A multi-year record of topographic changes on debris-flow fans in south-western British Columbia, Canada

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Abstract. Repeat observations of four debris-flow fans in south-western British Columbia, Canada, were made using a UAV-lidar system. Detailed measurements of deposit thicknesses and volumes have been generated from the data. We present channel measurements and characteristics for one of the sites to demonstrate the utility of the repeat lidar scanning technique to provide insights into where avulsions occur during debris flows. Through continued monitoring, we plan to obtain greater detail on a wider variety of events and the characteristics of avulsion locations.

1 Introduction

Debris flows are periodic, surging flows of water and debris, and are a common hazard in mountainous terrain [1]. Debris-flow mobility is affected by the channel and fan topography, the characteristics of the flowing material, and the number and type of surges within an event. The periodic nature of debris flows, with multiple events happening over time in the same channel, means that past events can be used as an indication of potential future events. The events are separated by days to years of inactivity or channel modification by fluvial processes, which may also affect the behaviour of future debris flows.

Modern techniques make it possible to collect repeated, high-resolution topographic surveys of debris flow channels. Airborne lidar surveys before and after debris flows have allowed the quantification of erosion and deposition with a level of precision not previously possible (e.g., [2], [3]). Photogrammetric techniques have been used to collect repeat surveys of the Gadria channel in Italy [4] and the Illgraben channel in Switzerland [5]. In both of these cases, the channel has been modified with control structures such as check dams. Physical modelling experiments have been conducted to examine fan evolution over time without the effects of control structures in the channel [6], [7].

This work focuses on the evolution of debris flow fans with little anthropogenic modification. We present the results of four annual, high-resolution topographic survey and imagery collection. We used a UAV-based lidar system to allow for accurate surface mapping, on heavily vegetated slopes where photogrammetric methods would have limited utility. Our goal is to capture detailed data on the event volume, erosion and deposition patterns of individual debris-flow events, and to examine the effects of small events and ongoing fluvial processes between the large events. Long-term, we want to use these data to better understand how previous debris flows and channel modifications between events control the future evolution of fans, particularly with respect to identifying potential avulsion locations.

2 Methodology

We used an uncrewed aerial vehicle (UAV) lidar system to collect high-resolution topographic data for four debris-flow fans. The system utilized a lidar scanner, inertial measurement unit (IMU), global navigational satellite system (GNSS) receiver, and a downward facing camera mounted to a UAV. A static GNSS base station was used to provide stable reference data for post-processing. Commercially available survey software was used to combine the data sources to create a lidar point cloud, refine the point cloud, and classify the points.

We compared lidar datasets at each site to quantify topographic changes between surveys. We performed the analysis using software that automatically completes the iterative closest point (ICP) alignment and multiscale model to model cloud comparison (M3C2) change detection [8].

Finally, we examined the results of the analyses in GIS software to identify debris-flow events and quantify their areas and volumes. Locations of channel avulsions, when present, were also recorded.

3 Study sites

Our study sites are within the Coast Mountain range of south-western British Columbia, Canada. We completed annual surveys on one fan at the base of the north face

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of Mount Currie, Currie D, from 2019 to 2022. An adjacent fan, Currie C, was surveyed from 2020 to 2022. The geology of the catchment area is characterized by igneous rocks, primarily foliated quartz diorites. Weathering of the rock has resulted in extensive talus slopes, and supply unlimited (also known as transport-limited) conditions for debris flows [9]. The climate is temperate, with warm dry summers and wet cool winters, including Pacific storms that bring heavy rain and snow [9].

We completed annual surveys at two fans on the west face of Fountain Ridge, Fountain North and Fountain South, from 2019 to 2022. The bedrock geology in the catchment area consists of sedimentary rocks including greywackes, argillites and conglometerates. Extensive talus slopes are present in the catchment area, leading to a supply unlimited condition [9]. The Fountain Ridge site is within the rain shadow of the Coast Mountains, where it is drier throughout the year, with warmer summers. Debris flows can be triggered by spring rain on snow events or summer thunderstorms [9].

4 Results

An approximately 100,000 m^3 event occurred at Currie D between July 3rd and 12th, 2019 [9]. Our first survey at Currie D was in October 2019, however, there was an airborne lidar survey available from 2017, allowing us to complete a change-detection analysis, detailed in Zubrycky et al. [9].

Debris flows were triggered on both Fountain North and South in 2021, and on Fountain North in 2022. The results of the topographic change detection for 2020 and 2021 relative to our 2019 baseline for Fountain South are shown in Figure 1. This event had a deposit volume of approximately 43,000 m^3. The Fountain South 2021 event is the subject of the more detailed characterization that follows.

We identified three avulsion locations from the 2021 event (Fig. 2) and extracted topographic data along the previous flow path (active channel) from the 2019 lidar (Fig. 3). The uppermost avulsion featured flow spilling over both sides of the channel. It is coincident with the presence of a road, channel curvatures, a reduction in channel gradient, and a reduction in channel depth (Fig. 3). The middle avulsion occurred at a slight bend in the channel, and where the channel downslope was slightly flatter and less-incised (Fig. 3, Fig. 4a). The lowermost avulsion featured a splitting of the flow, and is located upslope of where the previous channel begins to lose confinement (Fig. 3).

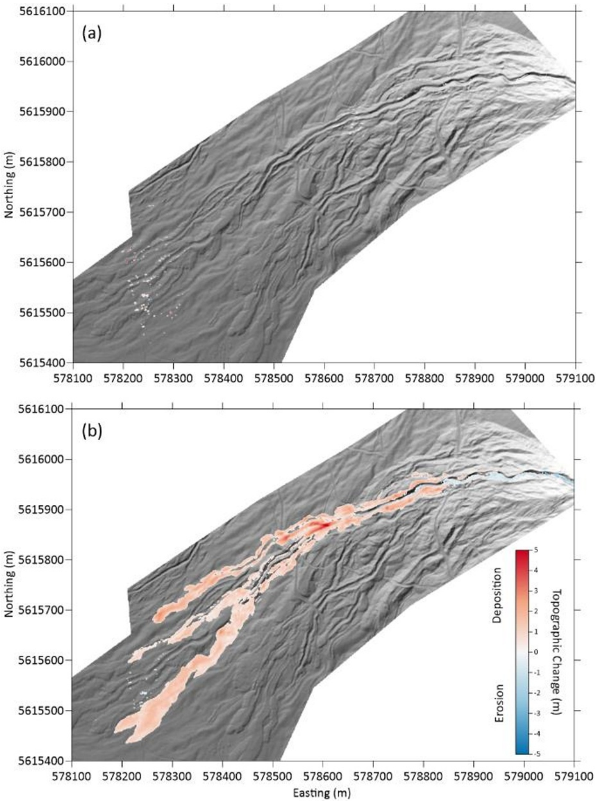

Fig. 1. (a) Topographic change between 2019 and 2020 (no event), and (b) topographic change between 2019 and 2021. Background hillshades for both panels are from the 2019 survey.

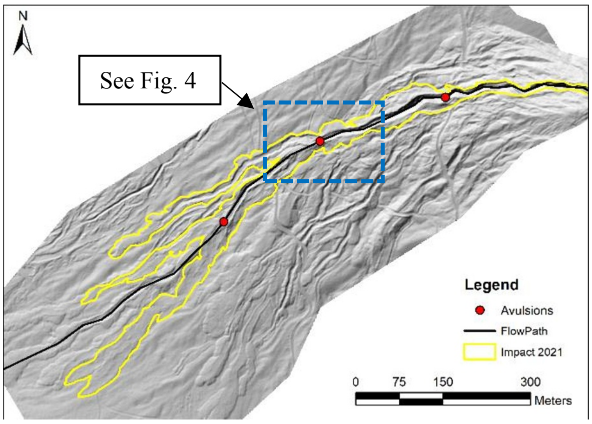

Fig. 2. Deposit mapping and avulsion locations from the Fountain South 2021 event and the flow path of the last event on this fan, showing the 2021 topographic hillshade.

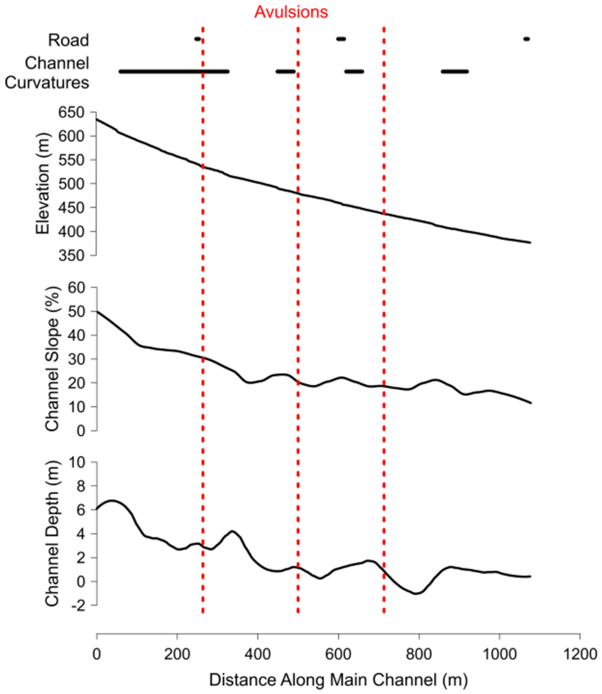

Fig. 3. Avulsion locations superimposed on data extracted along the previous flow path using pre-event (2019) lidar topography.

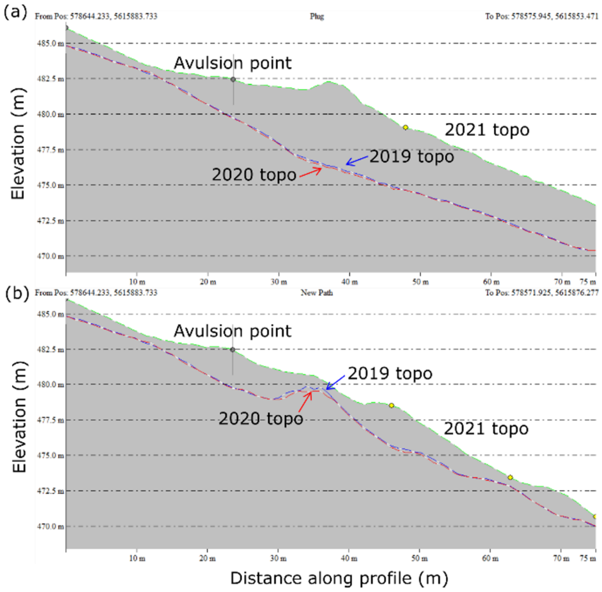

Fig. 4. Profiles through the middle avulsion location highlighted in Fig. 2, (a) going through the channel plug following the previous channel path, and (b) following the new flow path.

We have not identified any definitive small-scale channel changes leading to avulsions with the dataset we have to date. More data will likely be required to effectively evaluate the effects of these more subtle channel modifications between events.

5 Conclusions

Our first four annual UAV-lidar surveys have provided high-precision spatial data for four large debris-flow events. The detailed topographic data before and after debris-flow events allow us to examine the patterns of erosion and deposition and identify the topographic features of avulsion locations. Beyond the geomorphic analysis of events, the UAV-lidar data has been valuable for many other applications. The baseline data from both sites were valuable as part of an empirical dataset of debris-flow events in south-western BC [9], and have been made available through an online repository [10]. The Currie D event was also used as a test case to evaluate the performance of a numerical model [11].

Through these annual surveys, we hope to gain insights as to which conditions lead to avulsions, and get a better sense of the frequency of small magnitude events not often detected. Collecting full-scale, real-world data is an important part of evaluating predictive models, empirical or numerical, and interpreting the results of physical modelling.

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