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Wasatch, Utah: South Monitor Bowl. During the Thanksgiving avalanche cycle this slide was remotely triggered from the ridgeline, about 500 feet away. It ran on facets above an October crust at the ground. The same slope turned into a repeat offender about five times this season, until the whole bowl avalanched to the ground on February 5, 2019. *Photo Mark White*

THE AVALANCHE REVIEW

DECISION-MAKING ISSUE

THE AVALANCHE REVIEW

The Avalanche Review is published each fall through spring by the American Avalanche Association, Inc., a nonprofit corporation. *The Avalanche Review* welcomes the submission of articles, photographs, and illustrations.

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AMERICAN AVALANCHE ASSOCIATION

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The American Avalanche Association promotes and supports professionalism and excellence in avalanche safety, education, and research in the United States.

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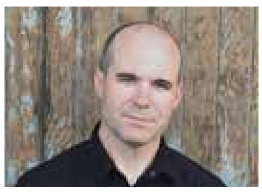
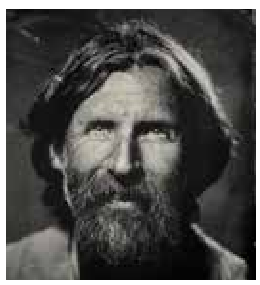
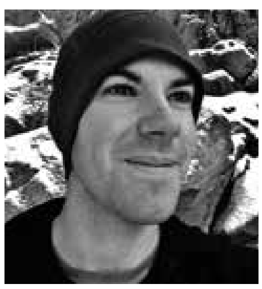


Jefferson Slagle lives in a small college town on the Idaho side of the Tetons. When he's not writing or teaching, he can be found in the mountains of Idaho and Wyoming, skiing, climbing, and biking.

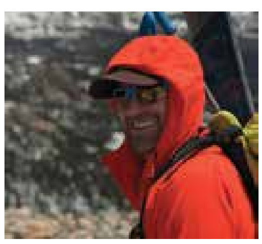
Marshall Swearingen is a writer/editor at Montana State University's News Service. He grew up skiing at Bridger Bowl and lives in Livingston, Montana.



Drew Hardesty has been a long time avalanche forecaster at the Utah Avalanche Center and just recently retired from a career as a summertime climbing ranger in Grand Teton National Park. He has Moby Dick, the Bible, and something by Cormac McCarthy on his bedstand. He's been sleeping well these days.



Derek DeBruin lives in Ogden, Utah where he teaches courses at Weber State University and owns Bear House Mountain Guiding with his wife. He also serves on the Diversity, Equity, and Inclusion Committee for the American Mountain Guides Association and volunteers for the Weber County Sheriff Search and Rescue team. When he's not out chasing lines in the local hills, he's chasing his two-year-old son.



Russ Costa is an Associate Professor of Honors & Neuroscience at Westminster College in Salt Lake City, Utah, where he teaches about minds, brains, data, science, decision-making, and many other things. He studies attention and perception inside the lab, and risk and decision-making outside of it—preferably in the mountains.

FROM THE EDITOR

BY LYNNE WOLFE

Driggs, Idaho, March 20. Finally it smells like spring. I went "out below" yesterday and saw grass on the ground. While we're digging out after a long winter, Colorado is still in the throes of the deep slab "low likelihood—high consequence" monster after a protracted battle throughout February and March. I look forward to presenting you with an in-depth look at their historic avalanche cycles in the October 2019 issue of TAR.

But until then, you'll have plenty of excellent stories to keep you busy in 37.4, our customary human factors and decision-making themed issue. I had a great time assembling and shaping this issue, and our graphic designer McKenzie Long's creativity then made it pop. Start with the Blue Ice/Green Anchors study from the Wasatch that blends science (Greg Gagne's investigation into a near-surface faceting layer) with forecasting and analysis from Drew Hardesty, Derek DeBruin, and Russ Costa, then correlated with cognitive science from Laura Maguire, in the first article in our decision-making multiple choice.

Insights about potential rescue comes in part 2 of Jay Whitacre and Curt Davidson's Western Colorado University survey research. Next, Liam Bailey brings his distinctive voice to a conversation about the Ignorance–Arrogance–Complacency triangle. I met Ken Wylie in December when he came down to the Tetons as keynote speaker for our annual avalanche night, then gave a full day workshop to the Exum Guides. His Tumbledown Mountain experience gives his presentations a certain gravitas; Dragons was a crowd favorite and as been reprinted from our friends at Avalanche Canada. Next in line is a compact essay from Gabrielle Antonioli of Bozeman, reprising her MSU-SAW presentation; I am sure this is not the last we will hear from this talented scientist, guide, skier, and teacher. With focused work on their Pro avalanche curriculum, AAI has come up with an adaptation of Roger Atkins' mindset concept with Mindset for Mitigators. For our G choice, perennial TAR writer and educator Jerry Isaak informs us about the curse of knowledge; luckily he gives us tools to break the curse.

Eeva Latusuo and Aleph Johnston-Bloom bring us the next episode of their mentorship work with Wise Ones. I wish we had more room for photos—some poignant shots of our mentors in action.

You'll find more great writing in Jefferson Slagle's piece Bottomless; save a chunk of time to sit with that essay and absorb his perspective.

37.4 isn't solely comprised of decision-making articles, however. Back in February I had a question about settlement that I pestered some of my science advisors to answer. It's remarkable how much insight can fit into so few words if an author really understands a topic; you'll find some pithy insight in our Settlement Round Table.

There's more of course, but that's all I have room to elaborate on. Please let me know your impressions of this issue, what resonates or fits into your world view, and what you'd like to see in TAR next year.

Have a great spring and summer, friends.

—Lynne Wolfe ▲

Above: Lynne Wolfe and one of her mentors, David Lovejoy, during one of the renowned Prescott College ski mountaineering courses in the Sierra.

FROM THE PREZ

BY HALSTED "HACKSAW" MORRIS

The famous alpinist and snow researcher, Andre Roch, is often attributed to have said, "The avalanche does not care you are an expert." I have often thought about this quotation.

From all that I have heard about Roch, he was a humble person. Being humble while in the presence of mountains and avalanches has been one of the strategies I have employed in my climbing and skiing career. I readily admit that I have turned back from many a summit and not skied many of "the choice gnarly lines," because I strongly believe that avalanches are tricky beasts.

As of January, I became the new president of **The American Avalanche Association** (A3). I do not consider myself to be "the expert" about avalanches. I have been on the A3 board of directors for over two decades. Back in the day, then AAAP president Knox Williams appointed me as the Affiliate Members representative. Since then I have worked my way up through both the professional avalanche world and the A3 board.

The avalanche does not care you are an expert.

I'm looking forward to the next two years serving as your president of A3. I have some big shoes to fill with John Stimberis retiring from the office of president. John stepped up from being the A3 vice president when the previous president resigned midterm due to family and health issues. John shepherded downsizing the board and rolling out the new Rec/Pro education program. The A3 membership and board is much in John's debt. Thank you, John.

I'd also like to say thank you to long serving A3 board member Blase Reardon; with 19 years of service, he is one of the longer serving members; he headed up the publications committee and was co-editor of TAR. Blase also has served in a number of other capacities on behalf of A3. Thank you, Blase.

I also want to extend a big thank you to all of you that donated during the December fundraising drive. Much gratitude goes to our anonymous donor with their $5,000 matching donation. Thank you so very much. Every dollar really counts for A3.

I recently spent a day with our Executive Director Dan Kaveney at the Outdoor Retailer Snow Sport show in Denver. I was impressed with Dan's drive and ability to get folks to support A3. The A3 membership should be very pleased to have him as our Executive Director.

My major goals are to get A3 on a more secure financial footing with fundraising and increasing the membership numbers. A3 also needs to find more ways to serve its membership better. If you have any ideas, I'm all ears. ▲

Halsted Morris got his nickname of "Hacksaw," while he was with the Loveland Ski patrol, when one senior ski patroller couldn't seem to remember his actual name, and the nickname stuck. Hacksaw has had a long career with A3; he started as the Member Affiliates Representative, was next in charge of Awards and the Memorial List, then Vice-President, and now President. He manages Heliskihistory.com with his wife Barb, in Avon Colorado.

JIM SPRINGER REFLECTS ON HIS YEARS AS A FORECASTER

INTERVIEW BY REBECCA REIMERS

When you roll over at first light and check the avalanche report on your phone, it's easy to forget that forecasters on the other end of that report have been up for hours analyzing information and preparing a report for backcountry travels. Jim Springer has been part of the dedicated BTAC team for nearly twenty years and will officially retire this year. Jim has devoted his life to helping keep people safe in the mountains. We are grateful for expertise we wanted to honor his contributions by sharing a little bit about his life and work. If you see Jim out and about in the mountains, please thank him.

Q: *How did you come to live in Jackson Hole?*
A: I first came to Jackson Hole to work as a Ranger in Grand Teton in 1984. I had been a Ranger at Mount Rainier for many seasons and had always wanted to climb in the Tetons.

Q: *How long have you worked as a BTAC forecaster?*
A: I believe in the mid to late 90s. I had been helping in the "Avy Lab" in the old Tram building for the ski resort, then began to write forecasts for the Forest Service. I was involved with avalanche education and rescues (body recoveries) in the Cascades since the early 70s and worked as a Ski Patroller at Crystal Mountain where there is a considerable amount of avalanche mitigation, similar to here. The patrol turnover was very high so it was in our (including my future wife, Kim) best interest to dive in and learn everything we could about snow science. We didn't have leaders with decades of avalanche knowledge like here.

Q: *What have you enjoyed most about working with the BTAC?*
A: I really loved the times when the snowpack was complex and unpredictable; the weather forecast underestimated the wind and snow. Around five AM we had to take all the information from remote weather stations and combine it with our knowledge of the snowpack and the weather forecast and make a decision, give the hazard a rating and write a succinct forecast, all in about an hour. It can be very intense and requires a great deal of efficiency and hopefully a bit of brainstorming with another forecaster, to get it done well, and on time.

Q: *What are the most memorable moments in your avalanche forecasting career?*
A: Memorable but not pleasant moments are when conditions are dangerous and although we have an accurate sense of the hazard and try to emphasize the seriousness in our forecast, someone is injured or dies in the very type of avalanche we warn is likely. Memorable pleasant moments are thousands of vertical feet skinning for thousands of vertical feet of virgin powder turns. I do enjoy the uphill, sometimes more than down. Yeah, addicted.

Q: *What are your plans after retirement?*
A: I plan to continue doing what I have been doing since my teen years: backcountry skiing and Nordic skiing in the winter and backpacking and climbing in the summers. I also hope to indulge my artistic side with more pen and ink drawing and painting. There are many sub-alpine and alpine ridges in the Rockies, Cascades and Olympics I still need to traverse. ▲

Springer gets the feel for some complex clockwork during a visit to Stanford University. *Photo courtesy Jim Springer*

MSU SAW

The 2018 Montana State University SAW wrapped up late this year. Due to scheduling issues, we ran it the Monday after Thanksgiving on Nov 26. With skiing well under way at our resorts and the backcountry enjoying stellar conditions, the crowd was primed to hear some presentations. Our theme this year was “How Does Your Day Roll?” The goal was to tap into the deep reservoir of experts in the Bozeman region to learn some tips and techniques for success from people who are in the snow every day. As always, we aim the SAW content directly at MSU students who may or may not be familiar with the area.

Our evening’s host, Jordy Hendrikx, director of the MSU Snow and Avalanche Lab, introduced Dan Kaveney, Executive Director of AAA. Dan made a push for the recreation community to be more involved in AAA activities by learning about their publications, training, and community.

Alex Marienthal, forecaster for the Gallatin National Forest Avalanche Center, kicked off the night by returning to basics. He explained in great detail how and why the forecast is as it is. He reminded us that it is a broad brush approach to conditions assembled from weather patterns, past conditions, observations, and contributions from the public. In the case of the GNFAC they are forecasting over 6,000 square miles of rugged remote terrain so it is important that users understand the nature of the information the Center provides. A snowpilot profile for Bacon Rind is likely very different than one near Cooke City. It was worth being reminded by forecasters how and why the forecast should be used and not used.

In her talk about self awareness and risk, Gabrielle Antonioli took the forecast into the realm of mindset and action. Gabrielle is a MSU snow science graduate student, an intern of Karl Birkeland, and an energetic skier with considerable familiarity with southeast Montana. See an in-depth story of her presentation in this issue of TAR, on page 38.

Drew Pogge, owner of the Bell Lake Yurt near Bozeman, framed the lessons of the earlier presentations around guiding the remote “Montana Haute Route.” This 32-mile tour is done without the benefit of forecasts, cell service, or guaranteed SAR services. It averages 8,000 vertical feet each day and climbs 11 summits over 10,000. In order to deliver the goods to a select few, Drew has designed a process that any serious recreationist could use in similar terrain anywhere in the world. Drew should be on the speaker list of other SAW organizers in future years. Among the lessons he applies to successful trips is above all—be able to self-rescue. The Tobacco Roots have almost nonexistent SAR so practicing extracting an injured skier is an imperative part of guest orientation. How many of us have practiced transporting an injured person in one of those nylon backcountry rescue sleds? Drew’s clients do. He also schedules turnaround times for each leg of the tour. Spring storms in Montana can be spectacular so having time to bail gives him a cushion of safety. Finally, he preaches Margin, Margin, Margin. Remoteness involves building a margin of error in all respects of the tour and he spends a good deal of time and resources to build that in. Drew is the consummate professional and it shows; amateur recreationists can adopt many of his professional practices.

Finally, we wrapped up with words of wisdom from a true Bozeman local legend. Doug Richmond, ski patrol director at Bridger Bowl, has been chasing cornices, powder pockets, deep layers, and wet slides for nearly forty years—and he still claims to not have figured them out. Doug’s style doesn’t mince words—you should be wary of this and that; don’t do this; do this. In an era where so many dance around with their opinions, Doug is the straight shooter.

You can take his advice to the bank or the backcountry. He explained how and why the Bridger Patrol opens the hill and tries to keep the area skiers relatively safe. Each morning they chisel the 2.5-mile ridge of overnight cornice buildup. These sloughs clean out a good deal of the many gullies and features that hang above the main runs. By doing so, he minimizes the number of shots his crew has to deploy. By opening the ridge terrain as often as possible, Bridger skiers can get the goods and help control much of the terrain. Doug’s philosophy is part of what keeps Bridger such an interesting place to ski.

The gorilla in the room at Bridger is, of course, access to Saddle Peak and every MSU SAW has a focus on this popular and potentially hazardous sidecountry terrain. Doug didn’t preach but did provide a stark public service announcement: To those who cross boundaries to explore the life accessed backcountry of Saddle—don’t expect a rescue from within the boundary, travel as if your life depended on it. You are taking a (calculated) risk. Full stop. This is probably good advice for all lift accessed backcountry terrain.

He discussed a late season accident last year where, had that advice been taken, it may have had a different outcome. That said, he urged us to go make some snow slide, try to figure it out, and start small. Good tip from an old pro. Thanks Doug.

The MSU SAW is sponsored by a grant from A3, MSU Deans of Students, and Letters and Science. ▲

Jerry Johnson is a research affiliate at the MSU snow and avalanche lab, and is involved with multiple projects looking at the human side of the mystery of skiing safely in the backcountry.

SNOWBIRD, MEET INFOEX

INTRO AND CONCLUSION BY SEAN ZIMMERMAN-WALL
BODY BY CHRIS BREMER

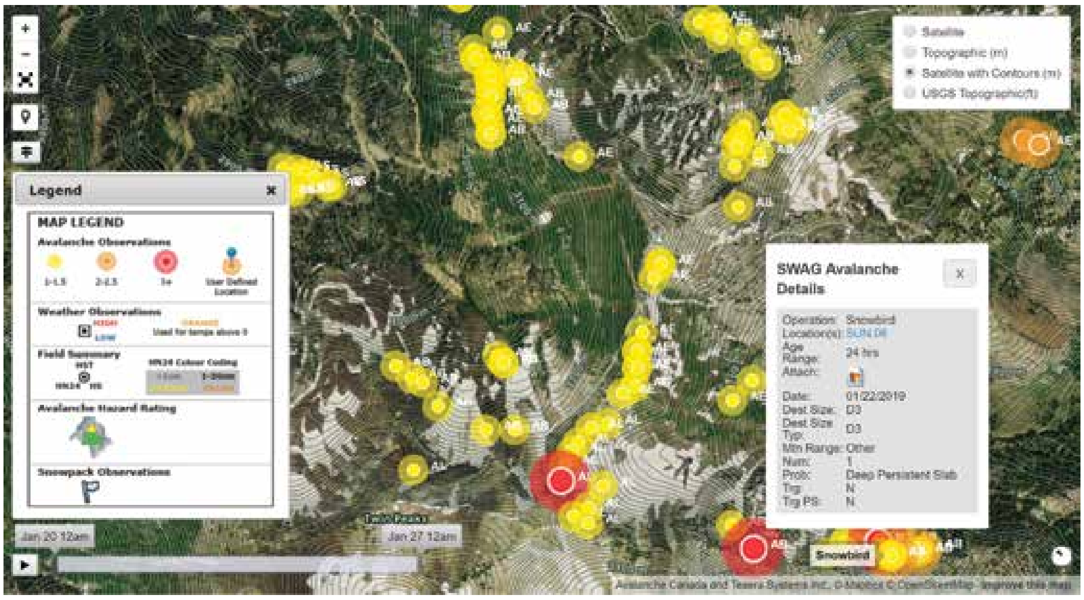
During a professional level avalanche course years ago, a sage instructor with a wealth of experience told us: "Data isn't information, information isn't knowledge, and knowledge isn't wisdom." To this day that quote sticks with us and is profound in its simplicity. It is a subtle reminder that when we collect things like sky cover, temperature, surface form, boot pen, or other SWAG-y bits, it is important to keep them in perspective of the big picture. Writing things down is a powerful memory aid, but what should we do with the stacks of field books or endless reams of paper to better ourselves as forecasters and practitioners? How can we actually improve our operational working memory? One solution comes to us from Canada by the name of InfoEx. The digital database came to fruition in the early 1990s when helicopter ski operators noticed a trend in avalanche involvements or accidents and decided to start sharing information about the snowpack and regional conditions. It has since been developed into a modern technological platform thanks to the hard work of researchers and legends like Pascal Haegeli and Bruce Jamieson. Through continued partnership with the firm Tecterra, InfoEx is now being offered to those outside Canada in an international version that provides flexibility for operations such as ski areas, backcountry guide services, and even educational providers. The following is our story of how this program is being used during its trial year in the United States.

In early 2018, the avalanche data entry computer program we had been using at Snowbird suddenly reached the end of its functional lifespan. It had served us well, but because of its sudden demise, we were forced to record our avalanche observations on paper for the remainder of the season. Fortuitously, Canadian Avalanche Association (CAA) representatives appeared at the National Ski Area Association conference held at Snowbird later that year. Stuart Smith and Joe Obad were there to discuss their international version of the exemplary Canadian InfoEx system. Much of what was shown in that brief overview escapes me, but I reported favorably on the InfoEx system when I returned to my supervisors. As the spring of 2018 continued, we hosted several exchange ski patrollers from Whistler and Revelstoke, all of whom were able to give us insight into their use and experience with InfoEx. It was during the Whistler patrollers' visit that the Snowbird Mountain Operations Director, Peter Schory, and the Snow Safety Director, Todd Greenfield, were sold on the benefits of InfoEx. Their decision to implement the platform gave me much to occupy my time during my first summer season of employment at Snowbird.

Hazard Assessment: Using the Conceptual Model of Avalanche Hazard as a backbone, InfoEx allows for clear assessment of the avalanche problem(s).

Once the ski season had come to an end in May, I began building out our location catalog. This entailed roughly drawing out Snowbird's many avalanche control routes and avalanche paths. Our avalanche recording in the past had centered around shot placements, so it was these locations that I was most meticulous in placing in the location catalog. Change is slow in any industry, and the ski industry is no exception. So, while filling out Snowbird's InfoEx profile, I made it a point to closely replicate the systems we had used previously. This helped ease Snowbird Ski Patrol's adaptation to the new system and also ensured continuity with the data we had been collecting for the last 47 years.

Over the course of the summer, I dedicated a little more than a month to the build out and fine tuning of the system. The location catalog and the selection of representative photos took the greatest portion of this time. Morning and afternoon workflows were created to provide a structure to what we historically had recorded every day, like weather reporting and assigning avalanche control routes. Incorporated into these workflows were features new to us at Snowbird and unique to InfoEx. Features such as their database-driven Persistent Weak Layers tracking and



Visual summary of avalanches triggered during a one week period in January. Red dots indicate large avalanches (D3).

Data isn't information, information isn't knowledge, and knowledge isn't wisdom.

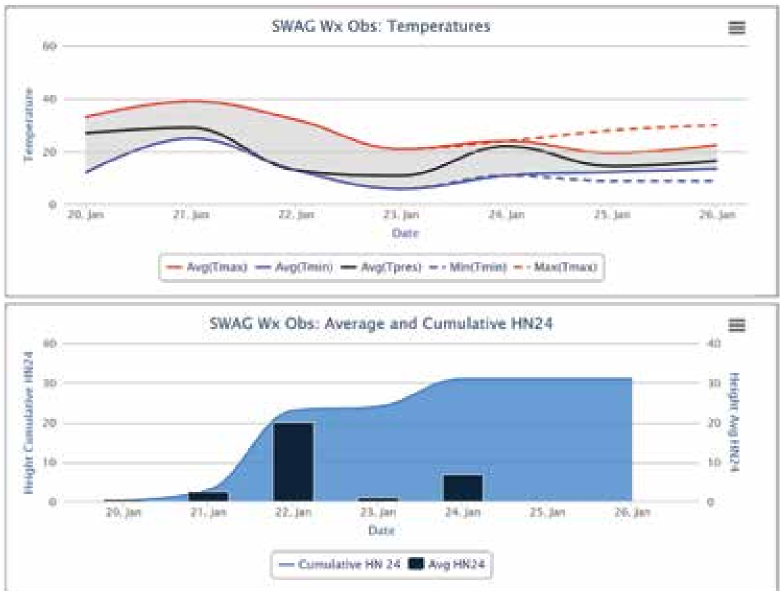
Snowpack Summary. InfoEx also provided an elegant way to generate forecasts using the Conceptual Model of Avalanche Hazard. By the time October arrived, Stuart Smith came back to Snowbird to spend a day advising and answering any lingering questions I had. This being my second sit down with Stuart I gained a greater understanding of the system. Without any actual avalanche or weather data entry due to that pesky thing called summer, our Snowbird InfoEx profile was still a hollow shell. Stuart showed me operations that had several season's worth of data and how the embedded maps and charts were auto-populating from the data entered. During this same meeting and since, Stuart has been very receptive to suggested changes and improvements to International InfoEx based on our use at Snowbird, with many of those suggested changes already implemented in subsequent updates.

Data collection began in early November and by mid-December, the Snow Safety department was very happy with the ease of use and speed with which we could generate useful and meaningful morning forecasts and afternoon summaries and route lists. The greater ski patrol became well versed in avalanche control route recording thanks to a few early storm cycles.

Future steps we are taking entail importing historic Snowbird data into the database with the help of the creator of our previous recording software. As the winter rolls on, our maps will get more detailed, the charts will provide more analysis, and Snowbird's InfoEx data will increase in value every day.

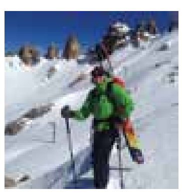
Coming into the spring at Snowbird, we are excited to continue using the platform and have even integrated it into our backcountry guiding program as a means to conduct our morning and evening meetings. Options like the Run List feature allow us to categorize terrain into operating zones and systematically select where we will go and where we will avoid. This feature in particular has great potential for our operation and gives us insight into how we use our terrain. We can also list our Strategic Mindset for the day and hold ourselves accountable for the way we approach our field operations. Being able to view what other operators in our area are seeing is perhaps the most useful tool for the guiding side of things. At this time, one other backcountry guide service in our area is actively using InfoEx and we benefit from sharing each other's observations and daily hazard assessments. A formalized system of information exchange is a sea change for our industry here in the United States and it represents a cultural shift in how we document. Overall, it is helping turn data into information and knowledge, which enables us to connect the dots and make evidence-based decisions. Wisdom, as they say, will only come with time.

For more details about the platform or how to subscribe to International InfoEx, visit www.avalancheassociation.ca/page/InternationalInfoEx. ▲



Weather charting allows us to view change overtime and relate critical observations to overall hazard.

Chris Bremer is a Colorado School of Mines graduate (BS Engineering, '03). Now, he is Snowbird's Snow Safety Supervisor and enjoys product testing pre-public.



Sean Zimmerman-Wall is consistently striving to improve his operational awareness by working for various entities such as Snowbird Ski Patrol, Snowbird Backcountry Guides, and Patagonia Ski Tours. As well, he serves as a pro program manager for AIARE and a board trustee of the American Avalanche Association.

A COLLECTIVE APPROACH TOWARD AVALANCHE CENTER WEB TECHNOLOGY

BY SIMON TRAUTMAN

The Web is the single most powerful means of collecting and distributing avalanche safety information. It can also be costly, technically complex, and maddeningly dynamic. Although being succinct about the ways technology affects avalanche centers is hard, it is easy to say that its impact is, and will continue to be, profound.

Avalanche centers in the United States operate independently. As a result there is a wide range of platforms used to collate and distribute public avalanche safety information; both from a technological and product-based perspective. In some cases this diversity caters to local needs and promotes growth and innovation. In others it results in redundant work and impedes collaboration and consistency in the design and function of public safety information.

Perhaps most importantly, growing technological overhead can further increase the resource gap between smaller and larger avalanche centers. For example, a larger avalanche center (annual budget ~$1m) may allocate 10-15% of its budget to technology development and support. It can also recruit and hire specialized positions to manage year-round in-house projects. By comparison, a smaller center (annual budget ~$60k) may need to spend 20-30% of its budget on technology and still have to cover the 1-2 seasonal field positions required to run the operation.

Operational needs are changing for avalanche centers. In order to keep up and improve, some centers need a collective approach to technology development. Luckily, shared platforms are not only available, they are attainable.

The foundation for this approach already exists. Avalanche.org is designed to both showcase avalanche center information and to house behind-the-scenes applications that provide shared avalanche center tools.

Avalanche.org works through a series of partnerships. The American Avalanche Association (A3) manages the business needs behind the website. The NAC provides the project management, technical expertise, and a little more than half of the funding. Avalanche centers provide the remainder of the funding and most of the information. Currently, the service manages the:

- National Avalanche Danger Map
- Avalanche Center Homepage Map
- National Avalanche Warning Platform
- Weather Station Platform

This spring we will formally convene a committee of avalanche center representatives tasked with managing the existing applications. Additionally, the group will begin work on a central platform where avalanche forecasts can be created, databased, and then displayed on independent avalanche center websites.

Our goals for the shared avalanche forecast platform are to:

- Improve consistency in design, messaging, training, and public education.
- Reduce costs through shared development, maintenance, and infrastructure.
- Improve the capacity to integrate, scale, and update our existing technologies.
- Create a nimble system with single maintenance and update points.

Avalanche centers are a diverse group, and this approach may not work for all. However, it is a valuable option for those aiming to improve consistency in their messaging and streamline their technology costs through shared developments. ▲

Simon Trautman is an Avalanche Specialist with the National Avalanche Center and the Director of Forecasting for NWAC.

BOOK REVIEWS

PLANNING METHODS FOR ASSESSING AND MITIGATING SNOW AVALANCHE RISK

Edited By Bruce Jamieson

The title of this book quite nicely defines its content. It is intended primarily for avalanche practitioners such as engineers, geoscientists, and consultants tasked with long term planning on the order of months to years. However, it has utility for workers on a shorter scale and provides a comprehensive overview on the state of the art for anyone interested in the topic. Bruce Jamieson, is well suited to the editorial task, bringing decades of experience and extensive collaborations. He is Professor Emeritus at the University of Calgary where he taught classes (the genesis of this text), conducted snow research, and where he received his PhD in avalanche mechanics. As a professional engineer, he has worked as a consultant on numerous projects directly relevant to the subject.

The book is well organized and logically presented. Depending on the reader's background, individual chapters are reasonably self-contained. However, cross references are made to notions developed in complimentary chapters, tying the volume together. Opening segments provide definitions and general characteristics associated with avalanches. Terrain characteristics such as the effect of slope angle and vegetation on avalanches are reviewed and nomenclature associated with an avalanche path defined. Avalanche type, size classification, and flow features are described.

The book offers methodologies to analyze the extent and frequency of avalanches, which need to be established for long term planning. These may be addressed utilizing historical records to chronicle past avalanche boundaries, observed foliage distribution, and vegetation damage. Shorter term records are compiled using information from airborne, satellite, lidar, and google earth imagery.

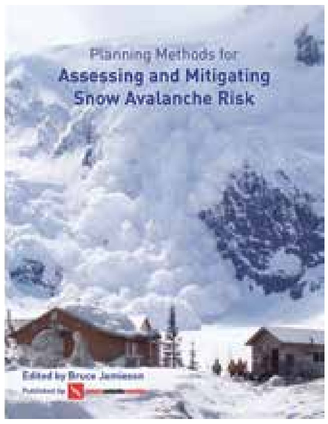
Statistical methods, utilizing data from similar paths in a region to quantify extent and size of an avalanche path of interest, are presented, as are physics-based avalanche dynamic models that are used to calculate runout distances and, in some cases, lateral extent. Dynamic models may be used in the determination of impact pressures as well. The primary sources from which these models are developed are appropriately referenced.

A distinction is made between hazard, which includes avalanche likelihood, frequency, and magnitude; and risk, which following hazard assessment, incorporates exposure, vulnerability and consequence. Consequence may include loss of life or economic consideration of property. A scenario may involve stationary structures or have a temporal component, such as vehicles moving through a path. The book presents assessments that utilize qualitative, semi-quantitative, or quantitative analysis in combination with expert judgment. Useful illustrative map types that include location, path, terrain class, risk, intensity and terrain exposure as used in assessment and zoning are provided.

A comprehensive compilation of mitigation measures includes fixed structures such as snow collection fences, deflection dikes, catchment dams, tunnels and sheds. Temporary measures implemented in consort with forecasting and expert judgment include road closures and evacuation, as well as active control, cataloging explosive deployment systems.

Overall, the presentation is accessible to its intended audience. It includes numerous useful photographs, figures, illustrations, and example case studies. In instances for which the conceptual detail is beyond the scope of this text, appropriate literature and links are referenced. This volume merits a place in the reference library of avalanche practitioners and workers.

—Ed Adams
Distinguished Professor Emeritus of Engineering Mechanics, Montana State University



Front cover image: An explosive controlled avalanche at the Galore Creek Project located in northwestern British Columbia, Canada. It is 370 kilometers northwest of the town of Smithers. The avalanche is farther from the workers and buildings than it appears. *Photo Wayne Ball*

STAYING ALIVE IN AVALANCHE TERRAIN, 3RD EDITION

By Bruce Tremper

Do I need to buy this book ASAP?

Do you own a copy of any edition of Tremper's exhaustive avalanche textbook, accessibly written for the high-end recreationist?

No? *No!* Then of course you do. His anecdotal style leads you on deceptively simple paths through complex topics, delineating parameters that help define the eternal snow reply, "it depends." Bruce shows us what stability depends on, and how to start weighing the factors professionally. This book should be an integral part of your library if you want to make informed decisions in complex terrain.

Yes. I own the 2nd edition of *Staying Alive*. Why do I need to get a new version? Isn't this Bruce's tricky strategy to fund his retirement?

Haha. First of all, no one gets rich from revising a pre-existing book. But to answer your question, do you go to all the snow and avalanche conferences, pay attention to theory and how to fit the innovations into your practice? No? Who has time for that? Well, Bruce does. And the Third Edition incorporates new material from the big-brained folks in our industry and community into every single chapter.

Even if you do go to the conferences, dutifully digest every TAR, and collect innovations, here's all that material in one place. Plus with a stunning avalanche photo on the cover.

Highlights:

- He reorganized the book to reflect the Conceptual Model of Avalanche Hazard and fit various chapters into the CMAH. This works for me, especially as I begin to teach in the new Pro curriculum, which is structured around the CMAH.
- Changed the mechanics of slab failure to reflect current thinking (Bruce notes that after attending the ISSW in Innsbruck he will need to change it more for the next printing).
- Bruce also notes that he changed the way he teaches terrain, simplifying it by addressing the snowpack variables of terrain in other chapters (aspect with respect to wind and sun). He also removed slope shape since the Swiss research shows little correlation between slope shape and avalanche frequency. His main terrain choices revolve around steepness and consequences, so the tenets revolve around the permanent, immovable aspects of terrain—steepness and consequences with some consideration of the positive and negative aspects of anchors.
- He changed the Human Factors chapter quite a bit to reflect more current thinking from researchers.
- The rescue chapter was updated.
- He added a chapter at the end titled Putting It All Together to include several decision frameworks and conceptual models—better ways to make decisions around risk.

—Lynne Wolfe

It’s early October. Fall storms have grizzled the high elevations of the Tetons, and the hard-core skiers are already in the mountains. Two people, a woman and a man, have died. They were climbing a long, steep couloir in Montana’s Madison Range when a weak layer in the snowpack broke and kept breaking all the way to the top. The avalanche ran down right on top of them. The man dug himself out and searched for the woman, his girlfriend, for three hours before marking the debris with his probe and hiking out to his truck. Then he drove to his home in Bozeman, wrote a note for the search and rescue team detailing where the woman had been buried, and took his own life.

Bottomless

Story and Photos By Jefferson Slagle

A version of this essay originally appeared in *Creative Nonfiction*.

While I wasn't skiing this day, the Madisons are an hour and a half from my home in Idaho and are among the mountains I ski frequently. I read the Gallatin Avalanche Center's report on the incident, which includes a photo of the peak the couple planned to ski. The avalanche path and the pile of debris at the bottom are visible in the picture. I find a map of the mountain and make a note to ski it in the spring. I know there is something wrong with this.

***

Late that October, I'm at a week-long retreat at a cabin in Teton Valley, Idaho. One afternoon, I take a break from writing and run up a narrow dirt two-track, into the mountains. Not a quarter-mile from the cabin, I hit the first patch of snow. The road narrows to a trail that follows a creek, then turns hard to the right. I follow it up a ridge, and now the snow is everywhere. The thin crystal glaze doesn't look malevolent, just out of place against the still-green brush. But it's already turning to sugar; the future of this snow is easy to predict.

Take last year, a typical season: October snow, warm days, rain, then, finally, in late November, the storms we'd waited for. The snow fell light and cold at first, then warm and wet and heavy, like piling steel beams on top of Styrofoam. Despite the warning signs, a pair of skiers on Teton Pass chanced a line through Wolf Trap, a notoriously touchy spot, and set off an avalanche that caught and carried both of them. They dug themselves from the debris and walked out.

The Bridger-Teton Avalanche Center had rated the hazard that day as High. What were those guys doing up there? What analysis led them to believe that slope was stable?

In retrospect, every decision seems easy, but what's easier is to convince yourself of what you already want to believe. What psychologists call "motivated reasoning," we call human factors, and perhaps the biggest is the impulse that draws us to snow in the first place. I feel some magic even in the remnants of this early season storm, and I climb higher on the ridge, though the snow is slick and treacherous and plasters my shoes so that I nearly fall.

In the coming weeks, new snow will bury the thin layer I'm sliding on now, and storms after that will bury it deeper, until, probably sometime around the first of the year, the weight of the snowpack will overwhelm its faceted structure, and it will all collapse. I just hope someone isn't on it when it does.

***

Snow science is a black art.

The basic principles are clear. Weather, for instance: one of the first things we learn about backcountry travel is to avoid steep slopes immediately after a storm. Or terrain: ski a low-angle slope, and it won't slide except on the kind of day where the danger's so high you should probably stay inside and tune your skis anyway. Simple enough. But the devilish paradox of powder days baits us into steep slopes like fish to a lure. Plot danger and desire as two curves on a grid; risk is the space where they link.

As pure science, it's easy. But translating it to a go/no-go decision at the top of a clean bowl of untouched powder when all your love is telling you to go ahead and ski it despite everything you don't know about the fragile menace buried beneath beguiling powder—that's the art.

***

May is late season in Wyoming, and I'm in the central Tetons with Braden. I spend the night in a cabin with a view of the mountains and watch rain fall on the high peaks until the sun goes down. The next morning, we meet early and drive to the trailhead and start to climb.

The surface of the snow is dimpled with fist-sized sun cups. The north face of the mountain is a wall of cliffs broken by narrow skiable chutes; a large bowl curves off the summit into a long, glacial valley that runs along the base of the cliffs. Our plan is to ski the bowl, but we stop at an overlook and take pictures of the crags and the canyon before continuing up.

It's windy on the summit, and cold. The serriform peaks of the Grand, Middle, and South Tetons splinter against the blue-gray sky. We see no one else—for all we can tell, we are the only skiers, the only humans, in the range. The sun hasn't yet softened the snow in the bowl, so we stop to rest, napping at the top for close to an hour.

When we finally peel the skins from our skis and drop in, the snow is still hard, and my skis scratch out turns against the crust. The valley below the bowl descends past the cliffs in a series of steep steps. I wait for Braden to join me at the bottom of the bowl, and together we ski the mellow stretch of the upper basin to the next step.

The scene from the edge is astonishing. The lower half of the valley has slid, from the top of the step, onto the flats, and around the corner where we can't see. It takes a moment to reconstruct the scene: the overnight rain must have softened a cornice as large as a van. It re-froze overnight, but as the day warmed, its mass overwhelmed the snow's cohesion and it fell, exploding onto the slope below with enough force to trigger an avalanche. The initial slide triggered at least two sympathetic avalanches, and hundreds of tons of snow rolled down the valley, snapping full-grown pines and gouging chunks of rock from the cliffs. A D4, I estimate. Friends who hike the area late in July will tell me the debris hasn't yet melted away.

In the photo I send to the newspaper in Idaho Falls, Braden stands on the icy bed surface near the spot where the cornice landed, the sheer bright crown rising above him. He holds his pole in the air. The distance from his feet to the point of his upraised pole measures the depth of the crown. But that's not the whole story.

When I get home that night, I upload photos from my phone to my laptop and click through them. In the pictures I snapped from the top of the cliffs on our way up, there is no avalanche debris in the canyon. The cornice broke and the whole valley slid between the time we stopped for pictures and the time we skied to the top of that step. Napping, we heard nothing. As we'd watched rain fall on the peaks the night before, we suspected nothing. The depth of our ignorance is unfathomable.

black art:
a technique or practice considered mysterious and sinister.


Wikimedia commons

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In Hindu mythology, Kali is the goddess of time and change, of power and destruction. She could easily, I think, be the goddess of snow.

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Then there's a clear spring day in the Lemhi Range—a dry, little-used spine of rock that runs up the center of Idaho. Braden and I make plans to ski Diamond Peak, the highest summit in the range, a 12,000-foot pyramid that juts from the sagebrush plain of the Birch Creek Valley. We've both climbed the peak before, but we've never attempted it on skis.

As the day warms and the snow softens, the eastern slopes of an adjacent peak known as the Riddler begin to shed snow in long white showers that arc over the cliffs guarding the base of the mountain. Every quarter of an hour, a new slide lets loose, the avalanches marching clockwise around the cirque, each one hitting closer to our position.

We huddle below a small cliff band to reassess our plan. I take off my skis and sink to my hips. We're at least an hour and a half from the summit; by that time, the avalanches' eastward march will have overtaken us. We decide to bail.

We ski a short slope into the basin below then climb a shaded north-facing couloir that still holds hard stable snow. From the top of the chute, we sit and eat jerky and trail mix and energy gels, watching the slides tick across Diamond Peak. Snow pours down the face of a cliff and onto the spot where we stood ninety minutes earlier. Braden and I look at each other and laugh like pardoned men.

***

These are the stories we tell in the truck on the way to the mountain on winter mornings while snow frenzies the air. Stories of almosts, of just made its. Of everything we didn't know made visible in surging, shattered snow.

We talk about "managing uncertainty," but it's hard enough to know what's happening when snowflakes are in the air, isolated and individual; once they hit the surface, the interactions multiply. Piled-up remnants of storms conjoin with or war against those that come after, fragile and knotty and convoluted, and sometimes deadly.

To understand snow takes a mind both diagnostic and analytic, both doctor and coroner. Every avalanche tells a story about the snow maladies endemic to that winter; but you have to see what's not visible, too. You have to feel where the sickness hides.

To take what I don't know and act based on that ignorance seems injudicious at best. Every piece of information I need to make a decision is hidden under the snow. When it's uncovered—if it's uncovered—it will already be too late for whatever story it tells to be useful to whoever started the slide. And whatever story they've told themselves may never be heard.

The truth is, so many of my stories, the explanations and justifications I give for my choices, are nothing more than pretextual fables. Uncertainty is part of what attracts me to the backcountry: I love the snow for what it refuses to confess, for what remains inarticulable. The silence of the winter woods, the solitude of skinning for hours up a ridge, the heart-plunge-and-catch of a powder turn, some alchemy of the physical and the spiritual—these reasons lurk beneath the surface, perceptible only when the snow is flying and I'm floating, touching nothing solid beneath.

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Bottomless. That's the word we use to describe the best of conditions, those days when the snow is so deep and light that, with every turn, it rushes into your face and streams around you in a pearly cloud, and skiing feels like nothing less than flying. Pure, bottomless experience.

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Another May day, and I'm in the Snake River Mountains. Jaren and I are skiing Mount Baird, the highest peak in the range at 10,025 feet. The route description says to follow the creek drainage to the ridge, then turn right and follow the ridge to the summit, but we're impatient and climb the ridge early. This turns out, unsurprisingly, to be a bad idea. We take turns sliding backward down the face as we lose traction on the icy crust. We strap the skis to our packs and try to boot, and we sink past our knees. But by some unforeseen act of mercy, it has snowed overnight at the higher elevations; our skins clamp tight to the new powder, and the last thousand feet are a pleasant tour through stunted pines dusted with snow.

When we reach the peak of Baird, we stop, astonished at the ranges that fold themselves around us in all directions: Tetons, Gros Ventres, Wyomings, Wind Rivers, Snake Rivers, Caribous, Big Holes, Centennials, Madisons. Jaren and I have been in all these ranges, have summited many of their peaks, but we've never seen them like this—the sheer mass and variety and spread of them, the way they fill the world with wonder. Neither of us speaks. Both of us are near tears.

Finally, we strip our skins and gear up and ski back down the mountain. The descent is some of the best skiing of the year, but it's not what I'll remember of that day.

It's been more than three years since that trip to Baird, and still it may be the closest I can get to explaining why I choose to ski the backcountry. I've not yet been in the mountains on a day that matched it. I don't know that I ever will.

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It's early November. Four feet of snow have fallen in the Tetons in the last week. The Teton Pass highway closed two days ago for avalanche control. This morning's avalanche report includes an ominous warning: "Assessing the stability of these slabs is problematic. Snowpack stability tests may not be reliable." Conditions today are far more uncertain, more dangerous, than that tragic day last month in Montana.

The snow that will take me may fall next month, or next year, or in ten years. It may be falling today. It may already cover the ground, waiting to be buried, waiting to contort into the small jeweled crystals that lie in ambush at the base of the pack—invisible, elegant, lethal. Snow makes no pretension to permanence. It changes at a breeze, at the emergence of the sun from behind clouds, at the half-moon bend of a pair of skis. To embrace snow is to acknowledge that nothing in this life lasts, but what there is in this moment I will take and love, not in spite of but because it will never come again. Its transience is its danger, but also its beauty. And what is a life without the possibility of that kind of wildness?

Tomorrow, I'll ski the backcountry. It will be my first trip of the year. The snow should be bottomless. ▲

first tracks

Carrying on a long tradition, engineers and earth scientists collaborate to push the boundaries of snow science

by Marshall Swearingen

This article first appeared in MSU's *Mountains and Minds* magazine.

The steep slopes of Bridger Bowl ski area have long played a role in MSU's snow science research. *Photo Kelly Gorham, © Montana State University Mountains & Minds*

As the night's storm tapered off one morning last February, light snowfall glittered in the sky and the Bridger Bowl ski area stirred to life. Seven inches of fresh powder lifted everyone's spirits despite arctic cold biting at cheeks.

Montana State University civil engineering professor Kevin Hammonds, along with student Katie MacLeod and research assistant Nicole Champion, unloaded from the top of the Alpine Lift. Rather than tighten their boot buckles for a ski down the slopes, they shuffled past the boundary rope and into an untracked meadow, where they dug a chest-deep pit and scooped samples from the snowpack's revealed strata.

"We try to find a way to do everything with gloves on," said Champion, who earned her bachelor's in civil engineering from MSU in 2017. Hammonds, occasionally grinning wide at the wintry splendor, weighed each sample and examined the snow crystals with a small field microscope.

Their project—comparing the accuracy of different methods used to profile snowpack density—is itself significant. But it's also a continuation of a long legacy of MSU snow science, and the landscape bears witness to that history.

For example, at the meadow's edge skiers checked their avalanche transceivers before heading for a backcountry clearing where MSU snow science pioneer Charles Bradley once conducted research that underpins modern avalanche forecasting. Nearby, a ski run is named for John Montagne, the late MSU earth science professor who mentored generations of snow researchers. And in a steep chute above, MSU civil engineering professor Ed Adams and his colleagues made national news hunkered in a plywood shack bolted to the backside of a boulder, measuring avalanches that roared overhead.

This melding of mountain and mind is the story of how MSU became a leader in snow science. It is a story in which—with a serendipitous twist—earth scientists once recruited engineers to push the young discipline's boundaries. And, ultimately, it is a story about the surprises of snow itself, a deceptively ordinary material.

"It's amazing how far we've come," Hammonds said as he captured the microscope's images on his cell phone. "The more we know, the more we realize what we don't know."

***

When the late Charles Bradley was hired as MSU's first geology professor in 1950, "he thought he'd died and gone to heaven," said his daughter, Dorothy Bradley. Like many veterans of a World War II alpine unit called the 10th Mountain Division, Bradley had developed a passion for skiing, and the nearby Bridger Range was a skier's haven. During his backcountry adventures, he helped scout the location of the first lifts at Bridger Bowl. He also encountered avalanches.

One time, he and a group that included former MSU President Roland Renne skied to the ridge near what is now Bridger Bowl's south boundary, where an avalanche had once killed three coal miners. When they descended, they found that a spectacular avalanche had swept the very slope they had earlier crossed.

"He had a couple of really close calls," Dorothy said. "He thought, 'I'd better learn about this.'"

Meanwhile, other 10th Mountain Division veterans established dozens of ski resorts on national forests, and the U.S. Forest Service hired its first snow rangers to monitor avalanches. They closed obviously hazardous areas after heavy snowfall, but little was known about what actually caused the phenomenon.

Bradley's curiosity led him to invent a device called the resistograph, initially little more than a broom handle topped with a pencil mechanism. When the broom handle was inserted and then pulled upward through the snowpack, a barb wiggled the pencil, charting the resistance of the snowpack's layers and indicating weaknesses that posed avalanche danger.

Using the resistograph, he made some of snow science's earliest measurements about variation in snowpack across the landscape due to different exposure to sun, wind, and other factors. The studies produced cross-sectional snowpack profiles like those routinely made with similar, high-tech devices for avalanche forecasting today.

"His work really underpins our whole idea of variation in a snowpack across a slope," said Karl Birkeland, director of the Forest Service's Bozeman-based National Avalanche Center, the umbrella organization for avalanche forecasting centers across the western U.S.

When Bradley recruited fellow 10th Mountain Division veteran John Montagne to teach in the MSU earth sciences department, Montagne, also an avid skier, quickly took interest in the notorious cornices that formed on the Bridger ridge. The wind-deposited snow pillow could become train-car-sized before breaking loose and triggering avalanches below.

William St. Lawrence

by Ron Perla

In the early 1970s, MSU's avalanche program produced a world-class avalanche scientist by any standard. Originally an electrical engineer employed at Livermore, Bill St. Lawrence was encouraged by Charles Bradley to enroll in the MSU Ph.D program under the guidance of the All-Star avalanche faculty of Bradley, John Montagne, Ted Lang, and Bob Brown. Bill instrumented an MSU test path above Bridger Bowl, and performed supporting studies in a cold lab in Bozeman. He pioneered work on the signals emitted by snow under stress in the slab start zone. Pete Martinelli's USFS team was highly impressed by Bill's research; Pete steered USFS funds from his project into a small grant to the MSU avalanche program. Motivated by Bill's research, Pete's group began a similar program at Berthoud Pass. Soon other teams around the world began to instrument start zones to record tell-tale signals of slab release, building upon Bill's pioneering MSU research. After Bill finished his Ph.D., Sam Colbeck, also impressed by Bill's talents, arranged for his employment at CRREL.

Bill St. Lawrence shoulders his load for the MSU avalanche program.

"He'd be up there on the ridge with his hand lens and camera, examining snow crystals, digging snow pits," remembers his son, Cliff Montagne, professor emeritus in MSU's Department of Land Resources and Environmental Sciences.

Those studies were some of the first to explore how and why cornices formed, according to Birkeland. Together with Bradley's work, the research "was really forward-thinking, really innovative," he said.

But Bradley and Montagne discovered that snow's behavior, particularly with regard to avalanches, was dynamic and complex in ways that defied their geologic training. To understand more precisely why snow suddenly slid down a mountain, they needed a different kind of expertise.

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One day in 1971, Bob Brown, a young MSU engineering professor, was in his office working on a research proposal when Bradley appeared in the doorway. Despite a reputation for brilliance and three years spent toiling on the rockets that sent the Apollo missions to the moon, Brown was struggling for funding in the competitive aerospace field. Brown had never seen Bradley before and was doubly surprised when Bradley announced that he wanted help studying the mechanical properties of snow.

"I chuckled," Brown recalled. "I said, 'Why would anyone want to know about the mechanical properties of snow?'" Few, if any, engineers studied the ordinary material at that time.

Bradley persisted in his genial way; Brown eventually acquiesced and invited fellow MSU engineering professor Ted Lang to join them for a later meeting.

"We laughed at the idea," recalled Lang, who had worked at NASA's Jet Propulsion Laboratory for seven years previous to coming to MSU. The duo quipped that they'd quickly solve the snow problem and get back to their real work.

Once they delved into it, however, they became intrigued.

As rocket scientists, Brown and Lang used sophisticated mathematics to model how materials responded to the heat and force of liftoff and the vacuum of outer space. Together with Bradley, Montagne and a growing number of graduate students, they took a similar approach to snow, defining the material's properties and conducting experiments to fill in unknowns.

Lang, together with then-graduate student and now-retired MSU engineering professor Jimmie Dent, focused on snow's dynamism during an avalanche. Brown, meanwhile, studied how snow crystals bonded or broke apart according to changes in temperature and other variables. In one experiment, he placed small blocks of snow on an electric heat plate in a freezer, replicating how the relative warmth of the ground can turn the bottom of a snowpack into sugar-like granules. He then used a device to push each block sideways while measuring the force required to shear it from the new weak layer, much the way an avalanche might be triggered.

"(Brown and Lang) were really at the forefront of taking the study of snow in a more quantitative direction," said engineering professor Adams.

An English graduate and devoted skier, Adams became fascinated by snow after witnessing avalanches smash the lodge at Utah's Alta ski area in 1974. By then, MSU's engineering-earth sciences partnership had become well known in the emerging field. When he volunteered to help a team of U.S. Army Corps of Engineers researchers conduct a snow experiment, and asked how he could get more involved, they advised him to get some formal education.

"The best place in the world to do that," Adams recalled one of them saying, "is Montana State University."

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When Adams enrolled at MSU in 1977, Montagne and Brown charted a path for him to earn a snow-focused bachelor's in earth sciences. The plan, which would eventually become a degree program offered to all students, was loaded with math and hard science classes, illustrating the engineers' influence on the field.

Adams also took Montagne's increasingly popular class called snow dynamics and accumulation. An outgrowth of trainings that Montagne gave in his role as the first director of Bridger Bowl's ski patrol, the course was the first in the country dedicated to snow and avalanches. On weekly trips to the ski area, MSU students donned skis, dug snow pits and assessed avalanche danger.

Under Brown's mentorship, Adams then earned a master's and doctorate in engineering while researching how snow crystals morph in a bewildering number of ways. The work—which continued through the mid-'90s-involved another graduate student, Dan Miller, who is now the head of MSU's mechanical engineering department. That work "was really inspiring for the groups (in Europe)," said Juerg Schweizer, director of the Swiss Federal Institute for Snow and Avalanche Research. The studies contributed to the development of SNOWPACK, a computer model used internationally for avalanche forecasting and research.

The science continued to be guided by practical concerns of avalanche hazard, and the engineers and earth scientists met weekly and partnered with ski patrollers for fieldwork. When Adams helped Montagne convene the growing community of snow scientists and avalanche professionals for the first International Snow Science Workshop in 1982, their chosen motto for the Bozeman event captured the spirit of the work: "A Merging of Theory and Practice." One of the main ways for avalanche forecasters and other professionals to exchange knowledge with snow researchers, the event continues to be held biennially in North America and Europe.

One effect of MSU's growing role in international snow science was increasing interest from students. "It started snowballing," said Steve Custer, who served as earth sciences department head for more than a decade and taught the snow dynamics class for 30 years after Montagne retired.

Among those students was Karl Birkeland, who earned his master's in snow science at MSU in 1990 while researching snowpack variability with an improved version of Bradley's resistograph.

Clockwise from left: MSU earth sciences professor John Montagne conducted some of the first-ever studies about how wind-blown snow creates cornices. Montagne's work finds him on the ridge above Bridger Bowl, likely in the late 1960s. *Photo courtesy of Cliff Montagne.* | MSU earth sciences professor Charles Bradley started snow research at MSU by combining scientific curiosity with a love of skiing. Bradley weighs a snow core sample in 1964 as part of a study on snowpack strength. *Photo courtesy of Charles Bradley, Jr.* | During a day of fieldwork at Yellowstone Club ski area in 2008, Ed Adams and engineering graduate student Pat Staron use a thermal imaging camera to map differences across the snow surface. *Photo Kelly Gorham. Photos originally printed in Montana State University Mountains & Minds.*

Like dozens of MSU snow science graduates, he found a livelihood in avalanche forecasting, first by establishing the Gallatin National Forest Avalanche Center and then co-founding and directing the National Avalanche Center.

Today's avalanche forecasters inform backcountry recreationists primarily based on field observation. Snow science provides a broad scientific underpinning for how forecasters make sense of what they see, according to Birkeland, and "there's not another university in the U.S. that has even a fraction of the research focused on snow avalanches (as MSU)."

The approach that was unusual five decades ago when Bradley first approached Brown is what continues to help avalanche forecasting advance, Birkeland adds. Lab studies and mathematics help answer questions that arise in the field, and increasingly, the result is computer models that can predict avalanche hazard based on known snowpack and weather conditions.

"That's what we're slowly moving toward," Birkeland said.

One example includes recent research by MSU earth sciences professor Jordy Hendrikx about landscape variations in surface hoar—feathery crystals that form during cold, clear nights, often creating a weak layer when buried. The fieldwork drew upon earlier lab-based studies by Adams and Brown.

Hendrikx's recent work has branched out. He has partnered with MSU political scientist Jerry Johnson to study how recreationists' risk-taking behavior contributes to avalanche danger. Their White Heat Tracks Project, a study of backcountry skiers and snowmobilers, was highlighted in a December 2016 article in The New York Times.

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MSU snow science pioneers like Brown had always been limited to some extent by their lab facilities. So it was significant when Adams, along with MSU ecology professor and Antarctic researcher John Priscu, secured $2 million from the National Science Foundation and others in 2008 to create what's now called the Subzero Research Laboratory.

"It's one of the best labs in the world," among only a few other specialized facilities in Japan and Switzerland, Adams said. "It has taken us to a whole different level."

The lab includes snow-making machines, powerful microscopes for taking detailed images of individual snow grains, and rooms where the temperature of the ceiling and other surfaces can be precisely controlled to mimic natural conditions. High-powered lamps simulate sunlight. Still, Adams feels somewhat outgunned by snow.

"We're still trying to figure (snow) out," Adams said. "We'll never completely solve it."

Brown, reflecting to colleagues when he retired, put it another way: "It turns out that snow research is a lot tougher than rocket science."

That's because even a rocket has relatively static properties compared to snow in its natural environment. Snow may feel cold, but it behaves more like red-hot metal—always relatively near its melting point, highly unstable and readily vaporizing or changing its crystalline structure. Nature dispenses snow in layers, and no two layers—like no two snowstorms—are the same. The layers interact with each other and can change in a matter of hours. Each layer varies across huge landscapes, and within each, individual snow crystals vary immensely.

A snow pit like the one at the top of the Alpine Lift last February is just a snapshot, a glimpse of snow's elusive shapeshifting. That's one reason why Hammonds is excited about new satellite technologies that have the potential to monitor snow remotely, peering in real-time into its changing layers. His team's fieldwork on the glittering morning, combined with later studies in the lab, could help calibrate those technologies.

"What I like is learning something meaningful about this medium that we see every day, that we recreate in, that provides water for our reservoirs," said Hammonds, who was hired in 2017 to direct the Subzero Research Laboratory upon Adams' retirement this year. Although avalanche forecasting still drives much snow research, "the applications will change in ways that we haven't even anticipated."

"What's been really important about the group at MSU is that it (has) taken a classical science approach to snow, which (otherwise) hasn't been done much in the U.S.," said Ethan Greene, director of the Colorado Avalanche Information Center. "It's had a huge impact on what we do."

By its very nature, MSU snow science continues to meld with the local landscape. Hendrikx carries on Montagne's tradition of taking students to Bridger Bowl to teach snow science in the field, something not done elsewhere, which he thinks is unique. "Most other places around the world can't offer something like this," Hendrikx said.

MSU attracts students from across the nation, and there are good jobs for snow science graduates. Nearly all of the 12 earth sciences master's graduates in snow science in the last five years are employed in key snow science positions, ranging from avalanche forecasters and snow hydrologists to weather forecasters and doctoral students.

As MacLeod, a senior from British Columbia, poked her head above the snow pit with another sample for Hammonds, she was another example of the ongoing MSU partnership pushing the boundaries of snow science: One of about 60 undergraduates currently working toward a bachelor's in snow science, she is also double majoring in civil engineering.

"Honestly, I find that the more time I spend in the snow, the less I understand it," she said. "That's what makes it so interesting." ▲

COMMUNITY SNOW OBSERVATIONS

Using Citizen Scientist Data to Build Better Snow Models

BY DAVID HILL

We all want information on the snowpack. It's just a question of what kind, where, and how often. Recreationists traversing exposed terrain might be looking for site-specific, detailed avalanche forecasts with information about the layering and stability of the snowpack. Other backcountry users might be more interested in simple information on coverage, wondering about how much a hike they'll have to do from the trailhead before clicking into their skis. Over a much larger scale, water planners are interested in basin-scale estimates of the water equivalent of the snowpack as they forecast water availability months ahead. Regardless of the specific informational need, all of the above users benefit from the availability of snow-related data.

Figure 1 (top): David Hill uses a Federal sampler to measure snow water equivalent near Thompson Pass, Alaska. *Photo Ryan Crumley*

Figure 2: Ryan Crumley uses an avalanche probe to measure snow depth near Tuckerman's Ravine, New Hampshire. *Photo Joe Klementovich*

These data come from a great many sources, all of which vary in terms of their accuracy, their spatial coverage and resolution, and their temporal resolution. For example, the National Resources Conservation Service operates the Snow Telemetry (SNOTEL) network in 13 western states that measures both snow depth and snow water equivalent (SWE). These stations number in the hundreds and provide daily information on the snowpack and basic weather variables. On a smaller scale, many individual states such as California support snow survey campaigns where monthly or semi-monthly transects of 'snow courses' are made. A snow course is a linear transect where manual snow coring measurements are made every few meters or so and then averaged. On an even smaller scale, individual avalanche centers collect valuable data in many ways, including manual field measurements by staff observers and in some cases including networks of automated stations.

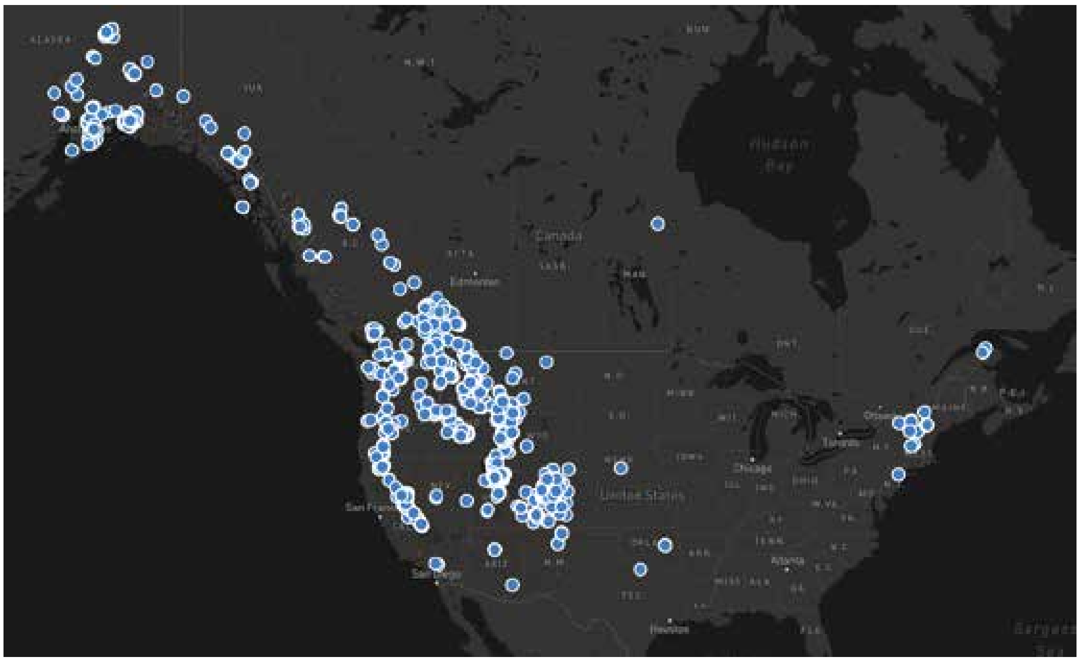
Since no measurement campaign can measure 'everywhere, every time,' computer modeling is used to provide estimates on snowpack conditions at other places and times. At the national level, the National Operational Hydrologic Remote Sensing Center produces the Snow Data Assimilation System (SNODAS) data product, which has a 1 km spatial scale and a daily time step. This 1 km scale is fine for many applications such as water planning, but is too coarse to resolve local snow redistribution properties such as drifting and avalanching.

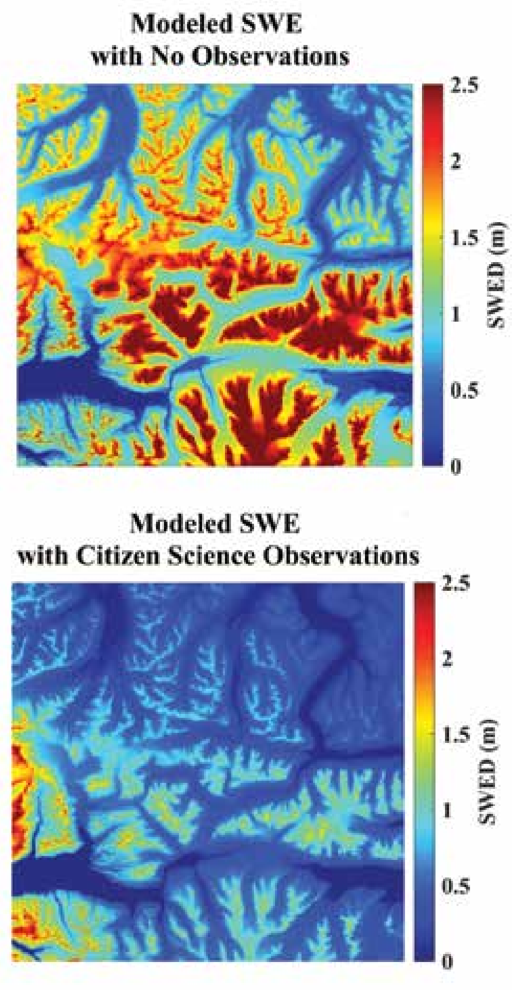
The Community Snow Observations (CSO; communitysnowobs.org; @communitysnowobs) project began in 2017 when researchers from the University of Alaska, The Alaska Department of Geological and Geophysical Surveys, the University of Washington, and Oregon State University began to wonder if the public could play a valuable role in collecting unique data on snow depth. The CSO team specifically identified the winter backcountry recreational community (including skiers, snowboarders, snowshoers, snowmobilers, and avalanche professionals) since those individuals often travel (i) over long distances, (ii) up to very high elevations, and (iii) far away from roads. All of these characteristics describe areas that tend to be poorly represented by fixed observations (e.g., SNOTEL) and therefore highly desirable to measure.

The idea of creating a large network of 'citizen scientists' is not a new one. In the context of weather and snow observations, the Community Collaborative Rain, Hail and Snow Network (CoCoRaHS) should be acknowledged as a success story. Started in 1998, the network has observers distributed throughout the United States who measure rainfall, snowfall, and hail. The relationship between citizen scientists and the projects they support is mutually beneficial. The project obtains additional data at little to no cost and the contributing citizen scientists, through the simple act of observing and recording data, can increase their understanding of and appreciation for the natural processes they are observing.

Citizen science does have some challenges. The measurements are opportunistic and depend upon decisions (routes taken, days traveled, etc.) made by the citizen scientists themselves. The project team can offer some suggestions and guidance, but ultimately must cede control of the experimental plan to the citizen scientists themselves. Another challenge has to do with data quality control. Tutorials can be provided but, in the end, the project team needs to accept that measurements are coming from a diverse body of contributors with differing levels of experience with data collection.

To maximize the success of the project, the CSO team decided that (i) measurements should require a minimum of equipment, (ii) the measurements should be extremely fast and easy to make, and (iii) the flow of data from citizen scientist to project team should be highly automated. To meet the first two criteria, the CSO team decided to focus solely on snow depth measurements rather than SWE measurements. Backcountry users (hopefully) have their beacons, shovels, and probes with them at all times. Most probes are 2.5-3.0 m in length, making for a perfect measurement tool! There are some nuances to making a good snow depth measurement (e.g., avoiding areas of significant wind scour), but with a bare minimum of training and practice, it takes only a minute to assemble a probe, make a measurement, re-stow a probe, and be on your way.





To meet the final criterion, the CSO team has partnered with Mountain Hub and Snow Pilot. Mountain Hub developed an outdoor oriented, community-fueled app (app.mountainhub.com) in 2015. Working together, CSO and Mountain Hub added a 'snow depth' field to the portion of their app that allows users to report on snow conditions. The app now logs location, time, and snow depth, and automatically transmits these data to the CSO team. Snow Pilot is a desktop program preferred by many snow professionals. It allows for information on the snowpack profile to be submitted, including the total depth. Again, these data are then made available to the CSO team.

The CSO team assimilates the snow depth data into our model simulations of snow processes. Every time a measurement is made, the error between the model predicted depth and the actual depth at the measurement location is used to steer the model back towards the ground truth. Initial tests of this assimilation strategy have shown that the contributed snow depth measurements dramatically reduce model errors. So, since we all want information on the snowpack (right?), CSO hopes that all backcountry users will recognize that their measurements directly improve the snow products available to them. There is no crowd-sourcing without the crowd, and CSO hopes to see more and more citizen scientists out in the snow. ▲

Figure 3 (left): Model simulations near Thompson Pass, Alaska. The upper image shows the model simulation without citizen scientist data. The lower image shows the corrected simulation with assimilation of citizen scientist data.

Figure 4: Scatter plot of CSO citizen scientist observations of snow depth. Several thousand measurements have been obtained in the first two years of the project.

David Hill is a Professor of Civil Engineering and Water Resources Engineering at the Oregon State University. He teaches undergraduate and graduate classes in hydrology and hydraulics and carries out research related to numerous aspects of the water cycle. Recent projects have included regional scale modeling of the hydrology of southeast and south-central Alaska, studies of climate-change related changes to coastal freshwater runoff, and studies of how hydrological models interface with satellite remote sensing products. He gets out skiing on the Cascade volcanoes as often as he can.

Settlement was one of Atwater's contributory factors, but I couldn't find a correlation between Alta avalanche activity and Alta study plot settlement. However, that was based on storm reports, i.e. how much settlement took place over the storm period,and how much avalanche activity was associated with the storm.

Reading all this, I'd like to point out that Atwater's % settlement was linked to a storm period, and was measured in a flat study plot, not in the higher start zones. In my 1970 Canadian Geotechnical J. paper "On contributory factors in avalanche hazard forecasting" I studied 107 storm reports, spread out over 20 years and found that, when it came to predicting large avalanche cycles on the slopes above Alta road and village, % settlement was simply overwhelmed by precipitation factors, and it would be hardly possible to use it as a contributory factor.

Surely, a 50-year-old study can't be the last word...and I forgot to add, when the forecast is limited to slope aspects, as was the Alta cases studied, wind-direction, not included in the Atwater list, also overwhelmed settlement.

....lots of threads from that question about "settlement threshold." Here's yet another thread: "What do we mean by a threshold?" A sudden jump in avalanche activity when the proposed threshold is exceeded?

—Ron Perla

I don't believe in any kind of threshold regarding settlement. It's more intuitive: "that's a big storm and a big load, warming up fast, and creating a slab with high continuity." Settlement is so far down the list of variables that it seldom is a factor that I weight in my decision-making and forecasting. Certainly watching a big storm settle into a cohesive slab over a PWL changes the game in comparison to non-PWLs. I would rather see how it feels under the skis and in the pit wall than try to make inferences from settlement values.

Regarding "locking up:" there are two situations: one happens when air temp is well below 0*F. Bruce Jamieson describes that one well. As with all snow science there are exceptions to the 'rules'. I asked Reid Bahnson (former AKDOT North Slope Forecaster) what the coldest temp he has a witnessed an avalanche and he talked about a slow groaning release at -60* or so.

The second situation occurs in a warm wet snowpack (near 0*C), when the sun goes OFF a slope and we see immediate avalanching. That quick cooling causes the surface to connect as a slab. What were variable creep rates across the slope in the sun then become more connected and consistent as the snow re-bonds from the surface down. Interesting mechanism, but a hard one to predict or test.
James Floyer talks about this phenomenon in the Temperature Effects issue of TAR, 31.3, February 2013.

—Don Sharaf

SETTLEMENT ROUND TABLE

Hello friends-

We are in the middle of an Atmospheric River here in the Tetons- 3.8" of SWE and 42" of snow from Feb 2- Feb 5 2019. Settlement has been 1" + 4" + 4" since 2/2 (http://www.snowpacktracker.com/btac/snowpacktracker) Temps have been relatively warm throughout the storm.

I am wondering if you all have a threshold of settlement that is a red flag for natural avalanche activity? A percentage? Can you explain its connection to changes in viscosity and effects on propagation propensity? In many cases, once the system passes, we feel the effects of a cold front and the vernacular/ ski patroller insight into the phenomenon is that the slabs "lock up."

thanks in advance,
Lynne Wolfe

First off, it's important to use the proper terminology, where "settlement" refers to snow deformation in a flat location (such as measured at a snow study plot). "Settlement" is often used as a proxy for "creep," which refers to snow deformation on a slope and involves both normal and sheer components of deformation. Although creep is the mechanism which can potentially be involved in avalanche initiation, settlement is usually what is measured.

Although loading rates and air temperature change can drive increased settlement rates, I often think of settlement as a separate mechanism that can potentially lead to failure. The idea is that as the snowpack creeps downhill during and immediately after rapid loading events (viscoelastic deformation), this motion is translated down through the snowpack leading to increased strain rates and shear stress at weak layers. My understanding from literature reviews and conversations with others indicates that this is mostly a theoretical description of a failure mechanism (generally lacking evidence from field or model experiments). However, one of the best field experiments is to carefully watch the timing of natural events: I'm always looking for the deep slab events that can be confirmed to have occurred the day after a storm, where active loading has stopped but the snow is still deforming.

Most avalanche operations do a good job of measuring 24-hr total snow depth and new snow. With this data you can calculate 24-hr settlement rates. In our 2016 ISSW paper we quantified the distribution of 24-hr settlement rates during storm periods, drought periods, and on days with deep slab events. The recent storm that hit the Tetons during Feb. 23 - March 1 had maximum measured settlement rates of 13-16"/day! These rates are at the very highest end of the distribution for storm settlement rates measured over 42 seasons at JHMR study plots, which average closer to 3"/day during storms.

Agreed about the general observation of the snowpack "locking up" after some period of time following a loading event. Settlement can work both ways: the long term effect (multiple days to weeks) of snow settlement is an increase in snow stability through increases in slab density, hardness and strength (McClung and Schaerer, 2006). So it's really all about timing and rates. If we see settlement rates during and immediately after a storm that are around 3-5"/day or higher, I'm thinking about the snow rapidly deforming and bonds at weak layer / sliding layer interfaces trying to accommodate some part of that deformation that has translated to depth (until the strain at the weak layer is pushed through ductile into brittle failure and crack propagation!). However, after a few days of settlement rates that stay at the average drought "background" rate of about 1"/day, I am thinking that the snowpack has mostly readjusted to the load.

The ultimate question is to know how deformation from settlement/creep is distributed in the snowpack with depth! As Howie mentions, one way to do this is to measure settlement on a storm board during hours/days immediately following a storm, compared with total snowpack settlement. There is lots of potential for additional experiments using total depth, storm board, and interval board measurements, where we should likely be looking at settlement rates at higher resolution (e.g. hourly) with focus on quantifying how deformation is partitioned through the snowpack with depth.

—Patrick Wright

Note: Patrick Wright of Inversion Labs, Wilson, WY, is also co-author of this paper from ISSW 2016: *Deep Slab Instability: Loading and Settlement Rate Thresholds Related to Failure—Part II*, along with Bob Comey, Chris McCollister, and Mike Rheam of the Bridger-Teton National Forest Avalanche Center.

Interesting responses from Ned and Bruce and I agree with their points. The effect of settlement really depends on your weak layer, your slab, and temperature clearly plays a role as well. Interestingly, I've heard from different folks that settlement either increases stability or decreases stability. You probably know that settlement was one of Atwater's 10 contributory avalanche factors. He found that high settlement rates (40% and above) indicate rapidly strengthening snow. Low settlement rates (15% and below) indicate the potential for increasing instability, though he also cautioned that you couldn't just base a forecast on settlement.

I've heard others say they've correlated large settlement rates with high avalanche activity. I think in some of those cases the reason the settlement rates were high was simply because they were getting lots of snow and so that was the factor driving the increase in avalanche danger.

—Karl Birkeland

Fun conversation that made me scratch my head. I really enjoyed reading Bruce's thoughts and I think he's spot on about the differences between settlement over PWL and NPWL.

These settlement guidelines go all the way back to Atwater and Kozoil (1953), at least in the US. I think it's important to keep track of what is settling and how much. In the field, it's difficult to do this, as the number we usually see is just the bulk settlement of the snowpack.

By definition, settlement is densification as you are reducing the volume of a layer. We know that densification is related to strengthening, as for example it increases coordination, the number of neighboring grains in contact. However, the amount of densification and the strain rate depend on the age and crystal form. After about two weeks, strain rates have been shown to be higher, by an order of magnitude, for nonpersistent forms compared to persistent forms. Armstrong (1980) has a great paper on this.

The practical takeaway for me is that a slab with a NPWL in the slab or at the old/new interface is going to rapidly strengthen, as is the NPWL. Thus, settlement will have a stabilizing effect. For the buried PWL, the slab above will strengthen, but the PWL is likely old and if you could measure its settlement, you'd find that it doesn't settle much, meaning it would have a much lower strain rate than the new slab. Thus, it would remain weak, while the slab got stronger, and you'd have a strong layer over weak layer classic avalanche layering.

Your question about how all of this and temperature affect natural avalanche activity is the most interesting part for me, and one that I don't have a good answer for. McClung (1996) shows that a cooling slab will be stiffer (a larger elastic modulus), which increases the critical flaw size needed to initiate fracture—this is a stabilizing effect. And I think Bruce's point about creep rates slowing with decreasing temperature is important. I'm interested to hear other perspectives.

I previously wrote 1956 by accident for Atwater and Koziol (1953). That's because 1956 is the year of an Army Corps of Engineers snow hydrology study that is still often cited for an age-based snow albedo decay equation, even though it doesn't work very well. Age alone is a poor predictor of albedo because albedo depends on microstructure and impurities, which, avalanche professionals know better than anyone, are the result of many different inputs besides age.

In the interest of Ron's comment about bringing this discussion up to date from Atwater and Koziol, Mareike Wiese and Martin Schneebeli (2017) have some new laboratory measurements on settling of isothermal and temperature gradient (TG) snow samples. Using a µCT and the Snobreeder 5, they find that TG samples develop stress bearing chains that reduce settling by about half or more compared to isothermal samples over a four-day period. The amount of settlement decreased as the TG increased. Both samples stiffened, i.e. increases in the E-modulus and compactive viscosity.

The practical takeaway for me is a confirmation of Armstrong (1980) showing that TG layers are going to settle less than isothermal layers because of the stress bearing chains.

—Ned Bair

During the month of February, the Tetons accumulated 16.71" of SWE within 192.8" of new snow at the Rendezvous Bowl Plot. The sum of daily settlement values during this period was 137.8". The Bridger-Teton Avalanche Center forecasted High Danger for three periods of two days or more.

Armstrong, R.L., 1980. An analysis of compressive strain in adjacent temperature-gradient and equi-temperature layers in a natural snow cover. Journal of Glaciology, 26(94): 283-289.

Atwater, M.M. and Koziol, F.C., 1953. Avalanche Handbook. 149 pp.

McClung, D.M., 1996. Effects of temperature on fracture in dry slab avalanche release. Journal of Geophysical Research: Solid Earth, 101(B10): 21907-21920.

Wiese, M. and Schneebeli, M., 2017. Early-stage interaction between settlement and temperature-gradient metamorphism. Journal of Glaciology, 63(240): 652-662.

As far as the paper itself, the settlement data I believe tracks the entire snowpack above a PWL.

So there is no way to tell if the settlement is taking place in the storm snow or also in the old snow?

Guess I'm old school now, but I've always thought it's not the slab that fails. It's the weak layer.

That's why I started looking and recording old snow settlement.

Although subjective on defining "old snow" when I started storm profiles, most of the storm profiles I recorded over the years were after time periods where there wasn't a new load and not much settlement taking place on the total depth prior to the storm.

On the report I sent you, the old snow settlement value needs Interval snow, storm snow, and total depth. We are lucky to have clean data since we visit the study plot and physically measure the Interval every 12 hours to check the automated sensor data. Very few times do we measure and "clean off" the Interval stake more than once every 12 hours in the past 40 years. The storm stake usually never gets cleaned off unless there is more than 24-36 hours w/o new snow. If we were expecting no snow for a couple of days and we suspect a PWL was going to get spicy, we'll let the storm stake sit until its settled out with little movement. Without that number, we can't tell if the "old" snow below the new load is moving.

—Dan Howlett,
aka "Howie from Alta"

Some random thoughts from the field:

I have seen settlement rate thresholds proposed for storm snow but in my experience the thresholds have not been adequately indicative of stability trends. When a slab settles over a non-persistent weak layer, sintering at the weak layer USUALLY favors improving stability. (Qualitatively, such a trend—as shown in the photos—is useful. But a quantitative threshold … not so much.)

When a slab settles over a persistent weak layer, fracture propagation USUALLY increases, favoring larger avalanches. These bigger avalanches with stiffer slabs are often less frequent because the weak layer is gaining strength and toughness (less frequent natural avalanches).

Re: "locking up" during cold weather. In my experience, this is a strong effect on natural avalanche release. Narita (1993) and others have shown that snow failure is related to the deformation (or strain) rate. Surface cooling is very effective at slowing creep in the upper snowpack and hence at reducing the deformation rate in a weak layer below its hard-to-measure threshold value. After cooling, I have found avalanches harder to trigger by ski cutting, etc. However, I'd want good consistent observations of other factors before I bet my life on it on a big slope.

Once when retreating from a traverse in the coast range, we needed to ascend a big slope with a recent snow load, the top few centimeters of which was moist. We were about to be overdue (and this was before satellite communicators). There were no fresh avalanches in the area. Nevertheless, I declined to ascend the slope until the moist surface had formed a stiff crust (and slowed creep). It was night before we uneventfully skinned up the slope.

—Bruce Jamieson

AVALANCHE DEBRIS AVALANCHES:

A possible mechanism for the 2007 Canyons inbounds avalanche accident, Park City, Utah

BY JEFF LONN

Avalanche debris avalanches are an uncommon type of slab avalanche that occur when debris accumulates below normal starting zones as slope steepness decreases but where the slope is still steep enough to slide. The accumulated debris creates or adds to a slab that then overloads an underlying, still-intact, weak layer. Most avalanche workers are familiar with graupel avalanches that occur low in a slide path (*figure 1*). These are really a type of debris avalanche: they occur when graupel rolls down steep slopes and accumulates where the slope angle lessens, eventually overloading an underlying weak layer. Similarly, debris from loose snow or slab avalanches can accumulate in a path where the slope angle decreases, potentially forming a thick slab below the normal starting zone. Many avalanche workers have had the experience of crossing avalanche debris and feeling a collapse as a buried weak layer fails. If this debris has accumulated on a steep enough slope, a slab avalanche may occur, and the crown will be located within the debris from the original avalanche (*figure 2*). This mechanism may have generated the fatal 2007 inbounds avalanche at the Canyons Ski Area in Park City, Utah, known as the Red Pine Chute avalanche accident.

Figure 1. Graupel avalanches are debris avalanches that occur low in a slide path when graupel rolls down steep slopes and accumulates where the slope angle lessens. a) Graupel avalanche crowns are visible to right of ski tracks. Note that debris from a later slough has accumulated in the area of the crown. b) Small graupel avalanche low in the slide path. Central Wasatch Mountains, Utah.

Figure 2. Lower crown shown by arrow is the result of an avalanche debris avalanche that occurred when avalanche debris from the higher avalanche accumulated where the slope angle decreases. Slope angle at the upper crown is 38° and is about 33° at the lower crown. New snow obscures the location of the debris avalanche toe, but the gentle slope angle suggests that it did not run far. Central Wasatch Mountains, Utah.

The Red Pine Chute avalanche occurred partway down a steep (38°), 40-foot-wide, NE-facing chute. The crown was located well below the normal starting zone where no crowns had been previously observed (*figure 3*). Canyons snow safety personnel had conducted thorough explosive-based mitigation during the three days preceding the accident and were surprised and perplexed by the location of the mid-path crown. I propose that mid-path accumulation of avalanche debris deeply buried, but did not collapse, the underlying weak layer, which then failed when a skier initiated a collapse in a nearby "sweet spot."

Conditions leading up to the accident

In late October 2007, a storm deposited 2-3' of snow that persisted on north aspects above 9,000' into the winter. During the following month of dry weather, the entire snowpack became weak and faceted. A thin, discontinuous rime or melt-freeze crust capped the old snow surface in some areas and helped preserve the underlying faceted snow as new snow began falling in early December. In the two weeks preceding the accident, a series of storms buried these October facets under 5.5" SWE, including 35" of snow with 2.78" SWE in the three days prior to the December 23 accident. Snowpits before this last storm revealed a stubborn but high quality shear at the top of the October faceted snow. Explosive-based testing/mitigation was performed three times during this long storm cycle, triggering two soft slab avalanches about 12" deep by 40' wide, the width of the Red Pine Chute, that ran from the top of the chute across the future crown of the accident slide and continued down the length of the chute. One of these slab avalanches was triggered after snowfall ended on December 22, the day before the accident. Also on December 22, explosives released a large, deep-slab avalanche that failed at the top of the October facets on an adjacent, similar slope, prompting the use of extra explosives in the known starting zones of Red Pine Chute. However, no other deep slides resulted. Snow safety personnel opened the area to the public for the first time that season on the afternoon of December 22, and it received a moderate amount of traffic, including at least five descents of Red Pine chute.

With only a trace of snow and light winds overnight, snow safety personnel re-opened the area the following morning (December 23) after a check that included two work runs down Red Pine Chute, bringing the number of prior descents of the chute to at least seven. The avalanche accident occurred at 11:30 am, apparently triggered by the victim's party near the crown partway down the chute. The victim was carried into a tree and partially buried; cause of death was trauma. An 11-year old child was completely buried in the runout and found unconscious by a probe line 45 minutes later, but eventually made a full recovery. For more details on the accident and conditions leading up to it, see Hutchinson and Lonn[1].

Geometry of the Red Pine Chute avalanche

The crown was located 85 feet vertically below the top of the path (9,660' elevation), averaged three feet deep, and tapering to less than a foot at each end, and extended outward from the main chute for a total width of 100 feet. It was classified as a hard slab D2.5-R2 avalanche[2]. All slides observed during the previous 10 years of avalanche work had produced crowns in the uppermost, typically wind-loaded, part of the chute; none had ever released in this mid-path location. The crown cut the edge of one bomb crater and within 20 feet of another, and had previously been overrun by a 12" x 40' soft slab avalanche triggered by a surface blast near the top of the chute.

A ground surface profile of Red Pine Chute avalanche path (*figure 4*) reveals the uppermost starting zone to be very steep, about 42°, with the slope angle decreasing to 35° near the location of the mid-slope accident crown. Farther down, the path rolls over to 38°, creating a lower-angle "bench" between the two steep sections (*figure 5*). The mid-path crown was located not at the lower break-over, but at the upper end of the lower-angle bench.

Figure 3. Red line shows the crown of the fatal Red Pine Chute avalanche well below the typical wind-loaded starting zone. *Photo Jake Hutchinson*

The avalanche debris avalanche theory

As the winter progresses, the 35° "bench" in Red Pine Chute typically disappears as it fills in with loose snow and avalanche debris released from above, smoothing the chute profile to a consistent 38° slope. I suspect that new snow sloughs and the two slab avalanches released Dec. 20 and Dec. 22 from the steep uppermost part of the chute filled in the 35° bench and created a thick, dense slab there without breaking down the underlying weak snow (*figure 4*). The thin rime crust at the top of the old snow probably helped support the heavy slab and preserve the weak layer.

Examination of the crown showed the slab to be harder and denser than would be expected from the 3' of 8% density snow that had fallen in the previous three days. There were also at least two layers of dense snow mixed with bomb debris exposed in the crown (*figure 6*) that were probably the result of the two soft slab avalanches released by explosives from the top of the chute on Dec. 22 and Dec. 20. These slides overran the bench and continued down the chute, but rather than breaking down the weak October facets and carrying everything down the chute, they instead added debris to the bench while preserving the weak layer. This dense avalanche debris slab would have been very strong and probably bridged the underlying weak layer throughout the extensive explosive testing that took place on December 22. It also held up as numerous skiers crossed and descended through the area. The underlying weak snow only failed when a skier impacted a thin "sweet spot," probably peripheral to the main chute. This

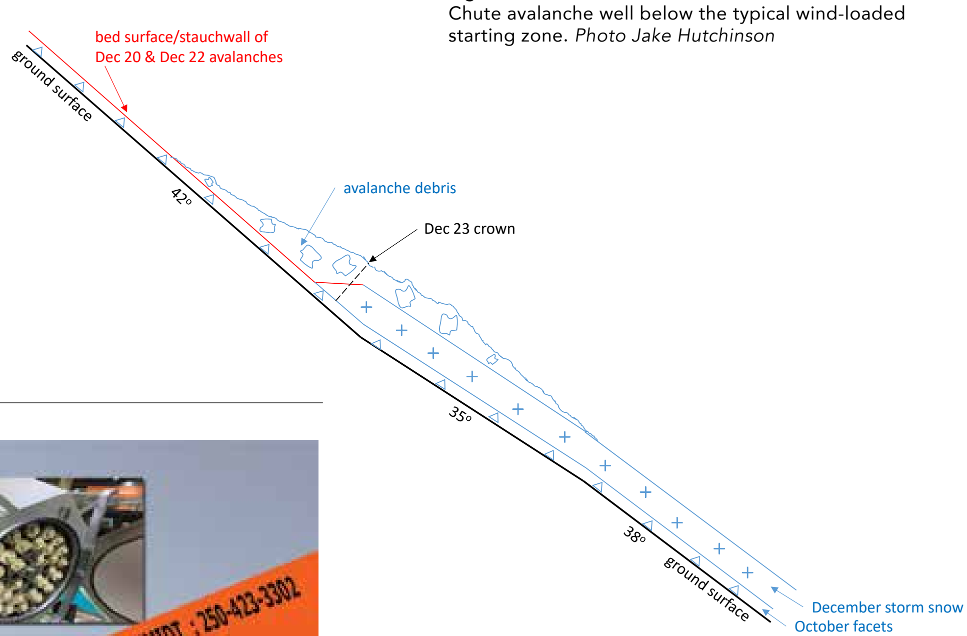


Figure 4. Schematic longitudinal profile of Red Pine Chute shows the ground surface and postulated snowpack cross-section prior to the accident. Two previous slab avalanches deposited debris in the area of the lower angle bench. The fatal Dec. 23 avalanche failed at the top of the October facets near the ground, with its crown located near the upper end of the bench.

failure was then able to propagate across the chute and release an avalanche where the slab was thickest and heaviest—at the upper end of the bench.

Figure 5. View down Red Pine Chute in low snow conditions illustrates the ground surface, and shows an apparent bench where the slope steepness decreases to 35°. Note that the crown developed at the upper end of the 35° bench.

Other possible explanations

Another explanation for the mid-path crown is that it developed below the effects of wind on the weak October snow. Wind could have removed or disturbed the faceted snow above the crown, near the ridgeline, creating a stronger snowpack there. Slides and sloughs descending the upper part of the path could have had similar effects. However, snowpits revealed that facets were preserved on nearby wind-affected slopes. In addition, this theory does not explain why the crown followed the lower angle bench. The boundary between the stronger, wind-affected snow and the weaker, undisturbed snow would have had to coincide with the change in slope angle, which seems unlikely. Perhaps most importantly, this hypothesis fails to explain why the slab avalanches that had earlier overrun this area did not trigger anything. It is unclear why the explosives deployed nearby did not release the slab, but trigger points for deep-slab instabilities are notoriously difficult to predict.

Subsequent changes to the Canyons snow safety program

It has now been 11 years since the Red Pine Chute accident and Canyons snow safety personnel have not recorded any other similar slides. The accident prompted implementation of an early season boot-packing program whenever a weak snowpack develops prior to the season opening (9 out of the last 11 years). The boot-packing program typically covers all slide-prone areas on the north face of Peak 9990. It has been very successful, with no slides into old snow recorded in any of the boot-packed areas. A bomb tram designed to deliver an air blast to the mid-path location of the Red Pine Chute accident was also constructed, but it has never released another similar slide, probably because of the boot-packing effects.

Figure 6. View up Red Pine Chute shows the crown of the December 23, 2007, avalanche, which exposed dark-colored layers of bomb and avalanche debris. The dark-colored debris accumulated when explosives released slab avalanches from the typical starting zone at the top of the chute prior to the accident. *Photo Jake Hutchinson*

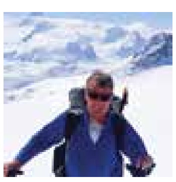
Summary

We will probably never know for sure why the Red Pine Chute avalanche released where and when it did. But a reasonable explanation is that mid-path accumulation of avalanche debris overloaded an intact deep slab instability, generating an avalanche debris avalanche when a skier affected a nearby sweet spot. This hypothesis explains the mid-path crown location on a lower-angled slope, the layers of bomb debris exposed in the crown, and the unusually hard, dense slab that resulted in the slab's ability to bridge the weak snow until the right spot was impacted. ▲

References

1. Hutchinson, J., and Lonn, J., 2014, *Red Pine Chutes Avalanche Accident—A case study: Proceedings, 2014 International Snow Science Workshop, Banff, Alberta, Canada, 8 p. http://arc.lib.montana.edu/snow-science/objects/ISSW14_paper_O15.04.pdf*

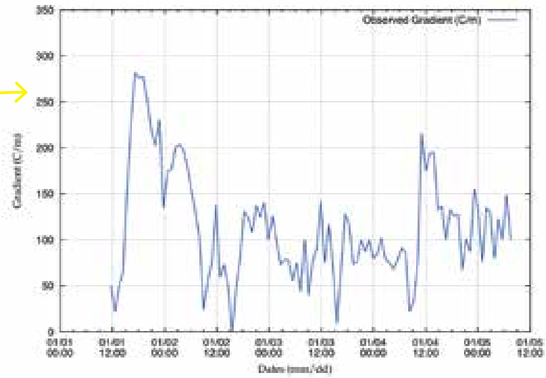
2. *Utah Avalanche Center, 2007, Canyons Avalanche Fatality Report: UAC Archives, https://utahavalanchecenter.org/avalanche/17452*



Jeff Lonn is the retired Snow Safety Coordinator for Canyons Ski Resort, Park City, Utah.

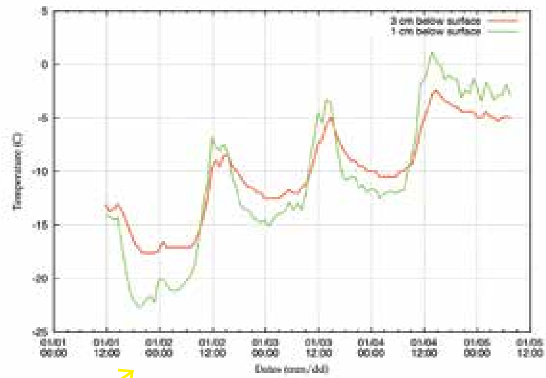
GROWTH OF THE FUNNY BUSINESS: NEAR-SURFACE FACETS

BY GREG GAGNE



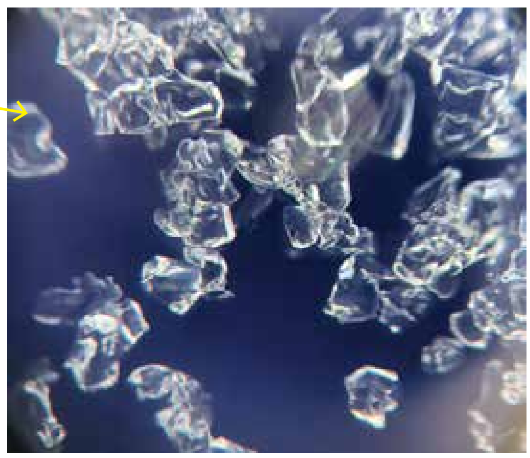
Overview: From December 21 through December 31, 2018, a significant storm system dropped nearly three feet of snow in the Cottonwood Canyons of the Wasatch Mountain of Utah. From January 1-4, 2019, cold clear weather prevailed, allowing the surface of the snowpack to weaken, producing a widespread layer of near-surface facets. Pre-frontal southwest winds began to increase on January 4, and into the day on January 5, depositing fresh wind drifts onto these weak facets, conditions which led several human-triggered avalanches occurring during the day on January 5.

The Faceting Event: With cold high pressure following the late December storm system, I knew the low-density snow at the snow surface would rapidly facet. Over the past several years, UAC colleague Brett Kobernik and I have monitored many different faceting events in the central Wasatch and Manti Skyline mountains, and I suspected this would be a significant faceting episode worthy of recording with instrumentation. On January 1, I deployed a pair of iButton thermochrons at 8800' at the UDOT snow study plot "Little Davos" in Big Cottonwood Canyon. An iButton thermochron is a temperature sensor and data logger, and is about the size of a watch battery. Brett and I have successfully used iButtons several times to capture temperatures both near the snow surface as well deeper into the snowpack. The thermochrons were placed 2 cms apart, with the top iButton 1 cm below the snow surface, and the lower iButton 3 cms below the surface. The iButtons recorded and logged temperature measurements every 10 minutes, until they were retrieved early in the morning on January 5, where the results were evaluated.



This graph illustrates the recorded temperature gradients during this period. The graph is normalized to display the gradient over a meter of snow (with 10 C/100 cms being the minimum threshold for faceting to occur). This graph illustrates gradients routinely in excess of 50 C/1m (or 5 times the required gradient), with some gradients even reaching 275 C/1m!

The recorded near-surface temperatures are even more interesting to observe in this graph. The green line is the temperature of the snow 1 cm below the surface, while the red line is the temperature 3 cms below the surface. Notice how the two lines fluctuate. During the day the snow surface warms (a relative term as it is routinely about -5 C). In particular, notice the spike at 12:00 on 1/2, 1/3, and 1/4. However, over the long winter night the snow surface cools and radiates its heat back to the clear sky, with snow surface temperatures in excess of -15 C (notice the dips around 00:00).



The red line (3 cms below the surface) changes less dramatically as it is insulated somewhat, a situation that also allows it to retain some of its heat during the cold, long winter night. The flipping between the surface being warmer during the day and colder at night is known as *diurnal fluctuation*, and it explains why facets can quickly develop on the snow surface and why the grains remain small.

The photo is taken from the snow surface on Jan 2, quite early in the period, when facets near the surface had already begun to develop:

Beginning on January 4, winds out of the south/southwest began to increase ahead of a Pacific trough forecasted to impact our region later that weekend. The gusts and average wind speeds for the afternoon and morning updates on 1/4 and 1/5 from four Cottonwood resorts operations are as follows:

DATE/TIME	LOCATION	AVERAGE	GUST	DIRECTION
1/4 PM	Alta	17	37	SW
1/4 PM	Brighton	16	37	W/SW
1/4 PM	Snowbird	23	37	W/SW
1/4 PM	Solitude	12	22	SW
1/5 AM	Alta	15	56	S
1/5 AM	Brighton	29	61	SW
1/5 AM	Snowbird	10	54	E
1/5 AM	Solitude	18	34	S/SW

Implications: Although many professional observations commented there was "little snow available for transport", on Saturday January 5 there were eight human-triggered avalanches recorded in the backcountry in the Salt Lake mountains, with one very close call that resulted in a trip to the emergency room. These were likely all hard wind slabs that formed on top of the Jan 1-4 faceted layer. These avalanches were 15-60 cms thick and 8-60 meters wide, with one slide running over 100 meters. In four of the slides, at least one member of the party went for a ride, with injuries involved in two of the occurrences. These slides were all in exposed alpine terrain above 9000' on aspects facing north, northeast, and east. Some of the slides were triggered remotely, with at least a few breaking well above a rider.

The distribution of the weak layer and the overlying slab were both more widespread than initially thought. The NSF layer isn't aspect or elevation dependent, and forms regardless of wind, unlike surface hoar. The winds were strong enough to create hard slabs both at expected locations on ridgetops as well as lower down, in less common deposition zones.

Pattern recognition is a tricky game, and subtle patterns are often evident only after a defining event. ▲

Greg Gagne is a forecaster and educator with the Utah Avalanche Center, as well as professor of computer science at Westminster College in Salt Lake City. He is also a continuing education student at the Brett Kobernik School of Garage Science for Snownerds, and can be reached at greg@utahavalanchecenter.org.

BLUE ICE

1 Low

1 LOW DANGER

WE'RE ALL IN THIS TOGETHER

By Drew Hardesty

GREEN ANCHORS

On Saturday, January 5th, I issued what turned out to be the most blown avalanche forecast of my 20-year career. And not by a little. My forecast stated that the avalanche danger in the backcountry was LOW. By the end of the day, we heard about eight skier-triggered avalanches with four people caught and carried in separate events, with one visit to the emergency room.

What happened?

The holiday storms wrapped up New Year's Eve after producing 31"/1.84" water from Christmas to New Years. On New Year's Day, the upper level trough pinched off and the winds picked up from the east and northeast and remained moderate with gusty winds from these directions and the northwest in the coming days. Over the course of the week, the snowpack had stabilized and by Friday January, 4th, our staff gained consensus that the danger could be dropped to LOW.

Saturday morning. Another storm was brewing in the Pacific and I knew we would be back to Considerable or High late weekend into early next week. Pre-frontal winds were picking up from the southwest. Precipitation was expected late or in the overnight hours. Even though the winds were strong and all the southerly and off aspects were crusted (academically little snow available for transport), the southwesterlies were a new direction and led to new and different loading patterns…especially onto hard snow surfaces or areas with particularly weak snow surfaces. These weak snow surfaces (facets and surface hoar) had been widely documented since the first of the year. Forecaster Greg Gagne wrote a wonderfully insightful piece on this faceting event as a separate blog post for us. *(See Greg's adaptation of this blog for TAR on page 23)*.

I wanted the danger to be LOW. "Wish-casting," we call it. The danger had been LOW the day before. "Back-casting," we call it. In the circular spinning of my mind that morning I felt that we don't use Low or Extreme enough.

I issued the LOW danger.

My Bottom Line:

Today's avalanche danger is generally LOW. Pockets of new and developing wind drifts may be found in isolated terrain. The danger may reach MODERATE in some areas later today. Remember that risk is inherent in mountain travel—even a small avalanche can be significant in radical, no-fall terrain.

And by 730 AM I sent out a text to the forecast staff. By mid-afternoon the results were in:

1		Generally safe avalanche conditions. Watch for unstable snow on isolated terrain features.	Natural and human-triggered avalanches unlikely.	Small avalanches in isolated areas or extreme terrain.

A few days later. Wednesday January 9th. I'm sitting at the bar waiting for Vlad and Jackie to show. On that Saturday, owing to the forecast, they had decided to head up into Broads Fork of BCC and up into the Blue Ice area near the Diving Board. It's steep, avalanche prone terrain that should be avoided with unstable avalanche conditions. Vlad was ahead, breaking trail. Jackie a couple hundred feet below. The collapse. Each carried a few hundred feet. Vlad buried to his chest, Jackie completely buried with only a ski above the snow surface. She remembers the fear and then blacking out.

We talk for an hour. I tell them of my close calls and of how my own partner lost her long-time boyfriend in the Teton Range. I tell Vlad that he is a hero. We sit. We talk some more. They talk of their poor decision-making that day. So do I. I tell them how grateful I am how things ended and that each of them are on this side of the line between life and death. I know that I am part of their story and shudder to think if things had gone a different way, knowing that I would feel complicit in the tragedy. We smile, shake hands, and leave. I promise to check in the following week.

Our last avalanche-related fatality (we have had four since I originally penned this mid-January) was the winter of 15/16 and I published a piece —*Analysis of Utah Avalanche Fatalities for the Modern Era* (1940-2016). The last sentiment of the opening paragraph reads like this:

As with any papers looking at statistics, it might be tempting to look at these fatalities as just numbers. But at the end of the day, each incident is not a number at all. Each incident is a human being, a person with a family and a community, with dreams and aspirations whose life was taken from them by an avalanche.

Indeed.

Since then, we have all been out skiing together —after all, we share the same love of the mountains. They told me how much it meant to them that I reached out in a personal way. For me, it was personal. In the end, it is not about statistics and numbers.

It's about us. ▲

A view up Broads Fork, with Blue Ice circled in the center
Photo David Martin

2

REPORT

INHERENT UNCERTAINTY

By Derek DeBruin

Blue Ice Avalanche

HS-ASu-R2-D2

2 skiers caught and partially buried

Wasatch Range, UT

Big Cottonwood Canyon, Broads Fork

5 January 2019

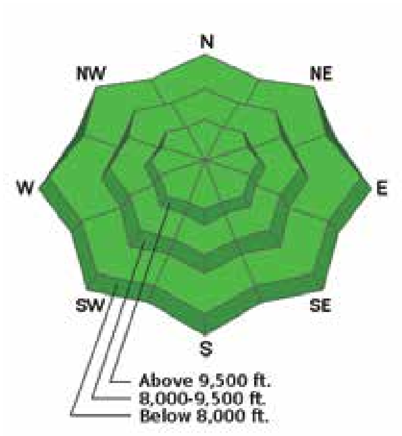


Figure 2: The avalanche rose for the 20190105 forecast issued by the Utah Avalanche Center.

While the conceptual model of avalanche hazard provides a reasonable framework for developing a hazard rating based on spatial distribution, triggering sensitivity, and destructive size, such evaluations are estimations based on incomplete data and are inherently subjective.

Derek DeBruin took an AAI Pro 2 avalanche course in February 2019. Writing an incident report is part of the curriculum, and Derek chose to write about his friends' accident in Broads Fork. TAR is pleased to offer excerpts from his report.

TERRAIN

This incident occurred at approximately 9,400 feet in Broads Fork, which has a overall northerly orientation as the canyon opens into the larger Big Cottonwood Canyon (BCC). Broads Fork is typically accessed from the north via a trailhead in BCC using a skin track in the bottom of the canyon drainage. This track accesses the ski zones in the upper reaches of Broads Fork after travel of some three miles and more than 3,000 vertical feet. The upper reaches of the canyon attain Twin Peaks, Sunrise Peak, and Dromedary Peak, major summits on the crest separating Big and Little Cottonwood Canyons with elevations in excess of 11,000 feet.

The Blue Ice zone is a northeast facing slope on the west side of Broads Fork near and above treeline at an elevation around 9,800 feet. Blue Ice is immediately adjacent to the "Diving Board" and "Bonkers," both northeast facing zones to the northwest. There are large slabby cliffs throughout the area. Blue Ice is so named for a short vertical cliff nears its upper reaches that frequently forms ice flows. *(See Figure 1 map.)*

SNOWPACK & WEATHER

The 2018-2019 winter season in the Wasatch began with pockets of persistent facets on shady aspects at high elevations throughout the basal snowpack as a result of early season October and November snow events interrupted by long periods of dry weather. By the end of December 2018 avalanches on persistent weak layers, both basal and those associated with crusts, had largely subsided in the central Wasatch with a few notable exceptions in repeat slide paths or with significant loading.

A storm the evening of Sunday, 30 December into Monday, 31 December 2018 delivered up to 16" of new snow, resulting in some avalanches due to wind loading that readily subsided. This storm was followed by cold, clear conditions from 1 to 3 January 2019, with temperatures as low as -10oF at the 11,000 foot ridgelines. This resulted in a mix of surface hoar and near surface facets throughout the range, resulting in long running loose dry human-triggered avalanches and creating a potential weak surface upon subsequent loading. Beginning late in the afternoon of 3 January 2019, winds shifted from the west to the south and finally to the southeast into the early morning hours of 5 January 2019. *(See Greg Gagne's story about near-surface faceting in this cycle on page 23.)*

With no recent new snow and moderate wind speeds at the ridgelines around 20mph (as low as 5mph the morning of 5 January), the avalanche forecast for 5 January 2019 reported a bottom-line hazard of "low" for all aspects and elevations *(see Figure 2)* and noted, "…Pockets of new and developing wind drifts may be found in isolated terrain. The danger may reach MODERATE in some areas later today…" The forecast noted "Normal Caution" as the only avalanche problem, but did offer some relevant details:

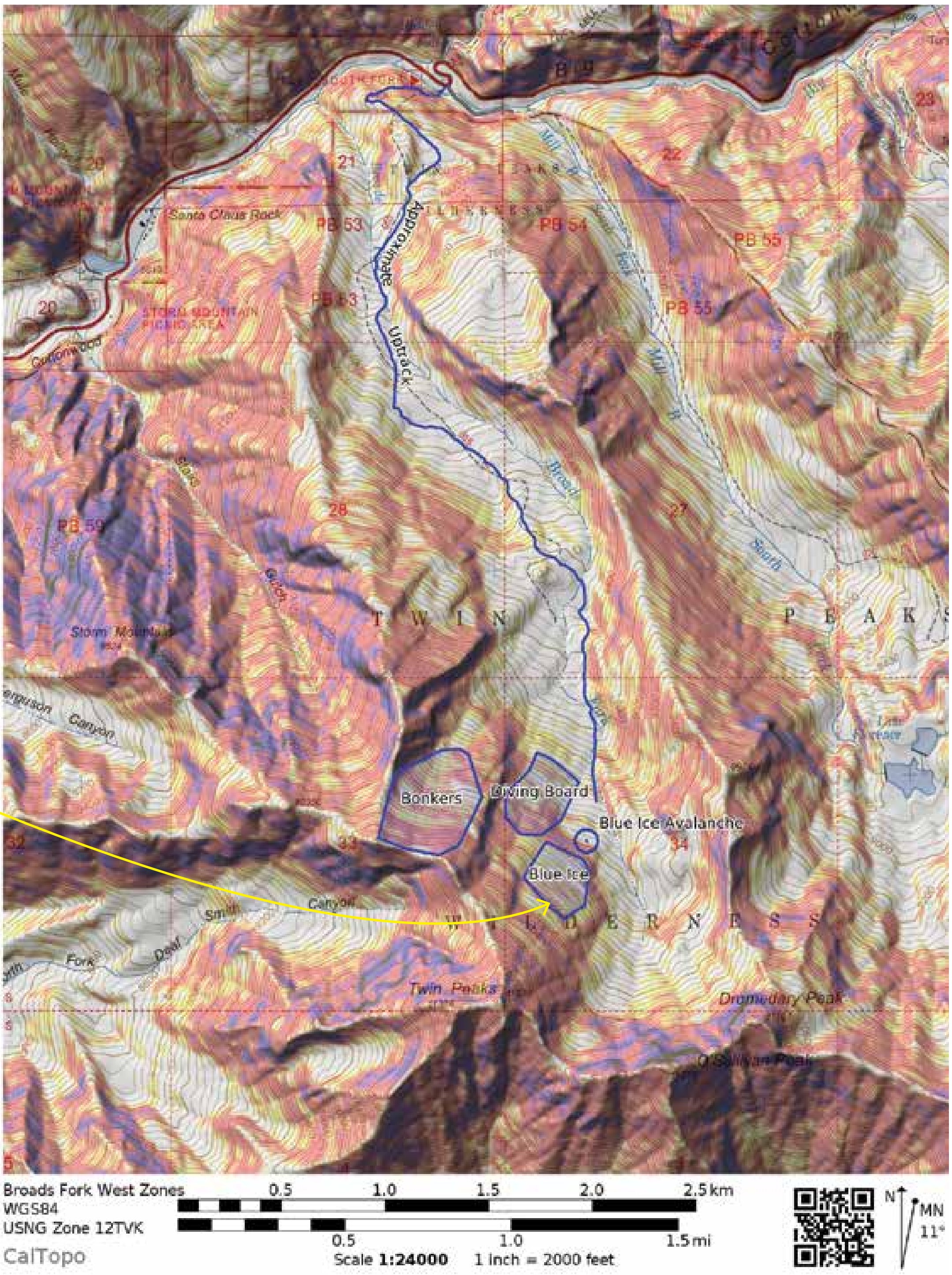
> *"The snow is mostly stable. The mountains have seen a fair bit of wind over the past week or so and much of it blew from the northwest, and north through east. The current winds, however, are from the south and southwest and while there isn't that much snow to blow around, there is some [sic] and shallow drifts may be found in isolated terrain today…The last avalanches breaking into older snow layering likely occurred New Year's Eve during the wind event. These were in upper Hogum Fork of LCC on upper elevation northeasterly facing slopes…The Airplane Peak avalanches (roughly 2.5' deep and 80' wide) were in thin, rocky areas that have likely avalanched previously this season. Not unlike, say, the northeast face of Lone Peak, the* Salt Lake Twins *[emphasis added]….you get the idea."*

Of note in this accident are three key points.

1. First, winds had largely traversed the entire compass rose following the most recent snowfall, resulting in difficult to predict wind loading.
2. Second, the continually weakening surface snow increased the potential for snow transport due to wind, despite no additional snowfall.
3. Third, avalanches had occurred in upper elevation, rocky, northeasterly terrain. Of particular salience is the forecaster's mention of the Salt Lake Twin Peaks, which creates the headwall of Broads Fork and describes almost exactly the terrain that resulted in the Blue Ice avalanche.

AVALANCHE EVENT NARRATIVE

Skier 1 and Skier 2 planned a tour for Saturday, 5 January 2019 into Broads Fork of Big Cottonwood Canyon. In anticipation of stable conditions based on the "green light" forecast issued by the Utah Avalanche Center, they planned to tour into the upper reaches of Broads Fork to



ski in the Blue Ice zone. Upon their arrival at the Broads Fork trailhead, they met a party of three of their friends who planned to ski the adjacent Diving Board and Bonkers. The two groups did not travel together, but they did anticipate potentially crossing paths throughout the day. Skiers 1 and 2 departed the trailhead and skinned up the standard Broads Fork approach, a summer trail/winter skin track that ascends the bottom of the Broads Fork drainage for roughly 3 miles and 3,100 vertical feet.

After this ascent, the pair was positioned near the base of the Diving Board zone, looking up into the Blue Ice zone to plan the best path to break trail. They noted active snow transport and wind loading on the crest ridgeline approximately 2,000 feet above. Anticipating potential wind affected snow, the party elected a conservative skin track keeping to the lowest angle terrain possible well below the short cliff that forms the vertical ice for which "Blue Ice" is named. Partway through the ascent, the party noted wind scouring and wind loading on the planned ascent route. Skier 1 and Skier 2 agreed to increase their separation on the skin track to approximately 50 to 75 feet.

At approximately 10:00am while traversing a slope below the Blue Ice cliff, Skier 1 triggered an avalanche (HS-ASu-R2-D2) in hard wind slab on a northeast facing slope at approximately 9,400 feet of elevation *(Figure 3)*. At the time of the avalanche, Skier 1 was approximately 75 feet above and ahead of Skier 2. Skier 2 reported that the crown of the avalanche formed approximately 50 feet above Skier 1. Skier 1 rapidly realized getting off the slab was not possible and began swimming, hoping to come to rest as soon as possible, but confident that Skier 2 would be a capable partner ready to provide rescue if needed. Skier 1 was carried the extent of the slide path (250 feet from the point where Skier 1 was caught) but did not suffer serious injury despite small to medium trees and shallow rocks in the path. Skier 1 was partially buried chest-deep in the debris.

Upon seeing the slab break above Skier 1, Skier 2 turned around to reverse the skin track as fast as possible to avoid being caught, as the fracture propagated approximately 125 feet across the slope. Skier 2 was caught near the flank of the slide path, which knocked them off their feet and onto their back and then impacted by several large chunks of wind slab. Skier 2 slid downhill between two trees. These large chunks of snow came to rest against the trees on top of Skier 2. Skier 2 was partially buried head down on their back in a tree well and large chunks of debris pressing down from above. At least one of Skier 2's skis was visible on the surface of the snow..

With no response to verbal cues, Skier 1 concluded Skier 2 must have also been caught. Skier 1 worked to extricate themselves from the snow as rapidly as possible, no easy task owing to the chest-deep burial. Once on the snow surface, Skier 1 began post-holing up the bed surface to the crown of the avalanche to begin a signal search. Skier 1 was hindered by a lack of skis which were lost in the avalanche. In the upper third of the slide path, Skier 1 identified the ski of Skier 2 sticking out of the snow surface near a tree. Skier 1 immediately began shoveling to extricate Skier 2. Skier 2 was found unconscious. Skier 1 established an airway and determined that Skier 2 was still breathing. Skier 1 finished extricating Skier 2 from the snow; Skier 2 eventually regained consciousness, approximately 30 minutes after the airway was established.

The pair continued their self-rescue by reversing their path to the main Broads Fork skin track to proceed to the trailhead. Without skis, Skier 1 was forced to travel on foot. Skier 2's skis were both broken at the tip but largely intact and skiable with care. After joining with their friends from the Diving Board to self-rescue, Skier 1 drove Skier 2 to the nearest hospital emergency room where they were immediately admitted, evaluated, and released.

DISCUSSION

This incident highlights a number of the factors related to humans traveling in avalanche terrain, from the perspective of the forecaster, Skiers 1 and 2 in particular, and forecast users in general. These include the difficulties both in creating a forecast and applying it in the field. This incident also highlights the value of consistent skills training.

Forecasting Challenges

Of particular concern to a forecaster is crafting a forecast that accurately evaluates the avalanche hazard for the forecast period and the forecast area. Frequent errors in assessment of the hazard can lead to end users abandoning the forecast altogether. If the forecast is consistently too conservative, users may perceive the forecast as inapplicable and be emboldened to engage with consequential terrain when it is inappropriate to do so given the actual hazard on site and their acceptable risk tolerance. Alternately, users may disbelieve the forecast when it does indeed accurately reflect the hazard because they feel that the hazard has been overrated in the past. Conversely, if the forecast is too aggressive, the avalanche hazard will be underrated and users may also engage with consequential terrain when it is inappropriate to do so. Thus, the avalanche forecaster has a relatively narrow acceptable operational band within which to situate the forecast (McClung 2011).

While the conceptual model of avalanche hazard provides a reasonable framework for developing a hazard rating based on spatial distribution, triggering sensitivity, and destructive size, such evaluations are estimations based on incomplete data and are inherently subjective (Statham et al. 2018). Consequently, the conceptual model can be limiting when probability and consequence must be distilled to a single word hazard rating based on the North American Public Avalanche Danger Scale (Statham et al. 2010). Any error in the estimation of spatial distribution, triggering sensitivity, or destructive size by even a single category (ex. whether the avalanche problem is "isolated" or "specific") can change the "bottom line" hazard from one category to the next. More than one poor estimation can dramatically change the forecast's hazard rating.

These criteria can be quite difficult to interpret from limited field observations and telemetric weather and snowpack data. While the forecast did note the possibility of hazard increasing to moderate throughout the day, the bottom line rating was low. The forecaster followed up with Skiers 1 and 2 after their near miss and stated that he "blew it" with the day's forecast as a result. This was likely simply a result of the wind slab problem being more distributed or more reactive than the forecaster's initial estimation, a challenge no doubt compounded by winds that were erratic in both intensity and prevailing direction as well as variable amounts of snow available for transport. Unfortunately, even in the Wasatch—which enjoys a large number of excellent professional field observations and an even greater number of amateur reports each day—we simply do not have the data or resources to remove the inherent uncertainty in avalanche forecasting. *See Laura Maguire's discussion of uncertainty in avalanche forecasting on page 31.*

Field Application of Forecasts

Despite the forecaster's perception of underrating the forecast, Skiers 1 and 2 place no blame on the forecaster and assume full responsibility for their own decisions in the field. Skier 1 noted that they began the day with an "open season" mindset—a forecast with a low hazard rating meant "green light" conditions despite the warnings in the forecast for the very place they intended to travel that day (Atkins 2014). This by itself indicates potential complacency by this party. Further, commitment and social facilitation may both have played a role in the day (McCammon 2004). The pair was likely committed to skiing something (as opposed to abandoning the day's tour entirely) given the relatively long approach up Broads Fork and the relatively few named zones in the area. *See Russ Costa's discussion of biases on page 30.*

Despite these psychological factors working against them, the pair did note wind loading at the ridgeline and wind affected snow in the immediate vicinity. They elected the most conservative skin track possible for their chosen terrain and also adjusted their spacing on the uptrack. Unfortunately, this was not enough to avoid an avalanche that caught both members of the party. Their skin track appears to traverse a slope with an angle less than 30 degrees. Regardless, three factors made the travel route ineffective at avoiding an avalanche and were immediately causal:

1. A faceted surface layer that had been growing for the preceding three days enhanced the possibility for significant propagation and remote triggering upon a new load.
2. The new snow loading atop this weak layer was comprised of very hard, fresh wind slab that was poorly bonded and capable of transferring energy across the top of the snowpack without the safety sometimes afforded by "bridged" hard slabs.
3. The terrain is known for relatively shallow snowpack with rocks and trees available as trigger points (as noted in the day's avalanche forecast).

Figure 3: Looking up the slide path, taken from the lower third of the avalanche path. *Photo David Martin*

Also significant were the number of other avalanches that day with similar precipitating factors. Eight additional avalanches were reported or can be inferred from publicly available reports to the Utah Avalanche Center.

Skiers 1 and 2 were not alone in their mis-estimation of the hazard presented to them in the mountains that day. Simply, current avalanche forecasting methods and their typically tightly coupled application by backcountry travelers do not create a particularly robust system. Given these linkages, **risk management in the field demands more active input in the form of observations and updated decision-making as a result**, particularly if backcountry travelers wish to enact plans that are not only robust (i.e. resistant to fragility), but actively anti-fragile.

Skills Training

Despite the severity of the outcome in the Blue Ice avalanche, the relatively positive result certainly highlights the luck of Skiers 1 and 2, but also their skills training. Skier 1 has only been backcountry skiing for four seasons but has taken a level 1 course, an avalanche rescue course, is a member of Salt Lake County Search and Rescue, practices diligently each season. He is also a skilled climber and no stranger to the mountains in winter. Skier 2 is a long-time mountaineering instructor with Outward Bound, has also completed a level 1 course and rescue course, and occasionally guides backcountry skiing during the winter. While it is clear avalanches don't care about expertise, Skiers 1 and 2 did make reasonable adjustments to their travel plan, short of abandoning the Blue Ice zone altogether.

Skier 1's actions are also particularly commendable, and their mindset during and immediately following the avalanche may be helpful for others in similar situations. When interviewed about the incident Skier 1 noted rapid recognition that moving off the slab was impossible. Their subsequent response was to remain calm and begin "to think three steps ahead, like when you're playing chess." Skier 1 reportedly accepted that a ride in an avalanche was about to occur, fought to stay on top, and remained as calm as possible as the debris slowed, confidently trusting that "[redacted] will come dig me out, so just stay calm." Skier 1 managed to maintain this levelheaded approach upon recognition of the partial burial.

When it became apparent that Skier 2 was not responding to shouting, Skier 1 knew they must assume that Skier 2 had also been caught, carried, and buried and would need rescue. Skier 1 reported self-extricating while thinking the entire time about how they would need to switch their transceiver to receive and search the entire slide path, which would likely mean post-holing up the bed surface. While doing exactly this, Skier 1 maintained situational awareness adequate to identify Skier 2's ski, isolate an airway, complete the extraction of Skier 2 from the snow, and stabilize Skier 2 until spontaneous regaining of consciousness. The fact that both members of the party then elected to continue self-rescuing and evacuation to the trailhead is laudable.

Having just barely survived an avalanche, it is unlikely that Skier 1would have performed so well at rescuing Skier 2 were it not for considerable personal and professional skills training and practice. High stress situations limit the ability to think critically, leaving rescuers heavily reliant on "system 1" processing (Kahneman 2011). History tells us that it is the rare case one rises to the occasion—all too often rescuers fall to their level of training and practice. Clearly, Skier 1 took these ideas to heart.

IMPLICATIONS FOR PRACTICE

Forecasting of any kind is a difficult endeavor. This is no less true in avalanche forecasting. For the mountain traveler, mountain weather forecasting has become so sophisticated with copious amounts of data and advanced weather models that it can be tempting to assume that avalanche forecasting is conducted in the same manner and with the same accuracy and precision. However, avalanche forecasts are considerably less certain, owing to limited and incomplete data and less powerful algorithms to apply to a similarly multivariate problem. Even in the case of weather, forecasts are often a subjective judgment based on the combination of multiple weather models. With so much complexity and uncertainty and so much at stake, the task of the forecaster is unenviable and made more stressful with the knowledge that forecast users of any kind will be applying the information provided to take risk. The forecast consumer must apply their own knowledge and judgment to the forecast as well as the conditions they perceive in the field in order to assume their own acceptable risk within the limits of their operational risk band.

Reducing the risk of travel through avalanche terrain is made all the more difficult owing to the Bayesian nature of current avalanche forecasting algorithms—such as the conceptual model of avalanche hazard—and their reliance on preceding observations, often detailed in AM/PM forms or other formal operational records. The avalanche forecast relies heavily on prior information about the snowpack and subsequent effects to the snow based on recent environmental conditions. Incomplete or inaccurate information necessarily creates greater uncertainty as the probability tree grows increasingly forked. Indeed, this is why an "assessment" mindset is applied when little is known about the current snowpack, its attendant stability, or recent weather effects on the snow.

Vigilantly maintaining an assessment mindset at all times regardless of prior knowledge is likely one of the best defenses against unusual and/or unexpected conditions that do not fit with prior knowledge, the resulting forecast, and assumptions about how these interact with the terrain and snowpack in front of travelers in the field. Even on "green light" days, observations should be taken regularly and used to challenge the forecast and planned travel route.

In the case of the Blue Ice avalanche and other human triggered avalanches of 5 January 2019 in the central Wasatch, the old adage that, "Low hazard doesn't mean no hazard," applies. Ideally, a group's "normal caution" includes consistent pertinent observations throughout backcountry travel with the expressed aim of disproving or disconfirming the current travel plan and its assumptions about the snowpack and terrain. However, simply making observations is insufficient—observations must be translated into meaningful action, as the Blue Ice event demonstrates. While the party recognized signs of increasing wind slab hazard, they failed to act in a manner that eliminated the risk of avalanche. This is made all the more compelling because they did indeed take proactive action, but the action did not match what the conditions demanded.

In such cases where the only effective mitigation strategy is avoidance, multiple plans are advised. With multiple plans, an implicit commitment heuristic might be avoided by naming plans not as "Plan A, B, C…" or "Plan 1, 2, 3" but rather by aspect, elevation, angle or other factors directly relevant to the hazard (ex. a "solar plan" and a "shady plan").

Finally, there is no substitute for practice, whether in planning, slope angle assessment, digging pits, or rescue skills. When the moment comes to search efficiently and shovel hard and fast to uncover a partner buried in avalanche debris, these skills will be far more timely and effective if they come from "system 1" thinking, well-practiced and automatic. In highly stressful situations, as time-sensitive life threats often are, system 1 tends to be the default. However, system 2 thinking is very useful for planning for crucial next steps during a rescue and maintaining situational awareness of surface clues, hazardous environmental conditions, etc. When rescue skills are practiced to the point of rote recitation without compromising effectiveness, this frees mental bandwidth for crucial system 2 thinking, increasing the effectiveness of the rescuer and chances for a positive outcome. ▲

Vigilantly maintaining an assessment mindset at all times regardless of prior knowledge is likely one of the best defenses against unusual and/or unexpected conditions. Even on "green light" days, observations should be taken regularly and used to challenge the forecast and planned travel route.

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3

ANALYSIS

ANCHORING AND ADJUSTMENT

By Russ Costa

BLUE ICE

GREEN ANCHORS

Small cracks broke out as we skied and skinned across it. We weren't particularly concerned though, as the wind-affected top layer was less than 10cm deep, and we weren't in steep terrain. Plus, it was a "green light" day. Nonetheless, I scanned the terrain above us, happy it was windward. It was a low danger day, but sometimes I look left and right when I proceed through a green light.

Having spent the morning of Saturday, January 5th sitting in a classroom, I was excited to get up in the mountains and onto the snow in the afternoon. I was observing a backcountry clinic that day, thinking about what I would be skiing if I weren't. I had read the Salt Lake area avalanche forecast in the morning, as is habit. Low danger across all aspects and elevations. A "green light" day.

The afternoon was colder and windier than I had expected. Small plumes wisped off the ridges above us. The snow was grabby on my skis as a thin wind skin had formed over its surface. Small cracks broke out as we skied and skinned across it. We weren't particularly concerned though, as the wind-affected top layer was less than 10cm deep, and we weren't in steep terrain. Plus, it was a "green light" day. Nonetheless, I scanned the terrain above us, happy it was windward. It was a low danger day, but sometimes I look left and right when I proceed through a green light.

The next morning, I read the reports. Eight skier-triggered avalanches. Four persons caught and carried in separate events. Only one injury. Reminders that aren't full-fledged disasters are probably a good thing for a community that (at the time) hadn't experienced an avalanche-related death in almost three years, despite seeing tremendous growth in the popularity of the sport.

When it comes to judging monetary values, from real estate values to civil litigation damage suits, research in cognitive science and behavioral economics has demonstrated that humans consistently anchor their judgments closely to some preset number, then subsequently adjust their estimates of the appropriate value too conservatively (their estimates remain too closely tied to the anchor value) in light of new information. This cognitive bias can operate when we estimate danger hazard and risks in the backcountry, with the forecasted danger levels serving as an "anchor." The **anchoring and adjustment heuristic** (Tversky & Kahneman, 1974) operates when decision-makers are compelled to make estimates (of value, of frequency, of danger, etc.) under uncertainty. We're uncertain about actual risk in the backcountry and must estimate it based on prior knowledge and observations. If the forecasted danger rating is "low," backcountry travelers may be too conservative in adjusting their evaluation of danger upward toward "moderate" or "considerable," even upon encountering information indicating the danger may be higher than "low." Their judgment of risk and their mental models of hazard remain too tightly anchored to the forecasted danger.

Anchoring acts in conjunction with other cognitive biases and heuristics. It's likely that this anchoring effect is *asymmetric* in backcountry decision-making. Ian McCammon's (2002) **commitment (or consistency) heuristic** trap suggests that skiers and riders are less likely to adjust their evaluation of danger upward (toward more hazard) from the forecast anchor than they are to adjust their estimates of risk downward, toward a lower risk judgment. Adjusting risk estimates upward would be inconsistent with objectives or goals the individual or party has committed to for the day, and thus less likely to occur.

Anchoring affects attention and perception, too. If we anchor our estimates too closely to the forecasted danger we're also more likely to notice information that *confirms* that hypothesis or estimate. If we expect the danger to be low, we'll likely notice signs of stability or, more importantly, ignore (or not perceive) signs of instability. This tendency to search for, interpret, and remember information that confirms one's preëxisting beliefs, hypotheses, or wishes (and to ignore or minimize information that disconfirms them) is known as the **confirmation bias** (Wason, 1960).

One of the speakers at the clinic I observed on January 5th noted that avalanche forecasts are only one tool. They provide valuable information. But we shouldn't become too anchored to them, especially when it snows more, blows harder, or warms faster than forecasted. Trust your observations on the ground when they conflict with the forecast even—or especially—when they conflict with your objectives or goals. ▲

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DECISION-MAKING

Multiple Choice

What affects your decision-making?

A) Ambiguity

Human Performance in Uncertain Environments

BY LAURA MAGUIRE

If you have been reading much about human factors lately, you might agree that mountain safety professionals are due for a pep talk.

However, contrary to the extensive literature decrying the fallibility of humans and their poor decision-making, the work done by avalanche professionals is quite exceptional.

So while it is true that part of how we perceive risk and make decisions can be subject to flawed thinking and dangerous biases, this is only one small dimension of a much broader understanding of what constitutes expert performance in uncertain, changing environments.

This article will describe the conditions that makes snow safety difficult while drawing comparisons to highly skilled practice in other high risk/high consequence domains and then make a pitch for using this perspective to explore some useful avenues.

When out in the field, snow safety professionals have to accurately perceive often very subtle cues.

What makes snow safety hard?

Looking into a field of practice and asking *'what makes this hard?'* is a fundamental question for understanding what is means to be an expert in that kind of work. It's a frame of reference that provides insights into the kinds of challenges faced by practitioners where simple proceduralization is not possible (or desired).

In other words, how do experts cope when the data is ambiguous, analysis remains uncertain, and rules are underspecified, insufficient or, inapplicable? The avalanche community already recognizes the limitations of strict rule following in making judgments about the snowpack. For example, in the Canadian Avalanche Association *Observational Guidelines and Reporting Standards for Weather, Snowpack and Avalanches* (OGRS), there are seven instances of the word "rule" whereby six of these indicated that a definitive rule was impossible! (The seventh instance was to describe a rule of thumb and indicate variability was required).

If the rules by themselves are unable to prescriptively define safe decisions, yet many outcomes are successful, then avalanche professionals must be doing something right! Given this paradox, we can make a guess that there is sophisticated cognitive work—in perception, reasoning, evaluation and judgment—that goes into successfully managing the ambiguity in forecasting and guiding work.

Given the extensive literature on the technical aspects of forecasting you might think this already exists. Yes and no. There is a solid foundation of work based on introspective self reports from interviews and surveying of experienced practitioners, but "cognitive psychologists have noted there are limitations to what people can actually tell us about their mental processes" (Nisbett & Wilson, 1977, p.232). This means studies based on self-reports will only provide a partial understanding. In addition, observational studies can be similarly limited. As the 'fluency law' (Woods, 2005) notes, most experts are really good at what they do; this often makes their work look easy to observers so it's hard to 'see' just how difficult it actually is! We need to use other methods and triangulate them to uncover cognitive aspects of managing risk in the mountains. A good place to start doing this is by examining 'the hard stuff.'

Challenges to performance in avalanche forecasting

Given what we know—based on studies in healthcare, air traffic management, and mission control in space exploration (Cook & Rasmussen, 2005; Patterson, Watts-Perotti, & Woods, 1999; Smith, P.J., McCoy, E. and Orasanu, J., 2001)- there are common patterns to what can make a job hard. In mountain environments, salience & discriminability, change, goal conflicts, and coordination are of particular interest. Studying how experienced practitioners handle these difficult aspects of their work helps provide insight into the nature of domain specific expertise.

Salience & discriminability of cues.

Salience refers to how noticeable or discriminable information is given the backdrop of the environment and all the other possible sources of information. For example, a rapid deformation and crack propagating fracture is a very salient cue—there is the movement of the snow shifting (even slightly) in crack propagation across a slope, changes in light and texture on the surface of the snow as the fracture line opens up, and perhaps even an auditory signal.

But that example is a bit of an outlier because to uncover many of the meaningful signals or cues about what is happening in the snowpack you literally have to go digging to extract the right kinds of information. In other high consequence monitoring environments like nuclear power plants or intensive care units there are often layered sensor networks providing real time data to aid the operator in monitoring the state of the system across multiple variables. In those environments, threshold alarms or visual displays can highlight minor variations to inform the plant operator or nurse that the state is changing. When out in the field, snow safety professionals have to accurately perceive often very subtle cues. And, even when assessing already existing data from previous reports or online databases, the information is presented in a way that requires mental effort to extract the meaningful data from the background information.

This represents the first of the challenges in forecasting—data has varying levels of salience and is collected over different points in time—so variations in that data requires ongoing interpretation to recognize when conditions change in a meaningful way.

Change is a constant.

Notice, in that last paragraph I didn't say if conditions change. Because this is another key factor of what makes avalanche forecasting cognitively demanding work: **conditions are continually changing, and often in an unpredictable and interactive manner.**

Because, while we may understand conceptually how windloading can influence the snowpack, there are only imprecise measurements of how much and where the loads are setting up. Even with telemetry devices, these can fail or be overcome with rime providing false information and adding to uncertainty. Also, the measurements taken are categorical (a point in time) not continuous. This means relevant cues take time to accumulate which can slow decisions about the trajectory of the stability *(Is it increasing? Decreasing? How slowly or quickly? What might this mean for my guiding plans today? What other factors will inform not only my assessment but my planning or revision when conditions change?)*

Noticing change (and rates of change) and interpreting its meaning is best supported with continuous telemetry with low time delay. However, field data will always come with some form of time delay (for instance, waiting for the sun to come up to be able to visually inspect a cornice or in the time it takes to ski out to a slope and dig a pit). Lag in any kind of system where the hazard, once triggered, is largely unstoppable severely compromises the capacity to manage the variability (and its corresponding risk) common in that system.

Multiple competing demands

Forecasting work, like most high demand practice, occurs within a system subject to constraints. For instance, control work must be completed before the hill can open to guests anxiously waiting for first chair or incoming weather is limiting the window for the helicopter meaning you have to prioritize the plan.

Even the most safety conscious organization does not exist solely to eliminate risk—instead they control risk to meet other objectives. These goals—running a successful ski hill, keeping a highway open, or enabling crews safe transit to keep a construction project on schedule- are subject to tradeoffs in order to maintain safe operations.

Managing these competing demands is part of successful expert performance. Pilots, at the bare minimum, are obviously expected not to crash the plane but they also balance responsibilities for having on-time departures, ensuring passenger comfort, minimizing fuel costs and keeping accurate flight records. These additional demands require consideration in making or revising plans as disruptions occur. Similarly, the analysis that a ski guide has to do to ensure clients who've paid thousands of dollars get to safely ski great lines means additional cognitive burden.

Coordination is key.

The multiple goals of the work system go hand-in-hand with another aspect that makes forecasting work hard: the need to coordinate across a distributed network.

The coordination may be so others can provide information (like when a team calls in the results of their control work), to adjust their actions (say, changing the pickup location with the cat driver), to provide approvals, or to communicate to public and other impacted users.

Well-coordinated groups run smoothly—minimizing downtime or unnecessary risk—and help to proactively identify issues. Coordination breakdowns increase the cognitive work by introducing lag or requiring more effort to determine what others are doing and how that may impact your plans.

So, what does this mean?

In outlining the characteristics that make the work hard, it is clear that snow safety work is cognitively demanding. Describing the "hard work" in this way provides more specific explanations into why things sometimes go wrong. Research into the cognitive work of avalanche forecasting in ski resort operations (Maguire & Percival, 2018) provides an example of how this new perspective can reframe how we think about professional practice.

Further studies can help generate rich descriptions that allow for comparing and contrasting performance across a variety of conditions and work environments. This gives us more nuanced understanding of when things like heuristics and biases help us cope with dynamic and demanding environments and when it can get us into trouble. This kind of data also provides promising design directions for engineering tools and technologies to better support practitioners. No matter what your opinion on why people make mistakes, avoiding oversimplifications about how work gets done is critical.

While we know a lot about the technical expertise in snow safety professions, making visible the strategies used to get work done in context—with all the messy details, goal conflicts, and complexities—can help improve training programs, develop new technologies, refine procedures and enhance teamwork to support more successful outcomes. ▲

Many thanks to Greg Gagne for the conversation that inspired this article and his feedback and to Jesse Percival for his feedback.

Cognition is distributed amongst the team. Multiple overlapping perspectives broaden assessments and broaden tentative hypothesis about what is happening in the snowpack. *Photo Jesse Percival*

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Oh I'll be okay, I can always just call for help...

BY JAY WHITACRE AND CURT DAVIDSON

Item	Not Likely		Somewhat Likely		Very Likely
	1	2	3	4	5
LM01 Helicopter in daylight	1	8	34	82	109
LM02 Helicopter at night	68	94	47	14	11
LM03 Snowmobile (in winter)	1	6	36	76	115
LM04 Carry out on a stretcher	10	23	57	64	79
LM05 Snow cat (in winter)	27	65	70	40	32
LM06 Ambulance	50	36	49	46	52
LM07 All-terrain vehicle (SUV)	40	50	68	48	26
LM08 All-terrain vehicle (4-wheeler)	34	46	67	58	28

As the ski industry continues to gain in popularity, according to the National Ski Area Association, there is evidence in sales and industry data that riders are looking for more ways to escape the crowded resorts and engage in side and backcountry skiing. The influx of new users warrants investigation of risky decision-making and accident prevention analysis. Focusing on Search and Rescue techniques and efforts are part of this equation, but understanding how and why people make risky decisions and become victims of avalanches is an equally, if not greater, consideration. After all, shouldn't we try to prevent avalanche and skiing accidents versus having to respond to them?

In an age where heli-skiing is the norm in ski films and we've all seen action movies where stars swoop in with the aid of a helicopter to rescue someone on a moment's notice, these authors thought it would be worth pausing to see how backcountry riders perceive their chances of rescue after an accident. The likelihood that someone makes a risky decision or takes a foolish chance seems more probable given the notion that they could be rescued in a short amount of time with little or no consequence to them or their partners.

This was one of the questions we sought to answer as part of a larger risk-taking, judgment, and decision-making project utilizing backcountry snow sport users. Particularly, this portion of the project was concerned with how the participant perceived the methods in which a rescue would take place, including how a participant in trouble might be reached (by outside sources and rescue personnel) in a remote backcountry setting. For the purposes of the study the participant was given example emergency situations and asked to approximate the following:

1. Contact time to the rescuers
2. Arrival time of rescue party and;
3. Timeframe in which it would take to get to a medical facility

These were thought to be the most important factors an individual would consider when analyzing their chance of rescue and thus impact the decisions they are making in real time. This section of the research project also included the use of vignettes to evaluate the users' judgment and decision-making in an effort to gauge the subjects experience level and perception of risk through scenarios. To clarify, this section had Likert-scale questions (from 1—"Not Likely" to 7—"Very Likely") that inquired about the perceived modality of the rescue operations and how quickly the rescue would occur.

While these data show perceptions of rescue modality, they do not show the actual method likely to be utilized in rescue scenarios. Data for a perfect comparison could not be found. However, SAR data from the state of Oregon from the years 1997 to 2003 indicate that of ALL the various SAR missions, only 1.9% involved the use of a helicopter. Relatedly, 0.01% utilized a snowmobile for rescues.

The statistically significant positive path coefficients provided sufficient evidence to demonstrate that stronger attitudes toward risk taking and more optimistic beliefs about rescue shifted attitudes toward increased risk taking. Additionally, beliefs about rescue capabilities were higher among those respondents who used a greater amount of technologies (or gear), and lower among those respondents who used fewer technologies. Following the analysis, the more technologies that the respondents used (e.g., Avalanche Beacon, Avalanche Probe, Smartphone, Blackberry, Snow Study Kit, GPS device, etc.) then the more participants perceived that (a) the use of technologies increased the safety associated with outdoor recreation activities; and (b) the more they believed that they would be rescued in the event of an accident (e.g., by use of a helicopter, snowmobile, snowcat, ambulance, SUV, all terrain-vehicle, etc.). This project showed that there is a strong link between the amount of technology a person carries and that person's perception of a potential speedy rescue.

The implications for these findings reach many aspects of the backcountry snows sport industries. First, avalanche professionals and educators need to consider how information is conveyed about rescue likelihood and timeliness. The fact that an individual carries an avalanche beacon and a cell phone might be instilling a false sense of security that encourages individuals to make more risky decisions when in avalanche terrain. These items seem to be conveying, to participants, a false sense of how much time is needed to wait for rescues as well as the type of rescue that might actually be undertaken to assist them. We suggest that avalanche education continue to focus on backcountry decision-making; emphasizing that unrealistic rescue expectations might lead backcountry travelers towards more risky decision making. ▲

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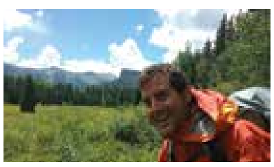


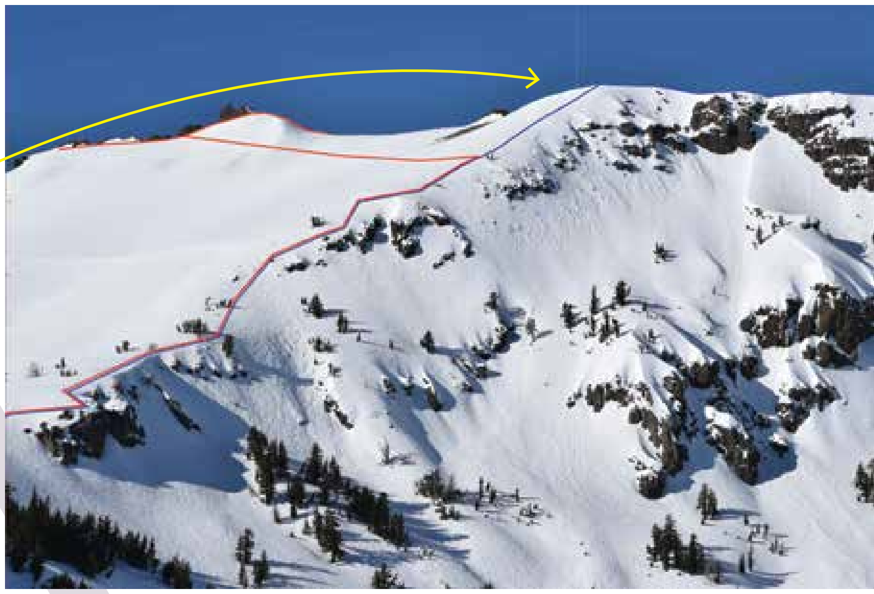
Jay Whitacre has been involved in educating and empowering individuals to strive for greatness for almost 20 years. He has his Ph.D. in Leisure Behavior and utilizes his professional knowledge in researching market trends and product needs analysis. As a former adventure programmer and guide he realized his passion for research and development can add to the Outdoor Industry by helping to develop better products that fill the desires of its customers.

In addition to his position at Alpenglow Education, **Curt Davidson** is a faculty member at California State University where he serves in the Recreation and Leisure Studies Department Having worked for over 10 years as a field instructor, he has been able to hone his skills as an experiential educator, while grounding his work in theory through obtaining his Doctorate. He is also the author of several peer-reviewed publications and two books including *The Outdoor Facilitator's Handbook* and *Behavior Management in Outdoor Adventure Education*.

C) Complacency

The Bermuda Triangle

STORY AND PHOTOS BY LIAM BAILEY



At Kirkwood the longest snow safety route is a four-person route where two teams work separate upper sections and join up lower down. I was the leader of the slower skier's left team (shown in blue) years back and the other route leader, a very senior person, assured me everything between us had been shot and was fine. He was at least a little perturbed that I was about to re-shoot paths he had already shot. While he certainly had thrown some shots, I was fairly sure it wasn't good (based on number and placement of what his team threw) but I followed orders and skipped down and joined him anyway.

Upon catching up, I threw a shot in the flattest slide path on the route (28 to 32-degree start zone-far left side of the overview photo) and triggered an R3/D2 HS with a four-foot crown.

I then hiked back up and re-shot everything I had been skipped over and got similar class 2/3 action. The other route leader would have vehemently denied being complacent.

The feedback loop is described here:

We start with **Ignorance**: "Lack of knowledge or information"

Then proceed to **Arrogance**: "Having or revealing an exaggerated sense of one's own importance or abilities," where our hubris assumes an attitude.

And circle around to **Complacency**: "Self-satisfaction, especially when accompanied by unawareness of actual dangers or deficiencies," when our arrogance takes action (or avoids taking action.)

Complacency is often cited as a cause in patroller incidents.

So where is complacency conceived and how does it evolve?

With objectivity and minus ignorance, one would be confident, not arrogant. Arrogance is not necessarily or not completely unaware and unskilled but is often unmotivated to assess or seek improvement (why, if you know it all…), allowing ignorance to not only remain but flourish. Ignorance and arrogance, as contributing factors to complacency, may be the parents of complacency.

Knowledge and humility are the chief weapons against ignorance and arrogance.

I once had a professional tell me after they triggered an avalanche that buried their partner that because they "assessed" a hazard and concluded nothing was going to happen that they weren't complacent. Stopping your risk assessment at "I'm confident there's no hazard/nothing is going to happen:" then jumping in and being proven wrong is the definition of complacency. That incident was a textbook example of the triangle feedback loop.

Statistics tells us there is a 65% probability that a 10-year return period event will NOT occur in any given 10-year period and a 67% probability a 50-year return period event will NOT occur in any 20-year period. This is why Art Mears wrote "…long return period avalanches…have not been observed at most North American locations. This is often true because the continuous observation periods are short (10-30 years) at many sites."[1] He wrote that in 1992 but the only amendment necessary is to time of observation.

Steeper than it looks in the overview photo, now with crown.

To get away from the math, this means with a professional avalanche career long enough to retire with pension, the probability is high you haven't seen all or even most of the significant avalanches your mountain is capable of producing. It's not hard for someone to become arrogant as they become one of the senior patrollers- to think that since they're one of the most knowledgeable people about so many other facets of the job, they must know all they need to about snow safety too. I've watched this happen even with patrollers who I wouldn't categorize as arrogant. Snow safety takes a lot of confidence, but that needs to be balanced with the aforementioned humility. Despite being counterproductive, it appears to me that denial of a mistake is sometimes chosen as a better alternative than facing the damage to confidence that may occur from self-reflection and acceptance of constructive feedback.

Any time "We've always thought that was a safe spot…" is uttered, I urge you to investigate if the ignorance-arrogance-complacency loop is in play. Snow safety done well (little avalanches often) actually further reduces the probability you will see significant avalanches, but due to the nature of the work, they could still happen at any time. While it certainly is possible to get multiple 100-year return period cycles in the same winter, you probably won't work or even live long enough to see the avalanches that cut the natural paths at your resort. I use that fact to remind myself to continually seek knowledge, to try to be objective and humble, and to never assume something wasn't going to slide or wasn't going to slide big.

IGNORANCE ⟷ ARROGANCE
↘ ↙
COMPLACENCY

Sidney Dekker notes "Outstanding performance and a constant search for maximum performance make unsafe systems work. Greater safety can sometimes be expected through increasing practitioner competence. That often takes care of itself, though, as participants in such activities tend to be competitive and constantly out to improve their own performance".[2]

In my experience people with the countenance and mindset needed to fight this feedback loop at all levels of an organization not only demonstrate objectivity but often attempt to shoulder more of the blame for an incident than is warranted. These are the people who will be aware of their mistake(s), trying to learn from their mistake(s), constantly trying to improve their performance, skillset, and knowledge and they are not your mountain's human factors problems.

Deep seated arrogance will be a hindrance to a team and its progress but is not difficult to spot. If the majority of your team is motivated to maintain or create a culture that strives for knowledge, humility, constantly improving performance, and skills facilitated by every available tool, you may at least be able to easily distinguish the outliers. Can people be trained out of the ignorance—arrogance- complacency loop? Admission is the first step to recovery. ▲

1 *"Snow-Avalanche Hazard Analysis for Land-Use Planning and Engineering" by A.I. Mears. Colorado Geological Survey Department of Natural Resources, 1992. p19.*

2 *"Field Guide to Understanding 'Human Error'" by Sidney Dekker, Ashgate Publishing Company, 2006. p190*

Thanks Scott for reminding me to do the math…

Liam Bailey has patrolled for 18 seasons, is an Aries, and likes race stock skis, excessive speed, baking, extreme weather, Holdener, plug boots, logic, primacord, live music, jape, slow double chairs, argument, Monet, and large destructive avalanches.

D) Dragons

Inside Out

BY KEN WYLIE

Over the last ten years there have been fantastic advances in the field of avalanche safety through research and technical development. Additions made to snow stability evaluations, terrain assessment tools and avalanche response technologies deepen our awareness of the snowpack, our decision-making skills and our response times. Yet when I look at these intense efforts, it frustrates me that people are still dying out there each winter. Even some of the best: Robson Gmoser. How do we make ourselves safer?

Ian McCammon's work with heuristic traps is helpful. He discusses how decision-making shortcuts work against us, like familiarity. As if a past experience will predict a future one. Or by seeking acceptance from others socially, yet not sharing what we know to be true for ourselves. Great steps toward the notion that our decisions are often flawed, but I propose that we go deeper and come to better know our situation inside.

Casting light on our character flaws frightens most human beings. In our industry, my observation is that we try to replace looking at ourselves with technical solutions. If Icarus (from Greek mythology) was plummeting to the sea, (and he was an avalanche professional), he'd say: "Daedalus should have used epoxy to glue the feathers to these wings instead of wax." When really the lesson was about hubris. When tragedy strikes, we often point to and wonder about technically obvious factors that were ignored, and we ask: Why?

In *Transforming Your Dragons*, Dr. Jose Stevens lays out seven archetypes that can afflict humans. His work is a powerful tool for putting language to our internal situational awareness in a way that we can easily identify, if not fully admit to recognizing in ourselves.

- Arrogance
- Self-Deprecation
- Impatience
- Martyrdom
- Greed
- Self-Destruction
- Stubbornness

According to Stevens, each of us is particularly plagued by one of these seven dragons and they surface, or gain control, in the presence of fear. However, it is also important to keep all of them in our awareness. Let's take a closer look at each one of these and see how they can play out in the backcountry skiing paradigm.

Arrogance. There is a big difference between confidence and arrogance. A confident winter backcountry guide or enthusiast also listens to input. There is a willingness on the part of the confident individual to welcome new information from anyone in the group. Conversely, a person with the arrogance dragon will say, "I am/know the best," and believe it. This individual is incapable of receiving input from others. The root of this behavior is insecurity.

Arrogance in avalanche terrain can and does lead to information gaps. Individuals have blind spots, a limited perspective grounded in biases and perceptions. If we invite others into the process, the scope of available information broadens, which can impart the choices we make.

Self-Deprecation. Self-deprecation is a lack of confidence to the point that we forfeit our voice. We may possess the most relevant piece of information, but we are too afraid to share it because we carry no value in our perceptions. If we consider that all parties exposed to the hazard of an avalanche are risking the same thing—their life—then we need to master social courage and speak up.

Impatience. People with the impatience dragon are stricken with the fear that if things are not happening quickly, something bad will happen. However, being in a hurry can lead to a failure to take the required time to do a task safely and efficiently. In the mountains there are many instances when going more slowly can help us maintain a higher level of diligence and therefore safety. Think of crossing an avalanche slope one at a time. It can be uncomfortable to travel slowly if we fear worsening conditions, but only time will tell if the conditions worsen. Rather than rush through a critical piece of terrain, explore other options and terrain choices.

Martyrdom. Martyrs are victims; they feel that they do not have the power of choice. Others make decisions for them and they are oppressed. This differs from self-deprecation in that martyrs have good ideas, but they are not heard or heeded by colleagues or friends. A martyr follows a leader onto a suspect slope, despite knowing the potential consequences of withholding their knowledge and information. We say, "Oh, I don't think this is okay, but they want to go there, so I guess I'll go with the flow. I don't want to make waves." In this case, the fear is about standing in one's truth and living it to the full, regardless of social fallout.

Greed. Greed is an easy dragon to understand, especially on a powder day when the sun is shining. The statistical fact that more avalanche tragedies happen on sunny days with new snow underpins the concept of greed. After a long period without any snow it becomes more likely that we may undermine our own ability to make rational decisions, making going for it easier and escalating our tolerance for risk. Our greed dragon also comes into play when we race ahead of other groups in order to get first tracks. Our focus on the race can erode good decision-making.

Self-Destruction. Self-destruction may be fueled by a general propensity for self-hate, depression, or a sense of despair. This does not make for good decisions in avalanche terrain. It brings a devil may care attitude to an activity that requires great care and diligence to preserve the well-being of self and others. This behavior often creates drama and subconsciously encourages poor outcomes. The underlying fear is one of success and the responsibility that it brings. Ironically, these individuals may have a long list of successes in the mountains, but the intention behind those successes is suspect. Were they reckless and lucky?

Stubbornness. When afflicted by the stubbornness dragon, we refuse to cooperate. It may be that we are afraid to be wrong, or we are so fixed on the objective of the day that we can't shake ourselves from achieving the goal. Single mindedness can be a required strength in hazardous environments, but the game is about seeking the best solution to the challenges we face.

Fear fuels these archetypes. Be it the fear of not being as good as we claim, our own self-efficacy, not enough time, personal responsibility or simply being incorrect, each of these fears is a hazard to the avalanche professional, as it is to human beings traversing through life. I believe I have been gripped by every one of these dragons at one time or another. However, mostly I have tripped on being a victim to others: martyrdom. What I can do to remedy my fear is to be aware of it.

There is a place for fear in the avalanche game. Fear keeps us on our toes and brings focus to hazardous situations. In the case of tragedies, rather than point out what appear as obvious flaws, let's instead try to understand what lead to the mistake. Let's identify that process within ourselves. That is the cure for fear of any unknown: facing it with full situational awareness. ▲

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E) Experience

Framing Experience

STORY AND PHOTOS BY GABRIELLE ANTONIOLI

Left: Some nice turns found on the south face of Divide Peak, North Gallatin Range.
Right: Texture in the North Gallatin Range.
Below: Snowy ridge walkers in North Gallatin Range.

I'd spent several years skiing in the backcountry before I realized that, although I understood the basics of snow and reading an avalanche forecast, I knew very little about how to mitigate risk and uncertainty in snow. I had several groups of peers, most of whom had been skiing for longer than myself, and felt I was gaining experience as we progressed into more challenging ski terrain without mishaps. It was only after I was taken under the wing of a mentor that I realized how incomplete my experience was. I cut corners and took on undue risk without ever realizing it. I understood fundamental concepts, but lacked the direction to incorporate that knowledge into a deeper understanding. Having mentors to point out things I didn't know to look for, and probe my assumptions and decision-making, was integral in my current understanding of how to move safely in avalanche terrain.

After many years spent as the beneficiary of mentorship, I started instructing avalanche courses. I see in my students many things that I identify in my past self—a strong urge to spend time in the mountains and the desire to do so safely, coupled with an understandable lack of knowledge about what they are diving into. Teaching about concepts like slabs, weak layers, and avalanche problems is far simpler than teaching how to see these concepts as part of a system that allows for good decision-making and safe travel in the backcountry. Learning these concepts individually can be accomplished in a classroom. Understanding how to integrate them into a systematic approach to backcountry travel generally only comes with prolonged mentorship and years spent in the snow. I feel the satisfaction that instructing avalanche courses can bring, but struggle with imparting a functional framework in just a few days.

These challenges were on my mind when I was asked to present at the Montana State University Snow and Avalanche Workshop (MSU SAW) this past November in Bozeman, Montana. I applied the theme of "How Does Your Day Roll" to the mental routine that I've developed through experience and mentorship. This routine aids me in dealing with the uncertainty that exists in every decision made while skiing in the backcountry. I focused on three deceptively simple concepts that make up the foundation of this mental routine: moving consciously, fostering familiarity, and knowing the limits of one's experience.

Moving consciously seems easy enough, but the pull to ignore a complex picture and focus on simpler things, like the danger rating or a single pit result, is strong. Beginners often get so caught up in the challenge of simply traveling in the backcountry that it is hard to incorporate the necessary search for evidence of instability, or lack thereof. Traveling in the backcountry can be a tremendously rewarding experience, but doing it consciously is far from easy.

In addition to directing your attention to the environment that you are traveling through, it is critical to direct your attention away from things can be detrimental to your focus. One major source of distraction that hinders conscious movement is the ever-present pull of the smartphone. Calls, texts, likes, posts... the list goes on and on. A snow-covered backcountry environment is a complex place. Anything that pulls focus away from that environment is limiting your ability to notice, appreciate, and absorb those complexities.

There are plenty of factors that change every time we go out in the backcountry. Fostering a deep familiarity with the things that are more constant (terrain, our partners, ourselves) can help us to keep the unknowns limited as much as possible. Managing terrain may be the only surefire way to avoid avalanches. However, in order to use terrain to our advantage, we really have to know it intimately, gradually building up to that familiarity over time. It is easy to feel comfortable in a place after spending a few days there, but a thorough understanding of large, complex terrain can take many seasons to establish. Familiarity can also cut both ways, as Ian McCammon described in his work detailing heuristic traps. As we foster familiarity with many things, we must also bear in mind the false sense of security it can endow if utilized incorrectly.

The same is true when it comes to partners on the skintrack. Understanding your partner's approach to the backcountry and how they arrived at that approach is fundamental to understanding how they travel and make decisions. A day spent with an unknown partner can often be more hazardous than a day spent alone. On the flip side, combining the brainpower of two experienced people can provide insights that are much harder to arrive at as a solo traveler.

At its root, cultivating familiarity with ourselves is about knowing the limits of our experience. Avalanches are not random, but when our understanding of a certain avalanche problem or type of snowpack is outside the realm of our experience, it can certainly feel that way. For

newcomers to the world of snow, everything is outside of the realm of their experience. Even seasoned resort skiers struggle to understand the nature of an ungroomed snowpack; there aren't a lot of things that we encounter in everyday life like it. Teaching people the importance of recognizing this fact, setting aside their preconceived notions, and building a foundation of experience from the ground up is critical.

Our habits form early. I was fortunate to have had mentors to guide my learning, but for many this isn't the case. Newcomers start building their fundamental backcountry knowledge and abilities in avalanche classes. Our goal as educators is to enable students to get into the backcountry in a safe, well thought out manner. When we are not there to point out things or encourage good practices, bad judgment can be practiced and become habit as well, particularly when good decisions and bad decisions both lead to good skiing. In my teaching and in presenting this idea to the audience at the MSU SAW, I hoped to help establish a framework upon which to build as they spend time in the mountains. ▲

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F) Framework

Mindset for Mitigators

MINDSET	TYPICAL CONDITIONS	TYPICAL OPERATING STRATEGY
Assessment/ Season Opening	There is a high degree of uncertainty about conditions, such as when first encountering the terrain for the season, entering new terrain, following a lengthy period with limited observations, or after substantial weather events. Season opening conditions are analogous to working in a backcountry snowpack where huge spatial variability and a host of avalanche problems are possible.	Identify terrain from which to get snow stability information safely. Look at your indicator paths for activity and identify suspect terrain based on season history and telemetry data. Be prepared for multiple passes and limited safe zones. You may be forced into large/consequential terrain given the nature of where early snowfall sticks, so early control efforts need to especially cognizant of safe zone selection and to exposure from above.
Stepping Out	Conditions are improving and/or we are gaining confidence in our assessment. The 'stepping out' mind-set covers a range from stepping out very cautiously to stepping out confidently. Stepping out cautiously occurs when there is limited confidence in extrapolation from the available observations, for example when persistent slab instabilities are becoming less easily triggered and for large storm instabilities in the early stages of recovery. Stepping out confidently occurs when one is confident to extrapolate from the available observations.	Stepping out occurs when you are confident that your core terrain is mitigated to your best ability and you want to expand to your secondary terrain. Once you feel that you understand the avalanche problem(s) of the day, you may start opening new terrain, terrain that has been temporarily closed, or terrain where avalanche control results have successfully mitigated the hazard. Lack of skier traffic/mitigation measures may have affected this terrain in a different way and may warrant a different approach than the core terrain that has seen continuous avalanche hazard reduction.
Status Quo	There is no substantial change in conditions or in the hazard assessment. The evidence continues to support operating as before and the comfort level for exposure under these conditions has been reached.	Change nothing and continue operating as before. Remain vigilant for subtle changes in weather and snowpack conditions.
Stepping Back	Weather changes increase the hazard or when events or observations cause uncertainty about the validity of the existing assessment. A small step back may result from minor or subtle weather changes while substantial weather events or observations of unexpected avalanches may result in a large step back.	The typical strategy when stepping back is to close terrain that has become suspect based on weather changes or evidence that creates uncertainty. Stepping Back may be planned as a storm increases in intensity, or unplanned if timing or intensity is unexpected.
Entrenchment	Dealing with a well-established persistent instability. Entrenchment is not a preferred operating mode and requires discipline to sustain it for the necessary time; this is the last resort short of closing operations completely.	Avalanche hazard reduction is applied methodically and well documented. Any change in weather conditions is assessed for its potential impact on open and closed terrain. Closed terrain may still be mitigated during these conditions if they can impact open areas. Traditional safe zones may not be appropriate during these conditions.
Free Ride	The hazard assessment suggests that only small avalanches are possible in very isolated terrain features, and there is a high degree of confidence in the hazard assessment.	Any skiable terrain may be considered with due attention to the possibility of small surface avalanches. Small hand charges and slope cutting are the primary assessment and mitigation tools during these conditions. Access to adjacent backcountry areas may be opened.
Maintenance	Just prior to or just after the arrival of a storm system when the hazard has not yet increased significantly.	Mitigation is focused on maintaining skier traffic to disturb the storm interface and reduce the need for future closures and control work. Carefully monitor the terrain for indications that the hazard is increasing and requires stepping back and closing terrain.
High Alert	Unusual avalanche conditions resulting from large storms and/or problematic persistent weak layers create the potential for avalanches to exceed historic extents or to occur in terrain that is historically not hazardous.	Extend closures as needed to areas that are not regularly closed and consider evacuating facilities that might be threatened. Maintain closures longer than usual and consider control work in terrain where it is not usually required.
Spring Diurnal	The hazard assessment suggests that the only substantial hazard is from wet loose avalanches during the afternoon thaw phase of the diurnal freeze-thaw cycle.	Watch closely for adequate overnight freeze and consider closing avalanche terrain during the thaw phase of the cycle. Mitigation success is strongly 'timing dependent.'

Authors: *Don Carpenter, Sarah Carpenter, Jake Hutchinson, Don Sharaf, and Roger Atkins with input from Pete Earle and Andy Lapkass*
History: *Used on AAI courses for past three seasons—enough people have been asking about it that it was time for a broader review.*
Main Differences from Roger's original framework: *a couple of different names (Free Ride vs Open Season), Assessment/Season Opening (note: this is NOT Open Season—big difference!) High Alert is a new category but worth consideration for guiding operations as well. Maintenance is also a new category.*
Typical conditions are not significantly different from his original table in Yin, Yang, and You *ISSW 2014, but the Operating Strategies are significantly different.*

G) Guidance

Knowledge, the Curse of the Expert

BY JERRY ISAAK

> Anyone who wants to lift the curse of knowledge must first appreciate what a devilish curse it is. Like a drunk who is too impaired to realize that he is too impaired to drive, we do not notice the curse because the curse prevents us from noticing it.
> *—Steven Pinker, Professor of Psychology, Harvard University*

It seems intuitive that the most knowledgeable individuals would be the best possible instructors. Yet, if that is true, why does it sometimes seem like experts have difficulty conveying their hard-earned knowledge to novice learners?

On January 19th, 2019 I entered my first *Oodarysh* (horse wrestling) competition. It took place in the community park of a small, ethnically Uzbek village situated high in the Babash Ata Mountains of southern Kyrgyzstan. I was definitely a novice. The object of *Oodarysh* is to pull your opponent off their horse without being pulled from your own horse. To picture the scene, think Genghis Khan meets WWE on horseback in a snowy field surrounded by an audience of hundreds of shouting, cheering locals. Add in the blaring sounds of traditional Uzbek horns and drums and a play-by-play announcer on a feedback-prone Soviet-era microphone. Turn up the volume. Those are the primary elements of *Oodarysh* (as well as every truly great party in central Asia).

Since this was my first match, I needed significant coaching if I was to have any chance of winning. So, before the match I sought out advice from the most expert people I could find. It seemed to me that I could learn most effectively from the top-rated competitors. My impromptu coaches were experts at the game and eagerly gave me large volumes of information. Unfortunately, I quickly became overwhelmed and could really only remember, "Don't let him pull you off!" and "When you grab on to him, pull him off his horse!" I also remember receiving oddly detailed instruction on precisely how high to adjust my outside stirrup. It was all well-meaning advice intended to help me survive the match, but I struggled to understand how all that expert advice would fit together in a winning combination. I wasn't able to process the knowledge of the experts.

In the context of instructing novices, the experts' knowledge seemed like more of a curse than a gift. Researchers and authors Dan and Chip Heath describe this "curse" in their book *Made to Stick,* "Once we know something, we find it hard to imagine what it's like not to know it. Our knowledge has 'cursed us.' And it becomes difficult for us to share our knowledge with others, because we can't readily re-create our listeners' state of mind."

If you are like me, you have experienced this curse both as a novice learner and as an expert instructor. The majority of TAR readers are experts in avalanche safety and education, especially when compared with the general population of the United States. In particular, students in recreational avalanche education courses are novices and the instructors are experts. If you are an avalanche expert who is interested in more effectively passing on your knowledge to novices, this article is for you.

The difference between novices and experts

Novices and experts are clearly different. The obvious difference between the two is a gap in experience and skills. Experts have more of both. However, the more fundamental and frequently overlooked difference is that experts engage differently with foundational knowledge. According to Adult Learning Advisor and Coach Rebecca Wallace, "Novices deal in explicit knowledge, facts and information, which is easy to talk about—know-what. But experts deal more in tacit knowledge. The sum total of what they have learnt from experience, formal and informal learning, which is hard to articulate—know-how." This distinction between novices and experts may sound familiar to readers of Iain Stewart-Patterson's article *Avoiding the Illusion of Validity* (TAR 34.4, April 2016). In that article (based partly on his PhD research on the role of intuition in expert decision makers) Iain highlights that "Experts typically make rapid, good decisions based on situational awareness and pattern recognition. They use a high quality mental model as a bridge between the current situation and a previously experienced pattern. Have I been here before? What did I do and did it work? If I am wrong, how will I know?"

The experts' mental model, based on tacit knowledge, contrasts with the explicit facts and information that are relied upon by novices. This distinction can create difficulty for experts when attempting to communicate their decision-making process with novices, resulting in the seemingly incongruent curse of knowledge.

Left: Jerry Isaak in his first Oodarysh match.
Right and opposite: SUNY Plattsburg Expeditionary students gain on-the-ground experience in Kyrgyzstan to match their classroom learning.
Photos Jerry Isaak

The rest of this article focuses on how expert instructors can break the curse of knowledge and create more effective learning environments by:

- Focusing on what people need to do, not what they know.
- Providing context before giving detail.
- Making ideas, theories and abstract statements accessible with examples.

Symptoms of the curse

(Based on Wallace's article *Curse of Knowledge: why experts struggle to explain their know-how*).

Symptom number one:
The hit-and-run information dump.

"It's like drinking from a firehose." That's how students of content-rich courses often describe their first few classes. Unsurprisingly, I've heard the phrase used to describe introductory avalanche education courses. Expert instructors want to be helpful and can be tempted to focus on sharing as much knowledge as possible with students in their allotted time. This leads to a *hit-and-run information dump* of the type where students might be introduced to nine classes of snow grains, eight avalanche problems, five snowpit tests and the entire metric system on the first morning of a recreational avalanche course. These topics are fundamentally important to the subject of study but the volume of information can become overwhelming for novices, especially outside of a specific context.

The cure to symptom number one: Focus on what people need to do, not what they know.

The most important element of every forecast based on the North American Public Avalanche Danger Scale is not the Danger Level. Public knowledge of an avalanche danger rating of *Extreme, High, Considerable, Moderate* or *Low* is just not that important. It is the corresponding *Travel Advice*, aimed at what people actually **do**, that is essential. The same distinction between knowledge and action holds true in avalanche education. What people will do is far more important than what they know. Wallace writes, "Experts often value their knowledge for its own sake. But this isn't about what they know. It's about supporting others to do things differently. And what people need to do sets clear parameters for what experts do and don't share." When instructing an avalanche class, try organizing your lesson plans around the following three questions:

1. What does your audience need to do?
2. What information do they need in order to take this specific action?
3. Can they take action without that piece of information—if yes, cut it.

Symptom number two:
Diving straight into the nitty gritty.

Avalanche education is a big, complex subject that can quickly be narrowed down to the size of a single snow grain or the number of taps in a compression test. Details matter, which is why experts emphasize them. However, without the frame of a particular context, details can be bafflingly dense to novices. Before my *Oodarysh* match I couldn't understand why my outside stirrup needed to be so high. It was undoubtedly important, but I didn't know why it mattered.

The cure to symptom number two:
Provide context before giving detail.

Wallace recommends, "To steer experts away from a detail tsunami use a painting metaphor. The big picture matters. Because diving into details like composition and palette is meaningless if you haven't first seen the whole landscape or portrait." For instructors of avalanche education courses, this requires that they encounter terrain and avalanche problems together with students and engage reality rather than hypothetical situations. One implication of this practice is that not all topics will receive equal treatment. Although eight avalanche problems could be introduced in a class, they are unlikely to all be encountered in the field during a single weekend, or even a single season. Make it clear to students that the contexts (of terrain + avalanche problems + people) are gradually built up over time to create the pattern recognition and mental models used by experts.

Symptom number three:
Speaking another language: Expertese.

Technical language can be a surprising barrier to knowledge. Although precise terms (what Wallace calls "Expertese") allow experts to communicate more fluently with one another these terms may actually obscure meaning for novices.

For example, cornice is a word describing an overhanging ledge of snow. Students are taught that cornices are formed by wind transporting snow onto the downwind side of an obstacle, typically a ridge. The image of a cornice appears instantly in my mind when I hear or use the word. Though rather than a single specific image, I recall many cornices I have encountered over years of winter travel, akin to the sum total of cornices I have seen. Until recently, I didn't think of cornice as a technical term, but as a descriptive one like apple or orange.

However, consider the perspective of novices, students of mine who completed their recreational level one course last winter. This January, during a university-based backcountry skiing class we ascended a low angle gully to gain a nearly flat ridge on which we would skin about 300 meters to a summit. At the top of the gully I asked the students if they planned to proceed along the ridge to the summit. They looked at me in horror as though I had suggested going skydiving without a parachute. "There's a cornice!" one student said, incredulous that I would even suggest something so dangerous. Technically, the student was correct. Wind drifted snow had extended over the ridge on the downwind side. Calling it a cornice though would be like calling a thirteen year-old boy's peach fuzz a handlebar moustache; it's the same growth process but hardly the same result. This was a peach fuzz cornice, not Tom Selleck's Magnum, P.I. moustache, but my students couldn't tell the difference. They knew the definition of a technical term, in this case a cornice, but didn't have the experience necessary to create a mental model when they encountered one.

The cure to symptom number three:
Make ideas, theories, and abstract statements accessible with examples.

My students had seen pictures of cornices in class and could describe what they looked like. However, they needed multiple examples, ideally experienced in person, in order to begin creating effective mental models. In order to help novices gain fluency when introducing ideas, theories, and abstract statements, use multiple examples or better yet, take students with you to experience these concepts for themselves.

Lifting the curse

In order to succeed at horse wrestling, or at least not get badly hurt in my first match, I needed to learn what to do, in that particular context, and I really could have used an example of how to do it. In the end I was matched up against one of my college students who, luckily for me, was even more of a novice. Judging by the cheers (and laughter) of the crowd, our attempts to unhorse each other were highly entertaining. I won a narrow victory in round two and was rewarded with a prize of 700 Kyrgyz Som as well as a memorable lesson about teaching, learning, and the curse of knowledge. ▲

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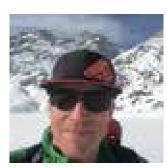

Wise Ones—Conversations With the Prominent Mentors of the U.S. Avalanche Industry

BY ALEPH JOHNSTON-BLOOM AND EEVA LATOSUO

There aren't enough days in the winter or winters in your career to see it all yourself and figure it out. The volume of decisions we have to make, relative to the amount of feedback that we get, is just incredibly out of whack. I think that being able to get insight from other people that have been doing it for a long time and learn their own lessons is really critical.

—Henry Munter

Mentorship is referenced as a crucial part of knowledge exchange and professional development in the avalanche industry. In mentorship, a mentor, a more experienced person, passes on the knowledge and expertise onto a newer or less experienced person, the mentee. Mentoring is often described as a long-term mutually beneficial relationship, different from teaching or coaching. In 2016 Eeva Latosuo, Lynne Wolfe, and I surveyed the members of the American Avalanche Association, confirming the high value placed on mentorship within avalanche professionals in the US. Latosuo et al (2016). While four hundred people were listed as mentors, the top mentors were referred to very frequently. These individuals have impacted a relatively large number of other professionals with their willingness and ability to share their professional expertise. Last summer Eeva and I conducted a set of 11 interviews that explored the how and the why of mentorship values that are being passed on between the generations of snow professionals in the US.

Based on the list of most frequently mentioned mentors within the US avalanche industry (Johnson et al 2016), we contacted eight current and retired avalanche professionals about participating in an interview. One individual declined. In addition, we interviewed four individuals that the mentors had identified as mentees that were also referenced as other professional's mentors. Interviewees were clustered in geographical regions of Idaho, Wyoming, Utah, Colorado and Alaska. (Table 1). Interviews were conducted July 13-30, 2018, and recorded digitally. Audio recordings were transcribed into text files and analyzed for content by the authors. The methodology was approved by Alaska Pacific University Institutional Review Board for ethical research of human subjects. All the interviewees gave consent to use their actual names in the research report. Structured interviews covered three main themes in ten questions. Interviewees were given the questions prior to the actual interview via email that included a pre-interview questionnaire. The first theme was the individual's history with mentorship, the second theme was the value of mentorship in professional development, and the final theme was the impact of mentorship on risk management and workplace safety. We also allowed for open conversation on spontaneous content about mentorship during the interviews.

Despite the generally recognized prevalence of mentorship in the avalanche industry, the definition for mentorship varied among the interviewees. During four of the interviews, we spent time discussing the boundaries between mentorship, coaching, teaching, training, guiding or being a role model. Lack of industry definition for mentorship muddles the views of being a mentor or a mentee. Similarly, the majority of workplaces do not have formal mentorship programs, which leaves organically formed mentoring relationships the norm.

He was one of my original interns. So yeah, it was kind of an interesting thing. I was asked by one of the professors up at the university [Montana State University] to give a talk to her mountain weather and climate course about avalanches and avalanche forecasting, and I did. And then this 18-year old kid comes up and goes, "I want to do that. I want to be an avalanche forecaster." And I said, "Well, that's great, 'cause I just started this Avalanche Center, and I need some interns.

—Karl Birkeland, National Avalanche Center Director, talking about Ethan Greene, Colorado Avalanche Information Center Director

The 11 interviewees were a broad cross section of professionals covering many sectors of the industry: backcountry avalanche forecasters, railroad forecaster, ski patrollers, mechanized guides, backcountry guides, academics, avalanche educators and avalanche center directors. They all shared the nuances of how their mentor and mentee relationships were formed spanning a time frame from 1970s to the present. In the 2016 survey conducted by Latosuo et al, mentorship was most often initiated by mentor, while mentees were initiators in a 26% of all professionals surveyed. This was noted as an important result because of the often-used directive "Find a mentor." Through our interview process we delved deeper into this, asking each person about the initiation of their mentor/mentee relationships and whether or not becoming a mentor was a conscious decision. Answers varied across the interviewees. Amongst the interviewees the mentor being the initiator was the case for over half of the mentor/mentee relationships described. Organic or symbiotic formation was reported in several of the relationships. There were two mentor/mentee initiations that were unique. Dave Hamre hired one of his mentors, Art Mears, and Don Sharaf's NOLS student Ian McCammon became his mentor. Workplace structure and being a supervisor was referenced in half of the mentor/mentee interviews as the reason the they stepped into the mentor role. Many illustrated their experiences with stories of snow safety directors moving through terrain talking about snow to new inquisitive patrollers and snow rangers reaching out to young patrollers and or brand new forecasters to provide guidance and lead heli-guides recognizing potential in young fuelies or aspiring guides. Many talked about not necessarily consciously choosing to be in the mentorship role but that were so appreciative of their own experiences that they realized the value of being a mentor to the next generation. Mentors spoke of recognizing the intellectual curiosity of the individuals that they were initiating a relationship with, consciously making time to answer questions, seeing passion in someone and deciding to invest in them, wanting to provide them opportunities, and trying help mentees connect with other people in the community.

You want to be like them if you're the mentee or you think, "I see something of value in this person," if you're the mentor. It starts as maybe a conversation after class or it starts with you going touring when you think to yourself, "This person is asking really good questions. How can I prompt them to ask even better questions?"

—Lynne Wolfe

Art Judson was the person that I had met some months before I was hired in 1970, and he became my original mentor, and was quite good in teaching me—someone who didn't know an avalanche from a snowball—what the game was all about, what my role would be, and so got me started.

—Knox Williams

While the avalanche industry has changed dramatically in the last five decades, mentorship as a professional development tool has kept its high value. In the early stages of career, it helps professionals to gain knowledge and skills as well as confidence for making decisions. A majority of the interviewees gave vivid examples how the field time with their mentors had taught them valuable lessons on terrain management, risk mitigation techniques, and avalanche mechanics. Several interviewees shared the view that becoming an avalanche professional requires robust and multifaceted continued education, but there are no clear pathways for that. Mentorship can be a way to gain the necessary competencies. Wendy Wagner stated that without mentorship, she would not have become an avalanche professional despite her graduate degree in the appropriate field of study.

Mentors	Interviewee	Mentees
Art Judson Ron Perla Ed LaChapelle	KNOX WILLIAMS	Nick Logan Dale Atkins Scott Toepfer
Binx Sandahl Ed LaChapelle Art Mears	DAVE HAMRE	Henry Munter Mike Overcast Ted Steiner
John Montagne Gene Urie Knox Williams	KARL BIRKELAND	Ethan Greene Ron Simenhois Doug Chabot
Sandy East Karl Birkeland Tom Kimbrough	ETHAN GREENE	Ian Hoyer Scott Savage
Ian McCammon Jake Hutchinson	DON SHARAF	AJ Linnell Matt Bohne Dan Corn
Jon Ueland Ethan Greene Karl Birkeland	SCOTT SAVAGE	Nick Armitage Ethan Davis Chris Lundy
Rod Newcomb Don Sharaf Janet Kellam	LYNNE WOLFE	Jaime Musnicki Scott Palmer Robby ReChord
Tom Kimbrough	DREW HARDESTY	Wendy Wagner Ian Havlick
Tom Leonard Dave Hamre Janet Kellam	HENRY MUNTER	Mike Welch Rich Petereson
David Lovejoy Lynne Wolfe Jerry Roberts	CHRIS MARSHALL	Andrew Kiefer Nils Meyer
Drew Hardesty Brett Kobernik Jake Hutchinson	WENDY WAGNER	Ian Havlick

Interviewed avalanche professionals (in orange boxes) listed in order of their earliest mentorship experience. The top boxes indicate the interviewees' mentors, bottom boxes indicate the interviewees' mentees.

Becoming a professional lineman or an electrician or a plumber you're looking at a 4,000-hour apprenticeship. Throughout that you have formal classes, you have examinations, a lot of on the job training. Then you become a journeyman and with another 4,000 hours of apprenticeship you get to the master process. For better or worse, we're looking at a profession with 13 days of formal training. That's a different model and our profession may be more risky than plumbing. I'd say that mentorship is crucial where formal training is quite short and finite.

—Don Sharaf

Four interviewees shared that their avalanche mentors also offered broader perspective for human nature and navigating life in general.

[Tom Kimbrough's] mentorship conveyed something about who we are in our communities and what role that we play in them. That our profession is not a game but to be taken very seriously in so far as that the line between joy and death are very closely interwoven within our profession. It was less about the mechanics of snow or less about messaging per se but more about the life and the sort of philosophy of forecasting.

—Drew Hardesty

In the advanced career stages, participating in mentorship helps the experienced professionals stay relevant and informed, even learning new hard skills, but in addition, many shared the motivation to help newer professionals to succeed in their jobs.

This is much a matter of ethics as anything for me. I recognize the fact that there was this person that invested in me, and spent their time to help me along, and I feel that's an obligation within our field, because it's really one of the few ways that you can. There's a lot more information avenues than there used to be, but it still doesn't substitute for working with somebody that has a lot of experience and learning from them. I have an obligation to contribute to others' success in the field.

—Dave Hamre

Yeah it gets harder when you run out of coaches. You want people to bounce ideas off of and when people are always coming to you for the answer then who do you go to?

—Don Sharaf

A key benefit of mentorship relationships is the establishment of direct communication lines between professionals. All the interviewed people appreciated the ability to have people "on speed dial" to go with questions and concerns or just to talk shop. Henry Munter gave an example on how much he values learning from Tom Leonard about legal side of avalanche business, "the dirty underbelly of what we do"; high quality expertise in legal matters is limited to those professionals who have real-life experience in it.

I still will use a lot of folks just as a sounding board because they can provide me really useful information about whether or not I'm really on the right track or not with different things.

—Karl Birkeland

In the early career phase, interviewees would seek out more experienced people to find answers to particular questions, but often these relationships develop into peer-to-peer support, where the person with questions and the person with answers would fluidly change in the conversation depending on content. Several of the interviewed professionals emphasized the openness for dialog "whether it be seeing things similarly or having different opinions on things" as Chris Marshall framed it. Mentorship clearly supports strong collegial collaboration and creates high-functioning professional networks.

Having those kind of career-long connections with other people and with the way that you can share information and just talking to people who live in different climates, snow climates and different operations and have these different perspectives, that's more valuable to me than people who are in the same place doing the same thing that I am.

—Scott Savage

We used the interview data to visualize the clustering of interactions between this group of prominent avalanche professionals (Figure 1). Some of the mentorship relationships are anchored in certain geographical region, i.e. Knox Williams in Colorado, but some of the relationships extend beyond states and regions, i.e. Ethan Greene's connections with Montana, Utah, Colorado, and Idaho. It is worth noting that this project did not illustrate the true impact of the early Forest Service

Top: Henry Munter coaching Chugach Powder Guides crew before loading with clients. *Photo Munter collection*

Bottom: ISSW provides invaluable time for us to connect with our mentors: left to right around the table: Blase Reardon, Rod Newcomb, Tom Kimbrough, and Ron Matous. *Photo Lynne Wolfe*

Snow rangers and snow researchers who have a big legacy in the 1970s and prior.

All interviewees agreed that their mentors had at least some influence on their risk management practices, while several did state that they definitely have their own individual risk tolerance as a particular starting point. Chris Marshall discussed how all three of his mentors instilled in him a conservative outlook and respect for the mountain travel; without having their influence, he would have fostered a different attitude as an upcoming ski guide. He shared a gem of a phrase from Lynne Wolfe that allows him to pause when making decisions; "Differentiate between what one wants to do and what one ought to do."

While the simplest examples of mentor influence included experienced pros demonstrating a safe way to complete a control route at the ski

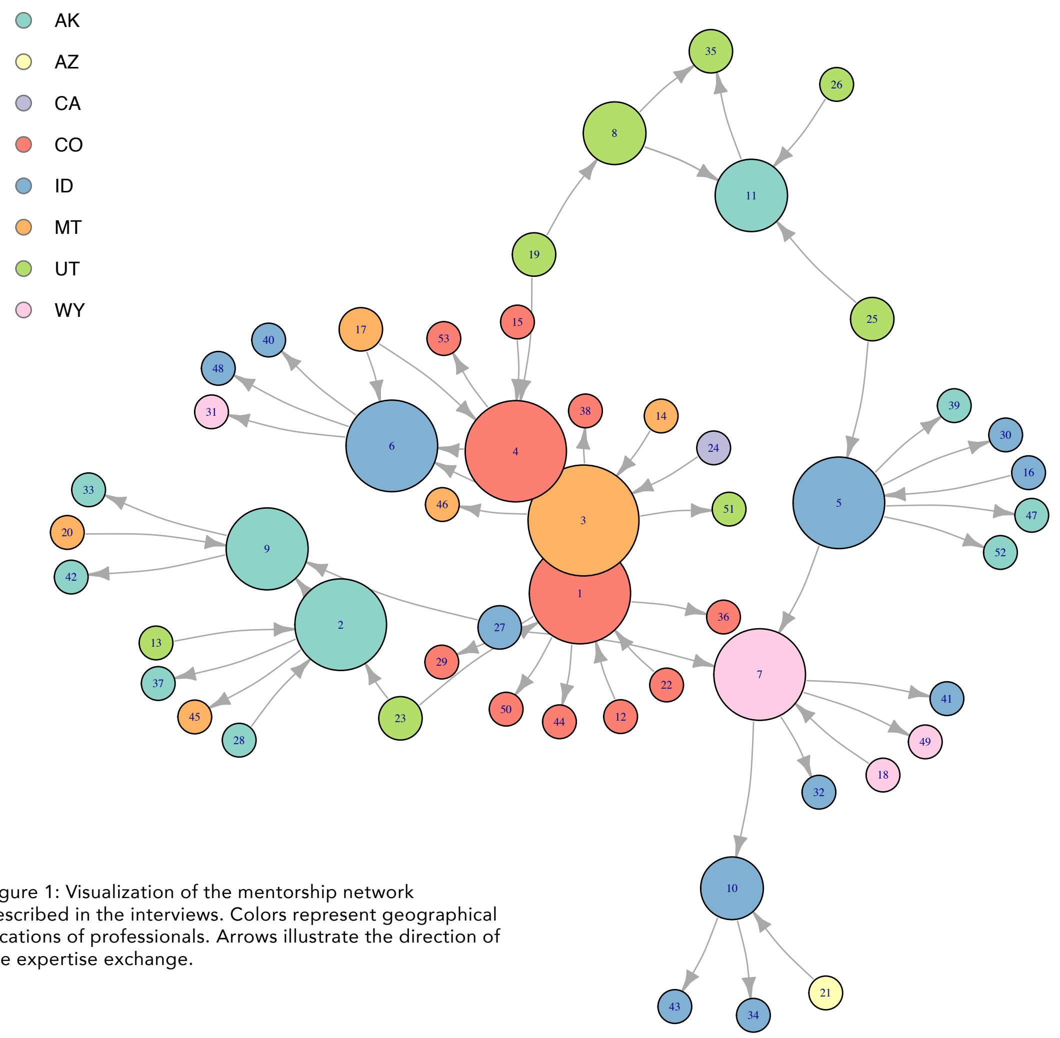

Figure 1: Visualization of the mentorship network described in the interviews. Colors represent geographical locations of professionals. Arrows illustrate the direction of the expertise exchange.

area, the more nuanced cases described surprising close calls in the field. Ethan Greene's mentors influenced the formation of travel habits that have stuck with him for decades; Wendy Wagner had a close call from her first season touring with her mentors that still impacts the way she approaches travel. Interviews repeated stories about exposure to practices and intentional conversations about day's events. Beyond sharing experiences, one of the important job of mentors is giving continued feedback on how to improve practices.

It's really important for people to get to be watched in their job and receive feedback, and, on the other side of that coin, for the people that go out into the field to come home and ask whether they did things right, or if there's a better way to do it. Just sort of sharpen the pencil on if we're actually doing a good job out there or not.

—Henry Munter

Several interviewees brought up the trust between mentor and mentee. David Hamre explained how, being a snow safety director, you will assign several teams out running routes and each one of those routes has to be done right.

"So you have to have faith that those people do their job and not carry a bunch of uncertainty about it." Lynne Wolfe approached the trust from a different perspective. "When there has been a mistake, we all feel vulnerable, but a mentor can provide a safe place to process and learn from the events. Numerous mentors have role modeled the transparency of mistakes and humility."

A huge lesson that I learned from my mentors is their forthcoming nature and their humility in being in the field and knowing that they don't know everything.

—Wendy Wagner

[on Jon "Yunce" Ueland] His overriding ideology was, "Okay, let's hang out our dirty laundry for everyone to see" He had that thick skin and was comfortable in his own shoes being able to talk about things like that in front of a group.

—Scott Savage

Many mentorship conversations continue to revolve around the concept of dealing with uncertainty, the pesky characteristic of avalanche field that can cloud even most confident decisions. Don Sharaf's mentor, Ian McCammon, was among the influential people who transformed the avalanche discourse to include the idea of uncertainty. "Even if you understand where you went wrong previously, it doesn't mean that you're not going to make different mistakes in the future. And it's too complex a situation to be living on the edge of our risk envelope all the time."

This project documented and visualized an example of the interwoven network of avalanche professionals spanning from 1970 to 2018 across the Western United States. The eleven interviews with prominent avalanche professionals who have engaged in mentorship as part of their professional development has helped describe the how and why of mentorship within avalanche industry in the United States. The minimal professional training to become an avalanche practitioner is balanced out by organic and informal conversations with supervisors, peers, and novices. Mentors help the newer professionals get up to speed with their roles and responsibilities, as has happened at least for five decades. Tapping into experience sharing over regions and generations improves a professional's ability to complete their job with improved efficiency and better understandings. Mentees help sustain the curiosity and intellectual engagement in the seasoned experts. In the end, mentorship facilitates collegial communication and builds high-functioning professional networks.

I guess one of the things I'd say about mentorship is that if there are folks out there that want to be mentored, the best thing to do is to be persistent when they're approaching people they want to mentor them, 'cause everyone's really busy, and they might not respond right away. And also, probably be respectful of the fact that they're busy and sort of be prepared, too.

—Karl Birkeland

Everyone in our greater profession should consider, ask themselves who have I mentored and who has mentored me and to think who might I reach out to on both sides of the coin. I think it only further strengthens the fabric of our community but also is in a way of giving back along the arc of your career.

—Drew Hardesty

Acknowledgments

We would like to thank the following:

- 11 interviewees; we are so honored.
- Participants in the original 2016 study
- The American Avalanche Association for permission to approach their professional members
- Friends of the Chugach Avalanche Information Center for sponsoring the professional transcription services
- Rachel Newell for helping to visualize the network of our data using R.
- Avalanche professionals who contributed to numerous conversations about the topic over the years
- The Snow Ranger program of the 70s that influenced this wild profession ▲

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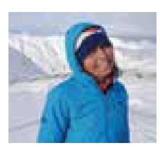
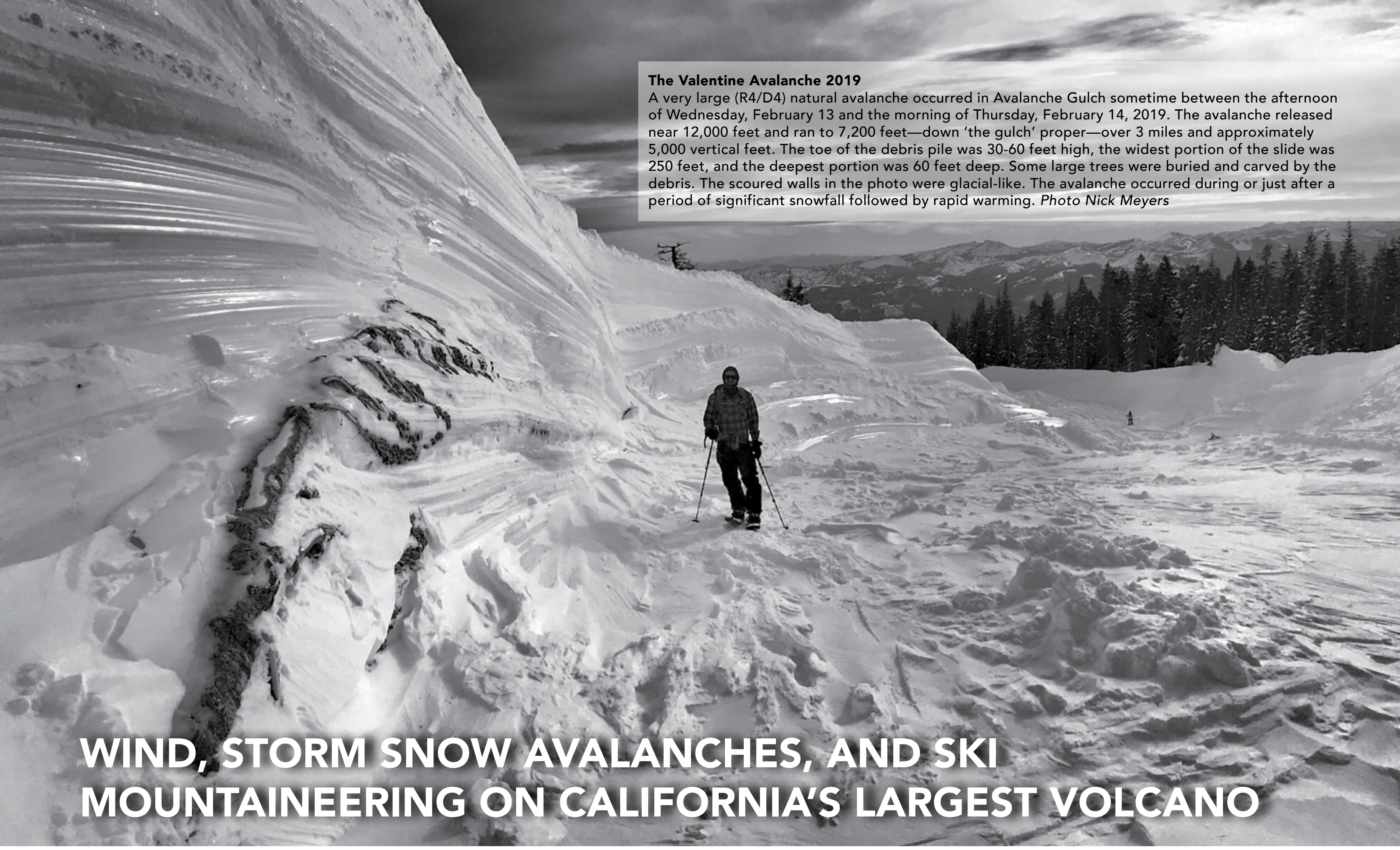


Eeva Latosuo is a full time faculty at Alaska Pacific University where she has an opportunity to exercise both hemispheres of her brain. Without the input from her mentors, Don Sharaf, Nancy Pfeiffer, and Paul Brusseau, her synapses would be firing differently in the avalanche domain.

Aleph Johnston-Bloom is an Avalanche Specialist for the Chugach National Forest Avalanche Information Center in Girdwood, Alaska. Conducting these interviews was a highlight of her summer. She would like to dedicate this article to David Lovejoy, Jerry Roberts, Andy Gleason, and Pat Ahern for their important mentorship.



The Valentine Avalanche 2019
A very large (R4/D4) natural avalanche occurred in Avalanche Gulch sometime between the afternoon of Wednesday, February 13 and the morning of Thursday, February 14, 2019. The avalanche released near 12,000 feet and ran to 7,200 feet—down 'the gulch' proper—over 3 miles and approximately 5,000 vertical feet. The toe of the debris pile was 30-60 feet high, the widest portion of the slide was 250 feet, and the deepest portion was 60 feet deep. Some large trees were buried and carved by the debris. The scoured walls in the photo were glacial-like. The avalanche occurred during or just after a period of significant snowfall followed by rapid warming. *Photo Nick Meyers*

WIND, STORM SNOW AVALANCHES, AND SKI MOUNTAINEERING ON CALIFORNIA'S LARGEST VOLCANO

BY SHANE RATHBUN

Successive eruptions of hot ash and magma have created layer upon layer of lava-carved plains below the massive stratovolcano that is Mount Shasta.

Shasta is perched 200 miles north of the Tahoe Basin and approximately 60 miles south of the Oregon border; it is the second tallest peak in the Cascade Range and there is no other mountain like it in California. At 14,179', the summit is guarded by large bands of pumice cliff and basalt gendarmes. As a result of violent winter storms, these rocks become plastered in twisted gargoyles of wind-sculpted rime ice that stand watch over the mountain like a gothic cathedral. The solitary nature of the mountain in the atmosphere creates unique orographics with high wind speeds.

With a vertical drop of more than 7000' off the summit in every direction and easy-to-navigate glacial terrain, Shasta offers more classic ski descent options than any other peak in the range. However, timing your ski descent off the upper mountain in ideal conditions can be tricky.

The wet season begins in October. Above 8000', thick stands of mixed conifer forest give way to an exposed alpine environment where significant snow accumulation can occur. As winter begins, the rugged volcanic landscape begins to change shape under a blanket of new snow. Rock anchoring become less effective. Eventually, large planar slopes develop, creating ideal bed surfaces that circle the volcano. This transformation process, to what Muir described as "the great white Shasta cone," can happen during one storm.

One tropical storm after the next, moisture-laden air is funneled north through the narrowing Sacramento River canyon until it violently impacts the mountain's south side. Above treeline, powerful wind creates widespread loading and deep wind slabs. Failures occur in non-persistent layers or at the old snow interface. Persistent weak layers are uncommon. These slides can be highly destructive and often run for long distances. Historically large events have even stopped a ski area from operating above treeline. When it finally stops snowing, wind and temperature fluctuations mean that the consolidation process happens quickly. Rapidly consolidated new snow becomes the bed surface for the next round of storms and the process repeats itself. It's not uncommon to find the winter snow surface above treeline overlain by sastrugi and frozen crust that can make uphill travel with climbing skins nearly impossible.

Winter ski descents from the summit are rare, but not unheard of. A complete descent in cold powder snow is even more elusive. New snow above treeline becomes wind affected quickly. Watching the forecast for warm weather is the most reliable approach to plan a descent from the upper mountain. During the winter, small warming anomalies offer a short window to ski soft snow near the icy summit before the arrival of spring. This type of weather window can arrive as little as once per month and sometimes will last just a single day. Steep and icy faces on the upper mountain will soften on south aspects as they are more directly exposed to the sun's low position in the winter sky. Look for a day when an upper level ridge is centered over northern California with a forecasted 700mb temperature of at least 0ºC and no wind. Timing can be tricky but if conditions align, you'll likely have the entire mountain to yourself.

Mount Shasta is a mecca for spring skiing. As spring rolls around, mountaineers, skiers, and guides all flock to the area. The mountain's southern latitude means the spring weather is generally stable in comparison to the other Cascade volcanos. With the transition to spring in April usually comes the beginning of a legendary corn cycle. As the freezing level begins to rise, sunny days and mild temperatures mean the timing for a ski descent becomes more predictable. Weather windows become more frequent and sustained. Reliable California weather between intermittent spring showers also affords the best opportunity to ski high density powder snow at upper elevations.

As April turns to May, precipitation becomes less frequent. Wide open faces and chutes abundant around the mountain begin to soften in the sun at all elevations. A strong melt-freeze cycle creates a smooth and flawless snow surface for thousands of vertical feet. Loose wet slides become more common. Rime covered rocks on the upper mountain begin to shed their winter coat. Pellets of melting ice and loose volcanic rock rain down on the slopes below. Falling debris poses a significant hazard and is critical to anticipate with the timing of your climb. However, this risk can certainly be worth the reward. To this day, I have not yet experienced better quality spring skiing than the corn snow found high on Mount Shasta.

The perfect combination of a deep maritime snowpack and warm sunny days keep the ski season often going strong into July. As spring gives way to summer, more desirable conditions are found on the sides of the mountain less directly exposed to the sun's increasingly high position in the sky. The window for perfect snow from top to bottom becomes smaller and more difficult to obtain as heating becomes more rapid and intense with each new day. Like skiing anywhere in the world, timing on Mount Shasta is everything. Get it right and the mountain will provide you some of the best spring conditions the Cascade volcanoes have to offer. ▲

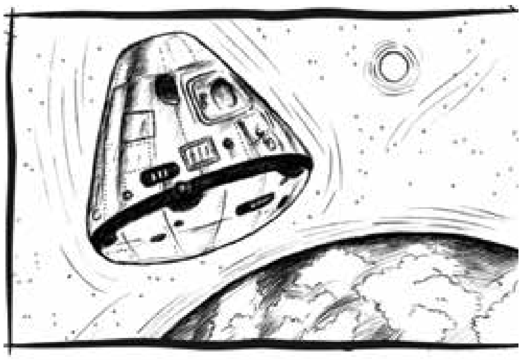
Shane Rathbun is a native of northern California who grew up mountaineering and learning about snow while skiing in the backcountry around Mount Shasta. He works as the the Snow Safety Director at the Temple Basin Ski Field in Arthur's Pass National Park, New Zealand.

O'BELLX

Where did the design come from?

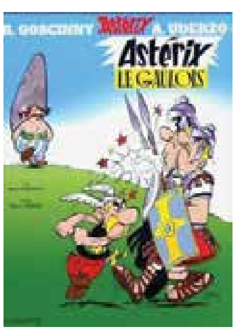
BY DALE ATKINS

Not sure about the inspiration for the design of the O'Bellx. It's kinda Jettsons-like looking, or maybe it's based on the design of an old beauty salon hair drier, or the Apollo Command Module, or maybe from the W German winner of the luge at the '76 Olympics, or maybe the design is based on the motorcycle helmets worn by the Coneheads in their 1993 movie.



From TAS: Inspiration for the O'BellX® name comes from the French comic book "Asterix," created in 1959 by Mr. Goscinny & Mr. Uderzo.

Obelix is Asterix's best friend who fell into a magic potion in his youth; he has amazing strength and he can carry a menhir (big standing stone) on his back. As our gas system looks like the menhir of OBelix, we gave it the "O'BellX®" name. The name also includes the "O" from Oxygen gas, the "Bell" where the two gases are mixed (same as our "DaisyBell" mobile heliported exploder), and finally the "X" of "eXplosion!"



O'BellX® (TAS / MND America) is the latest generation of gas RACS (Remote Avalanche Control System), installed on its foot on the top of dangerous avalanche paths and removable with a single helicopter rotation. The hydrogen/oxygen gas mix explosion is the most ecological way to currently trigger avalanches in the US (CDOT, Alta, Snowbird, UDOT, WyDOT) and worldwide.

MONTANA AVALANCHE INFORMATION CENTER EXPANDS TO SOUTHWEST MONTANA

BY ZACH GUY

The Montana Avalanche Information Center (MAIC), based out of Whitefish, MT, recently announced its plans to begin forecasting for Southwest Montana. The avalanche center will be expanding its forecast boundaries to include the mountains around Bozeman, including the Absarokas and Crazy Mountains.

"There's a real need for quality avalanche forecasting in those areas," said MAIC Director Zach Guy. "...an outcry from the public." The MAIC will be issuing daily avalanche advisories for the Gallatin, Bridger, Madison, Absarokas, Crazy, Lionhead, and Cooke City areas starting next November. The center plans to utilize some of the resources already in place in the Bozeman area, such as the Gallatin National Forest Avalanche Center (GNFAC). "I'm no stranger to overlapping forecast centers and duplicating resources if the need arises," said Guy, who previously served as the director for a small avalanche center in Crested Butte, CO. "My former forecast center in Crested Butte did all the hard labor on nickels and dimes, but we shared all of our data to the CAIC for their forecasts. I'm sure the GNFAC will happily do the same. They have some great field workers, guys like Doug or Eric or Alex, and I'm looking forward to working with them. Solid intern potential."

Chabot says, "We are super excited to work with Zach. Ever since he came to the state he's been pushing for an administrative position. Snowmobiling and skiing are not his strong suits. We are looking forward to abdicating all our administrative and office tasks, including the advisories to someone more dedicated to the computer. We'll continue to be the field experts. It's a win-win."

Simon Trautman, a specialist with the National Avalanche Center, applauded the move. "The GNFAC has been doing a good job of holding down the fort for the time being, but their forecast center doesn't seem to have an understanding of avalanche problems. Montanans have always been a little slow, but its time they caught up to the rest of the world on this stuff." Guy added, "That area hasn't really been on our radar until recently. They just don't get much snow, and their mountains are tiny. Its hard for me to believe there are even avalanches happening over there, but people are still finding ways to get caught."

Doug Chabot, with the GNFAC, was unavailable for comment but indicated that the center plans to continue operations next season. "Its really a win-win for the public," says Guy. "Backcountry users can take a look at both the GNFAC's blog and the MAIC's avalanche advisory and make a well-informed decision. It makes perfect sense. The model works flawlessly in Colorado."

MSU student Jason Crestone voiced a common sentiment among his Bozeman peers. "If I'm heading out to Saddle Peak, I'm gonna read whichever forecast tells me its good to go. And by good to go, I mean Considerable danger." ▲

MOUNTAIN HUB RELEASES NEW PIT PROFILING APPLICATION

The developers at Mountain Hub, in Park City, UT, are releasing an upgraded version of their snow profiling software using the latest Progressive Web Application technology. The design implements common mobile elements, such as GPS mapping, push notifications, and camera access, with offline capability. "This is finally a snow profile program we can get behind," says Karl Birkeland, the director of the National Avalanche Center.

"We've been dabbling in other programs for the past decade, such as SnowPilot, but they have been coming up short. Let's be honest, no one uses Palm Pilots anymore." Mountain Hub's new application is already gaining popularity across the US, Canada, and Europe, with over 16,000 user-submitted profiles this season. Brent Markle, president of Mountain Hub, is excited about the new release. "The best part is the app shares profiles directly through Snapchat, so everyone gets a 10 -second look at your pit. That's the attention span of today's generation." ▲

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