Assessing the risk of glacial outburst floods from Emmons Glacier, Mt. Rainier, Washington

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Abstract

Mount Rainier, a stratovolcano located in the Cascade Volcanic Arc of Washington State, is home to 27 major glaciers, many of which have debris-covered ablation zones. This study analyzes Emmons glacier supraglacial geomorphology in order to determine future risks of glacial lake outburst floods (GLOF). Future risk potential will be assessed by categorizing Emmons glacier into one of three glacial regimes established by Benn et al. (2012). Surface slopes of zero to six degrees, inefficient supraglacial drainage systems, concave-up glacial elevation profiles, and slowing ice velocities can all be indicators of water storage potential. These criteria were evaluated through analysis of LIDAR and satellite imagery. Through these remote sensing analyses we categorize Emmons glacier as low risk for supraglacial-water storage with potential for increasing risk in the near future. While the glacier has an efficient supraglacial drainage system, we observe a concave-up longitudinal elevation profile, as well as 0.14 square miles of debris-covered surface between zero and six degrees, both of which may promote future water storage. Field measurements, including glacial debris depth and cataloging of past and present water features, are needed to support our findings. If our assessment of Emmons glacier is accurate, continued ablation rates may create a positive feedback, promoting water storage, and thus increasing the risk of outburst floods.

Background

Mount Rainier's glaciers are retreating, losing ~14% of its ice volume between 1970 and 2007/2008 (Slison et al., 2011). Previous studies have observed a strong relationship between debris cover and reduced rates of melting in mountain glacier ablation zones (Anderson and Anderson, 2016; Dits and Moore, 2014; Peltola, 2000). Due to this relationship, debris-covered glaciers can have melting patterns that result in complex topography and geomorphology, which can lead to the formation of supraglacial lakes (Mortes et al., 2017). This study focuses on the lower 1200 m of Emmons glacier (Mont Blanc Massif, Italy).

Methods

Imported Mt. Rainier LIDAR (Slison et al. 2011) and 2016 Satellite Imagery into ArcGIS
Created hillshade and slope map (Fig. 4) using LIDAR DEM (Slison et al., 2011).
○ Extracted elevation profiles from LIDAR DEM
○ Applied fill, flow direction, and flow accumulation tools on DEM
○ Mapped terminus retreat across 2015 and 2016 imagery using field observations and ASTER satellite imagery
○ Analyzed slope maps, elevation profiles, and hydrologic flow maps (Figs. 6, 7, and 8)

Acknowledgements

Through our remote sensing analyses, we have categorized Emmons glacier in Benn et al. (2012) first glacial regime, with an effective supraglacial drainage system and minimal water storage. However, the glacier shows signs of transitioning to the second regime, such as stagnant ice near the glacier's terminus, and reduction of the glacier's surface gradient. Formation of a concave-up glacier elevation profile, increased water storage, and increased debris depth in areas that it can not be measured in-situ through a DEM-based analysis, suggests an increased risk of GLOFs or debris-flow events. Future work could include compared results to Benn et al. (2012) criteria for glacial regimes.

Motivation and Previous Work

As glaciers experience increasing rates of ablation, forming supraglacial lakes becomes more likely (Hess, 2014; Reynolds, 2000). These lakes are often overlooked by structures composed of soft and unstable deposited sediments, which pose a risk of rupturing, causing a glacial lake outburst flood (GLOF). GLOFs are also able to trigger large scale debris flow events (Hess, 2014) that can be catastrophic within the park. With Mt. Rainier seeing just over 1.8 million visitors in 2015, these GLOFs would pose a threat to park infrastructure, staff, and recreational visitors. This study will categorize Emmons glacier in one of the three glacial regimes established by Benn et al. (2012), in order to assess the future risk of water storage on Emmons glacier. This information will be critical to mitigating the future risk of GLOFs in Mt. Rainier National Park. Botch et al. (2008) suggests that analysis of glacial surface elevation models can suggest potential sites of glacial lake formation; this study will use similar tools to determine Emmons glacier’s current regime.

Results

Our analyses reveal multiple characteristics that could promote supraglacial water storage. From both a DEM-derived elevation profile of the glacier surface, as well as measurements of ice thickness change (Slison et al., 2011) we can see Emmons glacier has formed a concave-up glacier slope profile (Fig. 7). Figure 6 shows that 0.14 square miles of the glacier’s debris-covered ablation zone has a surface slope between 0 and 6 degrees. Additionally, Emmons glacier is experiencing slow to negligible ice velocities in its lower ablation zone (Fig. 5), with the majority of the ice near its terminus stagnant (~0.3 m day^-1; Allstott et al., 2015). We measured significant terminus retreat using imagery from July 2015 and August 2016 (Fig. 8). Despite these findings, DEM analysis shows an efficient dendritic supraglacial drainage system, with the majority of channels leading to the terminus. These channels allow meltwater to drain efficiently and prevent the formation of large supraglacial water features (Fig. 9). These analyses are supported by field observations of central, incised supraglacial streams, and of efficient, high discharge of subglacial water from the terminus.

Discussion

Through our remote sensing analyses, we have categorized Emmons glacier in Benn et al. (2012) first glacial regime, with an effective supraglacial drainage system and minimal water storage. However, the glacier shows signs of transitioning to the second regime, such as stagnant ice near the glacier’s terminus, and reduction of the glacier’s surface gradient. Formation of a concave-up glacier elevation profile, increased water storage, and increased debris depth in areas that it can not be measured in-situ through a DEM-based analysis suggests an increased risk of GLOFs or debris-flow events. Future work could include increased monitoring of supraglacial water storage on Emmons glacier, increasing the risk of GLOFs or debris-flow events. Future work could include increased monitoring of supraglacial water storage on Emmons glacier, increasing the risk of GLOFs or debris-flow events. Future work could include...