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10. Geomorphology

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10. Geomorphology

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Swiss Geomorphological Society

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10.1

Electrical Resistivity Soundings on a Stabilized Slope of a Subalpine Catchment: A new Approach to Detect the Spread of Root Systems

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Intense rain fall events considerably increase erosional processes and the risk of mass movements in general and, in particular on steep slopes in mountainous areas lacking a protecting vegetation cover. Consequently, such events are jointly responsible for an increasing natural and socio-economic damage potential. In view of hazard prevention, soil bioengineering measures, e.g. slope and soil stabilisation with living plants, gain more and more in importance.

In order to estimate the plant's influence on the stabilization processes, the observation of the aboveground plant development is a common practice. In contrast, the near subsurface is invisible, difficult to address and, therefore, often neglected. Soil samples, sensors (e.g. soil moisture) or rhizotrons allow for some information on the belowground plant/root development. These methods, however, provide only limited point-by-point data, alter parts of the study site, and are often time-consuming and expensive. In contrast, geophysical methods, e.g. electrical resistivity tomography (ERT) provide minimally-invasive and spatial information of the near subsurface. Unlike in mountainous and steep environments, this approach is often used in lowlands by soil scientists.

In May 2010, we established three new research plots at an erosion-prone talus slope (inclination: ~40 - 45 °; elevation 1220 – 1360 m a.s.l.), located in the Arieschbach catchment area (Eastern Swiss Alps). The slope, consisting of moraine and denudation-derived substrate, shows high geomorphic activity (e.g. debris flows, rill erosion). Two of the plots were stabilized with 1200 plants each. Additionally, mycorrhiza inoculum was added to one of these plots (*INOQ Forst*, 40 ml/plant). A mixture of eight saplings was planted per running meter in 15 rows of 10 m length. The assortment included four saplings of *Alnus viridis* and two of *Salix purpurea* as well as one further tree (*Acer pseudoplatanus*, *Betula pendula*, *Fraxinus excelsior*) and shrub species (e.g. *Viburnum lantana/opulus*, *Lonicera xylosteum*). Finally, both plots were hand-seeded with a site adapted seed-mixture. The third plot was not treated and serves as a control plot.

Data logging stations are installed on each plot, measuring soil moisture and soil temperature in 10 cm and 35 cm depth. Furthermore a climate station in between the plots records air temperature and humidity, precipitation and solar radiation. In September 2011 ERT monitoring lines (48 electrodes, 25 cm electrode spacing) were installed at all three plots.

At the end of the vegetation periods 2010 and 2011 all plants were counted and measured. In addition, soil samples were taken likewise, and analysed in respect to aggregate sizes and stability, (fine) root penetration and the degree of mycorrhization.

Aboveground, preliminary results indicate that the plot, which was mycorrhizal treated shows higher plant vitality. The ERT soundings provided plausible data and enabled the modelling of the rhizosphere. An obvious difference between the three plots is detectable, showing deeper and more spacious rooting in the inoculated plot compared to the non-inoculated one. The shape of the subsurface anomalies fits with the vitality of the plants next to the ERT lines.

10.2

Tectonics, Climate, and Mountain Topography

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By regressing simple, independent variables that describe climate and tectonic processes against measures of topography and relief of 69 mountain ranges worldwide, we quantify the relative importance of these processes in shaping observed landscapes. Climate variables include latitude (as a surrogate for mean annual temperature and insolation, but most importantly for the likelihood of glaciation) and mean annual precipitation. To quantify tectonics we use shortening rates across each range. As a measure of topography, we use mean and maximum elevations and relief calculated over different length scales. We show that the combination of climate (negative correlation) and tectonics (positive correlation) explain substantial fractions (> 25%, but < 50%) of mean and maximum elevations of mountain ranges (Figure 1A and 1B), but that shortening rates account for smaller portions, <25%, of the variance in most measures of topography and relief (i.e. with low correlations and large scatter). Relief is insensitive to mean annual precipitation (Figure 1C and 1D), but does depend on latitude, especially for relief calculated over small (~1 km) length scales, which we infer to reflect the importance of glacial erosion (Figure 1C). Larger-scale (averaged over length scales of ~10 km) relief, however, correlates positively with tectonic shortening rate. Moreover, the ratio between small-scale and large-scale relief, as well as the relative relief (the relief normalized by the mean elevation of the region) varies most strongly with latitude (strong positive correlation) (Figure 1E and 1F). Therefore, the location of a mountain range on Earth and corresponding climatic conditions, not just tectonic forcing, appears to be a key factor in determining its shape and size. In any case, the combination of tectonics and climate, as quantified here, can account for approximately half of the variance in these measures of topography. The failure of present-day shortening rates to account for more than 25% of most measures of relief raises the question: Is active tectonics overrated in attempts to account for present-day relief and exhumation rates of high terrain?

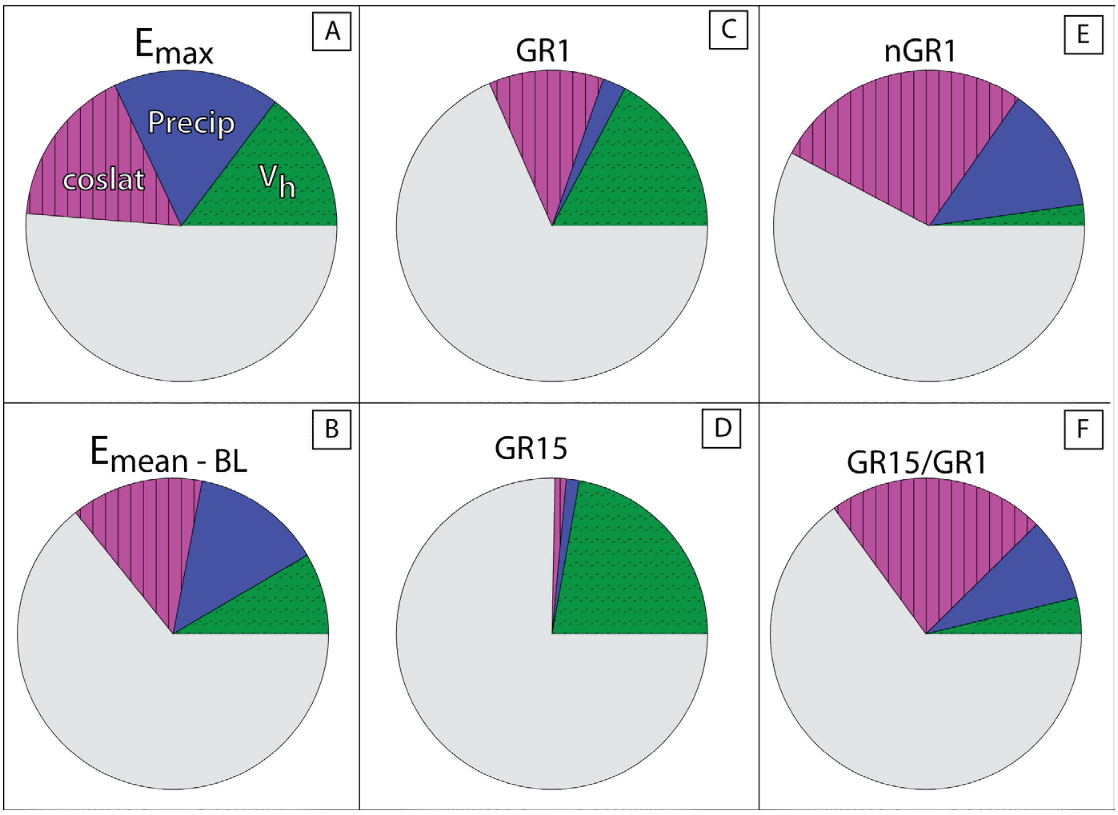

Figure 1: Pie charts of the relative contributions of each external variable – V_h (tectonic shortening rate), *precip* (mean annual precipitation), and *coslat* (cosine of the latitude)– to the observed variance of the topographic variables – E_{max} (maximum elevation of the topography average over a 10 km), E_{mean}–*BL* (mean elevation of the range above the base level *BL*), *GR1*and *GR15* (mean geophysical relief over 1 and 15km), *nGR1* (relative relief, i.e. geophysical relief normalized by the mean elevation of each range), *GR15/GR1* (Dimensionless ration between GR15 and GR1). The gray shading is the unexplained part of the variance that is due to unused variables and natural scatter.

10.3

Strong imprint of periglacial-environments dynamics on stream sediments seen trough a ^{10}Be-budget of an alpine catchment (French Alps).

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The Ecrins-Pelvoux massif (French Western Alps), like most of the European Alps, has been extensively glaciated during Quaternary glaciations, leading to a strong morphological imprint and a related rejuvenation. This massif therefore provides a suitable area to study the effects related to this inheritance, and to quantify erosional processes in changing landscape. To this extent, we sampled stream sediments in 12 catchments throughout the Ecrins-Pelvoux massif to measure in-situ produced ^{10}Be concentrations and derive catchment-scale denudation rates for late-Holocene timescales. Our results show a clear correlation between denudation rates and mean catchment elevation, in the absence of any significant relationship with other morphometric parameters (Delunel et al., 2010). We thus propose that postglacial denudation of Ecrins-Pelvoux massif is climatically driven trough increasing frost-controlled processes with elevation, providing a mechanistic link for the inferred feedback between uplift, elevation and denudation rates observed elsewhere in the European Alps (Wittmann et al., 2007; Champagnac et al., 2009).

^{10}Be concentrations of stream sediment alone cannot be used to identify potential about the intrinsic spatial variability of erosion and sediment discharge in a single catchment. Therefore we have measured ^{10}Be concentrations (n = 19) on both different morphologic features and detrital materials resulting from high-altitude erosion that ultimately feed the sediment routing system. For this purpose, we focussed on the Etages catchment (~14 km^2 catchment, Ecrins-Pelvoux massif), located within the altitudinal range where frost-controlled processes are most efficient (Delunel et al., 2010). This catchment also hosts a small cirque-glacier, which is a relict from the Little Ice Age (LIA) glacial advance. This basin allows us to identify the glacial influence on stream-sediments ^{10}Be concentrations.

The results show that ^{10}Be concentrations vary strongly from ~0.1x10^5 to 4.5x10^5 atoms g-1 in the Etages catchment, while displaying consistent ^{10}Be signature within each representative sources. ^{10}Be contents of glacial materials vary from 0 (i.e., undistinguishable from procedural blanks) close to the present-day glacier position to ~0.3x10^5 atoms g^{-1} towards the LIA moraines. Debris-flow materials collected at different catchment levels have slightly higher ^{10}Be concentrations (~0.4-0.7x10^5 atoms g^{-1}). Regolith material collected close to the highest crests (morphologic features currently affected by frost-cracking processes) carries much higher concentrations (~1.3-1.8x10^5 atoms g^{-1}), while bare rock surfaces are also characterized by relatively high and heterogeneous ^{10}Be concentrations ranging from ~1.4 to 4.5x10^5 atoms g^{-1}. Finally, stream sediments collected along the main stream and at the outlet carry ^{10}Be concentrations of only ~0.2x10^5 atoms g^{-1}, without any downstream trends either towards higher or lower concentrations.

We then interpret these ^{10}Be concentration measurements combining a geomorphological map and surface ^{10}Be production rates estimates within a mass-balance model (Brown et al., 1995; Granger et al., 1996). The model results evidence that the ^{10}Be signature of sediments exiting the Etages catchment does not fulfil the steady-state equilibrium required for inferring catchment-wide denudation rates implying a strong transience. Most important, the ^{10}Be concentrations measured in the alluvial sediments along the stream tightly reflect the glacial material signature, showing that the Holocene variability in denudation has not imprinted on the ^{10}Be concentration of the trunk stream yet. In summary, we propose that periglacial dynamics need to be considered as important constituents in the erosional factory either through the effects of frost cracking, or the recycling of glaciogenic deposits.

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10.4

Geomorphological catchment parameters affecting bed load transport in mountain torrents

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Information on potential bed load and bed load transport is essential to conduct hazard assessments of torrents and their possible consequences on settlements and infrastructures. A variety of methods and formulae have been developed to predict and estimate bed load transport in mountain torrents ranging from simple regression to complicate multi-step and multi-parameter approaches. However, the possibilities to test these formulae using field data are limited by the challenges of measuring bed load and detailed hydraulics due to their high variability in space and time.

The presented study takes up these challenges by comparing estimated bed load values applying a transport formula for steep channels and accounting for high flow resistance (Rickenmann, 2012) (here called calculated values) and values derived from sediment traps at the water intakes for water power plants (here called observed values). The considered water intakes and thus the study area are located in the Valais (Switzerland). All water intakes are maintained by the Grande Dixence Hydropower Company. The observed bed load values are associated with some uncertainties (grain size distribution of deposits, filling degree of sediment trap, numbers of flushing events). The discrepancy ratio of calculated to observed values varies considerably between 0.1 and 1400. The main objective of the study is to find possible geomorphological parameters within the catchments, which may clarify the discrepancies and partly explain the general overprediction. To achieve this objective, catchment parameters which are supposed to influence bed load transport are deduced from maps or analyzed from the DEM in ArcGIS. Field work was deducted for validating map and DEM interpretations and the input parameters for the bed load transport calculation. The geomorphological parameters such as catchment area, channel length on rock, loose sediment or vegetation and distance between the water intake and the glacier were compared with the discrepancy ratio of calculated to observed values. The analysis includes XY-diagrams and multiple regressions. First results of the graphical comparison show channel length on rock and loose sediment to be most strongly related to the discrepancy ratio, with a coefficient of determination of 0.39 for a logarithmic function. The form factor according to Horton and maximum height for instance seem to have no influence on the ratio of calculated to observed bed load values.

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10.5

Cosmogenic nuclide denudation rates in the debris-flow dominated Haslital-Aare and Matter catchments

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We have continuously sampled river sand for cosmogenic derived catchment wide denudation rate analysis in the catchments of the Haslital-Aare (5 years under observation) and Matter/Saas (2 years). Both catchments are known for their highly active debris-flow torrents causing considerable damage, pose a natural hazard risk and are under high technical surveillance and protection constructions.

While the widely measured cosmogenic nuclide derived denudation rates in alpine catchments are commonly only measured ones, we opted a seasonal to monthly and event based sampling scheme to evaluate the degree of perturbation caused by episodic events to assumed steady state systems (as the method requires).

The cosmogenic ^{10}Be and ^{14}C results for the Haslital-Aare show that the localized admixture of sediment from high-magnitude and trunk-stream channel coupled debris-flows in 2009 to 2011 have a marked effect on long-term ^{10}Be denudation rates compared to prior undisturbed years. Furthermore, though magnitudes were exceptional high in 2010 and 2011, a threshold was approached, where the higher sediment flux did not result in apparent higher denudation rates (Kober et al., 2012). This suggests that with time sediment-remobilization in the lower parts of the debris-flow torrents dominates that has no different cosmogenic signature than the material delivered from previous years or, that similar reservoirs were tapped. Individual torrent measurements and field observation support these results.

The Matter catchment has been observed for 2 years so far only, with rates obtained that are similar at all sites suggesting (i) mixing of sediment and (ii) no perturbation by large magnitude events that are coupled with the trunk stream. Field observation confirm these data where debris-flows were only of small volume and did run out in tributary systems. Furthermore, no significant perturbation by the Randa landslide/rockfall is observed, suggesting that the slope deposits and the modern channel are decoupled.

Overall, all apparent denudation rates fit current mean Alpine denudation rates of about 1 mm/yr, unless perturbed by events. This highlights the fact that a careful knowledge of the pre-sampling catchment process history is necessary in order to interpret data correctly.

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10.6

Alpine Cambisols and their genetic implications for eolian influence on karst soil development (Northern Calcareous Alps)

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This study focuses on striking Cambisols on the karst paleosurface of Reiteralpe (Trias,Cretaceous) (Figure 1).

Distinct B horizons forming Chromic Cambisols are not exclusively related to autochthonous residues. In contrast, pedology and mineralogy indicate a strong eolian addition (silt, fine sand, mica, feldspars) to the topsoils, underlining that recent dust influx is an ubiquitous phenomena in high-mountainous karst. The related mineralogy of both dust and soil samples reveals a heavy mineral spectrum congruent with detritus derived from Central Crystalline Alps. These results go along with dust deposited periodically by southerly foehn winds. More than exiting are special features (e.g. rounded quartz, hematite, gibbsite), implicating accessorily far-traveled Saharan dust.

Although apparently common, the addition of allochthonous silicate-rich dust is still a neglected factor for mineral soil development. Thus, it is for the first time that influx measurements upon the soil profiles face this challenging problem. What is also quite new is the combination of winter and summer deposition by using firstly the snow surface method (Thorn and Darmody, 1980) and secondly a simple construction of dust boxes near the soil surface.

The data of a meanwhile five-year-record yield in dust influx rates producing a mineral layer of 9.0cm per 10,000years. This is a multiple (factor 2 to 11) of the accumulated thickness of Holocene residue production out of limestone weathering only. These findings indicate that eolian dust is a major contributor to alpine karst soil genesis.

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Figure 1. Germany and the location of the study area (Maps of Germany, Munich 2007).

10.7

Río Mamoré - Holocene river dynamics in the Bolivian lowlands

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The Llanos de Moxos, which are located in the lowlands of north eastern Bolivia (Beni), are one of the largest seasonally inundated savannahs in the world (150.000 km^2). The region is characterized by a complex fluvial drainage pattern, where large-scale river migrations have been reported for the Río Grande, Río Beni and Río Maniqui (e.g. Allenby 1988; Dumont 1996; Plafker 1964). So far little is known however with regard to causes and timing of these river shifts.

Based on previous results, the Río Mamoré shift (Plotzki et al. 2011) has been investigated in more detail and results will be presented here. Remote sensing was used to analyse dimensions of palaeo meanders, which were then used for palaeo discharge calculations. Discharge of the modern Mamoré is 3-8 times that of the former Mamoré. Three infilled oxbows of the palaeo meander belt have been investigated in 2008, 2010 and 2011 and sediment cores have been taken. OSL and radiocarbon dates indicate that the Río Mamoré was at least active in its former meander belt until ~3 ka. Increase in discharge of the Río Mamoré must have occurred simultaneously or subsequently to its shifting. We propose that the increase in discharge in the Río Mamoré resulted in a reduction of the channel's capacity to accommodate the increased amount of water, and ultimately caused the avulsion. However, other possible mechanisms resulting in avulsion, e.g. tectonic tilting of the basin, have to be considered as well. The increase in discharge may be attributed to increase in humidity from the late Holocene on due to strengthening of the South American Summer Monsoon (SASM), which is evidenced by several archives from the Bolivian altiplano and the lowlands (e.g. Baker et al. 2001; Mayle et al. 2000).

Irrespective if the river shift is correlated to the increase in discharge or not, it is evident that i) climatic conditions changed markedly from the mid-to late Holocene, as evidenced by discharge alterations. Our results represent the first attempt to correlate meander dimensions and increasing discharge in the Beni basin with climatic changes on Holocene timescales. ii) High variability of the fluvial system in the Beni basin is indicated by several river shifts, yet this is the first approach to put one of these shifts into a temporal frame.

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10.8

Erosion and sedimentation rate variability following the LGM ice-retreat

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Paleo-erosion and sedimentation rates calculated for the Holocene in a formerly glaciated alpine catchment demonstrate a high variability of sediment supply during an interglacial stage. A combination of ^{14}C data and ^{10}Be-derived rates, allow interpreting the evolution of the Zielbach catchment (Venosta valley, Sudtyrol, Italy) in terms of sediment yield, sedimentation dynamics and landscape evolution. In addition, stratigraphic and seismic data allow us to interpret the relative importance of the Zielbach catchment and of the Adige River system (in the main valley) as a balance between sediment availability, supply and accommodation space in the Venosta valley. The two systems basically reflect the different response of the landscape to glacial retreat, highlighting the spatial and temporal variability of the deglaciation in the Venosta valley (Fig.1).

The ^{10}Be data show that erosion and sedimentation rates experienced a decreasing trend from ca. 10'000 yrs B.P. until at present, testifying one order of magnitude higher sediment discharge immediately after the deglaciation of the main valley than at present. In particular, during the first phase of deglaciation (from ca. 12'000 yrs B.P.), the catchment was affected by an extremely high erosion and sedimentation rate, which caused the exhaustion of the sediment deposited by the LGM glacier on the slopes. Subsequently, the activity of the trunk stream decreased, but the ongoing movement of a re-activated landslide on the eastern slope of the basin contributed to the rapid sediment delivery (mainly through debris flow) also during the first mid-Holocene. The continuous accumulation of sediment in the main valley probably caused the stabilization of the slope and resulted in a reduction of sediment supply by debris flows. This was then accompanied by an increase in the relative importance of alluvial processes. This phase coincided with the Holocene climatic optimum.

More recently, between ca. 3'500 yrs B.P. and present, the debris-flow activity regained a more important role in the supply of sediment. This behavior may be related to the Holocene climatic deterioration when more variable climatic conditions could have affected the stability of hillslopes and related debris flow processes. If this hypothesis is correct, the future evolution of the Zielbach catchment will be strictly linked with predicted climatic changes that may affect the decreasing trend of erosion and sedimentation rates characteristic of the recent past.

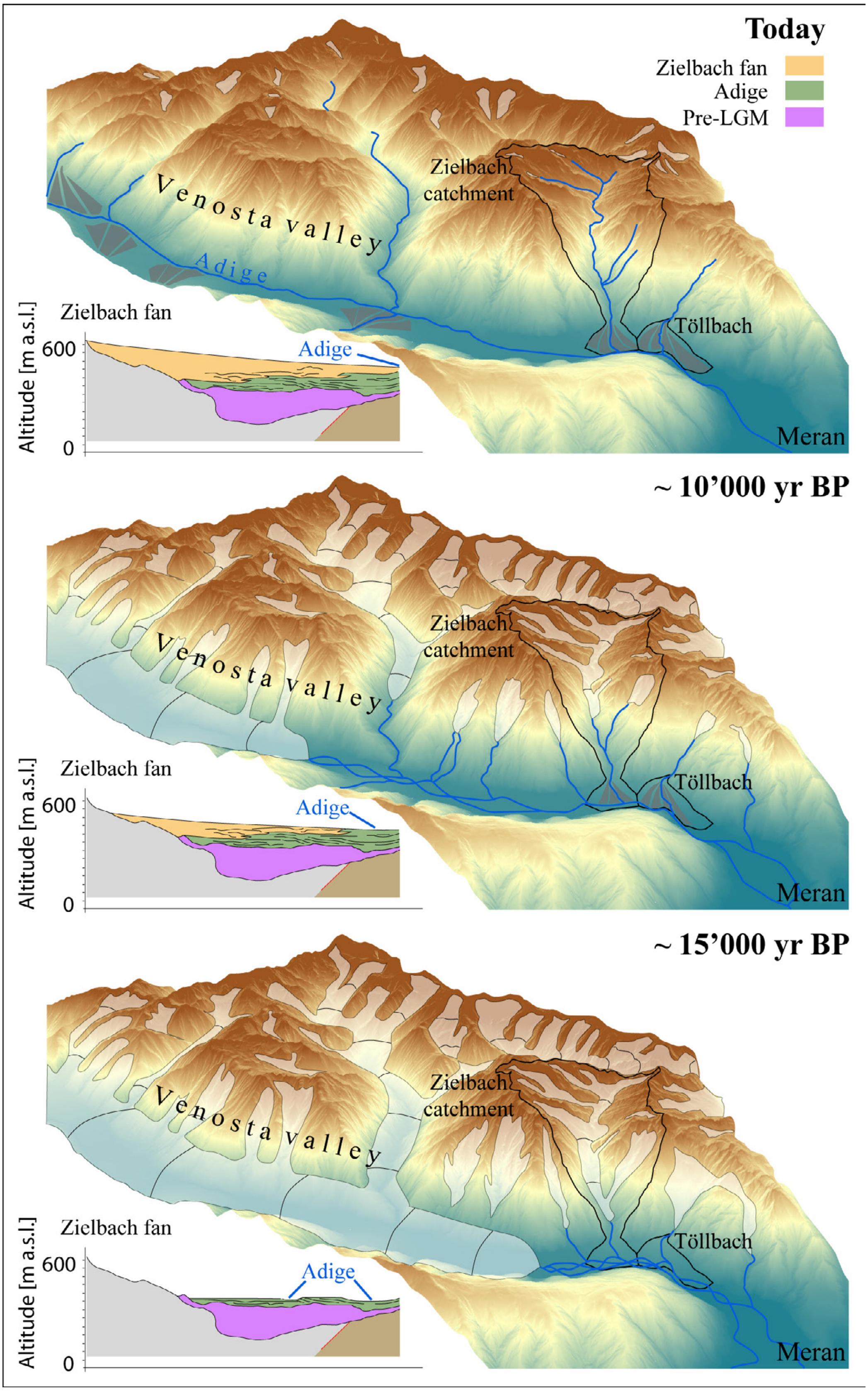

Fig.1. Evolutional model of the Zielbach fan. The model shows the interaction between the main valley (Adige River) and Zielbach sedimentation processes, following the deglaciation of the Venosta valley.

10.9

Sediment transfer in the Southern Swiss Alps since the Last Glacial Maximum: evidences of paraglacial crisis

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Continental hillslope deposits – in particular talus slopes and alluvial fans – and valley floor deposits, can be read as important palaeoenvironmental archives for the reconstruction of the morphogenesis, the evolution and the morphodynamics of alpine valleys since the last deglaciation (Scapozza 2012). The study of these deposits it is of particular importance because, especially in the actual context of a warmer climate, a « geosystemical » approach focusing on the sediment transfer in a whole alpine hillslope – from the rockwall to the valley floor – is of great importance to understand and evaluate the past processes and to try to assess how they might evolve in the future.

In this framework, we would present the state of the art concerning the knowledge about sediment transfer in the Southern Swiss Alps, allowing defining the major morphoclimatic crisis that have occurred during the Lateglacial and the Holocene, and which is based on the:

- compilation of detailed Quaternary geological maps;
- definition of the timing of deglaciation of the Ticino glacier and of the main steps of progradation of the Ticino river delta (fig. 1-A);
- collection of morphometrical analysis of several alluvial fans and palaeodeltas allowing the reconstruction of depositional processes;
- quantification of the sediment transfer from rockwalls to talus slopes in high mountain areas (in particular in the periglacial belt) (fig. 1-B);
- definition of the infilling chronology of the Ticino valley floor, allowing the quantification of sedimentation rates (fig. 1-C).

These preliminary data allow to show, for the higher part of the studied catchments, the existence of “paraperiglacial rockfall phases” related to the permafrost degradation in rockwalls which coincides with rapid climate warming periods, as at the beginning of the Bølling, during the Preboreal or, maybe, since 1980 (fig. 1-B; see Scapozza 2012). A similar behaviour was found by the analysis of the fluvial sedimentation rates (fig. 1-C) and of the Ticino river delta progradation rates, with the erosion/sedimentation dynamic during the Lateglacial and the Holocene that was putted in relation with the paraglacial sedimentation model, which implies a major morphogenetical crisis at the beginning of the deglaciation (Scapozza *et al*. 2012).

In future, these results will be improved by investigation at the local scale, including for example the assessment of sediment transfer from glaciers and rockglaciers to the valley floors, the study of the relationship between mass movements and alluvial fan development and the detailed study of the stratigraphy of some talus and alluvial cones thanks to the presence of outcrops dues to sand and gravel quarries or archaeological excavations.

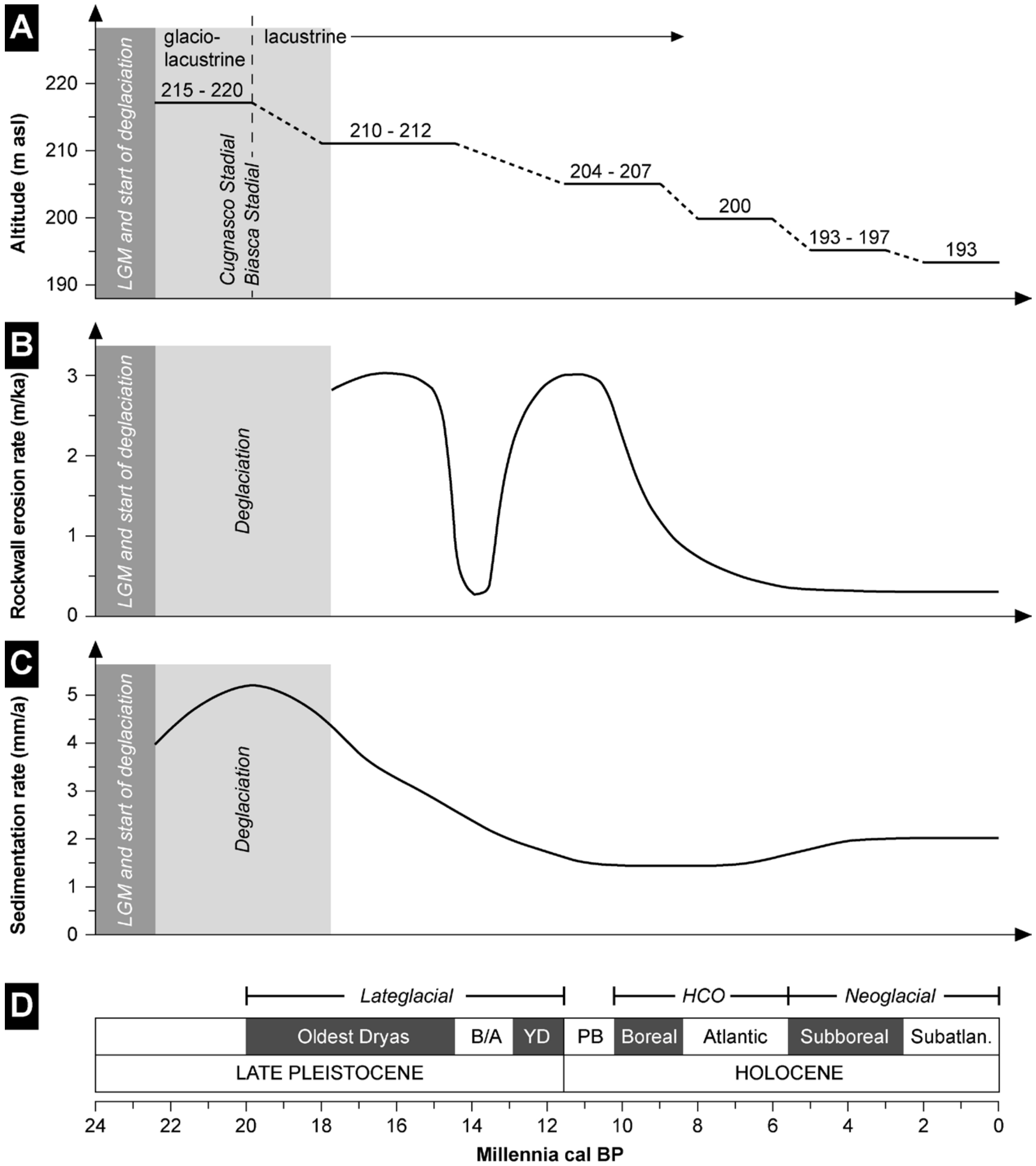

Figure 1. Evolution of some natural parameters related to the sediment transfer in the Southern Swiss Alps. (A) Main deglaciation stadials of the Ticino glacier and mean altitude of the Lake Maggiore; (B) Rockwall erosion rates in the alpine periglacial belt based on talus slope volume evaluation; (C) Mean sedimentation rates in the valley floor of the Ticino plain; (D) Chronostratigraphical framework (in "roman") and main morphoclimatic subdivisions (in "*italic*"). LGM: Last Glacial Maximum; B/A: Bølling/Allerød; YD: Younger Dryas; HCO: Holocene Climatic Optimum. (A) and (C): data from Scapozza *et al*. (2012); (B) and (D): data from Scapozza (2012).

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P 10.1

Transient fluvial incision and active surface uplift in the southern India

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The Southern Peninsular India is characterized by anomalously high topography in passive margin settings. Throughout the globe the research devoted to the understanding of feedbacks among topography, tectonics and climate are focused on tectonically active settings. In the Western and Central part of Southern Peninsular India, mountains are as high as 2600m, slopes are steep, monsoon rain is heavy, and temperatures are tropical. All these conditions provide an unique opportunity to test the coupling between topography, tectonics and climate. We utilize topographic analysis of channel profiles combined with field measurements to explore the distribution of fluvial incision and landscape transience in Southern India. We analyzed fluvial channel profiles of both the east and west flowing catchment system covering an extensive area between 10-16°N latitude. The channel profile analysis revealed systematic differences in morphology between the east and west flowing catchments. The east flowing channels of Cauvery catchments are approximately 800 km long and flowing across the subcontinent down to the Bay of Bengal. The trunk channel and its tributaries are characterized by one or more major knickpoint that separate channel reaches with different channel steepness. From field survey, we found that channels downstream of the knickpoints are carving through narrow deep gorges. The catchments flowing westward, to the Arabian Sea, are short and of two types. Type A channels are marked by one or more prominent knickpoints and the downstream channels are steep and cutting through narrow V-shaped gorges. Type B channels are devoid of knickpoint and marked by concave upward valley shapes. These preliminary results highlight the transient state of the landscape in Southern India and provide evidence for variable amounts of fluvial response to the adjusting landscape. Further work is in progress using insitu produced cosmogenic nuclide and low temperature thermochronology to better understand the timing and magnitude of landscape adjustment and its relation with changing boundary conditions.

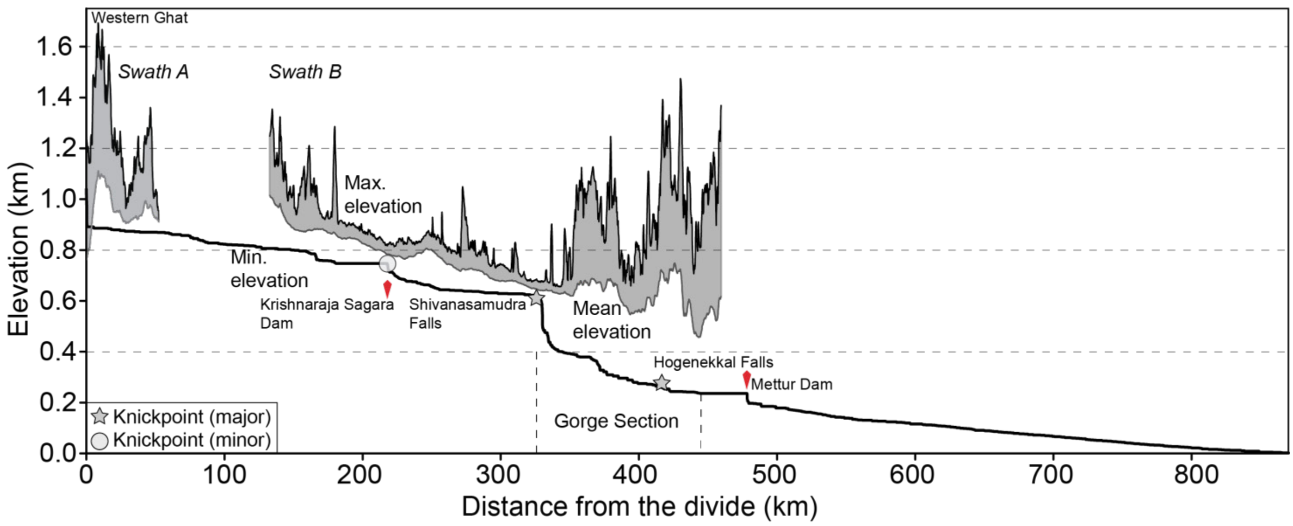

Figure 1. River profile along the Cauvery River. Grey and black lines (with area shaded between) indicate mean and maximum elevation values from the swath profiles.

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P 10.2

Climatic imprint on landscape morphology in the western escarpment of the Andes

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Over human timescales, the processes responsible for the long-term topographic evolution of a mountain range are typically not observable and hence, poorly constrained. Here we perform a space-for-time substitution with the western escarpment of the Andes between 10 and 20°S to identify the formative mechanisms.

We use this setting to propose that variations in the precipitation pattern play a primary role in setting hillslope relief in mountainous landscapes. We find that in dry climates topographic relief grows with increasing precipitation, independent of either the underlying lithology or prevailing rock uplift pattern. We proceed by differentiating between Andean landscapes with generally low precipitation rates (80-500 mm/yr, Peruvian Andes 10-20°S) where local relief correlates positively with precipitation, from those with higher precipitation rates (400-1400 mm/yr, Chilean Andes 35-40°S) where increases in precipitation lead to topographic decay. We suggest that these trends result from dominant bottom-up processes giving way to increasing top-down processes. With low precipitation, relief growth is controlled by stream incision and knickzone retreat into a largely undissected plateau. With higher precipitation rates, relief is set by the steepness of graded streams and the rates of sediment production and transport on hillslopes.

Trends of topography can also be interpreted in temporal terms, in which the higher precipitation results in shorter response times, such that the Peruvian Andes are still responding to Miocene uplift while in the Chilean Andes, these knickzones have already propagated through the entire fluvial network. We anticipate that such changes also operate during the formation and destruction of other mountainous plateau landscapes.

P 10.3

Dip direction controls of bedrock on channel morphologies and denudation rates in the eastern Swiss Alps

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The bedding orientation of bedrock exerts a prime control on the nature and the rates of sediment transfer on mountainous landscapes. Here, we address one particular situation, in which the dip angle of the bedrock is subparallel to the topographic slope (termed dip-slope). Such an arrangement results in the potential for large-scale deep-seated landsliding with bedding or jointing acting as glide planes. Hillslopes with the opposite situation (non-dip slope) have no such preconditioning, and will denude through standard mechanisms. The dip slope case is transport limited, with deep-seated landslides of up to tens of km^2 large transferring material towards the trunk stream. The opposing, non-dip slope, valley side is dissected by <150 m deep, supply-limited, bedrock channels.

Quantifying these effects is however difficult as surface sediment transfer rates in the dip-slope case may not reflect the depth integrated sliding rate. Likewise, in non-dip slope catchments, failure events tend to be episodic. We approach this problem with multiple methods, complementing geodetic surveys with morphometric analysis and ^{10}Be derived hillslope and channel denudation rates. In particular, we analyse the relationship between upstream size of drainage basins *A* and channel gradients *S*. In case where channels are graded and actively shaping the landscape, then channels gradients *S* are directly related to the size to the contributing area *A* following Flint's (1974) law:

$$S = k_s A^{-q} \qquad (1)$$

where k_s and θ denote the channels steepness and concavity, respectively. The type, magnitude, and relative contributions of hillslope and channel processes can result in deviations from this relationship, which are readily identified by changes in the concavity and steepness values. Accordingly, we calculated these parameters from tributary streams on dip slope and non-dip slope valley sides. Tributary channels on dip-slope valley side are characterized by low concavity values ranging from 0.1 to 0.2, and equally display low steepness indices of approximately 100 $m^{0.9}$. Streams on the non-dip slope valley side have substantially higher concavity values between 0.3 and 0.8 and higher steepness indices, reaching maximum values of ca. 200 $m^{0.9}$. Surface slip rates derived from geodetic data exceed 10 cm/yr on the dip-slope valley flank, but are below detection limits (~1 m horizontal shift) on non-dip slope hillsides (Schwab et al., 2009).

The high steepness and concavity values of streams on non-dip slope valley sides support the interpretation of rapid dissection of the channel network into landscape where low hillslope slip rates allow the channel network to stabilize and actively shape the landscape. This is in contrast to the dip-slope valley side, where low steepness and concavity values suggest that the channel network is continually destabilized by rapid deep-seated landsliding. ^{10}Be-derived denudation rates are expected to yield similar distinct relationships between landsliding, fluvial dissection and overall sediment yield.

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P 10.4

Bedrock surface model of Switzerland: indication for glacial erosion processes

Mirjam Dürst Stucki, Fritz Schlunegger

The bedrock topography without its quaternary sediments is an important archive for the indication of glacial erosion processes and evidence for the glacial impact on landscape. Based on stratigraphic investigations of more than 30,000 boreholes we generated a bedrock model of the entire Canton Bern. We combined our model with other models, which resulted in a map of the bedrock topography of nearly the entire area of Switzerland. Adapted on this map we calculated an erosion model based on the glacier velocity. Additionally, we were able to identify areas with high erosional potential of the subglacial meltwater. By analyzing hypsometry, slope distribution, lithology, and bedrock course and morphology of the different catchment areas, we characterized the history of the different glaciers within Switzerland.

P 10.5

Quaternary geological map of Sheet Reichenau (Canton Graubünden): improvement of several GIS tools

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In the framework of the Geocover project, the Institute of Earth Sciences of the SUPSI has realized during 2012 the digital map 1:25'000 of the Quaternary landforms and deposits of the Sheet 1195/Reichenau and of a part of the Sheets 1174/Elm and 1175/Vättis, located in the northern part of the Canton Graubünden between Flims and Chur (Vorderrhein Valley).

The mapping of the Quaternary landforms and deposits was based on the directives of the Swiss Geological Survey (see OFEG 2003) and was performed thanks to the software ESRI ArcGIS and thanks to an extension of it, called ArcGDS. This tool is particularly adapted for the cartography of Alpine valleys and hillslopes because it allows collecting, editing and updating of 3D features using a stereoscopic 3D interface. In addition to 2D (X-Y plane) data, ArcGDS captures altitude data (Z) by continuously connecting points in superposed images.

The goal, concerning the mapping of Quaternary geomorphology, was reached by the analysis of a 2 m resolution Digital Elevation Model (DEM), orthorectified aerial photographs (orthophotos) and summary maps and sketches published in literature. The perimeter of the landslides was interpreted and mapped using the ArcGDS tool.

One of the purposes related with the realization of these digital maps was also to improve the quality of digitalization work by reducing the presence of typical topology errors and problems that are generated by the use of editing tools on polygons (e.g., cutting, reshaping and clipping tools). For this reason, we have chosen to work only through lines (which represent the geological construction lines, as a geological boundary or linear geomorphologic landforms) and points and to generate the polygons at the end of the work, instead of generate directly the polygons (Figure 1). The points allow attribute the polygons generated by the intersection of the lines (*point main* for deposits; *point aux* for instabilities; see Figure 1) and the punctual geological elements (e.g. erratic boulders, springs, etc.).

The mapped area is characterized by a complex event stratigraphy, well known in literature, which presents a large number of landslides (with, in particular, the famous Flims rockslide; e.g. Poschinger 2005, Ivy-Ochs et al. 2009), DSGSD (deep seated gravitational slope deformations) and different hillslope and alluvial deposits.

This bibliographic knowledge is very important and represents the base to a correct interpretation of the different deposits and landforms visible through the hillshade of the DEM.

In the studied area, the valley floor is characterized by different rockslide deposits. First occurred the Tamins rockslide, which blocked the Vorderrhein river and caused the formation of the Bonaduz paleo-lake. At about 8'900 ± 700 yr BP (Ivy-Ochs et al. 2009), the Flims rockslide came down and caused a new dam of the Vorderrhein river, with a reworking and a resedimentation of the Bonaduz gravel and the formation of the Ilanz paleo-lake. This lake increased rapidly its level and induced a flow caused through the breaking of the dam. The part of the lake that remained was filled up by sediments and finally the Vorderrhein river started eroding the valley floor down to the actual level (Poschinger 2005).
In conclusion, the overlap of 2 m DEM analysis, orthophoto and cartographic information allow to collect a lot of information and also to recognize, correlate and map different type of Quaternary landforms and deposits.

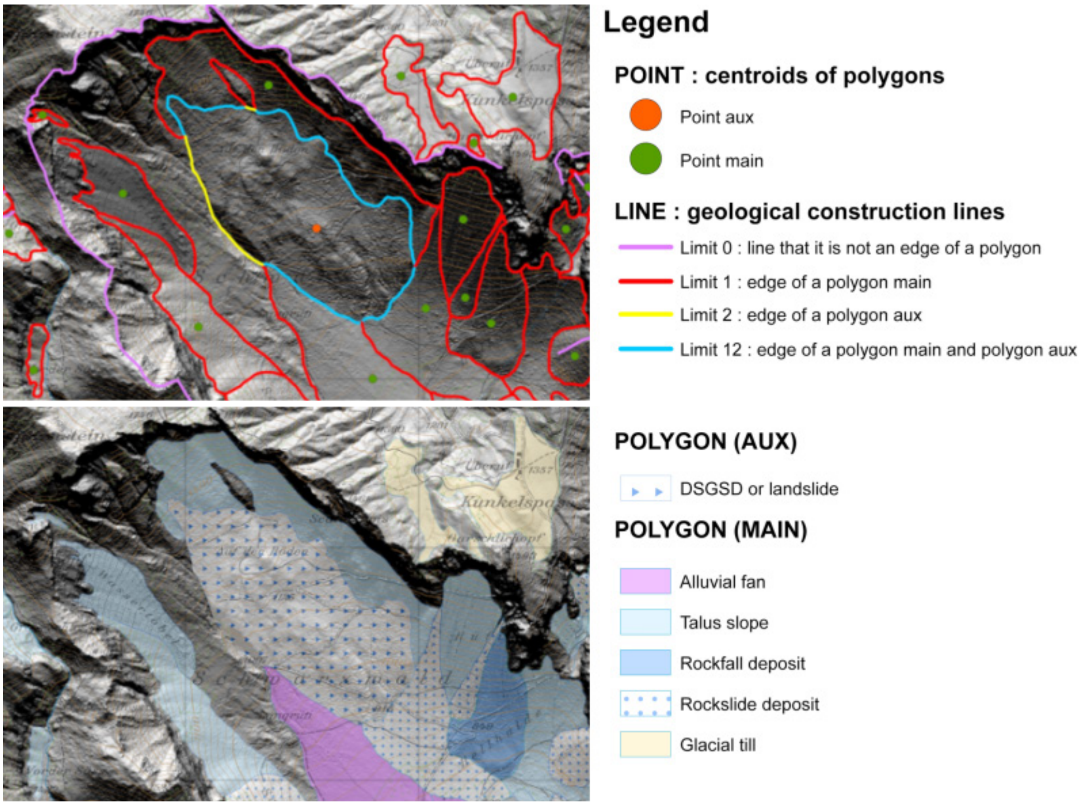

Figure 1. An extract of the Quaternary map of Reichenau: digitalization with points and lines (above) and the final result with polygons (below). See details in the text.

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P 10.6

Quantifying glacial erosion and relief evolution using luminescence thermochronometry (Granite Range, Alaska)

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Long-term exhumation and topographic evolution of mountain belts arise from complex coupling between tectonics, climate and surface processes. The recent development of luminescence thermochronometry (e.g., Herman et al., 2010; Guralnik et al., this volume) and its very low closure temperature (0-60°C) opens a new spatial and temporal "window" to study latest stages of rock exhumation, and address the nature of Quaternary topographic relief changes. We apply this new method in the Wrangell-St Elias National Park (Alaska), an alpine landscape that exhibits typical glacial features (U-shaped valleys, cirques, moraines). This setting provides an exceptional opportunity to study potential differences in relief evolution under a gradient of glacial forcing. We sampled four elevation profiles over an 80-km East-West transect across the Granite Range, where there is a consistent eastward increase in mean elevation, glacier activity, and topographic relief.

Feldspar separates from 15 bedrock surface samples were dated using the IR-50 protocol, and exhibit good internal reproducibility. Apparent ages vary from ~250 ka in the western part of the range, to younger ages of ~30 ka in the east, thus supporting the notion of amplified glacial activity on the east. Using a kinetic model to convert apparent ages into mean cooling histories, our work reveals spatially variable erosion rates during the late Quaternary, with preferential high-altitude erosion in the eastern part of the Granite Range and localized valley incision on its west. This represents the first quantification of relief limitation (so-called "glacial buzzsaw") in an active mountain range, and demonstrates the potential of luminescence thermochronometry in resolving topographic evolution and surface processes over 100-kyr timescales under high-frequency climate modulations (e.g., glacial-interglacial oscillations).

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P 10.7

Four years of avalanche erosion measurements in the Guggigraben catchment, Canton Valais

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Dense wet-snow avalanches breaking through to the base of the snowpack or overriding snow-free surfaces can entrain basal material and act as important agents of sediment transport in steep alpine catchments. Here we present results from four years of measurements quantifying the volume of coarse rock sediment transported by avalanches each winter. We then use these values to calculate catchment-wide erosion rates. The seasonal transported sediment load was estimated at the Guggigraben fan (Matter valley, Canton Valais) by measuring the debris content within a number of representative areas and then extrapolating the cumulative volume. Results reveal a total transported sediment volume of 150 m^3 in 2009, 13 m^3 in 2010, 13 m^3 in 2011, and 41 m^3 in 2012, which when distributed over the entire catchment area yield catchment-wide erosion rates of approximately 0.1, 0.01, 0.01, and 0.03 mm/year, respectively. Observed differences in transported sediment volumes are caused not only by varying total yearly snowfall, but also by the timing and rate of spring snowmelt. Sediment is sourced predominantly from within the main channel or one its four tributaries, originating first as rockfall or regolith landslides. Avalanches thus play an important role in the Guggigraben catchment in transporting loose sediment from temporary storages to the fan and main river system. As the avalanche deposits melt in spring, entrained sediment is set down gently, often resulting in precariously balanced boulders and rows of blocks perched on the walls of the fan's main channel. In flat lying areas, snowmelt results in sparse sediment deposits with no clear structure or sorting. Observations show that the fan surface is usually protected from erosion by snow and older avalanche deposits, which provide a smooth gliding plane for new events. Within the bedrock gully at the apex of the fan, and in the avalanche source region above, signs of abrasive wear were evident on exposed bedrock surfaces. These included rounded and scoured bedrock, fresh signs of boulder impacts, and scratch marks on the rock walls.

P 10.8

Quantifying rockfall hazards through injury counting on the bark of trees

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Introduction

Over the past decades, numerous studies revealed the great potential of dendrogeomorphic techniques for the analysis of natural hazards. In this contribution, classical tree-ring reconstructions were used to assess past rockfall activity focusing on conifers. This "classic method" allows a very accurate dating of historic events; however it represents a very time-intensive method. With the aim to reduce time and effort of tree ring studies dealing with rockfall, we suggest a new method requiring less effort and compare it to the classical approach. The new method is based on the counting of visible scars on the stem surface of Common beech (*Fagus sylvatica* L.).

The study site selected for analysis has a surface of 3ha, an inclination of 40° and is covered with a mixed forest composed of *Picea abies* (L.) Karst., *F. sylvatica* and *Pinus sylvestris* (L.). It is located in the Inn valley near the city of Innsbruck (Tyrol, Austria). A roughly 200m high, south facing limestone cliff is the release area for the rock fragments, which are generally stopped by the forest or by the rockfall nets above the railway line.

Methods

Increment cores were taken from 33 *P. abies* and 50 *F. sylvatica*. Different sampling strategies were applied for the different species: three to four cores (144 in total) were taken for *P. abies* and only one core per tree (50 samples) for *F. sylvatica*. Firstly, rockfall events in the spruce trees were identified by typical growth disturbances in the tree-ring series such as tangential rows of resin ducts, scars, callus tissue or reaction wood and dated with yearly precision. Secondly and as mechanical impacts remain clearly visible on the bark of beech trees, rockfall events in beech were derived by simply counting visible rockfall impacts on the stem surface. Recurrence intervals were calculated for each individual tree by dividing the age of the tree by the number of impacts. Results were visualized by spatial interpolation.

Results

The analysis of the spruce increment cores yielded a total of 431 growth disturbances corresponding to 277 rockfall events since AD 1819 whereas the systematic observation of injuries on the stem surface of the beech trees allowed the identification of 1140 rockfall impacts.

Significant differences in absolute numbers of rockfalls result in different return intervals of rockfall events. With the "classic" dendrogeomorphic approach used for the analysis of the spruce trees, a mean return period for the entire study area of 18.4 years was computed. In contrast, an average recurrence interval of 8.7 years was derived from the beech trees. Differences were less marked for observed average jump heights with 0.9m for spruce and 0.7m for beech trees, respectively.

Spatial patterns of return periods are comparable independently of the approach used (Fig. 1): in both cases, higher rockfall frequencies are observed in the upper part of the study area as well as a canalizing effect of activity stemming from the relief.

Conclusion

Both methods yield reliable data on the spatial distribution of rockfall frequencies and jump heights in the study area, but results vary for different reasons. Due to the bark properties of beech, smaller rocks or rocks with lower kinetic energy will not damage spruce trees but still leave scars in the thin bark of beeches. Differences in return intervals can be due to the differences in tree locations as well as to the fact that multiple impacts in the same year would only be counted one event in spruce whereas each injury in the beech trees would constitute an individual event. Hence, a reconstruction solely based on increment cores from spruce trees runs the risk of underestimating absolute recurrence intervals whereas impact counts on beech trees may lead to some overestimation of rockfall activity and resulting return intervals in case that the impact of individual rocks leaves multiple scars on the stem surface.

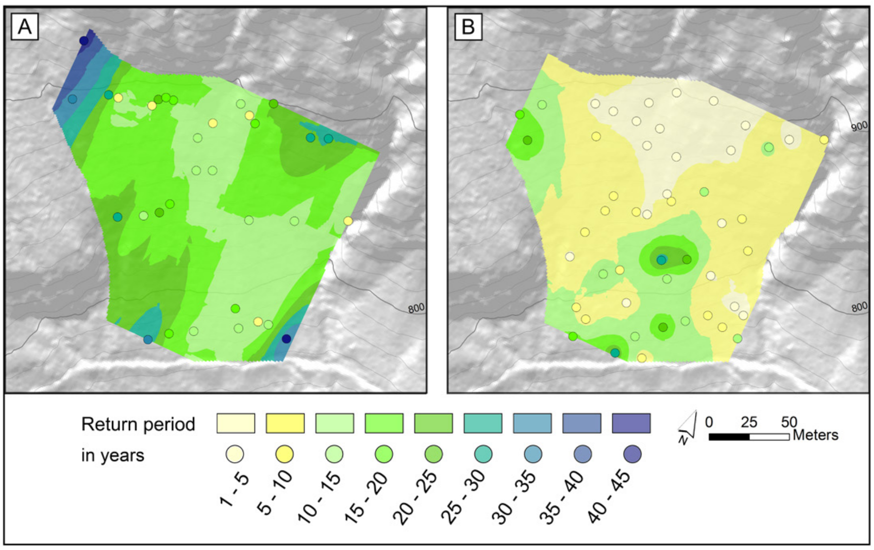

Fig. 1. Interpolated (inverse distance weighting) recurrence intervals (in years) for A) spruce trees and B) beech trees

P 10.9

Detection of surface changes in a torrent channel and comparison of surveying techniques

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Debris flow events have threatened mountain communities for centuries. The knowledge of triggers and process behavior is essential for an effective risk management. Recent events have shown that due to efficient erosional processes within the channel the debris flow can strongly increase in volume and cause unexpected high damage in the runout area. During the event the channel morphology is strongly reworked and debris entrainment changes the flow dynamics. Both highlighted factors are not included in numerical simulations of debris flows and debris flow erosion and deposition are still poorly understood. Methods to study the highly variable processes are in their infancy and standardized approaches are still missing. The present study aims to detect surface changes and quantify erosion and deposition caused by debris flow and bedload transport. A further topic is the evaluation and comparison of surveying techniques. The study contributes to a research project on improving simulation of debris flows (cf. Bühler et al. 2010; Christen et al. 2010). Due to the lack of debris flow events during the field season the work focuses upon methodological problems.

Field work was conducted during the summer season 2011 in the Dorfbach in Randa. The debris flow channel was surveyed by means of cross sections measured with a laser rangefinder (TruPulse 360B) combined with a differential GPS (Trimble GeoXH6000). In addition, further measurements were carried out with a terrestrial laser scanner (Leica ScanStation C10). Geomorphological mapping and a photo documentation were established in order to integrate punctual surveying data into the overall situation. The data collected allows the comparison of at least three terms and an evaluation of continuous as well as event-based changes. Surveying methods are evaluated with regard to the analysis of erosion and deposition by debris flows. The applied surveying techniques are compared with further methods described in literature, which in this study results in a methodological recommendation.

A first assessment of the collected data highlights, that no major morphological changes occur in the channel without a debris flow or bedload transport event. Detected continuous changes may be caused by variations in the watercourse or the collapse of instable bank segments. The volumetric change due to erosion amounts to 30 - 100m^3 and to 15 - 50m^3 caused by deposition within a surveyed channel area of 2460m^2. Furthermore, the surface changes as a result of a flood in August 2011 are clearly detectable and verifiable with photos. For this event, erosion amounts to 520 - 560m^3 and deposition to 680 - 730 m^3 for the same channel area. The applied surveying methods both allow change detection with an accuracy of a few decimeters. Therefore the collected data is by far detailed enough to detect surface changes caused by debris flow events. When evaluating the applicability of different methods for the aims stated, data quality issues are considered as well as local preconditions, resolution requirements and logistic aspects. Further results as well as their discussion and a conclusion are presented in the poster.

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P 10.10

Hazard mapping and an early warning system for lake outburst floods in the Cordillera Blanca, Peru

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The Peruvian Cordillera Blanca is strongly affected by climate change impacts, like many other high mountain regions around the world. The combination of a high population density in close vicinity to steep slopes and retreating glaciers has led to some of the most devastating glacier-related mass movement disasters where thousands of people were killed during various events over the past decades (Carey, 2005). The main hazards include ice/rock avalanches, debris flows and glacier lake outburst floods (GLOFs), which are often parts of complex process chains. There are strong concerns that climate change favors such mass movements by destabilizing perennially frozen bedrock and steep glaciers, and that the frequency and magnitude of these events might increase in future (Huggel et al., 2010).

To prevent such disasters, an early warning system is currently being implemented in the Río Chucchún catchment above the city of Carhuaz (~9000 residents). At this site, successful prevention measures took place in the early 1990's, when the water level of the proglacial rock-dammed Lake 513 has been lowered by 20m (Reynolds et al, 1998). However, the changing thermal conditions in the steep and glacierized rockwalls above the lake is a probable trigger of a huge rock-ice avalanche, which occurred on April 11, 2010. Its impact wave in Lake 513 overtopped the freeboard and led to a debris flow and flood which reached down to the alluvial fan of Carhuaz. Fortunately, no victims were claimed, but a lot of agricultural land and several bridges have been destroyed. According to the current state of the glaciers, larger avalanches with more serious consequences cannot be excluded.

In a first step, the hazards have been analyzed and the hazard map elaborated by the 'Instituto Nacional de Defensa Civil' in 2004 has been updated (Figure 1). This has been done by applying an avalanche model (RAMMS::avalanche) for different scenarios, a lake impact and flood wave simulation model (IBER), and by using segment-wise varying frictional rheologies for a debris flow model (RAMMS::DEBRIS FLOW) to account for the complex flow transformations.

As a second step, a technical early warning system is currently being implemented in the field. It is composed by two main measurement stations, a repeater station to transmit the signal, and a communication and data center in the town of Carhuaz (Figure 1). The stations cover two aspects: (I) a long-term perspective that includes high quality climatic and discharge measurements by a new station at 3600m a.s.l., and automatic multi-temporal daily photographic monitoring of the steep glacierized flanks of Nevado Hualcán. This will enable to better characterize the local climatic characteristics, the water balance of the catchment, and to detect changes in the stability of the hanging glaciers. The system further comprises (II) a real-time early warning system for rock-ice avalanches and debris flows. It is based on 4 geophones near the avalanche source area at 4491 and 4752m a.s.l., which activate two cameras in the case of an event. To reduce the risk of false alarms the civil defence needs to verify the alarm based on the video images, and the event needs to be confirmed by other geophones and the discharge measurement sensor at the lower station at 3600m a.s.l. Despite of the redundancy of the sensors, an intense testing and calibration phase will be particularly needed for the geophones to achieve a high level of confidence in the system.

The next steps include instructing the responsible authorities, establishing the alarm chains, informing the population about the hazards, and finally the implementation of acoustic alarms at some sites within the flood path and the alluvial fan to alert the population in time in case of a hazardous event.

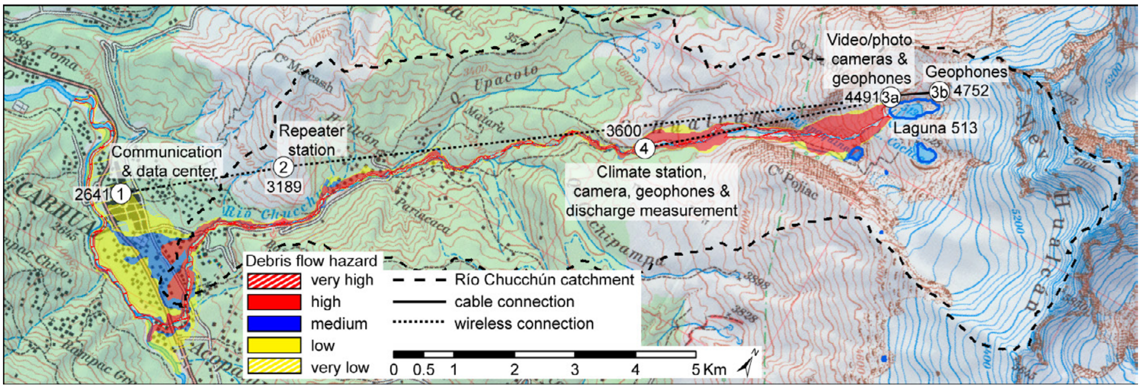

Figure 1. Río Chucchún catchment above the city of Carhuaz with the updated hazard map and the stations of the monitoring and early warning system (background: Alpenvereinskarte 1:100,000).

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P 10.11

Bewirkt ein Extremereignis eine Veränderung des Systemzustands in Wildbacheinzugsgebieten? Fokus: Auswirkungen auf den Geschiebehaushalt – Fallbeispiel Lötschental

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Aussergewöhnliche Witterungsbedingungen (langanhaltende Starkniederschläge, hohe Neuschneemengen und markantes Tauwetter) führten am 10.10.2011 an den Nordhängen des Lötschentals zu einem Extremereignis aus geomorphologischer Sicht. Während mehreren Stunden wurden ungewöhnlich grosse Mengen an Feststoff von den nördlichen Seitenbächen, insbesondere vom Golm-, Mili- und Tännbach, der Lonza zugeführt oder auf den Kegeln abgelagert. Dieses Ereignis führte zu Schäden hauptsächlich an der Infrastruktur und zur Unterbrechung der Strassenverbindungen im Lötschental. In den Einzugsgebieten wurde starke Tiefenerosion um mehrere Meter an den Bachsohlen sowie eine räumlich differenzierte Verbreitung des Gerinnebetts und Hanginstabilitäten festgestellt. Bemerkenswert ist, dass in direkt benachbarten Einzugsgebieten (Gafenbach, Gisentella) hingegen nur eine geringe Geschiebeführung beobachtet werden konnte. Spuren von geomorphologischer Aktivität fehlen in diesen Einzugsgebieten (Geoplan AG, 2012).

Ziel dieser Arbeit ist die Analyse der unterschiedlichen Reaktionen dieser Wildbacheinzugsgebiete auf die aussergewöhnlichen Witterungsbedingungen anhand des Konzepts der Disposition (Grunddisposition, variable Disposition, Auslöser; Zimmermann et al. 1997). Im Konzept der Disposition werden räumlich und zeitlich variable Aspekte, die zu Murgängen oder Geschiebeführung beitragen, beleuchtet und somit auch die Veränderung des Systemzustandes über die Zeit analysiert. Die Vergleichsanalyse erfasst daher räumlich und zeitlich differenzierte Informationen zu Relief, hypsometrische Flächenverteilung, Materialeigenschaften und -verfügbarkeit, Bodenbedeckung bzw. -nutzung und hydro-meteorologische Bedingungen in den fünf Einzugsgebieten. Das auslösende Ereignis (aussergewöhnliche Witterungsbedingungen) wird mit weiteren in der Vergangenheit erfassten Auslösebedingungen in diesen Einzugsgebieten verglichen. Zusätzlich wird mittels der Geschiebeabschätzungsmethode nach Lehmann (Lehmann 1993) das Geschiebepotential erfasst und jenen vor dem Ereignis gegenübergestellt. Ergebnisse der Studie werden aufzeigen, welche Unterschiede hinsichtlich Grunddisposition, variable Disposition und Auslöser in den Einzugsgebieten vorherrschten. Zudem sollen die Ergebnisse Auskunft geben über die Auswirkung des Extremereignisses vom 10.10.2011 und deren Bedeutung zur Beurteilung der aktuellen Disposition (mögliche gravierende Veränderungen der Grunddisposition oder der langfristigen variablen Disposition).

Eine ausführliche Beschreibung des Konzepts, inhärente Schwierigkeiten und Herausforderungen sowie erste Ergebnisse werden präsentiert.

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P 10.12

Process interactions during damage-relevant torrent events in the Swiss Alps

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Research on single geomorphological processes during damaging events has a long history; however, comprehensive documentations and analyses of the events have been conducted not until the late 1980ies. Thus, for high damaging events insights about triggering, the evolution and the impacts of processes during an event and the resulting damage were produced. Though, in the majority of cases the processes were studied in a well-defined procedure of one disciplinary focus. These focused studies neglect mutable influences which may alter the sequence of the process or the event. During damaging events multiple geomorphological processes are active which leads to the assumption, that they have a certain impact on each other and the course of damaging effect. Consequently, for a comprehensive hazard and risk analysis all processes of a catchment have to be analysed and evaluated quantitatively and qualitatively (MARZOCCHI, 2007). Although the demand for a sophisticated risk management is increasing, the research on interactions as well as on physical vulnerability to multiple hazards, including the different processes impact effects, is still very limited (KAPPES ET AL., 2010, 2011). The challenges in this field are the quantity of data needed and furthermore to conduct this kind of analysis is very complex and complicated (GREIVING ET AL., 2006, KAPPES et al. 2012). Yet, knowledge about possible interactions and resulting impact effects could significantly contribute to the reduction of risk in a region (DI MAURO ET AL., 2006).

The objective of this study is to analyse, i) how geomorphological processes interact with each other and with other factors of the surrounding during a damaging event, ii) what influences those interactions have on the resulting damage of the event and iii) whether or not different events are comparable in terms of those interactions and their impacts. To meet these objectives, 15 torrent damage events, which occurred between 2000 and 2011 in the Bernese Oberland or the Pennine Alps, were analysed on the basis of the event reports. The interactions were classified into different categories regarding a process and the interacting counterpart (another process, with structures or disposition) and the temporal and spatial extent in which these interactions occurred. Additionally positive and negative feedbacks of the processes were considered.

First results highlight that some types of interaction can be extracted in several events and that their temporal and spatial extent is comparable. However, the analysis (so far) indicates that single interaction exhibit multi-path consequences which complicate to educe general propositions for interactions influencing damage from event documentation. In the further step of this study, clusters of interactions which could occur in different events in similar ways are analysed in more detail.

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