The sediment yield at the front of active alpine rock glaciers, the case of the Gugla-Bielzug, Zermatt valley (Mattertal, Valais, Switzerland)

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1. Research question and study site

The Gugla-Bielzug rock glacier is located on the orographic right side of the Zermatt valley (Mattertal, ***Fig. 2***). During **spring 2013**, several **debris flow** were triggered from its front and reached the valley bottom (between the 13th and the 20th of June 2013, ***Fig. 1***). The steepness of the area, the high creep velocities (up to more than 25m/year during the snow-melt period of June 2013) and the direct connection with a torrential gully emphasized this activity. The events observed at Gugla-Bielzug brought an important question:

What controls the sediment yield at the front of the Gugla-Bielzug rock glacier?

2. Methods

In order to get information about the spatial and temporal variability of the sediment yield at Gugla-Bielzug rock glacier, a pannel of different methods were applied: observations (**webcam images**), movements measurements (**GPS**), **LiDAR** (**3 campaigns** during the summer 2013, **just after the debris flow events of June**) and **photogrammetric analysis** (based on 9 images between 1968 and 2011).

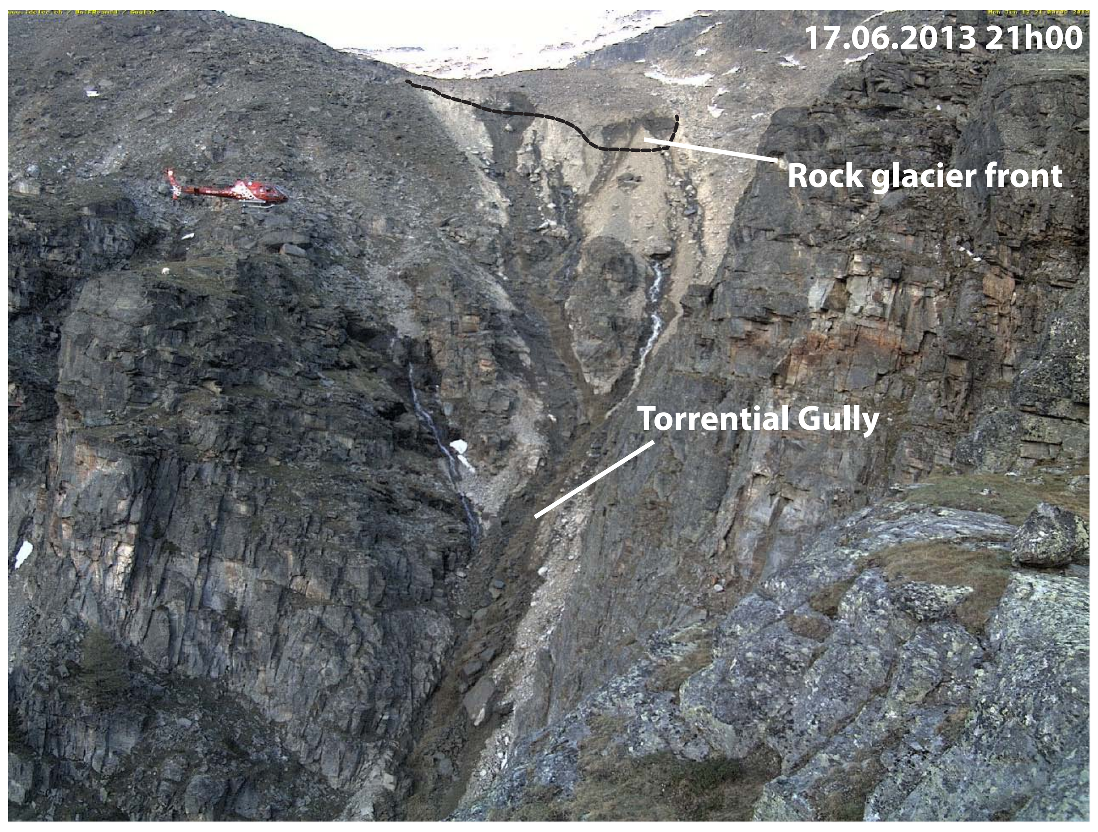

Figure 1: *The front of the rock glacier last June, during the triggering of a debris flow.*

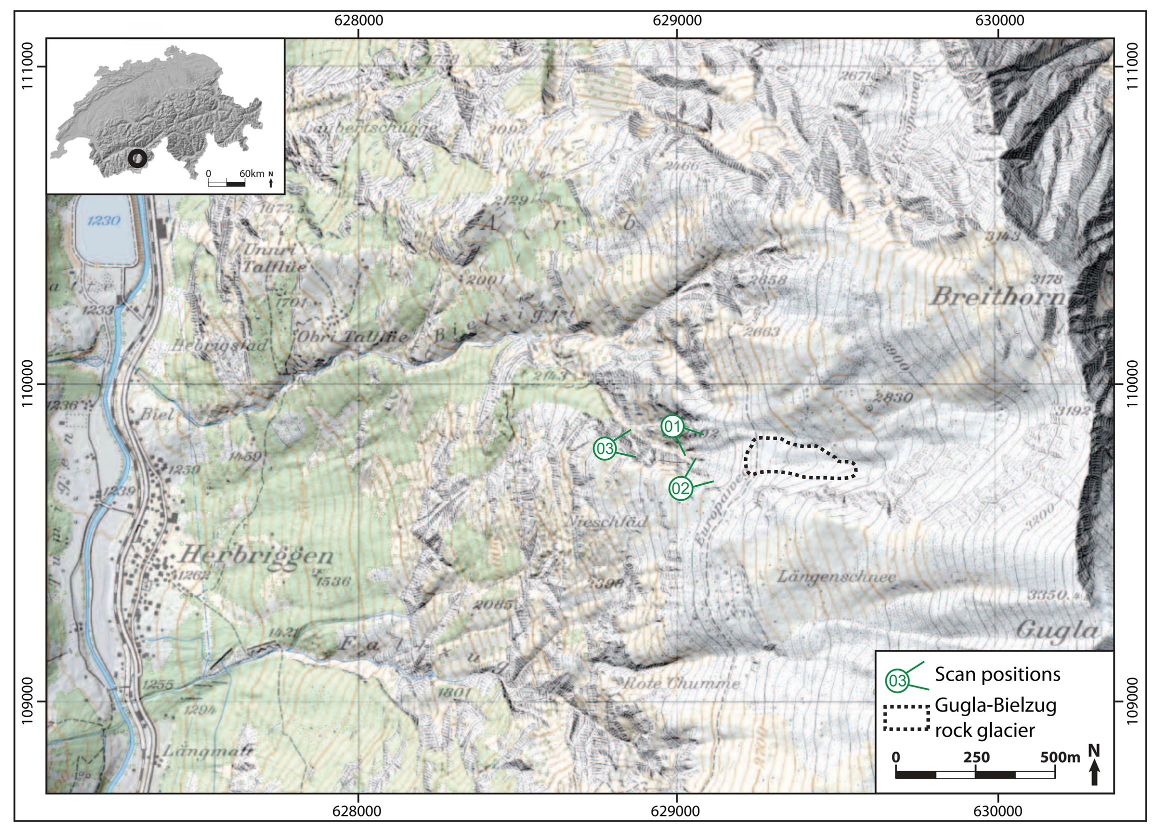

Figure 2: *Map of the Gugla-Bielzug area, including the LiDAR scan positions used in 2013*

3. The sediment yield at the front of Gugla-Bielzug rock glacier

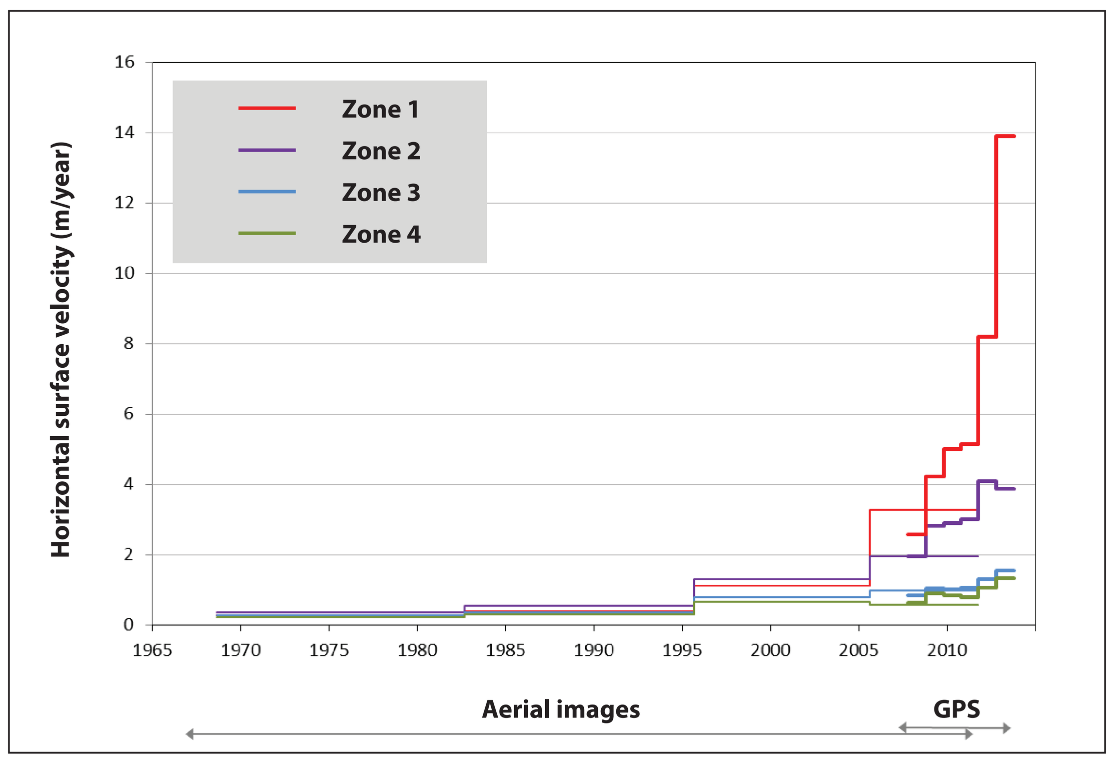

Figure 3: *Evolution of the surface velocities since 1968. The values were obtained using photogrammetry (1968-2011) and GPS (since 2007). See zones on **Fig. 4**.*

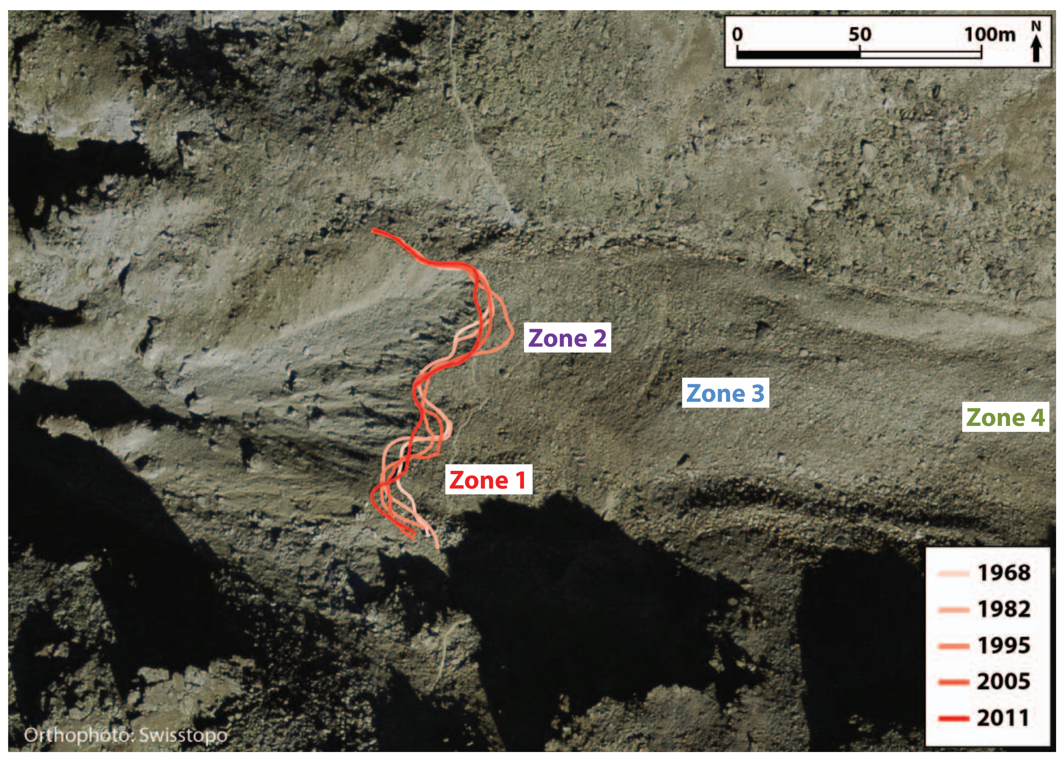

Figure 4: *Evolution of the front position between 1968 and 2011, based on the observation of orthorectified aerial images (© Swisstopo).*

	1968-1982	1982-1995	1995-2005	2005-2009	2009-2013	2013	2014-2033*	after 2033*
Sediment yield rate (m3/years)	250	400	1100	2300	4700	8500	constant	decrease

Table 1: *Evolution of the sediment yield since 1968. These values are estimation based on the creep velocity and the geometry of the rock glacier*

I. Long term evolution (1968 - 2011)

The **photogrammetric analysis** based on 9 orthorectified aerial images from Swisstopo provided information about the **evolution** of the surface velocity and the morphology of this rock glacier **over the last 45 years**.
The results (***Fig. 3***) show that the velocities were stable and quite low until the middle of the years 2000. Since then, we observe a strong acceleration of the rock glacier, especially in the frontal part (zones 1 and 2, ***Fig. 3 & 4***).
During this whole period, the position of the front did not significantly change (***Fig. 4***).
This implies that the **sediment yield of the rock glacier must have strongly increased during the last 10 years**, as shown in ***Tbl. 1***. This table depicts estimations of the sediment yield for different periods (* = estimation for the future based on the remaining volume of the fast moving part of the rock glacier).

II. Summer 2013

LiDAR generated DEMs comparisons provided sediment transfer maps (***Fig 6 & 7***) and volumes (***tbl. 2***) for the whole front-and-gully system for **three time intervals**:
25.06.2013-10.07.2013 and 10.07.2013-04.10.2013 and 25.06.2013-04.10.2013.
The maps show that there are **two main erosion zones** located on the front of the rock glacier (***Fig. 6 & 7: A***), and **one main deposition zone** (***Fig. 6 & 7: B***), devided by the outcrop of the bedrock located in the center of the gully (***Fig. 6 & 7: C***). The main erosion zones and the main deposition zone seem to be **linked by three main sediment flux paths** (***Fig. 6 & 7: D***).
The comparison of the two time intervals also shows that **the upper part of the gully** seems to be an **intermediate storage zone** (***Fig. 6 & 7: dotted line***)

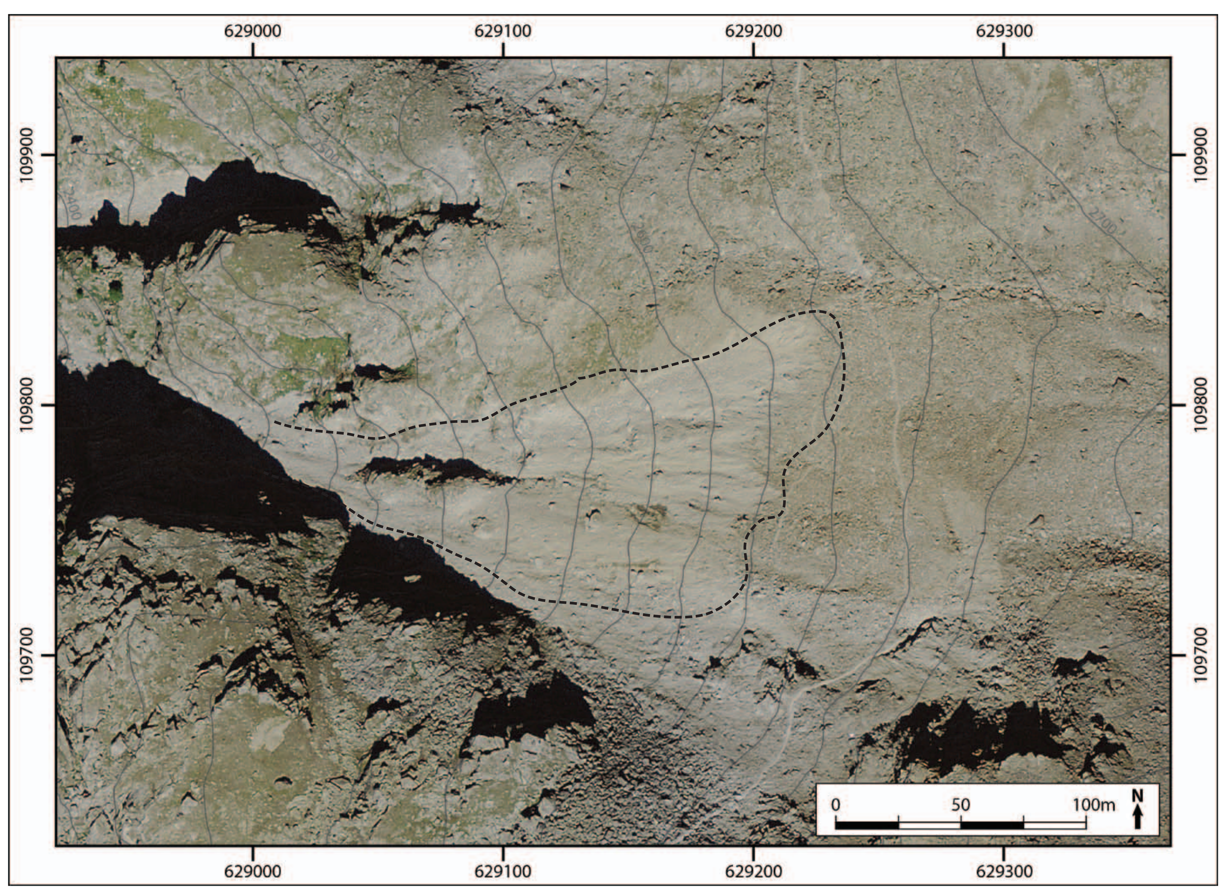

Figure 5: *Aerial vue on the Gugla-Bielzug rock glacier. The dotted line represents the area of interest for the volumes calculation*

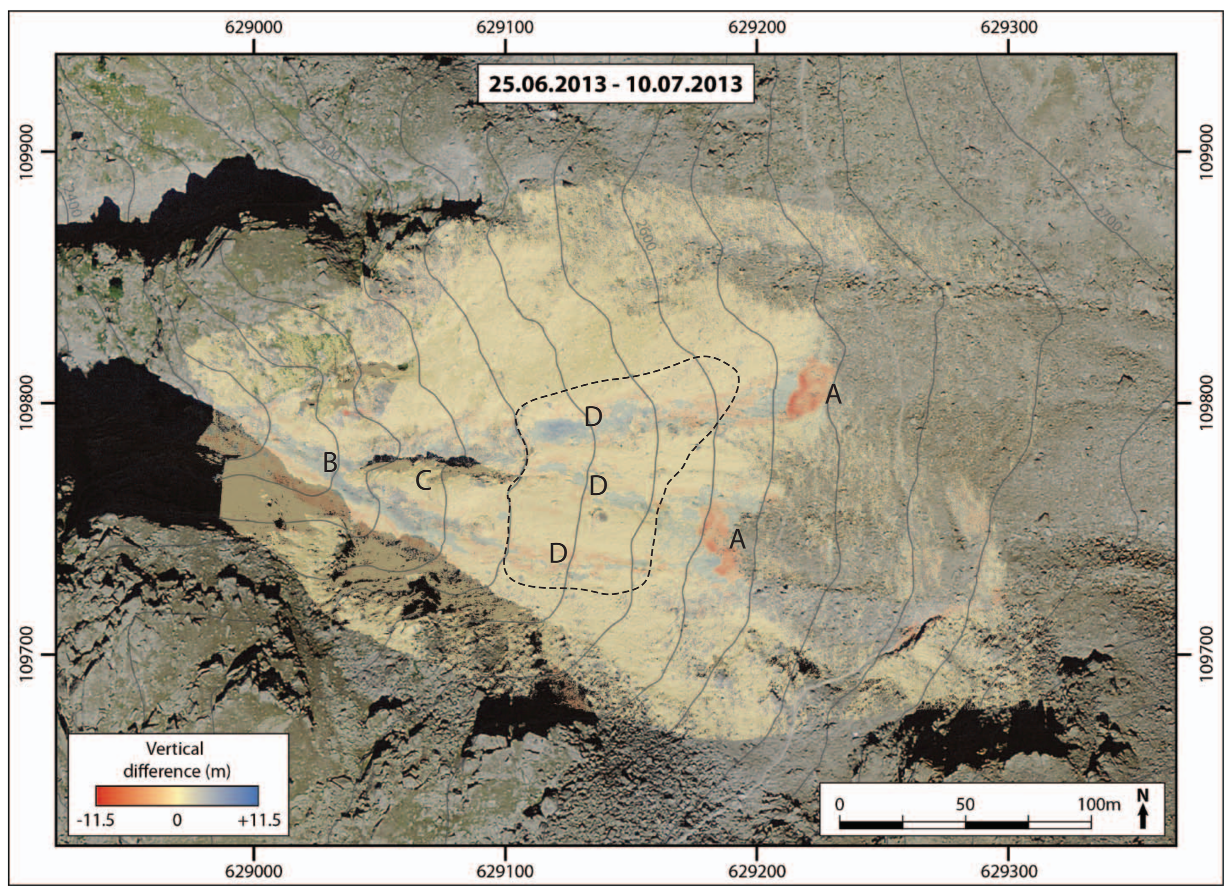

Figure 6: *Surface evolution between the 25th of June and the 10th of July 2013, based on LiDAR DEMs comparison. Blue = deposition and red = erosion (the letters are related to the text above).*

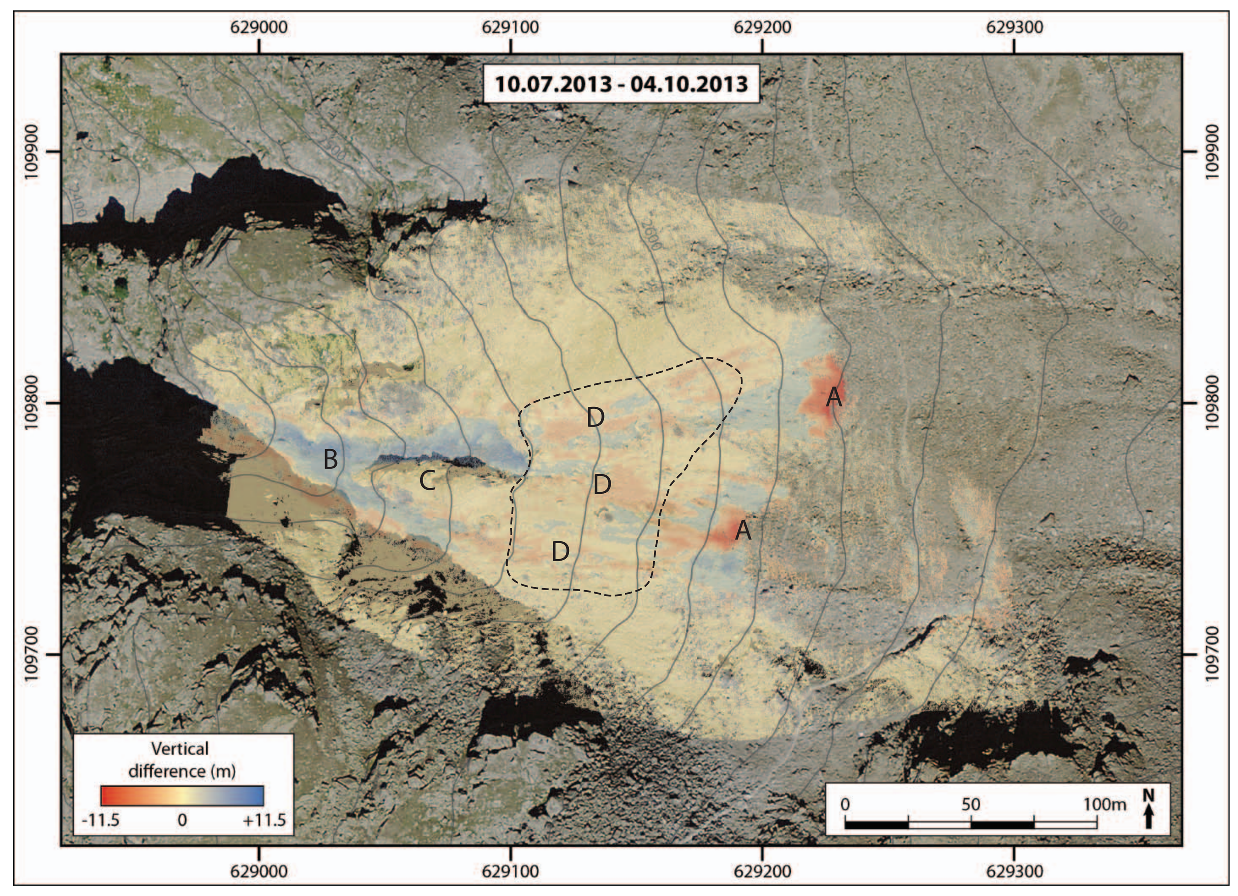

Figure 7: *Surface evolution between the 10th of July and the 04th of October 2013, based on LiDAR DEMs comparison. Blue = deposition and red = erosion (the letters are related to the text).*

Time interval		Erosion (m3)	Deposition (m3)	Budget (m3)	Transfer rate (m3/day)
25.06.2013 - 10.07.2013	*15 days*	1152	1198	46	77
10.07.2013 - 04.10.2013	*86 days*	2934	2740	-195	34
25.06.2013 - 04.10.2013	*101 days*	3549	3411	-138	35

Table 2: *Erosion and deposition volumes calculated from the LiDAR generated DEMs. Budget = deposition - erosion*

Tbl. 2 summarizes the calculated **volumes** for the different time intervals.These results were obtained by substracting LiDAR generated DEMs. Only zones of interest (the front of the rock glacier and the gully) were analysed (***Fig. 5***). This table show that:
- **The erosion rate** at the front of this rock glacier **was higher** at the beginning of the summer, **when snow-melt was still occuring** in the catchment.
- Most of the sediments were deposited in the gully. Only **a small amount was transported further down**. **About 3500 m3 of sediments were stored in the gully** during the study period.

4. Outcomes

Our study tried to **tackle the spatial and temporal variability of the sediment yield at the front of the Gugla-Bielzug rock glacier**. The results, based on a multi-method and multi-temporal approach allows to get an idea on how the processes are working in this case:
- **The current high intensity of the sediment transfer processes** is related to the **fast and strong acceleration of the rock glacier creep since 10 years**. The cause of this acceleration is still unknown but it could come from a warming of the permafrost body.
- In 2013, the erosion rate at the front was higher during the snow-melt period. **Water availabitity, and mainly snow-melt, seems to play a key-role** in the sediment yield, and in the triggering of debris flow.
- A**n important amount of sediment was progressively stored in the gully during the summer 2013** (around 3500 m3 in 101 days), and is now **available for the triggering of future debris flow events**.

Gugla-Bielzug is a typical case were the rock glacier provides sediment to a torrential channels and thus influences the triggering of debris flow events. In such cases, having a better understanding of what controls the sediment yield is fundamental to have a better capacity of response to the threats that represents debris flows. The continuation of such a study is then important to collect more information on what really controls the erosion of the front.

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