

Visualizing Glacial Retreat in Maps: An Empirical Evaluation Study

by

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THESIS ABSTRACT

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Title: Visualizing Glacial Retreat in Maps: An Empirical Evaluation Study

Effective climate change communication requires map designs that not only convey scientific accuracy but also resonate with public perceptions and emotions. This study investigated how different map designs influence cognitive and emotional responses to glacier retreat. Participants (n = 114) were randomly assigned to view one of three map types (Line, Polygon, or Imagery) and completed measures of awareness of glacial change, connection to climate change (CCC), influence on climate-related actions, trust in the map (MAPTRUST), attractiveness, and emotional responses. Results showed that the Polygon map led to significantly higher awareness of glacier retreat compared to the Imagery map, while the Line map fell in between without differing significantly from either. Attractiveness ratings also varied, with the Polygon map rated more attractive than the Imagery map, and the Line map again scoring in between. Regression models revealed that individual characteristics moderated interpretation: education level and Need for Cognition shaped awareness, while task load and Need for Cognition influenced attractiveness. Emotional responses, visualized through Geneva Emotion Wheel maps, indicated broad tendencies: the Polygon map elicited more negatively-valenced emotions such as sadness and guilt, the Line map showed a broader mix with less concentrated emotional reactions, and the Imagery map drew some admiration alongside many “No Emotion” responses. These findings demonstrate that map design affects both cognitive and emotional engagement with climate data, though the

explanatory power of the models was modest. By highlighting how cartographic choices influence awareness, perceptions of attractiveness, and affective responses, this study contributes to ongoing discussions in cartography and climate change communication and emphasizes the importance of user-centered geovisualization strategies.

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CHAPTER I

INTRODUCTION

1.1 Introduction

Climate change represents one of the most critical global challenges of the 21st century, requiring creative communication approaches to effectively convey its impacts. Cartographic visualization has emerged as an essential tool for bridging the gap between scientific data and public perception (Lieske, 2012; Goudine et al., 2020). By visually communicating the effects of climate change phenomena, such as glacier retreat, these maps help translate complex climate data into accessible and compelling narratives (Bishop et al., 2013; Fish, 2020).

Glacier retreat is a visible and well-documented indicator of climate change (Zemp et al., 2015; IPCC, 2021) and serves as a powerful case study for understanding how visual representation shapes public awareness and emotional engagement (Fish, 2020; Kiss et al., 2020). Maps are particularly useful for illustrating spatiotemporal changes in glacier extent. Their ability to show historical data alongside present conditions in space enables viewers to grasp the scale and speed of environmental transformation (Kostelnick et al., 2013; Roe & Baker, 2014; Huss & Hock, 2018).

This thesis explores how map design influences viewers' perceptions of glacier change and their emotional responses to those maps. The study investigates how different cartographic choices used to communicate glacial change affect cognitive processing and emotional engagement (Kiss et al., 2020; Christophe, 2020). In particular, this research used a between-subjects online user study where participants saw one of three different glacial retreat map designs using either lines, polygons, or remotely sensed imagery with the goal of identifying how the use of different visual

variables of the same phenomena contribute to public understanding, trust, and emotional connection with climate data (Lieske et al., 2014; Sugg, 2021).

As climate change communication increasingly seeks to foster meaningful action from a diverse set of communication devices, understanding the role of map design becomes crucial. This study contributes to that effort by offering insight into how cartographic representations can influence both what people perceive and how they feel, potentially shaping their responses to one of the defining environmental challenges of our time (Richards, 2015; Goudine et al., 2020).

1.2 Statement of Problem

Despite the growing availability of cartographic tools and glacier data, visualizations of glacier retreat often prioritize scientific precision over user-centered communication, which can limit their accessibility and emotional impact for general audiences (Bishop et al., 2013; Kostelnick et al., 2013). As climate change intensifies, effective communication depends not only on presenting accurate data but also on visual designs that foster understanding, trust, and engagement (Fish, 2020; Christophe, 2020). While glaciers are among the most visible indicators of climate change, the map design choices used to depict glacial retreat have rarely been evaluated for their communicative effectiveness or emotional resonance. This study addresses this gap by empirically testing how different map designs, shaping perceptions of glacier retreat and emotional responses to climate change.

1.3 Research questions

In doing so, the study tries to contribute to the development of more effective and accessible cartographic communication strategies for climate change. To address this issue, I ask two primary research questions.

RQ 1: How do map readers' perceptions of glacial retreat and climate change differ by map design?

The first research question is designed to understand how visual communication shapes cognitive engagement with climate change information. Cartographic design such as symbology and color schemes can influence what users take away from a map (Montello, 2002; Bishop et al., 2013; Kostelnick et al., 2013), and given that glacier retreat is a visible marker of climate change that has been described in prior work as potentially eliciting public responses (Fish, 2020; Kiss et al., 2020), my goal is to examine whether different representations of the same phenomenon might lead viewers to interpret the severity, cause, or urgency of glacier change differently. This question is rooted in the need for more nuanced cartographic design, especially as maps are often trusted sources of environmental information but may implicitly influence public understanding. This question is rooted in the need for more nuanced cartographic design, especially as maps are often trusted sources of environmental information but may implicitly frame the issue in ways that influence public understanding.

RQ 2: How do map readers' emotions about glacial retreat and climate change vary depending on map design?

There is a growing recognition in both geography and science communication literature that emotional engagement plays a key role in how people respond to environmental issues (Nerlich et al., 2010; Chapman et al., 2017). While cognitive understanding is necessary, emotion can drive motivation, concern, and action. Yet, few studies isolate how specific visual variables in maps may elicit different affective responses. In particular, one goal of this research is to understand whether maps which highlight glacial change might evoke different emotions and intensities. This line of inquiry builds on frameworks like Climate Visualizations for Adaptation Products (CVAP,

Goudine et al., 2020) and calls in the literature for more emotionally resonant geovisualizations (Richards, 2015; Lumley et al., 2022), and aims to explore how differences in visual representation can connect viewers more deeply with the realities of climate change.

1.4 Intellectual merit

This research contributes to the advancement of cartography, GIScience, and climate change communication by analyzing how variations in map design symbolization influences public perceptions and emotional responses to glacier retreat, a critical and visible indicator of climate change. This study addresses the pressing need to examine how different visual representations, such as the use of satellite imagery, differentiated colored lines of glacier extent, and polygonal outlines affect both cognitive understanding of glacial retreat and emotional engagement with glacier change maps. Building on recent work in geovisual analytics and user-centered mapping (Jin & Guo, 2020; Lumley et al., 2022), this study advances the field by empirically testing how distinct glacier retreat map designs influence both cognitive interpretation and emotional engagement (Garrison et al., in press). The study's interdisciplinary nature arises from integrating theories and methods from cartography, GIScience, environmental communication, and cognitive psychology. By combining spatial data visualization, user-centered design principles, and empirical assessment of emotional and perceptual responses, this research strengthens the link between geospatial visualization and science communication, offering design guidance for creating maps that not only convey information but also resonate emotionally with audiences confronting the realities of climate change.

1.5 Broader impacts

This research has the potential to enhance how climate change is communicated to the

public by demonstrating how specific map design choices influence emotional and perceptual responses to glacial retreat. By identifying which cartographic elements most effectively convey urgency, change, and environmental significance, the findings can inform the design of more engaging and accessible climate communication materials. These insights are valuable not only to cartographers and climate scientists, but also to educators, journalists, and policymakers seeking to reach broader and more diverse audiences. The project supports public understanding of climate change through visual literacy and offers practical guidance for designing maps that foster empathy and environmental awareness. Additionally, the research contributes to inclusive science communication by emphasizing emotionally resonant strategies that can connect with individuals across educational and cultural backgrounds. In the classroom, findings from this study can be integrated into geography, environmental science, and visual communication curricula to prepare future professionals to communicate climate change more effectively.

CHAPTER II

LITERATURE REVIEW

The goal of this literature review is to situate this thesis at the intersection of cognitive cartography, geovisualization, and climate change communication, with a specific focus on the design of maps depicting glacier retreat. As climate science increasingly relies on visual tools to convey abstract, often spatially complex information, the design of these tools, particularly static maps, plays a pivotal role in shaping public perception, emotional response, and trust in scientific narratives. This review draws on theoretical and empirical foundations across three interrelated domains to build the rationale for the user-centered study presented in this thesis.

[Section 2.1](#) begins with an overview of cognitive map design research, outlining how psychological and cartographic theories have shaped our understanding of how users process visual-spatial information. This includes attention to map readability, visual hierarchy, and the cognitive load imposed by different graphic variables. [Section 2.2](#) moves into the domain of geovisualization and visual analytics, focusing on how dynamic and static maps are designed to both inform and engage users. This section traces how the evolution of cartographic tools, from exploratory interfaces to emotionally resonant visual storytelling, impacts climate science communication. [Section 2.3](#) centers on the emerging literature of climate change communication through cartography. It addresses how trust, urgency, and perceived credibility are mediated by design choices, such as the use of satellite imagery versus stylized representations, and how these choices affect viewer interpretation and motivation.

Taken together, these strands of literature provide the conceptual foundation for this thesis's experimental approach. The study examines how different map designs of South Cascade

Glacier affect user awareness, trust, and aesthetic response, offering insight into the communicative potential and limitations of varied cartographic styles in climate discourse.

2.1 Cognitive Map Design Research

Cognitive map design research provides the theoretical and empirical foundation for understanding how individuals process visual spatial information. Montello (2002), in his review of twentieth-century map design research, emphasizes that the effectiveness of any map depends on its alignment with human cognitive structures. He distinguishes between theoretical studies grounded in psychology and empirical approaches that test user responses, highlighting themes such as symbolization, visual hierarchy, and complexity as central to how maps are read and interpreted. Even though Montello does not specifically address climate change communication, his framework underscores the importance of designing maps that reduce unnecessary cognitive load and align with human perceptual capabilities.

Similarly, Fabrikant and Lobben (2009) extend this perspective by situating geographic information visualization within broader cognitive processes of attention, memory, and perception. They argue that evaluating maps requires attention not only to technical accuracy but also to how designs resonate with users' cognitive processes. This connection between cartographic design and cognitive psychology provides a foundation for evaluating user performance and comprehension in different mapping contexts.

Recent research has also expanded into the domain of map trust. Prestby (2024) developed and validated the MAPTRUST scale, a multi-item instrument designed to measure trust in maps through indicators such as accuracy, reliability, honesty, and balance. Unlike earlier work that often conflated trust with credibility, the MAPTRUST scale operationalizes trust as a distinct construct related to veracity and reliability. This work highlights that trust is not a single-item

judgment but a multidimensional evaluation shaped by cartographic cues such as clarity, consistency, and sourcing. These insights are particularly relevant in contexts like climate change communication, where public skepticism can undermine the authority of scientific visuals.

Early experimental work on map perception, such as MacEachren (1995), demonstrates that map comprehension is shaped not only by the accuracy of representation but also by the persuasive qualities of design. As cognitive load increases, particularly in visually dense or unfamiliar map formats, users may shift from analytical to heuristic processing (Montello, 2002). This insight is directly relevant to climate cartography, where balancing data richness with clarity can determine whether a visualization is perceived as comprehensible or overwhelming. These cognitive perspectives inform the present study's examination of how different map designs influence participants' reported awareness and judgments of glacier changes.

2.2 Geovisualization and Visual Analytics

Geovisualization and visual analytics represent a paradigm shift in the cartographic sciences, one that merges traditional mapmaking with computational design and interaction models. The rise of geovisualization in climate science reflects the urgent need to present complex datasets in ways that are both interpretable and engaging for diverse audiences (Terrado et al., 2022). Slocum et al. (2001) laid the groundwork for this transformation, proposing a research agenda focused on user interaction, multiple linked views, and dynamic temporal visualization. While their work addressed geovisualization more broadly, these principles are especially critical in domains like glaciology, where temporal–spatial change is the core message.

Tools like VisAdapt™ (Neset et al., 2016) and Climate Visualizations for Adaptation Products (CVAP) by Goudine et al. (2020) demonstrate how interactivity enhances comprehension of climate data through geovisualization. These systems, designed for lay audiences, incorporate

downscaled regional projections and personalized risk scenarios. Their success, however, is mixed: while interactivity improves engagement, users may struggle with interpretive clarity when visualizations are overly complex or poorly contextualized (Glaas et al., 2017). This thesis study's use of static maps contrasts with these interactive systems, but it tests a similar hypothesis; namely, that design decisions directly shape interpretation.

Several studies advance the methodological frontiers of geovisualization for climate data. Jin and Guo (2020) developed interactive multivariate and spatiotemporal visualization techniques to explore climate change patterns in the United States. Their approach integrated multiple climate variables, such as temperature, precipitation, and seasonal trends, into linked visual displays that allowed users to compare temporal changes across regions. Drawing from visual analytics principles, the system employed color gradients, animations, and data aggregation layers to reduce cognitive load and help users intuitively interpret complex climate trends without sacrificing accuracy. Lumley et al. (2022) evaluated 74 online climate visualization tools, noting a trend toward explanatory rather than exploratory interfaces, reflecting a shift toward communication over analysis in public-facing tools.

2.3 Climate Change Communication Cartography

The intersection of cartography and climate change communication is a rapidly expanding area of research that examines how maps function not only as representational tools but also as persuasive narratives. Cartographers like Fish (2020) emphasize the critical role of visual design, particularly color, layout, and annotation, in shaping how people emotionally engage with climate maps. She proposes a “vividness principle,” arguing that emotionally charged yet scientifically accurate designs are more effective at motivating engagement. Christophe (2020) echoes this emphasis on intentional design through a multidimensional approach to geovisualization that

integrates cognitive load theory with interface design, ensuring that visualization facilitates user understanding without overwhelming the viewer.

Sheppard (2012) argues that effective climate risk visuals combine three key elements: visual realism, which grounds abstract climate processes in tangible imagery; transparency of uncertainty, which communicates the confidence and limitations of data; and narrative framing, which structures visuals to tell a coherent story that emphasizes particular causes, consequences, or solutions. By embedding climate data within such narratives, cartographers can guide audience interpretation, emphasize specific aspects of the issue and shape how viewers assign meaning and urgency.

Recent work by Fish (2020a) advances this narrative framing concept through a cartographic content analysis of compelling climate change communication, demonstrating that effective climate maps often blend scientific accuracy with story-driven design choices. Her analysis highlights recurring visual strategies, such as comparing “before-and-after” imagery, layering temporal sequences, and using human-scale visual anchors, that increase memorability and emotional resonance. In parallel, Fish (2020b) argue for explicit storytelling as a framework for making cartographic design decisions in climate change communication, particularly in the U.S. context. They show that design decisions about symbology, layout, and annotation can be more systematically justified when anchored to an overarching story that aligns with audience values and the intended communicative purpose.

Empirical studies further demonstrate how these design and communication principles affect engagement. Sugg (2021) shows how mapping climate belief clusters across the United States can personalize climate information, reflecting prevailing attitudes within specific communities and potentially influencing public opinion. Similarly, Glaas et al. (2017) evaluate

participatory tools like VisAdapt™, which use downscaled regional projections and personalized risk scenarios to support adaptation planning. Their findings suggest that interactivity can encourage reflection and foster a sense of agency, though overly complex or poorly contextualized designs may reduce interpretive clarity.

Collectively, these studies underscore that effective climate change communication cartography must balance emotional resonance, interpretive clarity, and scientific credibility. This balance is directly relevant to the present study, which evaluates how different static map designs (i.e. Line, Polygon, Imagery) shape perceptions of glacier retreat. By testing the interplay of visual form, audience interpretation, and emotional engagement, this research builds on established design theory while addressing the urgent communication challenge posed by accelerating climate change.

2.4 Summary

This review exhibits the present study within the intersecting domains of cognitive cartography, geovisualization, and climate change communication. Research in cognitive map design underscores that visual, spatial processing is influenced by symbolization, visual hierarchy, and cognitive load, which together shape comprehension, trust, and emotional engagement. Geovisualization and visual analytics scholarship demonstrate how design decisions, whether in interactive or static formats, mediate interpretation by balancing clarity, complexity, and affective impact. Climate change communication cartography further reveals that credibility, urgency, and perceived relevance are not solely products of accurate data representation but also emerge from visual realism, transparency of uncertainty, and narrative framing. Together, these literatures establish the conceptual foundation for this thesis's user study, which empirically examines how three distinct static map designs of South Cascade Glacier influence public awareness, perceived

trustworthiness, and emotional response. In doing so, this research contributes new insights into how cartographic design can enhance the communicative power of climate change visualizations.

CHAPTER III

METHODS

This study relied on a user study to investigate the two research questions concerning how map design influences viewers' perceptions and emotional responses to maps of glacial retreat. I conducted a between-subjects experiment to compare three map design types of glacial change where each one used a different design to illustrate the extent of South Cascade Glacier (SCG) over 56 years across five different time slices with: (1) Lines, (2) Polygons, and (3) Imagery (Figure 1). The goal was to isolate how design differences influence cognition and emotion interpreting glacial change. This study was reviewed and approved by the University of Oregon Institutional Review Board (IRB), ensuring adherence to ethical standards for research involving human participants (IRB Protocol Number: STUDY00001592).

3.1 Participants

A total of 114 participants were recruited through the online platform Prolific (2025). Participants needed to be at least 18 years old, reside in the United States, be fluent in English, and have access to an internet-connected device. I used Prolific's screening tools to enforce eligibility and distribute the survey. Each participant received \$2.40 as compensation via Prolific upon successful completion and approval of their responses, estimated to take approximately 12 minutes.

3.2 Development of Stimuli Maps

The goal of this study was to understand the cognitive and emotional responses of participants to different map designs. To do so, I created three distinct stimuli maps, as described below. The maps depict SCG, a vital research site for studying glacial dynamics, climate change

impacts, and hydrological processes in the Pacific Northwest. SCG is one of the United States Geological Survey's Benchmark Glaciers (USGS, 2023), a designation reflecting its intensive long-term monitoring and role in representing typical mass and energy processes for its climatic region (Fountain et al., 2009).

SCG is especially notable because it holds a continuous mass-balance record in North America, beginning in 1959 (USGS, 2023). This record, combined with over a century of documented retreat (Post et al., 1971; Josberger et al., 2007), has allowed researchers to conduct both retrospective analyses of glacier behavior and the calibration of predictive models for future climate-driven changes in glacier mass and runoff (Roe & Baker, 2014; Huss & Hock, 2018). These monitoring efforts, along with independent projects such as the University of Washington's Digital Glacier Time Machine (Knuth, 2022), have generated high-resolution Digital Elevation Models (DEMs), Digital Terrain Models (DTMs), orthoimagery, and remotely sensed datasets spanning multiple decades. Together, these resources provided the basis for creating consistent, high-quality visualizations of long-term glacial retreat in this study.

Figure 1 displays the three map conditions: 1) Line, 2) Polygon, and 3) Imagery. All three maps were developed in ArcGIS Pro 3.3.0 illustrating the glacier extent across five time periods: 1967, 1979, 1992, 2015, and 2023. Glacier extents were digitized by manually tracing boundaries using the corresponding orthoimages as reference, ensuring consistent, high-quality delineation of terminus positions and enabling clear visual comparisons of retreat across all map designs and time slices.

Each map maintained identical extent, scale, resolution, top-down orientation, and base imagery. By holding geographic extent, scale, and orientation across designs, only the cartographic technique varied between conditions, isolating the influence of design choices on participants'

perceptions and emotional responses.

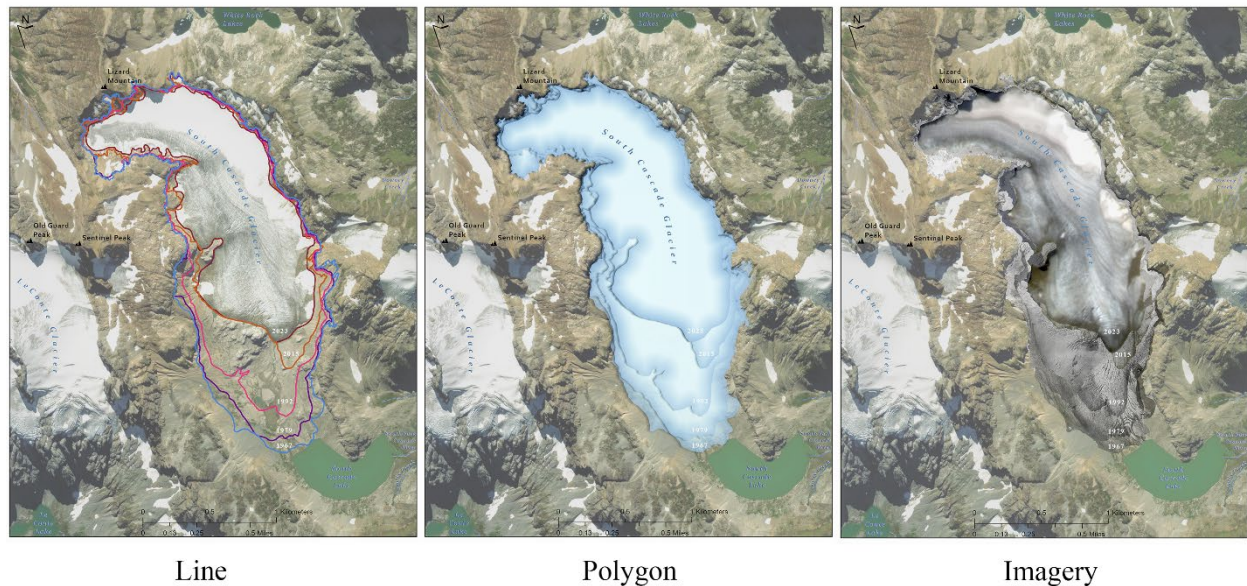


Figure 1. The three different map conditions tested in this study: Line, Polygon, and Imagery maps showing South Cascade Glacier retreat.

The data for the creation of the maps is shown in Table 1. Historical orthoimages and DEMs from the 1960s to 1990s were obtained from the University of Washington’s DGTM project (Knuth, 2022). The 2015 imagery was acquired from Planet Labs, while the 2023 imagery was acquired from the Esri World Imagery Wayback. A 1-meter high-resolution digital terrain model (DTM) for the SCG area was obtained from the Washington LiDAR Portal and the Washington Department of Natural Resources (WDNR). This DTM was processed to generate shaded relief background layer across map designs. Prior research demonstrates that shaded relief can enhance perceptions of realism and clarity in terrain visualizations (Douglass & Fish, 2022), and it was incorporated here with the intent of offering subtle topographic cues, such as ridgelines, valleys, and elevation changes surrounding the glacier. to provide viewers with spatial context and help

situate the glacier within its mountainous environment.

Table 1. Metadata for data used in this study, including source, spatial resolution, description, spatial extent, date of acquisition, and data type.

Name	Source	Spatial Resolution	Description	Extent	Date	Data type
Washington State LiDAR	Washington LiDAR Portal	1.5 ft	High resolution LiDAR, used to create hillshade.	South Cascade Glacier	2020	Raster
USGS 3DEP	USGS	10–30 m	Used to create hillshade, lower resolution compared to LiDAR.	South Cascade Glacier	2018–2023	Raster
UW Glacier Time Machine - South Cascade Glacier	University of Washington, Terrain Analysis and Cryosphere Observation Lab	1 m	UW restored historical survey images into high-resolution data (1m); available in ortho imagery and DEM. Digitized glacier extents for 1967, 1979, and 1992.	South Cascade Glacier	1967, 1979, 1992	Raster
National Agriculture Imagery Program (NAIP)	USGS	1 m	High resolution aerial imagery used as basemap. Digitized glacier extent from 2015 imagery.	South Cascade Glacier	2015	Raster
World Imagery Wayback	ESRI	1.9 cm	High resolution satellite imagery used as basemap. Digitized glacier extent from 2023 imagery.	South Cascade Glacier	2023	Raster
National Hydrography Dataset (NHD)	USGS	N/A	Vector dataset used to create water features.	South Cascade Glacier	2023	Vector

Geographic Names Information System (GNIS)	USGS	N/A	Contains geographic information, such as the names of mountains and other features.	South Cascade Glacier	2023	Vector
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The Line map (Figure 2) used lines to represent glacier extents at each of the five time periods. Each year was colored with a distinct hue. This design emphasized the different glacier extents for the corresponding year. The goal of this design was to be simple and clear by using lines and reducing all other visual clutter. This is also how I saw that most glaciers are mapped in peer-reviewed articles, thus it was designed to match those designs.

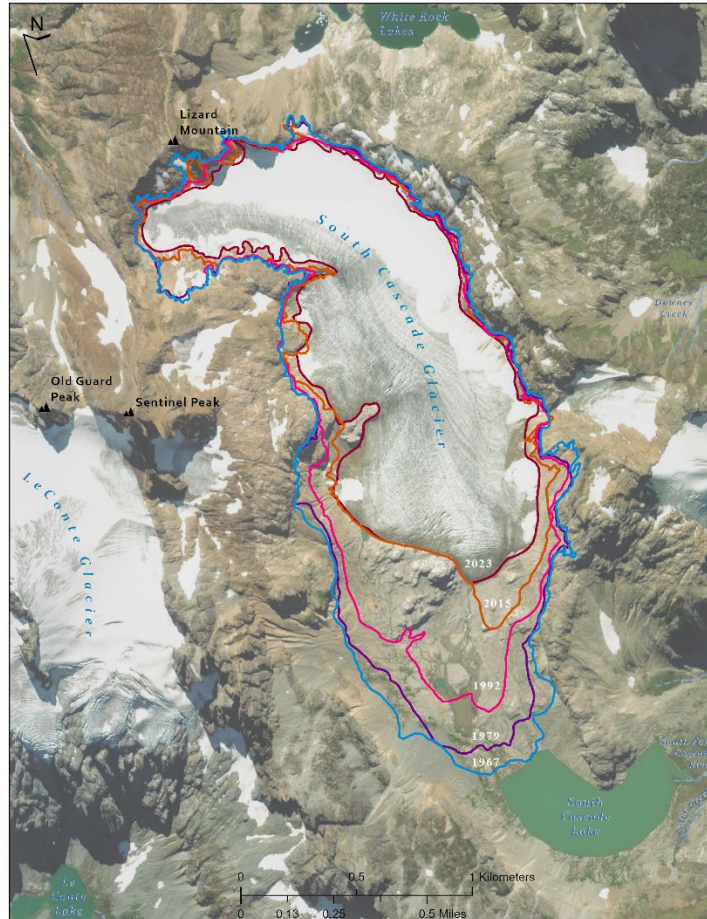


Figure 2. Line map of South Cascade Glacier extents (1967–2023), emphasizing boundary change with colored outlines.

The Polygon map (Figure 3) used the same digitized glacial extents as the Line map but applied semi-transparent gradient fills to each year’s extent. While the degree of transparency varied slightly between layers, this approach allowed portions of underlying polygons to remain subtly visible, making it possible, especially upon closer inspection, to discern areas of overlap between different years. The gradient fill was used to give a potentially stronger impression of volumetric coverage than simple outlines, helping viewers perceive the glacier as a physical volume rather than a flat surface. By representing the extents as filled areas, this design emphasized the areal magnitude of change over time, enabling more intuitive visual comparisons of glacier size and retreat across decades. In working with the University of Oregon InfoGraphics

Lab, this was one of the designs that was championed by expert cartographer Alethea Steingisser.

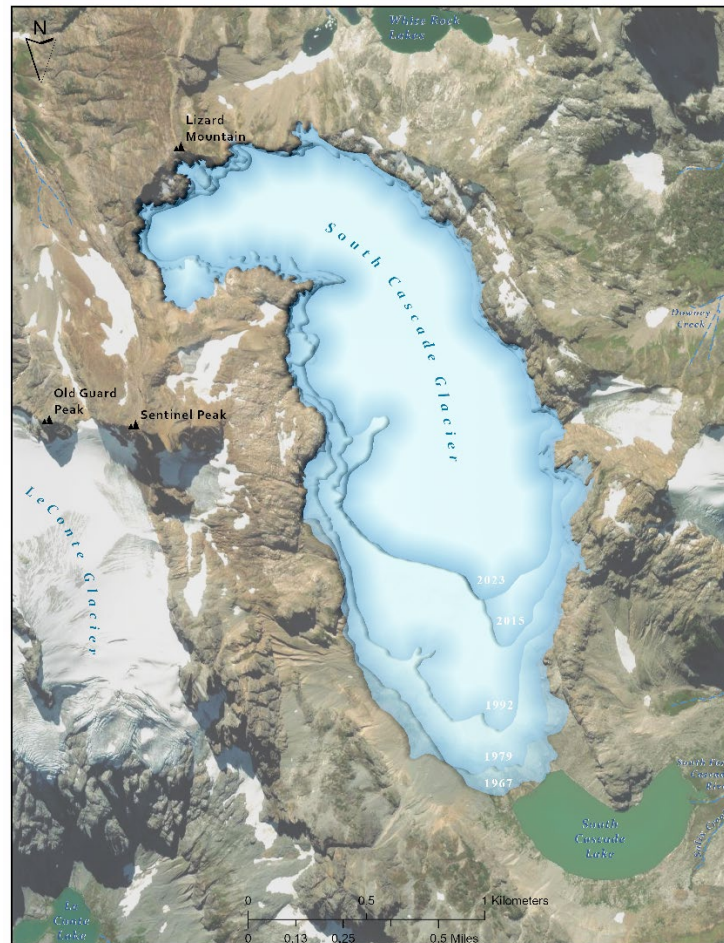


Figure 3. Polygon map of South Cascade Glacier extents (1967–2023), highlighting cumulative change with semi-transparent fills.

The Imagery map (Figure 4) used the same glacial extent lines as the other two maps. To create this map, I clipped the remotely sensed imagery of each of the corresponding photos to the glacier extents for each year so map readers could see what the glacier looked like in each of the years. High-resolution imagery provides textural details of the ice surface and surrounding terrain. This design blended scientific data with photo-realism, to identify if this map design potentially elicits stronger emotional responses due to the immersive and visually engaging

depiction of change. The visual realism aimed to enhance affective engagement while still preserving spatial accuracy and temporal detail.

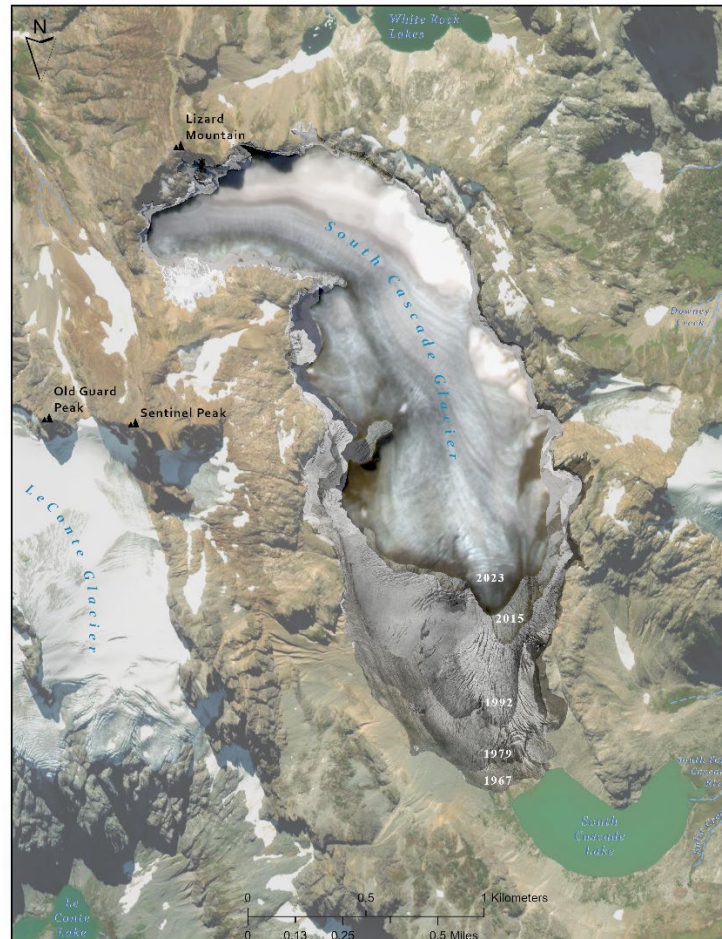


Figure 4. Imagery map of South Cascade Glacier extents (1967–2023), using clipped satellite and orthoimagery to provide photorealistic detail. The historical imagery (1967, 1979, 1992) consisted of black-and-white orthophotos, whereas the 2015 and 2023 datasets were color satellite images.

3.3 Materials

The study consisted of twelve parts listed below. The full panel of questions is available in [Appendix A](#).

3.3.1 Informed Consent Form.

Before beginning the survey, participants reviewed and electronically agreed to an

informed consent form outlining the purpose, procedures, risks, and voluntary nature of the study. This process upheld ethical standards and ensured that all participants entered the study with a clear understanding of risks and benefits.

3.3.2 Demographic Questions.

The demographic panel included questions about their age, gender, race, zip code, marital status, employment status, education, and income.

3.3.3 Need for Cognition Scale.

To measure individual differences in the tendency to engage in and enjoy effortful cognitive activities, participants completed the Need for Cognition Scale (NFC), a well-established psychological assessment tool (Cacioppo, Petty, & Kao, 1984). The scale consists of 18 items, adapted from the original long and short forms developed by Cacioppo and Petty (1982), Cacioppo, Petty, and Kao (1984), and further validated for reliability and internal consistency by Sadowski and Gulgoz (1992). Participants rated their agreement with statements such as “I prefer complex to simple problems” on a Likert scale, allowing me to account for how cognitive style may influence interpretation of the map. For analysis, responses to the 18 items were averaged into a composite NFC score which ranged from Likert scale ranging from 1 = Extremely Uncharacteristic to 5 = Extremely Characteristic.

3.3.4 Stimuli.

The stimuli consisted of the three static map designs of South Cascade Glacier (SCG) described in [Section 3.2](#). Each participant saw just one of these maps in the between-subjects design used. Participants were told to “Please view the map below of South Cascade Glacier in Washington State in the United States. You will be asked questions about this map in this study. You do not need to memorize the map; we will show it to you on each page of the survey.”

3.3.5 Geneva Emotion Wheel.

To assess participants' emotional responses, the study used the Geneva Emotion Wheel (GEW, Scherer, 2005; Scherer et al., 2013), a self-report instrument (Figure 5) designed to measure discrete emotions along two primary dimensions: valence (ranging from pleasant to unpleasant) and control/power (ranging from low to high activation). This spatial structure provides participants with an intuitive way to report emotions, as selecting closer to the center indicates weaker intensity, while farther selections reflect stronger emotions. Because of its design, the GEW has been widely used in psychology to examine how visual stimuli evoke nuanced affective responses. The specific design of the GEW allows participants to select their emotion type (e.g., anger, joy, compassion, etc.) and the intensity of that emotion depending on how close to the center of the wheel they choose. To allow participants to indicate their emotions to the glacier retreat map, participants could select the emotion(s) from the GEW that best described how they felt in response to the map. The GEW question was created using the Qualtrics "heat map" question-type which allows participants to select a point within an image. I designed the heat map question to allow participants to select up to 10 different emotion types and/or intensities simultaneously, offering a nuanced depiction of affective experience. Within the image, the locations of the clicks were recorded. Because of the spatial organization of the GEW, I analyzed the data using ArcGIS Pro. This allowed me to map frequency of clicks and conduct several hot spot analyses to identify emotional "hot spots" map areas most frequently associated with emotional reactions and the other variables in the study. This spatial-emotional analysis can provide insight into how map design may trigger emotional engagement.

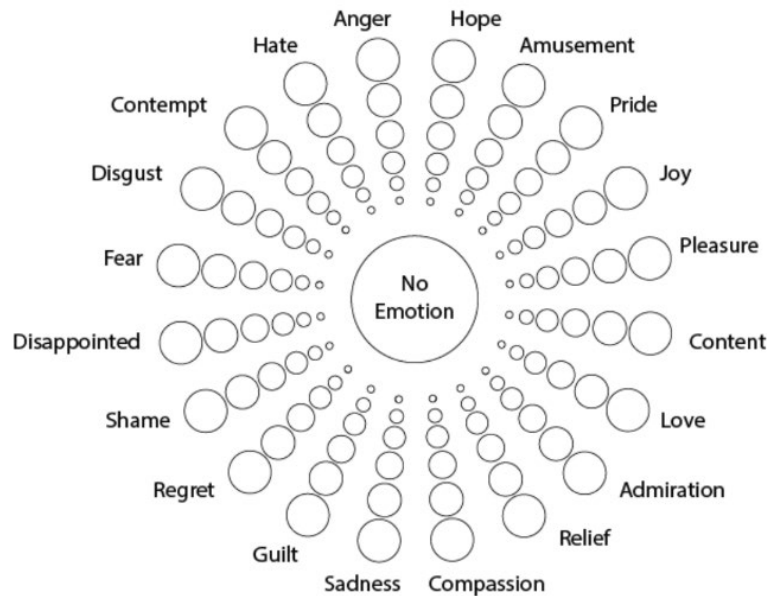


Figure 5. Geneva Emotion Wheel (GEW, Scherer et al., 2013) showing 20 discrete emotions arranged by valence and intensity. In the creation of this GEW, I removed “Other” and only left “No Emotion” in the center.

3.3.6 MAPTRUST Scale.

To measure perceived trust in the maps, the survey used the MAPTRUST scale, a validated 12-item instrument (Figure 6) developed to assess trust in cartographic products used for scientific communication (Prestby, 2024). Using this scale, participants could rate how well each of the twelve descriptors, such as accurate, credible, balanced, objective, and fair, applied to the map they observed. Responses were recorded using a 7-point Likert scale ranging from 1 (describes the map very poorly) to 7 (describes the map very well). This set of questions was designed to quantify the extent to which participants perceived the map as trustworthy, thereby offering insight into how different visual design strategies affect the credibility of climate-related geovisualizations. For analysis, the twelve items were combined and averaged into a single MAPTRUST index score, which ranged from Likert scale ranging from 1 = Describe the map very poorly to 7 = Describe the map very well.

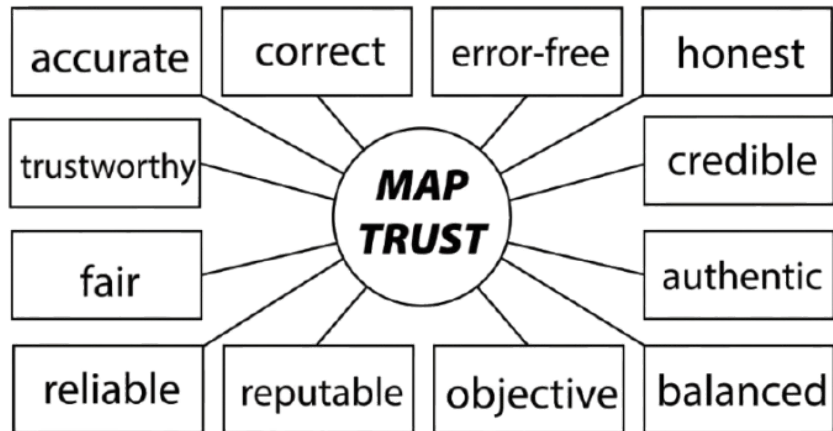


Figure 6. MAPTRUST scale with 12 descriptors is used to assess perceived trust in maps (Prestby, 2024).

3.3.7 Attractiveness Question.

To gauge participants' aesthetic evaluations of the map they viewed, the user study included a single-item attractiveness measure to rate the map using a 6-point Likert scale ranging from 1 (Not attractive at all) to 6 (Extremely attractive). This measure aims to capture users' immediate aesthetic impressions, which can influence both emotional response and perceived credibility of visual information. Evaluating attractiveness also helped contextualize participants' effective and trust-related responses within the overall visual appeal of the map design. Because this was a single-item measure, the raw rating was in subsequent analyses.

3.3.8 Accuracy Questions.

Participants were asked to interpret the glacial changes depicted in the map and consisted of four questions which were assessed for accuracy. The first question was a forced-choice question asking whether the map showed a gain, loss, or no change in glacial ice over time. In the second question, they rated their confidence in their answer to the first question on a 5-point Likert scale ranging from "Not confident at all" to "Extremely confident." The third question asked that participants to click directly on the map image to indicate the location where they believed the

greatest glacial change had occurred and was followed by the fourth question which was the same as second question where they could rate their confidence about the prior question. These questions were designed to measure both the accuracy of map interpretation and the participant's level of certainty in their response. Together, these measures allowed for a multifaceted evaluation of how effectively each map communicated glacial change, revealing not just what participants believed they saw, but how confidently and precisely they could locate those perceived changes. Since accuracy was assessed using individual interpretation items rather than a multi-item scale, the raw responses were analyzed directly without averaging or creating an index.

3.3.9 Awareness of Glacial Change Questions.

To assess participants' awareness of glacial change, participants were asked how well the map helped them understand 1) the size change of the glacier over time, 2) the clarity with which the map conveyed volume loss, 3) the extent to which it communicated long-term changes and shifts in glacial extent, and 4) the clarity of the map to understand changes in the glacial extent over time. Each question used a 5-point Likert scale ranging from "Not at all" or "Not clear at all" to "Extremely well" or "Extremely clear," enabling a nuanced evaluation of cognitive comprehension. This section aimed to determine which visual designs were most successful in conveying complex glaciological change in an accessible and interpretable format, with implications for improving climate change communication through maps. These items were designed to gauge the clarity and effectiveness of the map in communicating both the scale and temporal dynamics of glacier retreat. The four awareness items were averaged to create an overall awareness score that was included in subsequent analyses.

3.3.10 Connection to Climate Change Questions.

To understanding whether participants connected the loss in glacial ice to climate change, I

asked four questions about whether or how good the map was at 1) showing the urgency of climate change, 2) helping the map reader perceive the overall impact of climate change on glaciers, 3) making the map reader believe that immediate action is necessary to address climate change, and 4) providing evidence of climate change. These questions captured both cognitive and affective reactions, helping to assess whether participants connected perceived glacier loss to broader climate change impacts, including its urgency, consequences, and need for action. By collecting responses across a spectrum of agreement and perceived effectiveness, this section provided insight into how different map designs influence users' understanding of and emotional engagement with climate change narratives. Responses were aggregated into a mean Connection to Climate Change (CCC) score, which served as an input for the GEW hotspot analysis.

3.3.11 Influence on Decision Making and Actions.

Participants were asked to reflect on the likelihood that the map they viewed would prompt them to take personal actions, such as reducing energy use or supporting climate policies in four questions on a 5-point Likert scale ranging from "Not likely at all" to "Extremely likely." Additional items asked whether the map motivated them to learn more about climate change, encouraged discussions with others (e.g., friends or family), or inspired them to share the map or similar visual content on social media to raise awareness. This section aimed to measure the map's potential to move participants beyond passive viewing toward climate-related action and communication, offering insights into how visual design influences public agency and behavioral intentions in response to environmental change. The four items were averaged to calculate a composite influence score.

3.3.12 NASA Task Load Index.

To measure participants' perceived workload while interpreting the maps, the study

employed the 6-item NASA Task Load Index (NASA-TLX), a widely used and validated tool for assessing cognitive and physical demands in user tasks (Hart & Staveland, 1988). This instrument asked participants to rate six dimensions of workload: mental demand, physical demand, temporal demand (how rushed they felt), performance (how successful they felt), effort, and frustration. Each item was rated on a 5-point Likert scale ranging from “Not at all” to “Extremely.” This section provided insight into how cognitively and emotionally demanding the map interpretation task was, helping to assess whether different cartographic designs required differing levels of cognitive load. Scores across the six TLX dimensions were averaged into a composite workload measure.

3.3.15 Six Americas and Open-ended comments.

The final section of the survey included two parts. First, participants were asked to select one statement from the Six Americas framework that best described their feelings and beliefs about climate change. This measure categorizes the U.S. population into six categories ranging from Alarmed to Dismissive based on climate attitudes (Maibach et al., 2009). Including this question helped contextualize participants’ emotional and perceptual responses within broader climate concern typologies. Following this, participants were given an open-ended comment box to share any thoughts, reactions, or recommendations regarding the study. This allowed space for qualitative feedback that could inform future iterations of the research design or reveal insights not captured through closed-ended questions.

3.4 Procedure

Participants were recruited through the online survey platform Prolific and redirected to the Qualtrics survey. After providing informed consent, they proceeded through the study tasks in the following sequence: demographic questions, the Need for Cognition scale, exposure to one of the

three map designs, and subsequent measures of emotional response, trust, attractiveness, accuracy, awareness, connection to climate change, influence on decision making, and cognitive load. The survey concluded with the Six Americas question and an open-ended comment prompt. Upon completion, participants were automatically redirected back to Prolific, and the entire procedure took approximately 12 minutes.

3.5 Statistical analysis

All statistical analyses were conducted using R (R Core Team, 2024) in RStudio (Posit Team, 2025), utilizing packages such as tidyverse, broom, and patchwork for data visualization and regression diagnostics. The aim of the analysis was to evaluate how different map designs influenced participants' emotional and perceptual responses related to glacier retreat and climate change. One-way ANOVA tests were used to determine whether map design had a statistically significant effect on five key outcome measures: awareness of glacier change, perceived contribution to climate change (CCC), perceived influence (Influence), trust in the map (MAPTRUST), and visual attractiveness. If there were statistically significant differences found in any of the measures this prompted deeper analysis using regression models. Through iterative model comparison and assessment of adjusted R-squared values, the final models retained only those variables that contributed meaningfully to explaining variance in outcomes.

CHAPTER IV

RESULTS

4.1 Overview

This chapter presents the results of the user study, organized into four main sections. First, I summarize the demographic characteristics of participants, including geographic distribution, race, age, education, employment, and income, as well as baseline measures of climate change beliefs and Need for Cognition (NFC). Second, I present findings on participants' emotional responses, both in terms of overall patterns on the Geneva Emotion Wheel (GEW) and hotspot analyses linking emotions with individual difference variables such as Need for Cognition (NFC), trust in the map (MAPTRUST), awareness of glacier change, connection to climate change, perceived influence on climate-related actions, and cognitive workload (Task Load Index, TLX). Third, I report group differences by map design using ANOVA tests, focusing on awareness of glacier change, attractiveness, and other perceptual judgments. Finally, I present regression models that test the predictive roles of map type and participant characteristics on awareness and attractiveness outcomes. Together, these analyses provide a comprehensive picture of how map design and individual differences shaped both cognitive and affective responses to glacier change visualizations.

4.2 Demographics

Participants were geographically distributed across the United States, roughly reflecting major patterns of population density (Figure 7). Because each participant was randomly assigned to view only one of the three map designs, the demographic summaries across conditions are provided to show comparability between groups rather than to suggest map-related differences.

Most participants identified as White (~65.79%, Figure 8), were between 18–39 years of age (~65.45%, Figure 9), and reported a college-level education or higher (80.70%, Figure 10). The sample also represented a variety of employment categories (Figure 11) and income levels (Figure 12).

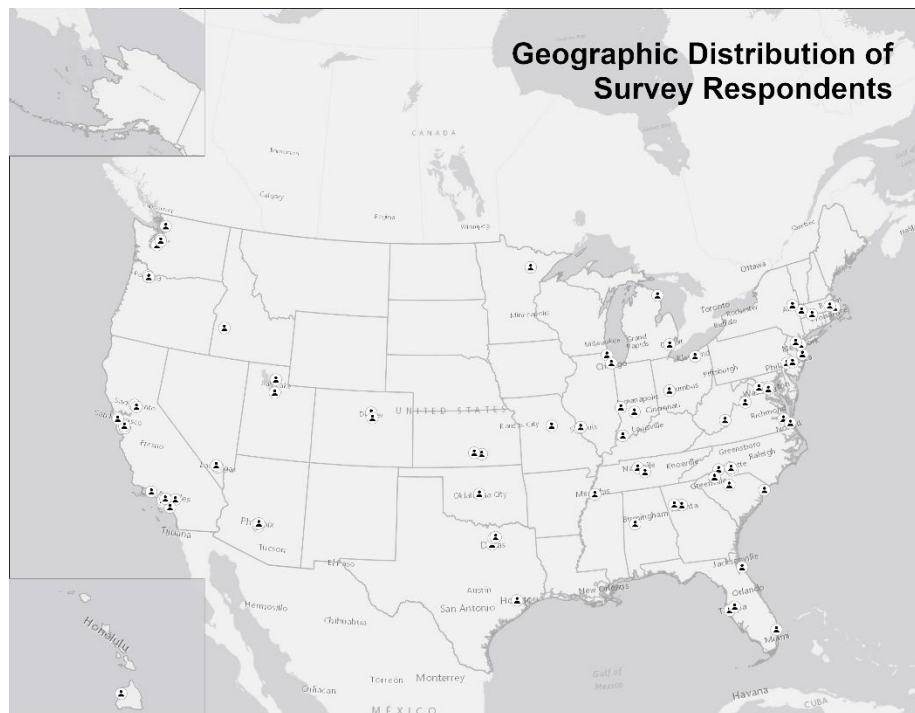


Figure 7. Geographic locations of survey respondents across the United States, mapped by ZIP code.

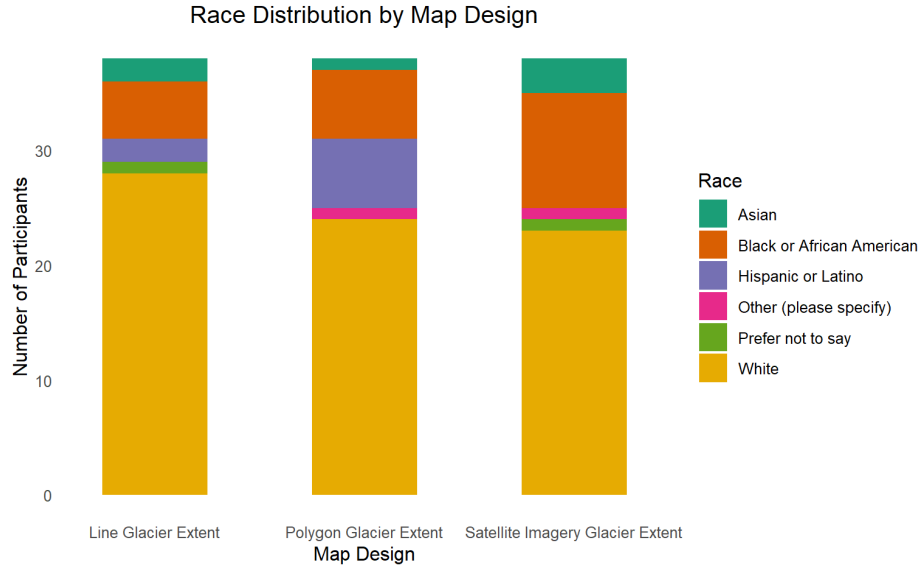


Figure 8. Race distribution of participants by map design condition.

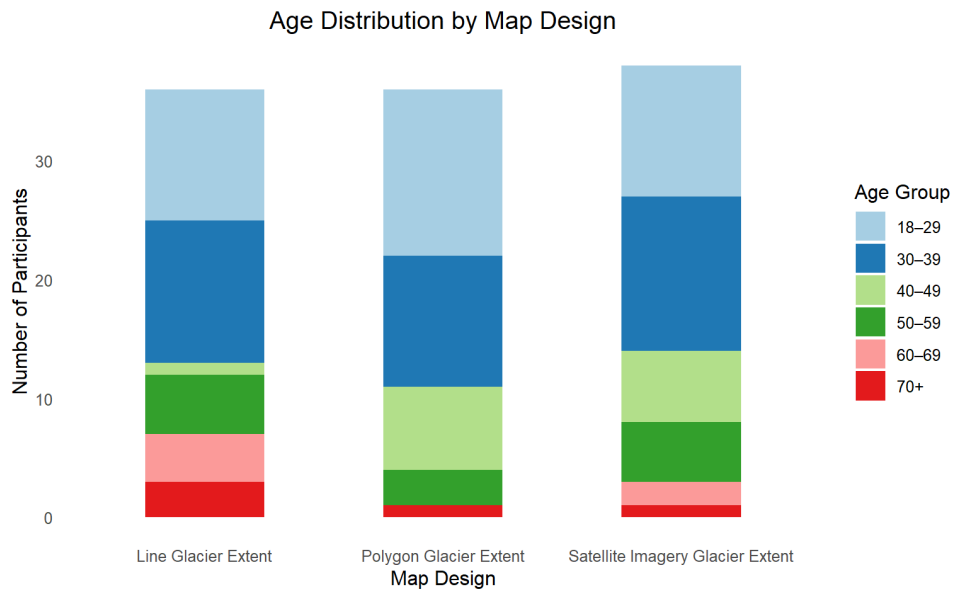


Figure 9. Age distribution of participants by map design condition.

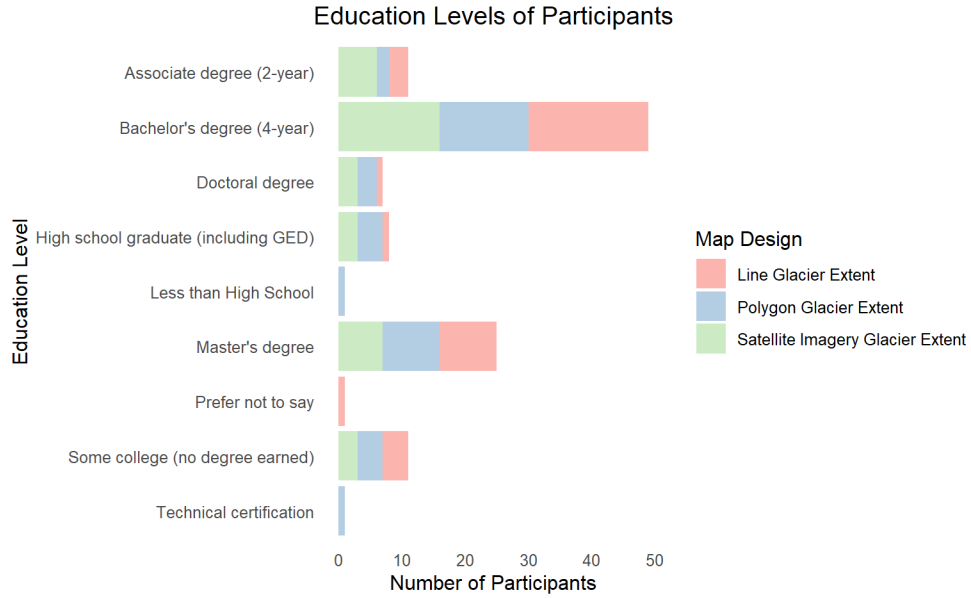


Figure 10. Education levels of participants by map design condition.

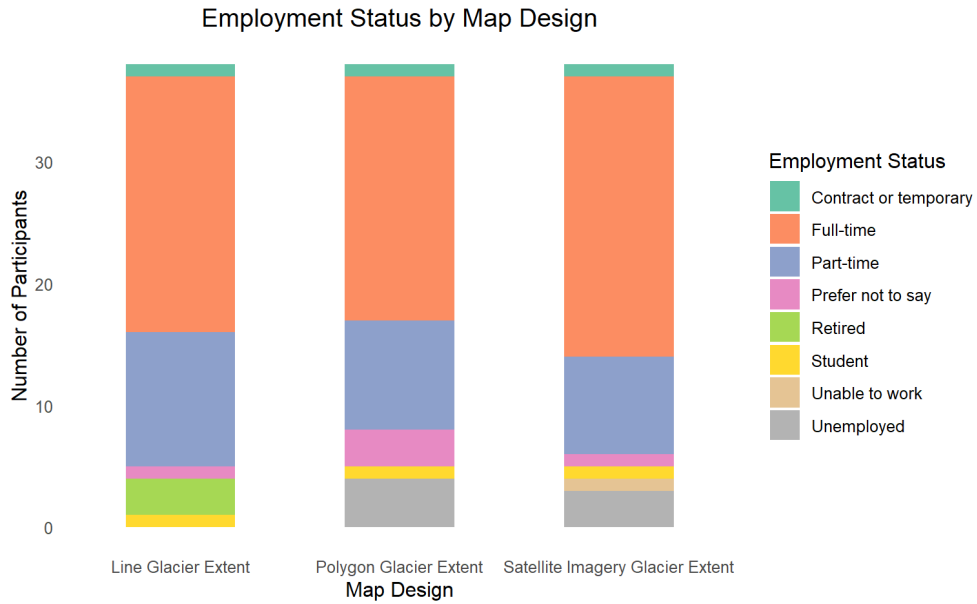


Figure 11. Employment status of participants by map design condition.

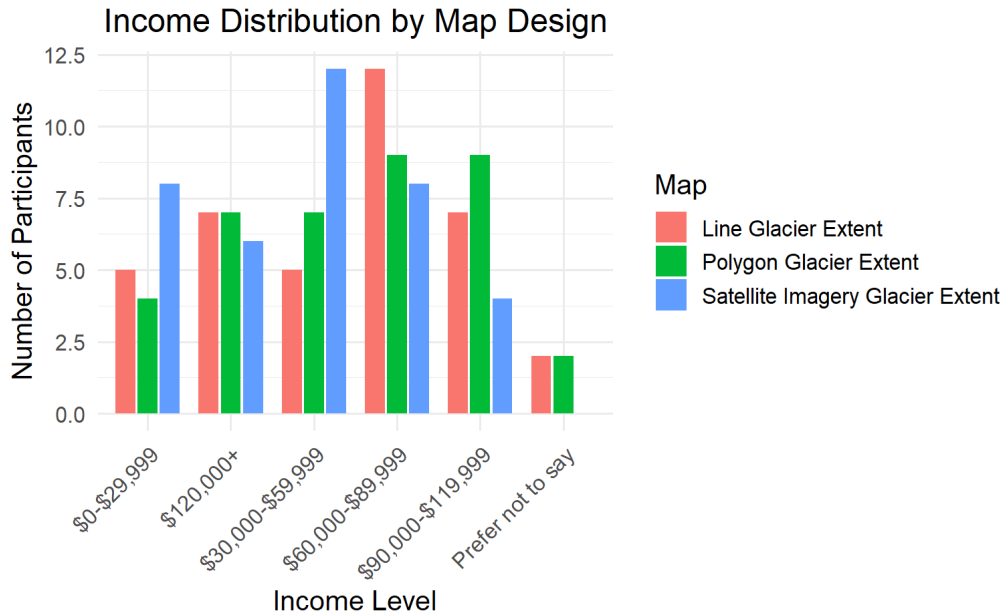


Figure 12. Income distribution of participants by map design condition.

Using the Six Americas framework (Figure 13), the majority of participants were classified as “Alarmed” or “Concerned,” reflecting high levels of concern about climate change. In terms of cognitive disposition, NFC scores were normally distributed across all three map conditions (Figure 14), with no major group differences detected.

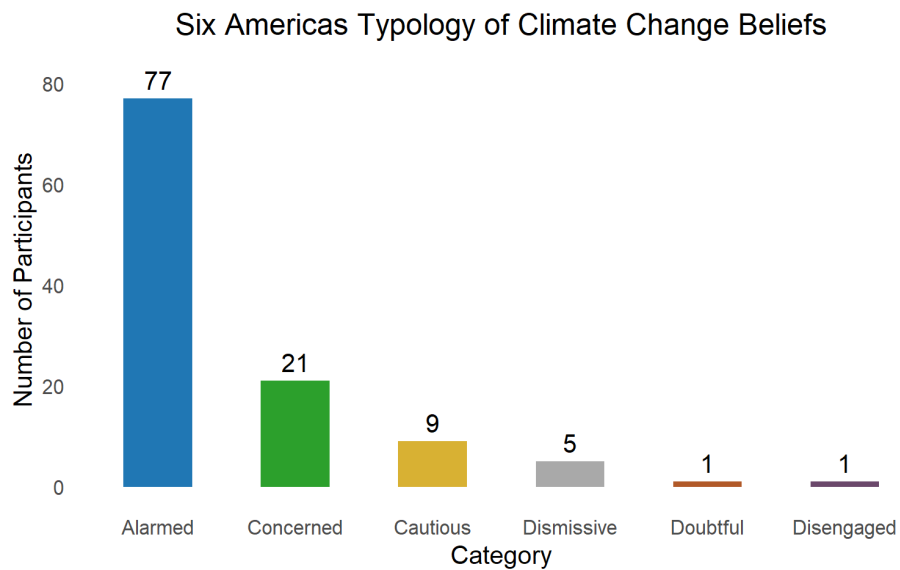


Figure 13. Six Americas typology of participants’ climate change beliefs.

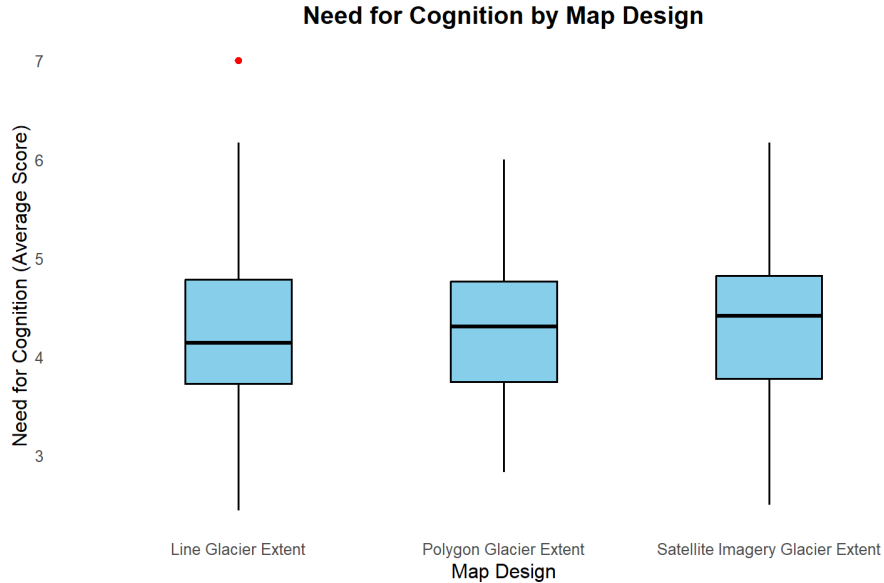


Figure 14. Need for Cognition (NFC) scores of participants by map design condition.

4.3 Emotion Results

To examine participants’ emotional responses to each glacier retreat map design, I mapped the first GEW click per participant in ArcGIS Pro and displayed them as choropleth-style maps (Figure 15). Subsequent clicks were not analyzed as a part of this thesis research. Darker shades represent more frequently selected emotions and intensities, while lighter shades indicate less frequent selections. Clear differences emerged across the three conditions. The Polygon map showed dense clusters around negatively-valenced emotions such as sadness and guilt, suggesting that filled polygons effectively conveyed cumulative loss in ways that resonated with concern and empathy. The Line map produced a more neutral profile, with concentrations near sadness and anger but fewer strong responses overall, indicating that while its structured clarity may have been perceptually appealing, it did not consistently prompt effective engagement. In contrast, the Imagery map generated more dispersed responses, with relatively higher frequencies in positive affective states such as admiration, suggesting that photorealistic imagery may inspire aesthetic appreciation rather than urgent concern, consistent with findings that beauty and realism ratings are

closely linked (Douglass & Fish, 2022; Fish, 2020). Across all three designs, a substantial portion of participants selected “No Emotion” or made no selection, indicating that not all viewers experienced strong affective reactions.

In addition to mapping where participants clicked, I also used the ArcGIS Hot Spot Analysis tool (Hot Spot Analysis (Getis-Ord G_i^* , n.d.)) to identify clusters of particular emotions that coincided with high values of other independent variables; these results are summarized in the following subsections.

Distribution of Participants’ GEW Clicks

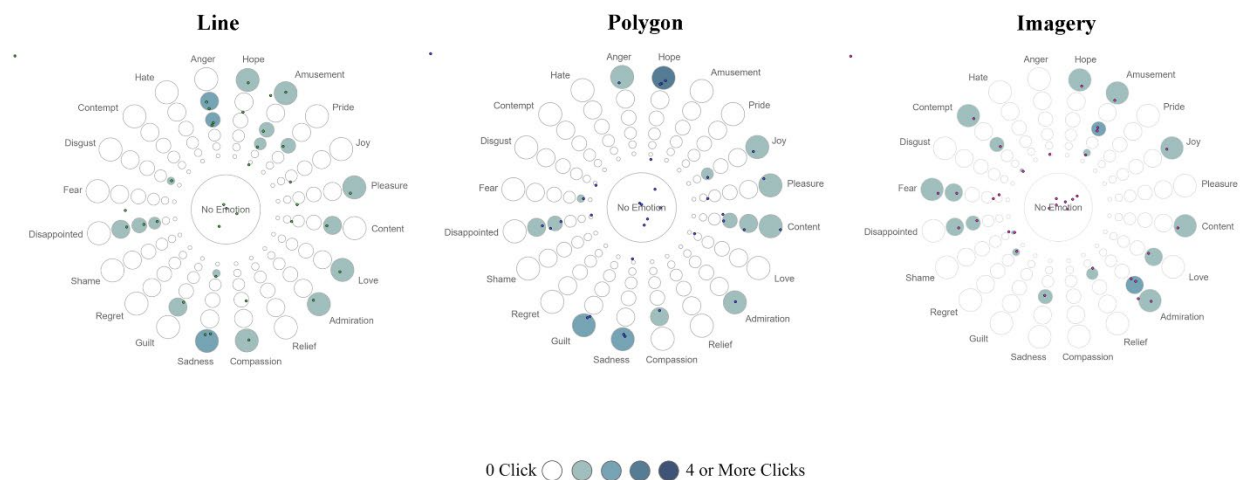


Figure 15. Distribution of participant clicks on the Geneva Emotion Wheel (GEW) across the three map designs (Line, Polygon, Imagery). Darker circles represent emotions selected more frequently, showing overall emotional tendencies by condition.

4.3.1 Emotional Responses by Need for Cognition (NFC)

The GEW hotspot analysis for NFC (Figure 16) shows distinct patterns across the three map designs. For the Line map, one significant hotspot occurred at Compassion and one slight cold spot at Joy. In this case, hot spots are those where there are high values of NFC and cold spots are locations of low values of NFC. No other areas of clustering reached statistical significance. For

the Polygon map, significant hotspots were located on the left side of the GEW, corresponding to negatively-valenced emotions, including Disgust, Fear, Disappointed, and Sadness. Slight cold spots occurred in positively-valenced areas near Content and Joy. For the Imagery map, slight hotspots were present on the left side of the GEW near negatively-valenced emotions, and multiple hotspots occurred in the center of the GEW at No Emotion.

Need for Cognition by Map Designs

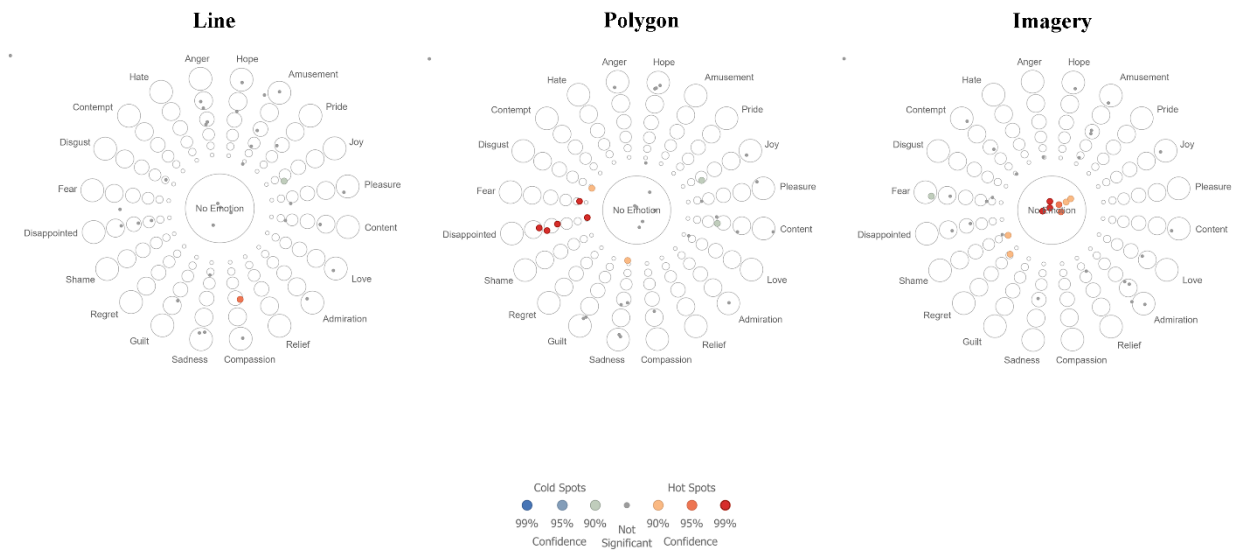


Figure 16. Hotspot analysis of Need for Cognition (NFC) by map design. Cold spots (blue) indicate emotions chosen by participants with lower NFC average score, while hot spots (red/orange) indicate significantly more frequent selections by participants with higher NFC average score.

4.3.2 Emotional Response by MAPTRUST

The GEW hotspot analysis for MAPTRUST (Figure 17) shows that for the Line map, there

were no statistically significant hotspots or cold spots. For the Polygon map, several slight cold spots appeared near the center of the GEW, including the No Emotion area, indicating clustering of low MAPTRUST scores with low emotional intensity. For the Imagery map, significant hotspots were found for Admiration, Relief, and Love, indicating clustering of high MAPTRUST scores with these emotions. Cold spots were located at the center of the GEW in the No Emotion category and at low-intensity Contempt, showing clustering of low MAPTRUST scores with little or no emotion.

MAPTRUST by Map Designs

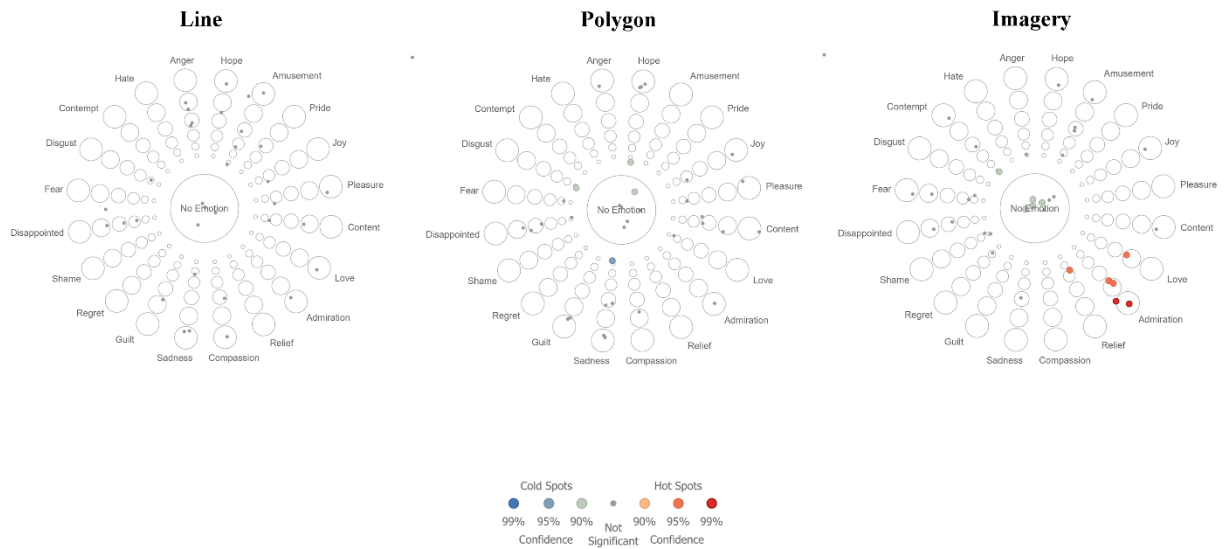


Figure 17. Hotspot analysis of MAPTRUST scores by map design. Cold spots (blue) indicate emotions chosen by participants with lower MAPTRUST average score, while hot spots (red/orange) indicate significantly more frequent selections by participants with higher MAPTRUST average score.

4.3.3 Emotional Responses by Awareness of Glacial Retreat

The GEW hotspot analysis for Awareness of Glacial Retreat (Figure 18) shows that for the Line map, a cold spot was located at No Emotion and a slight hot spot was present at Disappointed. For the Polygon map, cold spots were located at the center of the GEW in the No Emotion area, while hotspots were present at Guilt, Sadness, and Compassion. For the Imagery map, cold spots were again located at No Emotion, also around shame and amusement.

Awareness by Map Designs

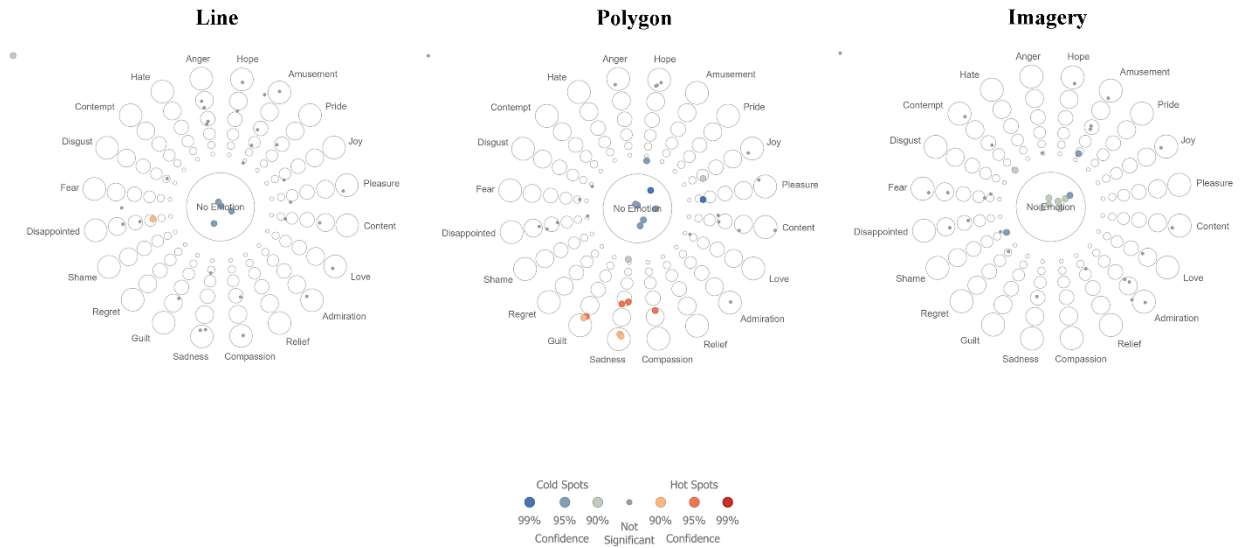


Figure 18. Hotspot analysis of awareness ratings by map design. Cold spots (blue) indicate emotions chosen by participants with lower awareness average score, while hot spots (red/orange) indicate significantly more frequent selections by participants with higher awareness average score.

4.3.4 Emotional Responses by Connection to Climate Change

The GEW hotspot analysis for Connection to Climate Change (Figure 19) shows that for the Line map, two slightly cold spots were present for those who selected Amusement. For the Polygon map, cold spots were generally located at Fear, Disgust, and Pleasure. Hotspots were located at Sadness, Guilt, and Compassion. For the Imagery map, cold spots were found in the No Emotion category and at a few other locations, such as Contempt, with low emotional intensity.

Connection to Climate Change by Map Designs

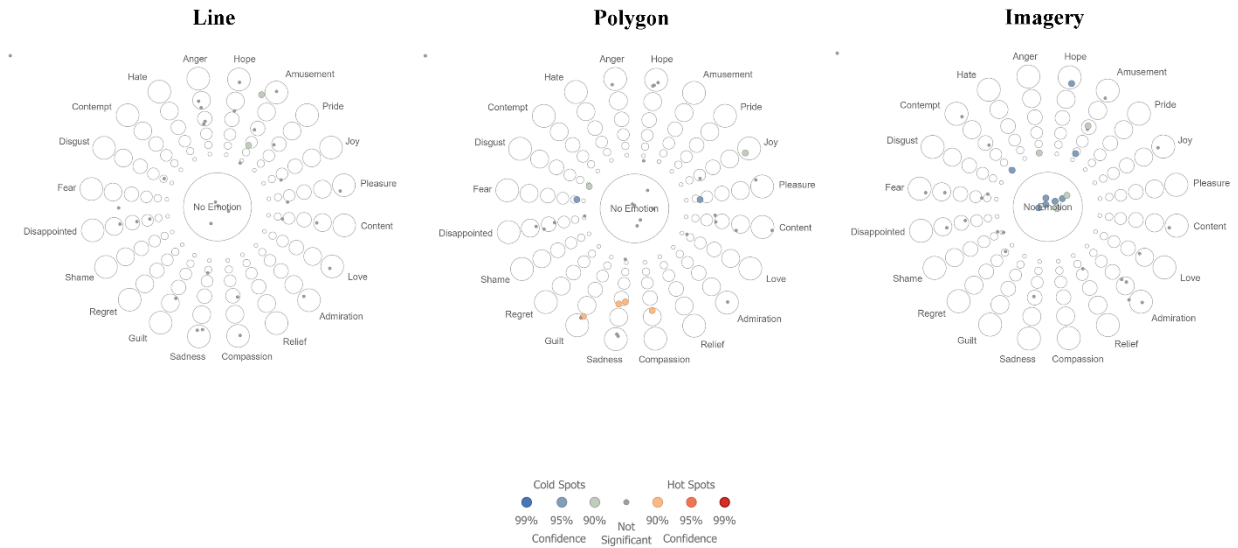


Figure 19. Hotspot analysis of climate change connection (CCC) scores by map design. Results show how stronger or weaker feelings of climate change concern mapped onto emotional responses for each visualization type. Cold spots (blue) indicate emotions chosen by participants with lower CCC average score, while hot spots (red/orange) indicate significantly more frequent selections by participants with higher CCC average score.

4.3.5 Emotional Responses by Perceived Influence on Climate-Related Actions

The GEW hotspot analysis for perceived influence on climate-related actions (Figure 20) shows that for the Line map, hotspots were located at Content and Pleasure. For the Polygon map, cold spots appeared in lower-intensity regions such as Pleasure, Fear, and Sadness. For the Imagery map, hotspots were found at Admiration and Relief, while cold spots clustered around No Emotion, with additional slight cold spots at Contempt, Hope, and Amusement.

Perceived Influence on Climate-Related Actions by Map Designs

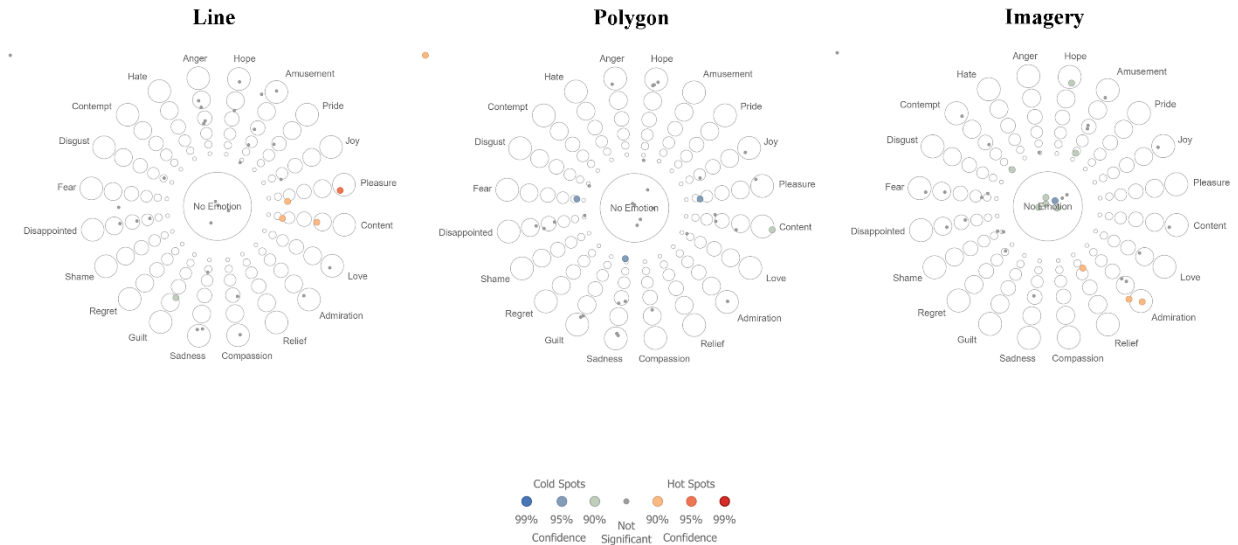


Figure 20. Hotspot analysis of perceived influence on climate-related actions by map design. Emotions clustered differently depending on whether participants felt more or less agency over decisions. Cold spots (blue) indicate emotions chosen by participants with lower average score, while hot spots (red/orange) indicate significantly more frequent selections by participants with higher average score.

4.3.6 Emotional Responses by Task Load Index (TLX)

The GEW hotspot analysis for TLX (Figure 21) shows that for the Line map, a few cold spots were located at Disappointed. Meaning those who found the task to be easy, were more likely to be disappointed. For the Polygon map, hotspots were located at Anger and Hope. These emotions were common for those who felt the task was difficult. For the Imagery map, cold spots were located at Regret and No Emotion.

Task Load Index by Map Designs

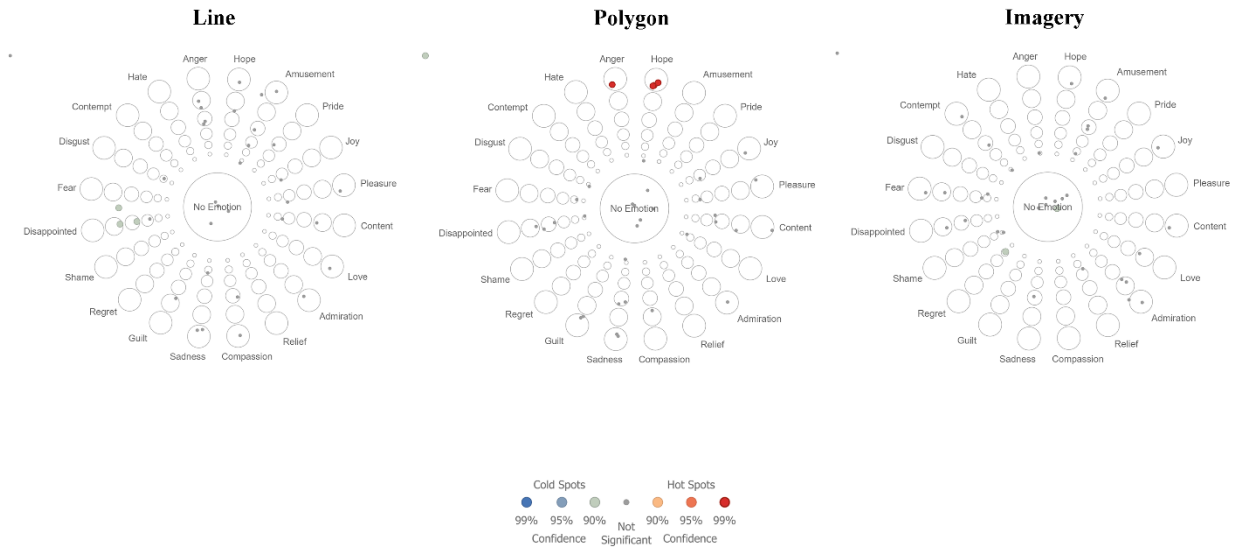


Figure 21. Hotspot analysis of task load index (TLX) by map design. Significant hotspots illustrate where participants who experienced higher cognitive effort reported stronger emotional reactions. Cold spots (blue) indicate emotions chosen by participants with lower TLX average score, while hot spots (red/orange) indicate significantly more frequent selections by participants with higher TLX average score.

4.4 Group Differences by Map Design

ANOVA tests revealed statistically significant effects of map type on two dependent variables:

Perceived awareness of glacier change differed significantly by map condition, $F(2, 111) = 6.14$, $p = .003$, indicating that differences map design explained meaningful variation in average of the participants' awareness scores. Post-hoc comparisons (Tukey HSD) indicated that participants who viewed the Polygon map reported significantly greater awareness than those who viewed the Imagery map ($p < .01$). Awareness scores for the Polygon and Line maps did not differ significantly, nor did scores for the Line and Imagery maps (Figure 23).

Attractiveness of the Map also varied significantly across conditions, $F(2, 111) = 7.11$, $p = .001$, indicating that participants' attractiveness ratings differed by map design. Tukey HSD post-hoc comparisons showed that the Polygon map was rated significantly more attractive than the Imagery map ($p < .01$). The Line map's attractiveness ratings did not differ significantly from either the Polygon or Imagery maps (Figure 22).

No significant group differences were found for trustworthiness, climate change urgency, or perceived influence on climate-related actions, indicating that while design affected awareness and attractiveness ratings, it did not significantly change participants' broader judgments on other measured factors.

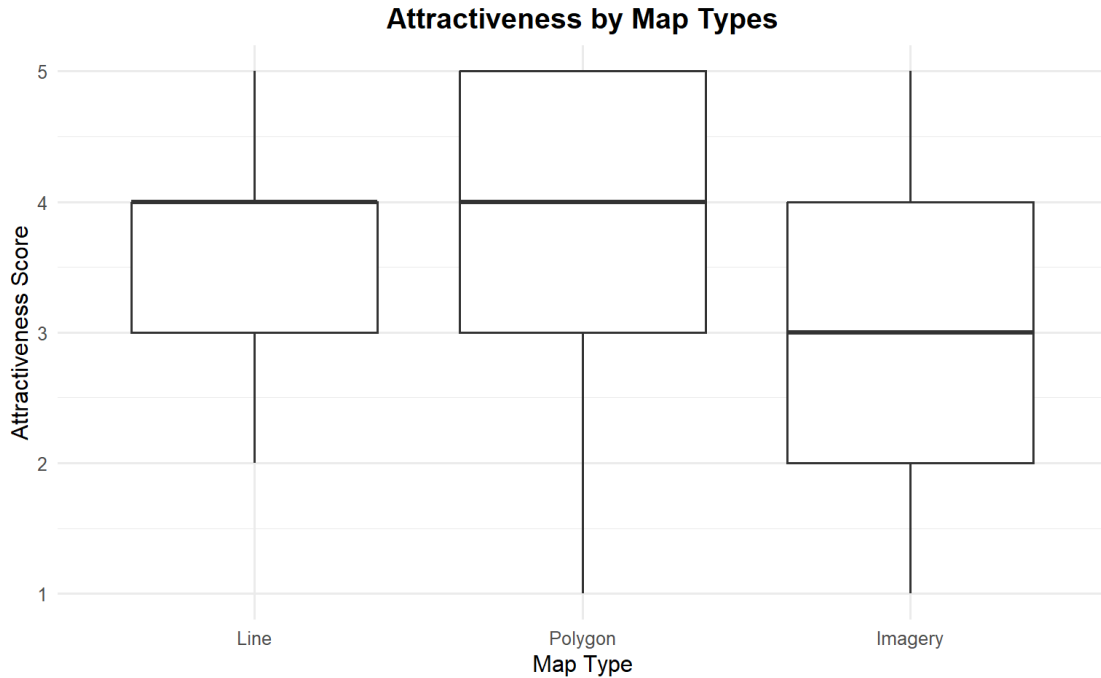


Figure 22. Distribution of attractiveness scores across the three map designs. Boxplots display the range, median, and variability of participant ratings for Line, Polygon, and Imagery maps.

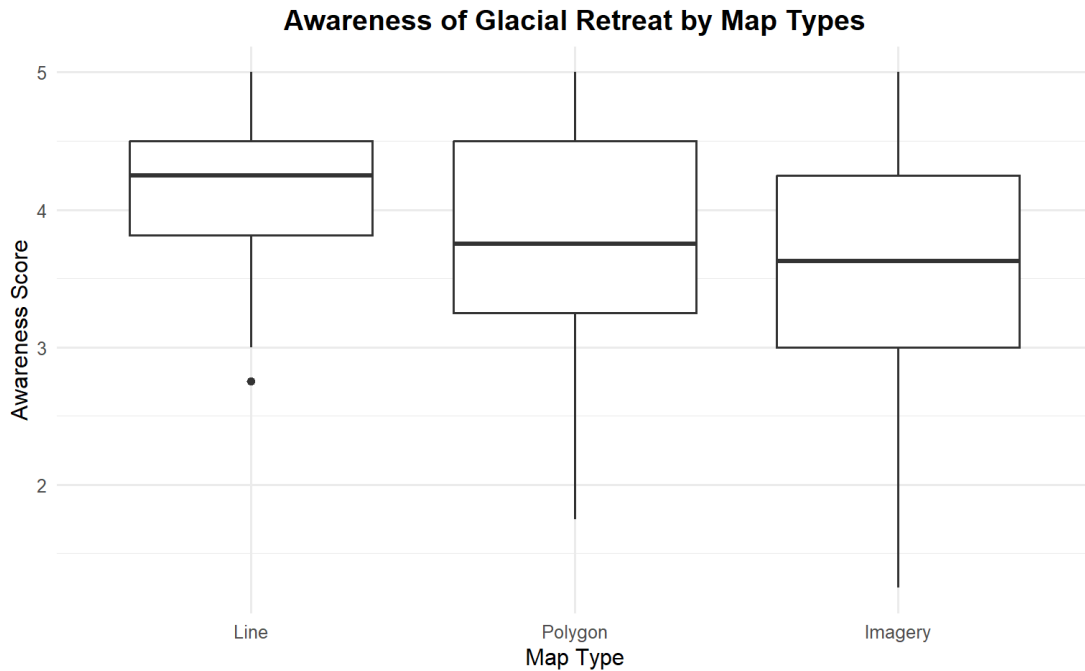


Figure 23. Distribution of awareness scores across the three map designs. Boxplots summarize differences in perceived awareness of glacier change, highlighting higher scores for the Polygon condition relative to Imagery.

4.5 Regression Models

Multiple linear regression analyses were conducted to identify predictors of perceived awareness of glacier volume loss and perceived attractiveness of the maps. The regression models in this study were estimated using ordinary least squares (OLS) through R's base `lm()` function (R Core Team, 2024), which provides a straightforward multiple linear regression framework without stepwise selection or regularization. Model fit was assessed using both R^2 and Adjusted R^2 . While R^2 reflects the proportion of variance explained by the predictors, Adjusted R^2 accounts for model complexity by penalizing the addition of predictors that do not improve explanatory power. In this study, Adjusted R^2 values were consistently lower than raw R^2 , reflecting the relatively modest explanatory power of the models once the number of predictors was considered. This suggests that, although map design and individual differences contributed meaningfully to the outcomes, other unmeasured variables likely play an important role.

4.5.1 Awareness Model (*Adjusted $R^2 \approx 0.22$*)

The awareness model included map type, education level, and NFC as predictors. The model was statistically significant and accounted for approximately 22% of the variance in awareness ratings. Multiple linear regression results predicting perceived awareness of glacier volume loss based on map type, education level, and Need for Cognition. Table 2 presents the regression coefficients, standard errors, t-values, p-values, and 95% confidence intervals. Compared to the Line map, those who saw the Polygon map had significantly lower awareness scores ($\beta = -0.358$, $p = 0.046$), and those who saw the Imagery map had even lower awareness scores ($\beta = -0.659$, $p < .001$). Participants with a technical/associate degree reported significantly higher awareness than those with a high school or some college education ($\beta = 1.967$, $p = 0.016$). NFC was a significant negative predictor, with higher NFC scores associated with lower awareness

ratings ($\beta = -0.282$, $p = 0.001$).

Table 2. Multiple linear regression results predicting perceived awareness of glacier volume loss based on map type, education level, and Need for Cognition.

Term	Beta	SE	t	p	CI_low	CI_high
(Intercept)	4.096	0.858	4.773	< .001	2.394	5.797
MapsPolygon	-0.358	0.177	-2.015	0.046	-0.71	-0.006
MapsImagery	-0.659	0.177	-3.725	< .001	-1.01	-0.308
EducationSimplifiedHS/SomeCollege	1.155	0.785	1.472	0.144	-0.401	2.71
EducationSimplifiedTech/Associate	1.967	0.8	2.459	0.016	0.381	3.552
EducationSimplifiedBachelor+	1.299	0.772	1.684	0.095	-0.231	2.829
EducationSimplifiedOther	1.657	1.092	1.517	0.132	-0.508	3.823
NeedForCogAvg	-0.282	0.083	-3.41	0.001	-0.446	-0.118

4.5.2 Attractiveness Model (Adjusted $R^2 \approx 0.21$)

The attractiveness model included map type, NFC, and TLX (cognitive workload) as predictors. The model accounted for approximately 21% of the variance in attractiveness ratings. Table 3 shows the regression coefficients. The Imagery map received significantly lower attractiveness ratings than the line-based map ($\beta = -0.819$, $p < .001$). TLX was a significant positive predictor ($\beta = 0.370$, $p = 0.001$), indicating that higher reported cognitive workload was associated with higher attractiveness ratings. NFC was also a significant negative predictor ($\beta = -0.251$, $p = 0.016$).

Table 3. Multiple linear regression results predicting perceived attractiveness of glacier maps based on map type, TLX, and Need for Cognition.

Term	Beta	SE	t	p	CI_low	CI_high
(Intercept)	4.004	0.516	7.76	< .001	2.981	5.026
MapsPolygon	-0.083	0.219	-0.377	0.707	-0.517	0.352
MapsImagery	-0.819	0.22	-3.728	< .001	-1.255	-0.384
NeedForCogAvg	-0.251	0.103	-2.44	0.016	-0.455	-0.047
TLX	0.37	0.104	3.566	0.001	0.164	0.576

CHAPTER V

DISCUSSION

This study examined how different map designs shaped participants' perceptions and reported emotional responses to glacier retreat using maps of South Cascade Glacier. The results indicate that cartographic design can meaningfully influence how viewers interpret and engage with environmental change information. Specifically, map design was shown to matter for perception of glacial change, perception of attractiveness of the map, and emotional responses. These findings can help guide cartographers and glaciologists as they map glacial change.

5.1 Perceptual Impacts of Glacier Retreat Map Design

Perception operates at a foundational level of human information processing, shaping how viewers initially attend to and evaluate visual stimuli before engaging in deeper cognitive interpretation (Fabrikant & Lobben, 2009). In this study, perceptual responses were measured primarily through participants' evaluations of map attractiveness. Results indicated that attractiveness ratings varied by map design. The Polygon map was rated as more visually attractive than the Imagery map, while the Line map received intermediate evaluations that did not differ significantly from either. Thus, the key difference was between the Polygon and Imagery maps, suggesting that symbolized clarity was perceived more positively than photorealistic imagery.

Regression analysis showed that attractiveness ratings were shaped not only by map design but also by individual differences in NFC and perceived workload. Participants who reported higher TLX tended to rate maps as more attractive, while those with higher Need for Cognition gave lower attractiveness ratings. In other words, individuals who enjoy engaging in complex thinking were more critical of the maps' visual appeal, whereas participants who experienced the

maps as cognitively demanding tended to value them more. One interpretation is that participants who found the task challenging appreciated the clear structure of the maps, whereas those who engaged more deeply were more critical. However, unmeasured factors also shaped these perceptions but was beyond the scope of this research. Together, these results show that attractiveness is influenced by both design and the viewer's own characteristics.

It is important to distinguish perceived attractiveness from comprehension or emotional impact. For example, while the attractive Polygon map correlated with higher awareness, the equally appealing Line map did not. This shows that visual appeal alone does not guarantee a better understanding of the data. Furthermore, the lower attractiveness of the Imagery map reveals that photorealism is not always valued, contrary to common assumptions.

In summary, these findings indicate that while design choices shape initial evaluations of maps, attractiveness functions in concert with other variables to form perception. Therefore, instead of presuming the universal effectiveness of either realistic or simplified designs, these findings highlight the necessity of evaluating how specific design strategies can either facilitate or hinder the communication of scientific content.

5.2 Cognitive Impacts of Glacial Retreat Map Design (Awareness)

In the awareness measure, participants who viewed the Polygon map rated their awareness of glacial change higher than those who viewed the Line or Imagery maps, and participants in the Polygon condition reported greater awareness than those in the Imagery condition. This suggests that the filled polygon design may have helped participants recognize spatial change of the glacier's extent, potentially by emphasizing cumulative change over time. This interpretation is consistent with prior work showing that simplified, thematic representations can aid comprehension of complex geospatial processes (Fish, 2020; Kostelnick et al., 2013). In this study,

I designed the polygons to be semi-transparent, allowing earlier extents to remain visible beneath later outlines, which may have helped convey temporal progression without overwhelming the viewer.

The participants who saw the Imagery map, despite its photo realism, consistently had the lowest awareness scores compared to the other designs. Although photorealistic imagery can be engaging, it may also introduce interpretive challenges, such as difficulty distinguishing change boundaries, particularly for audiences without technical mapping experience. This interpretation is consistent with the open-ended responses, which often described the imagery as visually powerful, urgent, and even disturbing, yet did not necessarily highlight clearer understanding of temporal change. Several participants praised the imagery for raising concern about climate change, but few explicitly referenced spatial clarity or comprehension, suggesting that realism alone does not guarantee effective communication of cumulative glacier retreat. These observations came specifically from participants' responses to the final open-ended survey question, which invited them to share any additional thoughts about the maps.

Regression results provided further insight into individual differences. Education level and NFC both influenced awareness ratings: higher education was positively associated with awareness, while higher NFC was negatively associated. In other words, more educated participants tended to recognize glacier change more readily, while those predisposed to deep analytical thinking actually rated awareness lower, particularly for the Polygon map. This pattern suggests that more direct, less analytically demanding visuals may be especially effective for audiences less inclined toward detailed cognitive processing. The regression model explained about 22% of the variance in awareness scores, indicating that while map design played a meaningful role, other unmeasured factors also contributed to how participants perceived glacier

change. This underscores that cartographic choices matter but are not the sole drivers of comprehension in climate change communication.

5.3 Emotional Impact of Map Design

Emotions affect people's processing of and responses to information about environmental change, and the GEW data provides a window into how different map designs shaped these affective responses. In this section, I first discuss the overall emotional distributions across map types as visualized through choropleth-style maps, which highlight broad tendencies in participant selections. I then summarize the hotspot analyses, which illustrate how participant characteristics such as cognitive style, trust, and perceived task difficulty were associated with clusters of particular emotions. Together, these analyses provide insight into how visual design and individual differences combined to shape participants' emotional engagement with glacier retreat.

5.3.1 Choropleth Patterns of Emotional Responses

The emotional analysis using the GEW offers insight into how visual design influences affective responses to glacier retreat. By visualizing the distribution of participant-selected emotions for each map condition in a choropleth-style format (Figure 15), patterns of emotional resonance can be directly compared without relying on spatial clustering statistics that may obscure overall tendencies.

The Polygon map showed the strongest clustering around negatively-valenced emotions, such as guilt, sadness, and compassion. These responses suggest that participants who viewed the polygon design were more likely to associate it with a heightened sense of environmental loss. This interpretation is supported by the survey results, where participants in the Polygon condition reported higher awareness scores than those who viewed the Imagery condition. The clear, cumulative representation of glacier retreat in the polygon design appears to have helped

participants both recognize spatial change and experience stronger affective reactions to it.

The Line map generates a more spread out distribution of emotional responses compared to the Polygon map. Participants selected a mix of emotions, including sadness, anger, and disappointed, without a strong concentration on any single reaction. This pattern suggests that while the line design was clear and visually simple, it tended to show weaker or less consistent emotional engagement, as viewers responded in various ways rather than converging on a shared affective response.

The Imagery map showed a more dispersed set of responses, with some clustering in positive emotions such as admiration and relief, along with a substantial share of “No Emotion” responses. Rather than reflecting perceived attractive, the Imagery map received the lowest attractiveness scores across map designs, these responses may reflect how photorealistic detail prompted recognition of visual realism without evoking strong affective engagement. The high number of “No Emotion” responses align with the finding that participants viewing the Imagery map reported lower awareness of glacier change than those who saw the Polygon map, even though the difference between the Imagery and Line maps was not significant. In other words, realism did not reliably translate into either stronger emotional engagement or clearer recognition of glacier change.

5.3.2 Hot Spot Patterns Across Participant Characteristics

While the choropleth maps reveal general tendencies by design type, the hotspot analyses (Figures 17–22) provide a deeper look at how individual differences shaped emotional responses. These analyses identify where participant characteristics, such as NFC, MAPTRUST scores, awareness ratings, influence ratings, and task load, coincided with clusters of particular emotions.

Across the Polygon map, participants with higher NFC were more likely to select negative

emotions such as sadness and guilt, while those with lower NFC showed fewer strong affective responses. This suggests that participants inclined toward deeper cognitive processing also reported stronger concern when engaging with the polygon design. The Polygon map also produced hotspots of anger and hope when task load (TLX) was high, indicating that participants who found the maps more demanding also experienced stronger emotional reactions.

In contrast, the Line map showed weaker or less consistent patterns across participant variables. For instance, participants who rated the task load of the user study as high were somewhat more likely to select disappointment, but overall I could not identify strong clusters to make any definitive conclusions. This reinforces the interpretation that line designs had less consistent emotional responses, regardless of user characteristics.

The Imagery map revealed a different pattern. Participants in this condition picked “NO Emotion” more than the participants in the other two conditions. It was clear that those with higher NFC often clustered around “No Emotion,” suggesting that more analytical viewers may have disengaged from the photorealistic design rather than connecting it to environmental concern. At the same time, hotspots in admiration and relief were observed among participants who reported greater influence over climate-related actions, suggesting that the imagery design was occasionally associated with more positive emotions in that context.

In summary, these results demonstrate that emotional engagement with glacier retreat was not uniform but depended on both the map design and individual user characteristics. The Polygon map tended to draw out stronger negative emotions tied to concern, particularly for participants predisposed to deeper thinking. The Line map showed weaker and less consistent responses, reinforcing their more neutral profile. Imagery map, by contrast, produced higher rates of “No Emotion” selections, indicating disengagement for many viewers, though some participants who

reported greater influence over climate-related actions associated the imagery with positive feelings such as admiration and relief. To summarize, the maps worked differently for different people: polygons prompted concern, lines remained comparatively neutral, and imagery often led to disengagement, with only occasional positive reactions.

5.4 Limitations

Several limitations must be acknowledged when interpreting these results. First, there are nearly infinite ways to design a map of glacier change beyond the three types tested in this study. Within each “type” (Line, Polygon, Imagery), design choices such as color, line width, annotation, or background symbology could have been varied in many ways. The maps used here were intentionally created to represent a clear and relatively attractive version of each type, with the goal of providing a fair comparison across categories. This approach allowed the study to isolate differences between major design strategies rather than evaluate every possible variation. However, these choices also introduce trade-offs. For example, the Polygon map was rated as the most attractive and supported higher awareness, yet its filled extents necessarily obscured the underlying imagery, reducing opportunities to perceive fine-grained texture or surface detail. Similar findings have been reported in terrain visualization, where simplification can enhance clarity but reduce visual richness (Douglass & Fish, 2022). Future studies could test alternative symbolization strategies, such as varying transparency, line thickness, or color ramps, to examine how more subtle design decisions influence perception.

Second, the study was conducted using a relatively small, U.S.-based online sample, primarily composed of participants who identified as White and who reported moderate to high levels of climate concern. This demographic composition limits the generalizability of the findings to broader or global populations. Third, the online survey context lacks the immersive qualities of

other communication settings, such as museum exhibits, classrooms, or public installations, where environmental visuals might be interpreted differently. The ecological validity of the findings is therefore bounded by the online, screen-based format of this study.

Design-related constraints also shaped the results. For example, the Imagery map may not have been fully optimized for communicating glacier change. Without explicit annotations, side by side year comparisons, or visual scaffolding to guide interpretation, participants may have found it more difficult to detect temporal patterns and cumulative retreat. Similarly, while the Polygon map effectively conveyed change based on the results, it might have benefited from explanatory cues or labeling to provide additional context for non-expert audiences, although such additions could introduce confounding variables. Additionally, the exclusive use of 2D planimetric designs imposes inherent limits when representing glacier dynamics. Glacier volume loss is a three-dimensional phenomenon, and flattening this into 2D reduces opportunities for viewers to intuitively perceive thickness and mass changes, a limitation observed in other studies of cryospheric visualization (Bishop et al., 2013). Finally, responses were collected at a single point in time; extended or repeated exposure to similar maps might produce different cognitive and emotional effects. Longitudinal research could help clarify how repeated engagement with climate change visualizations shapes perception, comprehension, and emotional connection over time.

5.5 Future Directions

Given these limitations, future research should explore more immersive and multidimensional mapping techniques, such as 3D visualizations, to better capture the volumetric aspects of glacier change. Since 2D maps may flatten complex environmental phenomena, 3D designs could offer greater spatial intuitiveness and emotional engagement by portraying elevation loss and topographic context more clearly. Additionally, testing these visualizations in diverse

educational and public outreach settings will help assess how context influences interpretation. Expanding the participant pool to include more global and demographically varied audiences is essential for improving generalizability and equity in climate communication research.

CHAPTER VI

CONCLUSIONS

This thesis examined how variations in map design influence public perceptions and emotional responses to glacier retreat, using South Cascade Glacier as a case study. In a user study, I compared three cartographic styles, Line, Polygon, and Imagery, to investigate how design choices shape both cognitive interpretation and affective responses to climate-related geospatial data. The findings demonstrate that map design affects perceptions of attractiveness, awareness of glacial retreat, and emotional engagement, though the explanatory power of the models was modest. Together, the regression analyses accounted for approximately 22% of the variance in awareness ratings and 21% of the variance in attractiveness ratings, suggesting that design effects are meaningful but also interact with individual differences.

Regarding the first research question, how perceptions of glacier retreat differ by map design, the results showed that participants who viewed the Polygon map reported higher awareness of glacier loss than those who viewed either the Line or Imagery map. The filled polygons emphasized cumulative change over time, likely making the progression of retreat more apparent. This finding is notable because the Polygon map was also rated as more attractive than the Imagery map, suggesting that clarity and visual appeal may work together to support comprehension. However, attractiveness alone did not guarantee higher awareness: the Line map was perceived as visually clear and appealing by some participants, but it did not consistently enhance awareness of glacier change. Similarly, while the Imagery condition offered photorealistic detail, participants rated it lower in awareness, indicating that realism without scaffolding does not ensure recognition of temporal change.

The second research question focused on emotional responses by map design, assessed through the Geneva Emotion Wheel. Choropleth-style maps of participant clicks revealed broad tendencies across designs: the Polygon map elicited more negatively-valenced emotions such as sadness, guilt, and compassion; the Line map produced more neutral emotional profiles; and Imagery map prompted a mix of positive responses such as admiration alongside high rates of “No Emotion.” Hotspot analyses added nuance by showing how these emotional patterns interacted with participant characteristics. For example, participants with higher Need for Cognition who viewed the Polygon map were more likely to cluster around negative emotions, while those with higher NFC in the Imagery condition often clustered around “No Emotion,” suggesting disengagement. Task load also influenced responses: participants who found the Polygon map more demanding reported hotspots of anger and hope, whereas those viewing the Line map and finding it easier were more likely to report disappointment. These results highlight that while design shaped general emotional tendencies, individual differences moderated how participants responded.

Overall, the findings underscore that maps are not only a visualization of some places; they are communicative tools whose design influences what audiences notice, how they interpret environmental change, and how they feel about it. The Polygon map may provide an advantage in conveying cumulative glacial loss and eliciting concern, while the Line map offers clarity without strong affective engagement. Imagery designs can be visually appealing but may require supplementary cues to enhance both comprehension and emotional resonance.

Looking ahead, future research should investigate multidimensional and immersive approaches, such as 3D visualizations, to better represent volumetric glacier loss and deepen emotional connection. Expanding this work to other climate-related phenomena, like sea level rise

or wildfire risk, and testing in diverse educational and cultural contexts will improve generalizability and impact. Building on this foundation, my future Ph.D. research will explore how 3D planimetric maps affect public trust, comprehension, and emotional engagement, advancing climate visualization strategies that are both scientifically rigorous and accessible to broad audiences.

REFERENCES

- Bishop, I. D., Pettit, C., Sheth, F., & Sharma, S. C. (2013). Evaluation of data visualisation options for Land-USE policy and decision making in response to climate change. *Environment and Planning B: Planning and Design*, 40(2), 213–233.
<https://doi.org/10.1068/b38159>
- Cacioppo, J. T., & Petty, R. E. (1982). The need for cognition. *Journal of Personality and Social Psychology*, 42(1), 116–131. <https://doi.org/10.1037/0022-3514.42.1.116>
- Cacioppo, J. T., Petty, R. E., & Kao, C. F. (1984). The efficient assessment of need for cognition. *Journal of Personality Assessment*, 48(3), 306–307. https://doi.org/10.1207/s15327752jpa4803_13
- Chapman, D. A., Lickel, B., & Markowitz, E. M. (2017). Reassessing emotion in climate change communication. *Nature Climate Change*, 7(12), 850–852. <https://doi.org/10.1038/s41558-017-0021-9>
- Christophe, S. (2020). Geovisualization: Multidimensional Exploration of the Territory. *In Proceedings of the 15th International Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications (VISIGRAPP 2020) - IVAPP*, 325–332.
<https://doi.org/10.5220/0009355703250332>
- Douglass, N. a. K., & Fish, C. S. (2022). That’s a relief: assessing beauty, realism, and landform clarity in multilayer terrain maps. *Cartographic Perspectives*. <https://doi.org/10.14714/cp100.1727>
- Fabrikant, S. I., & Lobben, A. (2009). Introduction: Cognitive Issues in Geographic Information Visualization. *Cartographica: The International Journal for Geographic Information and Geovisualization*, 44(3), 139–143. <https://doi.org/10.3138/carto.44.3.139>

- Fish, C. (2020a). Cartographic content analysis of compelling climate change communication. *Cartography and Geographic Information Science*, 47(6), 492–507.
<https://doi.org/10.1080/15230406.2020.1774421>
- Fish, C. (2020b). Storytelling for making cartographic design decisions for climate change communication in the United States. *Cartographica the International Journal for Geographic Information and Geovisualization*, 55(2), 69–84. <https://doi.org/10.3138/cart-2019-0019>
- Fountain, A. G., Hoffman, M. J., Granshaw, F. D., & Riedel, J. (2009). The ‘benchmark glacier’ concept – does it work? Lessons from the North Cascade Range, USA. *Annals of Glaciology*, 50(50), 163–168. <https://doi.org/10.3189/172756409787769690>
- Garrison, M., Reis, S., Zhang, S., & Fish, C. (in press). Narrative Transportation and Emotional Responses to Storytelling Maps. *CaGIS*. <https://doi.org/10.1080/15230406.2025.2526847>
- Glaas, E., Ballantyne, A. G., Neset, T., & Linnér, B. (2017). Visualization for supporting individual climate change adaptation planning: Assessment of a web-based tool. *Landscape and Urban Planning*, 158, 1–11.
<https://doi.org/10.1016/j.landurbplan.2016.09.018>
- Goudine, A., Newell, R., & Bone, C. (2020). Seeing Climate Change: A framework for understanding Visualizations for Climate adaptation. *ISPRS International Journal of Geo-information*, 9(11), 644. <https://doi.org/10.3390/ijgi9110644>
- Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In *Advances in psychology* (pp. 139–183). [https://doi.org/10.1016/s0166-4115\(08\)62386-9](https://doi.org/10.1016/s0166-4115(08)62386-9)

- Hot Spot Analysis (Getis-Ord Gi*)*. (n.d.). Esri. Retrieved August 9, 2025, from <https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-statistics/hot-spot-analysis.htm>
- Huss, M., & Hock, R. (2018). Global-scale hydrological response to future glacier mass loss. *Nature Climate Change*, 8(2), 135–140. <https://doi.org/10.1038/s41558-017-0049-x>
- IPCC. (2021). *Climate Change 2021: The Physical Science Basis*. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. <https://www.ipcc.ch/report/ar6/wg1/>
- Jin, H., & Guo, D. (2009). Understanding Climate Change Patterns with Multivariate Geovisualization. *2009 IEEE International Conference on Data Mining Workshops*, 217–222. <https://doi.org/10.1109/icdmw.2009.91>
- Josberger, E. G., Bidlake, W. R., March, R. S., & Kennedy, B. W. (2007). Glacier mass-balance fluctuations in the Pacific Northwest and Alaska, USA. *Annals of Glaciology*, 46, 291–296. <https://doi.org/10.3189/172756407782871314>
- Kiss, E., Zichar, M., Fazekas, I., Karancsi, G., & Balla, D. (2020). Categorization and geovisualization of climate change strategies using an open-access WebGIS tool. *Híradástechnika*, 12(1), 32–37. <https://doi.org/10.36244/icj.2020.1.5>
- Knuth, F. (2022, April 17). *Digital Glacier Time Machine*. UW TACO Lab. <https://uw-cryo.github.io/project/hsfm/>
- Kostelnick, J. C., McDermott, D., Rowley, R. J., & Bunnyfield, N. (2013). A cartographic framework for visualizing risk. *Cartographica: The International Journal for Geographic Information and Geovisualization*, 48(3), 200–224. <https://doi.org/10.3138/carto.48.3.1531>

- Lieske, D. J., Wade, T., & Roness, L. A. (2014). Climate change awareness and strategies for communicating the risk of coastal flooding: A Canadian Maritime case example. *Estuarine, Coastal and Shelf Science*, *140*, 83–94.
<https://doi.org/10.1016/j.ecss.2013.04.017>
- Lieske, D. J. (2012). Towards a framework for designing spatial and Non-Spatial visualizations for communicating climate change risks. *Geoinformatica*, *66*(1), 27–36.
<https://doi.org/10.5623/cig2012-006>
- Lumley, S., Sieber, R., & Roth, R. E. (2022). A framework and comparative analysis of web-based climate change visualization tools. *Computers & Graphics*, *103*, 19–30.
<https://doi.org/10.1016/j.cag.2021.12.007>
- MacEachren, A. M., & Kraak, M. (2001). Research challenges in geovisualization. *Cartography and Geographic Information Science*, *28*(1), 3–12.
<https://doi.org/10.1559/152304001782173970>
- Maibach, E., Roser-Renouf, C., & Leiserowitz, A. (2009). *Global warming's six Americas 2009: An audience segmentation analysis*. Yale University and George Mason University. Yale Program on Climate Change Communication.
<https://climatecommunication.yale.edu/publications/global-warmings-six-americas-2009/>
- Montello, D. R. (2002). Cognitive Map-Design Research in the Twentieth Century: Theoretical and Empirical Approaches. *Cartography and Geographic Information Science*, *29*(3), 283–304. <https://doi.org/10.1559/152304002782008503>
- Nerlich, B., Koteyko, N., & Brown, B. (2009). Theory and language of climate change communication. *Wiley Interdisciplinary Reviews Climate Change*, *1*(1), 97–110. <https://doi.org/10.1002/wcc.2>

- Neset, T., Glaas, E., Ballantyne, A. G., Linnér, B., Opach, T., Navarra, C., Johansson, J., Bohman, A., Rød, J. K., & Goodsite, M. E. (2016). Climate change effects at your doorstep: Geographic visualization to support Nordic homeowners in adapting to climate change. *Applied Geography*, 74, 65–72. <https://doi.org/10.1016/j.apgeog.2016.07.003>
- Neset, T., Opach, T., Lion, P., Lilja, A., & Johansson, J. (2015). Map-Based web tools supporting climate change adaptation. *The Professional Geographer*, 68(1), 103–114. <https://doi.org/10.1080/00330124.2015.1033670>
- Posit team (2025). RStudio: Integrated Development Environment for R. Posit Software, PBC, Boston, MA. <http://www.posit.co/>
- Post, A., Richardson, D., Tangborn, W. V., & Rosselot, F. (1971). Inventory of glaciers in the North Cascades, Washington. *USGS Professional Paper*. <https://doi.org/10.3133/pp705a>
- Prestby, T. J. (2024). Measuring trust in maps: development and evaluation of the MAPTRUST scale. *International Journal of Geographical Information Science*, 38(10), 2083–2107. <https://doi.org/10.1080/13658816.2024.2370076>
- Prolific. (2025). Prolific (Version 05/2025) [Online research platform]. London, UK. <https://www.prolific.com>
- R Core Team. (2024). *R: A language and environment for statistical computing* (Version 4.4.2) [Computer software]. R Foundation for Statistical Computing. <https://www.R-project.org/>
- Richards, D. P. (2015). Testing the waters. *Communication Design Quarterly Review*, 3(3), 20–24. <https://doi.org/10.1145/2792989.2792992>

- Roe, G. H., & Baker, M. (2014). Glacier response to climate perturbations: an accurate linear geometric model. *Journal of Glaciology*, 60(222), 670–684.
<https://doi.org/10.3189/2014jog14j016>
- Sadowski, C. J., & Gulgoz, S. (1992). Internal consistency and Test-Retest reliability of the need for cognition scale. *Perceptual and Motor Skills*, 74(2), 610.
<https://doi.org/10.2466/pms.1992.74.2.610>
- Scherer, K. R. (2005). What are emotions? And how can they be measured? *Social Science Information*, 44(4), 695–729. <https://doi.org/10.1177/0539018405058216>
- Scherer, K. R., Shuman, V., Fontaine, J. R. J., & Soriano, C. (2013). The GRID meets the Wheel: Assessing emotional feeling via self-report1. In *Oxford University Press eBooks* (pp. 281–298). <https://doi.org/10.1093/acprof:oso/9780199592746.003.0019>
- Sheppard, S. R. (2005). Landscape visualisation and climate change: the potential for influencing perceptions and behaviour. *Environmental Science & Policy*, 8(6), 637–654.
<https://doi.org/10.1016/j.envsci.2005.08.002>
- Slocum, T. A., Blok, C., Jiang, B., Koussoulakou, A., Montello, D. R., Fuhrmann, S., & Hedley, N. (2001). Cognitive and usability issues in geovisualization. *Cartography and Geographic Information Science*, 28(1), 61–75.
<https://doi.org/10.1559/152304001782173998>
- Sugg, J. W. (2021). Exploratory geovisualization of the character and distribution of American climate change beliefs. *Weather, Climate, and Society*, 13(1), 67–82.
<https://doi.org/10.1175/wcas-d-20-0071.1>

Terrado, M., Calvo, L., & Christel, I. (2022). Towards more effective visualisations in climate services: good practices and recommendations. *Climatic Change*, 172(1–

2). <https://doi.org/10.1007/s10584-022-03365-4>

U.S. Geological Survey (USGS). (2023). *Benchmark Glaciers*. Retrieved from

<https://www.usgs.gov/special-topics/water-science-school/science/benchmark-glaciers>

Zemp, M., Frey, H., Gärtner-Roer, I., Nussbaumer, S. U., Hoelzle, M., Paul, F., Haeberli, W., Denzinger, F., Ahlstrøm, A. P., Anderson, B., Bajracharya, S., Baroni, C., Braun, L. N., Cáceres, B. E., Casassa, G., Cobos, G., Dávila, L. R., Granados, H. D., Demuth, M. N., . . . Vincent, C. (2015). Historically unprecedented global glacier decline in the early 21st century. *Journal of Glaciology*, 61(228), 745–762. <https://doi.org/10.3189/2015jog15j017>

APPENDIX

SURVEY QUESTIONS

1. Prolific ID

Please enter your Prolific ID in the text box below:

1.1.

2. Consent page

Consent for Research Participation

Title: Visualizing Glacier Retreat with 2D Planimetric Maps: Cognitive and Emotional Perspectives

Researcher(s): Fangsheng (Jasper) Zhou, University of Oregon

Carolyn Fish, University of Oregon

Researcher Contact Info: jasperz@uoregon.edu, 541-357-6096

You are being asked to participate in a research study. The box below highlights key information about this research for you to consider when making a decision whether or not to participate. Carefully consider this information and the more detailed information provided below the box. Please ask questions about any of the information you do not understand before you decide whether to participate.

Key Information for You to Consider

- **Voluntary Consent.** You are being asked to volunteer for a research study. It is up to you whether you choose to participate or not. There will be no penalty or loss of benefits to which you are otherwise entitled if you choose not to participate or discontinue participation.
- **Purpose.** The purpose of this research is to examine how maps of glacier retreat influence individuals' cognitive processing, emotional responses, and engagement with environmental issues. About 300 people will take part in this research.
- **Duration.** It is expected that your participation will last 15 minutes.
- **Procedures and Activities.** If you agree to be in this research, you will be asked to complete a series of tasks, including answering questions, reading and viewing information, and sharing your opinions.
- **Risks.** The possible risks or discomforts of this study are minimal and do not exceed those encountered in daily life. The primary risk is the potential loss of confidentiality, which will be minimized through secure data handling and storage procedures.
- **Benefits.** Benefits you may gain include increased knowledge and awareness around glacial retreat.
- **Alternatives.** Participation is voluntary, and the only alternative is not to participate.

2.1.

What happens if I agree to participate in this research?

For today's study, you will be asked to complete several map reading tasks online that involve making judgments and decisions. We hope to learn how people interpret and use mapped information about changes to glaciers in North America presented to them in different ways to help us better understand the way people perceive information and their preferences. These tasks may take up to 15 minutes to complete, and they can be done on your computer, tablet, or mobile device.

What happens to the information collected for this research?

Information collected for this research will be used to test our research questions and will be published or presented in journal articles and/or conferences. Since we will not be collecting identifiable information about you, and since Prolific keeps your personal information confidential, your data will be anonymous in any results we publish.

How will my privacy and data confidentiality be protected?

We will take measures to protect your privacy, including not associating your responses with any identifiable data. We will only use your Prolific ID number for compensation and response quality control. After you are paid, your ID will be deleted from the dataset, and we will never share your ID. The only people with access to your data will be our research personnel. All data will be held and protected either on our own password-protected computers or by Qualtrics (a survey research company) using their online security features. Although every effort to protect confidentiality will be made, no guarantee of internet survey security can be given as, although unlikely, transmissions can be intercepted, and IP addresses can be identified. Absolute confidentiality can never be guaranteed.

What are the risks if I participate in this research?

The risks or discomforts of participating in this research do not exceed those associated with daily life. Risks of loss of confidentiality will be minimized.

What are the risks if I participate in this research?

The risks or discomforts of participating in this research do not exceed those associated with daily life. Risks of loss of confidentiality will be minimized.

What if I want to stop participating in this research?

Taking part in this research study is your decision. Your participation in this study is voluntary. You do not have to take part in this study, but if you do, you can stop at any time by exiting and closing the survey link. You have the right to choose not to participate in any study activity or completely withdraw from continued participation at any point in this study. Your decision whether or not to participate will not affect your relationship with the researchers or the University of Oregon. If you decide to leave this research, your responses will be treated as incomplete and removed from the final dataset. You will not be paid if you do not complete the survey because the code for receiving compensation will only be provided to participants who finish the survey.

Will I be paid for participating in this research?

You will be paid for taking part in this research through Prolific.

Who can answer my questions about this research?

If you have questions, concerns, or have experienced a research related injury, contact the research team at:

Jasper Zhou

541-357-6096

jasperz@uoregon.edu

Carolyn Fish, PhD

541-346-4197

cfish11@uoregon.edu

An Institutional Review Board (“IRB”) is overseeing this research. An IRB is a group of people who perform independent review of research studies to ensure the rights and welfare of participants are protected. UO Research Compliance Services is the office that supports the IRB. If you have questions about your rights or wish to speak with someone other than the research team, you may contact:

Research Compliance Services
5237 University of Oregon
Eugene, OR 97403-5237
(541) 346-2510
ResearchCompliance@uoregon.edu

STATEMENT OF CONSENT

I have had the opportunity to read and consider the information in this form. I have asked any questions necessary to make a decision about my participation. I understand that I can ask additional questions throughout my participation.

I understand that by signing below, I volunteer to participate in this research. I understand that I am not waiving any legal rights. I understand that if my ability to consent or assent for myself changes, either I or my legal representative may be asked to re-consent prior to my continued participation in this study.

Do you consent to participate in this study?

Yes

No

2.2.

2.3. No consent

As you do not wish to participate in this study, please return to Prolific and select the 'Stop without completing' button.

3. Demographic questions

What is your age?

3.1.

What is your gender identity?

Man

Woman

Transgender

Non-binary / third gender

Other (please specify)

Prefer not to say

3.2.

What is your race?

White

Hispanic or Latino

Black or African American

Asian

Native Hawaiian or Pacific Islander

Native American

Other (please specify)

Prefer not to say

3.3.

What is your zip code?

3.4.

What is your level of education? (If currently enrolled, highest degree received.)

- Less than High School
- High school graduate (including GED)
- Some college (no degree earned)
- Technical certification
- Associate degree (2-year)
- Bachelor's degree (4-year)
- Master's degree
- Doctoral degree
- Professional degree (e.g. MD, JD)
- Prefer not to say

3.5.

What is your marital status?

- Single
- Married or domestic partnership
- Widowed
- Prefer not to say

3.6.

What is your employment status?

- Full-time
- Part-time
- Contract or temporary
- Unemployed
- Retired
- Student
- Military
- Unable to work
- Prefer not to say

3.7.

What is your annual household income (before tax)?

- \$0-\$29,999
- \$30,000-\$59,999
- \$60,000-\$89,999
- \$90,000-\$119,999
- \$120,000+
- Prefer not to say

3.8.

4. Need for Cognition

	Extremely Uncharacteristic	Somewhat Uncharacteristic	Uncertain	Somewhat Characteristic	Extremely Characteristic
I would prefer complex to simple problems.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I like to have the responsibility of handling a situation that requires a lot of thinking.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Thinking is not my idea of fun.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I would rather do something that requires little thought than something that is sure to challenge my thinking abilities.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I try to anticipate and avoid situations where there is likely a chance I will have to think in depth about something.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I find satisfaction in deliberating hard and for long hours.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I only think as hard as I have to.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I prefer to think about small, daily projects to long-term ones.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I like tasks that require little thought once I've learned them.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

The idea of relying on thought to make my way to the top appeals to me.

I really enjoy a task that involves coming up with new solutions to problems.

Learning new ways to think doesn't excite me very much.

I prefer my life to be filled with puzzles that I must solve.

The notion of thinking abstractly is appealing to me.

I would prefer a task that is intellectual, difficult, and important to one that is somewhat important but does not require much thought.

I feel relief rather than satisfaction after completing a task that required a lot of mental effort.

It's enough for me that something gets the job done; I don't care how or why it works.

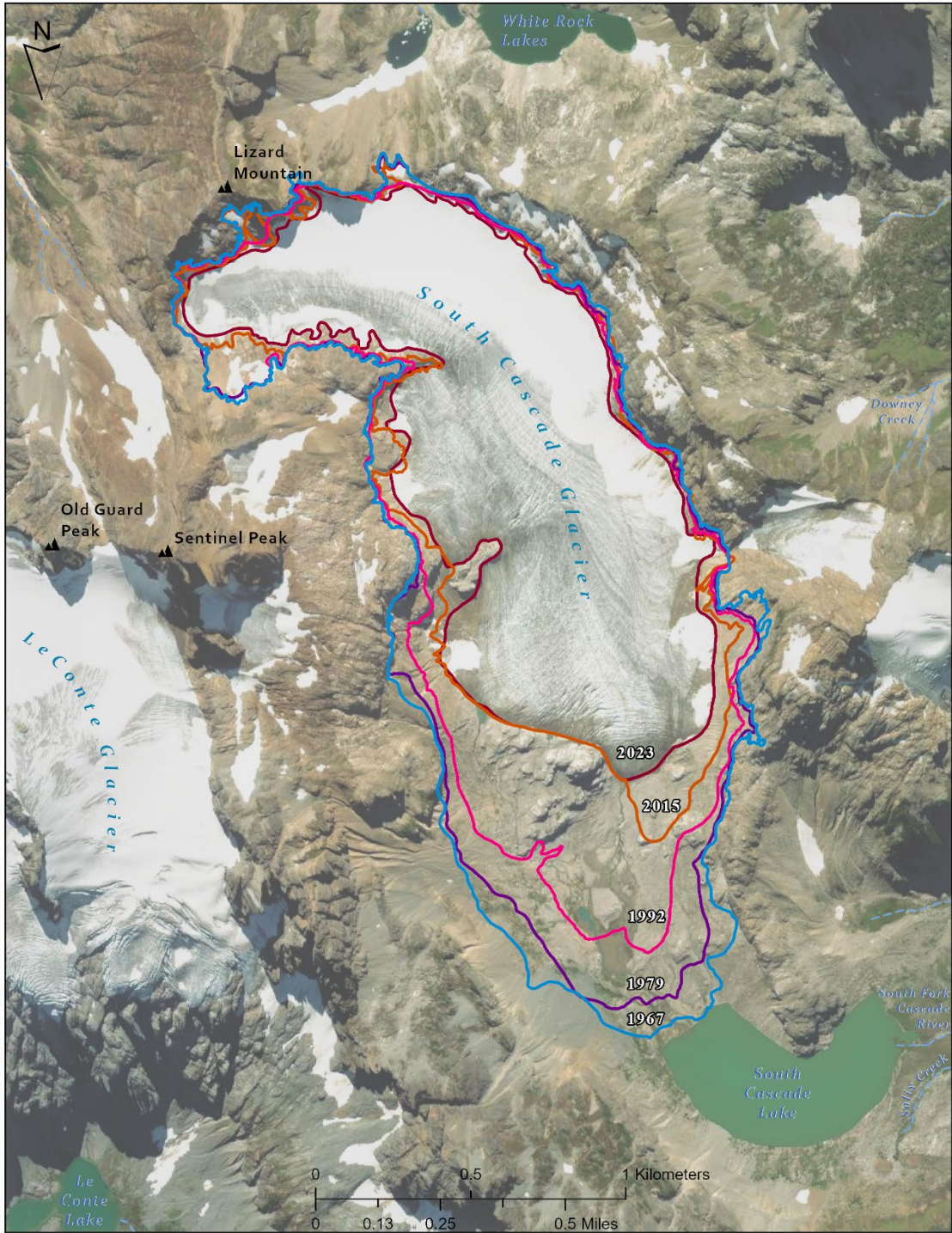
I usually end up
deliberating about
issues even when
they do not affect
me personally.



5. Stimuli - Maps

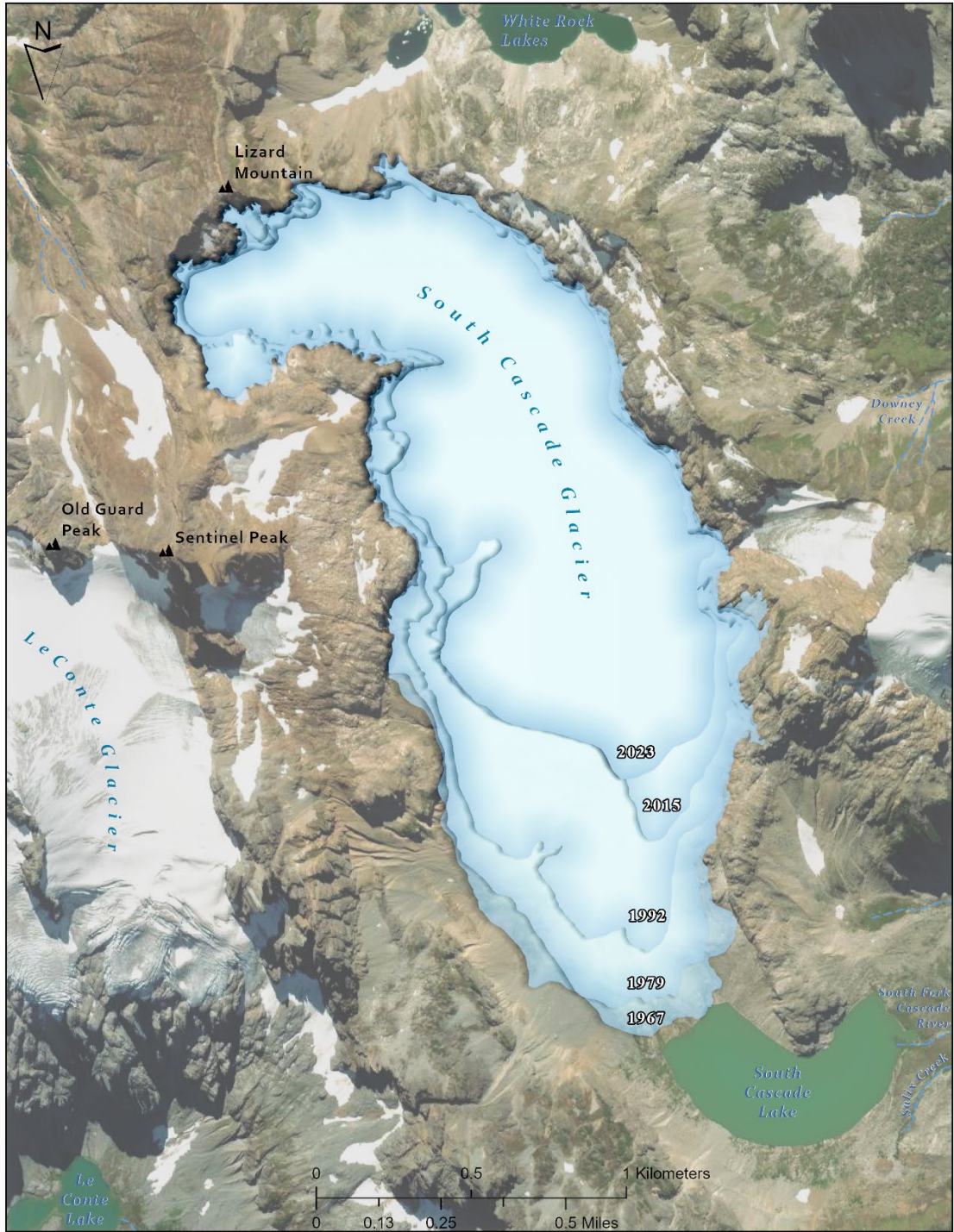
Please view the map below of South Cascade Glacier in Washington State in the United States. You will be asked questions about this map in this study. You do not need to memorize the map; we will show it to you on each page of the survey.

5.1.

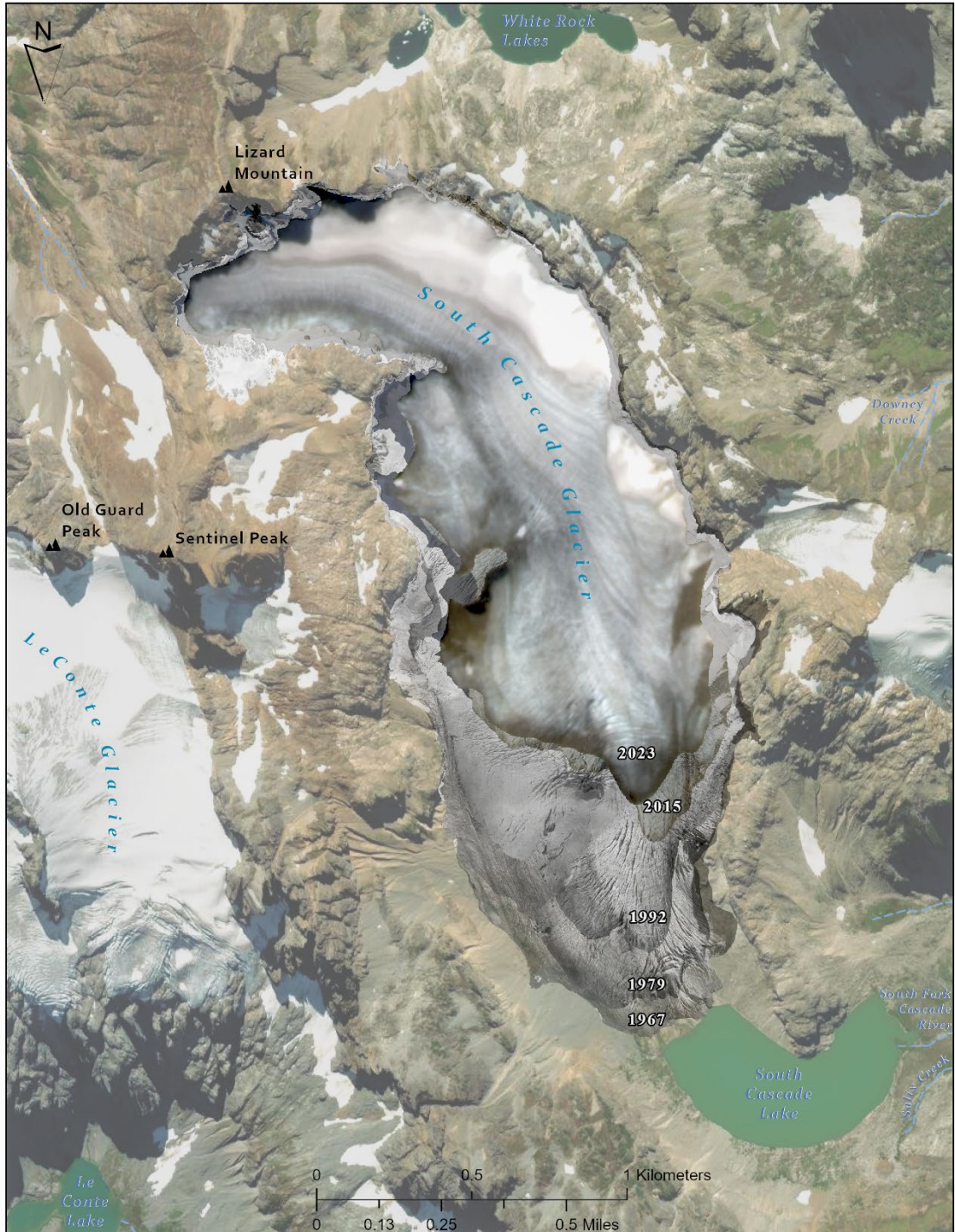


5.2.

Map 1

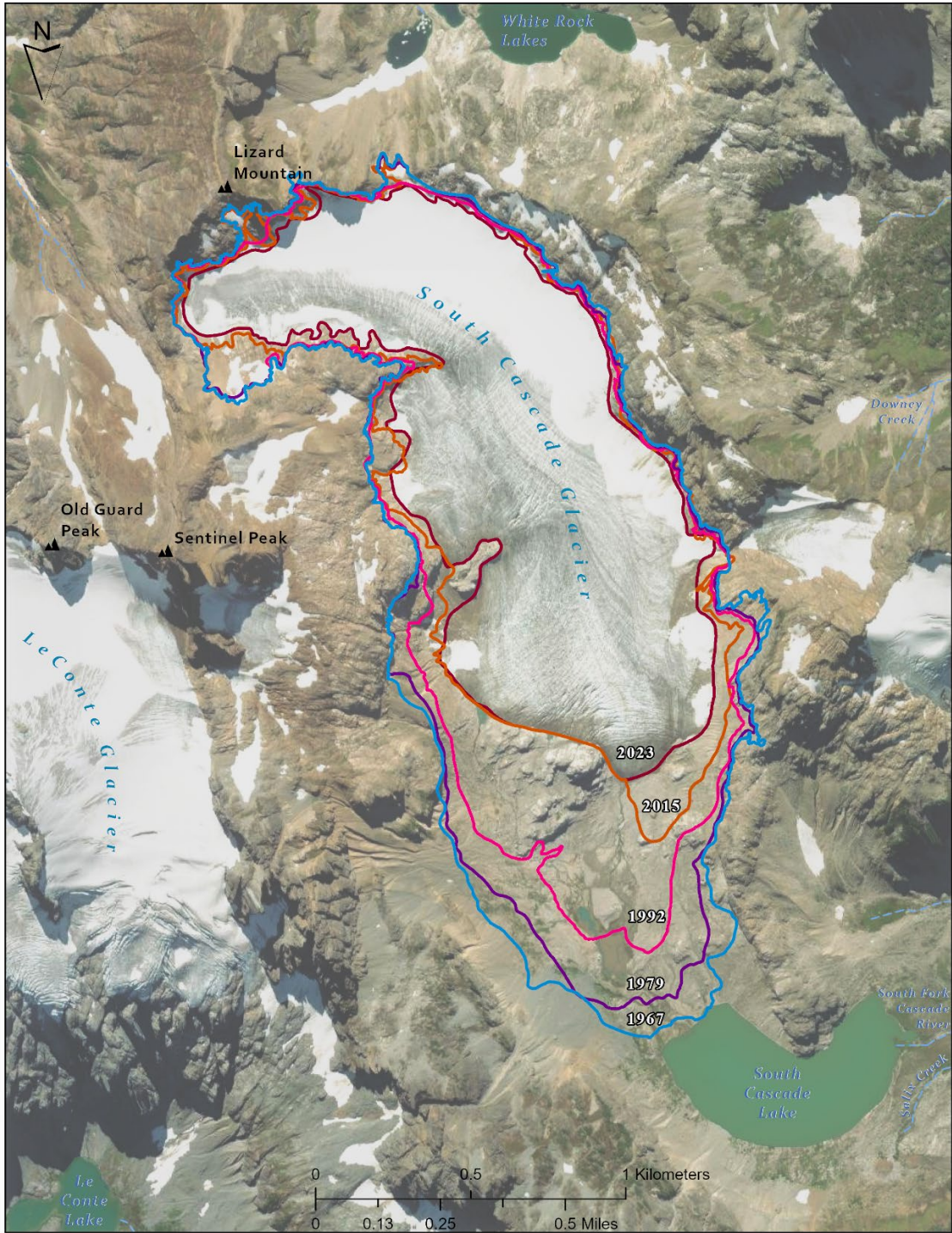


Map 2



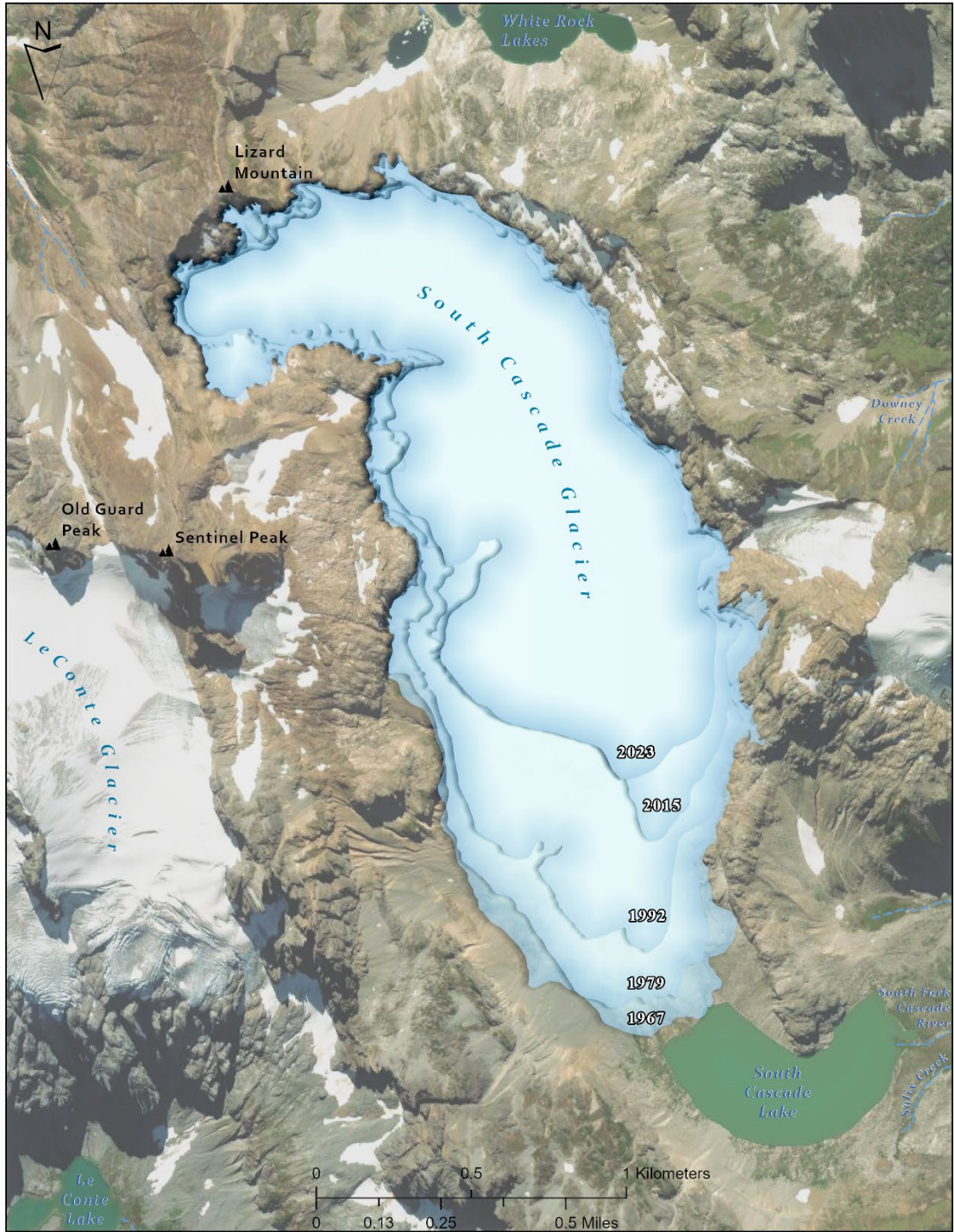
Map 3

6. GEW

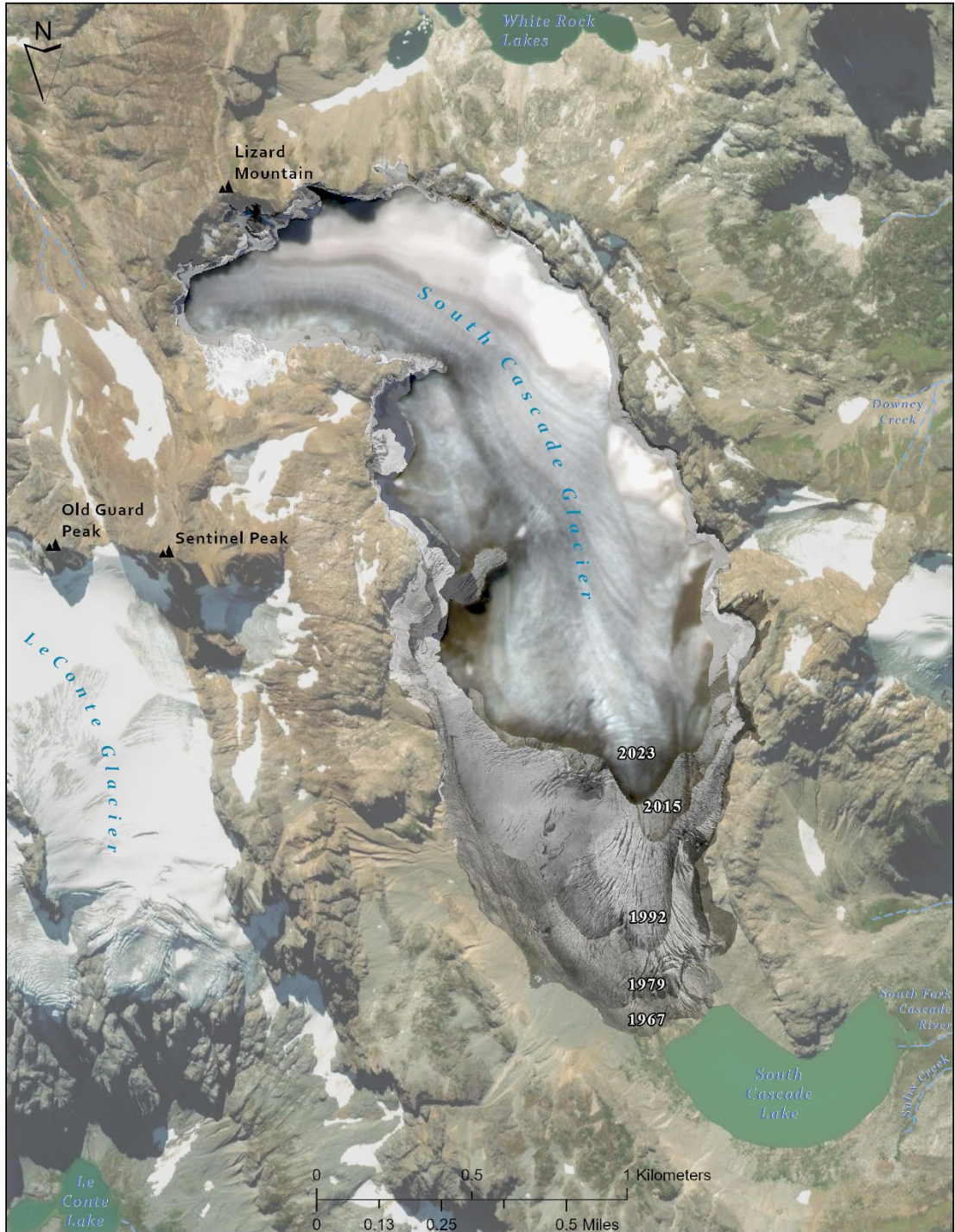


6.1.

Map 1

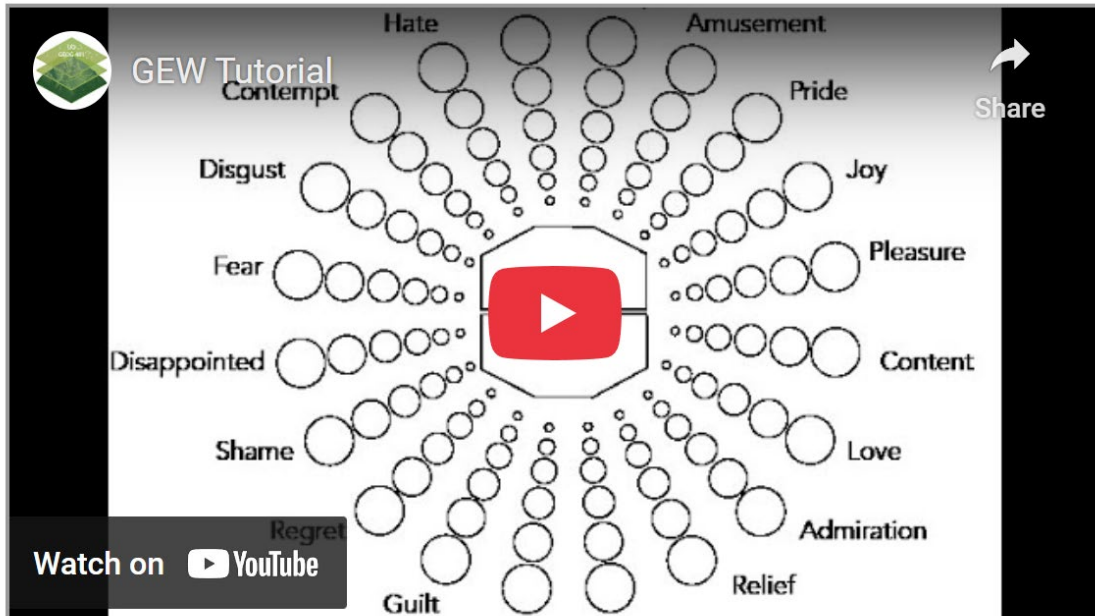


Map 2



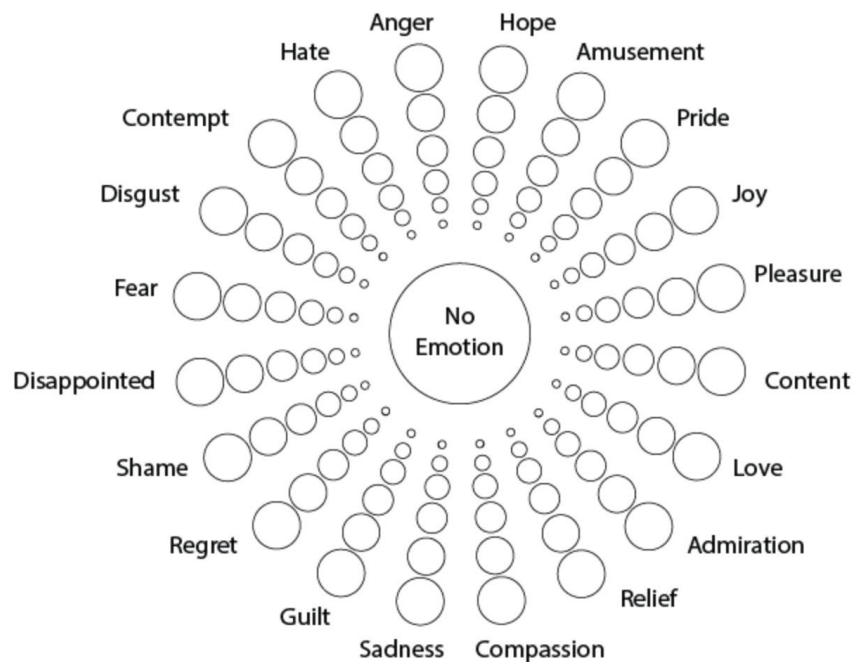
Map 3

GEW Tutorial



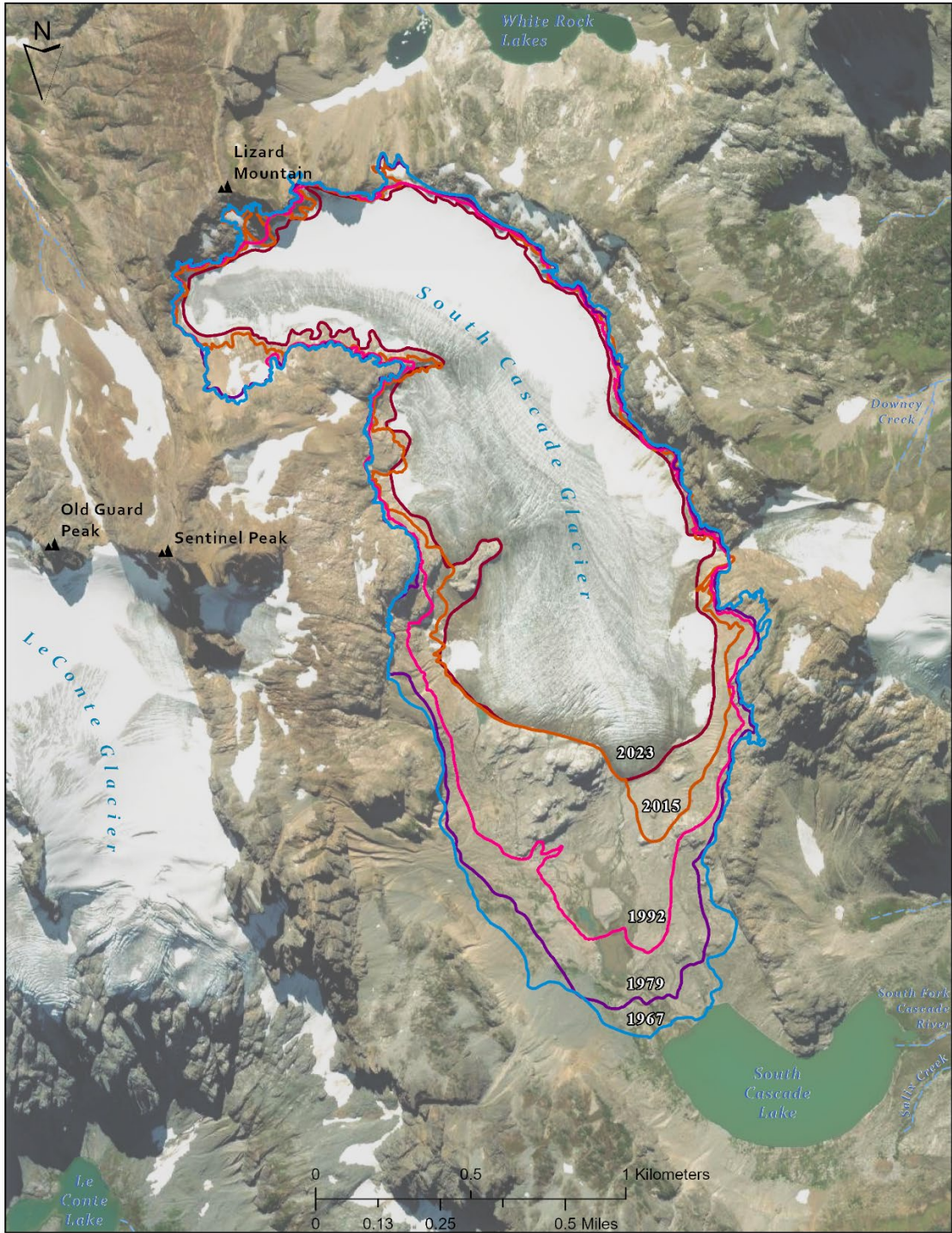
6.2.

After viewing the map above and watching the video to explain how to use this Geneva Emotion Wheel, please select the emotion word and intensity that you feel.



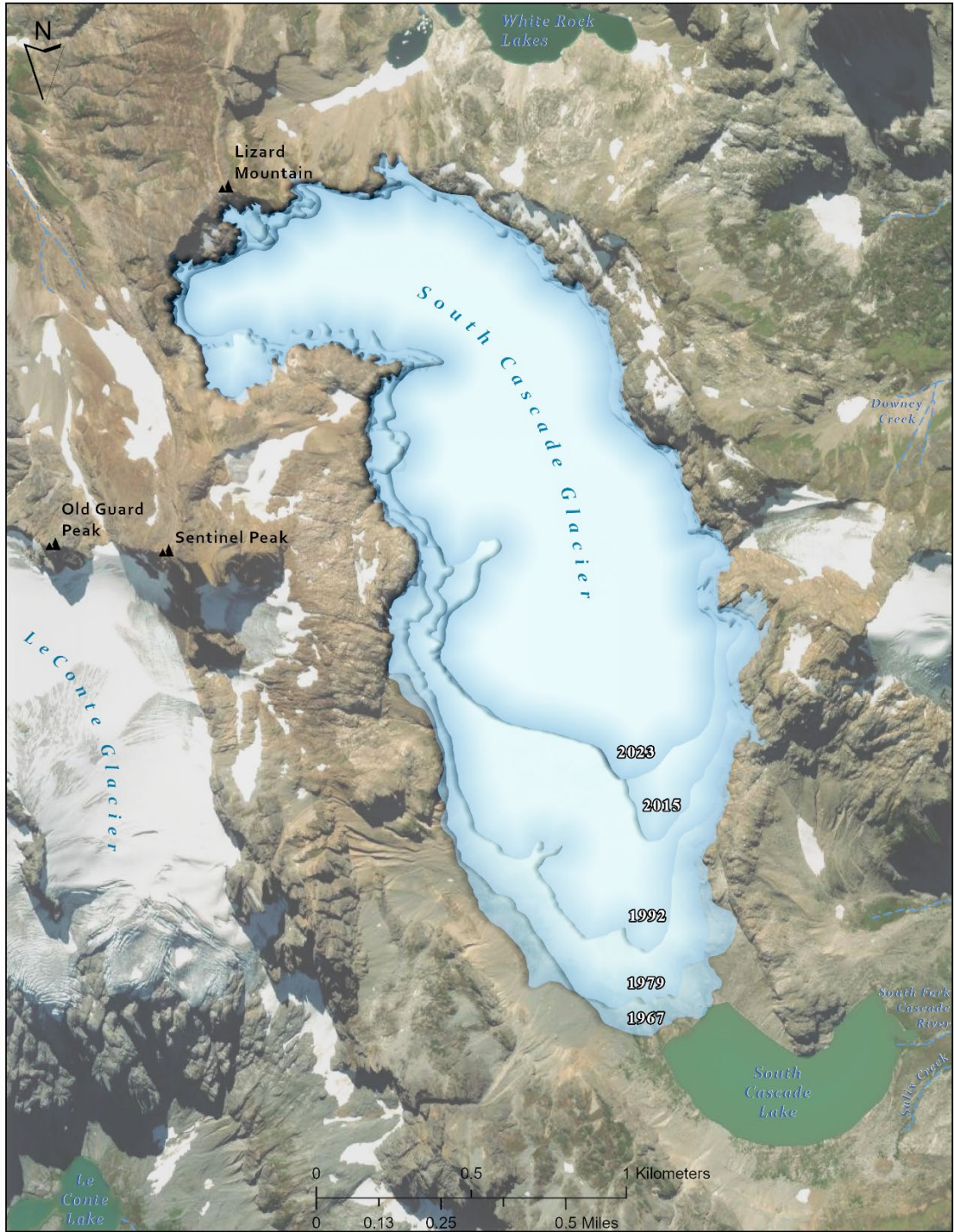
6.3.

7. MAPTRUST Scale

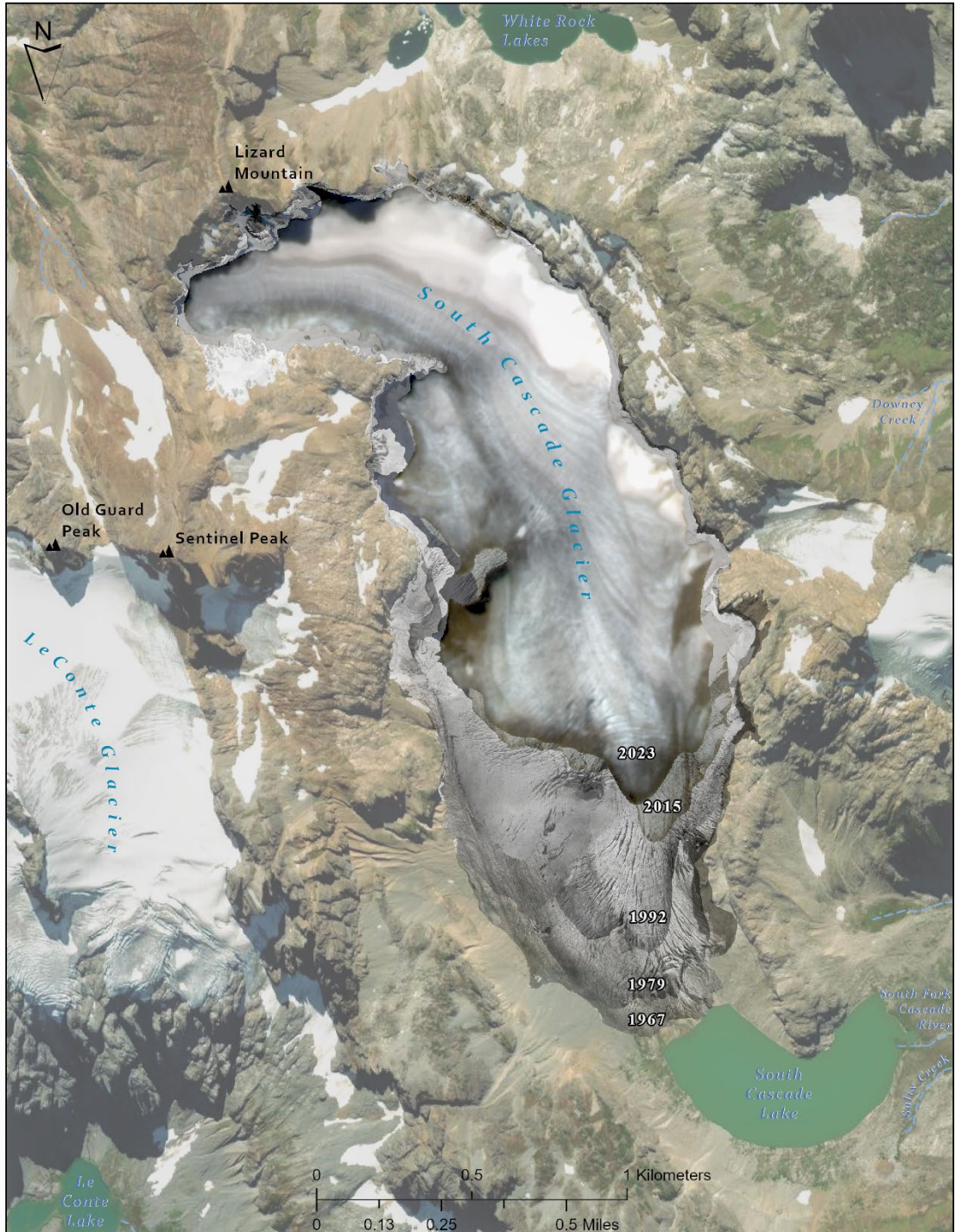


7.1.

Map 1



Map 2



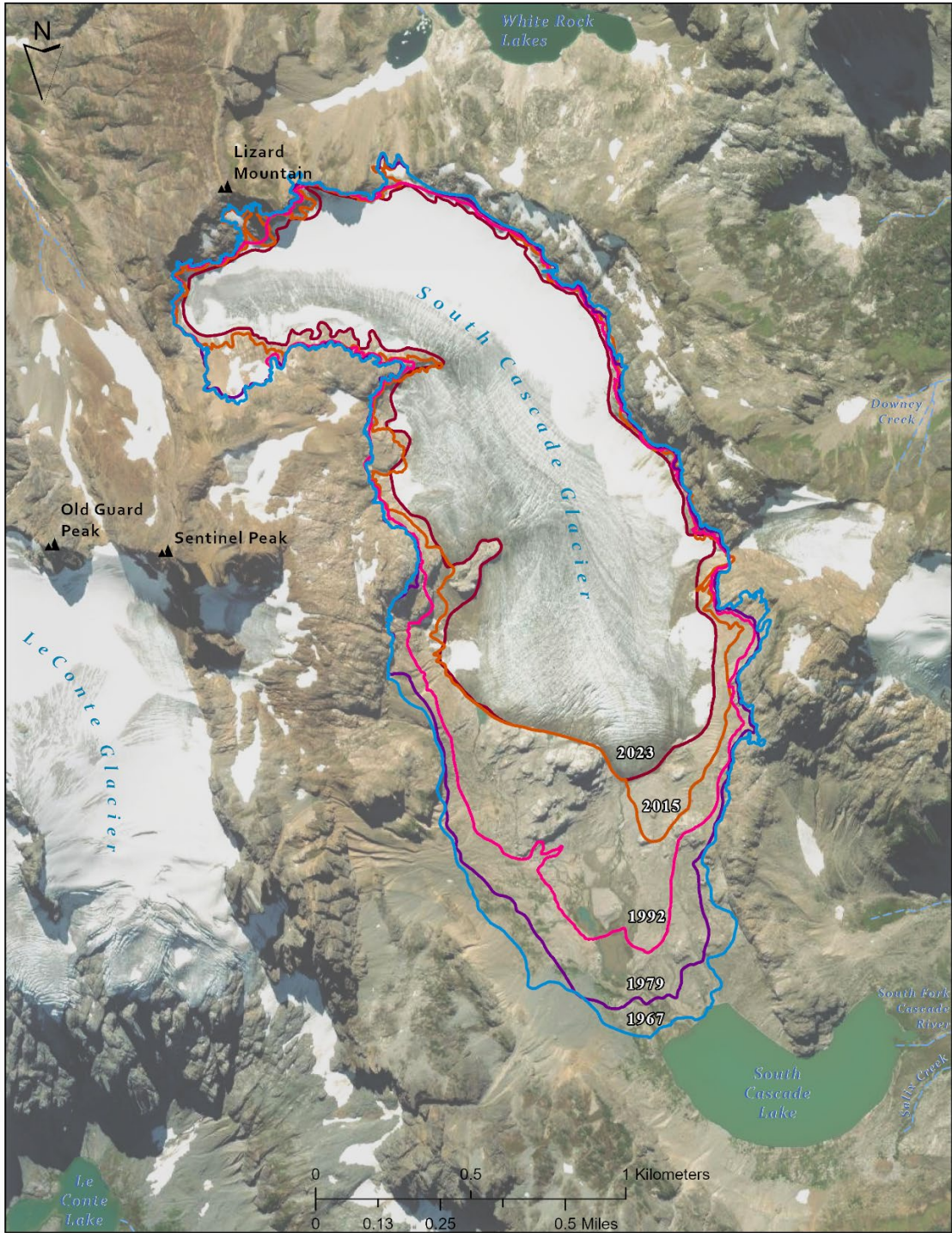
Map 3

How well do the following adjectives describe the map?

	Describes the map very poorly (1)	2	3	4	5	6	Describes the map very well (7)
Accurate	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Correct	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Error-free	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Honest	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Trustworthy	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Credible	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Fair	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Reliable	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Reputable	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Objective	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Authentic	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Balanced	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

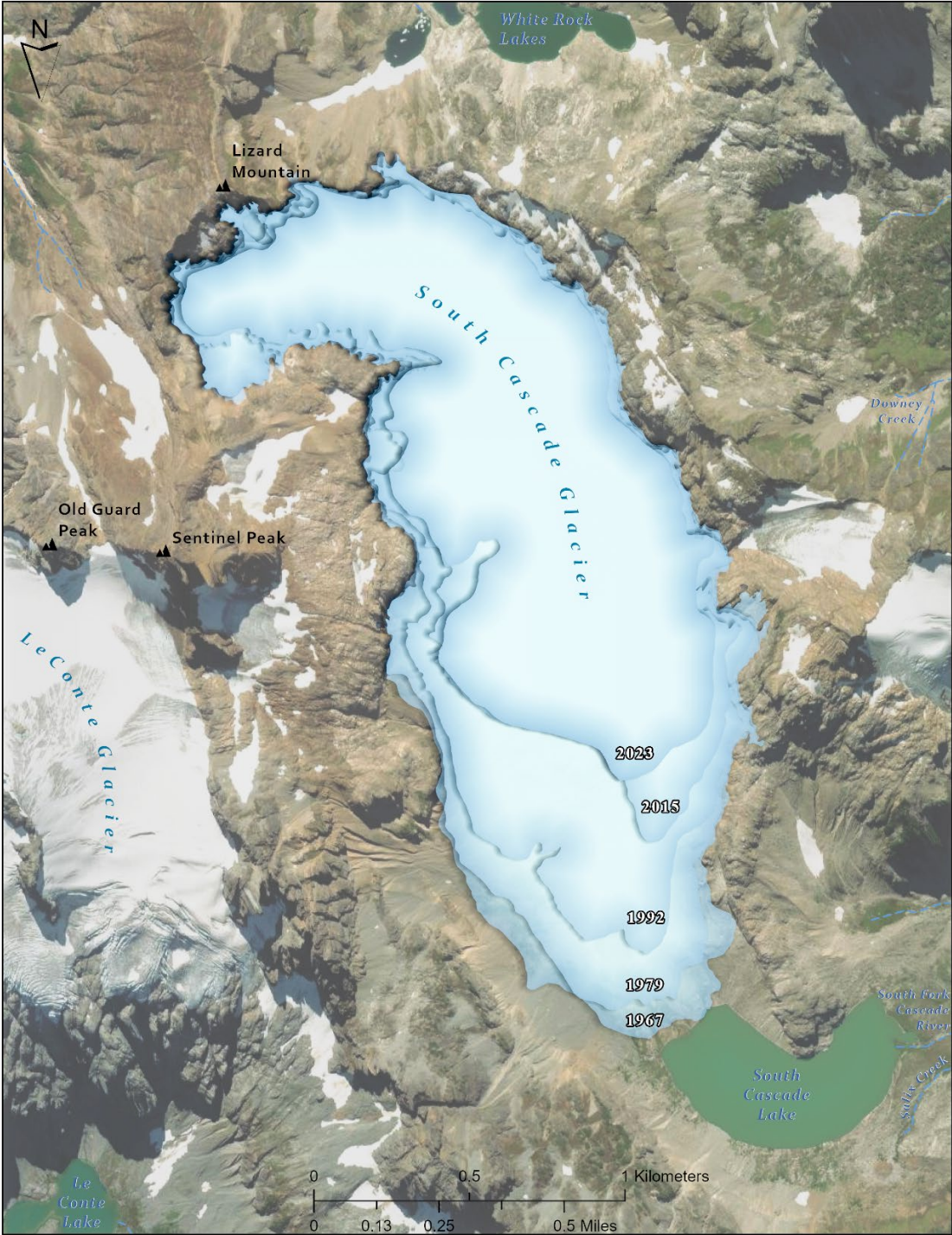
7.2.

8. Attractiveness

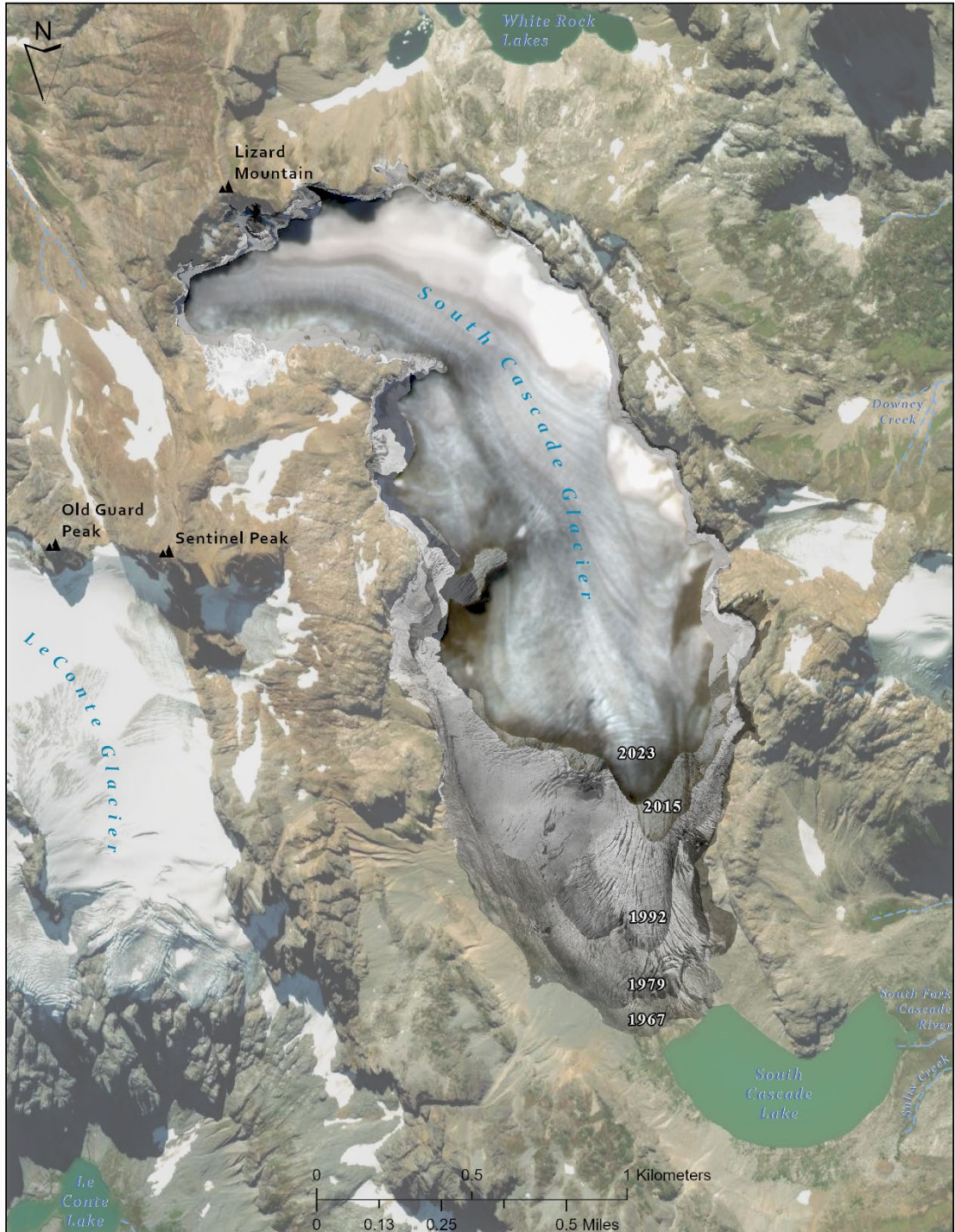


8.1.

Map 1



Map 2

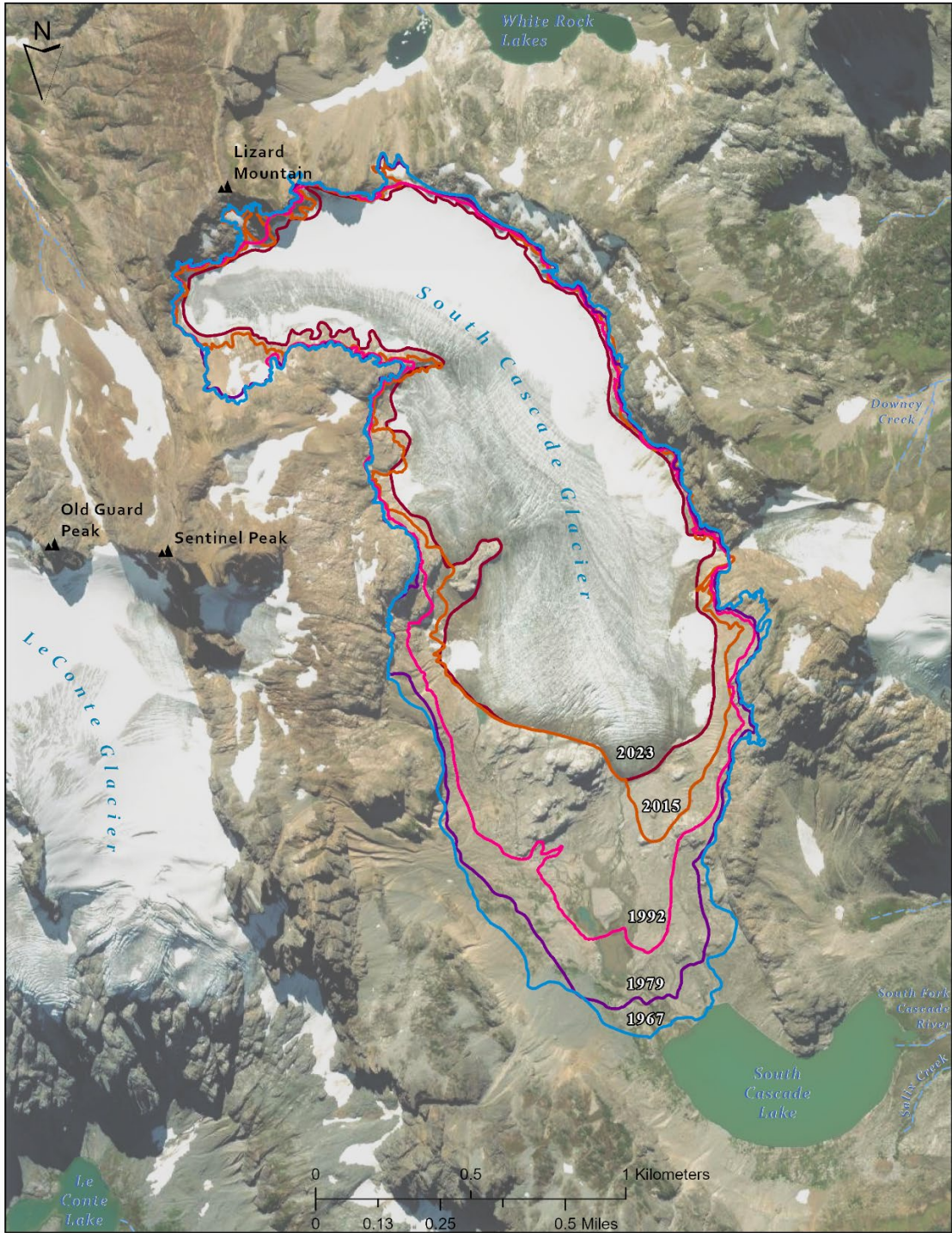


Map 3

	Not attractive at all	Slightly attractive	Moderately attractive	Very attractive	Extremely attractive
Rate the attractiveness of the map.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

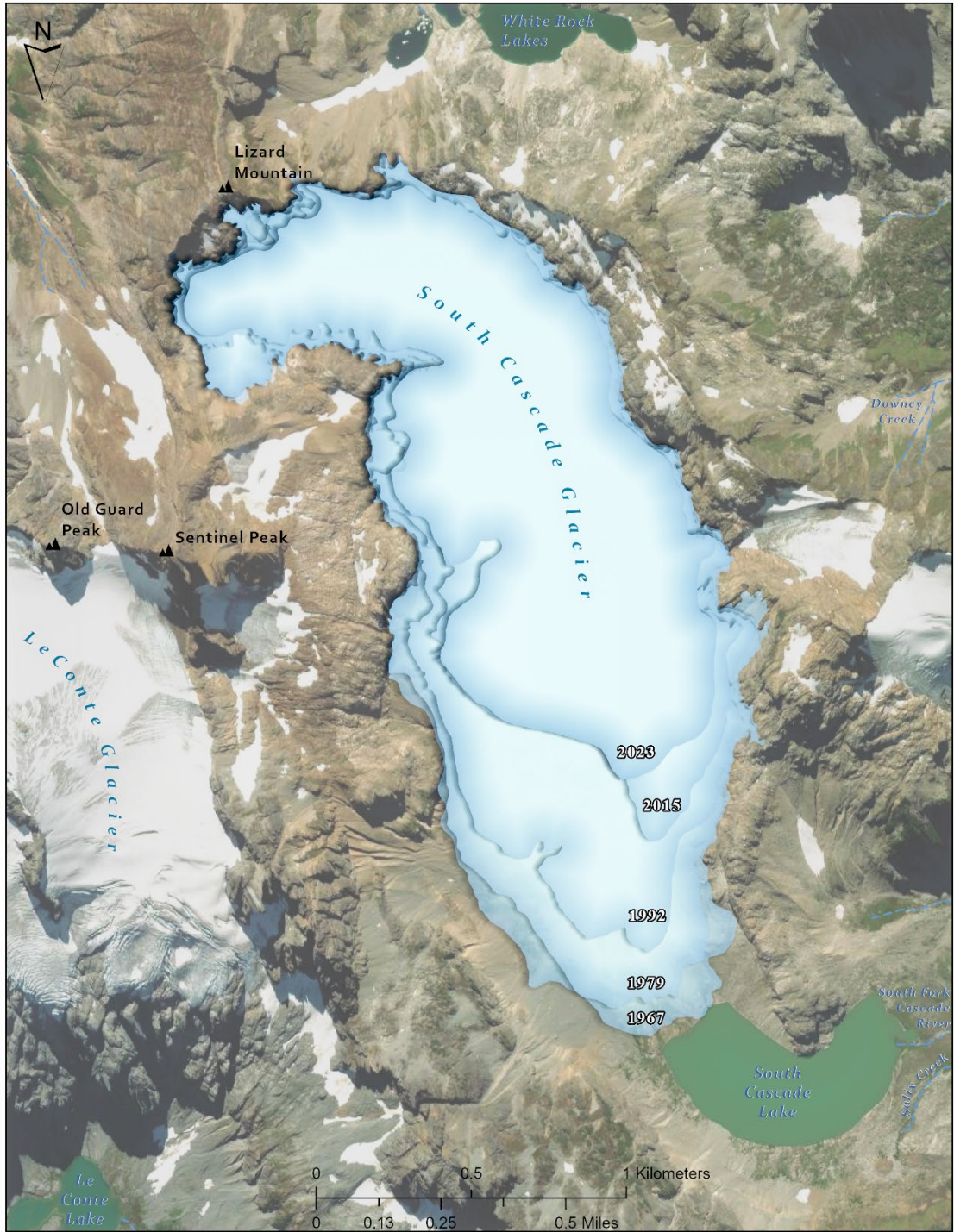
8.2.

9. Assessment of Accuracy

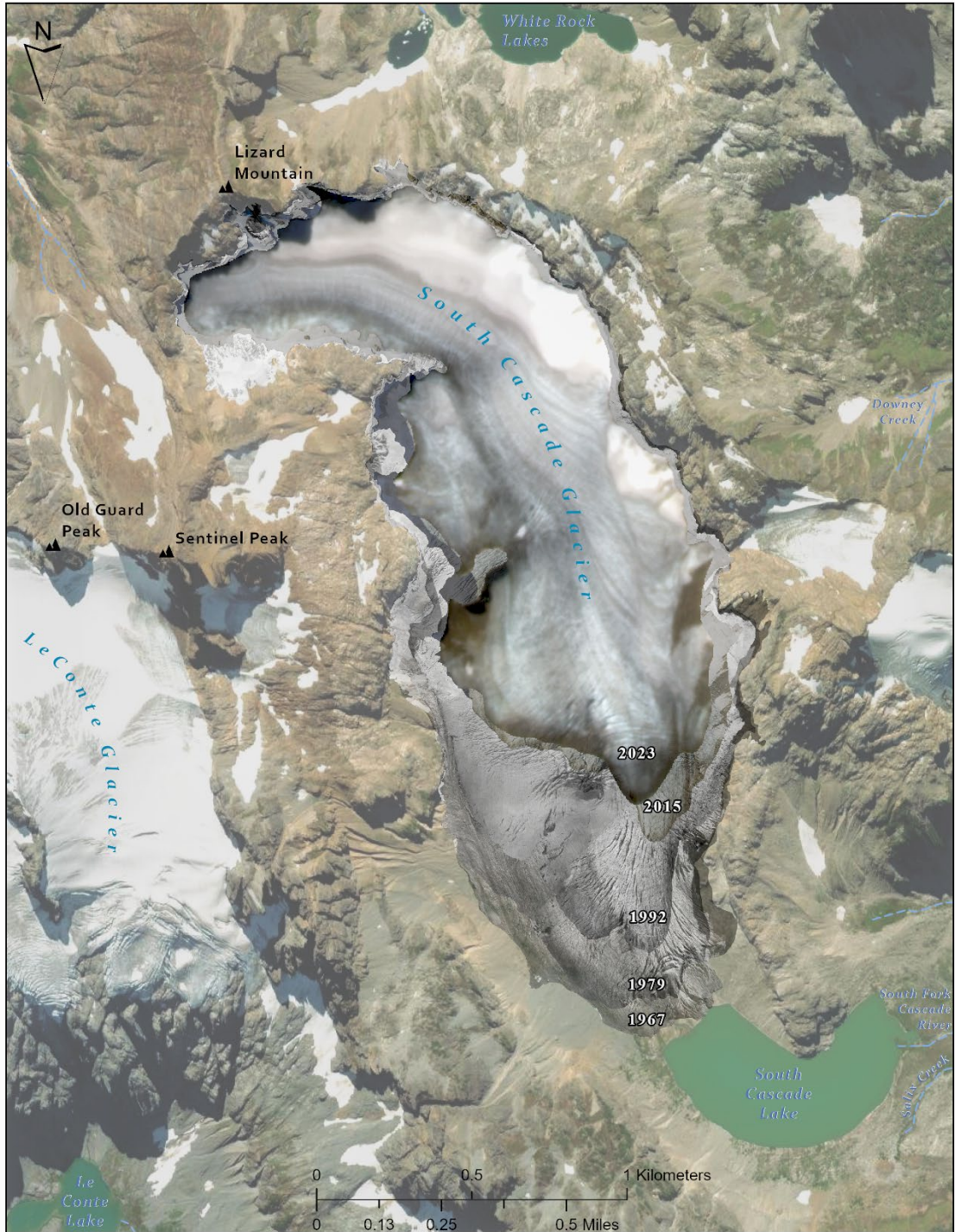


9.1.

Map 1



Map 2



Map 3

Does the map show a loss in ice on the glacier over time or a gain in ice over time?

Gain

Loss

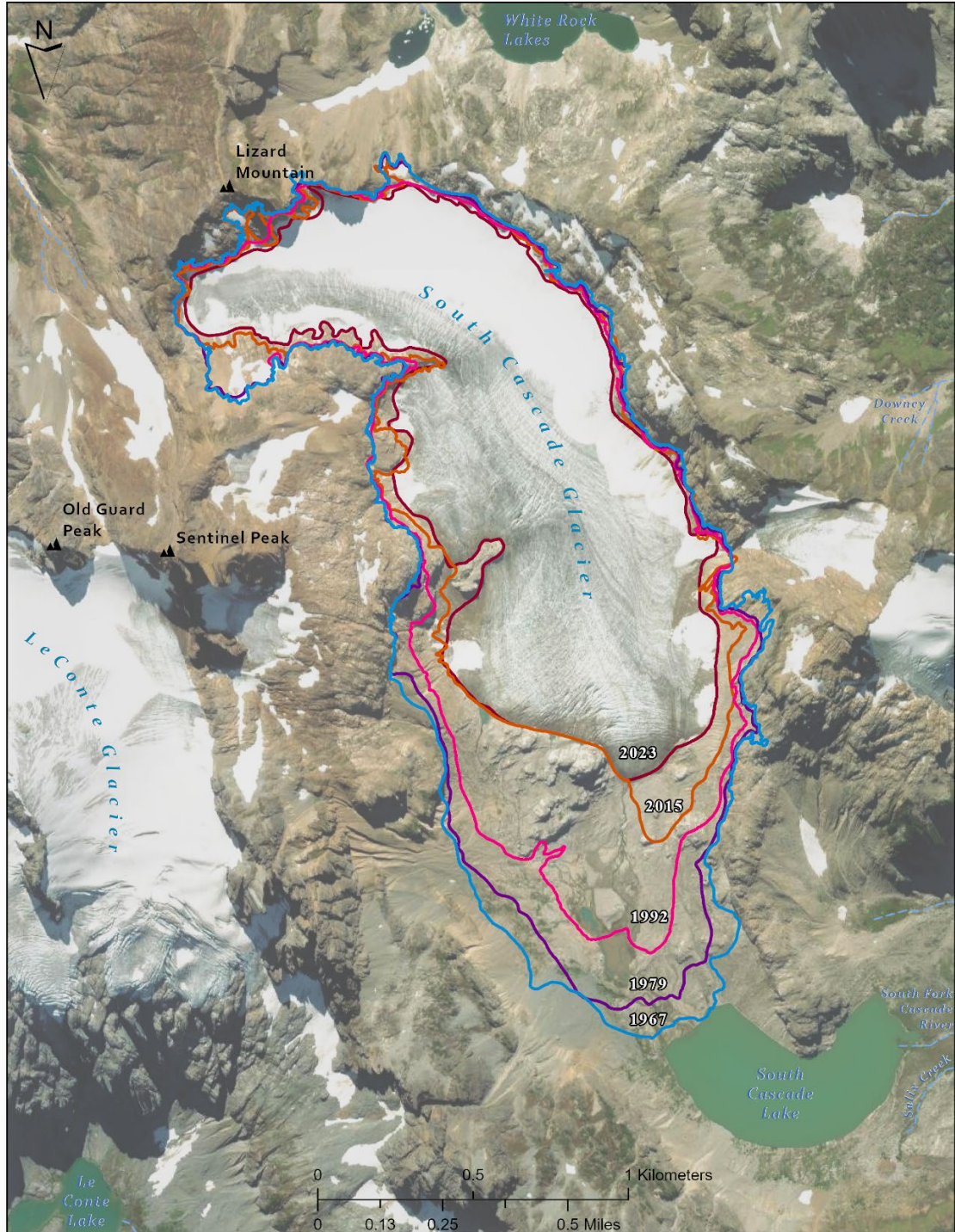
No change

9.2.

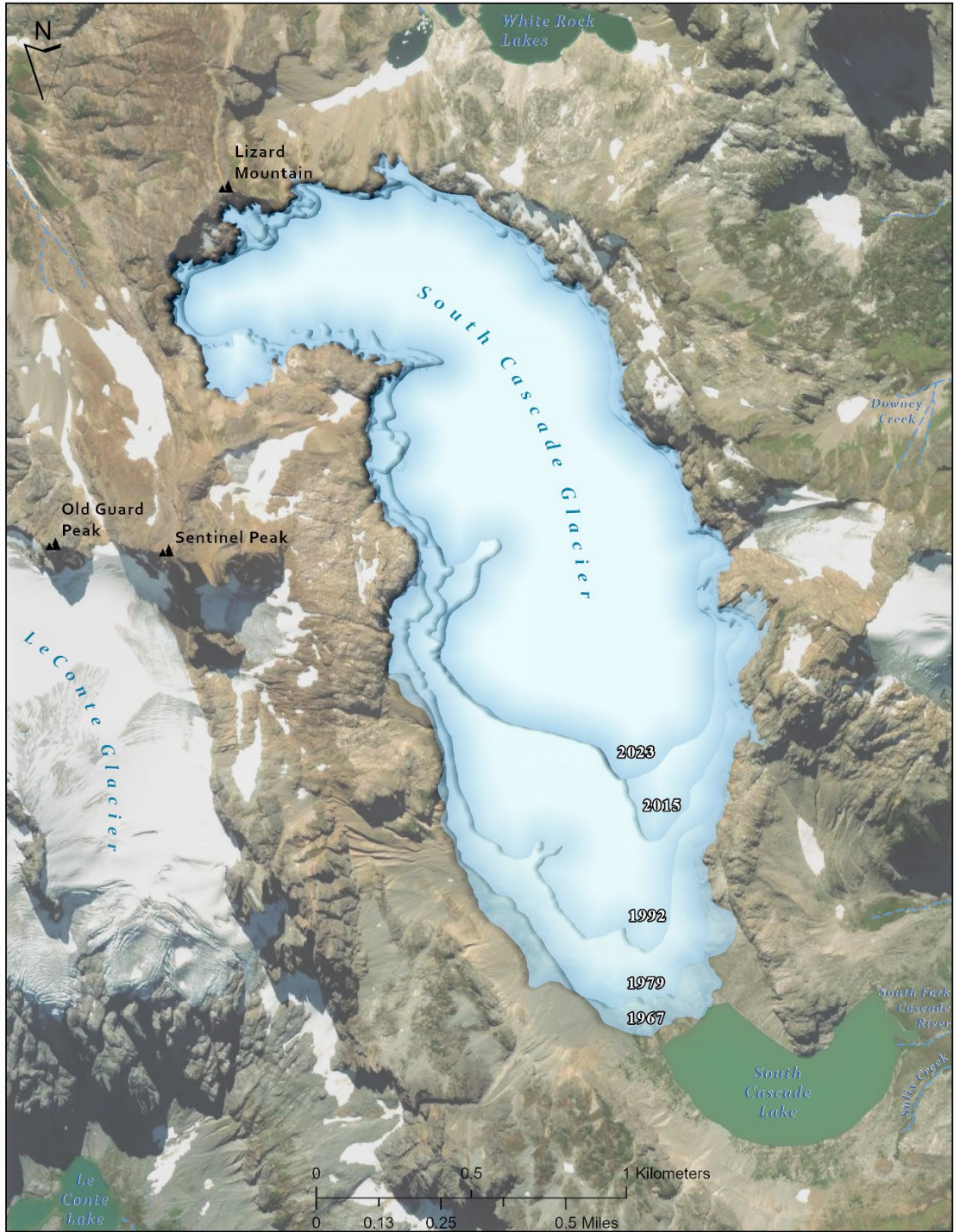
	Not confident at all	Slightly confident	Moderately confident	Very confident	Extremely confident
How confident are you in your response?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

9.3.

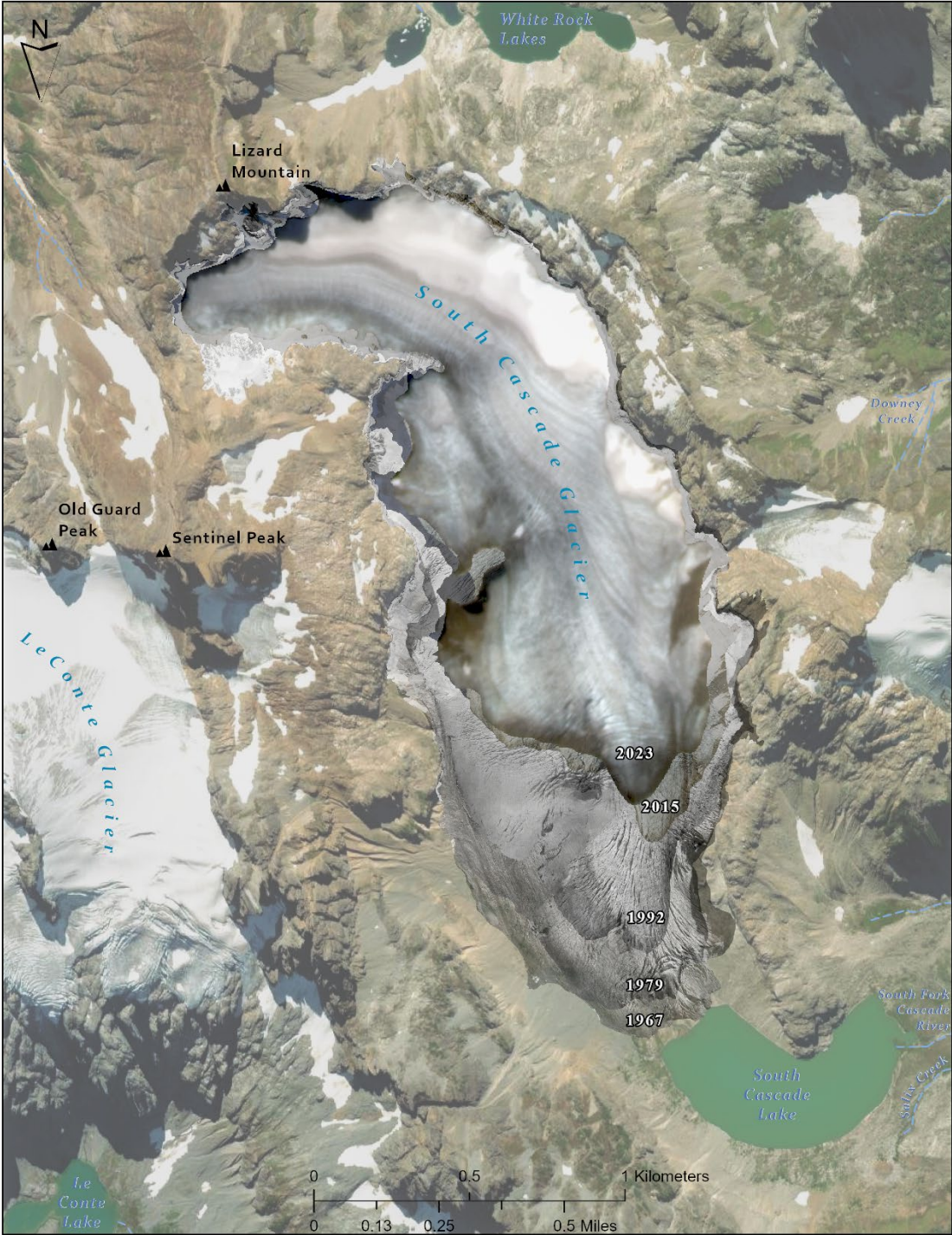
Click on the map below to indicate where you think there has been the largest change to the glacier over the time period 9.4. shown in the map.



Map 1



Map 2

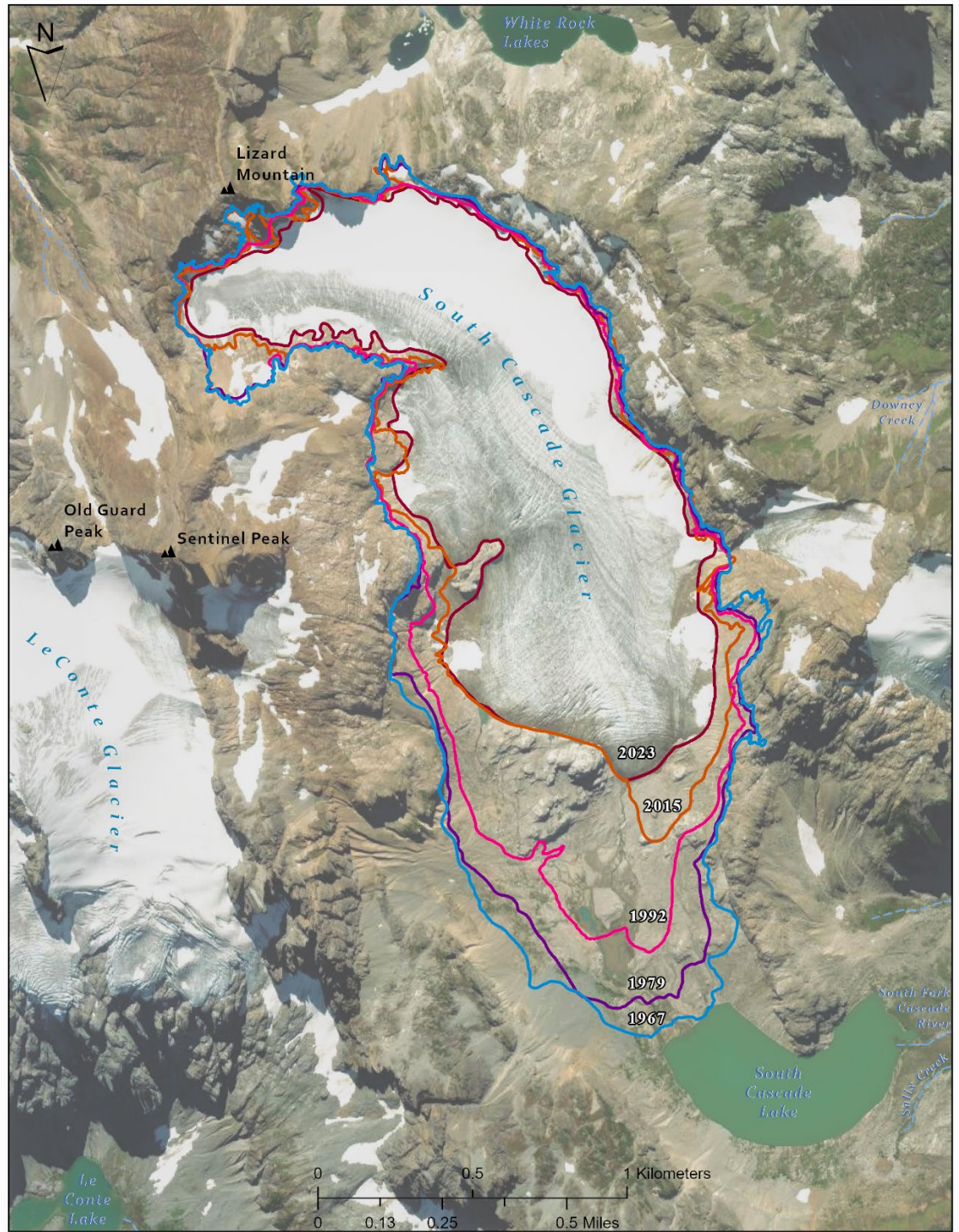


Map 3

	Not confident at all	Slightly confident	Moderately confident	Very confident	Extremely confident
How confident are you in your response?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

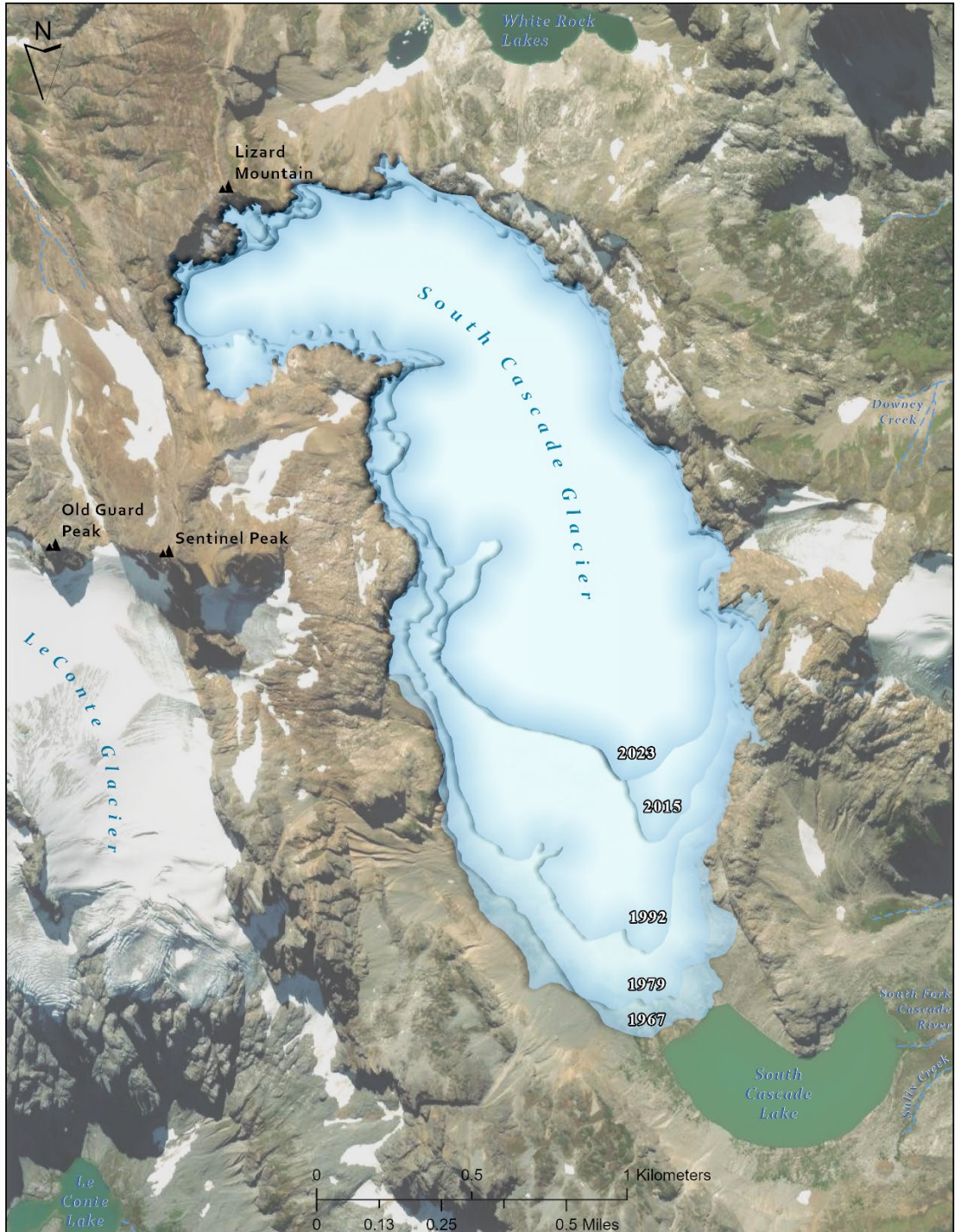
9.5.

10. Awareness of Glacier Volume Loss

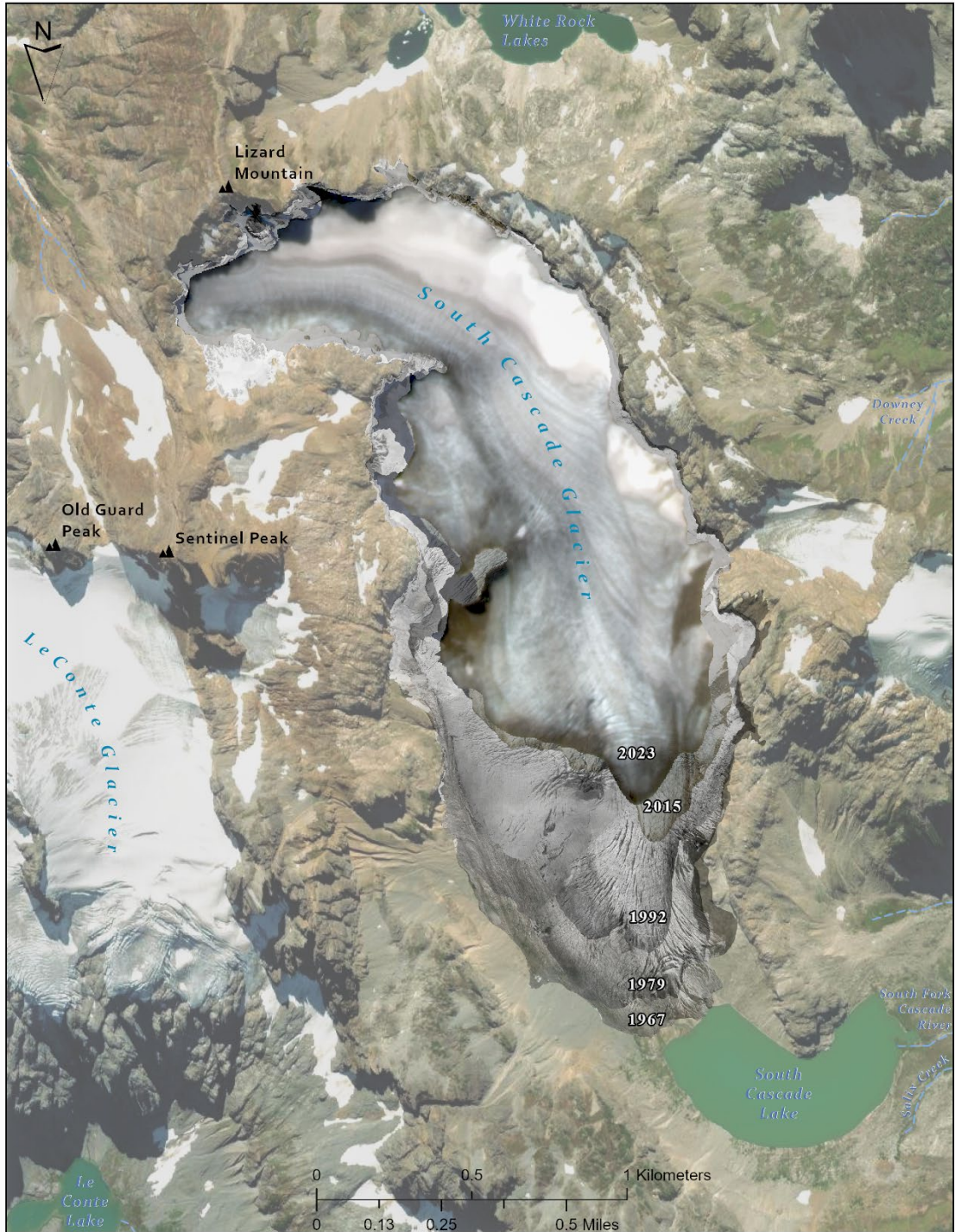


10.1.

Map 1



Map 2



Map 3

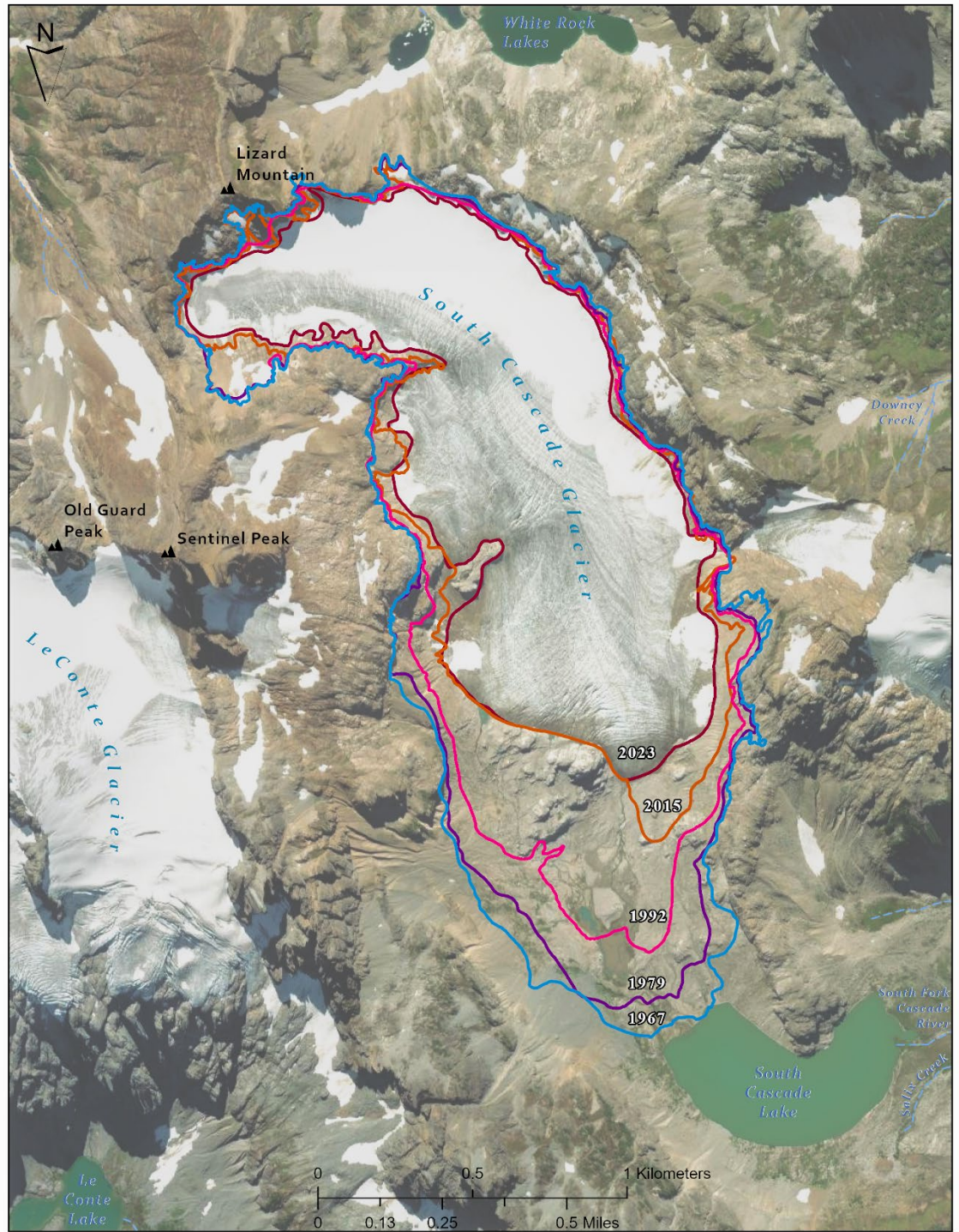
		Not well at all	Slightly well	Moderately well	Very well	Extremely well
10.2.	How well does this map help you understand the changes in the size of the glacier over time?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

		Not clear at all	Slightly clear	Moderately clear	Very clear	Extremely clear
10.3.	How clearly does this map convey the volume loss of this glacier?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

		Not at all	Slightly	Moderately	Very much	Extremely much
10.4.	How much does this map help you understand the long-term changes of this glacier's size?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

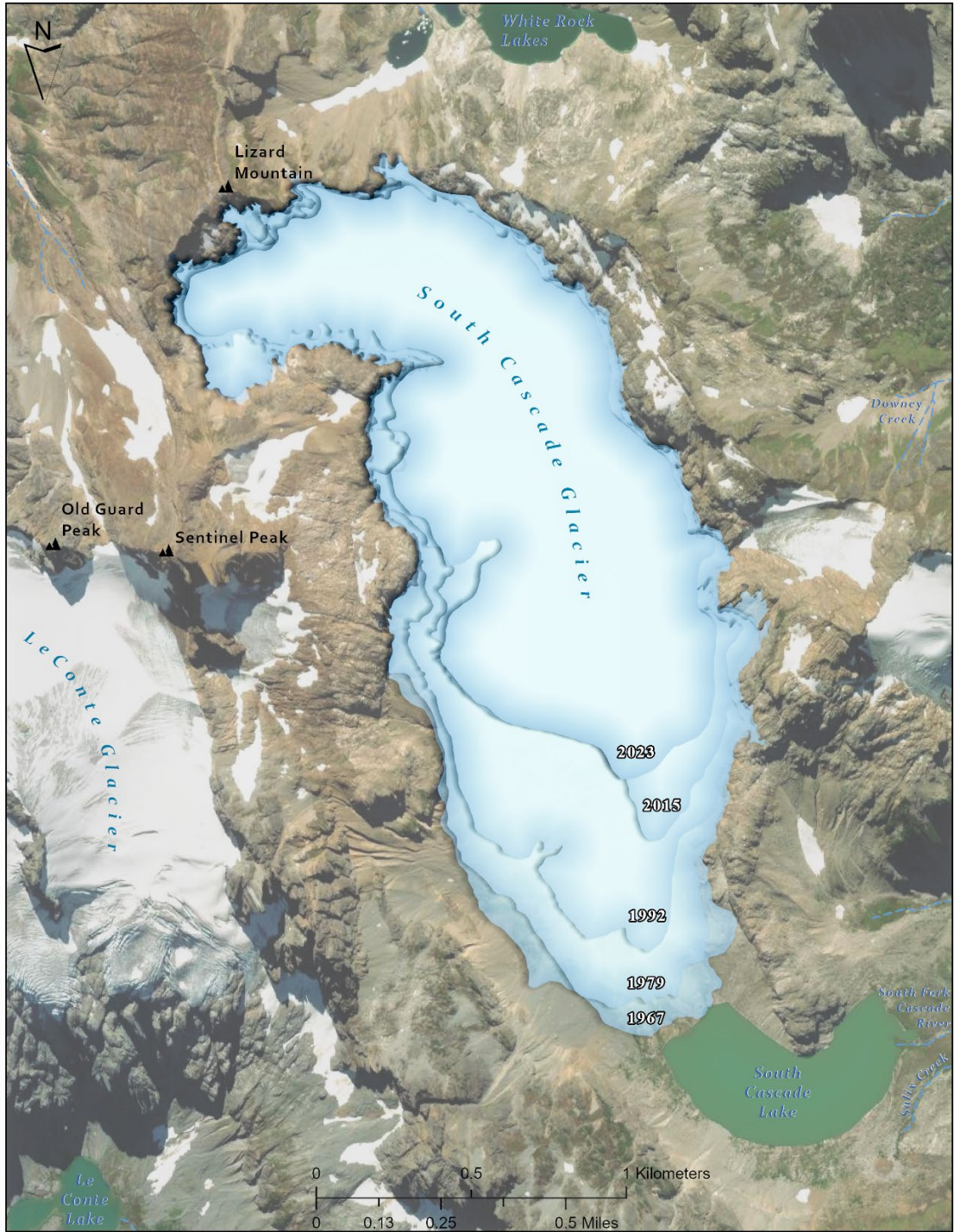
		Not clear at all	Slightly clear	Moderately clear	Very clear	Extremely clear
10.5.	How clearly does this map help you understand the changes in glacier extent over time?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

11. Connection to Climate Change

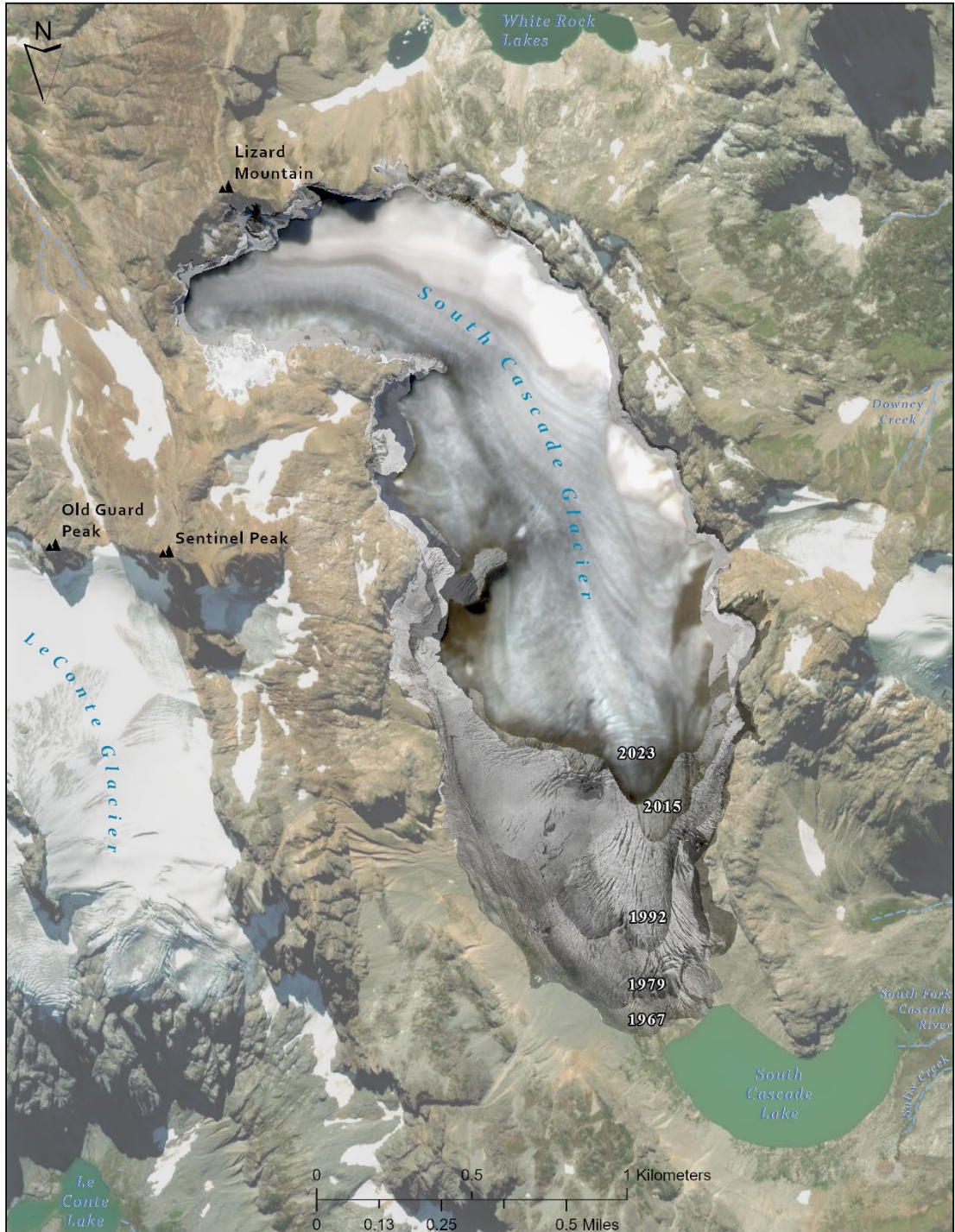


11.1.

Map 1



Map 2



Map 3

		Not urgent at all	Slightly urgent	Moderately urgent	Moderately urgent	Extremely urgent
11.2.	How well do you think this map shows the urgency of climate change?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
		Not effective at all	Not effective at all	Moderately effective	Very effective	Extremely effective
11.3.	How effective is this map in helping you perceive the overall impact of climate change on glaciers?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
		Strongly disagree	Disagree	Neutral	Agree	Strongly agree
11.4.	Does the map make you believe that immediate action is necessary to address climate change?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
		Not convincing at all	Slightly convincing	Moderately convincing	Very convincing	Extremely convincing
11.5.	How convincing do you find this map as evidence of climate change?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

12. Influence on Decision-Making and Actions

Please rate how this map influences your decision-making and actions.

	Not likely at all	Slightly likely	Moderately likely	Very likely	Extremely likely
How likely are you to take personal actions (e.g., reducing energy use, supporting climate policies) after viewing this map?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
How much does this map motivate you to learn more about the impacts of climate change?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Does this map encourage you to discuss climate change with others (e.g., friends, family)?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
How likely are you to share this map or similar visual information on social media to raise awareness of climate change?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

12.1.

13. NASA Task Load Index (TLX)

Please rate the level of effort and difficulty you experienced during this task.

	Not at all	Slightly	Moderately	Very	Extremely
How mentally demanding was the task of interpreting glacier retreat patterns on the map?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
How physically demanding was the task of interpreting glacier retreat patterns on the map?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
How hurried or rushed was the pace of the task of interpreting glacier retreat patterns on the map?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
How successful were you in accomplishing what you were asked to do?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
How hard did you have to work to interpret glacial retreat patterns on the map?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
How insecure, discouraged, irritated, stressed and annoyed were you while completing the task of interpreting the glacier retreat patterns on the map?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

13.1.

14. Six-Americas and Survey Feedback

Which of the following best describes your feelings and beliefs about climate change?

- "I am very concerned about climate change and think the government and individuals need to act now."
- "I am concerned and think we need to take action but we have time to decide what the appropriate responses should be."
- "I suspect climate change is happening but I am not certain. We have time to make careful decisions about when and whether to respond."
- "I have not really thought much about climate change."
- "I suspect climate change is NOT happening but I am not certain. I am concerned more about overreacting to climate change."
- "I do not believe climate change is occurring and certainly don't think humans have caused it. So, I am not motivated to take or support action to address it."

14.1.

Please feel free to write any comments you have for the researchers below:

14.2.