RAPID: Characterizing the Trigger and Evolution of the December 2020 Haines, Alaska Landslide

Introduction: On December 2, 2020, following record-breaking rainfall, Haines, Alaska experienced a landslide that tore through part of the community (Figure 1), destroying four homes, making several more uninhabitable, and resulting in two presumed fatalities (Kunze and Brooks 2020; Vera and Rose 2020). This landslide occurred where no one anticipated – in an area thought to be safe by residents and community planners (Godinez 2020). For example, focus has been on the only road connecting Haines to all points inland – the Haines Highway – that runs along the base of steep, ~1,500-m-high peaks notorious for producing debris flows during rain events (Figure 2). The Haines Highway milepost (MP) 19 area is one of the costliest stretches of road, requiring repeated maintenance and debris flow mitigation (see blue arrow in Figure 2; ADOT&PF N.D. a and b; Godinez 2020). Yet, during the early December 2020 record rainfall event, this area did not produce a landslide that impacted the road. As another example, a 1972 reconnaissance engineering geology report was produced for the area approximated by the green rectangle in Figure 2. Ironically, this map of geologic hazards stopped just short of the 350-m high ridge southeast of town that produced the December 2 landslide. Collecting perishable data from the landslide event may help to answer the question: "Why here?" Initial observations suggest that rockfall from the head scarp area may have impacted saturated soils, triggering the debris flow that swept downslope (R. Daanen, pers. comm., Dec. 2020). Alaska Division of Geological & Geophysical Surveys (DGGS) personnel who mobilized to the site immediately after the event remain concerned about the stability of the slopes immediately adjacent to the landslide, as preliminary investigations indicate that the joints potentially responsible for the initial rockfall event extend to either side of the failure area (G. Wolken, pers. comm., Dec. 2020).

Figure 1. View of the landslide, which is estimated to be 600-ft long and several hundred feet across (taken from Godinez 2020).

The early December storm also set records. The Haines area had over 22 cm of rain in two days (a one in 150-year event (Grove 2020)), which melted the roughly 60 cm of snow that was on the ground. The event was described as an "atmospheric river" of moisture. A similar "atmospheric river" also occurred in August 2015, leading to more than 40 landslides in the area of Sitka, Alaska, one of which killed three people (Patton et al. 2020; Woolsey 2019). More extreme events should be expected with a warming climate, including greater precipitation, higher intensity precipitation, and more rain instead of snow during certain parts of the year (Grove 2020). The rain-in-winter events also cause melting of the existing snowpack. Lifelong residents of the area have already recognized these trends, noting that although winter storms are not new, the heavy rainfall instead of snowfall is (Godinez 2020). While snowmelt-induced landslides have been investigated in Italy, Japan, and Argentina (e.g., Ayalew et al. 2005; Cardinali et al. 1999; Kawagoe et al. 2009; Marui and Koizumi 2014; Moreiras et al. 2012), there is a lack of data for similar events in the U.S., and specifically for Alaska.

It is important to capture the ephemeral data from the recent Haines landslide to understand its origin, motion, and location relative to residential structures in the area. It is also important to understand how people responded during this landslide, as a recent study indicates that simple actions people take during landslide events can save their lives (Pollock and Wartman 2020a). Collection and analysis of these data will help in landslide detection, hazard mapping, modeling, and risk analysis, all of which are essential in

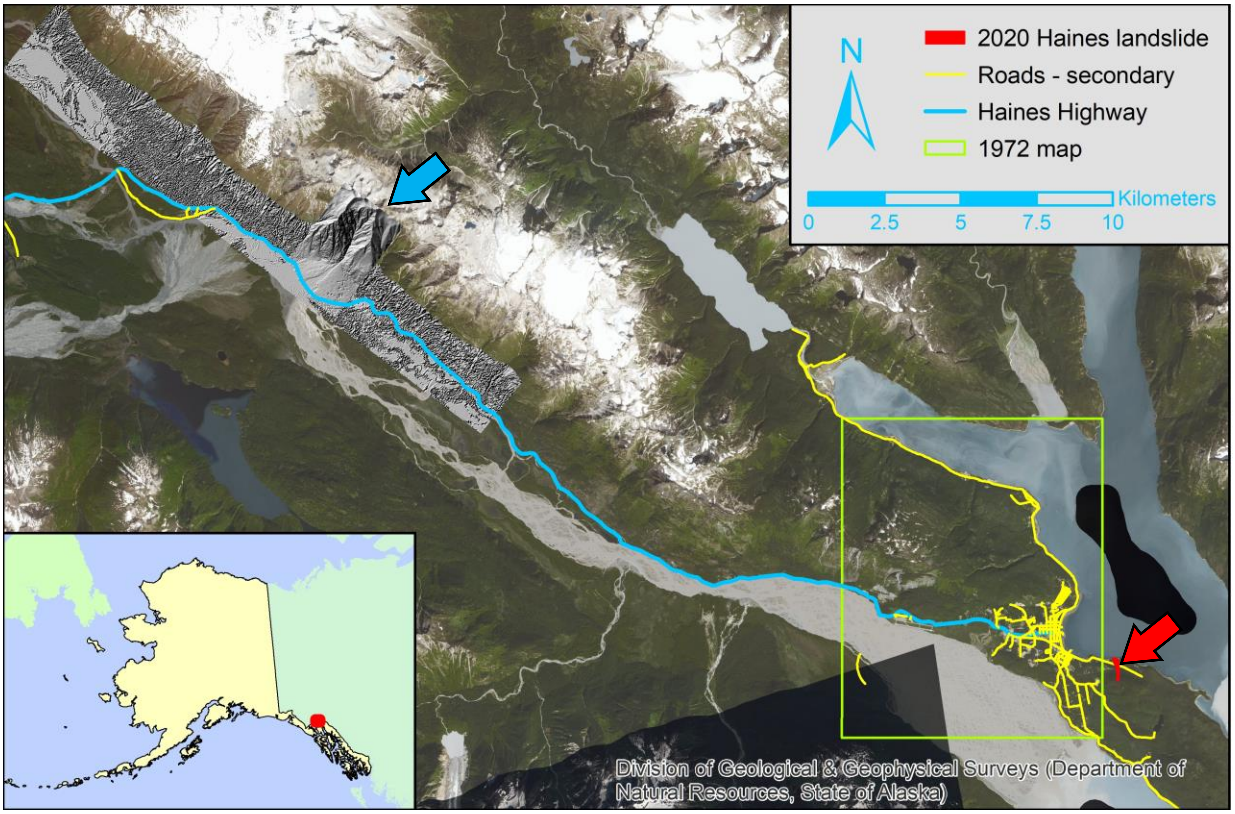

Figure 2. Haines, Alaska area, illustrating areas of previous data collection relative to the 2020 Haines landslide (indicated by red arrow). Area of previous LiDAR collection along the Haines Highway is indicated by gray-scale area to northwest, and specific MP19 LiDAR is indicated by blue arrow. Inset displays location of Haines relative to the state of Alaska. (Map data from Esri 2020, Haines Borough 2020, Macpherson et al. 2014, and estimated from Lemke and Yehle 1972).

community planning. **The primary objectives of this RAPID project are to understand why this particular slope failed during this record-breaking event, how it will respond to spring snowmelt, and how its surface will evolve with time.**

Intellectual Merit: Collecting and analyzing the perishable data from this landslide with both subaerial and submarine extents will provide a comprehensive case study for a mass movement event in a maritime, high latitude environment. The landslide represents a unique opportunity to investigate the snowmelt-induced rockfall trigger that potentially initiated the destructive debris flow; little data exists for similar events in the U.S. This project follows recommended approaches for geohazard reconnaissance, including data collection from different temporal, spatial, and social scales, as well as from multiple disciplines (Wartman et al. 2020). Analysis of the repeated data collections will provide an understanding of how this landslide – and adjacent affected areas – evolves with time, as well as the timing of community and infrastructure recovery, which will contribute to our understanding of geohazard interaction with the built environment. Data collected from this project will leverage and complement DGGS Light Detection and Ranging (LiDAR) and bathymetric data collection, providing analysis across multiple spatial scales. Multidisciplinary data sets that will be acquired include data associated with coastal processes, geomorphic processes, and social science. Through rapid data collection, we will document the extreme nature of the event, including amount and duration of rainfall and their effects on the mass movement, and any subsequent reactivation with spring snowmelt. In-depth analysis of this landslide event will provide greater understanding of climate change effects on mountainous coastal regions along the Pacific Ocean. While a full geotechnical investigation of the rock cliff in the head scarp area is necessary for slope stability analysis, the repeat LiDAR data acquired through this project will aid in the assessment of discernable creep in the rock mass in the landslide head scarp and along the adjacent ridgeline. Since the event, heavy equipment operators and repair crews have been trying to reach residents and to repair infrastructure and utilities. These crews, as well as emergency workers looking for survivors, were all put in harm's way because of continuing instability of the slide mass. What we learn through repeated data collections will translate into knowing how the landslide risk changes with time (e.g., answering questions such as "when can emergency responders walk on the landslide to look for survivors" or "how long until residents can reoccupy their nearby homes"). One Haines resident indicated that she knew she probably should not be in the area, but she wanted to seal a hole in the wall of her house caused by slope movement, before her pipes froze (Leasia 2020). This emphasizes the uniqueness of this event in a cold-weather setting, for which there is little data. At this point, it appears that this landslide had both survivors and, devastatingly, two fatalities (the search for two missing people was suspended on December 7, 2020 (Kunze and Brooks 2020)). Data that we gather from this event will add significant new information to the current dataset on human vulnerability to landslides in DesignSafe (Pollock and Wartman 2020b).

Justification for RAPID Grant: Already the surface of the landslide has changed, demonstrating the ephemeral nature of this data. We are uniquely poised to capture data on the landslide's response to snowmelt in the coming months, and to observe how the landslide surface changes with time. While these data will provide a comprehensive case study for this event, they also may provide critical information about safe reoccupation of the adjacent area.

Data Availability: All data collected through this RAPID will be hosted and curated in *DesignSafe* immediately after collection and processing. Additionally, DGGS will provide access to baseline LiDAR data through their online "elevation portal" for another avenue of public access (DGGS Staff 2013).

Research Plan and Project Team: The research plan consists of (1) field data collection, (2) data processing, (3) characterization of the landslide and analysis of its evolution, and (4) curation and archiving datasets. The reconnaissance field work and analysis will include collaboration from the University of Alaska Fairbanks (UAF), the Natural Hazards Reconnaissance Facility (NHERI RAPID) at the University of Washington, and the DGGS. UAF PI Darrow has a history of successful collaboration with both NHERI RAPID (current post-seismic rockfall analysis, Interior and South-Central Alaska) and DGGS (long-term frozen debris lobe investigation and monitoring, Northern Alaska (Darrow et al. 2016; Simpson et al. 2016; Darrow et al. 2017; Gong et al. 2019); and LiDAR-based landslide mapping and analysis, Interior Alaska (Miandad et al. 2020; Schwarber et al., in press)).

Task 1 – Field Data Collection: The reconnaissance team will conduct two data collection campaigns of the Haines landslide (Figure 2). The goals of these field visits are to: 1) collect repeat aerial LiDAR and high-resolution images of the landslide surface; 2) characterize the geology of the slide area; 3) capture the emergency response, repair, and rebuilding efforts of the community; and 4) collect local environmental data for analysis.

Four days after the landslide event, DGGS collected an initial LiDAR dataset and unmanned aerial system (UAS)-based imagery that will serve as baseline data for this RAPID project. We will use equipment from the NSF NHERI RAPID Facility, including: DJI Matrice 210 UAS with X5S Camera for imagery and Structure-from-Motion (SfM) photogrammetry data collection; MiniRanger UAS with LiDAR scanner for collecting 3D point cloud data; and Leica GS18 Global Navigation Satellite System (GNSS) – Global Positioning System (GPS) receivers for high accuracy georeferencing. Flight paths will be planned once in the field for full coverage of the landslide extent, with additional adjacent areas of concern identified for LiDAR data collection. Appropriate overlap will be applied to maximize point density in the priority area. Coverage will include the head scarp and full landslide runout area. The use of a UAS is especially important for this event, as we can capture high-resolution images of the head scarp area even if the landslide remains unsafe to traverse. Working with state and local officials to ensure safety of the reconnaissance team, we will travel onto the landslide surface to make on-the-ground measurements and observations that will rapidly disappear, including distribution of soil and/or bedrock throughout the landslide, orientation of displaced blocks and trees, presence of flowing or ponded water, and high water marks. Concurrent with these data collections, DGGS personnel will collect bathymetry data of the area where landslide debris accumulated in the bay. The combined data sets will represent complete coverage of the subaerial depletion and submarine accumulation zones of the landslide.

We will meet with personnel leading the Haines Emergency Operations Center to document the landslide timing and events immediately following the landslide, search and rescue response, and restoration of utilities, infrastructure, and services, to understand community response to this event. This documentation effort will be made in collaboration with DGGS personnel, who are already working closely with local city emergency response coordinators. Additionally, the reconnaissance team will work with representatives from the National Weather Service and the Haines community to collect precipitation, groundwater, and snow-water equivalent data from the December 2020 event and throughout the study period.

Task 2 – Data Processing: Real-time kinematic GNSS data paired with post-processed Inertial Navigation System (INS) trajectory data will provide accurate (<3 cm) georeferencing for the LiDAR scans and the high-resolution imagery. The software Pix4D, which is available to the research team through the RAPID Facility, will be used in conjunction with the UAS-acquired images to develop high-resolution georeferenced orthomosaic images, and digital elevation models (DEM) of the landslide region. The LiDAR will be post-processed by the RAPID Facility using their specialty aerial LiDAR registration software package. The products of this processing will include a classified (ground, vegetation) true-color point cloud model and both digital surface models (DSM – a type of DEM with vegetation) and digital terrain models (DTMs – a type of DEM without vegetation). All raw data will be uploaded into NSF NHERI DesignSafe.

Task 3 – Characterization of the Landslide and Analysis of its Evolution: The DTMs produced from this project's LiDAR collection and the baseline collection from DGGS will be compared for data concurrency, and then differenced to quantify changes in elevation with time (see Figure 3 for an example of DTM differencing for a slow-moving landslide). We will combine these results with those obtained from the bathymetry data to provide a complete analysis of the subaerial area of scour and the submarine area of deposition. Special attention will be given to the area of deposition, as this is where debris from the houses accumulated (G. Wolken, pers. comm., Dec. 2020). Using data from all epochs, timing of changes in landslide morphology will be correlated to rainfall, snowmelt, and subsequent changes in groundwater levels through the 2020/21 winter. Orthoimagery will be examined visually to identify changes in debris extent and vegetation over the project duration. We will use a combination of the orthoimagery and DSMs to track movement of standing trees along the head scarp area as another means of identifying creep within the exposed bedrock. In general, slopes that have moved in the past are at a greater risk of moving in the future (Burns 2007); studies suggest this is also true for snowmelt-induced landslides (Ayalew et al. 2005; Cardinali et al. 1999). Thus, as a broader element of this project, we will compare the orthoimagery to historic high-resolution images of the area for

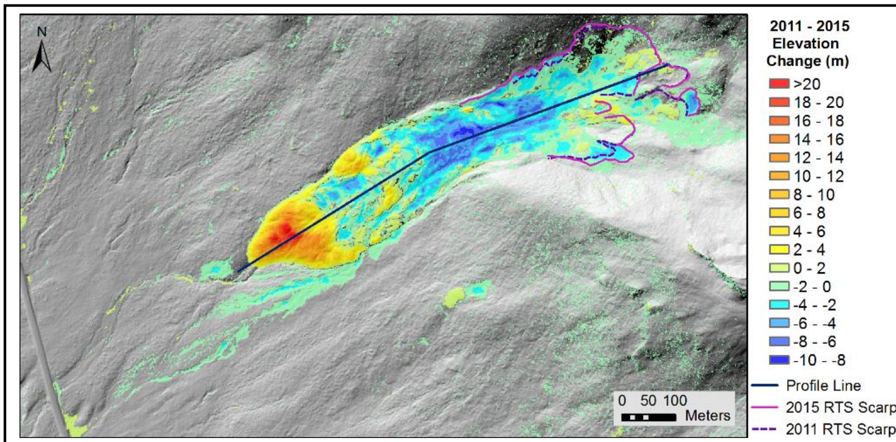

Figure 3. Example of DTM differencing for a slow-moving landslide in the Brooks Range of Alaska (taken from Gyswyt et al. 2017).

a long-term change detection analysis, and identify other prehistoric landslide areas discernable in the baseline LiDAR data.

Task 4 – Development of DesignSafe data archive: We will leverage the NSF NHERI DesignSafe data repository for project data organization, archiving, and curation. Members of the reconnaissance team will be added to the DesignSafe project so they can upload and download project files. The RAPID facility will upload all raw data collected by their instrumentation to the DesignSafe project immediately following reconnaissance activities. Processed data will be organized and later curated following the NHERI data curation guidelines.

Broader Impacts: Repeat terrestrial and submarine data collections will facilitate understanding of how the landslide surface evolves with time, how vegetation recovers on the surface, and how the submarine deposits interact with currents, the latter of which may provide information on how landslides entering navigable water ways impact shipping lanes. The high-resolution imagery that is collected with the LiDAR data will help to quantify the pattern of vegetation removal, displacement, and deposition, all of which may help with long-term biodiversity (Geertsema et al. 2009). Analysis of these data will lead to a better understanding of the life cycle of a large landslide, and the ecological role it plays in this high latitude, maritime environment. Collecting perishable data from the landslide will help us answer the question: "Why here?" Answering this question will obviously help the community of Haines, but also will guide other municipalities in future slope stability data collection that they can use for community planning (Godinez 2020). Results from this project will help inform local and state agencies how to adapt for long-term resilience while accounting for an increase in extreme weather events. Understanding the morphology of the full landslide extent, including the submarine deposition zone, will aid in future recovery efforts for similar events.

RESULTS FROM PRIOR NSF SUPPORT

PI: Margaret M. Darrow, **Title**: CAREER: Mobility of Unfrozen Water in Frozen Soil. **Grant**: CMMI-1147806, **Amount**: $424,954* (includes 2-$6k, 1-$10k REU Awards), **Duration**: 2012-2017 **Intellectual Merit** – Research quantified relationships among unfrozen water content and mobility, soil zeta potential, and soil micro-fabric (Darrow and Lieblappen 2020) producing a comprehensive suite of unfrozen water and zeta potential measurements for five cation-treated standard clays (Darrow et al. 2020). We improved pulse pNMR methodology (Kruse and Darrow 2017; Kruse et al. 2018). **Broader Impacts** – The project supported six URAs and two MS students, most from underrepresented groups, who presented their research at local, national, and international conferences. The PI taught a frozen ground engineering module to 7th and 8th grade students, including trips to the CRREL Permafrost Tunnel near Fairbanks.