Modeling The Erosion Rate of Emmons Glacier, WA

Daniel Purcell

Abstract

The erosion rates of glaciers are poorly quantified, due to the difficulty of measurement and estimation. Several studies have utilized a simple, one-equation erosion rule to model glacial erosion rates based on glacier velocity.[1] This study seeks to determine the applicability of this model for Emmons Glacier on Mount Rainier. Suspended sediment concentrations were collected in 2019, which were used to estimate erosion rates, and the model was used on a range of velocities to generate erosion rates. The distributions of erosion rates for these two methods were then compared to each other. Overall, both distributions were very similar, indicating that the model is sufficiently applicable to Emmons Glacier, and perhaps the other glaciers on Mount Rainier. The parameters for the model used in this study differ from those used in the original model, likely due to that study using average velocity as opposed to a spatial distribution of velocities.

Background

- Understanding glacial erosion is significant to the geological community, because it produces vast quantities of sediment which are transported by meltwater streams.
- Glacial meltwater streams on Mount Rainier deposit large quantities of sediment in hydroelectric reservoirs such as Alder Lake, which stresses the dam face and reduces its overall energy storage capacity.[1]
- Attempting to quantify glacial erosion rates is difficult; Direct observation is costly and requires unique circumstances, and indirect measurements have high degrees of uncertainty.[2]
- Previous PLU Summer Research has estimated the erosion rates on Emmons Glacier using suspended sediment concentrations based on a formula from Riihimaki et al, 2005.[1]
- A one-equation model has recently been developed and utilized in at least a dozen studies.[2]
- This study aims to answer the question: Is this erosion rule effective for estimating erosion rates on Mount Rainier glaciers?

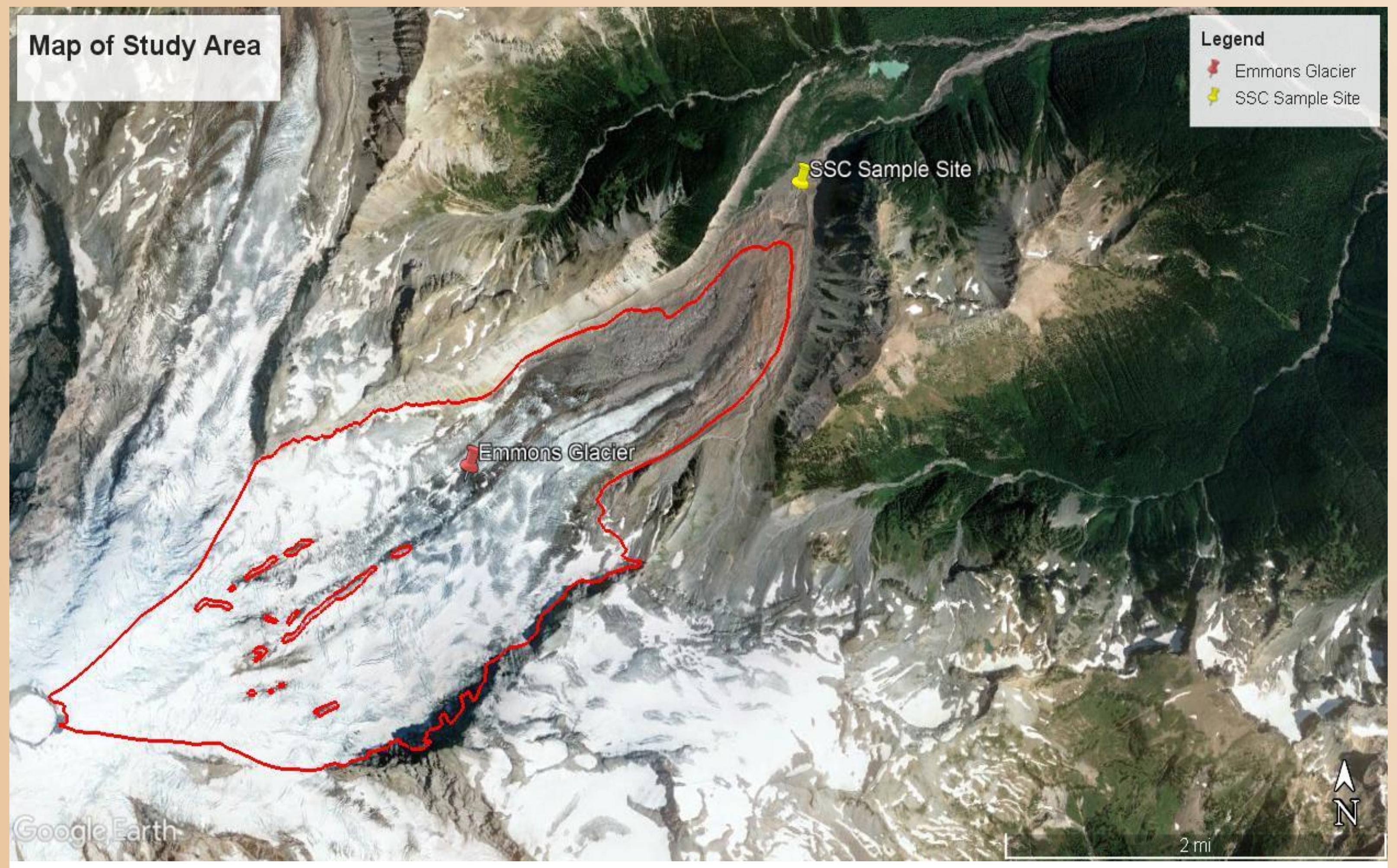

Figure 1: Location map showing Emmons Glacier[3], and the location where suspended sediment samples were collected to estimate the glacier's erosion rate

1. $$e = k_g U^l$$

Equation 1: Erosion rule established in Cook et al, where *e* is the erosion rate, k_g is a bedrock erodibility constant, U is the glacier's sliding velocity, and l is a constant, usually taken to be between 1 & 2.

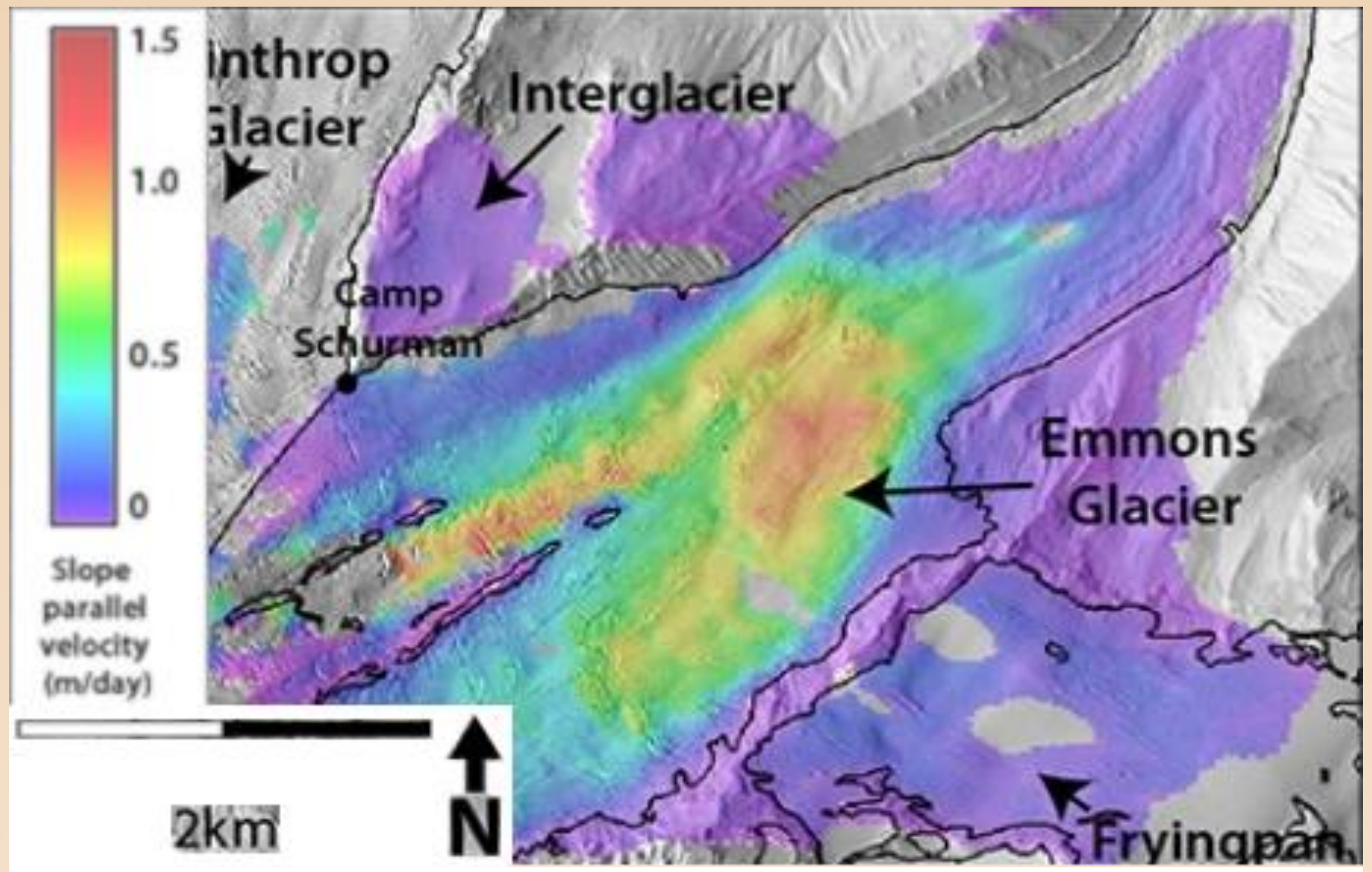

Figure 2: Map of velocities of Emmons Glacier[4]

Methods

- This study compares the distribution of erosion rates for Emmons Glacier, estimated from suspended sediment concentration, with the distribution of erosion rates generated using the erosion rule in Cook et al.[2]
- Glacier velocities used in Equation 1 were obtained from an interferometry study by Allstadt, et al in 2015,[4] and the range of values was determined visually as 0.1 – 1.1 m/day. (Figure 2)
- The parameters were determined experimentally by plotting Equation 1 as a function of k_g and *l*, with a *U* value of 1.1 m/day, to determine a range of values to yield the maximum erosion rate obtained from suspended sediment concentration (0.03 m/yr) (Figure 3)
- *l* was set to be 1.6, and two values of k_g along the 0.03 contour line were selected and used in two different models.
- The distributions were plotted in RStudio using notched box plots to compare them (Figure 4)

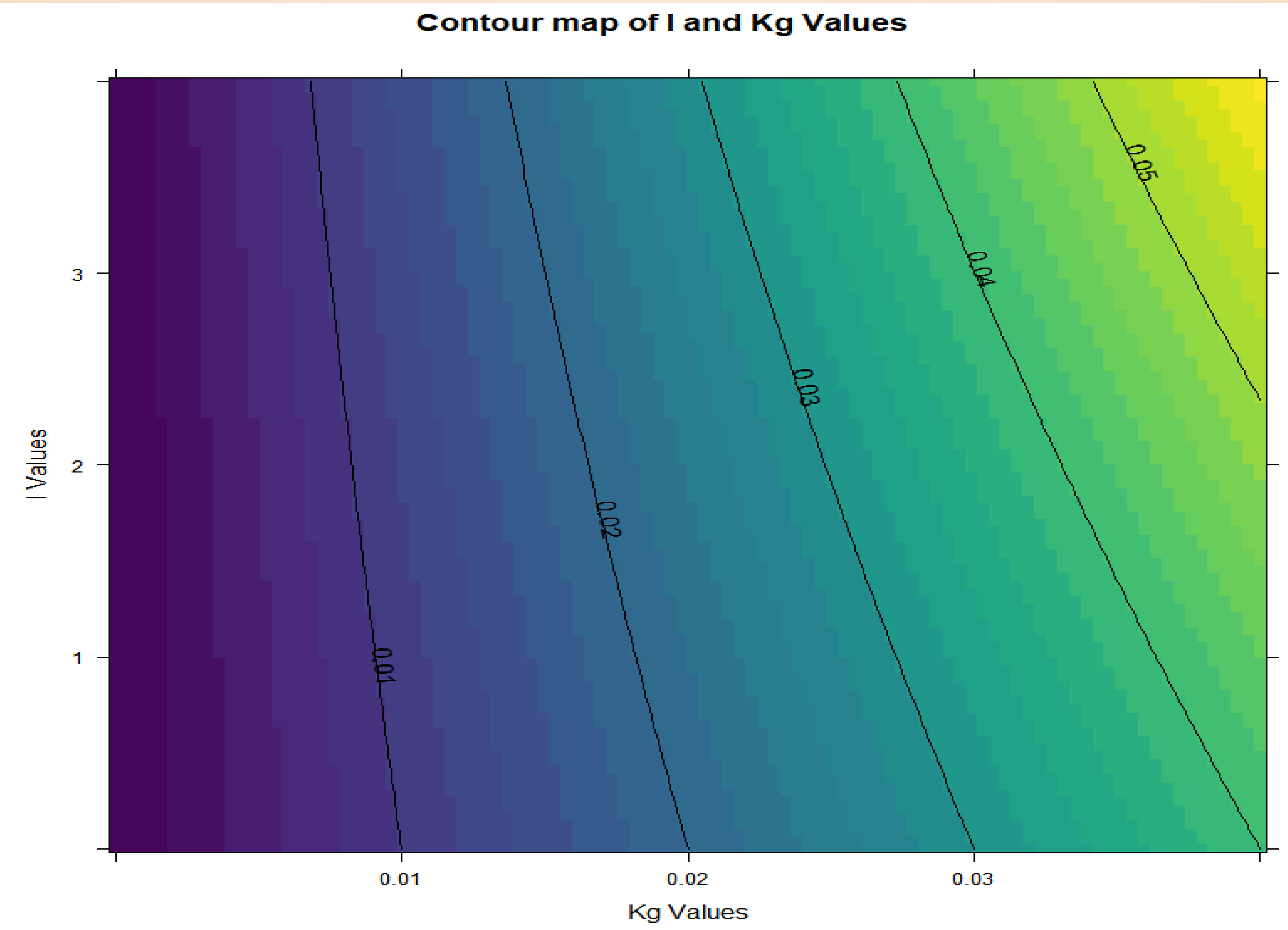

Figure 3: Contour map of equation one, as a function of *l* and k_g when *U* is held constant at 1.1 meters per day. Contour lines represent values of *e*, in meters per year.

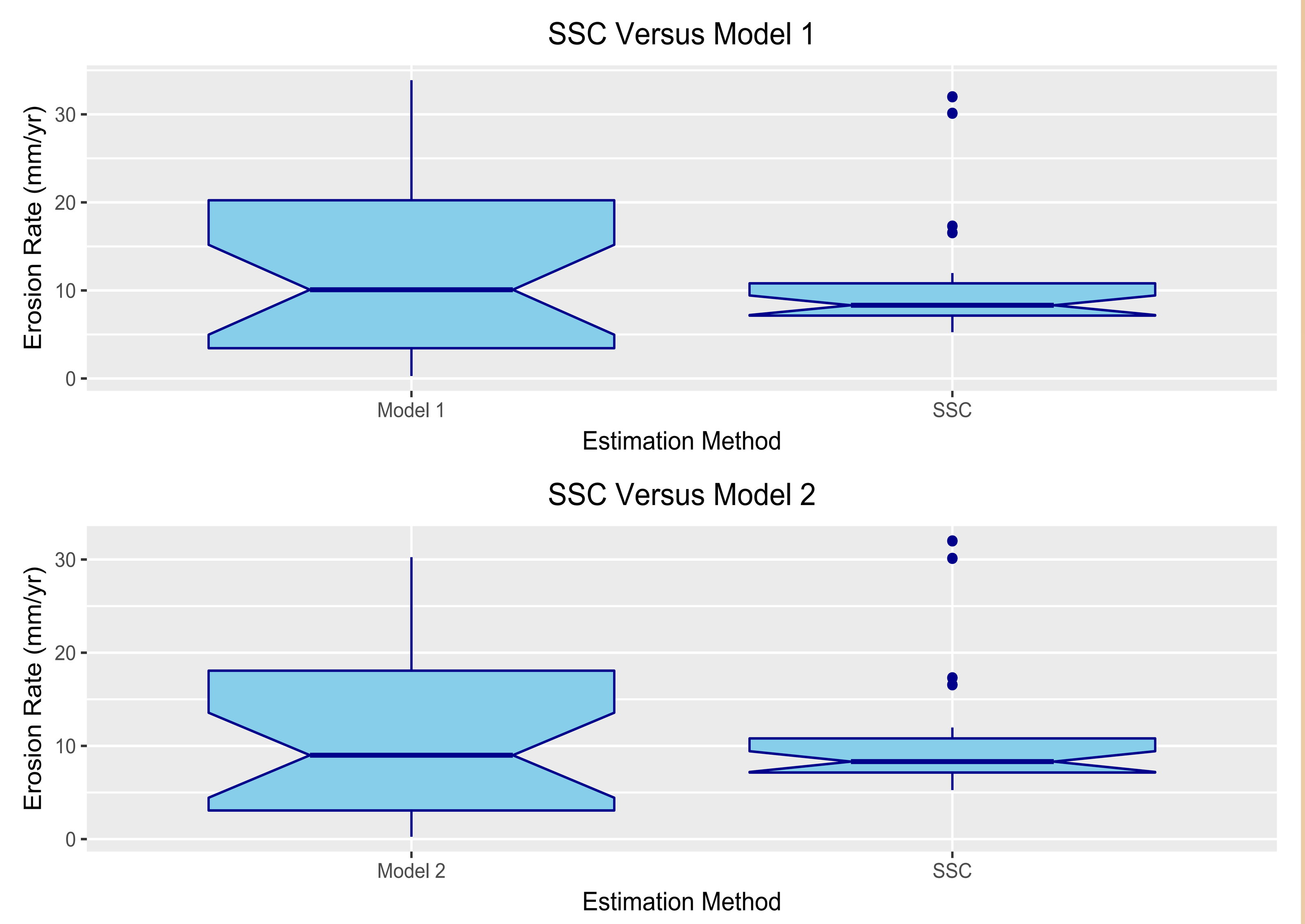

Figure 4: Graphical comparison of the distributions of erosion rates from Equation 1 and suspended sediment concentration estimation. Both models use *l*=1.6 Model 1 uses k_g=0.025, and Model 2 uses k_g=0.028.

Results

- The distributions of erosion rates from Equation 1 and SSC estimates are quite similar, as noted by the aligning of the boxplot notches.
- The upper quartile of Model one tended to align with the highest values obtained from SSC Estimation, while the upper quartile of Model 2 tended to be below the highest SSC values.
- Both Models generally underestimated the lowest erosion rate values.

Conclusion

- The similarity of the distributions suggests that the model is effective for estimating the erosion rate of Emmons Glacier based on its velocity.
- The general tendency of the model to underestimate erosion rates can be explained by the limitation of sediment samples, as well as sampling intervals
- This model may be utilized for other Mount Rainier glaciers with sufficient velocity data, such as Nisqually Glacier, or may be able to predict glacier velocity based on erosion rates.
- The parameters for the model differ from those in Cook, et al 2020.[2] This is likely due to the spatial variation of velocities, rather than the average glacier velocity, which was used in that study.

Acknowledgements

I would like to thank Dr. Michael Turzewski for mentoring me through this process, Dr. Claire Todd for her mentorship and for inspiring my love of Mount Rainier Glaciers, and my family and friends for their support.

References

[1] Riihimaki, C. A., MacGregor, K. R., Anderson, R. S., Anderson, S. P., and Loso, M. G., (2005). Sediment Evacuation and Glacial Erosion Rates at a Small Alpine Glacier. *Journal of Geophysical Research 110*(F03003) doi:10.1029/2004JF000189

[2] Cook, S. J., Swift, D. A., Kirkbride, M. P., Knight, P. G., and Waller, R. I. (2020). The Empirical Basis for Modelling Glacial Erosion Rates. Nature Communications, 11(759). doi: 10.1038/s41467-020-14583-8

[3] GLIMS Consortium, 2005. GLIMS Glacier Database, Version 1. [Analysis_IDs 761566--766732, Fountain, Andrew G. (submitter); Fountain, Andrew G. (analyst)]. Boulder, Colorado, USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. doi:10.7265/N5V98602 [4/22/22]

[4] Allstadt, K. E., Shean, D. E., Campbell, A., Fahnestock, M., and Malone, S. D., (2015). Observations of Seasonal and Diurnal Glacier Velocities at Mount Rainier, Washington, Using Terrestrial Radar Interferometry. The Cryosphere, 9. doi: 10.5194/tc-9-2219-2015