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Glacier or Not? The Importance of Nuance in Definitions of Vanishing Glaciers

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ABSTRACT. Glaciers provide critical ecosystem services, including water resources, biodiversity, cultural value, and climate signals. But what makes a glacier a glacier? Different definitions of what characterizes a glacier can conflict with each other. While a common scientific definition emphasizes "past or present flow," practical applications involve various criteria like minimum area, relative size, and observable ice flow or thickness. Increasingly, glacier inventories are applying multiple criteria, acknowledging the nuanced, continuous nature of glacier retreat rather than a simple binary transition. In the context of increasingly melting, shrinking, and vanishing glaciers, it is important to explore glacier definitions and their applications. Ultimately, the glacier definition applied depends on the specific context and purpose, highlighting the need for clear communication and localized expertise in considering glacier survival and loss.

INTRODUCTION

Glaciers are integral parts of our world. As we move towards a world with less ice, in addition to vanishing charismatic symbols of climate change, we also lose glaciers' important ecosystem services (Huss and others, 2017). Despite glaciers' multifaceted societal contributions, there is a clear consensus that the world will lose much of its ice global glacier volume, and that the extent of this loss is dependent on the emissions and warming pathways that society chooses in the future (e.g., Rounce and others, 2023; Zekollari and others, 2025).

Global glacier volume change estimates (Zemp and others, 2025) are dominated by changes to larger glaciers, but accelerating reductions in global glacier ice volume will also necessarily mean the disappearance of many existing smaller glaciers. When does that transition from glacier to not-a-glacier happen? How do we consider or talk about this transition? Is this simply an academic question or does it have real-world impacts? In the context of the United Nations declaring 2025 as the International Year of Glaciers' Preservation, this paper will explore these questions.

IMPORTANCE OF VANISHING GLACIERS

No matter what a glacier's end looks like, deglaciation has enormous impacts. Smaller glaciers, while diminutive, are critical components of the cryosphere. As glaciers recede and vanish, impacts will be felt differently nearest to their (former) locations versus downstream, and some impacts will be gradual while others are step changes. Shrinking and vanishing glaciers, in particular, are important to consider for their highly varied roles, including:

Water Resources: Small glaciers serve an important role in buffering and smoothing variability in interseasonal and interannual water resources (e.g., Schuster and others, 2025; Ultee and others, 2022) whether for agricultural, hydropower, or other uses. At different stages of glacial retreat, glacier recession and disappearance can either increase or decrease available water resources, as well as change sediment and nutrient loading and water quality of meltwater and runoff.

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Biodiversity: Glaciers are unique ecological niches themselves, and they also contribute to lower air and water temperatures and unique nutrient conditions downstream; changing the glacierized proportion of catchments impacts downstream ecosystems in glacial streams as well (e.g., Sudlow and others, 2023; Tsuji and others, 2022). In addition, as glaciers vanish, new ecosystems emerge (Bosson and others, 2023).

Archaeology: As glaciers shrink and vanish, they can uncover unique records of the past. From mummies like Austria's Ötzi to arrows and other tools in Norway and Alaska, vanishing ice can expose treasures, with glaciers' status leading archaeologists to search in particular areas (e.g., Caspari and others, 2023).

Cultural Value: The disappearance of glaciers leaves voids in culture and heritage, including recreation, tourism (both through last-chance tourism and loss of destinations), identity, religion, and more (e.g., Altemus Cullen and others, 2025; Cruikshank, 2007; Huss and others, 2017; Jackson, 2015b).

Communication and Advocacy: Glacier recession and disappearance can be an important tool in climate change communication and environmental advocacy.

Legal Protections: Some glaciers are specially protected natural resources, and so the specifics of glacier definitions in the law can have great significance (Fernández and others, 2021). As of publication, Argentina still retains the world's only glacier protection law, which limits industrial activity on or near glaciers; however, a respected Argentine glaciologist was indicted related to creation of the mandated national industry despite it being in compliance with international norms and standards (Fraser, 2017). Although glacier protection legislation was drafted and eventually rejected in Kyrgyzstan and Chile, Chilean glaciers are protected through broader environmental impact assessment processes (Rivera, 2022), and Swiss and Russian civil codes include their own forms of glacier protection via other environmental protections (Cox, 2016).

Hazards: As glaciers recede and vanish, they leave unstable terrain in their wake, increasing the potential for a variety of geohazards (e.g., Walden and others, 2025). Ironically, there are there are potential conflicts between glacier protection legislation and managing glacial hazards related to glacier retreat and disappearance (Anacona and others, 2018).

Clearly, there are many reasons to focus attention on vanishing glaciers, encouraging glaciologists to characterize and identify that process and/or point of transition.

RECOGNIZING VANISHING GLACIERS

There are a range of ways that both scientists and society more broadly are acknowledging vanishing glaciers. At the international level, glacier databases are now including former glaciers in their datasets (GLIMS Consortium, 2005), maps are literally having to be redrawn in response to glacier disappearance (e.g., Poll and Buricelli, 2022; Sigurðsson and others, 2017), and the Global Glacier Casualty List was started in 2024 to share stories of vanished glaciers in a dynamic, web-based format (Boyer and Howe, 2024). To communicate the threat to glaciers and their expected fates, Glacier Loss Day is observed when glaciers transition to a net negative mass balance (Voordendag and others, 2023).

Increasingly, the emotional component of glacier loss, and climate change more broadly, is also being recognized. Albrecht and others (2007) articulate the concept of solastalgia as "the distress that is produced by environmental change impacting on people while they are directly connected to their home environment," in opposition to nostalgia which is when people have been separated from their home environment. Relatedly, Cunsolo and Ellis (2018) define ecological grief as "emotional responses to climate change and the impacts of climate change," which may be in response to either current loss or anticipated future losses. When we mourn the death of glaciers, though, we aren't just thinking about water and nutrients; glaciers are also representative sentinels of human-caused climate change. In alignment with the desire to mourn glacier loss, people around the world have held glacier funerals and memorials in Iceland (2019), Switzerland (2019), the United States (2020), Austria (2023), France (2023), and Nepal (2025) to mark and solemnize the disappearance of glaciers.

GLACIER DEFINITIONS

As befits fundamental questions in understanding landscapes and environmental processes, it is important to be clear about what constitutes a glacier. However, while defining a glacier might seem straightforward, there is a surprising amount of ambiguity. Cogley and others (2011) document a community-consensus definition of "a perennial mass of ice, and possibly firn and snow, originating on the land surface by the recrystallization of snow or other forms of solid precipitation and showing evidence of past or present flow." Flow, as defined by Cogley and others (2011), includes both international deformation and basal sliding.

Clarke (1987) agrees with many glaciologists in stating that, "The most interesting property of glaciers is that they flow." However, the inclusion of past flow in Cogley and others' definition means that some features may retain their status as "glacier" even if they might not have it applied anew. Put another way, according to the Cogley and others (2011) definition, ice must start flowing to become a glacier, but it doesn't have to keep flowing to stay a glacier. Post and LaChapelle (1971) also pose the question in two directions: "When does a snowfield reach a sufficient size to become a glacier? Or, conversely, when does a retreating glacier cease to be one?" As glaciologists, they discuss both physical ice properties and evidence of current flow, while acknowledging that geomorphologists might point to evidence like moraines or glacial striae. This opens the door to evidence of past flow and ultimately contradictory definitions of a glacier. Practically, the definitions which include past flow can both allow glaciers to not lose their status as quickly and also potentially allow for a glacier to re-grow without needing to change its status, at the expense of not requiring what some glaciologists consider to be a fundamental characteristic. As in many things, context matters in defining a glacier.

Glacier Definitions in Practice

Where theory meets the real world, practical, pragmatic definitions of glaciers are required. In this section, I attempt to provide examples of widely applied methods of glacier definitions by glaciologists. Some of these criteria are objective, others are more subjective, and the application of applying particular criteria is a nuanced decision itself. There is, however, a consistent thread of recognizing the importance of local knowledge and context and deferring to local glaciologists in determining what criteria to apply when identifying glaciers and/or declaring them gone (e.g., Boyer and Howe, 2024; GLIMS Consortium, 2005).

Area

Many glacier inventories adopt an area-based threshold for glacier identification, as well as declaring glaciers as no-longer-glaciers. In addition to a minimum glacier area, size thresholds have been used to categorize glaciers; glacierets are smaller glaciers, typically defined as under 0.25 km^2 (Cogley and others, 2011; Ugalde and others, 2025), and “very small glaciers” are under 0.5 km^2 (Huss and Fischer, 2016). Ultimately, minimum-area based glacier definitions are a solution to practical issues raised by using remote sensing in glacier inventories. The selection of a glacier area threshold balances both glaciological factors and technological limitations.

These minimum glacier areas range widely, from 0.1 km^2 (USGS, 2022) and 0.09 km^2 (Selkowitz and Forster, 2015) down to 0.005 km^2 (Huss and Fischer, 2016) and 0.001 km^2 (Ugalde and others, 2025), the latter sometimes applying additional criteria. By far, the most common area threshold for glacier identification is 0.01 km^2 (e.g., Baumann and others, 2021; Barcaza and others, 2017; He and Zhou, 2022; Linsbauer and others, 2021; Paul and others, 2023; Pelto, 2008; Pfeffer and others, 2014; Tielidze and others, 2022; Way and others, 2014), with many surveys referencing a set of community recommendations (Paul and others, 2009). Some surveys choose to use higher thresholds like 0.05 km^2 (Bevington and Menounos, 2022; Bolch and others, 2010) and 0.09 km^2 (Selkowitz and Forster, 2015) in order to reduce the inclusion of non-glaciers at the expense of excluding very small glaciers; the latter also included a multitemporal requirement.

Relative Size. In addition to absolute area, some approaches use relative size to determine glacier disappearance. For example, Huss and Fischer (2016) "define the disappearance date of very small glaciers as the year in which their area is either <3% of their extent in 2010, or <0.005 km^2." Similarly, the Goodbye Glaciers Project (2025) provides outreach materials and defines glaciers as "mostly gone ... when either less than 10% of the glacier's 2020 volume or less than 0.01 km^3 is expected to remain - whichever threshold is crossed first."

Ice Flow and Thickness

Some definitions of glaciers require current movement to qualify as a glacier. A requirement of current ice flow would imply a glacier definition based upon measurable movement and/or some theoretical combination of minimum glacier thickness (30 m for pure ice, Cuffey and Paterson, 2010) and surface slope.

On the theoretical side, glaciers and perennial snowfields have been distinguished by estimating the ice basal shear stress using topographical measurements (Fountain and others, 2017). Using observations, Arie and others (2025) use thickness and flow to determine that two previously identified perennial snow patches are actually glaciers in the Japanese Alps. In Iceland, Hannesdóttir and others (2020) used DEMs to identify flowing vs non-flowing ice, and in Chile remote sensing methods were also used to identify glaciers and rock glaciers as flowing (Falaschi and others, 2025), also implementing a minimum area of 0.01 km^2. It is not uncommon to combine thickness and flow with area, with the USGS (2018) discussing size as a proxy for thickness and flow. Hartz and Carlson (2020) also regress thickness and glacier area to align a minimum thickness with minimum area for implementation.

Conversely, depth and lack of ice flow were used to determine that Uganda's Mount Speke no longer hosts a glacier (Dieckman, 2025), and lack of flow was used to declare the Southern Schneeferner as no longer a glacier (der Wissenschaften, 2022). Direct observations of stagnation caused Yosemite National Park's Lyell Glacier to be downgraded in 2013, with its neighbor the Maclure Glacier still demonstrating movement by sliding but not deformation (Miller, 2013; NPS, 2013).

Multiple Factors, Scorecards, and Checklists

While Pelto and Pelto (2025) summarized the demise of the Iceworm Glacier as insufficient to generate movement, multiple factors were identified as contributors, including thinning but also including crevasses and other melt features extending through to the bed and an ice cave traversing the full length of the glacier. Increasingly, glaciologists are pointing to a convergence of observations and proxies to identify vanishing glaciers in a range of complex environments.

The first of these was Leigh and others (2019), also partially applied by others (e.g., Andreassen and others, 2022), who identified "certain," "probable," or "possible" glaciers using weighted criteria including identifying crevasses, flow features/deformed stratification, multiple debris bands in ice, visible ice, a bergschrund, moraine, and/or unbroken snow accumulation with possible convexity. Similarly, Izagirre and others (2024) require a minimum number of 2 to 3 features demonstrating the demise of a glacier, including an absence of crevasses, melting processes leading to collapse, water incisions in the ice, disconnection of the accumulation area, no (false) bergschrund, debris cover, and fragmentation in relict ice bodies. In applying these criteria, Izagirre and others (2024) identified eight ice masses as no longer classified as glaciers, and one more nearby glacier has also since been added to that list (Revuelto and others, 2025). Most recently, Ugalde and others (2025) developed a schema to classify possible glaciers in Chile by using a decision tree based upon surface conditions and morphological context to categorize glaciers as either "extant," "presumably vanished," or "entirely vanished."

This transition from a glacier to a dead glacier can be messy. Thanks to varying topography, precipitation, melt, and other local characteristics, the death of a glacier looks different in each case. Approaches using multiple criteria are perhaps more accurate than others as they consider individual glaciers and reflect their varying local conditions. However, they are also more time consuming and depend on data availability, which can limit their usage. In addition, while these schemas follow a consistent structure, they provide guidelines moreso than strict definitions and therefore still leave open some uncertainty. The application of particular criteria can also conform with different definitions of glaciers which require evidence of past and/or present flow. Interestingly, based upon the needs of different use cases, they take two opposite approaches of either accumulating evidence to identify a glacier as existing (Leigh and others, 2019) or identify a glacier as vanished (Izagirre and others, 2024; Ugalde and others, 2025).

IF NOT A GLACIER, THEN WHAT?

The identification of glaciers implies the existence of non-glaciers, and so it begs the question of what a glacier may be called once it is no longer a glacier but before its ice completely vanishes. So, if it isn't a glacier, these are a few terms that might apply (acknowledging this is in an English language context and some terms may or may not translate well to other language contexts):

Terms Including "Ice": Serrano and others (2011) discuss a glacier in Spain transitioning into an "ice patch" (of glacial origin) as it no longer flows under its own weight, as do Securo and others (2025) in the Dolomites. Note that the term "ice patch" has also been used in non-glacial contexts (e.g., Davesne and others, 2023). Similarly, Cogley and others (2011) allow for the use of the terms "ice body" or "ice mass," which is a very inclusive all types of ice, but has been applied in glacial contexts (e.g., Way and others, 2014).

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Remnant: The terms "glacier remnant" and "remnant glacier" have been used (e.g., Field, 1947) and continue to be used colloquially in cases of significant deglaciation. These terms explicitly address the glacial source of ice bodies; the former implies that the ice mass is no longer a glacier while the latter implies that it still qualifies as a glacier.

Terms Including "Snow": In the context of possibly not ever having been considered a glacier, various terms including "snow" are applied when asking if something is a glacier or not. Leigh and others (2019) apply the terms "snow" or "perennial snow" to those features not meeting sufficient glacial criteria. Similarly, Fountain and others (2017) apply the term "perennial snowfields," while Selkowitz and Forster (2015) prefer the adjective "persistent" and Securo and others (2025) prefer the term "snow patch." Conversely, Post and LaChapelle (1971) apply the term "marginal glacier" in cases where there is uncertainty about a glacier's status. Interestingly, a community glossary includes the terms "snowfield" and "snowpatch" but does not include "ice patch"; this is consistent with a glacier definition that includes evidence of past flow rather than requiring current flow (Cogley and others, 2011).

Dead / Stagnant Ice: These terms refer to "any part of a glacier that does not flow at a detectable rate" (Cogley and others, 2011), but they are frequently also used to refer to former glaciers rather than glacier components. Indeed, the term "dead" calls to mind the funerals held to recognize glacier disappearance, as well as implicitly recognizing ecological grief.

Debris-Related Terms: Anderson and others (2018) identify a continuum in which climate warming can cause debris-covered glaciers to transform into (much shorter) rock glaciers. Like with standard glaciers, Cogley and others (2011) define rock glaciers as demonstrating evidence of past or present flow and could therefore face similar questions asked in this paper about standard glaciers. However, under future conditions, only about 3% of glacierized areas (namely cold, high elevation, moderate precipitation zones) will have potential for glacier to rock glacier transformation (Lute and others, 2024). The above-mentioned term "ice body" may also apply to an ice-cored moraines. These features, and identifying the extent of ice still present under debris, are important for understanding post-glacial hazards (Bernard and others, 2024).

DISCUSSION

In many academic disciplines which involve classification, there is a tension between "lumpers" and "splitters"; the former opting for merging into broader, inclusive categories and the latter advocating for recognition of specific, smaller categories. Glaciology is no different. Hooke (2019) articulates, however, that while glaciologists may attempt categorization, "the natural world persistently upsets these schemes by presenting us with particular items that fit neither in one such pigeonhole nor the next, but rather have characteristics of both, for continua are the rule rather than the exception. This is as true of glaciers as it is of other natural systems."

There are some areas where glaciers need to be considered in a binary, for example in some legal contexts. In addition, there are certain ecosystem services that glaciers provide that non-glaciers do not (e.g. erosion contributing to downstream nutrient fluxes). However, there are many other ways in which glaciers disappear on a continuum rather than in a binary. In some ways, this depends on the technology we use. For example, as sensors like satellites and GNSS receivers have improved, so has our ability to observe glaciers in higher temporal and spatial resolution; with higher resolution comes a reduction in the minimum size or flow speed we can measure.

Different lenses also provide different outcomes. Indeed, Meier and Post (1995) write that, "A strict definition of 'glacier' is virtually impossible. ... Few scientists would call ... tiny ice patches 'glaciers,' yet they are hydrologically indistinguishable from glaciers in all characteristics but size and rate of flow." As a perfect illustration, Paul and others (2023) choose to include smaller ice patches in their inventory "as they can still be considered as a water resource." A similar decision might be equally valid for, for example, ecologists or archaeologists studying these cryospheric features. Zooming out, considering basin-scale or regional averages may be more useful in some contexts than attempts at the individual glacier level.

While this paper is framed around defining vanishing glaciers, there is a problem with focusing only on the vanishing rather than the survival of glaciers. As Jackson (2015a) identifies, "a glacier-ruins narrative is understood as a narrative about glaciers that tends to overlook the existing state of a glacier and/or glacier systems and speaks instead to imagined states of loss." This, in turn, can possibly lead to increased solastalgia (Albrecht and others, 2007) and ecological grief (Cunsolo and Ellis, 2018). Projections of glacier disappearance (e.g., Rounce and others, 2023; Zekollari and others, 2025) walk an important line by acknowledging widespread glacier disappearance while crucially also identifying the importance of human agency in determining the extent of glacier loss and deglaciation.

Headlines of vanishing glaciers grab attention, but they can hide the important nuance behind how that determination has been made. Classification can be a useful tool, but at times it can also somewhat subjective or arbitrary. Understanding the implications of defining a glacier in a particular way is critical before selecting how the decision is made. Some applications might even call for novel criteria because of a unique context (e.g. Schaffer and MacDonnell 2022). As discussed above, the global glaciology community tends to defer to the determinations of specific experts, especially local glaciologists.

So, when is a glacier no longer a glacier? Ultimately, the answer to that question depends on who is asking and why.

CONCLUSION

Paradoxically, due to glacier fragmentation, the number of very small glaciers is increasing as glaciers recede. Thus, conversations about the definition of a glacier and when it vanishes are more important than ever and are moving from the academic to the applied.

Small and vanishing glaciers provide inter-seasonal water storage which in turn reduces drought resilience, changes sediment and nutrient fluxes, can reduce water quality, opens new habitats while removing existing ecological niches, impacts recreational opportunities, threatens cultural connections to the cryosphere, and more. While communities are holding glacier funerals to mourn vanishing glaciers, glacier disappearance is inspiring the glaciology community to rethink its approach to glacier inventories.

There are a range of theoretical and practical definitions of glaciers, considering various aspects of past and/or present flow, thickness, area, relative size, and more. These different definitions, and their application, embody an inherent tension and subjectivity in classifying glaciers. Other terms, like ice patch or glacier remnant, may be more appropriate terms for former glaciers.

As the U.N. Year of Glaciers' Preservation transitions to the U.N. Decade of Action for Cryospheric Sciences, it is important to recognize that society has some control over how many more glaciers vanish. As we consider and discuss vanishing glaciers, it is important to understand the nuance in the creation and use of definitions of glaciers. Ultimately, why we ask whether something is a glacier should determine which definitions, methods, and terminology are applied.

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REFERENCES

Albrecht G, Sartore GM, Connor L, Higginbotham N, Freeman S, Kelly B, Stain H, Tonna A and Pollard G (2007) Solastalgia: the distress caused by environmental change. *Australasian psychiatry*, **15**(1_suppl), S95–S98

Altemus Cullen K, Ayala Á and Spencer M (2025) The socio-cultural implications of glacier retreat demand further attention: a case study from cerro el plomo in santiago, chile. *Frontiers in Earth Science*, **13**, 1564881

Anacona PI, Kinney J, Schaefer M, Harrison S, Wilson R, Segovia A, Mazzorana B, Guerra F, Farías D, Reynolds JM and others (2018) Glacier protection laws: Potential conflicts in managing glacial hazards and adapting to climate change. *Ambio*, **47**, 835–845

Anderson RS, Anderson LS, Armstrong WH, Rossi MW and Crump SE (2018) Glaciation of alpine valleys: The glacier–debris-covered glacier–rock glacier continuum. *Geomorphology*, **311**, 127–142

Andreassen LM, Nagy T, Kjøllmoen B and Leigh JR (2022) An inventory of norway's glaciers and ice-marginal lakes from 2018–19 sentinel-2 data. *Journal of Glaciology*, **68**(272)

Arie K, Narama C, Fukui K and Iida H (2025) Identification and persistence mechanism of very small glaciers and perennial snow patches in the northern japanese alps. *Frontiers in Earth Science*, **13**, 1442884

Barcaza G, Nussbaumer SU, Tapia G, Valdés J, García JL, Videla Y, Albornoz A and Arias V (2017) Glacier inventory and recent glacier variations in the andes of chile, south america. *Annals of Glaciology*, **58**(75pt2), 166–180

Baumann S, Anderson B, Chinn T, Mackintosh A, Collier C, Lorrey AM, Rack W, Purdie H and Eaves S (2021) Updated inventory of glacier ice in new zealand based on 2016 satellite imagery. *Journal of glaciology*, **67**(261), 13–26

Bernard E, Friedt JM, Prokop A, Tolle F and Griselin M (2024) Is a glacier gone when it looks gone? subsurface characteristics of high-arctic ice-cored slopes as evidence of the latest maximum glacier extent. *Earth Surface Processes and Landforms*, **49**(11), 3251–3260

Bevington AR and Menounos B (2022) Accelerated change in the glaciated environments of western canada revealed through trend analysis of optical satellite imagery. *Remote Sensing of Environment*, **270**, 112862, ISSN 0034-4257 (doi: https://doi.org/10.1016/j.rse.2021.112862)

Bolch T, Menounos B and Wheate R (2010) Landsat-based inventory of glaciers in western canada, 1985–2005. *Remote Sensing of Environment*, **114**(1), 127–137, ISSN 0034-4257 (doi: https://doi.org/10.1016/j.rse.2009.08.015)

Bosson JB, Huss M, Cauvy-Fraunié S, Clément JC, Costes G, Fischer M, Poulenard J and Arthaud F (2023) Future emergence of new ecosystems caused by glacial retreat. *Nature*, **620**(7974), 562–569

Boyer D and Howe C (2024) Global Glacier Casualty List

Caspari G, Schou TP, Steuri N and Balz T (2023) Glacial archaeology in northern norway—the island of seiland. *Remote Sensing*, **15**(5), 1336

Clarke GK (1987) A short history of scientific investigations on glaciers. *Journal of Glaciology*, **33**(S1), 4–24

Cogley JG, Hock R, Rasmussen LA, Arendt AA, Bauder A, Braithwaite R, Jansson P, Kaser G, Möller M, Nicholson L and Zemp M (2011) Glossary of Glacier Mass Balance and Related Terms. *IACS Technical Report*, **86**

Cox J (2016) Finding a place for glaciers within environmental law: An analysis of ambiguous legislation and impractical common law. *Appeal: Rev. Current L. & L. Reform*, **21**, 21

Cruikshank J (2007) *Do glaciers listen?: Local knowledge, colonial encounters, and social imagination*. ubc Press

Cuffey KM and Paterson WSB (2010) *The physics of glaciers*. Academic Press

Cunsolo A and Ellis NR (2018) Ecological grief as a mental health response to climate change-related loss. *Nature Climate Change*, **8**(4), 275–281

Davesne G, Fortier D, Domine F and Kinnard C (2023) Mass-balance and ablation processes of a perennial polar ice patch on the northern coast of ellesmere island. *Journal of Glaciology*, **69**(278), 1598–1615

der Wissenschaften BA (2022) Gletscherschwund: Der Südliche Schneeferner verliert seinen Status als Gletscher

Dieckman E (2025) A New 3D Map Shows Precipitous Decline of Ugandan Glaciers. *Eos*, **106**, ISSN 2324-9250 (doi: 10.1029/2025EO250126)

Falaschi D, Blöthe J, Berthier E, Tadono T and Villalba R (2025) Monitoring recent (2018–2023) glacier and rock glacier changes in central patagonia using high-resolution pléiades and alos prism satellite data. *Frontiers in Earth Science*, **13**, 1601249

Fernández A, MacDonell S, Somos-Valenzuela M and González-Reyes Á (2021) Chile's Glacier Protection Law Needs Grounding in Sound Science. *Eos*, **102**, ISSN 2324-9250 (doi: 10.1029/2021EO160569)

Field WO (1947) Glacier recession in muir inlet, glacier bay, alaska. *Geographical Review*, **37**(3), 369–399

Fountain AG, Glenn B and IV HJB (2017) The Geography of Glaciers and Perennial Snowfields in the American West. *Arctic, Antarctic, and Alpine Research* (doi: 10.1657/AAAR0017-003)

Fraser B (2017) Argentine scientist indicted over design of glacier inventory. *Science*, ISSN 0036-8075, 1095-9203 (doi: 10.1126/science.aar6762)

GLIMS Consortium (2005) Glims glacier database, version 1 (doi: 10.7265/N5V98602)

Hannesdóttir H, Sigurðsson O, Þrastarson RH, Guðmundsson S, Belart J, Pálsson F, Magnússon E, Víkingsson S, Kaldal I and Jóhannesson T (2020) A national glacier inventory and variations in glacier extent in iceland from the little ice age maximum to 2019. *Jökull*, **12**, 1–34

Hartz A and Carlson AE (2020) Glacier disappearance in the high alpine of oregon, usa. In *AGU Fall Meeting Abstracts*, volume 2020, C056–0006

He X and Zhou S (2022) An assessment of glacier inventories for the third pole region. *Frontiers in Earth Science*, **10**, 848007

Hooke RL (2019) *Principles of glacier mechanics*. Cambridge university press

Huss M and Fischer M (2016) Sensitivity of very small glaciers in the swiss alps to future climate change. *Frontiers in earth science*, **4**, 34

Huss M, Bookhagen B, Huggel C, Jacobsen D, Bradley RS, Clague JJ, Vuille M, Buytaert W, Cayan DR, Greenwood G and others (2017) Toward mountains without permanent snow and ice. *Earth's Future*, **5**(5), 418–435

Izagirre E, Revuelto J, Vidaller I, Deschamps-Berger C, Rojas-Heredia F, Rico I, Alonso-González E, Gascoin S, Serrano E and López-Moreno JI (2024) Pyrenean glaciers are disappearing fast: state of the glaciers after the extreme mass losses in 2022 and 2023. *Regional Environmental Change*, **24**(4), 172

Jackson M (2015a) Glaciers and climate change: narratives of ruined futures. *Wiley Interdisciplinary Reviews: Climate Change*, **6**(5), 479–492

Jackson M (2015b) *While Glaciers Slept: Being Human in a Time of Climate Change*. Green Writers Press, s.l, ISBN 9780996087261

Leigh J, Stokes C, Carr R, Evans I, Andreassen L and Evans D (2019) Identifying and mapping very small (< 0.5 km2) mountain glaciers on coarse to high-resolution imagery. *Journal of Glaciology*, **65**(254), 873–888

Linsbauer A, Huss M, Hodel E, Bauder A, Fischer M, Weidmann Y, Bärtschi H and Schmassmann E (2021) The new swiss glacier inventory sgi2016: from a topographical to a glaciological dataset. *Frontiers in Earth Science*, **9**, 704189

Lute AC, Abatzoglou JT, Fountain AG and Bartholomaus TC (2024) Projected loss of rock glacier habitat in the contiguous western united states with warming. *Journal of Glaciology*, **70**, e27

Meier M and Post A (1995) Glaciers: A water resource. Report, USGS, Washington, D.C. (doi: 10.3133/70039226)

Miller J (2013) California's Vanishing Glaciers: A Defining Moment | KQED

NPS (2013) Yosemite National Park's Largest Glacier Stagnant

Paul F, Barry R, Cogley JG, Frey H, Haeberli W, Ohmura A, Ommanney CSL, Raup B, Rivera A and Zemp M (2009) Recommendations for the compilation of glacier inventory data from digital sources. *Annals of Glaciology*, **50**(53), 119–127

Paul F, Baumann S, Anderson B and Rastner P (2023) Deriving a year 2000 glacier inventory for new zealand from the existing 2016 inventory. *Annals of Glaciology*, **64**(92), 159–169

Pelto MS (2008) Impact of climate change on north cascade alpine glaciers, and alpine runoff. *Northwest Science*, **82**(1), 65–75

Pelto MS and Pelto J (2025) The loss of ice worm glacier, north cascade range, washington usa. *Water*, **17**(3), 432

Pfeffer WT, Arendt AA, Bliss A, Bolch T, Cogley JG, Gardner AS, Hagen JO, Hock R, Kaser G, Kienholz C and others (2014) The randolph glacier inventory: a globally complete inventory of glaciers. *Journal of glaciology*, **60**(221), 537–552

Poll Z and Buricelli L (2022) The People Who Draw Rocks. *The New York Times*, ISSN 0362-4331

Post A and LaChapelle ER (1971) *Glacier ice*. University of Washington Press

Project GG (2025) Goodbye Glaciers!?

Revuelto J, Izagirre E, Rico I, Rio L, Serrano E, Vidaller I, Rojas-Heredia F and López-Moreno JI (2025) The last years of infiernos glacier and its transition to a new paraglacial stage. *Journal of Glaciology*, **71**, e35

Rivera A (2022) Current status of Chilean glaciers and the discussion of a glacier law'

Rounce DR, Hock R, Maussion F, Hugonnet R, Kochtitzky W, Huss M, Berthier E, Brinkerhoff D, Compagno L, Copland L and others (2023) Global glacier change in the 21st century: Every increase in temperature matters. *Science*, **379**(6627), 78–83

Schuster L, Maussion F, Rounce DR, Ultee L, Schmitt P, Lacroix F, Frölicher TL and Schleussner CF (2025) Irreversible glacier change and trough water for centuries after overshooting 1.5° c. *Nature Climate Change*

Securo A, Del Gobbo C, Baccolo G, Barbante C, Citterio M, De Blasi F, Marcer M, Valt M and Colucci RR (2025) The glaciers of the dolomites: the last 40 years of melting. *The Cryosphere*, **19**(3), 1335–1352

Selkowitz DJ and Forster RR (2015) An automated approach for mapping persistent ice and snow cover over high latitude regions. *Remote Sensing*, **8**(1), 16

Serrano E, González-trueba JJ, Sanjosé JJ and Del Rio LM (2011) Ice patch origin, evolution and dynamics in a temperate high mountain environment: the jou negro, picos de europa (nw spain). *Geografiska Annaler: Series A, Physical Geography*, **93**(2), 57–70

Sigurðsson O, Williams RS and Víkingsson S (2017) Jöklakort af íslandi / Map of the glaciers of Iceland

Sudlow K, Tremblay SS and Vinebrooke RD (2023) Glacial stream ecosystems and epilithic algal communities under a warming climate. *Environmental Reviews*, **31**(3), 471–483

Tielidze LG, Nosenko GA, Khromova TE and Paul F (2022) Strong acceleration of glacier area loss in the greater caucasus between 2000 and 2020. *The Cryosphere*, **16**(2), 489–504

Tsuji M, Vincent WF, Tanabe Y and Uchida M (2022) Glacier retreat results in loss of fungal diversity. *Sustainability*, **14**(3), 1617

Ugalde F, Valenzuela-Astudillo H, Toledo M, Carrasco J, Ruiz L, Apey A, Pinto D and Marangunic C (2025) Ice loss detection of glacierets in the desert and central andes of chile between 2018 and 2023. *Frontiers in Earth Science*, **13**, 1565290

Ultee L, Coats S and Mackay J (2022) Glacial runoff buffers droughts through the 21st century. *Earth System Dynamics*, **13**(2), 935–959

USGS (2022) Is there a size criterion for a glacier?

Voordendag A, Prinz R, Schuster L and Kaser G (2023) Brief communication: the glacier loss day as indicator for extreme glacier melt in 2022. *The Cryosphere Discussions*, **2023**, 1–7

Walden J, Jacquemart M, Higman B, Hugonnet R, Manconi A and Farinotti D (2025) Landslide activation during deglaciation in a fjord-dominated landscape: observations from southern alaska (1984–2022). *Natural Hazards and Earth System Sciences*, **25**(6), 2045–2073

Way RG, Bell T and Barrand NE (2014) An inventory and topographic analysis of glaciers in the torngat mountains, northern labrador, canada. *Journal of Glaciology*, **60**(223), 945–956

Zekollari H, Schuster L, Maussion F, Hock R, Marzeion B, Rounce DR, Compagno L, Fujita K, Huss M, James M, Kraaijenbrink PDA, Lipscomb WH, Minallah S, Oberrauch M, Van Tricht L, Champollion N, Edwards T, Farinotti D, Immerzeel W, Leguy G and Sakai A (2025) Glacier preservation doubled by limiting warming to 1.5°C versus 2.7°C. *Science*, **388**(6750), 979–983, ISSN 0036-8075, 1095-9203 (doi: 10.1126/science.adu4675)

Zemp M, Jakob L, Dussaillant I, Nussbaumer SU, Gourmelen N, Dubber S, A G, Abdullahi S, Andreassen LM, Berthier E, Bhattacharya A, Blazquez A, Boehm Vock LF, Bolch T, Box J, Braun MH, Brun F, Cicero E, Colgan W, Eckert N, Farinotti D, Florentine C, Floricioiu D, Gardner A, Harig C, Hassan J, Hugonnet R, Huss M, Jóhannesson T, Liang CCA, Ke CQ, Khan SA, King O, Kneib M, Krieger L, Maussion F, Mattea E, McNabb R, Menounos B, Miles E, Moholdt G, Nilsson J, Pálsson F, Pfeffer J, Piermattei L, Plummer S, Richter A, Sasgen I, Schuster L, Seehaus T, Shen X, Sommer C, Sutterley T, Treichler D, Velicogna I, Wouters B, Zekollari H, Zheng W and The GlaMBIE Team (2025) Community estimate of global glacier mass changes from 2000 to 2023. *Nature*, **639**(8054), 382–388, ISSN 1476-4687 (doi: 10.1038/s41586-024-08545-z)