# Climate Change and extreme events in the Alpine area: how to be prepared

TRANS-ALP Extended Policy Brief

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# Climate Change and Extreme Events in The Alpine Area: How to be Prepared

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## Acknowledgments


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*This publication and all project deliverables and materials can be downloaded from https://project-transalp.eu/*


## Disclaimers

# Preface

The 2018 Vaia event has been a wake-up call for both civil protection authorities, decision makers and the scientific community. Although such extreme events are deemed as being extremely rare, the effects of climate change might increase the likelihood of such events to be observed in the future, possibly significantly increasing the severity of the associated risks for the esposed socio-ecological systems. It is therefore with great interest that we followed the activities of the TRANS-ALP project.

# This Publication in a Nutshell

The consortium of the TRANS-ALP project in 24 months spanned across a wide range of activities, addressing the broad topic of risk assessment in case of extreme events such as large storms in the Alpine regions and better understand the complex interplay between hazard, exposure and vulnerability also related to cascading effects in different alpine areas across the border between Italy and Austria. The concept and objective definition of extreme event in the region of interest has been explored with statistical means, leading to a selection of past events occurred between 1980 and 2020 characterized by strong hydrometeorological anomalies and associated to observed adverse impact to the affected areas.

An empirical analysis of these events has shown an apparent positive trend in the frequency and in the intensity of such events in the past decade. This observation has been substantiated by a preliminary analysis of climate scenarios which indicates a potential likely increase of extreme events in the next future due to climate change. The project also addressed the challenge of properly documenting the impacts of extreme events on the affected socio-ecological systems and advanced a preliminary proposal for a standard surveying and reporting procedure. In terms of exposure and vulnerability, an innovative aggregated exposure model has been developed and exemplified to provide a consistent framework for multi-hazard quantitative impact forecasting and risk assessment for risk mitigation and warning applications. Furthermore, TRANS-ALP addressed the issue related with the likely change in risk conditions due to cascading impacts to the forested areas in the aftermath of an intense storm, as observed in the case of VAIA.

A systematic avalanche risk re-assessment protocol has been proposed and exemplified in the test area of the Cordevole Valley and includes innovative analytical procedures and recommendations to dynamically adapt avalanche risk assessment that have been successfully used by the local civil protection authorities. Finally, all data collected, assembled, or generated in the TRANS-ALP project have been collected, stored and made accessible to consortium partners and project stakeholders in an advanced web-based GIS and data visualization platform that allows for a consistent data management and sharing for further integration of the available information and the proposed methodologies in the current and forthcoming civil protection activities.

# Introduction

*Massimiliano Pittore (EURAC Research), Francesca Borga and Mauro Borin (EPC)*

The increasing intensity and frequency of occurrence of extreme weather events in the Mediterranean region, connected to climate change, represents a tangible threat especially for the most vulnerable environmental and socioeconomic territorial systems.

A significative example is represented by the Vaia storm (classified as Hurricane) which, between the end of October and the beginning of November 2018, affected the entire alpine region felling around 42 million trees and changing the geomorphology of entire valleys in north-eastern Italy and in some areas in Austria and Switzerland. The study of Vaia and similar extreme meteorological events, led to the concept of the European project TRANS-ALP, 'Transboundary Storm Risk and Impact Assessment in Alpine regions', aimed at increasing the capacity to understand and manage the risk from extreme weather phenomena in the Alps.

Vaia was indeed an event of high interest for the researchers in the field of Disaster Risk Reduction and Prevention. Unfortunately, it was neither isolated nor unrepeatable. On the contrary, an analysis of the events classifiable as 'extreme' that have affected the Alpine region between Italy and Austria in the last fifty years provided evidence that such events - for example, the great snowfalls in 1985 - have become increasingly more intense and more frequent in recent years. For instance, as many as six cases of storms classifiable as 'exceptional' in terms of precipitation have been recorded in the three-year period between 2018-2020 alone.

Unfortunately, the peculiar intensity of the Vaia storm, gives us a realistic picture of the challenges the Civil Protection will be facing in the next future. Hence the need and willingness to contribute to the development and adoption of solutions that can help prevent and, if necessary, react promptly to these phenomena, in order to reduce the risks, above all to people and territory, as much as possible.

TRANS-ALP is a two-year project that started in January 2021, co-funded by the European Union within the framework of the Programme for Prevention and Preparedness in the Field of Civil Protection and Marine Pollution. The project is coordinated by the Institute for Earth Observation at Eurac research in Bolzano, Italy. The other organisations completing the Italian-Austrian cross-border partnership are: ARPAV, the Veneto Regional Agency for Environmental Prevention and Protection (ARPAV); GEOSPHERE Austria (formerly ZAMG), the Austrian Central Institute for Meteorology and Geodynamics; BFW, the Austrian Forestry Research Institute; and EPC srl, a company with expertise in management and communication of complex European projects based in Vicenza.

The main feature of the TRANS-ALP project was to consider extreme meteorological events from a multi-hazard and cross-border perspective, i.e., focusing not only on a single phenomenon, but taking into account the multiple hazards that are often compounded in extreme events and that expose the territory and the population to different threats. Referring to Vaia's example, the combined impact of rain and strong wind caused several main risk situations to unfold in a very short period of time: falling trees on roads and buildings, flooding of streams and rivers, and triggering of landslides and debris flows. Furthermore, a series of follow-up processes and phenomena with a "cascade effect", have continued to impact the territory for years after the occurrence of the event. In fact, in the affected area, there is an increase in runoff, erosion or avalanche risk, due to the loss of forest areas, as well as an increased risk of fires and parasite problems (e.g., the *Ips typographus* that is already affecting many areas in north-eastern Italy and in the Austrian Tyrol), favoured by the extensive windthrows of the Vaia's exceptional wind gusts.

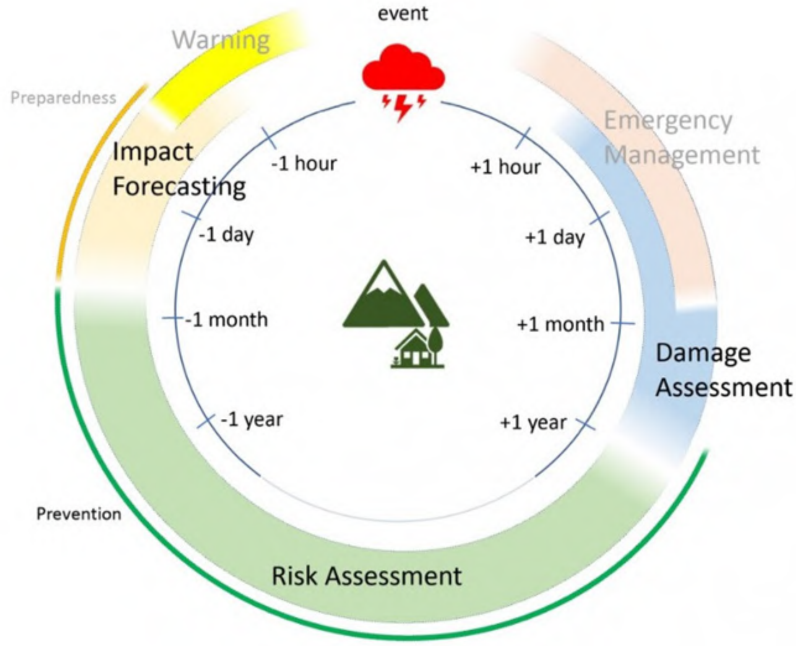



*Fig. 1: Schematic visualisation of the risk management cycle*

Based on these considerations, the TRANS-ALP project consortium initially carried out an analysis of the extreme events that have occurred in recent years in the Alpine area. In parallel, the main methodologies and approaches for risk and damage assessment related to these events were analysed, and the availability to share data and information on these issues at local and/or transnational level has been evaluated. Based upon this information, a number of specific topics related to risk assessment were then investigated, with particular reference to three pilot areas: the Cordevole valley in the Veneto Region, the province of South Tyrol in Italy, and the district of East Tyrol in Austria. Furthermore, a Web-GIS platform has been created and populated with the data collected during the project. It can be accessed via the website (http://www.project-transalp.eu).

This publication provides a description of the most significant project results achieved through fruitful and effective transnational cooperation.

# Part 1
# Towards Cross-Border Risk Assessment

## Relevant Past Events and Their Characteristics and Impact

*Sebastian Lehner, Katharina Enigl and Klaus Haslinger (Geosphere Austria), Alice Crespi (EURAC Research)*

We often hear about how extreme events are occurring with higher frequency due to climate change, but when is an event “extreme” and how can we describe it? Intuitively we refer to events of particular intensity, that impacted significantly on a large area, but significant hydrometeorological events can be characterized through various approaches and from different angles. In this section, a few different methods are described, and their results shown. First, we tested how extreme events can be identified within multi-decadal observations via the use of so-called “percentile methods” where extreme events are determined by observed anomalies in the precipitation statistics. These events can be subsequently analysed by comparison with observed damage records. A special focus is given to the description and analysis of the VAIA storm. Next, large-scale weather types (i.e., weather pattern defined at synoptic scale) are determined and linked to identified extreme events, yielding critical weather types that are especially relevant for hazardous weather events for the cross-border region of Austria-Italy. Finally, so-called “Hazard Trigger Patterns” are derived, describing local time precipitation patterns preceding damage-inducing weather events. Altogether, the various methods employed allow for both a large-scale (zoomed-out) as well as a local-scale (zoomed-in) look on the characteristics of hazardous weather events in the cross-border region of Austria and Italy.

## Data and Methods

Two different gridded datasets were employed for the identification of extreme events: the SPARTACUS dataset of GEOSPHERE (Hiebl and Frei, 2017) for the Austrian target region (East Tyrol and Carinthia) and the dataset of EURAC (Crespi et al, 2021) for the Italian target region (Trentino-South Tyrol). Both datasets include daily precipitation totals on a 1 km grid in the period from 1980 to 2020.

For the identification of extreme events that have affected both target regions in the past, we adopted two percentile method approaches that do not contradict but rather complement each other. The first methodology aims at determining extreme events producing the highest precipitation amounts at a regional scale, i.e., large-scale phenomena which affected a large portion of the analyzed area. On the contrary, the second method focuses on the identification of small-scale events with high local precipitation amounts. For further methodological details, please refer to deliverable D2.2. The resulting extreme events, identified by combining both methods, are listed in Table 1.

Gridded sea level pressure fields over Europe and the Atlantic Ocean from ERA5 (Hersbach, 2020) serve as an input for the derivation of weather patterns. The COST733 weather type classification software (Philipp et al., 2014) is used to determine the so-called 'Gross-Wetter-Typen' (GWT) class for each day from 1961 to 2020. Subsequently, the list of selected extreme events is intersected with derived GWT weather types to determine a distribution of potentially critical weather types that are connected to extreme events.

So-called 'Hazard Trigger Patterns' (HTP) aim at describing the meteorological development prior to a damage event. For their derivation, two main steps have to be followed: the compilation of available damage data and subsequently their intersection with meteorological data.

For the first step, we collected damage data from multifarious data sources in both target regions. For Italy, we use the IFFI (Triglia et al., 2008) as well as the ED30 dataset (Macconi and Sperling, 2008), comprising damages induced by landslides and floods, respectively. The GEORIOS dataset (Tilch et al., 2011) and the WLK database (BMNT, 2018; WLV, 2017) comprise damage event data for the same processes in Austria. These data are combined altogether into one data set by applying harmonization processes. Damage records for flood events are especially concentrated in the cross-border region in East Tyrol, while for mass movements there is generally more data available on the Italian side. The Austrian (East Tyrol and Carinthia) subset of the data contains roughly equal amounts of flood and mass movement events with a maximum of recorded damage entries during summer. In South Tyrol the data is not evenly distributed across categories. Flood events have their maximum during autumn, while the most mass movement events are recorded during summer. Furthermore, there are roughly 3.5 times more mass movement events recorded than flood events.

The second step in the derivation of HTPs deals with the combination of damage data with meteorological data. In this study, we use daily precipitation totals combined with damage records, which is then subject to empirical orthogonal function (EOF) analysis, yielding patterns of precipitation related to the triggering of extreme events (Enigl et al, 2019). For technical details see the reports on deliverables D2.1 and D2.4.

## Results – list of extreme events

Based on the two percentile method approaches outlined above, 15 extreme events between 1980 and 2020 were identified, that affected both the Austrian and the Italian target regions: East Tyrol, Carinthia (ET-C), and South Tyrol (ST). The dates of occurrence as well as the local maximum (in mm) for both target regions are listed in table 1. Events determined only based on one region lined up with events found in the other, hence, both approaches show consistency for the whole cross-border region.

| Event date | Local max (ET-C) [mm] | Local max (ST) [mm] |
|---|---|---|
| 18.07.1981 | 157,7 | 128,5 |
| 31.01.1986 | 166,6 | 162,9 |
| 25.11.1990 | 93,60 | 173,4 |
| 02.10.1993 | 151,0 | 144,3 |
| 20.09.1999 | 157,2 | 144,6 |
| 01.11.2003 | 158,7 | 127,3 |
| 29.10.2008 | 92,0 | 148,0 |
| 27.05.2011 | 91,5 | 150,6 |
| 05.11.2014 | 248,1 | 195,7 |
| 25.08.2018 | 72,7 | 119,7 |
| 29.10.2018 | 212,0 | 184,6 |
| 01.02.2019 | 103,2 | 240,5 |
| 15.11.2019 | 118,6 | 166,3 |
| 29.08.2020 | 115,30 | 107,4 |
| 05.12.2020 | 251,5 | 274,4 |

Tab. 1: Events selected as significant according to both percentile method approaches. The Austrian region contains East Tyrol and Carinthia, the Italian region contains South Tyrol.

## Description of Events – Focus on VAIA, Analysis on Return Periods

For all identified extreme events, the meteorological description as well as the registered damages were described in the associated deliverable D2.2. As an example, we focus in the following on the VAIA storm, which strongly affected the study region at the end of October 2018.

Comprehensive damage data sets are available for both Austria and Italy. Figure 2 exhibits the registered damage events for the Vaia event from October 27$^{th}$ to October 31$^{st}$ 2018 in the target regions South Tyrol (ST) as well as East Tyrol and Carinthia (ET-C). Grey points represent damages from the Italian IFFI and ED30 database, comprising damages induced by landslides and floods, respectively. Grey dotted polygons show the Austrian VIOLA dataset, representing districts or municipalities in which damage were registered. The grid in the background depicts the precipitation totals for the VAIA event from the SPARTACUS dataset. The 6-day precipitation sum exceeded 200 mm in large areas of the target regions, with peaks up to 475 mm in the Southern parts of Carinthia. The majority of damages in the target region were registered in the areas with highest precipitation totals.

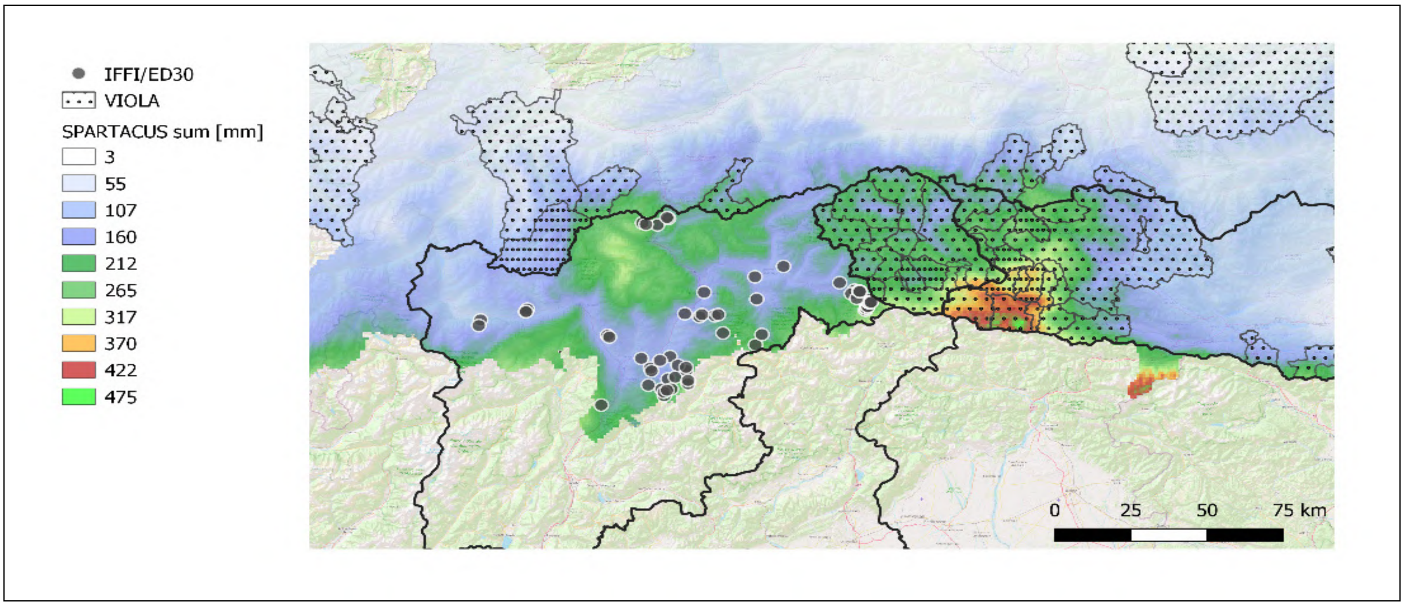



Fig. 1: Registered damage events and precipitation sum during the VAIA storm (GEOSPHERE).

## Weather Types Associated with Past Extreme Events

The GWT (Gross-Wetter- Types) weather types describe 8 cyclonal (No. 1 to 8) and 8 anti-cyclonal weather types (No. 9 to 18). The former is related with low-pressure systems affecting Central Europe, while the latter is characterized by high-pressure systems. In Figure 2 the GWT weather types for the selected extreme events based on the methodology explained before (see Table 1) is shown. All of the specific extreme events are hence related to cyclonal weather types and specifically the majority of them to the combined subset of GWT 2, 7 and 8, which are weather patterns with similar characteristics. The storm VAIA also falls into this subset of GWT weather types. Figure 3 shows the average surface level pressure field for GWT 8. Central Europe is dominated by a low-pressure system over the British Isles, reaching into France, and a blocking high pressure system over Northeast Europe. The resulting flow direction can cause heavy precipitation in the Southern Alps and is hence an important feature for Austria-Italy cross-border analysis of hazardous weather events. GWT 2 and 7 (not shown) are similar weather patterns, with slight differences in the location and extent of the low- and high-pressure systems, but with comparable resulting flow structures for the target region. Therefore, these three GWT weather types are of special importance for extreme weather events related to the cross-border region of Austria-Italy.

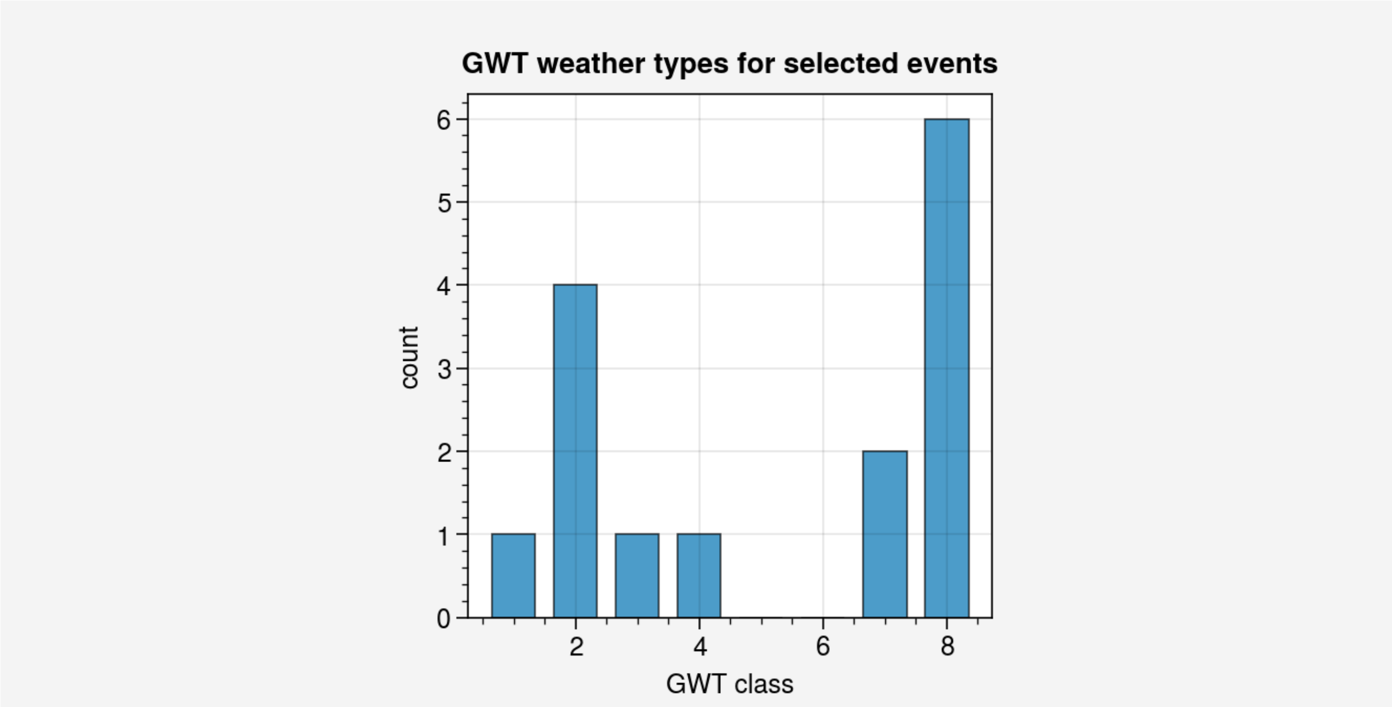



Fig. 2: Histogram of GWT weather types for the selected extreme weather events of Table 1.

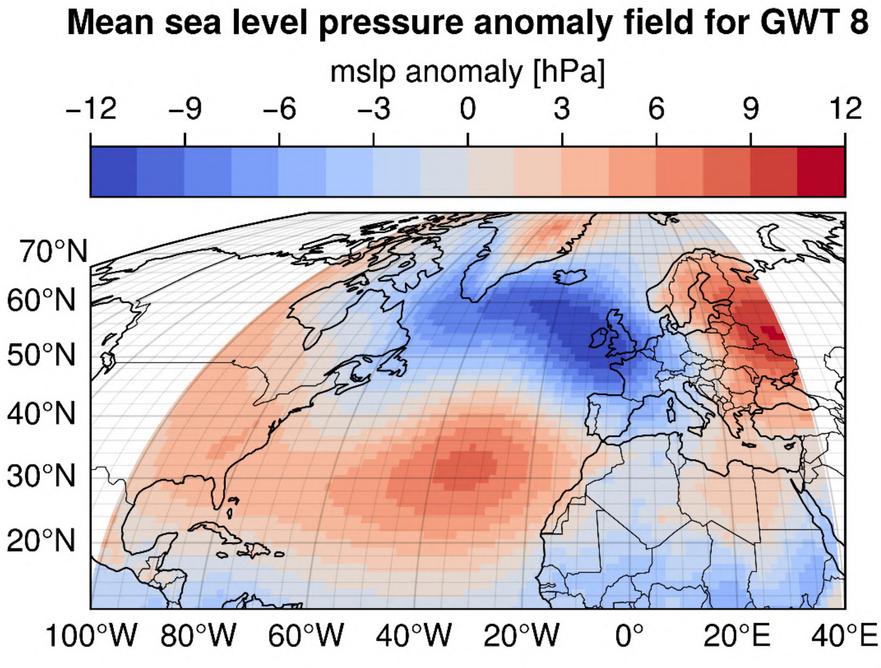



Fig. 3: Average surface pressure anomaly field for days with GWT 8 in the ERA5 data.

## Hazard Trigger Patterns – Characteristic Precipitation Patterns

The derived HTPs describe the precipitation development preceding hazardous weather events based on observational data. In Figure 4, the HTP for flood events in the summer season for East Tyrol and Carinthia is shown. The first empirical orthogonal function (EOF), which has an explained variance of 24%, is characterized by a weather sequence of substantial precipitation amounts a week before the event and especially concentrated precipitation on the day of the event and the 2 days prior. The second EOF, with an explained variance of 20%, shows a different characteristic and highlights intermediate and short-term pre-moistening (1-3 and 5-6 days prior). Lastly, the third EOF, with an explained variance of 15.5%, shows mostly intermediate pre-moistening, 5 to 6 days prior to an event, and a smaller but visible immediate precipitation signal. The applicability of the derived HTPs was cross-validated by reconstructing precipitation patterns for out-of-sample damage events using the EOFs and comparing these constructed patterns with observed patterns. The validation results indicate that EOFs carry substantial signal value and can be used to investigate precipitation patterns preceding hazardous weather events. In conclusion, the HTPs highlight the importance of both short-term precipitations, as well as pre-moistening up to a week in advance, for the triggering of hazardous weather events.

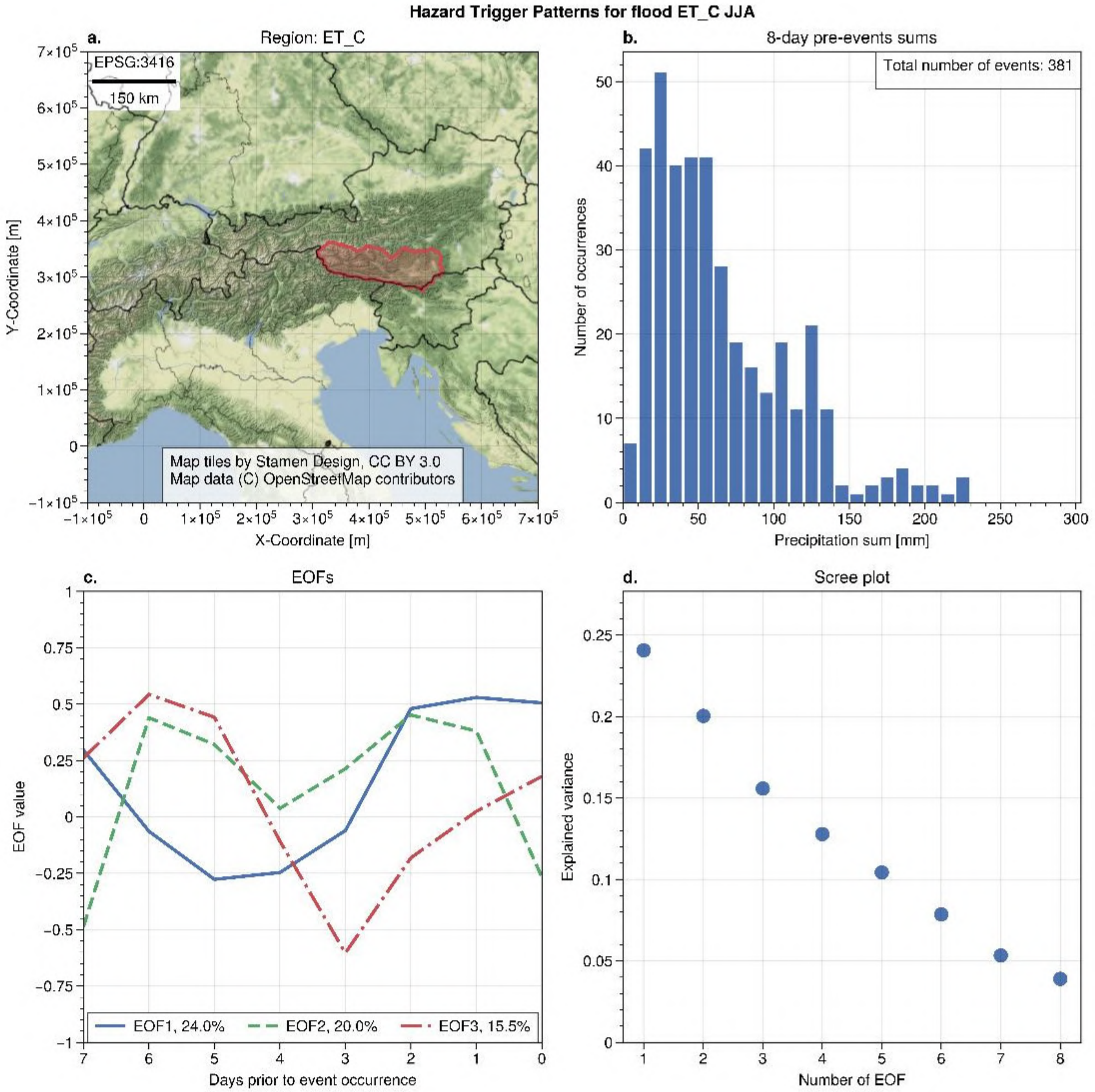



Fig. 4: Hazard Trigger Patterns for the hazard category 'Floods' in the target region 'East Tyrol – Carinthia'. a) depicts the region of interest, b) a histogram, showing the precipitation sum of the eight days before an event, c) the three leading EOFs, depicting the preceding weather sequence, and d) the scree plot examining the explained variances of the EOFs.

## Synthesis and Recommendations

We found that statistical percentile-based methods are simple and consistent in extreme event identification across the whole region and are also in line with observational data of extreme events and hence, can be used for climate impact assessments. As an example, we focused on the meteorological conditions and damage events registered during the VAIA event. Furthermore, we derived critical weather types, based on the GWT weather type classification, which are especially relevant for the target region. These weather types can be used for large-scale climate change analysis and have already also been used to determine expected changes under different climate change scenarios (see TRANS-ALP deliverable D2.3). Finally, Hazard Trigger Patterns were derived to describe statistically significant local-scale precipitation patterns preceding damage events. Those patterns were validated and found to be possibly useful to investigate precipitation development preceding hazardous weather events and can furthermore be used in climate impact models.

# Future Climate Changes for High-Impact Weather in The Alpine Cross-Border Region

*Sebastian Lehner, Katharina Enigl, Klaus Hasslinger (Geosphere Austria)*

Extreme weather events and corresponding natural hazards have always been a major threat to people all over the globe. By now, it is common scientific consensus that climate change comes along with increases in both frequency and intensity of extreme weather events (IPCC, 2021; Feyen, 2012). Consequently, this development entails increasing amounts of associated natural hazard events (EEA, 2016). This poses a major challenge for decision-makers in the field of civil protection who are in need of an integrated multi-hazard storm risk assessment and impact forecasting methodology tailored to their needs.

In a climatological context we need to classify high-impact weather in some form that allows robust statistical assessments across time. Therefore, relevant information must be derived from the past and projected under different climate scenarios such that a climate change assessment is feasible. Weather types contain relevant large-scale information regarding the weather situation for any given day and thereby allow a meteorological and statistical characterization of large-scale phenomena that can lead to regional high-impact weather, or extreme weather events. We apply the GWT weather type classification (Beck et al. 2007) to assign each day one of 18 weather type classes for historical and climate projection data, which allows to determine future changes in frequency of weather types and intensity changes in terms of regionally averaged precipitation for the cross-border region of Austria and Italy.

## Data and Methods

To calculate changes of potential future development, a historical reference is needed. We employ historical Global Circulation Model (GCM) data taken from the CMIP6 (Coupled Model Intercomparison Project Phase 6) archive to determine the reference frequency and associated precipitation intensity in the target region, for all of the calculated weather types. Gridded sea level pressure fields over Europe and the Atlantic Ocean are used and fed into the COST733 weather type classification software (Philipp et al., 2014) to calculate the so-called 'Gross-Wetter-Typen' (GWT) class for each day. The precipitation totals are taken from downscaled GCMs as area average over the cross-border region of Austria and Italy. The 30-year period from 1961 to 1990 serves as historical reference for future changes to be determined.

Future climate data were taken from the CMIP6 (Coupled Model Intercomparison Project Phase 6) and follow the categorization into SSPs (Shared Socioeconomic Pathways). The four main scenarios of CMIP6 are SSP1-2.6, SSP2-4.5, SSP-3.70, SSP5-8.5. In this study, the two scenarios SSP1-2.6 and SSP3-7.0 are considered, representing a climate-friendly and a carbon fossil fuel intensive scenario, respectively. The first digit represents the socio-economic scenario (SSP1 for sustainability, SSP2 for the "middle of the road" path, SSP3 for regional rivalries, SSP5 for fossil development) and the last two numbers represent the considered RCP ("Representative Concentration Pathway") indicating the radiative forcing in W/m². A comparison between SSP scenarios and the RCP scenarios known from CMIP5 can be found in Deliverable 2.4 and refers to Riahi et al. (2016). In this study, we make use of the aforementioned SSP scenarios (SSP1-2.6, SSP3-7.0) that cover a plausible range of potential future developments.

For the purpose of weather type classification, we only consider the parameter "mean sea level pressure" for a subset of quality-checked GCM runs. A detailed list of the 13 employed models can be found in deliverable D2.3 in table 1. For the intensity of corresponding precipitation, area means over the cross-border region of Austria and Italy are calculated from downscaled GCM data of the same models.

For the determination of changes in the frequency of calculated weather types, we evaluate their occurrence in two different future time periods. We thereby consider an ensemble of CMIP6 data, comprising the aforementioned socio-economic pathways, SSP1-2.6 and SSP3-7.0. The first time period refers to the so-called 'near future', spanning from 2036 to 2065, whereas the second time period, the 'far future', stetches from 2071 to 2100. Changes in frequency are depicted as percentage changes relative to the frequency over the historical period of GCMs from 1961 to 1990.

To assess changes in intensity, we determine the change of different precipitation metrics calculated for days corresponding to specific weather types. In both cases the baseline was determined by historical GCM simulations and a reference period from 1961 to 1990. The changes were calculated for both scenarios SSP1-2.6 and SSP3-7.0 and both the 'near' and the 'far future'.

We evaluate intensity changes corresponding to different weather types by extracting precipitation totals for days on which respective weather types prevailed. Subsequently, the mean over time and space for a given subset of days corresponding to a specific weather type is calculated and evaluated. The changes of the GCM ensemble are then again analyzed in the context of the two already outlined scenarios and time periods.

## Changes of Weather Types Under Different Climate Projections

### Frequency changes

Figure 1 displays the results of frequency changes for both investigated scenarios in the 'far future'. Outcomes for SSP1-2.6 reveal that approximately half of the 18 GWT weather classes experience an insignificant amount of change compared to the variability across the GCM ensemble.  Overall, outcomes feature comparable tendencies for both scenarios, but especially in the 'far future' more pronounced changes are visible for scenario SSP3-7.0

Especially the high-impact weather type GWT 7 that prevailed during the VAIA event in October 2018 (see chapter 1.1 for further details) shows a substantial increase in frequency in the 'far future' of about 10 and 20% for the ensemble mean of SSP1-2.6 and SSP3-7.0, respectively. Overall, the considered models agree not only on the direction of change, but show a significant increase for all three critical weather types (GWT 2, 7, 8; see D2.3 for details) with varying magnitudes. Projected changes for all GWTs feature high ensemble agreement in general, indicating robustness about the direction and confidence of changes.

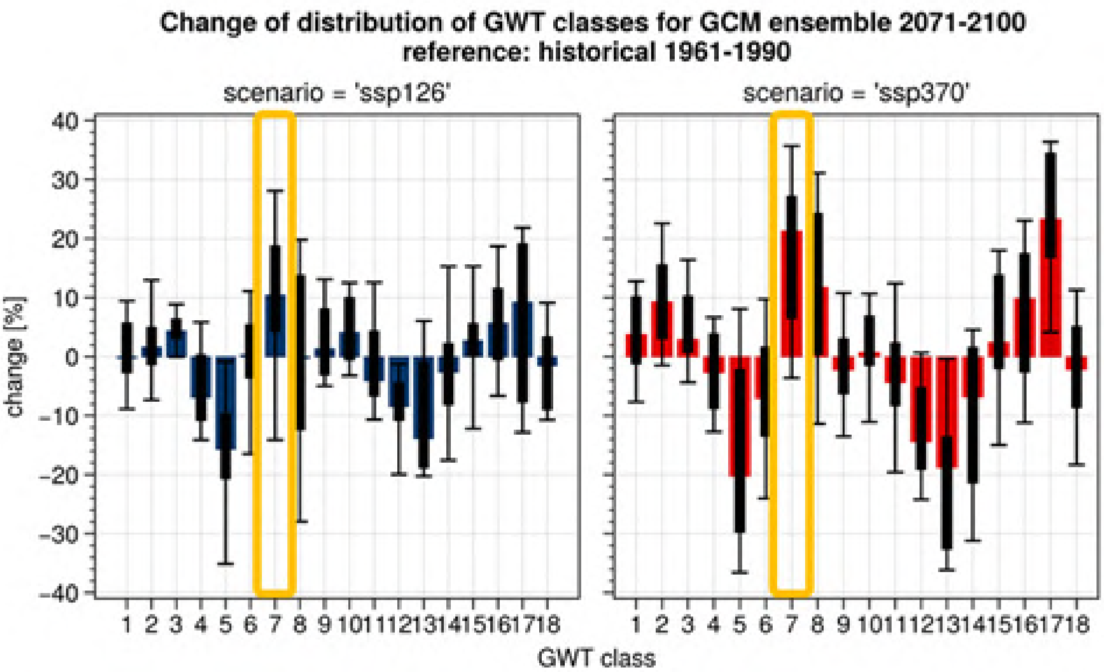



Fig. 1: Changes of frequency for all 18 GWT weather types in the 'far future' - 2071-2100. The left side refers to the 'climate-friendly' scenario SSP1-2.6, the right side represents outcomes for the 'carbon-fuel-intensive' scenario SSP3-7.0. Yellow boxes indicate the VAIA associated weather type GWT 7.

**Intensity changes**

Results for the 'near future' (not shown, see D2.3) show that the high-impact weather types (GWT 2, 7, 8) yield slight increases in precipitation amounts of roughly 2 to 10 % in terms of the ensemble mean for both scenarios. Figure 2 illustrates changes in intensity for all 18 weather types for the 'far future' with respect to the precipitation mean over the target region. The resulting changes are different depending on the weather type. Mean precipitation shows inconclusive changes for GWT 2 and 8, but for GWT 7 increases of about 4 and 11 %, for SSP1-2.6 and SSP3-7.0 respectively. Furthermore, especially for GWT 7, ensemble agreement is high and hence, provides high confidence in the direction of the change.

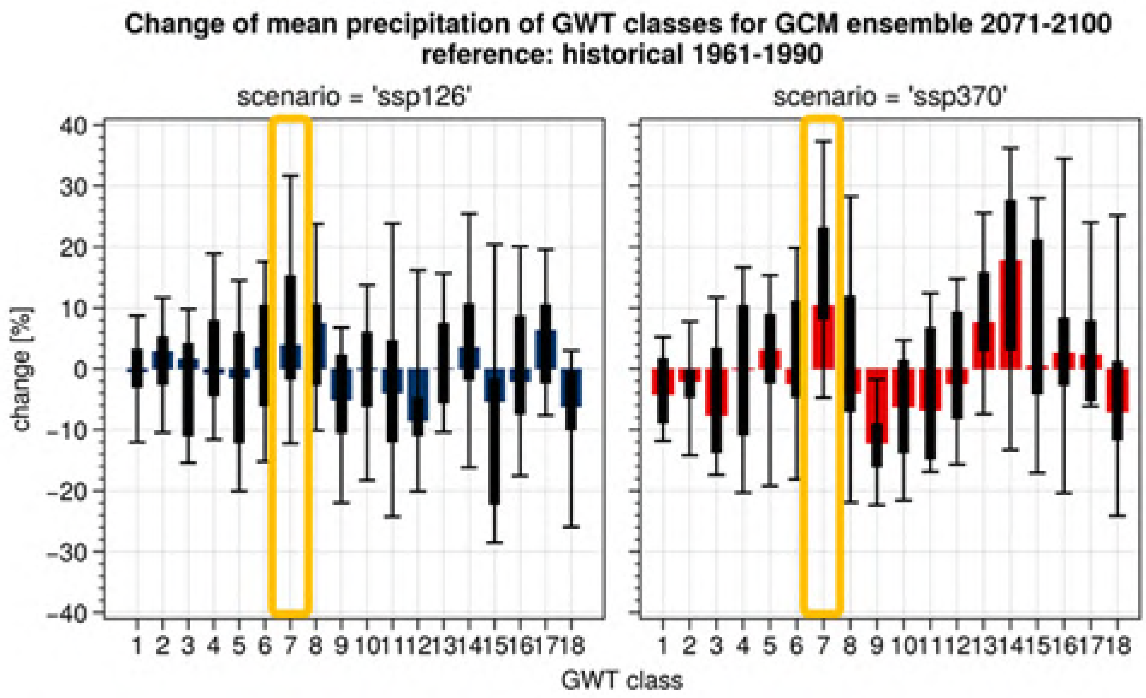



Fig 2: Changes of intensity for all 18 GWT weather types in the 'far future' - 2071-2100. The left side refers to the 'climate-friendly' scenario SSP1-2.6, the right side represents outcomes for the 'carbon-fuel-intensive' scenario SSP3-7.0. Yellow boxes indicate the VAIA associated weather type GWT 7.

## Synthesis and Recommendations

Projected changes are heterogeneous across scenarios and weather types for both frequency and intensity, but a subset of high-impact weather types show substantial increases in frequency and intensity. Especially the VAIA associated weather type (GWT 7) shows significant increases in frequency and intensity with high ensemble agreement and hence high confidence. Potential risks from increasing or intensifying storms therefor needs to be considered for risk management and civil protection. Furthermore, the changes are more drastic, with increasing global warming, which highlights the importance of climate change protection strategies.

# Exposure and Vulnerability Analysis with Existing Data and Applications in Pilot Regions

*Piero Campalani, Kathrin Renner, Massimiliano Pittore (EURAC Research), Fabrizio Tagliavini, Roberta Dainese, Gianni Marigo (ARPA Veneto)*

Exposure and vulnerability are two fundamental components in the assessment of risk. Exposure refers to all the people, assets (e.g., buildings), systems (e.g., the transportation infrastructure) and functions that are exposed to one or more hazards. Vulnerability refers to the degree of susceptibility of the exposed assets to be damaged, and in general to other institutional or environmental conditions that can further amplify the overall risk severity. A wide range of exposure information from the regions of South Tyrol, the Agordino Valley (IT) and East Tyrol (AT)was collected and aggregated onto a common spatial framework, represented by a regular tessellation of hexagons at a resolution of . The resolution was chosen as the minimal common spatial denominator suitable for bringing the various data sets together in a harmonised common framework. A spatial resolution of 250m allows to reduce the high complexity of a regional scale analysis whilst preserving a sufficiently large aggregation thus avoiding privacy concerns on sensitive assets such as the location of the population. Hexagons, as opposed to the usually used squares, enable a richer explanation of the connectivity among the locations (or "cells") because of the increased number of adjacent neighbours (6 instead of 4). The exposure model developed in TRANS-ALP allows to visualise not only tangible exposure assets but also *flows* (e.g., of people, or vehicles) as well as their spatial distribution in a simple and consistent geo-spatial framework, underpinning a more realistic risk assessment on the regional level.

Table 1 presents the complete and detailed list of assets that were considered in the exposure model. In addition to buildings, population, and roads infrastructure, several additional asset data sets were collected: e.g. health sites, education facilities, tourist accommodations, protection forest, sealed surfaces and forested areas (Figure 2 shows two example maps). The process of harmonising the data across regional and national borders was straightforward. Asset data that was not available from official sources, were gathered from global datasets. Pre-processing of the data was required for representing population at a high spatial resolution for East Tyrol and Agordino. Very high-resolution data on resident population was readily available at the address level from the authorities of the Autonomous Province of Bolzano. For Agordino and East Tyrol gridded population distributions were created by disaggregating the most recent population figures per municipality to building locations using the freely available GHS-POP2G tool. Data on the movements of people from resident to workplace locations – "Commuter flow" in the table – were available for the Autonomous Province of Bolzano, for a total of around  point-to-point trips, which is about half of the resident people in South Tyrol ( ca).

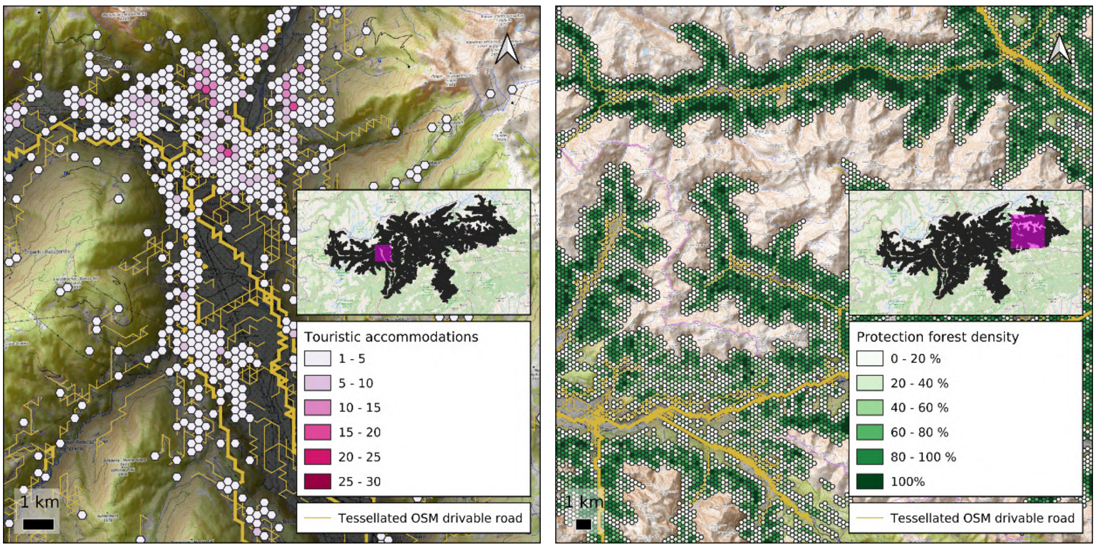



Fig. 1: Two examples of trans-national exposure data after being aggregated onto the hexagonal tessellation at  of resolution: number of touristic accommodations on the left, and density of protection forest on the right.

| # | Name | Description | Unit | Source |
|---|---|---|---|---|
| 01 | **Buildings** | Number of buildings | - | OpenStreetMap, 2021; Veneto regional administration, 2022; Tyrol regional administration, 2003 |
| 02 | **Buildings** | Area covered by buildings | $m^2$ | OpenStreetMap, 2021; Veneto regional, 2022; Tyrol regional administration, 2003 |
| 03 | **Population** | Number of people | - | Autonomous Province of Bolzano, 2022, Italian National Statistical Office, 2021; Austrian National Statistical Office, 2019 |
| 04 | **Hospitals** | Number of health facilities | - | Autonomous Province of Bolzano, 2022; OpenStreetMap; 2022 |
| 05 | **Schools** | Number of education facilities | - | Autonomous Province of Bolzano, 2022; OpenStreetMap, 2022; Tyrol regional administration, 2021 |
| 06 | **Tourist accommodations** | Number of hotels and guesthouses | - | Autonomous Province of Bolzano, 2022; OpenStreetMap, 2022 |
| 07 | **Protection forest** | Proportion of the cell covered by protection forest | % | Autonomous Province of Bolzano, 2013; Veneto regional administration, 2009; Tyrol regional administration, 2021 |
| 08 | **Artificial surface density** | area density of artificial surfaces | 1 | CORINE Landcover 2018 |
| 09 | **Forest surface density** | area density of forest and semi-natural areas | 1 | CORINE Landcover 2018 |
| 10 | **Main roads** | Length of main roads (motorways, primary) | m | OpenStreetMap, 2022 |
| 11 | **Other roads** | Length of roads not included in #10 (secondary, tertiary, etc.) | m | OpenStreetMap, 2022 |
| 12 | **Commuter flow** | Daily flow of residents from home to work | - | Autonomous Province of Bolzano, 2019 |

Tab. 1: The list of the exposure datasets that were aggregated onto the common hexagonal tessellation at  of resolution over the cross-border study area that includes South Tyrol (IT), Agordino (Veneto, IT) and East Tyrol (AU).

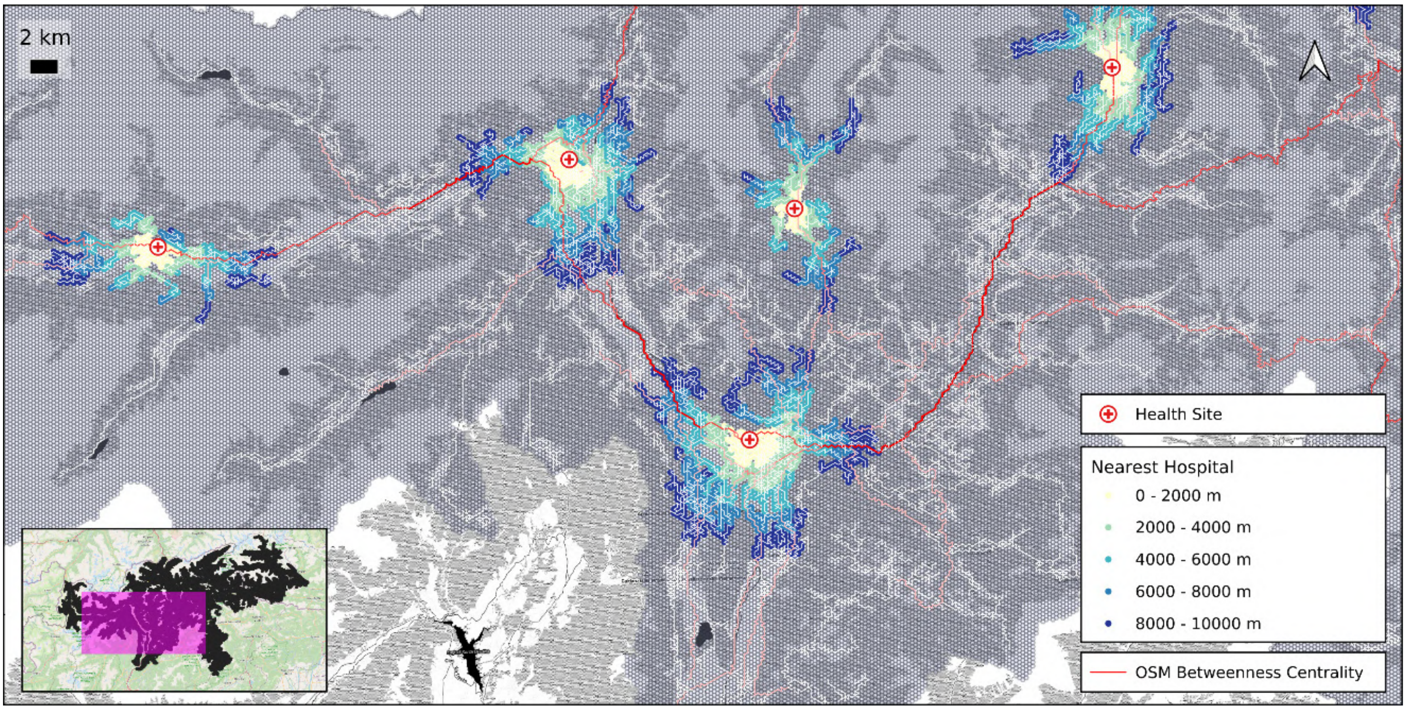



Fig. 2: From exposure to vulnerability: visualizing together on-road distance to nearest health facility (up to ) and roads topological criticality – "betweenness centrality" – on the hexagonal tessellation at  of resolution. The darker red a section of a road the more critical, i.e. important for accessibility of a nearest hospital it is.

## Synthesis and Recommendations

In TRANS-ALP an innovative aggregated exposure model has been developed and exemplified in a cross-border region between Italy and Austria. The model is specifically designed for multi-hazard risk analysis applications and can effectively combine different sources of information in a consistent common framework (either attributed to hexagon cells or the dual network of centroids links), thus going beyond a static data container towards a dynamic and interactive risk and vulnerability tool. Figure 2 exemplifies how visualising the distance to the nearest hospital together with the roads network's critical hotspots can help identify areas of high potential vulnerability for the population: areas near dark red roads in the figure are less likely to provide alternative routes upon interruption and combined with large distances to health sites they identify vulnerable sectors of the territory. Such models are not expected to replace high resolution information (e.g., building by building) which is still highly important for localized civil protection applications. On the other side, the use of efficient, aggregated and harmonized models defined over regular or irregular tessellation can provide an efficient framework to carry out quantitative risk analysis and impact forecasting based on specific scenarios or on simulated conditions, hence providing a useful support to the design and improvement of risk assessment and warning applications.

# Cross Border Cascading Hazards and Risks

*Fabrizio Tagliavini, Roberta Dainese (ARPA Veneto), Matthias Plörer, Michaela Teich (BFW)*

## Cascading Effects in Alpine Storms

Storm-related land cover changes can increase the susceptibility for hazard processes (Kaltenböck et al. 2019). In particular, cascading effects can lead to hazard amplification over several stages (Pöppl & Sass 2019) in form of coupled events, i.e., simultaneously occurring process combinations such as rockfall release due to falling trees during storms or process chains where one event is changing the predisposition for following hazards, e.g., higher probability of avalanche formation and release after forest cover loss (Fig. 1).

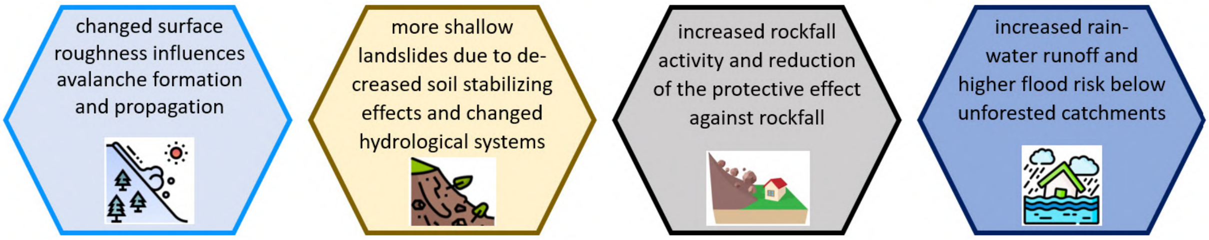



Fig. 1 Most important storm related cascading effects.

## Synthesis and Recommendations

To improve a harmonized and trans-boundary identification and mapping of potential cascading effects of storm-related forest cover changes, 6 steps were identified (Fig. 2).

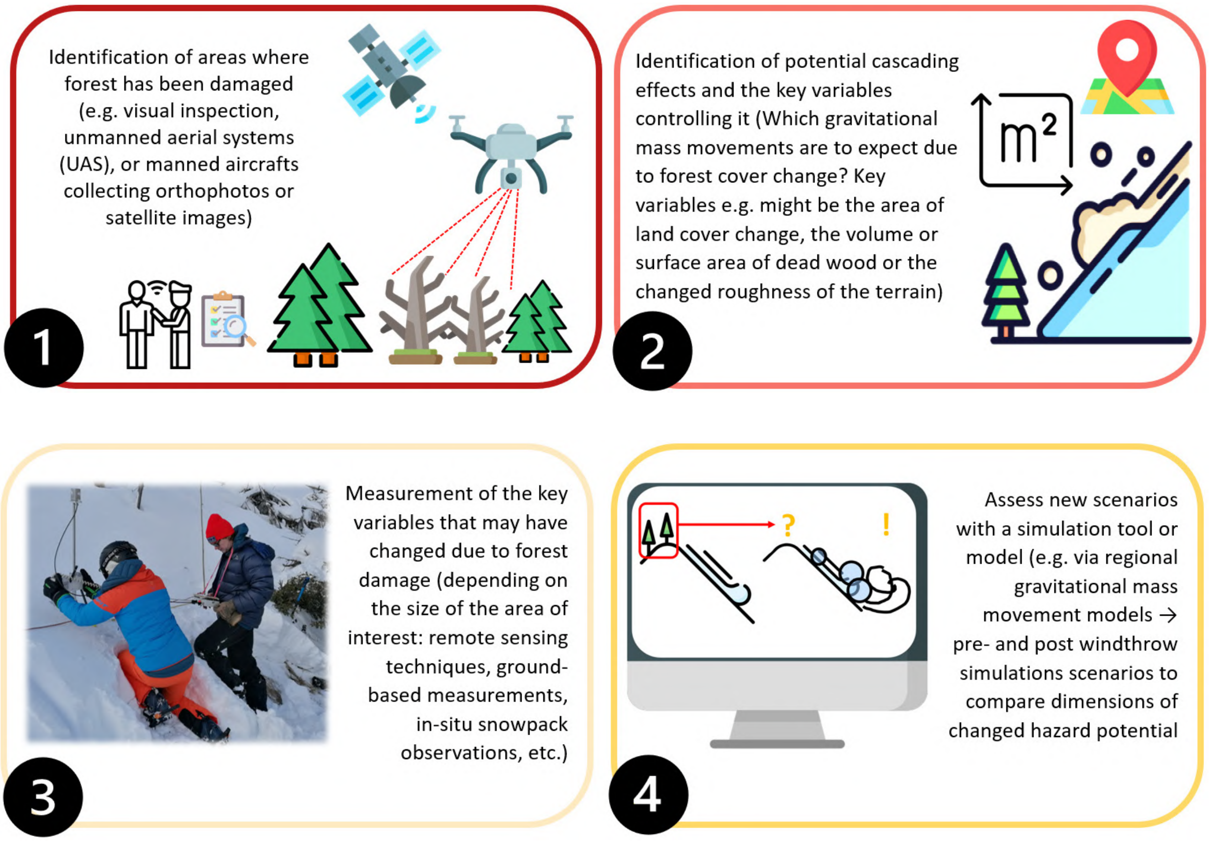



Fig. 2 : 6 steps for identifying, mapping and assessing the impacts of storm-related cascading effects

In the trans-alp project, we focused our efforts on determining an optimal workflow for civil protection purposes for avalanche hazard and risk assessment. In order to identify a correct workflow, it is first necessary to determine the reasons why a particular study needs to be developed. In the two pilot sites of the TRANS-ALP project (East Tyrol and Cordevole valley in the province of Belluno, Italy), the effects of forest disruption due to an intense storm on avalanche risk were therefore studied. The two pilot sites were chosen because of certain similarities, both in terms of morphology and the extent of the damage to the forest heritage caused by the storm VAIA. However, the objective to be achieved at the two different test sites were different. While in the case of the East Tyrol, the aim was to identify the key variables to be analysed in the windthrow areas in order to better understand the development of the snowpack layering, in the Cordevole Valley, a methodology has been studied and a series of GIS tools have been developed in order to speed up the implementation of civil protection plans to mitigate avalanche risk. Although the objectives to be achieved are different, the correct procedure in both examples starts with the avalanche hazard and risk assessment, and then diverges in the conclusions. It should also be taken into account, that the different purposes assume different time requirements: While understanding the key variables that may underlie snowpack stability in windthrow areas can be deployed in processes that are also time-consuming, it becomes imperative, for civil protection purposes, to apply methodologies that enable mitigation plans to be drafted in time before the winter season. The following paragraphs will present the methodology applied in the Cordevole Valley and a table of comparison between this and the methodology applied in East Tyrol to highlight the similarities and differences, but above all, as a starting point for further improvement by taking inspiration from both for an integration and harmonisation in future applications.

# Methodological Guidelines for Communicating Impact Forecasting

*Roberta Dainese, Fabrizio Tagliavini (ARPA Veneto)*

Risk reduction associated with intense weather events –and possible following ground effects –is implemented through actions aimed at mitigating or reducing loss and damage, as long-term processes of accurate territorial planning, the creation of appropriate constructions projects, the development of civil protection plans aiming at the reduction of vulnerability under hazardous conditions. A preliminary and fundamental phase of all these actions is the geographical localization, and therefore mapping, of the hazard distribution and of the vulnerable elements. Maps are designed by experts to convey in a prompt and efficient way the characteristics of defined hazards. The use of maps allows the hazard to be visualised across a whole territory, it often conveys a message in a faster and more efficient way than just textual or numerical data, and it helps the user to promptly identify his reference area. Multi-risk and multi hazard maps can be used as a support for planning –in order to minimise vulnerability and optimise the use of investment and resources (as for the case of the report produced by the World Bank[1], in Figure 1.a)–, or to collect information about recent phenomena and to create a database of events, to be used as starting point for a successive risk analysis –as for the case of global platforms **GDACS** or **Disaster Alert** (Figure 1.b)–or to represent hazard forecast and communicate hazardous situations and their evolution to the population.

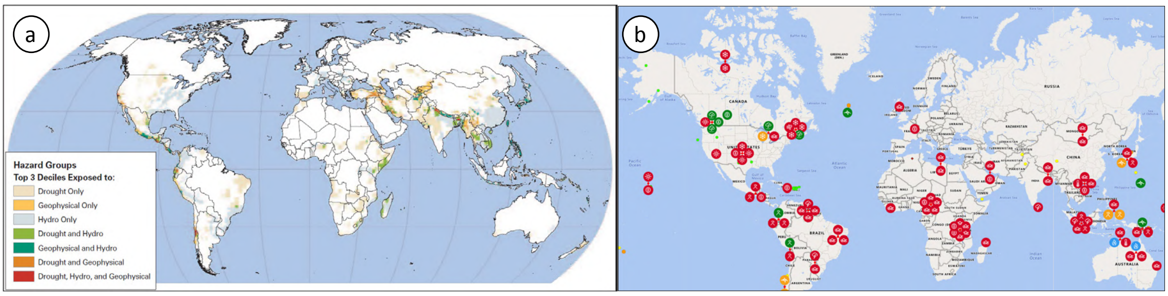



Fig.1 a) Natural Disaster Hotspots, a report by the World Bank: Global distribution of areas exposed to one or more hazards, by hazard type. b) Active Hazards page, extract from *Disaster Alert*

This last group of maps aims to: i) Inform about regions and infrastructures that may be affected by some risk, the severity of the event and possible ground effects ; ii) Suggest or prescribe site-specific behaviour or safety rules; iii) Indicate possible institutional aids and services available to the population in the area. Hazard forecast requires frequent updates of the situation, and a prediction for the upcoming hours. Products related to Civil Protection usually issue a daily bulletin, with further updates during times of alert. Forecast maps are usually nation-wide, as they are usually issued by national offices, but they may even cover wider areas, or focus on smaller regions. A selection of maps designed to communicate hazard forecast is reported in Table 1, with details regarding the type of hazard taken into account and the spatial and temporal scale.

In order to be effective, maps need to be devised to convey the hazard distribution in a prompt and clear way: the design choices play therefore an essential part in evaluating the efficacy of a map. Researchers have made a number of recommendations to improve map comprehension, especially for the case of hazard maps related to civil protection, analysing different visual elements and their efficacy. As a first point, the common suggestion is to use a base map that helps users to clearly identify areas at risk, possibly retracing clear administrative borders, or relevant elements such as rivers, and representing the main landmarks; however, the **base map should never distract from the primary message**, and always be only complementary to the highlighted elements. An **overview map**, containing all current hazards with a clear

1 Dilley, M. (2005). Natural disaster hotspots: a global risk analysis (Vol. 5). World Bank Publications.

priority of visualisation based on severity, is usually considered to be preferable by users and it can give access to additional single-hazard maps. Visual salience draws the viewer's attention to the most important features: in the case of multi-hazard maps it is often achieved with a **well-consolidated colour scale related to severity**. The use of **self-explaining iconic symbols** that do not need the use of a legend should be preferred, as it makes the comprehension faster and more accurate among users. The use of a limited colour palette, made of **4-5 hazard classes** is advisable, **possibly reflecting the severity of the hazard**, and harmonized across the different hazards. This is the case for almost all the maps reported in Table 1, that in general adopt a 4-5 classes of hazard scale, from green to red.

An additional element that can have an important impact on the comprehension of a map by users, is the presence of additional information in a simplified textual form, as a complementary element to the main map. The delivered information should include **warnings** and **further information about the current hazard**, and it should possibly include **recommendations for action**, presented in a **clear and concise manner**.

| Platform | Country | Hazard type | Time Scale | Geographical Scale | Harmonised hazard category | Hazard classes (including green-no risk) | Overview map | Warnings | recommendations for action |
|---|---|---|---|---|---|---|---|---|---|
| **NINA** | Germany | Natural, anthropogenic & socionatural | short-term & real-time | National & local | Y | 4 | Y | Y | Y |
| **Natural Hazard Portal- Switzerland** | Switzerland | Natural | Short-term & real-time | National & local | Y | 5 | Y | Y | Y |
| **Meteo Swiss** | Switzerland | Primary weather | Short-term & real-time | National & local | Y | 5 | Y | Y | Y |
| **Naturgefahren Bayern** | Germany | Primary weather | Short-term & real-time | Local | Y | 5 | Y | Y | Y |
| **GDACS** | International | Natural | Short-term & real-time | Global,national & local | Y | 3 | Y | N | N |
| **Unwetter Zentrale** | Germany | Weather | Short-term & real-time | National & local | Y | 6 | Y | Y | N |
| **KATWARN** | Germany | Anthropogenic & socionatural | Short-term & real-time | National & local | Y | 2 | Y | Y | N |
| **Met UK weather warnings** | UK | Weather | Short-term & real-time | National & local | Y | 4 | Y | Y | Y |
| **Vigilance Metèo France** | France | Weather | Short-term & real-time | National & local | Y | 4 | Y | Y | Y |
| **Iceland SafeTravel** | Iceland | Natural and weather | Short-term & real-time | National | Y | 4 | Y | Y | Y |
| **ARPA Piemonte** | Piemonte, Italy | Natural | Long-term & short-term | Local | Y | 4 | Y | Y | N |
| **Protezione Civile- Warning Bulletin** | Italy | Natural, anthropogenic & socionatural | Long-term & short-term | National | Y | 4 | N | Y | Y |
| **Province of Bolzano -Warning Bulletin** | Prov. of Bolzano, Italy | Weather & natural | Short-term & real-time | Local | Y | 4 | Y | Y | N |
| **GEOSPHERE (ZAMG) Warning System** | Austria | Weather & natural | Short-term & real-time | National | Y | 4 | Y | Y | Y |

Tab. 1 List of platforms supporting hazard maps for civil protection applications

A platform designed following the design principles described above is the **Natural Hazard Portal - Switzerland**, shown in Figure 2. It was designed to communicate current and forecasted hazardous situations to the population, and to convey behavioural recommendations. The default map is an overview of the current situation, where all hazards are represented, and –in the case of multiple hazards for the same location –priority is given to the visualisation of the most severe hazard. The legend is clearly visible and valid for all hazards, which are characterised by their highest current danger level in the bar above the main map. Just below the map (right side of Figure 2) are reported the warnings issued for the area: they are ordered in terms of decreasing severity, with a textual message and a descriptive icon describing the hazard type and colour coded accordingly to the hazard level. It is possible to access additional documentation about the danger level and the recommended behaviour (through text and pictograms).

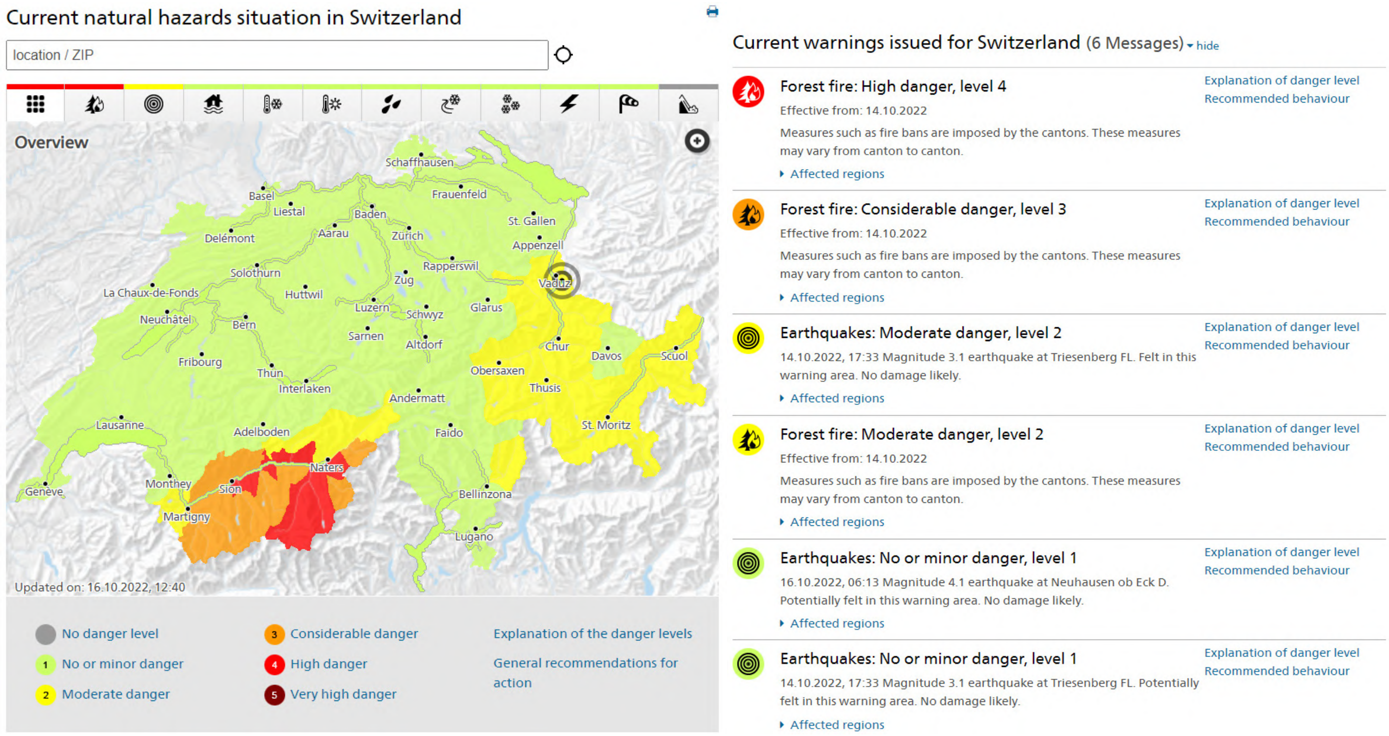



Fig. 2 Current Natural Hazard and current warnings issued for Switzerland *(Natural Hazard Portal)*

As shown in Table 1, several maps are available worldwide and Europe-wide to describe the distribution of hazard, each one with its own format, design, and selection of information to convey to users. However, in the case of intense weather events, it would be useful to have the possibility to monitor the event and the associated hazard across borders: in this case, the homogenisation of practices would be a key point. In the hypothesis of developing a trans-boundary multi-hazard platform, it would be advisable to learn from successful existing maps, both at a wider scale and at a national scale. As shown in Figure 1.b, the platform **Disaster Alert** reports recent events occurring all over the world: events are represented in an homogeneous way, as colour coded icons, representing the nature of the event and its severity, from green to red. The in-detail representation of hazard can take inspiration from the Swiss platform, or from a similar platform developed by the province of Bolzano (**Province of Bolzano -Warning Bulletin**).

## Synthesis and Recommendations

Based on the review of current approaches and the analysis of specific applications in the TRANS-ALP focus regions, a few recommendations can be outlined to improve the multi-hazard impact forecasting and communication.

Cross-boundary multi-hazard platforms should consider the following points:

- Have shared criteria to identify areas of homogeneous characteristics in terms of hazard;
- Have a homogeneous hazard scale for the different hazards, spanning from green to red. Such scale should be adopted by all countries collaborating to the platform;
- Have shared criteria to assess the hazard level associated to a predicted event;
- Provide simple descriptions of potential adverse impacts and consequences based on the estimated intensity of the hazards and on the specific exposure and vulnerability conditions in the different regions;
- The provision of behavioural recommendations (what to do and what not to do in the expected environmental conditions) can be very helpful in raising people´s awareness of risk and foster risk-averse, self-protection behaviours;
- Define a homogeneous set of rules for the issue of warnings, their content and the behavioural recommendations;
- Adopt the best practices for map design described above: use of a simple but complementary base map, use of an overview map, adopting a 4-5 classes well-consolidated colour scale related to severity and –when possible –self-explaining icons.;
- Report the offices in charge, and possible support, for every country/region involved.

# TRANS-ALP Practical Application:
# Reassessing Avalanche Risk in The Aftermath of The VAIA Storm

*Fabrizio Tagliavini, Roberta Dainese (ARPA Veneto)*

Climate change is expected to have adverse impacts and implications for a range of human-environment systems. There is widespread evidence showing that climate change will result in adverse effects for much of the world, including higher temperatures, sea-level rise, increased heavy rainfall, and associated heat stress and inundation damage. Although the scope and scale of their effects are not yet well understood, empirical examples are beginning to suggest that climate change impacts and implications will propagate as cascades across physical and human systems. For example, the combined effect of increased frequency of high-intensity storms, will have compounding impacts on the capacity of individuals, governments, and the private sector to adapt in time before loss and damages occur. In the framework of the project "TRANS-ALP," cascading effects have been addressed on storm events focusing on land cover changes and their impacts on the alpine natural hazards snow avalanches and landslides.

Civil protection plans are an essential tool for the mitigation of the cascading effects deriving from climate change. Thanks to civil protection plans it is possible to reduce loss of life and property by minimizing the impact of disasters. Although civil protection plans are generally the result of careful programming, it is possible that due to sudden changes in the natural state of things, e.g., following severe storms that disrupt the forest layout of the territory, it is necessary to develop specific risk mitigation plans within a short timeframe. In the TRANS-ALP project, specific tools were therefore developed to accelerate the decision-making process behind the creation of such plans. The following pages give an example on how these tools can be used to draw up or integrate existing plans. The example given refers to the avalanche risk mitigation in the Cordevole Valley (BL) in Italy, test site of the TRANS-ALP project.

A correct avalanche risk analysis must consider several aspects:

1) the Potential Release Area (PRA) must be determined;
2) the avalanche runout must be assessed;
3) any vulnerable elements that may be affected by the avalanche path must be identified.

The avalanche release area is an important parameter to be estimated for the avalanche hazard mapping procedure. While parameters like runout distance or deposition height are usually easy to measure, the PRA is often difficult to determine, due to terrain inaccessibility and/or severe weather conditions in the upper areas of an avalanche track. By using specific algorithms in a GIS environment, the tool developed within the TRANS-ALP project automatically identifies all potential release areas in an extremely large area.

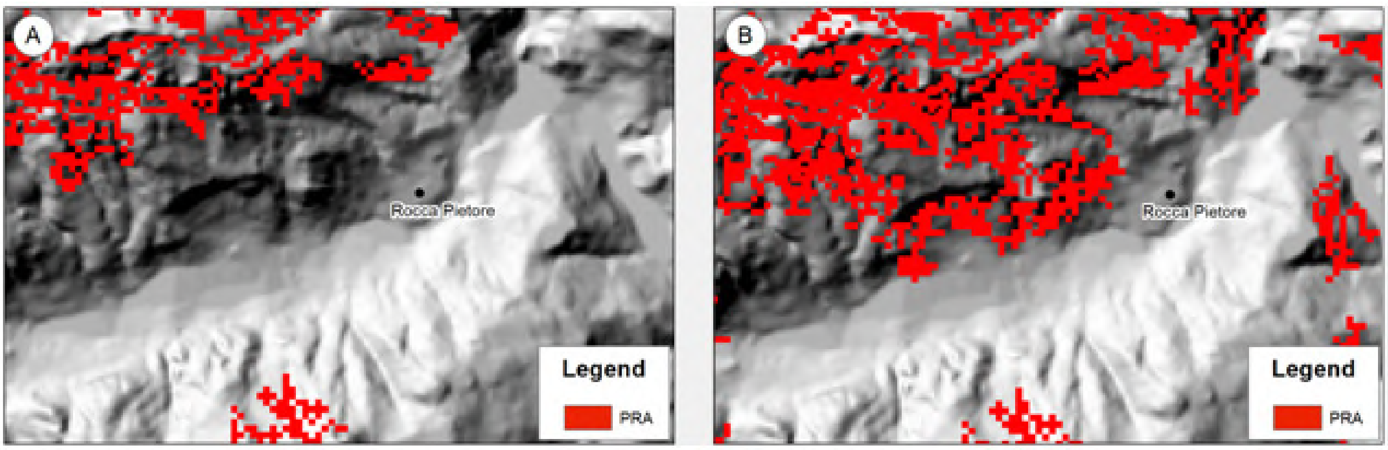



Fig. 1: The Potential Release Areas evaluated by the tool developed within the TRANS-ALP project. A) with the pre-storm Vaia forest condition; B) with the post-storm Vaia forest condition.

Once the PRAs have been identified, the GIS tools developed is furthermore capable of simulating, based on a morphological analysis, hundreds of avalanches simultaneously.

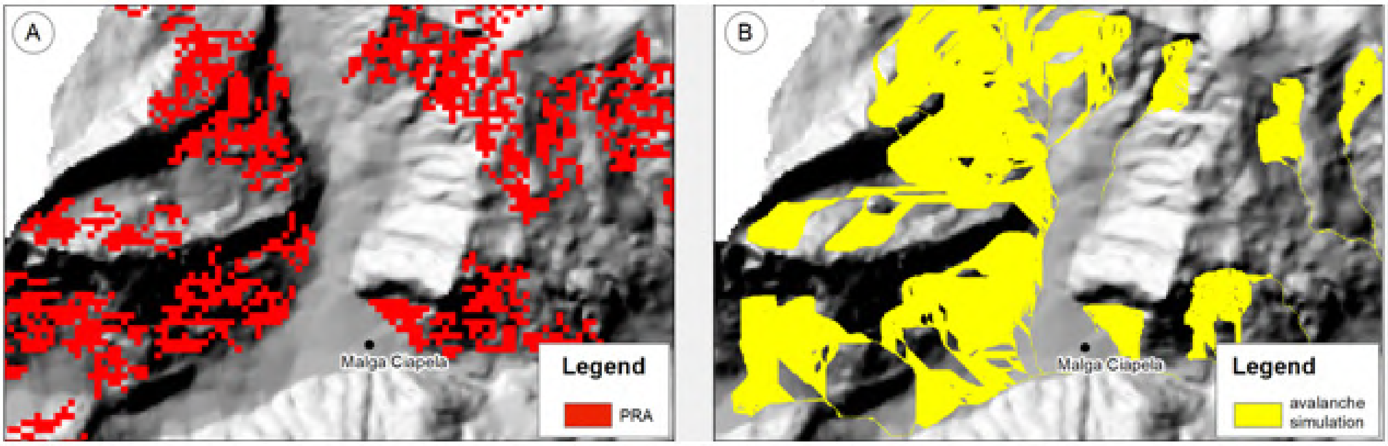



Fig. 2: Example of how the tool developed by the Arabba Avalanche Centre (ARPAV) works: Once the PRA have been identified (A); from these, the runout of all potential avalanches in the study area are simulated simultaneously (B)

A supplementary extension of the GIS tool developed for the TRANS-ALP project makes it possible to identify which elements at risk may be affected by avalanches. Elements at risk is a generic term that signifies everything that might be exposed to hazards, ranging from buildings to the economy and from individual persons to communities. Elements at risk are about exposure to the hazard: What is there that can be damaged or destroyed, injured, or killed, hampered, or interrupted. The degree to which this happens depends on the intensity of the avalanche and the vulnerability of each element at risk to suffer loss due that particular hazard with that particular intensity. The tools developed within the TRANS-ALP project therefore allows, based on the avalanche runout map, to automatically extrapolate the elements at risk concerned. Based on which elements at risk may be affected by avalanches, it is then possible to make a priority list on which to base the dynamic avalanche calculation and civil protection interventions.

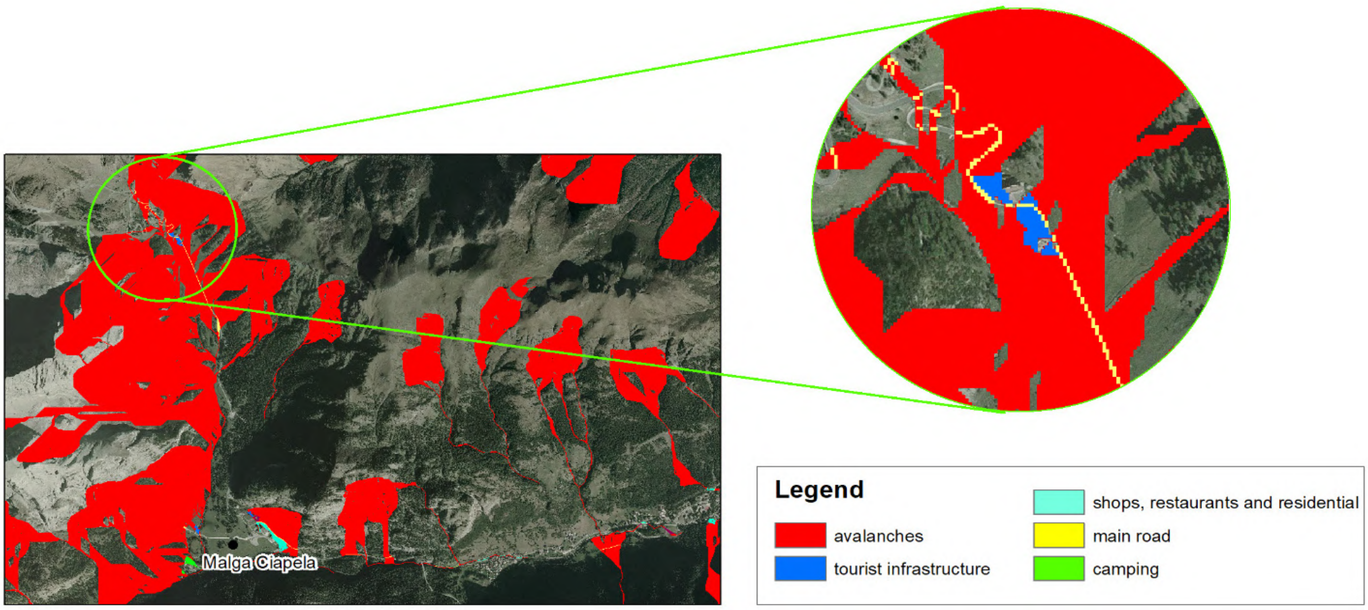



Fig. 3: the map of the elements at risk as calculated by the application developed by the Arabba Avalanche Centre overlaid on the avalanche map

Once the areas characterized by a higher degree of vulnerability have been identified, a series of dynamic modelling can be conducted to indicate along the avalanche path the maximum flow heights, impact pressures and the perimeter of the avalanche itself. The results of this final modelling can be used for the implementation of special civil protection plans.

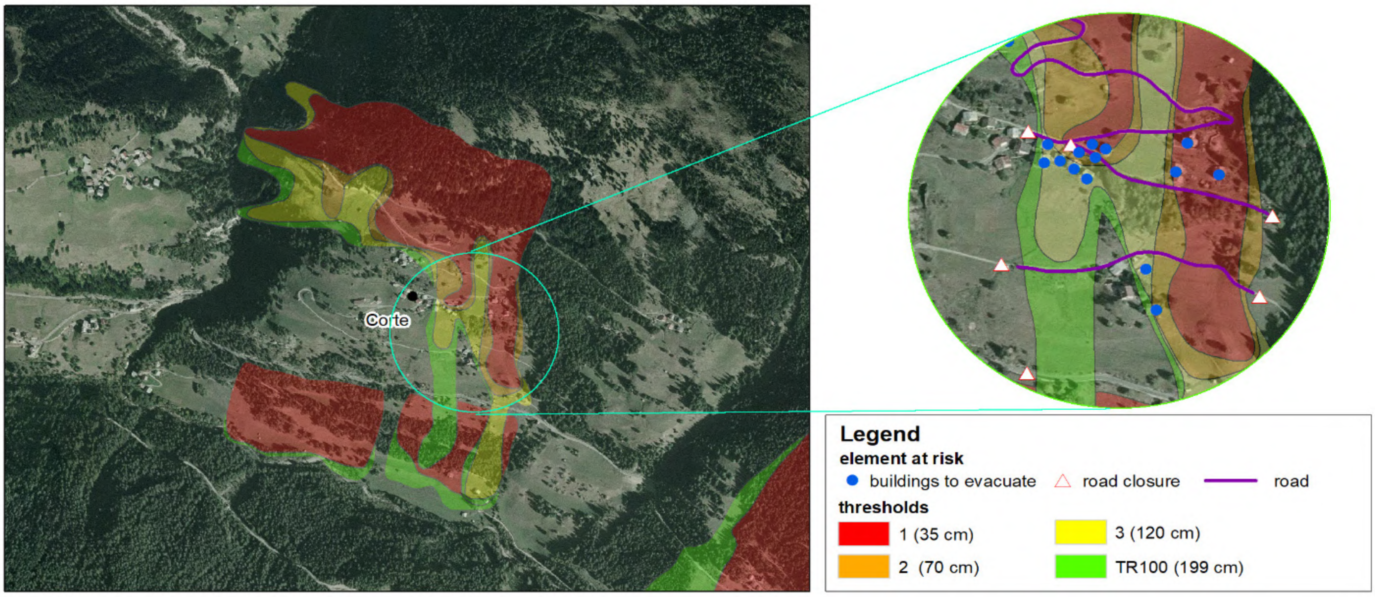



Fig. 4: The risk classification in Lasta Sief site as a function of ground snow thresholds recorded. In the box is outlined which houses must be evacuated depending on the DH3gg threshold reached and where the road should be closed to traffic.

The civil protection plans implemented in the Cordevole Valley to mitigate the cascading effects due to the VAIA storm provide the evacuation of houses and road closures according to specific thresholds of snowpack height identified for each site. Such thresholds do not, however, consider the stabilising effect of fallen trees left on the ground. It is therefore necessary to find a threshold, called 'threshold 0' from which to make the above considerations. This threshold must be somehow linked to the average height of the felled vegetation. Within the TRANS-ALP project, a methodology able to find out the Avalanche Initiation Freeboard has been developed.

In floods risk, the freeboard is defined as the space between the water level and the level where the river starts to overflow the bank. The term "avalanche initiation freeboard" describes the maximum height of the snowpack accepted before an avalanche can be triggered, i.e., the snow depth required so that fallen vegetation on the ground is not completely buried.

Over the last decades, the role of remote sensing gained importance for monitoring applications in precision agriculture and for the evaluation of topographic surface roughness. It is possible to use the Digital Terrain Model (DTM) to identify the roughness of the topographical surface, as well as the Digital Surface Model (DSM) to evaluate different parameters related to vegetation. It is also possible to combine both models to obtain essential information on the vegetation height, identifying the so-called Canopy Height Model (CHM).

Canopy Height Model is a measurement of the height of vegetation above the ground topography. This product is used in a variety of forestry applications including tracking vegetation and trees in a forest over time, calculating biomass, and estimating leaf area index.

To convert the roughness derived from the CHM into the freeboard map, many algorithms have been considered and tested in the TRANS-ALP project, but none fully met the objective. A new algorithm has then been developed in order to carry out a particular focal analysis of the Canopy Height Model. The focal analysis performs, for each pixel in the map, 8 different subtractions, one for each neighbouring pixel. The output map will represent, for each pixel, the maximum value of this difference.

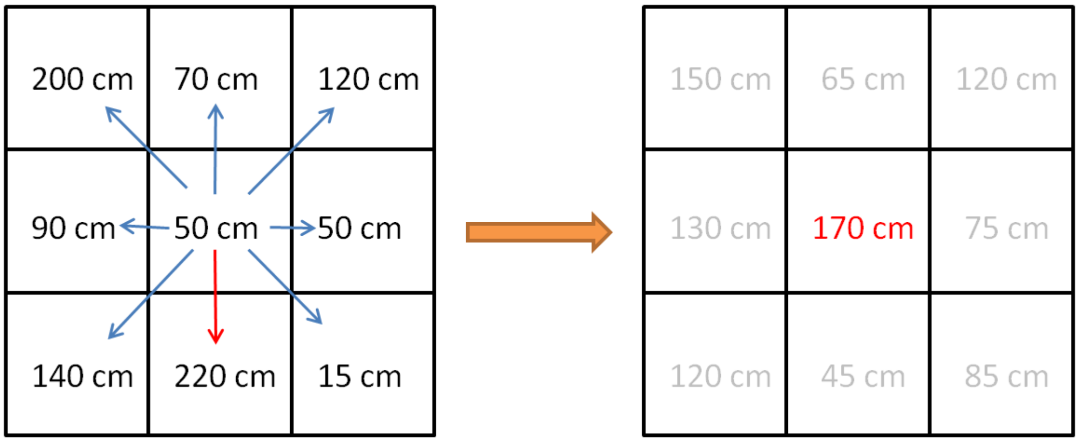



Fig. 5: schematic representation of how the algorithm works: once the Canopy Height Model has been calculated from this, each pixel in the map performs a subtraction with the eight neighbouring pixels. The output map represents the maximum values of this subtraction.

The result is a raster map that does not faithfully represent reality, but is perfectly meaningful for determining the average values, for each windthrow area, of the avalanche initiation freeboard.

The map shows that in the 311 areas analysed in the test site, the average heights of the avalanche initiation freeboards are different from each other. This result is not entirely unexpected, as the freeboard value is influenced both by the density of the damaged forest and the slope on which it is lying. Figure 6 shows the two extremes of the result obtained and figure 7 is an extract of the GIS project in which for each withdrawn area the correspondent avalanche freeboard is represented.

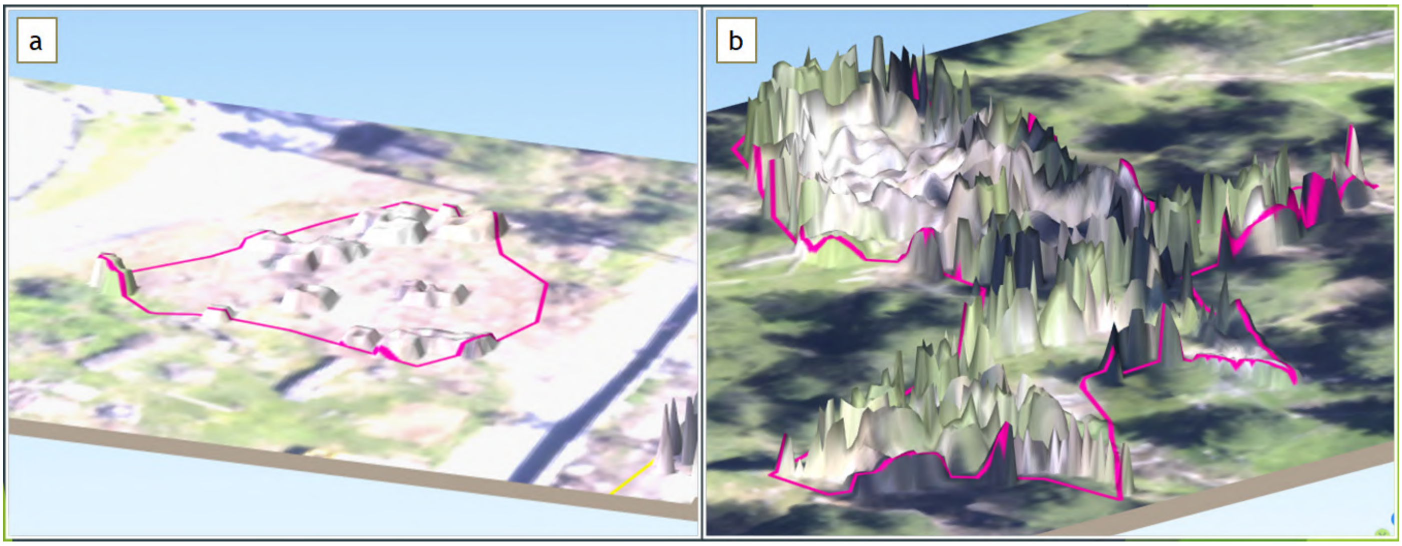



Fig. 6: two examples of the avalanche Initiation Freeboard a) withdrawn area near the village of Alleghe with an average freeboard of about 80 cm; b) withdrawn area near the village of Livinè with an average freeboard of about 2.3 meters

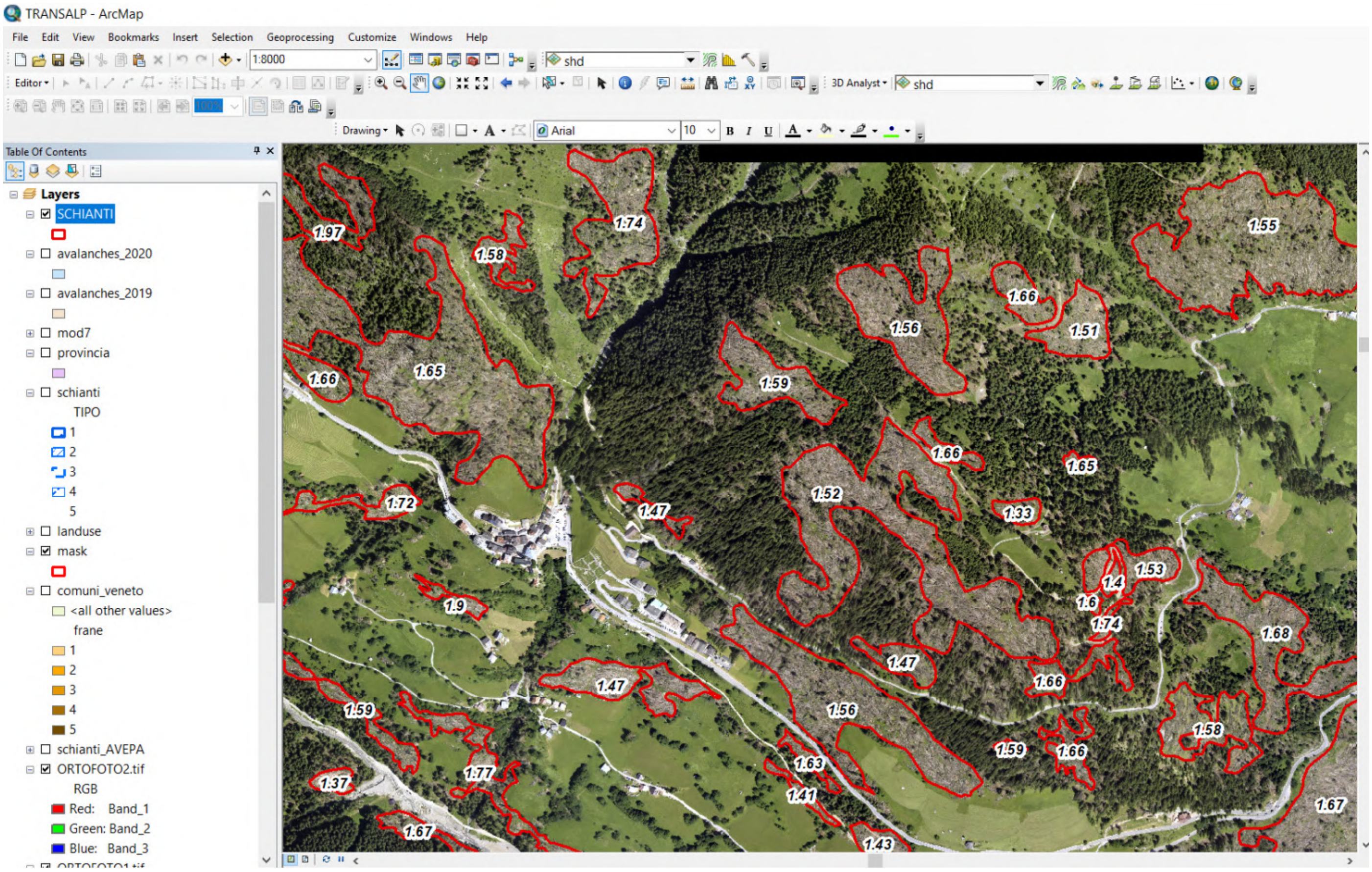



Fig. 7: the label inside each windthrow area polygon represents the Avalanche Initiation Freeboard that can be considered as the "threshold 0" to be adopted in civil protection plans

As mentioned in the introduction to this work, the tools developed for avalanche hazard and risk assessment within the TRANS-ALP project are aimed at speeding up the decision-making processes underlying the implementation of civil protection plans. Particularly, the identification of the avalanche initiation freeboard will allow the aforementioned plans to be activated only when the snowpack height reaches values that could become a risk to the population.

## Comparison Between The Two Test Areas

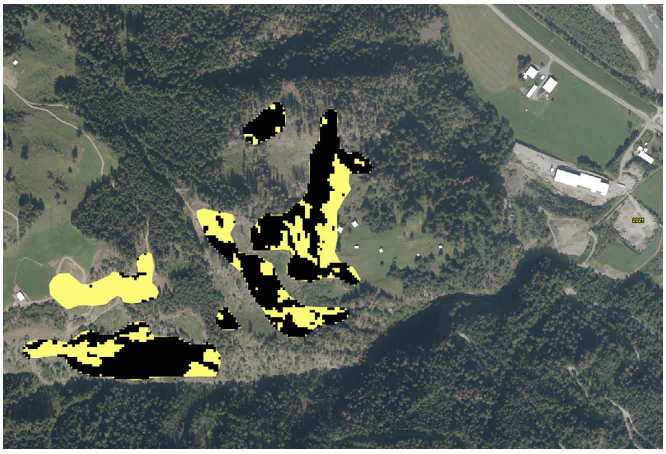
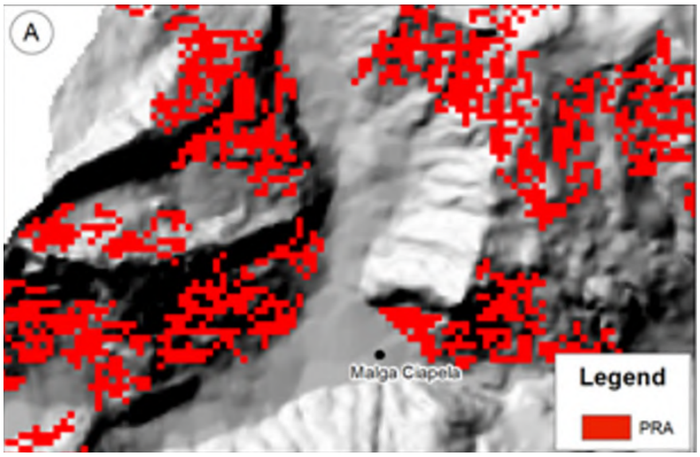
The following tables highlight the similarities in the approaches taken to determine the different objectives. In particular, table 1 shows the types of data needed to determine the key variables of the different test sites with regard to the steps 1-3 of figure 2:

| East Tyrol | Cordevole Valley |
|---|---|
| **Data acquisition / data provider (of spatial explicit damaged forest areas)** | |
| State of Tyrol (Office of the Tyrolean Government) | Arabba Avalanche Center of ARPAV |
| **Data collection procedure** | |
| manned aircraft orthophotos; airborne laser scan surveys | A) Manual mapping<br>B) vegetation indices compiled from satellite images<br>C) lidar flight for DEM & DSM |
| **Identification where significant vegetation changes occurred** | |
| differential digital surface models before & after the storm ("NDSM") | for each index, the difference (post-event index) - (pre-event index) was calculated; differential digital surface models before & after the storm ("NDSM") |
| **Determination of the area of the damaged forest stands** | |
| via GIS operations | via GIS operations |
| **Overall windthrow areas [hectares]** | |
| 2.155 (1,1 % of the entire area of East Tyrol) | 100 (0.5 % of the Cordevole Valley) |
| **Determination of key variables** | |
| terrain roughness identification in direction of the slope's fall line was developed to quantify the effect downed trees have on the susceptibility of snow avalanche release; as a basis for improvement of determination of avalanche release areas; | lidar data were used for the definition of avalanche initiation freeboard through the analysis of the Canopy Height Model and the development of a specific algorithm |
| **Used techniques for determination of key variables** | |
| snow micro penetrometer, snow pits, drone flights (photogrammetric analyses); overarching aim of the study is to quantify how the roughness affects the snowpack including the snowpack stratigraphy, which is linked to the possibility of avalanche release | GIS techniques |

Tab. 1 : different approaches for steps 1-3 in the pilot regions.

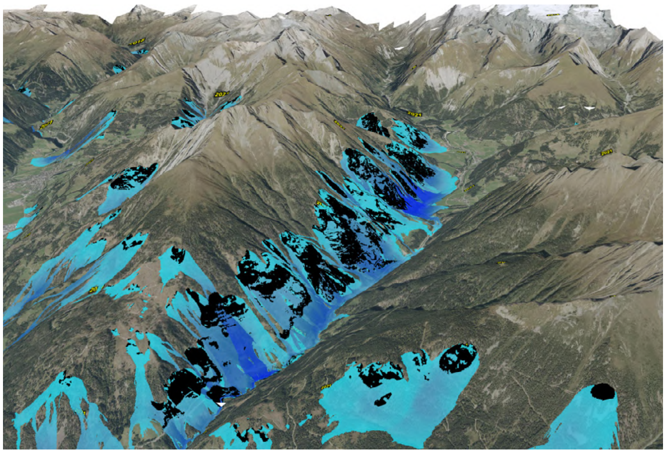
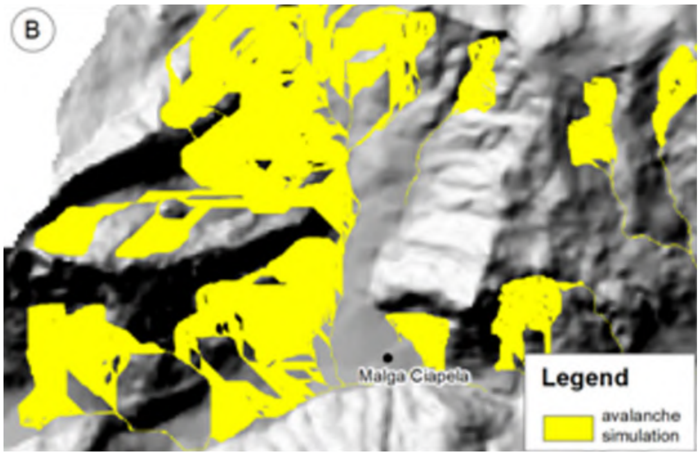
## Determination of New Potential Avalanche Release Areas, Runout Simulations for Exposure Assessment & Assessment of Newly Exposed Assets Due to Post-Windstorm Avalanche Hazards (Steps 4 & 5)

The identification of Potential Release Areas (PRA´s) and the simulation of avalanche runout is essential for both study purposes, nevertheless, the necessity to identify a priority of intervention for the implementation of civil protection plans in the case study of the Cordevole valley requires a more accurate definition of PRA's through the use of a greater number of parameters.

| East Tyrol | Cordevole Valley |
|---|---|
| • slopes with 34°-55° slope inclination are considered as PRA´s (based on Perzl & Kleemayr 2020)<br>• morphologically coherent terrain chambers or terrain curvature are not considered<br>• slope inclination generated in QGIS via raster analysis<br>• slope pixels with inclination of 34°-55° were intersected with downed forest stands<br>• total new PRA´s: 1077 hectares (50 % of the entire VAIA storm areas) | • large-scale topographic parameters are derived from the DEM to automatically define PRA´s<br>• slope inclination 30°- 60° were used<br>• main ridges as a separating feature for the PRA is used; these is automatically derived from the DEM<br>• Terrain roughness and curvature have been considered in the PRA's calculation<br>• destruction of forest vegetation leads to a significant increase in the number of potential avalanche sites (75 % of the VAIA windthrow areas) |
|  |  |
| **Identified PRA´s in the pilot region of East Tyrol** | **Identified PRA´s in the pilot region of Cordevole Valley** |

*Tab. 2 : Determination of new potential avalanche release areas* (step 4)

As far as avalanche runout is concerned, both approaches used calculation models that were not physically based, but rather on a morphological basis. Nevertheless, in the case of the Cordevole valley, it was necessary to use a model capable of simulating thousands of avalanches at the same time, in order to speed up the implementation of civil protection plans.

| East Tyrol | Cordevole Valley |
|---|---|
| • usage of the data-driven empirically based runout model for gravitational mass movements on regional scale: "Flow-Py" ( https://github.com/avaframe/FlowPy)<br>• creation of input and output data in QGIS (raster formats: ASCII or TIFF)<br>• primary required input data: "DEM layer" (terrain model) & "release layer" (raster defining potential release cells)<br>• process paths based on "stopping routine" and "routing routine"; 4 parameters necessary to define;<br>• runout by alpha angle: line formed from the top of the release to the farthest-reaching runout mass; according to Kobal et al. (2019), the used 25° alpha angle represents avalanches with a 100-year return period (Huber et al. 2017) | • hydrologic terrain analysis software tauDEM (Tarboton 1997) has been adapted to derive avalanche paths identified from the DEM<br>• detection of all downslope locations of a given starting cell until a predefined alpha angle (from the starting cell is reached.<br>• alpha-angle based on studies of return periods in the study area; angles between 20° and 23° are sufficient to stop most avalanches<br>• advantage: simultaneous analysis over large areas to identify potential hazard areas in a short time |
| <br>**New potential avalanche runouts in East Tyrol.** | <br><br>**New potential avalanche runouts in Cordevole Valley.** |

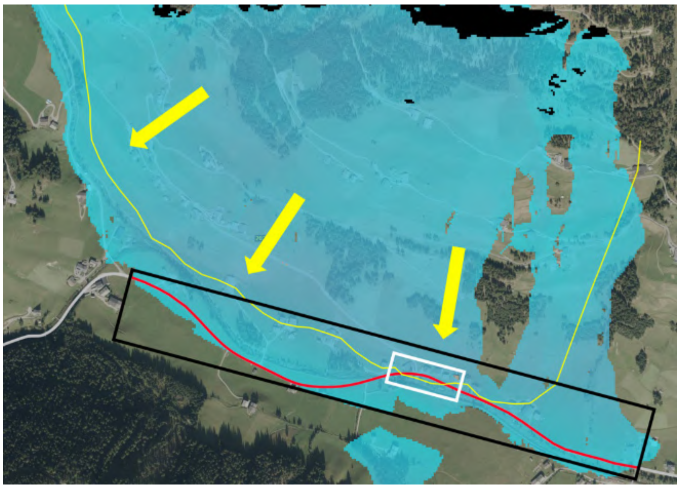
Tab. 3 : simulation of new runout and deposition zones (step 4)

The most important differences between the two pilot sites concerns the identification of the newly exposed assets downstream the windthrow areas. Once again, the differences in the approaches used are closely linked to the different goals to be achieved. In the East Tyrol pilot site, the whole procedure, in addition to identifying the key variables indicated in table 1, is suggested as a reference guide for a first step for reclassifying the national avalanche hazard map after VAIA. A different approach is needed for the purposes in the Cordevole Valley. As mentioned above, the model developed from the Arabba Avalanche Center of ARPAV is capable of simulating thousands of avalanches at the same time, but it is necessary to prioritise intervention for civil protection purposes. A further model has therefore been implemented that is capable of making an analysis of the vulnerable elements affected by avalanches and therefore discriminating the potential risk. This analysis is then used to implement deterministic and physically based models to structure civil protection plans in detail.

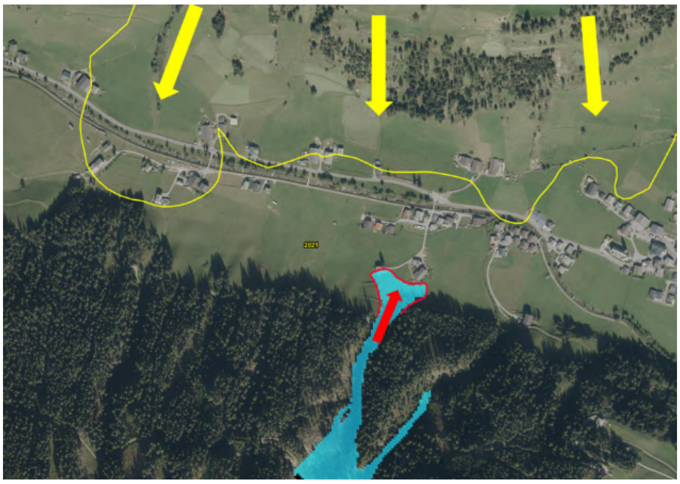
Newly exposed assets due to post-windstorm avalanche hazard on the examples of East Tyrol & Cordevole Valley:

<table>
<tr><th>East Tyrol, Kals (Austria)</th><th>Cordevole Valley (Italy)</th></tr>
<tr><td>

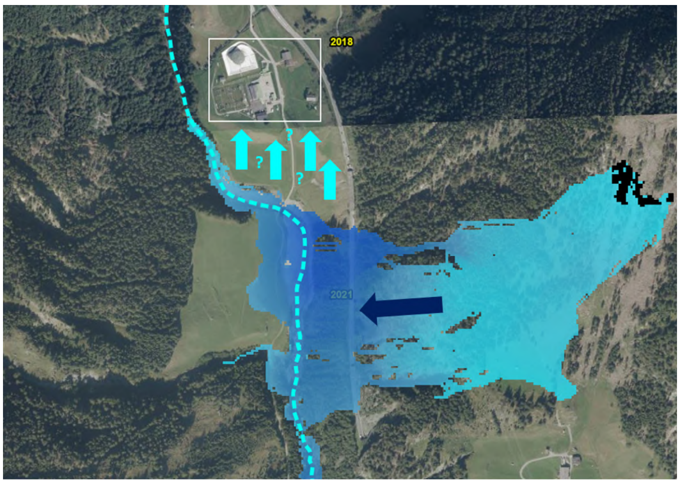
- exacerbation of the hazard situation due to increased avalanche runout lengths beyond the red and yellow hazard zones defined by regional experts and authorities



- New avalanche runout paths and deposition zones within the settlement area, which could not yet be considered by the official hazard zone planning

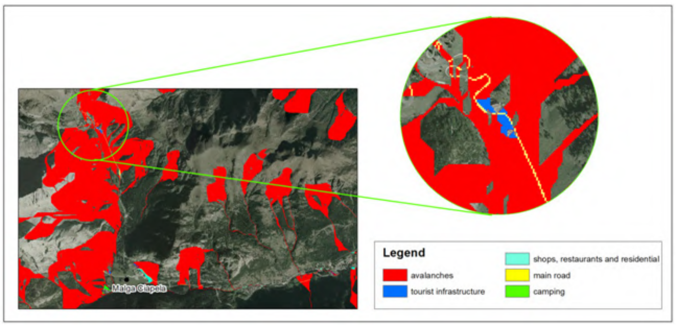



- Sudden exposure of sensible infrastructure to avalanches and associated potential for cascading effects

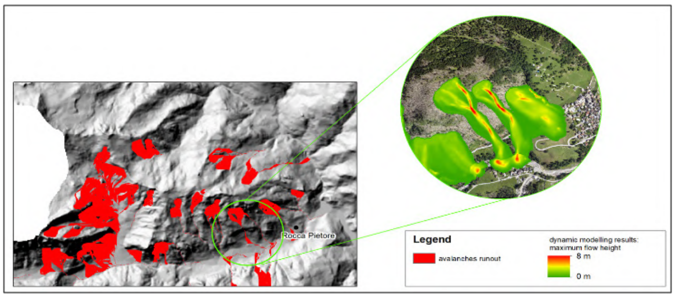



</td><td>

- a tool developed by the Arabba Avalanche Centre allows, based on the avalanche runout map, to automatically extrapolate the elements at risk concerned
- priority list on which to base the dynamic avalanche calculation and civil protection interventions; essential to prepare a map, as input data, with the elements at risk ranked by importance; to understand the priority of the intervention in the Cordevole Valley, two different scales of analysis, ranging from national scale to a detailed scale were used
- the final result is a raster map in which each element at risk has been indexed; such indexing allows the identification of a priority for action in risk mitigation




- once areas characterized by a higher degree of vulnerability have been identified, a series of dynamic modelling was conducted to model flow heights, impact pressure (via "RAMMS", developed by the WSL Institute for Snow and Avalanche Research SLF (Christen et al., 2010)); this results were used for implementation of new special civil protection plans

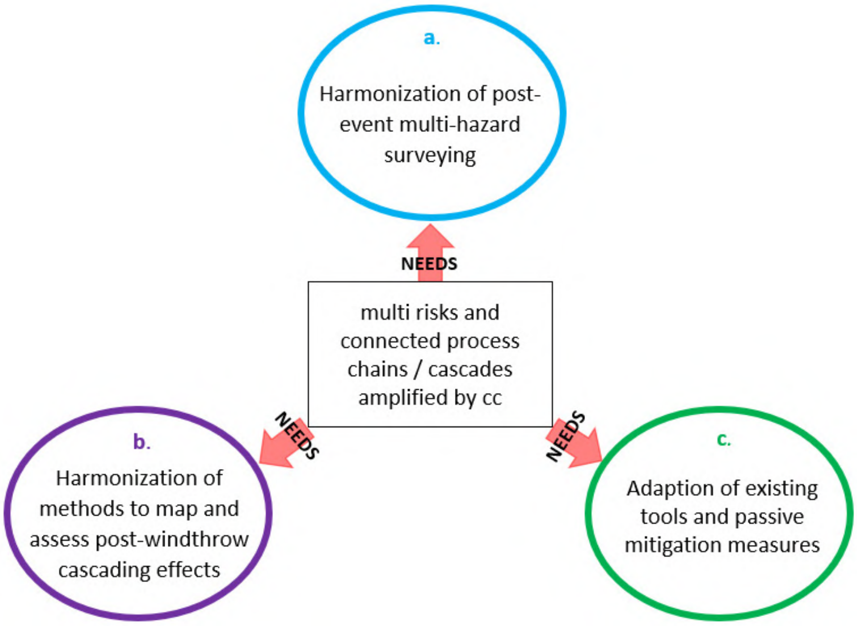



</td></tr>
</table>

Table 4 : Newly exposed asses due to post-windstorm avalanche hazard (steps 4 & 5)

## Synthesis and Recommendations

As illustrated in the previous tables, an analysis of exposure and vulnerability adapted to climate change impacts, considering multiple natural hazards and cascading effects, entails a consequent need for appropriate natural hazard and risk management. Whenever the storm events impact large areas, it appears advantageous to develop a harmonized trans-boundary management, for stakeholders to support each-other across the alpine space and to describe the event at its original scale. The realization of a harmonised approach is based on the following three basic recommendations for action:




### Harmonization of Post-Event Multi-Hazard Surveying

The VAIA storm affected the territory through a series of cascading effects, ranging from floods, geological instabilities and the creation of windthrow areas – in the short term – and leading to successive effects – such as the creation of new avalanche sites and the spreading of the bark beetle – in the upcoming months. The surveys undertaken in the aftermath of the event highlighted the requirement for a structured procedure for data collection in the field, firstly to assess the damages, and secondly to evaluate residual risks and possible cascading effects, in order to develop the appropriate mitigation strategies. The time constraint related to this last aspect has shown the necessity of and efficient, and possibly multi-risk data collection. With this purpose, a series of post-event multi-hazard survey sheets have been created within the TRANS-ALP project, containing information about date and location, type of event and impact, first assessment of the damages and the specification of any relevant interference with a watercourse. Sub-sheets have been structured in two main parts, one relating to the survey of the event (present situation) and one relating to the impact assessment (future scenario). The goal of the survey sheets, used for a specific phenomenon assessment (e.g., focused on avalanches), is to promptly identify other potentials generally relevant process (such as impending rockfalls) in a structured way in the often hectic post-event phases. The data collection will be possibly done with the collaboration of different agencies, that will assess the local situation through the whole territory. Specific cases can be assessed in depth in a second moment by the dedicated bodies. The use of standard survey sheets in trans-boundary regions could encourage the exchange between authorities and the collection of all relevant data that can be used in follow-up trans-boundary event analysis to strengthen the preparedness, response and recovery from such events in the future. The general sheet and the 4 sub-sheets are attached to the detailed “Report on cascading effects of storm-related land cover change on alpine natural hazards” (D.3.3).

### Harmonization of Methods to Assess Ground Effects and Potential Cascading Effects

After the surveys for ground effects data collection, the following step aims to characterise the potential cascading effects previously identified in a qualitative way. The purpose is to evaluate the hazard, any possible protective effect still present, and identify areas where mitigation measures should be implemented. The evaluation of the hazard distribution in the aftermath of the event can be a time-consuming task that should however be settled within a time frame compatible with the civil protection requirements.

A simplified procedure has been developed within the TRANS-ALP project for the specific case of windthrow areas and the subsequent creation of new avalanche sites. The application on the case studies in East Tyrol and Cordevole Valley of similar methods has been described in the tables 1-4. It is based on the evaluation of the loss of forest protective effect, via the identification of new Potential Release Areas within the windthrow stands, and the later application of algorithms to evaluate the avalanches runout, and possibly identify the threaten elements.  The choice of the different parameters differed for the two case studies. Such parameters settings – as well as input data for risk analysis – should be harmonized in the future, or further studies should be done to evaluate the necessity of different values for different geographical areas (E.g. due, for example, of different climatic conditions), to ensure trans-boundary comparisons and risk mitigation strategies being homogenized.

Identifying and mapping windthrow areas, especially in steep terrain combined with site visits to further quantify remaining protective effects against natural hazards or areas where other measures must immediately take place is a major task after large-scale severe forest disturbances.

### Passive Mitigation Measures

Once the current situation is assessed and the characterisation of the residual risk for the vulnerable elements is available, the next step aims at the definition of adequate countermeasure to mitigate such risk. In a time frame of a few years, several of the windthrown areas created by VAIA were secured through the construction of avalanche protection work, while the main long-term solution is to let the forest natural regeneration to reinstate its protective functions.

On the short term, however, such solutions are not feasible. To mitigate the risk, specific civil protection plans can be used. Regarding the avalanche risk in the Cordevole valley, extraordinary civil protection plans were made to ensure adequate safety conditions, as preventive avalanche control measures such as the artificial avalanche release cannot be considered due to the presence of buildings potentially subject to damage. Such plans were developed based on simple snow height measurements and the comparison of the measured data with predefined alert thresholds, defined on the base of avalanche simulations that may lead to damages to buildings and infrastructures and/or fatalities. The tools developed within the TRANS-ALP project allow to compare the runout of the avalanche with the distribution of vulnerable elements on the territory, in order to identify the buildings/infrastructures/etc. to be included within the civil protection plans.

The creation of a civil protection plan is a temporary measure aiming at reducing the impact of specific phenomena, defining different scenarios and the subsequent actions to be implemented. Such plans should be used as a temporary and short-term solution, and should be revised whenever relevant changes to the situation occur, both reducing (e.g. forest regeneration) or increasing the risk (e.g. biomass decay of the fallen trees).

# Part 2
# Data and Information Sharing Tools

## Storm Impact Data Collection and Mapping Methodologies

*Matthias Plörer, Michaela Teich (BFW), Katharina Enigl (Geosphere Austria), Kathrin Renner, Piero Campalani (EURAC Research)*

### Storm Impact Data Collection in Europe: Why Do We Need to Record Impacts, Damages and Losses & What Is The State of The Art?

The so called extra-tropical cyclones (XTC or European windstorms), mesoscale convective systems (MCS) and also local scale types of thunderstorms like the rarely occurring but very severe supercells cause high amounts of losses and can be extremely impacting. Since the footprint of these large-, meso-, and local-scale events can affect hundreds of kms, harmonized records of impacts, damages and losses should be pursued. A screening of techniques and data sources at European, national and sub-national scale, with particular interest and focus on Austria and Italy, was carried out. The storm damages and losses are generally related to the following meteorological causes:

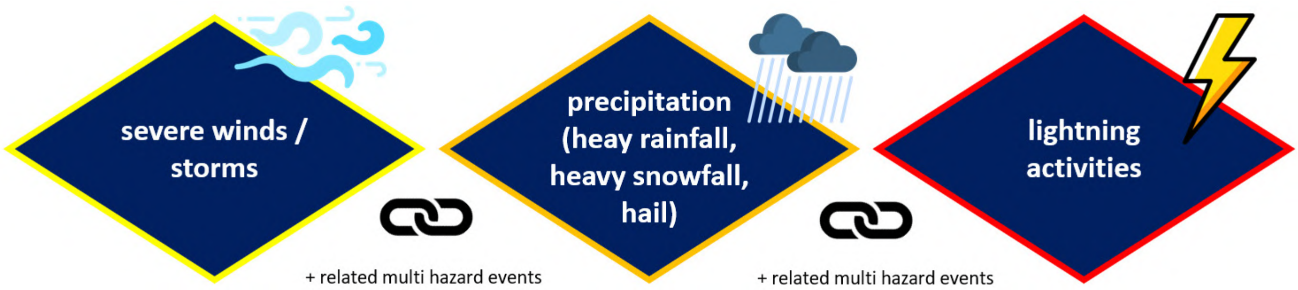



Fig 1. : types of damaging processes in the focus of storm impact data collection

Loss accounting, disaster forensic and risk modelling represent at least three applicaton frameworks which justify increasing efforts related to impact and damage recording:

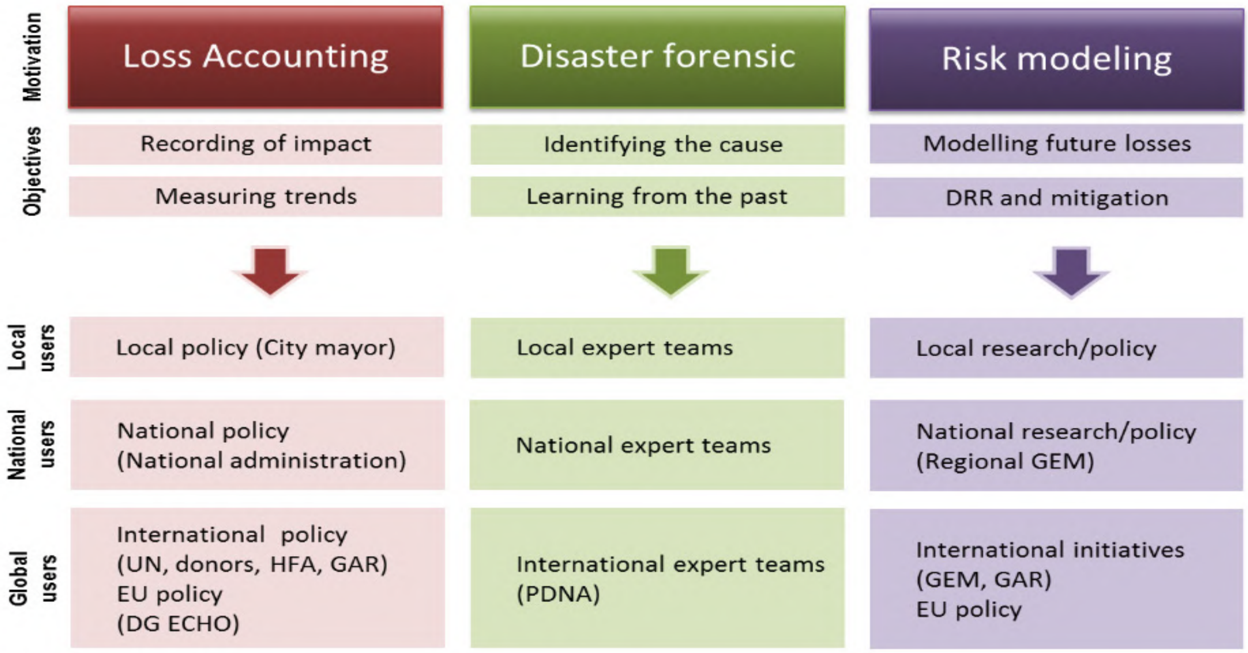



Fig. 2: each application framework has different objectives and different users and stakeholders are involved, at local, national or global level (JRC, 2013)

The available documentation approaches and data sources were evaluated in terms of their scale (local, national, global), classification systems (e.g. level of standardization of impact types and severity), level of geocoding, relevance/compliance with respect to PDNA and DALA guidelines issued by national and trans-national bodies (EU Commission, UN, the World Bank, WMO, etc.) and reference initiatives (e.g. GRADE from the GFDRR, NWS from NOAA).

In the last decade an increasing attention has been paid to damage and loss recording, in Europe notably advocated and pushed by the JRC with several reports, publications and activities since 2012:

- JRC (2013) – **Recording disaster losses (Recommendation for a European Approach)**
- JRC (2014) – **Current status and best practices for Disaster Loss Data Recording in EU**
- JRC (2018) – **Disaster damage and loss data for policy**

Furthermore, in the DRMKC a specific working group on disaster loss and damage has been active since 2013. Despite obvious well elaborated reports and established recommendations of e. g. how to record disaster losses, a broad variation of ways and techniques of data acquisition over the alpine countries exists. Therefore, existing damage and impact classification systems were compared and evaluated, and a recommendation for a harmonized cross-border classification system is proposed.

## Which Institutions are Responsible and Usually Predestined for Storm Impact Data Collections in The Alpine Space?

The following diagram shows that the recording and documentation of storm damages can by far not be attributed to only one area of responsibility, but is much more the task of a consortium of institutions, interest groups and also private companies:

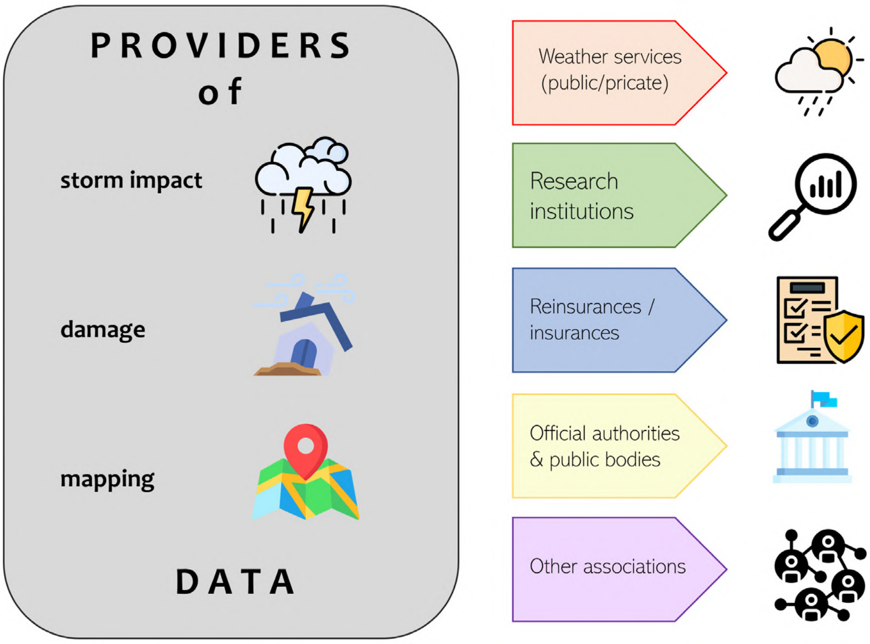



*Fig. 3: different types of storm impact, damage and event mapping providers*

The following table provides a more detailed overview of which institutions, companies, etc. collect or offer storm damage-related data in the project relevant area:

| Private & public weather services (selection) | | |
|---|---|---|
| **short name** | **official name** | **geographical scope of operation** |
| **GEOSPHERE (ZAMG)** | Zentralanstalt für Meteorologie und Geodynamik | Austria |
| **ARPA** | Regional Agencies for the Protection of the Environment | Italy, regional level |
| **Meteo Aeronautica** | Meteorological Service of the Italian Airforce | Italy, national level |
| **MeteoNetwork** | Associazione MeteoNetwork OdV | Italy |
| **Research institutions (selection)** | | |
| **short name** | **official name** | **geographical scope of operation** |
| **EFI** | European Forest Institute | EU |
| **GBA** | Geological Survey of Austria | Austria |
| **WSL** | Swiss Federal Institute for Forest, Snow and Landscape Research WSL | Switzerland |
| **JRC / DRKMC - RDH** | Joint Research Centre of the European Commission – Risk Data Hub | EU |
| **Reinsurances & insurances (selection)** | | |
| **short name** | **official name** | **geographical scope of operation** |
| **Deutsche Rück** | Deutsche Rückversicherung | Europe |
| **Munich RE** | Münchener Rückversicherungs-Gesellschaft | global |
| **Swiss Re** | Swiss Re Group | global |
| **ANIA** | Italian National Association of Insurers | Italy |

| Official authorities & public bodies (selection in the cross-border region) | | |
|---|---|---|
| **short name** | **official name** | **geographical scope of operation** |
| **WLV** | Forest Engineering Service in Torrent and Avalanche Control | Austria |
| **BML** | Federal Ministry for Agriculture, Regions and Water Management | Austria |
| **LWD** | Group Tyrolean Center for Crisis and Disaster Management – Department of Hazard and Evacuation Management – Avalanche Warning Service | Austria, regional (Tyrol) |
| **Land Tirol** | Construction and technology group –Department of Water Management – Section Hydrography and Hydrology | Austria, regional (Tyrol) |
| **BWV** | Department of Water Management – Hydraulic engineering | Austria, regional (Tyrol) |
| **ARPA** | Regional Agency for Environmental Prevention and Protection | Regional, operates in most regions in Italy (e.g. in Veneto is named ARPAV, in Liguria ARPA Liguria, etc.) |
| **Autorità Bacini Montani** | Mountain Basins Authority | Regional, e.g. operates in Trentino / South Tyrol, Veneto, Lombardy, Val d'Aosta |
| **Dipartimento di Protezione Civile** | Dept. of Civil Protection | Operates at National and regional level. |
| **Provincia Autonoma** | Autonomous Province Authority | In Trentino and South Tyrol a more autonomous provincial status grants different powers to local authorities. |
| **Direzione Difesa del Suolo – Regione Veneto** | Land Conservation Department of Veneto Region | Regional, in the Veneto Region includes the functional center of the Civil Protection Dept. |
| **Other associations (selection)** | | |
| **short name** | **official name** | **geographical scope of operation** |
| **ESSL** | European Severe Storms Laboratory. | Europe |
| **MeteoNetwork** | Associazione MeteoNetwork OdV | Italy |
| **TornadoListe** | TornadoListe (Deutschland) | Germany, Luxembourg |
| **LFV** | State Fire Brigade Association | Austria, regional (Tyrol) |

Tab. 1: overview of storm impact data collecting institutions in the Italian, Austrian, German and EU space

## Synthesis and Recommendations

In the frame of the TRANS-ALP project, all listed institutions, companies, authorities, etc. and their current procedure of data collection, mapping and sharing of storm impacts have been reviewed. The findings and evaluations of the available data are varying greatly, due to the different nature, objectives and purposes of all these actors. A summary is given below:

**Data availability & kind of data format/documentation**

- Data is mostly offered in digital form. 80 % of data sources are available online (open-source). Details (e.g. metadata, shapefiles, etc.) are available in 80 % upon request / user agreement.
- Data is visualized as a web application in 70 % of cases. 50 % of the providers offer data also in form of GIS-compatible files or tables. 30 % of data sources are in the form of PDF-files (which are difficult to use).

**Event documentation**

- Over 50% of records are spatially located (some of it inaccurate) and temporal assignments (date/time) are provided for 80 % of all event data. Event durations are often not clearly indicated.
- 6 out of 11 event databases refer to a national level, 3 cover EU area, one collection describes events globally.

**Data acquisition**

- Manifold ways of data collection exist! 3 collections are obtained from media reports. In 6 cases, collections are done through measurements/fieldwork. In 3 cases, references are made to official publications. In 2 cases, the information origin cannot be determined.
- In almost all cases, data collection is done by experts but in only one case, a quality control is added.
- In some cases, databases fed by laypersons or hobby observers are also integrated.

**Hazard process details**

- Over 70% of data providers make a clear distinction between the different processes.
- Overall data contained continuous rain, heavy rain, drought, heavy snowfall, ice accumulation, hail, thunderstorms, various storms (tornadoes, funnel clouds, gustnados, whirlwinds, etc.), lightning, various types of avalanches (slab, loose, wet, dry), mass movements/landslides (falls, topples, slides, flows), floods, pluvial floods, groundwater, heat and cold waves, wildfire, rime, deadwood.
- But no database dealt with multi-hazards / cascade effects. Temperatures, precipitation sums, wind speeds are addressed in certain cases while the “intensity” in some way in general is cited in over 60% of data collections.
- Damage is mentioned by 50% of data holders but quantified less frequently (30%).

**Adherence to standards, guidelines, recommendations**

- The inclusion of internationally standardised thresholds or scales is still lagging.
- After all, however, Fujita, Torro or EAWS scales are mentioned in one third of the data collections.
- Only 3 out of 11 analysed event collections can be directly linked to the EU Commission

| Advantages & “best practice” cases | Disadvantages, “major obstacles” & gaps |
| --- | --- |
| • increasing understanding of the need to systematically collect data<br>• this is clearly visible in the efforts devoted on this topic by the EU Joint Research Centre<br>• by “impact” is usually interpreted as the broad set of effects of a given “root” phenomenon (e.g., a storm). This includes mostly cascaded hazards such as landslides and debris flows, fluvial and flash floods, and avalanches.<br>• to better capture these impacts, tailored and standardized methods are increasingly used and gaining importance (e.g. EU floods directive, Italian IFFI database on landslides, etc.)<br>• the scope, resolution, quality control, and operational protocols vary widely across countries. Best practice approaches are mainly followed by Switzerland and Slovenia<br>• most data on impacts are collected from personal testimonies, newspapers and media, and direct witnesses. A good example based on such an approach is the VIOLA system operated by GEOSPHERE (ZAMG) in Austria, which provides an overview of observed impacts. | • Impacts of damage and loss are perceived but usually not systematically captured and recorded. Some particularly structured reporting protocols allow information on damage and loss to be recorded, but these are often not detailed enough, for example, to build vulnerability models. Loss data from insurance companies, usually cannot be obtained due to data protection.<br>• Damage with secondary causes is usually not systematically recorded as well as cascade phenomena such as traffic disruptions, business interruptions and power outages.<br>• Open data is on the rise, but information on severe weather impacts is often not freely available. Publicly provided basic data, usually do not include details on victims and fatalities.<br>• Attributing impacts to events that are not directly attributable to the associated hazards is difficult and makes it difficult to track indirect damages and losses.<br>• Often, information on the impact of events is published only in text form and a specific local language. The underlying data are often difficult to access, which prevents systematic analysis. |

Tab. 2: the summarized advantages and disadvantages of the diverse studied institutions as data collectors

# Impact Data Collection in The TRANS-ALP´s Cross-Border Study Areas

*Katharina Enigl, Sebastian Lehner and Klaus Haslinger (Geosphere Austria), Kathrin Renner, Piero Campalani (EURAC Research)*

A variety of different data are collected in the target region of the TRANS-ALP project. In the following, data sets which we have received and analysed during the project are described in detail. Furthermore, we lay emphasis on harmonization procedures which are necessary for using all datasets combined.

## Italian Damage and Event Data

### ED30 hydrological event data base

The "Event Documentation of the 30th Division of the Autonomous Province of Bolzano (ED30)" (Macconi and Sperling, 2010) started in 1998. Over the years, the ED30 system, which allows organized and standardized surveys of hydrogeological events on watercourses (floods, debris flows, landslides, falls and avalanches), has been continuously improved. After the notification of an event that has occurred, the investigation procedure starts with the dispatch of a documentalist and, if necessary, with the organization of a reconnaissance flight with the helicopter. The field work includes the collection of the main data of the process, the photo documentation and the elaboration of maps in the appropriate scale (at least 1:25,000). All these data are further digitized and archived in a database structured in modules. This dataset is a mere event database comprising over 1700 hydrological events in South Tyrol. Its 14 attributes contain information on the exact location (point geometry) and time on a daily basis of the event, details on the prevailing processes as well as on the affected water bodies; information about damages induced by these hazards are not included in this database. The ED30 hydrological event data base comprises the following hazard categories: "Overbank sedimentation", "Landslide", "Flood (inundation)" and "Urban flood".

### IFFI

The Geological Survey of Italy manages the national Italian landslide registry ("Inventario dei fenomeni franosi in Italia (IFFI)"). This inventory aims at identifying and mapping gravitational mass movements over the whole Italian territory, following standardized criteria.

This very comprehensive dataset includes over 11 000 landslide events characterized by 174 attributes for South Tyrol. These comprise information on the geographic location (district, municipality, point geometry), the type of hazard and its activity status, as well as - in about one fifth of entries - the exact date of the event. Other features deal with the damages induced by these events: personal injuries (deads, evacuated or injured), physical damages (e.g. to critical infrastructure) and costs. It has to be mentioned that not all information is available for every event. Regarding hazard categories, IFFI differentiates between

"fall/topple", "rotational/translational slide", "complex", "fast flow", "deep-seated movement", "slow flow", "area with diffuse falls/topples", "area with diffuse shallow slides", "subsidence" and "area with diffuse subsidence".

## Austrian Damage and Event Data

### WLK

The Austrian Service for Torrent and Avalanche Control ("Wildbach und Lawinenverbauung" (WLV)), founded in 1884, is a subordinate agency of the Austrian Federal Ministry of Agriculture, Regions and Tourism (BMLRT). WLV traditionally deals with torrents and avalanches, which mainly occur within the alpine region. Amongst WLV's tasks are: declaration of danger zones potentially yielding settlement-prohibitions, civil protection management and providing advisory capacity towards climate-change adaptation. These (and many more) responsibilities require diligently collected long-term records of hazard-processes that are compiled in the "Wildbach- und Lawinenkataster (WLK)" (WLV, 2017). It covers fluvial sediment transport processes, which are floods containing amounts of solids up to one fifth their volume; debris-flow-like processes – as before, but with a fraction of solid material exceeding one fifth; mud flows, carrying solid contents exceeding 50%; flooding; and surface water. Landslides are distinguished into rotational slides, which are movements exhibiting a rotation about an axis parallel the slopes; translational slides, i.e. slides with negligible rotation; earth- and debris flows, where the material sliding down is subjected to strong deformation; shallow landslides; individual blocks with block sizes up to 1 m; large blocks with sizes exceeding one meter; as well as rock creeps (Enigl et al., 2019).

**GEORIOS**

Founded in 1849, the Geological Survey of Austria ("Geologische Bundesanstalt" (GBA)) is a subordinate agency of Austrian Federal Ministry for Education, Science and Research (BMBWF). Fields of activity encompass geological mapping, process-monitoring and issuing of maps featuring high-risk areas for planning purposes. Just as in case of WLV, the accomplishment of GBA's governmental obligations requires a highly dependable, comprehensive, and statistically robust data basis. Such sound, conscientiously collected, long-term records of damage-events are compiled in "Geologischen Risiken Österreich (GEORIOS)" database (Tilch et al., 2011). Therefore, various observation systems are employed. Amongst these are, for example, remote-sensing, field surveys, geographical photographs, systematic expert-inventories of indexed areas, reports from the population and the digitization of historical archives. To avoid inhomogeneities, which may result from different formats, quality criteria and degrees of information content, GBA devotes a substantial fraction of its resources to maintain an extensive quality assurance program, ensuring just that. GBA-records used in this study start in 1950 and cover the following gravitational processes: slides, flows, falls, general mass movements, mass movements in loose rock, and complex large-scale movements (Enigl et al., 2019).

**VIOLA**

Since 1948, extreme weather events related to observed damage and loss have been recorded by GEOSPHERE (ZAMG) on the basis of media reports and published as an annual severe weather chronicle in the GEOSPHERE Yearbooks or on the GEOSPHERE website. The records were kept in tabular and textual form until the end of 2015, and these data were not fed into any database.

As part of the VIOLA (VIolent Observed Local Assessment) project, the development of a digital severe weather platform has been taking place since 2014. "VIOLA" makes it possible to retrieve information on severe weather events in Austria up to a sub-daily basis. Short-term events such as heavy rain, hail, lightning strikes and winds of any kind are displayed, as well as events of pronounced duration such as continuous rain, drought and heat or cold periods that cause socio-economic damage. In addition, events are presented that are due to indirect effects of extreme weather events, e.g., floods due to continuous rain, debris flows due to heavy rain, or even avalanches due to intensive snowfall. The web service "VIOLA" is publicly available[2] but contains only a fraction of the entire data set.

2 https://www.zamg.ac.at/cms/de/klima/klima-aktuell/unwetterchronik?jahr=2022&monat=11

## Harmonization Procedures

Different hazard categories are used within different data sources. In order to integrate these data sets into one, the development and application of a uniform vocabulary is essential. For this project, the vocabulary from the code list "Specific Hazard Type"[3], an extension of the Austrian Inspire Registry established within the CESARE project[4], is used.

Looking at mere event data, the harmonization process is completed with the harmonization of the hazard categories as well as date and location. However, if damage databases are merged, further indicators like the type of the affected element and the object owner have to be harmonized. For these, too, a controlled vocabulary has been created within the CESARE project. All definitions are based on international standards and recommendations, national standards and best practices. For further details on the CESARE project, please refer to Themessl et al., 2022.

## Synthesis and Recommendations

- Usage of standardized methodologies for data management is highly desirable.  Trade-off solution: implementation of lightweight interoperability interfaces, to extract subset of the available data in accordance to e.g., European standards and publicly sharing without disrupting existing workflows.
- Where no systematic collection of impact data is not yet in place, simple operational solutions could be adopted (e.g., based on subset of existing damage reporting templates) in order to start a systematic data collection activity without impacting significantly on available resources.
- An open, fair approach to data and information should be pursued as long as sensitive data are not concerned.
- In general, and specifically in regions which are close to national borders, information and reports on impacts and damage should be provided also in English or in the language(s) of the neighbours. This would allow an easier circulation and sharing of relevant information with clear mutual benefits.
- A thorough analysis of impacting mechanisms related to different hazards and their conditioning factors should be carried out to better understand (and formalize) the causal relationships leading to complex impacts and allowing a more consistent attribution of direct and indirect impacts to their root causes in the case of complex, extreme events. This would also allow to track indirect impacts over longer timeframes and well beyond the extent of the causative hazards (e.g., the increase in frequency of avalanches in a given area could be traced back to a former windstorm downing trees).

3 https://registry.inspire.gv.at/codelist/SpecificHazardTypeValue
4 https://projekte.ffg.at/projekt/3307382

# The TRANS-ALP Web-GIS Mapping Platform

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The possibility to collect, visualize and share geospatial data related to the different components of risk is of great relevance for civil protection authorities. Although several high-quality free and open-source software solutions are available, the implementation of a platform able to harmonize data from different sources in an efficient and sustainable manner might still prove challenging. The project TRANS-ALP has successfully customized a technical solution provided by EURAC Research to collect data from project partners and stakeholders and make it available throughout the project and beyond. The developed platform has proved useful and might provide a good example for stakeholders and practitioners in need for technically sound and sustainable data managing solutions aimed at improving management of natural risks.

## Description of The Platform

The project TRAN-ALP has based upon the *Maps* web portal, managed by Eurac Research, to collect, analyse and share spatial datasets and documents. The portal is a component of the Environmental Data Platform (EDP) that provides researchers with different web tools to simplify research and collaborations among project partners. *Maps* portal is deployed as a GeoNode application (*geonode.org*), an open-source Geospatial Content Management System (GCMS) of the Open-Source Geospatial Foundation (OSGeo). It allows users to upload spatially explicit datasets ("layers"), both vector- and raster-based, auxiliary documents, and manage their metadata in a rich and standard-compliant way, fostering collaborative development.

The portal provides a user-friendly interface for both administrators and users for the management of the datasets' metadata and includes a fine-grained authentication and authorization control. The possibility to create groups of both users is a particularly cost-effective feature for the management and maintenance of datasets and their access control: groups are associated to specific projects or other working groups of users, such as administrative or topic related groups. Currently about 10 different projects are using the *Maps* portal successfully, totalling 100+ active accounts and a catalogue of 250+ datasets, as seen in Figure 1.

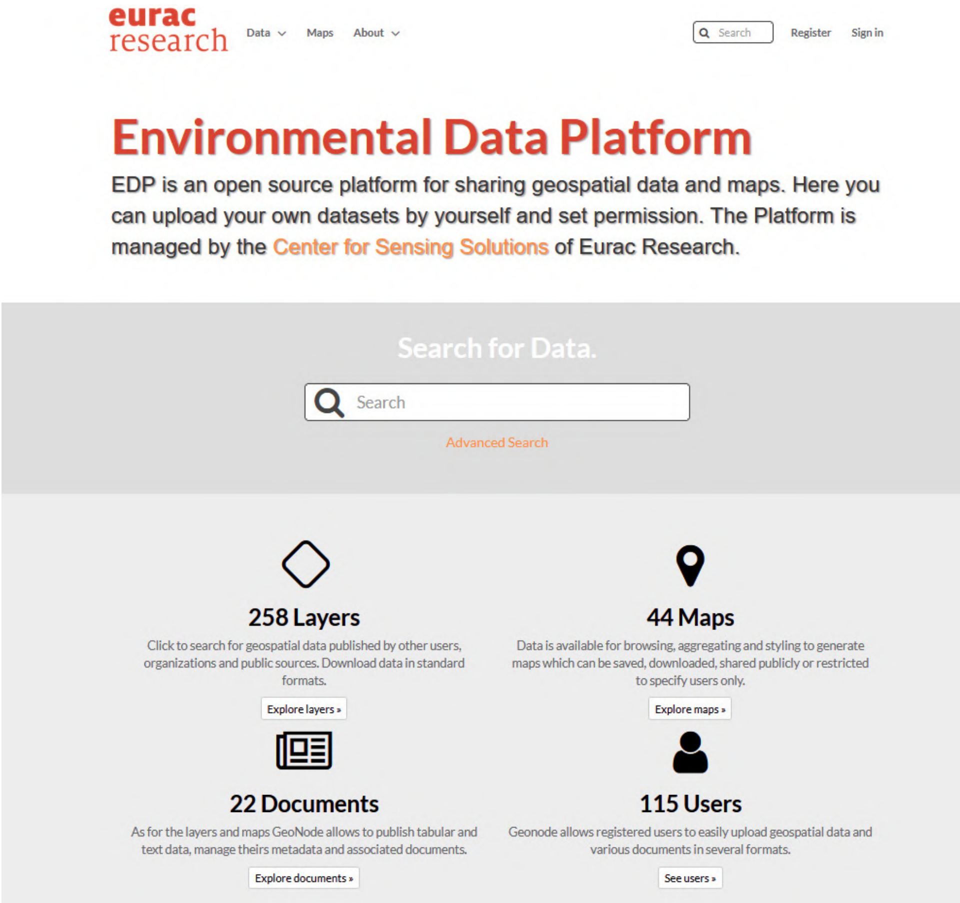


Fig. 1: Home Page of the Environmental Data Platform's "Maps" component, available at https://maps.eurac.edu.

The *Maps* platform is based on a set of well-known robust building blocks:

1. *PostgreSQL*: the relational database management system;
2. *Django*: a high-level Python web framework;
3. *Geoserver*: an open-source server for sharing geospatial data;
4. *Mapstore*: modern web mapping with OpenLayers, Leaflet and ReactJS;
5. pycsw: an OARec and OGC-CSW catalogue service implementation written in Python.

When uploading a new vector or raster dataset to *Maps*, the *data responsible* can tune its access to both registered user and external visitors, controlling all aspects of data access: from simple visualization, to download of the actual data, styling, metadata record, etc. Such layer then becomes instantly available in the online catalogue through the well-known W*S OGC web services, and the URL to its landing-page is given (in Figure 2 an example). Afterwards, the user is guided in a step-by-step wizard-like compilation of its metadata – highlighting which fields are strictly mandatory for a FAIR accessibility to the layer.

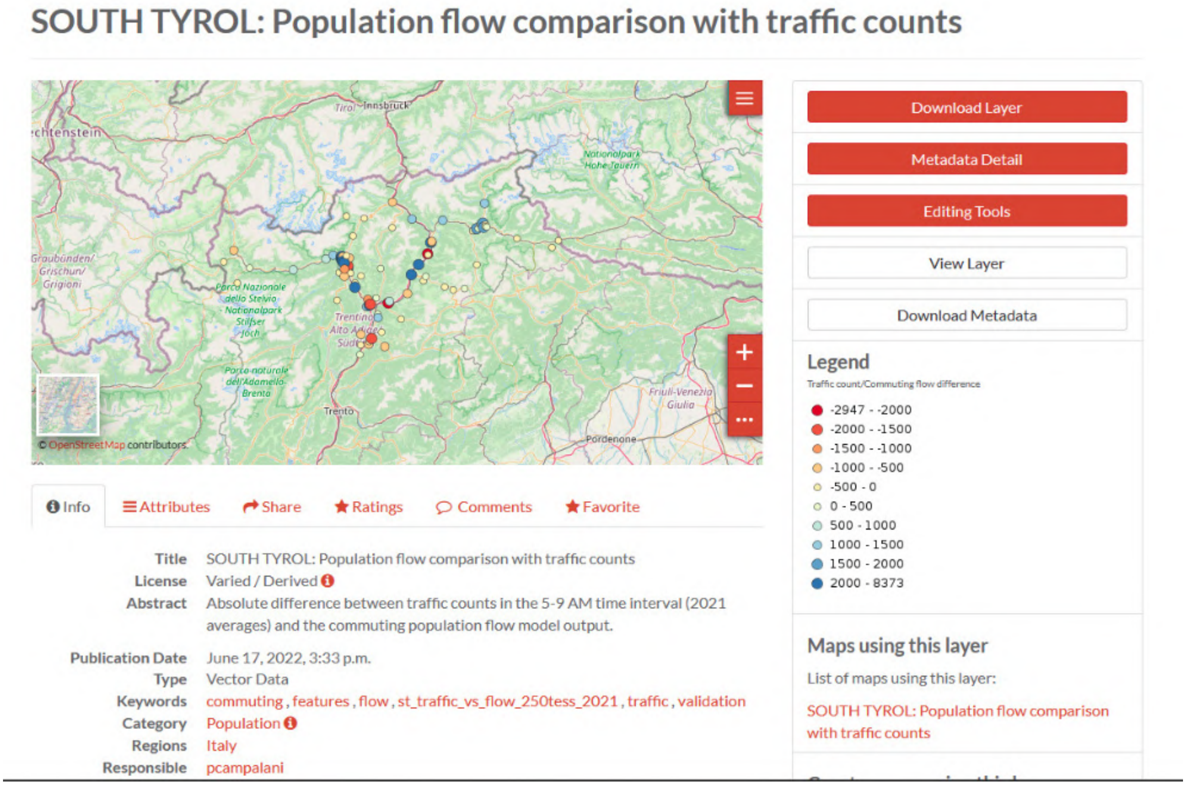


Fig. 2: Example of landing page of a geo-spatial layer in the "Maps" portal: interactive map, metadata visualization, data attributes description, sharing and rating options, (meta)data download links, and other features are provided by the GUI.

On top of that, *Maps* acts as a web-based GIS too, letting users overlay together different sources of data – the layers – to form richer "maps". When creating a map, the user can fully customize its styling and appearance, the Z-order order of its layers, or decorate it with a wide range of widgets so to maximize the ability to communicate results to an external audience (Figure 3 provides a visual example). When saved, a map can be very easily shared with just an HTTP link, or even embedded into external web pages (as HTML *iframes* objects).

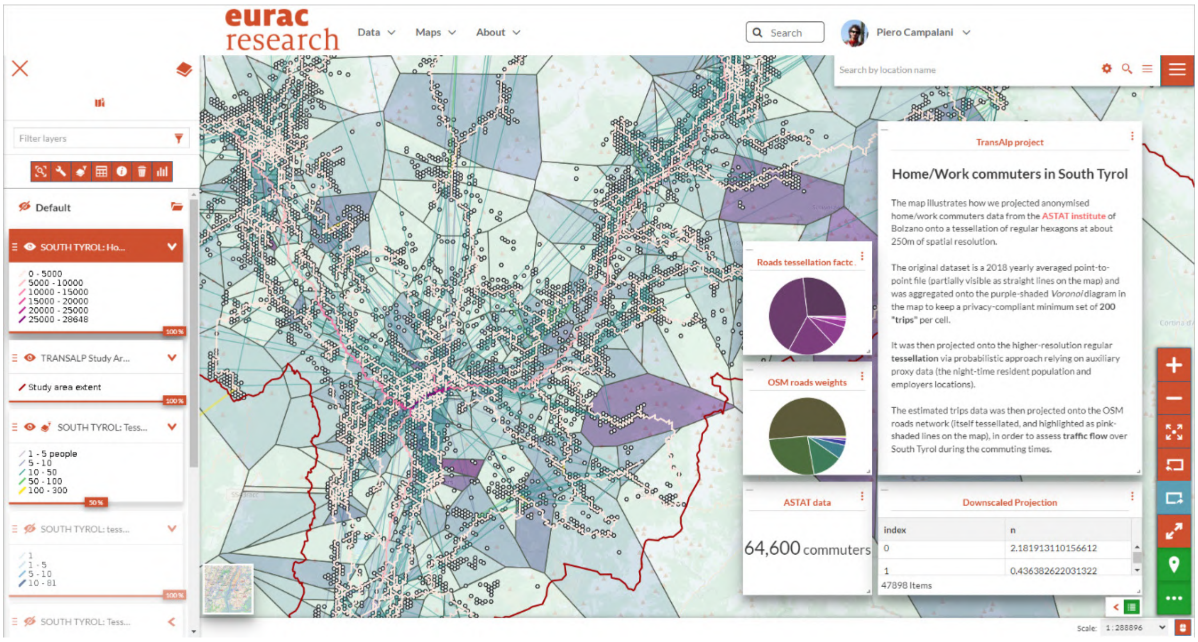


Fig. 3: An example of a "map", i.e. a composition of multiple data sources – "layers" – with custom styling and informative widgets overlaid on top, including data counters, pie-charts, attribute tables, or descriptive text: maps provide a powerful mean for effective communication of outputs to external audiences.

*Maps* can import – "cascade" – datasets from external interoperable endpoints by consuming OGC web services, further increasing the potential of the portal for creating meaningful maps, without having to duplicate efforts on ready-to-use geo-spatial resources.

## Discussion

Within the frame of the TRANS-ALP project, we made continuous use of the *Maps* portal, which proved to be a very effective tool for both building an organized data catalogue and making the sharing of results straightforward. As evidence of such intense use of the *Maps* portal is represented by the almost 80 geo-spatial datasets (most of them publicly available), 14 maps, and 20 auxiliary documents that were produced and immediately published online for both registered users and external actors.

The most evident benefit of the portal was surely the saving of time and effort derived by the browser-based online interaction with the outputs: interactive visualization, quick metadata exploration, along with some basic analysis capability, all had a great impact in promoting agile collaboration and sharing among the project partners. Furthermore, being able to link to the *Maps* online catalogue effortlessly from external well-known GIS software like QGIS or ArcGIS, made also the collaborative *creation* of the outputs a much easier process.

However, it must be stressed that the *Maps* portal must not be confused with an online monitoring tool for, e.g., early-warning or now-casting of information related to hazards and risks, although it would surely be a fundamental building block of such applications. Its capabilities are those of an agnostic content management system, an interactive library of data sources with some moderately advanced GIS features.

## Synthesis and Recommendations

As outlined in the previous sections, the experience with the *Maps* portal has been overall extremely positive, and its usage for disaster risk assessment will cross the borders of the project's timeline, also given that the development of the open source GeoNode software which *Maps* deploys, is continuously supported by a wide range of users and developers worldwide. This means that the availability of the tens of layers and maps produced within the TRANS-ALP project will continue in the future, further supporting the collaboration with the project´s stakeholders.

Decision-makers or interested researchers are encouraged to explore the group's related catalogue of layers[5] and maps[6] in the portal, and to contact the members of the "TRANS-ALP Project – Public" group[7] to communicate intents of collaborations and discussion on the matter.

5 https://maps.eurac.edu/layers/?group__group_profile__slug__in=trans-alp-project-public

6 https://maps.eurac.edu/maps/?group__group_profile__slug__in=trans-alp-project-public

7 https://maps.eurac.edu/groups/group/trans-alp-project-public

## Conclusions

The activities of the TRANS-ALP project paved the way towards a better understand the complex interplay between hazard, exposure and vulnerability also related to cascading effects in the Alpine areas across the border between Italy and Austria. A more objective definition of extreme event in the region has been provided, based on simple statistical analysis. This allowed to review the past climatological data and better describe the spatial and temporal anomalies, for instance in terms of precipitation, associated to cross-border damaging events. This information could be further used by the civil protection to refine hazard and impact models. The apparent positive trend in the frequency and in the intensity of extreme events in the past decade is supported by the analysis carried out on climate scenarios, meaning that climate change might lead to an intensification of extreme events in the next future. This finding should foster further efforts in harmonising Disaster Risk Reduction (DDR) and Climate Change Adaptation (CCA) activities, seeking for a tighter collaboration between Civil Protection authorities and local decision makers, addressing longer time frames and considering explicitly the potential time evolution of the hazards directly (intense raining, wind gusts) and indirectly (flash floods, landslides) connected with climate. In the project it was also found that despite the many ongoing efforts, a consistent, systematic, and comprehensive framework for documenting the impacts of extreme events on the affected socio-ecological systems is still missing. This challenge should be addressed to provide better data and knowledge to improve impact forecasting and warning procedures. In terms of risk analysis, the project´s activities highlighted the need for consistent frameworks for multi-hazard quantitative impact forecasting and risk assessment. This might entail the integration of methodologies and procedures currently not yet routinely employed by Civil Protection authorities, including for instance computational simulation procedures using aggregated multi-hazard exposure and vulnerability models, also including systemic components such as for instance road transportation. A prototype model has been implemented in the project and is available to both researchers and practitioners for further test and integration.

To provide a practical exemplification of some of the proposed methodologies in the context of risk mitigation, TRANS-ALP addressed the change in risk conditions due to cascading impacts to the forested areas in the aftermath of a intense storm, as observed in the case of VAIA. A systematic avalanche risk re-assessment protocol has been proposed and exemplified in the test area of the Cordevole Valley, and includes innovative analytical procedures and recommendations to dynamically adapt avalanche risk assessment that have been successfully used by the local civil protection authorities. This test case could provide a useful example for practitioners and authorities across the Alps.

All data collected, assembled or generated in the TRANS-ALP project have been collected, stored and made accessible to consortium partners and project stakeholders in an advanced web-based GIS and data visualization platform that allows for a consistent data management and sharing for further integration of the available information and the proposed methodologies in the current and forthcoming civil protection activities. The outcomes of the TRANS-ALP project have clearly shown the need for more in-depth research activities in the field of extreme events and for a further strengthening of the collaboration of research-oriented institutions and the civil protection authorities and practitioners involved in Disaster Risk Reduction and Climate Change Adaptation activities.

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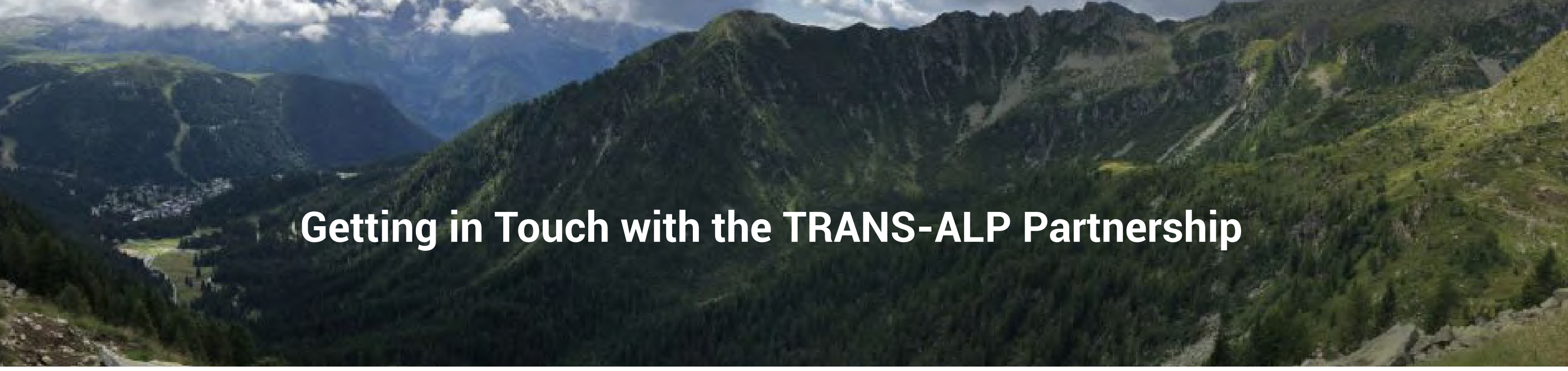

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