Comparisons of Arctic River Geomorphology and Analysis of River Width Using the SWOT River Database

Research Thesis

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By

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TABLE OF CONTENTS

ABSTRACT

The SWOT River Database (SWORD) provides new opportunities in analyzing rivers on a global scale. The research in this thesis presents a comparison of river width, slope, sinuosity, and meander length between the arctic regions of Asia, North America, and Europe to the non-arctic regions split along the 66.56 North latitude line. The results show an arctic with a river width median that is 20m and a slope median 20cm greater than the non-arctic subset. Arctic river sinuosity and meander length are similar in each percentile with the largest difference in the 3rd quartile of meander length being about 35m greater than the arctic subset. The greater widths observed in the arctic can be associated to an environment that promotes braiding as a channel formation. Braided rivers tend to have wider channels and greater slope values. Braiding is common in arid environments due to lack of vegetation coverage and increased slope values, leading to support the results of larger river widths observed in the arctic subset.

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LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

River geomorphology is challenging given the difficulty in obtaining data and the ever-changing nature of river systems. Remote sensing has given scientists opportunities to view rivers throughout this change and at larger scales. Analysis of river width at a continental scale (Allen and Pavelsky 2015), and river geomorphology at a pseudo-global scale that considers multiple different geomorphological attributes of rivers to review relationships and trends (Frasson, 2019), and a global look into river width (Feng, 2022)

SWOT and SWORD

The Surface Water and Ocean Topography (SWOT) mission is a satellite launched in December of 2022 and is a collaboration between multiple international agencies to map the world's surface water and how these complex systems change over time (Altenau et al. 2021). The mission requires a prior database called the SWOT River Database (SWORD). Separating the world's rivers into segments called reaches that are on average 10 km in length and 200 m river nodes. SWORD allows SWOT to make vector products through SWORD and its predetermined nodes and reaches (Altenau et al. 2021). `

Braided River Formation

The three types of rivers are straight, meandering, and braided. Straight and meandering channels are sorted based on sinuosity values which is a ratio of the channel length over a valley length. Braided channels on the other hand show multiple small streams of water intertwined in a low-sinuosity and wide channel (Bierman, P. R., & Montgomery, D. R, 2014) These different types of channel formations are influenced by many different factors. Vegetation coverage plays an important role in the shape of a channel. Root systems hold together soil, stabilize riverbanks, and hinder soil erosion (Bierman, P. R., & Montgomery, D. R, 2014; Murray & Paola, 2003). Plant material that is above soil also aids in preventing bank erosion by reducing flow velocity from friction and promoting deposition (Julien, 2018). Another factor that influences the initiation of braiding is greater slope.

Environments that promote braided river formation are arid, arctic, and alpine regions (Murray & Paola, 2003). Limited vegetation, as seen in arctic environments, allows a channel to initiate and become braided. Braided rivers have greater width, channel and valley slope, and bank erodibility (Rhoads, 2020).

Objective

The goal of this thesis is to compare the river geomorphology of the arctic and non-Arctic utilizing the SWORD database as well as analyze arctic river width and present literature-based reasoning to why arctic rivers would have greater widths. Braided channels typically have greater width values, and the arctic is a favorable environment for rivers to exhibit braiding due to low vegetation coverage and greater slope values (Rhoads, 2020).

METHODS

Overview

Four major geomorphological river attributes were used for this analysis, river width, slope, sinuosity, and meander length. Breaking down SWORD into two major subsets used for this study, one of them being the arctic subset and then another for the non-Arctic. Using the subsets to analyze the reaches and nodes of SWORD and compare the four river attributes (Table 2).

Variable	Description	Units
Width	Average width of a reach	m
Slope	Average elevation change in a reach.	m/km
Sinuosity	Reach length with the corresponding node divided by the distance between the reach endpoints.	none
Meander Length	Length of meander within the node.	m

Table 1: River geomorphology variables and descriptions.

Subsets

The arctic circle is 66.56 degrees North. This is the boundary between the two subsets used for this study. Three landmasses in SWORD make up the arctic subset: Asia, North America, and Europe. All three landmasses are then concatenated for the arctic subset and allow for histograms and other plots to analyze the geomorphology attributes of rivers in the arctic region.

Landmass	Reaches	Nodes
Asia	12,495	673,411
North America	8,539	139,140
Europe	3,765	81,914

Table 2: Landmasses that make up the arctic subset and the corresponding amount of Reaches and Nodes in each landmass.

The non-Arctic subset is made up of 6 landmasses in SWORD: North America, South America, Europe, Asia, Africa, and Oceania. The 3 landmasses that are split along the arctic circle line, Asia, North America, and Europe, are made up of the continents' landmass that is below the 66.56 North latitude line.

RESULTS

Width

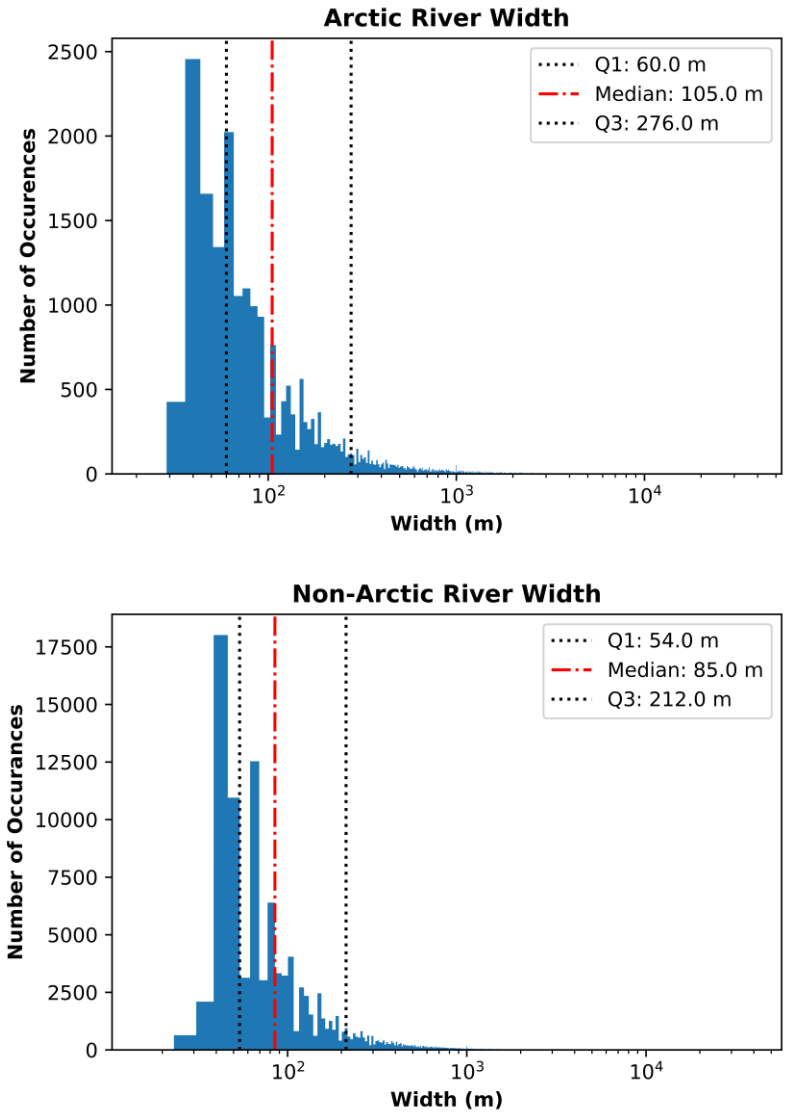

Figure 1: Arctic subset river width (top) and the non-Arctic subset river width histogram (bottom).

River width is generated using the SWORD reaches (Table 2). The arctic and non-arctic river width are both skewed to the right. Non-arctic has much greater spike in river widths under 100m than the Arctic. The arctic river width shows greater width in its 25th percentile, median, and 75th percentile. Overall showing greater river widths in the arctic than the non-arctic. The arctic width histograms were put on a logarithmic x -axis to better visualize the width values.

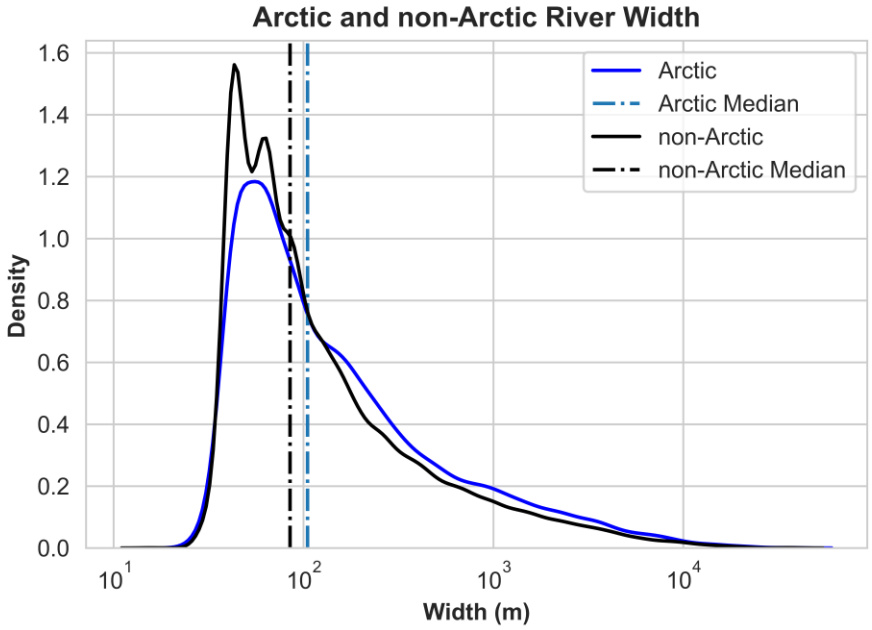

Figure 2: Kernel Density Estimation plot of the arctic subset (blue) and the non-Arctic (black) subset river width.

A kernel density estimation (KDE) plot comparing the two positively skewed distributions seen in the width histograms in figure 1. Non-arctic river width has a great spike in density of rivers that are less than 100m wide with the Arctic having a similar yet smaller peak of river width in the same area of about 100m. The black line, non-arctic river width, has a greater density of occurrences until about 110m where the blue, arctic, line shows a greater number of occurrences a width greater than 110m.

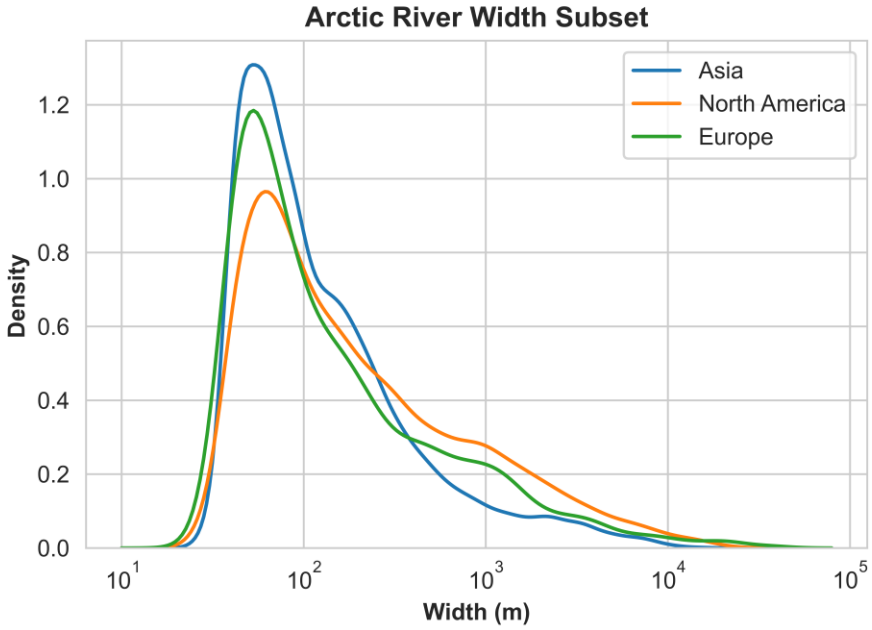

Figure 3: KDE plot of river width in the arctic subset.

The breakdown of width distributions that make up the arctic subset used for this research. All three landmasses share a similar spike in density. Asia and Europe both have a steep decline after the spike in density. North American shows a different decline with more of a gradual slope that surpassed both Asia and Europe around 150m of river width.

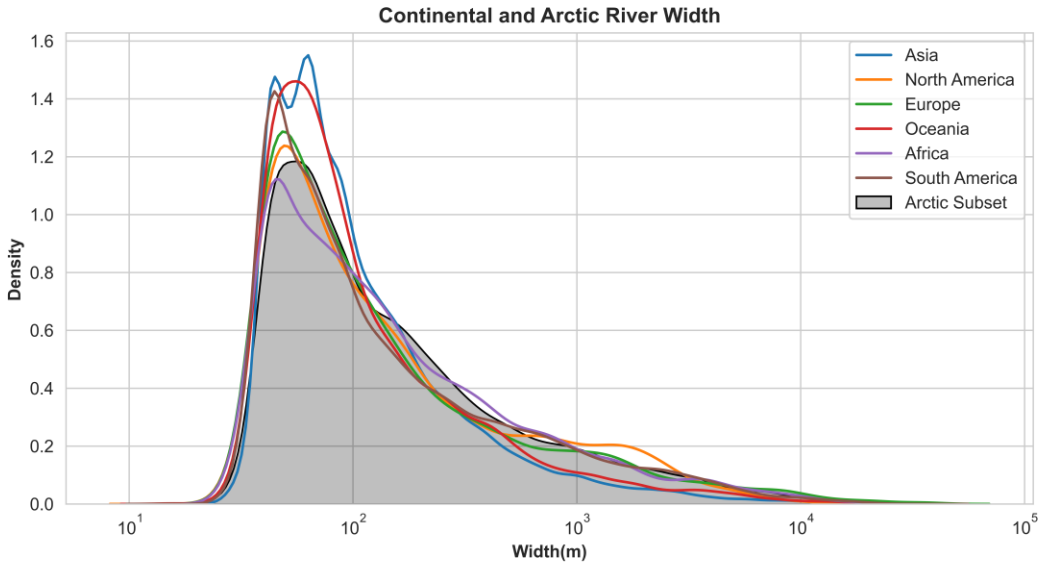

Figure 4: KDE plot with the arctic subset (shaded) individual landmasses that make up the non-arctic subset.

A KDE plot with each landmass that makes up the non-arctic subset compared to the arctic subset shown by the black line and shaded area on the plot. Asia (blue) has the greatest spike in density with two peaks compared to all other landmasses with the closest being Oceania (red). The arctic subset (black) has the second lowest peak with Africa (purple) having the lowest. This contrasts with what is shown between 130m and 180m which shows the arctic with the greatest density of river width in that range along with Africa.

Slope

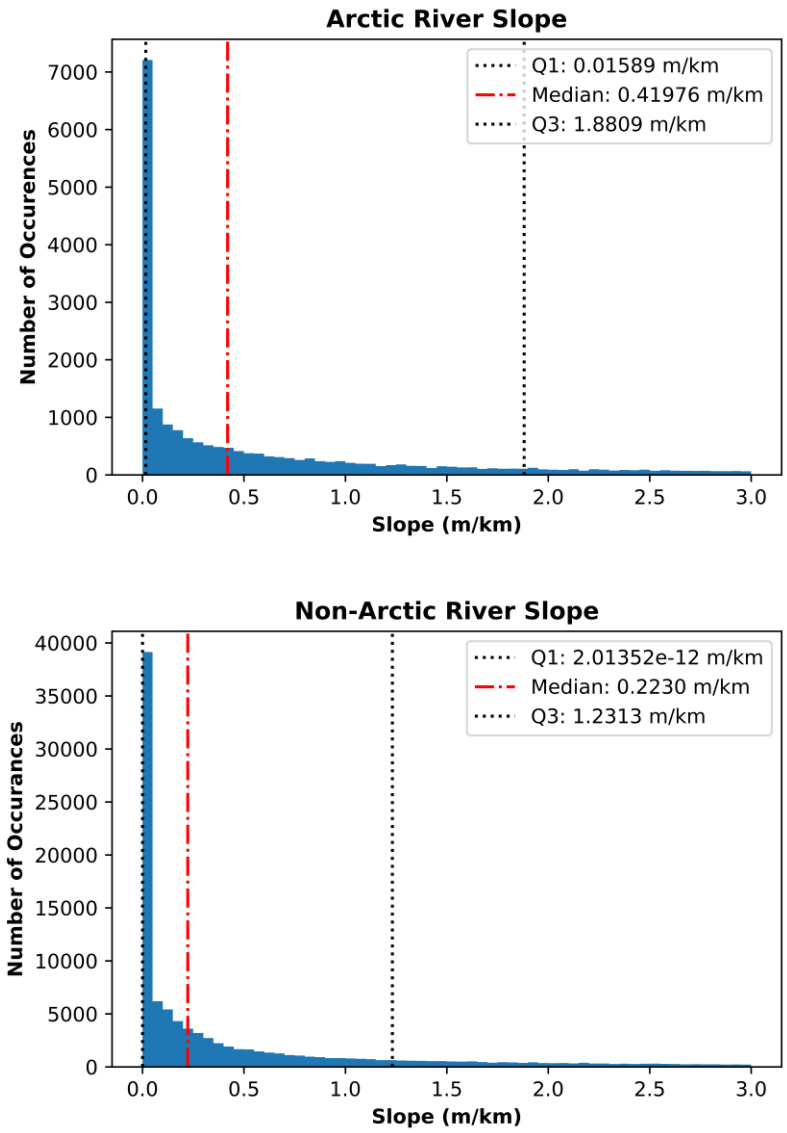

Figure 5: Arctic river slope distribution (top) and non-Arctic river slope distribution (bottom).

The arctic river slope has a similar result to that of the width, where arctic river slope has a greater 25th percentile, median, and 75th percentile. Both histograms share a very similar shape in number of outcomes per value of slope. Slope is given a normal x-axis due to the relatively small number of values common for the slope of a river. Both histograms are positively skewed, and both have a large spike in occurrences at very low slope values.

Sinuosity

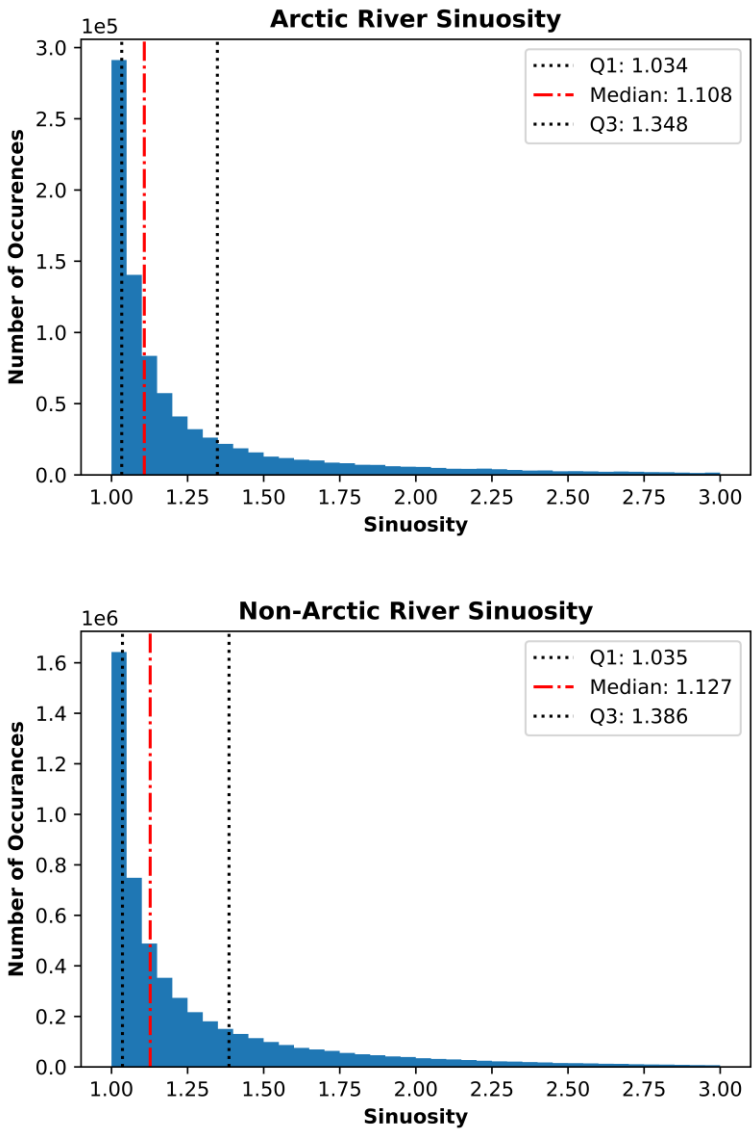

Figure 6: Arctic sinuosity distribution (top) and non-Arctic sinuosity distribution (bottom).

The comparison of sinuosity has the largest difference in percentile being at the median and 75th percentiles, showing an increase in difference as you increase in percentile. The non-arctic has greater sinuosity values than the arctic. Both histograms are positively skewed.

Meander Length

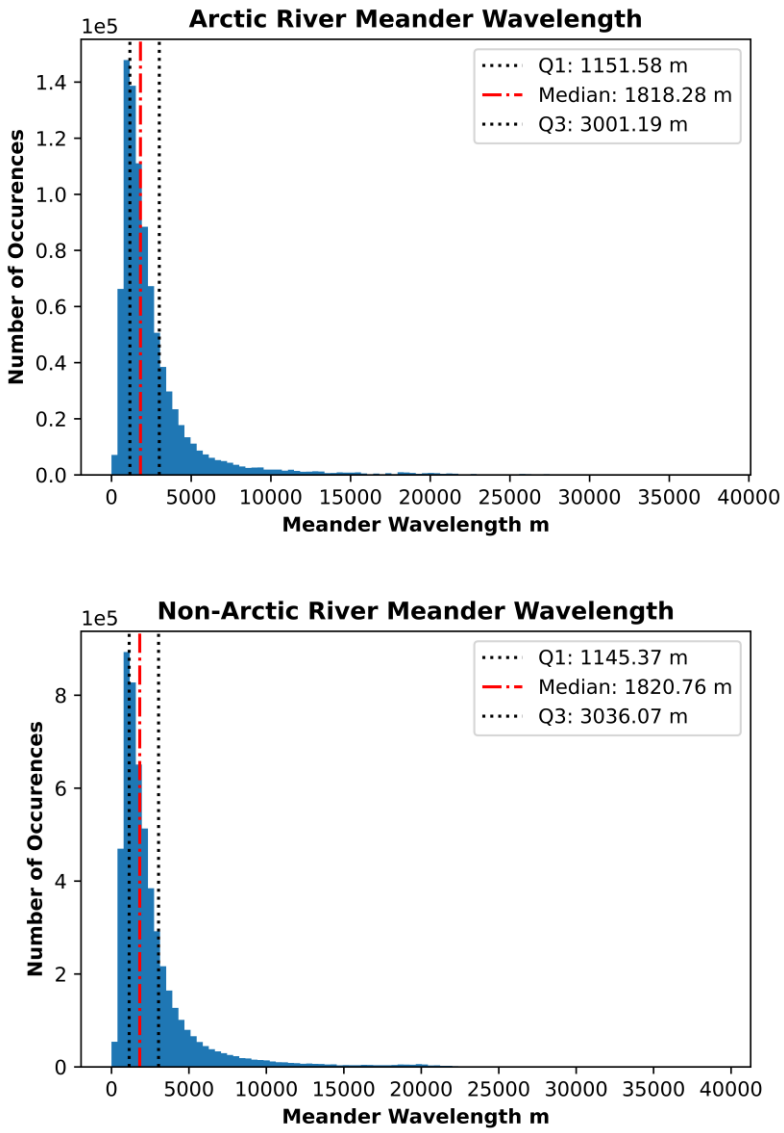

Figure 7: Arctic meander length distribution (top) and non-arctic meander length distribution (bottom).

Meander length has a greater 25th percentile value for the arctic but as you move towards the median and 75th percentile the non-arctic becomes larger by 2m at the median and about 35m at the 75th percentile. Both histograms are positively skewed.

Discussion

Overview

The comparison of river geomorphology using SWORD has shown an arctic that has greater river width and slope. The river sinuosity and meander length show very similar values to that of the non-arctic subset and did not result in any significant findings.

River Width and Braiding

The comparison of river width in the arctic and non-arctic has shown a greater width in arctic rivers. The arctic width has greater values in all percentiles (Figure 1). The occurrences of arctic width values that are greater than the non-arctic subset is densest in the region above 120m wide, shown in the KDE plot (Figure 2). Both the width and slope histograms (Figure 1) support what would be expected of an environment where the conditions for braiding are present and favorable. The lack of vegetation coverage and its impact on bank stability is well known (Bierman, P. R., & Montgomery, D. R., 2014; Rhoads, B. L., 2020; Julien, P. Y., 2018). The lack of vegetation observed in the arctic would explain the results shown as without the support of plants and their root systems, a channel can initiate braiding. This is also consistent with the increased slope values that are shown in the results, as increased slope provides energy for erosion and is associated to conditions for braiding to occur (Rhoads, B.L., 2020).

CONCLUSION

The research for this thesis shows a comparison of river geomorphology between the arctic region and the rest of the global landmasses using SWORD. The four major attributes used are river width, slope, sinuosity, and meander length. River width and slope show an arctic with larger widths and an arctic that is similar in sinuosity and meander length to the non-arctic comparison. Larger river widths are seen in the arctic than the non-arctic regions. The results can be related to factors that lead to braided rivers and how they are greater in width than other types of rivers, straight and meandering. The arctic is an arid environment that has low vegetation coverage which can allow for bank erosion and for the initiation of braiding of a river. (Julien, P. Y., 2018: Rhoads, B. L., 2020) The comparison of arctic width and slope both supports what is expected of an environment for braiding to occur (Bierman, P. R., & Montgomery, D. R., 2014; Rhoads, B. L., 2020; Julien, P. Y., 2018).

RECOMMENDATIONS FOR FUTURE WORK

The work being done with SWOT is very promising and the relatively ease of using SWORD can lead to a wider understanding of the world's hydrological cycle and a view into global fluvial geomorphology. The attributes used during this paper, river width, slope, sinuosity, and meander length can be looked at globally or at a continental scale to look for relationships. A relationship that specifically could be looked at using SWORD is between width, slope, and sinuosity. Where you would expect to see a greater width when slope and sinuosity are low (Frasson, 2019). SWORD allows for many different fluvial geomorphological attributes to be examined at a global scale.

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APPENDIX

URL to python code

https://github.com/camhershey/Comparisons-of-Arctic-River-Width-SWORD.git

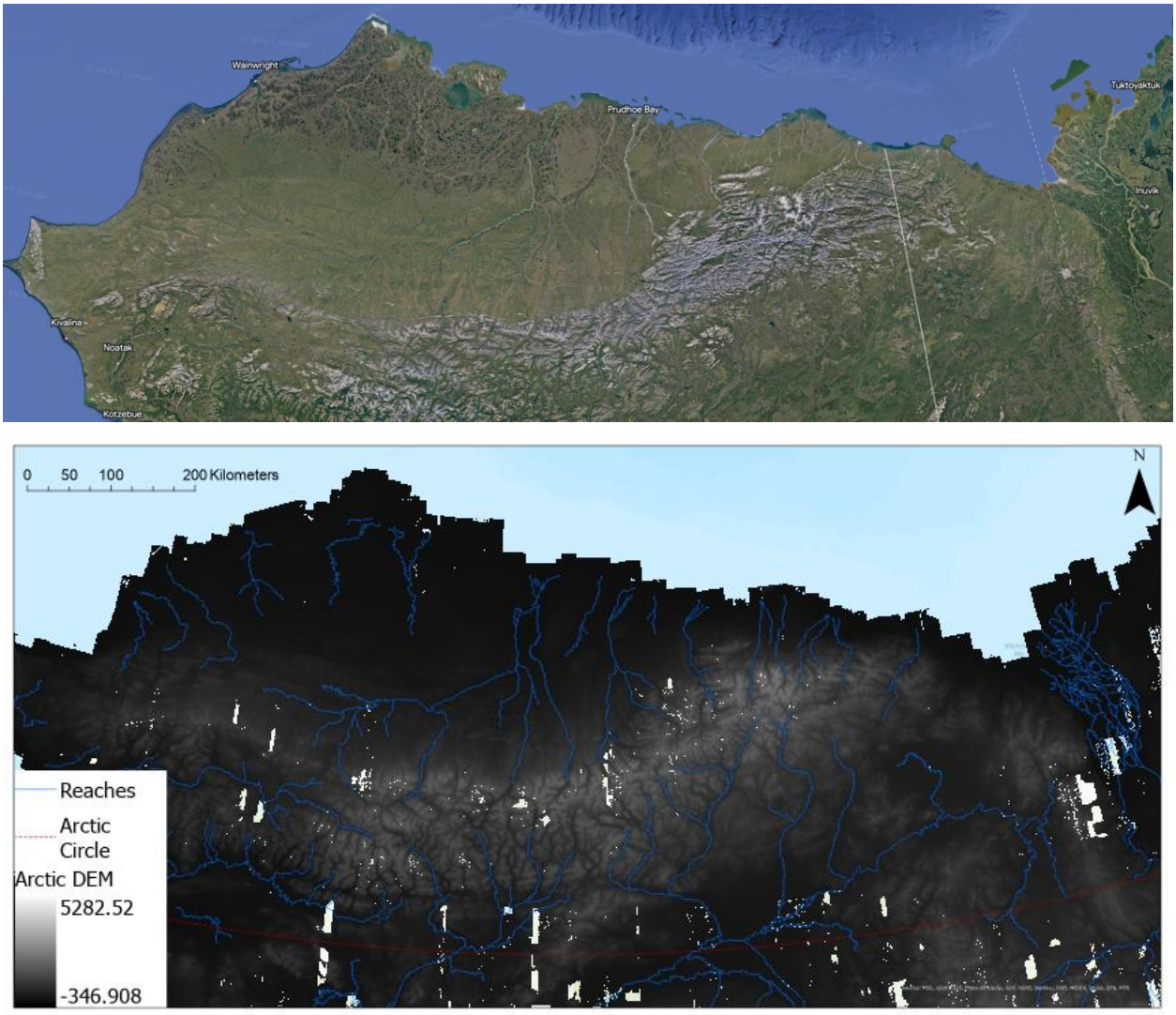

Figure 8: The arctic region of Alaska shown in both maps, the bottom map shows a visualization of the reaches from the Alaskan Arctic and the red line shows the cut off between the Arctic and the non-Arctic subsets.