DEBRIS FLOWS: Disasters, Risk, Forecast, Protection

Proceedings
of the 5th International Conference

Tbilisi, Georgia, 1-5 October 2018

Editors
S.S. Chernomorets, G.V. Gavardashvili

Publishing House “Universal”
Tbilisi   2018

СЕЛЕВЫЕ ПОТОКИ: катастрофы, риск, прогноз, защита

Труды
5-й Международной конференции

Тбилиси, Грузия, 1-5 октября 2018 г.

Ответственные редакторы
С.С. Черноморец, Г.В. Гавардашвили

Издательство Универсал
Тбилиси 2018

ღვარცოფები: კატასტროფები, რისკი, პროგნოზი, დაცვა

მე–5 საერთაშორისო კონფერენციის მასალები

თბილისი, საქართველო, 1–5 ოქტომბერი, 2018

რედაქტორები
ს.ს. ჩერნომორეც, გ.ვ. გავარდაშვილი

გამომცემლობა "უნივერსალი"
თბილისი 2018

УДК 551.311.8
ББК 26.823

Селевые потоки: катастрофы, риск, прогноз, защита. Труды 5-й Международной конференции. Тбилиси, Грузия, 1-5 октября 2018 г. – Отв. ред. С.С. Черноморец, Г.В. Гавардашвили. – Тбилиси: Универсал, 2018, 671 с.

Debris Flows: Disasters, Risk, Forecast, Protection. Proceedings of the 5th International Conference. Tbilisi, Georgia, 1-5 October 2018. – Ed. by S.S. Chernomorets, G.V. Gavardashvili. – Tbilisi: Publishing House “Universal”, 2018, 671 p.

ღვარცოფები: კატასტროფები, რისკი, პროგნოზი, დაცვა. მე–5 საერთაშორისო კონფერენციის მასალები. თბილისი, საქართველო, 1–5 ოქტომბერი, 2018. გამომცემლობა "უნივერსალი", თბილისი 2018, 671 გვ. პასუხისმგებელი რედაქტორები ს.ს. ჩერნომორეც, გ.ვ. გავარდაშვილი.

Ответственные редакторы С.С. Черноморец, Г.В. Гавардашвили
Edited by S.S. Chernomorets, G.V. Gavardashvili

Верстка: С.С. Черноморец, К.С. Висхаджиева, Е.А. Савернюк
Page-proofs: S.S. Chernomorets, K.S. Viskhadzhieva, E.A. Savernyuk

При создании логотипа конференции использован рисунок из книги С.М. Флейшмана «Селевые потоки» (Москва: Географгиз, 1951, с. 51).
Conference logo is based on a figure from S.M. Fleishman’s book on Debris Flows (Moscow: Geografgiz, 1951, p. 51).

ISBN 978-9941-26-283-8

How to effectively monitor geomorphic changes in debris-flow channels

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Debris flows are among the most hazardous landslides. It is hypothesized that climate change leads to an increasing number of debris-flow events in alpine regions [e.g. *Dietrich et al., 2017*]. In June 2015 a rainfall event of about 90 mm in 45 min triggered two debris flows near Oberstdorf (Bavaria, Germany) in the Northern Alps. The debris flows resulted in damage costs of several million Euros and over 300 citizens had to be evacuated. In order to quantify the event magnitude and to monitor geomorphic changes after the event, high resolution digital elevation models (DEMs) were derived from terrestrial laser scanning (TLS) on several dates in the Roßbichelgraben. To avoid areas without data, the 800 m long channel was observed with over 70 laser scan positions on each date and DEMs of difference (DoDs) were calculated with spatially variable uncertainty. Simultaneously, DEMs were derived photogrammetrically from images taken with an unmanned aerial vehicle (UAV). Therefore, the structure from motion – multi-view stereo workflow (SfM-MVS) was used to create point clouds from images. The performed change detection shows that both methods provide reliable and similar results and can be both used to monitor geomorphic changes in debris-flow channels.

debris flow, unmanned aerial vehicle (UAV), structure from motion, terrestrial laser scanning (TLS), geomorphic change detection

Как проводить эффективный мониторинг изменений рельефа селевых русел

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Селевые потоки относятся к числу наиболее опасных типов природных явлений. Высказывается гипотеза о том, что изменение климата приводит к увеличению числа событий, связанных с селями в альпийских регионах (например, *Dietrich et al., 2017*]). В июне 2015 года количество осадков около 90 мм за 45 минут вызвало два селевых потока вблизи Оберстдорфа (Бавария, Германия) в Северных Альпах. Сели привели к ущербу в размере нескольких миллионов евро, и более 300 граждан пришлось эвакуировать. Чтобы количественно оценить величину события и контролировать геоморфологические изменения после события, были получены цифровые модели рельефа (DEM) путем наземного лазерного сканирования (TLS) на несколько дат в Россбихелграбене. Чтобы избежать областей без данных, русло длиной 800 м наблюдалось с более чем 70 положений лазерного сканера на каждую дату, и разница между DEM была рассчитана с пространственной неопределенностью. Одновременно DEM были получены фотограмметрически с изображений, снятых с беспилотного летательного аппарата (БПЛА). Поэтому для создания точечных облаков из изображений использовалась структура из многопользовательского стереопроцесса (SfM-MVS). Выполненное обнаружение изменений показывает, что оба метода обеспечивают надежные и сходные результаты и могут использоваться для мониторинга геоморфологических изменений в селевых руслах.

сель, беспилотный летательный аппарат (БПЛА), структура движения, наземное лазерное сканирование (TLS), мониторинг изменений рельефа

Introduction

Debris flows have caused nearly 80,000 fatalities worldwide between 1950 and 2011 [*Dowling et al., 2014*] and lead to costs of approx. 30 million € every year in Austria [*Oberndorfer et al., 2007*]. Intense rainfall events are known to be a typical triggering mechanism for debris flows [e.g. *Zimmermann et al., 1997*]. Investigations of *Scherrer et al.* [2016] have shown that frequency and intensity of such events have generally increased in the past 100 years, which applies particularly for the northern slopes of the Alps. Results of different climatic models show that this development is expected to persist or even intensify [*Frei et al., 2006; Rajczak et al., 2013*]. This leads to an increasing probability for the occurrence of debris flows, which has already been observed by several authors [e.g. *Stoffel et al., 2006; Dietrich et al., 2017*].

Knowing the magnitude of possible debris flows is very important for a variety of tasks, like the efficient design of retaining structures or the calibration of numerical models [*Jakob, 2005*]. However, the volume of a debris flow is highly depending on the entrainment of material during the event [*Hungr et al., 2005*]. Different methods have been developed for volume estimations: empirical correlations with varying characteristics of the watershed [e.g. *Rickenmann et al., 2010*], geometrical approximations of the volume of debris-flow cones [e.g. *Rickenmann et al., 2013*] or geometrical mapping of the debris-flow channel [e.g. *Gertsch, 2009*]. While these conventional methods are relatively easy to use and can deliver a fast and often good estimation of debris-flow volumes, their application can be subjective or limited to a particular region.

With LiDAR and UAV technology and high-end technical infrastructure becoming accessible to more people, studies that determine debris-flow volumes by topographic surveys of torrents have increased in recent years. While investigations with LiDAR-derived data (i.e. airborne and/or terrestrial laser scanning) have been carried out by several authors [e.g. *Bremer et al., 2012; Blasone et al., 2014; Theule et al., 2015*], studies with photogrammetrically derived data remain rare [e.g. *Sotier et al., 2013; Adams et al., 2016*]. This work focusses on the difficulties and differences in data acquisition with TLS and UAV. It shows (i) what problems can occur in TSL data acquisition, (ii) how they can be addressed and (iii) what new possibilities are offered by UAV.

Study site

The study site is located near Oberstdorf in the Northern Calcareous Alps in southern Germany (Fig. 1). The studied part of the channel is 800 m long, descends with an average angel of 19° and lies between 1410 m and 1220 m a.s.l. A debris flow occurred on 14 July 2015, which was triggered by an exceptionally intense inductive rainstorm event (90 mm in 45 min).

The main source for debris is the Late Triassic Hauptdolomit, which is known to have formed large taluses in the Alps by weathering [*Scholz, 2016*] and forms the bedrock in the upper parts of the channel [*Zacher, 1990*]. The rock formation can reach a thickness of up to 1,000 m [*Scholz, 2016*]. While the original bedding is widely spaced, closely spaced joints have been formed during the deformation by the alpine orogenesis [*Scholz, 2016*]. A smaller part of the debris consists of sandstones of the Rehbreingraben-Formation that forms the bedrock in the lower parts of the channel [*Zacher, 1990*]. Alternating marly claystones and quartz-rich sandstones are characteristic for this flysch rock formation that was deposited in the Cretaceous as a result of turbidites [*Zacher, 1990; Scholz, 2016*].

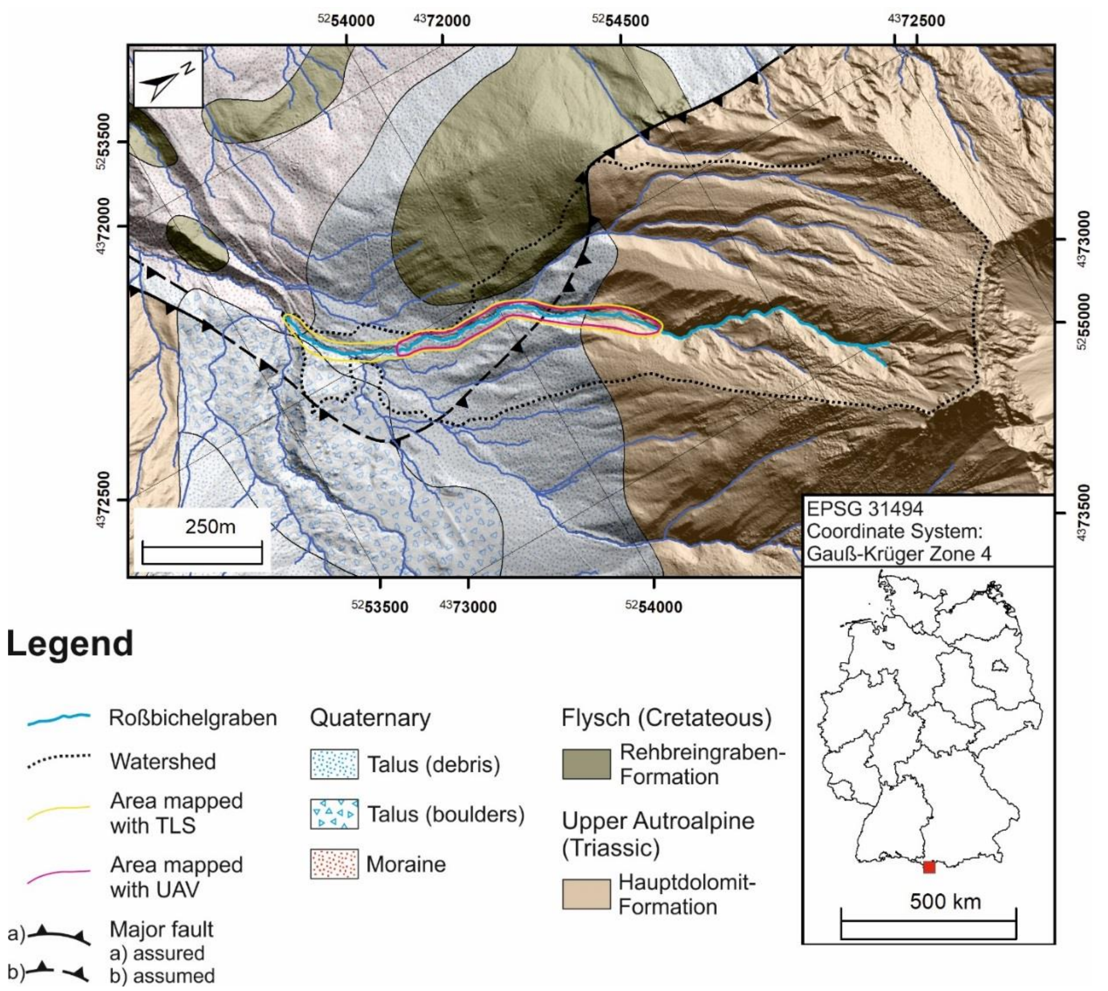

Fig. 1. Location of the surveyed Roßbichelgraben in southern Germany. Hillshade provided by Bavarian Land Surveying Office; geological information after [*Zacher*, *1990*].

Methods

Terrestrial Laser Scanning

Laser measurements were made with a VZ-400 by Riegl LMS. The device uses laser pulses of near infrared wavelength with a measurement rate of 122,000 pts/s. The first survey was carried out on 21 June 2015 with 26 scan positions, 7 days after the event to estimate the magnitude of the event. Two surveys were carried out in 2016 and five in 2017 in order to monitor geomorphic changes in the channel. To minimize occlusion in the resulting point clouds the number of scan positions increased to nearly 80 at each survey date. The increment during the scanning process was at least 0.06°, which corresponds to a point distance of 1 cm at a distance of 10 m.

Point clouds were processed in RiSCAN Pro. Registration was performed in two steps. Firstly, the point clouds were registered using a point-to-point registration with four identical points in two corresponding point clouds. This resulted in a standard deviation of differences between point clouds of 2-8 cm. Secondly, to refine the registration, a multi station adjustment was carried out using plane patches. This method is a feature-based registration comparing planes that can be identified with an algorithm and represent small areas of the point clouds (Fig. 3). By comparing these planes, the standard deviation of differences between point clouds dropped to 0.2-1 cm. Registration of consecutive point clouds was executed with reference to the previous point cloud following the approach of *Schürch et al.* [2011]. The registered point clouds were filtered to remove errors and vegetation and to reduce and homogenise point density with a variety of automatic algorithms.

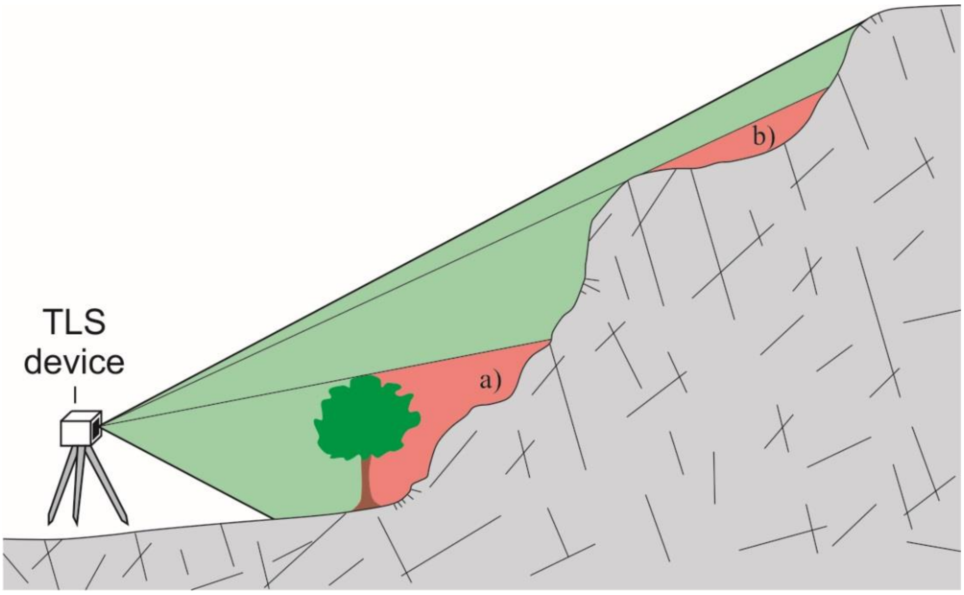

Fig. 2. Occlusions (red) in TLS point clouds can have different reasons. a) a tree blocking the field of view causing occlusion; b) topography of a rock face or embankment causing occlusion. After [*Abellán et al., 2014*]

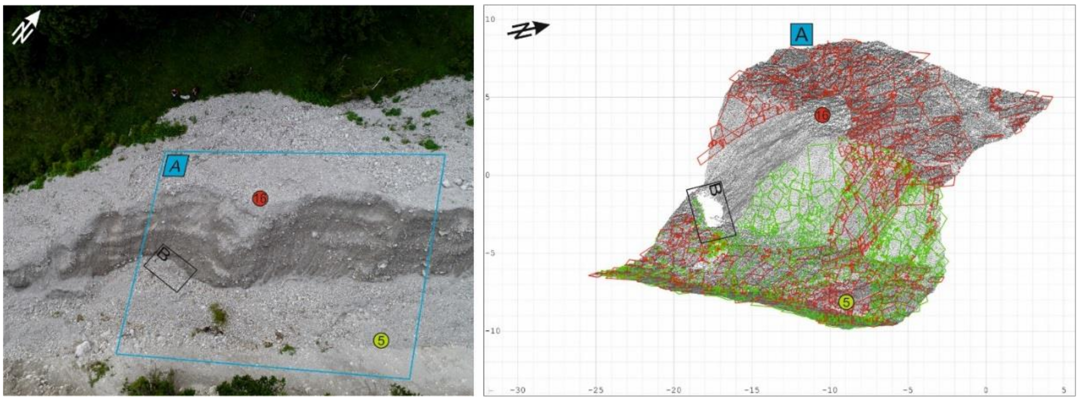

Fig. 3. Plane patches were used to register the point clouds. Left: Image of the channel embankment. Right: Point cloud of area A (left) with plane patches of scan position 5 (green) and 16 (red). B: Area without data points due to occlusion

Unmanned aerial vehicle

In 2017, an UAV was used to map the channel on four occasions simultaneously to the TLS surveys. The used UAV was a DJI Phantom 4 Pro, a low-cost drone with a 20-megapixel camera. Due to more dense vegetation and limitations in flight time in the lower parts, the UAV mapping was exclusively carried out in the upper 550 m of the channel. Images were taken every two seconds. The shutter speed, aperture and ISO were set manually. To fulfil the requirements for optimal 3D reconstruction [e.g. *Westoby et al., 2012*], the images were taken with four different camera orientations. Spatial information of the images was given by the UAVs internal GNSS system.

We processed the images with Agisoft PhotoScan Pro. The software offers a complete workflow of SfM-MVS, from image filtering, keypoint matching to dense cloud generation. However, the functioning of the single algorithms is mainly secret and unknown making the program a "black box". Images were processed following the predefined workflow of PhotoScan Pro. After aligning the images (structure-from-motion algorithm), we used the gradual selection tool to filter the resulting sparse cloud in order to minimize errors before calculating the dense cloud (multi-view stereo algorithm). Ground control points (GCPs) were identified in the TLS point clouds and implemented in Photoscan Pro.

In a final step the dense cloud was filtered in RiSCAN Pro to remove erroneous points and vegetation and to reduce and homogenize point density.

Geomorphic change detection

The point clouds derived with TLS and UAV were interpolated into DEMs in ArcGIS (v. 10.4). Geomorphic changes were calculated with the plugin GCD (v. 6.1.14) developed by *Wheaton et al.*, [2010] resulting in DEMs of difference (DoD). As this method is a 2.5D based calculation, it has disadvantages in very steep areas. However, it is possible to calculate volume errors with a spatially variable error model, which is a major advantage over the 3D calculation with the M3C2 algorithm developed by *Lague et al.* [2013]. Uncertainties were considered using a fuzzy inference system (FIS) that considers, that DEM uncertainty is higher in areas with low point density and steep slopes [e.g. *Wheaton et al., 2010; Schürch et al., 2011; Blasone et al., 2014*].

Results

During processing of the first survey it became clear, that although 26 scan positions were used to map the channel (in average every 30 m) there still remain some occluded areas (Fig. 4 A). By substantially increasing the number of scan positions to nearly 80 (in average every 10 m), we managed to map all parts of the channel almost completely without occlusions (Fig. 4 B).

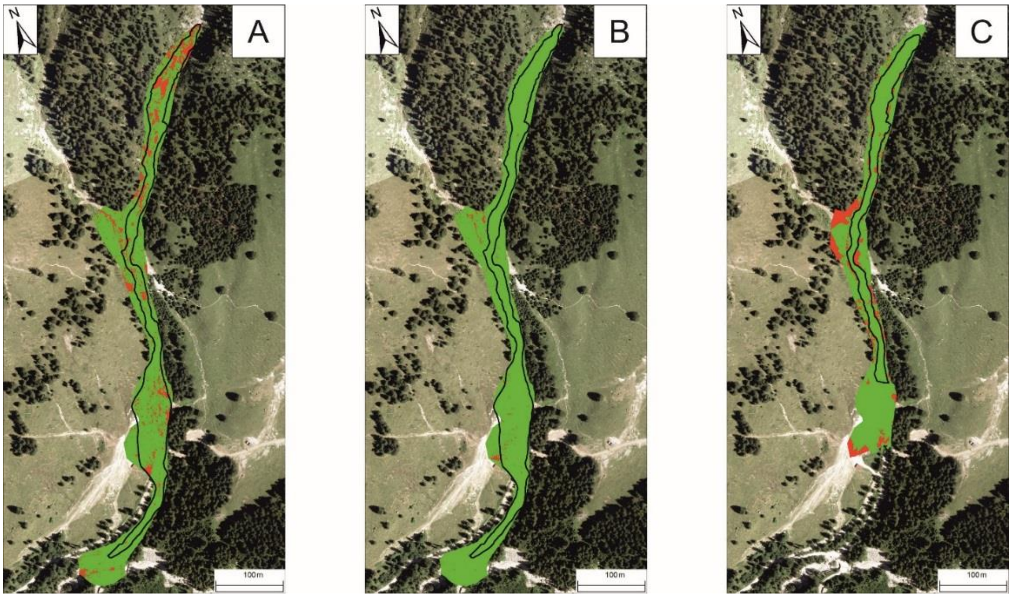

Fig. 4. Due to occlusion the generated DEMs have areas without data (red) that have to be interpolated in order to calculate geomorphic changes. A: TLS of June 2015; B: TLS of June 2017; C: UAV of July 2017. Black outline: Area of interest. Orthophoto provided by Bavarian Land Surveying Office

These time-consuming TLS surveys in field (8 h) result in an equally time-consuming data processing and big data volumes. Therefore, UAV mapping emerges as a more time-efficient method with survey times of 1.5-2 hours resulting in almost occlusion free point clouds (Fig. 4 C). Large data lacks in Fig. 4 C (red areas) are mainly caused by manually filtered points that represent vegetation.

While field surveys are much more time-efficient using UAVs, the accuracy of TLS-data remains unreached. However, geomorphic changes can be equally identified with both UAV derived DoDs (left) and TLS derived DoDs (right) (Fig. 6).

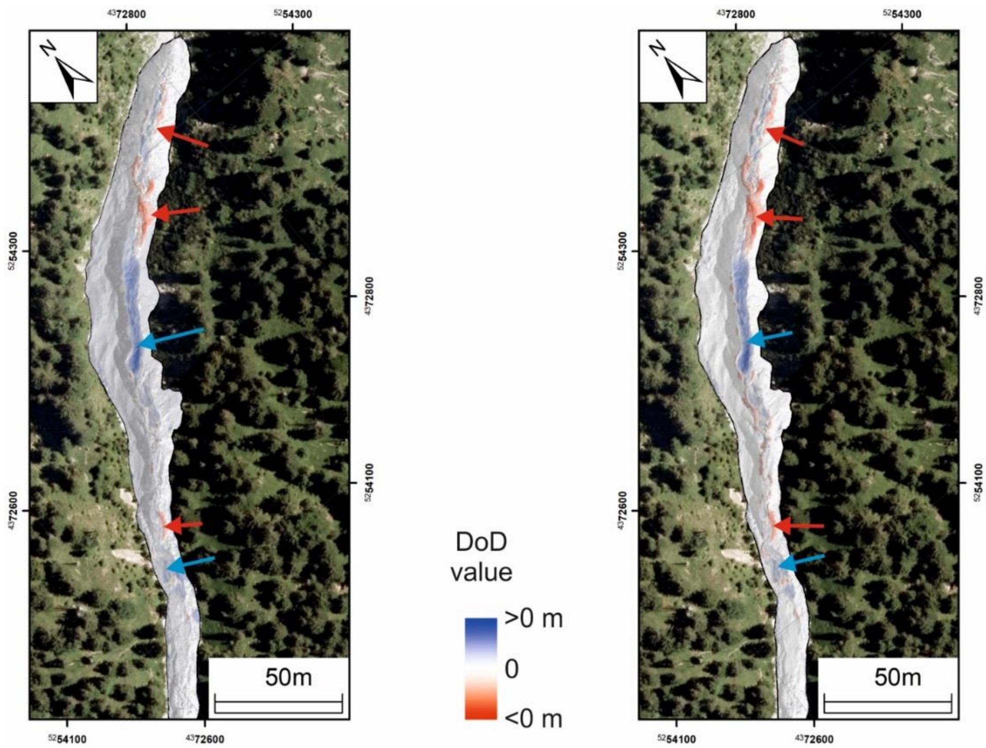

Fig. 5. DoDs derived with SfM-MVS (left) and TLS (right) between May and July 2017. Orthophoto provided by Bavarian Land Surveying Office

Discussion

Results of TLS data analysis have shown that a very high number of scan positions is necessary to create an occlusion-free data set, resulting in time-consuming surveys and data processing. Therefore, UAV mapping and photogrammetric reconstruction of the terrain have emerged as a more cost- and time-efficient method for topographic surveys. In principle, it is possible to identify geomorphic changes with DEMs derived from UAV mapping, but much effort has to be put into identifying and implementing GCPs, filtering images and optimizing the point cloud. An important factor influencing the quality of the photogrammetric point clouds is image quality. By keeping shutter speed and ISO low to avoid image blur and noise and adjusting the aperture in order to equally expose images the best results were achieved.

Conclusions

UAV mapping has emerged as a new method for topographic surveys and has advantages in terms of time and cost efficiency over TLS. While there are still issues regarding DEM accuracy, it is an alternative to the conventional TLS surveys. In near future further improvements in the SfM-MVS workflow will even enhance the advantages of this method.

We showed that (i) it can be very difficult to eliminate occlusion in TLS point clouds of debris-flow channels, (ii) a large number of scan positions is needed to avoid data lacks and (iii) how UAV can be used to obtain comprehensive data.

References

Abellán A., Oppikofer T., Jaboyedoff M., Rosser N.J., Lim M., Lato M.J. (2014). Terrestrial laser scanning of rock slope instabilities. Earth Surface Processes and Landforms, 39(1): 80-97.

Adams M.S., Fromm R., Lechner V. (2016). High-resolution debris flow volume mapping with unmanned aerial systems (UAS) and photogrammetric techniques. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences XLI-B1: 749–755.

Blasone G., Cavalli M., Marchi L., Cazorzi F. (2014). Monitoring sediment source areas in a debris-flow catchment using terrestrial laser scanning. CATENA, 123: 23–36.

Bremer M., Sass O. (2012). Combining airborne and terrestrial laser scanning for quantifying erosion and deposition by a debris flow event. Geomorphology, 138: 49–60.

Dietrich A., Krautblatter M. (2017). Evidence for enhanced debris-flow activity in the Northern Calcareous Alps since the 1980s (Plansee, Austria). Geomorphology, 287: 144–158.

Dowling C.A., Santi P.M. (2014). Debris flows and their toll on human life. Natural Hazards, 71(1): 203–227.

Frei C., Schöll R., Fukutome S., Schmidli J., Vidale P.L. (2006). Future change of precipitation extremes in Europe. Journal of Geophysical Research, 111(6): D06105.

Gertsch E. (2009). Geschiebelieferung alpiner Wildbachsysteme bei Grossereignissen – Ereignisanalysen und Entwicklung eines Abschätzverfahrens. PhD-Thesis, Geographical Institute, University of Bern, Bern.

Hungr O., McDougall S., Bovis M. (2005). Entrainment of material by debris flows. In: Jakob M., Hungr O. (eds.) Debris-flow hazards and related phenomena, pp. 135–158. Springer, Berlin.

Jakob M. (2005). Debris-flow hazard analysis. In: Jakob, M. & Hungr, O. (eds.) Debris-flow hazards and related phenomena, pp. 135–158. Springer, Berlin.

Lague D., Brodu N., Leroux J. (2013). Accurate 3D comparison of complex topography with terrestrial laser scanner: application to Rangitikei canyon (N-Z). ISPRS Journal of Photogrammetry and Remote Sensing, 82:10-26.

Oberndorfer, S., Fuchs, S., Rickenmann, D. & Andrecs, P. (2007): Vulnerabilitätsanalyse und monetäre Schadensbewertung von Wildbachereignissen in Österreich. BFW-Berichte, 139: 1–55.

Rajczak J., Pall P., Schär C. (2013). Projections of extreme precipitation events in regional climate simulations for Europe and the Alpine Region. Journal of Geophysical Research: Atmospheres, 118 (9): 3610–3626.

Rickenmann D., Koschni A. (2010). Sediment loads due to fluvial transport and debris flows during the 2005 flood events in Switzerland. Hydrological Processes, 24(8): 993–1007.

Rickenmann D., Scheidl C. (2013). Debris-flow runout and deposition on the fan. In: Schneuwly-Bollschweiler M., Stoffel M., Rudolf-Miklau F. (eds.) Dating torrential processes on fans and cones, pp. 75–93. Springer, Dordrecht.

Scherrer S.C., Fischer E.M., Posselt R., Liniger M.A., Croci-Maspoli M., Knutti R. (2016). Emerging trends in heavy precipitation and hot temperature extremes in Switzerland. Journal of Geophysical Research: Atmospheres, 121 (6): 2626–2637.

Scholz H. (2016). Bau und Werden der Allgäuer Landschaft. 3rd edn. Schweizerbart, Stuttgart.

Schürch P., Densmore A.L., Rosser N.J., Lim M., McArdell B.W. (2011). Detection of surface change in complex topography using terrestrial laser scanning. Earth Surface Processes and Landforms, 36 (14):1847–1859.

Sotier B., Graf A., Kammerlander J. (2013). Einsatz von UAV im alpinen Gelände. Erfahrungsbericht und Anwendungsbeispiel aus der Naturgefahrenpraxis. Österreichische Zeitschrift für Vermessung und Geoinformation, 101(2+3): 110–118.

Stoffel M., Beniston M. (2006). On the incidence of debris flows from the early Little Ice Age to a future greenhouse climate: A case study from the Swiss Alps. Geophysical Research Letters, 33(16): L16404.

Theule J.I., Libault F., Laigle D., Loye A., Jaboyedoff M. (2015). Channel scour and fill by debris flows and bedload transport. Geomorphology, 243: 92–105.

Westoby M.J., Brasington J., Glasser N.F., Hambrey M.J., Reynolds J.M. (2012). 'Structure-from-Motion' photogrammetry. Geomorphology, 179: 300-314.

Wheaton J.M., Brasington J., Darby S.E., Sear D.A. (2010). Accounting for uncertainty in DEMs from repeat topographic surveys: improved sediment budgets. Earth Surface Processes and Landforms, 35(2):136–156.

Zacher W. (1990). Geologische Karte der Republik Österreich 1 : 50,000, Blatt 113 Mittelberg. 1st edn. Geologische Bundesanstalt, Vienna.

Zimmermann M., Mani P., Romang H. (1997). Magnitude-frequency aspects of alpine debris flows. Eclogae geologicae Helvetiae, 90 (3): 415–420.