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An inventory and assessment of glaciers, rock glaciers, perennial snowfields, and permafrost landforms in the Teton Range, WY, USA

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Abstract Glaciers, rock glaciers, and permafrost landforms store water within ice reserves in alpine and periglacial zones. In the Greater Yellowstone Ecosystem of northwestern Wyoming, U.S.A., these landforms charge the hydrological system through meltwater, which raises questions about the ecological impacts of these limited water reserves in a regime trending toward warmer and drier conditions. Here, I investigate the impact of glacier and rock glacier meltwater on the ecological systems within the Grand Teton, Wind River, and Gros Ventre mountain watersheds. This investigation relies on remotely sensed satellite imagery, aerial photography, and Lidar, as well as *in situ* field data. With these data, I provide a high-resolution inventory of glacial, rock glacial, and permafrost landforms in the GYE.

Introduction

The Teton Range in Wyoming (USA) hosts glaciers, rock glaciers, perennial snowfields, ice bodies, and gelifluction lobes in alpine and periglacial zones. These landforms supply regional hydrology through water storage in ice reserves (Krainer and Mostler, 2002; Giardino et al., 1987; Barsch, 1965). In the GYE, cryospheric landforms contribute to the hydrological system (Goff, 2016*b*,*a*), which raises questions about climate change impacts to those limited water reserves. This project provides a high-resolution inventory and classification of cryospheric landforms in the Teton Range through remotely sensed data (satellite imagery, aerial photography, LiDAR) and *in situ* observations.

My geomorphological investigation relies on remote sensing and *in situ* observations of glaciers, rock glaciers, gelifluction lobes, debris covered perennial snowfields, and other ice bodies. Through the combination of *in situ* and remotely sensed data, I will provide an inventory and classification of cryospheric landforms and associated meltwater features in the Teton Range.

Further, the extensive loss of high elevation snowpack and glacial ice within the Middle Rocky Mountains Province is a distinctive indicator of anthropogenic climate change. Present day climate models are effective in predicting the broad regional trends in montane cryospheric change, but they fail to capture the degree to which the changes in snowpack have been observed in Grand Teton National Park. This project will detail change from the 1990s to the present day in order to best inform and test a hindcast model and predict future change. Broadly, I predict that recent climate trends toward a warmer and drier regime will stress this particular inventory of rock glaciers through factors that negatively affect water availability, thus impacting ecology (Sorg et al., 2012; Millar and Westfall, 2008).

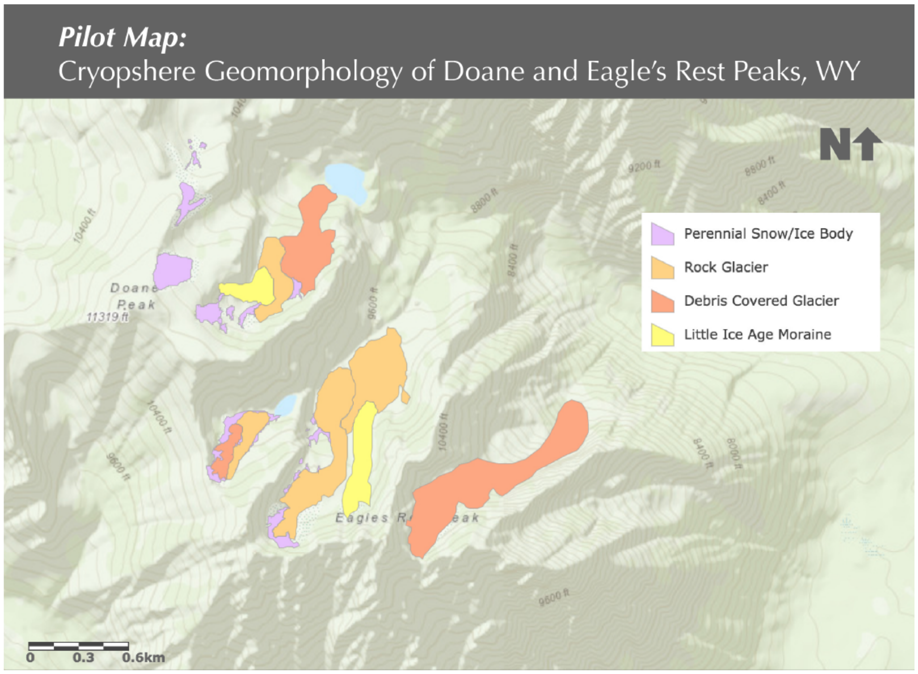

Figure 1. A landform map for Doane and Eagle's Rest Peaks in the Teton Range.

Significance

A primary motivation for this research is to fill the existing knowledge gap surrounding rock glaciers as water suppliers for proximate watersheds. To date, an incomplete analysis exists for cryopsheric landforms in the Teton Range. This project hopes to investigate the role these landforms play in the regional hydrologic system - this knowledge could be used to inform policy decisions regarding environmental flows and aid recommendations as to the future of water supply for biota and human populations. Furthermore, this information could help to serve studies of riparian habitats along the Snake River, which depend on accurate predications of water availability. Knowledge regarding melt-induced water supply would be particularly valuable to land and resource managers and would also offer increased accuracy to the scientific community through hydrological models that must necessarily depend on water input variables.

Research Questions, Objectives, and Hypotheses

This project combines *in situ* data with remote sensing observations to answer the following research questions:

1. What are the characteristics of cryospheric landforms in the Teton Range?
2. How many distinct cryospheric landforms (glaciers, rock glaciers, gelifluction lobes, perennial snowfields etc...) exist in the Teton Range today?
3. What is the change in perennial snowfield surface area in the Teton Range from the 1990s to the present day?
4. What is the forecast for cryospheric landform change into the next decade and century?

This project will meet the following objectives:

1. Identify the characteristics of cryospheric landforms in the Teton Range.
2. Create an inventory of distinct cryospheric landforms (glaciers, rock glaciers, gelifluction lobes, etc...) in the Teton Range today.
3. Calculate the change in perennial snowfield surface area in the Teton Range from the 1990s to the present day.
4. Employ hindcast modeling to predict cryospheric landform change into the next decade and century.

I hypothesize that:

1. Cryospheric landforms in the Teton Range have mostly eastern or southern aspects, related to the fault block tilt, and are largely debris-covered.
2. In addition to the ten established glaciers in the Teton Range, this study will demonstrate that rock glaciers, gelifluction lobes, and perennial snowfields characterize the range and contribute to seasonal streamflow.
3. There have been significant changes to perennial snowfield surface areas in the Teton Range from the 1990s to the present day.
4. Hindcast modeling will predict significant change to cryospheric landforms in the next decade and century.

Methods

Remote Sensing Data

Rock glacier landforms exist in high-alpine environments that are difficult to access through terrain that is dangerous to traverse. I employed remote sensing techniques to create a complete inventory of cryospheric landforms and their characteristics in the Teton Range to answer RQs 1, 2, and 3. A pilot study of Eagle's Rest and Doane Peaks (Figure 1) indicates that a complete inventory will be valuable in assessing water inputs from alpine and periglacial regions.

In Situ Data

I have gathered water samples from each of the identified sites, as originally proposed. All sites exist proximate to established park trails and I have verified their accessibility as suggested in past reports.

- Site 1: Schoolroom Glacier Runoff
- Site 2: Proximate Snow Schoolroom Glacier Runoff
- Site 3: Debris-covered perennial snowfield (43.794668°, -110.814978°)
- Site 4: Gelifluction Lobe
- Site 5: Sunset Lake
- Site 6: Stream Water Skillet Glacier
- Site 7: Proximate Snow Lake Mica/Sol
- Site 8: Down-valley of Mica/Sol
- Site 9: Paintbrush long-term site
- Site 10: The Gusher
- Site 11: Meltwater stream up-valley of Mica/Sol
- Site 12: Lake Solitude East Shore
- Site 13: Debris-covered perennial snowfield snowpack
- Site 14: Meltwater stream at Trail Mica Lake

I collected meltwater samples from each study site to analyze stable isotopes to further inform RQ 1 (Peterson and Fry, 1987; Barnes and Allison, 1988; Masson-Delmotte et al., 2008). The Reston Stable Isotope Laboratory analyzed the oxygen 16/18 ratio of each sample to help pinpoint the water source for each meltwater feature to make predictions about future water supply to answer RQ4 (Thompson et al., 2016). Those data will help determine the source of meltwater and provide reasonable estimates as to the expected supply for nearby reservoirs.

Preliminary Results, Conclusions, and Future Work

This research took place over the course of 6 weeks in the GYE of Wyoming and extended into Banff National Park in Canada. Over the course of this fieldwork trip, myself and a research assistant tackled the questions proposed in the grant application. Below are the preliminary results based on my research objectives and hypotheses:

This project resulted in an inventory of cryospheric landforms to help answer questions 1 and 2. This inventory will be published in my final dissertation (anticipated in Fall, 2019). Research question 3 pertained to perrenial snowfield surface area. Thus far, results indicate that perrenial snowfield surface areas have uniformly decreased from the 1990s to the present day. Although still in progress, this project aims to provide a quantitative description of this phenomenon in relation to climatic events.

Finally, this project explored the effect that large scale climatic events may or may not have on cryospheric landforms and water flow in Grand Teton National Park. Here, we relied on our water samples to better understand the source of melt (seasonal, multiseasonal, decadal, etc.). Though I set out to collect five samples, I brought home a total of 14. I have received results from the Reston Stable Isotope Lab to be analyzed and included in the final dissertation, expected in Fall of 2019.

Future Work

My next trip into the field is planned for the summer of 2020. During that time, I will follow up on repeat photography field work, water sample collection, and ecological data collection in the GYE. Although that anticipated work is beyond the scope of this proposal and my dissertation, I am confident that the results will be closely tied to this project and will provide a valuable contribution to Grand Teton National Park.

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