SUMMARY OF THE NSF CRYOSLIDERISK WORKSHOP 2, UAF, SEPTEMBER 6-8, 2023

ABBREVIATED WORKSHOP AGENDA

SEPTEMBER 6: An informal (and LITERAL) icebreaker was held at the Permafrost Tunnel Facility in Fox, Alaska, operated by the US Army Corps of Engineers (USACE) Cold Regions Research and Engineering Laboratory (CRREL).

SEPTEMBER 7 - DAY 1:

- Welcome, overview, and summary of Workshop 1 (*Margaret Darrow and Louise Farquharson, UAF*)
- Impacts of permafrost on critical infrastructure in Denali National Park: *Denny Capps (NPS) and Orion George (FHWA)*
- Slope Movement at the West Abutment of the Susitna River Bridge, Denali Highway, Alaska: *Matt Billings (ADOT&PF)*
- Toward a better understanding of cryosphere-related slope instabilities in Alaska: *Gabe Wolken (DGGS)*
- Active Layer Detachments along the North Klondike Highway: *Derek Cronmiller (Yukon Geological Survey)*
- Permafrost-related landslides folling 2017 wildfire, Dempster Highway, Yukon: *Heather Clarke (Simon Fraser University)*
- Using Computer Vision to Inventory Landslides; Predicting Landslide Susceptibility using AI/ML: *Tong Qiu and Chaopeng Shen (Penn State)*
- ROUND 1: Lightning Talks - Pair with others with your area of expertise; select one of the following topics for brainstorming
    - AGENCIES - Identify problem areas related to your work (e.g., infrastructure, mitigation, ecosystem impacts)
    - ML/AI - What can AI tools do to help solve these problems
    - FIELD RESEARCHERS – What are problems with identifying landslides in the cryosphere
- Coffee breaks, lunch, and dinner provided the opportunity for informal networking between attendees. There was an informal poster session during the lunch period.

SEPTEMBER 8 - DAY 2:

- Summary of Day 1 *(Tong Qiu)*
- ROUND 2: Lightning Talks – Now we are mixing it up! Work with others in different areas of expertise; develop an "elevator pitch" (short summary of a research idea and approach) on how to solve the problems identified during Day 1.
- Closing remarks, next steps, future events *(Workshop hosts)*

The CryoSlideRisk Workshop 2 convened on Thursday, September 7, 2023. Although mostly in-person, some participants attended via Zoom. The following people were in attendance (33 total participants):

Workshop co-hosts: Margaret Darrow and Louise Farquharson (UAF), Tong Qiu and Chaopeng Shen (Penn State)

<u>In person:</u> Daisy Herrman, Mike West, Dmitry Nicolsky, Claire Anovick, Daniel Vazquez, Christopher Kalev, Evan Joyce, Mike Ophoff (UAF); John Thornley (WSP); Matt Billings and Jeff Currey (ADOT&PF); Orion George (FHWA); Denny Capps (NPS); Shemin Ge (University of Colorado, Boulder); Ning Lu (Colorado School of Mines); Gabe Wolken and Jill Nicolazzo (Alaska DGGS); Lukas Arenson (BGC Engineering); Heather Clarke (Simon Fraser University); Ellen Clark (US CRREL); Derek Cronmiller and Moya Painter (Yukon Territory Geological Survey); Eva Stephani (USGS); David Wright (FNSB); Qianyu Chang (U of Guelph)

<u>Online:</u> Rafael Caduff (gamma-rs.ch); Kaytan Kelkar (UAF); Taylor Sullivan (CRREL); Darren Beckstrand (LT); Te Pei (Penn State)

<u>Summary of presentations and discussion:</u>

Impacts of permafrost on critical infrastructure in Denali National Park, Alaska; joint presentation by Denny Capps (NPS) and Orion George (FHWA). There is a disproportionate magnitude of climate change in US National Parks (example of Pretty Rocks Slide). The unstable slope management program identified 150 landslides along the Parks Road (e.g., Zena Slide, Bear Cave Landslide). Extensive subsurface investigations have been done for the Bear Cave Landslide, identifying different mitigation options. The main conclusions from the investigations are: wedge-like failure along possible fault, relatively stable above road; drainage ditch installed in 1999 and 2022 and movement slowed. Aerial LiDAR surveys were conducted in 2018 and 2022, along with surface movement and GPS measurements from 2018-2019. Complex stratigraphy, highly to completely weathered bedrock.

Discussion:

- Q: Does the rate of mass movement correlate with season/year in terms of amount of precipitation and temperature? A: current monitoring program does not have the temporal resolution to make the correlation; however, field evidence suggests a strong correlation.
- Scale of movement is masked by construction operations, FHWA does monitoring at depth while NPS does monitoring at the surface.
- This looks like a perfect dataset to validate Sentinel Data (InSAR). It is a work in progress and will have something to report soon. Accurate for some places.
- Q: What are other agencies and stakeholders involved? A: ADOT&PF helped with subsurface investigation and provided expertise.

Slope Movement at the West Abutment of the Susitna River Bridge, Denali Highway, Alaska; Matt Billings (ADOT&PF). This landslide is located at Mile 79.5 on the Denali Highway. Movement of ~0.5-inch per year requires routine maintenance (e.g., reestablishing bearing surfaces at piers and adjusting girders). There were drilling and instrumentation activities in 2014, 2019, and 2022, as well as unfrozen moisture content and creep testing. The majority of movement is occurring in ice-rich permafrost soils on site. A ditch-like depression is evident in historic stereo-pair imagery; it may be a block separating from upslope land mass. The movement is too large to mitigate practically. They will continue with slope movement monitoring to analyze if rate of movement correlates with presence of groundwater or permafrost temperature.

Discussion:

- How many years of design life is left for that bridge? A: not sure, but a new bridge to replace the existing one is unlikely anytime soon.
- The rotational feature of the slope movement is identified by analyzing the movement data with depth (e.g., inclinometer data). Movement data are shown to have seasonality.
- Funding is a constraint for a monitoring/maintenance program to acquire sufficient data.

Toward a Better Understanding of Cryosphere-related Slope Instabilities in Alaska; Gabe Wolken (Alaska DGGS). The topics that he investigates as part of DGGS are snow avalanches, snow variability and distribution, glacier change, and unstable slopes. They stress the co-production of actionable science; partnership is key. DGGS is currently developing a landslide inventory for Alaska (Jill Nicolazzo is lead on that effort). A major issue for Alaska is the lack of data - we need to set up instrumentation whenever feasible to acquire data (e.g., spatial distribution of soil moisture and temperature). Examples of big events are the Barry Arm 2020 rockfall event (>600,000 m^3 release volume, but just a small part of the possible volume that could move) and the 2016 Lamplugh Rock Avalanche, known associated with permafrost. Unstable slope needs include: baseline data including geologic spatial data, observational and model-derived data (hydrometeorological and permafrost distribution), downscaled climate reanalysis and projections, and inventories including landslide and potential unstable slopes. Automated mapping and prediction would be useful (e.g., identify potentially unstable slopes and to reduce area of interest).
Discussions:

- Q: How to identify potentially unstable vs. stable slopes? A: It is not a process-based decision now. It is often reported by citizens and we conduct subsequent investigations to monitor movement to identify unstable vs. stable slopes. Some partners are very good at mapping unstable areas from Google Earth.
- We are here to see how AI/ML can help us map these unstable areas.
- Q: What models are currently being used to derive data? A: We are currently using Stephan Gruber’s permafrost distribution model, which has a coarse spatial resolution. We need higher resolution permafrost maps, and better “downscaled climate data" for the past and future.

Active Layer Detachments on the North Klondike Highway, Yukon; Derek Cronmiller (Yukon Geological Survey). The Klondike regional climate has experienced significant warming since the 1970s. The last 10 years show a decline in extreme cold in the winter, warmer throughout the year, and an extended thaw season. There has been above average snowpack for the last three years, with 2022-2023 having the snowpack of record since 1975. In September 2022, there was a 25-yr rainfall event for Dawson (likely higher in the slide area), which triggered >60 landslides above the Klondike Highway. Of these, 14 slides reached the highway, leaving 45 people stranded within the slide area. For this event, Derek documented landslide occurrence per hour since the end of peak rainfall (0 occurrence after 48 hours past the peak rainfall). The active layer with organics controls the slide mobility. Extreme weather is a strong driver of permafrost slope instability. The depth of thaw, soil moisture content, and the ratio of the organic materials to surficial materials may predict the style of slope movement, slide mobility, and damage potential. A good permafrost database is service.yukon.ca/permafrost. The Preliminary Canadian Landslide Database contains an increasing number of permafrost landslides: Brideau et al. (2023) Preliminary Canadian Landslide Database (6.1) [Dataset] Zenodo.

Discussion:

- Q: What is the distribution of weather stations and other monitoring instruments in the area? A: Sparse. Q: Do you plan to develop a landslide hazard map for the roadside in the future? A: Yes, we are working on that area. We need to collect better dataset.

Permafrost-related landslides following 2017 wildfire, Dempster Highway, Yukon; Heather Clarke (Simon Fraser University). Heather presented on the influence of wildfire, and its effective degradation of the insulating organic cover. There is an uptick of slope movement/landslides after a wildfire, including retrogressive thaw flows (RTF). These are cascading effects: wildfire - ALD - RTF.

Discussion:

- Will produce a map of paleo-landslides in the region.
- Q: Do you see correlation to greater depth over time? A: No, but could go back to check. Should be in LiDAR.

Landslide Susceptibility Mapping using Physics-Guided Machine Learning (PGML); Tong Qiu (Penn State). Some general questions are: how can we apply this approach to predict landslides in Alaska? And what kinds of data are necessary? For debris flows, contributing factors to their analysis are: (derived from USGS 3DEP) elevation, slope, aspect; topographic wetness index; (derived from Landsat 8) normalized difference vegetation index; (derived from OpenLandMap) % sand and clay, bulk density, and field capacity. We used the infinite-slope model for shallow debris flows. The AUC score indicates how well the model matches reality. The physics-based approach yielded 0.885 with blind prediction. ML does not care about the physics, but rather the input and the output, so we need to train it well. We used an artificial neural network. Then the AUC score increased to 0.932; this was higher but was done after the events. Next, how do we incorporate physics-based models into machine learning? We train the model, and this reduces false positive and false negative areas. We took the PGML model from one region and applied it to other regions for blind predictions; this yields a much better performance with the PGML than with traditional ML. PGML models can improve ML model performance under limited data conditions, improve physics consistency, and make ML models more generalizable and explainable.

AI-assisted cataloging and modeling of landslide events - an ever-evolving landscape; Chaopeng Shen. Some regions in the world have great data inventories while others do not. One challenge is that current DL models give too many false positives. Differentiable modeling allows us to generate new knowledge, to identify/check/validate missing relationships, and/or to improve empirical correlations.

Discussion:

- The Canadians seem to have enough data to have initial training of ML models. In the Canadian preliminary database, there are about 6,000 landslides, and a few hundred to 2,000 permafrost-induced mass movement hazards (as point or polygon, locations associated with events, date and time for some events).
- NASA's Daymet has precipitation data available for any location.
- Eventually, we want to develop ML models that can be used to predict landslides at global scales (landslide predictive robot). Landslides are the results of resisting forces and driving forces. The physics is relatively well-understood. It seems promising to develop predictive ML models.
- Precipitation vs thawing, the latter might be more important for permafrost-induced mass movements. It is important to understand the distribution of ice content.
- It is challenging to map ground ice content (this was also noted during Workshop 1). Our understanding of permafrost-induced mass movements is not as advanced as that for landslides triggered by rainfall. We are still in the process of developing physics-based models for permafrost-induced mass movements. We may not need detailed distribution of ice content. There might be correlations among ice content and other features we can infer. For example, topography, minerals, and soil have connections to geology.
- What is the objective of our task: mapping or predicting? Using ML models trained using existing landslides, we will be able to identify hazards for similar landslides (e.g., texture, physics) but will not be able to identify landslide hazards that are different from the existing ones. Perhaps we can develop a model that can reasonably predict the past events, take climate projections, and then make predictions for future occurrences.
- Federal agencies do not move as fast. We are interested in knowing what federal agencies can do to help ML communities move forward with this work.
- It is about workforce development at federal agencies. Folks who are attracted by rapidly-moving/evolving ML fields are unlikely to be attracted by federal agencies.
- ML models can be effective in surficial geological mapping (e.g., landforms and soils) at the regional/state scale. This will make agencies' work more efficient and cost-effective.
- We expect to have the first surficial geological mapping of landslides for the Denali Park in collaboration with USGS.
- The Yukon started geological mapping in the 1940s.
- Q: How many landslide points do you need to develop a good ML model? A: We don't know until we try something to see how it works.
- We need data from different regions and mass-movement types to develop ML models that are more generalizable.
- How can we predict landslides if we do not even have spatial distribution of ice-rich permafrost? How many data points in each region are needed? Are proxies for ground ice content available? We might be able to feed information like elevation, ground temperature, glacial boundaries, etc. as proxies for permafrost distribution.
- When I do mapping of rock glaciers, I do not look at satellite images. I would rather look at topography and surrounding features. Can ML models look at surrounding features?

Yes, convolutional neural network (CNN) can already do this in processing images, where information is fed into different channels from surrounding regions.

- Perhaps we can develop something similar to ChatGPT to predict what features are most likely to occur in a landform / geological setting.

<u>Results from Round 1 Lightning Talk Discussions</u>

Land Management Agencies Group

- Variable risk tolerance is really important. ADOT&PF has done risk tolerance assessment; however, funding is an issue for this line of work.
- Risk tolerance is different in different communities; it is important for communities to learn from each other.

ML/AI Group Discussion

- Predictions will degrade across regions. Models are overfitted with information specific to the training dataset. It is important to exercise caution in interpreting ML results.
- Differentiable parameter learning can help us gain insight into unknown relationships or quantify unknown coefficients.
- We could use ML to predict current topography to see how much we can infer from current topography.
- ML proposals need to justify why you are using it as a tool or what advances can ML bring that would not be possible using other approaches. Mapping is easier to sell; however, prediction is trickier.

Field Researchers Group

- We could conduct Independent testing of modeling benchmark data, or a blind prediction contest (e.g., pile load test results). These would be excellent avenues for community outreach.
- Concerns: outreach at different levels; issues with retaining students in academia once they are familiar with ML; could collaborate with big tech companies on this; develop short courses on ML models for geoscientists.

The CryoSlideRisk Workshop 2 continued on Friday, September 8, 2023. The following people were in attendance in person on Day 2 (21 total participants):

<u>Workshop co-hosts:</u> Margaret Darrow and Louise Farquharson (UAF), Tong Qiu and Chaopeng Shen (Penn State)

<u>In person:</u> Daisy Herrman, Claire Anovick (UAF); John Thornley (WSP); Jeff Currey (ADOT&PF); Orion George (FHWA); Denny Capps (NPS); Shemin Ge (University of Colorado, Boulder); Ning Lu (Colorado School of Mines); Jill Nicolazzo (Alaska DGGS); Lukas Arenson (BGC Engineering); Heather Clarke (Simon Fraser University); Ellen Clark (US CRREL); Derek Cronmiller and Moya Painter (Yukon Territory Geological Survey); Eva Stephani (USGS); David Wright (FNSB)

<u>Online:</u> Kaytan Kelkar (UAF)

<u>Summary of Day 1</u>

Major lessons learned:

- We learned the disproportionate impact of permafrost on critical infrastructure in the cryosphere through several vivid examples, including the Pretty Rock landslide, Bear Cave landslide, the issues with the west abutment of the Susitna River Bridge, and failures along the Klondike Highway in the Yukon. Some of the movements are too large to mitigate practically. In some cases, we are building a bridge to cross over the landslide/unstable area. Agencies, engineering firms, and local communities have worked closely and collaboratively to address these challenges.
- We learned that wildfire also has an impact on permafrost-related landslides due to the degradation of the insulting organic cover through a case study along the Dempster Highway, Yukon. We learned about the cascading effects of wildfire to active layer detachment to retrogressive thaw flows.
- We learned that permafrost-related mass movement generally has seasonality, although we sometimes do not have monitoring data to show the correlation quantitatively due to budget constraints.
- We learned that different government agencies have different topics of investigation in permafrost-related mass movements.
- We also learned about examples on how to map/forecast landslides using ML and computer vision. We discussed the type of data needed, the framework, and how to incorporate landslide physics into ML algorithms to make ML predictions consistent with domain knowledge and more generalizable from one region to another.

Following each talk we had engaging discussion, we also had breakout group discussions. Some common issues emerged from these discussions:

- There is a lack of data in Alaska due to the state being so big and vast; many areas are remote, and there are budgetary constraints and a lack of manpower. Luckily we learned that Alaska's DGGS is compiling a landslide database, and that the Yukon Geological Survey also has compiled a large permafrost-related landslide database.
- We had questions on how much data is needed for developing ML models. The best way to answer this question is to start with a small area with a small amount of data to see how the ML models perform. We can gradually increase the amount of data and fine-tune the ML models. A warning is: do not let perfection be the enemy of progress. We may be able to work on a small dataset to generate results for a paper or two to present at the upcoming International Conference on Permafrost (2024) in Whitehorse, Yukon.
- Our understanding of permafrost-induced landslides is not nearly as advanced as our understanding of rainfall-induced landslides; hence, more understanding of the processes is urgently needed.
- Ground ice content is difficult to map. We discussed that we could have proxies for ice content or even permafrost distribution to feed into ML models, such as elevation, ground temperature, and glacial boundaries.
- Risk tolerance is different for different communities. It is important for different communities to learn from each other.

- We discussed the importance of developing independent data for model benchmark testing. We should develop protocols in creating and sharing data for ML researchers to test their models. This would require a concerted effort from the international communities.

Proposal ideas:

1. Datasets/Mapping
2. Physics-informed modeling
3. Solving equation efficiently
4. Foundation model