

The Title page  
does NOT get a  
page number

BEGIN TITLE HERE IF IT REQUIRES THREE LINES

BEGIN HERE IF ONLY TWO LINES

USE ALL CAPITAL LETTERS

Type title in ALL  
CAPS; create inverted  
pyramid shape if more  
than one line

by

Your Name (First Middle Last)

“by” should sit on the  
same line as your  
copyright page

Use the fullest  
form of your name

A [thesis/dissertation/professional paper] submitted in partial fulfillment  
of the requirements for the degree

of

Appropriate Degree (e.g. Master of Science)

in

Appropriate Program Name (e.g. Chemistry)

If you do not know  
your degree type or  
official degree name, it  
can be found in the top  
heading of your  
DegreeWorks page

MONTANA STATE UNIVERSITY  
Bozeman, Montana

Month and Year ETD is accepted by Grad School (e.g. December 2023)

Make sure your page margins are  
set to 1 inch on all sides

This should be the  
month and year of the  
ETD deadline of the  
semester your ETD is  
being approved

The Copyright page  
does NOT get a  
page number

©COPYRIGHT

by

Your Name (First Middle Last)

Year

All Rights Reserved

“by” from previous  
page should sit on the  
same line as your  
copyright page

Use the fullest  
form of your name

Set header margin (top of page to top of page number) to 1 inch

The page following Copyright Page is the first to get a page number (start with ii)

Page numbers should be in the same font and size as your ETD text

ii

## DEDICATION

Delete if not using.

Dedication may be no longer than one page and should precede the acknowledgments page.

The “Front Matter Title” accessibility style is used on this page’s title. There is no space above the title and a triple space below.

Paragraphs on this page are left aligned or justified, with the first line indented, and single spaced. There should be no additional space between paragraphs.

Dedication, Acknowledgements, Vita, and/or American Heritage pages are **OPTIONAL**, but if included, each should be on a separate page. Titles of these pages must be in **ALL CAPS**

## ACKNOWLEDGEMENTS

Delete if not using.

Acknowledgments are limited to one page. Consider that you may need to include a funding acknowledgement.

The “Front Matter Title” accessibility style is used on this page’s title. There is no space above the title and a triple space below.

Paragraphs on this page are left aligned or justified, with the first line indented, and double spaced. There should be no additional space between paragraphs.

VITA and/or AMERICAN INDIAN HERITAGE

Delete if not using.

If you include a vita, it can include background information such as full name of author, education, place of birth, and family heritage. The vita should be written in essay form in the third person and may not exceed one single-spaced page. Note that your document will be published in an open access database and that this information will be public.

American Indian/Alaska Native students wishing to include heritage and tribal information may do so as part of a vita or as a separate single-spaced page.

The “Front Matter Title” accessibility style is used on this page’s title. There is no space above the title and a triple space below.

Paragraphs on this page are left aligned or justified, with the first line indented, and single spaced. There should be no additional space between paragraphs.

Don't let long titles/headings automatically wrap to the next line. Stop the line about 3/4 way to the page number and continue on next line directly below the first letter of the title above. **Stop approximately here** ↓

TABLE OF CONTENTS

All Chapters are numbered. References & Appendices do not get a number

All first level headings should line up directly below the first letter of the chapter title

Second level headings are indented a full tab

1. INTRODUCTION .....	1
First Level Heading.....	1
Second Level Headings: If Heading is too Long, Wrap to the Next Line, Single Spaced. ....	1
Third Level Heading .....	2
Another First Level Heading .....	2
Another Second Level Heading .....	2
Another Third Level Heading .....	2
Don't Let Headings Sit at Bottom of the Page w/o Text Below.....	2
2. METHODOLOGY .....	3
Long Direct Quotes.....	3
Footnotes.....	3
3. TITLE OF CHAPTER THREE .....	4
Accessibility.....	4
Figure and Table General Guidelines .....	4
Hint for Automatic List of Tables and List of Figures .....	11
4. TITLE OF THE CHAPTER/MANUSCRIPT IN ALL CAPS. IF VERY LONG, INVERTED PYRAMID STYLE AND DOUBLE SPACED .....	12
Contribution of Authors and Co-Authors .....	12
Manuscript Information .....	13
Abstract.....	14
Section 1 of Manuscript Example.....	14
Section 1.2 of Manuscript Example.....	14
References for Manuscript.....	14
5. TITLE OF THE CHAPTER/MANUSCRIPT IN ALL CAPS .....	15
Contribution of Authors and Co-Authors .....	15
Manuscript Information .....	16
General Info Again .....	17
Abstract.....	17
Section 1 of Manuscript Example.....	17
Section 1.1 of Manuscript Example.....	17
Section 2 of Manuscript Example.....	17
Section 3 of Manuscript Example.....	17
Section 3.1 of Manuscript Example.....	17

All additional Table of Contents pages must include Table of Contents Continued Title (IN ALL CAPS)



TABLE OF CONTENTS CONTINUED

Section 4 of Manuscript Example.....	18
Section 5 of Manuscript Example.....	18
Section 5.1 of Manuscript Example.....	18
Section 6 of Manuscript Example.....	18
References for Manuscript.....	18
6. TITLE OF THE CHAPTER/MANUSCRIPT IN ALL CAPS .....	19
Contribution of Authors and Co-Authors .....	19
Manuscript Information .....	20
Abstract.....	21
Introduction.....	21
7. CONCLUSION.....	23
[CUMULATIVE] REFERENCES CITED.....	24
APPENDICES .....	29
APPENDIX A TITLE.....	30
APPENDIX B TITLE.....	32

All subdivisions in your ETD must be included in your Table of Contents (word for word)

A cumulative references section must be included in your Table of Contents and at the end of your thesis/dissertation even if you choose to include references at the end of each chapter

Don't let long titles/headings automatically wrap to the next line. Stop the line about 3/4 way to the page number and continue on next line directly below the first letter of the title above. **Stop approximately here** ↓

LIST OF TABLES CONTINUED

Table	Page
1. Table 1. Physical characteristics and trout of 11 watersheds sampled in the headwaters of the Colorado River, 2008-2009. ....	5
2. Table 2. Experimental results: Reaction rates of different catalysts.....	6
3. Table 3. Comparison of pH levels in different soil samples.....	7
4. Table 4. Elemental composition of Earth's atmosphere. ....	7
5. Table 5. Literary analysis of novels.....	8
6. Table 6. Comparison of artistic styles and techniques.....	10
7. Table A1. Any tables or figures in the Appendices need to have titles and captions like they do in the body text. ....	31

Page numbers must line up exactly



LIST OF TABLES CONTINUED

Table

Page

All additional List of Tables pages must include List of Tables Continued Title (IN ALL CAPS) and the Table/Page headers

Don't let long titles/headings automatically wrap to the next line. Stop the line about 3/4 way to the page number and continue on next line directly below the first letter of the title above. **Stop approximately here** ↓

LIST OF FIGURES

Figure	Page
1. Figure 1. Distribution of sampled watersheds, which are currently occupied by Colorado River cutthroat trout ( <i>Oncorhynchus clarki pleuriticus</i> ) in the upper Colorado River basin, based on level IV ecoregions boundaries. For creek name codes, see Table 1.....	5
2. Figure 2. NASA astronaut Sally K. Ride, STS-7 mission specialist, is seen sitting in the aft flight deck during deorbit preparations. Photo credit: NASA.....	6

Page numbers must line up exactly

LIST OF FIGURES CONTINUED

Figure

Page

All additional List of Figures pages must include List of Figures Continued Title (IN ALL CAPS) and the Figure/Page headers

GLOSSARY or NOMENCLATURE

Delete if not using.

If using, match spacing of entries to List of Tables/List of Figures.

## ABSTRACT

Begin abstract here. **Single spaced and no more than 350 words**. Indent first line one full tab. The abstract must contain the following elements: (1) statement of the problem, (2) procedure or methods, (3) results, and (4) conclusions. Mathematical formulas, abbreviations, diagrams, and other illustrative materials should not be included. It should be written to be understood by a person who does not have expertise in the field.

Set header margin (top of page to top of page number) to 1 inch  
Page numbers should be in the same font and size as your ETD text

Chapter One starts on page 1 and continues in Arabic numbers through the end of the ETD

1

INTRODUCTION

See another way to format your chapter title on the following pages

\*\*For the manuscript option, it is required that your Chapter One is an introduction. The introductory chapter should outline the problem context for the work, establish its purpose and objectives, and explain how the manuscripts presented in the body address the purpose and objectives. This is required even if you have an introduction chapter in your manuscript(s).\*\*

Chapter titles should be centered and all caps, with a triple space below. Use the pre-formatted styles headings in the Word template to do a lot of the spacing work: highlight headings and apply the correct style from the Home tab. Beginning at Chapter One, the accessibility style “Chapter Title” is used for chapter titles. There is no space above and a triple space below. Chapters may either have only a title, such as the example on this page, or a line for “Chapter Number” and then the chapter title, such as the example in Chapter Two. You cannot use “Chapter Number” as your only chapter title. Pick one style for these titles for your ETD and be consistent throughout.

ALL major words in headings are capitalized

First Level Heading

First level headings should be centered and underlined. Capitalize the first letter of each heading word except articles, conjunctions, and prepositions. Triple-space (two blank single-spaced lines) above and below centered headings.

Second Level Headings: If Heading is too Long, Wrap to the Next Line, Single Spaced.

The lines of a multi-lined heading should be as equal as possible; only bottom line underlined

Leave a triple space above (two blank single-spaced lines) and a double space (one blank single-spaced line) below second level headings; align with the left margin.

Capitalize, punctuate, and underline the same as first level headings.

If a second level heading is longer than half the width of the page, create a multi-lined heading, which is single-spaced with only the second line underlined. The template has been created so that second-level headings wrap at approximately the half width of the page, but lines of a multi-lines heading should be as equal as possible. You can use Shift + Enter to wrap to the next line while keeping the single spacing within the second-level heading. You will then need to manually remove the underline on the top line by highlighting and removing the underline on the Font section of the Home tab.

Third Level Heading. Triple-space from paragraph above. Indent in normal paragraph style and underline. Capitalize the same as other headings. Begin text on same line. Separate with a period, colon, or no punctuation (be consistent).

More than three levels of subheadings are not recommended. If more than three levels are necessary, contact The Graduate School for acceptable sequencing instructions.

### Another First Level Heading

Paragraph text example example example example example example.

### Another Second Level Heading

Another Third Level Heading. If a third level heading immediately follows a second level heading without text in between, follow second level heading spacing rule.

Don't Let Headings Sit at Bottom of the Page w/o Text Below.

You may include “Chapter Number” in addition to your Chapter Title (separated from title by a triple space), but you cannot use “Chapter Number” as your only chapter title

CHAPTER TWO

METHODOLOGY

\*\*For the manuscript option, it is highly recommended that your Chapter Two provides more detail on the methodology/ies of your work than there was space for in the published paper.\*\*

Long Direct Quotes

Example of Long Direct Quote: First line of text starts here (a triple space below first level heading above) and long direct quote follows a double space below.

Direct quotes of four lines or more must be single-spaced and “blocked” (Indented on both sides and the text within the quote justified). To justify text, click the “Justify Text” button next to the Align Left/Right and Center Text buttons. The space above and below a long quote should be a double space. You can use the “Long Quote” style format to format it for you.

Line of text following direct quote should begin here (a double space below). Indent this line if it is the start of a new paragraph; do not indent this line if this paragraph is a continuation.

Text should continue from here to be double spaced, paragraphs indented.

Footnotes

Text that has a footnote.<sup>1</sup> Text that has another footnote.<sup>2</sup> Paragraph text example example example example example example. Text that has another footnote.<sup>3</sup>

---

<sup>1</sup> Footnotes should be the same font and font size as the rest of the document.

<sup>2</sup> Footnotes should be single spaced. If there are multiple footnotes on one page, do not add extra space in between each footnote.

<sup>3</sup> Footnotes should not be so long that they cannot fit on one page.



## CHAPTER THREE

## TITLE OF CHAPTER THREE

The next several pages cover figure and table formatting.

Accessibility

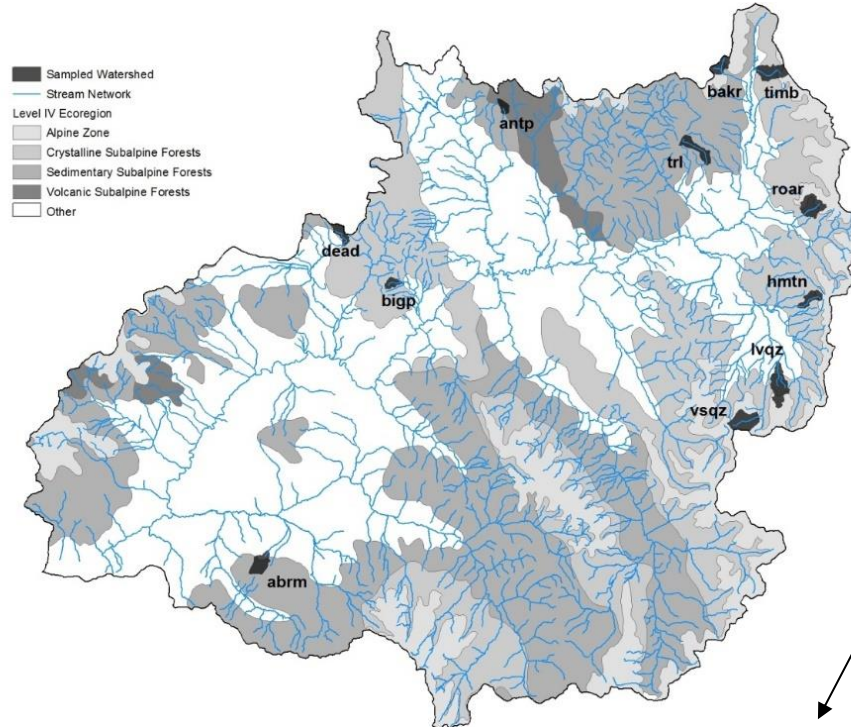
Be sure to add Alt Text to tables and figures. See the ETD accessibility page for more instructions on adding Alt Text.

Figure and Table General Guidelines

Figures and tables must fit within the standard 1” margins on every side of the page. Figures and tables need to be readable. If a figure or table contains text, the text cannot be blurry and should be large enough that the average person can read it without zooming in. If your figure or table is too wide to comfortably fit on a portrait orientated page, you may turn that page to landscape view. See the “How Do I...?” section of the ETD website for full instructions on turning a page to landscape.

Table/figure titles and captions can go above or below; be consistent throughout.

If a figure or table is too large to continue after your paragraph text on a page without being cut in half, begin the figure or table on the next page. A figure or table and its caption should stay together on one page if possible.



Table/Figure titles and captions can go above or below; be consistent throughout.

Figure/Table titles and captions should be single-spaced and in the same font and font size as the rest of the ETD text. Do not bold text.

Figure 1. Distribution of sampled watersheds, which are currently occupied by Colorado River cutthroat trout (*Oncorhynchus clarki pleuriticus*) in the upper Colorado River basin, based on level IV ecoregions boundaries. For creek name codes, see Table 1.

There should be a triple space between figure/title captions and paragraph text; as in, triple spacing above and below figures and tables separating them from paragraph text.

Table 1. Physical characteristics and trout of 11 watersheds sampled in the headwaters of the Colorado River, 2008-2009.

Watershed	Level IV ecoregion	Watershed area (km <sup>2</sup> )	Mean elevation (m)	Stream length (km)
Baker Gulch	Alpine	7.10	3505	5.62
Roaring Fork	Alpine	11.86	3350	4.28
Vasquez Creek	Alpine	13.21	3534	7.81
Big Park Creek	Crystalline Subalpine	3.29	2799	3.44
Hamilton Creek	Crystalline Subalpine	5.59	3253	6.81
Little Vasquez	Crystalline Subalpine	14.48	3202	6.12
Timber Creek	Crystalline Subalpine	11.14	3316	5.81
Trail Creek	Sedimentary Subalpine	8.52	3125	7.45
Antelope Creek	Volcanic Subalpine	2.95	3068	3.27

This page contains additional examples of figures and tables so students can see proper spacing. Notice that there is no additional space above a figure or table when it is at the top of the page, such as Figure 1 on the previous page, but there is triple spacing above a figure or table when it begins after a paragraph, such as Figure 2.



Figure 2. NASA astronaut Sally K. Ride, STS-7 mission specialist, is seen sitting in the aft flight deck during deorbit preparations. Photo credit: NASA.

Students can either center or left-justify their figures and tables as long as they are consistent throughout the document. This example has centered tables and figures. Titles and captions should remain left-justified.

Table 2. Experimental results: Reaction rates of different catalysts.

Catalyst	Temperature (°C)	Reaction Time (s)	Product Yield (%)
Catalyst A	50	120	82
Catalyst B	60	90	95
Catalyst C	70	75	78
Catalyst D	65	110	89
Catalyst E	55	85	91
Catalyst F	75	70	76

See below how there should be a triple space between figures or tables when they come one after the other.

Table 3. Comparison of pH levels in different soil samples.

Soil Sample	pH Level	Moisture Content (%)
Sample A	6.8	23
Sample B	5.5	18
Sample C	7.2	20
Sample D	6.1	15

Table 4. Elemental composition of Earth's atmosphere.

Element	Percentage by Volume	Molecular Formula
Nitrogen	78.08%	N <sub>2</sub>
Oxygen	20.95%	O <sub>2</sub>
Argon	0.93%	Ar
Carbon Dioxide	0.04%	CO <sub>2</sub>
Others	0.01%	Various

In these cases, you may need to manually add space above the second caption in order to achieve the full triple space. Add the desired caption above accessibility style, then while the title/caption is still highlighted, select the line and paragraph spacing drop down on the Paragraph section of the Home tab, and select line spacing options. Modify the spacing so that there are 24pts of space before that single caption. Do not modify the accessibility style itself.

Next, view an example of a table that is too long to fit on one page. It begins on its own page, it does not cut onto the second page in the middle of a cell, and its second page has a "Table [#] Continued" title.

Table 5. Literary analysis of novels.

Novel	First Sentence	Symbolism	Foreshadowing	Irony
Novel A	“It was the best of times, it was the worst of times.”	High	Moderate	Low
Novel B	“In a hole in the ground, there lived a hobbit.”	Moderate	High	Moderate
Novel C	“Call me Ishmael.”	Low	Low	High
Novel D	“It was a bright cold day in April, and the clocks were striking thirteen.”	Moderate	Low	High
Novel E	“All children, except one, grow up.”	High	High	Moderate
Novel F	“It is a truth universally acknowledged, that a single man in possession of a good fortune, must be in want of a wife.”	Low	Moderate	Low
Novel G	“Marley was dead, to begin with.”	Moderate	Moderate	High
Novel H	“Happy families are all alike; every unhappy family is unhappy in its own way.”	Moderate	High	Moderate
Novel I	“It was a pleasure to burn.”	High	Low	Low
Novel J	“It was a dark and stormy night.”	Low	Moderate	Low
Novel K	“All this happened, more or less.”	Moderate	High	Moderate
Novel L	“It was a queer, sultry summer, the summer they electrocuted the Rosenbergs.”	Moderate	Moderate	High

The table does not cut onto a second page in the middle of a cell; see how the “Novel L” row is completely on this page and the “Novel M” row is completely on the next page.

The second page of a figure or table should have a “Table [#] Continued.” title. This table also includes the column names again on the second page for clarity.

Table 5 Continued.

Novel	First Sentence	Symbolism	Foreshadowing	Irony
Novel M	“The sun shone, having no alternative, on the nothing new.”	High	Low	Moderate
Novel N	“It was the day my father exploded.”	Low	Moderate	High
Novel O	“Once upon a midnight dreary, while I pondered, weak and weary.”	Moderate	Low	Moderate
Novel P	“In my younger and more vulnerable years my father gave me some advice that I’ve been turning over in my mind ever since.”	Low	High	Low

Finally, view an example of a table that is too wide to fit on a normal portrait page. The page (including page number) is turned to landscape orientation. The table itself and the page number follows the same 1” margin rules as it does on portrait pages. Notice that paragraph text does not continue on the landscape page, either above or below the table.

Make sure your page margins are set to 1 inch on all sides. Tables and figures must always fit within the 1" margins on all sides.

Set header margin (right side of page to top of page number) to 1 inch. This must match the page number spacing of the portrait pages.

10

Table 6. Comparison of artistic styles and techniques.

Artwork	Artist	Medium	Style	Brushwork	Composition	Subject	Year
Artwork A	Artist A	Oil Paint	Impressionism	Loose	Balanced	Nature	1875
Artwork B	Artist B	Acrylic	Cubism	Angular	Fragmented	Portrait	1920
Artwork C	Artist C	Watercolor	Realism	Delicate	Centered	Still Life	1955
Artwork D	Artist D	Charcoal	Surrealism	Expressive	Dynamic	Dreams	1968
Artwork E	Artist E	Photography	Minimalism	Clean	Symmetrical	Architecture	1992
Artwork F	Artist F	Sculpture	Abstract	Organic	Asymmetrical	Human Form	2010
Artwork G	Artist G	Mixed Media	Pop Art	Collage	Playful	Popular Culture	1985
Artwork H	Artist H	Digital Art	Contemporary	Experimental	Unconventional	Technology	2021

### Hint for Automatic List of Tables and List of Figures

This template contains a few accessibility styles for captions that work in tandem with the automatic List of Tables and List of Figures in the front matter.

There are two accessibility styles for Tables: “Table’s Caption Above” and “Table’s Caption Below.” There are similarly two accessibility styles for Figures. Students should only be using ONE of these captions for tables, and ONE for figures, depending on whether they choose to place their captions above or below. The automatic List of Tables and Figures in this template have been programmed to use either/or.

After you apply the appropriate accessibility style to a title/caption, scroll back up to the List of Tables or List of Figures. Right click on the list. Select “Update Field”. You will see the list automatically update to include your new table or figure.

In the example of the table that was so long that it went onto a second page, the “Table’s Caption Above” style was used for the first caption, but no style was used for the second caption, so that the automatic List of Tables updated correctly.

If the numbering on these lists changes when updating it, you may need to manually change it back so it begins at 1. Double click on a number in the list to highlight it. Select the drop down for the numbering icon that pops up. Select “Set Numbering Value,” and then set the value to 1.

**\*\*Figures and tables must be incorporated within the text as close to their reference as possible (preferred method) OR at the end of each chapter (before the reference section). Choose one method for entire ETD.**

**\*\*There should be a triple space above and below all figures and tables (Unless they start at the top of a new page)**

**\*\*All figures and tables must meet the 1-inch page margin requirements**



CHAPTER FOUR

TITLE OF THE CHAPTER/MANUSCRIPT IN ALL CAPS. IF VERY  
LONG, INVERTED PYRAMID STYLE AND  
DOUBLE SPACED

If Chapter Title is more than one line, double space the title. Notice that the triple spacing below "Chapter Number" and below the Chapter Title itself remains

Contribution of Authors and Co-Authors

Manuscript(s) in Chapter(s) 4

Author: [type author name here]

Contributions: [list contributions here, single-spaced]

Co-Author: [type co-author name here]

Contributions: [list contributions here, single-spaced]

Co-Author: [type co-author name here]

Contributions: [list contributions here, single-spaced]

Fill out the appropriate fields and delete any instructions on this page.

Fill out the appropriate fields and delete any instructions on this page.

Click in one of the boxes to check mark it.

Manuscript Information

[Type Author and Co-author(s) Names Here]

[Type name of journal here]

Status of Manuscript: [Put an x in one of the options below, then delete instruction in brackets]

- Prepared for submission to a peer-reviewed journal
- Officially submitted to a peer-reviewed journal
- Accepted by a peer-reviewed journal
- Published in a peer-reviewed journal

[Type name of publisher here]

[Type date of submission here (submitted manuscript – otherwise leave blank)]

[Type date the manuscript will appear here (accepted work – otherwise leave blank)]

[Type issue in which manuscript appears here (published work – otherwise leave blank)]

[Type DOI, if available]

Do not repeat the chapter title on the page where your content starts.

Manuscript content begins here. Students should either use Grad School formatting for this section or journal formatting for this section. You cannot combine formatting within a section. The following pages give additional examples of Grad School formatting.

The title of your manuscript chapter is your chapter title. If you include an abstract, different sections within the chapter, and references within this manuscript chapter, they should all begin as first level headings. All headings should appear fully integrated in the Table of Contents, whether you use Grad School formatting or journal formatting.

### Abstract

Abstract paragraph text.

### Section 1 of Manuscript Example

Paragraph text example example example example example example example example example example example example.

### Section 1.2 of Manuscript Example

Paragraph text example example example example example example example.

### References for Manuscript

If you include references for individual chapters, “References” should be formatted as a first-level heading within the chapter. Cumulative References Cited at the end of the document must include all references and is the only references section that should be formatted in all caps.

References are single-spaced with a double-space in between citations. Students choose their citation style, typically in discussion with their advisor. All references must follow the same, consistent citation style.

CHAPTER FIVE

TITLE OF THE CHAPTER/MANUSCRIPT IN ALL CAPS

Contribution of Authors and Co-Authors

Manuscript(s) in Chapter(s) 4

Author: [type author name here]

Contributions: [list contributions here, single-spaced]

Co-Author: [type co-author name here]

Contributions: [list contributions here, single-spaced]

Co-Author: [type co-author name here]

Contributions: [list contributions here, single-spaced]

Manuscript Information

[Type Author and Co-author(s) Names Here]

[Type name of journal here]

Status of Manuscript: [Put an x in one of the options below, then delete instruction in brackets]

- Prepared for submission to a peer-reviewed journal
- Officially submitted to a peer-reviewed journal
- Accepted by a peer-reviewed journal
- Published in a peer-reviewed journal

[Type name of publisher here]

[Type date of submission here (submitted manuscript – otherwise leave blank)]

[Type date the manuscript will appear here (accepted work – otherwise leave blank)]

[Type issue in which manuscript appears here (published work – otherwise leave blank)]

[Type DOI, if available]



**Section 4 of Manuscript****Example**

Paragraph text example example example example example example example example example example. Example example example example example example example example example example. Example example example example example example example example example example.

**Section 5 of Manuscript****Example**

Paragraph text example example example example example example example example example example. Example example example example example example example example example example. Example example example example example example example example example example.

*Section 5.1 of Manuscript Example*

Paragraph text example example example example example example example example example example. Example example example example example example example example example example. Example example example example example example example example example example.

**Section 6 of Manuscript****Example**

Paragraph text example example example example example example example example example example. Example example example example example example example example example example. Example example example example example example example example example example.

**References for Manuscript**

1. Smith, J. D. (2020). *The Art of Fiction: A Comprehensive Guide*. Fiction Publications.
2. Johnson, A. B., & Thompson, C. D. (2019). The Effects of Examples on Mental Health. *Journal of Example Psychology*, 25(2), 123-145. doi:10.example

CHAPTER SIX

TITLE OF THE CHAPTER/MANUSCRIPT IN ALL CAPS

Contribution of Authors and Co-Authors

Manuscript(s) in Chapter(s) 4

Author: [type author name here]

Contributions: [list contributions here, single-spaced]

Co-Author: [type co-author name here]

Contributions: [list contributions here, single-spaced]

Co-Author: [type co-author name here]

Contributions: [list contributions here, single-spaced]



Manuscript Information

[Type Author and Co-author(s) Names Here]

[Type name of journal here]

Status of Manuscript: [Put an x in one of the options below, then delete instruction in brackets]

- Prepared for submission to a peer-reviewed journal
- Officially submitted to a peer-reviewed journal
- Accepted by a peer-reviewed journal
- Published in a peer-reviewed journal

[Type name of publisher here]

[Type date of submission here (submitted manuscript – otherwise leave blank)]

[Type date the manuscript will appear here (accepted work – otherwise leave blank)]

[Type issue in which manuscript appears here (published work – otherwise leave blank)]

[Type DOI, if available]

Article

# Quantifying the Effect of River Ice Surface Roughness on Sentinel-1 SAR Backscatter

Ross T. Palomaki <sup>1,\*</sup> and Eric A. Sproles <sup>1,2</sup>

<sup>1</sup> Department of Earth Sciences, Montana State University, Bozeman, MT 59717, USA

<sup>2</sup> Geospatial Core Facility, Montana State University, Bozeman, MT 59717, USA

\* Correspondence: rosspalomaki@montana.edu

**Abstract:** Satellite-based C-band synthetic aperture radar (SAR) imagery is an effective tool to map and monitor river ice on regional scales because the SAR backscatter is affected by various physical properties of the ice, including roughness, thickness, and structure. Validation of SAR-based river ice classification maps is typically performed using expert interpretation of aerial or ground reference images of the river ice surface, using visually apparent changes in surface roughness to delineate different ice classes. Although many studies achieve high classification accuracies using this qualitative technique, it is not possible to determine if the river ice information contained within the SAR backscatter data originates from the changes in surface roughness used to create the validation data, or from some other ice property that may be more relevant for ice jam forecasting. In this study, we present the first systematic, quantitative investigation of the effect of river ice surface roughness on C-band Sentinel-1 backscatter. We use uncrewed aerial vehicle-based Structure from Motion photogrammetry to generate high-resolution (0.03 m) digital elevation models of river ice surfaces from which we derive measurements of surface roughness. We then compare these measurements to repeat previous ice classification studies to determine relationships between ice surface roughness and ice class. The results are similar to those reported in previous studies, indicating that SAR backscatter is primarily a function of surface roughness metrics (5–113% mean difference between river ice surface roughness and ice class). We conclude that SAR backscatter can be used to determine which physical ice properties are most relevant for ice jam forecasting.

**Keywords:** river ice; synthetic aperture radar; Sentinel-1; structure from motion; surface roughness



**Citation:** Palomaki, R.T.; Sproles, E.A. Quantifying the Effect of River Ice Surface Roughness on Sentinel-1 SAR Backscatter. *Remote Sens.* **2022**, *14*, 5644. <https://doi.org/10.3390/rs14225644>

Academic Editors: Ulrich Kamp, Dmitry Ganyushkin and Bijeesh K. Veetil

Received: 7 September 2022

Accepted: 4 November 2022

Published: 8 November 2022

**Publisher's Note:** MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



**Copyright:** © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

First-, second-, and third-level headings in your published manuscript must appear in the Table of Contents like any other chapter.

## 1. Introduction

Seasonal ice cover on high latitude rivers affects the ecology [1], morphology [2], sediment transport [3], and hydraulics [4] of river systems. Perhaps the most consequential aspects of river ice for human society are ice jams and associated flooding. Many types of ice jams and jamming mechanics are well-described [5], and rapid-onset, damaging ice jam floods are often associated with mechanical spring breakup [6]. This scenario occurs at the end of the ice season when a sudden increase in river discharge (e.g., from a rain-on-snow event) causes ice to release from the river channel before significant thermal deterioration of the ice has taken place. As the broken ice pieces run downstream, they may jam in a bend, constrict, or reach with stronger ice cover and cause backwater flooding. Later, the sudden release of the blocked ice sends an ice jam wave (“jave”) of ice and water downstream which can cause rapid flooding. The April 2020 mechanical breakup of ice on the Athabasca River in Alberta, Canada resulted in an ice jam more than 20 km in length that formed near the town of Fort McMurray and caused an estimated C \$1.1 billion in flooding damages, the evacuation of more than 13,000 residents, and one death [7]. These events are difficult to forecast due to the dynamic interactions between many hydrological, meteorological,

46. Probst, P.; Wright, M.N.; Boulesteix, A.L. Hyperparameters and Tuning Strategies for Random Forest. *WIREs Data Min. Knowl. Discov.* **2019**, *9*, e1301. [[CrossRef](#)]
47. Belgiu, M.; Drăguț, L. Random Forest in Remote Sensing: A Review of Applications and Future Directions. *ISPRS J. Photogramm. Remote Sens.* **2016**, *114*, 24–31. [[CrossRef](#)]
48. Palomaki, T. *iceroughness\_RF* (v1.0.0). 2022. Available online: <https://zenodo.org/record/7296543#.Y2ofkORBw2w> (accessed on 18 June 2022).
49. Li, H.; Calder, C.A.; Cressie, N. Beyond Moran's I: Testing for Spatial Dependence Based on the Spatial Autoregressive Model. *Geogr. Anal.* **2007**, *39*, 357–375. [[CrossRef](#)]
50. Pham, L.T.; Luo, L.; Finley, A. Evaluation of Random Forests for Short-Term Daily Streamflow Forecasting in Rainfall- and Snowmelt-Driven Watersheds. *Hydrol. Earth Syst. Sci.* **2021**, *25*, 2997–3015. [[CrossRef](#)]
51. Anselin, L. Local Indicators of Spatial Association—LISA. *Geogr. Anal.* **1995**, *27*, 93–115. [[CrossRef](#)]
52. NISAR. *NASA-ISRO SAR (NISAR) Mission Science Users' Handbook*; Technical Report; NASA Jet Propulsion Laboratory: Pasadena, CA, USA, 2018.
53. García Fernández, M.; Álvarez López, Y.; Arboleya Arboleya, A.; González Valdés, B.; Rodríguez Vaqueiro, Y.; Las-Heras Andrés, F.; Pino García, A. Synthetic Aperture Radar Imaging System for Landmine Detection Using a Ground Penetrating Radar on Board a Unmanned Aerial Vehicle. *IEEE Access* **2018**, *6*, 45100–45112. [[CrossRef](#)]
54. Lindenschmidt, K.E.; Demski, A.; Drouin, H.; Geldsetzer, T. Characterising River Ice along the Lower Red River Using RADARSAT-2 Imagery. In *Proceedings of the 16th Workshop on River Ice*, Winnipeg, MB, Canada, 18–22 September 2011; p. 16

You should include the entire article. This example only shows the first and last pages for brevity.

CHAPTER SEVEN

CONCLUSION

\*\*A conclusion is required. Your conclusion should thematically link your research and expand on future directions for research. This is required even if you have an conclusion chapter in your manuscript(s).\*\*

**\*\*Pages 24-25 give an example of how to format References Cited if you have at least one Appendix.\*\***

If you have at least one Appendix, add this divider page before References.

[CUMULATIVE] REFERENCES CITED

Cumulative references begin here. Cumulative references should include every reference within your whole document and all manuscript chapters.

References are single-spaced with a double-space in between citations. Students choose their citation style, typically in discussion with their advisor.

All references must follow the same, consistent citation style; however, if you have numbered references in your manuscript chapters, and the numbering will cease to make sense when compiled, you may skip numbering your references here and instead order them alphabetically.

This page is an example of how to format your references if you DO have appendices. Use a References Cited divider page as shown in this example ONLY if you also have appendices. Use the “End Matter Title” accessibility style for this title in order for it to feed correctly into the automatic Table of Contents at the beginning of the document.

If you include URLs in your references, format them consistently throughout. For example, this URL <https://www.montana.edu/etd/> and this URL <https://www.montana.edu/etd/> are formatted differently. Pick one of these styles for your ETD and use it consistently throughout.

Smith, J. D. (2020). *The Art of Fiction: A Comprehensive Guide*. Fiction Publications.

Johnson, A. B., & Thompson, C. D. (2019). The Effects of Examples on Mental Health. *Journal of Example Psychology*, 25(2), 123-145. doi:10.example

National Institute of Example Studies. (2022). *Climate Change and its Impacts*. Retrieved from <https://www.example.gov/climate-change-impacts>

This page intentionally left blank  
in order to show different  
examples of Back Matter.

Your own ETD should not have  
any blank pages.

## [CUMULATIVE] REFERENCES CITED

References begin here. References are single-spaced with a double-space in between citations. Students choose their citation style, typically in discussion with their advisor. All references must follow the same, consistent citation style.

This page is an example of how to format your references if you do NOT have any appendices. Type REFERENCES CITED (or the heading of your choice) at the top of the same page as your references, triple-spaced above your first reference entry. Use the “End Matter Title” accessibility style for this title in order for it to feed correctly into the automatic Table of Contents at the beginning of the document.

If you include URLs in your references, format them consistently throughout. For example, this URL <https://www.montana.edu/etd/> and this URL <https://www.montana.edu/etd/> are formatted differently. Pick one of these styles for your ETD and use it consistently throughout.

Smith, J. D. (2020). *The Art of Fiction: A Comprehensive Guide*. Fiction Publications.

Johnson, A. B., & Thompson, C. D. (2019). The Effects of Examples on Mental Health. *Journal of Example Psychology*, 25(2), 123-145. doi:10.example

National Institute of Example Studies. (2022). *Climate Change and its Impacts*. Retrieved from <https://www.example.gov/climate-change-impacts>

**\*\*Page 27 gives an example of how to format References Cited if you do not have any Appendices.\*\***

**If you do not have Appendices, put the References Cited title at the top of the page.**



This page intentionally left blank  
in order to show different  
examples of Back Matter.

Your own ETD should not have  
any blank pages.

**\*\*Pages 29-33 give an example of how to format multiple Appendices. \*\***

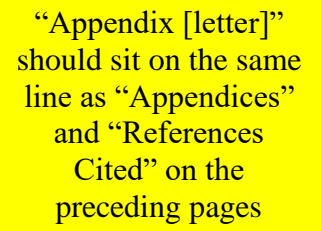
If you have **multiple** appendices, you must have multiple divider pages: one page for appendices (this page) and one for each additional appendix.

Type APPENDICES on the same line you typed REFERENCES CITED.

APPENDICES

APPENDIX A

APPENDIX A TITLE



“Appendix [letter]”  
should sit on the same  
line as “Appendices”  
and “References  
Cited” on the  
preceding pages

Appendix A content begins here.

Continue to follow ETD formatting in the Appendices where applicable. For example, original writing like a paragraph of text and a few figures should be formatted according to Graduate School guidelines. A copy of a letter that was sent as part of a student's research should be formatted exactly as it was sent.

Table A1. Any tables or figures in the Appendices need to have titles and captions like they do in the body text.

Fruit	Quantity (per day)	Color
Apple	2	Red
Banana	1	Yellow
Orange	3	Orange
Strawberry	10	Red
Kiwi	2	Green

Tables and figures in the appendices can be numbered in several different ways. They can continue numbering from the body text; they can restart numbering at 1; they can restart numbering but be preceded by the letter of the appendix such as in this example. Pick one way of numbering and be consistent.

APPENDIX B

APPENDIX B TITLE

Appendix B content begins here.

This page intentionally left blank  
in order to show different  
examples of Back Matter.

Your own ETD should not have  
any blank pages.

**\*\*Pages 35-36 give an example of how to format a single Appendix. \*\***

If you only have one appendix, this is the only divider page that is needed. Since you only have one appendix, you do not need to use the letter A.

APPENDIX

APPENDIX TITLE

“Appendix” should sit on the same line as “References Cited” on the preceding pages



Appendix content begins here.

Pages 29-33 show an example of how to format your appendices if you have multiple appendices. Pages 35-36 show how to format your appendix if you only have one.