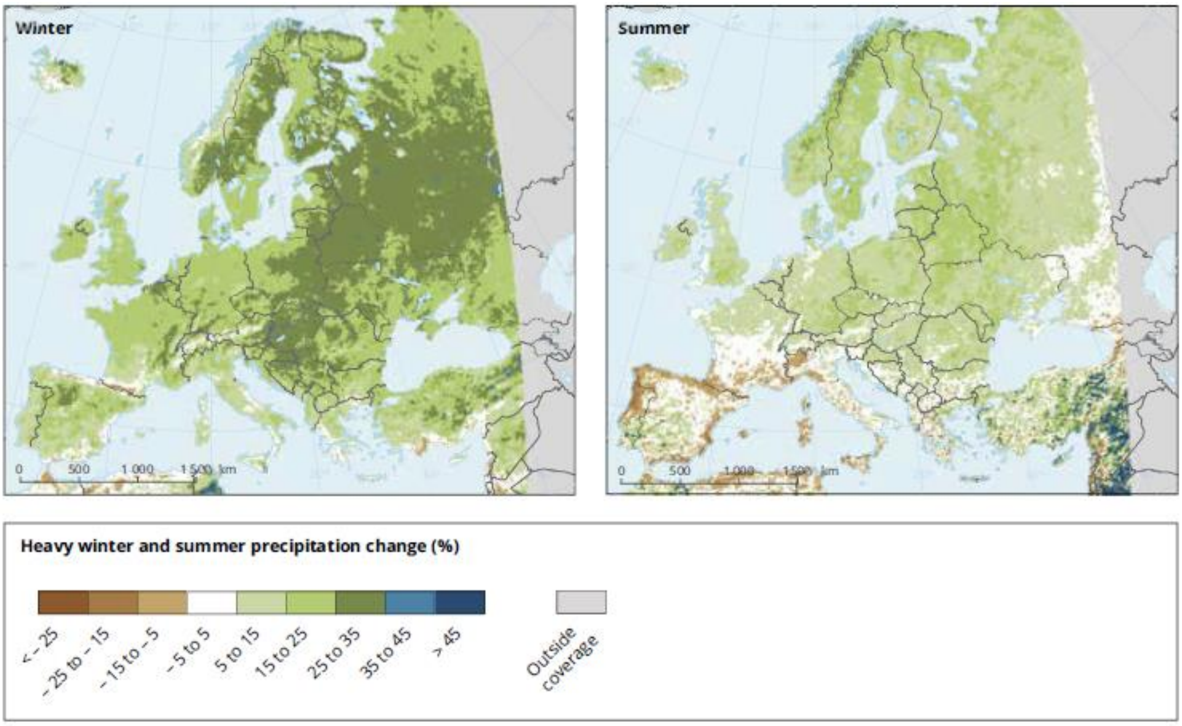

Figure 20: Figure 20 Projected Changes in Heavy Precipitation in Winter and Summer in Europe[7]. Source. EURO-CORDEX (Jacob et al., 2014) and reproduced from EEA, 2017, p.84

3.3.4 Wind Storms

Modelling studies show diverging results on changes in number of storms across Europe, but they generally agree on increases in the strongest, most damaging storms in most European regions. A study using a multi-model ensemble runs 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 (see map below) (Donat, Leckenusch et.al., 2011).

[7] Note: The map shows projected changes in heavy daily precipitation (%) in winter and summer for 2071-2100 compared with the baseline periods 1971-2000 for the RCP8.5 scenario based on the ensemble mean of different RCMs nested in different GCMs.

A comprehensive review study covering the North Atlantic and the northern, north-western and central Europe shows large agreement that the intensity of winter storms will increase in all these regions over the 21-century (Feser et al., 2014). Another recent study focusing on central Europe concluded that models consistently projected an increased frequency and intensity of severe storms over central Europe. Under SRES A1B conditions[8] , increases in frequency towards the end of the 21-century range between -11% and + 44% with an ensemble average 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 IPPC AR5 (Zappa et al., 2013). One recent study with a single, very high resolution (~25km) GCM indicates that the frequency and intensity in Europe of severe autumn storms originating in the tropical Atlantic will increase in a warmer future climate as will the area affected (Baatsen et al., 2015). However, this result cannot be considered robust, as it has not been yet confirmed by other studies.

In summary, the risk of severe winter storms, and possibility of severe autumn storms is projected to increase in many regions in Europe, particularly in the Northern Atlantic and northern, north western and central Europe.

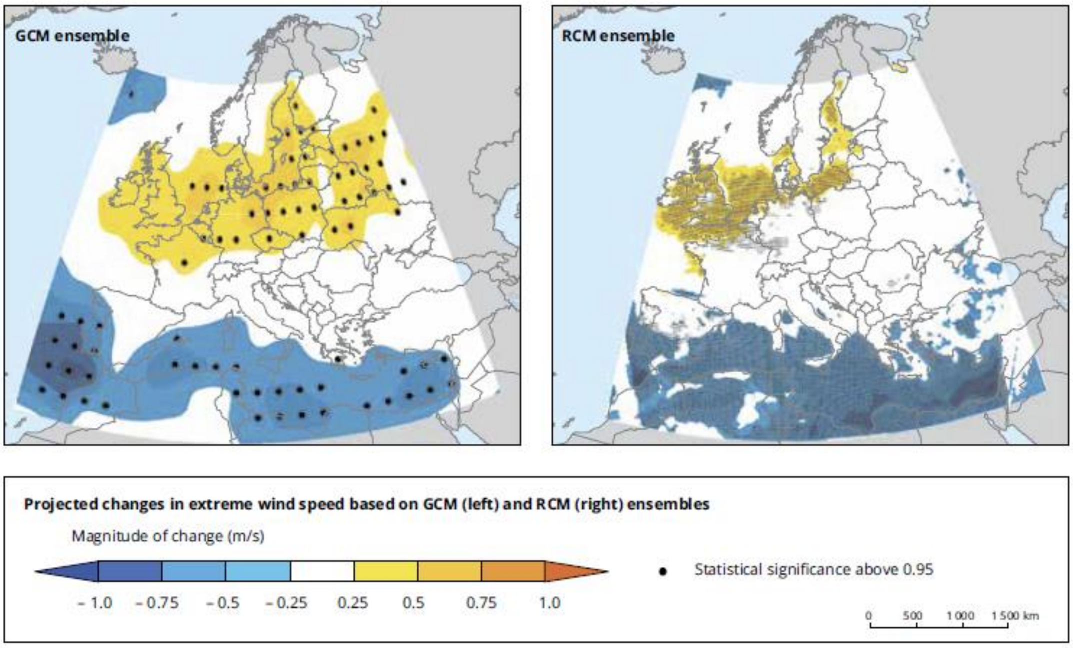

Figure 21: Projected Changes in Extreme Wind Speed Based on GCM and RCM Ensembles for 2071-2011 (EEA; 2017)[9]. Source: Adopted from Donat, Leckebusch et al.,2011 and reproduced from EEA, 2017. p.87

[8] The range of SRES (The Special Report on Emissions Scenarios) scenarios (from E1-low, A1B -medium to A1F1 – very high) provide a trajectory of anthropogenic green house emissions coupled with the underlying storyline of socio-economic development. (EEA, 2017, p.38)

[9] Note: The above map shows the ensemble mean of changes in extreme wind speed (defined as the 98-the percentile of daily maximum wind speed) for AIB scenario (2071-2100) relative to 1961-2000. Left: based on nine GCMs. Right: based on 11 RCMs. Coloured areas indicate the magnitude of change (unit: m/s) and statistical significance at the 5% level is shown in black dots.

3.3.5 Flooding

Figure 22 shows the change in the level of one-in-a-century (Q100) floods between the reference period and three future time periods based on the hydrological model LISFLOOD and an ensemble of seven climate models(Alfieri, Burek et al., 2015). Blue rivers indicate an increase in flood level and red rivers indicate a decrease. 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, decreases in 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.

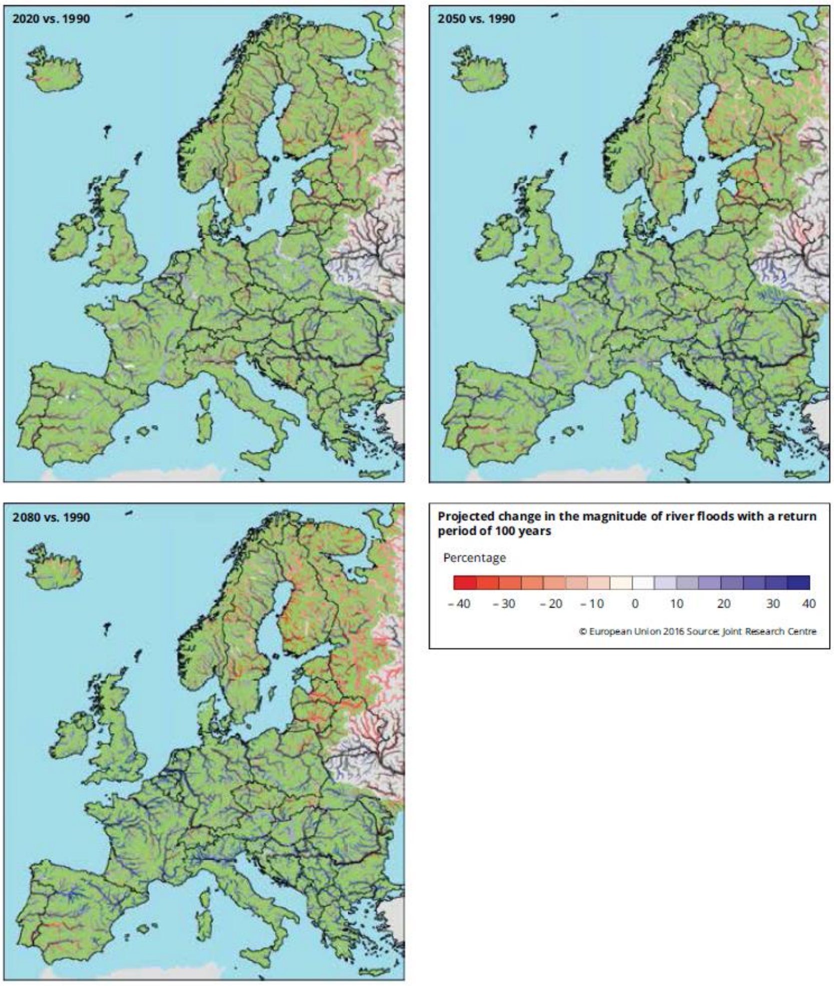

Figure 22: Projected change in river floods with a return period of 100 years (EEA; 2017)[10]. Source: Adapted from Alfieri, Burek et al., 2015

[10] Note: This map shows the projected change in the level of one-in-a-century river floods (Q100). The relative changes for the time slices 2006–2035 (2020), 2036–2065 (2050) and 2066–2095 (2080) are 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 of the projected mean change. Data points with CV > 1 are greyed out.

3.3.6 Forest fires

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 (EEA; 2017). 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 (Moreno, 2014).

¡Error! No se encuentra el origen de la referencia. also includes fire danger projections for projected climate conditions in 2071–2100 (upper right map: projected state; lower right map: projected change). The results suggest that climate change would lead to a marked increase of fire potential in south-eastern and south-western Europe; in relative terms, the increase in SSR would be particularly strong in western-central Europe (Khabarov et al., 2014). Similar results were obtained for other forest fire indices, such as the FWI (Bedia et al., 2013).

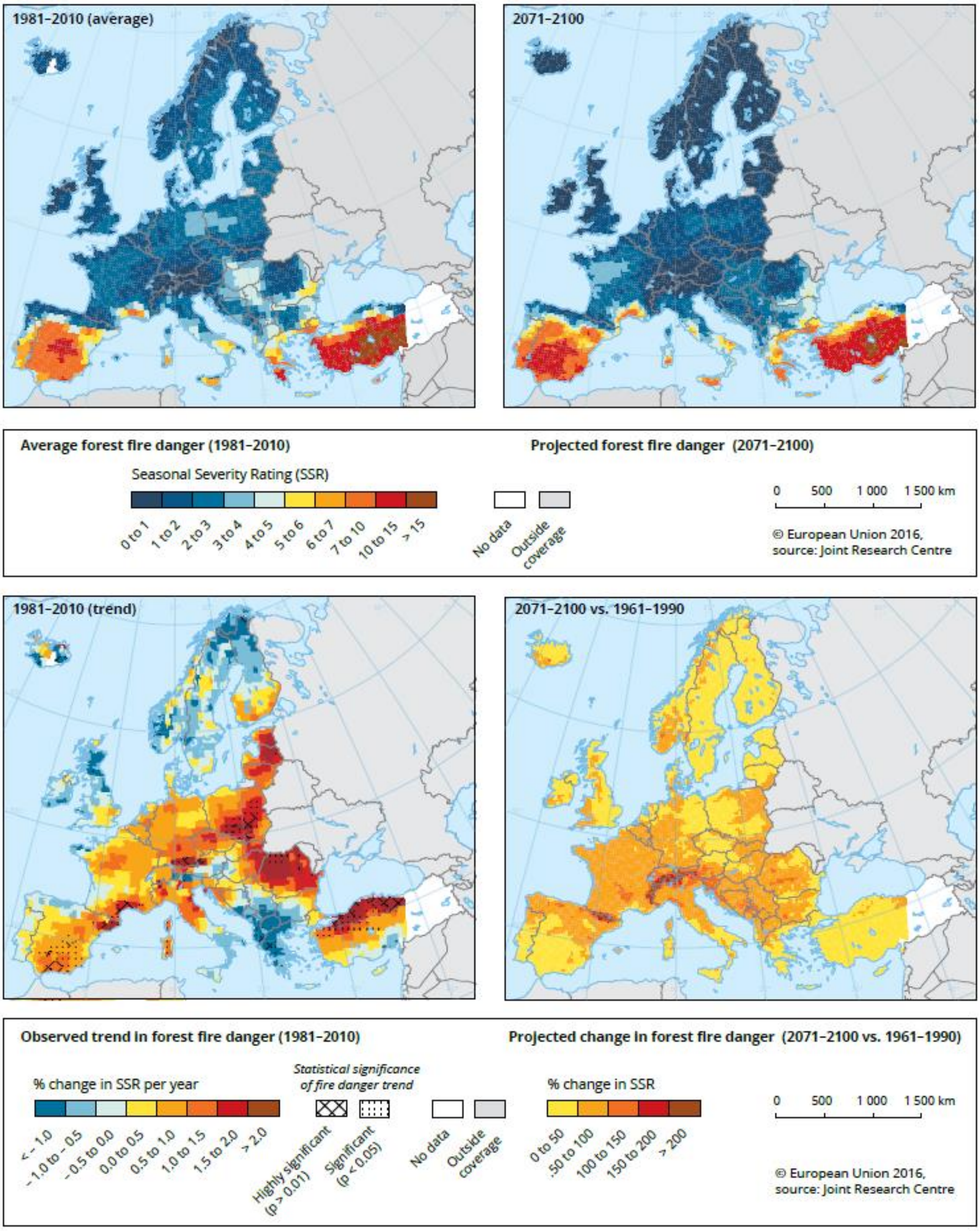

Figure 23: Current state, past trend and projections for forest fire danger (EEA; 2017)[11]. Source: Camia, 2012 (personal communication), based on Camia et al., 2008

[11] *Note: Fire danger is expressed using the SSR. Daily severity values can be averaged over the fire season using the SSR index, which allows for objective comparison of fire danger from year to year and from region to region. The coarse scale of the map does not allow specific conditions of given sites to be accounted for, as, for example, in the Alpine region, where the complex topography may strongly affect local fire danger.*

3.4 European dynamic hazard maps used for monitoring and forecasting

3.4.1 ANYWHERE

ANYWHERE (EnhANcing emergencY management and response to extreme WeatHER and climate Events) is a program funded within EU's Horizon 2020 research and innovation programme, ongoing until August 31, 2019. The principal objective is to enable society as a whole and the main civil protection agencies to respond more rapidly than today to extreme climate and weather events, and to better cope with the high social, environmental and economic impacts related to these extremes.

The project aims to establish a pan-European platform on extreme climate risks, where identification of and early warning systems should improve protection measures as well as ameliorate the coordination of rescue operations.

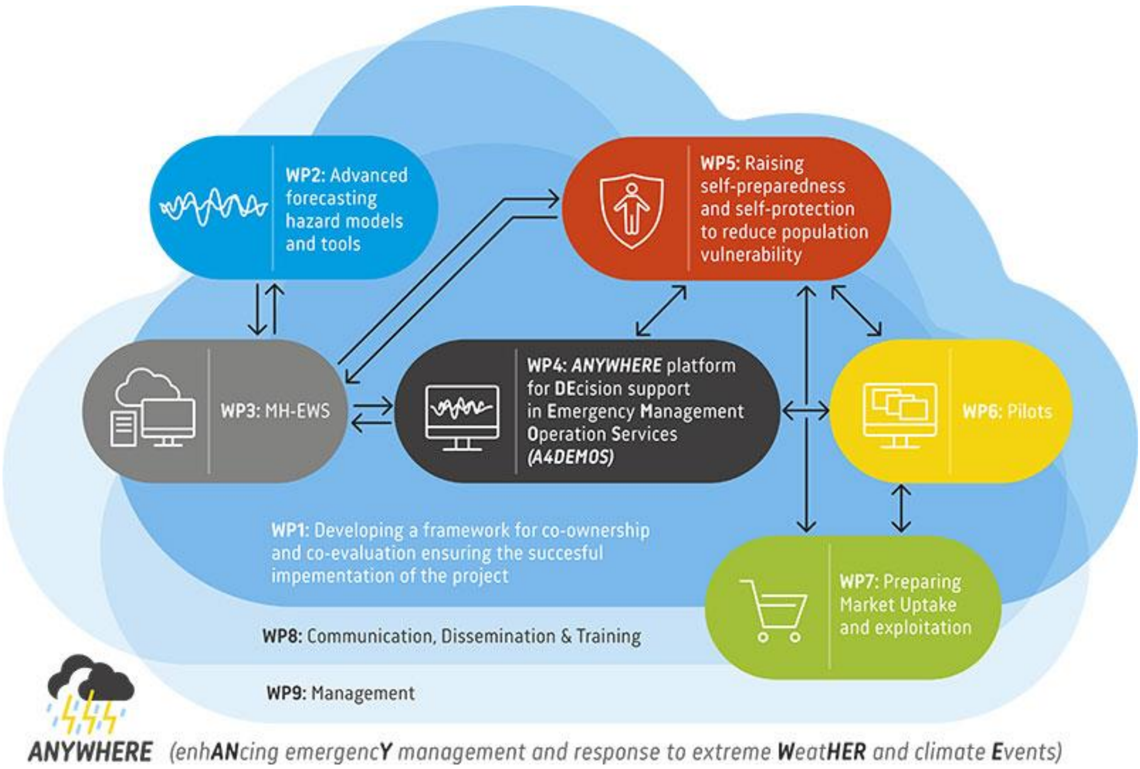

Figure 24: Structure of Anywhere Work packages (ANYWHERE; 2017)

Products from the work packages aim to establish tools to forecast hazards induced by weather and climate events (WP2), and integrating these tools into a multi-hazard operational early warning system (WP3). In WP4 a prototype of a platform for decision support in emergency management operation services will be built. WP5 and -6 are focused on end-users and improved communication and awareness.

From the website, these are/will be available services (WP2/WP3/WP4):

- Hydro meteorological forecasts
- Floods, flash floods, debris flow and landslides
- Weather-induced forest fires
- Droughts
- Heatwaves and weather-induced health impacts
- Convective storms, severe winds
- Storm surges
- Snowfall

Each service category includes several products pertaining to the service. For floods, as an example, these products include (but are not limited to) observations of rainfall and temperatures, accumulated forecasts (rainfall), forecasts on flash floods and river flood impact as well as probabilistic river flood hazard forecasts.

3.4.2 COPERNICUS Emergency Management service

COPERNICUS Emergency Management service is a system for monitoring and forecasting floods across Europe (EFAS).

The aim of EFAS is to support preparatory measures before major flood events strike, particularly in the large trans-national river basins and throughout Europe in general. EFAS is the first operational European system monitoring and forecasting floods across Europe.

It provides complementary, added-value information (e.g. probabilistic, medium range flood forecasts, flash flood indicators or impact forecasts) to the relevant national and regional authorities. Furthermore, EFAS keeps the Emergency Response Coordination Centre (ERCC) informed about ongoing and possibly upcoming flood events across Europe.

The data is accessible for for all users, but real-time products are restricted to EFAS partners only. Products older than one month are universally accessible.

3.4.3 I-REACT

I-REACT is aiming to be the first European-wide platform to integrate emergency management data coming from multiple sources, including that provided by citizens through social media and crowdsourcing (I-REACT, 2019). This way, information is produced faster and allow citizens, civil protection services and policy makers to effectively prevent and/or react against disasters. Their aim is to give flood early warning information up to 10 days in advance.

The platform aims to integrate emergency management data from multiple sources, among others crowdsourcing. As of now, an Android app is available on Google Play.

3.4.4 UrbanAdapt

The European Environment Agency (EEA) has compiled UrbanAdapt map layers for Urban forest fire and flood projections (EEA, 2019), sourcing maps from several sources including the EEA (https://www.eea.europa.eu/data-and-maps). This is presented via ESRI's ArcGIS Online map viewer.

This is an interactive map viewer, for climate adaptation of European cities, open and accessible for anyone. The service consists of 8 interactive maps plus city fact sheets for the cities included in Eurostat's Urban Audit (City Statistics). Data is received from different sources (or data source, European Environment Agency, Eurostat, Joint research Centre (JRC), Copernicus Urban Atlas, E-OBS via European Climate Assessment & dataset (ECA&D), EU-funded research projects (e.g. RESIN, RAMSES) and other research, etc.).

The aim of the map viewer is to provide an overview of the current and future climate hazards facing the European cities, the vulnerability of the cities to these hazards and their adaptive capacity. The map viewer collates information from various sources on the observed and projected spatial distribution and intensity of high temperatures, flooding, water scarcity and wild fires. It also provides some information on the causes of cities' vulnerability and exposure to these hazards, linked to the characteristics of cities and their population. Finally, the map viewer provides information on adaptation planning and actions of European cities.

The information contained in the maps, combined with the Urban Audit city factsheets allows gaining understanding about the current and projected climate impacts in European cities. It is also possible to compare individual cities to each other, and to identify other cities in similar situations. Additional sources of information, illustrative case studies and relevant indicators are suggested for learning more about the climate risks to European cities.

3.4.5 EFFIS

The European Forest Fire Information System (EFFIS) supports the services in charge of the protection of forests against fires in the EU countries and provides the European Commission services and the European Parliament with updated and reliable information on wildland fires in Europe (EFFIS, 2019). They offer services on current fire situation in Europe and the Mediterranean as well as a news service on wildland fires in Europe, updated daily.

Since 1998, EFFIS is supported by a network of experts from the countries in what is called the Expert Group on Forest Fires, which is registered under the Secretariat General of the European Commission. Currently, this group consists on experts from 40 countries in European, Middle East and North African countries. In 2015, EFFIS became one of the components of the Emergency Management Services in the EU Copernicus program.

Among the applications offered are monthly and seasonal fire weather forecasts, current situation view and a service for downloadable data.

4. National hazard maps

4.1 Portugal

4.1.1 Flooding

There are several flood hazard maps available for Portugal. Some of them derive by European or Worldwide database, such as: Joint Research Centre Data Catalogue; The Global Risk Data Platform; Global Assessment Report on Disaster Risk Reduction; The Socioeconomic Data and Applications Center (see section 3.1 and 3.2 for details). Even if the information of these databases is valid and reliable, some detailed datasets are available for Portugal at a bigger scale. In fact, detailed maps are provided by the Sistema Nacional de Informacao Geografica (SNIG). It is a national agency, created in 1990, dealing with the catalogue and analysis of geographical datasets for public and private institutions. The publication of the EU directive 2007/60/CE INSPIRE[12] and its transposition was an important step in the development and access to geographic information in Portugal and in the development of SNIG. Since then, SNIG made a lot of effort to gather data and produce maps of natural hazards. Several detailed datasets are freely available at the following website[13]. Hazard, consequence and risk maps (figure 25) for several return periods (20, 100, 1000 years) have been produced. Four levels for both hazard and risk classes have been defined. Other noteworthy datasets available are: the water depth, flux velocity and inundation boundary maps. These maps have been evaluated for 3 different scenarios with return periods of 20, 100, 1000 years (an example of these datasets is provided in figure 26). Also, these datasets are provided in a shape format and are available on the SNIG website.

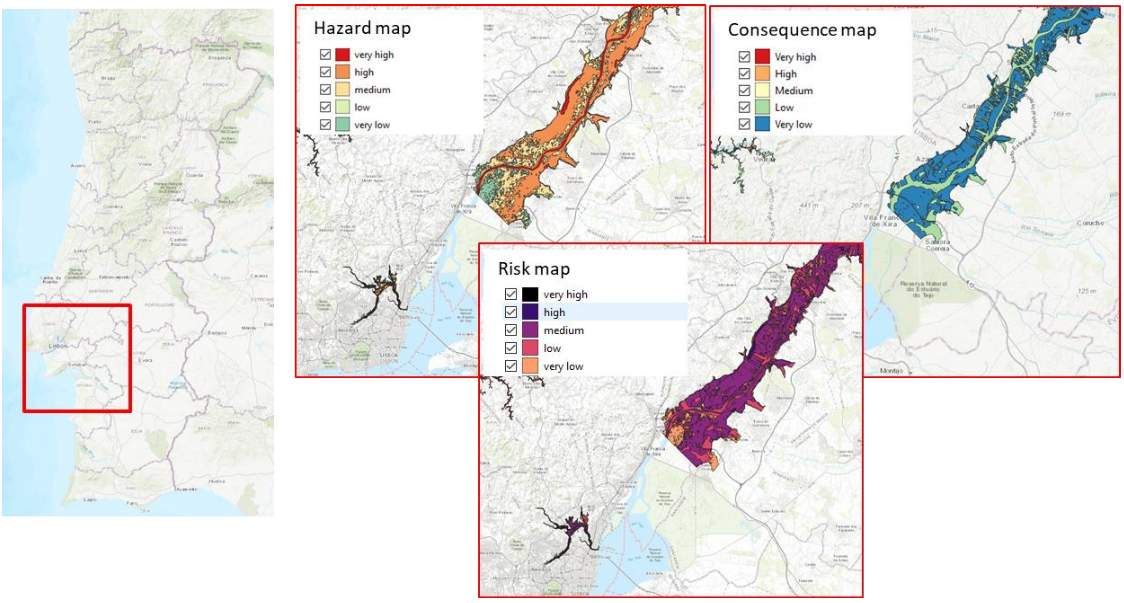

Figure 25: Example of a) hazard, b) consequence and c) risk map of flood available for Portugal

[12] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=OJ:L:2007:108:TOC
[13] http://snig.dgterritorio.pt/portal/index.php?option=com_wrapper&view=wrapper&Itemid=292&lang=pt

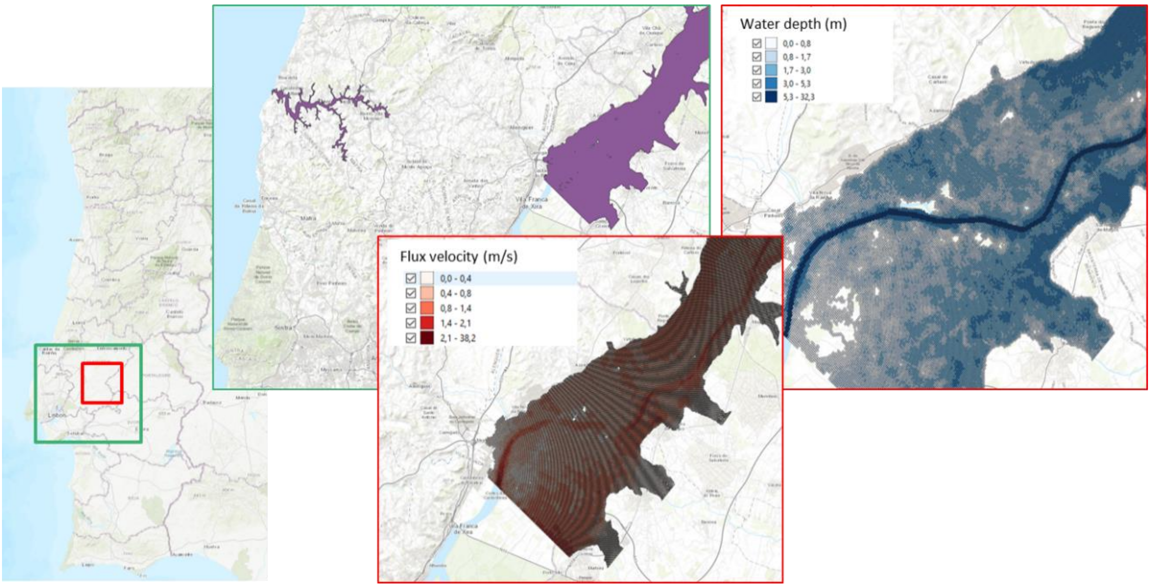

Figure 26: Example of the a) inundation areas, b) flood water depth, c) flux velocity maps available for Portugal

4.1.2 Wildfire

The Global Risk Data Platform provides a global dataset for the fire density in the years 1997-2010. It can be also considered for risk analysis regarding Portugal. However, such information has a low level of detail and it gives just few insights about some possible fire susceptible areas in Portugal. A detailed dataset on wildfire is provided by Instituto de conservacao de natureza e das florestas (ICNF). ICNF is a public institute integrated in the indirect administration of the State, completely independent. The mission is to propose, monitor and ensure the implementation of nature conservation and forest policies, aiming at the conservation, sustainable use, valorisation and public recognition of the natural heritage, promoting the sustainable development of forestry and associated resources, fostering the competitiveness of forest ranks, and other activities directly associated with forestry. The ICNF provides detailed maps of the burned areas and a fire catalogue in Portugal (an elaboration is provided in figure 27 a). Those datasets, together with the map of the use of soil, have been used to derive the hazard map for wildfire (figure 27 b). Specifically, the hazard was produced based on the CSP methodology (Cover, Slope and Probability) developed at the National Forest Authority by Dr. João Verde (Verde and Zezere, 2011). The basic information used was: i) 2007 Soil Occupancy Chart Level 3 (COS2007); ii) slope chart produced from pan-European MDE, iii) cartography of burning areas (1997-2016). The map is available in a GeoTIFF format and it is freely available on the ICNF web site.

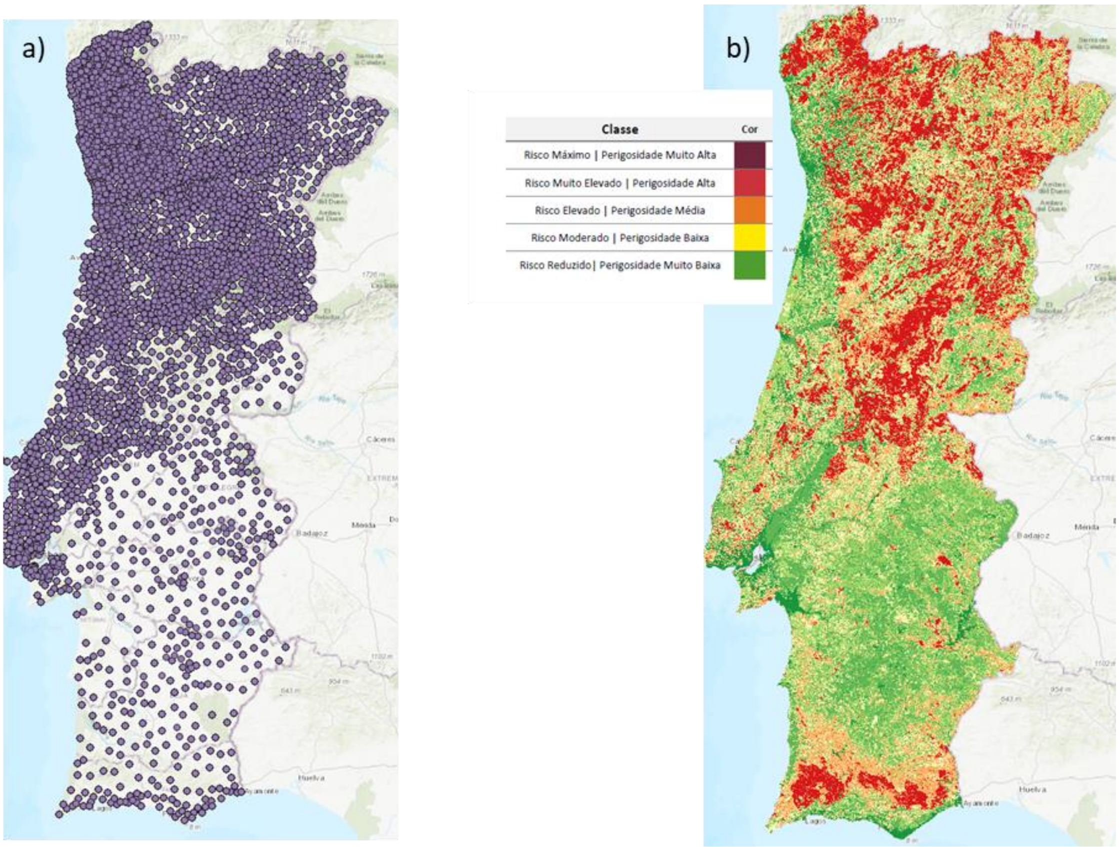

Figure 27: a) Wildfire events catalogue 1988-2015, b) hazard map for wildfires in Portugal

4.2 Spain

4.2.1 Flooding

The Joint Research Centre Data Catalogue (see section 3.2.1) provides European flood hazard maps for different return periods: 10, 20, 50, 100, 200, 500 years. The database collection contains a set of flood hazard maps, based on streamflow data from the European and Global Flood Awareness System (EFAS and GloFAS) and computed using two-dimensional hydrodynamic models. Maps are in GeoTIFF format and can be used in any GIS program. Figure 28 shows the data available for Spain.

Another dataset collection, useful to describe the flood hazard in Spain, is provided by Global Assessment Report on Disaster Risk Reduction (GAR) (see section 3.2.6). A probabilistic approach for modelling the riverine flood of major river basins around the globe is used. This has been possible after compiling a global database of stream-flow data, merging different sources and gathering more than 8000 stations over the globe, in order to calculate the range of possible discharges from very low to the maximum possible scales at different locations along the rivers. Hazard maps for several return periods (25, 50, 100, 200, 500, 1000 years) were obtained. The hazard maps are developed at 1kmx1km resolution (figure 29).

The Global Risk Data Platform (see section 3.2.2) estimated a global risk index for floods worldwide. Four classes of risk are defined for each 7x9 km pixel (figure 30). This dataset is less detailed than the previous ones, in fact the minimum unit is coarser.

The Socioeconomic Data and Applications Center (sedac) produced global Flood Hazard Frequency and Distribution (see section 3.2.3) maps as a function of extreme flood events occurred between 1985 and 2003. However, also this grid is coarser than the previous first two datasets (i.e.: Joint Research Centre Data Catalogue, Global Assessment Report on Disaster Risk Reduction).

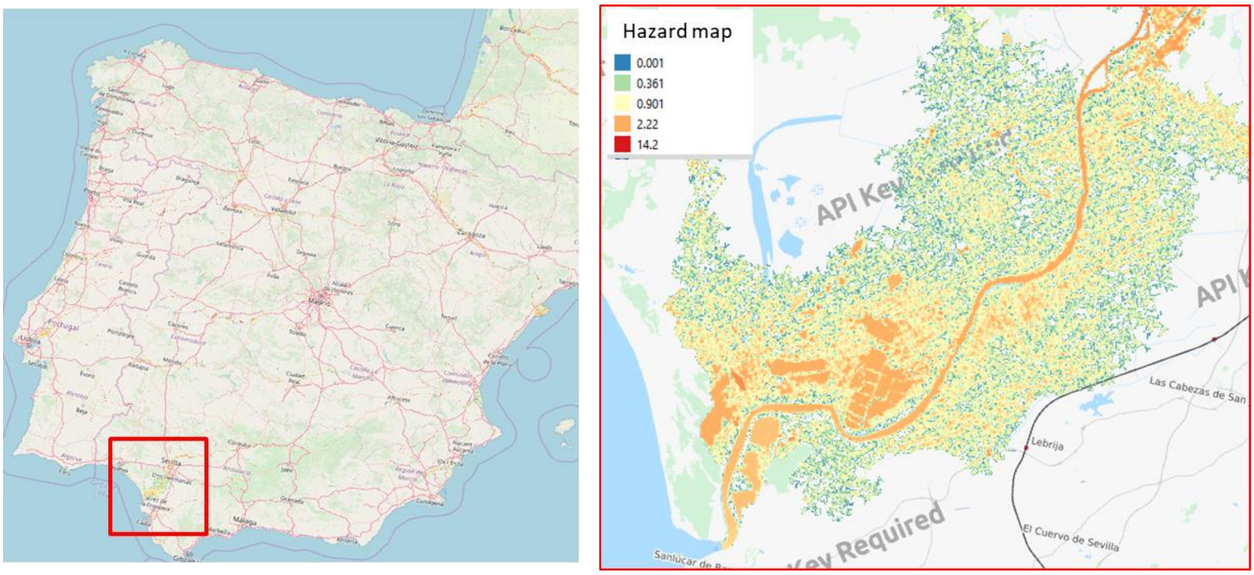

Figure 28: European flood hazard map for Spain. The map is expressed in terms of flood depth (m). Source of the dataset: Joint Research Centre Data Catalogue

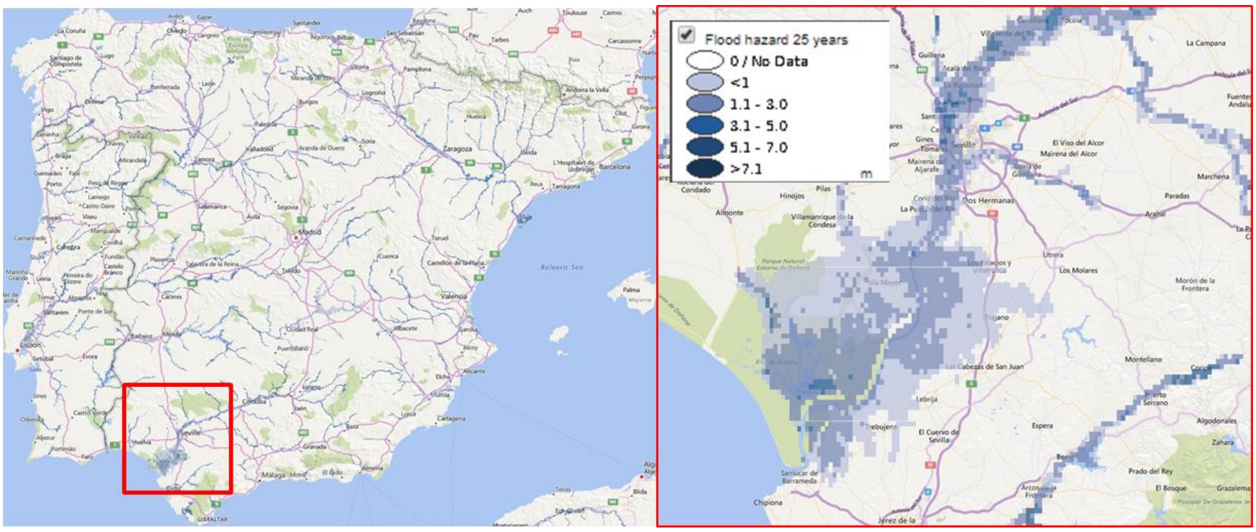

Figure 29: Flood hazard considering 100 years as return period. Source: Global Assessment Report on Disaster Risk Reduction

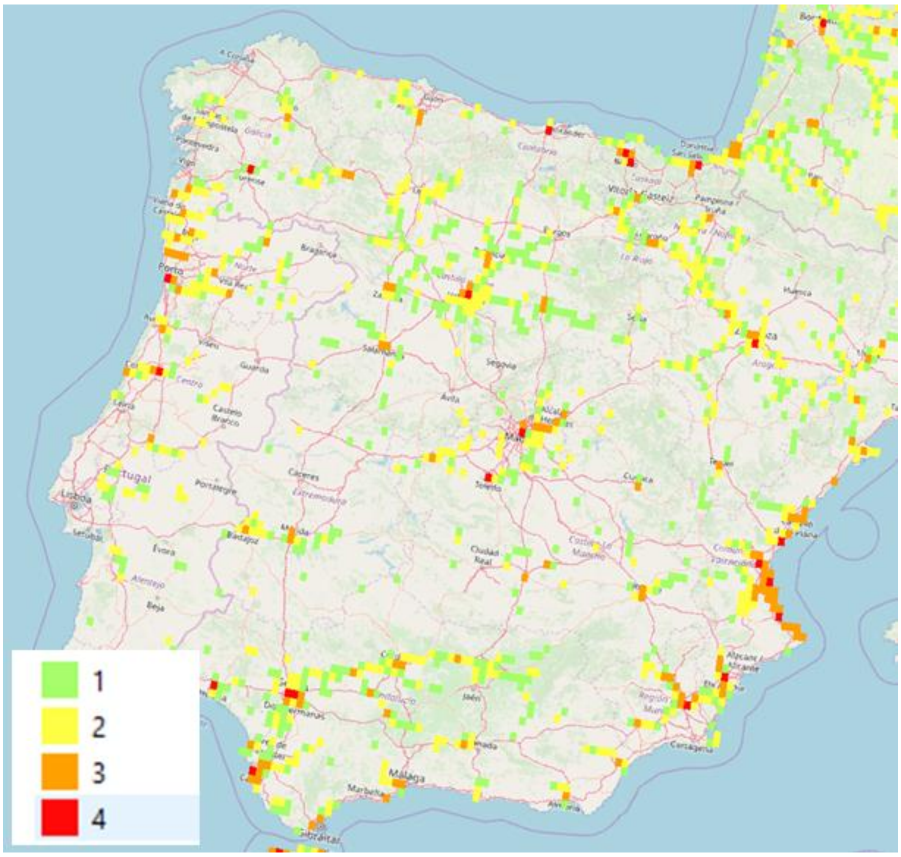

Figure 30: A global risk index for floods for Spain. Source: Global Risk Data Platform

More detailed hazard and risk maps for flood can be found on the website of the Ministerio para la Transición Ecológica (Ministry for the Ecological Transition[14]).

4.2.2 Wildfire

Concerning maps of wildfire for Spain an estimation of the average fire density over the period 1997-2010 is provided by the Global Risk Data Platform. The map unit (figure 31) is the expected average number of event per 0,1 decimal degree pixel per year multiplied by 100 (e.g. 64 value means 0.64 events per year).

[14] https://www.miteco.gob.es/es/agua/temas/gestion-de-los-riesgos-de-inundacion/mapa-peligrosidad-riesgo-inundacion/

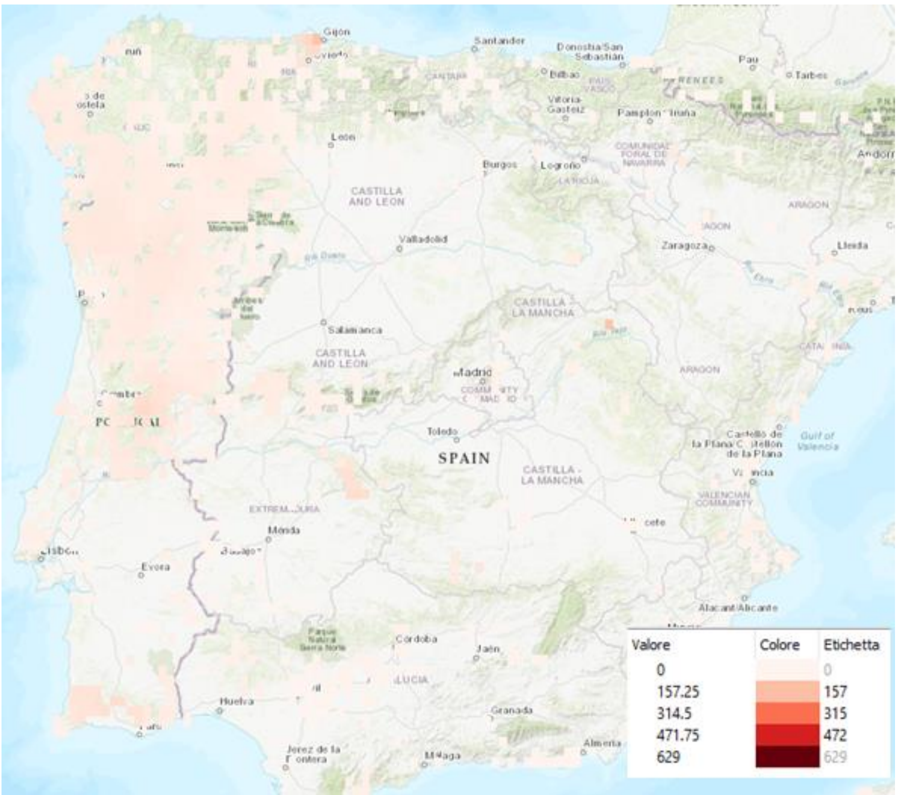

Figure 31: Fire density map for Spain and Portugal. Source: Global Risk Data Platform

4.2.3 Heatwave

In Spain the Agencia Estatal de Meteorología (AEMET), i.e., the Spanish meteorological agency, provides general meteorological information. It gathers climatological data, operates climate monitoring and seasonal and long-term forecasts. A summary of standard and extreme values of some meteorological indicators is provided for the period 1981-2010, for each meteorological station. Also, a summary of the values of rainfall and wind that exceeded the thresholds is provided for the latest four months. The regional projections of climate indicators give a forecast of several meteorological variables (such as: max and min temperatures, rainfall, wind velocity, soil moisture, humidity, 95^{th} and 5^{th} percentile of maximum and minimum temperatures, etc..) up to 2100 for different scenarios. Besides data on forecasts, historical data are also available for the mentioned variables for the period 1961-2005. The data are furthermore divided as a function of the global and regional models utilized. As an example, Figure 32 depicts the average maximum temperature in August 2005 (C^0).

Other database providing information on meteorological variables are the NASA Earth Observations (see section 3.2.4) and the European Climate Assessment & Dataset project (see section 3.2.6) databases. The first provides information on: average land surface temperature [day], average land surface temperature [night], global temperature anomaly, land surface temperature anomaly [day], land surface temperature [day], etc... As an example of the type of data available, the land surface temperature (C^0) for July 2018 is depicted in figure 33. The colours on these maps represent temperature patterns of the top millimetre (or "skin") of the land surface as observed by MODIS in clear-sky conditions for the time period indicated. Yellow shows the warmest temperatures (up to 45°C) and light blue shows the coldest temperatures (down to -25°C). Black means "no data."

Finally, the European Climate Assessment & Dataset project (ECA&D) provides an accessible database of different meteorological variables[15]. The indices belonging to the "temperature" group are: mean of daily mean temperature; mean of daily minimum temperature; mean of daily maximum temperature; mean of diurnal temperature range; intra-period extreme temperature range; mean absolute day-to-day difference. The information is provided on a daily basis. Figure 34 displays an example of the dataset and it shows the maximum temperature for the 1rst July,2017.

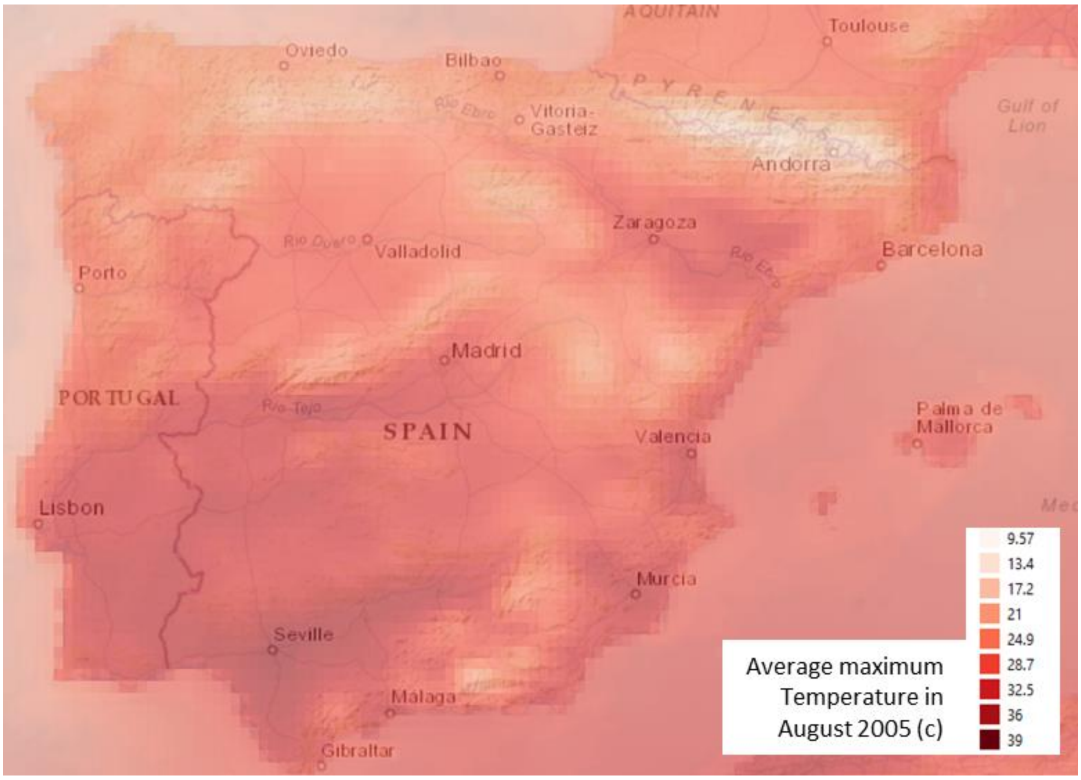

Figure 32: Average maximum Temperature in August 2005 (C0). Source of the dataset: Agencia Estatal de Meteorologia (AEMET)

[15] https://eca.knmi.nl/download/millennium/millennium.php

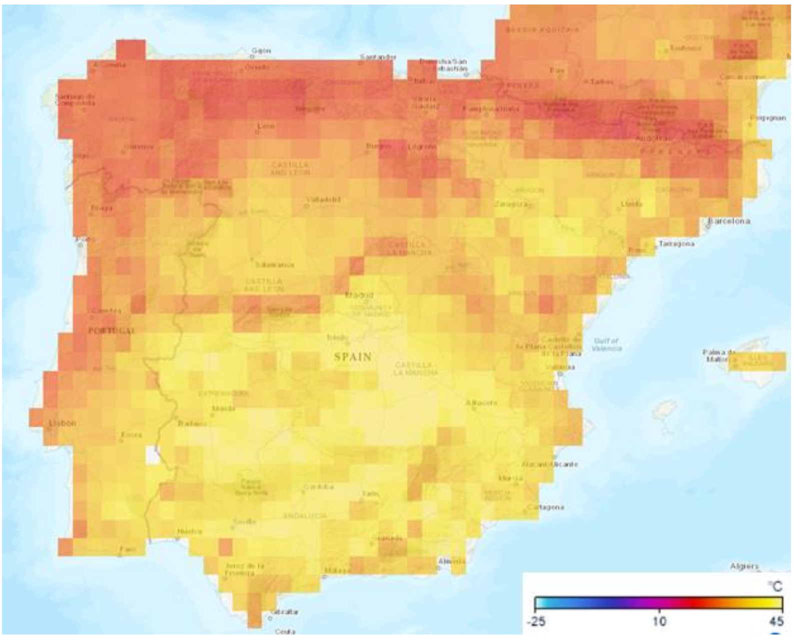

Figure 33: Land surface temperature (C0) in July 2017. Yellow shows the warmest temperatures (up to 45°C) and light blue shows the coldest temperatures (down to -25°C). Source of the dataset: NASA Earth Observations (NEO)

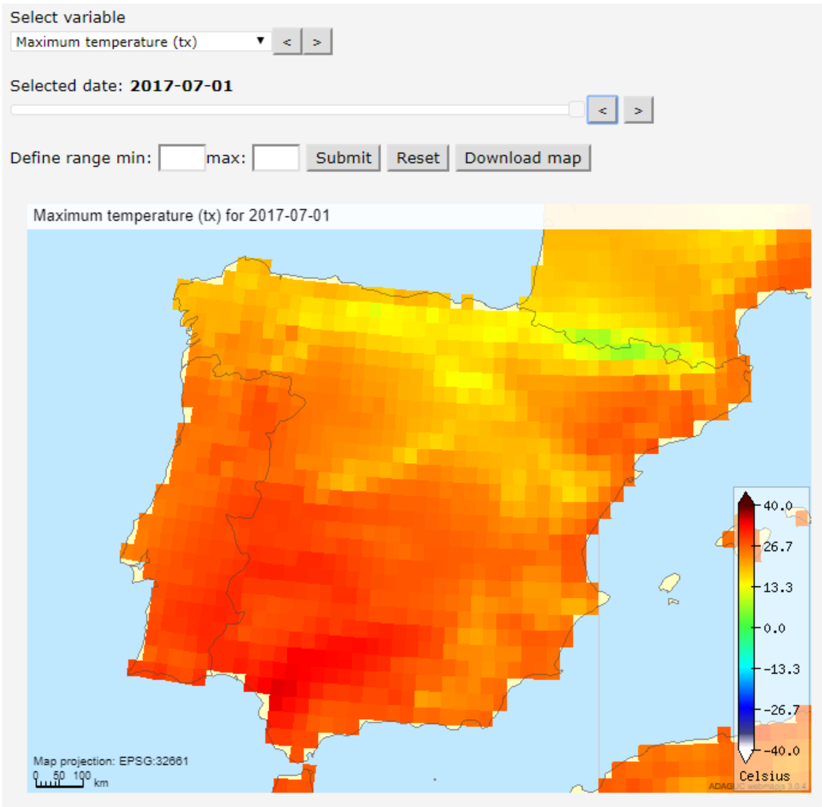

Figure 34: Maximum temperature for the 1rst July 2017. Source: European Climate Assessment & Dataset project

4.3 United Kingdom

4.3.1 Flood maps

The UK government publish several flood maps: flood risk from reservoirs, risk of flooding for land-use planning for England and development advisory map for Wales. There is also a 5-day flood risk map.

In addition to these, a new map (beta version) has been published on long-term flood risk. The map is a general indicator of an area's flood risk from rivers, the sea, surface water and some groundwater (**¡Error! No se encuentra el origen de la referencia.**). Flood risk is classified as high (risk >3.3%), medium (1.1%> risk < 3.3%), low (0.1%> risk < 1%) or very low risk (risk <0.1%) for floods from rivers or the sea as well as from surface water, while flooding from groundwater or reservoirs do not have a risk classification (The British Crown, 2019a).

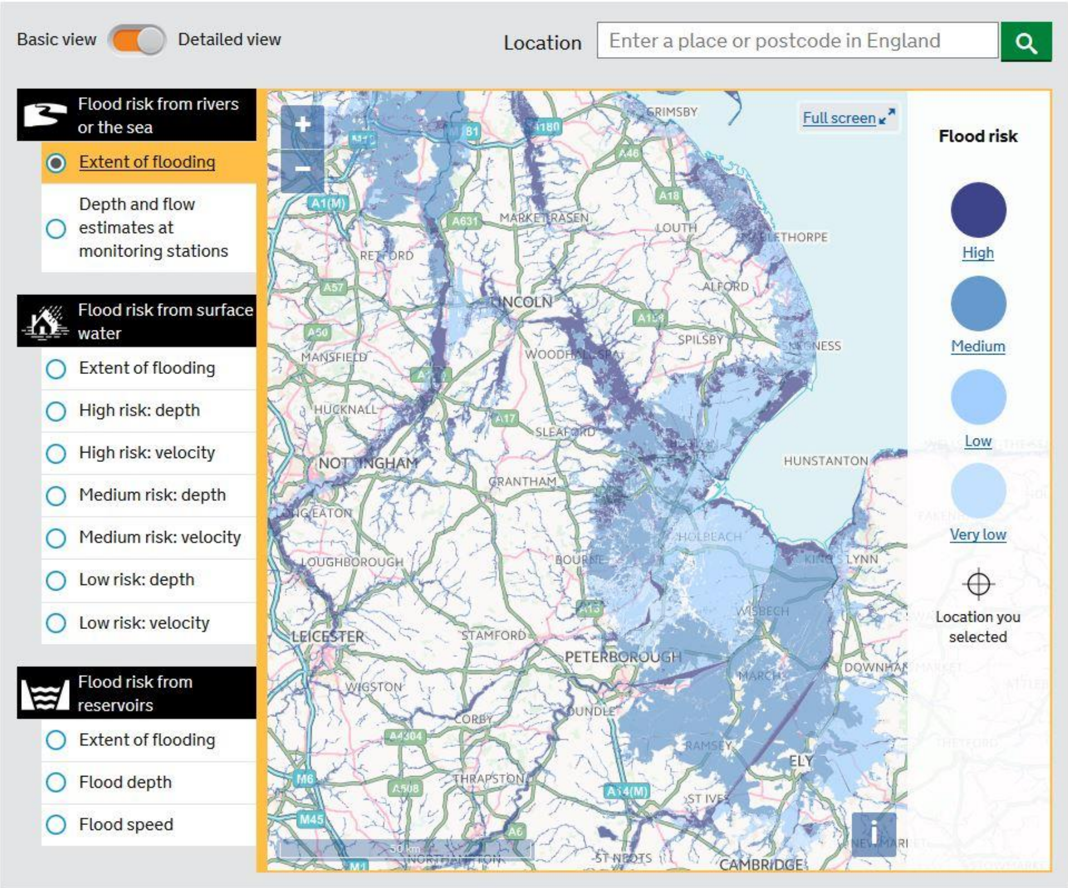

Figure 35: An example map from the long term flood risk map provided by the UK government (The British Crown, 2019a).

Flood maps for planning are published by the UK government as a useful tool for flood risk assessment for planning application. The maps include flood zones (classed from 1-3), flood defences, river and any flood storage areas (**¡Error! No se encuentra el origen de la referencia.**). Here, the floods are modelled without any defences ("natural" flooding). Zone 1 is low probability, zone 2 medium probability and zone 3 high probability (Figure 37). The flood zones in the maps for planning do not take climate changes into account.

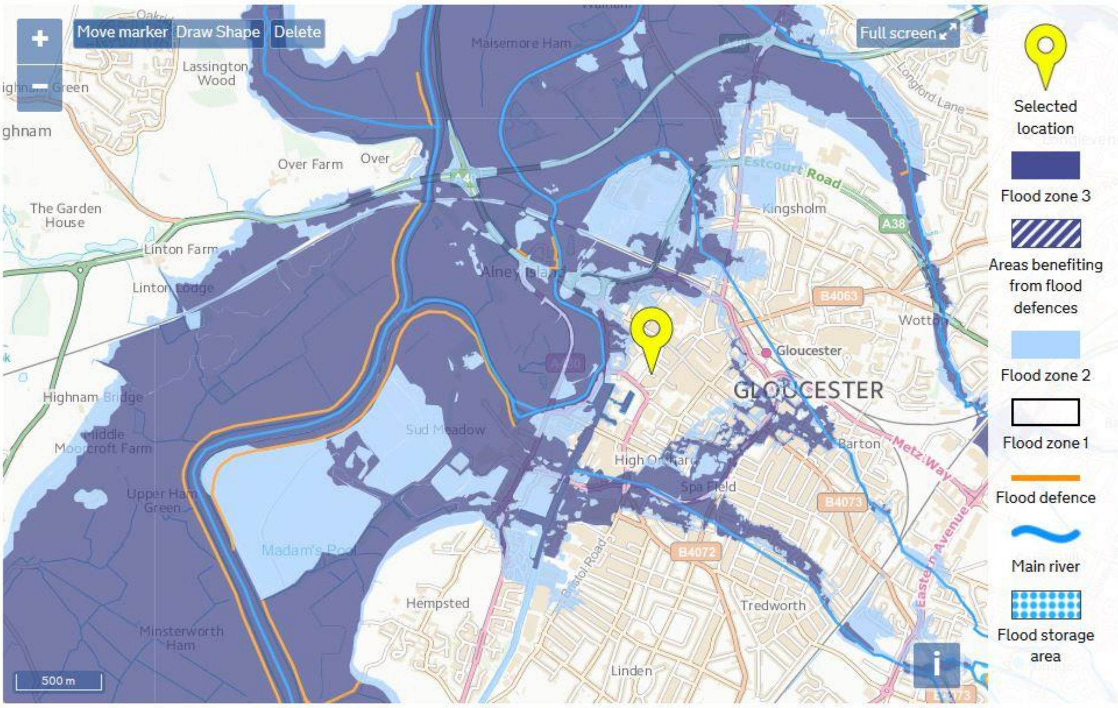

Figure 36: Flood map for planning tool from the UK government (The British Crown, 2019a)

Flood Zone	Definition
Zone 1 Low Probability	Land having a less than 1 in 1,000 annual probability of river or sea flooding. (Shown as 'clear' on the Flood Map – all land outside Zones 2 and 3)
Zone 2 Medium Probability	Land having between a 1 in 100 and 1 in 1,000 annual probability of river flooding; or land having between a 1 in 200 and 1 in 1,000 annual probability of sea flooding. (Land shown in light blue on the Flood Map)
Zone 3a High Probability	Land having a 1 in 100 or greater annual probability of river flooding; or Land having a 1 in 200 or greater annual probability of sea flooding.(Land shown in dark blue on the Flood Map)
Zone 3b The Functional Floodplain	This zone comprises land where water has to flow or be stored in times of flood. Local planning authorities should identify in their Strategic Flood Risk Assessments areas of functional floodplain and its boundaries accordingly, in agreement with the Environment Agency. (Not separately distinguished from Zone 3a on the Flood Map)

Figure 37: Flood zone classification for planning (The British Crown, 2019a)

4.3.2 Wind maps

The UK meteorological office publishes a wind map with up to 5 days forecast, but no hazard maps are freely available. However, the met office has a commercial service for the insurance industry (and other interested parties), where early alerts on windstorms are available, as well as a catalogue of windstorms used for hazard and risk modelling.

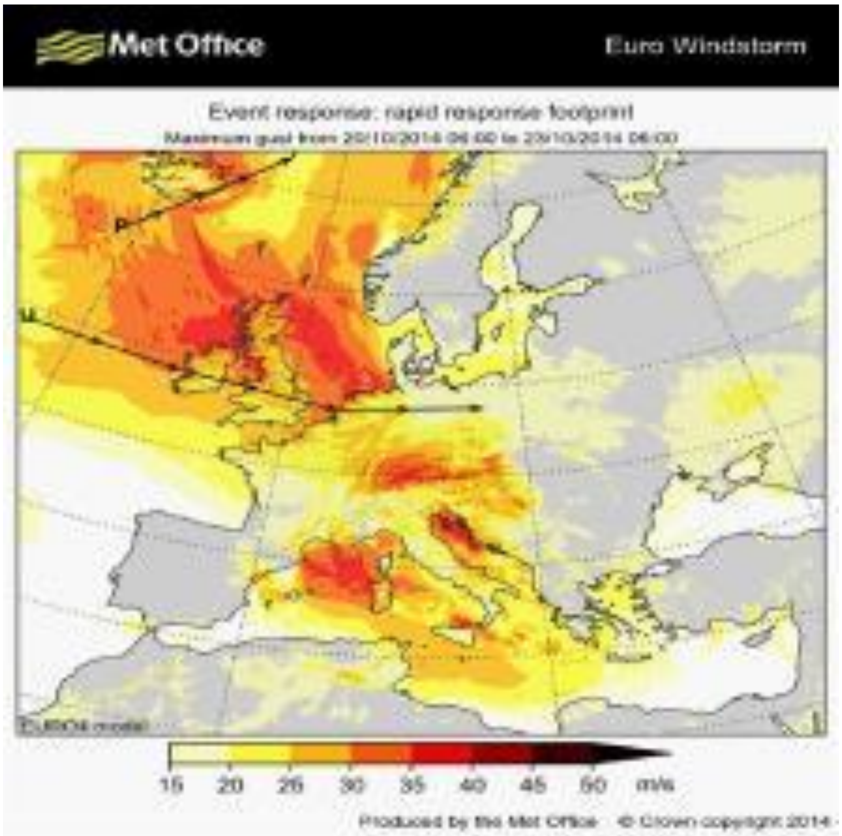

Figure 38: Windstorm modelling (The British Crown, 2019b)

The Global Wind Atlas (Global Wind Atlas, 2019) is a free, web-based application developed to help policymakers and investors identify potential high-wind areas for wind power generation. The tool facilitates online queries and provides freely downloadable datasets based on the latest input data and modelling methodologies. Users can additionally download high-resolution maps showing global, regional, and country wind resource potential.

The current version of the Global Wind Atlas (GWA 2.0) is the product of a partnership between the Department of Wind Energy at the Technical University of Denmark (DTU Wind Energy) and the World Bank Group (consisting of The World Bank and the International Finance Corporation, or IFC). It is part of the global ESMAP initiative on Renewable Energy Resource Mapping that includes biomass, small hydropower, solar and wind.

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