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Terrain parameters of glide snow avalanches and a simple spatial glide snow avalanche model

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ABSTRACT

Glide snow avalanches are dangerous and difficult to predict. Despite substantial recent research there is still inadequate understanding regarding the controls of glide snow avalanche release. Glide snow avalanches often occur in similar terrain or the same locations annually, and repeat observations and prior work suggest that specific topography may be critical. Thus, to gain a better understanding of the terrain component of these types of avalanches we examined terrain parameters associated with the specific area of glide snow avalanche release in comparison to avalanche starting zones where no glide snow avalanches were observed (i.e. non-glide snow avalanche terrain).

Glide snow avalanche occurrences visible from the Going-to-the-Sun Road corridor in Glacier National Park, Montana from 2003 to 2013 are investigated using a database of all avalanche occurrences derived of daily observations each year from 1 April to 1 June. This yielded 192 glide snow avalanches in 53 distinct avalanche paths. Each avalanche was digitized in a GIS using satellite, oblique, and aerial imagery as reference. A set of 117 non-glide snow avalanche starting zones were also selected in this manner. These were start zones with avalanche activity potential, but without glide avalanches observed. Topographical parameters such as area, slope, aspect, curvature, potential incoming solar radiation, distance from ridge, and elevation were then derived for the entire dataset utilizing tools with a GIS and a 10 m DEM. Ground class and a glide factor were calculated using a four level classification index with in-situ observations and a land surface type layer in a GIS.

A total of 21 terrain variables were examined using a univariate analysis between areas where glide snow avalanches occurred and areas where glide snow avalanches were never observed, despite crack formation. Only two variables were not significantly different. The significantly different variables were then used to train a classification tree to distinguish between glide and non-glide snow avalanche terrain. A 10-fold cross validated tree resulted in four decision nodes to classify the data. The nodes split on glide factor, maximum slope angle, seasonal sum of incoming solar radiation, and maximum curvature to distinguish between glide snow avalanche and non-glide snow avalanche terrain with an unweighted average accuracy (RPC) of 0.95 and probability of detection of events (POD) of 0.99.

Finally, the results of the cross-validated tree were used in a GIS to examine other areas, not used in the training dataset of the classification tree, of potential glide snow avalanche release within Glacier National Park. Using this understanding of the role of topographic parameters on glide snow avalanche activity, a spatial terrain based model was developed to identify other areas with high glide snow avalanche potential outside of the immediate observation area. This simple spatial model correctly classified 78 percent of actual glide snow avalanche terrain (pixel count) of a small test area of four independent observed glide snow avalanches.

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1. Introduction

Glide snow avalanches are dangerous and difficult to predict. The difficulty associated with forecasting glide snow avalanches and the ineffectiveness of most explosive mitigation techniques render this type of avalanche a troublesome forecasting and management problem (Clarke and McClung, 1999; Jones, 2004; Simenhois and Birkeland, 2010). Glide snow avalanches are especially a concern for operational avalanche forecasting programs, particularly highway and railroad programs, because they can occur repeatedly in the same paths but the precise timing of release remains a challenge to understand (Clarke and McClung, 1999; Reardon and Lundy, 2004; Simenhois and Birkeland, 2010; Stimberis and Rubin, 2011; Wilson et al., 1996).

Glide is the downhill movement of the entire snowpack along the interface with the ground (In der Gand and Zupancic, 1966). A glide crack can form on a slope when glide rates vary, forming a crack upslope

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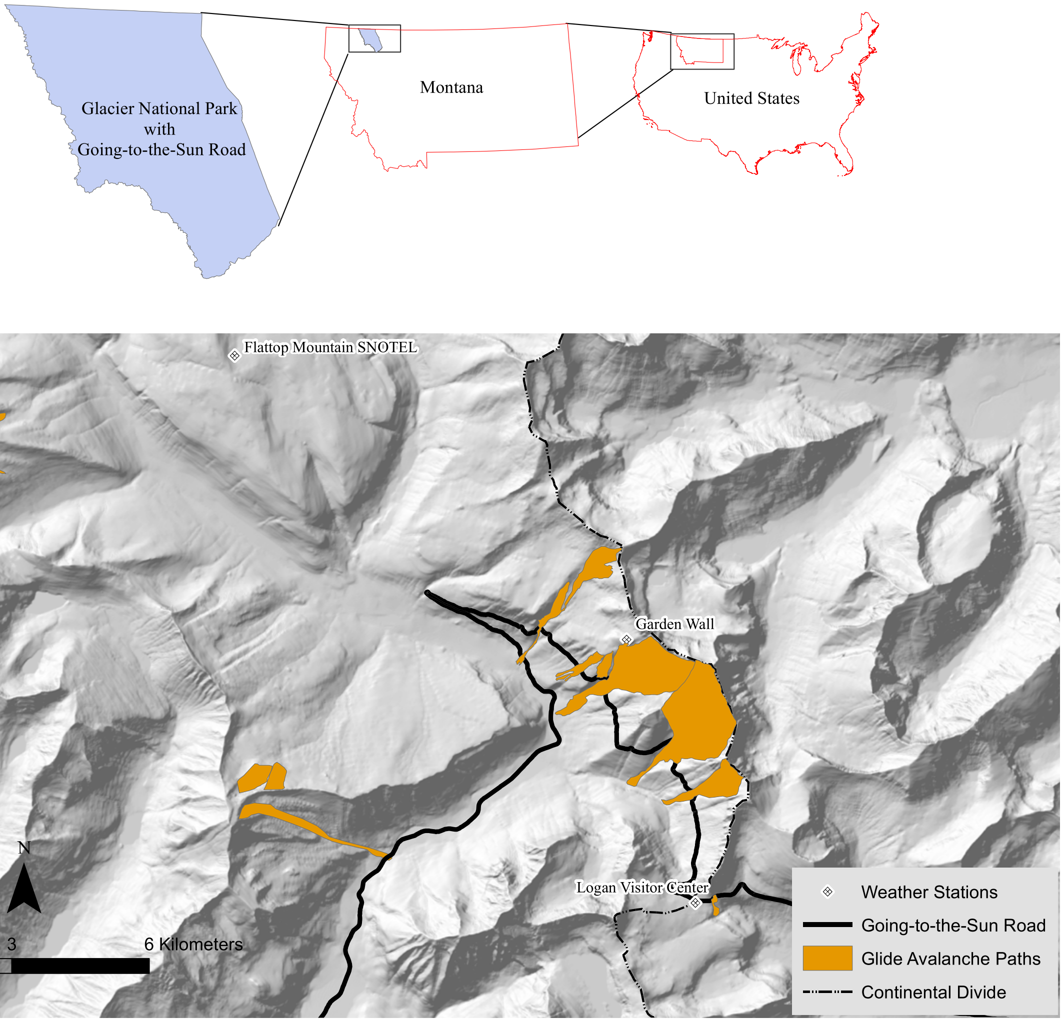
of the area of faster glide where stresses are concentrated (Clarke and McClung, 1999; Jones, 2004; LaChapelle, 2001). Glide snow avalanches sometimes follow the formation of a glide crack, but the exact timing of release can be highly variable and not all glide cracks culminate in avalanches (Reardon et al., 2006). For those that do, the time between crack formation and avalanche release can range from several hours to weeks or even months (Feick et al., 2012; McClung and Schaerer, 2006; Simenhois and Birkeland, 2010).

Höller (2013) provides a comprehensive chronological review of glide snow avalanche research noting the substantial improvements in understanding glide snow avalanche processes within the past century, and especially in recent years (Bartelt et al., 2012; Feick et al., 2012; Feistl et al., 2014; Mitterer and Schweizer, 2012). However, determining if a glide crack will indeed fail as a glide snow avalanche, melt in-situ, or calve into pieces still perplexes avalanche professionals and researchers alike. Numerous recent studies investigated meteorological and snowpack parameters associated with glide snow avalanche release from a forecasting perspective (Dreier et al., 2013; Peitzsch et al., 2012b; Simenhois and Birkeland, 2010; Stimberis and Rubin, 2011). Technological methods including time-lapse photography of known glide snow avalanche zones have also aided in understanding the timing of glide snow avalanche release (Hendrikx et al., 2012; van Herwijnen and Simenhois, 2012; Van Herwijnen et al., 2013).

A few studies have quantified parameters of gliding, including ground cover and friction, slope, and stauchwall dynamics (Bartelt et al., 2012; Feistl et al., 2013; Feistl et al., 2014; Höller, 2013; Lackinger, 1987; Leitinger et al., 2008; Newesely et al., 2000). However, limited research quantifies terrain parameters associated with glide snow avalanche release (Feick et al., 2012; Margreth, 2007a). Leitinger et al. (2008) developed a statistical spatial snow glide model where forested areas had the highest influence on snow gliding due to the trees intercepting snowfall and interfering with glide processes. They also found in non-forested areas that the combination of slope angle and winter precipitation affects the snow glide process. McClung (1994) investigated the glide process on a representative rock slope (yet not steep enough for normal glide snow avalanche activity) where they examined glide rates and parameters influencing the glide process. Many of the aforementioned studies examined terrain parameters related to the glide process, but few investigated terrain variables associated with glide snow avalanche release (Dreier, 2013; Feistl et al.,



(a)

Fig. 1. Location of study area within Glacier National Park, northwest Montana. The Going-to-the-Sun Road corridor: (a) Orange polygons depict avalanche paths where glide snow avalanches are observed and recorded annually. John F. Stevens Canyon in southern Glacier National Park contains well documented and observed avalanche paths along a major transportation corridor (b). This area, located 50 km south of the GTSR corridor, was used as part of the dataset where known avalanche paths exist, but glide snow avalanches have not been observed. The two avalanche paths in this corridor where glide avalanches have been infrequently observed were completely removed from any analysis.