Quantification of debris flow events in the upper Kauner valley (Ötztal Alps) for the years of 1953-2012

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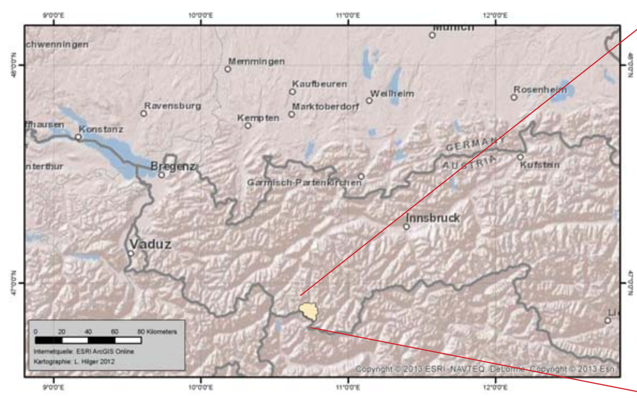
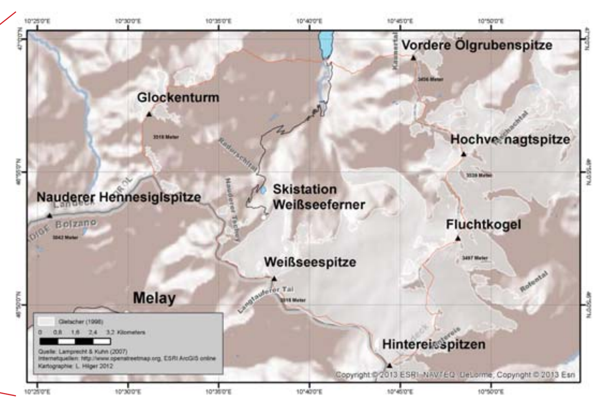
Introduction

When it comes to transport power, debris flow are among the geomorphologically most potent processes in high mountain areas. In addition, they often constitute an important process coupling slope and channel systems. In order to be able to quantify the contribution of these episodic processes to the sediment budge of a catchment, the magnitude-frequency relationship of debris flows of the area needs to be determined. The volume of debris flows can be measured using the so-called direct **morphological method** from multitemporal, high-resolution digital elevation models. Both, study area-wide airborne LiDAR data from different timesteps and georeferenced terrestrial LiDAR data have been made available. From single digital elevation models, volumes can be estimated by **reconstructing the pre-event surface**. For early time periods (pre 2006), only the debris flow deposition area can be mapped from orthophotos of comparatively many orthophotos (aerial images from eight different points in time (1953-2006) had been orthorectified). Using **empirical area-volume-relationships**, the debris flow volumes could be estimated. We present results from the quantification of debris flow from all three named workflows.

Study area

The Kauner valley is located in the Ötztaler Alpen (Austrian central alps). It is a tributary of the Inn river and is drained by the Fagge brook. Crystalline rocks (silicious para- and orthogneisses). The landscape is dominated by glacial landforms. The two main glaciers of the valley are deteriorating rapidly in terms of volume and length (Abermann et al. 2009).





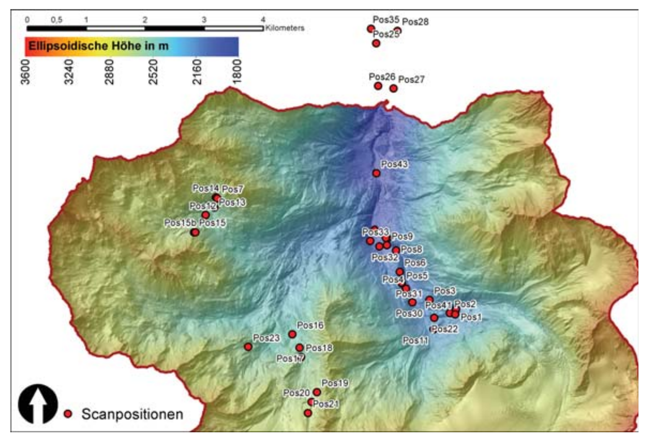


Fig.: TLS monitoring stations in the study area

Fig.: TLS Riegl Z-420i at monitoring position 29(left) and VZ-4000 at position 20 (right)

Data acquisition

- ALS: The topographic data used in this study were acquired in two ALS flight campaigns. The first campaign was conducted in September 2006, the second in September 2012. While the first mission yielded a point density of ~ 2 pt / m^2, the second resulted in ~ 10 pt / m^2. The first campaign was conducted by the Tyrolean State and the second was flown specficly for the PROSA project using the Riegl LMS-Q680i (= 1550 nm) sensor. 72 fight strips were adjusted and georeferenced using mountain hut roofs as tie surfaces (Kager, 2004).

- TLS: Almost 40 monitoring stations have been regularily visited since summer 2012. Until fall 2013, the Z-420i TLS model was used, later, the VZ-4000 of the same maufacturer was applied.
  The about 90 reflectors distributed at most TLS monitoring positions were levelled via total station (Leica TCRM 1205) and differential GPS (Leica GS09).

- Orthophotos: In order to be able to investigate the development of debris flow activity within the study area, aerial images of the years 1953, 1954, 1969, 1970, 1971, 1979, 1982 und 1990 and orthophotos of the years 2003, 2009 and 2010 were acquired. The aerial images were orthorectified and georeferenced using the Inpho software package.

Point cloud processing

The TLS scans were referenced in the scanner-own reference system using reflectors fixed in stable rock areas. Afterwards, all scans were transformed to the local UTM system (EPSG: 25832) by applying the reflector coordinates obtained via DGPS and total station.
Together with all ALS points, the TLS data (in total, there are several billion measurement points made available for the project) were stored and managed in a Postgres / PostGIS database (Rieg et al. 2013).
All processing steps on the point level were accomplished using different ready-made algorithms available in the software package LIS (http://www.laserdata.at). All processing steps on the grid level were accomplished using a combination of SAGA GIS (Conrad, 2006) and R's spatial extentsion packages (Brenning, 2009; Hijmans, 2013; Pebesma et al., 2014).

Mapping of debris flow extents

A geomorphological map of the study area, corresponding to the state of September 2009, was prepared at a scale of 1:6000. Field data, literature consideration, orthorectifed aerial images of different temporal volumes and multiple DEM-derived land surface parameters like slope, aspect, height above channel network or local percentile and a moving-window based delineation of rock wall sections were used facilitate the mapping process.

Budgeting

Sediment transport by debris flows can be quantified using multi-temporal high-resolution DEMs („the so-called morphological method"). The disposition areas of 156 debris flow events were mapped on orthorectified historical aerial images and raw DTMs of difference (DoDs) representing 10 different time periods.
Then, four different workflows were used to arrive at the debris flow volume, depending on the data available for the respective mapped debris flows:

a) differencing of georeferenced TLS-data
b) differencing of georeferenced ALS-data
c) differencing of ALS and TLS-data
d) differencing of ALS-data and a reconstructed pre-event surfaces
e) estimation of the volume based on a fitted relationship between planimetric debris flow disposition area and volume

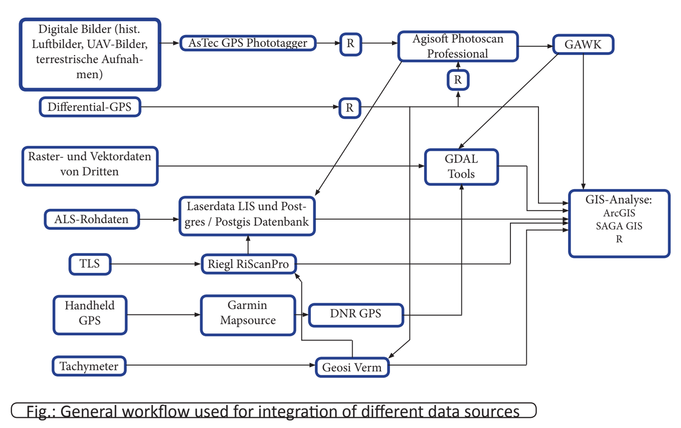


Fig.: General workflow used for integration of different data sources

Later, for each disposition area of the debris flows in categories a)-c) (#90), DEMs were constructed for each time steps using the method of moving planes which also returns grids of the standard deviation of the residuals resulting from the plane fitting for each timestep (σ_1 and σ_2). These were used to arrive at a grid of cellwise propagated error (σ_c) following the methodology described in Taylor (1997):

$$\sigma_c = (\sigma_1^2 + \sigma_2^2)^{0.5}$$

T-values for each cell were calculated to relate the raw cell difference to the propagated error:

$$t = \frac{z_1 - z_2}{\sqrt{\sigma_1^2 + \sigma_2^2}}$$

Then, probabilistic thresholding at the 95% confidence level was used to sort out DoD values considered to result from measurement errors. The error was also propagated cellwise into volumes and the significant volume measured within a debris flow deposition area was recorded for the event:

$$\sigma_v = d^2 \left(\sum_{i=1}^{I} \sum_{j=1}^{J} [\sigma_{1ij}^2 + \sigma_{2ij}^2] \right)^{0.5}$$

, where d is the cellsize and i, and j iterators for cell rows and columns in the error grids and σ_V is the propagated error in volume

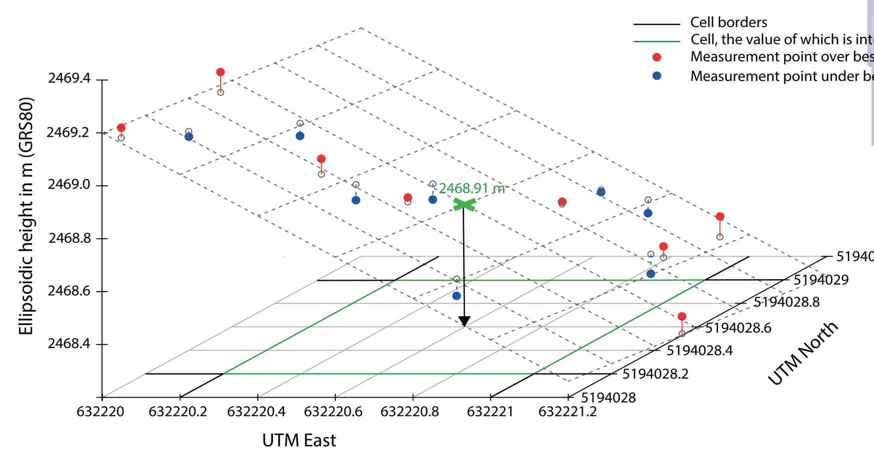


Fig.: Principle of gridding used in this stu-

SIMPLIFIED WORKFLOW (FOR EACH OF THE 153 DEBRIS FLOWS)

Automatic sorting and spliting of mapped debris flow polygons into years, geomorphic zones and possible budgeting methods
↓
Automat. generation of areas of interes (buffering of debris flow deposition zones)
↓
Export of ALS and TLS data for each AOI from the spatial postgres / postgis database
↓
Filtering of the point clouds-based on point neighbourhood statistics (esp. outlier detection and removal)
↓
First classification based on color attributes (TLS data only) (cf.. Haas et al. 2008)
↓
Classification: Rule-based segmentation followed by region growing (cf. Ying Yang & Foerster, 2010)
↓
Gridding & error propagation: Best fitting plane (see. Glira et al. 2014, Taylor 1997, Lane et al. 2003)
↓
Calculation of significant DoDs and volumes with spatially distributed errors and probabilisticly determined threshold (Wheaton 2008)

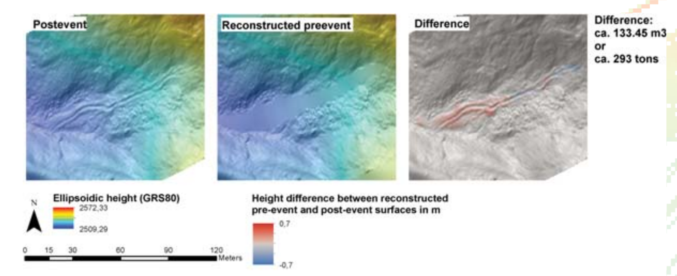
It has often been reported that the distribution of volumes of gravitational mass movements follow a simple power law:

$$p(x) = ax^{-\alpha}$$ (e.g. Bennett et al. 2012)

We fitted this and, as a comparison, a log-normal distribution to our data using the maximum liklihood method of (c.f. Clauset et al., 2009). Right now, the log-normal distribution looks more promising, but further work on the subject will be undertaken.

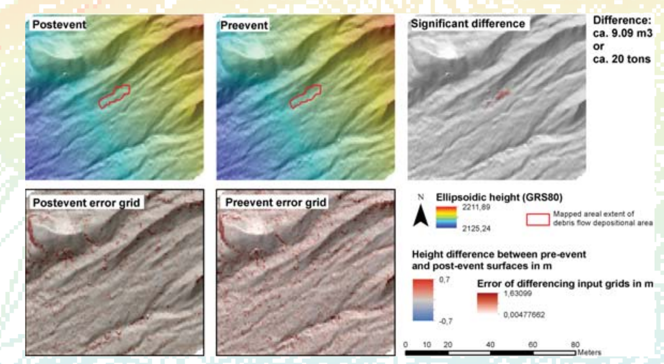
Results: Examples for some of the 153 events and different quantification startegies

d) differencing of ALS-data and reconstructed pre-event surface



Debris flow Nr. 1 (1953-1969)

b) differencing of georeferenced ALS-data



Debris flow Nr. 69 (July 2012 - Sept. 2012)

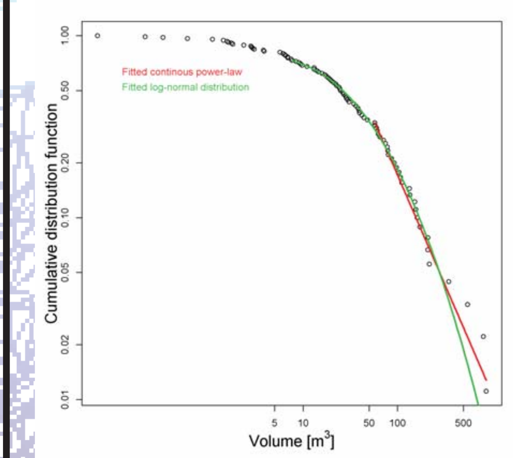


Abb.: Cumulative empiral distributions of the 153 debris flow volumes with power law and log-normal distribution fits

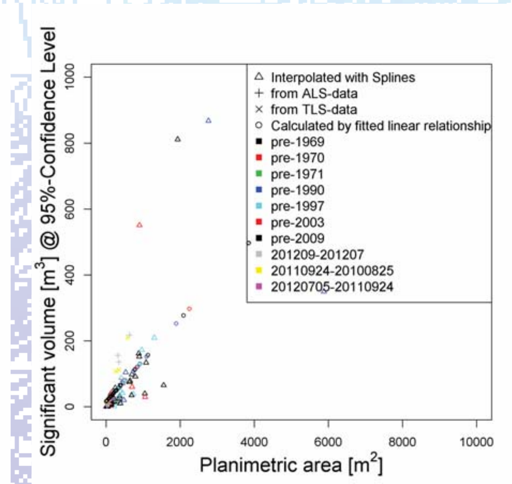


Abb.: Flächen-Volumen scatterplot für 153 Murgänge im Untersuchungsgebiet

Total debris flow volume 1953-2012: at least 29,300 tons

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