Disappearing glaciers of the Oregon Cascades, USA

Journal:	*Annals of Glaciology*
Manuscript ID	AOG-95-0506.R4
Manuscript Type:	Letter
Date Submitted by the Author:	n/a
Complete List of Authors:	Carlson, Anders; Oregon Glacier Institute Bakken-French, Nicolas; Oregon Glacier Institute Thayne, Megan; Oregon Glacier Institute Pappas, Sam; Oregon Glacier Institute Molnar, Daniela; Oregon Glacier Institute Rood, Dylan; Imperial College London,
Keywords:	Mountain glaciers, Glacier mapping, Climate change
Abstract:	The Oregon Cascades had 35 named glaciers on seven volcanos in the 1980s, with 34 of those glaciers remaining by 2000. Here we document the glaciers that fall into the Global Glacier Casualty List categories based on five years of field observations of these 34 glaciers. Five glaciers have disappeared, four have almost disappeared, and eight are critically endangered. Thus, half of the Oregon Cascade named glaciers have disappeared, almost disappeared, or reached critically endangered status in the 21st century. Between 1980 and 2024, the May-October ablation season of the Oregon Cascade region warmed at ~0.3°C per decade, with a 2020-24 mean temperature ~1.7°C warmer than the 1975-84 mean. In contrast, there was no significant trend in November-April accumulation season precipitation. Given the significant rise in melt-season temperature, we attribute ongoing glacier disappearance in the Oregon Cascades to the warming climate.

Disappearing glaciers of the Oregon Cascades, USA

Anders E. Carlson[1], Nicolas Bakken-French[1], Megan Thayne[1], Sam Pappas[1], Daniela Molnar[1], Dylan H. Rood[2]

[1]*Oregon Glaciers Institute, Corvallis, OR 97330, USA*

[2]*Department of Earth Science and Engineering, Imperial College London, London SW7 2AZ, UK*

Correspondence: Dylan H. Rood (d.rood@imperial.ac.uk)

The Oregon Cascades had 35 named glaciers on seven volcanos in the 1980s, with 34 of those glaciers remaining by 2000. Here we document the glaciers that fall into the Global Glacier Casualty List categories based on five years of field observations of these 34 glaciers. Five glaciers have disappeared, four have almost disappeared, and eight are critically endangered. Thus, half of the Oregon Cascade named glaciers have disappeared, almost disappeared, or reached critically endangered status in the 21st century. Between 1980 and 2024, the May-October ablation season of the Oregon Cascade region warmed at ~0.3°C per decade, with a 2020-24 mean temperature ~1.7°C warmer than the 1975-84 mean. In contrast, there was no significant trend in November-April accumulation season precipitation. Given the significant rise in melt-season temperature, we attribute ongoing glacier disappearance in the Oregon Cascades to the warming climate.

1. Introduction

Globally, glacier retreat has reached historically unprecedented rates (e.g., Zemp and others, 2015) in response to anthropogenic greenhouse gas emissions (Roe and others, 2021) that are predominately from the combustion of fossil fuels (Wolf and others, 2025). In western Canada and the United States, glaciers lost ~23% of their mass between 2000 and 2023 (The GlaMBIE Team, 2025). Such mass loss is resulting in glacier disappearance in the

United States' Pacific Northwest, including the state of Oregon (Fig. 1a) (e.g., Pelto, 2010; Fountain and others, 2023; Bakken-French and others, 2024; Pelto and Pelto, 2025).

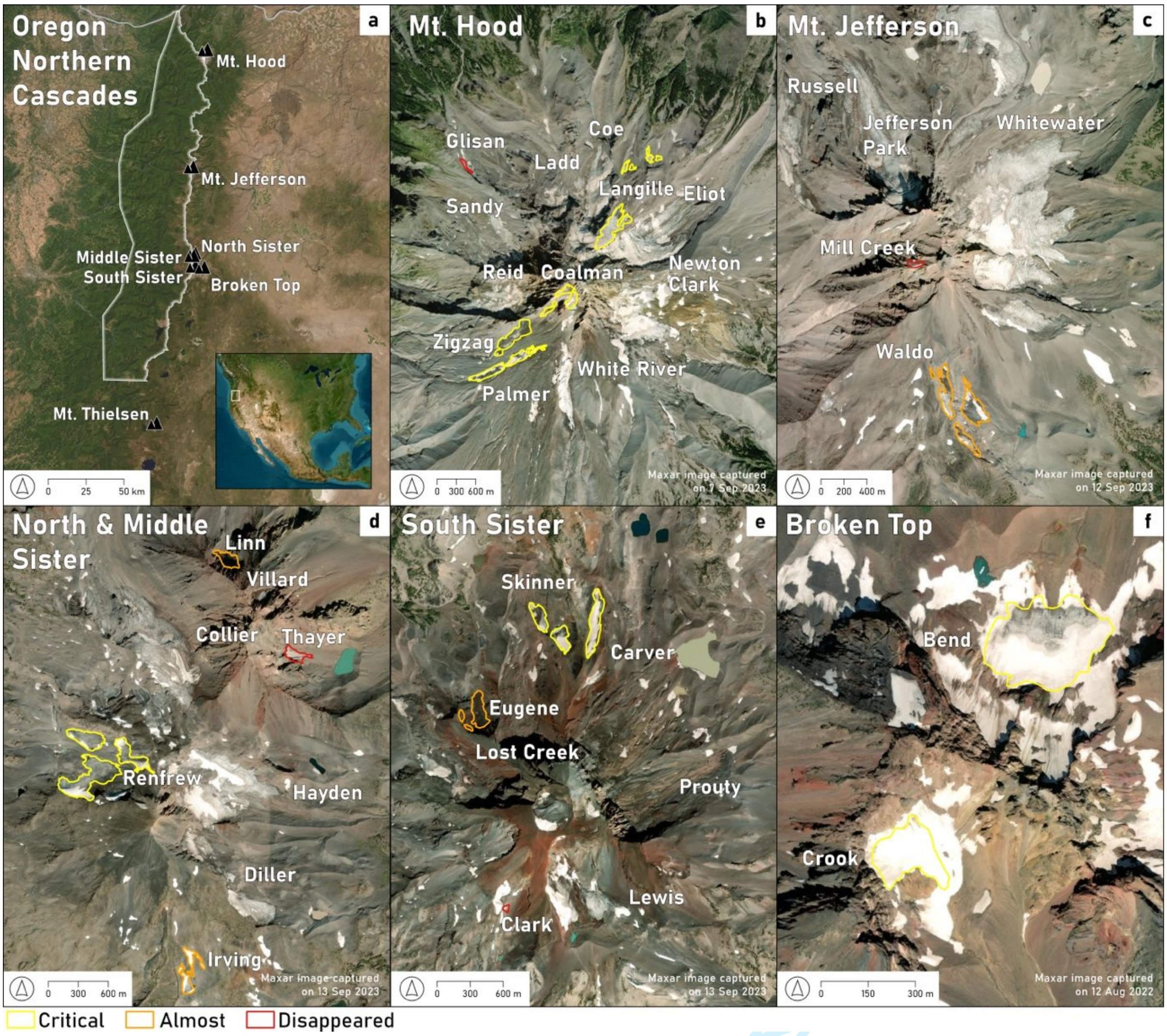

Figure 1. Location of Oregon glacierized volcanos (a) with inset showing location. Oregon North Cascade climate division outlined. Glaciers discussed in text for Mt. Hood (b), Mt. Jefferson (c), North and Middle Sisters (d), South Sister (e), and Broken Top (f). Glacier outlines were manually digitized from the imagery shown here, field mapping and supplemental Sentinal-2 imagery. In the case of (f), the imagery shown is from 12 Aug 2022, but the Broken Top glacier outlines were finalized using 19 Sep 2023 Sentinal-2 imagery due to lack of 2023 Maxar imagery for this volcano. Orange outline critically endangered; yellow outline almost disappeared; red outline disappeared. Imagery from ESRI (2024).

The Cascade volcanic range of the Pacific Northwest consists of 14 glacierized volcanos from northern California to Oregon, and then Washington. Based on the extinct glacier database of the Global Land Ice Measurements from Space (GLIMS) of the U.S.

National Snow and Ice Data Center (NSIDC), there are no reported extinct glaciers on Mt. Shasta in California as of 2025 (GLIMS and NSIDC, 2025; Raup and others, 2025). In Washington (excluding Mt. St. Helens due to its geologically recent eruption that impacted its glaciers), no glaciers are noted as extinct on Mt. Adams while two glaciers are gone in the Goat Rocks (a series of volcanic vents) and one glacier has disappeared on Mt. Rainier (GLIMS and NSIDC, 2025; Raup and others, 2025). While no glaciers are listed on extinct on Glacier Peak and Mt. Baker farther north in Washington, both have extinct glaciers that used to flow on ridges extending from the volcanos' flanks (one and three extinct glaciers, respectively) (GLIMS and NSIDC, 2025; Raup and others, 2025).

In the early 1980s, the Oregon Cascades had 35 named glaciers distributed across seven volcanos (Fig. 1a), with one glacier (Palmer Glacier; Fig. 1b) ceasing to flow on Mt. Hood by the 1990s (Fountain and others, 2023; Bakken-French and others, 2024). Fountain and others (2023) provided an updated inventory for the other 34 glaciers using remote sensing imagery from 2015, 2016, 2018, or 2020, but with no field observations to check imagery interpretation. As of 2015-20, six of the 34 glaciers that existed in 2000 were listed as no longer being glaciers (Fountain and other, 2023).

With 2020 as the most recent observation, which is for only one of the seven volcanos, the Fountain and others (2023) inventory missed the effects of post-2020 warmth (Bakken-French and others, 2024). This period includes one of the most extreme heatwaves ever recorded on Earth in late June 2021 (Thompson and others, 2022) that impacted glaciers in the Pacific Northwest (Pelto and others, 2022). In Oregon, glaciers are also experiencing increased rock fall and debris cover, necessitating field observations to accurately map glacier extent and confirm glacier flow (Bakken-French and others, 2024). Furthermore, remote-sensing-alone investigations that use snow/ice area to delineate between flowing glaciers and a perennial snowfield can mischaracterize features whereas field verification can directly determine such characterizations (Pelto and Pelto, 2025). Here using field observations, we document the Oregon Cascade named glaciers that have reached one of the three vanishing glaciers classifications of the Global Glacier Casualty List (GGCL; Boyer and Howe, 2024; Howe and Boyer, 2025).

2. Methods

We used field observations from August-October from 2020 through 2024 for the 34 glaciers on the seven glacierized volcanos in the Oregon Cascades (Fig. 1) to place them in the three classifications used by the GGCL: "critically endangered", "almost disappeared" and "disappeared" (Fig. 2) (Boyer and Howe, 2024). The categories are not precisely defined by the GGCL (Boyer and Howe, 2024), but Howe and Boyer (2025) defines a glacier to be critically endangered if it is predicted to expire by 2050. Here we use these three GGCL categories and define a "disappeared" glacier to be between a stagnant ice mass and complete absence. An "almost disappeared" glacier is expected to reach disappeared status any year now. A "critically endangered" glacier is expected to reach disappeared status by 2050. We note that our study is not a full glacier inventory for these volcanos, nor do these classifications correspond with the methodology for glacier inventories (Müller and others, 1977). Rather, we classify Oregon Cascade named glaciers within these GGCL categories based on our interpretation of these categories.

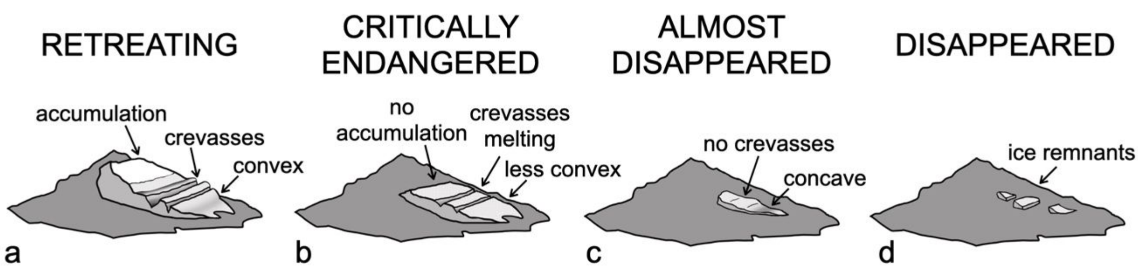

Figure 2. Graphic depicting glacier transition from a retreating (a) to critically endangered (b) to almost disappeared (c) to disappeared (d). Field-based characteristics noted.

Our criteria thus focused on determining if a glacier was still actively deforming and flowing under its own weight or had stagnated (Fig. 2). Evidence of flow were the presence of crevasses where we noted if the crevasses were being actively maintained open by flow (Fig. 2a, 3a) or were melting in on themselves, implying waning ice flow (Fig. 2b, 3b) (Leigh and others, 2019; Bakken-French and others, 2024; Pelto and Pelto, 2025). Termini were examined in the field. Termini were classified as either having a convex or concave topographic profile where the profile is defined as the cross-sectional view of elevation along the glacier flow line. A convex terminus was taken as indicating ice flow (Fig. 2a, 2b, 3a, 3c) while a concave terminus was used as evidence for the lack of ice flow (Fig. 2c, 3d) (Meier and Post, 1962; Leonard and Fountain, 2003; Lillquist and Walker, 2006; Leigh and others, 2019; Bakken-French and others, 2024). Each of these criteria was checked with high-resolution (0.3 m) Maxar (Vivid) imagery captured on 8 and 13 September 2023 for all of the volcanos except Broken Top where a 12 August 2022 was used (ESRI, 2024) (Fig. 1). Lastly, accumulation area ratios consistently smaller than 0.3 are indicative of glaciers that are no longer viable in the current climate (Fig. 2b, 3b) (Pelto, 2010). We thus mapped the area of any remaining prior-winter snow at the end of summer using Sentinal-2 satellite imagery provided in the application CalTopo (www.caltopo.com) and then calculated the accumulation area ratio by dividing by the area of the glacier.

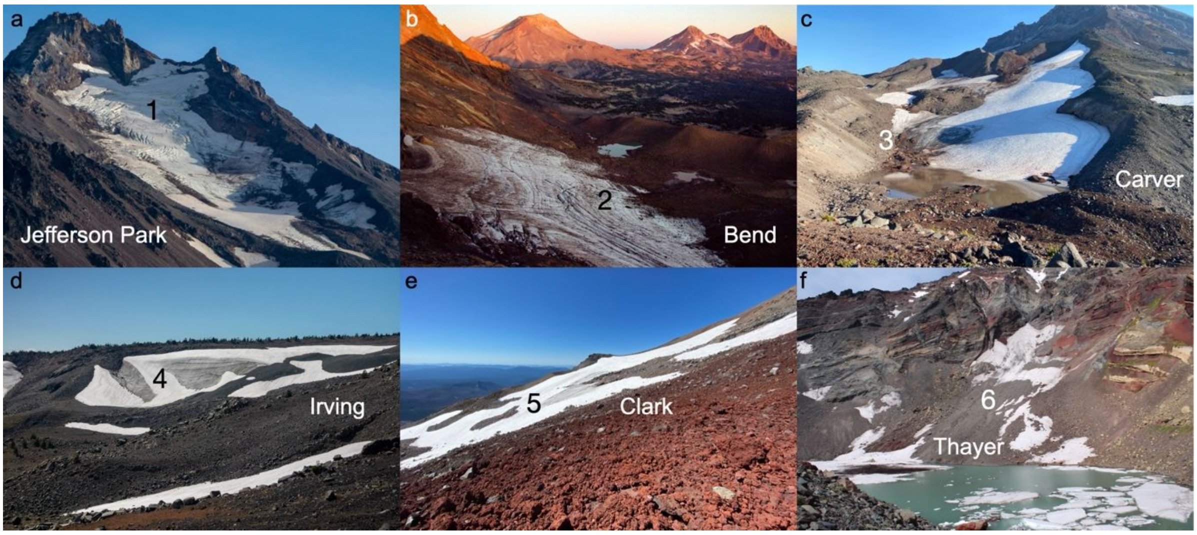

Figure 3. Example field observations used to place glaciers in GGCL categories. (a) Jefferson Park Glacier on Mt. Jefferson is an actively flowing glacier (1) that is retreating but not considered critically endangered. (b) Bend Glacier is critically endangered with crevasses melting in on themselves (2) and lacks an accumulation zone. (c) Carver Glacier is critically endangered with a convex terminus (3). (d) Irving Glacier has almost disappeared with a concave terminus and no crevasses (4). (d) Clark Glacier has disappeared and consists only of remnant patches of ice (5). (f) The basin that used to hold Thayer Glacier, which now has debris covering stagnant ice (6).

We placed a glacier in the disappeared status if its ice was completely gone or if it lacked evidence of flow (no crevasses and concave terminus), lacked an accumulation zone and the remaining ice was small, disconnected remnants to buried stagnant ice (Fig. 2d, 3e, 3f). An almost disappeared glacier lacked evidence of flow (no crevasses, concave terminus) and lacked an accumulation zone, but the remaining ice covered an area that still resembled its former flowing glacier area (Fig. 2c, 3d). A critically endangered glacier showed some evidence of flow with a convex terminus (Fig. 3c) or had crevasses, but the crevasses were remnants melting in on themselves (Fig. 2b, 3b) and the glacier lacked an accumulation area (Fig. 2b), or the accumulation area ratio was consistently below 0.3.

There is thus a clear demarcation between a critically endangered glacier that still flows (Fig. 2b) and an almost disappeared glacier that does not flow (Fig. 2c). We placed a glacier in the disappeared category if its ice was completely gone or if the remaining ice was small, disconnected remnants to just buried stagnant ice.

The 2023 extents of these glaciers (Fig. 1) were mapped over the course of five years following our methodology described in Bakken-French and others (2024). Specifically, we used late-summer Sentinal-2 satellite imagery from 2020, 2021, 2022, and 2023 to manually develop initial glacier outlines. We used manual digitization because of the debris cover on many of these glaciers (Paul and others, 2013). These outlines were subsequently revised iteratively by field mapping of termini during the late summers of 2020-23 when glacier termini were physically walked shortly after the Sential-2 satellite imagery was available. These Sentinal-2/field-based extents were finalized by manual digitation of 8 and 13 September 2023 Maxar imagery. The one exception is Broken Top (Fig. 1f), which lacked September 2023 Maxar imagery. We thus used 12 August 2022 Maxar imagery and then 19 September 2023 Sentinal-2 imagery to finalize the 2023 extents of Bend and Carver glaciers on Broken Top. In late summer 2024, field verification of the final 2023 outlines was conducted. Bakken-French and others (2024) estimated a conservative final area uncertainty for this iterative methodology of ±7% that we adopt here.

3. Climate Data

We assessed the changing regional climate using May-October average temperature and November-April cumulative precipitation for the Oregon Northern Cascades climate division of the U.S. National Oceanic and Atmospheric Administration (NOAA, 2025) (Fig. 1a). The Oregon Northern Cascade climate division is the climatic region encompassing the glacierized Oregon Cascade volcanos with the exception of Mt. Thielsen, which is only ~40 km south of the climate division. May-October is the maximum length of the melt season while November-April is the maximum length of the accumulation season in the Oregon Cascades (Bakken-French and others, 2024). We calculate the change in temperature from the 1975-1984 mean. We analyze these data for the period 1980 through 2024.

4. The Disappearing Glaciers

With Lathrop Glacier on its north face, Mt. Thielsen was the southernmost glacierized volcano in in the Oregon Cascades in the latter half the 20th century. Around the turn of the millennium, this small glacier was still present (Lafrenz, 2001) and a photo shared with us by M. Beagle (written communication 23 July 2021) indicated ice presence on 26 August 2012. Fountain and others (2023) listed Lathrop as gone as of an unknown date. Our visit in 2020 confirmed the disappearance of Lathrop Glacier (Table 1).

Table 1. Oregon Cascade named glaciers, and their GGCL category as of 2023-24. Data in columns Year, Area, and 2015-20 status from Fountain and others (2023). Note that the 2023 areas for Crook and Bend glaciers on Broken Top are based on 2022 Maxar imagery and 2023 Sentinal-2 imagery.

Volcano	Glacier	Lat	Lon	Year	Area (km²)	2015-20 Status	No Crevasses	Concave	Broken up	No Accum.	2023 Area (km²)	GGCL 2023-24 Category
Mt. Thielsen	Lathrop	43.155	-122.066	2018	0.000	Gone	-	-	-	-	-	Disappeared
Broken Top	Crook	44.080	-121.700	2018	0.051	Glacier		X		X	0.033	Critical
Broken Top	Bend	44.086	-121.693	2018	0.219	Glacier		X		X	0.084	Critical
South Sister	Clark	44.100	-121.776	2018	0.081	Snowfield	X	X	X	X	0.025	Disappeared
South Sister	Skinner	44.109	-121.773	2018	0.100	Snowfield				X	0.050	Critical
South Sister	Eugene	44.110	-121.780	2018	0.048	Glacier	X	X		X	0.034	Almost
South Sister	Carver	44.112	-121.767	2018	0.131	Snowfield				X	0.067	Critical
Middle Sister	Irving	44.137	-121.780	2018	0.068	Snowfield	X	X		X	0.033	Almost
Middle Sister	Renfrew	44.155	-121.792	2018	0.310	Glacier		X		X	0.215	Critical
North Sister	Thayer	44.164	-121.766	2018	0.000	Gone	X	X	X	X	0.022	Disappeared
North Sister	Linn	44.173	-121.775	2018	0.040	Glacier	X	X		X	0.025	Almost
Mt. Jefferson	Waldo	44.662	-121.797	2020	0.123	Glacier	X	X		X	0.097	Almost
Mt. Jefferson	Milk Creek	44.674	-121.808	2020	0.016	Glacier	X	X		X	0.006	Disappeared
Mt. Hood	Zigzag	45.366	-121.708	2015	0.351	Glacier		X		X	0.239	Critical
Mt. Hood	Coalman	45.371	-121.700	2016	0.099	Glacier		X			0.052	Critical
Mt. Hood	Langille	45.382	-121.690	2016	0.316	Glacier		X			0.169	Critical
Mt. Hood	Glisan	45.387	-121.709	2015	0.082	Glacier	X	X	X	X	0.009	Disappeared

Broken Top has two named glaciers: Bend and Crook (Fig. 1f). Fountain and others (2023) included these as glaciers in their inventory as of 2018. Our field observations place both glaciers as critically endangered because they consistently lack accumulation zones and have concave termini but do have crevasses that are melting in on themselves (Fig. 3b; Table 1).

South Sister had seven named glaciers that were flowing as of 2000 (Ohlschlager, 2015), four of which we place in the GGCL categories: Clark, Carver, Skinner, and Eugene (Fig. 1e; Table 1). Fountain and others (2023) listed Clark, Carver, and Skinner as snowfields in 2018 with Eugene being an active glacier. Whereas Clark has disappeared, with only small remnant of ice remaining as of 2020 (Fig. 3e), our field observations require revisions to the other three glacier statuses. In 2020, we found that Eugene lacked crevasses and had a concave terminus but still consisted of an intact ice body. As such, we place it in the almost disappeared category as it is not an actively flowing glacier but has yet to fragment into multiple remnant ice bodies. Conversely, both Carver and Skinner lack accumulation areas, but have convex termini (Fig. 3c) and crevasses that are melting in on themselves, implying potential ice flow. We list them as critically endangered.

Middle Sister had four named flowing glaciers in 2000 (Ohlschlager, 2015), of which two are in the GGCL categories: Irving and Renfrew (Fig. 1d; Table 1). Whereas Fountain and others (2023) listed Irving as a snowfield in 2018, glacier ice still remains although it does not flow. We place Irving as almost disappeared because this ice area is continuous but has a concave terminus and lacks crevasses and an accumulation zone (Fig. 3d). Fountain and others (2023) found Renfrew to still be a glacier in 2018. Renfrew has crevasses that are melting in on themselves, but its terminus is concave, and it has no accumulation zone. We thus consider Renfrew to be critically endangered.

North Sister also had four named flowing glaciers in 2000 (Fig. 1d) (Ohlschlager, 2015). Fountain and others (2023) listed Thayer Glacier as completely gone and we identify it as disappeared (Table 1), but we have found remnant stagnant ice that underlies debris (Fig. 3f). In contrast, Fountain and others (2023) documented Linn as an active glacier in 2018. By 2020, the glacier lacked crevasses and an accumulation zone, and its terminus was concave. Linn still is a continuous ice body and so we list it as almost disappeared (Table 1).

Mt. Jefferson had five glaciers with Fountain and others (2023) listing them all as active glaciers in 2020 (Fig. 1c). By 2023, we found that Milk Creek Glacier was almost entirely gone, or disappeared, with only a small, stagnant (~0.006 km^2) ice patch remaining (Table 1). Fountain and others (2023) also listed Waldo Glacier as active in 2020. Subsequently, Waldo has lacked crevasses and an accumulation zone and has a concave terminus. We thus consider Waldo to be almost disappeared, because it is still a contiguous ice body (Table 1).

For the 11 named glaciers on Mt. Hood that existed in 2000, we use our observations in Bakken-French and others (2024) to place four of them into the GGCL categories (Fig. 1b; Table 1). Glisan Glacier had stagnated by 2020, and we categorize it as disappeared because the glacier has broken up into a discontinuous ice body. Coalman, Zigzag, and Langille glaciers are all still flowing. However, all three have crevasses that are melting in on themselves and have concave termini. Zigzag lacks an accumulation zone, whereas Coalman and Langille have small (<0.3) accumulation zones. As such, we consider these three glaciers to be critically endangered.

5. Discussion and Conclusion

Based on our field observations, we place 17 of the 34 named glaciers that existed in the Oregon Cascades at some GGCL status (Table 1). This means that half of the Oregon Cascade named glaciers that existed in 2000 have now either disappeared (~15%), will disappear in the coming few years (~12%), or will disappear by 2050 (~24%).

When Palmer Glacier is included, ten named glacier in the Oregon Cascades have ceased to flow since 1990, nine of which occurred since 2010 (Fig. 4c). Six of these non-flowing glaciers have disappeared while another four have almost disappeared (Table 1). We consider the six disappeared glaciers as “extinct” in the terminology of GLIMS (Raup and others, 2025). These six lack evidence of ice flow and past ice flow (e.g., Fig. 3e, 3f), which is the definition of a glacier according to Cogley and others (2011). The four almost disappeared glaciers lack evidence of ice flow but contain visible folded ice layers indicative of past ice flow (e.g., Fig. 3d); these would not be considered extinct glaciers following Cogley and others (2011). However, using a definition that requires glaciers to have evidence of current movement would define the four almost disappeared glaciers as being “extinct”. As mentioned by Raup and others (2025), the transition from “glacier” to “extinct glacier” is complex and GLIMS follows the recommendation of the regional collaborators for registering a glacier as “extinct”. For comparison, three glaciers have been officially recorded as extinct on Washington’s Cascade volcanos, noting Mt. St. Helens’ recent eruptive impacts, and none have been officially reported for Mt. Shasta in California (GLIMS and NSIDC, 2025).

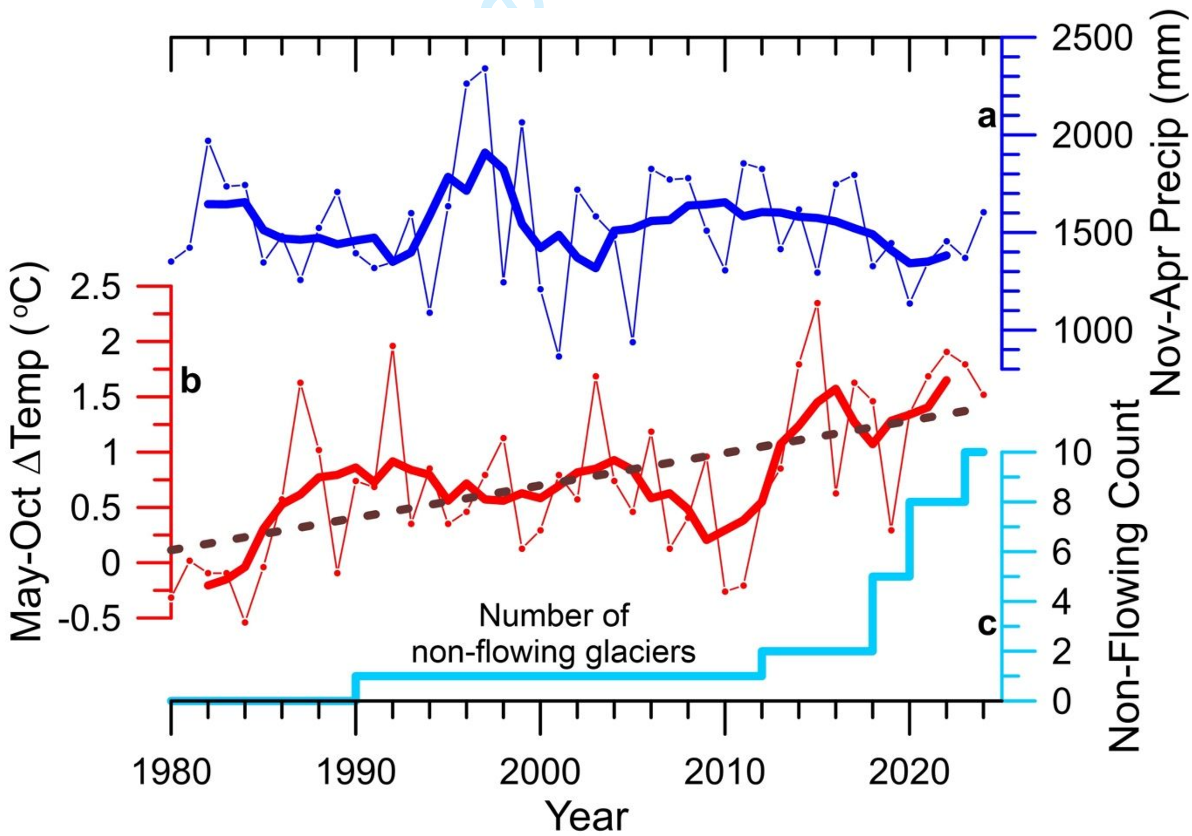

Figure 4. November-April precipitation (a) and May-October temperature change relative to 1975-84 mean (b) for the Oregon Northern Cascades climate division (NOAA, 2025). Symbols are yearly data,

thick lines are 5-year running mean, and dashed line is significant ($p<0.05$) trend. (c) Number of non-flowing glaciers in the Oregon Cascades.

The five glaciers that disappeared in the Oregon Cascades since 2000 have remnant stagnant ice bodies that range in area from 0.000 km^2 to 0.025 km^2, which are distributed across five volcanos from Mt. Thielsen in the south to Mt. Hood in the north (Table 1). The four almost disappeared glaciers have stagnant ice areas between 0.025 km^2 to 0.097 km^2, underlining their greater area relative to disappeared glaciers, despite both categories lacking evidence of current ice flow. These four almost disappeared glaciers are restricted to one on each of the Three Sisters volcanos and on Mt. Jefferson. The eight critically endangered glaciers have areas of 0.033 km^2 to 0.239 km^2, which overlaps with almost disappeared glaciers, showing how glacier area alone is not sufficient to distinguish between a flowing glacier and an ice mass that used to flow (Pelto and Pelto, 2025). These eight critically endangered glaciers are distributed across the Oregon Cascade glacierized volcanos, spanning from Broken Top to Mt. Hood, but with North Sister lacking a glacier in this GGCL category.

May-October average temperature for the Oregon Northern Cascade climate division (Fig. 1a) has significantly ($p=0.0002$) warmed at ~0.3°C per decade from 1980 through 2024 (Fig. 4b). The 2020-24 May-October mean was ~1.7°C significantly ($p<0.0001$) warmer than the 1975-84 mean. Conversely, there was no significant ($p=0.6353$) trend in November-April precipitation (Fig. 4a). While the precipitation amount has not significantly changed ($p=0.4240$), spring (e.g., April) heatwaves in the Pacific Northwest have increased since the 1990s, which can reduce snowpack accumulation (Musselman and others, 2021; Reyes and Kramer, 2023).

Given the statistically significant trend in May-October temperature, we attribute the glacier retreat in the Oregon Cascades to increasing temperature, including the impact of spring heat on snowpack, that has moved half of their named glaciers into a GGCL category and caused ten glaciers to stagnate, nine of which occurred after 2010 (Fig. 4c). This temperature-control on glacier retreat is similar to what Bakken-French and others (2024) found for overall glacier recession on Mt. Hood since 1900 and what Roe and others (2021) demonstrated for glacier recession in general. We conclude that glacier retreat and disappearance will continue in the Oregon Cascades until this warming trend is reversed.

Acknowledgements

We thank the U.S. National Forest Service for permitting research access to wilderness areas. Research was supported by a Mazamas Mountaineering Club conservation grant. The Oregon Glaciers Institute is a 501-c-3 nonprofit supported by private donations. We also thank two reviewers for their insights that improved this manuscript along with the Associate Chief Editor L. Andreassen and Scientific Editor L. Ruiz. All data in this manuscript are available upon request to the authors and will be available in the GLIMS Glacier Viewer ((https://www.glims.org/maps/glims).

References

Bakken-French N, Boyer SJ, Southworth BC, Thayne M, Rood DH and Carlson AE (2024) Unprecedented 21st century glacier loss on Mt. Hood, Oregon, USA. *The Cryosphere*, **18**, 4517-453

Boyer D and Howe C (2024) Global Glacier Casualty List. DOI: 10.25613/CZJA-9V56 www.glaciercasualtylist.rice.edu (last access 1 July 2025)

Cogley J and 10 others (2011) Glossary of glacier mass balance and related terms. *Technical Report 86*, IHP-VII Technical Documents in Hydrology, IACS Contribution No. 2, UNESCO-IHP

ESRI (2024) World Imagery Basemap. https://services.arcgisonline.com/ArcGIS/rest/services/World_Imagery/MapServer (last access: 2 February 2025)

Fountain AG, Glenn B and Mcneil C (2023) Inventory of glaciers and perennial snowfields of the conterminous USA. *Earth Syst.Sci. Data*, **15**, 4077-4104

The GlaMBIE Team (2025) Community estimate of global glacier mass changes from 2000 to 2023. *Nature*, **639**, 382-388

GLIMS and NSIDC (2025). Global Land Ice Measurements from Space Database, Compiled and Made Available by the International GLIMS Community and the National Snow and Ice Data Center. https://doi.org/10.7265/N5V98602 (last access 1 July 2025)

Howe C and Boyer D (2025). Social impacts of glacier loss. *Science*, **388**, 914-915

Lafrenz MD (2001) The Neoglacial History of Mt. Thielsen, Southern Oregon Cascades. *Portland State University Dissertations and Theses*, paper 2429

Leigh JR, Stokes CR, Carr JR, Evans IS, Andreassen L and Evans DJA (2019) Identifying and mapping very small (< 0.5 km2) mountain glaciers on course to high-resolution imagery. *J. Glaciol.*, **65**, 873-888

Leonard KC and Fountain AG (2003) Map-based methods for estimating glacier equilibrium-line altitudes. *J. Glaciol.*, **49**, 329-336

Lillquist K and Walker K (2006) Historical Glacier and Climate Fluctuations at Mount Hood, Oregon. *Arct. Antarct. Alp. Res.*, **38**, 399-412

Meier MF and Post A (1962) Recent variations in mass budgets of glaciers in western North America. *International Association of Hydrologic Science*, **58**, 63-77

Müller F, Caflisch T and Müller G (1977) Instructions for Compilation and Assemblage of Data for a World Glacier Inventory. *Temporary Technical Secretariat for World*

Glacier Inventory, International Commission on Snow and Ice, https://wgms.ch/downloads/Mueller_etal_UNESCO_1977.pdf

Musselman KN, Addor N, Vano JA and Molotch NP (2021) Winter melt trends portend widespread declines in snow water resources. Nature Climate Change, **11**, 418-424

NOAA (2025) Climate at a Glance. https://www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/divisional/time-series/ (last access 1 July 2025)

NSIDC (2025) Glacier. https://nsidc.org/learn/cryosphere-glossary/glacier (last access 7 November 2025)

Ohlschlager JG (2015) Glacier Change on the Three sisters Volcanoes, Oregon: 1900-2010. *Portland State University Dissertations and Theses*, paper 2488

Paul F and 19 others (2013) On the accuracy of glacier outlines derived from remote-sensing data. *Ann. Glaciol.*, **54**, 171-182

Pelto MS (2010) Forecasting temperate alpine glacier survival from accumulation zone observations. *The Cryosphere*, **4**, 67-75

Pelto MS and Pelto J (2025) The Loss of Ice Worm Glacier, North Cascade Range, Washington USA. *Water*, **17**, 432

Pelto MS, Dryak M, Pelto J, Matthews T and Perry LB (2022) Contributions of Glacier Runoff during Heat Waves in the Nooksack River Basin USA. *Water*, **14**, w14071145

Raup R, Andreassen LM, Boyer D, Howe C, Pelto M and Rabatel A (2025) Tracking Extinct Glaciers in GLIMS. *Ann. Glaciol.*, **66**, accepted

Reyes L and Kramer MG (2023) High-elevation snowpack loss during the 2021 Pacific Northwest heat dome amplified by successive spring heatwaves. npj Climate and Atmospheric Science, **6**, 208

Roe GH, Christian JE and Marzeion B (2021) On the attribution of industrial-era glacier mass loss to anthropogenic climate change. *The Cryosphere*, **15**, 1889-1905

Wolf S and 11 others (2025) Scientists' warning on fossil fuels. *Oxford Open Climate Change*, **5**, kgaf011

Zemp M and 36 others (2015) Historically unprecedented global glacier decline in the early 21st century. *J. Glaciol.*, **61**, 745-762

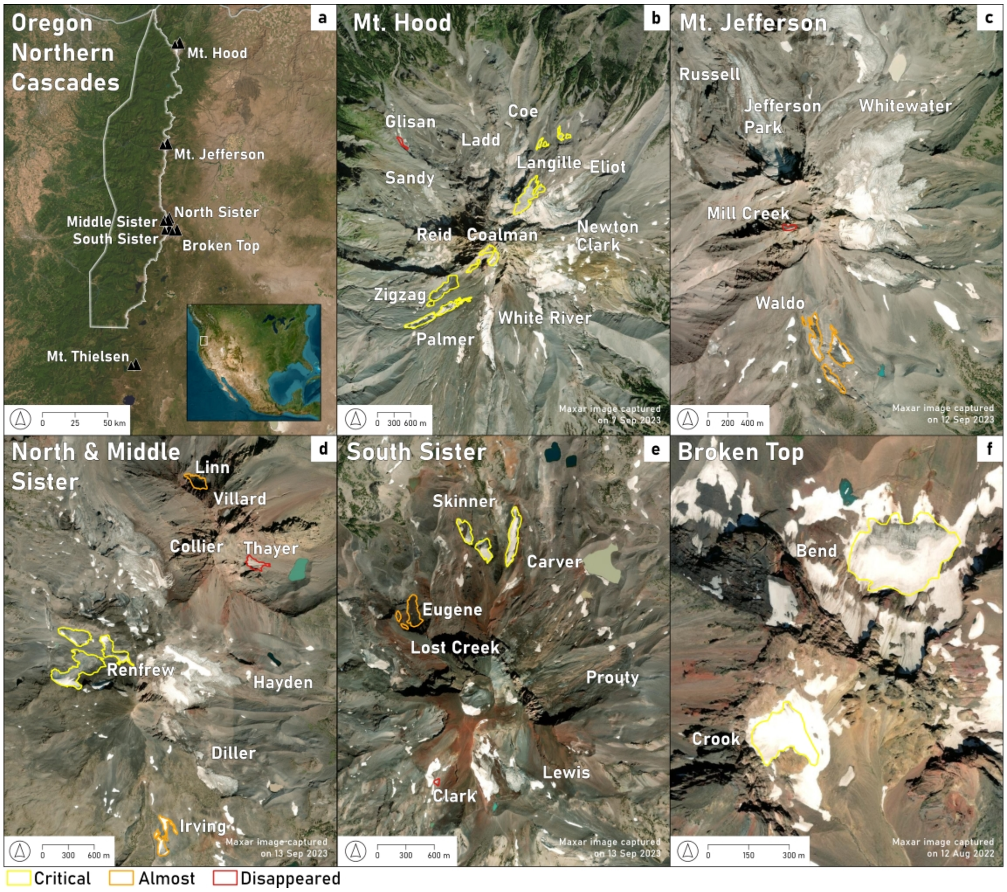

Figure 1. Location of Oregon glacierized volcanos (a) with inset showing location. Oregon North Cascade climate division outlined. Glaciers discussed in text for Mt. Hood (b), Mt. Jefferson (c), North and Middle Sisters (d), South Sister (e), and Broken Top (f). Glacier outlines were manually digitized from the imagery shown here, field mapping and supplemental Sentinal-2 imagery. In the case of (f), the imagery shown is from 12 Aug 2022, but the Broken Top glacier outlines were finalized using 19 Sep 2023 Sentinal-2 imagery due to lack of 2023 Maxar imagery for this volcano. Orange outline critically endangered; yellow outline almost disappeared; red outline disappeared. Imagery from ESRI (2024).

510x451mm (300 x 300 DPI)

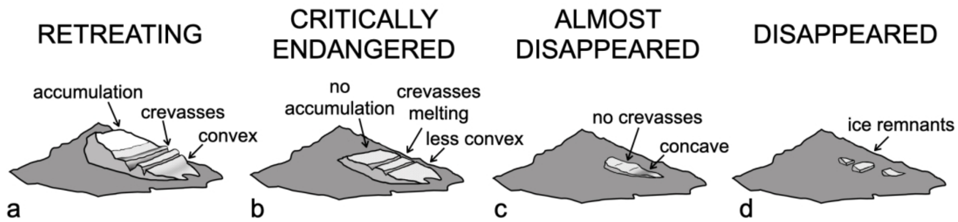

Figure 2. Graphic depicting glacier transition from a retreating (a) to critically endangered (b) to almost disappeared (c) to disappeared (d). Field-based characteristics noted.

677x152mm (72 x 72 DPI)

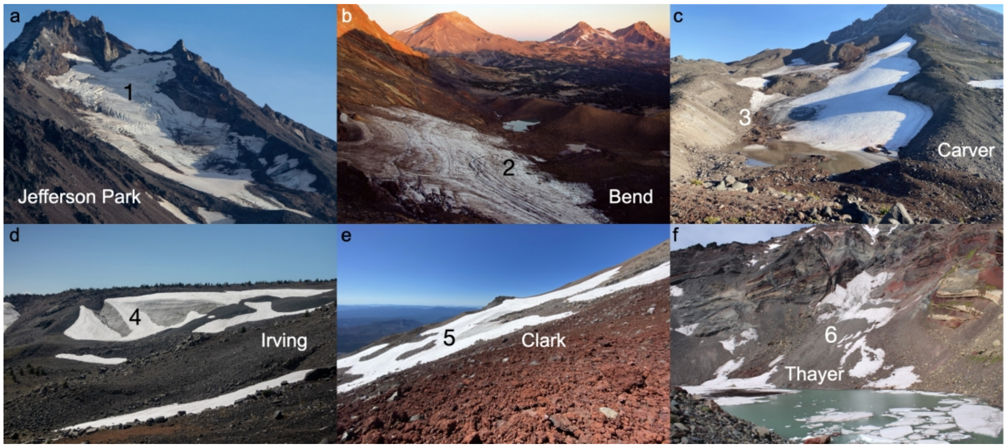

Figure 3. Example field observations used to place glaciers in GGCL categories. (a) Jefferson Park Glacier on Mt. Jefferson is an actively flowing glacier (1) that is retreating but not considered critically endangered. (b) Bend Glacier is critically endangered with crevasses melting in on themselves (2) and lacks an accumulation zone. (c) Carver Glacier is critically endangered with a convex terminus (3). (d) Irving Glacier has almost disappeared with a concave terminus and no crevasses (4). (d) Clark Glacier has disappeared and consists only of remnant patches of ice (5). (f) The basin that used to hold Thayer Glacier, which now has debris covering stagnant ice (6).

920x406mm (72 x 72 DPI)

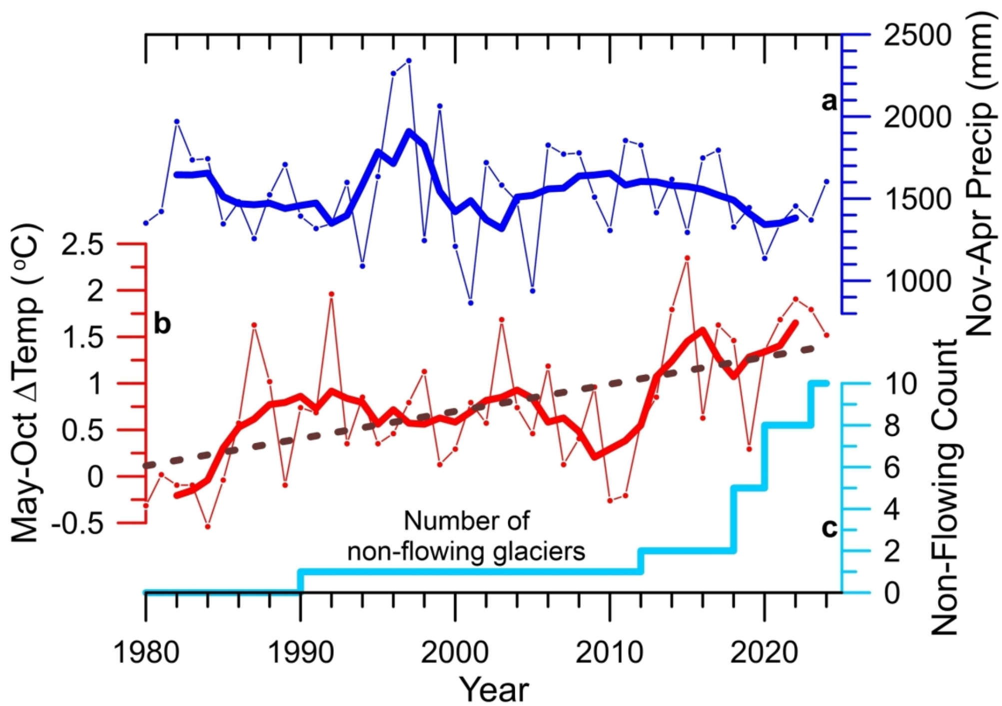

Figure 4. November-April precipitation (a) and May-October temperature change relative to 1975-84 mean (b) for the Oregon Northern Cascades climate division (NOAA, 2025). Symbols are yearly data, thick lines are 5-year running mean, and dashed line is significant ($p<0.05$) trend. (c) Number of non-flowing glaciers in the Oregon Cascades.

182x127mm (300 x 300 DPI)