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Transboundary Storm Risk and Impact Assessment in Alpine Regions

DELIVERABLE D5.2
MULTI HAZARD RISK MAPPING

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1 INTRODUCTION

Proper and careful urban and regional planning passes through the assessment and mapping of the natural risks from which the community of a given territory is potentially threatened. Risk reduction associated with any instability is implemented through actions aimed at mitigating or reducing loss and damage by controlling the natural event or protecting exposed elements. Risk mitigation can therefore be addressed through actions to reduce hazard or improve vulnerability. The preliminary and fundamental phase of this process is however the mapping of hazard, vulnerability and risk.

Maps are designed by expert to convey in a prompt and efficient way the characteristics of defined hazards. The use of maps has several advantages, in comparison to numerical data: i) they allow the hazard to be visualised across a whole territory; ii) they often deliver the message in a faster and more efficient way; iii) maps can be understood by people not speaking the local language (even if several maps are translated in several languages), iv) the use of visual information on a topographic base is more understandable, especially if known spatial references are highlighted (i.e. a river, or administrative borders).

The creation of multi-risk maps requires a significant effort in terms of time, data and resources, therefore the availability of such products is quite limited. The World Bank has created a global-scale multi-risk map for natural hazards that visualise the risk in terms of simple indexes (e.g. potential loss, mortality) (Dilley M., 2005). The Federal Emergency Management Agency of United States [2] has developed a GIS-based tool, HAZUS (FEMA2011, 2011), to estimate potential losses related to several hazards. The New Zealand RiskScape, developed by GNS Science (GNS NIWA, 2010; Schmidt J., et al., 2011), and the GIS-tool CAPPRA (Bernal G., 2010), developed by Central American Coordination Centre for Disaster Prevention (CEPREDENAC), allow a quantification of potential losses related to natural hazards, considering the interaction between different hazards and possible secondary hazards. However, such maps are rarely intended for the wide public, and given the complexity of the analysis, they usually based on long-term investigations, and do not include the monitoring of the current situation and the development of the risk. In order to capture different approaches to maps design, we have included hereby multi-hazards maps, and in some specific cases, where it is useful for the comparison of design choices, even single-hazard or single-risk maps. There are different approaches for the design of multi-hazards maps, with a common goal of trying to convey a message that is comprehensible,, useful, and consistent to everybody, and possibly immediately understandable, especially in the case of maps used for civil protection purposes (Kundu S. & Nawaz M., 2019). Each map is designed in order to fulfil its goals, and the choices of time and spatial scale, as well as the frequency of update of the map, the graphic choices, and the additional features, must be in accordance with its purposes. Maps related to hazard, risk and vulnerability can be produced for very different goals. From the review of a wide selection of maps undertaken for this study, three main goals have been identified for the creation of multi-risk maps:

- **Scientific Information**: Maps are usually developed by scientists and research institutes, to report a specific situation, show the results of recent findings, or represent the outcomes of models developed in order to explain specific phenomena. This kind of maps usually have a strong scientific component, and maps usually display with accuracy the results of the study;

- **Transmission of technical data**: risk and hazard maps are developed to be of support of professionals and policy makers, in order to define appropriate actions for risk reduction, by addressing the hazard itself, or modifying the territorial vulnerability via regional and local planning;
- **Communication with the population:** local maps are developed to inform the population about an incumbent hazard, or on the development of a current situation. This maps can be an integrated component of specific civil protection plans. Specifically, this kind of maps aims to:
    - Inform about regions that may be affected by some risk
    - Inform about infrastructure that may be affected by some risk
    - Suggest or prescribe site-specific behaviour or safety rules
    - Indicate possible institutional aids and services available to the population in the area

  Some studies have explored the use of maps and the features that make a map a better support for stakeholders, like civil protection authorities , or more easily understandable by the public (Dallo I., et al., 2020).

Several times the main goal of a map can be an hybrid of two different tasks, and some platforms may even have imbedded multiple maps, in different modalities, responding to different requirements.
This report analyses the design choices behind a selection of maps, produced by different nations and bodies, and to compare those choices to the goals and the context of the map. The study presents a selection of maps that have been considered significant, and analyses their characteristics, especially in terms of design choices. The maps shown in this report focus on natural risk, such as intense weather events, floods, landslides, avalanches, earthquakes, etc. Specifically, this report will focus on: temporal and spatial scale, the use of multiple single-hazard maps, or the use of a summary single map, the design choices to represent the risk/hazard distribution. In the last part, the specific case of maps used for civil protection purposes is analysed, especially in relation to intense weather events, or storms, taking into account the different design choices for the inclusion of warnings and possibly behavioural recommendation. The different platforms are then analysed in the light of common best practices for the visual content of risk maps.

1 Hazard Vulnerability and Risk

A multi-risk assessment should start from the analysis of its basic components, so the characterisation of possible hazards, and an analysis of the elements at risk, through an evaluation of their exposure and vulnerability. Hazards are the phenomena occurring in nature that may lead to fatalities and economic/environmental/social/etc losses. Exposure express the presence of elements at risk, which may include human lives, but, in broad sense, even infrastructures, economic facilities, cultural and social networks, or other (Field C. , et al., 2012); however, most specialist usually focus only on physical and environmental vulnerability (Glade T. & von Elverfeldt K., 2005) (Kappes M., et al. 2010). Finally, vulnerability it is expressed by the degree of damage that can be done to the elements at risk in relation to the specific hazard.

The use of multi-risk approaches has been more and more recommended in the last decades, especially when related to applications and initiatives aimed at the assessment of risks derived from different natural and anthropogenic hazards. Specifically, the IPCC highlights the relevance of a multi-hazard approach in order to provide more effective adaptation and mitigation measures (Field C., et al., 2012).

In this study we mainly analyse the case of hazard and multi-hazard maps, as for the case of storms, or intense weather events in general. The multi-hazard concept is based on the analysis of the pertinent hazards, and possibly the correlated cascading effects, that may affect the vulnerable elements in the domain (Komendantova N., et al., 2014). (Gallina V., et al., 2016) reports two different approaches to consider both hazard and vulnerability. The first approach is a multi-hazard risk assessment (Kappes M. , 2011): it provides an analysis of different hazards, and an evaluation of the total territorial vulnerability. The second approach is a multi-risk assessment, and it considers both multi-hazard and multi-vulnerability: for each hazard an analysis of related exposure and vulnerability is carried out. The aggregation of the assessment of each individual risk allows a multi-risk index evaluation (Carpignano A., et al., 2009) (Garcia-Aristizaba A. & Marzocchi W., 2012).

At a global scale, the World Bank (Dilley M., 2005) and the insurance company Munich Re [1] have developed a large scale analysis of natural hazards, represented as localised hot-spots, through the use of specific indexes (e.g. potential mortality and economic losses). The Federal Emergency Management Agency of the United States [2] developed the HAZUS GIS-based tool to estimate the potential losses from several individual hazards, but it does not take into account any cascading effect.

The use of a hazard-by-hazard approach is usually adopted for the evaluation of the impact of individual natural hazards, such as in the case of storms and their possible cascading effects, on vulnerable systems (Kappes M., et al., 2010; Santini M., et al., 2010). The use of single-risk approaches are therefore used to study the risk arising from a specific hazard, in a defined area and within a specific time interval (Bell R. & Glade T., 2004), while it does not consider the interaction between different hazards and the assessment of the multiple risks (Glade T. & von Elverfeldt K., 2005). In this deliverable we report several cases of multi-hazard maps, where the event magnitude is either modelled or forecasted. However, we decided to mention even platforms such as DisasterAlert [3] where recent events are reported. This kind of maps do not represent the hazard entity, but the analysis of the past events, that is a key point, together with the magnitude, for the definition of final hazard. For this reason this typology of map has been included in this review.

In order to give an example of the difference between hazard and risk maps, Figure 1 shows an hazard map for earthquake and the correspondent risk map. The maps are produced within the project Global Earthquake Model (GEM), a public–private partnership initiated in 2006 by the Global Science Forum of the OECD to develop global, open-source risk assessment software and tools. GEM has built its first working global earthquake model and provides an authoritative standard for calculating and communicating earthquake risk worldwide [4].

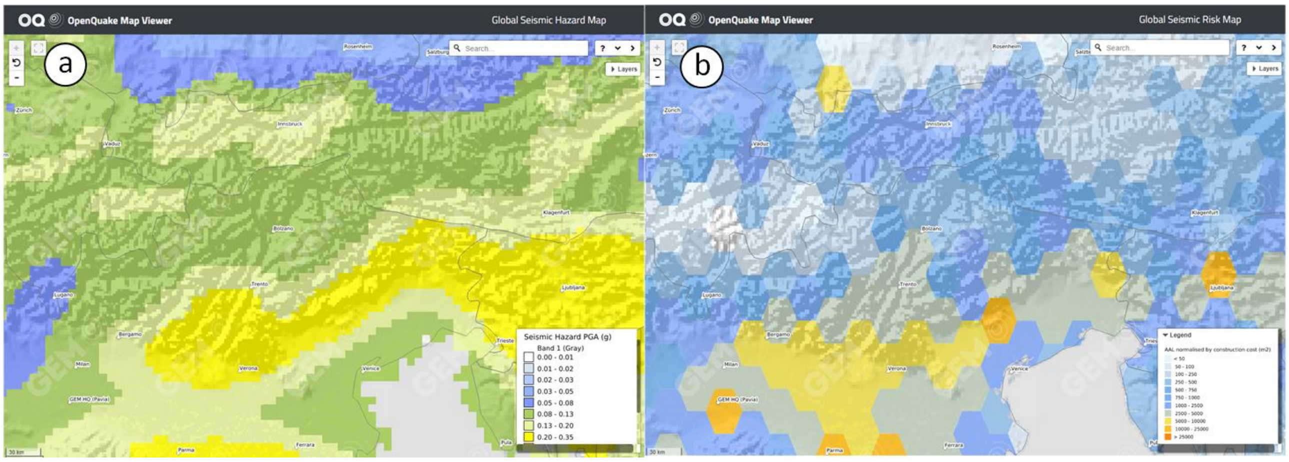


Figure 1 a) Global Seismic Hazard Map (Pagani, et al., 2018); b) Global Seismic Risk map (Silva, et al., 2018)

Figure 1.a is an extract of the north-east of Italy and a portion of Austria from the Global Earthquake Model (GEM) Global Seismic Hazard Map (version 2018.1) (Pagani, et al., 2018), which depicts the geographic distribution of the Peak Ground Acceleration (PGA) with a 10% probability of being exceeded in a period of 50 years, using as rock subsoil as reference. The map is created via the combination of national and regional seismic hazard models, and by the OpenQuake Engine, an open-source seismic hazard and risk calculation software mainly developed by the GEM foundation. An extract of the Global Seismic Risk Map (v2018.1) (Silva V., et al., 2018) is reported in Figure 1.b. It represents the spatial distribution of average annual loss due seismic events. The total loss is normalised by the average construction cost of the country, in order to allow a direct comparison of risk between different countries. It considers the damages related to ground shaking, but not the impact of secondary effects, such as tsunamis, liquefaction, landslides, and fires. The average annual losses were computed using the event-based calculator of the OpenQuake engine.

The use of multi-risk maps can give useful information on the long term, which can be used for planning new infrastructures and for policy maker to develop strategies of adaptation throughout the territory (Gallina V., et al., 2016). However, the creation of such products requires significant resources, both in terms of data, time and economic investment. Furthermore, they do not really work in the short-term, such as in the case of forthcoming extreme weather events. For storm-like events, the vulnerability of the population can be greatly reduced by the intervention of Civil Protection authorities, throughout the communication of the risk, local intervention and behavioural recommendations. The use of maps for this purpose is of great help, as they can be used to clarify the distribution of hazards, risk levels of areas that may be affected, and possibly convey useful information from local authorities (Haynes K., et al., 2007). Maps are as a matter of fact a fundamental elements of emergency plans, where they play a key role in the coordination of actions, to the extent of possible evacuation in the most affected areas (Dymon U. & Winter N., 1993) (Nourbakhsh I., et al., 2006).

In this report the use of hazard maps and risk maps are explored, considering the different design choices in the light of their purpose.

2 Maps Characteristics

Maps may vary greatly accordingly to the purpose they were designed for. We hereby explore through some significant examples the following technical and design choices of the selected maps: spatial scale, temporal scale, the use of hazard-by-hazard maps or the presence of a single summary-map and the adopted simbology.

1.1 SPATIAL SCALE

The scale of the map is related to the level of detail that wants to be reached. Therefore, a risk or hazard map can be displayed at a world scale, when it wants to give a general overview of the situation globally, at a national scale (especially when related to the management of critical situations, so that the framing of the problem corresponds to the administrative borders), or even at a more local scale, in specific situations.
Several platforms report risk and hazard at a world scale [3], [4] (Field C., et al., 2012). These kind of maps want to give a general overview worldwide about the hazardous situation, or current events occurring.
Disaster Alert is a platform reporting hazardous events from all over the world. The hazards included in the webpage are: Earthquakes, Tornadoes, volcanic eruptions, floods, etc. The vulnerability is taken into account by adding layers about population density and demography, infrastructures, and hydrography, such as rivers, lakes and dams. An evaluation of risk is given in the form of colour coded maps about Volcano density, Earthquake intensity zones, Storm intensity zones and tectonic plate boundaries.
An example of the maps produced by the platform DisasterAlert is shown in Figure 2: at the top we find the PDC Active Hazard layer, that presents a collection of current and real-time incidents which have been considered to be potentially hazardous to people, property or assets by PDC DisasterAWARE decision support system. Each event is reported as an icon, representing the typology of hazard. The colour of the icons is dependent on the severity of the situation reported. Data are provided by different sources, i.e. warnings from local authorities, analysis of satellite, aerial observations and ground observations, etc. At the bottom of Figure 2, the second map represents the hazard of tropical storms, expressed as storm intensity zones, each area representing a range of wind intensity in Km/h. This dataset is derived from the Munich Reinsurance Company's World Map of Natural Hazards [1]. This data layer shows zones based on the probability of occurrence of storms falling within five different wind speed categories of the Saffir-Simpson Hurricane Scale, the scale used by the National Weather Service to give public safety officials a rough estimate of a tropical storm's potential for wind and storm surge damage. The Storm Intensity Zone layer shows areas where each of these wind speed categories has s a 10% probability of occurring within the next 10 years.
The first map is kept up to date and shows only relatively recent events (icons are shown for a period of time depending on the entity of the hazard), therefore is useful to give an overview of the current situation, but it is necessary to access the complete database of events to get an idea of the frequency and probability of specific events occurring. The second map is indeed based on a long-term collection of past events, in which the magnitude has been recorded as well, and a statistic analysis has been done to define the hazard classes. However, it does not give up-to-date information on the current or recent situation.

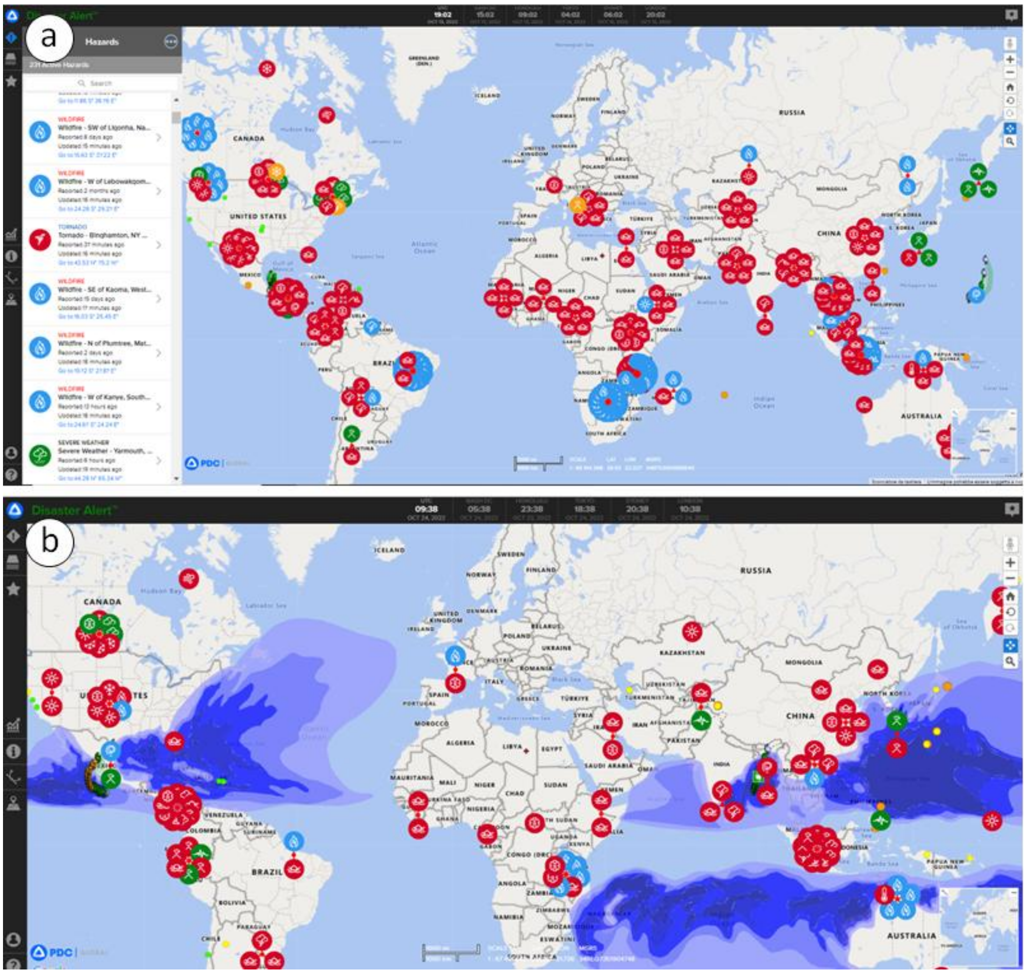


Figure 2 Disaster Alert (Disaster Alert): a) PDC Active Hazard; b)map for Storm Intensity zones

National wide maps [5, 6, 7, 8, 9], or lower levels of administrative boundary maps [10] are usually issued by local authorities, and they may want to give information about the current situation, or the distribution of risk/hazard. An example of national platform with the aim to inform about the hazard distribution, but without a purpose related to civil protection actions, is the GIS based Informative Multi-risk map created in Switzerland [11]. The FOEN service of Switzerland (Federal Office for the Environment) is responsible for the protection against natural hazards, safeguarding the environment and human health against excessive impacts, and conserving biodiversity and landscape quality. The office has created a Web-GIS application containing information about several environmental issues, from biodiversity to soil, water and air quality. Specifically, it has site-specific information about Natural Hazards, obtained mainly by geomorphological data (Losey S. & Wehrli A., 2013). The map section related to natural hazard has been created within the project SilvaProtect-CH, trying to assess the effect of the protective forest against main natural hazards. It is possible to visualise multiple layers on the map, but the interaction between different hazards and possible cascading effects it is not taken into account.

The natural risks reported are:

i) related to slope instability (i.e. Landslides, Debris Flow and Rockfall): map of the potential release areas based on the modelling of the avalanche process, ignoring the possible protective contribution of the forest

ii) Avalanches: map of the potential release areas based on the modelling of the avalanche process, ignoring the possible protective contribution of the forest

iii) Earthquakes: this layer reports the location and intensity of recent earthquakes, and seismic zones

iv) Windstorm Gusts and Dynamic pressure: The maps provide a country-wide basis for the estimation of the regional windstorm risk, calculated on the basis of 83 winter storm periods between 1871 and 2011 and the 20th Century Reanalysis global data.

Maps that use a local scale usually provide a great level of detail. An example are the maps produced for specific hazards, such as volcanic hazard, where the hazard maps are usually reported with great detail, as they must convey information about the hazard distribution in a clear way, possibly in relation to physical elements (strets, rivers, etc), in order to be immediately understandable (Cronin S., et al., 2004; Leonard G., et al., 2014). An example, related to the case of avalanches, is the creation of evacuation plans in relation to different critical heights of snow (Menegus F. & Martinelli M., 2019).The avalanche runout is calculated though a dynamic avalanche model, which returns the runout and the flow height, pressure and velocity of the avalanches. The elaboration of the models for the small settlement of Corte (BL) is shown in Figure 3: this plans were elaborated following VAIA storm, when the loss of the protective forest above several villages in the area had lead to the creation of several new potential release sites for avalanches. Given it nature and its purpose, the map is highly detailed, and reports precisely the runout of the avalanche for different snow heights: red for 35 cm, orange for 70 cm, yellow for 120 cm, and green for a snow height corresponding to a return period of 100 years. The blue dots identify the buildings to evacuated, the purple line the roads portion to restrain access to, and the white triangles the points at which to close the road.

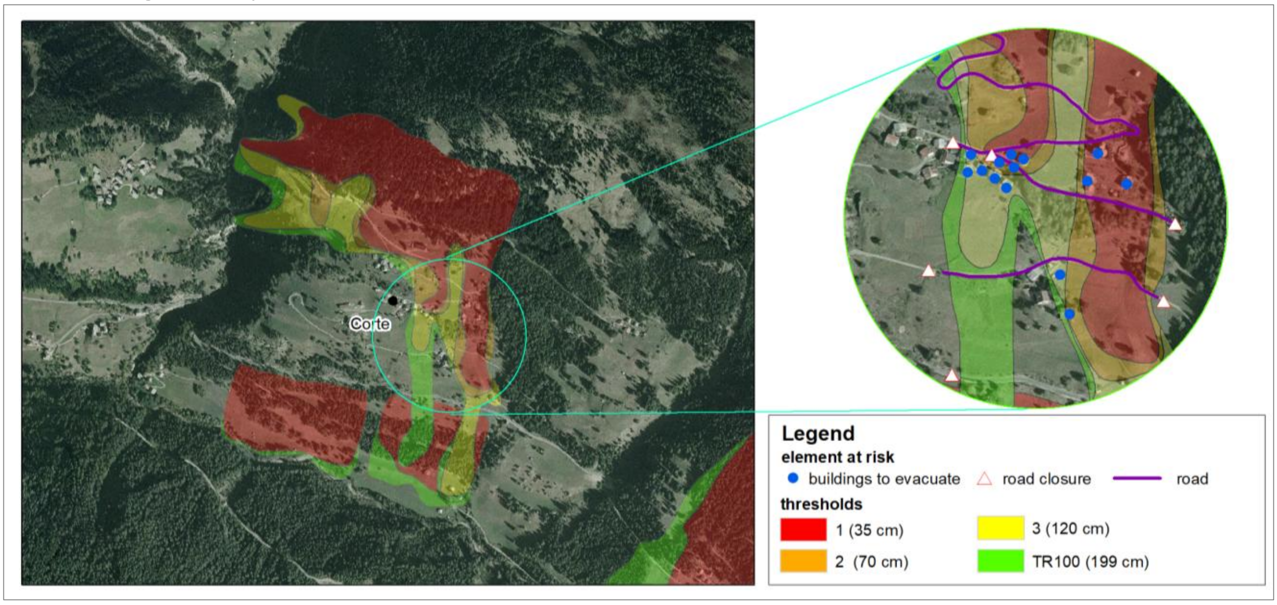


Figure 3: extract from civil protection plans for the settlement of Corte (BL)

Another examples of national and local scale are the maps created by the Project ANYWHERE [12](Figure 4). The maps developed within the project are supposed to be a tool in support of civil protection organism, in order to predict floods and forecast the evolution of wildfires. The model is a flood forecasting system (Figure 4.a) (Pignone F., et al., 2020), based on rainfall observations and prediction to provide a quantitative evaluation in terms of ground effects in terms of discharge and peak flow. The visualised maps shows the rivers as classified in a 3 levels colour scheme, accordingly to the hazard category. Figure 4.b shows a typical output of the model PROPAGATOR developed within the ANYWHERE project. PROPAGATOR is a stochastic cellular automated model for forest fire spread simulation. It was developed as a tool for a prompt wildfire risk assessment. The model is based on high-resolution tomography and vegetation cover, and it requires information about wind speed and direction and ignition point as input parameters (Trucchia A., et al., 2020). The stochastic fire propagation process gives at each time step a map representing the probability of each cell of the domain of being affected by the fire. The map shown in Figure 4.b represent the evolution of a wildfire, through isochrones identify the simulated burnt areas with probability higher than 50%.

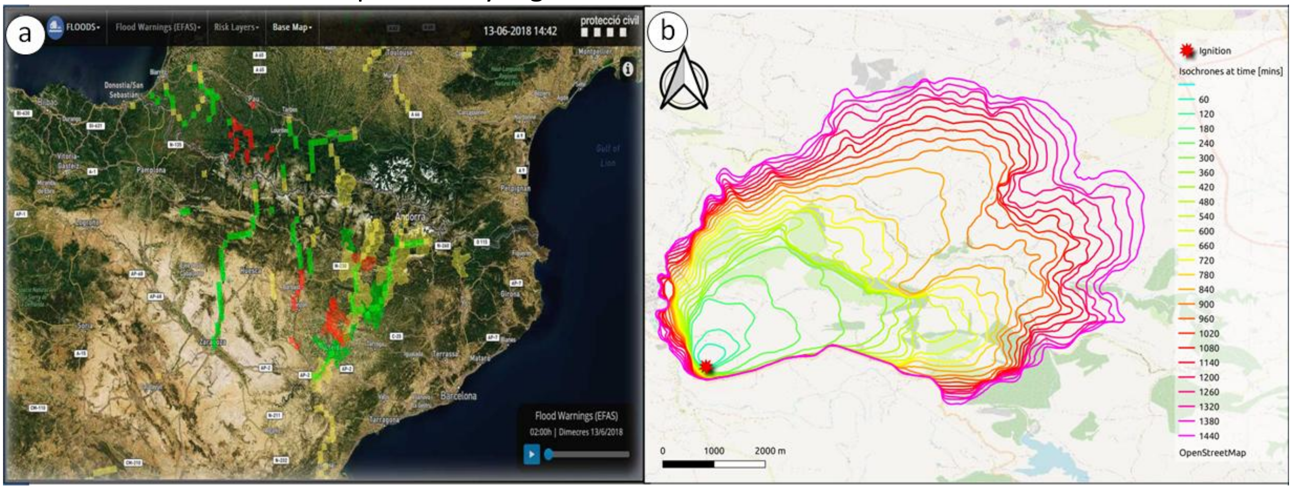


Figure 4 extract from project ANYWHERE. a) map of flood modelling; b) map of wildfire propagation projection, the isochrones identify the simulated burnt areas with probability higher than 50%.

The spatial scale of hazard and risk maps may vary greatly, from a global scale to a single settlement. Usually the size is related to the level of information delivered by the map: wide scale maps will give therefore quite a generic overview of the situation, while local scale maps may deliver in detail descriptions and possibly applications of dynamic models, to forecast the hazard evolution. This being the specific case of the avalanche simulation and the tools developed by the ANYWHERE Project.

An interesting exception is the Italian database for slope instability phenomena, called IFFI (Inventario dei Fenomeni Franosi in Italia), and the maps of hazard and risk indicators, produced by ISPRA on the Idrogeo platform [13]. In these two cases, maps are available at a national scale, but with a very accurate level of detail. The level of detail is given by the process of data entry is based in fact on the collaboration of local bodies, which are in charge of keeping the database up to date for the area concerning them.

1.2 Temporal scale

The temporal scale of a map may vary from long-term, short-term, real-time, to various degrees of forecasting. The selected scale depends on the hazards described, and especially on the purpose of the of the visual aid created.

Usually, maps adopting a long-term scale derive their data from historical series of events, (Dilley M., 2005) (Field C., et al., 2012), which can be a useful information to identify the probability of occurrence or the return period of certain events. This kind of maps are extremely useful for policy makers and for planning future development efforts and economic investments. The maps produced by the World Bank (Dilley M., 2005) analyse the hazardous areas at a world scale, depicted in the maps as hotspots of increasing intensity, as for the relevance of the specific Hazard in the area (Figure 5).

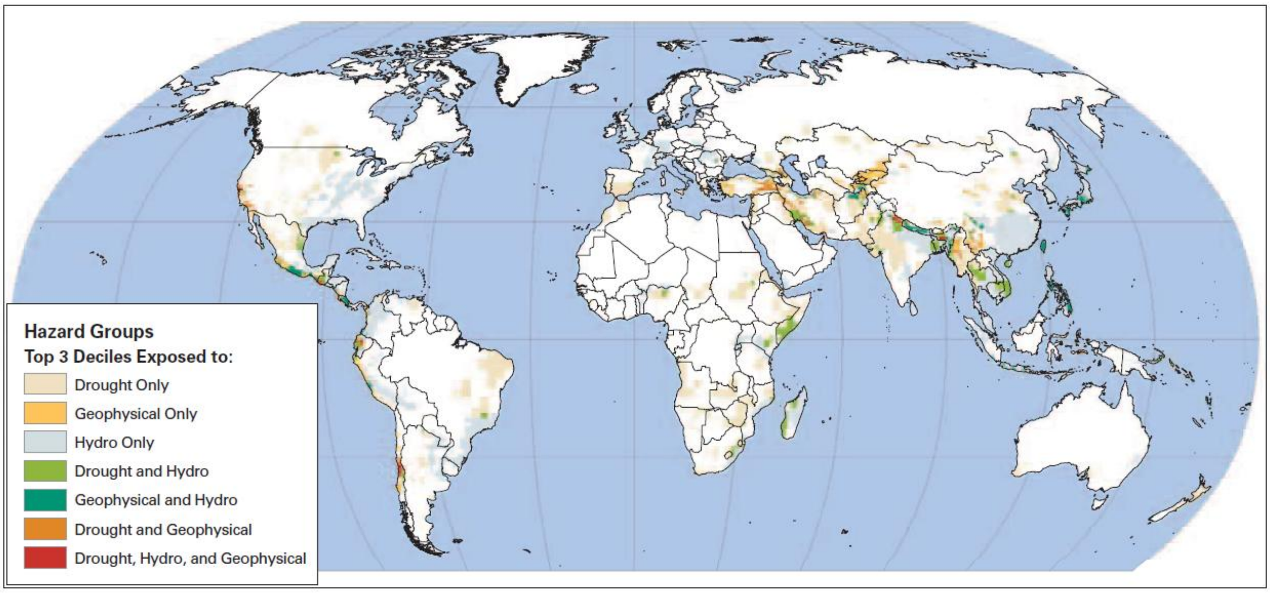


Figure 5 Global distribution of Areas Exposed to one or more hazards, by hazard type (Dilley, 2005)

Data come from the Emergency Events Database (EM-DAT) [14], a global disaster database maintained by the Centre for Research on the Epidemiology of Disasters (CRED) in Brussels. This project has attempted to develop a global, synoptic view of the major natural hazards, assessing risks of multiple disaster-related outcomes and focusing in particular on the degree of overlap between areas exposed to multiple hazards. The overall goal is to identify geographic areas of highest disaster risk potential in order to better inform development efforts.

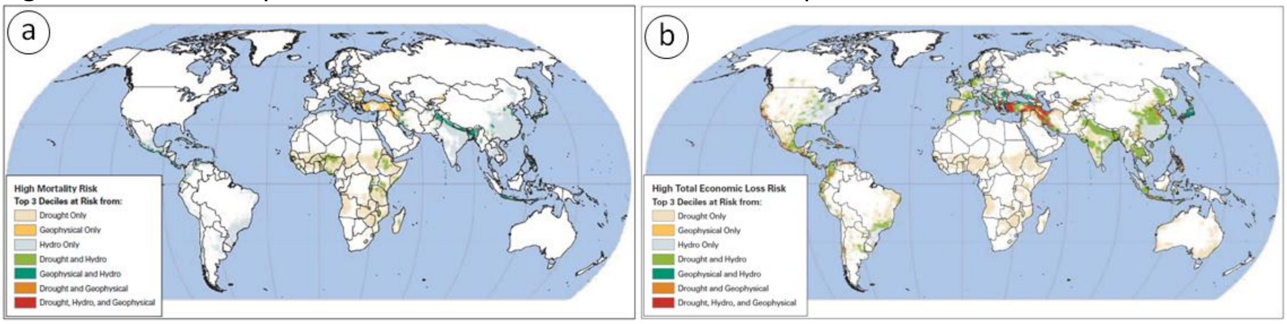


Figure 6 Global distribution of highest risk disaster hotspots by hazard type: a) Mortality Risk; b) Total Economic loss risk

The maps shown in Figure 6 report the assessed risk of two disaster-relates outcomes: mortality (Figure 6.a) and economic loss (Figure 6.b) . The risk levels were calculated considering the hazard exposure from the available dataset, and the historical vulnerability from gridded population and gross domestic product (GDP) per unit area. The hazards considered are: earthquakes & volcanoes (geophysical hazard), landslides & floods and cyclones (Hydro), and drought. Single hazard regions are represented in pastel colours in the three maps reported, while the combination of two or three hazards is represented in light green, dark green, bold orange and red.
The use of short-term maps have usually the aim of monitoring events, and their development. Instead of being of support for long-term planning, they share information, both globally and locally, in order to “react” to events, or share information about the development of the situation. An example is Disaster Alert [3], a platform that we already in the previous paragraph (Figure 2). The web-based map displays updated information about recent events or even warnings from government entities, world-wide. Data about events come from national warnings or from satellite/aerial/on ground interpretations (e.g. for the case of volcanic hazards). The development of hazard maps, such as the volcano density, the seismic zones and the tropic storms intensity

zones (Figure 2.b), however, is based on the long-term analysis of events recorded in the database.
The use of real-time maps, adopting short-term forecast techniques, is of great use for civil protection applications, especially at a regional or national scale. This is the case for several app-based maps, intended for civil protection purposes, and to share warnings with the population, such as AlertSwiss for Switzerland [5], NINA for Germany [7] or, for the specific case of weather alerts, Unwetter Zentrale for Germany [8] and Vigilance Metèo France [9], among others.
NINA (Notfall Informations- und Nachrichten- APP) (Figure 7) is an APP designed in Germany for civil protection purposes. The map shows the affected areas in Germany, in a colour-coded scheme for an easy interpretation of the hazard severity. By selecting the area it is possible to obtain further information about the hazard, and behavioural reccomendation issued by authorities. It is posssible to register the user preferences, selecting the specific areas and the level of hazard for which to receive a warning. The app contains flood information, weather warnings (from severe weather to storm and estreme storm), to general Civil protection warnings. It includes information about health hazards, related to covid or contamined water, or other sources.

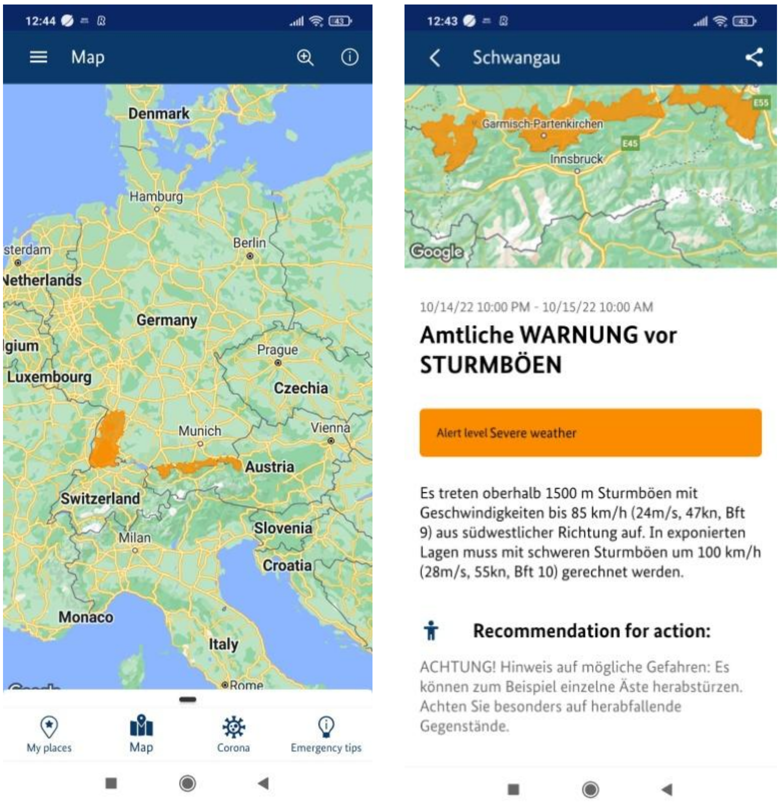


Figure 7 NINA –Notfall Informations- und Nachrichten- APP (Germany)

In addition, the application of models may allow to forecast the appearance or evolution of the event. This is especially the case for maps developed by research institutes and universities. An example are the models produced by the project ANYWHERE, already described in the previous paragraph, where the different models forecast the evolution of hazardous areas due to floods (Figure 4.a) or the propagation of wildfire, based on topography, vegetation cover, and wind characteristics (Figure 4.b). This kind of products may be of great interest for civil protection purposes, once their reliability is assessed. Several models for flood forecasting are already in use in several CFDs (Centro Funzionale Decentrato, regional support to Civil Protection for early warning systems) all over Italy. In the case of Veneto region, the model relies on a network of hydrometers and rain gauges spread along the most relevant waterways, and on a simplified geometry of the main rivers, to determine the changes of flow rate and eventually issue a warning when critical flow height are reached.

Some efforts are done in the scientific community to develop an approach for multi-risk assessment under, addressing cumulative climate change impacts on different natural and human system and activity. This would have to take into account natural climate variability, and biophysical and environmental aspects of vulnerability (Gallina V., et al., 2016). The analysis can only be done at a climatological scale (20-30 years), and with a coarser spatial scale. We are now at a preliminary stage, where some climatological projections are produced. An example is reported in Figure 8, showing a map produced by IPCC (Field C., et al., 2012). It represents the projected return periods for the maximum daily temperature that was exceeded on average once during a 20-year period (1981-2000). A reduction of the mean value corresponds to an increase of extreme events frequency. Projections are made for the period 2046-2065 and 2081-2100, under 3 climatic scenario (B1, A1B, A2). The map is extremely synthetic, reporting values for a 20 year period, considered for macro-regions.

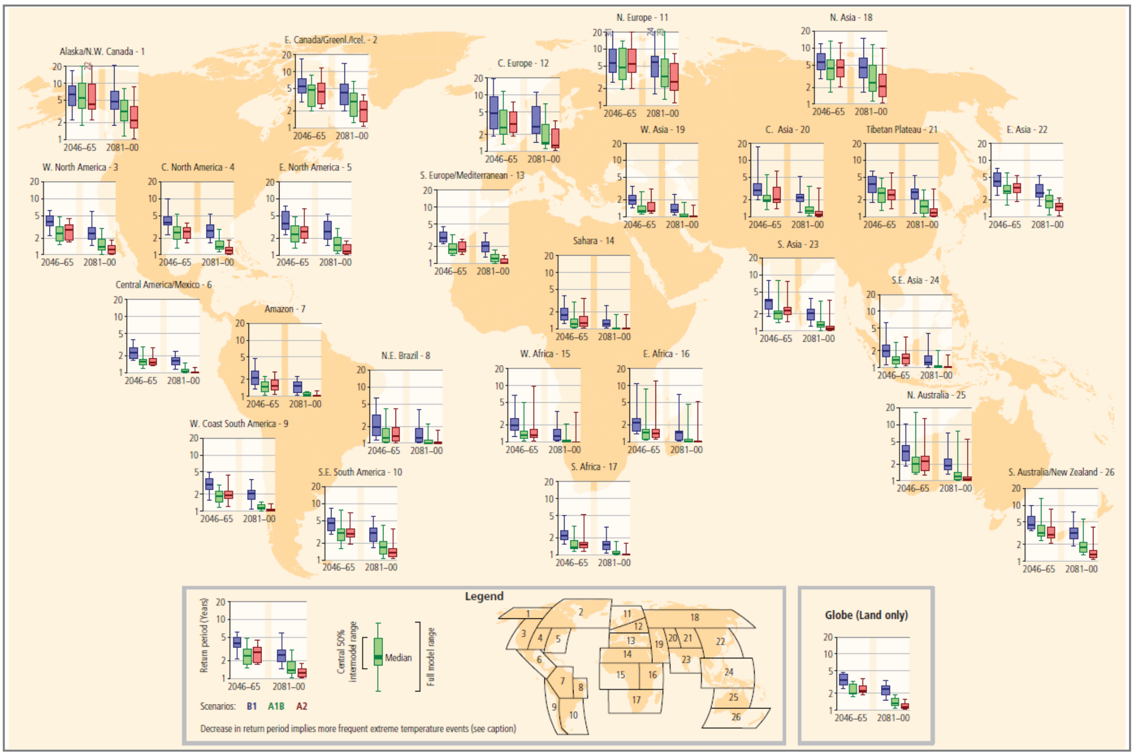


Figure 8 Projected return periods for the maximum daily temperature that was exceeded on average once during a 20-year period (1981-2000) (Field C. , et al., 2012)

1.3 Single map – Multiple map

The approach to multi-risk maps may be via singular maps of each hazard/risk analysis, or via the use of a synthetic map, containing a summary of the single maps. In both cases, areas threatened by an impending hazard are usually coloured according to the corresponding hazard category, from green to red, or from yellow to red. In addition, in the case of a single map, an icon related to the higher-level of hazard may be associated to the affected region, in order to communicate at a first glance the specific hazard encountered.

The use of multiple maps is commonly adopted for weather early warnings services [8, 9]. In some cases they are used to assess the hazard level at the regional scale, producing an independent map for each hazard. This is the case of the map produced by ARPA Piemonte for hydrogeological hazards [10], the district multi-hazard maps produced by the state of Odisha in India [15], and the maps produced by the project ThinkHazard! [16]. *ThinkHazard!* provides a general view of the hazards, for a given location, that should be considered in project design and implementation to promote disaster and climate resilience. The tool highlights the likelihood of different natural hazards affecting project areas (very low, low, medium and high), provides guidance on how to reduce the impact of these hazards, and where to find more information. The hazard levels provided are based on published hazard data, provided by a range of private, academic and public organizations. An example of the maps produced by ThinkHazard! is shown in Figure 9: at the top of the image is represented the selection bar, containing the icons for the hazards reported: River flood, Urban flood, Costal flood, Earthquakes, Landslides, Tsunami, Volcano, Cyclone, Water scarcity, Heath Wave and Wild Fires. Maps are produced only if relevant for the selected country. The lower part of the bar is colour coded, accordingly to the maximum hazard level for each phenomenon. In the lower part of the image (figure 9) are reported two different maps related to the hazard of Landslides in Austria: i) the map on the left represents the susceptibility to landslides, calculated with regards to rainfall patterns, terrain slope, geology, soil, land cover and (potentially) earthquakes that make localized landslides a frequent hazard phenomenon; ii) the map on the right represent an homogenised hazard level for each sub-region. The hazard scale is here of 4 colour levels. The maps produced have the intent of being of support to designers or other professionals, they do not need a frequent update and work on the long-term scale. The website is used give a general overview about the country, it reports the local agencies in charge of giving more in-detail information about the specific hazard.

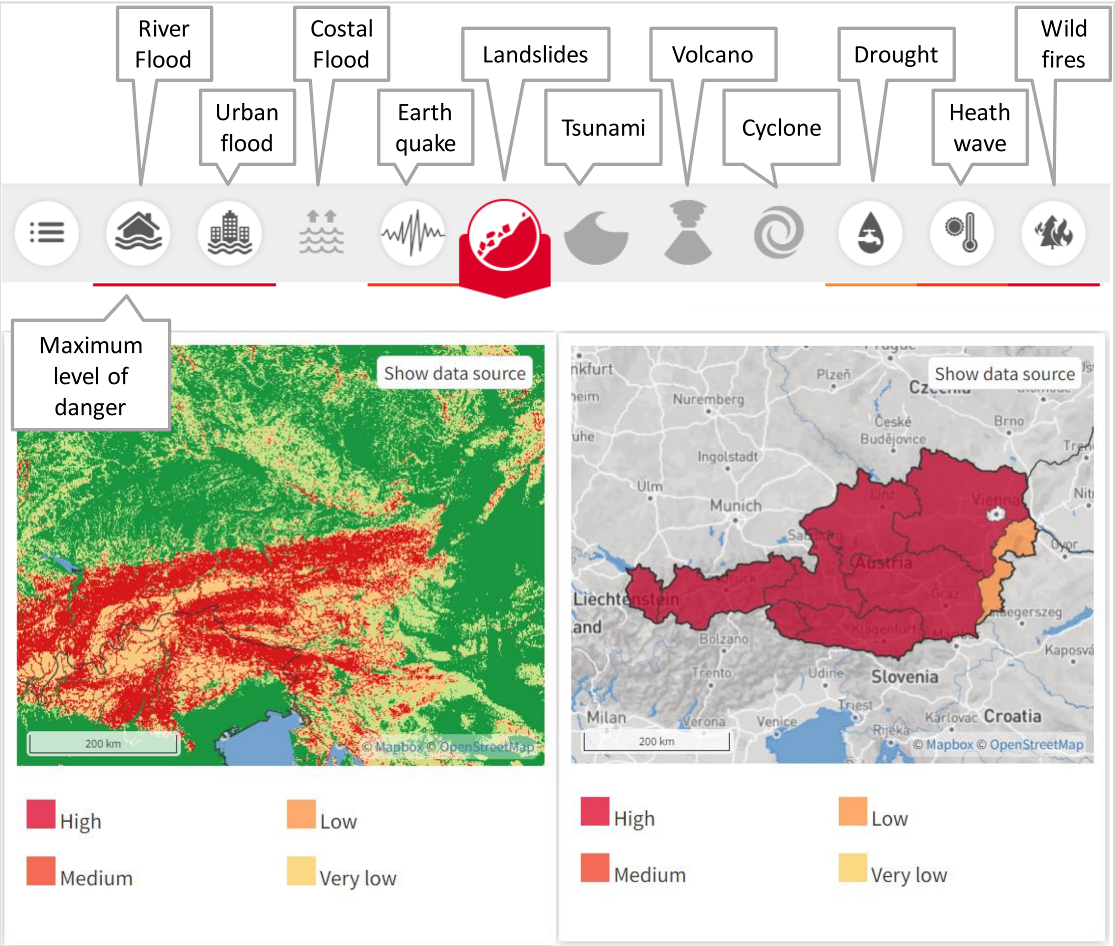


Figure 9 Excerpt from ThinkHazard! webpage, regarding the hazard of Landslide for the territory of Austria. The upper bar allows the selection of the hazard-specific maps. Below, map of the susceptibility to landslides on the left, and the omogeneised hazard level by sub region

An interesting example is the case of the portal Current Natural Hazards created by Switzerland [6]. The webpage presents the possibility to display the hazard distribution both as a single map (Figure 10.a) or represented as a collection of the maps for each hazard (Figure 10.b). This map is designed to be a tool for direct communication with citizens for Civil Protection purposes. As it is shown in Figure 10, the map represents Switzerland, and the territory is divided into sub-areas. In each area, the single hazards are taken into account and it is defined a level of danger. Hazard taken into account are: forest fire, flood, frost, heath wave, rain, slippery roads, snow, thunder storm, wind, avalanches, earthquakes. Various Swiss government agencies are in charge of monitoring the natural hazard situation, and are responsible for issuing appropriate warnings in the event of an impending hazard. The warnings are issued by each individual agency on a scale of 1-5 to identify the hazard category for each hazard warning instance. Whenever an area is affected by 2 or more hazards, only the higher level is displayed. In order to display the higher hazard level for each category, a bar (Figure 10.c) is represented above the main map, containing the icons for all the hazards reported in the map, and the colour of the higher level of each hazard for the current situation. Furthermore, just below the main map a written summary is reported, containing the description of each hazard, the hazard level from 1 to 5, colour coded accordingly from green to dark red, and useful links to explanation of the danger and behavioural suggestions.

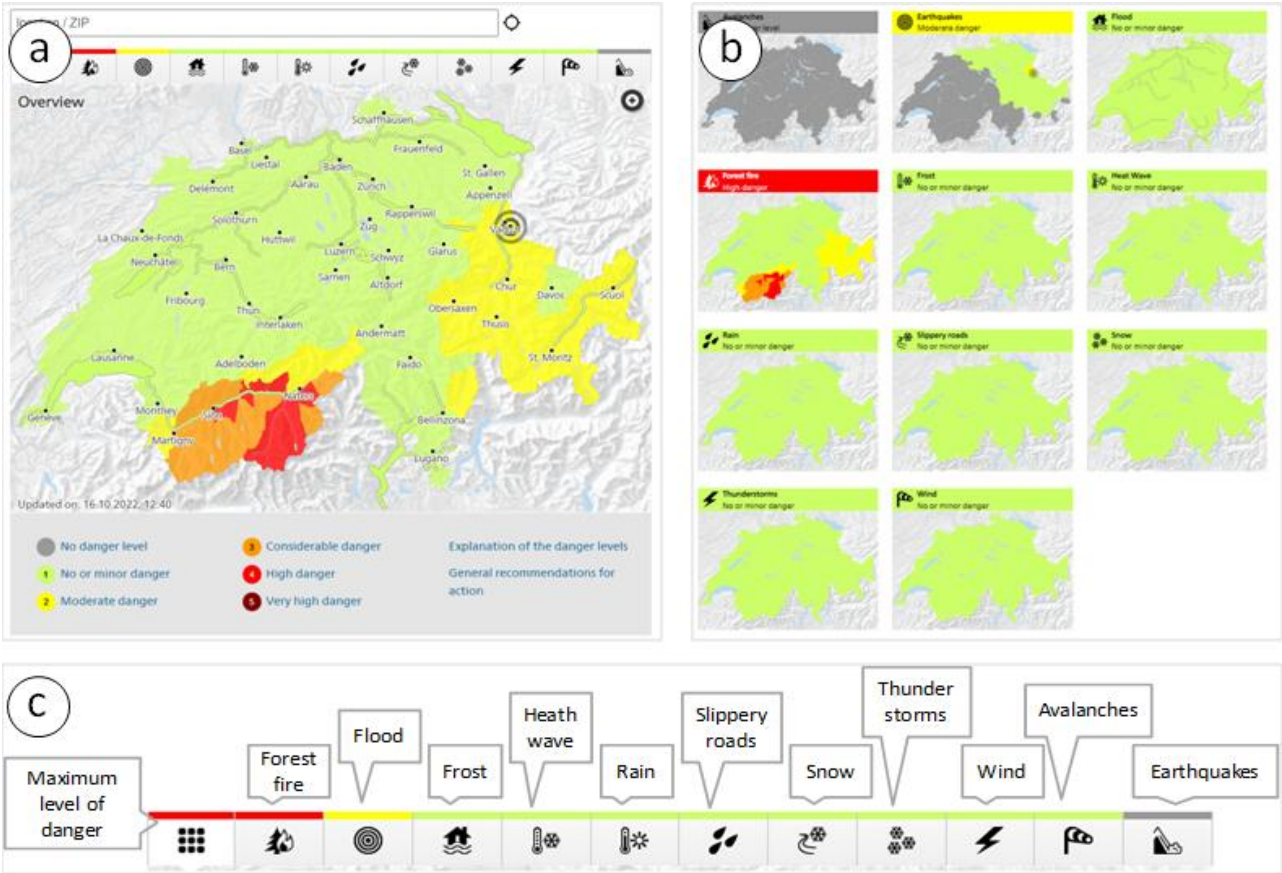


Figure 10 Current natural hazard situation in Switzerland. a) hazard distribution displayed on a single map; b) the hazard distribution represented as a collection of the maps for each hazard. c) the summary bar of all the hazard represented

Switzerland made available both options, i) a unique map summarizing all the current hazards, and ii) a collection of maps, each one describing the hazard distribution for one specific aspect all over the country. However, the summary map seems to be preferable: it is set as default option and it appears in the main page. A study done by (Dallo I., et al., 2020) on users preferences showed how the use of a single map is indeed considered to be preferable to multiple maps by users.

1.4 SYMBOLOGY

Communicating the content of a map in a precise and comprehensible manner is the key element in hazard mapping (Thompson M. A., et al., 2017) (Marti M., et al., 2019). It was observed that the use of certain colour schemes could lead to the misinterpretation of maps information (Haynes K., et al., 2007), and the use of standardised colours in relation to hazard, or alert, levels, may help communications and the understanding of maps (Fearnley C. & Beaven S., 2018).
The hazard classifications and icons vary across the different platforms. The geographical hazard distribution over a given domain is usually represented as: i) shading of the area over a continuous palette; ii) classification onto hazard levels/classes with clear borders between them; iii) identification of a significant hazard class for each administrative area. An example of the three different approaches is represented in Figure 11, with a selection of maps showing earthquake hazard distribution at national level.

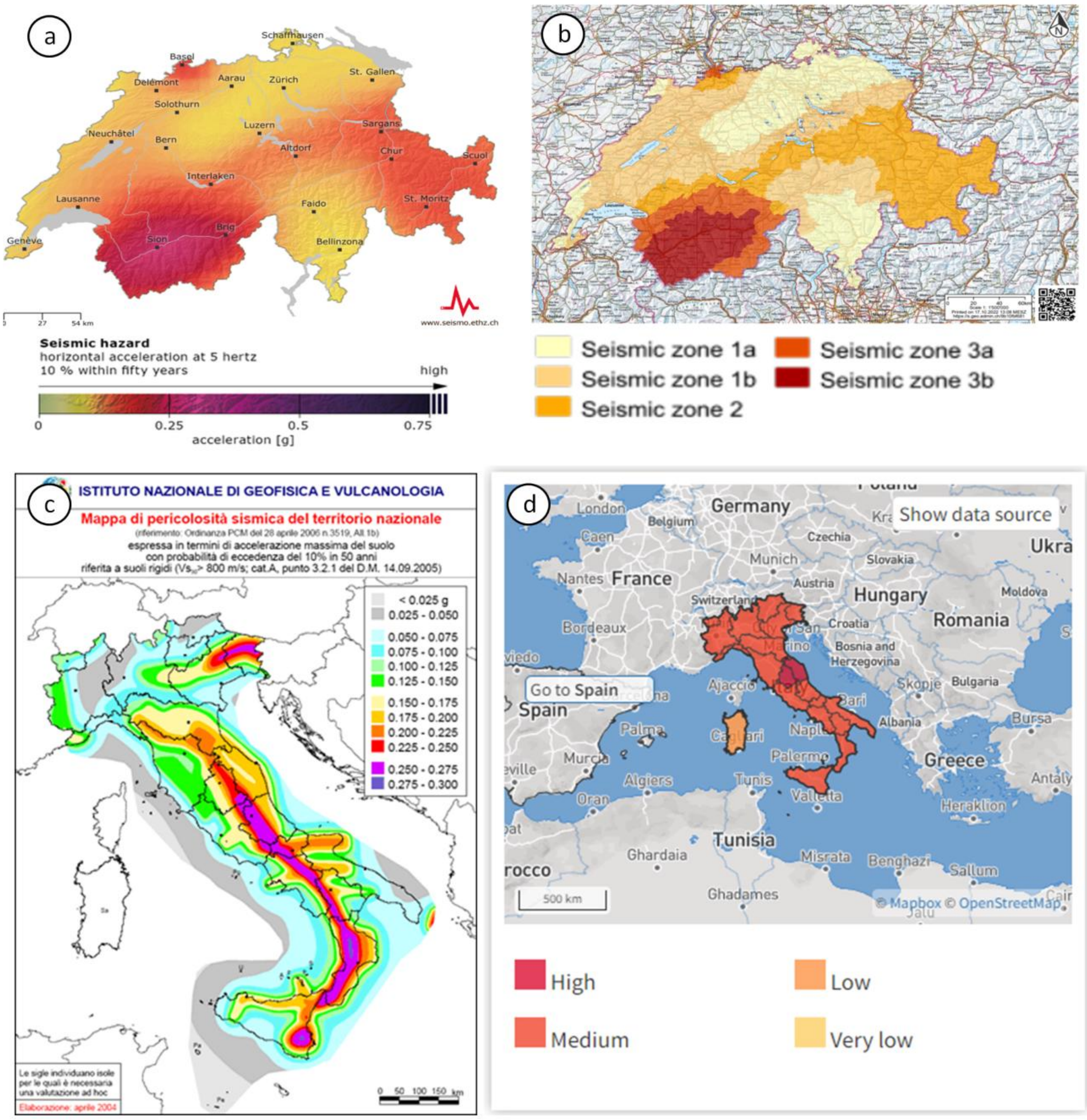


Figure 11 Seismic Hazard maps: a) Swiss seismic hazard maps (Swiss Seismological Service); b) Seismic zones SIA 261 (Federal Office for the Environment; c) "pericolosità sismica di riferimento per il territorio nazionale" (Istituto Nazionale di Geofisica e Vulcanologia; d) Eathquakes hazard distribution (ThinkHazard!).

Figure 11.a represents the expected horizontal acceleration at 5 Hz caused by an earthquake with a return period of 500 years (10% of probability of exceeding such acceleration in a 50 years time frame), considering a reference homogeneous rock subsoil [17]. The map is the output of the Seismic Hazard Model 2015 for Switzerland, based on integrated knowledge of tectonics and geology, information about the history of earthquakes, damage reports and wave propagation models (Wiemer, et al., 2016). The expected accelerations scale spans between 0g and 0.75g, even though only a shorter range is represented on the map for a return period of 50 years. The acceleration distribution is represented as a continuous shade, from light yellow to dark purple, and it reflects the outcome of the model used. This is the case of other maps produced by seismic models, such as for the case of New Zealand [18]. Those maps are usually created though mathematical models, where the value is calculated for each cell, resulting in a degradation of colour shades, where it is difficult to discriminate between different values/classes of colour. A similar map about earthquakes hazard in Switzerland is shown in Figure 11.b. The map is issued by the Swiss Federal office for the Environment and it represents the seismic zones from the SIA 261 Standard “Action on Structures” (2020)[11]. It can be appreciate from the image that the national territory is divided into 5 seismic zones, with a colour scheme from light yellow to dark red. This map is used as reference by designers, the seismic project area –and related project values –can be easily identified by the identification of the specific seismic zone from the construction site location.
Another example of territory partition into hazard classes is shown in figure Figure 11.c. The map is issued by the National Institute for Geophysics and Volcanology and it represents the reference values of seismic hazard for Italy (Stucchi M. et al., 2004)[19], based on the maximum acceleration expected for a return period of 500 years. The territory is divided into 11 classes, from an acceleration <0.025g on the southern islands, to an upper class of 0.275-0.3 g, in Calabria and in the surroundings of Etna volcano. This kind of representation is common for earthquakes hazard: similar maps, with different distributions of hazard classes and colour palettes, have been conceived, among others, for United States [20], Canada [21], and at a global scale [22] (Pagani M., et al., 2018). Although the map is divided into clear and separate hazard zones, it results of difficult interpretation for a professional. For the case of Italy and the map of Figure 11.c, in order to support the selection of the right hazard zone, it is possible to access a more detailed map, containing all municipalities and the indication of the reference hazard class within a 0.05° grid. The design for the seismic hazard map for Italy is therefore a combination of the second and third design choice described above, where the hazard classes are indicated both as continuous areas and as specific administrative units. An example of the last category of design choices is represented in Figure 11.d, it is a map produced by the project ThinkHazard! [16]. The project, already presented in a previous section, is a multi-hazard platform: it collects information about different hazard, evaluated on a long-term scale, and it represents the hazard level for each administrative unit (in this case the Italian regions) with a representative hazard class for each area. The results is often an excessive simplification, but it is in accordance with the goal of the website, that wants to provide a general idea about the local hazard, and useful information about authorities and publications were in-detail knowledge and instructions can be acquired.
A fourth design choice is shown in Figure 12. The map does not strictly represent hazard levels, but it points out reported hazardous events from all over the world. The map is issued by GDACS (Global Disaster Alert and Coordination System), a cooperation framework between UN, EC and disaster managers worldwide to improve alerts, information exchange and coordination of efforts after sudden disasters [23]. Emergency situations are represented as icons referred to the typology of hazard (earthquake, flood, tropical cyclone, forest fires, eruptions), colour coded

according to the severity of the event (orange and red). It is possible to access a detailed report issued by local authorities by selecting the interest icon.

Figure 12 Alerts map at a global scale (Global Disaster Alert and Coordination System- GDACS, GDACS - Global Disaster Alert and Coordination System

There are different ways to convey information about hazard distribution throughout a large domain, that can be a region, a nation or at a global scale. As we just saw, the conventional way is the use of colour coded classifications, or continuous patterns of shading colours. This last design is mainly used for products designed by scientists, where the colour represents punctual values of a model applied. The use of continuous areas with well defined boundaries and classes of hazard represented by a single colour is normally used to give specific information to professionals, as for the cases we just saw, or to convey information in a prompt and easily understandable way; the use of classes of colours in association to administrative units works in the same way. While different representation may work fine in terms of viewers' performance when maps can be examined without time constraints, it was found out that under increasing time pressure, a spectral-colour map is the most immediately understandable for users (Cheong L., et al., 2016). This is especially true for hazard and risk maps designed for Civil protection purposes, where the requirement is for the warnings to be given in a clear and prompt way, easily understandable by users. The spectrum usually goes from green to red, or from yellow to red, including sometimes the dark red for extreme situations. There is also a considerable heterogeneity in the number of classes with which a certain risk or hazard is subdivided, ranging from 3 [23], 4 [5, 9, 16, 24] or 5 classes [6, 8].
In the case of civil protection websites or apps, the map is usually aided by some textual information, providing an explanation of the current hazard situation and possibly indications about the suggested behaviour. The case of civil protection maps and written warnings is taken into account in a later section.
An interesting use of simbology to express the geographic distribution of hazard in combination with the vulnerable elements is given by the case of Iceland SafeTravel platform [26]. Iceland is characterized by an extremely low population density, often severe weather conditions and it is characterized by several different hazards (earthquakes, volcanic eruptions, avalanches, etc). However, in recent years, tourism in Iceland has known a considerable increase , bringing people not used to Icelandic weather conditions to travel in situations they may be unprepared to face. The Icelandic Association for Search and Rescue has created a webpage containing the status of the roads and the main weather warnings and useful information (Figure 13). The tool was created specifically for the road system, not for anthropized areas, the graphic choice is to focus on the

main vulnerable elements, the roads, and to give specific information about the behaviour to keep. The colour code gives an immediate message about the situation in different areas of the country, without focusing on the hazard distribution, but only on the elements affected. The colour code, reported in the bar below the main map, expresses the condition of the different roads, from good conditions (easily passable: light green), to difficult (pink), and Impassable (red).

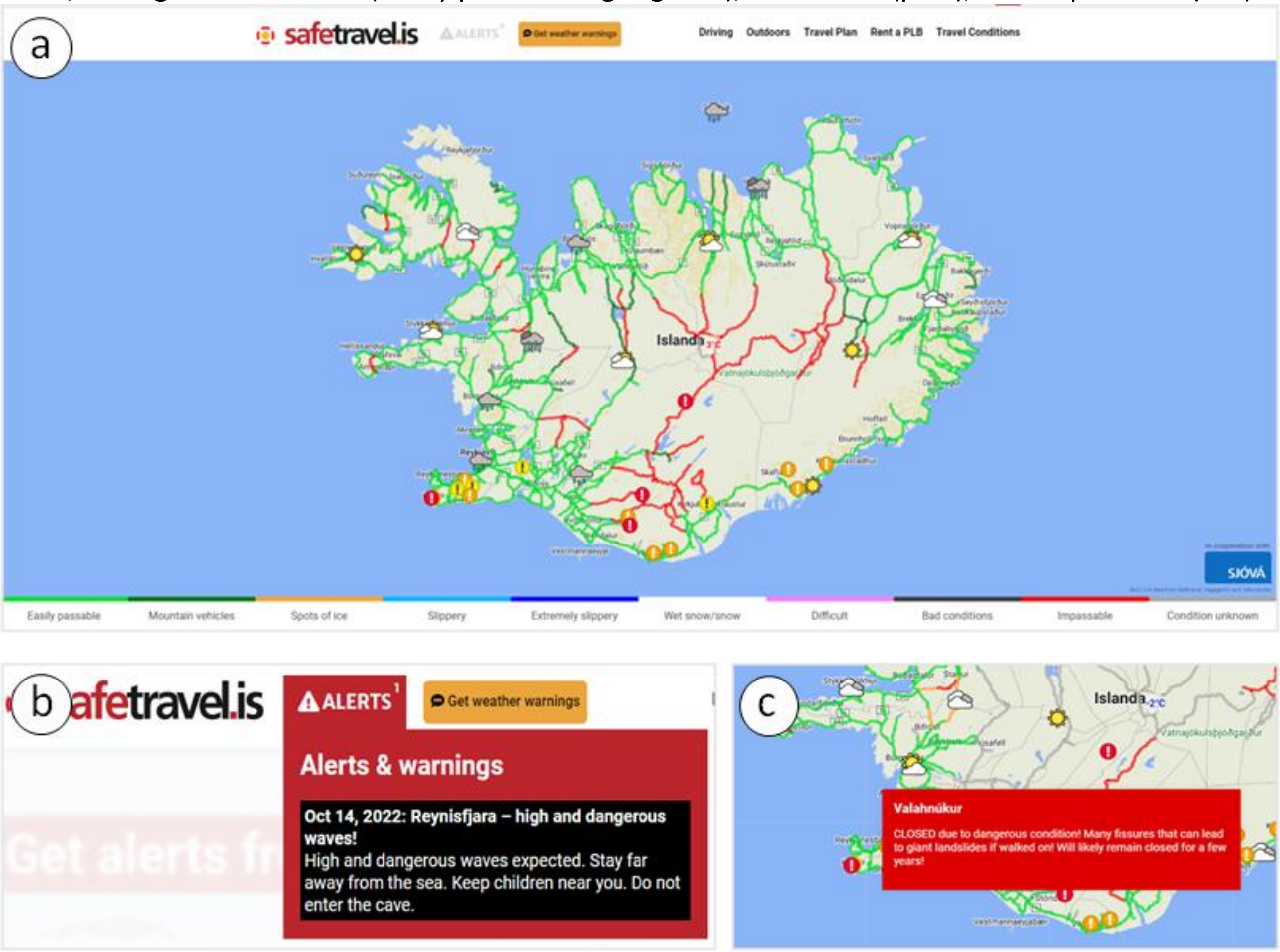


Figure 13 a) Map of Island roads condition; warnings and alerts b) as text and c) visualised on the map

3 Civil Protection maps for storm related hazard

The use of maps for civil protection purposes is of great help for the coordination of actions, and maps are indeed an integral part of emergency plans (Dymon U. & Winter N., 1993; Nourbakhsh I., et al., 2006). Even more, they have become a fundamental means of communicating hazard to the public: they are used to explain the geographical distribution of hazard and discriminate between areas that may be at different level of risk; as for the single user, they are used to promptly and efficiently identify the hazard class he should refer to, and the correlated warnings or suggested behaviours that may be of help and reduce his exposure and/or vulnerability (Haynes K., et al., 2007).

In this paragraph we present different platforms designed for the communication of current and imminent hazard to the population, through the use of web-based or App-based hazard maps. We focus especially on platform developed by local or national authorities to warn the population and

possibly recommend specific behaviours. Some best practices for visual communication in hazard mapping have been made by researchers and different visual choices have been compared.
The effectiveness of maps in delivering a prompt and clear message is extremely important in the applications related to Civil Protection, being essential for users to clearly understand the current hazards and the recommendations issued by the authorities. Examples of Apps and Websites where multi-hazard and multi-risk maps are used for Civil Protection purposes are reported in Table 1. The selected platforms are mainly focused on natural hazards, we neglected the analysis of maps purely developed for the assessment of anthropogenic hazards. The features of several maps contained in this have already been discussed in previous sections, the table summarise the main characteristics of the different tools in terms of hazard type, time scale and geographical scale. Some of the main design choices are reported: presence of recommendations for generic hazards, or hazard-specific recommendations, the presence of separate maps for each hazard and of a summary map, the homogenization of hazard scale for the different hazards taken into account.

	Name	Web Reference	Country	Hazard type	Time scale	Geographical scale	General behavioural rec.	Hazard-specific behavioural rec.	Separate maps for each hazard	One single map	Harmonized hazard categories
APP	NINA	[7]	Germany	natural, anthropogenic & socionatural	short-term & real-time	national & local	Y	Y	Y	N	N
APP	FEMA	[2]	USA	weather	short-term & real-time	local	Y	N	Y	Y	Y
WEBSITE+APP	AlertSwiss	[5]	Switzerland	natural & socionatural	long-term,	national & local	Y	Y	N	Y	Y
WEBSITE+APP	MeteoSwiss		Switzerland	primary weather,	short-term & real-time	national & local	Y	Y	Y	Y	Y
WEBSITE+APP	Umweltinfo Bayern	[29]	Germany	primary weather,	short-term & real-time	local	N	Y	Y	N	Y
WEBSITE+APP	GDAC	[23]	international	natural	short-term & real-time	global, national & local	N	N	N	Y	Y
WEBSITE+APP	WIND	[8]	Germany	weather	short-term & real-time	national & local	N	Y	Y	Y	Y
WEBSITE+APP	KATWARN	[25]	Germany	anthropogenic & socionatural	short-term & real-time	national & local	N	Y	Y	N	Y
ONLY WEBSITE	Met UK weather warnings	[27]	UK	weather	short-term & real-time	national & local	Y	Y	N	Y	Y
ONLY WEBSITE	Natural Hazards Portal	[6]	Switzerland	natural	long-term, short-term & real-time	national & local	N	Y	Y	Y	Y
ONLY WEBSITE	ARPA Piemonte	[10]	Piemonte IT	natural	long-term & short-term	local	N	N	Y	Y	Y
ONLY WEBSITE	Protezione	[28]	Italy	natural,	long-term	national	N	Y	N	N	N

	civile			anthropogenic & socionatural							
	Vigilance Meteorologique	[9]	France	weather	Short-term & real-time	national & local	N	N	N	Y	Y
	Warning Bulletin-Bolzano	[31]	Italy, Prov. of Bolzano	Weather and natural	Short-term	local	N	N	Y	Y	Y
	ZAMG Warning system	[33]	Austria	Weather and natural	Short-term	National	N	N	Y	Y	Y

Table 1 List of App and website based hazard maps for civil protection applications

The type of hazard reported in the maps depends on the selected platform. Websites associated with weather forecast offices usually represent only weather hazards, such as in the case of severe events with intense precipitations, snow or strong winds –this is the case for the German [8], the French [9] and the British platforms [27]. Other maps reports the current hazards, such as landslides, avalanches, floods, etc. This is the case for the Swiss [6], the German [7],the Austrian [33], and the Italian portal of civil protection department [28] [31]. Some platforms, usually issued by agencies with a specific expertise, may focus on a limited number of hazards, such as the case of the map produced by ARPA Piemonte for the hydro-geological risk [10].
The geographical scale of all maps is either local or national, in most cases the map is produced at the national scale and can then grant access to a local scale map [8, 9]. Most maps are subdivided into sub-areas that coincide with administrative units, like municipalities, or clusters of them [6, 7, 28]. The choice of using administrative borders as domain results to be ideal for the coordination and management of Civil Protection Action: the hazard class for each unit can be clearly identified, both by citizens, that will more easily adopt the recommended behaviour, and by local authorities, who can react accordingly and efficiently coordinate the efforts (Thompson M. A., et al., 2017).
The platforms reported in Table 1 represent two different approaches in terms of spatial scale: a part of the maps have some components based on long-term analysis, while all of the maps have at least a section based on short-term and real-time updates. As we already discussed in the paragraph about the Temporal scale, long term maps are usually based on the analysis of topographic data [6, 10], or on the elaboration of historical databases. This kind of maps can be adopted as a reference by policy makers for a more efficient land planning and the coordination of possible mitigation measures. However, as already explored, the use of maps for Civil Protection purposes related to current hazards has the requirement to give information about the evolution of the hazardous situation, both to the population and to local authorities. To do so, it is necessary to have platforms that are always kept up to date, and that work on a short-term to real-time scale, as in the case of all platforms selected for this paragraph.
Most of the platforms provide a single multi-hazard map as main page, displaying all the current hazards at national level. Only the German website Naturgefahren Bayern [29], the APP KATAWARN [25], and the Italian platform for Civil Protection [28] have only single-hazard maps. Most of the platforms adopt an hybrid solution: a main map, as default setting, in which to identify all the current hazard –possibly with a colour scale to aid in the identification of the hazard severity –and the possibility to expand the map both in its spatial scale and for the visualisation of single hazard in-detail maps. Studies on the interpretation of maps by users have in fact appreciated how an initial general overview of the situation is preferable for the overall comprehension of the map (Dallo I., et al., 2020).

Whenever two or more hazards are present in the same area, the higher class one is represented on the map. The colour scheme used is quite homogeneous, all platforms chose a spectral colour distribution, in 3 [23] to 5 levels of hazard, usually spanning from green to red, or from yellow to red, with sometimes the presence of a 5th level in dark red for extreme events [6]. Most of the maps have homogenised the hazard categories for the different hazards: the presence of maps where the same colour means different levels of hazard can be indeed really misleading in the interpretation of the information given. An exception is the German APP NINA [7]: hazardous areas are presented on the main map as semi-transparent orange or red (depending on the severity of the situation) shapes; when two or more hazards are present in the same location, the transparency allows the visualization of both areas. However, no icons are used as aid in the comprehension of the map, it is therefore necessary to select the area to access the various single-hazard maps.

1.5 COMPARISON WITH BEST PRACTISES FOR VISUAL COMMUNICATION

Researchers have made a number of recommendations to improve map comprehension, analysing the use of base maps, the importance of elements to display, the simbology used and the hierarchical structure of the information. For example, visual salience, in our case often achieved with a well-consolidated colour scale related to severity, draws the viewer's attention to the most important features (Kunz M. & Hurni L., 2011; Brewer C., 2005). And the research behind the use of icons and abstract representations, demonstrating how the use of self-explaining iconic symbols that do not need the use of a legend make the comprehension fastest and most accurate among users (Taylor H., 2005).
We hereby analyse compare the structure and visual characteristics of the maps for intense weather (among others) hazard, reported in Table 1. We selected the approach provided by (Mac Pherson C., et al., 2020) for map visual communication: the publication has developed a rubric for Hazard Map Evaluation, based on a collection of several studies. The visual component is assessed through 9 points, and it can be classified as High-performance, Moderate-performance and low-performance for each of them. The hazard map used to assess the contribution of the suggested practises to map comprehension was however representing a single state in the US. Not all of the suggestions seems therefore applicable at a national scale, such as for the case of the platforms reported in Table 1.

1. ***Aerial imagery base map used (or pops up as first map).***
   None of the platforms selected an aerial image as base map, due to the scale of the domain
2. ***Landmarks clearly visible to help viewers orient/locate themselves.***
   Most of the analysed maps use as a reference administrative areas, which can be easily recognised by users. Some platforms completely avoid the use of a background map, and rely exclusively on the administrative borders [9, 8, 10, 28]. Other platforms adopt a base map representing the main roads and settlements as reference [7], or a combination of topography and administrative borders [5, 6].
3. ***Important map components are present and well-positioned on page.***
   All of the platforms are designed to be user-friendly and favour a prompt comprehension. Most of the websites use a hazard-selection-bar above the main map, to represent all the possible hazard and the corresponding class, and to switch between the single hazard-maps (Figure 9.a, Figure 10.c) [8, 6]. However, most of the maps produced, especially if APP-based, rely deeply on the usability of the interface, but sometimes neglect to create

an easy access to further information, such as an explanation of the symbology and a legend. A negative example of user friendly interface is the German platform Umweltinfo Bayern [29], where the visualisation of maps and data cannot be considered straight forward.

4. ***Visual hierarchy is achieved through appropriate colours, symbols, font size, line width, and other symbolization techniques. Most important map elements are emphasized. Base map is complementary, and does not distract from primary message.***
   All of the maps coherent with this point: i) a well identified colour scheme helps to identify the different severity classes, in this way situations of high danger (identified as red) are immediately spotted by the user. The background map is usually of a lighter colour compared to the hazard areas [5], or they use green to indicate the absence of critical situations [9, 8, 10]
5. ***Appropriate colour schemes used on all data—sequential for increasing values (intensities) diverging schemes for values above/below critical value (temperature - freezing), and qualitative for nominal data (trees, water, and desert are green, blue, and yellow, respectively).***
   Given the nature of the selected platforms and their applications for the diffusion of warnings, the hazard classes are well codified and follow an intensity-scale usually spanning from green to red (with subtle differences). Other information
6. ***If applicable, map colours match hazard colour.***
   They use a well recognisable palette of colours easily associated to hazard levels. An exception is the APP-based German platform KATWARN [25], that reports natural hazards as well as issues on the road network. The latter kind is not represented with a colour scale, but through blue areas.
7. ***Fewer than 7 colour classes used (5 or fewer is ideal).***
   Maps usually adopt a 3 [7], 4 [28, 10] or 5 (all Swiss platforms) classes scale. An exception is the German platform WIND, that uses 6 classes
8. ***Legend colours are matched exactly with those on map.***
   This is the case for all maps, there can be the use of a light transparency [6, 7], but with the presence of only few hazard levels, the colours are still easily identified on the map
9. ***Colour-blind friendly schemes are used.***
   All of the maps reported hazard colours in Table 1 span from green to red

The overall evaluation of the reported maps confirms that the design choices implemented in the maps reported in Table 1 are generally coherent with the visual best practises suggested by the Hazard Map Rubric compiled by (Mac Pherson C., et al., 2020). However, there are two main disagreement: i) the base map suggested in study requires the use of aerial imagery, that is never adopted as a base map for the reported maps, probably because of the wide spatial scale because a complex map is oftern difficult for most audience to understand (MacEachren A. M., 1982); ii) 7-10% of male population is red-green colour blind (Harrower M. & Brewer C., 2003), and this is indeed a problem for hazard maps, a the hazard scale usually spans from green to red.

1.6 WARNINGS AND WRITTEN COMMUNICATIONS

Another focal point is the presence of written warnings, possibly in the form of pop-ups and independent text in the page, to focus the user's attention on the most critical situations. This aspect, together with messages describing the recommended behaviour for the current situation, are a key aspect in the use of these kind of platforms to alert and suggest caution and specific actions to the population, in order to reduce its exposure (and therefore the potential risk). In case of emergency, the behavioural recommendations should include clear and locally relevant instructions about measures to be taken (Potter, et al., 2018). The presence of a brief list of textual information below the main map is beneficial, (Savelli S. & Joslyn S., 2013) reports than only visual messages are more favourable to lead to erroneous interpretations than text messages alone, in the case of weather forecast, the same conclusion was given by Bean et al. (2015) for hurricane forecast graphics. Best practices for content elements (MacPherson-Krusty C., et al., 2020) include the presence of auxiliary information along with mapped data, as well as written warnings, both expressed in a clear and concise manner, avoiding specialised terms. Furthermore, it is suggested that protection measures should be included alongside to the risk description.
A clear example of this best practice is the case of the Swiss platform [6]. The main map and the various visual characteristics have already been described in Figure 10. All hazards are represented in a single map, where the hazard with the higher level is superimposed above other hazards in the same locations. In order to clarify the information delivered by the map, a series of messages is reported below it. It contains a summary of the hazard, with an icon representing the typology and the hazard class, which are repeated in the title, and the period of interest. There are some links that help the user identifying the affected regions, and provide a further explanation of the danger level and of possible behavioural recommendations.

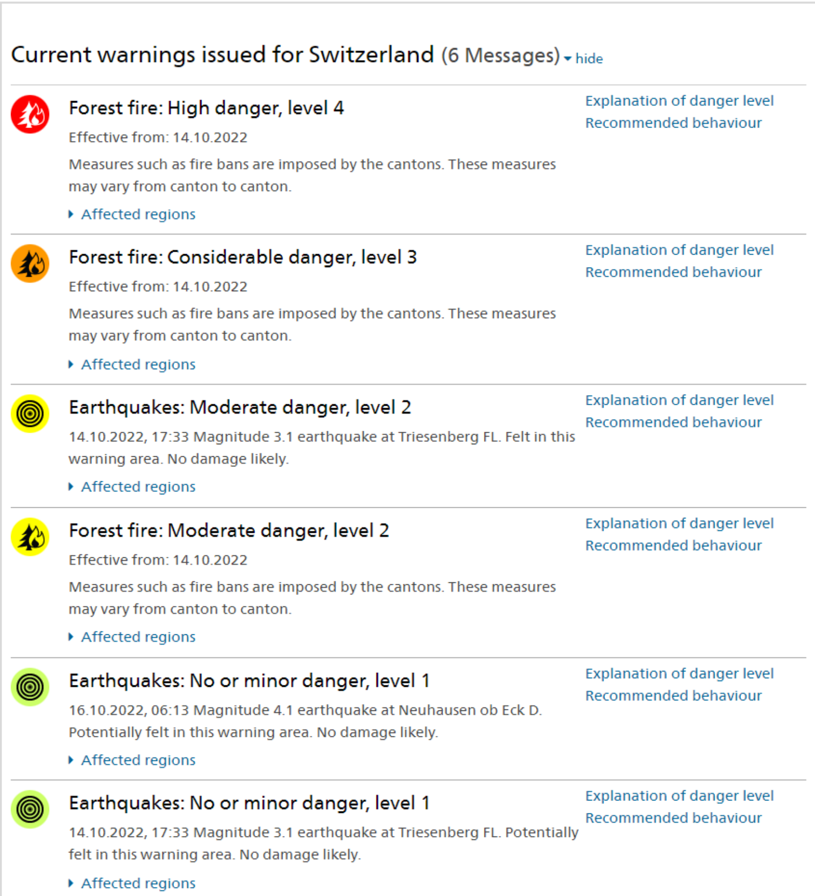
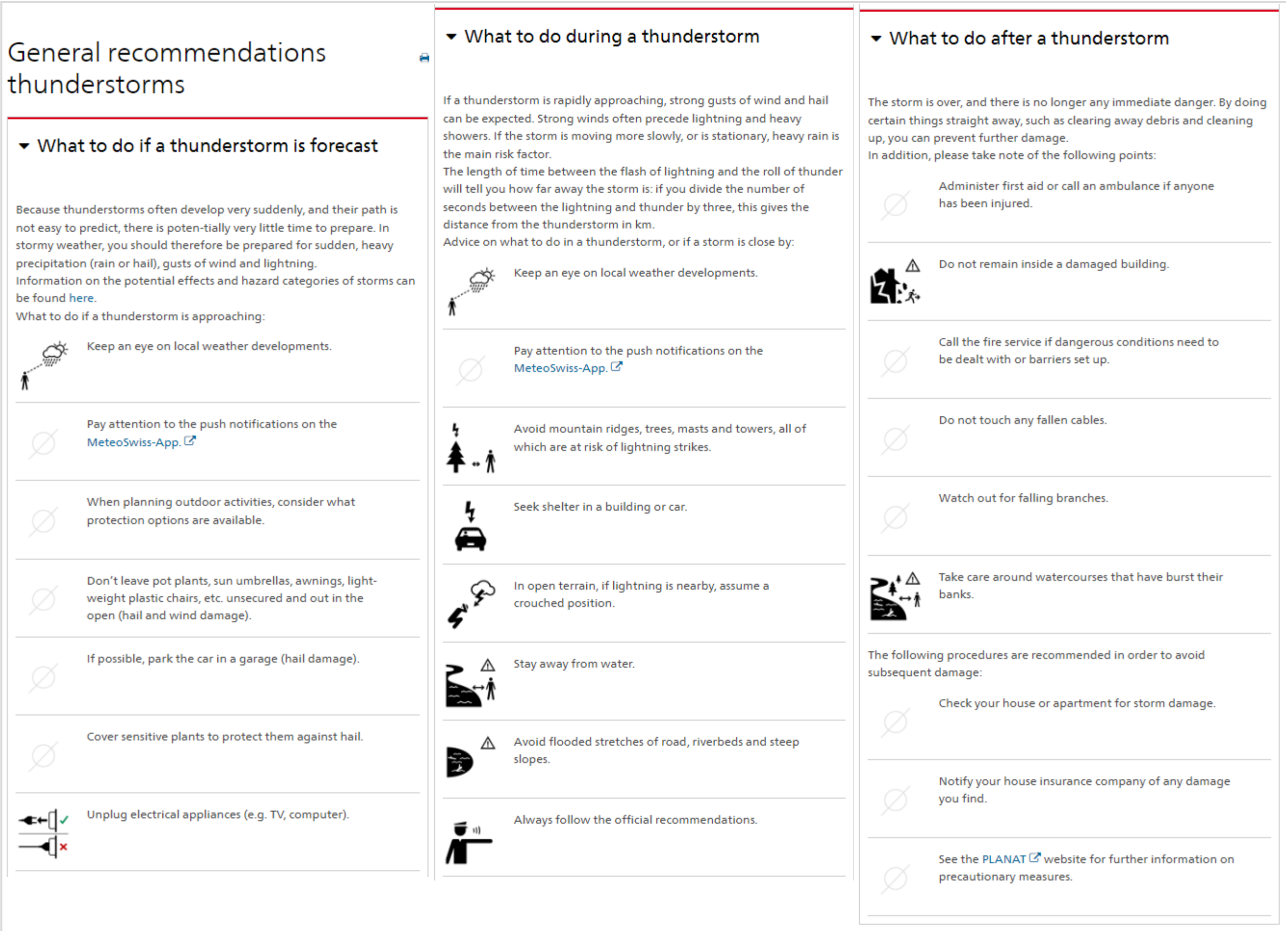


Figure 14 Messages associated to the main map in the Current Natural Hazards map for Switzerland [6], on the 14.10.2022

An example of behavioural recommendations issued by Swiss authorities is shown in figure 15. It is easily accessible from the main page and it reports recommended behaviours in case of thunderstorm. The recommendations are divided into 3 classes: what to do if a thunderstorm is forecast, during the thunderstorm and after the thunderstorm. The textual information is often aided by the use of easily comprehensible pictograms, which are considered to be helpful by users (Dallo I., at al., 2020).



General recommendations thunderstorms

What to do if a thunderstorm is forecast

Because thunderstorms often develop very suddenly, and their path is not easy to predict, there is poten-tially very little time to prepare. In stormy weather, you should therefore be prepared for sudden, heavy precipitation (rain or hail), gusts of wind and lightning.
Information on the potential effects and hazard categories of storms can be found here.
What to do if a thunderstorm is approaching:

- Keep an eye on local weather developments.
- Pay attention to the push notifications on the MeteoSwiss-App.
- When planning outdoor activities, consider what protection options are available.
- Don't leave pot plants, sun umbrellas, awnings, light-weight plastic chairs, etc. unsecured and out in the open (hail and wind damage).
- If possible, park the car in a garage (hail damage).
- Cover sensitive plants to protect them against hail.
- Unplug electrical appliances (e.g. TV, computer).

What to do during a thunderstorm

If a thunderstorm is rapidly approaching, strong gusts of wind and hail can be expected. Strong winds often precede lightning and heavy showers. If the storm is moving more slowly, or is stationary, heavy rain is the main risk factor.
The length of time between the flash of lightning and the roll of thunder will tell you how far away the storm is: if you divide the number of seconds between the lightning and thunder by three, this gives the distance from the thunderstorm in km.
Advice on what to do in a thunderstorm, or if a storm is close by:

- Keep an eye on local weather developments.
- Pay attention to the push notifications on the MeteoSwiss-App.
- Avoid mountain ridges, trees, masts and towers, all of which are at risk of lightning strikes.
- Seek shelter in a building or car.
- In open terrain, if lightning is nearby, assume a crouched position.
- Stay away from water.
- Avoid flooded stretches of road, riverbeds and steep slopes.
- Always follow the official recommendations.

What to do after a thunderstorm

The storm is over, and there is no longer any immediate danger. By doing certain things straight away, such as clearing away debris and cleaning up, you can prevent further damage.
In addition, please take note of the following points:

- Administer first aid or call an ambulance if anyone has been injured.
- Do not remain inside a damaged building.
- Call the fire service if dangerous conditions need to be dealt with or barriers set up.
- Do not touch any fallen cables.
- Watch out for falling branches.
- Take care around watercourses that have burst their banks.

The following procedures are recommended in order to avoid subsequent damage:

- Check your house or apartment for storm damage.
- Notify your house insurance company of any damage you find.
- See the PLANAT website for further information on precautionary measures.

Figure 15 Extract of the Natural Hazard Portal, Switzerland [6]. General recommendations for thunderstorms

1.7 WARNING BULLETINS FOR TRANS-ALP PROJECT AREA

The presence of natural hazards has led to the development by most countries of different solutions and applications, usually related to the National Civil Protection department, aiming at communicating risk levels, warnings and recommendations for action, in order to minimize or prevent possible damage to people and property caused by the forecasted phenomena.
In Italy the network of CFD's, belonging to the national Civil Protection Department, issues a daily national warning bulletin on hydrogeological, hydraulic and avalanche forecast critical situations for the next 24 hours. The alerts are divided into 4 different levels of potential risk, varying from green (no risk) to red (high risk). Whenever the expected risk is higher than the green threshold, a special civil protection warning is issued with a detailed description of the expected meteorological phenomenon, its possible effects on the ground, and specific civil protection prescriptions. In addition to being published on the Civil Protection's institutional website, the

warning is sent to a series of qualified users such as mayors, public service managers, police forces, etc., so that each of these stakeholders can be prepared for the event and carry out their own competent actions. At the same time, an SMS is sent to the same users with the recommendation to read the above mentioned warning (figure 16). Italy is a country extremely exposed to natural hazards. This makes it necessary to have a system that ensures the presence in every area of resources capable of intervening quickly and in a coordinated manner in emergencies, but also of working to prevent and, as far as possible, predict possible disasters. This is the reason why, in Italy, civil protection is not a task assigned to a single authority, but a function assigned to an integrated system, composed of public and private, central and territorial structures: the National Civil Protection Service.
An example of the bulletin issued by Veneto region [30] is reported in figure 16.a. The domain is divided into 8 sub-areas, defined with respect to the administrative units and a coherent/homogeneous hydro-geological risk and hydraulic response. The bulletin reports the predicted risk level for each of the sub-domain, in terms of hydraulic and hydro-geological risk, on a 4 levels scale spanning from green (no risk) to red (high risk). The hazard level for each area is reported in a table, with the categorization of each hazard level. The bulletin reports the weather forecast, a note explaining the hazard and the possible ground effects. Furthermore, a note reports the specific municipalities affected by the hazard, possible communications and the reference offices to contact. In the case of a critical situation regarding hydro-geological risk, thunderstorms, snowfall and frost, avalanches and strong wind, a support document is issued, called 'Prescrizioni di Protezione Civile' (figure 16.b). The document describes the emergency level for the local authorities to be adopted, and the main suggestions for action to be applied to mitigate the hazard.

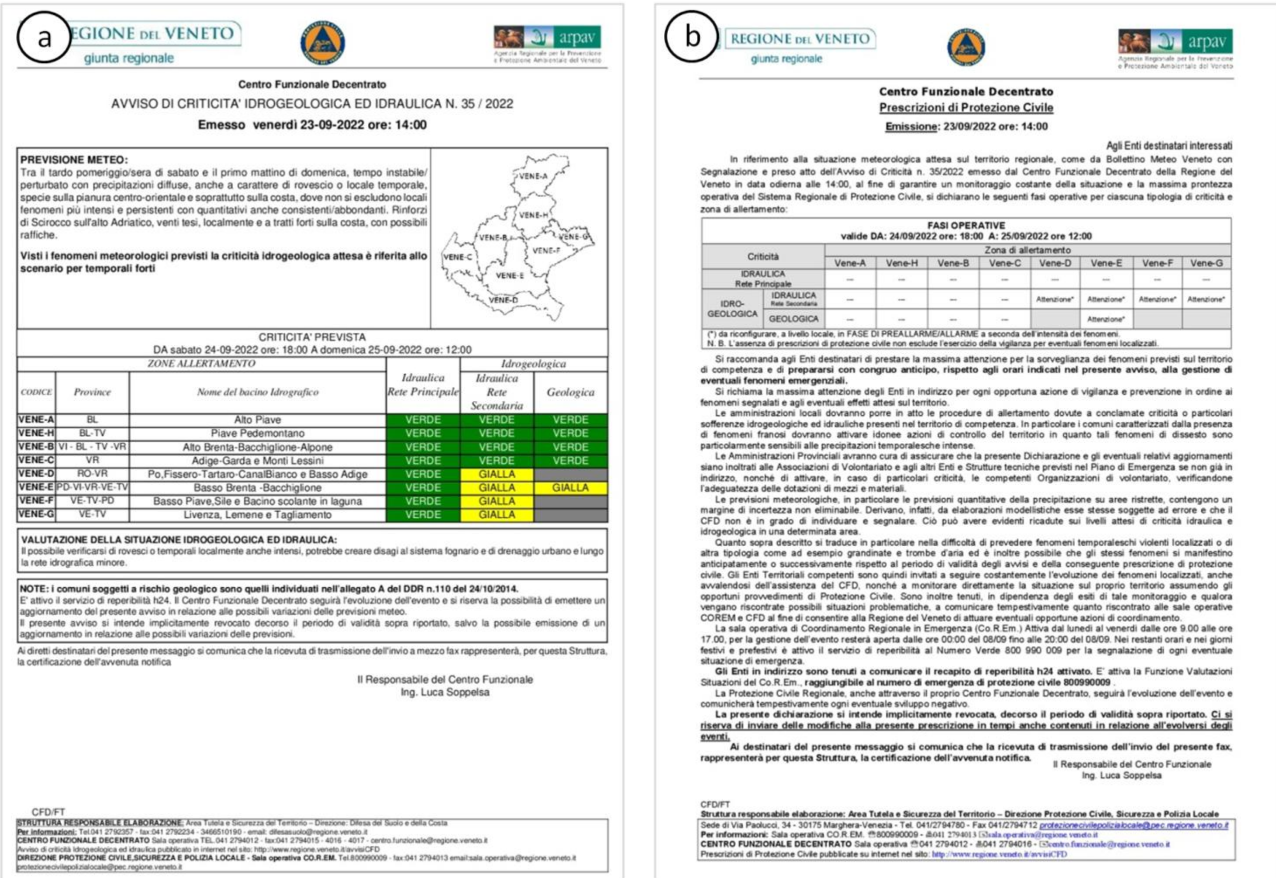


Figure 16 the early warning bulletin of the Veneto Region a) the forecast bulletin with expected risk levels for the next 24 hours b) *the corresponding civil protection prescriptions with particular indications of individual behaviour and level of activation of the regional civil protection system [30]*

A similar approach is followed for the alert maps produced by the province of Bolzano [31] (figure 17). Single hazard maps are produced daily by the competent authority to describe the distribution of the following hazards (figure 17.a): landslides and debris flow, thunderstorms, floods, snowfall, avalanches, strong wind, extreme weather temperatures, wildfires. The bulletin reports the predicted situation for each hazard for the upcoming 72 hours. The hazard level is defined for each sub-area, spanning from green (no risk) to red (high risk). A support table (figure 17.b) is issued to express the highest hazard level for every single hazard over the whole province, associated with a hazard-class colour code. The last table produces (figure 17.c) describes the characteristics of the ground-effects that may occur on the territory, in terms of intensity and frequency, and the possible damage they may create; such scenarios are used to identify the hazard level for each of the natural hazards taken into account.

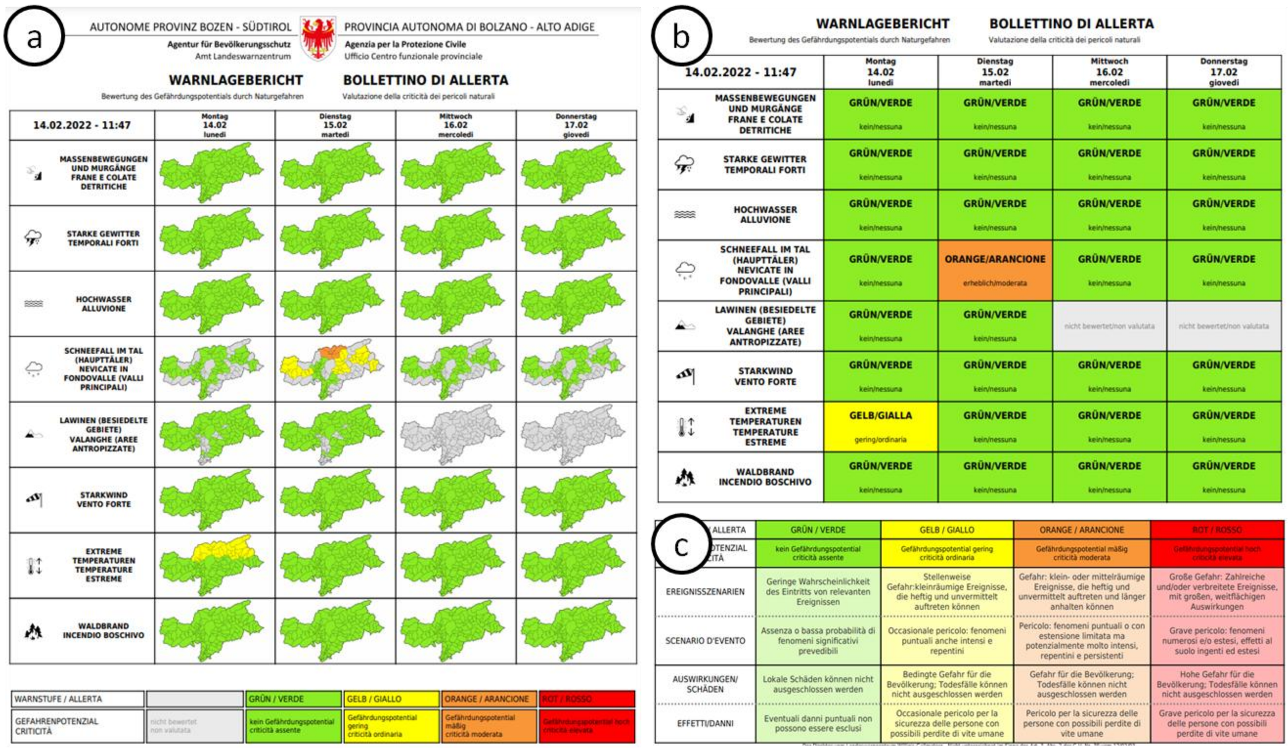


Figure 17 the alert bulletin of Province of Bolzano a) the forecast alert bulletin with expected hazard-specific risk levels for the next 72 hours b) a summary table of the maximum risk levels to be expected for the upcoming days c) description of the scenarios associated to the different alert levels [31]

The document reported in figure 17 was designed for civil protection purposes, as a tool adopted by the network of CFD of the Civil Protection Department all over Italy, and intended for local Civil Protection Authorities. However, the province of Bolzano developed a more immediate and user-friendly platform [31](Figure 18), to report the forecasted hazard distribution to the general public as well as to official bodies. The design reminds to the Swiss platform, and it is highly intuitive: an overview of all hazards distribution is presented as default choice, with priority of visualization given to the highest hazard level present. It is possible to visualize single-hazard maps, selecting the chosen hazard from the list on the left. The icon is associated with the color of the highest hazard class present within the territory (I.e. all hazards are represented in green, a part from a low risk situation associated with strong wind, identified by a yellow circle). It is possible to consult the forecasted situation from the tabs above the picture: the evolution of the hazard situation up to 72 h is represented in the map, and the highest hazard level for the day over the whole territory is reported with a bar of the the associated colour below the specified date.

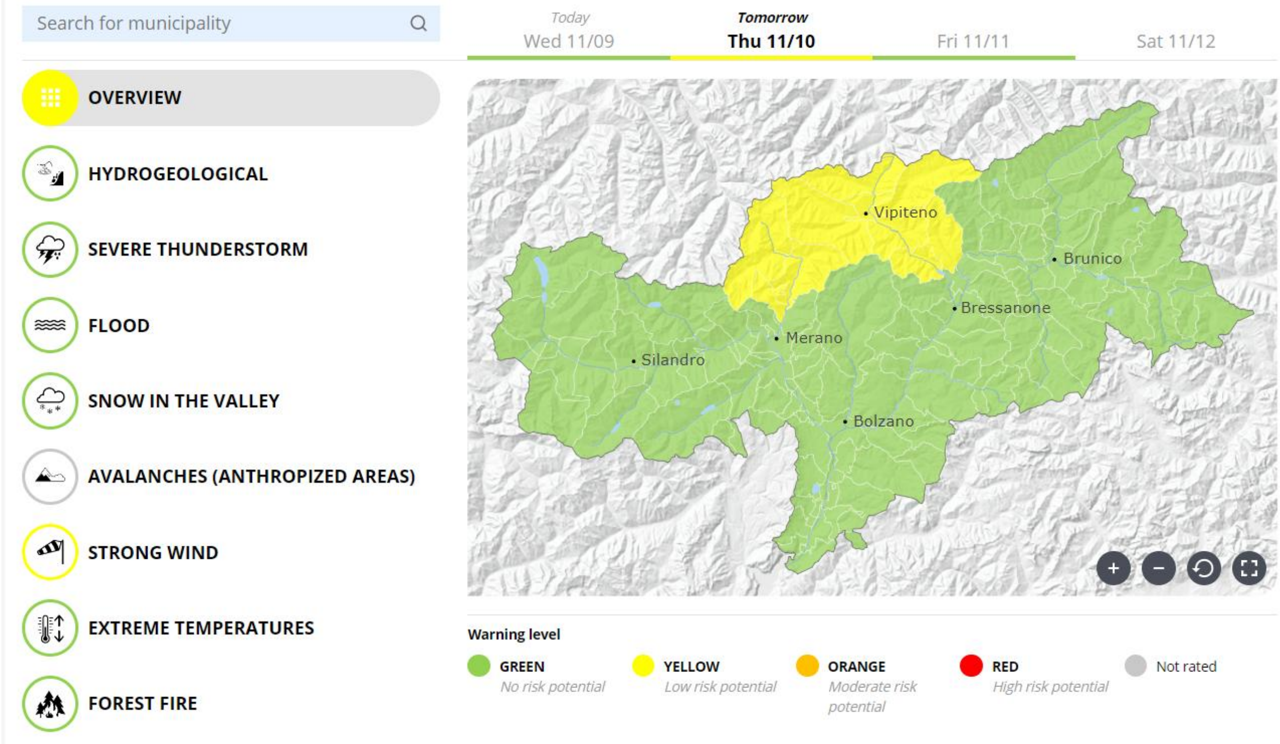


Figure 18 Warning bulletin issued by the Provincial Warning Centre of the Autonomous Province of Bolzano - South Tyrol [31]

In Austria the Civil Protection and Disaster Management is in charge of the rapid transmission of warnings and alarm to the public in disaster or crisis, through a warning and alarm system that is operated by the Federal Ministry of the Interior jointly with the offices of the provincial governments [32]. In parallel to this official structure, the ZAMG warning system [33] (figure 19) provides information to protect people from possible weather hazards. The map represents the forecasted hazard distribution for the upcoming 72-96 hours, and it was designed in order to inform the population and allow a rapid communication of possible warnings. The weather warnings apply to permanently settled residential zones, areas not described by this definition – such as the high alpine regions of Austria –are not covered by the warnings. The platform (figure 19.a) reports the hazard level for: strong wind, rain, snow, black ice, thunderstorm, heath stress and cold stress. A simplified representation of the hazard levels for a 4 days interval can be visualized in terms of maximum hazard level prediction (figure 19.b). The colour palette is associated with the hazard levels, from green (no risk) to red (high risk), where the explanation of the scenario associated to the colour level is reported in the Legend (figure 19.c). The instrument developed by ZAMG focuses on the possible effects (“impact”) of the expected weather situation: the assigning of warning colours does in fact take into account not only statistical recurrence intervals, but it takes into account factors that may possibly amplify the effects –and therefore the potential damage –of the forecasted weather scenario. In such a way, strong wind gusts will be associated with greater damage in deciduous trees, in comparison to conifers, or an intense rain outburst will have a greater impact if it follows a period of heavy rainfall, than if following a period of dry spell. The platform provides a list of active warnings and behavioral recommendations, in order to minimize or prevent as much as possible damage caused by the expected warning situation to people and property.

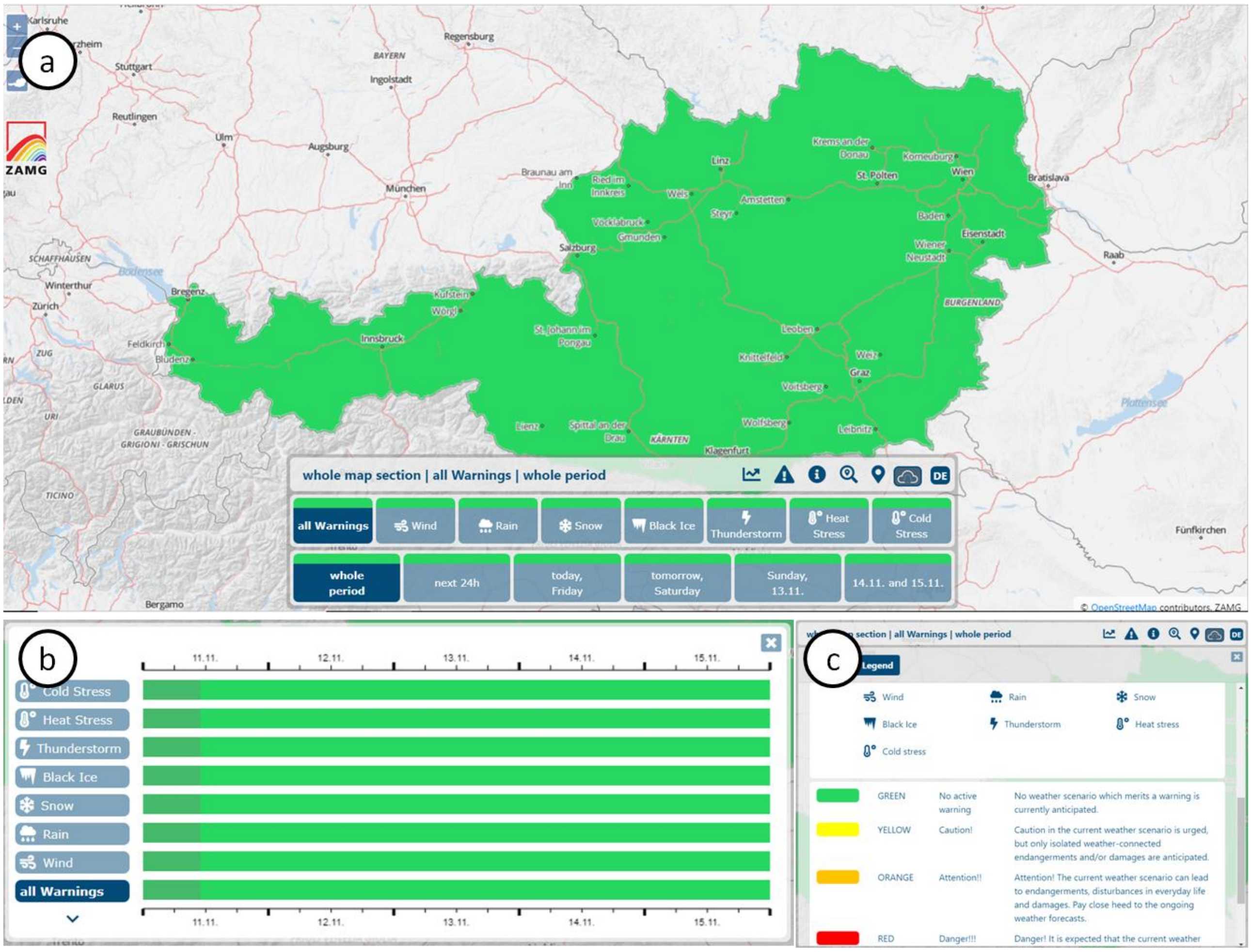


Figure 19 the ZAMG Warning System for Austria, a) whole map section b) summary table reporting the maximum hazard-specific level expected in the upcoming days c) map legend and description of the scenarios associated to the different hazard levels [33]

4 CONCLUSIONS

Multi-hazard and multi-risks maps can be developed for very different reasons, from the communications of the outcome of a scientific study, to the diffusion of warnings issued by local authorities to the population for the case of an incumbent storm.

In this review about hazard and risk maps, the background structure and visual content of a selection of maps has been discussed, focusing on the choice of representing hazard, risk or vulnerability/exposure, and on the chosen spatial and temporal scale for each map. The design choices have been considered, primarily through the options of available maps (hazard specific maps or a single summary-map) and the default choice, and the use of simbology, that can vary greatly, as it can be noticed in the related paragraph.

The design choices have been taken into consideration in the light of the purposes for which each map has been designed, in order to find common practices for each goal. From the selection of hazard maps, three main design goals have been identified: i) Scientific communication, ii) transmission of technical information, iii) communication with the population. Several of the platforms presented have hybrid goals, or present multiple maps, with different goals. We have presented examples for each category, although we have mainly focused on maps developed to be accessible to the wide public.

Maps developed by scientists and research organisation usually study the hazard and try to understand processes underlying. Maps are produced for scientific publications and represent the outcomes of a study (such as the multi-hazard hotspots maps developed by the World Bank) or the output of a model. An example of the latter is Swiss seismic hazard maps developed by the Swiss Seismological Service (Figure 11.a), or the Global Seismic Hazard map (Figure 1), both of whom have a hybrid aim, between scientific communication and support to professionals and governance bodies. The spatial scale may vary in accordance to the studied phenomena, from global to very limited domains, when the hazard localised and site-specific. The temporal scale is usually based on historic datasets. The simbology may vary greatly, from the continuous colour palette of the Swiss case –that focuses on the accuracy of the delivered data –to the subdivision into classes, as for the GEM [4].

Maps developed to convey technical data can be of two kinds, they report hazards in order to : i) be of support to policy makers, in order to address in the most efficient way eventual development efforts (Diley M., 2005) and take hazard distribution into account for territorial planning (Alberico, I., & Petrosino P., 2015); ii) to be of support to professionals, and indicate/prescribe adequate project values for the evaluation of hazard: this is the case for national tools addressing seismic hazard, for example, in order to provide project values to consider the actions impacting on the structure, and adapt the design accordingly (Figure 11.b-c). These maps are based on solid scientific studies, and are designed to give in-detail site-specific information. They are usually designed to be understood by professionals with a solid knowledge base, but that may be not excessively familiar with the topic. These maps are usually based on long-term datasets, that in some cases have been used to developed a hazard-model. The spatial scale may vary greatly, from the global scale of the World Bank report, to the detail of the municipality reported in some technical maps for seismic hazard [19]. The simbology used must be easily understandable, the geographical borders of each hazard zone should be clearly identifiable. These maps commonly use a sub-division into several classes of hazard with a spectral colour palette and a visible legend.

The last purpose is the use of maps to inform the population about the evolution of current hazards, and possibly to allow a more direct communication between the local authorities –even in relation to civil protection –and the community in case of critical situations. These maps must reflect the current situation, they work therefore on a short-term scale, often in real time and possibly with components of forecast. The spatial scale may vary, but they are usually produced at a national scale, or regional, and may give the possibility to access details from smaller administrative units.

The visual content of a selection of 13 platforms of this latter group of maps has been considered in the light of the best practices reported by MacPherson et al. (2020). The nine points suggested spans from the choice of base maps, to the colour scale and the additional elements. Contrary to what suggested, the selected maps do not use aerial imagery as base map, but a simplified representation of hte territory that simplify the localisation of geographical points on the map –using infrastructures or administrative borders as reference –and allows to highlight the message convey by the map (both characteristics being reported in the best practices). The third practice concerns the easy accessibility of all important elements: the maps are designed to promptly convey a message, they are therefore designed to be as essential and user friendly as possible. However, in several cases, especially on APP-based platforms, it may be difficult to find in-detail information about the legend or other elements. The maps are almost perfectly in-line with the best practices regarding the adopted simbology: they are indeed designed to promptly communicate the local hazard class at the user's location. Almost all the platforms reported use a

3 to 5 classes hazard discrimination, with hazard colours spanning from green to red (with slight differences between the different platforms). This common design choice is coherent with the best practices:

i) the hierarchy of information is clearly conveyed: accordingly to the conventional meaning associated to colours, the user's eyes is lead to red areas, that are immediately identified as most dangerous;
ii) the hazard colours represent the hazard class;
iii) the number of classes is narrow, always corresponding or lower to the 5 classes suggested by the best practices.

However, the use of colour-blind friendly schemes it is not possible: the conventional colours for the lower and higher level of hazard are in fact green and red, which is the most common colour-blindness combination (Harrower M. & Brewer C., 2003).

Finally, the presence of additional textual warnings or information has been described. Written warning in the form of pop-ups or written messages in the main page is often included in the association to the maps described, while the recommended behaviour is less common.

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