TIME-LAPSE PHOTOGRAPHY AS AN APPROACH TO UNDERSTANDING GLIDE AVALANCHE ACTIVITY

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ABSTRACT: Avalanches resulting from glide cracks are notoriously difficult to forecast, but are a recurring problem for numerous avalanche forecasting programs. In some cases glide cracks are observed to open and then melt away in situ. In other cases, they open and then fail catastrophically as large, full-depth avalanches. Our understanding and management of these phenomena are currently limited. It is thought that an increase in the rate of snow gliding occurs prior to full-depth avalanche activity so frequent observation of glide crack movement can provide an index of instability.

During spring 2011 in Glacier National Park, Montana, USA, we began an approach to track glide crack avalanche activity using a time-lapse camera focused on a southwest facing glide crack. This crack melted in-situ without failing as a glide avalanche, while other nearby glide cracks on north through southeast aspects failed. In spring 2012, a camera was aimed at a large and productive glide crack adjacent to the Going to the Sun Road. We captured three unique glide events in the field of view. Unfortunately, all of them either failed very quickly, or during periods of obscured view, so measurements of glide rate could not be obtained. However, we compared the hourly meteorological variables during the period of glide activity to the same variables prior to glide activity. The variables air temperature, relative humidity, air pressure, incoming and reflected long wave radiation, SWE, total precipitation, and snow depth were found to be statistically different for our cases examined. We propose that these are some of the potential precursors for glide avalanche activity, but do urge caution in their use, due to the simple approach and small data set size. It is hoped that by introducing a workable method to easily record glide crack movement, combined with ongoing analysis of the associated meteorological data, we will improve our understanding of when, or if, glide avalanche activity will ensue.

1. INTRODUCTION & BACKGROUND

Glide avalanches are difficult to predict, yet seem to be a recurring problem for many avalanche forecasting operations (e.g. Stimberis, 2010; Simenhois and Birkeland, 2010). Observations of glide cracks indicate that there are two main situations that commonly occur. In both situations, a glide crack must first form and open. The rate of opening and resulting failure (if this occurs) can be variable. However, once the glide crack has opened, we observe that they either; 1) melt in situ, or 2) fail catastrophically as full-depth avalanches. Our understanding of these phenomena is limited and as such we are currently unable to predict which glide cracks will and will not fail.

Previous work has indicated that there are some typical preconditions for glide avalanches to occur: smooth surface at the ground-snow interface, temperature at the bottom of snowpack must be at 0°C, free water exists at the bottom of the snowpack, and slope angle at least 15° for typical alpine ground surface (Clarke and McClung, 1999). However, many, if not all, of these are present when glide cracks melt in situ or fail catastrophically as avalanches. The only indication that something more hazardous may be about to occur is potentially the rate of glide. Clarke and McClung (1999) suggested that an increased rate of snow gliding occurs prior to full-depth avalanche activity. Therefore, measurement of the rate of gliding should help in forecasting these events.

A range of methods to measure creep and glide have been previously employed, with the most popular being tension or strain gauges / recording potentiometers (Clarke and McClung, 1999; Stimberis, 2010), acoustic sensors (McClung and Schaerer, 2006), GPS tracked stakes (Hendrikx et al., 2010) and time-lapse photography (van Herwijnen and Simenhois , 2012). Excluding the

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time-lapse camera method, these current methods have the disadvantages of high equipment cost and/or the need to have direct access to the start zone.

Therefore, the purpose of this paper is to present an alternative approach to the measurement of glide cracks and glide avalanches using a cost effective, remote, and automatic time-lapse camera. Our work is similar to that presented by van Herwijnen and Simenhois (2012) except it is more exploratory in nature rather than providing guidance in a "real-time" operational setting. We will show some preliminary results about how we can use these avalanche/snowpack data to correlate with meteorological variables to provide additional insight into the potential precursors for glide avalanche activity.

2. METHODS

2.1 Instrumentation

Glide imagery data were collected using a remote automatic time-lapse camera enclosed in a weather proof enclosure. For this study we used the Harbortronics Time-Lapse Camera Package (https://www.harbortronics.com/Products/TimeLapsePackage/) as it provides an "off the shelf" solution which has been extensively tested in a range of environments, but still provides a high level of user customization. This package includes a high resolution Canon SLR Camera, intervalometer, fiberglass housing with a glass window, 5 watt solar panel, internal battery pack, solar charger, and mounting hardware to attach to a range of different structures. Another benefit of this system is that it uses an SLR camera which has a high resolution allowing for more detailed image analysis. Each photo also includes a date and time stamp.

The camera was installed on a tree for the 2011/12 season, just above the section of the Going to the Sun Road called the Loop. From this vantage the camera had a clear view of several avalanche paths, namely Heavens Peak Remnant Glacier path and Heavens Gate as well as a number of smaller, unnamed paths (Figure 1). The camera was installed on 23 April 2012 and successfully captured three glide avalanche events within the period 23 April – 29 April. An almost complete, hourly photographic record of this period was obtained.

Figure 1: A clear image showing the initial onset of glide avalanche activity, with a clear crack being visible across the main face of Heavens Peak (outlined by rectangle). Image taken 26 April, 2012, 15:11.

2.2 Data Analysis

The hourly images were manually reviewed and periods of glide activity were noted. The number of hours over which glide cracks opened and then failed was noted. During the 2011/12 season we observed three unique glide events in the field of view. Unfortunately, all of them either failed very quickly (within one hour), or during periods of obscured view (such as at night or during a storm), so meaningful measurements of glide rate could not be obtained for these events.

One event occurred with a clear view and within one hour, and for this case, we employed a pixel counting technique as first proposed by van Herwijnen and Simenhois (2011) and van Herwijnen and Simenhois (2012) to quantify changes in the glide crack. This technique simply counts the number of dark pixels within a set area. As the crack gets larger, the dark pixel count increases. We used ESRI ArcGIS 10.1 to achieve this, and recorded both pixel count (i.e. area) and number of pixels on the perimeter.

To further understand the relationship between glide avalanches and their meteorological drivers, we undertook a simple nonparametric statistical analysis to compare periods of glide activity (glide), as described above, with periods of no glide activity (non-glide). We used the Kolmogorov-Smirnov two-sample test (Conover, 1999). To undertake this analysis we selected an equal number of hours without glide activity (non-glide) immediately (with a minimum of two hours separation) before and after the glide activity period (glide). Using these periods of glide and non-glide, we then selected the associated hourly meteorological data from both of the nearest weather stations, i.e. the U.S. Geological Survey (USGS) operated Garden Wall (GWWX) weather station and the National Resource Conservation Service (NRCS) Flattop Mountain (FTM) SNOTEL site, as described in Peitzsch et al., (2012). (Table 1).

Table 1: Hourly meteorological variables from Garden Wall weather station (GWWX) and Flattop Mountain SNOTEL site (FTM).

Maximum wind speed (GWWX)	m/s
Wind direction (GWWX)	degrees
Average wind speed (GWWX)	m/s
Air temperature (GWWX)	°C
Relative humidity (GWWX)	%
Barometric pressure (GWWX)	mb
Incoming shortwave radiation (GWWX)	W/m^2
Reflected shortwave radiation (GWWX)	W/m^2
Incoming longwave radiation (GWWX)	W/m^2
Reflected longwave radiation (GWWX)	W/m^2
Lysimeter (GWWX)	Mm
Air temperature (FTM)	°C
Snow Water Equivalence, SWE (FTM)	mm
Total precipitation (FTM)	mm
Snow depth (FTM)	mm

3. RESULTS

Based on analysis of our images, periods of active glide avalanche activity occurred from:

1. 24 April, 21:11 to 25 April, 06:11 (9 hours)
2. 26 April, 15:11 to 27 April, 19:11 (27 hours)
3. 28 April, 14:11 to 28 April, 15:11 (1 hour)

The two images from the third and final glide period are shown in Figure 2. For this event we were able to utilize our pixel counting technique, and recorded the number of pixels showing area and perimeter. Our count of pixels (roughly equivalent to area) went from 6709 to 15297, while our pixel count for the perimeter went from 679 to 964. However, because this event occurred within a one-hour period we were unable to use these data in a meaningful way to examine and assess if glide increased before the event. The accuracy of glide time measurements is one hour.

Periods of glide and non-glide activity were examined against air temperature at GWWX, SWE at FTM, and snow depth at FTM (Figure 3). For simplicity the periods of glide were assigned a value of +10, while the periods of non-glide were assigned a value of 0, and were plotted based on the primary Y axis (temperature). This shows that the selected periods of non-glide were evenly distributed between the glide periods and that no selective sampling occurred. It also shows that the glide events did not occur under similar meteorological conditions. For example, some occurred with sub-zero (°C) temperatures and others with above zero (°C) temperatures.

The results of the Kolmogorov-Smirnov two-sample test statistical analysis indicate that 8 of 15 meteorological variables were statistically different at the $p < 0.05$ level for periods of glide compared with periods of non-glide activity (Table 2).

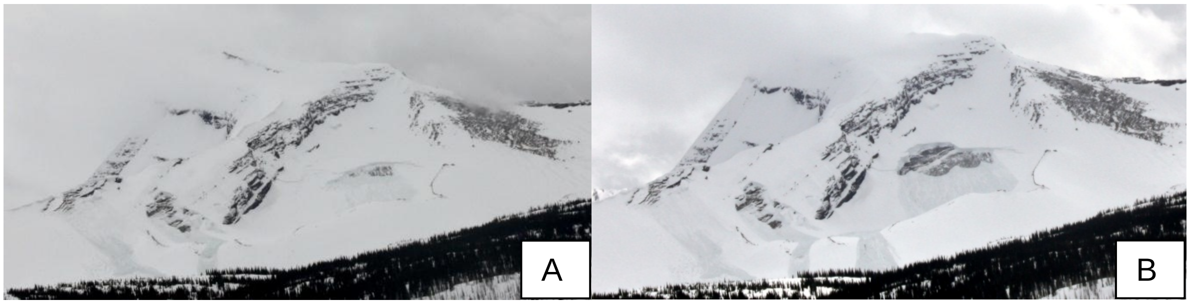

Figure 2: (A) An image showing the prior glide avalanche activity on Heavens Peak in the center of image and on the ridge on the left hand side. Image taken 28 April at 14:11. (B) An image taken one hour later showing the larger crown line and resulting avalanche debris from the subsequent glide avalanche on the main Heavens Peak slide path. Image taken 28 April at 15:11.

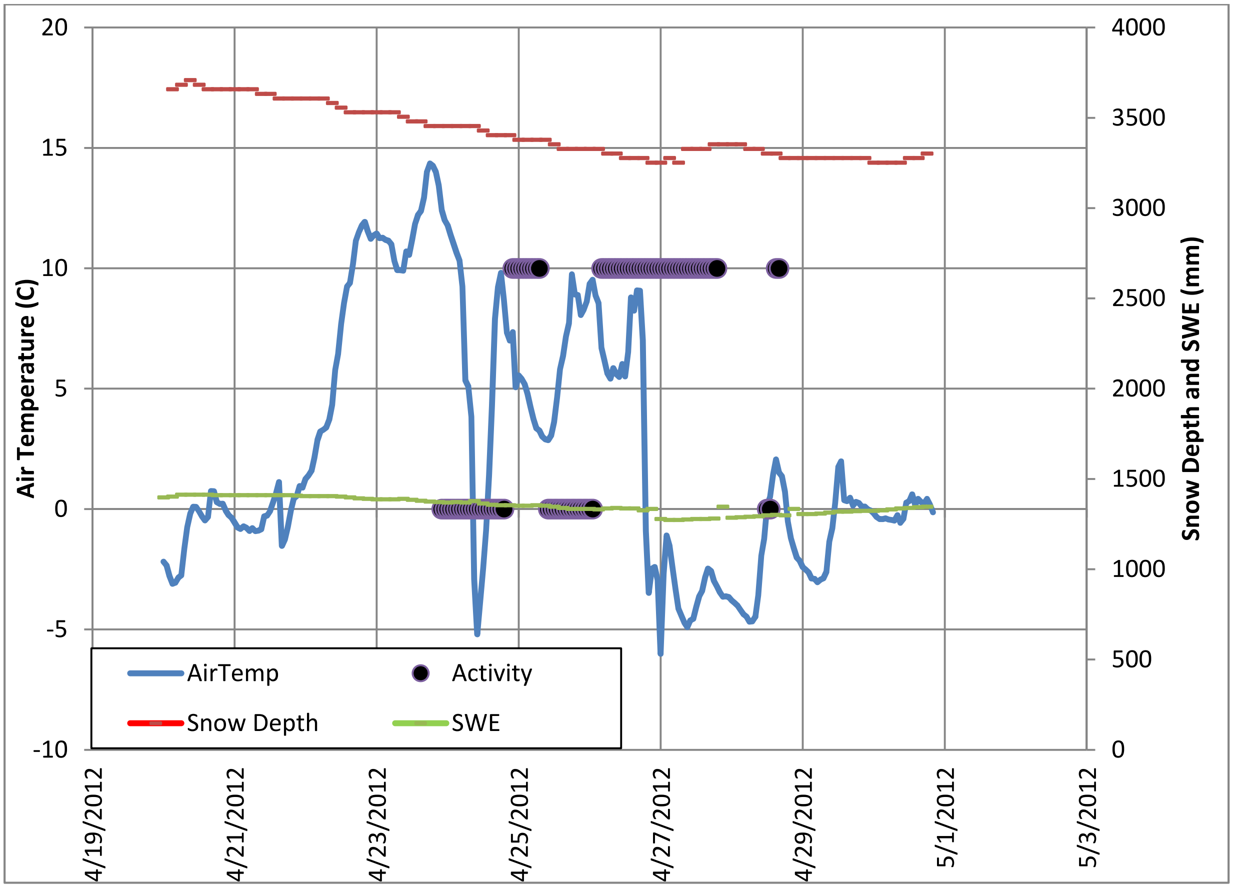

Figure 3: Periods of glide and non-glide activity over-plotted against air temperature at GWWX, SWE at FTM and snow depth at FTM. For simplicity the periods of glide were assigned a value of +10, while the periods of non-glide were assigned a value of 0, and have been plotted based on the primary Y axis (temperature).

Table 2: Kolmogorov-Smirnov two-sample test for hourly data from periods of glide and non-glide. Marked test were significant at the $p < 0.05$ level.

Variable	**p-value**	**Mean NON-GLIDE**	**Mean GLIDE**	**Std. Dev. NON-GLIDE**	**Std. Dev. GLIDE**
Maximum wind speed (GWWX)(m/s)	p < .10	29.24	23.89	10.52	12.71
Average wind speed (GWWX)(m/s)	p > .10	16.04	13.82	6.39	7.83
Wind Direction (GWWX) (Degrees)	p > .10	163.02	148.10	39.51	51.15
Average air temperature (GWWX)(°C)	p < .001	6.06	1.36	4.72	4.78
Average relative humidity (GWWX)(%)	p < .001	72.42	89.39	20.53	13.61
Barometric pressure (GWWX) (Mb)	p < .001	1014.15	1009.54	1.29	3.95
Incoming shortwave radiation (GWWX) (W/m^2)	p > .10	239.15	178.41	269.40	287.66
Reflected shortwave radiation (GWWX) (W/m^2)	p > .10	170.12	124.16	187.16	191.89
Incoming long wave radiation (GWWX) (W/m^2)	p < .05	297.08	307.24	28.79	16.76
Reflected long wave radiation (GWWX) (W/m^2)	p < .001	320.27	313.28	3.58	10.78
Lysimeter (GWWX) (mm)	p > .10	0.00	0.00	0.00	0.00
Snow Water Equivalence, SWE (FTM) (mm)	p < .05	1351.87	1314.38	23.31	32.03
Total precipitation (FTM) (mm)	p < .01	1636.93	1651.60	9.76	13.93
Air temperature (FTM) (°C)	p > .10	7.88	4.31	3.67	4.23
Snow depth (FTM) (mm)	p < .05	3386.02	3307.98	59.91	44.48

4. DISCUSSION AND CONCLUSION

During the 2012 season we experienced some problems with the camera function. The time-lapse component was unreliable and additional unwanted images were taken. This occurred at such a rate to completely fill the memory card within a 24-48 hour period. This was in stark contrast to the 2011 season, when the camera worked flawlessly for the entire period (April – July), with over 700 hourly images captured. Unfortunately, in 2011, all glide cracks melted in situ and glide rates could not be measured. Despite this problem in 2012 we did manage to capture an active glide avalanche cycle at the end of April. Using these data we were able to successfully employ the pixel counting technique, but its usefulness was limited as no meaningful glide rates could be obtained for this season.

Our preliminary statistical analysis indicates that there are several significant correlations between a number of meteorological variables and periods of glide and non-glide activity. These variables were air temperature, relative humidity, air pressure, incoming and reflected long wave radiation, SWE, total precipitation, and snow depth. However, we urge caution with their use and interpretation, as correlation does not necessarily mean causation. In addition, this analysis is based on only three unique events and a small sample of 50 hours of meteorological variables for glide and non-glide periods. As highlighted by previous work, simple correlations to short term meteorological data are likely to be problematic for glide avalanches (e.g. Clarke and McClung, 1999; Stimberis, 2010). This is mainly due to the fact that glide avalanches are not thought to be solely in response to the current conditions, but rather a combination of the antecedent conditions and the cumulative effect of the recent meteorological conditions. In our results, we suspect that the correlations actually show the reverse of what we might expect to see with the glide events occurring during periods of cooler, more inclement weather. This is probably because the most likely mechanism responsible for the ensuing activity is the warmer period 2-12 hours prior, which is sampled as a non-glide period (Figure 3; Table 2). Future analysis considering these issues, and more critically, lagging of meteorological variables should provide additional insight.

Despite these limitations, we believe that this methodology using a simple time-lapse camera has great promise to become a useful tool to start collecting data on glide crack activity. With the addition of more documented events, along with the associated hourly meteorological data, we believe that this approach can provide further insight into glide crack behavior. The camera was relatively easy to deploy and despite its problems still captured data. We believe that this method has great potential and we will aim to repeat the experiments in the 2012/13 winter and spring.

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DISCLAIMER

REFERENCES

Clarke, J., and McClung, D., 1999. Full-depth avalanche occurrences caused by snow gliding, Coquihalla, British Columbia, Canada. Journal of Glaciology, 45 (151), 539–546.

Conover, W.J., (1999). Practical Nonparametric Statistics (3rd Edition). Wiley, USA. 592pp.

Hendrikx J., Peitzsch E. and Fagre, D.B., 2010. A practitioner's tool for assessing glide avalanche activity. In: R. Osterhuber (Editor), Proceedings of the International Snow Science Workshop, Squaw Valley, California, USA., pp. 395-396.

McClung, D.M., and Schaerer, P.A., 2006. The Avalanche Handbook. The Mountaineers Books, Seattle. 342 pp.

Peitzsch, E.H., Hendrikx, J., Fagre, D.B., and Reardon, B., 2012. Characterizing wet slab and glide avalanche occurrence along the Going-to-the-Sun Road, Glacier National Park, Montana, USA. Cold Regions Science and Technology, 78, 73–81. DOI: 10.1016/j.coldregions.2012.01.012

Stimberis, J. and Rubin, 2008. Rockface glide avalanche detection. In: C. Campbell, S. Conger, and P. Haegeli (Editors), Proceedings of the International Snow Science Workshop, Squaw Valley, California, USA., pp. 698-700.

Simenhois, R. and Birkeland, K., 2010. Meteorological and Environmental Observations from Three Glide Avalanche Cycles and the Resulting Hazard Management Technique. In: R. Osterhuber (Editor), Proceedings of the International Snow Science Workshop, Squaw Valley, California, USA., pp. 846-853.

van Herwijnen, A., and Simenhois, R., 2011. Monitoring glide avalanches using time-lapse photography. XXV IUGG Abstract, 28 June – 7 July, 2011. Melbourne, Australia.

van Herwijnen, A., and Simenhois, R., 2012. Monitoring glide avalanches using time-lapse photography. In: Proceedings of the 2012 International Snow Science Workshop, Anchorage, Alaska, USA. This Issue.