THE STORIES BEHIND THE DATA: 30 YEARS OF SNOWPACK SURVEYS ON NIWOT RIDGE

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ABSTRACT: My work is a case study about the co-development of an academic field safety program with a high alpine fine-scale snow depth and snow profile record spanning 30 years in the Front Range of the Southern Rocky Mountains.

The Niwot Ridge Long Term Ecological Research (LTER) Project maintains a long-term snow data set through a mid-May snow survey designed to capture peak snowpack. Up to 20 volunteers overnight at a high alpine laboratory (3,505 m) to access the otherwise restricted City of Boulder Watershed. Over three days they record ~ 500 snow depth points and six 2 m snow pit profiles across the upper Green Lakes Valley (3,567 m to 4,042 m). This record has been used to understand how snow redistributes across mountain terrain, develop an index of wind drifting and scouring, inform a model of wind slab release, validate satellite products, and track one of the leading abiotic drivers of a changing mountain watershed.

I first joined the survey as a volunteer in 2007. By then, it had run for over a decade in remote, high-elevation avalanche terrain, with no formal safety or avalanche protocols or training requirements. Coming from ski patrol, I found this alarming. After several years in academia, I learned it was unremarkable. Field safety provision was, and in places remains, uneven. Programs operating through polar or international logistics organizations had real requirements, while local fieldwork had whatever an individual investigator thought to provide. Field leaders in academia were trained as scientists, not practitioners, with few bridges between the two. Field safety was not taught, if it was addressed at all. Proposal budgets did not include funding for it. When I joined the program in 2010, I brought some knowledge of standard operational practices: protocols, training, and the habit of using close calls as data.

Beyond bridging research and practice, this presentation describes the circular evolution between them. Field practice enabled the continuation and consistency of annual data collection in a remote, high-risk environment. The ongoing data collection improved the field practice through building years of experience from which to learn and improve. The results are an increasingly robust field safety program, enabling one of the longest fine-scale records of high alpine snowpack in the Rocky Mountains.

KEYWORDS: academic field safety, long-term snowpack monitoring, near-miss reporting, alpine snow distribution, risk management, field research

1. INTRODUCTION

Beginning in 1996, a group of 10 to 20 volunteers has skinned up Niwot Ridge in Colorado's Front Range to measure snowpack in the City of Boulder Watershed's Green Lakes Valley at peak snowpack, typically early to mid-May. The result is a record of fine-scale snow depth and snow profile data (density, temperature, stratigraphy) in a complex high-elevation alpine basin where longevity of such records is rare.

The snowpack record has been used in several ways. Winstral et al. (2002) used a single survey year to develop terrain-based wind sheltering parameters Sx (exposure index), Sb (terrain breaks) and D0 (wind drift index), widely used in snow modelling and adapted into methods for identifying potential avalanche release areas (Veitinger et al., 2016). Erickson et al. (2005) used multiple years of surveys to show that topographic controls on snow distribution in this basin persist between years, an assumption underlying many statistical snow mapping models. Badger et al. (2021) used the record to ask what happens if a changing climate weakens this relationship; specifically, how snowmelt changes if warmer, denser snowfall produces a more uniform snowpack (fewer drift and scour areas). The survey has supported other snowmelt modelling efforts (Jepsen et al., 2012), work on soil moisture and nutrient patterns driven by snow redistribution (Litaor et al.,

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2008), and the calibration and validation of remotely sensed SWE products (Schneider and Molotch, 2016).

The survey is conducted on skis or split boards, over three days, by up to twenty volunteers in avalanche terrain above 3,500 m. While the location in this complex high elevation catchment makes the record unique and scientifically valuable, it also means collecting the data is hazardous. When I was hired by the Niwot Ridge LTER as a field technician in 2010 we were working in serious avalanche terrain with no requirement for beacon, shovel or probe, and no one leading the survey, my supervisor included, had avalanche or remote medical training. This was not unusual at the time for an academic field program.

While some academic field programs now maintain safety manuals and guidance for fieldwork (University of California, 2026; University of New Hampshire, 2026), the peer-reviewed literature remains small. Increasing attention to interpersonal safety and accessibility in fieldwork (Emery et al., 2021; Rudzki et al., 2022), supported by new funding agency requirements (National Science Foundation, 2022), has brought increased attention and support for conventional field safety along with it at the Niwot Ridge LTER. The MRS now maintains its own safety resources page (University of Colorado Boulder, 2026). It is my hope that others in academia can learn from the case studies presented here, within the larger story of building an academic field safety program.

2. LOCATION

The Green Lakes Valley (GLV) is a 700-hectare headwater catchment in the Front Range of the Southern Rocky Mountains, Colorado. It lies within the City of Boulder Watershed, which is closed to public access. The snow survey covers the upper catchment, which ranges from 3,567 m to 4,042 m at the Continental Divide. The catchment receives approximately one meter of precipitation annually, of which about 80% falls as snow (Williams et al., 2015). It is above tree line throughout, and strongly wind-affected: prevailing winter winds are northwesterly, while upslope storms arrive from the east and southeast. The combination of high wind, open terrain and steep lee slopes produces the pronounced scour-and-drift mosaic that the survey was designed to measure.

The valley is adjacent to the University of Colorado Mountain Research Station (MRS) and the Niwot Ridge Long Term Ecological Research (LTER) site. Two facilities support the survey. The MRS sits at 2,895 m, below tree line, and is the road-accessible base. The Tundra Lab, at 3,505 m on Niwot Ridge, is a high alpine facility where survey crews overnight. In winter, the 6.5 km Forest Service Road between the two stations is typically snow-covered, and travel is limited to snow machine or backcountry equipment.

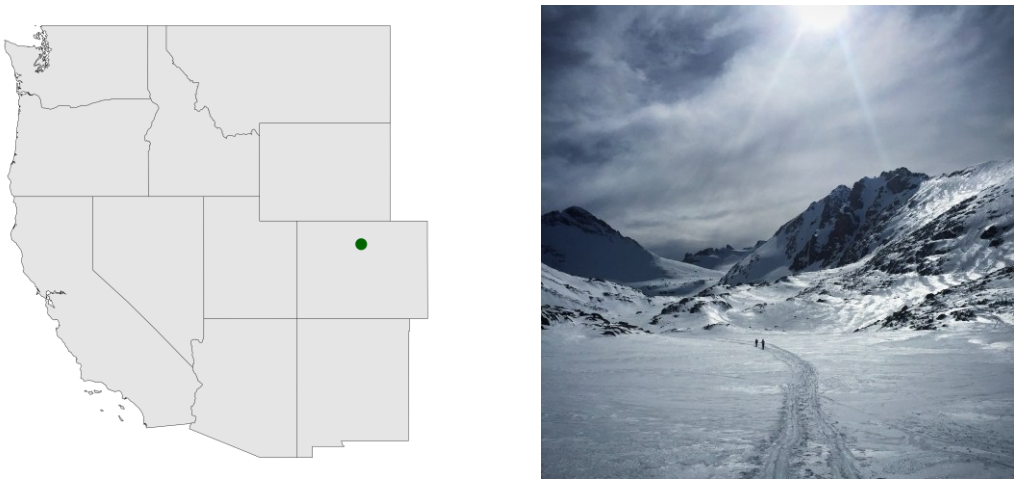


Figure 1: Location of Green Lakes Valley marked with green circle in context of Western United States, and a photo looking into the Green Lakes Valley from the lower southeast edge of the catchment (2015 survey, photo by author).

3. METHODOLOGY

3.1 Timing

The survey is conducted at approximately peak snow accumulation; median date May 10th on Niwot Ridge, derived from snow pit and federal sample density data using linear regression to combine the records (Morse et al., 2024; Williams et al., 2024). Timing has varied by up to two weeks depending on conditions. For example, in 2012, the survey was moved forward to capture peak accumulation. In 2013, the survey was moved back to account for snowpack instability.

3.2 Personnel

Crews have historically numbered up to twenty volunteers, drawn from the university, the research station community and the wider public. Skill levels range from experienced backcountry travelers and avalanche professionals to people on backcountry skis for the first time. Crews are led by two to three staff members.

3.3 Access and logistics

Participants ski or are transported from the Mountain Research Station to the Tundra Lab, where they stay for the duration of the survey. Tracked vehicles are used to move equipment and personnel along the Forest Service Road as conditions permit each year. Crews work in small groups over three days, descending from Niwot Ridge into the catchment near one of our remote climate stations (D1, 3,743 m) approximately 3 km from the Tundra Lab.

3.4 Measurements

Each survey records approximately 500 snow depth points distributed across the catchment, measured by avalanche probe, with positions recorded by handheld GPS. Six snow pits are excavated to a depth of up to two meters along a transect spanning the elevation and aspect range of the catchment, and profiled for density, temperature and stratigraphy.

3.5 Products

Survey depths and snow profile measurements for each year of the survey are archived through the Environmental Data Initiative (Morse, 2023). Survey depths have been interpolated across the catchment on a 10 m grid using a geostatistical model parameterized with terrain variables including elevation, slope, potential solar radiation and wind sheltering and drifting parameters (Erickson et al., 2005). The resulting dataset of spatially distributed snow depth and density spans 1997 to 2019 (Yang et al., 2021).

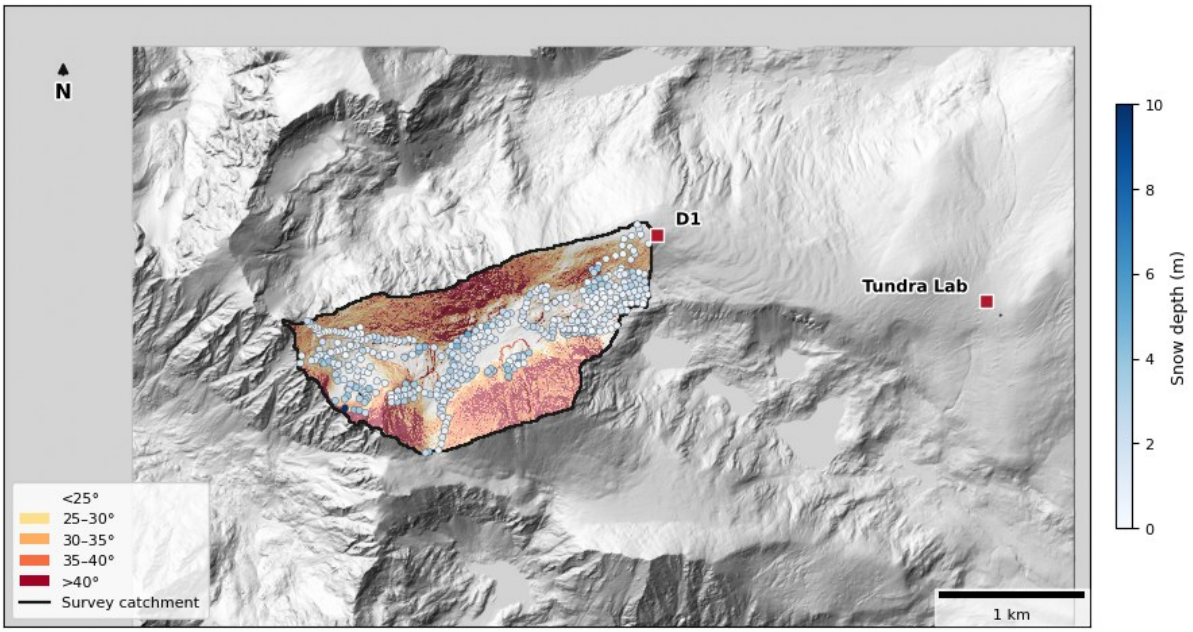


Figure 2: Upper Green Lakes Valley in the City of Boulder Watershed. Snow survey catchment depicted by black boundary line. Slope angle within the survey catchment classified into colored bands. Snow depth points from 2015 snow survey in shades of blue corresponding with snow depth in meters. The

D1 climate station and Tundra Lab shelter are labeled with red squares. The MRS is located approximately 6 km to the east of the map extent, below tree line. The map is produced from a 1 m LiDAR digital terrain model (Anderson, 2014).

4. CASE STUDIES

This paper describes four incidents from the Green Lakes Valley snow surveys between 2007 and 2025; two avalanches (one during a whiteout), a high-altitude pulmonary edema evacuation, and a second whiteout in high winds where a party of fifteen became separated above tree line. Results share how each incident was applied as a learning experience to advocate for and improve the field safety program at the Niwot Ridge LTER and MRS. I hope this account will be useful to others working in academia or other areas to help advise or advocate for their own field safety programs.

4.1 Loose Wet or Wet Slab Avalanche, May 2007

South-east facing slope below Niwot Ridge, approximately 3,650 m. Early afternoon, mid-May. One skier caught and carried approximately 150 m; no injuries.

Several centimeters of new snow had fallen overnight and wind had redistributed the snow onto east and south-east facing slopes. The forecast called for warming through the day. After lunch at the Tundra Lab, volunteers skied along Niwot Ridge and dropped into the Green Lakes Valley at various points. At approximately 13:00, two skiers descended past the D1 meteorological station onto a south-east facing slope roughly 350 m long, with a 40 degree roll at the top over a 35 degree slope, terminating above Green Lake 4. Exposed rock and talus were present on the slope. The first skier made several turns; as the second began to descend, snow released from several points, 30-35 cm deep and spreading to roughly 100 m across. The first skier was able to ski out of the debris, the second skier was knocked over and carried approximately 150 m before being able to get back on their skis and ski out of the sliding snow.

Result: In 2007 I was a volunteer on the snow survey. No protocol, debrief or requirement followed. The incident allowed me to advocate for formal avalanche training for field leaders when I began working at Niwot Ridge first as a field technician, and later as the director and field lead for the Mountain Climate Program.

4.2 Wind slab avalanche in snowcat, May 2011

Northeast-facing roll between the Tundra Lab and tree line. Mid-morning, heavy snow and high wind. Snowcat caught and carried approximately 50 m; no injuries.

On the third morning of the 2011 snow survey, we woke at the Tundra Lab (3,505 m) to heavy snow, high winds and near-zero visibility. We judged that the combination of low visibility and active loading on the survey slopes made it unsafe to work and decided to return to the Research Station. Reaching the Forest Service Road requires roughly 800 m of low-angle skiing above tree line, and descending a slope known as the trough. I drove the snowcat from the Tundra Lab toward the road with a second volunteer. The rest of the volunteers (~18) left the Tundra Lab on skis or split boards.

With visibility down to a meter or so I became lost in the whiteout and drove the snowcat over a steep wind-loaded roll southwest of the trough and FS road. A wind drift formed by loading during the storm released around the snowcat at roughly 1 m depth, and we were carried about 50 m, coming to rest just above tree line. Neither of us was injured and the cat was not buried. Due to the wind loading continuing above us, and steepness of the slope we came down, we could not climb the snowcat back over the roll, and the trees below were too tightly spaced to descend through. We left the machine and skinned roughly 200 m northeast through the trees to the trough and the road, returning on skis to the station.

At the Station we learned that several skiers had also become disoriented above tree line between the Tundra Lab and the road. All eventually found the road, and everyone was accounted for.

Result: Carrying a beacon, shovel, probe had been suggested for the 2011 survey; after this it became a formal requirement for all participants. A written set of best practices and guidelines for fieldwork on Niwot Ridge was initiated, including posting written safety plans at remote shelters. Efforts to secure funding for personal locator beacons and licensed radios operating on the county public safety repeater system began. Notably, no protocol was put in place for whiteout conditions, such as group travel procedures, communication plans, or go/no-go criteria for low visibility. No recommendations were yet made for avalanche training requirements for survey leaders.

4.3 High-altitude pulmonary edema (HAPE), May 2012

Tundra Lab, 3,505 m. Overnight onset; evacuation by snowcat, on foot, and by vehicle to Boulder Community Hospital.

On the second day of the survey, I noticed that one participant was unusually winded and slow skiing out of the Green Lakes Valley, having been fitter on a previous survey and on the first day of this one. I made a mental note and thought little more of it.

That night the same person coughed for several hours. At around 03:00 I found them sitting up over a bucket, coughing up a yellow liquid I recognized from my EMT training as sputum. Another volunteer, waking at the same time, offered their inhaler. I recognized this as difficulty breathing, possibly caused by HAPE. Without my EMT training it is unclear if I would have understood the need for the patient to descend from the Tundra Lab to lower altitudes.

I woke several volunteers to help evacuate and woke a graduate student I trusted to keep the remaining group together and lead them down in the morning. I had no cell phone in 2012, only email, and did not alert emergency services before leaving. Had the evacuation gone badly, no one would have been expecting us.

The Principal Investigator had emailed the previous day to say that high winds had brought trees down across the Forest Service Road. We descended in the snowcat with the patient until we reached the deadfall, then sent two people ahead on foot for a pickup truck while the rest of us began walking the patient down. The road was only partly snow-covered; 2012 was a low snow year with one of the earliest melt-outs in our records. The patient's breathing grew steadily more labored as they hiked. We moved slowly and stopped often. The truck reached us after about 30 minutes. The patient was driven to Boulder Community Hospital, where they were diagnosed with HAPE, placed on supplemental oxygen and released later that day.

Result: Supplemental oxygen was placed at the Tundra Lab. A meeting with our institute’s director produced formal support for remote first aid training and field safety supplies at remote field stations. Visits and assistance from the CU Police and Risk Management Departments followed, beginning the work of building formal safety protocols and emergency response plans for the Mountain Research Station.

4.4 Whiteout and separated party, May 2025

Above tree line between the top of the Forest Service Road and the Tundra Lab. Late afternoon. Approximately 15 skiers separated in 110 km/h gusts and heavy snow; all accounted for, no injuries.

On the first afternoon of the 2025 survey, we travelled the first 1.6 km from the Research Station on foot and by vehicle, to roughly 3,050 m where there was enough snow to ski. The group had been delayed by rain and thunderstorms, and as group leader I did not regroup everyone to review the plan we had discussed earlier in the day before setting off. One colleague drove up to the Tundra Lab in a UTV and a second took the snowcat. I stayed to ski with the volunteers.

The National Weather Service forecast called for high winds above tree line, gusting to 95 km/h, with a trace to 2.5 cm of snow. Two things concerned me as we climbed. The group was strung out along the road, some skiers struggling with bindings where I hung back to help, the strongest well ahead, and conditions were deteriorating well beyond the forecast as we approached tree line. (Our met station recorded gusts to 110 km/h that evening with 40 cm of new snow).

I called the snowcat driver for conditions above tree line and asked them to relay a message to the volunteer I had designated as group leader, hoping to hold everyone at a regrouping point below tree line. The call was not received. I left the group I had been skiing with at the back with instructions to stay together and skied ahead to catch the group in front.

My colleague then radioed that both vehicles had reached the Tundra Lab. Still more than a kilometer below tree line, I asked whether conditions were good enough for the group to follow the snowcat tracks up. The response was no. I asked that one of my colleagues with someone to help navigate be sent down in the UTV to intercept the skiers before they skied above tree line.

By the time I reached tree line, roughly 15 skiers, many of whom had never been to the Tundra Lab, were now in a whiteout somewhere in the 800 m between the top of the road and the building. The UTV appeared a few minutes after I reached tree line, but the drivers had not seen anyone on their way down. I sent the UTV to turn around and search through the whiteout while I waited for the group behind me. Between 30 and 60 minutes passed before everyone was accounted for. Some had reached the lab alone or in small groups using the waypoint we had distributed; others were found by the UTV. We

learned afterward that the group had made no attempt to stay together, having assumed that because the snowcat and UTV had continued up, following was the plan.

Result: Group size was reduced for the 2026 survey, with documented backcountry travel experience requirements for participants. Leadership training, including planning and communication best practices, is planned for future seasons, as is hiring a certified guide to join a survey and provide feedback to improve our safety standards.

5. DISCUSSION AND CONCLUSIONS

This program is now part of the institutional framework at the Mountain Research Station and Niwot Ridge LTER, suggesting that operational field safety practices transfer well into an academic setting. Pre-trip planning, leadership and communication, equipment standards, training, and debriefing are standard in ski patrol, emergency medical services and professional guiding, and they work in a research context largely as they do anywhere else.

Two practices in particular would improve academic field safety programs: better training for those who lead fieldwork, and the use of case studies and near misses. Faculty running field programs are trained in their disciplines rather than in wilderness medicine, outdoor leadership or group management. That does not necessarily mean every principal investigator needs those certifications, but it does mean either acquiring the relevant training or designating field leaders who hold it, and then supporting their decisions in the field. Until baseline field leadership requirements are standard and funded, these gaps will persist. On the second point, academic programs tend to keep incident reporting internal and may not have mechanisms for recording near misses separate from formal reporting. Sharing near misses and case studies more openly would let programs address their own vulnerabilities and learn from others without each having to encounter the same problems directly.

Field safety decisions are also methodological decisions. The 2013 survey was moved back to account for snowpack instability, trading proximity to peak accumulation for an acceptable margin of hazard. The 2011 survey was cut short on its third morning. In 2025, no distributed depth survey was collected: after the first evening described above, high winds and new snow continued, preventing any sampling. The group waited at the Tundra Lab until mid-day, then descended together with the UTV leading and the snowcat following, in low but manageable visibility. A reduced effort by two of us the following week included only a federal sampler transect where snow pits would normally have been dug, preserving SWE and density for the year but not the spatial record. The 2026 crew was capped at ten, which reduces the number of points a survey can collect. These changes were made for safety rather than scientific reasons, but each one shaped, and continues to shape the record.

Airborne or UAV LiDAR surveys now provide distributed snow depth at high resolutions. It is possible future surveys may become hybrid, perhaps with fewer snow depth points but aided by UAV surveys, while continuing to collect the snow profile data airborne surveys cannot reproduce. This could allow for continuing the spatial coverage of the snow surveys even with the change to smaller, safer group sizes. Planned analysis will extend the spatially distributed dataset to the present using a random forest model with terrain predictors like those of Erickson et al. (2005), together with dynamic wind scour and drift predictors, to examine whether the spatial distribution of snow in the catchment has changed over the thirty-year record.

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