# Lines, Polygons, and Imagery: Comparing Map Designs for Communicating Glacial Retreat

**Jasper Fangsheng Zhou [1]* and Carolyn Fish [1]**

[1] Department of Geography, University of Oregon, Eugene, USA
* jasperz@uoregon.edu

**Keywords:** cartographic design, climate change communication, empirical user study, geovisualization map evaluation, glacier retreat

## Introduction

Glacier retreat is among the most visible and well-documented indicators of climate change, yet communicating glacial loss to general audiences remains a persistent challenge. Maps are widely used to convey spatiotemporal environmental change, but the design choices that shape those maps have rarely been evaluated for their cognitive and emotional effectiveness. Scientific accuracy alone does not guarantee effective climate change communication; the visual designs shaping that communication must also engage diverse audiences (Fish, 2020; Goudine et al., 2020).

This study addresses two primary research questions: (RQ1) How do map readers' perceptions of glacial retreat differ by map design? (RQ2) How do map readers' emotional responses vary depending on map design? To investigate these questions, we conducted a between-subjects online user study in which participants (n = 114) were randomly assigned to view one of three cartographic representations of glacial retreat: a Line map using colored boundary outlines, a Polygon map using semi-transparent filled extents, and an Imagery map using clipped orthophotos and satellite imagery. The glacier we used in this study was South Cascade Glacier (SCG) in Washington State in the United States. SCG is a USGS Benchmark Glacier with a continuous mass-balance record dating to 1959 (USGS, 2023).

This research contributes to the intersection of cartography, geovisualization, and climate change communication by empirically testing how distinct visual representations of the same geographic phenomenon influence both cognitive interpretation and affective response. Drawing on previous research (Lumley et al., 2022; MacEachren & Kraak, 2001; Montello, 2002; Richards, 2015), this study offers design guidance for cartographers and science communicators seeking to develop maps that are both informative and emotionally engaging.

## Methods

Participants (n = 114) were recruited via Prolific and required to be at least 18 years old, reside in the United States, and be fluent in English. The sample was majority White (~66%), predominantly aged 18 to 39 (~65%), and held an associate degree or higher

(81%). Using the Six Americas framework (Maibach et al., 2009), most self-reported themselves as either “Alarmed” or “Concerned” about climate change.

Three stimuli maps (Figure 1) of SCG retreat were developed in ArcGIS Pro 3.3.0, each depicting five time slices (1967, 1979, 1992, 2015, and 2023) while holding extent, scale, resolution, and orientation constant across designs. Glacier extents were digitized from orthoimagery and remotely sensed datasets sourced from the University of Washington Digital Glacier Time Machine (Knuth, 2022), Planet Labs, and Esri World Imagery Wayback. A 1-meter LiDAR-derived digital terrain model from the Washington LiDAR Portal was processed into a shaded relief base layer, providing consistent topographic context across all three designs. The Line map represented each glacier extent as a colored boundary outline. The Polygon map used semi-transparent filled extents to emphasize cumulative spatial change over time. The Imagery map clipped historical orthophotos and color satellite imagery to glacier boundaries, providing photorealistic visual context. Each participant saw just one of the map designs.

After viewing their assigned map, participants completed measures of: (1) awareness of glacial change, (2) connection to climate change (CCC), (3) perceived influence on climate-related actions, (4) map trust using the MAPTRUST scale (Prestby, 2024), (5) map attractiveness, and (6) emotional response via the Geneva Emotion Wheel (GEW; Scherer et al., 2013). Cognitive workload was assessed using the NASA Task Load Index (TLX; Hart & Staveland, 1988), and individual differences in analytical thinking were measured with the 18-item Need for Cognition scale (Cacioppo et al., 1984), which captures how much a person seeks out and enjoys effortful thinking through items such as preferring complex problems to simple ones. Statistical analyses included one-way ANOVA with Tukey HSD post-hoc tests for group comparisons, multiple linear regression using ordinary least squares (OLS) in R for modeling predictors of awareness and attractiveness, and ArcGIS Hot Spot Analysis (Getis-Ord Gi*, 110 m fixed distance band) applied to GEW response data to identify emotional clustering by participant characteristics.

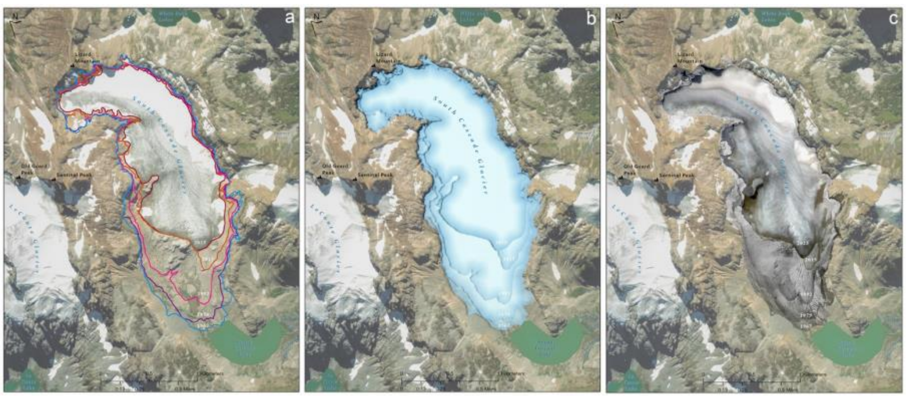

Figure 1: The three map designs tested in this study, showing South Cascade Glacier, Washington, United States: (a) Line, (b) Polygon, and (c) Imagery.

## Results

ANOVA revealed significant effects of map design on two of five outcomes (Figure *2*). Awareness of glacial change differed by condition, $F(2, 111) = 6.14$, $p = .003$, $\eta^2 = .10$. Tukey HSD comparisons showed that the Line map ($M = 4.24$, $SD = 0.54$) produced significantly higher awareness than the Imagery map ($M = 3.59$, $SD = 1.00$), $p = .002$, while the Polygon map ($M = 3.82$, $SD = 0.87$) differed significantly from neither. Attractiveness followed a related pattern, $F(2, 111) = 7.11$, $p = .001$, $\eta^2 = .11$, with both the Line map ($M = 3.82$) and the Polygon map ($M = 3.76$) rated more attractive than the Imagery map ($M = 3.03$), $p = .003$ and $p = .006$, and no difference between Line and Polygon. Map trust, connection to climate change, and perceived influence on climate-related actions showed no group differences (all $p > .27$).

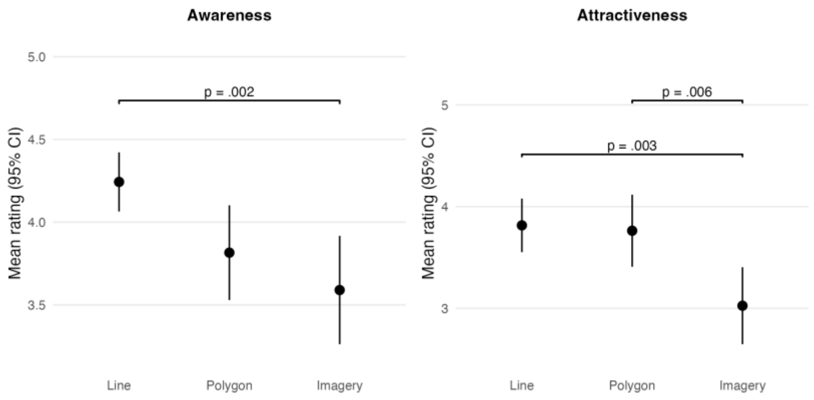


Figure 2: Mean awareness and attractiveness ratings by map design with 95% confidence intervals. Brackets mark significant Tukey HSD contrasts.

Regression models identified participant characteristics as independent predictors of both outcomes, with the Line map as the reference category. The awareness model (adjusted $R^2 = .21$) showed lower awareness for Imagery ($\beta = -0.66$, $p < .001$) and Polygon ($\beta = -0.36$, $p = .050$), and a negative association with Need for Cognition (NFC; $\beta = -0.40$, $p = .002$). Education contributed without a linear trend, since only the technical or associate degree group differed significantly from the lowest education band ($\beta = 2.01$, $p = .014$). The attractiveness model (adjusted $R^2 = .21$) showed lower ratings for Imagery ($\beta = -0.81$, $p < .001$), a negative NFC association ($\beta = -0.37$, $p = .022$), and a positive association with task load (TLX; $\beta = 0.37$, $p = .001$). Exploratory models adding map by NFC interaction terms improved fit for neither outcome (both $p > .28$).

The first-click responses on the GEW varied by map design (Figure *3*), and none of the three conditions was confined to negative emotions alone. The most frequently selected first click response came from the Polygon condition, where three participants selected Hope, which sits in the positive valence and high control quadrant of the GEW, at the wheel's highest intensity level. Line and Imagery responses spread across a wider mix of categories instead. Eleven of the 114 participants made no selection at all.

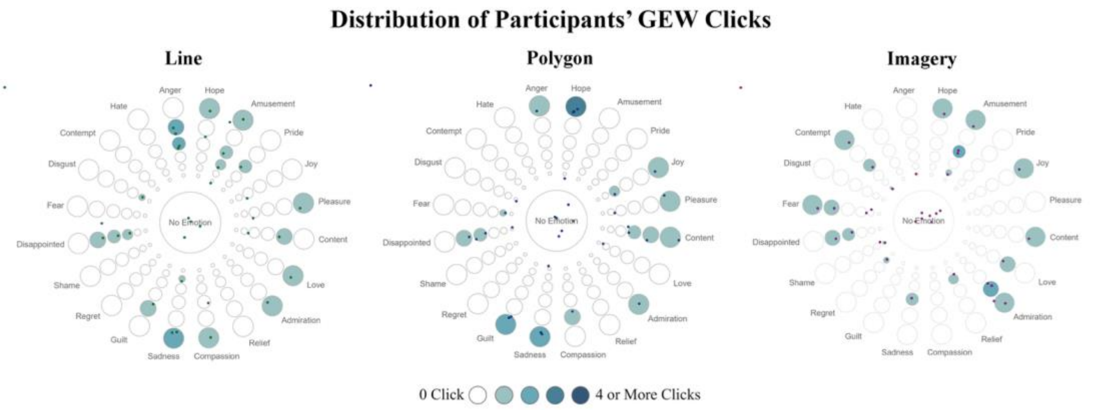


Figure 3: Geneva Emotion Wheel response distributions by map design, showing first-click frequency across the twenty emotion categories and the No Emotion center.

## Discussion and Conclusion

Cartographic design shapes how viewers interpret and emotionally engage with glacier retreat data, but the results show that cognition and emotional engagement do not necessarily work together. The Line map supported the clearest recognition of glacial change, which suggests that a spare boundary encoding is the easiest to read for change over time. Under the Polygon condition, Hope was the most often selected first click, though only three of 38 participants chose it, too small a difference to interpret confidently. The pattern is still worth pursuing in future research, since hope has been studied elsewhere in the climate literature (e.g., Swim & Bloodhart, 2015). Hope sits in the positive valence and high control quadrant of the GEW, suggesting the participants who chose it read the glacier's retreat as something they had some power to act on. The Polygon condition, however, showed no matching advantage in the awareness measures. The Imagery map, despite its photorealistic quality, produced both the lowest awareness and the lowest attractiveness ratings, indicating that realism alone does not guarantee effective communication of temporal change.

Participant characteristics predicted these outcomes independently of design. Education level and NFC were associated with awareness, while task load and NFC were associated with attractiveness. Participants with higher NFC reported lower awareness and gave lower attractiveness ratings, which suggests that more analytically oriented viewers applied greater scrutiny to the maps. Since the maps by NFC interaction terms were not significant, we describe these as parallel effects and not as moderation.

Three limitations constrain the scope of these results. First, all three stimuli share a LiDAR-derived shaded relief base layer, and the Polygon condition carries greater visual contrast than the other two, so representation type was not the only property that varied across conditions. Second, the sample was US-based, predominantly White, and already concerned about climate change, which bounds generalizability. Third, we applied uniform response anchors across all six NASA-TLX items rather than the original opposing anchors, so the Performance item runs counter to the other five and the composite workload score should be read with that adaptation in mind.

This study contributes to the literature on user-centered geovisualization by showing that cartographic choices shape both cognitive and emotional responses to environmental data, and that the design which communicates change most clearly is not necessarily the one that moves people. Future research should test three-dimensional and immersive approaches, extend evaluation to other climate phenomena, and recruit more demographically diverse samples.

## Acknowledgements

Financial support for this study was provided by the Center for Science Communication Research, the Rippey Grant from the Department of Geography, the Sandra F. Pritchard Mather Graduate Fellowship, the Everett G. Smith Graduate Scholarship, and the Climate Change and Environmental Justice Student Research Awards funded by the Andrew Mellon Foundation, all at the University of Oregon. The authors thank Alethea Steingisser and Dr. John Christian for their contributions to study design and glaciological context.

## References

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

Fish, C. (2020). 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

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

Knuth, F. (2022). Digital Glacier Time Machine. UW TACO Lab. https://uw-cryo.github.io/project/hsfm/

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.

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

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

Richards, D. (2015). Testing the waters: Local users, sea level rise, and the productive usability of interactive geovisualizations. Communication Design Quarterly, 3(3), 20–24. https://doi.org/10.1145/2792989.2792992

Scherer, K. R., Shuman, V., Fontaine, J. R. J., & Soriano, C. (2013). The GRID meets the Wheel: Assessing emotional feeling via self-report. In J. R. J. Fontaine, K. R. Scherer, & C. Soriano (Eds.), Components of Emotional Meaning (pp. 281–298). Oxford University Press.

Swim, J. K., & Bloodhart, B. (2015). Portraying the perils to polar bears: the role of empathic and objective perspective-taking toward animals in climate change communication. Environmental Communication, 9(4), 446–468. https://doi.org/10.1080/17524032.2014.987304

USGS. (2023). South Cascade Glacier. U.S. Geological Survey. https://www.usgs.gov/centers/washington-water-science-center/science/south-cascade-glacier