



the avalanche journal

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Fracture Dynamics **33**

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WORK SAFE BC

Scenes from the 2024 Spring Conference

Photos by Alex Cooper

Scan QR for more pictures, or visit avalanchejournal.ca.



SIMON HORTON, AN AVALANCHE FORECASTER AND RESEARCH OFFICER FOR AVALANCHE CANADA, CATCHES UP WITH DR. DAVID MCCLUNG, A LONG-TIME AVALANCHE RESEARCHER AT UBC.



KELSEA KRAWETZ, A MASTER'S STUDENT AT SIMON FRASER UNIVERSITY'S AVALANCHE RESEARCH PROGRAM, PRESENTS ON HER RESEARCH INTO THE IMPACTS OF PRECIPITATION INPUTS ON SNOWPACK SIMULATIONS.



BRADEN SCHMIDT OF CIL (LEFT) PRESENTS A CHEQUE FOR \$13,369.86 TO JOE OBAD, CAA EXECUTIVE DIRECTOR. THE MONEY IS A PORTION OF ALL CIL SALES TO THE AVALANCHE INDUSTRY.



JOE OBAD, CAA EXECUTIVE DIRECTOR, ADDRESSES THE MEMBERS DURING THE AGM.



GRANT HELGESON, PRODUCT MANAGER AT AVALANCHE CANADA, AND LISA ERVEN, METEOROLOGIST WITH ENVIRONMENT CANADA AND ITP INSTRUCTOR, SHARE A LAUGH AT THE MEMBER SOCIAL.



THE MEMBER SOCIAL BURGER BAR HAD A LONG LINE ALL NIGHT, WHICH GAVE PEOPLE PLENTY OF TIME TO CATCH UP.



Eirik Sharp
CAA President

CAA President's Message

EMBRACING SELF-REGULATION

Professional requires more training, time, and financial investment than ever before. Membership application processes are more rigorous, and the demands of CPD are more onerous. Meanwhile, the benefits of self-regulation seem less tangible.

Although CAA courses remain the gold standard for professional avalanche education worldwide, you don't need to be a member to work in the avalanche industry in Canada. Avalanche workers don't have the right of title, nor are avalanche workers certified and recognized as a licensed trade. Aside from avalanche education, few stakeholders require membership for employment. It's reasonable to ask, "What has self-regulation delivered?"

Self-regulation has spared us from regional and external oversight from bodies like Engineers and Geoscientists British Columbia, Applied Science Technologists & Technicians of BC, and WorkSafeBC. Previous boards recognized the importance of self-regulation to avoid the fragmentation of our industry between different regulatory agencies, and the risk of highly prescriptive external oversight. They understood the diversity of our profession was not only part of what made the avalanche patch such a dynamic and engaging community, but also what made external regulation challenging. Their solution was to unify our industry around shared competencies through a model of self-regulated professional practice.

By avoiding regulatory fragmentation, self-regulation allows avalanche workers greater control over our practice, enabling us to conduct our work to best meet operational needs. It provides us greater flexibility in practice areas,

OVER THE LAST YEAR,

I have talked frequently with mentors, colleagues, and friends about the value of CAA membership (we recently conducted a member survey for more formal polling). I have been particularly interested in understanding the zeitgeist of our association around professional self-regulation. One of my takeaways is while most members support our metamorphosis from an association of professionals to a self-regulating professional association, there is a sense we have yet to fully realize the potential it promises.

It is undeniable that over the last decade we have dramatically increased the burdens of membership.

Becoming a Practitioner or

business models, and career advancement. As a self-regulating professional association, the CAA can advocate with a unified voice for members' interests, lobby for favourable legislation, promote professional development opportunities, and defend professional autonomy. Perhaps most importantly, self-regulation fosters trust and confidence among stakeholders, including clients, employers, and the public, by upholding standards and ensuring competence through oversight mechanisms that promote continuous professional improvement and adherence to best practices.

The goal of self-regulation is to ensure CAA members are respected, trusted, and valued by all stakeholders. When we achieve this, membership will be the implicit standard for avalanche workers. This, in turn, will provide greater autonomy, protection, and economic opportunities for avalanche workers, thereby supporting rewarding and sustainable careers in our industry.

We're not quite there yet though. To fully capitalize on these benefits, we must hold our peers accountable to our collective standards. We have the policies and procedures to support this, such as detailed competency frameworks, CPD requirements, a robust code of ethics, and a transparent grievance and disciplinary process. However, our community is small, and calling out breaches of conduct or ethical standards can be uncomfortable. Developing a culture where members can hold each other accountable in a fair and equitable way is essential to maintaining the integrity, reputation, and value of the CAA.

So, how do we build this culture? An obvious place to start is the one area of practice where membership is required for employment—avalanche education. A significant focus of the Board in the next year will be the full integration of Avalanche Educators into the CAA. Working with the Governance Committee, we will explore models to grant them voting rights and Board representation, ensuring they benefit from and contribute to the self-regulatory framework.

The Board also intends to work with the Membership, Ethics and Standards, and Complaints Investigation Committees to review the accessibility of compliance mechanisms related to various professional elements, such as scope of practice, ethics and standards, and CPD. These are just the first steps. Culture change can be a slow and uncomfortable process, but I firmly believe that only by embracing the ethos of self-regulation can we fully enjoy its benefits.

As always, I encourage anyone interested in being involved in this work to reach out to me at president@avalancheassociation.ca. In the meantime, I wish you all a safe and enjoyable summer.

Eirik Sharp, President



Joe Obad
CAA Executive Director

Executive Director's Report

DEVELOPING RESOURCES

dues increase proposed for Basic and Advanced Avalanche Educators to 80% of the recommended changes. This was not the outcome Board and staff sought, but the discussion was principled and ultimately resolved in a graceful manner that heard out all perspectives.

As an added bonus, we all successfully negotiated one of the subtleties of Robert's Rules of Order. Former CAA Director Ryan Buhler marvelled at the success of the motion to amend the original resolution for Educator dues.

The presentations this year were rich and evocative. Kananaskis Mountain Rescue's Mike Koppang explored the frontiers of applying an automatic version of the Avalanche Terrain Exposure Scale (version 2.0) as a public risk communication tool. Unleashing ATES on an area adjacent to a city of a million potential users quickly revealed the potential and limits of auto-ATES. Though it is predominantly used in the public realm, Cam Campbell observed in his presentation on ATES 2.0 that there are openings for industrial and commercial applications of ATES.

Colin Zacharias's presentation, "You've Had a Serious Avalanche Incident—Now What?" held the standing-room-only crowd in rapt attention. He explored the lessons of his long history as a consultant to operations and individuals who, following serious critical incidents, commonly find themselves involved in agency and insurance investigations that can involve a series of daunting interactions. He

AN ANNUAL HIGHLIGHT

for staff is engaging with members and stakeholders at the Spring Conference. For all of us, this is by turns uplifting and a reminder of our responsibility to you, our members and stakeholders.

The conference also serves as a bellwether of issues affecting the membership and the industries you all serve. I'll offer a few highlights here, followed by consideration of the value of the Spring Conference for all members, whether you attended or not.

At the AGM, members showed their commitment by voting for the recommended general dues increase of 5% nearly unanimously. A spirited but informative discussion followed where members voted to modify the

detailed how organization, record-keeping, currency with CPD, and other preparations can reduce stress and anxiety often faced during investigations of serious incidents.

Several presentations explored tools for mental health. Sidney Badger and Wren McElroy offered their finding and experience with creating resilience toolboxes for avalanche teams. Sean Zimmerman-Wall dialed in from Salt Lake City to offer uplifting and tough lessons from the Snowbird patrol's peer-support team.

These are just some of the presentations that lifted the perspectives of members in attendance. Beyond these excellent presentations, meetings of all stripes were happening around the conference. We invited Federal Explosives Regulatory Division (ERD) Inspector David Mohn to discuss explosives storage. In a one-hour meeting following his formal presentation, CAA members leading ski area operations met with David and appeared to reach some common ground that could positively shape ERD policy, which has been challenging since 2016.

Elsewhere, InfoEx manager Stuart Smith and InfoEx Advisory Chair Bree Stefansson laid out the goal of the subscriber survey and the aim to potentially shape a fairer set of subscription costs for InfoEx subscribers.

As you read this issue (hopefully in the warm summer sun), you may ask, "What does this all mean to me?" Beyond any specific presentation or meeting, the Spring Conference forms much of the agenda for the CAA and its partners. Some items, like votes at the AGM, have immediate implications. Others, may plant the seeds that grow to change the industry over time.

The conference should not belong to the lucky few who are able to attend in person, but to every member. This year, 256 members were in Penticton, and another 82 participated online. This represents roughly 27% of the membership. I hope the other 73% understand the resource the Spring Conference is. Getting to Penticton in person may not be an option for everyone; for this reason, we have worked to make the online experience as accessible as possible. I hope members consider the option that best suits them.

In the meantime, we are bringing as many elements from the Spring Conference to members through *The Avalanche Journal*, and our growing library of presentations is available in the Members-only section of our website. I hope you take advantage of these resources and have an excellent summer!

Joe Obad, CAA Executive Director



Alex Cooper
Managing Editor

From the Editor

TALE OF TWO CONFERENCES

big group mountain bike rides at the end of the day.

Attending both conferences back-to-back was eye opening. The mountain bike industry is seemingly still in its infancy, despite many trail associations being more than 20 years old. We're still grappling with liability and insurance. We've entered a new land-management regime, and new trail approvals take longer and require more work. Sustainability and environmental protection are at the forefront of provincial policy. First Nations reconciliation is just as important and we enjoyed a provocative discussion from four First Nations mountain bikers on the intersection of our sport and reconciliation.

We're getting used to the new regime. The industry is becoming more professional, with more clubs hiring paid staff to manage increasingly complex affairs. While our work is not as vital or valuable to the economy, there are some things we can learn from the avalanche patch.

Notably, a provincial association has only just formed with the Mountain Bike Tourism Association transforming itself into the BC Mountain Bike Association. The focus is on advocacy rather than tourism. It's a welcome shift, one that is still evolving. When this was announced in 2022, I wondered how this would be handled. I compared it to the creation of Avalanche Canada in 2003. For a decade, the CAA and AvCan were under the same roof until the latter matured and branched out on its own. I still wonder if this will happen to the mountain bike industry, or if marketing and advocacy can co-exist peacefully under one roof.

IT'S ALWAYS SO NICE

to head to Penticton for the Spring Conference. While spring came early to Revelstoke, it doesn't compare to the South Okanagan in May. This year, I got to extend my stay, as I attended the BC Mountain Bike Symposium in Naramata the previous week on behalf of my other employer, the Revelstoke Cycling Association.

The two-day MTB Symposium is more communal than the Spring Conference, and had a bit of a summer camp vibe this year, with it being hosted at the fairly rustic Naramata Centre. There are group breakfasts and lunches, and more opportunities for questions and answers during the presentations. And, of course,

After a weekend of mountain biking, I shifted gears into the CAA Spring Conference. Our conference felt more professional, for better and for worse. I enjoyed the more casual vibe of the MTB Symposium, but the variety and quality of presentations at the CAA meetings stood out. I really enjoy meeting people and each year there are more familiar faces. As of writing, I haven't really had time to digest everything, but a few presentations that immediately stood out are:

- Colin Zacharias, on what to do following an incident;
- Eirik Sharp, on using drones to measure snowpacks in start zones;
- Mark Staples, on being effectively alone in avalanche terrain;
- Wren McElroy and Sydney Badger, on creating a resiliency toolbox; and
- Brad Roach, on the importance of being a good follower.

As usual, I'd love to hear from you on your favourite presentations, and which ones you think are worth including in *The Journal* for all CAA members to read. Additionally, in future issues, I'm hoping to explore developments in the Avalanche Hazard Index and reflect on the Conceptual Model of Avalanche Hazard. I'd also like to take a closer look at the snowmobiling side of the industry. If you'd like to contribute on these or other topics, email me at acooper@avalancheassociation.ca

IN THIS ISSUE

This issue is bursting with stories. There's a lot of CAA news you may have read about already, but I feel it's worth including these updates here as well. Through my work on the History Project, I've relied greatly on past issues to inform my research and I've realized one significance of this magazine is it serves as a record of our association's history. Therefore, you will find updates on the new membership categories, ITP course progression, CPD, and more.

In Front Lines, you can read about how Avalanche Canada divided its forecast regions, the collaborative Kicking Horse Canyon project, and Fernie's experiment with a RACS. For the In The Loupe section, I'm happy to present updates on avalanche fracture mechanics research by three experts in the field: Alec Van Herwijnen, Bastien Bergeld, and Ron Simenhois. Finally, we conclude with an interview with Geoff Freer on the 1974 North Route Café avalanche and the establishment of the B.C. highways avalanche program.

I sincerely hope you enjoy this issue and have a great summer.

Alex Cooper, Editor

InfoEx Development and Funding Update

Stuart Smith, InfoEx Manager

IN WINTER 2022-23, I wrote in *The Avalanche Journal* about the Mobile Avalanche Information Exchange (MAInEx) project, outlining the launch of InfoEx v4 in 2022. At that time, we expected the three-year project would conclude at the end of March 2023. While many of the project goals were successfully completed, a few remained outstanding or in-progress when it was due to end.

Fortunately, Public Safety Canada's Search and Rescue New Initiatives Fund (SAR NIF) provided a one-year extension until March 31, 2024, and an additional \$350,000 in funding to support MAInEx's completion. This hugely appreciated support from SAR NIF increased the four-year funding for MAInEx to approximately \$1.75 million.

SAR NIF's contribution to complex avalanche software applications cannot be understated. Their contribution to InfoEx development has complemented funding for Avalanche Canada's three-year Avalanche Information Distribution project, which built new forecasting software and the foundation for new data aggregation and visualization software. These applications are now essential to both professional and public avalanche safety organizations.

Sometimes funding is the "easy part." Software development progress is subject to a variety of challenges. In fall 2023, MAInEx work had to be temporarily paused due to an unforeseeable need to change the project contractors. New contractors were sought and after receiving many strong proposals, Hookano (which built InfoEx v3 with Pascal Haegeli), and Cream + Sugar Creative started working on the project in January 2024.

At the same time, the CAA were notified of another approval for funding. Our April 2023 application to Transport Canada's National Trade Corridors Fund: Advancing Supply Chain Digitalization was approved. Transport Canada recognized InfoEx's important economic role keeping transportation corridors open while supporting public and worker safety on our road and rail networks. Transport Canada and the CAA have signed a contribution agreement for \$395,000 for a new project called Mobile Tools for Avalanche Impact Reduction (MTAIR).

Dealing concurrently with two large federal funding agencies could present challenges; however, discussion with SAR NIF and Transport Canada was productive. A time

extension was approved (without additional funding) to continue MAInEx until the end of July 2024. The rationale for this extension was to ensure effective use of the remaining project funding after the unexpected hiatus in the fall. MTAIR should start in August 2024 and is expected to run until December 2025.

The plan is for the newly hired contractors to complete the MAInEx project and then move on to MTAIR. The funding supports two Hookano software developers working around half-time each, and some design work from Cream + Sugar. The structure of a single project team comprising the contractors and CAA InfoEx staff continues.

MAInEx's overarching objective was to develop a versatile platform for both mobile and desktop devices, capable of accommodating ongoing feature enhancements amidst a rapidly evolving technological landscape. MTAIR will build on this by extending mobile functionality.

MAInEx has been a collaborative effort with subscribers, stakeholders, the InfoEx Advisory Committee (IAC), and the project's working group making valuable contributions, including testing, bug reporting, troubleshooting assistance, suggestions for improvements, and providing letters of support for funding. It is expected MTAIR will continue in a similar vein.

The federal funding for these two projects is fundamental in keeping InfoEx running and progressing after v3 reached end-of-life. We've received feedback that v4 has enhanced subscribers' InfoEx experience through its custom design and improved features. However, there is still much work to do, with many enhancements and new features in the planning pipeline to be implemented when time and resources allow. These efforts proceed alongside the work to ensure InfoEx's technical infrastructure evolves as new and improved technologies become available.

While the invaluable project funding will help keep InfoEx moving forward until the end of 2025, CAA staff, supported by the IAC and Board of Directors, are conscious that core revenues are currently below the level required for long-term sustainability of a complex on and offline web app for mobile and desktop devices. A number of strategies to enhance revenues have been identified and will be pursued before the MTAIR project ends. 🍷

Enhancements Unveiled: Elevating AvSAR Training Standards in Canada

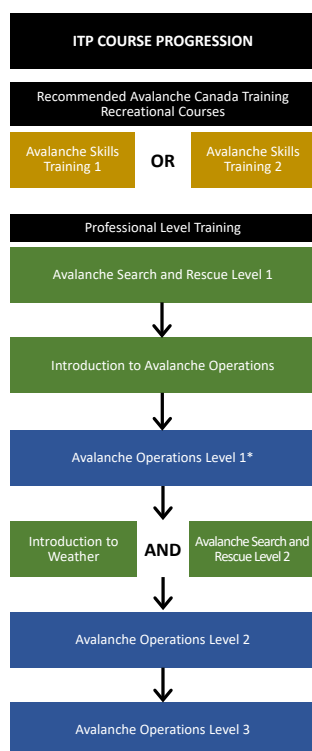
Kristin Anthony-Malone, Project Manager

QUICK RECAP:

The CAA's Industry Training Program is in the final year of a three-year project funded by Public Safety Canada's Search and Rescue New Initiatives Fund aimed at updating the CAA's avalanche search and rescue (AvSAR) training. This initiative introduces a new AvSAR Level 1 course and replaces the AvSAR Advanced Skills course with a new AvSAR Level 2 course. These enhancements were designed to better equip students for entry into the avalanche profession, serving diverse professionals. The primary impetus behind this project stemmed from stakeholder concerns regarding the readiness of graduates from the Operations Level 1 course in the fundamentals of search and rescue.

NOW WHAT?

AvSAR Level 1 is now the first stage of the CAA's Industry Training Program. It begins by introducing participants to the CAA and AvSAR in Canada, then delves into essential AvSAR concepts and techniques crucial for snow and avalanche workers who may respond to avalanche incidents as a team member.



* Students who completed the Avalanche Operations Level 1 before April 30, 2024, will not be required to take AvSAR L1

FIG. 1: THE UPDATED ITP COURSE PROGRESSION.

The course is divided into two components: an online pre-course and an in-person session. The self-paced pre-course covers topics such as risk management, transceiver functions, and rescue procedures. The in-person component spans four days and includes both classroom and outdoor sessions. It focuses on responder mental wellness, incident command system principles, risk management in AvSAR, and the practical application of search and rescue techniques and strategies.

Avalanche Search and Rescue Level 2 follows Operations Level 1 and is tailored for snow and avalanche workers who may participate in avalanche incident responses as a team leader. This advanced training

emphasizes leadership skills, techniques, and strategies. It is designed for industry professionals and advanced search and rescue volunteers; and serves as a CPD refresher for working professionals.

The course spans three days in person and focuses heavily on practical scenarios, with evaluation based entirely on practical skills. Prerequisites include completing Operations Level 1 and ICS-100.

HIGHLIGHTS

The introduction of new courses has amplified the need for instructors, prompting a large-scale recruitment, hiring, and training initiative. In April, ITP conducted training sessions for approximately 30 new ITP instructors and updated 10 existing instructors to align with the new curriculum. This marks the CAA's largest mass-hiring initiative to date.

Curriculum development is a time-consuming and intricate process, compounded by the multitude of perspectives on best practices. The project team aimed to bridge the gap between theoretical ideals and practicality, acknowledging that various techniques can be effective. While we've selected specific training standards, it's important to recognize that best practices are continuously evolving, and many other viable options exist.

To support consistency in this dynamic field, the team developed an instructional AvSAR video library. These videos will serve as a resource for learners and members to review and refine specific techniques.

THANK YOU!

A special mention goes out to the 40 individuals who joined us in Revelstoke in early-April for instructor training. Their invaluable feedback throughout the sessions provided incredible insights, allowing us to fine-tune and enhance the courses. This summer, we're incorporating the requested changes, clarifications, and improvements; and working diligently through editing and translation processes. With these adjustments in place, we're excited to announce that these courses will be launching winter 2024-25. We eagerly anticipate showcasing them to our students.

A heartfelt thank you to the project team and the Search and Rescue Secretariat for their unwavering support and funding, enabling us to advance avalanche search and rescue training across Canada.

For more information regarding course registration and preparation, please visit the AvSAR FAQ webpage at avalancheassociation.ca/page/AvSARFAQ.

Avalanche Educator Update

Rosie Denton, Operations Managers
Joe Obad, Executive Director

IT HAS BEEN OVER A YEAR since CAA members voted to create Basic and Advanced Avalanche Educator membership categories at the 2023 AGM. Since then, a project team has worked hard to create and implement the new categories and supporting ITP courses (Fig. 1).

Three pathways were set up:

- Course-based
- Recognized certification
- Competency portfolio

The status of the different application methods is:

- Basic: applications are open for all three streams. The Instructing in Avalanche Terrain—Basic course will open to applicants in December 2024.
- Advanced: recognized certification is open; the competency portfolio is being developed this summer; and course-based applications will start following the beta course in early-2025.

The categories were opened to applicants in December; twenty Basic Educators and two Advanced Educators have successfully applied so far.

AVALANCHE CANADA CHANGES

With these categories, Avalanche Canada has removed the exemptions from CAA membership to teach AST courses that were in place the last three years. AST instructors are now required to be an Avalanche Educator, Avalanche Practitioner, or Avalanche Professional. For more information, contact Avalanche Canada.

CHANGES TO EDUCATOR DUES

At the 2024 AGM, Members voted for Basic Educator dues to be set at 80% of Avalanche Practitioner dues, and Advanced Avalanche Educator dues to be at 80% of Avalanche Professional dues. These changes take effect on Dec. 1, 2024.

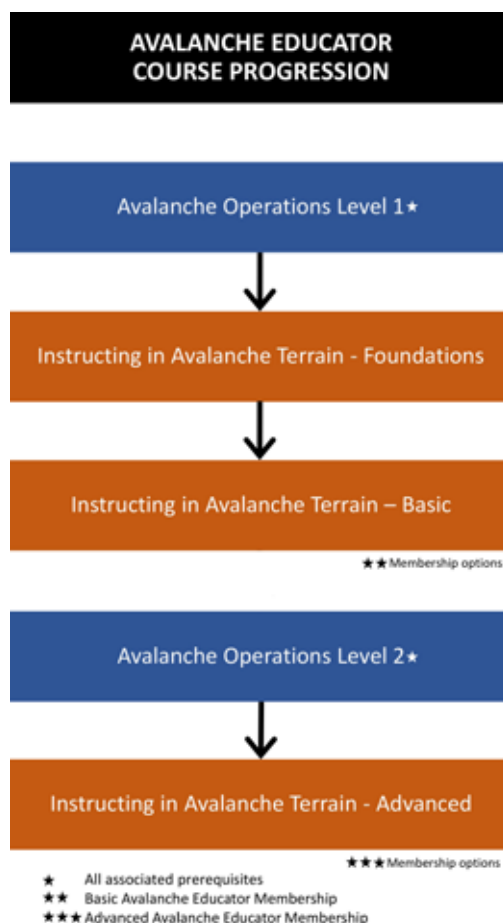
CONTINUING PROFESSIONAL DEVELOPMENT

The Membership Committee developed initial CPD requirements for Educators that will be reviewed annually for the first few years to ensure the currency of Educators meets the requirement of their scopes of practice. The first audits will take place next summer, for CPD in 2024. Educators will be required to provide the Avalanche Safety Plan they work under.

VOTING RIGHTS

Educators do not currently have voting rights. As membership requirements, scopes, and courses are developed, the place of Educators within CAA membership is being defined incrementally. The Governance Committee has been tasked by the board to review voting rights, with the goal of presenting an option to members at the 2025 AGM. ■

INSTRUCTING IN AVALANCHE TERRAIN COURSE PROGRESSION



INSTRUCTING IN AVALANCHE TERRAIN—BASIC

IATB will equip participants with the skills and knowledge needed to instruct AST 1 and CRS. The CAA hosted a beta course in January. The course will be updated this summer and offered to the public next winter.

INSTRUCTING IN AVALANCHE TERRAIN—ADVANCED

IATA will equip participants with the skills and knowledge required to instruct AST2 and MAT. Development will take place this summer and a beta course will run next winter. Courses will be offered to the public in 2025-26.

Special thanks to the curriculum team who worked tirelessly to quickly develop these courses: Iain Stewart-Paterson, Terry Palechuk, Lisa Larson, Emily Grady, and Chris Dyck.

CPD: A Core Element of Professional Self-Regulation And Part of Your Defence Following a Major Incident

Kerry MacDonald, Membership Chair
Rosie Denton, Operations Manager

ENSURING THE CURRENCY of CAA members through Continuing Professional Development is essential. Commitment to CPD is a requisite for professional self-regulation. Ensuring member compliance is not optional. It is a commitment made by every practicing CAA member, and a commitment by the CAA to the public. From seasoned forecasters to aspiring educators, ongoing learning and skill enhancement are essential to earn and maintain the trust of Canadians.

CPD compliance is monitored through annual member audits. Recently, the CAA and its Membership Committee embarked on a process that brought evidence-based requirements to align audit processes with competency-based membership requirements. This shift revealed many members were not CPD-compliant, or had difficulties providing suitable evidence.

In 2023, 2.5% of members—16 Professionals and 10 Practitioners—were audited. Several common challenges for the members under audit were identified:

- Many did not know the current CPD requirements.
- Some members were not engaging in sufficient CPD activities to meet the annual recommended CPD points and/or their three-year CPD requirements.
- Some members were not making use of tools and opportunities like career recess and point carry-forward.
- Many members did not track their CPD until they were audited.
- Some members took many months to submit supporting evidence, which was outside of the stated policy.

The majority of audited members needed significant extra help, leniency, or alternative methods to be successful. The pass rates were 50% for Practitioners and 75% for Professionals.

The annual audit of 2.5% is a small sample of the membership. Nevertheless, the results make it evident the CAA must make efforts to achieve greater compliance. A working group has been formed to review the CPD policy to make it easier to track points and stay up to date without reducing standards.

Policy updates were recently made that provide more options for those unable to work at full capacity for a period, and that establish a formal remediation policy for those who

have not maintained their CPD. The new policy can be found in the Members-only section of the website. The working group will continue looking at further tools to support compliance.

Members of the CAA and other mountain professions need to view CPD as a key tool supporting them, rather than an administrative burden. Recently, evidence has emerged in civil cases against mountain professionals following major incidents where claimants have probed the CPD currency of the professionals within their associations. Where this line of inquiry goes in respect to future litigation, and regulatory or criminal investigations is uncertain. It is certain members have the power to maintain and demonstrate currency in CPD, and the CAA is here to help. Every member should view CPD as a pillar of their professionalism that may be reviewed following an incident. Viewed in this light, CPD is not a painful administrative task, but a professional duty that safeguards the ability of members and the CAA as a whole to practice effectively into the future.

This responsibility extends beyond individual members. Conversations at the spring meetings of the CAA, Helicat Canada, and Canada West Ski Areas Association emphasized the need for employers to support members with CPD compliance. Having staff who are involved in avalanche risk mitigation as CAA members is a benefit to employers and program supervisors as the competency-based membership process requires applicants to demonstrate they can perform their work, and the CAA has set standards and scopes of practice that support avalanche mitigation decision-making skills. The ability of an operation to provide evidence of reasonable diligence in an investigation may be affected by the operation's ability to demonstrate worker CPD compliance. The CAA will continue to work with these associations to emphasize the need for employer support.

The CAA's path to self-regulation depends on the support, commitment, and professionalism demonstrated by the membership and its employers. The CAA is committed to developing its CPD education and systems, and is confident that by doing so, the path to competency-based CPD will reflect the same commitment and professionalism. We look forward to engaging members to ensure we provide a sound CPD system that meets the needs of members and objectives of the association. 



Shattering the Ice Ceiling: ITP Hosts First All-Women Ops 1

Sue Gould, Wren McElroy, and Caroline Poole

TRADITIONALLY DOMINATED BY MEN, the avalanche industry has seen a gradual but significant shift in recent years as women increasingly redefine belonging in the mountains. For women venturing into the avalanche industry, the journey requires more than just mastering technical skills—it's about breaking stereotypes and forging a path where they're accepted and celebrated.

Of the many incredible women who lift and inspire others within the CAA, Wren McElroy and Sue Gould played important roles in the 2023-24 season. Wren began her career as a ski patroller in 1993, often finding herself as one of the only women at work in the field. Likewise, Sue began her career in 1993 as an avalanche technician for the Ministry of Transportation as the only woman in the sector. Neither women were then considered the “typical” faces of avalanche safety.

With help from both the Ministry of Transportation and Infrastructure (MoTI) and the CAA Diversity, Equity and Inclusion (DEI) Committee, this gender imbalance is beginning to change. In April, Sue and Wren were invited to instruct the CAA's first all-women's Avalanche Operations Level 1 course at Kootenay Pass in B.C. Twelve women, eager to learn and expand their skill sets, arrived on day one ready to apply themselves. By the end of the week, they had forged strong bonds and had become a cohesive unit.

Despite extremely challenging digging through spring snow conditions, long days of fieldwork and homework, and a few tears, these 12 Level 1 students passed confidently. The “Wrath of Wren” and “Mama Sue,” as the instructors became known, pushed the students to their limits. In return, this all-female cohort approached their learning experience as a collaborative endeavor, using mealtimes as opportunities for collaboration and shared inquiry. This was an adjustment for Sue and

Wren, given that many of their early professional experiences involved a more competitive and individualistic “grind-it-out” mindset amongst their male peers. Even Cate Shaw, the chef for courses at Kootenay Pass, commented she had never had such a noisy kitchen as the students collaborated on their coursework and problem-solved together.

One of the challenges women face in the avalanche industry is representation. Seeing few, if any, women in leadership roles or as instructors can be disheartening for those aspiring to enter the field. For Sue and Wren, this course represented a passing of the torch in training and mentorship. The week started with a group of self-perceived recreationists who, when asked, stated their goal for the week was, “To pass.” They didn't yet see themselves as future avalanche professionals. By the end of the week, there was much buzz about what jobs they would apply for with their newly minted CAA Level 1 certifications.

Sue and Wren would like to extend their thanks to the MoTI team at Kootenay Pass for being the driving force behind the inception of this course. Thanks also go out to ITP staff and Maris Fraser for making this course a reality. Finally, they also want to celebrate the fantastic women who worked hard and challenged themselves as learners.

One member of the MoTI team mentioned that many on the crew have daughters themselves and would like to ensure they may see themselves in the avalanche industry. Women's increasing visibility in the industry is a testament to the resilience, determination, and dedication of those who challenge gender norms and defy stereotypes. The CAA hopes to continue this professional empowerment in the avalanche industry with women-specific courses in the ITP seasons to come. ■



CAA Service Awards

Rick Schroeder and Iain Stewart-Patterson Honoured

Alex Cooper

TWO LONGTIME STALWARTS of our industry were recipients of the CAA Service Award at the 2024 CAA AGM.

Rick Schroeder was recognized for his lengthy career and contributions to the Industry Training Program as an instructor on over 100 courses. "He influenced many future CAA instructors along the way. He was a big mentor and reason I became a CAA instructor," wrote Garth Lemke in his nomination. "He deserves (this award) for all his hard CAA work and contributions to students and bringing instructors along."

Iain Stewart-Patterson was recognized for his recent contributions to the development of the Canadian Motorized Backcountry Guides Association (CMBGA). Iain has enjoyed a 40+ year career in the industry as a guide, instructor, researcher, and consultant. "Iain has been a catalyst and BOD mentor for the development of the CMBGA," wrote Jason Smith in nominating Iain. "He's a wealth of knowledge and experience on all fronts, a builder of relationships, peacemaker, and an all-round deserving great guy."

We reached out to Rick and Iain on their awards:

RICK SCHROEDER

How does it feel to receive the CAA Service Award?

Well, I must say that it was a complete and very pleasant surprise! I feel honoured to be recognized by my colleagues.

What attracted you to this industry when you started out?

Initially it was self-preservation. I was chasing powder skiing and recognized that I needed to learn about the environment in order to survive. After taking several avalanche courses, I was looking for more training and Rudi Gertsch pointed me in the direction of the ACMG training program.

What do you enjoy most about working in the avalanche patch?

As an industry, I would say that all of us are very lucky! I have been fortunate to work and play in some of the most spectacular mountain terrain in the world. Very few people get to visit the areas that we travel in on a daily basis. We are a small community, and to be part of this tribe and experience the amazing things that we see is truly a gift.

What's your number one piece of advice for someone new to the industry?

I would say learn all you can and the doors will open. You will be able to choose the path that is most suitable for yourself. Enjoy the journey!

IAIN STEWART-PATTERSON

How does it feel to receive the CAA Service Award?

It is incredibly humbling, based on the list of previous recipients. It feels very meaningful to be acknowledged for contributions to an industry that is filled with incredible, talented people. The development of the CMBGA training and certification process was the result of a tremendous synergistic effort by a group of people and I am just happy to have played a role.

What attracted you to this industry when you started out?

My initial motivation for learning was generated by a series of three avalanche near-misses while climbing waterfall ice and a big peak in the Himalayas. I took the Operations Level 1 course immediately after returning from a trip to Nepal and it opened my eyes to the breadth and depth of the avalanche industry. This led to a guiding career path with ACMG certification and work as a ski and alpine guide.

What do you enjoy most about working in the avalanche patch?

The best part of working in this industry is the opportunity for continued growth. As an educator, I need to know enough to pass along. As a researcher, I need to ask good questions. Any posturing of expertise is confronted by the realization that this industry has insurmountable opportunity. Will we ever know everything there is to know about avalanches?

What's your number one piece of advice for someone new to the industry?

Be a reflective practitioner. Strive to develop expertise by learning from your experiences and through dedicated, deliberate practice. Realize that you will never know it all and there will always be people in the room who you can learn from. ■

Fuse News

Tyler Carson, Andre Laporte and Chris Argue

ON BEHALF OF THE CAA MEMBERSHIP, we would like to start this Fuse News by thanking Steve Brushey and Kevin Marr for their many years of service to the Explosives Advisory Committee (EAC). Steve came to the EAC in a time of need, brought energy and discipline to the committee through his grounded and practical approach, and was recognized with the CAA Service Award in 2022. Kevin joined the committee in 2018 and provided valuable representation for mechanized guides. With Steve stepping down as Chair, Chris Argue has taken the reins and will continue to build on the strong foundation laid by Mr. Brushey over the last nine years.

Over the winter, the EAC has been engaged with helicopter avalanche control guidelines, quantity distance (QD) standards affecting ski resort hillside magazines, updates to magazine construction, the use of airbag packs during avalanche control, and the new Alberta blasting exam. We summarize these topics below.

A recommendation for the development of helicopter control guidelines will be formally submitted to the Board of Directors this spring. The goal is to come up with a best-practices document with a broad scope to allow for flexibility within different operational contexts. This document would also support content for the Avalanche Control Blasting course.

In an unexpected turn of events, the Bureau de Normalisation du Quebec (BNQ), the standards organization that authored the 2015 QD standard, has abandoned the standard and will no longer work on the new version (which was near completion) or continue to publish the previous one. The QD standard specifies minimum separation distances between explosive storage magazines and exposed sites, such as public traffic routes, ski runs, ski lifts, and inhabited buildings. Natural Resources Canada's Explosives Regulatory Division (ERD) plans to produce its own policy to fill the void. The EAC is aware some explosives industry groups are advocating for an alternate standards organization to take over the QD standard, rather than ERD directly developing policy. The EAC is following the topic as it evolves.

David Mohn (Manager, Senior Inspector of Explosives, ERD) presented at the Spring Conference on the proposed changes to ERD's QD policy. The main impact is to ski resorts, which would be brought under the main QD policy,

which would supersede Guideline G06-03, under which ski resorts are currently regulated. Notable proposed changes are: D5 distance (minimum of 180 m) would be applied to ski lifts; and ski runs would be treated as public traffic routes, which stakeholders have expressed would lead to significant operational challenges.

A letter highlighting the concerns of stakeholders was sent to ERD. The response from ERD stated ski runs with more than 100 skiers per day would be required to meet the D4 distance, while runs below this threshold would not be subject to QD. This is a more achievable solution that would allow ski resorts to balance hazards from avalanches and explosives in the interest of public and worker safety.

Keeping on the topic of magazine storage, remember all upgrades to magazine doors, locks, and walls must be completed by July 31, 2026. For further information on the requirements, please refer to the 2015 standard—CAN/BNQ 2910-500. The main issues include: magazine wall fill materials must be appropriate gravel, not sand; doors must be partially or fully recessed into the wall; and locks must be updated. Contractors who are approved by ERD to complete this work are limited, so please plan accordingly to be compliant by the deadline.

Over the winter, the issue of the compatibility of electrical airbag packs and explosives was brought forward by CAA members. Braden Schmidt at CIL took the lead on this topic, working with airbag manufacturers to provide test data and formal recommendations on compatibility. The issue seems to be resolved, with major manufacturers providing recommendations that can be found at www.avalancheassociation.ca/page/CIL-ExplosivesElectric-Airbag-Compatibility.

A new Alberta blasting exam has been implemented through Alberta Occupational Health & Safety. The exam generates questions randomly from the OH&S Act - Part 33 Sections 466(1) to 514. The focus of the exam is blasting processes and procedures inclusive of perforating and surface blasting. Additionally, nuances have been noted in the Alberta Blasters log requirements, such as recording the movement of explosives to and from magazines.

The EAC is always open to member input. Please contact your practice area representative or the Chair. We wish everyone a safe and restful summer. 🍷

Contributors



ALEC VAN HERWIJNEN

After growing up and studying in the flatlands of Belgium and Holland, Alec embarked on a journey to learn about snow and avalanches. This quest began with a PhD thesis in Calgary within the legendary research program of Bruce Jamieson, and eventually led him to Davos, Switzerland, where he now leads the Avalanche Formation and Dynamics research group at SLF. With over 20 years of experience in snow and avalanche research, Alec remains deeply fascinated by snow, and he enjoys digging in it almost as much as skiing on it.

27 SCORING SNOW PITS



BASTIEN BERGFELD

Since the end of his physics studies in Munich, he has been working on snow and its properties at the SLF in Davos. In his doctoral thesis, he experimentally investigated crack propagation and its dynamics in dry snow slab avalanches. Bastian is still involved in field experiments and loves getting his hands dirty as he tries to uncover the secrets of avalanches.

32 MAPPING SNOW MECHANICAL PROPERTIES



RON SIMENHOIS

Ron has been mucking around in the snow for a wee while now. He lives with his wife and two kids in Leadville, Colorado, and works at the Colorado Avalanche Information Center.

27 SCORING SNOW PITS



NEVILLE BUGDEN

Neville Bugden is an Avalanche Professional with the CAA who began his career in 2003 as a ski patroller at Sunshine Village in Banff. He now works as an Avalanche Technician with the British Columbia Ministry of Transportation and Infrastructure in Golden, B.C. In the off-season Neville loves mountain biking and camping with his wife and two daughters.

36 THE BLADE HARDNESS GAUGE

CAA Welcomes New Staff

MAKAYLA HOGAN, MEMBERSHIP SERVICES & PARTNERSHIPS COORDINATOR

Makayla has joined the CAA in the role of Membership Services & Partnerships Coordinator. After moving to Canada in her teens, and bouncing around mountain towns, Makayla has made Revelstoke home. When not in the office, you can usually find her skiing, surfing, or climbing. She is stoked to combine her previous experience in the freeride/freestyle ski world with the avalanche safety industry. 





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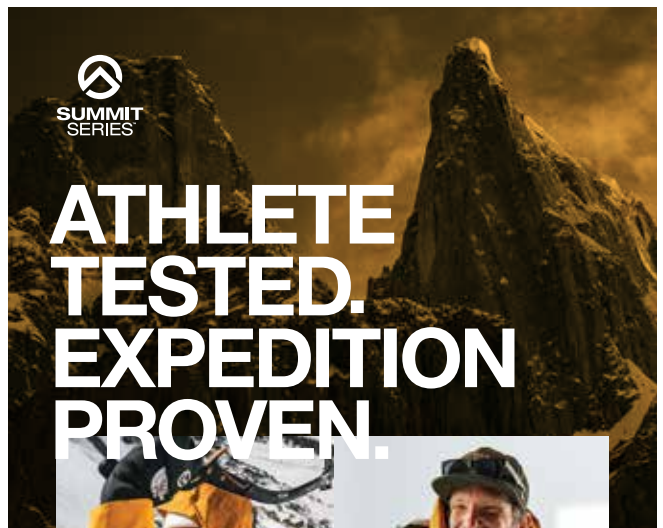
Occupational first aid regulatory changes

Effective November 1, 2024, under the amended Occupational Health and Safety Regulation, employers will be required to:

- Provide at least the supplies, facilities, and first aid attendants required by Schedule 3-A.
- Perform a written risk assessment for each workplace, in consultation with workers.

Visit worksafebc.com/first-aid-requirements

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Team Athlete:
Andres Marin

Location:
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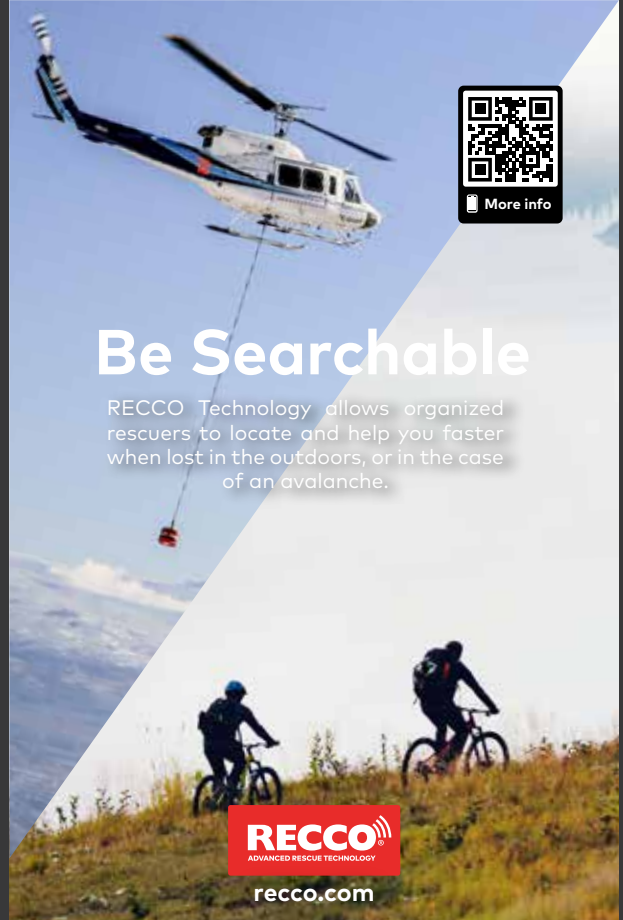
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front lines

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O'BELLX IN FERNIE

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REGIONS

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The Great Divide

How Avalanche Canada Went from 16 to 94 Forecast Regions

Simon Horton, Research Officer and Forecaster, Avalanche Canada

PUBLIC FORECASTING IN CANADA has evolved significantly due to increasing demand, resources, and data availability. Initially, forecasts were limited to national parks, then expanded to broad regions like the South Coast, North and South Columbias, and Rockies. Over time, more areas have been served with a greater number of smaller forecast regions.

In the 2022-23 winter season, a flexible forecasting system was introduced, allowing forecasters to adjust region boundaries to better communicate variability in regional avalanche conditions. A key step to achieving this was dividing our existing forecast regions into smaller subregions that could be grouped into custom configurations.

Avalanche Canada forecasters, along with our partners at Parks Canada and Kananaskis Country, were tasked with drawing new subregions over the summer of 2022. The end result was splitting 23 regions into 122 subregions (Avalanche Canada went from 16 regions to 94; the rest were in National Parks), effectively reducing the average size from 17,000 km² to 3,300 km². While some splits, such as those between the Duffey and Coquihalla, the Monashees and Selkirks, and the western slopes of the North Rockies from the eastern slopes, were readily apparent, others posed more complex challenges. To address this, we explored various approaches and datasets to inform the drawing of meaningful polygons. This article shares our discoveries and debates when creating these new subregions.

USING PREDEFINED REGIONS

Before drawing new regions from scratch, we first considered several existing classifications:

- **Political regions:** Some European forecasting agencies use political regions such as districts or counties. The political regions of western Canada are far too large and do not accurately reflect different snow climates.
- **Mountain ranges:** The Canadian Geographical Names Database contains polygons with named mountain ranges. This could work relatively well in areas with multiple tiers of named ranges and subranges; however, the resolution of mountain range names is not consistent across western Canada. Also, wider ranges often have distinct snow climates on the windward and leeward sides.
- **Watersheds:** Defining regions along watershed divides creates regions with relatively homogeneous snow climates. However, popular recreation areas often straddle divides, so drawing a line through

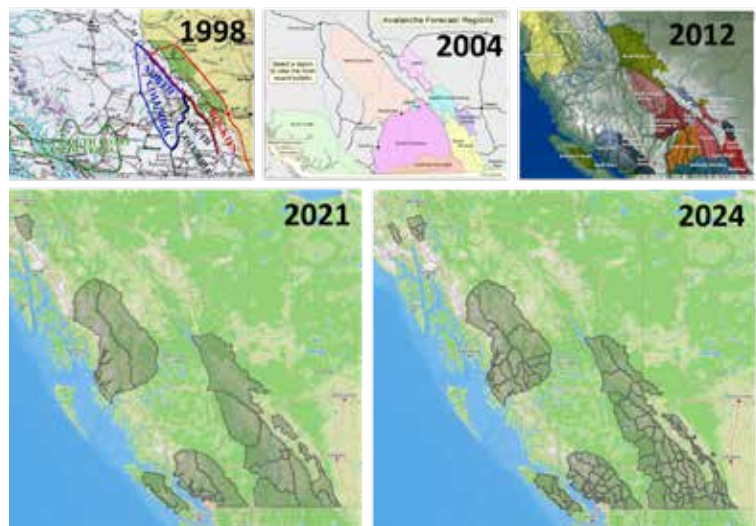
the middle would not necessarily support recreational trip planning. Also, heavy precipitation often spills over the divide into adjacent drainages on the leeward side of divides.

Given these considerations, it was clear avalanche forecasts would benefit from a unique set of regions tailored to our specific needs.

PHYSICAL FACTORS

We explored some data-driven approaches by compiling gridded datasets, including:

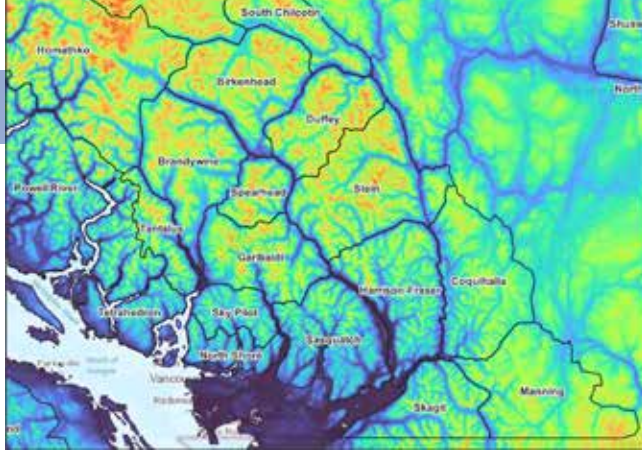
- **Elevation:** Digital elevation models helped us visualize mountain range boundaries and the typical elevation of avalanche terrain.
- **Land cover:** Products such as the North American Land Cover Classification and the BC Ministry of Forests' biogeoclimatic zones¹ helped identify vegetation and climate zones. Forestry data was particularly useful for distinguishing between wet and dry drainages based on vegetation types. Wet areas tend to have more hemlock and cedar, while dry areas have more pine and fir. A good example is the sudden transition in forest type just north of Coquihalla Summit.
- **Climate data:** Average precipitation and temperature estimated from the Pacific Climate Impacts Consortium's climate data² revealed snow climate patterns; however, we found the satellite-derived forestry data was a more reliable proxy for snow climate than these statistical interpolations from weather stations.



PROGRESSION OF PUBLIC FORECAST REGIONS IN WESTERN CANADA FROM 1998 TO 2024 (REGIONS FOR QUEBEC AND NEWFOUNDLAND ARE NOT SHOWN).

¹ <https://www.for.gov.bc.ca/hfd/library/documents/treebook/biogeo/biogeo.htm>

² https://data.pacificclimate.org/portal/bc_prism/map/



PHYSICAL FACTORS CONSIDERED INCLUDED TERRAIN AND CLIMATE. THE LEFT IMAGE SHOWS ELEVATIONS (M) IN THE SOUTH COAST AND THE RIGHT IMAGE SHOWS THE ANNUAL PRECIPITATION (MM) FROM PRISM.

We experimented with automated methods to statistically cluster these data into snow climate regions, but ultimately found these approaches did not fully capture the regions we thought would be relevant for backcountry trip-planning.

Nevertheless, these datasets have become a valuable training resource for our forecasters, and we have incorporated them into an interactive ArcGIS forecast region atlas. Notably, the land cover data has enabled us to objectively estimate treeline elevation across various mountain ranges, as the treeline tends to be lower towards the coast and further north. Moving forward, there is potential to further analyze these datasets to identify and characterize new forecast regions, particularly in remote areas.

HUMAN FACTORS

After considering various approaches, it became clear the top priority should be splitting popular backcountry recreation areas, so our focus shifted towards understanding recreation patterns using several proxies:

- **Mountain Information Network (MIN):** With over 18,000 reports submitted between 2014 and 2023, the MIN provided valuable insights into the location of popular recreation areas. However, we acknowledged these reports were historically biased towards experienced backcountry skiers and this data would not represent all recreation areas.

- **Avalanche Terrain Exposure Scale (ATES):** Since many popular areas have been ATES mapped (e.g., BC Rec Sites and Trails, snowmobile areas, provincial parks), combining ATES maps with MIN reports offered a more accurate, albeit incomplete, representation of recreation areas.

By analyzing proxies for recreational use, the main subregions became evident by grouping popular recreation areas according to their snow climates.

DATA SOURCES

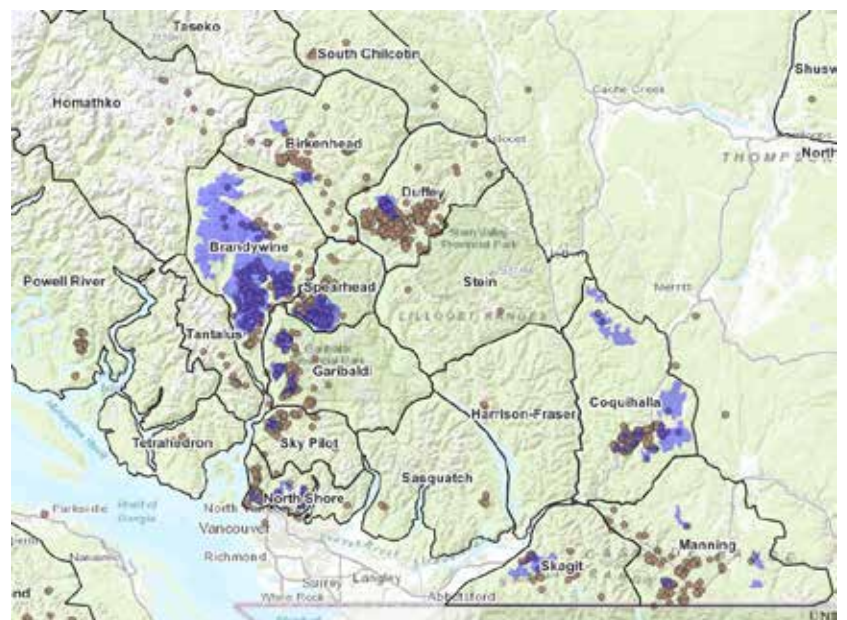
The sizing of subregions was influenced by the availability of data sources and the level of recreational activity. We carefully assessed the spatial coverage provided by InfoEx operators and automated weather stations—both integral data sources for precise forecasting. Smaller subregions were feasible in well-covered areas like the Sea to Sky and

Selkirks, while regions with sparse data, such as the northern Rockies and eastern Caribos, required larger subregions. Additionally, areas with minimal recreational activity, such as those near the Homathko Icefield and Cassiar Highway, were maintained as larger subregions.

DRAWING BOUNDARIES

After identifying key recreation areas with sufficient data availability, a technical challenge became placing the boundaries between them. A key consideration was avoiding drawing boundaries through recreation areas so people would only need to consult one forecast when planning a trip. To achieve this, boundaries were predominantly drawn along low terrain features such as rivers, roads, and cols, rather than following high terrain features such as divides, ridges, and peaks.

Dividing subregions along low terrain features resulted in some polygons encompassing both wet and dry sides of mountain ranges, introducing climatic variability within each subregion. However, delineating wet and dry areas within a mountain range is a complex task that requires extensive local knowledge of weather system interactions with the terrain. As a general practice, boundaries were drawn through low terrain, though some exceptions were made using local expertise to



PROXIES FOR RECREATIONAL PATTERNS IN THE SOUTH COAST INCLUDED HISTORIC MIN REPORT LOCATIONS (BROWN DOTS) AND ATES-RATED AREAS (PURPLE POLYGONS).



SUBREGION BOUNDARIES IN THE TERRACE AREA PRIMARILY FOLLOW LOW TERRAIN (LEFT) VERSUS THE PURCELLS WHERE SPECIFIC DRAINAGES WERE SPLIT INTO WET AND DRY AREAS (RIGHT). THE WET AREAS INCLUDE SPECIFIC DRAINAGES ON THE LEEWARD SIDE OF THE WATERSHED DIVIDE.

delineate wet and dry drainages through high terrain.

IMPLEMENTING INTO FLEXIBLE FORECASTING

Draft polygons were initially sketched in Google Earth and then refined and merged in QGIS to create a master copy map, which is accessible in GeoJSON, KML, and Shapefile formats at github.com/avalanche-canada/forecast-polygons. Each subregion was given a short name to help internal discussions amongst forecasters, and then added to our flexible forecasting system for the 2022-23 winter.

Forecasters initially faced a learning curve to decide where and why to update forecast region boundaries, but we have since become relatively fluid at adapting to evolving snowpack conditions and weather forecasts. Ryan Buhler, Avalanche Canada's Forecast Program Supervisor, presented an analysis of common forecast region configurations during the inaugural season at the 2023 ISSW in Bend. The analysis highlighted how the system allowed us to better communicate regional variations in hazard, most notably the distribution of the prevalent deep persistent slab problem of 2022-23. Following the inaugural winter, minor adjustments were made to the subregion boundaries, and we are now largely satisfied with how the current subregions accommodate the majority of situations.

NEXT STEPS

The flexibility to adjust our region boundaries has undoubtedly been a significant improvement, but we see even more potential for enhancing the delivery of forecast information. The current forecasting workflow typically limits a forecaster to write four forecasts per day. This has resulted in a tendency towards maintaining a similar number of regions as the past.

We recognize regional variations still often exist within these broader regions and in the future we would like to provide more localized forecasts for smaller regions. We are exploring ways to make forecasting workflows more efficient, including enhanced data visualization tools and initializing parts of the forecast with weather and snowpack model data.

Additionally, with the increasing adoption and accuracy of snowpack modeling, we are considering the implementation of automated gridded forecasts. Such forecasts could serve as a starting point for human

forecasters, who would then have the flexibility to dynamically group areas into regions and complement the model predictions with their expert interpretation and communication skills, thereby providing more nuanced forecasts.

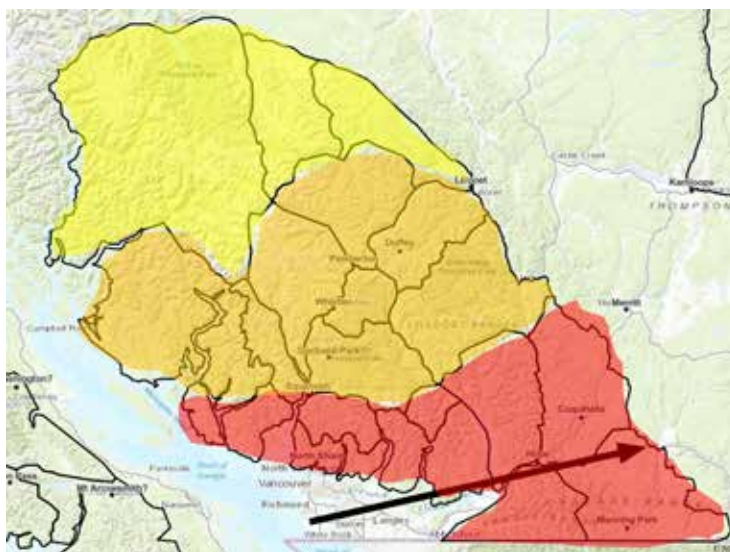
CONCLUSION

This initiative to redraw public forecast regions represents a significant stride towards producing more precise forecasts for smaller, localized areas. We have identified 122 distinct regions, and although we are far from producing a unique forecast for each one, we are progressively improving our ability to capture the vast variability of terrain and climates in the mountains of Canada.

REFERENCES

Subregions can be viewed on ARFI

Buhler, R., Horton, S., Schroers, B., 2023. An analysis of Avalanche Canada's flexible forecast regions. Proceedings of the International Snow Science Workshop, Bend, OR, USA.



A HYPOTHETICAL EXAMPLE OF A STORM TRACK MOVING FROM VANCOUVER TO HOPE WITH BANDS OF DECREASING DANGER LEVELS TOWARDS THE NORTH.

O'bellX in Fernie

A Taste of the future?

Tyler Carson, Forecasting Supervisor, Fernie Alpine Resort

PRIOR TO THE 2020-21 SEASON, Fernie Alpine Resort (FAR) partnered with TAS by MND, Avatek, and Mountain Technical Canada Inc. to provide a demonstration site for their O'bellX Options+ remote avalanche control system (RACS) at the 2020 International Snow Science Workshop (ISSW).¹ The goal was to demonstrate the application of the technology at a ski area, which had not yet been explored in the Canadian market, and provide an easily accessible opportunity for other sectors of the avalanche industry to observe this device in operation.

RACS have been widely used at European ski areas for upwards of 30 years, and more recently at U.S. ski areas such as Alta, Jackson Hole, Squaw Valley, and Taos. FAR's avalanche program has similarities to these American resorts, and is comparable to programs found in many Canadian industrial resource and transportation programs where RACS have gained traction. Our operation features complex terrain that can produce size four avalanches. FAR operates a highly intricate and broad risk treatment program, including explosives and terrain closures, to manage a variety of conditions in this terrain. Our goal is always to safely open as much terrain as possible.

LOCATION

The O'bellX unit provided to FAR was powered by a hydrogen and oxygen mixture, and was remotely controlled with a tablet via

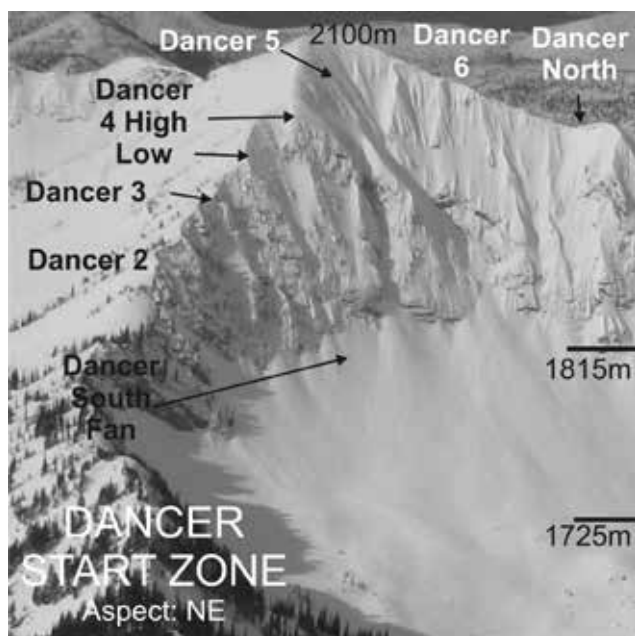


FIG. 1. THE DANCER PATH FEATURES A SERIES OF START ZONES.

radio communication. It was installed in the Dancer 5 start zone (Fig. 1) in order to optimize the demonstration purposes of the installation and because it would serve as an effective addition to our avalanche mitigation program. The Dancer 5 start zone is the largest in a series of start zones (Fig. 1). Avalanches that initiate in Dancer 5 can affect the second largest start zone in the Lizard bowl—the Dancer South Fan. This combination of paths and start zones can pose avalanche hazards to the public in the south end of Lizard Bowl, to staff travelling on the Tower 6 road corridor, and, at times of heightened hazard, the fixed infrastructure of upper Deer and upper Lizard runs (Fig. 2). This area is a major corridor for beginner skiers and all key mountain operation departments. More drastic measures to reduce exposure during times of high hazard reduces the product for guests and increases the possibility of guest and snowmobile interaction as all traffic is routed down a shared run away from the runout zones of Lizard Bowl. It can also affect the liaison terrain between Currie and Lizard Bowls, and reduces the availability of Easter Bowl from the Timber side.

The challenge with conducting avalanche control in Dancer 5 is the inability to target it with the Lizard Avalauncher due to the proximity of the infrastructure surrounding the start zone. This includes the unload terminal of the Polar Peak chairlift, the Polar patrol hut, Polar explosives magazine, and the Lizard ridgeline safety system. The alternate to using the Avalauncher involves patrol teams skinning uphill to Polar Peak from Currie Bowl to access the Polar magazine, and then targeting the start zone with hand charges. The success of this strategy is highly dependent on acceptable avalanche and travel conditions.

The key to the success of this strategy is to consider the operational goals of the day, which are based on avalanche hazard and weather. Sending teams to Polar Peak is beneficial to the Lizard Bowl control sequence, but at times places resource strains on the Timber and Currie Bowl control sequence. There is often a fine line of benefit depending on the operational goals of the day. Our hope was installing the O'bellX would reduce some of these challenges.

ASSESSING THE BENEFITS: 2020-21

The ability to fire the O'bellX unit remotely as and when required during times of suitable hazard, unsuitable weather, and high human resource demand outwardly appeared as the largest and most obvious benefit. Anecdotally, firing as and when may have also reduced the return rate of larger destructive avalanches because of the increased regularity and consistency of control.

¹ The workshop was unfortunately cancelled due to the global pandemic

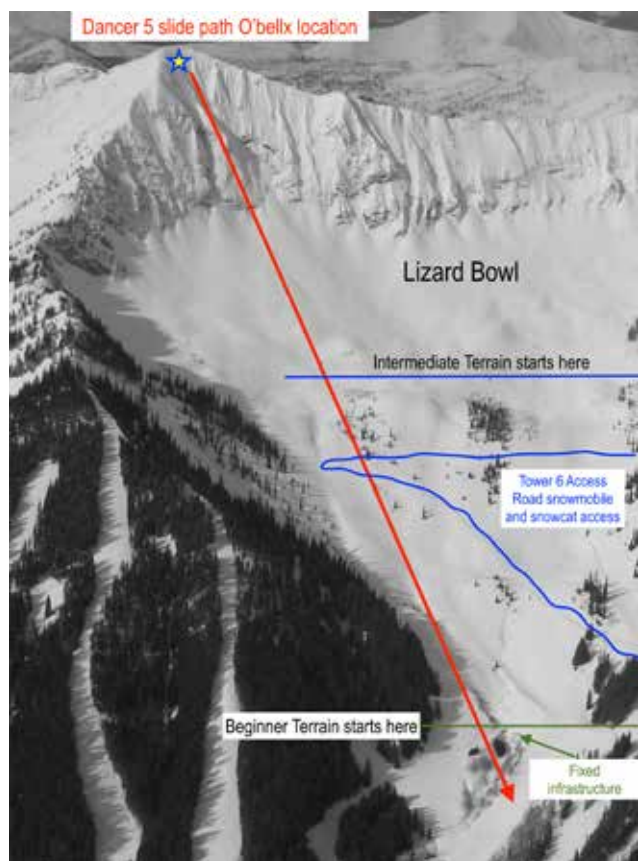


FIG. 2. THE DANCER PATH CAN IMPACT INTERMEDIATE AND BEGINNER TERRAIN.

Review of the efficacy of the O'bellx was challenged due to the timing of final commissioning of the unit. Delays in delivery and extended poor weather meant commissioning was not complete until Jan. 21, 2021. December 2020 had provided consistent storm cycles with large loading patterns and avalanche cycles, while the rest of the season consisted of smaller loading increments and smaller avalanche cycles. However, we can extrapolate the efficacy of the O'bellx by comparing the avalanches it produced to the results of the adjacent Avalauncher work and scaling it to larger avalanche cycles. The examples on page 27 demonstrate the efficacy of the O'bellX unit in comparison to Avalauncher work on two separate control missions .

Upon reviewing these avalanche occurrences—and keeping in mind this was only one unit in one path over just two seasons—the O'bellX provided a markedly more effective and reliable impact on the start zone compared to an Avalauncher round due to the accuracy of targeting and size of detonation. Of note, the unit was only fired at half-capacity (13-second fill time), which equates to about six times the detonation of an Avalauncher round. In periods where a more stubborn instability existed, the unit was capable of firing with a 26-second fill time. This was a function of the unit that we only used in setup testing and not during operations.

The unit would have also provided an opportunity for control work with reduced exposure to technicians, but

without multiple seasons with differing weather patterns and changes, this was hard to quantify for actual benefit as we were unsure if weather, experience, daylight, or operational goals were the main contributing factors.

ROUND 2: WINTER 2021-22

We were fortunate enough to use the O'bellX for a second season. The results were similar to the first season, but due to favourable snowpack structure and poorer visibility, we actually received less feedback. We used it through the early part of the season to mitigate the build-up of deeper instabilities, but these tapered rapidly as the winter dried out.

Other notables from this season were that fall service, maintenance, and testing went as per the manual, with no problems before installation. We managed to get the O'bellX installed earlier in the season, but still later than would have been optimal due to operational challenges such as use agreements, long-line insurance confirmation, and, of course, weather.

We completed a total of 17 fires that season and did one bottle change. Looking at our historical use of explosives in this path, that seems about right and would have taken us all the way to the end of the season. The bottle change was easy for us (Fig. 4). The pilot did have some challenges connecting to the unit due to wind and visibility, but he said it would get easier with practice (he only had four opportunities to move the O'bellX).

Putting the O'bellX to bed for the season went smoothly and it was easy to transport to its storage area.

CHALLENGES

Through both seasons, our main challenge was making observations due to poor visibility and high exposure. Our goal is always to reduce uncertainty of hazard from our upper start zones. With the challenges in making good quality observations, we can only anecdotally say there was a reduction in avalanche magnitude. Our data was too limited to change our operating procedures.



FIG. 4. THE BOTTLE CHANGE WENT SMOOTHLY, DESPITE SOME CHALLENGES. PHOTO BY YURI LORTSCHER.



A COMPARISON OF RESULTS BETWEEN THE O'BELLX AND THE AVALAUNCHER FROM CONTROL MISSION ON FEB. 22 (LEFT) AND FEB. 26, 2021. IN BOTH IMAGES, THE RESULTS FROM THE O'BELLX ARE IN YELLOW AND THE RESULTS FROM THE AVALAUNCHER ARE IN GREEN. THE O'BELLX PRODUCED CONSISTENTLY LARGER AVALANCHES.

From Nov. 1 until opening day, access to the Dancer 5 start zone was challenging and there were few staff resources on site to draw from for hand-control missions. We would have loved to test it out during this period, but were unable to get it in place in time, which was a bit of a lost opportunity for us.

One improvement we would like to have seen is robust lightning protection. We suffer lightning at times during the fall and spring. Out of an abundance of caution, we removed the unit earlier than was optimal to prevent lightning damage, thus not giving us an opportunity to test it during the shoulder season.

Another challenge was this was only one unit in one start zone. To achieve the goal of maintaining open terrain below the headwall with confidence, we would have required 10 or 11 units to tie the terrain together from one end to the other. As a recreational operation with a variety of reduction tools, the \$3 million required for the one bowl would be a hard pill to swallow, whereas if you had millions of dollars of commerce passing through this zone daily, it would be a no-brainer.

VALUE

Moving through avalanche terrain with explosives has inherent risks. We will likely be using this method for the foreseeable future. In saying that, any opportunity to reduce the interaction of staff and explosives is an improvement in safety. The O'bellX achieves this with a gas-powered initiation system and remote firing capabilities that completely remove staff from the physical firing sequence and immediate blast area, and negates the need to travel to the start zone for explosives deployment.

From a financial end, MND suggests the working lifespan of the O'bellX is at least 20 years. Componentry, such as plumbing, is serviceable, and communication is upgradable. After the upfront cost, yearly operation would be significantly cheaper than the historical cost required to control the Dancer 5 start zone. We estimated the operational costs for us to be approximately 1.5 hours of helicopter time seasonally to place and reload the unit, and \$600 for an entire season of

gas, inclusive of fees and taxes. For comparison the equivalent number of Avalauncher rounds to achieve the same number of placements is \$8,100. Additionally, no extra licensing or ticketing is required to operate the O'bellX units.

CONCLUSION (YOU DON'T KNOW WHAT YOU GOT TILL IT'S GONE)

FAR was gifted with this unique opportunity to trial technology that is at the leading edge of snow avalanche risk management in our own terrain. The O'bellX highlighted the possibility of immense benefits in risk reduction that a RACS could bring to our avalanche safety program. The O'bellX itself operated flawlessly; the greatest benefit was its convenience and reliability. Being able to fire it immediately before providing public clearance was incredibly valuable and knowing that the target was affected every time provided some reassurance. While we did see some evidence of avalanche size reduction in this start zone, the many days of poor visibility really did not allow for a lot of confidence in this benefit.

Though we chose not to purchase it at this time, the MND TAS gas-based family of RACS proved reliable and functioned as promised. The key benefits were the obvious ones: remote firing and lack of actual explosives required for its operation both brought high value.

Looking to the future and reflecting on the opportunity and experience we were given through these two seasons, a single O'bellX unit may not have been sufficient for our needs; however, we have now been presented with an option for solving some of our larger overhead hazard problems should we face regulatory, public expectation, or management expectation changes in the future.

We would once again like to thank MND TAS, Avatek and Phil Hein, Chad Rigby and Mountaintek, and the folks who valiantly attempted to bring the ISSW to Fernie for providing us with this opportunity. I would also like to thank Steve Brushey and Scott Garvin from BC MoTI for their help with our safe operating procedures. 

The Kicking Horse Canyon Phase 4 Avalanche Mitigation Program A Lesson in Collaboration

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BEGINNING IN 2001, 26 KM of the Trans Canada Highway (TCH) through the Kicking Horse Canyon east of Golden, B.C., underwent major upgrades to improve it from a tight two-lane highway that hugged the cliffs to a largely elevated causeway-style, four-lane divided highway. The project included four construction phases. Phases 1, 2, and 3 were completed between 2003 and 2013, and Phase 4 was substantially completed in November 2023 (Fig. 1). Phases 1–3 included 21 km of construction that cost \$326 million—an average of \$15.5 million per kilometre. Phase 4 was projected to cost \$601 million for 4.8 km of highway—an average of \$125 million per kilometre. The significantly higher construction cost highlighted the project's very challenging nature. This section of highway is perched on the south side of Table Mountain, 200 m above the Kicking Horse River and the Canadian Pacific Kansas City Railway (CPKC) track. Steep terrain located both above and below the highway presented significant challenges to construction due to frequent avalanche and rockfall hazards.

All four phases involved upgrading the highway from two to four lanes, straightening horizontal curves and vertical grade profiles, improving sightlines (e.g., reducing blind corners), and increasing protection from avalanche and rockfall hazards. Improvements included a combination of snow retention fences, rockfall attenuation nets, concrete barriers, and wider ditches.

A unique feature in Phase 4 is the Blackwall Bridge (Photo 1) that allows avalanches from Table Mountain to travel below the highway, effectively mitigating the area of highest avalanche

frequency and magnitude. The nine-year average up to 2023 showed 4.1 control missions per winter, which resulted in an average of just under 19 hours of closure time. In 2023-24, the only closure lasted just over an hour, a result of a low snowpack and improved highway alignment.

By comparison, the Washington State Department of Transportation (WSDOT) reduced the number of avalanche control missions by 90% on Highway I-90 through Snoqualmie Pass after their elevated bridges were constructed (John Stimberis, WSDOT, personal communication 2022). Following the completion of construction of the avalanche bridges in 2016, WSDOT estimated the elimination of over 100 avalanche closures at the East Shed avalanche area during the seven-year period from 2017-2023 (Stimberis, 2023). With an average delay period of 30 minutes to two hours per typical avalanche closure period, the improvement in highway reliability during the winter is substantial.



FIGURE 1. LOCATION OF PHASE 4 OF THE KICKING HORSE CANYON PROJECT (KHCP4) IN RELATION TO THE PREVIOUSLY COMPLETED PHASES 1 THROUGH 3 CONSTRUCTION PROJECTS. CREDIT: BC MOTI IMAGE [HTTPS://WWW.KICKINGHORSECANYON.CA/ABOUT/PROJECT-OVERVIEW/](https://www.kickinghorsecanyon.ca/about/project-overview/)



PHOTO 1. THE PARTIALLY COMPLETED BLACKWALL BRIDGE THROUGH THE TABLE MOUNTAIN AVALANCHE HAZARD AREA. THE OLD HIGHWAY GRADE CAN BE OBSERVED ADJACENT TO THE SLOPE. THE NEW FOUR-LANE BRIDGE WILL ALLOW LARGE AVALANCHES TO PASS UNDER THE HIGHWAY TO REDUCE THE HAZARD.



PHOTO 2. AVALANCHE PATH 4.8 AT THE WEST END OF PHASE 4 CLEARLY SHOWS RISK TO THE HIGHWAY AND A WORKSITE. THE CPKC TRACK IS LOCATED IMMEDIATELY DOWNSLOPE OF THE WORKSITE.

Kicking Horse Canyon Constructors (KHCC) was the prime contractor for the project. During the winters of 2020-21 (from February onwards), 2021-22 and 2022-23, there were two independent avalanche hazard management programs working concurrently in the Kicking Horse Canyon: D6

Avalanche Services (D6), a joint venture between 6 Point Engineering and Dynamic Avalanche Consulting, was retained by KHCC to be responsible for avalanche safety throughout the worksite. The BC Ministry of Transportation and Infrastructure (MoTI) was responsible for the traveling

public on the highway. The key difference between the two programs was how the elements at risk were exposed and their vulnerability to avalanche hazards (Photo 2).

KHCC workers were frequently stationary and working outside of vehicles very close or within (i.e., on the slopes) avalanche terrain during periods of low hazard. During periods when the avalanche hazard increased, additional worksite restrictions were implemented to manage worksite risk, such as staying out of ditches or only working in enclosed equipment (e.g., excavators and loaders).

The traveling public crossed through avalanche hazard areas in vehicles, which reduced their vulnerability compared to a worker on foot. They were also continuously moving through the hazard area, which reduced their exposure time. The MoTI and D6 teams had several areas with avalanche problems that were separate; however, the main section of the highway below Table Mountain was the primary focus area and presented comparable avalanche management challenges for both programs.

Both programs also had to consider the CPKC railway track, located between the highway and Kicking Horse River, prior to explosive avalanche control and construction work that could initiate avalanches on downslope terrain. Explosive avalanche control by either team required coordination with CPKC and temporary closure of the railway (Photo 3).

On a daily basis, both teams evaluated the avalanche hazard separately, and the resulting weather and avalanche observations, and avalanche information were reported to stakeholders and InfoEx. During significant changes in weather or avalanche conditions, both teams were in constant communication to create and update avalanche control plans well in advance of an expected highway closure and control. Stakeholders were notified in a timely manner, which allowed KHCC to modify its construction activities. For example, vulnerable equipment (e.g., cranes and excavators) was moved out of the hazard areas, while loaders and trucks were strategically located in the canyon to help facilitate the timely and efficient removal of avalanche deposits.

Once avalanche control was completed, both teams discussed the results, updated the forecast weather conditions, and then were able to make their respective decisions for when the highway or worksite could safely be re-opened. There were times when avalanche control work proceeded as expected and both the worksite and highway could be re-opened immediately; however, there were also times when the highway and worksite needed to remain closed due to continuing elevated avalanche hazard to one or both programs.

When avalanche control was required, both D6 and MoTI forecasters would develop a plan and work collaboratively to complete the mission. During a typical helicopter control



FIGURE 1. LOCATION OF PHASE 4 OF THE KICKING HORSE CANYON PROJECT (KHCP4) IN RELATION TO THE PREVIOUSLY COMPLETED PHASES 1 THROUGH 3 CONSTRUCTION PROJECTS. CREDIT: BC MOTI IMAGE [HTTPS://WWW.KICKINGHORSECANYON.CA/ABOUT/PROJECT-OVERVIEW/](https://www.kickinghorsecanyon.ca/about/project-overview/)



PHOTO 4. MOTI AND D6 AVALANCHE TEAMS DURING A COORDINATED PRE-WINTER TRAINING SESSION. FROM LEFT: HEATHER HORDOWICK, ALAN JONES, CHAD HEMPHILL, GREG JOHNSON, STEFANIE MACDIARMID, NICK COMSTOCK, KEVIN WEIR, NIGEL FISHER, DAVE CAVANAGH, DARREN COOK, MARK GRIST, NATALIE ANDERSON, NEVILLE BUGDEN, GREG PALTINGER.

mission, one worker from each program would be present. Control work typically included 2 kg boosters and 12.5 kg ANFO bags when needed. Explosive costs were shared by each team. There were several instances where there was a team on the ground deploying explosives at the same time as the helicopter control mission. In this case, the helicopter completed the work on a closed section of the worksite/road and then handed that section over to the ground crew. Communication was vital in these situations, so a strong plan and forward-thinking were necessary. Radio communications needed to be clear, concise, and understood by all involved. It was crucial for both teams to continuously be in contact and share information to help inform decisions. Collaboration proved critical during the heavy snowfall and avalanche winter of 2021-2022. Our teamwork increased the safety for the public, workers and infrastructure while minimizing highway closures and construction delays.

The completion of Phase 4 marked the end of the Kicking Horse Canyon project, which has spanned 22 years and cost just under \$1 billion. The avalanche and rockfall hazard will be drastically reduced, resulting in a safer and more reliable highway corridor. The three-year Phase 4 construction project highlighted coordinated and cooperative avalanche safety programs by MoTI and D6, that strove to provide safety and minimize highway closures and construction delays. (Photo 4). We consider our work a success.

EPILOGUE

Phase 4 was substantially completed in November 2023. The 2023-24 winter was a low snow year in Kicking Horse Canyon. We estimate about 12 size 1.5–2 avalanches would have reached the old highway alignment this year. This compares to an average of 29 avalanches per winter that reached the highway within the Phase 4 construction area during the 2003-2022 (20-year) period. One slide reached the barrier just past the new ditch, and two slides reached the old alignment but were 20 m short of the new alignment.

The path that produced the most activity was Path 5.3 (Photo 3), which was heavily modified by machinery during construction. It previously had distinct gullies, but these were smoothed over and steepened. Avalanche size and frequency have increased slightly in Path 5.3, but the catchment ditch was substantial enough to contain all debris this winter.

The area between Paths 7.2 and 7.7 is typically the greatest concern, however, it did not produce large results this winter. It remains to be seen how this new alignment performs under a normal snow winter.

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MUSINGS ON THE DYNAMICS OF
CRACK PROPAGATION IN SNOW

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37 DRY SLAB AVALANCHE FORMATION



Musings on the Dynamics of Crack Propagation in Snow

Alec van Herwijnen and Bastian Bergfeld, WSL Institute for Snow and Avalanche Research SLF

A VERY BRIEF HISTORY OF AVALANCHE RELEASE PROCESSES

Decades ago, snow avalanches were still relatively simple. Avalanche release was understood to result from an imbalance between the shear strength of buried weak layers and the shear load of the overlying slab. People were pulling shear frames and measuring slab densities to calculate stability indices (the ratio of stress to strength) that did not predict avalanches particularly well (Jamieson and Johnston, 1995). The key to understanding this discrepancy was fracture mechanics, which describes how failures can propagate when the overall stress levels are still below the strength of the weak layer. The key concept here was *crack propagation*.

In the early-2000s, upon realizing the importance of fracture mechanics, practitioners and researchers set out to develop indices and new tests to assess crack propagation. Initial attempts included describing shear quality or fracture character in existing field tests such as the compression test and the rutschblock test (Johnson and Birkeland, 2002; van Herwijnen and Jamieson, 2005). Subsequently, tests tailored to specifically assess crack propagation were developed, namely the extended column test (ECT; Simenhois and Birkeland, 2006) and the propagation saw test (PST; Gauthier and Jamieson, 2006). The latter was really a game changer in the snow avalanche community as it helped us drastically improve our understanding of avalanche release processes (Fig. 1).

We learned that at the heart of snow avalanches lay a delicate equilibrium disrupted by a few key elements. It

begins with a weak layer beneath a cohesive slab of snow, which creates a precarious situation awaiting a trigger. This trigger, often the weight of a skier or a recent snowfall, acts locally to create an initial failure. Once initiated, gravity takes over, setting the stage for the rapid spread of the crack in the weak layer across the snow slope.

The recognition that locally initiated cracks could extend over large distances was not new. The pioneering work of Dave McClung in the late-1970s and early-1980s represented some of the earliest efforts to apply fracture mechanic concepts to describe avalanche release in terms of propagating shear cracks (McClung, 1979; McClung, 1981). However, it was the PST that enabled us to directly measure the relevant processes in the field. Video recordings of PSTs highlighted the role of the structural collapse of weak layers during crack propagation (Figure 1), with surprisingly low estimates of initial crack speed of around 20 m/s.

These low crack speed values indicated that collapse waves, which are bending waves propagating in the slab associated with the collapse of the weak layer, were the primary driving force behind crack propagation rather than shear cracks (van Herwijnen et al., 2008). This spurred the development of new theoretical and numerical frameworks to explain avalanche release processes, introducing the term "anti-crack" in the snow avalanche community to describe compressive failures in snow (Heierli et al., 2008; Gaume et al., 2018). While compressive failures are typically not possible in most materials, the porous nature of snow allows weak layers to fail in compression (anti-mode I) rather than tension (mode I in classical fracture mechanics).

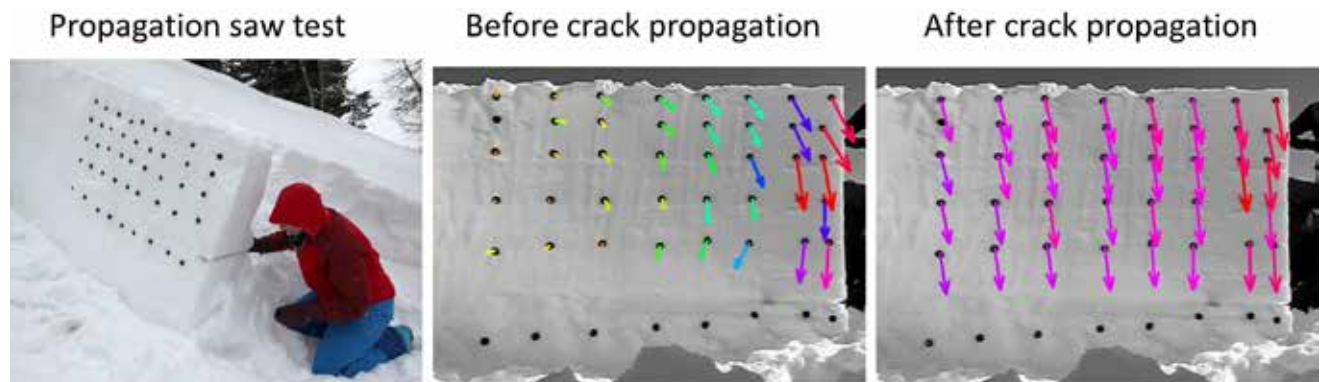


FIG. 1: WITH THE PROPAGATION SAW TEST, RESEARCHERS CAN DIRECTLY MEASURE AVALANCHE RELEASE PROCESSES IN THE FIELD. LEFT: BLACK MARKERS IN THE EXPERIMENT ARE USED TO TRACK SNOW DISPLACEMENT. MIDDLE: DISPLACEMENT JUST BEFORE CRACK PROPAGATION (NOT TO SCALE). RIGHT: DISPLACEMENT AFTER CRACK PROPAGATION (NOT TO SCALE)

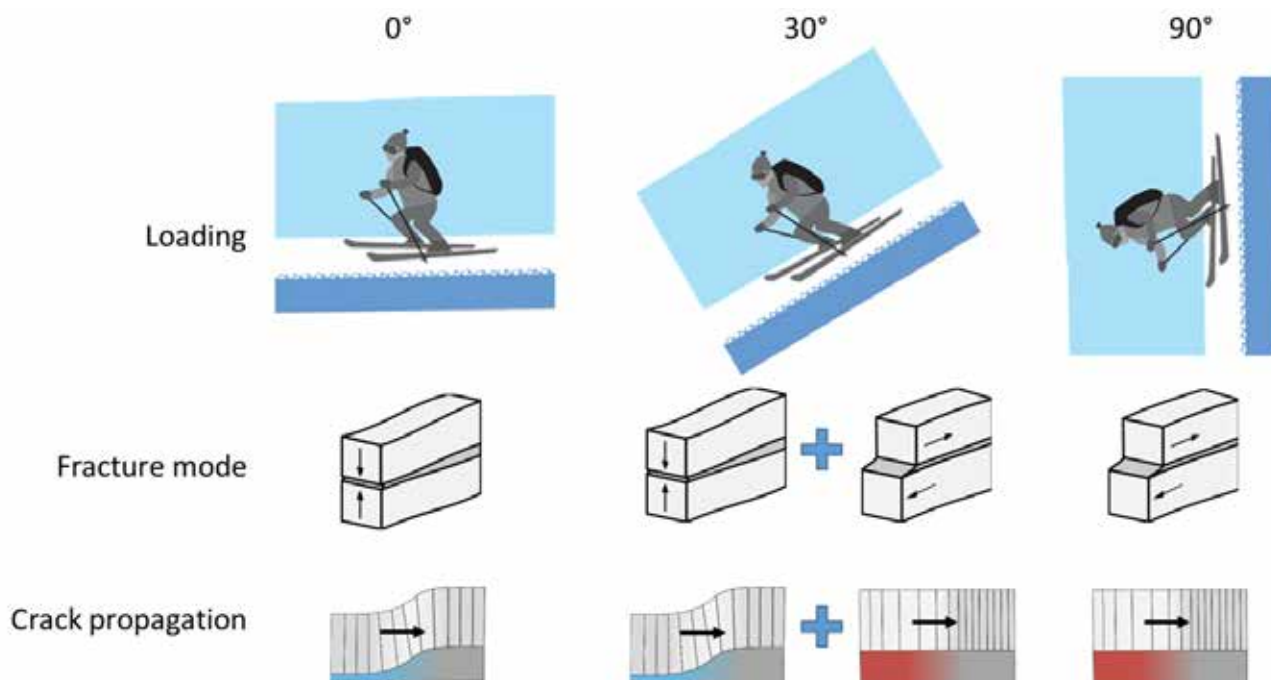


FIG. 2: SCHEMATIC REPRESENTATION OF DIFFERENT LOADING MODES (TOP), FRACTURE MODES (MIDDLE), AND CRACK PROPAGATION MODES (BOTTOM). ON FLAT TERRAIN (LEFT), THE SKIER WOULD CREATE A SO-CALLED ANTI-CRACK, CHARACTERIZED BY CRACK FACES MOVING TOWARDS EACH OTHER, AND CRACK SPEED IS BOUND BY THE FLEXURAL WAVE SPEED OF THE SLAB. ON A 90° SLOPE (RIGHT), LOADING FROM THE SKIER WOULD CREATE A SHEAR CRACK WHERE THE CRACK FACES MOVE PARALLEL TO THE PLANE OF THE CRACK, AND CRACK SPEED IS BOUND BY THE P-WAVE SPEED OF THE SLAB. ON A REAL SLOPE (MIDDLE), MIXED-MODE CRACKS CAN TRANSITION FROM COMPRESSION-DOMINATED FLEXURAL WAVES TO SHEAR-DOMINATED P-WAVES—SO-CALLED "SUPERSHEAR" CRACKS.

These new theories and models offered a more refined understanding of avalanche release, and elucidated how remote triggering from flat areas was possible. Very recently, however, numerical simulations and detailed analyses of avalanche videos have introduced a new fracture mode, suggesting a transition from collapse-driven anti-crack propagation to what is termed "supershear" crack propagation on steep slopes (Bobillier et al., 2023), once again challenging our understanding of avalanche release processes.

FRACTURE MODES AND THE ROLE OF CRACK SPEED

By now, it should be apparent that crack propagation plays a central role in avalanche release. It might thus be relevant to understand the differences between shear cracks, anti-cracks, and supershear cracks. We therefore turn again to the PST and fracture mechanics.

In a PST, when we cut into the weak layer with our snow saw, the unsupported section of the slab above the saw-cut bends downwards as a cantilever beam (Figure 1). This causes high stresses at the crack tip, where the slab is still attached to the weak layer. Eventually, when the critical cut length is reached, this stress intensification can advance the crack in the weak layer in a domino-like process.

In fracture mechanics, both stress concentrations and energy release rates can be used to analyze crack

propagation. In this context, energy is required to fracture the weak layer over a given area. This specific fracture energy is a material property of the weak layer and indicates how much resistance it has against crack growth. Thus, energy is needed to advance a crack within the weak layer, and this energy comes from the snowpack itself, independent of the triggering. Therefore, crack propagation is essentially a balancing act between the energy released by the deformations and relaxations in the slab-weak layer system, and the energy needed to expand

To understand, describe, and possibly predict crack propagation in a snowpack, we must thus assess the specific fracture energy of the weak layer and the energy release rate of the slab-weak layer system. However, neither is a simple, universally valid numerical value. To make things worse, it also depends on how the system is loaded, as this will determine which strain causes the weak layer to crack. Since the weak layer is embedded between the slab and the substrate, one could also say that crack propagation depends on how these two sides move in relation to each other.

Focusing on skier loading, we can imagine two extreme scenarios. In the first scenario, the skier loads the snowpack on perfectly level terrain (left in Fig. 2). In this case, crack propagation is dominated by compressive strain as the crack faces (slab and substrate) move towards each other. In the second scenario, our hypothetical skier loads the snowpack

on a 90° slope (right in Fig. 2). In this case, crack propagation is dominated by shear strain as the crack faces move parallel to the plane of the crack. In a real avalanche, however, crack propagation is driven by a mixture of these two modes (middle in Fig. 2).

At first glance, the loading on our imaginary 90° slope looks like 'normal' pure shear loading, so why talk about supershear? For this, we must delve into crack speeds, as these are closely tied to crack propagation modes. As mentioned before, crack propagation requires the transfer of energy to the crack tip, a process that is driven by elastic waves within the slab. On level terrain, the energy is transferred by so-called flexural waves (bottom left in Fig. 2)—elastic bending waves in the slab that propagate rather slowly. On our extreme 90° slope, an increasingly large portion of the slab will pull downslope, causing the slab to deform in an analogous manner to an elastic P-wave (pressure wave), the fastest of all elastic waves. The crack speed is thus limited by the speed of P-waves along the slab. This is surprising, because shear cracks are limited by slower shear waves in traditional fracture mechanics. Hence, we use the term "supershear" to describe the faster crack speeds.

The existence of supershear cracks in avalanche release was recently suggested in numerical simulations and further backed by crack speed estimates derived from videos of skier-triggered avalanches (Simenhois et al.,

2023; see page 37). In these simulations, crack propagation started with a compression-dominated anti-crack limited by flexural wave speeds. As the crack progressed across the slope, the gravitational pull on the slab progressively increased the tension in the slab. After a certain crack propagation distance, this tension in the slab caused an abrupt transition into P-wave dominated shear cracks (Fig. 3). These numerical predictions have triggered a renewed interest among scientists to measure crack speeds during propagation as it could provide direct information on crack propagation modes.

DOES IT MATTER?

Unlike a few decades ago, we now understand that avalanches are not as straightforward as previously thought. The processes involved in avalanche release are influenced by the complex interplay of strength and fracture energy, various fracture modes, and the propagation of elastic waves through the slab.

Although our current understanding of this topic has significantly improved, it is primarily derived from numerical simulations; direct experimental evidence is often lacking. Measuring the deformation behaviour of the slab during crack propagation at a scale of tens of metres is challenging, if not impossible. Furthermore, we are still missing reliable data for many relevant mechanical properties and their

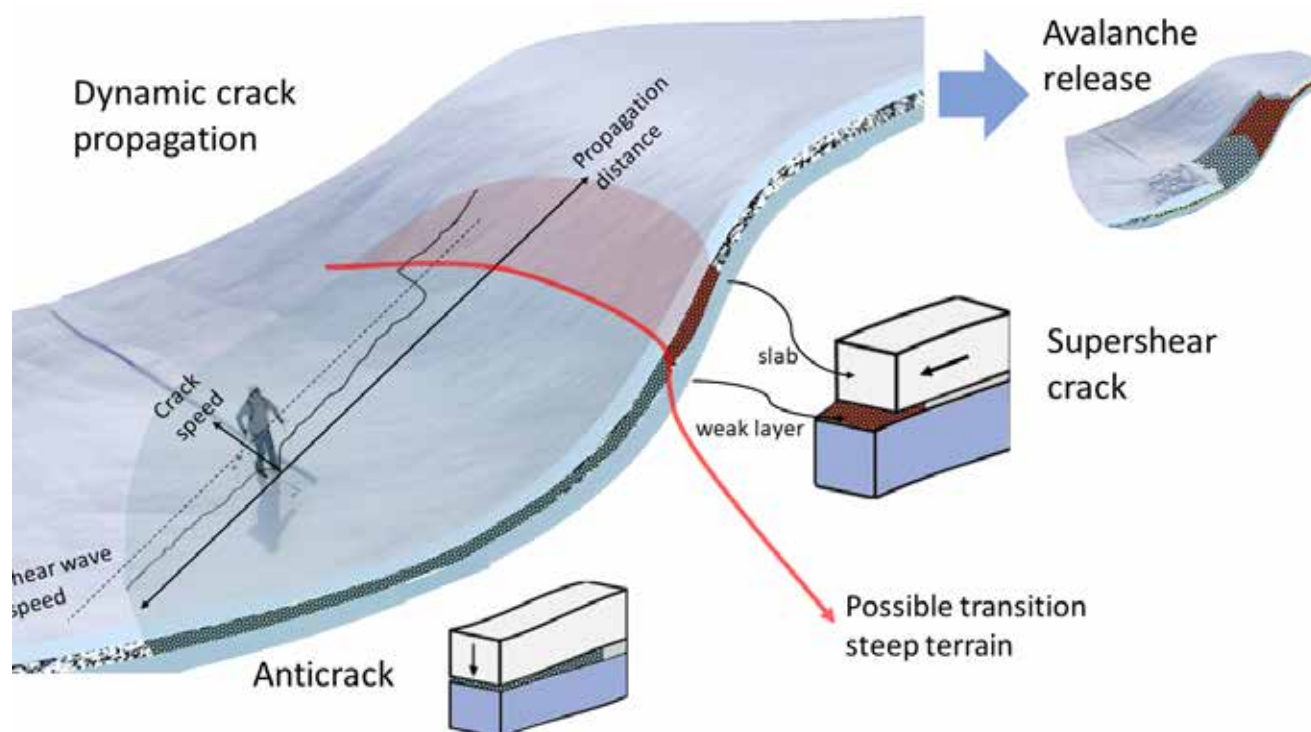


FIG. 3: SCHEMATIC DIAGRAM SHOWING THE TRANSITION FROM A COMPRESSIVE-DOMINATED ANTRICRACK PROPAGATION ON FLAT TERRAIN TO A SHEAR-DOMINATED SUPERSHEAR CRACK ON STEEP TERRAIN.



correlation with snow cover characteristics such as density and grain type. Nevertheless, we can confidently assert that we now better understand what to look for, and we have increasingly powerful tools at our disposal to do so.

Still, one might ask: "Shear, anti-crack, supershear, flexural waves, P-waves—do they really matter?" As usual in snow and avalanche science, the answer is a resounding, "It depends." From a scientific perspective, this is, of course, fascinating stuff, as it can have implications for crack propagation distances and thus potentially avalanche size. From a practical perspective though, the implications are still rather limited. We do not yet know how common supershear crack propagation is in nature or what role slab properties play in this process.

That being said, compared to the good old days of shear cracks and shear frames, when most of the attention was on the weak layer, we now understand that slab properties also play a crucial role beyond merely loading the weak layer. When looking at the snowpack and trying to assess if avalanches are probable, you therefore do not necessarily need to think about flexural waves and supershear fractures. Yet, it is prudent to carefully look for and test potential weak layers and evaluate if the properties of the overlying slab are conducive to crack propagation.

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Dry Slab Avalanche Formation

What We Know, Why We Think We Know, and Practical Implications

Ron Simenhois, Avalanche Forecaster and Data Scientist, Colorado Avalanche Information Center

AVALANCHE FORMATION

Dry-snow slab avalanches originate from a series of fracture events within the snowpack. Initially, a failure occurs within a weak layer beneath a cohesive slab, forming a localized crack. If this crack reaches a critical size, it begins to propagate. This dynamic process leads to the extension of the crack across the slope. Ultimately, an avalanche is released if the gravitational sliding force on the slab surpasses the frictional resistance of sliding. Typically, visible cracks along the snow surface initiate at various points on the avalanche, including its crown, flanks, and stauchwall, as the slab breaks from its surroundings and starts its descent down the slope (Schweizer et al., 2003; Schweizer et al., 2016).

Until recently, understanding crack propagation relied on two competing theories: the collapse-mode anti-crack and the shear mode. However, both theories have proven inadequate in predicting the critical crack length where dynamic crack propagation starts. The shear mode's critical crack lengths appear unrealistically large for slopes under 35°, while the anti-crack mode indicates similar issues for slopes over 45°. Consequently, neither theory offers a comprehensive explanation for the formation of dry slab avalanches.

Recently, Bertil Trottet, Johan Gaume, and others introduced an analytical model that bridges the gap between pure shear and weak layer collapse theories (Trottet et al., 2022). This model proposes that cracks initially originate in a collapse anti-crack due to weak layer collapse and subsequently transition into a supershear mode after surpassing a supercritical crack length (usually 3-5 m). The size of this supercritical crack length is contingent upon the slope's steepness and the snowpack's characteristics. The supershear mode bears similarities to the simple shear mode (Mode II), albeit with a notably higher crack speed. This transition concept from anti-crack to supershear

draws parallels with the mechanics underlying deep strike-slip earthquakes (Weng & Ampuero, 2020).

MODEL VALIDATION

Analytical models serve as tools for anticipating the behaviour of the events they represent. The alignment between real-world observations and these predictions serves as a litmus test, offering a degree of confidence in the accuracy and reliability of the analytical framework employed to characterize the underlying processes.

One significant outcome of the shift from weak layer collapse to the supershear mode involves crack propagation speeds. Models indicate exceptionally high supershear speeds (>100 m/s) in the up/downslope direction and slower Mode III speeds in the cross-slope direction. These supershear speeds surpass common speed measurements from propagation saw tests (PST) and whumphs, which rarely exceed 60 m/s. This discrepancy is anticipated, considering the supercritical crack length (typically between three to five meters) significantly exceeds standard PST measures and is on slopes steep enough to avalanche. Thus, to validate the new model, slope-scale measurements were essential.

At ISSW 2014, Dave Hamre and others presented a set of crack speed measurements derived from avalanche mitigation videos. Approximately one-third of their measurements recorded speeds exceeding 100 m/s; however, these measurements were limited as they stemmed from explosives-triggered avalanches, potentially influencing crack speeds. Moreover, the reliance on the appearance of surface cracks introduced errors for avalanches where these cracks appeared within 200 m of the initiation point, and failed to discern between up/downslope and cross-slope crack propagation.

To address these limitations, we developed a new method

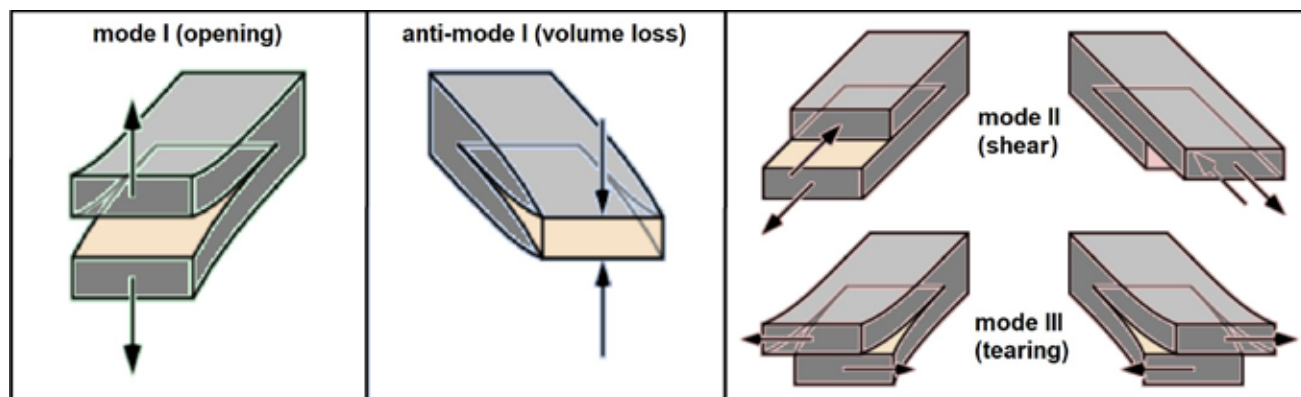


FIG. 1: THE MAIN BASIC FRACTURE MODES. THE ANTI-MODE I IS ASSOCIATED WITH THE INITIAL STAGES OF THE DYNAMIC CRACK PROPAGATION. MODE II CORRESPONDS TO PROPAGATION IN THE UP/DOWNSLOPE DIRECTION ALONG THE HORIZONTAL PLANE, WHILE MODE III DENOTES PROPAGATION TRAVERSING ACROSS THE SLOPE. (THIS IMAGE IS ADAPTED FROM [HTTPS://WWW.NATURALFRACTIONS.COM/1.1.1.HTM](https://www.naturalfractions.com/1.1.1.htm).)

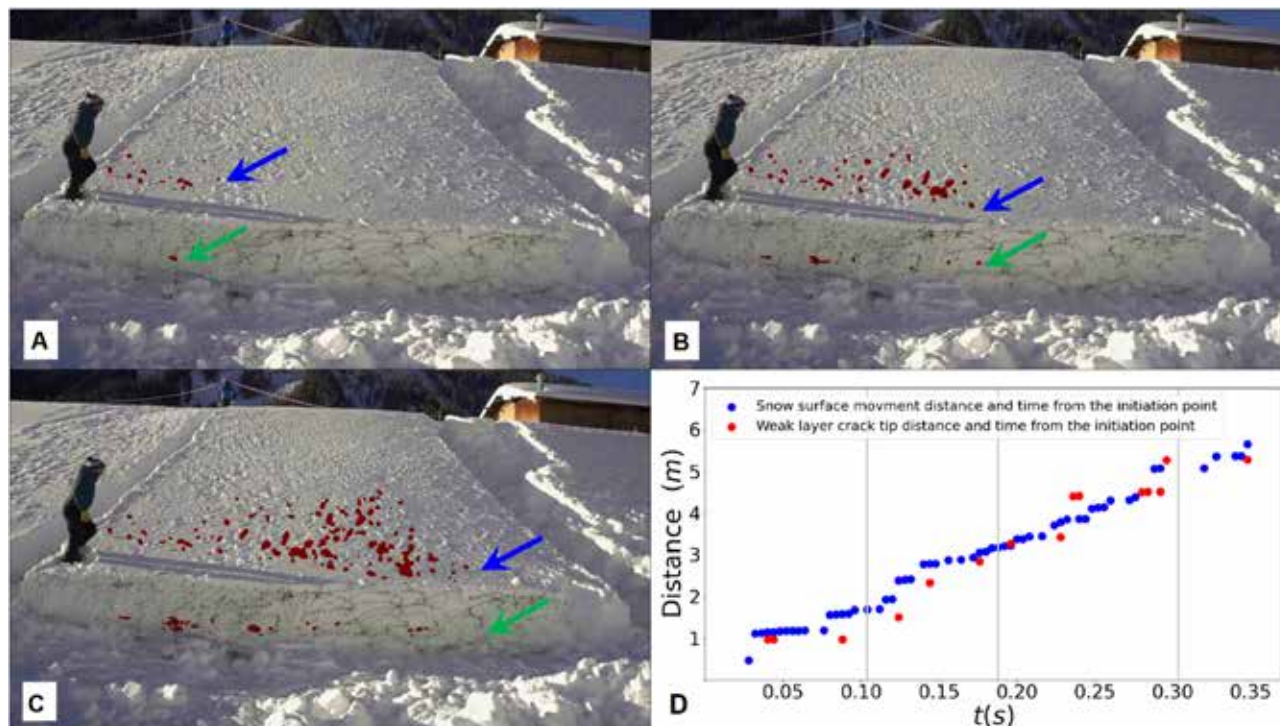


FIG. 2: A SEQUENCE OF VIDEO FRAMES WHERE BOTH SNOW SURFACE MOVEMENTS (MARKED IN BLUE ARROW) AND WEAK LAYER CRACKS WERE DETECTED (MARKED IN GREEN ARROW) AFTER 0.1 SECONDS (A), 0.18 SECONDS (B), AND 0.3 SECONDS (C). D SHOWS THE DISTANCE AND TIME FROM THE INITIATION POINT AND TIME FOR BOTH DETECTED SNOW SURFACE MOTION (BLUE) AND DETECTED WEAK LAYER CRACK TIP (RED). THE GRAY VERTICAL LINES IN D SHOW THE TIME OF FRAMES A, B, AND C.

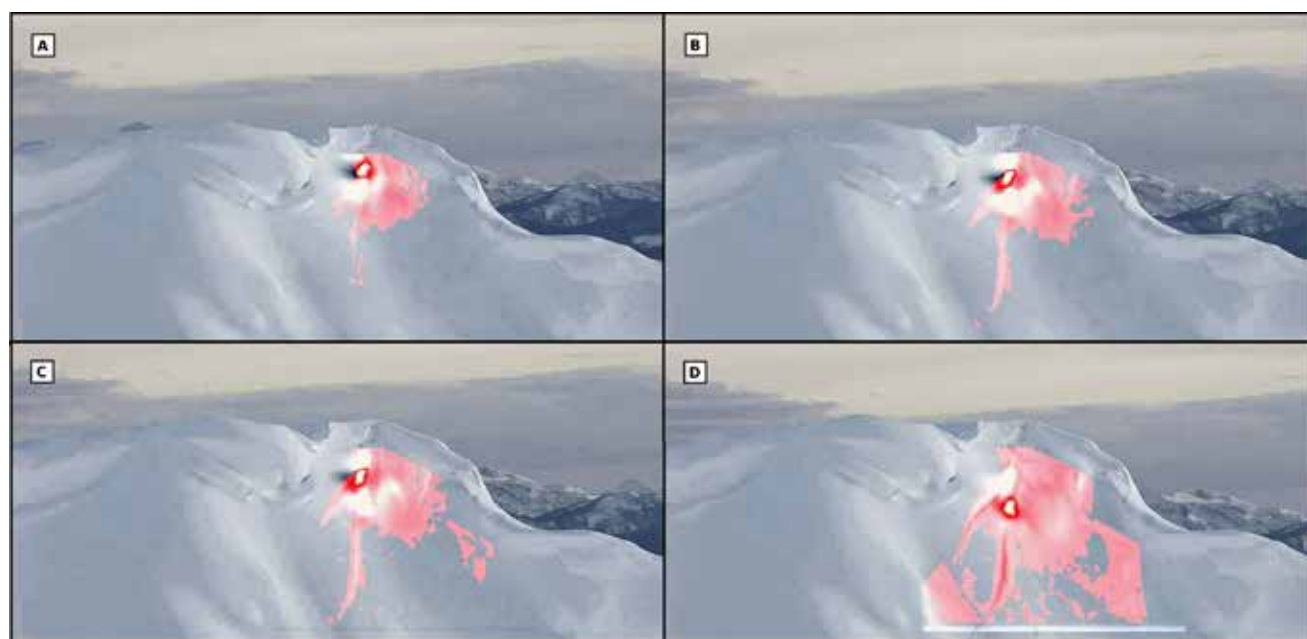


FIG. 3: A SEQUENCE OF VIDEO FRAMES OF AVALANCHE RELEASE. IN RED ARE THE LOCATIONS WHERE WE DETECTED SNOW SURFACE MOVEMENT UP TO THE TIME OF THE FRAME. INITIALLY, WEAK LAYER CRACK PROPAGATION IS DETECTED RAPIDLY ADVANCING DOWNSLOPE FROM THE SNOWBOARDER (A AND B). AS LARGER AREAS OF THE WEAK LAYER FRACTURED DOWNSLOPE FROM THE SNOWBOARDER, CRACK PROPAGATION ADVANCES SLOWER IN THE CROSS-SLOPE DIRECTION.

to estimate crack speed from videos of avalanches. This method employs subtle changes in pixel intensity to detect small movements on the snow surface, invisible to the naked eye (Simenhois et al., 2023a and 2023b). We assumed these movements were proxies for the advancing weak layer crack within the snowpack. We validated our assumption in a small avalanche experiment. The experiment was conducted on an isolated 10m by 10m section of a 30° slope, where both the snow surface and a wall exposing the entire snowpack were visible in the video. Comparing the snow surface movements and the crack tip in the weak layer confirmed our assumption. The detected snow surface movements reliably corresponded to the progressing crack tips within the weak layer (Fig. 2).

Subsequently, we applied our method to six avalanche videos, estimating crack propagation speeds in both up/down and cross-slope directions. Our findings revealed a significant increase in vertical crack speeds beyond 15 meters when compared to lateral crack speeds, averaging 138 m/s vertically and 34 m/s laterally (Fig. 3 and 4). By indirectly confirming the transition from mix-mode collapse to supershear, these speed estimates bolstered confidence in the model's validity. In addition, our results also suggested that the processes governing flat, up/down, and cross-slope crack propagation are different. On flat terrain, cracks propagate in collapse mode (anti-mode I). In the up/down slope direction, cracks propagate in the supershear mode (mode II) after reaching

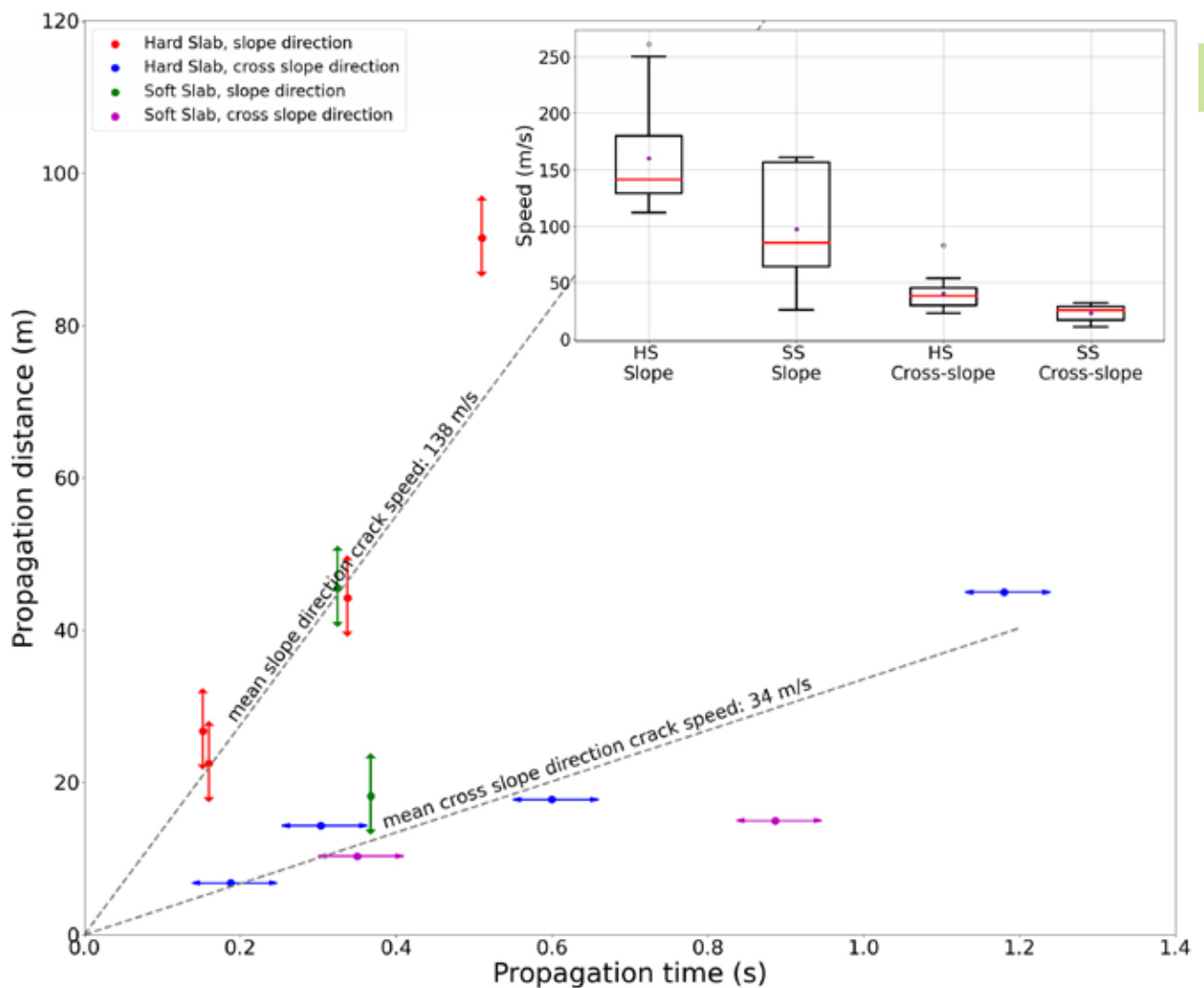


FIG. 4. REPRESENTATION OF THE MEAN VALUES FOR EACH AVALANCHE. THE ARROWS REPRESENT THE DIRECTION OF PROPAGATION (SLOPE AND CROSS SLOPE), AND THE COLORS REPRESENT SLAB HARDNESS. THE STEEPNESS OF THE DASHED LINES REPRESENTS THE MEAN SPEED FOR THE DIRECTION OF PROPAGATION. THE BOX PLOT IN THE UPPER RIGHT CORNER SHOWS THE CRACK SPEEDS BY PROPAGATION DIRECTION AND SLAB HARDNESS. WE SEE FASTER PROPAGATING CRACKS IN THE SLOPE DIRECTION COMPARED TO THE CROSS-SLOPE DIRECTION AND FASTER-PROPAGATING CRACKS UNDER HARDER SLABS.

the supercritical crack length. In the cross-slope direction, cracks propagate in mix mode III and the collapse mode. Researchers in Davos, Switzerland, are currently engaged in direct verification efforts for this model, further augmenting the scientific understanding in this domain.

PRACTICAL IMPLICATIONS

The concept of cracks propagating at varying speeds and propagation modes presents an intriguing perspective. Yet, as a highway avalanche forecaster, this knowledge doesn't help me sleep better at night during snowy weather. However, the observation of slower cross-slope crack propagation implies that cracks traversing the slope are more susceptible to being arrested compared to cracks progressing up/downslope. If this theory holds true, the installation of wall-like structures oriented in the vertical or downhill direction on a slope could locally reduce the slab thickness, enhance the spatial variability of the snowpack, and restrain avalanche sizes by arresting cracks before they span the entire starting area or by fragmenting a large avalanche into several smaller ones. Smaller avalanches tend to run shorter distances than larger ones, potentially mitigating their impact on vital infrastructure like transportation corridors.

Although the idea of employing up/downslope-oriented avalanche defense structures may seem unconventional, it mirrors natural occurrences. Natural sub-ridges have shown their ability to arrest cracks and restrict avalanche sizes.

Enhancing these natural interactions within the terrain, which influence spatial snowpack variability and arrest crack propagation, could prove beneficial.

Currently, avalanche defense structures in start zones aim to prevent avalanches entirely. This requires robust and dense deployment across start zones. By employing structures that limit avalanche size rather than prevent their occurrence, there's potential to reduce the need for such extensive and robust installations, translating to cost savings. However, it's crucial to note this approach may not be universally applicable, and in some scenarios, limiting avalanche size might not be an effective strategy. For example, assets at the bottom of start zones or locations within reach of avalanches, regardless of the avalanche size would be better protected with the more traditional, cross-slope defense structures. On the other hand, assets affected only by large avalanches relative to the start zone are good candidates for up/downslope defense structures.

Collaborating with Francis Meloche, a researcher from the University of Quebec at Rimouski; Grégoire Bobillier, a researcher from SLF; Johan Gaume, the Chair of Alpine Mass Movements ALMO at ETH Zurich and SLF Davos; and Ethan Greene, the director of the Colorado Avalanche Information Center, our preliminary work involves conducting simple numerical simulations on various structure configurations, such as different structure lengths up and down the slope and the number of structures on the slope to assess the

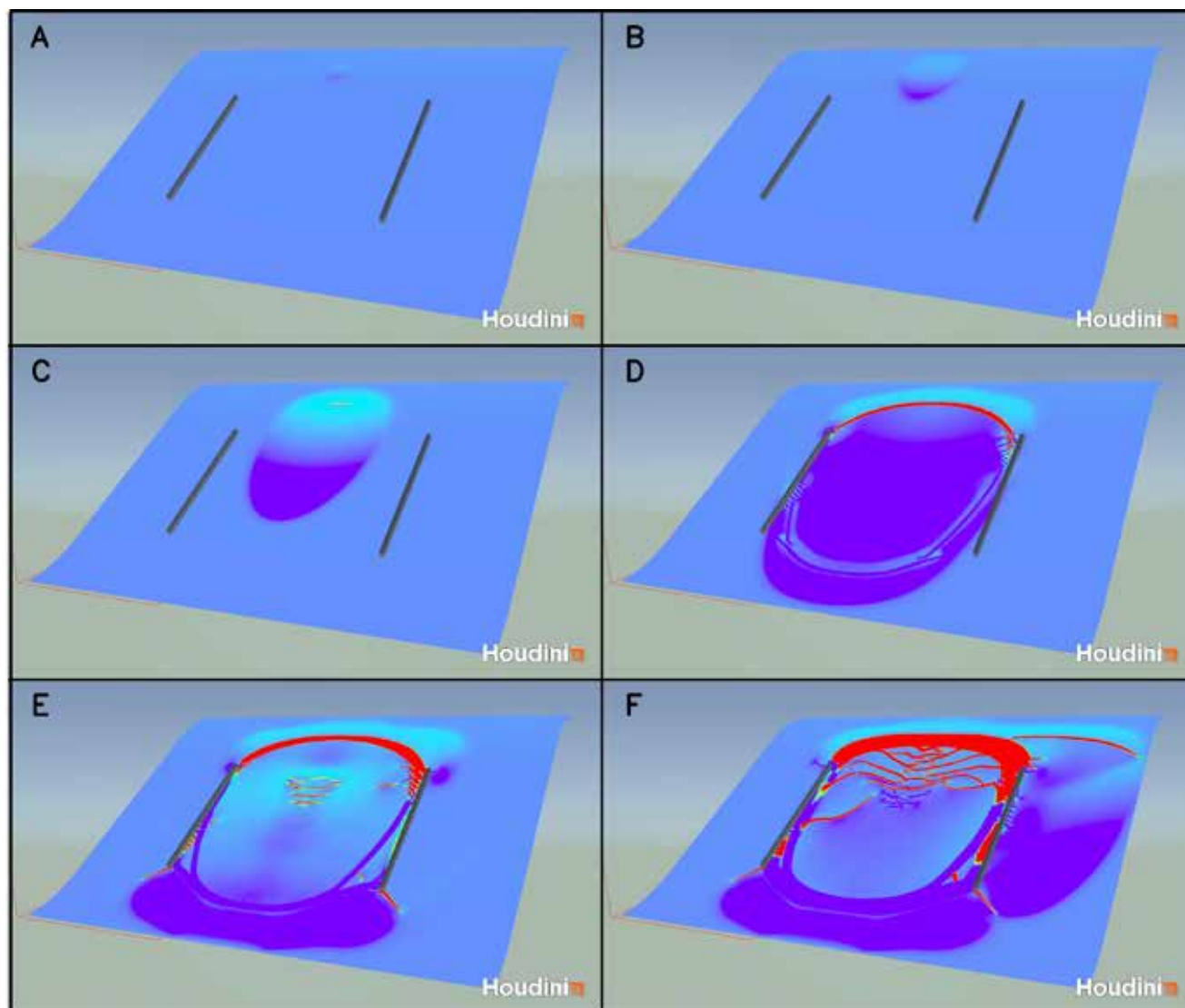


FIGURE 5: A NUMERICAL SIMULATION SEQUENCE DEPICTING TWO SHORT VERTICAL STRUCTURES ON A 50 M BY 60 M SLOPE COVERED BY A 0.5 M THICK SLAB AND 250 KG M⁻³ SNOW DENSITY SLAB ATOP A WEAK LAYER. A (TIME=0): THE SIMULATION INITIATES WITH A CRACK REACHING THE CRITICAL LENGTH, INITIATING DYNAMIC CRACK PROPAGATION. B (TIME=0.54S): AS THE CRACK EXTENDS BEYOND THE SUPERCRITICAL LENGTH, IT TRANSITIONS TO SUPERSHEAR CRACK PROPAGATION DOWNSLOPE. C (TIME = 0.73S): THE EMERGENCE OF THE CROWN WALL BECOMES EVIDENT. D (TIME=0.83S): CROSS-SLOPE CRACKS ARE ARRESTED BY THE VERTICAL WALLS, AND SLIDING MOTION IN THE SLAB BETWEEN THE WALLS BECOMES EVIDENT. E (TIME=0.96S): CROSS-SLOPE CRACKS CONTINUE PROPAGATING BEYOND THE RIGHT WALL FROM ABOVE. F (TIME=1.25S): THE CROWN WALL ON THE RIGHT SIDE OF THE SLOPE BEGINS FORMING WHILE THE AVALANCHE IN THE SLOPE'S CENTRE HAS BEEN IN MOTION FOR ALMOST 0.5S.

theoretical feasibility of this concept. Initial results suggest these structures can effectively constrain avalanche size by arresting cracks from traversing across the entire start zone. In cases where cracks persist across the slope, these structures tend to fragment a potential large avalanche into smaller ones. This prevents them from merging due to slower cross-slope propagation, thus limiting the overall runout distance (Fig. 5).

We're in the initial stages of exploring these ideas and require more numerical validations and field testing to solidify their viability. Nevertheless, we're enthused about the prospect of translating theoretical concepts into pragmatic solutions.

ACKNOWLEDGMENTS

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snow globe

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GEOFF FREER ON 1974 NORTH
ROUTE CAFE AVALANCHE

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CAA History Project

Geoff Freer on the 1974 North Route Café Avalanche and its Aftermath

Alex Cooper

ON JAN. 22, 1974, AN AVALANCHE STRUCK the North Route Café on Highway 16, 45 km west of Terrace. A major storm over the previous week had sent numerous avalanches down onto the highway. The café was located in large trees and believed to be a safe location. Eight people, including the owner and his family, were sheltered at the café, waiting for the road to re-open, when at 8 a.m., they heard a loud crack and suddenly found themselves being enveloped in snow.

The avalanche was discovered a few hours later by a passing helicopter and a major rescue operation was launched; there was only one survivor. In the months that followed, the B.C. government formed the Avalanche Task Force to look at avalanches across B.C., particularly as they pertained to highways. The lasting result of this work was the creation of the Ministry of Highways avalanche program.

Geoff Freer was working for the National Research Council (NRC) under Peter Schaerer when the task force was formed. He was appointed to the Task Force and went



on to establish the highway avalanche program. We spoke to him about his experience as part of an interview for the CAA History Project.



Note: This excerpt has been edited for brevity and clarity. A full transcript of our interview with Geoff Freer will be available on avalanchejournal.ca.

Alex Cooper (CAA): Can you tell me what you remember about that avalanche? Where were you?

Geoff Freer: We were at Rogers Pass working on snow avalanche research projects. It was, of course, big in the media, and being in the business, anytime you have any big avalanches or incidents, everybody's interested in trying to find out right away what happened.

The North Route Café was right beside the highway, and behind it were a bunch of pretty mature trees. But a very dry avalanche came and enveloped the café. One of the people that was killed was a Ministry of Highways snowplow operator that had stopped there for coffee. If you've been between Terrace and Prince Rupert, there's not too many places to have coffee. That was the place where people would stop on their way.

The MLA for the area, Graham Lea, happened to also be the Minister of Transportation. The government of the day decided they would form a task force and have a look at avalanches affecting highways across the province. In addition, the task force was to look at avalanches impacting hydro lines, ski areas, and industrial operations; but the focus was on highways.

The minister formed the task force in the Ministry of Transportation. There was a regional director out of Burnaby named Dudley Godfrey. He was an engineer, but he was also a ski touring fanatic and he had taken some of our NRC (avalanche) courses. He was chosen as the chairman. They hired Peter Schaerer, myself, and a snow control specialist working at Granduc Mine at the time, Roger Tremblay. In addition, a geotechnical engineer, Stephen Evans, provided support to the task force.

The assignment was to look at avalanches and transportation across the province and come up with recommendations for the minister in about six months. I think we started in May of '74, and we had to have a report in by October 1. The process: we went around the province,

looked at pretty much every avalanche area that was known at the time by Ministry people, and talked to a lot of locals as well.

Dudley Godfrey, being in the ministry, was pretty familiar with staff and also familiar with avalanches and incidents that had happened in the past on provincial highways. Of course, all the local people knew about avalanches, although they generally called them snow slides. Everybody was very forthcoming.

We did a report, presented it to the minister, and the government of the day said, "We're going to go with these recommendations." One was to hire a person to come into the ministry and set up a snow-avalanche program. As it turned out, the government asked me if I would take on the job, with Peter Schaerer's agreement, as I was currently working for the NRC.

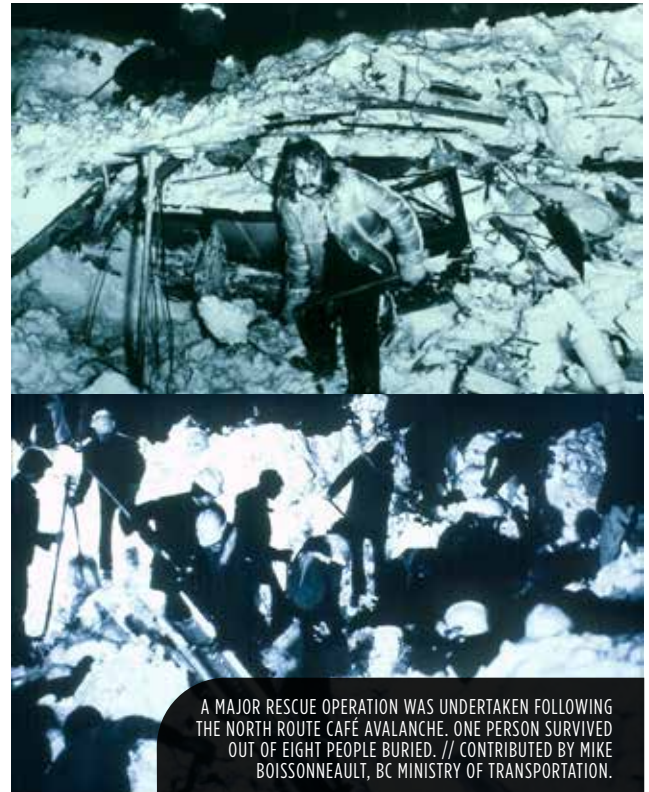
Being part of this task force, you had six months to get this report done. It sounds like it was pretty broad—it's focused on highway avalanche problems, but you mentioned ski areas, and I think is there was building codes or zoning as well mentioned as part of your mandate.

There's a lot to go into here, but what did you? What did you learn about how avalanche hazard was managed in the province while undertaking that work? What existed and how was it handled to that point?

Well, how it was handled was avalanches would come down and people would go with equipment and clean it up. In some places where people had been around a while, you would have a road foreman that was aware that if one avalanche came down, there might be more coming, so he or she would hold the crews back for a while. But that wasn't the practice generally. The practice generally was avalanches are down, just get the cats and loaders and go in and get the road open.

In terms of other considerations like zoning, like many natural hazards at the time, there wasn't much consideration given to these, even though there were subdivisions and other developments located in avalanche areas. A lot you wouldn't notice unless you were in the business. The same with ski areas and snowmobiling and recreation side of things—avalanches really weren't particularly considered from a government perspective.

Certainly, places like Whistler had ski patrol and did avalanche control work, but the government really hadn't taken a look at that from a ski area development perspective. At the time, there was a B.C. ski coordinator, and their job was to look at developing new ski areas and working with ski areas that wanted to expand their boundaries. That ski coordinator involved us as snow specialists in reviewing proposed new ski areas and expansions to ensure snow avalanche issues and mitigation



were considered. There was more government oversight to ensure snow avalanches were considered across the province; this hadn't happened much before the task force.

What was your role specifically with the task force?

I was the junior kid on the block, so I was the guy that did whatever and soaked up everything I could from people like Peter Schaerer, Dudley Godfrey, from a transportation perspective, and Roger Tremblay.

We did a whole lot of mapping, air photo work, mapping out the avalanches as best we could in the time frame we had. Just doing all the nitty gritty work, looking up historical information, interviewing people about historical things, trying to get a sense for each avalanche area in the province. And, of course, there were basically no records, so it was taking a 1:50,000 map, going out there again to find all the avalanche paths.

The best source was talking to the local road foreman about what had happened in the past. How frequently do these come down here, here, and here? They would really try and give us some data to then decide what should the ministry do.

We divided avalanche sites into three areas. High avalanche hazard areas, with lots of avalanches frequently, etcetera. Then ones that are more moderate. And then there's your low-hazard areas, where things don't happen very often, but they need to be paid attention to.



My work was a lot of the technical work in the background. We travelled a lot, visiting as many sites and talking to as many people as possible. The government of the day was very committed to the project.

For me and for Peter, for that matter at the time, we went to lots of places that neither of us had been to before. You go to a place like Stewart and Bear pass, and at that time the Bear Glacier came right down to the highway. There's just some beautiful places in this province, as you know. It was good.

You mentioned low-frequency paths. The one that hit the North Route must have been low-frequency, with mature timber right above it. So, understanding all those hazards or where they might exist?

I mean as much as possible, we were trying to put some science to terrain evaluation, avalanche frequency to the whole province in a space of six months. A big part of our recommendations was to continue doing that and create some accurate snow-avalanche atlases. One of the early-day projects was creating detailed snow avalanche atlases for each site.

Then we got down into the nitty gritty. We started a system to record avalanche occurrences. We set up weather stations and weather training for all the crews. We hired some avalanche technicians for the high-hazard areas.

But during the task force, it was do the best you can and give the ministry a sense for what is the problem and what are we recommending to mitigate the hazards—and that's what we did.

OK. And then you're brought on to implement these recommendations. How did you prioritize what to do when you were first starting the program?

Well, the report laid out things pretty well from that perspective. But really, the main focus right off the bat was the safety side of things. Making sure workers are trained, making sure all the workers have got the proper equipment, weather stations for forecasting, making sure that worker safety got taken care of right away. That was developing one-



AN IMAGE OF THE MOUNTAINS ABOVE THE NORTH ROUTE CAFÉ FROM THE AVALANCHE ATLAS CREATED FOLLOWING THE TRAGIC SLIDE. // CONTRIBUTED BY MIKE BOISSONNEAULT, BC MINISTRY OF TRANSPORTATION.

and two-day training courses. Every road foreman and shift foreman went for a five-day course that we were putting on at the NRC.

Worker safety was a first priority, and safety measures, rescue beacons, rescue equipment, etcetera. Signage was another one, and that was the public safety side of things. You can't train all the public, but at a minimum we've identified the avalanche paths. Now let's get some signs up to say, "Avalanche area, do not stop." Highway closures during high-hazard periods became more common as our knowledge and forecasting improved.

Those very basic things were the priorities. Let's make sure workers are safe, and let's get public safety going as

much as we can right away, and we'll figure out a lot of the more in-depth things going forward.

For example, we had made some recommendations about looking at areas for structural control, diversion dams, things like that. We left that as a lower priority and worked on that as we had time.

How did it shift from this into becoming a more active avalanche control program with forecasters in place? I imagine that was a process over a number of years, but how did that develop?

The task force identified high-hazard areas that we thought should have avalanche specialists for forecasting and avalanche control, so that was something else that we did right away. It took some time, but there really weren't any avalanche people in the ministry. There were some people interested, but they were for the most-part starting from Square one.

Some people from the ministry volunteered to fill those roles in Hope, Kootenay Pass, Stewart, Terrace, and Revelstoke. Those were the high-frequency areas and the areas that we thought deserved a more active program.

The focus was the same thing: weather stations, avalanche mapping, signing, training crews, and then also getting started on active avalanche control. Early days, we did helicopter bombing because we didn't have rifles or anything like that. We also did some case charging. As we had more time, and as things developed, the Coquihalla tried out an aerial tramway bomb system and also used recoilless rifles.

At the time it was interesting because in the avalanche industry, there was quite a bit of skepticism that the ministry would actually make this happen. Was this going to be just a one-time wonder? Was it going to be a report that ended up on a shelf and government never would never do anything about it? As it turned out, they were committed. I think as people in the industry saw government was committed, more people in the ski side of the business were willing to come in and work for the ministry because they knew the avalanche program was sticking around.

And now I think it's the biggest overall avalanche program in Canada when you combine all the areas. That's quite the thing to be at the start of. For you personally, what was it like for you to be involved in getting this off the ground? And how old were you at the time?

I was 24 years old.

Really, they needed somebody with a lot more experience than I had, but it just happened. There weren't a lot of people in the business in Canada at that time. Park wardens, heli-ski guides, which was a much smaller industry then; national parks, like Fred and Walter Schleiss' team at Rogers Pass; and



then some ski areas—Whistler in particular had a program.

That was an opportunity for me, but it was pretty scary at the time. Twenty-four, you're also trying to learn about everything else, and leading people, and trying to understand government and how government works, which was all new to me. But I had lots of help. The people that we did hire were very helpful. We've had great teams all the way through, and it was very interesting.

With mentors like Peter Schaerer, Paul Anhorn, Willi Pfisterer, and Fred and Walter Schleiss, I could call those people up and we had all worked together. That was actually the easier part, because they were all there to help me in the background, and we were still doing courses together and all that good stuff.

Probably the bigger scary thing was developing a whole team of people across the province and introducing the avalanche business into the ministry. There were certainly a number of folks in the ministry that thought this was way over-the-top and we shouldn't be doing any of this. It was a big organization and I'm a 24-year-old kid coming into the organization. I have to say, I had great support from the executive. We had assistant deputy ministers, deputy ministers and operations staff that were all very supportive. The chief engineer of the day also became a big supporter and mentor. They helped me in the organization. 📌

Flakes

ROB BUCHANAN

Question: What if new research in avalanche fracture mechanics was done by Buffalo Springfield?





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