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The Randolph Glacier Inventory: Scientists Gatheres in the White Mountains to Count the World's Glaciers

W. Tad Pfeffer

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Slow, steady work can be challenging. The effort of pushing ideas forward, shaping thoughts, ordering knowledge, and finding the end of a thread of ideas that will lead to new knowledge is an uneven trail, and faint in places. The thread, once found, can easily be lost. Good, steady work needs effort, time, order, peace, discipline, and—though many may not know it—beauty helps. It's hard to do good work in ugly surroundings. Good designers know this, and those of us who live and work in beautiful places benefit from that beauty in ways we frequently don't recognize. For most of my life, I've been attracted to graceful, harmonious places—many of them in mountains—and I have been fortunate to live, work, and think in those places. This is a story about the part played by a particular place in the creation of a particular piece of knowledge.

I'm a glaciologist. I work with snow and ice of all kinds, but mostly I work on glaciers. My job involves understanding how glaciers work: what makes them grow and shrink, how they change shape or slide along the bedrock beneath them, how water affects the ends of glaciers flowing into the ocean, and how icebergs break off from the ends of glaciers and into the ocean. I've done this work for nearly 40 years, investigating glaciers of the past and present, but also the changing fate of glaciers in the future. Climate change, of course, is a major part of this work. Snow and ice play many roles in the changing environment of the Earth, from altering the reflectivity of the Earth's surface to storing water that, once released from snow and ice on land, is destined to raise sea level. Discovering the magnitude and timing of these future changes has become one of my most important jobs, and one that I do in company with scientists from all over the world. My research was pretty esoteric 40 years ago and pursued by a small handful of people, but not today. Now, I have many colleagues, a lot of attention from the media, and a to-do list of tasks that need to be done soon, and done right. We need many resources to do this: satellite imagery, computer software, field observations. Among them, however, a small item: a good working space—quiet, harmonious, conducive to concentration—would be a nice asset.

In 2010, I was nominated to join the group of some 300 other scientists who compose the authorship of Working Group 1 of the fifth assessment

Glaciologists took a break from their inventory of the world's 197,654 frozen rivers to climb New Hampshire's Pine Mountain. Valentina Radic (left), Alex Gardner, W. Tad Pfeffer, and Jon-Ove Hagen chatted at the overlook. GEORG KASER

of the Intergovernmental Panel on Climate Change, or IPCC. We were charged with making a synthesis and assessment of the scientific basis of climate change, including an update of what was known about the state of global climate change since 2007, when the fourth assessment had been published. My designated role in the fifth assessment was to coordinate and assess projections of the portion of future sea level rise coming from the world's 200,000 "small" glaciers (these are all of the world's glaciers with the exception of the Greenland and Antarctic ice sheets). Although these glaciers store only a very small fraction of the total ice volume on Earth, they are nonetheless major sea level contributors. The total volume is small, but the rate of ice being lost from these glaciers is enormous, and it has dominated the losses from the Greenland and Antarctic ice sheets during the several decades that these changes have been monitored. And this appears to be true for the immediate future as well: the best numerical models all indicate that the small glaciers will be major sea level contributors throughout the coming century. Similar sea level rise projections had been made in the fourth assessment, but the information available to modelers at that time was incomplete, and the uncertainties of those projections was quite large. Among other problems, only about one-third of the world's glaciers had been inventoried, meaning that their specific location, altitude, size, and shape (all needed for accurate modeling) were unmeasured or at best crudely estimated. Observations of snowfall and snowmelt on representative glaciers were also very incomplete. One of the goals the community sought for the fifth assessment was a complete global inventory of the small glaciers. Progress had been made toward this objective in the years following the fourth assessment, but as the deadline for the fifth assessment approached, those inventories that existed still hung sluggishly at around 45 or 50 percent of the global total. Without this very basic information, it was going to be very difficult to meet our goals and improve on the projections of 2007.

I met for dinner with a group of eight colleagues at a Chinese restaurant in San Francisco in December 2010. We were all there for a yearly meeting of geophysicists held in that city every December, and so for a few days we were all together in one place. We were meeting to discuss how to handle the problem of assembling a complete inventory of glaciers, and we had come to a practical but possibly risky decision. For years, a lack of funding had hampered progress on understanding the state of the small glaciers. In the United States in particular, ice sheet research—regarded by many of my colleagues as more rewarding than the effort of counting and measuring tens

of thousands of little glaciers, seemingly more significant, and easier to sell to agency administrators—had exhausted whatever grant sources we could seek. We felt pessimistic that we could find other support at this late date, and we now took a step we could not reverse. In the roughly eighteen months left before our work was due, we had time to either write grant proposals or do research, but not both. We decided that we would work on our own, without funding, and rely on our colleagues around the world to assist us by volunteering their time and effort as well.

We would have to work efficiently and set realistic goals in view of our limited time and resources, and this meant that our concept of the global inventory would have to be quite fine-tuned: we must include enough information to accomplish the goals set by the IPCC assessment, but nothing extra. This meant we would have to design simple procedures for categorization and definition that had bogged down other inventory projects. Our group of eight would act as an executive committee of sorts, but the full authorship would necessarily be much larger. We left the meeting in San Francisco unsure that we could make this plan work, but with a sense that we were headed in the right direction.

My training and background made me a logical choice for the task given to me in the IPCC assessment: I had spent almost my entire career thinking about the particular challenges of the world's small glaciers, and I knew the ways in which knowledge of the ice sheets informed the study of small glaciers, as well as how small glaciers inform understanding of the much larger ice sheets. I had to accomplish two tasks, really: first, compile and assess knowledge required for the IPCC's report, and, second, help in the effort to do the research. This is an important distinction because the IPCC reports on science; it does not actually do the science. These tasks had to stay separate. Fortunately, I found the distinction easy to make. The inventory would require mapping and analysis of satellite images, skills that were not my particular specialties. I was always more fascinated by the work that could be done on the ground, and even beneath glaciers, accessed by drilling holes and placing instruments at the glacier bed, where forces and movement could be monitored. Other scientists who could accurately and efficiently extract the needed information from satellite images would map the glaciers. My job would be to ensure that the inventory brought together exactly the right information for the subsequent modeling tasks. I also would keep the project on a timetable that would mesh with the IPCC deadlines. This meant careful planning. We would do it right and do it once. We would have no second chance.

We felt an urgency to this task, but the work would be meticulous—an exercise in slow, steady progress. Certainly, we needed a commitment to the values underlying the study of climate, and the willingness to invest effort and take action on potentially threatening environmental change. These approaches are always required to retain focus in projects like this, but even the most worthy cause can become tiring after too many long days of labor. Staying focused and engaged despite setbacks (such as lack of money or encountering nearly unsolvable problems) requires that we love the subject. We must feel an aesthetic attraction that makes what one is doing intrinsically pleasurable. This is one of my advantages. I have been fascinated since childhood with snow and ice. Winter has always been my favorite season, and cold storms my favorite weather. As a young child, I waited for snow every autumn, and derived intense pleasure from seeing the first snow of the season. One of my very earliest memories is from my childhood home outside Boston, looking out into the night and seeing snow falling in sparkling traces through the bright beam of a porch light.

My love of snow was also nurtured by many winter days and nights spent in Randolph, New Hampshire. My parents had discovered this mountain-centered community a few years before my birth and were regular summer and winter visitors throughout my childhood and beyond. Randolph felt like home as much or more than did our residence in Wellesley, Massachusetts (where my father was a pediatrician). We took six- or ten-week summer vacations that were far more possible 50 years ago than they are today. We also would make the journey from Wellesley to Randolph most weekends in winter—an arduous trip in our underpowered, underheated, VW Microbus—for skiing, hiking, and evenings with our Randolph friends who (to my great envy) lived there all year. As a small child, I scrambled over snowbanks. Later I took winter trips to the Randolph Mountain Club huts and the summits of the Northern Presidentials. Later still, I mountaineered in Alaska and the Pacific Northwest. Ultimately, I took research expeditions to mountain regions all over the world, from Arctic Canada, to Alaska and Antarctica, to Mount Kilimanjaro. Throughout all of this travel and experience, from childhood to a career in geophysics and glaciology, I have kept in my head those images of snow falling in the porch light in Wellesley and my earliest summits achieved on roadside snowbanks in Randolph.

Progress on the inventory was gratifyingly quick. Every colleague we contacted for assistance recognized the project's value and

volunteered his or her support. Our eight-person "executive committee," plus a few more experts we recruited after the San Francisco meeting, provided constant and constructive oversight. We met regularly and received some travel expenses from the International Association of Cryospheric Sciences, a European organization that supports a range of glacier-related activities. At these meetings, we developed a scheme of organization, adapted from other inventory projects, that would keep the data we were accumulating in accessible and understandable forms and allow us to use other inventories, reducing duplication of effort.

Glacier modelers prepared to work with our inventory data as soon as we finished it. They would combine the size and location of today's glaciers, taken from our inventory, with a range of potential future climate conditions as calculated by atmospheric modelers. The future conditions are based on "emissions scenarios," the variety of estimated rates of future fossil fuel consumption and release of atmospheric carbon dioxide that, overwhelmingly, drives future climate warming. These, combined with mathematical models of the movement of mass and heat through glacier systems, would predict

Even in clouds, Mounts Madison and Adams provide inspiration from the window of Tad Pfeffer's study in Randolph, New Hampshire, thousands of miles from his usual field sites in Alaska and Canada. W. TAD PFEFFER

quite accurately the growth or shrinkage of glaciers in every part of the world. Net gains would come out of the oceans, and net losses would go into the oceans. Our group and the modelers would work as quickly and carefully as we could.

Randolph is a wonderful place to live for someone who loves the mountains and wants to take advantage of every chance to get out hiking, climbing, running, or skiing. For farmers, Randolph's close association with the White Mountains determined the town's reputation, character, and primary economic draw starting in the 1870s. Since the first quarter of the nineteenth century, farmers had struggled to cultivate both the valley of the Moose River, at the foot of Mounts Adams and Madison, and the level ridge above the valley's north side. For farmers, Randolph's cold, high-elevation location and clay-rich morainal soil produced indifferent results. Like much of New Hampshire, the area produced more timber than food and consequently could support few people year-round. But artists sought out the summer hotels in the late 1800s, and after 1900, some of them became long-term seasonal residents. Tourism in Randolph became linked to the region's fame as an outdoor destination.

The summer population of Randolph, and of many comparable seasonal communities in New England, was composed mostly of families of academics and clergy, these being two groups that normally enjoyed extended summer vacations. Randolph, and similar destinations, such as Caspian Lake at Greensboro in Vermont's Northeast Kingdom, or the Rangeley Lakes in western Maine, required long and often rather arduous journeys to reach a century ago, and families could not easily make a weekend outing to their summer cottage. Only those with extended free time during the summer could typically manage such remote destinations. Academics and clergy both made use of the summers for writing and study, interspersing desk work in rainy periods with hikes on the crisp, blue "mountain days." Randolph's academic residents, drawn largely from Harvard University, included two Nobel laureates, a Harvard president, and many notable theologians. They surely regarded the mountains and the town's overall aesthetic as an agreeable backdrop for intellectual work. Similarly, at Caspian Lake, where academics of comparable stature were mostly associated with Princeton and Yale universities, the lakeside setting of Greensboro's cottage colony would have provided a comparable aesthetic setting that supported extended periods of study. There, small buildings detached from the main house served as studies

and were referred to as "think houses." Similar small studies, often little more than a tool shed adapted to a new purpose, could be found behind many of Randolph's cottages.

Over the many years that I have returned to Randolph, often only for brief visits in summer or winter from our home in Colorado, I have thought back to the many professors who made Randolph into a supportive backdrop for their studies. More recently, I did so myself. In our present small cottage on Randolph Hill, my study looks out over our garden to forest beyond, and rising above that, the summits of Madison and Adams. Those mountains, whether shadowed at dawn, bathed in the rich light of sunset, or, for that matter, shrouded in clouds and rain, never fail to give me the sense that I am in the right place and working on the right thing.

As the IPCC deadline drew nearer, and our travel funds for inventory meetings depleted, I tried a new means of cutting costs. People would still have to travel, but I invited the group to stay for free in Randolph, where my wife's family's house could accommodate a fairly large group. We would save more by doing our own cooking. The expense of time spent in the kitchen rather than at work shrank in comparison to the social benefits of the group working around a stove. I also looked forward to working with my colleagues in the aesthetically stimulating setting of Randolph, which I wanted to share with the group.

Eight people joined us in Randolph in September 2011. We worked productively for two days during which we made difficult decisions on how this new inventory would relate to the older inventories and how, moving forward, the several other inventories would merge with ours into a single, complete, and detailed inventory and be maintained by updates for future users. In addition to work, however, our group enjoyed a short afternoon hike up nearby Pine Mountain, and just before breaking up, we drove up Mount Washington. One of our group, originally from Croatia, had heard of the Mount Washington Observatory during her meteorological studies, and the drive to the observatory on a perfect "mountain day" made her trip doubly rewarding. All of my colleagues, having come from Canada, Austria, Switzerland, and Norway in addition to the United States, felt the aesthetic support that the place gives to study—and to life generally.

In the final meeting of our group, held at the University of California at Berkeley shortly before we released the inventory to the

public, we asked what we would name it. We needed a name that reflected the international and cooperative nature of the effort. A name drawn from an individual or an institution would not do because so many people had contributed; the number of contributors in the end totaled 76, so no single institution name would be appropriate. Our Austrian member then suggested the Randolph Glacier Inventory. That settled the issue. A neutral name identified our project uniquely but without attaching credit unduly to any specific person or institution. "Randolph" would have no specific association for the vast majority of people encountering the name, except for those of us who had been there. And for us, it commemorated a cooperative effort to provide the scientific community, and through that the world at large, with a crucial tool for understanding one aspect of the possible fate of our environment. It also represents, for me, and I think for my friends and colleagues as well, a brief but important encounter in an aesthetically ideal place for intellectual and personal effort.

The Randolph Glacier Inventory project is now complete. We delivered the inventory to the modelers in time for them to complete their tasks; they were then able to write their own papers, get them through peer review, and into print in time to meet the IPCC deadlines for consideration in the fifth assessment. The results form only a part of the larger sea level rise puzzle, but the conclusions of the fifth assessment are substantially advanced and more robust than are those of the fourth assessment of 2007. The inventory and the models that use it tell us just how critical the smallest glaciers are: their contributions to the ocean will determine, more than anything else, the sea level changes that will occur in the near term, the crucial next few decades when engineers and risk managers will be able to act most effectively. The fate of the small glaciers will also shape the future of water resources in parts of the world, including India, Nepal, Pakistan, and other countries in the shadow of the Himalaya. Even the Arctic Ocean may be altered by water lost from the glaciers of southern Alaska, where glacier runoff entering the Gulf of Alaska is swept northwestward, through Unimak Pass and into the Arctic Basin, where it will mix with Arctic waters, adding another variable to the already complex system of Arctic sea ice.

The Randolph inventory is being updated regularly, and plans for its future use and adaptation are progressing. I have moved on to other projects, and it is very unlikely that my friends who joined me in September 2011 will all meet

in Randolph again. New projects will require new collaborations, however, and other meetings are possible. In the meantime, I value the days I have in Randolph for all of their merits, including not only mountains to be climbed, but also the setting and support the place provides for creative work. Every day has its own ideal use, from the cold days of June, soaking wet, shrouded in mist, and best spent in thought, to the brilliant days of August, when the sun rises into a deep blue sky, and we drop whatever projects we have for a trip in the mountains: a perfect mountain day.

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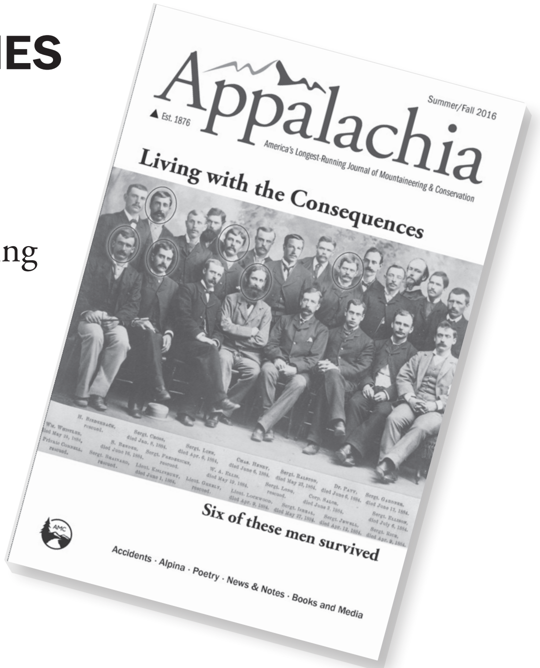

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