The Scientific Discovery of Glaciers in the American West

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The American West has been the proving ground for a number of earth sciences, including the study of glaciers. From their discovery by Western science in the late 1800s and continuing to the present day, studies of these glaciers have made important contributions to our understanding of glacial processes and to the recent assessments of global sea level rise. The growth of this science was founded on the interplay between trained scientists and dedicated nonprofessionals. This report summarizes the early history of glacier discovery and explorations in the West. *Key Words: climate change, environmental history, glaciers, historical geography, western United States.*

美国西部长久以来是若干地球科学的实证场域，包含冰川研究。从西方科学自 1800 年代晚期发现冰川至今，冰川研究对我们对于冰川过程与晚近对全球海平面上升的评估，做出了重要的贡献。此一科学进展，建立在受训练的科学家和勤奋的非专业者之间的互动之上。本报告摘要西部发现及探索冰川的早期历史。 *关键词： 气候变迁, 环境历史, 冰川, 历史地理学, 美国西部。*

El Oeste norteamericano ha sido campo de pruebas para un número de ciencias de la tierra, el estudio de los glaciares incluido. Desde su descubrimiento para la ciencia occidental a finales de los años 1800, hasta el presente, los estudios de estos glaciares han contribuido de modo importante a nuestro entendimiento de los procesos glaciales y a las recientes evaluaciones del ascenso del nivel del mar. El desarrollo de esta ciencia se fundamentó en la interacción entre científicos de formación y legos dedicados. Este informe resume la historia temprana del descubrimiento y exploración de los glaciares del Oeste. *Palabras clave: cambio climático, historia ambiental, glaciares, geografía histórica, Estados Unidos occidentales.*

The scientific history of the glaciers in the American West, defined by the Rocky Mountains from California north to Washington, east to Montana and south to Colorado, has not been well explored. Previous reports have either emphasized mountain explorations (e.g., Farquhar 1965; Becky 2003) or focused on the broader careers and context of the explorers (e.g., Goetzmann 1966; Wilson 2006). A notable exception is O'Connor's (2013) examination of the history of glacier observations on the Three Sisters volcano in Oregon. This report examines the "discovery" of glaciers in the American West, encountering the notion of discovery in a scientific sense, and summarizes the history of glacier observations from these early years to the rise of "modern" glaciology after World War II.

The discovery of glaciers in the American West is somewhat clouded and follows a common experience in the earth sciences—the locals knew what was there before science announced the discovery. A classic example is the discovery of Lascaux cave and its paintings by two local teenagers and the subsequent scientific investigation (Bahn 2007). For commercial discoveries like oil and minerals, their importance is self-evident by financial investment, exploitation, and profits obtained. For noncommercial, scientific discoveries, like a new species of butterfly, verification and importance are established by science via publication of a peer-reviewed journal article. From that article, credit of discovery is bestowed. Where the layperson might make a discovery, it is typically a scientist who understands its relevance to science. The discovery of glaciers in the American West follows this theme, in addition to a relatively unusual situation, in which an amateur challenged the established scientists.

The Native Americans clearly encountered glaciers prior to the arrival of Europeans (Cruikshank 2005). More than 10,000 years ago the Bering Land Bridge connected Russia to Alaska and migrating peoples taking the land route had to pass through the ice-free corridor between the Laurentide and Cordilleran ice sheets to make their way into the warmer climates to the south (Hopkins 1967). Alternatively, a coastal route passed by immense maritime glaciers in southern Alaska (Fladmark 1979). Along either route, glaciers were encountered, but no written or pictorial record of these experiences remains. Since that time,

Annals of the American Association of Geographers, 0(0) 2017, pp. 1–10
Initial submission, January 2016; revised submission, August 2016; final acceptance, October 2016
Published by Taylor & Francis, LLC.

archeological and historical evidence testifies to the presence of Native Americans in alpine glacial environments (Coleman 1869; Kautz 1875; Lee 2012).

For Western science, the presence of glaciers in southeast Alaska was well known. These glaciers, large and terminating in the ocean, were reported by the first Russian fur traders and later mapped by Captain Vancouver (Vancouver 1798). The presence of glaciers in the American West was less clear. The settlement of the West, between the 1840s and the 1880s, occurred during the end of the Little Ice Age, that period of time from about 1450 to 1850 when global air temperatures were cool and cold, snowy winters were common across the Northern Hemisphere (Masson-Delmotte et al. 2013). In the high alpine landscape, winter snows typically lasted until late in the summer, blanketing the glaciers and hiding them from view, much like it does today after a snowy winter and cool summer. As we see later, this became the central question asked of amateur sightings of glaciers: Were they true glaciers or just accumulations of seasonal snow?

A few observations of glaciers were recorded as early as the 1840s, but they were buried in internal military reports or land survey reports, and only a few made it to newspaper accounts (Coleman 1877). In no case were the reports particularly detailed or widely distributed. Moreover, these claims, if known to science, were not followed up and critically examined. According to the informal rules of scientific "discovery," the person who first publishes the findings in a peer-reviewed journal receives the credit. Just announcing it in a newspaper is insufficient; the claim has to be critically examined by professionals. The discovery of glaciers in the American West is credited to Clarence King, who walked on a glacier in September 1870 and published his account in March 1871 (King 1871b; California Academy of Sciences 1872). The first credible published account predates King by two years, however, in the November 1869 issue of *Harper's Magazine* by E. T. Coleman, a landscape artist and enthusiastic climber living in Victoria, British Columbia, Canada (Coleman 1869; Stevens 1876). He described a mountaineering trip in 1868 to reach the top of Mount Baker, across the sound from Victoria in the Washington Territory of the United States (Figure 1). His narration describes a number of glaciers encountered, including observations of glaciers on nearby mountains. Coleman, whose climbing experience in Switzerland was known at the time (Stevens 1876), must have had experiences with glaciers in Europe and was readily able to identify one. *Harper's Magazine* might not be a scientific journal but, unlike today, there were few science-dedicated journals, and it was common for alpine observations to appear in publications such as *Harper's*, *The Atlantic Monthly*, *Overland Monthly*, or the *Sierra Club Bulletin*. Coincidently, the same month that the Coleman article appeared, George Gibbs, a naturalist on the Northwest Boundary Survey (1857–1862) between Canada and the United States, reported on his landscape observations at a meeting of the American Geographical Society of New York. His report included observations of glaciers in the Cascade Range of Washington (not far from Mount Baker), and his written report, which was published four years later, included a sketch of one of the glaciers he observed (Gibbs 1873).

The Scientist

Clarence King was a graduate of Yale College in 1862, where he studied chemistry and the relatively new discipline of geology (Goetzmann 1966; Wilson 2006). After graduation, rather than enlist in the Army and serve in the Civil War, King traveled west, finding volunteer employment with another Yale man, Josiah Whitney, director of the California Geological Survey. The Survey spent the summers exploring and mapping the high Sierra Nevada including Yosemite Valley. Returning east in 1866, King conceived a plan to map the geology of the Western United States and lobbied Congress for the funding. By 1867, he was leading the United States Geological Exploration of the 40th Parallel, sponsored by the War Department (King and Gardiner 1878). The composition of his survey team departed from the practice of previous surveys by hiring specialists (e.g., geologists, botanists), rather than naturalists, helping to usher in a new era of scientific exploration (Goetzmann 1966). By late summer, King's survey had reached California and he journeyed to Mt. Shasta, thought to be the highest mountain in the continental United States (Wilson 2006). While exploring the mountain he encountered a glacier and was photographed standing it on 11 September 1870 (Figure 2). Like Coleman, he had also been to Switzerland and knew a glacier when he saw one. He named the glacier Whitney Glacier, after his friend, supervisor, and state geologist of California (Guyton 1998). This must have been a bit of fun on King's part at Whitney's expense because prior to the discovery Whitney wrote that no "living" glaciers

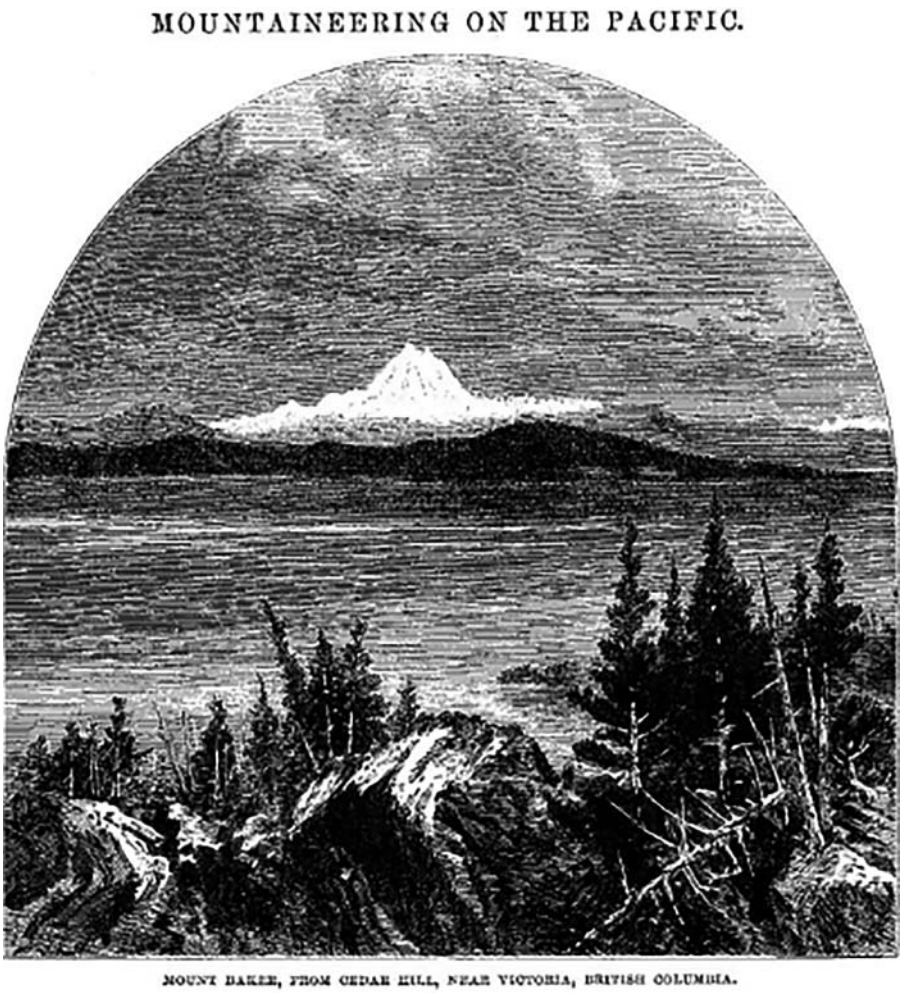

Figure 1. Image of Mount Baker from Coleman's (1869) article on climbing Mount Baker and observing glaciers. *Source*: Courtesy of *Harper's Magazine*.

Figure 2. Clarence King on the Whitney Glacier, 11 September 1870. *Source*: Photograph by C. E. Watkins, courtesy of the U.S. Geological Survey.

existed in California (Whitney 1869). In addition to exploring Mt. Shasta, King had sent team members north to Mt. Hood, outside of Portland, Oregon, and to Mt. Rainier, not far from Seattle, Washington, where they found more glaciers. He quickly announced his discovery at a February 1871 meeting of the Connecticut Academy of Sciences and the report was printed in newspapers across the nation (e.g., "Discovery of Glaciers" 1871a; "Discovery of Glaciers" 1871b; "The Glaciers of the Northwest" 1871).

The news of King's discovery in February 1871 must have come as some surprise to Coleman, who was living in Portland, Oregon, at the time. Coleman immediately wrote a letter to the editor of the *Morning Oregonian*, published two days after King's news, pointing out that he discovered a glacier on Mount Baker years earlier and published the account in *Harper's* (Coleman 1871). After doing their own research into the issue, a month later the *Morning Oregonian* published a short article about Coleman, Gibbs, and King, concluding that the proposed existence of glaciers as opposed to perennial snowfields would evoke much discussion among geologists ("Oregon Glaciers" 1871). Not letting the matter rest there, Coleman revisited the issue with an article in the *Alpine Journal* six years later summarizing the various reported sightings of glaciers that predated King's (Coleman 1877). Although there was some discussion in the scientific community about King's claims of discovery relative to earlier reports (California Academy of Sciences 1872), these discussions did not lead to any formal reexamination of King's claim. King himself largely ignored Coleman's claims in his official reports of his geological exploration of the 40th parallel (King and Gardiner 1878). He saved his criticism for John Muir.

Today, King is the acknowledged discoverer of the first glacier in the American West (Goetzmann 1966; Wilson 2006), whereas Coleman and Gibbs are overlooked. A number of factors might explain why. First, King's report is entitled, "On the Discovery of Actual Glaciers on the Mountains of the Pacific Slope" (King 1871b), and the content was focused on describing the glaciers and their environment. The title states his claim. In contrast, the reports of Coleman and Gibbs were titled with their respective journeys, "Mountaineering on the Pacific" (Coleman 1869), and "Physical Geography of the North-western Boundary of the United States" (Gibbs 1873). Their glacier observations were cursory, just another interesting feature found on this otherwise unknown landscape. They did not highlight the uniqueness of their observation, nor did they include context for the importance of their observation. Perhaps they were unaware that the presence of glaciers was unknown and felt it only natural to find them in high alpine environments. The scientifically uninformed writer or reader would probably not recognize the significance either.

The second reason was that Clarence King published his findings prodigiously, making his claim well known. His observation was made in September 1870 and by March 1871 he had published in the *American Journal of Science and Arts* (King 1871b), perhaps the best scientific journal in the United States at that time ("Silliman's American Journal of Science and Arts" 1871). He went on that year to publish his discovery twice more in the *Atlantic Monthly*, a popular literary journal still in publication today. The first article appeared in March, summarizing his discovery, followed by a thrilling travelogue piece about climbing Shasta published in December (King 1871a, 1871c). Also, it was the practice for many newspapers to list the contents of the most recent issue of the *Atlantic Monthly*, which included King's article. Essentially, it was a media blitz and it was probably difficult for the reading public not to know that Clarence King discovered a glacier in California. Aside from the publications, another important factor favoring King's recognition was his strong social and scientific connections, as he was a member of many elite social and scientific societies in the Eastern United States (Goetzmann 1966; Wilson 2006).

The Poet

After King's published account, John Muir's (Figure 3) publication followed closely. He discovered the first glaciers in the Sierra Nevada in early autumn 1871 (Muir 1872), about the same time King was on Mt. Shasta. The amateur Muir recognized the presence of glaciers by asking whether the landforms fit the definition of a glacier—perennial snow or ice that moves (Cogley et al. 2011). Muir observed two indicators of movement, glacial "flour"—fine sediment in suspension that gives glacial streams a milky greenish color—and crevasses (Cuffey and Paterson 2010). The flour results from glacial sliding—rocks embedded in the ice abrade the bedrock floor. Crevasses result from differential movement: Some parts of the glacier move faster than other parts, causing tension that exceeds the ice strength. By peering into the crevasses, Muir observed ice beneath the seasonal snow, an indication

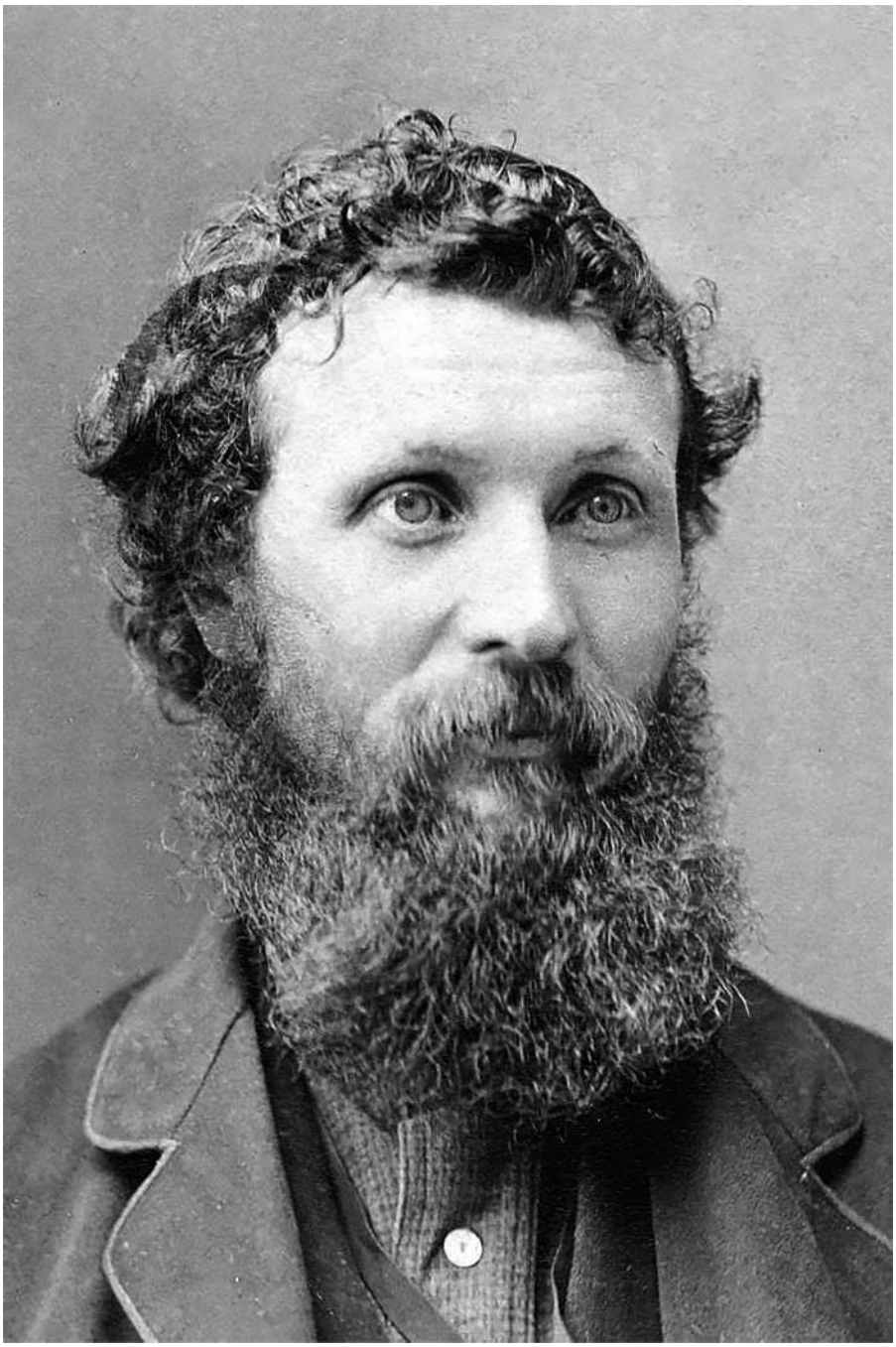

Figure 3. John Muir about the time of his glacier writings, ca. 1875. *Source*: Photographer C. E. Watkins, University of the Pacific Digital Collections. Licensed under Public Domain via Commons: https://commons.wikimedia.org/wiki/File:John_Muir_by_Carleton_Watkins,_c1875.jpg#/media/File:John_Muir_by_Carleton_Watkins,_c1875.jpg

of their perennial nature and clinching the notion that he indeed discovered a glacier. His friends, when told of the discovery, remained unconvinced (Muir 1874). Responding to their skepticism, Muir did not include his glacier observations in his December 1871 article for the *New York Tribune* describing his recent explorations of the Yosemite region (Muir 1871). To remove any doubt, Muir returned to the glacier the following summer to *measure* its movement, the first scientific measures of a glacier in the American West. He set a line of alder poles into the glacier across its width. Returning forty-six days later, all of the stakes moved down slope and the one in the middle moved almost four feet (Muir, 1872, 1875). Muir had done all the

things he needed to do to prove it was a glacier, it was perennial—evidenced by the observation of ice in the crevasse—and it moved, as indicated by the stakes, the crevasse, and the glacial flour.

During this second trip to the glacier, Muir encountered Professor Joseph LeConte, a geology professor from the University of California (LeConte 1873; Muir 1875). Muir guided him to the glacial features he had observed in the valleys of the Yosemite region and to the source of these features—the "living" glacier he found the year before (LeConte 1873). LeConte was surprised and almost convinced, saying,

> Here, then, on Mt. Lyell we have now existing, not a true glacier perhaps, certainly not a typical glacier . . .; yet, nevertheless, in some sense a glacier, since there is true differential motion and a well-marked terminal moraine. It is in fact a glacier in its feeble old age. (332)

LeConte's concern was the lack of visible ice, particularly at the terminus of the glacier. This was the scientific concern of the discipline; the feature might be just an accumulation of seasonal snow that is slowly moving downslope. His conclusions about the glacier were first read before the California Academy of Sciences in late 1872, subsequently appearing in the *American Journal of Science and the Arts* (LeConte 1873), the same journal in which King's discovery paper was published. Muir later took the professor to task in his next article (Muir 1875), saying that LeConte had never seen a glacier before and did not look into crevasses for the ice below the snow. Muir went on saying that in August during LeConte's visit, the glaciers are commonly entirely covered in snow and had LeConte visited a few weeks later the seasonal snow would have been gone, revealing bare ice. In short, LeConte's conclusions were premature and based on little evidence. In any case, LeConte's support, if somewhat equivocal, must have been important to Muir, as he was an amateur in the new discipline of geology that was rapidly establishing professional standards.

When Muir's (1872) article appeared there must have been a small firestorm in geological circles. His observations challenged those of the state geologist of California, Whitney, and of the scientist in charge of the U.S. Geological Exploration of the 40th Parallel, King. Whitney's professional survey parties, including King at the time, extensively explored and mapped the Sierra and there was no way they could have missed any glaciers. Muir, on the other hand, was a complete amateur, as pointed out independently by both Whitney and King. To make matters worse, Muir was advocating the glacier origin of Yosemite rather than the faulting origin promoted by Whitney (Muir 1874). King eloquently expressed their views of Muir in his official and public expedition report describing their geological findings (King and Gardiner 1878):

> It is to be hoped that Mr. Muir's vagaries will not deceive geologists who are personally unacquainted with California, and that the ambitious amateur himself may divert his evident enthusiastic love of nature into a channel, if there is one, in which his attainments would save him from hopeless floundering. (478)

What separates Muir from other amateur discoveries and why he is recognized today were his prodigious writings in nationally recognized outlets and his connections to the science community (e.g., LeConte) and to the luminaries of the era. Yosemite, unlike Mt. Baker and the northwestern United States, was and is currently of popular national interest to the public and science community. The majesty of the new national park and the scientific discussion regarding its formation created a national focal point.

The irony in Whitney's and King's dismissal of Muir's study is that Muir did the science better than his scientifically trained critics. Whitney entirely overlooked the glaciers and King merely stated that the glaciers looked just like the ones he saw in Switzerland. Muir identified the perennial nature and its movement unambiguously. King's criticism ignored Muir's findings and focused on the issue of *neve*, or what is now called *firn*. Firn (neve) is snow that survived the summer's melt season but has not yet turned to ice (Cogley et al. 2011). Metamorphic processes of heat and refreezing transform the fine-grained seasonal snow into coarse-grained snow, and by early autumn the coarse grains freeze together, forming a hard, pavement-like surface. King essentially accused Muir of mistaking a perennial snowfield for a glacier. Perhaps we just needed to wait a century for King to be right, but not for the reason he stated. With climate warming and the shrinkage of the glaciers, the Lyell Glacier, the one Muir studied, has stopped moving and is technically no longer a glacier (National Park Service 2013).

More Discoveries and the Importance of Outdoor Clubs

In the decades following King and Muir's discoveries, a gold rush of glacier discoveries across the west followed. These included discoveries in the Wind

River Range, Wyoming (Hayden 1878, 1883), Colorado Front Range (Stone 1887), the Lewis Range, Montana—now Glacier National Park (Culver 1891; Cheney 1895)—and the Beartooth Mountains, Montana (Kimball 1899). At that time, interest in glaciers of the American West was geographical, with most attention on their location and physical appearance. After repeated visits it became clear the glaciers were changing and the scientific interest focused on their advance and retreat activity (e.g., Russell 1892; Reid 1906). At the same time, mapping the glacial history of the region and former extent of the ice sheet was of intense interest (Whitney 1869; LeConte 1873).

Prior to World War II, only a small group of scientists, mostly from the U.S. Geological Survey with a few university scientists, were interested in and reported on glacier activity (Russell 1898; Gilbert 1904; Reid 1906). Alpine recreational activity was becoming popular, however, and soon hiking clubs became interested in glaciers. Since the late 1800s, Americans were becoming outdoor recreation enthusiasts (Collingwood 2006). The rapid rise of U.S. industrialization combined with the settlement of the West triggered a sense of a lost American frontier. The passenger pigeon and bison were gone and almost half of the national forests had been cleared. In response, a national conservation movement formed to save what was left, leading to the establishment of the Adirondack forest wilderness area in New York (1872), Yosemite National Park (1890), the National Park System, and the Yellowstone Timberland Reserve (1891)—the first of the national forest system. Outdoor recreation clubs were established to provide exercise and the chance to experience these vanishing landscapes. Clubs included the Appalachian Mountain Club (1876), Sierra Club (1892), Mazamas (Portland, Oregon, 1894), and the Seattle Mountaineers (1906). The most well-known U.S. conservationists date from this period, including John Muir, Gifford Pinchot, and President Theodore Roosevelt. The expansion of the railroads made access to remote landscapes easier than ever before.

Realizing the scientific potential of this alpine activity, scientists such as Reid (1906) and Mazamas and Gilbert (1904) with the Sierra Club encouraged their respective clubs to take repeated photographs of glaciers from established camera locations to track glacier change. This encouragement probably met with little enthusiasm because relatively few photographs in the archives of the hiking clubs date from this period. Perhaps the lack of interest was a response to the expensive, heavy, and delicate camera equipment required. Furthermore, the glaciers were not changing much. During the glacier explorations of the late nineteenth century, glacier change was equivocal (Figure 4; Russell 1892; Basagic and Fountain 2011). Perhaps the combination of the high cost in labor and materials posed by the bulky cameras and the small payoff resulting from little glacier change did not make monitoring the glaciers worthwhile.

The climate was warming, however; the Little Ice Age was past (Mann et al. 2009), and things were about to change. Camera technology was improving with smaller, lighter, less expensive cameras. By the 1930s, the climate was warming rapidly and the glaciers were retreating quickly (Mann et al. 2009; Basagic and Fountain 2011; DeVisser and Fountain 2015). Seeing the obvious signs of rapid glacier recession, and perhaps fearing the loss of the glaciers (e.g., "Glaciers Disappear" 1932), hiking clubs initiated programs of glacier monitoring through photography. The most extensive programs were by the Sierra Club and the Mazamas. In fact, the Mazamas's "Research Committee" designed a field-monitoring program on the Eliot Glacier, Mt. Hood, Oregon, and flew aerial photographic surveys over glaciers in Oregon and Washington (e.g., Phillips 1938). The clubs collected data on glacier change, fulfilling the hopes of Reid and Gilbert. Because of these important activities, members of the hiking clubs were represented on scientific committees constituted by professional scientific societies to track glacier change. The 1939 roster of the American Geophysical Union's Committee on Glaciers included a representative from the Sierra Club's "Committee on Glacier Studies," and the Research Committee of the Mazamas (Matthes 1939). Our understanding today of the rate of glacier retreat during the first half of the twentieth century is based on the studies organized and executed by members of these outdoor clubs.

The Professional Scientists

Glacier studies slowed during World War II as men and material were focused on conflicts overseas. The war invigorated science research in the United States, however, and the surge in science funding came after the Soviet launch of the Sputnik satellite in 1957 (Schweber 1988). The geophysical sciences held the International Geophysical Year in 1957–1958, which coordinated geophysical measurements globally (Collis and Dodds 2008). It was during this time that

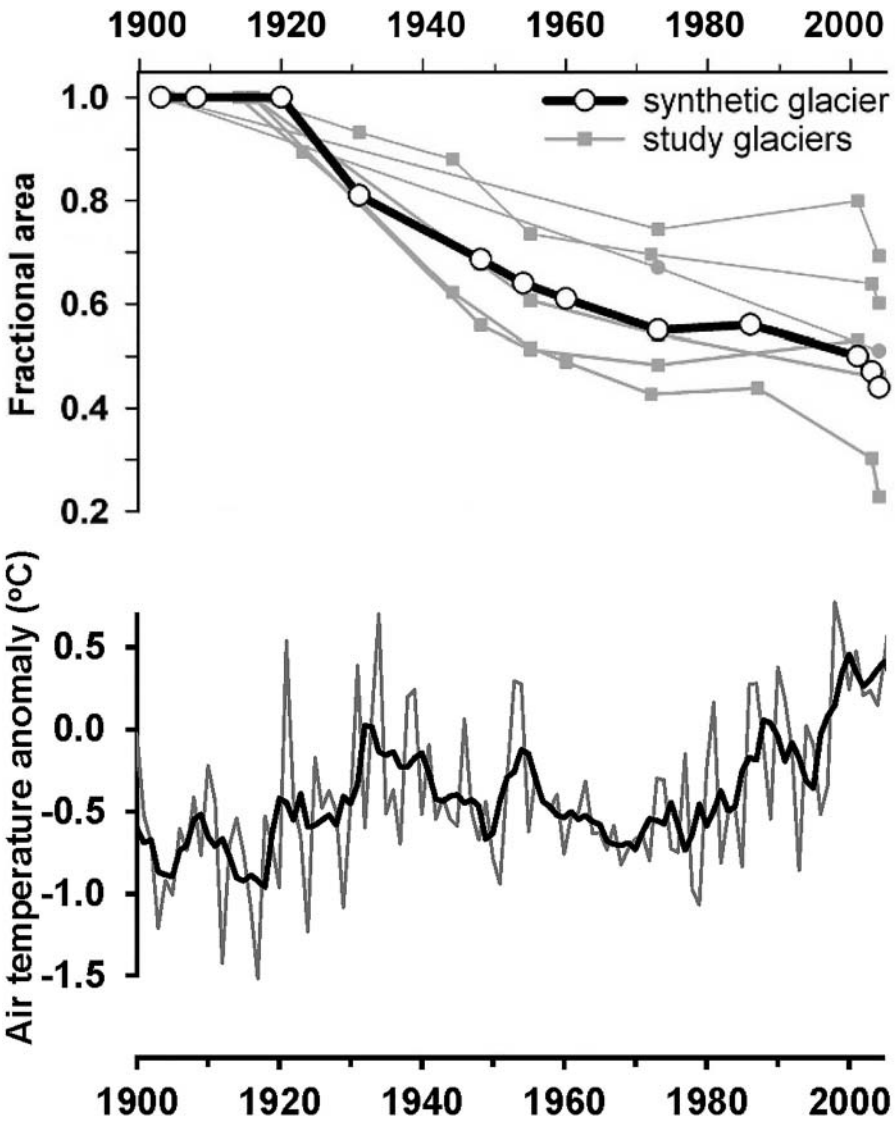

Figure 4. Fractional area changes of six glaciers in the Sierra Nevada and a hypothetical "synthetic" glacier inferred from averaging and interpolating the data from the measured glaciers. Fractional area is the ratio of the glacier area to its initial area. Air temperature anomaly is for the continental United States; the light gray line is annual data and the bold black line is a five-year running mean. *Source*: Adapted from Basagic and Fountain (2011). Data from the National Oceanic and Atmospheric Administration nClimGrid data set (Vose et al. 2014) with a base period of 1981 to 2010. The anomaly data were downloaded from the National Centers for Environmental Information, National Oceanic and Atmospheric Administration (n.d.).

the U.S. Geological Survey initiated a systematic glacier monitoring effort at South Cascade Glacier in the Cascade Range of Washington (Meier 1961). A similar program at Blue Glacier, Olympic Mountains, Washington, by the University of Washington (LaChapelle 1959). The collaboration between these two groups, with the participation of the California Institute of Technology, resulted in a remarkable number of advances in our understanding of glaciers (Kamb 1959; LaChapelle 1960; Post 1960; Meier 1961; Meier and Tangborn 1961). These projects were the vanguard of modern glacier studies in the Western United States, employing state-of-the-art scientific instrumentation and a geophysical approach toward understanding glacier behavior. The transition from outdoor club–based projects to professionally trained scientists was largely complete by the mid-1960s.

Conclusion

The discovery of glaciers in the American West closely coincided with scientific interest in the geology of the region. Unlike in Europe, where farming communities and villages shared valleys with glaciers, in the

West, European inhabitation was distant from such alpine environments and these regions had yet to be explored by scientists. Although it is clear that the first recorded observations of the glaciers were by amateurs, neither the scientific significance nor the wide dissemination of the discovery occurred until the first scientist, Clarence King, published his findings. He was able to add scientific value to the discovery by providing the critical context for establishing the unique nature of the observation and describing its importance to science. During this time, many professionals in the emerging field of geology dismissed amateur efforts. Ironically, the best glacier science in these early days was done by the amateur John Muir. By the twentieth century, glacier scientists worked in close collaboration with amateurs in making important observations about the advance and retreat activity of the glaciers. This collaboration was motivated by the rapid glacier shrinkage during the warming of the 1930s and potential loss of the alpine glaciers. Many of the early observations and photographs of glaciers were in fact compiled by hiking clubs in the Western states. We see reflections of this today with current rapid glacier shrinkage and the increasing attention and engagement of the public. Since World War II, the approach to glacier studies shifted from observing glacier change to a more geophysical, process-oriented, approach toward understanding why and how they change. Echoing the naturalist to specialist transition of scientific field parties encouraged by King, scientific glacier studies left the realm of the amateur and became the domain of professional scientists.

Acknowledgments

Thanks to Adrian Howkins, who made key suggestions that improved the article significantly, and to the editor and anonymous reviews who helped to clarify the text.

Funding

This work was funded by the U.S. Geological Survey as part of the Western Mountain Initiative.

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