Natural hazard events affecting transportation networks in Switzerland from 2012 to 2016

J., Voumard[1], M.-H., Derron[1], M., Jaboyedoff[1]

[1] Risk analysis group, Institute of Earth Sciences, FGSE, University of Lausanne, Switzerland

Abstract

Switzerland is a country threatened by a lot of natural hazards. Many events occur in built environment, affecting infrastructures, buildings or transportation networks and producing occasionally expensive damages. This is the reason why large landslides are generally well studied and monitored in Switzerland to reduce the financial and human risks. However, we have noticed a lack of data on small events, which have ~~impacted~~affected roads and railways during these last years. Therefore, we have collected all the reported natural hazard events which have affected the Swiss transportation networks since 2012 in a database. More than 800 events affecting roads and railways have been recorded in five years from 2012 to 2016. These events are classified into six classes: earth flow, debris flow, rockfall, flood, snow avalanche and "others~~.~~".

Data ~~come~~coming from Swiss online press articles were sorted by Google Alerts. The search is based on more than thirty keywords, in three languages (Italian, French, German). After verifying that the article relates indeed an event which has affected a road or a railways track, it is studied in detail. We get finally the information on ~~about sixty~~more than 170 attributes ~~by event about~~of events such as event date, event type, event localisation, meteorological conditions as well as impacts and damages on the track and human damages. From this database, many trends over the five years of data collection can be outlined thanks to the high number of event attributes: in particular, the spatial and temporal distributions of the events, as well as their consequences in term of traffic (closure duration, deviation, costs of direct damage, etc.).

Even if the database is imperfect because of the way it was built and because of the short time period considered, it highlights the ~~not~~ non-negligible impact of small natural hazard events on roads and railways in Switzerland at a national level. This database helps to better understand and quantify this type of events and to better integrate them in risk assessment.

Keywords

Natural hazard events, floods, landslides, earth flows, rockfalls, debris flows, snow avalanches, transportation networks, Switzerland, database.

1 Introduction

Natural hazardhazards cause many damages onto transportation networks around the world (Nicholson & Du, 1997; Hungr et al., 1999; Tatano et al., 2008; Dalziell & Nicholson, 2001; Karlaftis et al., 2007; Tatano et al., 2008; Erath et al. 2009; Muzira et al., 2010; Erath et al. 2009; Jelenius et al., 2012;;). Particularly on mountainous areas, floods, landslides (considered as earth flows in this study), debris flows, rockfalls and snow avalanches (called avalanches in this paper) can seriously affect the traffic on roads and railways tracks, isolating areasvillages or regions and generating infrastructure and economic damages (Bunce et al., 1997; Budetta et al., 2004; Evans et al., 2005; Collins, 2008; Salcedo et al., 2009; Guemache, et al., 2011; Jaiswal, et al., 2011; Michoud et al., 2012; Laimer, 20172017b).

While large natural hazard events affecting roads and railways are generally well studied and documented, e.g. the Séchilienne landslide (Kasperski et al, 2010), La Saxe landslide (Crosta et al. 2014) or La Frasse landslide (Noverraz and Parriaux, 1990), thisit is mainly not the samecase for minor and medium-sizedsize events ranging from a few cubic decimetersdecimetres to a few thousand of cubic meters. Some reasons why minorThey are numerous and medium-sized natural hazard events are not well documented are because their direct consequences are often quite rapidly fixed i.e. the road can be re-opened few hours after the event or is only partially closes. They are also too small, difficult to detect and too localized to be easily monitoredexpensive to monitor (Jaboyedoff et al. 2013) and there is less interest to study them than for of large events that concern scientists and politic people for years.2016a).

ThisThe society tendency is to collect mainly largedisasters events or events generatinghaving any high damages is observablesocial impact (death, high cost, highlighting societal problems, etc.) in existing natural hazard spatial databases anda database. The criterion to be listed in the main global disaster databases. Thus, global disaster databases (EMD-DAT from University of Louvain, Swiss Re, Dartmouth) illustrate this since it needs at least ten causalities or other politics or economic criterions (Guha-Sapir et al., 2015), Sigma from Swiss Re reinsurance (; Swiss Re, various dates) and Dartmouth from University of Colorado (; Dartmouth Flood Observatory, 2007) have a disaster entry criteria of respectively at least 10

~~people killed and/or 100 people affected, 20 people killed and/or 50 injured, and large floods (Guha-Sapir et al. 2002; Tchögl, 2006; Guha-Sapir et al., 2015,) . If~~). The insurance possesses databases that are more detailed but they are usually not available such as the NatCat ~~database~~ from Munich Re reinsurance~~, (~~ (Tchögl et al, 2006; Bellow et al., 2009~~)~~ ~~seems to collect any property damage and/or any person affected (~~; Munich R. E., 2011~~), its data are only partially available to the public and cannot be analysed as an unrestricted access database (Tschögl et al, 2006). In the same way, numerous~~). At present, most of worldwide, national and regional ~~spatial natural hazard~~ databases do not generally deal with ~~very~~ small events that can be considered as insignificant for the experts (Guzzetti et al. 1994, Malamud et al. 2004; Petley et al. 2005; Devoli et al. 2007; Kirschbaum 2010, Foster et al. 2012; Damm et al. 2014). ~~Furthermore, with~~With noteworthy exceptions ~~as the~~like RUPOK database (Bíl et al. 2017), ~~natural hazard databases usually do not have much~~which collects information about consequences of ~~geohazard events~~geohazards on transportation networks. ~~For example, the~~The Swiss flood and landslide damage database (Hilker, 2009) contains also small events but no information about track and traffic.

~~Problematic paused by the lack of data of small events is nowadays well acknowledged.~~ Gall et al. (2009) ~~highlight that small events~~ highlighted the underreporting ~~generates a bias~~ of small events inducing ~~natural hazards loss~~bias in data ~~fallacy~~. The director of Global Resource Information Database at the ~~United Nations Environment Programme recognises a difficulty~~UNEP recognised a problem to evaluate ~~losses from~~ the true impact of natural hazards since EMD-DAT database records only events with estimated losses of above 100 000 US$ ~~are collected in the EMD-DAT database~~ (Peduzzi, 2009). The Head of the ~~United Nations International Strategy for Disaster Reduction~~UNISDR, R. Glasser, alerts that governments underestimate ~~particularly~~ the low cost ~~of small~~ disasters~~, which result from the incapacity to know small events that are below the radar screen, that still~~ that affect ~~many people~~significantly to the societies (Rowling, 2016).

~~From the observation of the recognized lack of data~~ In order to fill partially a gap in the knowledge about small events, we focused on the impacts of natural hazard ~~small events in the existing databases added to the need of data about event impacts~~ on road and railways tracks, ~~we collected all natural hazard~~collecting as much information as possible on the events affecting the Swiss transportation network since 2012. ~~It is not an exhaustive~~

The goal of this database ~~referred~~is to ~~geomorphic features~~determine the main trends of ~~the~~these events ~~but it is a database focused on traffic~~and to evaluate the relevance of such concerns.

~~The aim of this study is to remedy the deficiency of information about natural hazard events affecting transportation network in Switzerland through a significant effort on small events that are generally bellow radar screen. The database created for this purpose is used to determine trends of the natural hazard events in order to help decision makers to minimise their impacts on roads and railways.~~

2 Study area

The study ~~area~~ is applied to the whole Switzerland~~. Its~~, which possesses a surface area ~~is~~of 41 285 km^2 ~~and its~~, with an elevation ~~ranges~~ranging from 193 m (Lake Maggiore) to ~~4634~~4 634 m a.s.l. (Dufourspitze). The Swiss geography can be divided into three major geomorphologic-climatic regions: the Alps, the Swiss Plateau and the Jura. The Alps cover about 57 % of the Swiss territory ~~and are composed of a high-altitude mountain range~~(23’540 km^2) with 48 summits over ~~4000~~4 000 m a.s.l~~.,~~., and many inhabited valleys. The Swiss Plateau, located northwest to the Alps, covers about 32 % of the territory (13 360 km^2) at an average altitude of about 500 m a.s.l. and is partially flat with numerous hills. Two-thirds of the Swiss population lives on ~~this plateau~~the Plateau (13 360 km^2) which has a population density of about 450 inhabitants per square kilometre. The Jura Mountains (11% of the territory, 4 385 km^2) is a hilly and ~~parallel~~a mountain range situated on the north-western border of the plateau with a top summit of ~~1679~~1 679 m a.s.l. (Mont-Tendre). ~~Due to its situation in Europe, the~~The Swiss climate is a mix of oceanic, continental and Mediterranean climates ~~and~~which varies ~~largely at a regional scale.~~greatly because of the reliefs. The average annual rainfall is around 900-~~1200~~1 200 mm years^{-1} on the Swiss Plateau, ~~1200-2000~~1 200-2 000 mm years^{-1} on the Jura Mountains and between 500 and ~~3000~~3 000 mm years^{-1} in the Alps (Bär, 1971). The Swiss average temperature is about 5.7 °C (MeteoSwiss, 2018).

~~The Swiss road network length is about 72’000 km with 1850 km managed by the Swiss Confederation whose 1450 km of high and motorways, 18000 km of cantonal roads and about 55000 km of communal roads (Federal Statistical Office, 2018). The Swiss railway network is 5200 km long whose 130 km of cogwheel train lanes and 330 km of tram lanes (Federal Statistical Office, 2018).~~

3 Data and methods

A database to collect all natural hazard event that affect the Swiss roads and railways since 2012 was designed. The present study focuses on the built over five years timeduring the period 2012-2016 were, collecting 846 events were collected.

3.1 Information sources

As there is no such . The minimum threshold for being included in the database is a traffic disruption (for example, a large velocity reduction) for at national level andleast 10 minutes following a natural hazard event that have reached to a transportation track.

We used online press channels as not all cantons have such a database, it was necessary to find the information from a non-administrative channel. The online press channel was chosensources, because it haspossesses the best ratio in simplicity/efficiently. Google™ alerts were used to collect the events from the / efficiency. While an online press, review was made every working day from 2012 to 2014, since May 2014, Google™ Alerts (Google, 2018) was introduced with more than fifty keywords in German, French and Italian as tool to scan the (see Table 1-SM in Supplementary material (SM)). These around ten received alerts per day permitted to collect the events from the Swiss online press (see Table 25 in Additional material (AM)). Each day, about ten Google™ alerts were received. .

Each alert contained on average two online press articles in average containing one of the fifty keywords. Each of these online press articlesarticle was manually analysedread in order to identify if the related information concerns or not ana natural hazard event or not which has affected ana transportation tracknetworks. If not, it is removed. was not considered.

About 10 % of all online press articles these highlighted by Google alerts referarticles referred to a real natural hazard event. About 1200 online press800 articles were kept in three years (2014-2017).from mid-2014 until the end of 2016. The Swiss traffic information website iswere also periodically manually checked, as well as few social media pages susceptible to havecontain some pictures of events., as the official page of the commune of Montreux on Facebook (Montreux, 2014). Otherwise, some events were collected directly in the field.

3.2 Natural hazard processes considered

In the present manuscript,Here we assignedclassified natural hazards processes affecting the Swiss transportation network according to six natural hazard processes categories:

- ~~Flood: static~~Static or dynamic ~~flooding processes~~floods with only little sedimentation material on the tracks including a few hail events ~~fell~~.
- Debris flow~~:~~, that are often not well described in the media and confounded with landslides or floods~~, debris flows~~. They were often ~~recharacterized~~characterized with pictures from the press articles.
- Landslide: superficial or deep sliding of ~~a mass of~~ soil mass including shallow landslides.
- Rockfall~~: stones and~~ refers indifferently to rock falls~~,~~ and rockslide.
- Avalanche~~:~~ refers to snow avalanches.
- Other: snowdrifts (mainly during February 2015 in West of Switzerland) and falling trees (mainly during windstorms).

~~3.3 Event attributes~~

172 attributes are used to describe the events (~~Figure 25 in the~~ Table 1; Figures 1-SM and 2-SM in Supplementary material~~). There~~ (SM)) and they are ~~distributed into~~subdivided in eight categories: date, location, event characterization, track characterization, damage, weather, geology and ~~source (Table 1). Date attributes describe when the event occurred, at which season or at which day part it occurred . Location attributes describe the region, the topography, the landscape and the coordinates of the event. Event~~ sources. Data about date, location, event characterization ~~attributes explain the natural hazard process and its features. If available, a picture is given to illustrate the event. Track characterization attributes describe especially the track type (road, railway), its class (highway, main track, secondary track, etc.), its sinuosity, its closure duration~~ and ~~its deviation possibility. Damage attributes highlight the different damages due to the event on the track infrastructure but also on the vehicles and on people. Weather attributes describe the weather conditions (sun, rain, temperature, storm, wind and snow) from the event day to ten days before the event occurrence. The weather data~~damage come from the ~~closest weather station of the 24 MeteoSuisse weather stations considered. Temperatures were corrected from the altitude difference between the event location and the weather station according the common lapse rate. The geology attributes characterize the soil (types of geology, hydrogeology, watershed, soil productivity) where the event occurred. Finally, the sources attributes provide the addresses of the consulted~~ online press articles. Attributes of the database are shortly presented in Table 1.

3.4 Types of analysis and statistics

Events were analysed according their 172 attributes making possible to carry out numerous Images from the press articles are used to estimate many attributes as the event classification and the volume estimation of the deposit material if it is not estimated in the press article.

The analyses were either performed in a Geographic Information System (GIS) environment for spatial data or numericallyin a standard statistical way for all other data. We have thus extracted simple statistics for each analysis (average, sum, mode, median, standard deviation minimum, maximum, etc.) as well as charts and histograms with trend lines and principal component analysis (PCA) especially for the weather data. The aim of the analyses is In order to extract general trends base onof the 846 events collected natural events affecting the Swiss transportation network during the five years period 2011 from 2012 to 2016., the data were characterized by basic statistics descriptors and displayed with histograms and charts.

Weather data come from 24 weather stations of MeteoSwiss. For each event the reported weather conditions are not always coming from the closest station but from the one with a similar topo-climatic situation. The average distance between weather stations and events is 20 km (SD of 18 km) and the average absolute elevation difference is 200 m (SD of 366 m). The rainfall data are given for: the event day, the last five days and the last ten days, providing the antecedent situations.

The deviation lengths for roads were measured using a GIS. Density maps were made using the kernel density function in a GIS with a search radius of 10 km for events map and 20 km for the road density map with both a 500 m output cell size. Results are classified using 10 classes with the Jenks natural breaks method.

The damage levels have been characterized by four levels partially based on Bíl et al. (2014). The first damage level concerns “no closure or no track damage”. Events of this first level generate only traffic slowdowns and small disruptions. They concern mainly floods often triggered by strong storms (vehicles can drive slowly on a flooded road without the need to close the track) (Figure 6E). The reduction of the traffic velocity generally lasts less than two hours. The second level refers to a complete or partial track closure because of the material deposition on the track. If only one lane is closed, the second lane allows to have an alternated traffic moderated with temporarily traffic lights or traffic regulators. Tracks of the second level of damage can reopen after evacuation works, without any repair work.

The third level, “partial damage”, needs superficial repairs and / or minor stabilization of the track embankments because the events generated small damages on the tracks. Finally, the “total destruction” level means that the track embankment has to be reconstructed, requiring many repair works.

For each damage class, costs per square meter was attributed according to the event intensity (small, middle and large) for both the road and railway. A surface area of 100 m^2 is assumed for small events, 200 m^2 for medium and 300 m^2 for large events. Costs are given in Euros with values in mid-January 2018 of 1 EUR = 1.17 CHF = 1.23 USD. On average a “no closure” cost was estimated at EUR 6 per square meter, at EUR 230 for a “closure”, at EUR 400 for a “partial damage”, at EUR 1 000 for a “total destruction” and at EUR 230 for a “unknown” (Table 2-SM). Direct damage costs evaluation was based on road and railways reports (Canton de Vaud et du Valais, 2012; SBB CFF FFS, 2017) and on the basis of repair works experience by civil engineers. Since direct damage costs are difficult to assess (this is event more true for indirect damage costs), the proposed methodology to determine them must be considered, above all, as a tool to compare the costs of the different damage classes. The cost values should not be considered as true costs for all events but as a order of magnitude of the projected costs (please see also section 5.4).

Table 1: Attributes categories to describe events in the database.

Attribute category	Answer the question	Contains	Number of attributes	Main source
ID	Event ID	-	1	-
Date	Which date and time	Year, season, day part	15	Online press article
Location	Where did the event occur?	Region, topography, coordinates	21	Online press article and GIS[1]
Event characterization	Which natural hazard event?	Type of hazard, features, picture	12	Online press article
Track characterization	On which track?	Road/railway, features, deviation	17	Swisstopo[2]
Damage	Which kind of damage?	Damage on track, vehicle, people	11	Online press article
Weather	What was the weather?	Sun, rain, temp., storm, wind, snow	68	MeteoSwiss[3]
Geology	On what soil did it occur?	Soil features	11	Swisstopo[2]
Source	What are information sources?	Addresses of online press articles	16	Online press article

[1] GIS: Geographic Information System
[2] Swisstopo: Swiss Federal Office of Topography
[3] MeteoSwiss: Swiss Federal Office of Meteorology and Climatology

4 Results

~~4 Results~~

~~The 846 collected natural hazard events affecting roads and railways in Switzerland from 2011 to 2016 were analysed according:~~

- ~~The types of natural hazard processes,~~
- ~~The temporal distribution,~~
- ~~The spatial distribution,~~
- ~~The type of location with the topographic features at large and small scale,~~
- ~~The types of affected tracks,~~
- ~~The meteorological distribution,~~
- ~~The impacts, deviations and closures.~~

4.1 Types of natural hazards processes

~~Half~~421 (~50%) of the 846 collected events ~~concerns~~are floods~~ with 50% of all collected events with 421 events~~, including hail flooding events (~~1% and ~~8 events~~)~~, i.e. 1%) (Figure ~~1~~1A). The second most frequent ~~process is~~processes are landslides (~~23% and ~~192~~ events),~~; 23%), followed by rockfalls (96; 11~~% and 96 events)~~%) and debris flows (~~8% and ~~68~~ events).~~; 8%). The ~~rest~~remaining concerns snow avalanches (~~2% and ~~15~~ events)~~; 2%) and “other” events processes (~~6% and ~~54~~ events), including~~; 6%) includes snowdrifts (~~5% and ~~40~~ events)~~; 4.5%) and falling trees (~~2% and ~~14~~ events).~~; 1.5%). Snowdrifts mainly result from a unique ~~and sporadic ~~event in February 2015.~~ In a simplified way, it can be said that half of the natural hazard events that have affected the Swiss transportation network for the period 2011-2016 is due to floods, a quarter concern landslides and the rest concern rockfalls, debris flows and other natural hazard events processes.~~

~~4.2 Factors of influence~~

4.2 Spatiotemporal conditions

4.2.1 Spatial distribution

Natural hazard events affecting the Swiss transportation network for the period 2012-2016 are equitably distributed on the geomorphologic-climatic ~~region~~regions Plateau ~~et~~and Alps (371 and 377 events respectively; 44% each). The remaining 12% (98 events) occurred in the Jura area (~~Figures~~Figure 1B and Figure 2 and~~ 3,~~; Table ~~4 in Supplementary material (~~3-SM~~)). Flood events are responsible~~). The spatial distribution of ~~the high percentage of events on the~~

Plateau with more than half of the floodnatural hazard events (57%) that occurred on the beside floods is quite proportional to the surfaces areas of Swiss Plateau; debris flow events occurred mostly in theregions: Alps (96with 60% of the Swiss territory surface account for 64% of them); more than halfevents expect floods, the Plateau for 30% and 31% and Jura for 10% and 5% respectively. The kernel density maps of landslides events occurred in the Alps (55%); rockfalls events occurred mostly in the Alps (88%); avalanches occurred exclusively in the Alps (100%) and the "other" events occurred mostly on the Plateau (78%).all event types as well as the road density map are shown in Figure 2-SM.

Considering all events processes besides flood events, the spatial distribution of events, on the three geomorphologic-climatic Swiss regions is quite proportional to the surface of those areas: Alps with 60% of the Swiss territory and 64% of events, Plateau with 30% of surface and 31% of events and finally Jura with about 10% of the territory surface and 5% of all events. Rockall events occurred mainly in the Alps consecutively to the high proportion of cliffs above tracks in this region. Likewise, debris flow events are based almost exclusively in the Alps where are located large steep slopes with mobilizable soil required to trigger them.

Looking more in detail the location of events, we observe that half of events (The majority of the floods (239; 57%) occurred in the Swiss Plateau. Debris flows are occurred mostly in the Alps (66; 96%), as well as rockfalls (84; 88%) and avalanches (16; 100%), which not surprising considering the strong control of the presence of steep slopes. Landslides are more equally distributed with only 55% (107) in the Alps, because they usually occur in moderate slope (Stark and Guzzetti, 2009); The "other" events (snowdrift and falling trees) occurred mostly on the Plateau (41; 79%).

Half of events (412 events; 49%)%,) occurred in built environment (towns, agglomerations, villages and hamlets) and half (434; 51%) of events occurred in a natural environment (countryside: 211, 25%;%, ; forest: 185, 22%; mountain above forest limit: 38, 4%) (Figure 4 and1C; Table 5 in 4-SM).

By making risk ratios (Miettinen, 1972; Zhang and Kai, 1998; Spiegelman and Hertzmark, 2005) related to the surface of the regions, floods and "other" are over-represented in the Jura and in the Plateau while debris flow, avalanche and rockfalls are over-represented in the Alps (Figure 3A). Risk ratio related to the length of the roads of the three regions indicates that the Alps have over-represented debris-flow, landslides, rockfalls and avalanches (Figure 3B)

The slope angle distribution (Figure ~~5 and~~1D; Table ~~6 in~~ 5-SM), ~~based on~~ extracted from a 25 m DEM~~,~~, (Swisstopo, 2018), indicates that 40% (339 events) of all events ~~occurred~~afftect the tracks on ~~a slope range~~slopes ranging from 0° to 5° and 30% ~~of events on a~~ (257) between 5° and 15°. 62% (260) of floods affected tracks on the almost flat slope ranging from 0° to 5°, and 43% (30) of debris-flow in 5°-15° slope. A third of landslides (63) and a third of rockfalls (30) events occurred on a 15°-25°. 76% (12) of snow avalanches cross tracks at a slope angle of 10°-30°. Two-thirds (36) of “other” were observed at 0 to 5°.

Eight slope orientations were estimated based on the Swisstopo maps for 72% (609 events) of the recorded events (Figure 3-SM). The slopes oriented to south, south-east and west account for 17% (144) each. The over-representation of these orientation are caused by the debris-flows occurring in the western slopes (mainly because of debris flows that occurred in the the S-Charl valley in 2015). Landslides seems more prone in south and west oriented slope.

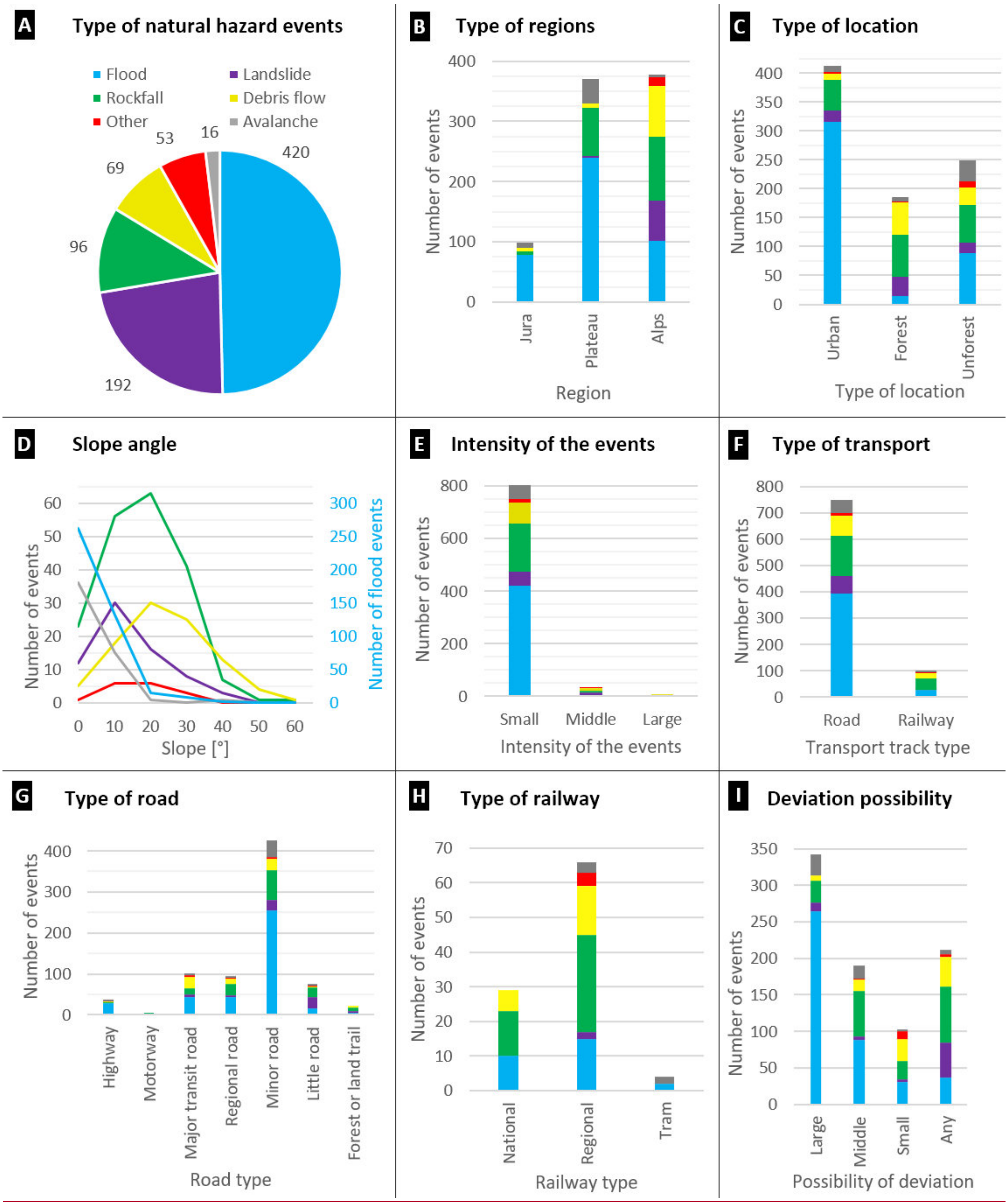

Figure 1: A: Number of events according to natural hazard events on the Swiss transportation network from 2012 to 2016. B: Distribution according to the three large geomorphologic-climatic regions. C Distribution of the type of location. D: Slope angle distribution. Flood events are on the secondary vertical axis. E: Distribution of the events according to intensity. Small event: 0-10 m3; middle event: 10-2000 m3, large event: >2000 m3. F: Distribution of transport mode. G: Road types distribution. H: Railways types distribution. I: Distribution of possibility of deviation. Large possibility of deviations: >3 possibilities; middle: 2-3, small: one possibility; any: no possibility.

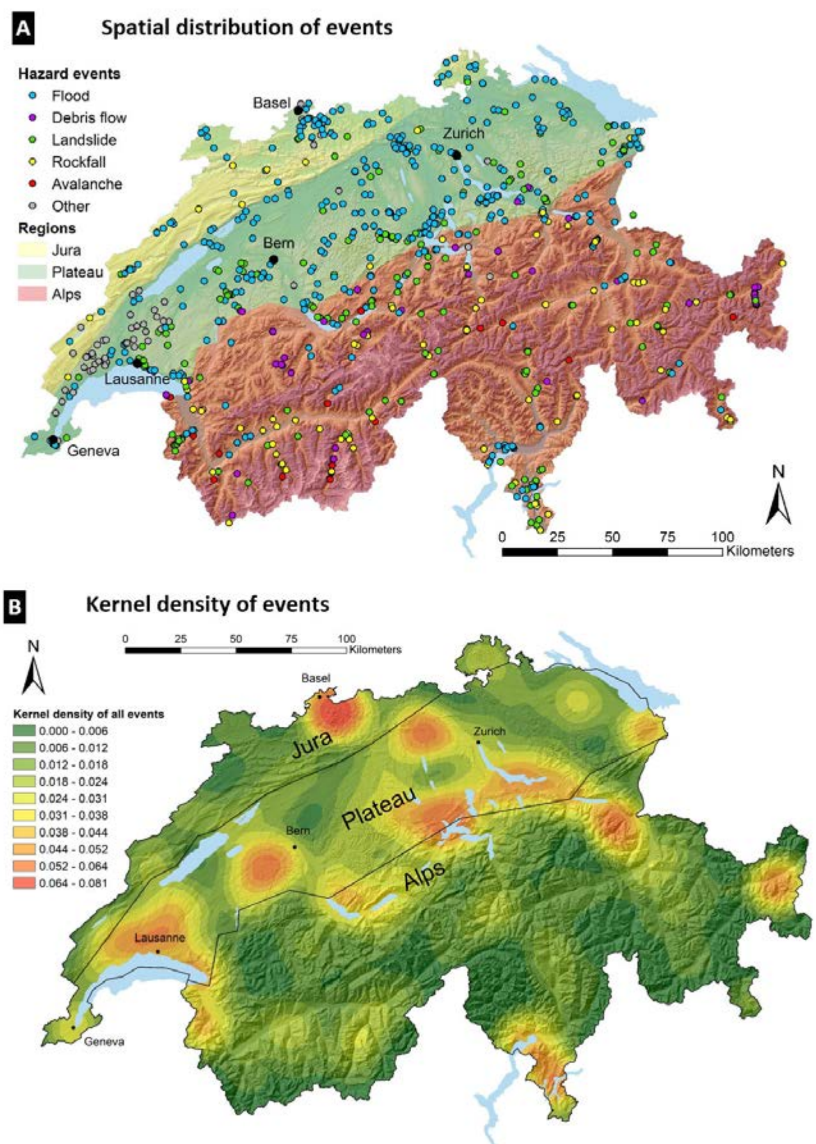

Figure 2: A: Spatial distribution of natural hazard events affecting roads and railways in Switzerland from 2012 to 2016. Source of the map: swisstopo. B: Kernel density of the events (20 km search radius and results classified using 10 classes with the Jenks natural breaks method.).

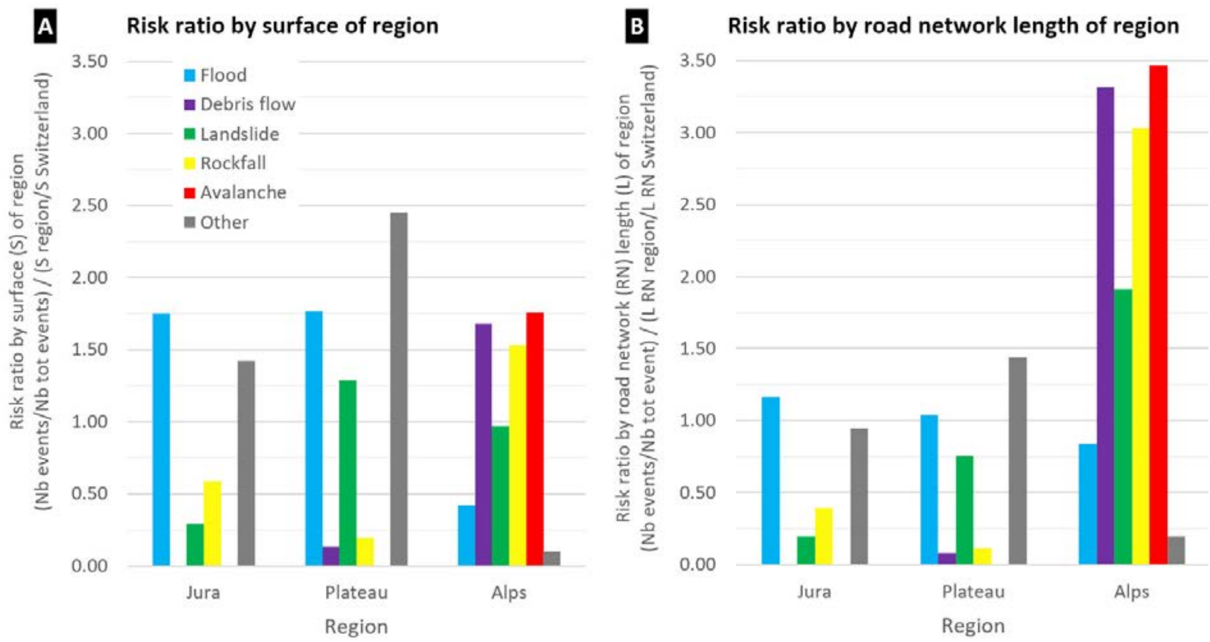

Figure 3: A: Risk ratio by surface of the three geomorphologic-climatic swiss regions. B: Risk ratio by the road network (RN) length of the three geomorphologic-climatic swiss regions.

4.2.2 Event intensity

The debris flow, landslide, rockfall and avalanche events were classified into three intensity classes (Figure 1E and Figure 4; Table 6-SM) defined by volumes:

- Small: below ten m^3.
- Medium: from ten cubic meters to two thousand m^3.
- Large: larger than two thousand m^3.

With one exception (medium intensity), floods were classified -on the basis of the water level and the flooded area- as events with a small intensity (419 floods). “Other” events (snowdrifts and falling trees) were also all categorised as small events (53 events). 95% (804) of all events are classified as small, 4% (33) as medium and 1% (9) as large events. Note that a third (32) of rockfalls are large.

Excluding floods, 39% (146) of the event sources are located at more than 50 m from the track, 35% (185) are located between 0 and 50 m (Table 7-SM). A quarter (95) of the source locations are unknown. Almost all sources close to the tracks (that represents 35% (185) of all events) are human-induced natural hazard events. The sources of debris flows and avalanches in the Alps are located far from the track with natural origin (100% (69) for debris flow, 94% (15) for avalanche). Excluding floods, 80% (339) of the sources are located above the track, 7% (29) below and 14% (58) possess unknown origin (Table 8-SM).

Figure 4: Examples of events affecting roads. Left: small event already removed but still unstable on the uniquely accessible road to the small village of Morcles (Canton of Vaud). Middle: middle event on a minor road in Ollon (Canton of Vaud). Right: large event with a volume estimated at 3500 m^3 that cut a 50 m length on

the international road between France and Canton of Valais near the Forclaz pass (Trient). Road closure is estimated of six weeks. Images taken on 24 January 2018 after a winter storm.

4.2.3 Rainfall

The average rainfall during the day of the event is 17 mm (Figure 5A; Table 9-SM). On average, rain amount during the event day is 22 mm, 17 mm, 14 mm, 5 mm and 4 mm for flood, landslide, debris flow, rockfall and avalanches respectively. The maximal precipitation recorded (154 mm) in the database occurred in Canton of Ticino, in November 2014, which triggered a landslide.

The debris flows mostly occurred following strong convective summer storms after a quite sunny day. This means that the precipitations at the location of the debris-flow may be higher than those recorded by the station. Landslides occurred after the greatest amount of rainfall recorded in the last ten days preceding the event. The debris flows occurred a few ten of minutes to a few hours after heavy precipitations, floods after about one day of heavy rainfalls and landslides occurred up to several days after intense precipitations.

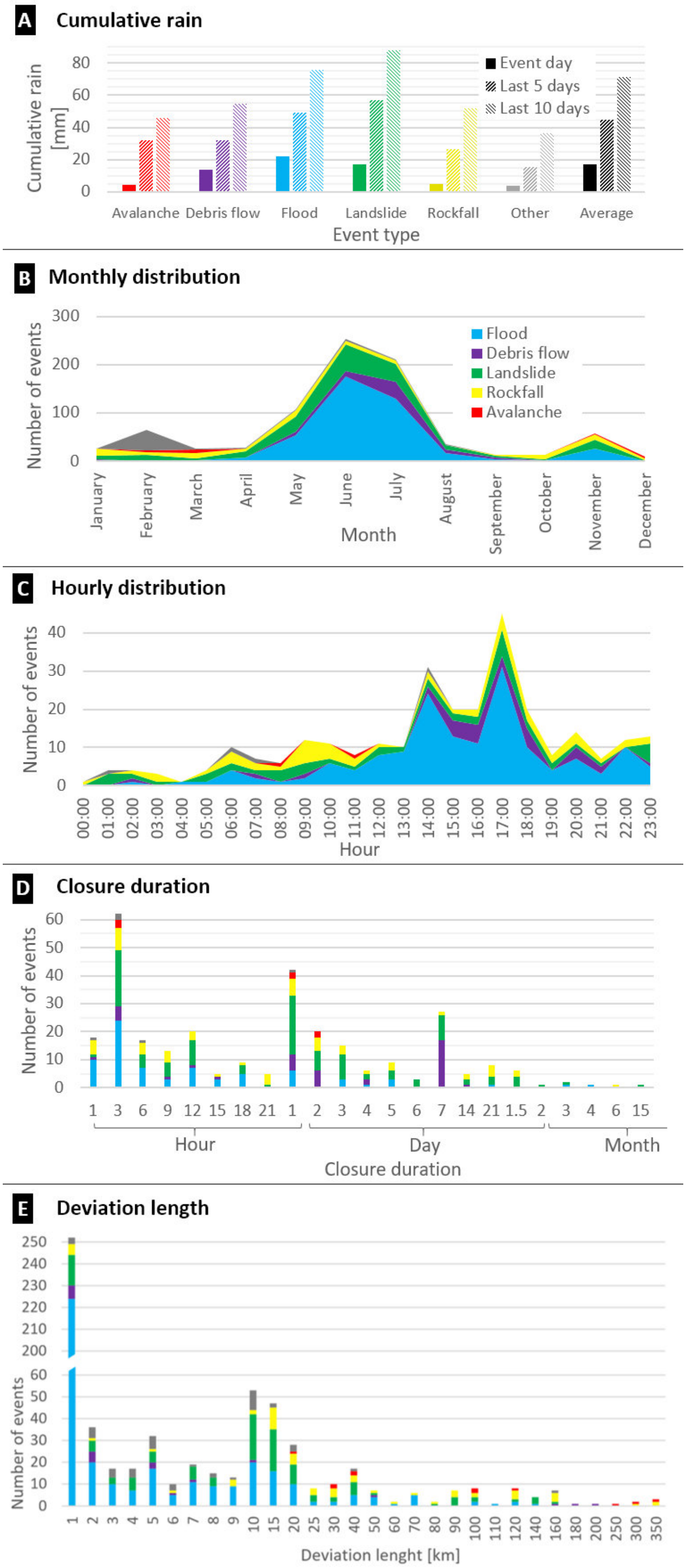

Figure 5: A: Cumulative rain [mm] distribution of the day of natural hazard events and last five and ten days. B: Monthly distribution. C: Hourly distribution. D: Closure duration distribution. E: Deviation length distribution of road closures. The vertical axis is cut between values 60 and 200.

4.3 Temporal parameters

4.3.1 Clustering in time

Fifteen long-lasting rainfalls were selected during the five considered years (Table 2) with durations of two days to fifteen days. 515 events, (i.e. 61 %) affected roads and railways during the 115 days (corresponding to 6% of the five considered years; 4.5 events per days) indicating the negative impact of long-lasting rainfalls. A third of these 515 events are among the 50 major loss events around the world, according to the Munich Re Topic Geo annual reports.

Table 2: Long-lasting rainfalls where occurred 61% of the collected natural hazard events on the Swiss transportation network during from 2012 to 2016.

Date	Number of days	Number of events	Avg number of event by day[2]	Munich Re event[3]
2012.01.06-07	2	2	1	2012.01
2012.11.04-14	11	12	1.1	-
2013.06.01-03	3	26	8.7	2013.06
2014.02.15-18	4	4	1.0	2014.02
2014.06.03-12	10	10	1.0	2014.06
2014.07.04-15	12	44	3.7	-
2014.07.22-31	10	51	5.1	-
2014.11.13-18	6	35	5.8	-
2015.04.27-05.07	11	55	5.0	-
2015.06.05-15	11	75	6.8	-
2015.07.22-25	4	37	9.3	-
2016.06.02-09	10	80	8.0	2016.06
2016.06.15-25	14	49	3.5	-
2016.07.22-28	7	35	5.0	-
Total	115	515[1]	4.5	-

[1] 61% of all events.
[2] Events number / number of days.
[3] Sources: Munich Re, 2013, 2014, 2015 and 2017.

4.3.2 Monthly distribution

The events effecting Swiss roads and railway from 2012 to 2016 are one average 71 events per month with a median value of 32. It ranges from 9 events for December to 253 events for July (Figure 5B; Table 10-SM). Two-thirds of all events (570 events; 68%) occurred during the three months May (107; 13%), June (253; 30%) and July (210; 25%).

85% (357) of floods and 64% (123) of landslides occurred in the period May - July. 89% (61) of debris flow occurred in from May to August. 64% (61) of rockfalls are distributed during the months January, March, May, October and November. 50% (8) avalanches occurred in March. 81% (43) of "other" events occurred in February.

4.3.3 Time of day and hourly distribution

The hour of occurrence is included for 33% (281) of the events (Figure 5C). 57% (89) of floods with a known hour of occurrence occurred between 2 pm to 7 pm, 61% (17) of debris flows occurred between 3 pm and 7 pm. Landslides and rockfalls are fairly well distributed during a day. Nevertheless, 23% (10) of rockfalls occurred between 9 and 11 am.

4.4 Infrastructure parameters

4.4.1 Types of tracks

88%, i.e. 747 of all collected events, affected road tracks, while 12%, i.e. 99 events, affected railway tracks (Figure 1F; Table 11-SM). Among the events affecting roads, 53% were floods, 20% landslides, 10% rockfall, 9% debris-flows and 8% other types. For the railway tracks 42% were landslides, 27% floods, 20% rockfalls, 5% others, 4% avalanches and 2% debris-flows. 79% (668) of all events occurred on minor roads or railways tracks while 21% (178) occurred on major roads or railways.

4.4.2 Roads

The Swiss road network length is about 72 000 km with 1 850 km managed by the Swiss Confederation, among which 1 450 km are highways and motorways, 25 000 km are major (cantonal) roads and regional roads, and about 45 000 km of roads are at the municipal level (Federal Statistical Office, 2018).

Swiss roads are classified into seven classes, according to the Swiss Federal Office of Topography (Figure 1G: Table 12-SM). Highways have separated traffic and a speed limit of 120 km/h, motorways with a 100 km/h speed limit, both account for 3% of the network length accounting for 5% of the events. Major transit roads with a high traffic load (12%) are affected by 13% of the events and roads of regional importance (22%) account for 12% of the events with a lower traffic load, both have a maximum speed of 80 km/h. The three remaining road classes (63%) based on the width of the road, are related to small roads with a low traffic. 65% of flood affected minor roads, and 42%, 48%, 36% and 82% respectively for debris flow, landslide, rockfall, avalanches and other events.

Interestingly, the frequency along highways and motorways corresponds to one event in every 200 km in each year, one in every 650 km for major and transit roads, and one in every 450 km for all types of minor road (minor roads, little roads and forest trails).

4.4.3 Railways

The Swiss railway network is 5 200 km long including 130 km of cogwheel train and 330 km of tram (Federal Statistical Office, 2018).

Railway tracks are classified into three classes: major (34% of the railway network), minor (62%) and trams lines (4%) (CFF, 2018; Federal Statistical Office, 2018) (Figure 1H; Table 13-SM). The major tracks, usually with two lanes, linking the main Swiss or crossing the Alps cities account for 29% (29) of railway events. The minor tracks, often with one lane, are affected by two-thirds (67%; 66) of events. Tram tracks, in or around towns, are affected by 4% (4). 56% of flood occurred on minor tracks and 37% on major tracks.

All debris-flows occurred on minor railways. 68% of landslide affected minor tracks and 32% affected major tracks. 70% of rockfall occurred on minor tracks and 30% on major tracks. All avalanches occurred on minor railways. 60% of "other" occurred on minor tracks and 40% on tram tracks (trees falls).

Concerning the network length of track types, railways tracks are affected by one event in every 250 km in each year, while all tram tracks are affected by one event in every 400 km in each year.

4.4.4 Possibility of deviation

For each event we checked how easy it was to find a deviation track (an alternative route in order to reach the next village avoiding the closure area) (Figure 1I; Table 14-SM). For 40% (342) of the events, more than 3 possibilities of deviation exist, for 23% (190) 1 to 3 deviations possibilities and for 12% (102) only one possibility was found. For 25% (212) of events, it is not possible to take an alternative track to bypass the closure because they occurred in valleys containing only one track

Almost two-thirds (264) of flood events and half (27) of "other" events could be bypassed. There are no deviation possibilities for 70% (48) of debris flow events, 43% (41) of rockfall events and 40% (77) for landslide events. This indicates that it is often impossible to find a deviation path for numerous debris-flows, landslides, rockfalls and avalanches.

4.5 Impacts and damages

4.5.1 On track

80% (677) of all events generated track damages (Figure 6A and Table 15-SM). 149 events (~18% of all events) are categorized in this first damage level "no closure or track damage".

146 of those events are floods. For 463 events (55%), the tracks were closed because of material on the tracks. In addition to closure, 143 events (17%) belong to the third level “partial damage”. Finally, the “total destruction” level accounts for 6% of all events (53). 38 events (4%) induced damages that could not be estimated.

A third of flood events caused no track closure and the remaining two-thirds of events generated only track closure, floods are the natural hazard which generate the least damages. Floods that does not require track closure come from the fact that vehicles or train can pass through a certain water level. 39% (27) of debris flows generated partial damages and a quarter (18) of debris flows caused the total destruction. Half (96) of landslides generated no track damages but only a track closure and about one-third (71) of landslides generated partial damages on tracks. Half (48) of rockfalls generated only track closures and 39% (37) generated partial damages. Avalanches generated track closures (13; 81%) as well as “other” events (51; 96%) due to snowdrifts.

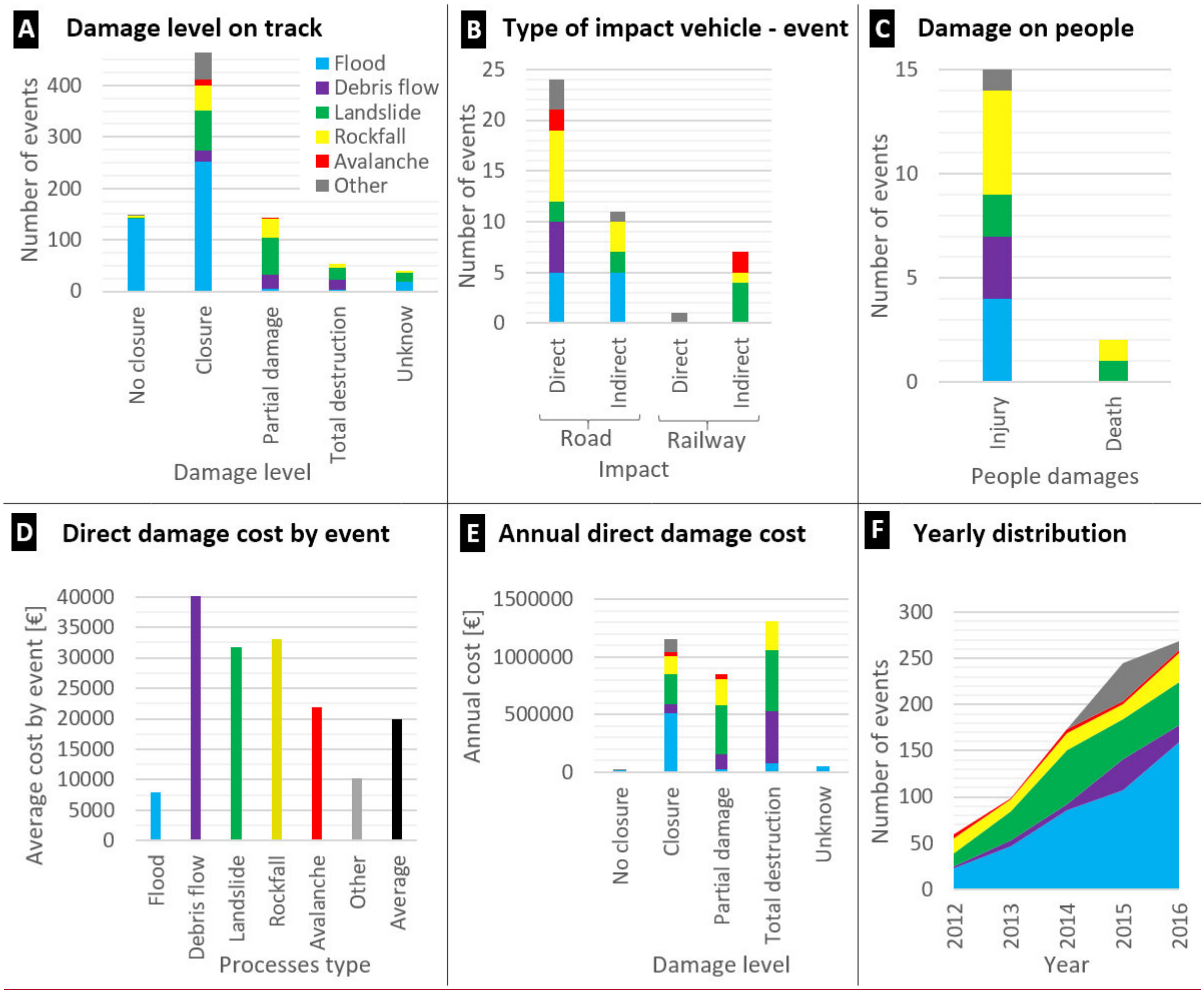

Figure 6: A: Damage distribution. B: Distribution of impact types between vehicle on roads or railways and natural hazard events. C: Distribution of injuries and deaths. D: Average event direct cost distribution. E: Annual direct cost distribution. F: Annual distribution.

4.5.2 On vehicle

43 (5%) of all collected events generated damages on vehicles (Figure 6B and Table 16-SM). 25 (3%) events included direct impact on vehicles, while 18 events (2%) caused indirect impacts on vehicles(when a vehicle collides the material falling on the track). Except a falling tree, which affects a tram directly, all direct impacts concern roads. Two trains were affected indirectly by avalanches, four trains by landslides and one train by rockfalls. Only 1% of all events affecting railways caused direct impact whereas 7% of the events caused indirect impacts. Conversely, 3% of all events affecting roads generated direct impacts while 1% caused indirect impacts.

4.5.3 On people

People are rarely directly affected by events. 831 events (98.2%) of all events did not cause injuries while 1.8% of events (15 events: 13 on roads and 2 on rail tracks) have caused injuries (Figure 6C and Table 17-SM). With 5.2% (5) and 4.3% (3) of events generating injuries, rockfall and debris flow events are natural hazard which generated the highest percentage of injuries. Twenty injured persons have been identified among which 10 were in a train derailment in the Canton of Grisons due to a landslide in August 2014.

Two events (0.2%) caused death in the above-mentioned event in Grison and in a second event occurred in March 2012, which was also in Grisons, where a coach without passengers was directly impacted by a rockfall, killing the driver instantly. Only 0.1% of events on roads caused the death while 1% of events killed people on railways..

4.5.4 Closure duration

Closure duration of 296 events (35%) were collected from the online press articles. Half of those closures (148) lasted less than one day while 41% (121) lasted from one day to one week and 9% (27) lasted over one week with a maximum of 15 months (Figure 5D). Thus, 87% of flood induced closures duration were less or equal to one day. While this percentage decreases to 71% for avalanches, 62% for rockfalls, 59% for landslides and 37% for debris flows.

4.5.5 Deviation length for roads

For the three quarter (638 events) of the case for which the deviation was possible, there lengths vary from 1 km to 350 km (Figure 5E and Table 18-SM). Forty percent (255) of all deviation track lengths are equal to or less than 1 km. One quarter (159) of deviation lengths measure from 2 to 9 km long, 16% (100) from 10 to 19 km long and the remaining 19% (124) deviation paths are over 20 km. The average deviation length in the Alps is 40 km, 9 km in the Jura and 7 km in the Swiss Plateau.

4.5.6 Direct damage costs

Direct damage costs include all costs directly related to the reparation of the track to guaranty the normal traffic service, including the full repair costs of the tracks only. If they are difficult or almost impossible to be assessed, direct damage costs are important in order to five a order of magnitude of the costs directly induced after a natural hazard event on a transportation track.

For the period 2012-2016, the annual direct damage costs for Swiss transportation track was estimated at EUR 3.4 million. For one event the average is EUR 19 900. For flood, it corresponds on average to EUR 8000, to EUR 47 800 for a debris flow, EUR 31700 for a landslide, EUR 33 100 for a rockfall, EUR 21 900 for an avalanche and EUR 10 200 for an "other" event (Figure 6D and Table 19-SM). "The annual costs for "total destruction" correspond to EUR 1.3 million, EUR 1.2 million for "closure" and EUR 0.8 million for "partial damage" (Figure 6E). A "small" event costs, in average, EUR 15 800, EUR 76 200 for a "medium" and EUR 175 700 for a "large" event.

Small events (95% of all events, i.e. 804 events) represent 76% (2.6 mio EUR) of the total direct costs; middle events (4%; 33) represent 15% (0.5 mio EUR) of the costs; large events (1%; 9) represent 9% (0.3 mio EUR) of costs. Roads (86% of the total transportation network length) represent 73% (2.5 mio EUR) of the total cost, while railways tracks (14% of all Swiss tracks) represent 27% (0.9 mio EUR) of all costs.

5 Discussion

5.1 Completeness of the database

~~° to 15°.~~ The quality of the presented database is affected by several factors. The online press articles, the main source of this database, does not report all natural hazard events affecting Swiss transportation network. The reporting of such events in articles depend on the number of casualties, the severity of the injuries, the resources available in the article redaction, the preventive or educational interest, the presence of images, etc. Article occurrence is theoretically higher in summer, when the actuality is lower because the quieter political activity. In some cases, the sensitivity increases, like after the two tourists killed in Gotthard highway in 2006 while a side of the Eiger summit was collapsing, this made the journalist prone to look at no slope mass movements (RTS, 2006a and 2006b; Liniger M. and Bieri, 2006; Oppikofer et al., 2008). On the contrary, when a lot of events occur simultaneously like during intense storms, only the most significant disasters are reported in the press. The event reporting is probably depending on the perception linked to the region of occurrence. For instance, a 0.5 m^3 rock falling on a track in the plateau has more media impact than if it occurs in the Alpine area, where it is more common.

The collected events from 2012-2016 range from 60 to 269 events per year (Figure 6F and Table 20-SM). But it is biased because Google Alerts were used since May 2014. The data collection was less systematic for the years 2012 and 2013 with 60 and 99 collected events respectively. With Google Alerts the number increased to 245 and 269 for the years 2015 and 2016 respectively. In 2014, the 173 collected events, is a transitional year with about half of the year using Google Alerts. An advantage of the Google Alerts is the variety of the online from almost all the available online newspapers, which is better than unique source as for Badoux et al. (2016). Google Alerts permits mainly to improve the event collection of floods. Moreover, the total number of event increases year after year, even after the use of Google Alerts because of the increase of floods disruptions (Figure 6F). This shows that the use of Google Alerts is not fully responsible of the yearly increase of number of events. Those numbers depend strongly to the weather conditions that are different each year.

Statistical predictions about a small sample of events are intrinsically imprecise (Davies 2013). The annual cost damage by natural hazard in Switzerland (Hilker, 2009) in the period 1972-2007 shows great damages disparities over the years, because some extreme rainfall events or successive storms greatly increase the number of events collected in one year, which was not the case during our period of record.

The collected data must be considered as a photography for a period of time capturing the background composed of “small” intensity events representing 96% of the total amount of events and 76% of the total direct costs.

5.2 Event definition

The terminology of natural hazard event on road and railways is partially inappropriate, because if the origin of the direct event is natural i.e. rainfall, etc., the indirect origin is very often anthropic. slopeTransportation network construction, use and maintenance induce seven changes or actions, potentially affecting slope stability according to the Terzaghi (1950) classification of mechanism of landslides (Jaboyedoff et al., 2016a). These causes of destabilisations are slope re-profiling, groundwater flow perturbation, surface water overland flow modifications, land degradation, inappropriate artificial structures, traffic vibration and ageing of infrastructure that modifies landslide occurrence (Larsen and Parks, 1997; Jaboyedoff et al, 2016). Furthermore, new infrastructures around tracks often induced an under-sizing of existing, which can induce concentration of the surface or ground water flow destabilizing slopes. People are thereby very often responsible for the aggravation of the hazard consequences with constructions built without the sufficient knowledge of natural hazard risk. Laimer (2017b) indicated that along Austrian railway, 72% of events are human-induced.

5.3 Events trends

Some reasons why minor and medium-sized natural hazard events are not well documented are because of their direct consequences, which are often quite rapidly fixed, i.e. the road can be re-opened within a few hours after the event or is only partially closed.

Slope angle values are lower than common values for natural hazard slopes because there are not slope angles at the event origin but at the end of the propagation, as tracks are located generally much ~~below than sources of propagation. 62% of flood events occurred on a slope almost flat (0°-5°). 43% of debris flow events occurred on a 5°-15° slope. A third of landslides and rockfalls events occurred on a 15°-25°. 40% of snow avalanche events occurred on a 5°-15° slope. Two-thirds of “other” events occurred on a almost flat slope (0-5°).~~ lower than sources of propagation.

~~Slope orientations of events occurring on mountainsides were estimated based on the Swisstopo map for 72% of events (Figure 6). Divided into eight slope orientations, half of events whose slope orientation was estimated occurred on south oriented, south-east oriented and west oriented slopes (each 17%). North and north-east oriented slopes contain the less events (8% each). Slope orientation of all Swiss mountainsides shows that south-west and north-east slopes are underrepresented unlike north-west and south-east facing slopes that are overrepresented. Comparison between distributions of slope orientation of events and of all of Swiss slopes shows that events on north-west-facing slopes are underrepresented and that they are overrepresented on west slopes. A raison for this west overrepresentation are the debris flows that occurred in the the S-Charl valley.~~

Several factors must be considered in the slope distribution. An explanation for the lower number of events on north-facing slopes is that there are less tracks on those slopes because there are less buildings on those shadowed slopes. Furthermore, ~~North~~north oriented slopes have less solar heat ~~as~~than south oriented slopes, and thereby, less freeze-thaw cycles. This can partially explain the high number of rockfall events on west, south and east oriented slopes.

~~4.2.2 Event volume and location of release zone~~

~~Events were classified into three classes of importance (Figure 7 and 8). The “small” class concern little events of volume bellow ten cubic meters. “Middle” event class concern events with a volume from ten cubic meters to two thousand of cubic meters. “Large” event class are events with a volume with a volume larger that two thousand of cubic meters. 95% of all~~

events were classified as “small” events, 4% as “middle” events and 1% and “large” events. With a third of rockfall events classified as “ large” events, rockfall processes have the largest proportion of large events (Table 7 in SM).

Without considering flood events, 39% of origins of events are located far to the track (more than 50 m from the track). 35% of origins of events are near to the track (between 0 and 50 m from the track) (Table 8 in SM). One quarter of the location of origins of events is unknown. Generally, all event origin near the track are Human-Induced natural hazard events. This not the case for event origin far from the track where a part of them are natural hazard, particular with debris flows and avalanches in the Alps. All debris flow event origins arise far from the track as well as the majority of avalanche events. Without considering flood events, 80% of the origin of the events are located above the track, 7% are located bellow and 14% of event have an unknown origin (Table 9 in SM).

4.2.31.1.1 Rainfall

Different meteorological features have been attributed for each event. Data come from 24 weather stations from MeteoSwiss. For each event is a assigned a weather station which is not always the closest but which is in a similar topographic situation. Average distance between weathers stations and events is 20 km and absolute average elevation difference is 200 m. All weather data were given for three following time periods: the event day, the five last days and the ten last days. Those three periods allow to consider the weather condition from the event day until the last ten days.

17 mm of rainfall during the event day were recorded on average per event (Figure 9 and Table 10 in SM). Flood events are the natural hazard process with the highest rainfall amount with 22 mm fallen the event day. After flood events, landslide (17 mm) and debris flow (14 mm) events are the events with the most rainfall amount. Rockfall (5 mm), avalanches (4 mm) and “other” events brought up the rear. The absolute maximal precipitation recorded during the event day is 154 mm in canton of Ticino in November 2014 where a landslide occurred.

It can be highlighted that debris flows mostly occurred following strong summer storms after a quite sunny day. Floods generally occurred during days of the highest recorded rainfall compared to the daily precipitation of all processes. Landslides occurred after the greatest amount of rainfall recorded in the last ten days preceding the event. This shows general that, on a temporal scale, debris flows occurred few ten of minutes to few hours after heavy precipitations, floods after about one day of heavy rainfalls and landslides occurred up to several days after intense precipitations.

4.31.1 Temporal parameters

4.3.11.1.1 Clustering in time

Natural hazard events occurred often during bad weather meteorological events when precipitations last for several days. Fifteen long-lasting rainfalls were selected during the five considered years (Table 2) whose duration last from two days to fifteen days. 515 events (61 % of all events) have affected roads and railways during the 115 days of the fifteen considered meteorological events. Thus, 61% of events occurred during 6% of the five years time period 2012-2016 which shows the huge influence of intensive long-lasting rainfalls. This gives an average of 4.5 events per days. A third of the meteorological events are part of the Munich Re Topic Geo reports that annually reports the 50 major loss events around the world.

4.3.2 Monthly distribution

The monthly distribution of natural hazard events on Swiss roads and railway from 2012 to 2016 ranged from 9 events in December to 253 events in July which give a multiplication factor of 28 between those extremes (Figure 10 and Table 11 in SM). The average monthly number of all events is 71 events with a median value of 32 events, which highlights the influence of extreme weather conditions generating many events in few hours or days. Two-thirds of all events (67%) occurred during the three months May (12%), June (30%) and July (25%).

86% of flood events occurred in the three months May, June and July. 89% of debris flow events occurred in the four months May, June, July and August. Almost two-thirds (64%) of landslide events occurred in the three months May, June and July. Although almost two-thirds of rockfall events are distributed into five months (January, March, May, October and November), they are relatively well distributed. More as half of the collected snow avalanches events occurred in March. 81% of “other” events occurred in February.

This monthly distribution indicates that flood events mostly depend mostly on two meteorological conditions: thunderstorms and long-lasting rainfalls, which occur mainly in spring, particularly with the conjunction of snowmelt, and in summer. The near absence of floods in winter is the result of the Swiss winter climate with the absence of long or brief but intense precipitations and ~~the~~ by the fact that the ~~precipitation~~precipitations in mountains ~~are~~fall as snow. However, exceptions are possible with floods caused by winter storms as in January 2018~~.~~ (RTS, 2018). Debris flow events mostly occurred in summer~~,~~ as ~~the results~~a result of powerful and stationary thunderstorms. Landslide events occurred mainly in spring as a result of long-lasting rainfalls ~~added~~ with the melting snow ~~melt~~, which generate many water, saturated soils and low evaporation. ~~Snow melt~~Snowmelt is the second trigger, after intense rainfalls, for landslides on Austrian railway tracks for the time period of 2005-2015 (Laimer, ~~2017).~~ 2017b). Laimer (2017b) has shown that intense precipitations are triggers for 78% of landslides on railway tracks in Austrian during the time period of 2005-2015. Freeze-thaw cycles during the winter season are also the strong trigger for rockfalls.

Rockfalls events do not follow the trend to ~~occurred~~occur mainly in spring and summer. ~~There~~They occur in every season but mainly in autumn, winter and spring ~~as the results of~~ due to numerous freeze-thaw cycles at those seasons, which ~~weak~~weaken the cohesion of rocks. ~~Without surprise~~Not surprisingly, avalanches occurred mostly in winter. They occurred also in autumn as the result of fresh avalanches on soils, which are not yet covered with snow, and ~~because of still~~ non-effective winter track closures of roads in the Alps. The ~~almost~~ total absence of ~~avalanches~~avalanche events in the spring can probably be ~~explain~~explained due to the still current road winter closures ~~that avoid spring snow avalanches, as well as rockfall and landslide events, on summer opened tracks.~~

~~4.3.31.1.1 Time of day and hourly distribution~~

~~We analysed the hourly distribution based on the 33% of events having an event local standard time value (Figure 11). Half of floods occurred in the afternoon during 4 hours from 2 pm to 6 pm. 61% of debris flow events during 4 hours between 3 pm and 7 pm. Except between 5 pm and 18 pm and 11 pm to midnight are landslides fairly well distributed. Comparable situation for rockfall events that are fairly equitably distributed over all hours of the day except between 9 am and 10 am containing 14% of rockfalls. The two avalanches with a precise event time occurred in the morning at 8 am and 11 am~~.

Flood events mostly occurred in the afternoon, probably after strong thunderstorms. Debris flow events mostly occurred in the evening, again probably after strong evening thunderstorms. Landslide ~~events~~event triggers are not time concentrate ~~as~~like the previous event processes. Rockfall events seem to be triggered during thawing which occur mostly in the morning. Snowdrifts from the “other” category began in the afternoon, after a few hours of strong wind. That is why the “other” category events are so concentrated in the afternoon.

It should be noted that the time of event does not always match with the real event time, especially for events occurring during the night or on track with little traffic like country roads.

4.41.1 Infrastructure parameters

4.4.11.1.1 Types of tracks

88%, i.e. 747 events, of all collected events have affected road tracks while 12%, i.e. 99 events, have affected railway tracks (Figure 12 and Table 12 in SM). Flood events represent 53% of events that have affected roads and 27% of events that have affected railway tracks. Debris flow events represent 9% of events that have affected roads and 2% of events that have affected railway tracks. Landslides events represent 20% of events that have affected roads and 42% of events that have affected railway tracks. Rockfall events represent 10% of events that have affected roads and 20% of events that have affected railway tracks. Snow avalanches events represent 1% of events that have affected roads and 4% of events that have affected railway tracks. "Other" events represent 7% of events which have affected roads and 5% of events that have affected railway tracks.

While floods events represent more than half of events affecting roads, they are two time less (27%) for events affecting railways. On the contrary, landslide events represent 42% of all event affecting railways and two times less (20%) for events affecting roads. 79% of all events occurred on minor roads or minor railways tracks while 21% occurred on major roads or major railways. The high proportion of landslides on train tracks can be explained in particular by the presence of very earthlysoil embankments or unsuitable fill material along railway tracks.

4.4.21.1.1 Roads

Roads are classified into seven classes, according the Swiss Federal Office of Topography, swisstopo, classification (Figure 13 and Table 13 in SM). In order of importance, there are firstly highways with a usually speed limit of 120 km/h and separated traffic, followed by motorways with a 100 km/h speed limit. Both represent 3% of the Swiss road network length. There are then major transit roads with a high traffic load (12% of Swiss roads) and roads of regional importance (22% of Swiss roads) with a lower traffic load (both 80 km/h maximum speed). The three remaining roads classes (63% pf Swiss roads) concern small roads with a (very) low traffic load and with track width ranging from 2 to 6 m: minor roads including

~~most streets (4-6 m width), little roads (3-4 m width) and the forest or land trails (2-3 m width).~~

~~57% of events on roads occurred on minor roads, 13% occurred on major transit roads, 12% on regional roads, 10% occurred on little roads. 5% of events affecting roads occurred on highways, 3% on forest and land tracks and 0.3% on motorways. According to event processes, 65% of flood events affected minor roads. 42% of debris flow events affected little roads occurred on minor roads. 48% of landslide events occurred minor roads. 38% of rockfall events affected minor roads. 36% of snow avalanches events affected minor roads. 82% of "other" events affected minor roads. Reported to the network length of track classes, highways and motorways are affected by one event every 200 km each year, major and transit road every 650 km each year and all types of minor road (minor roads, little roads and forest trails) every 450 km each year. This shows that~~ and due to their grade limitations. In addition, despite more protections than the average, highways are proportionally more vulnerable than other roads ~~maybe~~ because of the alignment with many imposing cuts and fills.

~~4.4.3 Railways~~

Railway tracks ~~are classified into three classes: major, minor and trams lines (Figure 14 and Table 14 in SM). Major tracks which represent 29% of events affecting railways are national tracks linking the big towns and few tracks crossing the Alps with often double lanes. Minor tracks, often with one lane, are affected by two-thirds (67%) of events affecting railways. Tram tracks, in or around towns, are affected by 4% of events affecting railways. 56% of flood events affecting railways occurred on minor tracks and 37% on major tracks. All debris flow events affecting railways occurred on minor railways. 68% of landslide events affecting railways occurred on minor tracks and 32% on major tracks. 70% of rockfall events affecting railways occurred on minor tracks and 30% on major tracks. All snow avalanches events affecting railways occurred on minor railways. 60% of "other" events affecting railways occurred on minor tracks and 40% on tram tracks. An issue related to regional tracks may be their lack of maintenance on track embankments during the last decades, causing landslides and rockfalls. Reported to the network length of track types, railways tracks are affected by one event every 250 km each year, all tram tracks by one event every 400 km each year.~~, as motorways, require a balanced gradient ratio, and therefore, they must run along the valley sides over far distances. This requires long and steep cut slopes (Laimer, 2017b).

4.4.4 Track sinuosity

The sinuosity of the track where events occurred and whose location was enough precisely known, was established on the basis of the swisstopo map. To define the curvature of the event location, six categories were defined: straight line (no curve), near a wide curve (on one side there is a straight line, on the other there is a wide curve which is close), wide curve (the event is located into a wide curve), near a tight curve (on one side there is a straight line or a small curve, on the other there is a tight curve which is close) and tight curve (the event is located into a tight curve). Distinction between wide and tight curve is the curve radius. Both for roads and railways, wide curves require to release the accelerator pedal to pass the curve with a speed which is equal or slightly lower as the straight line speed. In tight curve, drivers have to brake to reduce significantly the speed.

All track sinuosity of events which localisation was "accurate" or "middle" have been estimated (65% of events). About a third of events occurred in a wide curve or near a wide curve while 9% of event occurred in or near a tight curve. 21% of events occurred in a straight line (Figure 15 and Table 15 in SM). Considering event types, flood events occurred mostly on straight tracks while debris flows, landslides, rockfall and avalanche events occurred firstly on wide curve. "Other" events (snowdrifts and fallen trees) occurred both mostly on straight line and wide curves. Events that are located in wide curves can both be avoided by drivers if they are attentive but they can also generate an impact between the vehicle and the fallen material if the driver is not attentive because the visibility is lower than on straight lines.

4.4.5 Intersections

It was analysed if the 65% of events with an enough precise location were located in, near or far track intersections (Figure 16 and Table 16 in SM). In the majority of cases (38%), events occurred on tracks with any intersections, followed by 19% events located near intersection (from few meters to about 100 m). 8% of events are located in intersections. Except flood events, all events occurred mostly on tracks with any intersections around. Because of its urban qualification, flood events occurred mostly near intersections. Intersection means generally greater deviation possibility than track sections without intersection.

4.4.61.1.1 Possibility of deviation

For each event has been defined, how easy it was to find a deviation track (Figure 17 and Table 17 in SM). Four categories of possibilities of deviation were selected: large (many possibilities (>3), mostly in urban areas), middle (few possibilities (1-3), mostly in country areas), small (only one possibility) and any possibility of deviation (mostly in alpine areas).

For 40% of events, it was a large possibility of deviation, for 23% of events the possibilities of deviations were qualified as “middle” and for 12% of events there were given as “small”. For one quarter of events, it was no possible to take an alternative tracks to bypass the closure.

By event types, almost two-thirds of flood events and half of “other” events could be bypassed. In contrary, it existed any deviation possibilities for 70% of debris flow events, 43% of rockfall events and 40% for landslide events. Thus, it is sometime difficult or even impossible to find a deviation path for numerous debris flow, landslide, rockfall and avalanche events.

4.51.1 Impacts and damages

4.5.11.1.1 On track

A damage level on tracks and track infrastructure was estimated for all event Damages have been characterized by four levels partially based on Bill et al. (2015). First level is “no closure or track damage” where the event generates any traffic perturbation neither track damage. 149 events -i.e. less 18% of all events- are categorized in this first damage level. Second damage level is “closure” when the track is closed due to material carried landslide by the natural hazard event and contain 463 events i.e. 55% of all events. After evacuation work, tracks can be used again, without any repairing work. The third damage level is “partial damage” when tracks, in addition of its closure, require superficial repairs and minor stabilization of the track embankment (143 events, 17% of all events). Fourth level is “total destruction” when the track embankment has to be reconstructed (53 events, 6% of all events). 4% of all events (i.e. 38 events) have damages that could not be estimated. Three-quarters of all events that generate no track damages, while one-quarter generates track damages (Figure 18 and Table 18 in SM).

With about a third of flood events that cause no track closure and two-thirds remaining events that generated only track closure, floods are the natural hazard which generate the least damages. The high percentage of floods which does not require track closure come from the An issue related to regional tracks may be due to their lack of maintenance on track embankments during the last decades, causing landslides and rockfalls on old age infrastructure that were built long before the basics of soil mechanics (Terzaghi, 1925; Michoud et al., 2011; Laimer 2017a, 2017b).

The fact that vehicles on roads or railways can pass through a certain water level. It is not uncommon to have flooded tracks and keep nevertheless a restricted traffic level. 40% of debris flows generated partial damages of the track and a quarter of debris flows generated damages of total destruction level. Half of landslides generated no track damages but only a track closures and one-third landslides generated partial damages on tracks. Almost similar for rockfalls with half of event generating only track closures and 39% generated partial damages. Avalanches generated mainly only track closures (81%) as well as “other” events (96%) due to snowdrifts. Due to their configuration of massive and heavy material, landslides generate often massive damage. Furthermore, when they are located just below the track, they almost always generated total damage to the track infrastructure. Similar for debris flows that could generate high damages due do their high energy stone blocks.

4.5.2 On vehicle

About vehicle damage, 5% of all collected events (i.e. 43 events) have generated damages on different vehicles (Figure 19 and Table 19 in SM). Those vehicle damages can be categorized into two classes: “there are more direct impact” when a vehicle is directly reach by a hazard and “impacts (24) than indirect impact” when a vehicle collides an event mass already fallen on the track. 25 events with a direct impact on vehicles were collected while 18 events caused indirect impacts on vehicles. Except a falling tree impacting directly a tram, all direct impact concern roads. Concerning indirect impacts, two trains impacted indirectly avalanches, four trains impacted indirectly landslides and one train impacted indirectly rockfalls. 1% of all events affecting railways caused direct impact whereas 7% of events on train tracks caused indirect impacts. Conversely, 3% of all events affecting roads generated direct impacts while 1% caused indirect impacts. The fact that there are more direct impacts than indirect(11) impacts on roads show that drivers can generally stop their vehiclevehicles before to impactbeing affected by a fallen event unlike trains that cannot stopbe stopped on a short distance and that reachreaching the fallen mass. (7 indirect impacts and one direct impact). In addition, there is a much higher probability that a vehicle on a road will be directly impacted by an event than a train on a track because road traffic is excessively more densedenser than on a railway linerailways traffic.

4.5.31.1.1 On people

People are rarely affected by events. 98.2% of all events, i.e. 831 events, did not cause injuries while 1.8% of events (15 events: 13 on roads and 2 on rail tracks) have caused injuries (Figure 20 and Table 20 in SM). With 5.2% and 4.3% of events generating injuries, rockfall and debris flow events are natural hazard which generated the highest percentage of injuries. 20 injured persons have been identified whose 10 in a train derailment in the Canton of Grisons due to a landslide in August 2014. Three events (0.4% of all events) generated each one death. Once of the three events was the same as previously mentioned in canton of Grisons while the second, again on a train track, occurred in Gurtnellen (Canton of Uri) in June 2012. A rockfall killed a specialist working on a cliff where consolidation works were carry out following several rockfall on the track. The third event occurred also on the Canton of Grisons where a coach without passengers has been directly impacted by a rockfall killing instantly the driver in March 2012. According to track types, 0.1% of events on roads caused the death while 2% of events on railways generated deaths. Thus, there is one killed people for three injuries during the considered time period which is to short to extract mortality and injuries trends.

4.5.41.1.1 Closure duration

Closure duration of 296 events (35% of all events) were collected from the online press articles. Half of those closures 50% lasted less than one day while 41% lasted from one day to one week. 9% of closures lasted over than one week with a maximum of 15 months (Figure 21). Closure duration depends largely on the damage level generated by the event. Thus, 87% of flood events closures lasted less or equal to one day. While this percentage decreases to 71% for avalanches, 62% for rockfalls, 59% for landslides and 37% for debris flows.

4.5.51.1.1 Deviation length for roads

When they were known, deviation lengths for roads were collected from the online press articles. For all other events who needed a track closure, they were measured on a GIS. There are no possibilities for deviation tracks for one quarter of events because it exists any alternatives tracks. Those events with any deviation tracks are located mostly in narrow alpine valley. For the remaining three quarter, the deviation length varies from 1 km to 350 km (Figure 22 and Table 21 in SM). Thirty-one percent of all deviation track lengths are equal or less than one kilometre long. 28% of deviation lengths measure from 2 to 9 km long. One quarter of deviation lengths measure from 10 to 20 km long. The remaining 16% of deviation paths measure over 20 km. Deviation length is dependent with the event location. Thus, the average deviation length in the Alps is 40 km, 9 km in the Jura and 7 km in the Swiss Plateau.

4.5.61.1.1 Direct damage costs

Deviation lengths for railways are difficult to evaluate. In case of replacement buses, the distance of deviation is calculated with the distance of the replacement buses on the road. For 72 events on railways (75% of all events on train tracks), there were no possibility of deviation using other train tracks. In case of no replacement service, the deviation length for railway is the distance on train track between the two stations on both sides of the track closure. The average distance of deviation for this last configuration is 65 km.

Comparatively, annual damages caused by natural disasters in Switzerland for the time period of 1972-2011 are estimated at EUR 290 millions per year (OFEV, 2013). Switzerland allocates EUR 2.5 billions each year for protection against natural hazards, which corresponds to 0.6% of its GDP. 21% (EUR 0.5 billion) of this allocated amount concerns intervention and repair (OFEV/OFS, 2007; OFEV/OFS, 2011).

A synthetic example of an event of our database can be summarized as follow: a flood event occurs in June during an afternoon within the Swiss plateau on a small south-oriented slope and on a minor road. It generates a road closure of few hours with a deviation distance of less than one kilometre and causes no injuries or death. The possibility of road deviation is large. On the day of the event, the sun shined for half of the event day and 10 mm of rain fell (20 mm during the last 5 days and 35 mm during the last 10 days) and the average temperature during the event was 20°C. There have been about 1000 lightings around the event location on the event day and the wind speed was 7 km/h blowing a north-east.

5.4 Direct damage cost estimation

Direct damage costs include all costs directly related to the rehabilitation of the track to guaranty the traffic service. All repair costs of the tracks are included. The estimated direct costs did not take into account indirect costs like vehicle repairs (a train repair costs a lot), implementation of deviations, ~~replacements~~replacement buses in case of railway closure, all costs generated due to the traffic restriction for road and railway users, as well as all mitigation works and protective measures.

~~Direct costs were estimated on the basis of the damage on the track. For each damage class was attributed six estimations of costs per square meter according to the event importance (small, middle and large event) and the track type (road or railway). Costs, initially estimated on Swiss francs, were estimated on surface area defined at 100 m^2 for small events, at 200 m^2 for middle events and 300 m^2 for large events. Costs are given in Euros with value as mid January 2018 of 1 EUR = 1.17 CHF = 1.23 USD. A “no closure” cost was estimated on average at EUR 6 per square meter, at EUR 230 for a “closure” cost, at EUR 400 for a “partial damage” cost, at EUR 1000 for a “total destruction” cost and at EUR 230 for a “unknown” cost (Table 22 in SM). Costs were evaluated in the basis of road and railways reports (Canton~~

de Vaud et du Valais, 2012; SBB CFF FFS, 2017) and on the basis of repair works experience in the civil engineering.

The annual direct damage on infrastructure of natural hazard events on Swiss transportation track was estimated at EUR 3.4 million. On average, cost of one event is EUR 19900. Direct costs of a flood is, on average, EUR 8000; EUR 47800 for a debris flow; EUR 31700 for a landslide, EUR 33100 for a rockfall, EUR 21900 for an avalanche and EUR 10200 for an "other" event (Figure 23 and Table 23 in SM). "Total destruction" costs are the highest costs (EUR 1.3 million), followed by "closure" and costs (EUR 1.2 million), followed by "partial damage" costs (EUR 0.8 million) (Figure 24). A "small" event costs in average EUR 15800, EUR 76200 for a "middle" event and EUR 175700 for a "large" event. Small events (95% of all events) represent 76% of the total direct costs; middle events (4% of all events) represent 15% of the costs; large events (1% of events) represent 9% of costs. Roads (86% of total transportation network length) represent 73% of the total cost, while railways tracks (14% of all Swiss tracks) represent 27% of all costs.

Floods generate the least damage by event with about a third of flood events that cause no track closure and two-thirds remaining events that generated only track closure. The high percentage of flood events which does not require track closure come from the fact that vehicles on roads or railways can pass through a certain water level. It is not uncommon to have flooded tracks and to keep nevertheless an unrestricted traffic level. Debris flows are the more costly process by event because they generate high track damages. The 17 destructing debris flow in the S-Charl valley in July 2015 influence those results.

Although floods are the less costly process by event, their annual cost comes in second place (EUR 0.58 million per year) because of their high number of events. Annual cost of debris flows is estimated to EUR 0.54 million, almost almost as much as floods because of their high individually damage cost. Annual cost of landslides reach almost the million Euro (EUR 0.95 million) which the highest annual cost of all processes. The reason is because their individually cost is high and because they are numerous. Similar to debris flow annual cost, the annual cost of rockfall is evaluated to half million Euro. With EUR 50000 and EUR 90000 per year, avalanches and "other" events costs are much lower than other processes.

51 Discussion

61 Results

6.1 Data quality

6.21.1 Completeness of the database

The integrity of the presented database is affected by several factors. Natural hazard events affecting Swiss transportation network are not all identified in the online press articles. The publications of those type of articles depend of numerous criteria such the number of casualties, the severity of the injuries, the resources available in the article redaction, the preventive or educational interest, the presence of images, etc. Article occurrence is theoretically higher in summer when the actuality is lower because the quieter the actuality, the less likely it is that a subject will be published. If an terrorist attack occurs in the middle of the summer, the likelihood of the natural hazard article appearing decreases. When a large natural hazard event occur, small events affecting roads or railways are not in a priority list. Sources for the articles are press agencies, concurrent media, social media as well as reader reporters.

A advantage of the Google Alerts is the variety of the online sources as all available online newspapers are checked and not only one unique source as for Badoux et al. 2016. To publish press articles about natural hazards affecting transportation tracks is challenging because we talk here mostly not about fatalities which are usually well reported in newspaper. For example, a Swiss-German newspaper will relate with a high probability a death resulting of a natural hazard on a track in the Swiss french part of Switzerland or in Ticino (Badoux et al. 2016), while it will probably not relate a forest path closure near of the redaction building.

Another factor influencing the data collection is the difference of perception between different areas as the Swiss Plateau and the Alps. A 0.5 m^3 rock fallen on a track in the plateau have more probability to be related in a press article as a similar event in the Alps. That because for people living in mountainous areas, those events are more or less common while they are exceptional for people living in the Swiss Plateau. Furthermore, when several events occur simultaneously like during an intensive a bad weather meteorological event, the probability that events are related in press articles decreases because media do not relate all events because they focus on the most impressive ones.

In order to estimate the proportion of missed events with our methodology, we compared our results for the Canton of Vaud with data from the natural hazard division of the administration of the same canton. The missing proportion of data our database for the canton de Vaud compared with the database of the canton de Vaud administration is about two-thirds. Many of those missing events occurred on forest paths and were collected by the forest service. If we extrapolate the missing data proportion to the entire country, we must multiply our total number of collected events by three, which gives about 2'500 events for the 5 considered years and thus gives 500 events by year and 1.4 event by day. Compared with results of events affecting roads and railways in 2014 derived from the Swiss flood and landslide damage database (Hilker, 2009), the missing proportion of data our database is a third. If we extrapolate the missing data proportion, we must multiply our number of events by 1.5, which gives about 1'250 events in five years and thus about 250 events by year and 0.7 event by day. We see here the difficulty to have a complete database and we note that a database at a large scale, i.e. Switzerland, is less complete as a little scale database, i.e. canton of Vaud even though we collected events that were not considered in the canton of Vaud database.

6.2.1 Range of considered years

During the 5-year period 2011-2016, 846 events were collected. They ranged from 60 to 269 events by year (Figure 25 and Table 24 in SM). Google Alerts were only used since May 2014. Before this date, event collection was less systematic which generated less events observations. Thus, we observe a average number of events of 80 for the years 2012 and 2013 (data collected without Google Alerts) and a average number of events of 257 for the years 2015 and 2016 (data from Google Alerts). 2014, with 173 collected events, is a transitional year with about half of the year carries out with Google Alerts and the other part without.

The observed period of five years (2012-2016) is too short to show trends of the events. Statistical predictions about a small sample of events are intrinsically imprecise (Davies 2013). The annual cost damage by natural hazard in Switzerland (Hilker, 2009) in the period 1972-2007 shows great damages disparities overs the years. This indicates that some extreme meteorological events as long-lasting rainfall or successive storms greatly increase the number of events collected in one year.

Our database must be considered as a focus on the time period 2012-2016 and must not be considered as representative of natural hazard events affecting roads and railways during the last 50 years. Collected data are like a photography at time *t* capturing the events and their impacts of a high number of events which could be classified at 95% as "small" with low

~~impacts on the track and low material volume (lower than 10 m^3). Those small events are like a background noise of natural hazard events where large events are well studied. But together, this background noise represent a certain amount of roads and railway disturbance that could be highlighted.~~

~~6.3~~ Estimation of direct damage costs

~~Estimation of direct damage costs~~ depend ~~of~~on many factors that are difficult to estimate. The hour has an impact ~~of~~on the cost: repair works during the night or the weekend are greater ~~as during~~than office hours. The event location ~~impacts~~affects the costs too: costs in ~~a~~an alpine valley far away ~~of~~from any construction companies ~~is~~are higher than works in ~~a~~an agglomeration where construction machines and landfill for the excavated material are close to. The date has also ~~in~~an impact on the costs: an event occurring during a time period where weather conditions are difficult will last longer. The emergency of the situation has also an influence ~~of~~on the direct cost: damage on a secondary road or~~ on~~ a highway will be treated with a different emergency level. We can also notice the influence of the ~~among of~~ traffic, the presence of damaged retaining walls and protective measures, the slope angle, the financial situation of the responsible administration for the repair works, necessity of work in the slope or the cliff above the track, etc~~...~~. Works on railways cost more than ~~repair costs on~~ roads because the access is often more difficult~~ as on roads~~ and because contact line and rails repairs can become very quickly expensive. All those factors can easily vary costs by plus or minus 50%.

An estimation of the direct costs of the “small” events is ~~possible~~more credible than the costs of events of greater damage, because the main work is to release the road from fallen materials. Costs estimation for the “middle” events and especially for “larges” ones is more complicated because the repairs require large construction sites which have their own characteristics that can not be compared~~ that can not really be compared.~~.

The estimated costs must be considered as order of magnitude of the direct costs generated by natural hazard events on the Swiss transportation network. However, obtained results are more refined ~~as results in~~than the previous study of Voumard et al. (2016~~)~~), where costs of event ~~bellow~~below EUR 8500 were not considered.

~~6.4 Events trends~~

~~Statistic analyses and data analysis with especially PCA did not highlight particular or unexpected trends. Rain precipitations, with on average 17 mm water the event day, 45 mm~~

the last 5 days and 71 mm the last 10 days, seems to have a undoubted influence as event trigger. As well as long precipitation periods as short strong storms are strong triggers for floods, debris flows, landslide and rockfalls. Laimer (2017) has shown that intense precipitations are triggers for 78% of landslides collected on railway tracks in Austrian during the time period 2005-2015. Freeze-thaw cycles during the winter season are also strong trigger for rockfalls.

With a summary of all the values of attributes, features of the mean natural hazard event affecting the Swiss transportation network for the time period 2011-2016 are the following: it is a flood occurring in Spring, in June, during the afternoon, located on the Swiss plateau, on a small South oriented slope, in the canton of Bern, on a minor road, on a straight path near an intersection in a village. It generates a road closure of few hours with a deviation distance less as one kilometre but causes no injuries or death. The possibility of deviation is large. Population is moderately directly affected by the road closure and little indirectly affected (minor road in a village). The soil of the event location is composed of gravel and sand and the soil productivity is a exploitable saturated zone. The day of the event, the sun shone half of the event day and it fell 10 mm of rain (20 mm the last 5 days and 35 mm the last 10 days) and the temperature average during the event was 20°C. There have been about 1000 lighting around the event location the event day and the wind speed was 7 km/h and a North North-East.

6.51.1 Event definition

The terminology of natural hazard event on road and railways is quite usurped because if the direct event origin is natural i.e. rain, heat, etc., the indirect origin is very often anthropic. Transportation network construction, use and maintenance induce the seven changes or actions potentially affecting slope stability proposed by Jaboyedoff et al. (2016) that is based on Terzaghi (1950) classification of mechanism of landslides. Those causes are slope re-profiling, groundwater flow perturbation, surface water overland flow modifications, land degradation, inappropriate artificial structures, traffic vibration and ageing of infrastructure. Indeed, track construction generates a modification of the slope topography that imbalance the natural slope stability and that modify landslide occurrence (Larsen and Parks, 1997). Furthermore, new infrastructures added in an already built area often generate an under sizing of existing drains that are are not suitable to the adding of new track. Water can be concentrated into slope parts and generate its destabilisation. People are thereby very often responsible to aggravate the hazard consequences with constructions build without an enough

~~knowledges about natural hazard risk. Those natural hazard events can be hence characterised as Human-Induced natural hazard events (Jaboyedoff et al., 2016). This high proportion of Human-Induced events on transportation tracks is shown in the study of Laimer (2017) with 72% of events that are Human-Induced events.~~

~~6.6~~5.5 General discussion about natural hazard and transportation networks

~~If~~Several methods exist to quantify the ~~thematic~~costs of ~~natural hazard affecting roads and railways has interest for some experts working with this topic, this is not the case for the most of political people and population. Compared with other societal thematises like health, old-age pensions or even transport sector, our interest obtains only little financial support because it is not in the prior list of the political people as a result of a lack of knowledge of the involved risk.~~

~~However, depending of current latest events, natural hazard affecting transportation network becomes a current thematic in Switzerland. For this, the event in Bondo, canton of Grisons, Switzerland, where a mountain collapse of 3 million m3 generated a debris flow which destroyed an international road in August 2017 is a good example. Thus, the magazine of the Touring Club Suisse, the largest motor club in Switzerland, dedicated twelve pages to natural hazards impacts on transportation network in its newspaper in autumn 2017.~~

~~Recent events in Switzerland ask the questions of the cost of~~track closures ~~that are very difficult to estimate. Several methods exists~~ (Nicholson, 1997; Erath 2009~~)~~), but they are ~~all more or less imperfect~~not satisfactory because of the quantification of costs, especially ~~for~~ indirect costs~~, depends of many factors that are various and whose damage costs~~ are difficult to ~~estimate. We think that~~calculate, and the resilience must be carefully considered since people ~~find~~ often find solutions to skirt the track closure (deferred travel, meeting realized with digital technologies, alternative sources of supply, etc.). ~~This question concerns more scientists as political since~~The closure costs due to natural hazards, such as traffic jam costs, are not compensated in Switzerland~~.~~

~~If issues~~, but models must include the potential loss of ~~natural hazard affecting~~ income by taxes if the economy of the region is slow down. In addition, there are several ways to replace a transportation ~~tracks are not understood, there is no interest to have database of such~~route or means. For example, train can be replaced by buses between two stations. Using other train routes can be very complicated and long. For road deviation, they are usually much easier; however, in some valleys in the Alps, deviation lengths can reach more than hundreds of

~~event~~km and ~~thus there~~sometimes, it is ~~any interest to collect data, particularly~~even impossible. It must be noted that the increase of the travel duration in case of railway closures is more relevant for ~~small events. Event if any natural event can always be qualified as a large event, depending on the point of view of the affected people. Similarly to~~passengers than the distance of deviation itself. Davies (2013~~), which~~) puts back the importance of the event in the context of the affected person~~, a~~. A minor landslide that affect a person is completely unworthy of notice to the vast majority of ~~a~~the population, but is also momentary considered as catastrophic for the person that must reconsider its travel and find an alternative route or even cancel its displacement.

~~After different discussions with several people using natural hazard databases, observations are clear-cut concerning data acquisition: information~~Information acquisition is challenging and hard for such database, because it depends ~~of~~on several people working ~~on~~in field like ~~roadmenders~~road menders, railway maintenance workers and forestry workers, who have sometimes no time or little interest ~~in~~to fill the ~~natural hazard thematic. Their primary purpose is to guarantee the passage of vehicles or trains. They usually have little time and/or interest to collect event data. This generates a loss of information and special situations where it is not uncommon for a state service to obtain information about an event in the press rather than through their services. Events can also be reported in a very inhomogeneous matter according the responsible person of the event announcement.~~relevant database fields. Hence, there are possible improvements of database quality by ~~the state governments (municipal, cantonal and federal levels) and for semi or private companies as SBB (Swiss main railway company) to collect data. To this end,~~ using new tools such as off-line collaborative web-GIS (Balram, 2006; Pirotti et al., 2011; Aye et al. 2016; Olyazadeh et al., 2017) that can ~~help to facility~~facilitate the event ~~collect~~collection in field.

~~Acquaintance~~The collection of the natural ~~hazards impacts on~~hazard events affecting roads and railways ~~also goes through make known events for the population. This~~ can be ~~made by~~improved using different communication channels ~~as the traditional media (newspapers, TV, radio) or the social media. As example of tool to sensitize the population is the~~such as Facebook page of the Colorado Department of Transport (CDT) in United States. ~~In addition of preventive posts, all daily traffic restrictions are related on an active Facebook page.~~ This diffusion channel allows the CDT to highlight all natural hazard events that affect roads in the Colorado department ~~as thus~~, allowing to sensitize drivers of their travel impacts.

~~7~~6 Conclusion and perspectives

~~In this study, we collected from online press articles~~Using newspapers and Google Alerts, natural hazard events that have affected the Swiss transportation network ~~for a 5-year period~~ from ~~2011~~2012 to 2016~~. With 172 attributes by event in different domains like~~ were collected. Collected 846 natural hazard~~, traffic and track infrastructures, this database is, from our point of view,~~ events were characterized by 172 attributes, which makes it unique ~~at the Swiss level. We are able to describe in detail the 846 collected events classified into six hazard processes -flood, debris flow, landslide, rockfall, avalanche and "other" processes- with their damages and consequences on the traffic~~ for Switzerland (Table ~~3).~~

~~We can thereby estimate that the frequency of a natural hazard event affecting a track is of one event every two days. We estimate, on the basis of a database of a cantonal administration, that our database represent a third of known events by the experts.~~1). Our results highlight the ~~certain importance~~impact of natural hazard ~~events~~ on the Swiss roads and railways, especially ~~of little event~~for small events with ~~a fallen~~ volume of less ~~as~~than 10 m^3 that are ~~commonly are~~ rarely or not collected~~ and that~~. They represent 95% of the database events. The direct costs of all events were estimated at EUR 3.4 million ~~by~~per year ~~and the~~with an average cost per event ~~cost~~ at EUR ~~19900~~19 900. Direct ~~cost~~costs of small events ~~was~~were estimated at EUR 2.5 million by year, which represents three quarter of the total direct costs. ~~Comparatively, annual damages caused by natural disasters in Switzerland for the time period 1972-2011 are evaluated at EUR 290 millions (OFEV, 2013). Switzerland allocates EUR 2.5 billions by year for protection against natural hazards, which corresponds to 0.6% of its GDP (OFEV/OFS, 2011). 21% (EUR 0.5 billion) of this allocated amount concerns intervention and repair (OFEV/OFS, 2007).~~

~~With several factors as climate change generating always more extreme weather conditions and permafrost melt~~Because of heavy storms, densification of the infrastructures, traffic increase and lack of funding for track maintenance, we could ~~wait for always~~expect more natural events affecting the Swiss transportation networks~~ with an increase of damages on tracks and people. Moreover, a lot of events like flood and landslide events could occur almost everywhere and it is impossible to protect every meters of road and railways tracks with protective measures as the financial help is only just enough or even insufficient to protect the most critical areas.~~. As usual, the key to reduce the natural hazard risk ~~due to natural hazard~~ on tracks is obviously financing. ~~In canton of Valais, the third canton in number of collected events and that has a lot of mountain roads, there is a lack of money of~~

~~about EUR 35 million per year to provide services of the 1800 km of cantonal roads (Le Temps, 2018). Even worse, there is a lack in the road maintenance and the rehabilitation of this cantonal road network is estimated at EUR 1.3 billion. The Valais mobility strategy will reduce on a third the length of the network by transferring 600 km to the communes. These will leave the least used tracks. There is also different projects to reduce costs like for example to replace a 10 km road whose rehabilitation and security would cost EUR 30 million by a 6.6 km cable car whose investment is estimated at EUR 21 million (Le Temps, 2018).~~

~~In view of obtained results and, we perceive in winter storms one of the greatest threat for the Swiss transportation network because they can trigger many natural hazard events that requires track closures preventively or following an event occurrence. Winter storms, that are relatively rare occurrence, produce generally heavy precipitations falling in the form rain on the Swiss plateau and that can fall of the form snow in the Jura and the Alps with a zero degree limit around 1000 m a.s.l.. In such a case, many roads and railways are preventively closed because of the danger of avalanche in the Alps and rockfall, landslide, debris flows and floods affect the Swiss plateau since runoff water can no longer infiltrate into a saturated soil. After few hours or days in this precipitation configuration, it is quite possible that zero degree limit takes altitude up to 2000 – 2500 m. This generates high snowmelt producing many floods and other natural processes in all country. Winter storms can generate also many track closures due to falling trees. First half of January 2018 has seen successively three winter storms that produced a lot of track closure. As example, 150 road and railways track closures were identified for the single day of 13 January 2018. This number represents almost 90% of the average annually number of events collected in the five years time period 2012-2016.~~

The presented database and its event analysis can be helpful for the decision makers at the three Swiss politic levels (the Confederation, the cantons and the municipalities) to plan and ~~enforce protective measures. For this purpose, we create open access online maps of the events in Google Maps and ArcGis Online (Figures 26 and 27 in SM) in order to promote the problematic. Our analysis also useful to take notice of the real impacts of known little events that can be considered as almost insignificant taken separately and that are generally unknown.~~to enforce protective measures in case of observable hot spots in the database.

Risk management in Switzerland may therefore be improved with such a database. For examples, it shows the important alternative ways to bypass the obstacles. We have highlighted that for one quarter of events, there were no deviation routes. This proportion is high and must be reconsidered by the authorities. It is evident that to protect all swiss tracks against natural hazard processes would me much to expensive. Thus, it is essential to guaranty alternative tracks and to fund protective measures with the best ratio cost / risk reduction. Minor roads often belong to the municipalities which does not have a great interest to maintain them. The Cantons and the Confederation would be advised to participate or even to take over the maintenance of some of them that can be vital in case of closure of main roads or railway tracks. This is particularly appropriate in transportation corridor when the minor road is located on the other valley side than the major road. With its national scale, this database helps to consider the risk of transportation networks tracks more from a network perspective than from a track scale.

For this purpose, we created open access online maps of the events in Google Maps and ArcGIS Online (Figure 5-SM-AA and Figure 6-SM-AA) in order to promote the problematic issue. Our analysis also useful to take notice of the real impacts of known little intensity events that can be considered as almost insignificant and that are generally largely unrecognized.

Data availability

Date used in this paper are available on demand.

Competing interests.

The authors declare that they have no conflict of interest.

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Supplementary Material

Table 1-SM: 51 key words (in red) used in the Google Alerts to create the database. Numbers between brackets in the following tables refer to the number of considered elements according to the line or column attribute.

English	French	German	Italian
avalanche	avalanche	Lawinne	valanga
bad weather	intempéries	Unwetter	
flood		Hochwasser	
hail	grêle	Hagel	
heavy rainfall	forte pluies	Heftige Regen	
ice avalanche		Eislawine	
inundation		Überflutung	
inundation	inondation	Überschwemmung	
landslide	glissement de terrain	Erdrutsch	frana
landslide		Hangrutsch	
landslide		Hachrutsche	
landslide		Rüfenniedergang	
landslip	glissement	Rutschung	
mountain	pan de montagne		
mud	boue	Schlamm	
mudflow	coulée de boue	Schlammlawine	
mudslide		Erdlawine	
pirock	caillou	Stein	massi
rockfall		Bergsturz	
rockfall		Felsabbruch	
rockfall	éboulement	Felsbrock	
rockfall	écroulement	Felsbrocken	
rockfall		Felssturz	
rockslide	chute de blocs	Steinschlag	cadono sassi
scree		Geröll	
scree	éboulis	Schutt	
storm	tempête	Sturm	
thunderstorm	orage	Gewitter	
under water	sous l'eau		
wine	vent	Wind	

Table 2-SM: Cost values estimation by square meter for the cost evaluation according event importance, damage level and transport mode.

Damage level [EUR]	Cost by m², small event, road	Cost by m², middle event, road	Cost by m², large event, road	Cost by m², small event, train	Cost by m², middle event, train	Cost by m², large event, train
No closure	5	5	5	5	5	5
Closure	85	130	170	300	340	385
Partial damage	255	300	340	470	510	555
Total destruction	850	890	980	1065	1105	1145
Unknown damage	130	170	215	255	300	340

Table 3-SM: Distribution of event location according the three Swiss geomorphologic-climatic regions and according event processes.

Geomorphologic-climatic region	Flood (420)	Debris flow (69)	Landslide (192)	Rockfall (96)	Avalanche (16)	Other (53)	Average
Jura (98)	19%	0%	3%	6%	0%	15%	12%
Swiss Plateau (371)	57%	4%	42%	6%	0%	79%	44%
Alps (377)	24%	96%	55%	88%	100%	6%	44%
Total (846)	100%	100%	100%	100%	100%	100%	100%

Table 4-SM: Distribution of event location according event processes.

Event location	Flood (420)	Debris flow (69)	Landslide (192)	Rockfall (96)	Avalanche (16)	Other (53)	Average
Town (151)	15%	0%	9%	1%	0%	6%	18%
Village (261)	46%	14%	12%	6%	13%	4%	31%
Forest (185)	4%	46%	38%	58%	13%	13%	22%
Unforest (249)	0%	6%	5%	12%	69%	0%	29%
Total (846)	100%	100%	100%	100%	100%	100%	100%

Table 5-SM: Distribution of slope angle according event processes.

Slope angle	Flood (420)	Debris flow (69)	Landslide (192)	Rockfall (96)	Avalanche (16)	Other (53)	Average
0°-10° (339)	62%	17%	12%	5%	6%	68%	40%
10°-20° (257)	31%	43%	29%	19%	38%	28%	30%
20°-30° (131)	4%	23%	33%	31%	38%	2%	15%
30°-40° (85)	2%	12%	21%	26%	19%	0%	10%
40°-50° (26)	0%	4%	4%	14%	0%	2%	3%
50°-60° (6)	0%	0%	1%	4%	0%	0%	1%
60 and more (2)	0%	0%	1%	1%	0%	0%	0%
Total (846)	100%	100%	100%	100%	100%	100%	100%

Table 6-SM: Distribution of events importance according event processes.

Location of process origin	Flood (420)	Debris flow (69)	Landslide (192)	Rockfall (96)	Avalanche (16)	Other (53)	Average
Small[1] (804)	100%	78%	96%	24%	81%	100%	95%
Middle[2] (33)	0%	19%	3%	43%	19%	0%	4%
Large[3] (9)	0%	3%	1%	33%	0%	0%	1%
Total (846)	100%	100%	100%	100%	100%	100%	100%

[1] Small event: volume <10 m^3.
[2] Middle event: volume between 10-2000 m^3.
[3] Large event: volume > 2000 m^3.

Table 7-SM: Distribution of distances of the process origin types processes according event processes.

Distance of the process origin	Debris flow (69)	Landslide (192)	Rockfall (96)	Avalanche (16)	Other (53)	Average
Near[1] (185)	0%	52%	33%	6%	100%	35%
Far[2] (146)	100%	11%	43%	94%	0%	39%
Unknown (95)	0%	37%	24%	0%	0%	26%
Total (426)	100%	100%	100%	100%	100%	100%

[1] Near: 0-50 m from the track.
[2] Far: > 50 m from the track.

Table 8-SM: Distribution of location of process origin according event processes.

Location of process origin	Debris flow (69)	Landslide (192)	Rockfall (96)	Avalanche (16)	Other (53)	Average
Above track (339)	100%	60%	89%	100%	100%	80%
Below track (29)	0%	14%	2%	0%	0%	7%
Unknown (58)	0%	26%	9%	0%	0%	14%
Total (426)	100%	100%	100%	100%	100%	100%

Table 9-SM: Rainfall [mm] during the natural hazard events.

Rainfall* [mm]	Flood	Debris flow	Landslide	Rockfall	Avalanche	Other	Average
Event day	22	14	17	5	4	4	17
Cum. last 5 days[1]	49	32	57	27	32	15	45
Cum. last 10 days[1]	76	55	88	52	46	36	71
Daily rain avg last 5 days[2]	10	6	11	6	6	3	9
Daily rain avg last 10 days[2]	7	5	9	5	5	4	7
Max daily rain last 5 days[3]	30	21	32	15	18	11	27
Max daily rain last 10 days[3]	33	26	36	20	21	15	30
Abs max daily rain[4]	100	65	154	42	13	39	-
Abs max daily rain last 5 days[4]	154	75	154	77	140	39	-
Abs max daily rain last 10 days[4]	154	75	154	109	140	39	-

* Average by event processes except for absolute values (last three lines of the table).
[1] Cumulative rainfall of the 5 and respectively 10 days ago from the event day.
[2] Daily rainfall average of the 5 and respectively 10 days ago from the event day.
[3] Maximum daily rainfall of the 5 and respectively 10 days from the event day.
[4] Absolute maximum rainfall recorded (i.e. for one event) of the event day, the 5 and respectively 10 days from the event day.

Table 10-SM: Monthly distribution of events according event processes.

Year	Flood (420)	Debris flow (69)	Landslide (192)	Rockfall (96)	Avalanche (16)	Other (53)	Average
January (27)	0%	4%	4%	15%	6%	0%	3%
February (65)	0%	1%	6%	6%	19%	81%	8%
March (26)	1%	0%	2%	13%	50%	2%	3%
April (28)	2%	0%	6%	7%	0%	2%	3%
May (107)	13%	10%	16%	15%	0%	2%	13%
June (253)	41%	16%	29%	7%	0%	8%	30%
July (210)	31%	51%	19%	8%	0%	2%	25%
August (35)	4%	12%	4%	1%	0%	2%	4%
September (14)	1%	6%	2%	2%	0%	0%	2%
October (14)	1%	0%	1%	10%	0%	0%	2%
November (58)	6%	0%	9%	11%	6%	2%	7%
December (9)	0%	0%	1%	4%	19%	0%	1%
Total (846)	100%	100%	100%	100%	100%	100%	100%

Table 11-SM: Distribution of transport mode according event processes.

Transport mode	Flood (420)	Debris flow (69)	Landslide (192)	Rockfall (96)	Avalanche (16)	Other (53)	Total
Road (747)	53%	9%	20%	10%	1%	7%	100%
Railway (99)	27%	2%	42%	20%	4%	5%	100%

Table 12-SM: Distribution of road classes according event processes.

Road classes	Flood (393)	Debris flow (67)	Landslide (151)	Rockfall (76)	Avalanche (12)	Other (48)	Average
Highway (34)	7%	0%	2%	1%	10%	2%	5%
Motorway (2)	0%	0%	1%	0%	0%	0%	0%
Major transit road (99)	11%	8%	11%	36%	36%	6%	13%
Regional road (94)	11%	7%	18%	18%	9%	8%	12%
Urban road (426)	65%	37%	48%	38%	36%	82%	57%
Minor road (72)	4%	42%	15%	4%	9%	2%	10%
Forest or land trail (20)	2%	6%	5%	5%	0%	0%	3%
Total (747)	100%	100%	100%	100%	100%	100%	100%

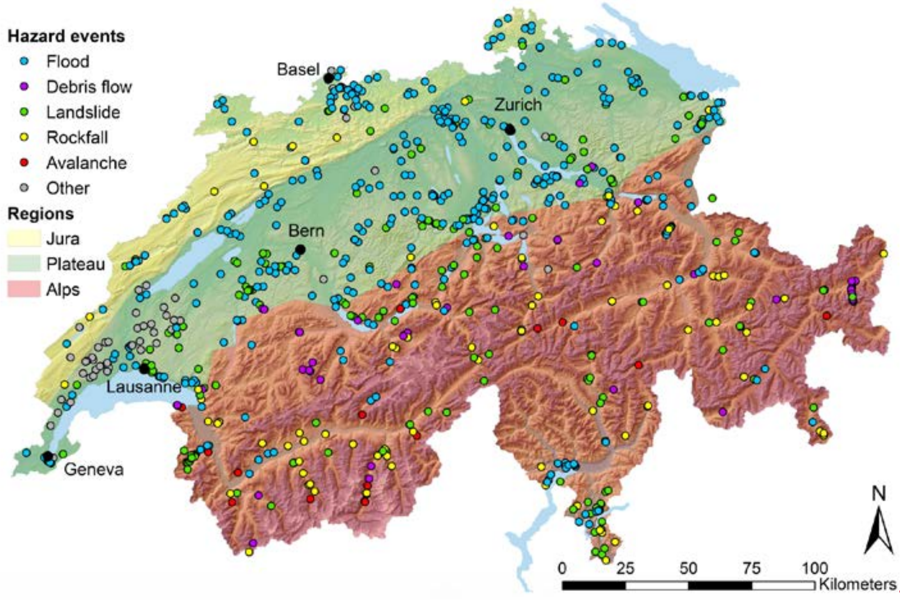


Figure 2: Spatial distribution of natural hazard events affecting roads and railways in Switzerland from 2012 to 20126. Source of the map: swisstopo.

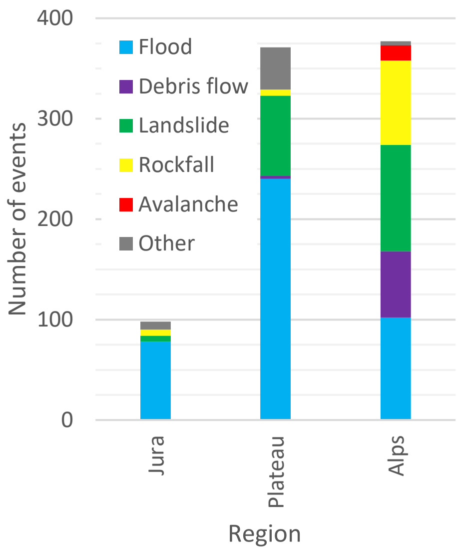
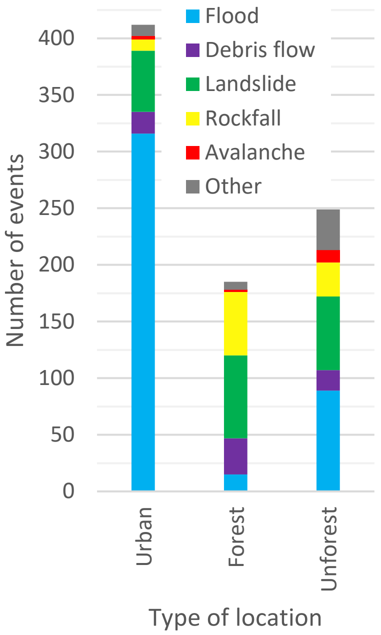
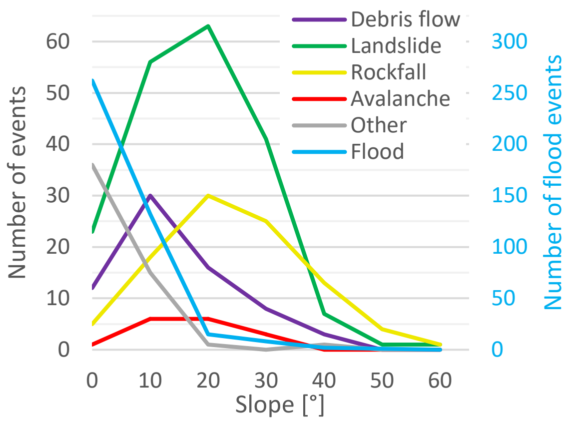


Figure 3: Distribution of natural hazard events on the Swiss transportation network from 2012 to 2016 according the three large geomorphologic-climatic regions.



~~Figure 4:~~

Table 13-SM: Distribution of *~~the type of location of natural hazard events on the Swiss transportation network from 2012 to 2016.~~*



~~Figure 5: Slope angle distribution of natural hazard events on the Swiss transportation network from 2012 to 2016. Flood events are on the secondary vertical axis.~~

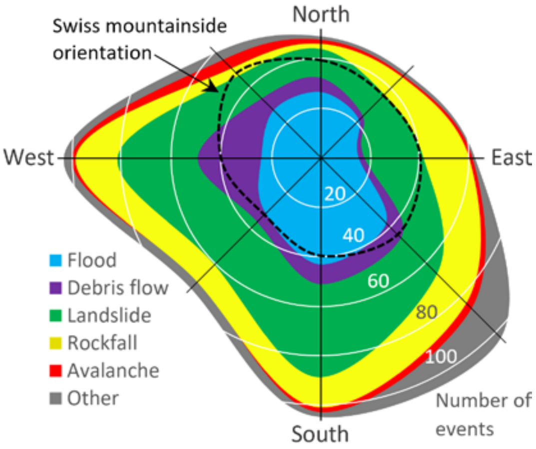
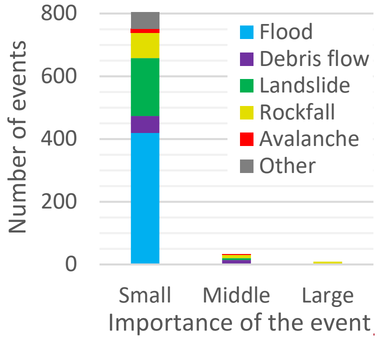


Figure 6: ~~Slope orientation distribution of natural hazard events on the Swiss transportation network from 2012 to 2016. Relative distribution of Swiss mountainsides orientation is given with the black dashed line.~~



~~Figure 7: Importance of natural hazard events on the Swiss transportation network from 2012 to 2016. Small event: 0-10 m^3; middle event: 10-2000 m^3, large event: >2000 m^3.~~

Figure 8: Examples of events affecting roads. Left: smallrailway classes according event already removed but still unstable on the unique access road to the small village of Morcles (canton of Vaud). Middle: middle event on a minor road in Ollon (canton of Vaud). Right: large event with a volume estimated at 3500 m^3 that cut on a 50 m length the international road between France and canton of Valais near the Forclaz pass (Trient). Road closure estimated of six weeks. Images taken on 24 January 2018 after a winter stormprocesses.

Track class	Flood (27)	Debris flow (2)	Landslide (41)	Rockfall (20)	Avalanche (4)	Other (5)	Average
National (29)	37%	0%	32%	30%	0%	0%	29%
Regional (66)	56%	100%	68%	70%	100%	60%	67%
Tram (4)	7%	0%	0%	0%	0%	40%	4%
Total (99)	100%	100%	100%	100%	100%	100%	100%

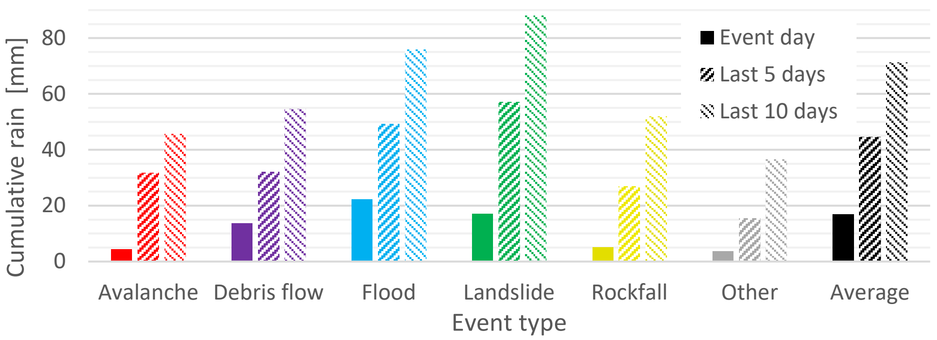
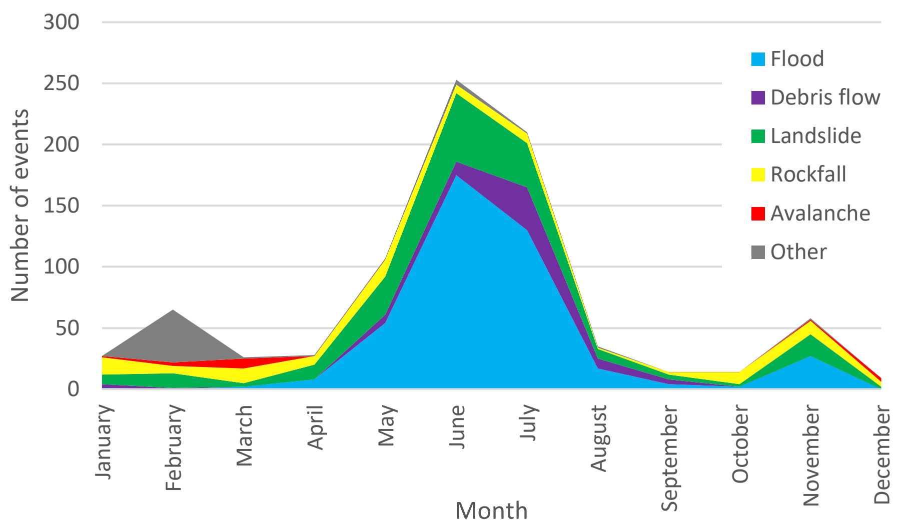


Figure 9: Cumulative rain [mm] distribution of the day of natural hazard events and last five and ten days.



~~Figure 10:~~ *Table 14-SM: Distribution of possibility of deviations according event processes.*

Possibility of deviation	Flood (420)	Debris flow (69)	Landslide (192)	Rockfall (96)	Avalanche (16)	Other (53)	Total
Large (342)	63%	17%	15%	8%	0%	52%	40%
Middle (190)	21%	7%	32%	17%	7%	33%	23%
Small (102)	7%	6%	13%	32%	66%	4%	12%
No (212)	9%	70%	40%	43%	27%	11%	25%
Total (846)	100%	100%	100%	100%	100%	100%	100%

Table 15-SM: Distribution of track damage according event processes.

Damage level	Flood (420)	Debris flow (69)	Landslide (192)	Rockfall (96)	Avalanche (16)	Other (53)	Total
No closure (149)	34%	0%	1%	3%	6%	4%	18%
Closure (483)	60%	35%	50%	50%	81%	96%	57%
Partial damage (143)	1%	39%	37%	39%	13%	0%	17%
Total destruction (53)	1%	26%	12%	8%	0%	0%	6%
Unknown damage (18)	4%	0%	0%	0%	0%	0%	2%
Total (846)	100%	100%	100%	100%	100%	100%	100%

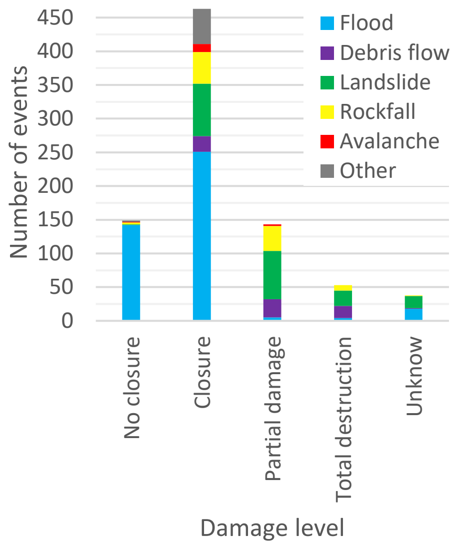
Table 16-SM: Distribution of damage and impact on vehicle according event processes.

Damage and impact type on vehicle	Flood (420)	Debris flow (69)	Landslide (192)	Rockfall (96)	Avalanche (16)	Other (53)	Total
No damage (803)	98%	93%	96%	89%	80%	89%	95%
Vehicle damage: direct impact[1] (25)	1%	7%	1%	7%	7%	7%	3%
Vehicle damage: indirect impact[2] (18)	1%	0%	3%	4%	13%	4%	2%
Total (846)	100%	100%	100%	100%	100%	100%	100%

[1] Direct impact: a vehicle is directly reach by a hazard.
[2] Indirect impact: a vehicle collides an event mass already fallen on the track.

Table 17-SM: Distribution of injury and death importance according event processes.

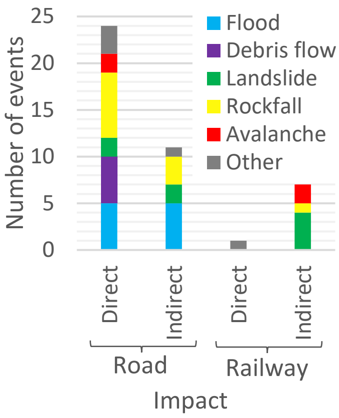
Injury and death	Flood (420)	Debris flow (69)	Landslide (192)	Rockfall (96)	Avalanche (16)	Other (53)	Total
No damage on people (828)	99%	96%	98%	93%	100%	98%	98%
Injury (15)	1%	4%	1%	5%	0%	2%	2%
Death (3)	0%	0%	1%	2%	0%	0%	0%
Total (846)	100%	100%	100%	100%	100%	100%	100%



~~*Figure 18: Damage*~~*Table 18-SM: Distribution of deviation length on roads according event processes.*

Deviation length	Flood (383)	Debris flow (21)	Landslide (116)	Rockfall (58)	Avalanche (11)	Other (49)	Mean
0-1 km (255)	58%	29%	12%	9%	0%	12%	40%
2-5 km (102)	14%	38%	16%	3%	0%	39%	16%
6-9 km (57)	9%	10%	9%	7%	0%	14%	9%
10-19 km (100)	9%	5%	34%	21%	0%	22%	16%
20-49 km (63)	5%	0%	17%	26%	45%	8%	10%
50-99 km (24)	3%	5%	5%	12%	0%	0%	4%
100-249 km (30)	2%	14%	6%	17%	18%	4%	5%
250-350 km (7)	0%	0%	0%	5%	36%	0%	1%
Total (638)	100%	100%	100%	100%	100%	100%	100%

Table 19-SM: Direct damage costs distribution ~~of natural hazard~~according events ~~on the Swiss transportation~~



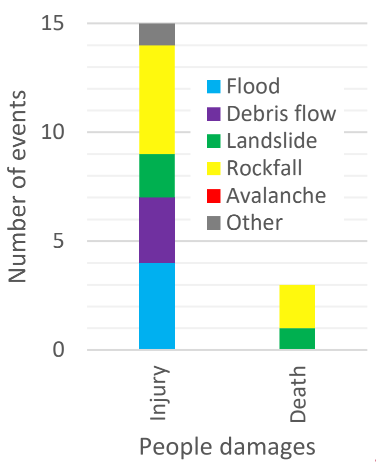
~~network from 2012 to 2016.~~

~~Figure 19: Distribution of impact~~ types.

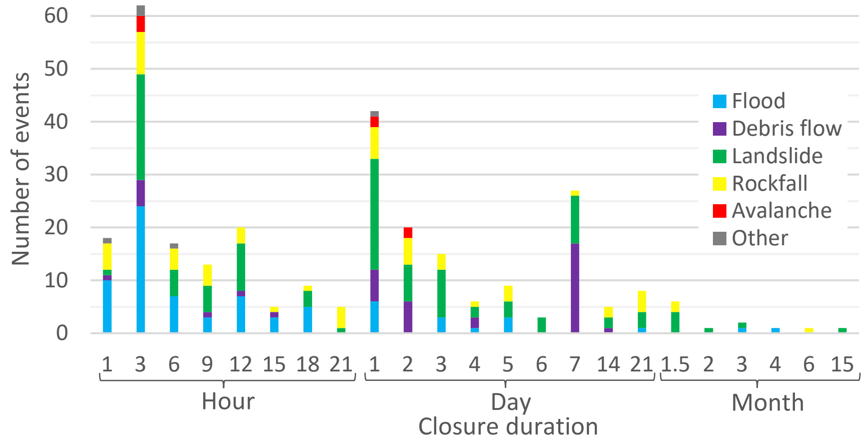
Damage level [EUR]	Flood (420)	Debris flow (69)	Landslide (192)	Rockfall (96)	Avalanche (16)	Other (53)	Total
	Annual cost [EUR]						
No closure (149)	12 665	340	85	765	255	170	14 280
Closure (483)	514 250	71 400	262 650	160 650	28 900	107 950	1 145 800
Partial damage (143)	25 500	127 500	425 000	227 800	40 800	0	846 600
Total destruction (53)	72 250	459 850	528 700	246 500	0	0	1 307 300
Unknown damage (18)	45 900	0	0	0	0	0	45 900
Annual cost [million €]	0.67	0.66	1.22	0.64	0.07	0.11	3.36
Avg. cost by event	8 000	47 800	31 700	33 100	21 900	10 200	19 900

Table 20-SM: Annually distribution of events according event processes.

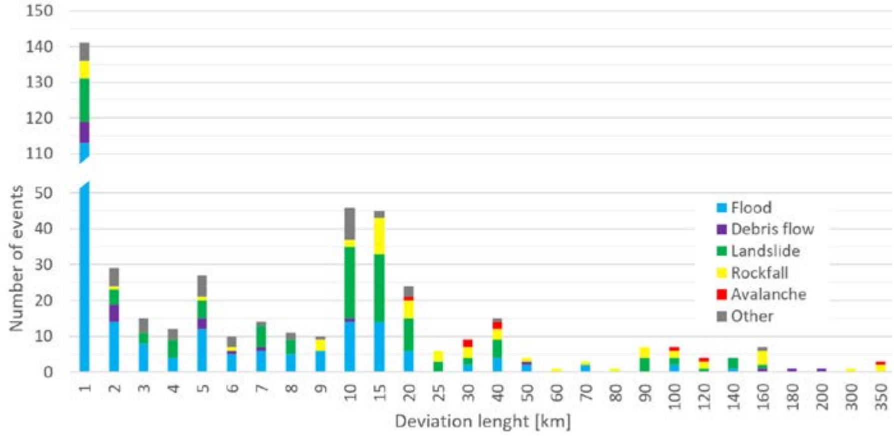
Year	Flood (420)	Debris flow (69)	Landslide (192)	Rockfall (96)	Avalanche (16)	Other (53)	Average
2012 (60)	5%	3%	7%	17%	25%	2%	7%
2013 (99)	11%	10%	16%	14%	6%	2%	12%
2014 (173)	20%	10%	30%	20%	25%	0%	20%
2015 (245)	25%	49%	22%	17%	25%	77%	29%
2016 (269)	38%	28%	24%	33%	19%	19%	32%
Total (846)	100%	100%	100%	100%	100%	100%	100%



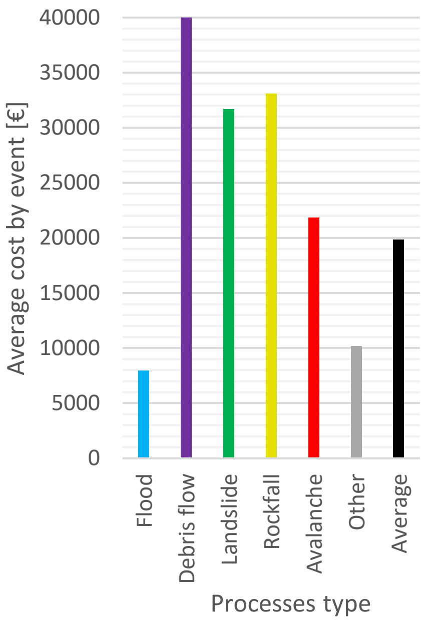
~~Figure 20: Distribution of injuries and deaths resulting of natural hazard events on the Swiss transportation network from 2012 to 2016.~~



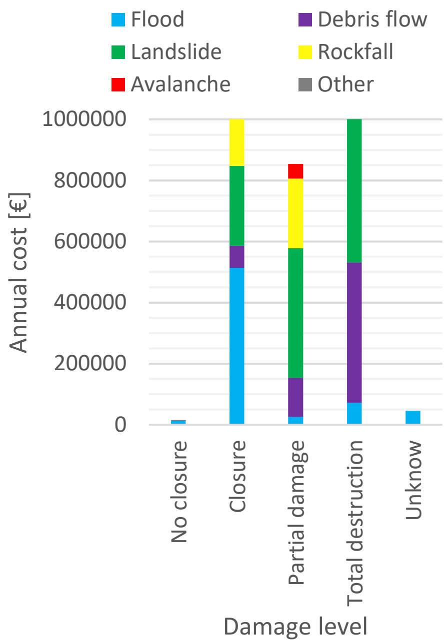
~~*Figure 21: Closure duration distribution of natural hazard events on the Swiss transportation network from 2012 to 2016.*~~



~~*Figure 22: Deviation length distribution of road closures due to natural hazard events on the Swiss transportation network from 2012 to 2016. The vertical axis is cut between values 50 and 110.*~~



~~*Figure 23: Average event direct cost distribution of natural hazard events on the Swiss transportation network from 2012 to 2016*~~



~~*Figure 24: Annual direct cost distribution of natural hazard events on the Swiss transportation network from 2012 to 2016.*~~

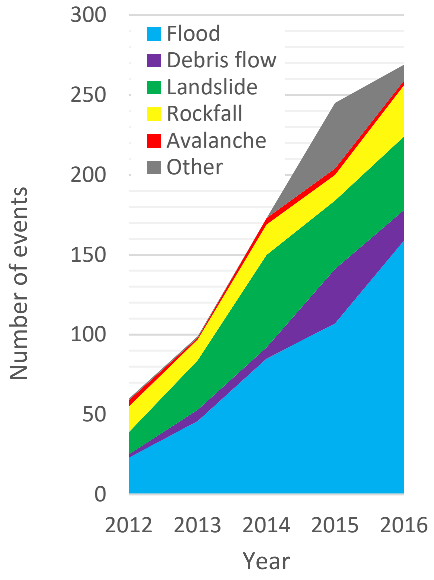


Figure 25: Annual distribution of natural hazard events on the Swiss transportation network from 2012 to 2016.

Table 1: Attributes categories to describe events in the database.

Attribute category	Answer the question	Number of attributes	Main source
ID	Event ID	1	-
Date	When did the event occur?	15	Online press article
Location	Where did the event occur?	21	GIS[1]
Event characterization	Which natural hazard event?	12	Online press article
Track characterization	On which track?	17	Swisstopo[2]
Damage	Which kind of damage?	11	Online press article
Weather	What was the weather?	68	MeteoSwiss[3]
Geology	On what soil did it occur?	11	Swisstopo[2]
Source	What are information sources?	16	Online press article

[1] GIS: Geographic Information System
[2] Swisstopo: Swiss Federal Office of Topography
[3] MeteoSwiss: Swiss Federal Office of Meteorology and Climatology

Table 2:2012, 2013, 2014 and 2016.

Table 21-SM:~~3:~~ Summary of event processes key features.

Attribute (with values of the greatest occurrence)	Flood	Debris flow	Landslide	Rockfall	Avalanche	Other	Mean
Event importance	Small	Small	Small	Small	Small	Small	Small
Yearly number of events	84	14	38	19	3	11	169
Months	6, 7	7, 6	6, 7, 5	1, 5, 3, 11, 10	3	2	6, 7
Season	Spring	Summer	Spring	Spring, Winter	Winter	Winter	Spring
Day part	Afternoon	Afternoon	All day	All day	Morning	All day	Afternoon
Hour	12-19	15-19	0-24	0-24	8-13	0-24	14-19
Region	Plateau	Alps	Alps	Alps	Alps	Plateau	Alps, Plateau
Canton	Bern	Graubünden	Valais	Valais	Valais	Vaud	Bern
Slope angle	0-10	10-20	20-30	20-30	10-20	0-10	0-10
Slope orientation	S	W	S	W	N-W	S-E	S, S-W and W
Location	Village	Forest	Forest	Forest	Mountain	Country	Village
Damage on track	Closure	Partial dam.	Closure	Closure	Closure	Closure	Closure
Direct costs by event (Euro)	6 900	39 000	25 700	261 000	155 000	8 600	16 000
Track geometry	Str. line	Wide curve	Wide curve	Wide curve	Wide curve	S. line & w. curve	Wide curve
Crossing	Near	No	No	No	No	No	No
Closure duration	3 hours	1 week	1 day	3 hours	1-2 days	3 hours	3 hours
Possibility of deviation	Large	~~Any~~No	~~Any~~No	~~Any~~No	Small	Middle	Large
Deviation length	0-1 km	No deviation	No deviation	No deviation	250-350 km	2-5 km	0-1 km
Event origin distance	-	Far	Near	Far	Far	Near	Near
Event above bellow	-	Up	Up	Up	Up	Up	Up
Altitude [m a.s.l.]	525	1139	809	897	1274	614	701
Track type	Road	Road	Road	Road	Road	Road	Road
Track importance	Minor	Minor	Minor	Minor	Minor	Minor	Minor
Rainfall event day [mm]	22	14	171	5	4	4	17

9 Supplementary material

9.1 Tables

Numbers between brackets in the following tables refer to the number of considered elements according to the line or column attribute.

Table 4:Table 5:Table 6:Table 7:Table 8:

Table 9:Table 10: Rainfall [mm] during the natural hazard events on the Swiss transportation network during from 2012 to 2016.

Table 11:Table 12:

Table 13: Distribution of road classes according event processes.

Road classes	Flood (420)	Debris flow (69)	Landslide (192)	Rockfall (96)	Avalanche (16)	Other (53)	Average

Table 14: Distribution of railway classes according event processes.

Track class	Flood (420)	Debris flow (69)	Landslide (192)	Rockfall (96)	Avalanche (16)	Other (53)	Average

Table 15: Distribution of track sinuosity according event processes.

Sinuosity	Flood (420)	Debris flow (69)	Landslide (192)	Rockfall (96)	Avalanche (16)	Other (53)	Total
Straight Line (175)	29%	6%	11%	9%	0%	35%	21%
Near Wide Curve (30)	2%	14%	2%	4%	0%	4%	4%
Wide Curve (265)	14%	55%	49%	44%	80%	35%	31%
Near Tight Curve (39)	2%	3%	8%	14%	0%	4%	4%
Tight Curve (40)	4%	9%	3%	6%	0%	13%	5%
Unknown* (297)	49%	13%	27%	23%	20%	9%	35%
Total (846)	100%	100%	100%	100%	100%	100%	100%

*Localisation at communal level.

Table 16: Distribution of track intersection according event processes.

Sinuosity	Flood (420)	Debris flow (69)	Landslide (192)	Rockfall (96)	Avalanche (16)	Other (53)	Total
No intersection (319)	15%	61%	55%	71%	73%	56%	38%
Near intersection (158)	23%	12%	16%	6%	7%	31%	19%
In intersection (72)	13%	14%	2%	0%	0%	4%	8%
Unknown* (297)	49%	13%	27%	23%	20%	9%	35%
Total (846)	100%	100%	100%	100%	100%	100%	100%

*Localisation at communal level.

Table 17: Distribution of possibility of deviations according event processes.

Possibility of deviation	Flood (420)	Debris flow (69)	Landslide (192)	Rockfall (96)	Avalanche (16)	Other (53)	Total
Large (342)	63%	17%	15%	8%	0%	52%	40%
Middle (190)	21%	7%	32%	17%	7%	33%	23%
Small (102)	7%	6%	13%	32%	66%	4%	12%
Any (212)	9%	70%	40%	43%	27%	11%	25%

Table 18:

Table 19:Table 20:Table 21: Distribution of deviation length on roads according event processes.

Deviation length	Flood (231)	Debris flow (21)	Landslide (115)	Rockfall (56)	Avalanche (11)	Other (46)	Mean
1 km (146)	51%	28%	11%	9%	0%	11%	31%
2-5 km (84)	17%	38%	16%	4%	0%	39%	18%
6-9 km (45)	10%	10%	9%	7%	0%	15%	10%
10-20 km (116)	16%	5%	44%	31%	12%	31%	25%
25-50 km (41)	4%	5%	9%	18%	50%	2%	7%
60-90 km (15)	1%	0%	4%	11%	0%	0%	3%
100-200 km (27)	1%	14%	7%	15%	25%	2%	5%
250-350 km (6)	0%	0%	0%	5%	13%	0%	1%
Total (480)	100%	100%	100%	100%	100%	100%	100%

Table 22:Table 23: Direct damage costs distribution according events types

Damage level [EUR]	Flood (420)	Debris flow (69)	Landslide (192)	Rockfall (96)	Avalanche (16)	Other (53)	Total
	Annual cost [EUR]						
No closure (149)	12665	340	85	765	255	170	14280
Closure (483)	514250	71400	262650	160650	28900	107950	1145800
Partial damage (143)	25500	127500	425000	227800	40800	0	846600
Total destruction (53)	72250	459850	528700	246500	0	0	1307300
Unknown damage (18)	45900	0	0	0	0	0	45900
Avg. cost by event	8000	47800	31700	33100	21900	10200	19900

9.2 Table 24:Key words

Table 25: Key words (in red) used in the Google Alerts to create the database.

English	French	German	Italian
avalanche	avalanche	Lawinne	valanga
bad weather	intempéries	Unwetter	
flood		Hochwasser	
hail	grêle	Hagel	
heavy rainfall	forte pluies	Heftige Regen	
ice avalanche		Eislawine	
inundation		Überflutung	
inundation	inondation	Überschwemmung	
landslide	glissement de terrain	Erdrutsch	frana
landslide		Hangrutsch	
landslide		Hachrutsche	
landslide		Rüfenniedergang	
landslip	glissement	Rutschung	
mountain	pan de montagne		
mud	boue	Schlamm	
mudflow	coulée de boue	Schlammlawine	
mudslide		Erdlawine	
pirock	caillou	Stein	massi
rockfall		Bergsturz	
rockfall		Felsabbruch	
rockfall	éboulement	Felsbrock	
rockfall	écroulement	Felsbrocken	
rockfall		Felssturz	
rockslide	chute de blocs	Steinschlag	cadono sassi
scree		Geröll	
scree	éboulis	Schutt	
storm	tempête	Sturm	
thunderstorm	orage	Gewitter	
under water	sous l'eau		
wind	vent	Wind	

~~9.3 Database attribute~~

Figure ~~26:~~1-SM: Attributes of the database.

Attributes of the UNIL database of natural hazard events affecting the Swiss transportation network (2012-2016) — Number of attributes: 172

EventID — **Date** — Number of attributes: 15

Category		DATE														
Attribute	EventID	D_IDdate	D_Year	D_Month	D_Day	D_MonthWeek	D_DayName	D_Season	D_Hour	D_HourPrecise	D_DayPart	D_IDDay	D_IDEventSameDay	D_SameClimLongPeriod	D_SameClimShortPeriod	MuenichRe
Description	Unique ID for each event	Unique ID for each event containing the date	Year of the event	Month of the event	Day of the event	Month divided into 4 quarters	Name of the day of the event	Season of the event	Hour of the event hourly rounded	Hour of the event	Day part of the event	Unique ID for each event day (same ID when >1 event per day)	Unique ID for event occured the same day	Long time period in which the event is included	Short time period in which the event is included	Period given by MünichRe in which the event is included
Unit	-	y m d XX	year	month	day	-	-	-	h:m:s	h:m:s	-	y m d	-	y.m.d-y.m.d	y.m.d-y.m.d	y.m.d-y.m.d
Exemple	431	2015050400	2015	5	4	5-1	Monday	Spring	10:00:00	10:15:00	Morning	20150504	2	2015.04.27-2015.07.25	2015.04.27-2015.05.07	2014.06.03-2014.06.12
Comment	-	-	From 2011 to 2015	-	-	First quarter (1) of the 5th month (5)	Useful to categorise business day and weekend	-	-		5 parts: morning, afternoon, evening, night and unknown	Allow to recognise the day when with several events	The maximal ID by event day gives the nb of events during this day			From MuenichRe yearly natural catastrophes analysis
Source	-	-	Online article	Online article	Online article	Online article	Online article	Online article	Online article	Online article	Online article	-	-	-	-	MünichRe
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

Location — Number of attributes: 21

Category										
Attribute	L_Canton	L_Commune	L_Detail	L_Precision	L_SitGeo	L_OriSlope	L_Urbanity	L_Slope	L_SlopeRound	L_Lanscape
Description	Canton where occurs the event	Commune where occurs the event	Detail to help the location	Precision of the location	Geographical situation of the event	If slope: orientation of the slope	Urbanity of the event	Slope angle average in an 25 meter radius around the event	Slope angle rounded to the nearest ten	Lanscape of the event locaiotn
Unit	-	-	-	-	-	-	-	[°]	[°]	
Exemple	Valais	Bagnes	-	Accurate	Slope	North-East	Forest	13	13	Dry mountainous landscape of western central Alps
Comment	-	-	-	Three levels of accuracy: accurate, middle and communal accuracy	Four classes: plain, ridge, slope and valley bottom	Nine classes: north, north-east, south-east, south, south-west, west, noth-west and any slope	Seven classes: mountain, forest, country, hamlet, village, agglomeration and town	From 0 ° to 56°	From 0 ° to 60°	36 types
Source	Online article	Online article	Online article	Online article and map	Map	Map	Map	GIS	GIS	GIS
	17	18	19	20	21	22	23	24	25	26

LOCATION										
L_Areas	L_Area_reg	L_MN03_X	L_MN03_Y	L_MN03_Z	L_MN95_X	L_MN95_Y	L_MN95_Z	L_WGS84_Lo	L_WGS84_La	L_WGS84_Z
Areas of the event location	Regional area of the location	X coordinates in CH1903 coordinate system	Y coordinates in CH1903 coordinate system	Z coordinates in CH1903 coordinate system	X coordinates in CH1903+ coordinate system	Y coordinates in CH1903+ coordinate system	Z coordinates in CH1903+ coordinate system	Longitude in WGS84 coordinate system	Latitude in WGS84 coordinate system	ALtitude in WGS84 coordinate system
		[m]	[m]	[m]	[m]	[m]	[m]	[°]	[°]	[m]
Alpine region	Alps	588456	98247	1377	2588455	1098247	1377	7.289538659	46.03566307	1431
5 types: Alpine region, Swiss Plateau, Tabular Jura, Folded Jura and Independent	3 types: Jura, Plateau and Alps	-	-	-	-	-	-	-	-	-
GIS	Map	GIS	GIS	GIS	GIS	GIS	GIS	GIS	GIS	GIS
27	28	29	30	31	32	33	34	35	36	37

Event characterization Number of attributes: 12

Category	Event characterization											
Attribute	E_Type	E_TypePrec	E_UpDownst	E_UpDownst Risk	E_Provenan	E_Volume	E_Masse	E_Width	E_Importan	E_Other	E_PictureName	E_Picture
Description	Type of natural hazard event	Precise type of natural hazard event	Origin up or downstream of the natural hazard event	Origin up, downstream or only risk of the event	Estimation of the distance of the event origin	Volume of the event	Masse of the event	Width of the event mass on the track	Importance of the event	Other information	Picture name of the event	Picture
Unit	-	-	-	-	[m] or -	[m^3]	[kg]	[m]	-	-	-	-
Exemple	Landslide	Landslide	-	-	-	-	-	-	Small	-	2015050400.jpg	-
Comment	6 types: rockfall, debris flow, landslide, avalanche, flood, other	8 types: rockfall, debris flow, landslide, avalanche, flood, hail, snowdrift, falling tree	3 classes: upstream, downstream and unknown	4 classes: upstream, downstream, risk (no event, only preventive closure) and unknown	3 classes: near (few meters to 10 meters, far (> 10 m) or prevention (only proventive closure)	Estimation of the falled volume on the track of the event	Masse of the event (only for rockfall)	-	3 classes: small, middle, big (huge event)	-	-	-
Source	Online article	Online article	Online article	Online article	Online article	Online article	Online article	Online article	Online article	Online article	Online article	Online article or field visit
	38	39	40	41	42	43	44	45	46	47	48	49

Track caracterization Number of attributes: 17

Category	Track caracterization																
Attribute	T_Type	T_TrainClasses	T_RoadClasses	T_MajorMin	T_Closure	T_DetailClosure	T_ClosureDuration	T_ClosureDurationRound	T_Deviation	T_DistDev	T_DistDevRound	T_DevDetai	T_PossDevi	T_PopDirAf	T_PopIndAf	T_Sinuosity	T_crossing
Description	Distinction between road and railway	Classes of the affected train tracks	Classes of the affected road tracks	Simplified classification of track importance	Track closure or not	Detail of the track closure	Time of track closure in hours	Ronded time of track closure in hours	Deviation or not	Distance of the deviation path	Rounded distance of the deviation path	Deviation detail	Capacity to have other deviation paths	Population directly affected by the track closure	Population indirectly affected by the track closure	Sinuosity og the affected track	Crossing near of the event or not
Unit	-	-	-	-	-	-	[h]	[h]	-	[km]	[km]	-	-	-	-	-	-
Exemple	Road	White	White	Minor	Yes	-	23	24	-	8	10	-	Large	Any	Small	NSC	NO
Comment	2 types: road or railwa	3 classes: national, regional, tram	8classes: highway, semi-highway, red, yellow, white, white dash and black	2 classes: minor and major	Three classes: yes, no, unknown	-	-	-	2 classes: yes or no	-	-	-	4 classes: large, middle, small, any	5 classes: very large, large, middle, small, any	5 classes: very large, large, middle, small, any	6 types: Straight Line, Wide Curve, Tight Curve, Near Wide Curve, Near Tight Curve	4 types: IN a crossing, NEAR a crossing, NO crossinf in the area and unknown (not enough location accuravy
Source	Online article	Map	Map	Map	Online article	Online article	Online article	Online article	Map	Map	Map	Map	Map	Map	Map	Map	Map
	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66

Damage Number of attributes: 11

Category	Damage										
Attribute	D_Form	D_Injured	D_InjuredNb	D_Death	D_DeathNb	D_Vehicule	D_ImpactTy	D_VehiType	D_VehiNb	D_TrackDetail	D_Infras_type
Description	Form of track damage	Injured people?	Number of injured people	Killed people?	Number of killed people	Damage to vehicle	Type of impact between vehicle and event	Type of damaged vehicle	Number of damaged vehicle	Detail of track damage	Type of instrastructure damage
Unit	-	-	-	-	-	-	-	-	-		-
Exemple	?	No	-	No	-	No	-	-	-		-
Comment	6 classes: ? (unknown), NC (no closure), C (closure due to sedimentation), P (partial damage), T (total destruction), and not studied	2 types: yes or no	-	2 types: yes or no	-	2 types: yes or no	Three types: no impact, direct impact or indirect impact	-	-		-
Source	Online article	Online article	Online article	Online article	Online article	Online article	Online article	Online article	Online article		Online article
	67	68	69	70	71	72	73	74	75	76	77

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Weather Number of attributes: 68

Category																			
Attribute	M_Meteo	M_Sun	M_Sun_avg_5d	M_Sun_avg_10d	M_Sun_max_5d	M_Sun_max_10d	M_Sun_min_5d	M_Sun_min_10d	M_Rain	M_Rain_5d_cum	M_Rain_10d_cum	M_Rain_max_daily_5d	M_Rain_max_daily_10d	M_Rain_avg_daily_5d	M_Rain_avg_daily_10d	M_Storm_near	M_Storm_near_sum_5d	M_Storm_near_sum_10d	M_Strom_near_max_daily_5d
Description	Rain information for a given time period	Percentage of sun during the event day	Percentage of sun of the last 5 days from event	Percentage of sun of the last 10 days from event	Maximum percentage of sun of the last 5 days from event	Maximum percentage of sun of the last 10 days from event	Minimum percentage of sun of the last 5 days from event	Miximum percentage of sun of the last 10 days from event	Rain the event day	Cumulative rain of the last 5 days from event	Cumulative rain of the last 10 days from event	Maximum daily rain of the last 5 days from event	Maximum daily rain of the last 10 days from event	Average daily rain of the last 5 days from event	Average daily rain of the last 10 days from event	Number of near storms the event day	Number of near storms of the 5 days days from event	Number of near storms of the 10 days days from event	Maximum daily number of near storms of the 5 days from event
Unit		%	%	%	%	%	%	%	mm	mm	mm	mm	mm	mm	mm	-	-	-	-
Exemple	-	4	29.4	34.1	77	98	0	0	0.2	28.7	38.4	19.9	19.9	5.74	3.84	0	0	0	0
Comment	Only for som events	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Near storm: <3 km around the weather station	Near storm: <3 km around the weather station	Near storm: <3 km around the weather station	Near storm: <3 km around the weather station
Source	Sturmarchiv	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss
	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96

Weather

M_Strom_near_max_daily_5d	M_Strom_near_max_daily_10d	M_Storm_far	M_Storm_far_sum_5d	M_Storm_far_sum_10d	M_Strom_far_max_daily_5d	M_Strom_far_max_daily_10d	M_Storm_all	M_Storm_all_sum_5d	M_Storm_all_sum_10d	M_Strom_all_max_daily_5d	M_Strom_all_max_daily_10d	M_Temp_min	M_Temp_min_5d	M_Temp_min_10d	M_Temp_max	M_Temp_max_5d	M_Temp_max_10d	M_Temp_avg	M_Temp_avg_5d
Maximum daily number of near storms of the 5 days from event	Maximum daily number of near storms of the 10 days from event	Number of far storms the event day	Number of far storms of the 5 days days from event	Number of far storms of the 10 days days from event	Maximum daily number of far storms of the 5 days from event	Maximum daily number of far storms of the 10 days from event	Number of all storms the event day	Number of all storms of the 5 days days from event	Number of all storms of the 10 days days from event	Maximum daily number of allstorms of the 5 days from event	Maximum daily number of all storms of the 10 days from event	Minimum temperature the event day	Minimum temperature the last 5 days from event	Minimum temperature the last 10 days from event	Maximum temperature the event day	Maximum temperature the last 5 days from event	Maximum temperature the last 10 days from event	Average temperature the event day	Average temperature the last 5 days from event
-	-	-	-	-	-	-	-	-	-	-	-	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]
0	0	0	0	2	0	1	2	3	10	1	5	7	1	-3	14	14	15	10	7
Near storm: <3 km around the weather station	Near storm: <3 km around the weather station	Far storm: >3 km around the weather station	Far storm: >3 km around the weather station	Far storm: >3 km around the weather station	Far storm: >3 km around the weather station	Far storm: >3 km around the weather station	-	-	-	-	-	-	-	-	-	-	-	-	-
MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss
96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115

M_Temp_avg_10d	M_Temp_min_Corr	M_Temp_min_5d_Corr	M_Temp_min_10d_Corr	M_Temp_max_Corr	M_Temp_max_5d_Corr	M_Temp_max_10d_Corr	M_Temp_avg_Corr	M_Temp_avg_5d_Corr	M_Temp_avg_10d_Corr	M_Temp_amp_Corr	M_Temp_amp_5d_Corr	M_Temp_amp_10d_Corr	M_Wind_avg
Average temperature the last 10 days from event	Corrected minimum temperature the event day	Corrected minimum temperature the last 5 days from event	Corrected minimum temperature the last 10 days from event	Corrected maximum temperature the event day	Corrected maximum temperature the last 5 days from event	Corrected maximum temperature the last 10 days from event	Corrected average temperature the event day	Corrected average temperature the last 5 days from event	Corrected average temperature the last 10 days from event	Ttemperature amplitude the event day	Temperature amplitude the last 10 days from the event	Temperature amplitude the last 5 days from the event	Average wind speed the event day
[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[km/h]
7	9	3	-1	16	16	17	12	9	9	9	12	15	8
-	Correction with height difference bewteen weather station and event location with lapse rate of -0.65 °C for + 100m altitude	Correction with height difference bewteen weather station and event location with lapse rate of -0.65 °C for + 100m altitude	Correction with height difference bewteen weather station and event location with lapse rate of -0.65 °C for + 100m altitude	Correction with height difference bewteen weather station and event location with lapse rate of -0.65 °C for + 100m altitude	Correction with height difference bewteen weather station and event location with lapse rate of -0.65 °C for + 100m altitude	Correction with height difference bewteen weather station and event location with lapse rate of -0.65 °C for + 100m altitude	Correction with height difference bewteen weather station and event location with lapse rate of -0.65 °C for + 100m altitude	Correction with height difference bewteen weather station and event location with lapse rate of -0.65 °C for + 100m altitude	Correction with height difference bewteen weather station and event location with lapse rate of -0.65 °C for + 100m altitude	-	-	-	-
MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss
116	117	118	119	120	121	122	123	124	125	126	127	128	129

M_Wind_avg_5d	M_Win_avg_10d	M_Wind_max	M_Wind_max_5d	M_Wind_max_10d	M_Wind_dir	M_Win_dir_5d	M_Win_dir_10d	M_Snow	M_Fresh_snow	M_Fresh_snow_5d	M_Fresh_snow_10d	M_Accronym_Stn_Weath	M_Alt_Stn_Weath	M_Diff_Alt_Stn_Weath_Event	M_Dist_Stn_Weath
Average wind speed the 5 last days from event	Average wind speed the last 10 days from event	Maximum wind speed the event day	Maximum wind speed the 5 last days from event	Maximum wind speed the last 10 days from event	Average wind direction the event day	Average wind direction the last 5 days from event	Average wind direction the last 10 days from event	Snow cover height the event day	Fresh snow cover height the event day	Fresh snow cover height the 5 last days from event	Fresh snow cover height the 5 last days from event	Accronym of the used weather station	Altitude of the used weather station	Altitude difference between the weather station and the even location	Distance between the weather station and the even location
[km/h]	[km/h]	[km/h]	[km/h]	[km/h]	[°]	[°]	[°]	[cm]	[cm]	[cm]	[cm]	-	[m] a.s.l.	[m]	[km]
9	10	32	38	46	47	48	63.9	0	0	0	0	ZER	1638	-261	36
-	-	-	-	-	0° = North, 90° = East, 180° = South, 270° = West	0° = North, 90° = East, 180° = South, 270° = West	0° = North, 90° = East, 180° = South, 270° = West	-	-	-	-	-	-	-	-
MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss
130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145

Geology Number of attributes: 11

Category	Geology										
Attribute	G_watershed	G_Geol	G_Tecto_f	G_Geol_f	G_Tec1_f	G_Tec2_f	G_Tec3_f	G_Acquifer	G_Hydrogeology	G_Productivity	G_Geology
Description	Watershed on the event			Geology	Tectonic 1	Tectonic 2	Tectonic 3	Aquifer	Hydrogeology	Productivity of the event field	General geology
Unit	-	-	-	-	-	-	-	-	-	-	-
Exemple	RHONE	er	pi	Gneiss et micaschistes (y compris migmatites et phyllites; princ. metasediments)	Nappes de socle cristallin penniques moyennes	Nappe du Mont-Fort	-	Aquifer reservoirs in coherent rocks	Sparsely productive aquifer reservoirs in non-karstified, cracked and porous coherent rocks	Variable productivity	Sericite gneiss
Comment	-	-	-	-	-	-	-	-	-	-	-
Source	Swisstopo	Swisstopo	Swisstopo	Swisstopo	Swisstopo	Swisstopo	Swisstopo	Swisstopo	Swisstopo	Swisstopo	Swisstopo
	146	147	148	149	150	151	152	153	154	155	156

Source Number of attributes: 16

Category	Source							
Attribute	Source1	Source2	Source3	Source4	Source5	Source6	Source7	Source8
Description	Source 1 for the event	Source 2 for the event	Source 3 for the event	Source 4 for the event	Source 5 for the event	Source 6 for the event	Source 7 for the event	Source 8 for the event
Unit	-	-	-	-	-	-	-	-
Exemple	https://www.rts.ch/info/suisse/6749453-le-chablais-et-le-bas-valais-restent-en-etat-d-alerte-face-aux-pluies.html	http://www.24heures.ch/vaud-regions/riviera-chablais/A-Monthey-les-secours-sont-prets-a-evacuer-les-riverains-de-la-Vieze/story/22490259	http://www.24heures.ch/suisse/geneve-subit-grande-crue-arve-1935/story/10943703	http://www.24heures.ch/vaud-regions/monthey-reveille-soulagee-evacuation-300-personnes/story/19307318	http://www.lenouvelliste.ch/articles/valais/canton/inondation-a-st-gingolph-temoignages-du-president-et-de-restaurateurs-378561	https://www.letemps.ch/Page/Uuid/b0e525de-f0c0-11e4-8a43-4ad205b10b56/Les_eaux_en_furie_dans_toute_la_Suisse	http://www.arcinfo.ch/articles/regions/neuchatel-et-littoral/inondations-a-cornaux-et-a-lignieres-378552	http://www.romandie.com/news/Le-Chablais-fortement-touche-par-les-inondations/589780.rom
Comment	-	-	-	-	-	-	-	-
Source	Google Alerts	Google Alerts	Google Alerts	Google Alerts	Google Alerts	Google Alerts	Google Alerts	Google Alerts
	157	158	159	160	161	162	163	164

Category	Source							
Attribute	Source9	Source10	Source11	Source12	Source13	Source14	Source15	Source16
Description	Source 9 for the event	Source 10 for the event	Source 11 for the event	Source 12 for the event	Source 13 for the event	Source 14 for the event	Source 15 for the event	Source 16 for the event
Unit	-	-	-	-	-	-	-	-
Exemple	http://www.rts.ch/info/suisse/6749453-inondations-et-rivieres-en-crue-apres-les-fortes-pluies-.html	http://www.24heures.ch/suisse/suisse-romande/certaines-routes-valaisannes-fermees-cause-deluge/story/27182180	https://www.rfj.ch/rfj/Actualite/Region/20150501-La-Roche-Saint-Jean-a-deux-doigts-de-l-inondation.html	http://www.20min.ch/ro/news/romandie/story/25748211	-	-	-	-
Comment	-	-	-	-	-	-	-	-
Source	Google Alerts	Google Alerts	Google Alerts	Google Alerts	Google Alerts	Google Alerts	Google Alerts	Google Alerts
	165	166	167	168	169	170	171	172

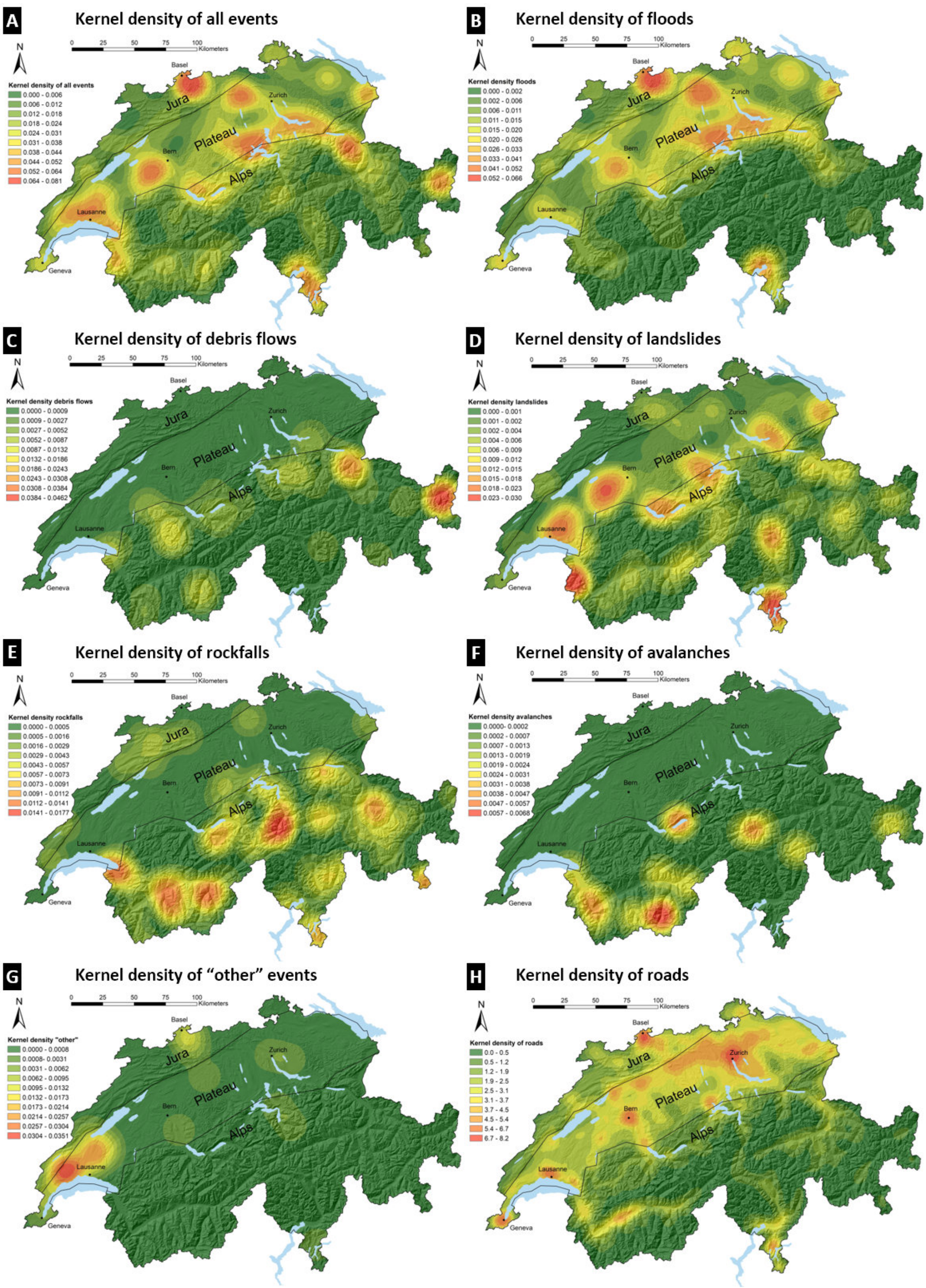

Figure 2-SM: Kernel densities maps. Search radius for events: 20 km. Search radius for road network: 10 km. Results were classified using 10 classes with the Jenks natural breaks method. A: All events; B: Floods; C: Debris flows; D: Landslides; E: Rockfalls; F: Avalanches; G: "Other"; H: Roads. Hillshade and map ground sources: swisstopo.

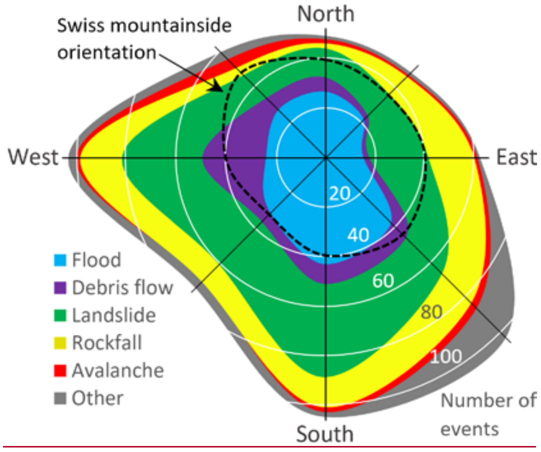

Figure 3-SM: Slope orientation distribution of natural hazard events on the Swiss transportation network from 2012 to 2016. Relative distribution of Swiss mountainsides orientation is given with the black dashed line.

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Attributes of the UNIL database of natural hazard events affecting the Swiss transportation network (2012-2016) Number of attributes: 172

EventID **Date** Number of attributes: 15

Category	EventID	DATE														
Attribute	EventID	D_IDdate	D_Year	D_Month	D_Day	D_MonthWeek	D_DayName	D_Season	D_Hour	D_HourPrecise	D_DayPart	D_IDDay	D_IDEventSameDay	D_SameClimLongPeriod	D_SameClimShortPeriod	MuenichRe
Description	Unique ID for each event	Unique ID for each event containing the date	Year of the event	Month of the event	Day of the event	Month divided into 4 quarters	Name of the day of the event	Season of the event	Hour of the event hourly rounded	Hour of the event	Day part of the event	Unique ID for each event day (same ID when >1 event per day)	Unique ID for event occured the same day	Long time period in which the event is included	Short time period in which the event is included	Period given by MünichRe in which the event is included
Unit	-	y m d XX	year	month	day	-	-	-	h:m:s	h:m:s	-	y m d	-	y.m.d-y.m.d	y.m.d-y.m.d	y.m.d-y.m.d
Exemple	431	2015050400	2015	5	4	5-1	Monday	Spring	10:00:00	10:15:00	Morning	20150504	2	2015.04.27-2015.07.25	2015.04.27-2015.05.07	2014.06.03-2014.06.12
Comment	-	-	From 2011 to 2015	-	-	First quarter (1) of the 5th month (5)	Useful to categorise business day and weekend	-	-		5 parts: morning, afternoon, evening, night and unknown	Allow to recognise the day when with several events	The maximal ID by event day gives the nb of events during this day			From MuenichRe yearly natural catastrophes analysis
Source	-	-	Online article	Online article	Online article	Online article	Online article	Online article	Online article	Online article	Online article	-	-	-	-	MünichRe
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

Location Number of attributes: 21

Category										
Attribute	L_Canton	L_Commune	L_Detail	L_Precision	L_SitGeo	L_OriSlope	L_Urbanity	L_Slope	L_SlopeRound	L_Lanscape
Description	Canton where occurs the event	Commune where occurs the event	Detail to help the location	Precision of the location	Geographical situation of the event	If slope: orientation of the slope	Urbanity of the event	Slope angle average in an 25 meter radius around the event	Slope angle rounded to the nearest ten	Lanscape of the event locaiotn
Unit	-	-	-	-	-	-	-	[°]	[°]	
Exemple	Valais	Bagnes	-	Accurate	Slope	North-East	Forest	13	13	Dry mountainous landscape of western central Alps
Comment	-	-	-	Three levels of accuracy: accurate, middle and communal accuracy	Four classes: plain, ridge, slope and valley bottom	Nine classes: north, north-east, south-east, south, south-west, west, noth-west and any slope	Seven classes: mountain, forest, country, hamlet, village, agglomeration and town	From 0 ° to 56°	From 0 ° to 60°	36 types
Source	Online article	Online article	Online article	Online article and map	Map	Map	Map	GIS	GIS	GIS
	17	18	19	20	21	22	23	24	25	26

LOCATION										
L_Areas	L_Area_reg	L_MN03_X	L_MN03_Y	L_MN03_Z	L_MN95_X	L_MN95_Y	L_MN95_Z	L_WGS84_Lo	L_WGS84_La	L_WGS84_Z
Areas of the event location	Regional area of the location	X coordinates in CH1903 coordinate system	Y coordinates in CH1903 coordinate system	Z coordinates in CH1903 coordinate system	X coordinates in CH1903+ coordinate system	Y coordinates in CH1903+ coordinate system	Z coordinates in CH1903+ coordinate system	Longitude in WGS84 coordinate system	Latitude in WGS84 coordinate system	ALtitude in WGS84 coordinate system
		[m]	[m]	[m]	[m]	[m]	[m]	[°]	[°]	[m]
Alpine region	Alps	588456	98247	1377	2588455	1098247	1377	7.289538659	46.03566307	1431
5 types: Alpine region, Swiss Plateau, Tabular Jura, Folded Jura and Independent	3 types: Jura, Plateau and Alps	-	-	-	-	-	-	-	-	-
GIS	Map	GIS	GIS	GIS	GIS	GIS	GIS	GIS	GIS	GIS
27	28	29	30	31	32	33	34	35	36	37

Event characterization Number of attributes: 12

Category	Event characterization											
Attribute	E_Type	E_TypePrec	E_UpDownst	E_UpDownst Risk	E_Provenan	E_Volume	E_Masse	E_Width	E_Importan	E_Other	E_PictureName	E_Picture
Description	Type of natural hazard event	Precise type of natural hazard event	Origin up or downstream of the natural hazard event	Origin up, downstream or only risk of the event	Estimation of the distance of the event origin	Volume of the event	Masse of the event	Width of the event mass on the track	Importance of the event	Other information	Picture name of the event	Picture
Unit	-	-	-	-	[m] or -	[m^3]	[kg]	[m]	-	-	-	-
Exemple	Landslide	Landslide	-	-	-	-	-	-	Small	-	2015050400.jpg	-
Comment	6 types: rockfall, debris flow, landslide, avalanche, flood, other	8 types: rockfall, debris flow, landslide, avalanche, flood, hail, snowdrift, falling tree	3 classes: upstream, downstream and unknown	4 classes: upstream, downstream, risk (no event, only preventive closure) and unknown	3 classes: near (few meters to 10 meters, far (> 10 m) or prevention (only proventive closure)	Estimation of the falled volume on the track of the event	Masse of the event (only for rockfall)	-	3 classes: small, middle, big (huge event)	-	-	-
Source	Online article	Online article	Online article	Online article	Online article	Online article	Online article	Online article	Online article	Online article	Online article	Online article or field visit
	38	39	40	41	42	43	44	45	46	47	48	49

Track caracterization Number of attributes: 17

Category	Track caracterization																
Attribute	T_Type	T_TrainClasses	T_RoadClasses	T_MajorMin	T_Closure	T_DetailClosure	T_ClosureDuration	T_ClosureDurationRound	T_Deviation	T_DistDev	T_DistDevRound	T_DevDetai	T_PossDevi	T_PopDirAf	T_PopIndAf	T_Sinuosity	T_crossing
Description	Distinction between road and railway	Classes of the affected train tracks	Classes of the affected road tracks	Simplified classification of track importance	Track closure or not	Detail of the track closure	Time of track closure in hours	Ronded time of track closure in hours	Deviation or not	Distance of the deviation path	Rounded distance of the deviation path	Deviation detail	Capacity to have other deviation paths	Population directly affected by the track closure	Population indirectly affected by the track closure	Sinuosity og the affected track	Crossing near of the event or not
Unit	-	-	-	-	-	.	[h]	[h]	-	[km]	[km]	-	-	-	-	-	-
Exemple	Road	White	White	Minor	Yes	-	23	24	-	8	10	-	Large	Any	Small	NSC	NO
Comment	2 types: road or railwa	3 classes: national, regional, tram	8classes: highway, semi-highway, red, yellow, white, white dash and black	2 classes: minor and major	Three classes: yes, no, unknown	-	-	-	2 classes: yes or no	-	-	-	4 classes: large, middle, small, any	5 classes: very large, large, middle, small, any	5 classes: very large, large, middle, small, any	6 types: Straight Line, Wide Curve, Tight Curve, Near Wide Curve, Near Tight Curve	4 types: IN a crossing, NEAR a crossing, NO crossinf in the area and unknown (not enough location accuravy
Source	Online article	Map	Map	Map	Online article	Online article	Online article	Online article	Map	Map	Map	Map	Map	Map	Map	Map	Map
	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66

Damage Number of attributes: 11

Category	Damage										
Attribute	D_Form	D_Injured	D_InjuredNb	D_Death	D_DeathNb	D_Vehicule	D_ImpactTy	D_VehiType	D_VehiNb	D_TrackDetail	D_Infras_type
Description	Form of track damage	Injured people?	Number of injured people	Killed people?	Number of killed people	Damage to vehicle	Type of impact between vehicle and event	Type of damaged vehicle	Number of damaged vehicle	Detail of track damage	Type of instrastructure damage
Unit	-	-	-	-	-	-	-	-	-		-
Exemple	?	No	-	No	-	No	-	-	-		-
Comment	6 classes: ? (unknown), NC (no closure), C (closure due to sedimentation), P (partial damage), T (total destruction), and not studied	2 types: yes or no	-	2 types: yes or no	-	2 types: yes or no	Three types: no impact, direct impact or indirect impact	-	-		-
Source	Online article	Online article	Online article	Online article	Online article	Online article	Online article	Online article	Online article		Online article
	67	68	69	70	71	72	73	74	75	76	77

Weather Number of attributes: 68

Category																		
Attribute	M_Meteo	M_Sun	M_Sun_avg_5d	M_Sun_avg_10d	M_Sun_max_5d	M_Sun_max_10d	M_Sun_min_5d	M_Sun_min_10d	M_Rain	M_Rain_5d_cum	M_Rain_10d_cum	M_Rain_max_daily_5d	M_Rain_max_daily_10d	M_Rain_avg_daily_5d	M_Rain_avg_daily_10d	M_Storm_near	M_Storm_near_sum_5d	M_Storm_near_sum_10d	M_Strom_near_max_daily_5d
Description	Rain information for a given time period	Percentage of sun during the event day	Percentage of sun of the last 5 days from event	Percentage of sun of the last 10 days from event	Maximum percentage of sun of the last 5 days from event	Maximum percentage of sun of the last 10 days from event	Minimum percentage of sun of the last 5 days from event	Miximum percentage of sun of the last 10 days from event	Rain the event day	Cumulative rain of the last 5 days from event	Cumulative rain of the last 10 days from event	Maximum daily rain of the last 5 days from event	Maximum daily rain of the last 10 days from event	Average daily rain of the last 5 days from event	Average daily rain of the last 10 days from event	Number of near storms the event day	Number of near storms of the 5 days days from event	Number of near storms of the 10 days days from event	Maximum daily number of near storms of the 5 days from event
Unit		%	%	%	%	%	%	%	mm	mm	mm	mm	mm	mm	mm	-	-	-	-
Exemple	-	4	29.4	34.1	77	98	0	0	0.2	28.7	38.4	19.9	19.9	5.74	3.84	0	0	0	0
Comment	Only for som events	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Near storm: <3 km around the weather station	Near storm: <3 km around the weather station	Near storm: <3 km around the weather station	Near storm: <3 km around the weather station
Source	Sturmarchiv	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss
	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96

Weather																			
M_Strom_near_max_daily_5d	M_Strom_near_max_daily_10d	M_Storm_far	M_Storm_far_sum_5d	M_Storm_far_sum_10d	M_Strom_far_max_daily_5d	M_Strom_far_max_daily_10d	M_Storm_all	M_Storm_all_sum_5d	M_Storm_all_sum_10d	M_Strom_all_max_daily_5d	M_Strom_all_max_daily_10d	M_Temp_min	M_Temp_min_5d	M_Temp_min_10d	M_Temp_max	M_Temp_max_5d	M_Temp_max_10d	M_Temp_avg	M_Temp_avg_5d
Maximum daily number of near storms of the 5 days from event	Maximum daily number of near storms of the 10 days from event	Number of far storms the event day	Number of far storms of the 5 days days from event	Number of far storms of the 10 days days from event	Maximum daily number of far storms of the 5 days from event	Maximum daily number of far storms of the 10 days from event	Number of all storms the event day	Number of all storms of the 5 days days from event	Number of all storms of the 10 days days from event	Maximum daily number of allstorms of the 5 days from event	Maximum daily number of all storms of the 10 days from event	Minimum temperature the event day	Minimum temperature the last 5 days from event	Minimum temperature the last 10 days from event	Maximum temperature the event day	Maximum temperature the last 5 days from event	Maximum temperature the last 10 days from event	Average temperature the event day	Average temperature the last 5 days from event
-	-	-	-	-	-	-	-	-	-	-	-	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]
0	0	0	0	2	0	1	2	3	10	1	5	7	1	-3	14	14	15	10	7
Near storm: <3 km around the weather station	Near storm: <3 km around the weather station	Far storm: >3 km around the weather station	Far storm: >3 km around the weather station	Far storm: >3 km around the weather station	Far storm: >3 km around the weather station	Far storm: >3 km around the weather station	-	-	-	-	-	-	-	-	-	-	-	-	-
MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss
96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115

M_Temp_avg_10d	M_Temp_min_Corr	M_Temp_min_5d_Corr	M_Temp_min_10d_Corr	M_Temp_max_Corr	M_Temp_max_5d_Corr	M_Temp_max_10d_Corr	M_Temp_avg_Corr	M_Temp_avg_5d_Corr	M_Temp_avg_10d_Corr	M_Temp_amp_Corr	M_Temp_amp_5d_Corr	M_Temp_amp_10d_Corr	M_Wind_avg
Average temperature the last 10 days from event	Corrected minimum temperature the event day	Corrected minimum temperature the last 5 days from event	Corrected minimum temperature the last 10 days from event	Corrected maximum temperature the event day	Corrected maximum temperature the last 5 days from event	Corrected maximum temperature the last 10 days from event	Corrected average temperature the event day	Corrected average temperature the last 5 days from event	Corrected average temperature the last 10 days from event	Ttemperature amplitude the event day	Temperature amplitude the last 10 days from the event	Temperature amplitude the last 5 days from the event	Average wind speed the event day
[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[km/h]
7	9	3	-1	16	16	17	12	9	9	9	12	15	8
-	Correction with height difference bewteen weather station and event location with lapse rate of -0.65 °C for + 100m altitude	Correction with height difference bewteen weather station and event location with lapse rate of -0.65 °C for + 100m altitude	Correction with height difference bewteen weather station and event location with lapse rate of -0.65 °C for + 100m altitude	Correction with height difference bewteen weather station and event location with lapse rate of -0.65 °C for + 100m altitude	Correction with height difference bewteen weather station and event location with lapse rate of -0.65 °C for + 100m altitude	Correction with height difference bewteen weather station and event location with lapse rate of -0.65 °C for + 100m altitude	Correction with height difference bewteen weather station and event location with lapse rate of -0.65 °C for + 100m altitude	Correction with height difference bewteen weather station and event location with lapse rate of -0.65 °C for + 100m altitude	Correction with height difference bewteen weather station and event location with lapse rate of -0.65 °C for + 100m altitude	-	-	-	-
MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss
116	117	118	119	120	121	122	123	124	125	126	127	128	129

M_Wind_avg_5d	M_Win_avg_10d	M_Wind_max	M_Wind_max_5d	M_Wind_max_10d	M_Wind_dir	M_Win_dir_5d	M_Win_dir_10d	M_Snow	M_Fresh_snow	M_Fresh_snow_5d	M_Fresh_snow_10d	M_Accronym_Stn_Weath	M_Alt_Stn_Weath	M_Diff_Alt_Stn_Weath_Event	M_Dist_Stn_Weath
Average wind speed the 5 last days from event	Average wind speed the last 10 days from event	Maximum wind speed the event day	Maximum wind speed the 5 last days from event	Maximum wind speed the last 10 days from event	Average wind direction the event day	Average wind direction the last 5 days from event	Average wind direction the last 10 days from event	Snow cover height the event day	Fresh snow cover height the event day	Fresh snow cover height the 5 last days from event	Fresh snow cover height the 5 last days from event	Accronym of the used weather station	Altitude of the used weather station	Altitude difference between the weather station and the even location	Distance between the weather station and the even location
[km/h]	[km/h]	[km/h]	[km/h]	[km/h]	[°]	[°]	[°]	[cm]	[cm]	[cm]	[cm]	-	[m] a.s.l.	[m]	[km]
9	10	32	38	46	47	48	63.9	0	0	0	0	ZER	1638	-261	36
-	-	-	-	-	0° = North, 90° = East, 180° = South, 270° = West	0° = North, 90° = East, 180° = South, 270° = West	0° = North, 90° = East, 180° = South, 270° = West	-	-	-	-	-	-	-	-
MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss	MeteoSwiss
130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145

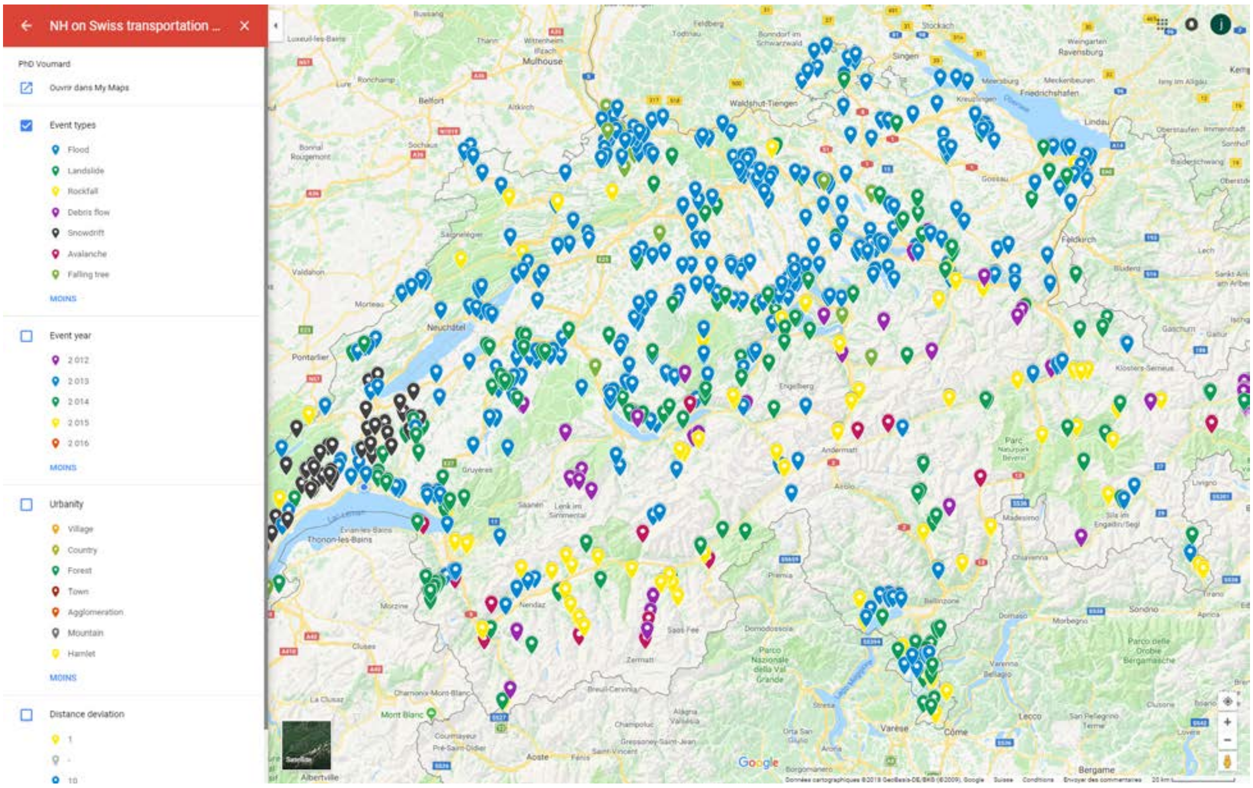
Geology Number of attributes: 11

Category	Geology										
Attribute	G_watershed	G_Geol	G_Tecto_f	G_Geol_f	G_Tec1_f	G_Tec2_f	G_Tec3_f	G_Acquifer	G_Hydrogeology	G_Productivity	G_Geology
Description	Watershed on the event			Geology	Tectonic 1	Tectonic 2	Tectonic 3	Aquifer	Hydrogeology	Productivity of the event field	General geology
Unit	-	-	-	-	-	-	-	-	-	-	-
Exemple	RHONE	er	pi	Gneiss et micaschistes (y compris migmatites et phyllites; princ. metasediments)	Nappes de socle cristallin penniques moyennes	Nappe du Mont-Fort	-	Aquifer reservoirs in coherent rocks	Sparsely productive aquifer reservoirs in non-karstified, cracked and porous coherent rocks	Variable productivity	Sericite gneiss
Comment	-	-	-	-	-	-	-	-	-	-	-
Source	Swisstopo	Swisstopo	Swisstopo	Swisstopo	Swisstopo	Swisstopo	Swisstopo	Swisstopo	Swisstopo	Swisstopo	Swisstopo
	146	147	148	149	150	151	152	153	154	155	156

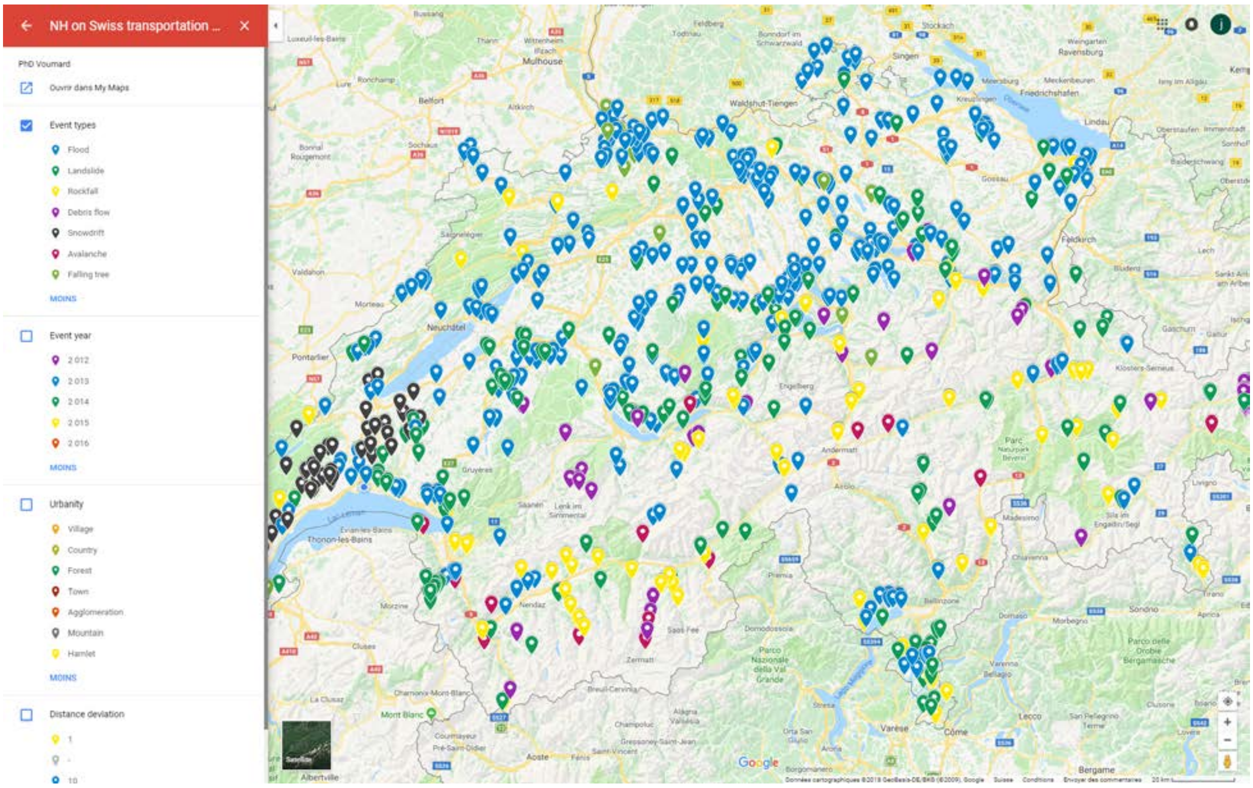
Source Number of attributes: 16

Category	Source															
Attribute	Source1	Source2	Source3	Source4	Source5	Source6	Source7	Source8	Source9	Source10	Source11	Source12	Source13	Source14	Source15	Source16
Description	Source 1 for the event	Source 2 for the event	Source 3 for the event	Source 4 for the event	Source 5 for the event	Source 6 for the event	Source 7 for the event	Source 8 for the event	Source 9 for the event	Source 10 for the event	Source 11 for the event	Source 12 for the event	Source 13 for the event	Source 14 for the event	Source 15 for the event	Source 16 for the event
Unit	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Exemple	https://www.rts.ch/info/suisse/6749453-le-chablais-et-le-bas-valais-restent-en-etat-d-alerte-face-aux-pluies.html	http://www.24heures.ch/vaud-regions/riviera-chablais/A-Monthey-les-secours-sont-prets-a-evacuer-les-riverains-de-la-Vieze/story/22490259	http://www.24heures.ch/suisse/geneve-subit-grande-crue-arve-1935/story/10943703	http://www.24heures.ch/vaud-regions/monthey-reveille-soulagee-evacuation-300-personnes/story/19307318	http://www.lenouvelliste.ch/articles/valais/canton/inondation-a-st-gingolph-temoignages-du-president-et-de-restaurateurs-378561	https://www.letemps.ch/Page/Uuid/b0e525de-f0c0-11e4-8a43-4ad205b10b56/Les_eaux_en_furie_dans_toute_la_Suisse	http://www.arcinfo.ch/articles/regions/neuchatel-et-littoral/inondations-a-cornaux-et-a-lignieres-378552	http://www.romandie.com/news/Le-Chablais-fortement-touche-par-les-inondations/589780.rom	http://www.rts.ch/info/suisse/6749453-inondations-et-rivieres-en-crue-apres-les-fortes-pluies-.html	http://www.24heures.ch/suisse/suisse-romande/certaines-routes-valaisannes-fermees-cause-deluge/story/27182180	https://www.rfj.ch/rfj/Actualite/Region/20150501-La-Roche-Saint-Jean-a-deux-doigts-de-l-inondation.html	http://www.20min.ch/ro/news/romandie/story/25748211	-	-	-	-
Comment	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Source	Google Alerts	Google Alerts	Google Alerts	Google Alerts	Google Alerts	Google Alerts	Google Alerts	Google Alerts	Google Alerts	Google Alerts	Google Alerts	Google Alerts	Google Alerts	Google Alerts	Google Alerts	Google Alerts
	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172

9.4 Open access maps

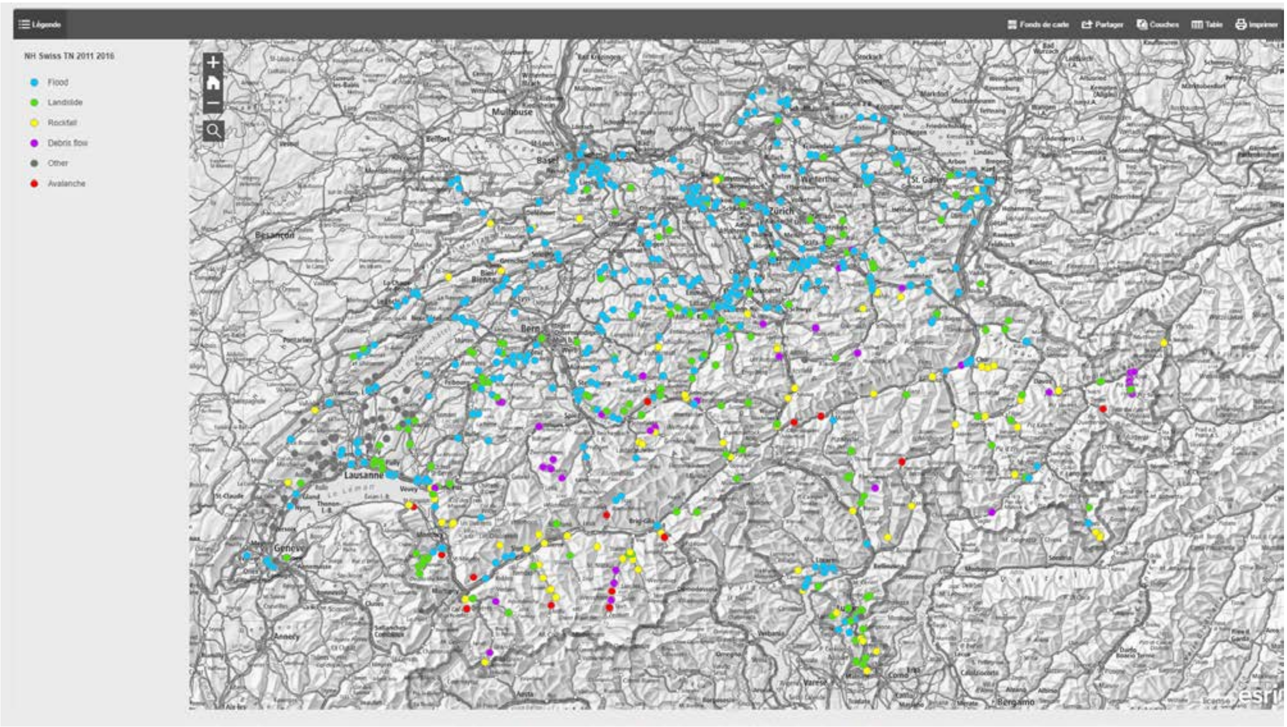


~~9.4.1~~ Figure 4-SM: Database on Google Maps

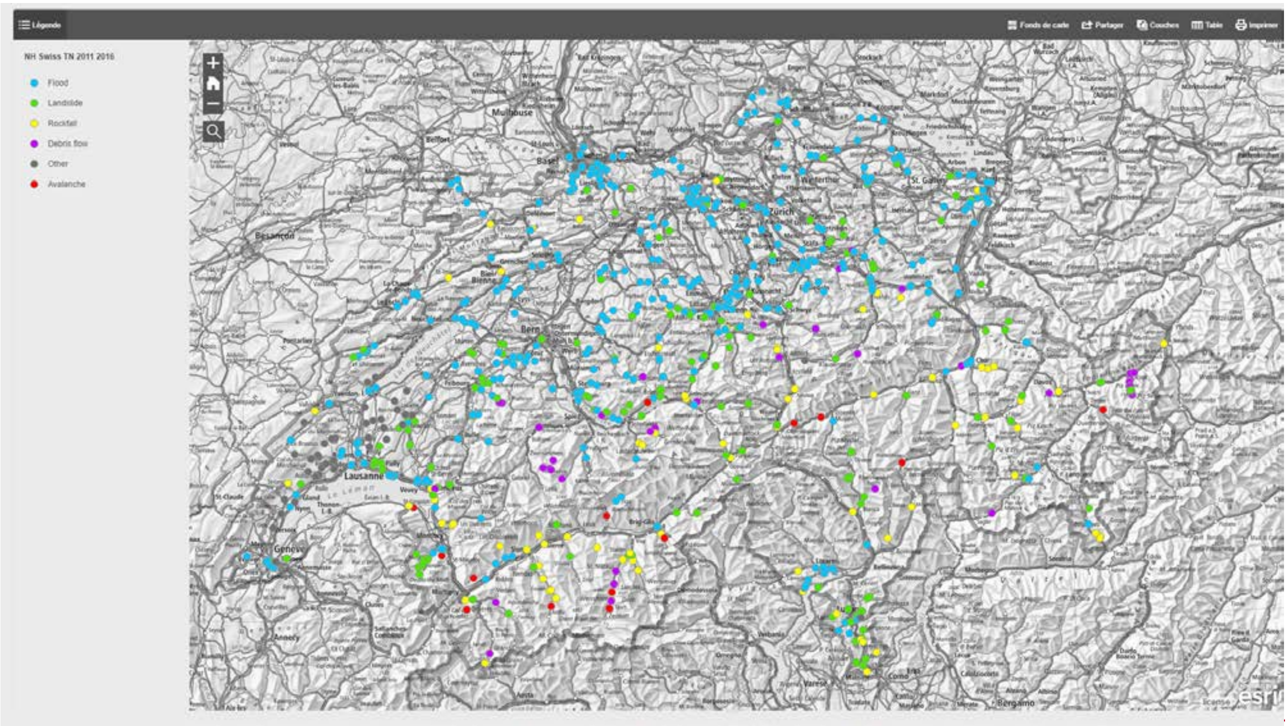


~~*Figure 27: Database on Google Maps.*~~

. Available at (last access: 25 January 2018) : https://www.google.ch/maps/@46.7199391,7.1246016,8z/data=!4m2!6m1!1s1qtu6LEYum-7ghpPg9WWzWwgPHYA?hl=fr, last access: 25 January 2018.



~~9.4.2~~ Figure 5-SM: Database on ArcGIS online



~~*Figure 28: Database on ArcGIS online.*~~

. Available at (last access: 25 January 2018): http://unil.maps.arcgis.com/apps/MapTools/index.html?webmap=34ee3eb719a647889abd341 75969d781, last access: 25 January 2018