MONITORING OF THE WEISSMIES GLACIER BEFORE THE FAILURE EVENT OF SEPTEMBER 10, 2017 WITH RADAR INTERFEROMETRY AND HIGH-RESOLUTION DEFORMATION CAMERA

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ABSTRACT: When parts of the glacier on the northwest face of Weissmies in the Saas valley in Switzerland showed first signs of instability in the summer of 2014, local authorities requested that a monitoring system be installed. Between October 2014 and April 2017, our interferometric radar system allowed us to predict several small (< 20’000 m^3) ice avalanches, providing authorities with advance warning times of hours to days. In February 2017, we complemented the system with a 42 megapixel camera to assess the suitability of camera-derived deformations for monitoring purposes. After the radar was removed in April 2017, the camera-based system provided a continuous, cost-effective way of monitoring the glacier when visibility is good, which was deemed sufficient while velocities remained stable. In mid-August 2017, the camera system detected a significant acceleration of the glacier and the radar was reinstalled to provide around-the-clock monitoring. On September 9th, extrapolation of inverse velocities predicted that failure would occur within the next 24 hours, and 220 people in the valley floor were evacuated. In the early morning of September 10, about 400,000 m^3 of ice detached in several small portions over about ten minutes and caused no damage.

1. INTRODUCTION

A large part of the glacierized northwest face of Weissmies in the Saas Valley (Switzerland) recently became unstable. The likely causes of this instability are climate-change induced glacier thinning of the supporting Trift Glacier and a transition from freezing to melting temperatures at the ice-bed interface. The situation at Weissmies is critical because the glacier immediately below the unstable part is frequently travelled by mountaineers on their way to the summit of Weissmies, and large avalanches (several 100,000 m^3) off the northwest face pose a threat to infrastructure and people in the valley. Since fall 2014, a combination of radar and camera-based systems have been in place to monitor the instability and provide advance warning. Terrestrial radar interferometry is a tried and tested tool for monitoring displacements across large rock faces (Monserrat et al., 2014), and has been successfully used to predict slope failures in the past (Loew et al., 2016). Similarly, time-lapse images can also be used to resolve the velocity field of a glacier (Ahn & Box, 2010), but due to the need of good visibility, they cannot provide around-the-clock monitoring. Avalanching glacier instabilities from steep hanging glaciers are known to show a distinct acceleration of their surface flow velocities prior to failure, so accurate records of the surface velocity field can be used to infer the much-needed advance warning (Faillettaz et al., 2015).

2. SYSTEM DESCRIPTION

In October 2014, we installed an IDS IBIS-FM ground-based radar interferometer on the roof of the cable-car station Hohsaas at 3,142 m a.s.l. Until April 2017, the Ku-band (1.76 cm wavelength) radar continuously scanned the northwest face of Weissmies to obtain highly precise surface velocity measurements. The radar is protected by a custom-built plywood casing that protects it from high winds and snow drift. Power and network connection are available from the cable-car station, and redundant communication is available via the cellphone network. The radar data allowed us to predict several small size ice avalanches (<20’000 m^3) a few hours to days in advance, giving authorities time to assess the situation.

In February 2017, we added a high-resolution camera with a resolution of 42 megapixels to monitor the glacier. Every day, an image processing algorithm automatically determines the surface deformations based on 2-D cross-correlation analysis (Figure 1). The goal was to provide a more cost-effective monitoring solution that could remain on site long-term. To compare the deformation measurements, we operated both instruments simultaneously for three months.

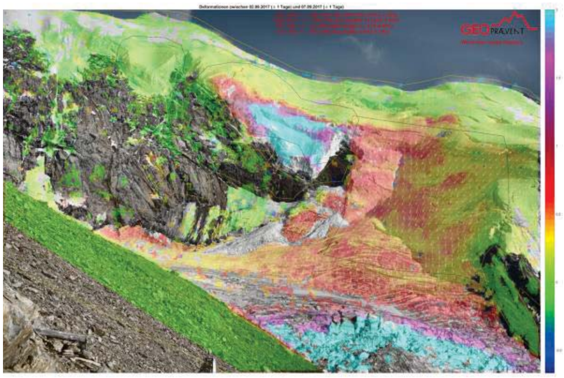

Figure 1: Surface deformations mapped from image analysis between September 2 and 7, 2017. The unstable glacier area appears in light blue in the center of the image.

3. RESULTS AND DISCUSSION

We compared the deformations obtained with both systems. While the radar data allows a prediction of even small ice avalanches when visibility is poor, the camera only provides data during the day and good visibility conditions. The image processing technique is sensitive to deformations of a few centimeters between two acquisitions, while the radar can provide sub-millimeter accuracy. Additionally, the radar and camera-based deformation measurements are inherently different. The radar system measures line-of-sight deformation, and thus only captures the component of deformation moving towards the radar. On the other hand, the camera system can only capture motion parallel to the image plane (perpendicular to the line-of-sight). At a distance of 1.5 km, the ground range resolution of the radar interferometer is approximately 0.75 x 6.5 m, whereas each camera pixel only covers a few 100 cm^2. The radar measures the change in the phase response between consecutive measurements (Rödelsperger et al., 2010), while the cross-correlation algorithm tracks similar looking features between one image and another. It thus relies on the existence of persistent surface features, a requirement that can be hard to fulfill during snowfall. While the radar had a data availability of 95% (defined as at least one “good measurement” per day), the camera reached 69% during the period when both instruments were operating simultaneously. With no immediate threat of a large detachment, the camera performance turned out to be a sufficient and cost-effective monitoring solution.

In the second half of August 2017, a pronounced acceleration of the unstable part of the glacier was observed on the camera analysis. On September 7, we re-installed the interferometric radar to provide around-the-clock monitoring that is less susceptible to weather influences and reacts faster to surface velocity changes. The radar measurements confirmed the 5-fold increase in surface velocities (Figures 3 and 4). Around noon on September 9, extrapolation of the inverse velocities predicted a large failure within approximately 24 hours. As a consequence, 220 inhabitants of Saas Grund were evacuated. Mid-day on September 9, the radar had to be reconfigured to measure velocities that exceeded 2.5 m/d by reducing the azimuth resolution of the synthetic aperture from 4.4 to 8.8 mrad, allowing to measure speeds of up to 5.2 m/d. In the early morning of September 10, velocities reached more than 3 m/day before the initial detachment. Luckily, the collapse of a total of approximately 300,000 m^3 (Guetg, 2018) happened in several smaller portions over about 10 minutes. Even though this happened in the dark, minute-by-minute radar interferograms clearly showed which parts of the glacier just collapsed. Those areas including the runout showed a strongly reduced spatial coherence (Figure 4). Thanks to the collapse in small portions, none of the ice avalanches reached the valley floor and no damage was caused. Over the following days, several secondary avalanches could be predicted, with inverse velocities consistently reaching between 2 and 3 days/m before detaching.

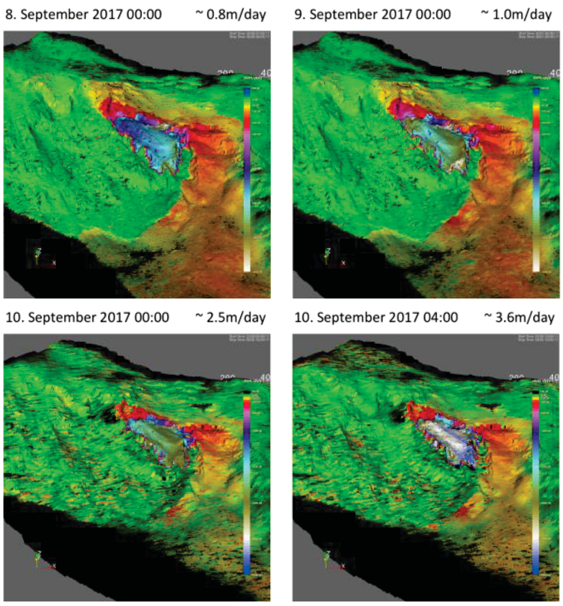
8. September 2017 00:00 ~ 0.8m/day
9. September 2017 00:00 ~ 1.0m/day
10. September 2017 00:00 ~ 2.5m/day
10. September 2017 04:00 ~ 3.6m/day

Figure 2: Progression of surface velocities as measured by the radar interferometer on unstable part of the glacier during the two days prior to avalanching.

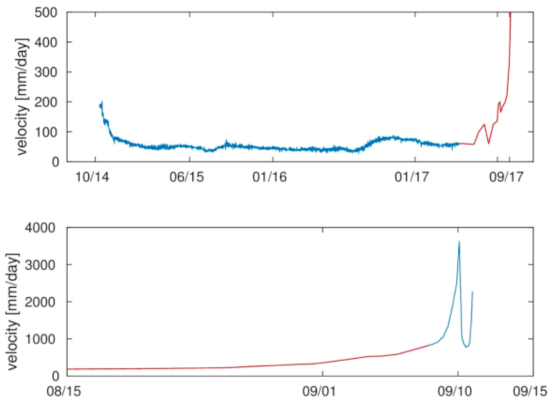

Figure 3: Surface velocities measured throughout the monitoring period since October 2014. Radar measurements are plotted in blue, velocities measured with the high-resolution camera system are plotted in red. x axis shows the date (DD/MM).

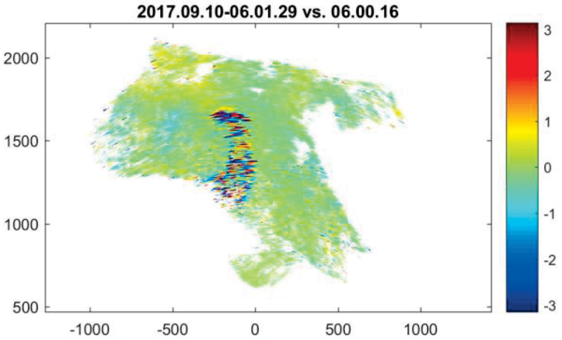
2017.09.10-06.01.29 vs. 06.00.16

Figure 4: Interferogram of consecutive measurements during the avalanching event. Axis are radar coordinates in meters. The loss of spatial coherence due to the ice debris is clearly visible on the avalanche runout.

4. CONCLUSION

Both the radar interferometer and the high-resolution camera are suitable tools for measuring surface flow fields of an unstable glacier located in the accumulation area. The camera constitutes a more cost-effective tool than the radar, but it does not provide the 24-h surveillance that is vital in an emergency situation. As such, the two instruments can complement each other to ensure year-round monitoring of an instability, with the radar providing the 24-h, all weather tool necessary to direct emergency operations when a major breaking off is imminent.

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