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THE VOICE OF **CANADA'S** PROFESSIONAL AVALANCHE COMMUNITY

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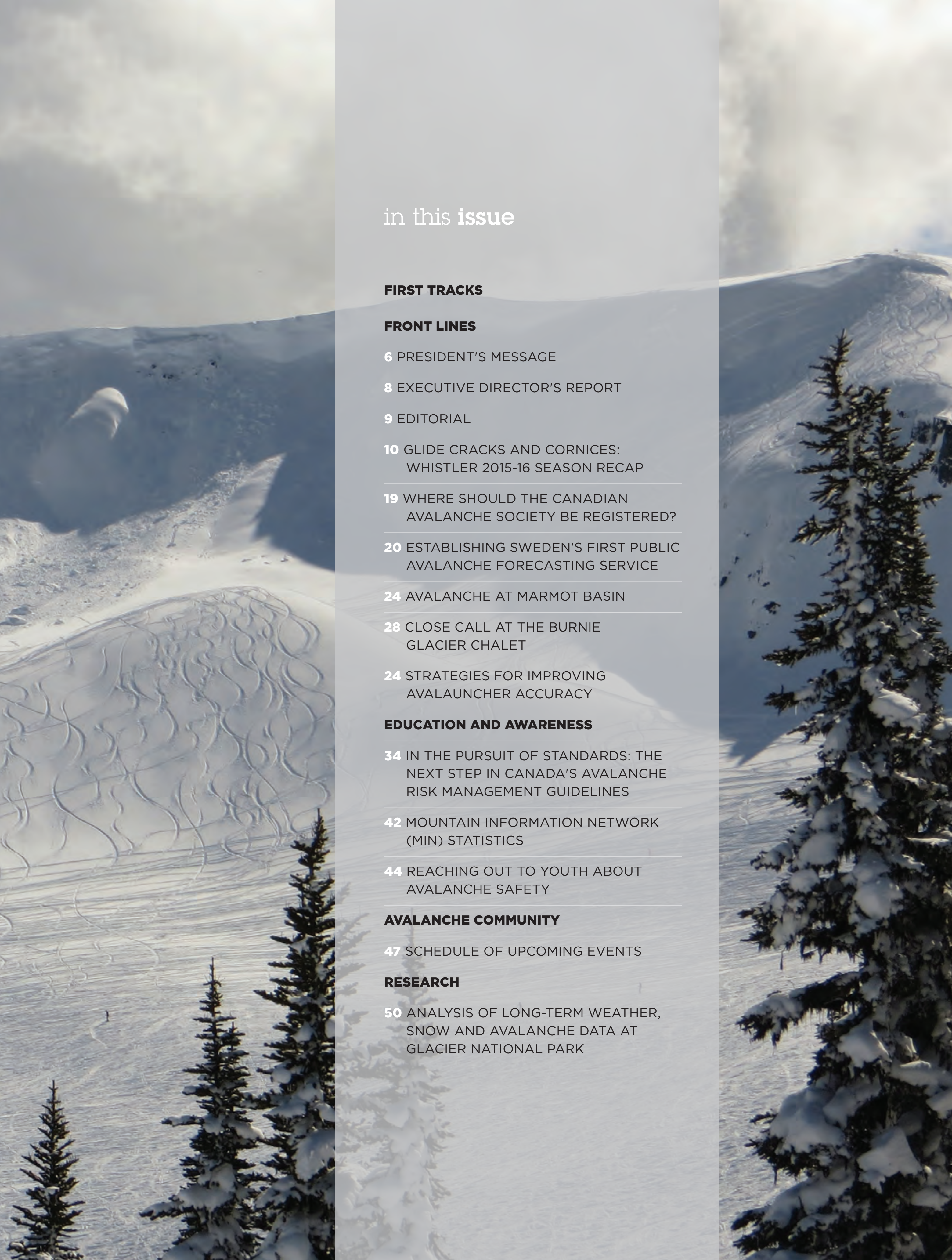

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Contributors

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TIM HAGGERTY
An Ontario transplant, Tim Haggerty moved to Banff in 2001 to take a year off university and ski. He then spent 10 years in the Rockies and five seasons in NZ working ski patrol and snow safety. He then moved to Whistler where he divides his time between ski patrol and snow safety in the winter and trail building and bike park patrolling in summer.
Tim will start teaching ITP Level 1 courses this year.
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PER-OLOV WIKBERG
Per-Olov Wikberg lives in Östersund, northern Sweden. He has been responsible for national coordination of Sweden's mountain safety-related issues since 2007. He also been leading an ICAR working group since 2011 focused on the international development of mountain safety. Since 2014, he has led the establishment of a national Swedish avalanche forecasting service. He will be in Canada this winter for his CAA L2.
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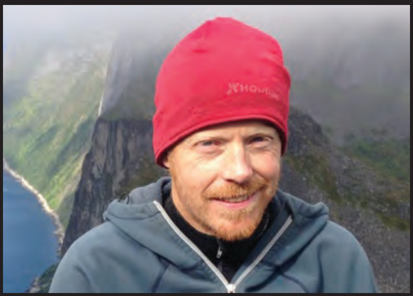

PETTER PALMGREN
Petter works with the establishment of the national avalanche forecast service at Swedish environment protection agency. Before joining the agency he had various occupations in the avalanche industry working with forecasting, ski guiding, ski – patrolling and as an avalanche instructor.
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JULIE MCBRIDE
Julie McBride lives in Squamish but spends winters in Jasper where she is the Assistant Director of Public Safety at Marmot Basin. Since leaving her native coastal snowpack to join Marmot Basin's avalanche control team in 2013, the Rockies have given her a new appreciation of depth hoar and redefined the term *bottomless powder*.
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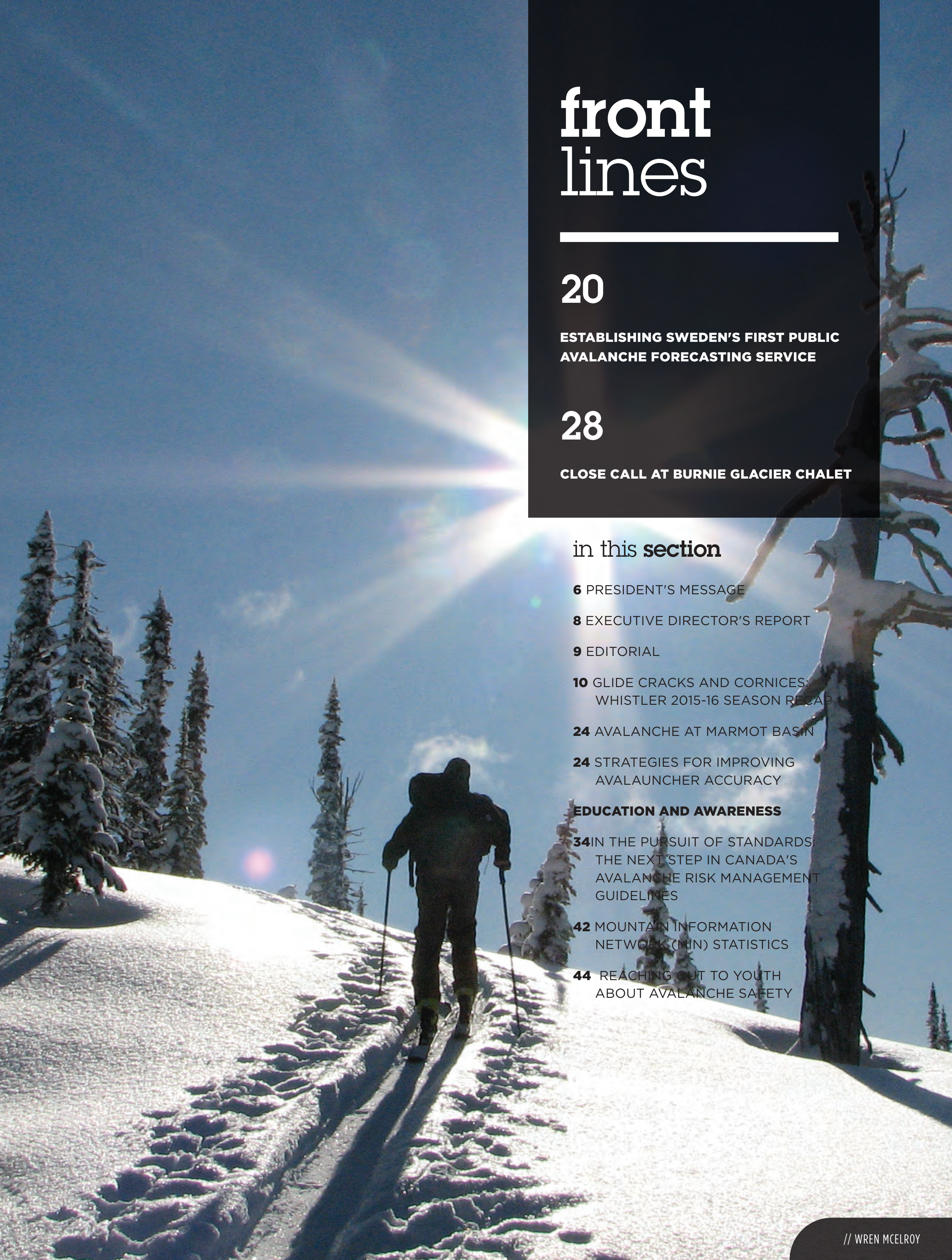

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// WREN MCELROY

President's Message

Walter Bruns
CAA President

IT HAS BEEN QUITE A RIDE to witness the evolution of our association over the past 35 years. From simple beginnings, we have come a long way to becoming an increasingly professional and sophisticated organization. It is now my honour to serve on the board of directors as president and to contribute directly to the CAA's future.

Aaron Beardmore presided over a huge surge in worthwhile initiatives during his six years as a director, the last two as president. On behalf of the entire membership, I extend a sincere thank you to Aaron and the many others who have worked so hard on our progression. As he passed the baton, Aaron was very clear in his outgoing message in the previous issue of this journal. There remains a lot to do.

We are off to a good start. Albi Sole and Mark Vesely conducted an exceedingly thorough independent member audit of the association's affairs last winter, offering many excellent recommendations. These are being implemented. We plan to change the fiscal year-end to November 30 and align the membership dues cycle accordingly.

Rocket Miller, who has served tirelessly as a director for the past five years and secretary/treasurer for the past year, has always advocated strongly for increased financial prudence and discipline. He outlines the need for CAA fiscal policy on page 7, along with his takeaway points from a year in the position. The intent is to clarify accounting practices for the three main pillars of our association: member services, the industry training program, and InfoEx. Each cost centre will strive to achieve self-sufficiency and ongoing sustainability by setting financial performance targets. Surpluses are to be accumulated separately and dedicated to their individual intellectual property development needs.

John Martland, our legal expert on the board, has monitored upcoming changes to the BC Societies Act and how those changes may affect the CAA. After extensive investigation and consultation, his recommendation is that we dissolve our BC and Alberta societies and incorporate federally. The required steps are no additional burden. Furthermore, they align nicely with other initiatives. For details, see his article on page 19.

Joe Obad drafted me (rather craftily) two years ago to join the competency profile working group. It was a delight to work with our highly effective facilitator David Cane, and the other group members. It was quite a challenge to come up with the 100 or so competency statements in a clear and comprehensive form.

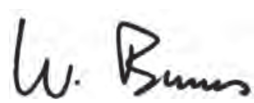
Well, what follows poses even greater challenges. ITP Manager Emily Grady identified gaps between the competencies we listed and the competencies we deliver in our courses. Doug Wilson and Colin Zacharias, after much head scratching and brain storming, forged a path forward. Bringing Steve Conger into the mix, we are well underway to map out, approve and implement next steps. Stay tuned to this work-in-progress.

In July, the board met in person for one and a half days to review the 2014-16 CAA Strategic Plan. It is a robust and relevant document, which we modified only slightly to guide the organization's path moving forward. The updated 2016-20 CAA Strategic Plan will be posted to the membership when edits are complete.

First and foremost, my role is to represent your interests as a CAA member. It is also to serve the interests of the organizations that engage CAA members, many of whom are associate members in turn. Finally, in keeping with our vision and mission, my role is to ensure that the CAA aligns ever more closely with the public interest.

Our association is a complex organization with many moving parts. I will strive for simplicity and clarity whenever possible. I will advocate for openness and transparency, collaboration and consensus in the conduct of our affairs. I look forward to working with my fellow directors, the many committee chairs and their members, and with Joe and the entire CAA staff in a team-based and collegial manner.

Best wishes for the fall and your preparations for the winter season.



Walter Bruns, CAA President

Notes From the **CAA Secretary/Treasurer**

Rocket Miller, CAA Secretary/Treasurer

THERE'S NEVER A DULL MOMENT when weathering the Secretary/Treasurer front—after all, money counts. The first year experience has been enriching. We are in a good financial position for a not-for-profit business. If you were not at the May AGM in Penticton, we explained our financial position as it is obligatory to do so when the membership gathers for an AGM.

There are three cost centres: ITP, InfoEx and Association. These combine to make up the beans of the CAA. Each cost centre is operated separately, however they ultimately work together to float the CAA financial boat. The idea is to produce black ink for each, with a target margin of 5-10%—and when they combine to equal $1.5 million, a $150K surplus sure sounds sweet. However, it isn't easy.

The nature of the ITP program, our biggest cost centre, is such that between advanced scheduling, registration and all the effort of the ITP staff, so much can happen before the course rubber hits the pavement. This can result in a drop of margins affecting the surplus. That's why this year we have decided to charge tuition based on course location in order to more accurately reflect associated cost (see page 41).

InfoEx operates on narrow margins. International sales have benefitted the bottom line on this cost centre. Both the aforementioned cost centres are controlled by their respective managers, and prices are set for fair market value and just downright good value for the end users.

The Association cost centre relates to all things membership and its revenues come from membership dues, which we set and pay. Dues must be ratified by membership at an AGM, thus we decide what we pay. At any rate, we need money to operate and maintain our relevance. The relevance of our association and others like ours is our raison d'etre. Hopefully this ain't a news flash to anyone.

Lately we have acknowledged the untimely nature of our fiscal year end. We have known for a long time that ending our year on March 31 and then producing the year end numbers in time for the AGM is uncomfortably tight. We heard the staff's plea loud and clear this year so we are looking at shifting to November 30 as our year end. So far it looks good, and while there are numerous hurdles to leap, our goal is a gold medal (this may not be Rio 2016 but it's fun to pretend). We'll keep you posted.

We are reviewing present fiscal policies and how they benefit the CAA, its staff, its members and those who engage the CAA in all manners. Fiscal policy sounds official and it is—fiscal policies are set and provide guidance on how we handle the finances of the CAA. The goal is financial health, stability and sustainability. We have many assets, including intellectual properties, real estate and dynamic human resources, and we must fairly and carefully exploit these assets to progress our association.

As I enter my second year as Secretary/Treasurer, I also enter my sixth year on the board—the swan song year. Among all my desires, at the top is departing the board with the CAA in a better financial position. The folks on the CAA staff are very capable, as is the board. Together we'll get a few things done and by next spring's AGM some new fiscal policy will be ready to present. Be there or be square, because, as always, you may be sitting in a whole chair but you'll only need the edge for this presentation.

ROCKET DOING MARKET RESEARCH IN CHAMONIX

Joe Obad
CAA Executive Director

CAA Executive Director's Report

AS WE HEAD TO PRINT WITH THIS EDITION of *The Avalanche Journal* the harbingers of fall are in the air: cooler nights, touches of yellow at elevation, and calls from CAA members preparing for the season ahead. I hope all CAA members enjoyed the summer. Riffing off the fall for this issue is a cliché, but suffering for lack of a unifying theme I offer these updates like those yellow leaves quickly dropping!

At the AGM in May, the membership affirmed the direction we're taking towards competency-based training, entry-to-practice requirements and ongoing competency management. Following the AGM, the CAA Board of Directors was quick to push for a plan to deliver on this promise. There's no moss growing on new President Walter Bruns, I tell you—Walter has keenly pursued the direction laid out by out-going President Aaron Beardmore.

In June we locked ourselves in a room to look at what's required to align the Industry Training Program, membership requirements and Continuing Competency Management with competency profiles developed for future Active and Professional members. We explored, we argued, we haggled, and in the end we wrestled into shape a four-year plan to deliver the bold promises of competency-based membership. Why so long? In a word, training.

To assess members in a competency-based system, the CAA must ensure those individuals have a reasonable chance of meeting assessment criteria—this is mainly, though not entirely, done through training. Overhauling the Avalanche Operations Level 1 and 2 programs and other courses to ensure they align with the competency profiles is a foundational next step. We have conducted an initial gap assessment to identify where the Level 1 and 2 programs would change, but more work needs to be done to turn the initial assessment into a work plan for the subject matter experts and curriculum writers to overhaul the programs. Unsurprisingly, this kind of effort requires significant funding. After several development-intensive years at the CAA, the board wants staff to look at several external funding avenues so we don't stretch our resources on this effort. Stay tuned for more news on this front in the months ahead.

In InfoEx news, we are working with the InfoEx Advisory Group on a simpler subscriber agreement we hope to get in place this fall. InfoEx Developer Luke Norman and InfoEx Manager Stuart have chipped away at the development list that users identified and the IAG prioritized. Lastly on the tech front, we are looking at an open source tool to phase snow profile functionality into InfoEx.

In ITP there is a changing of the guard as we welcome Emily Grady back from project work to her usual ITP manager position. Emily's transition back to ITP Manager is also aided by the creation of a dedicated project team to develop the forthcoming Incident Commander course that will first run in December 2018. We owe a big thanks to Bridget Daughney for stepping into the ITP Manager role while Emily was on leave or working on special projects. Juggling students, instructors and all other aspects of ITP is not easy, but Bridget's commitment benefitted all CAA members. We thank her for that, and for doing so with humour and a ready stash of chocolate when things got tense. We wish her well in her travels in Europe.

Beyond the ongoing competency work, association updates include finalization of an application process for members wishing to be considered retired or late in career. The board and several staff also met in July to develop a draft strategic plan that is currently under reviewed by committees and will be sent out to the membership this fall.

Finally, I would like to point out two member-driven initiatives that lever the advantages of the CAA. This past spring, some of you may recall ski resorts with explosives control programs struggling with new rules from the federal Explosives Regulatory Division (ERD). The rules severely restricted the quantity of explosives stored at hillside magazines, forcing more handling and transport of explosives by practitioners as restocking cycles made up for small storage. While some might view the problem as an industry issue for Canada West Ski Areas Association (CWSAA), there's also a practitioner component due to our members suddenly handling many more explosives.

CAA Members and the Explosive Committee came together to work with me and the new CWSAA head Christopher Nicolson. We slugged away on several conference calls responding to ERD and engaging some consultant experts thanks to CWSAA funding. After pressure from our group, ERD relented and placed regulation G06-03 into abeyance for the summer with a commitment to engage practitioners before bringing in another regulation. Three cheers for everyone in this group for showing again CAA that members working together can advance practice and stand up for safety in the field.

Practitioners of all sorts will come together at ISSW 2016 in

Breckenridge but CAA members should start setting eyes on Fernie. Professional member Steve Kuijt has led the member charge to host ISSW 2020 in Fernie. Any former ISSW member recognizes this huge commitment. The Fernie bid for 2020 is pivotal for future ISSWs. Recent ISSWs have tended to be nestled into professional conference centres, while Fernie offers an alternate vision where a small town creatively uses its facilities to bring the world's practitioners together. Their bid should be cheered by every small mountain town around, as well as by CAA members!

The commitment of the "explosives gang" and the ambition of Kuijt and Fernie offer us all examples to follow heading to this season. I wish all members the best with the season ahead—set ambitious goals and pursue them with resolve.

Joe Obad, CAA Executive Director

Welcome Back, **Snow**

Karilyn Kempton
Managing Editor

IN JULY, I WAS FORTUNATE TO ATTEND the strategic planning session with the CAA Board of Directors, along with ED Joe Obad and Operations Manager Kristin Anthony-Malone. The board and staff spent hours poring over all six goals and their respective objectives in the current strategic plan and discussing where to go next with that living document. The 2014-16 plan has been a solid reference point for the board on how to govern its own actions and advance the CAA, and the group agreed that the main themes of the plan continue to apply. The exercise really highlighted what a thorough and impressive job was done creating the 2014-2016 Strategic Plan, and while we have accomplished many of the objectives laid out in that plan it continues to be the reference point for our path forward.

If you think any of this sounds boring, you're wrong. Discussion was energetic and passionate, and it's clear that the board continues to feel strongly in the work that this organization is doing, even the directors who have joined well after the current strategic plan was created. Sure, it's not always thrilling, but board and committee work is a rich experience and it really helps you to feel invested in the future because you're a part of it. Joining organizational or local boards is a really effective way to get more involved in your community, network with peers and grow as a leader, and you can be proud of what you help accomplish. If you've never considered joining a CAA committee or the board of directors, spend some time thinking about what interests you and where you think your specific skills and interests might be of value to the association and consider dropping your name in the hat in years to come.

President Walter Bruns brings you his first president's message and it's obvious we're lucky to have him at the helm for his enthusiasm and knowledge. Two other board members, Rocket Miller and John Martland, also contributed to this issue to update you on association business.

If you were at the technical presentations at the spring conference you may remember a several of the case studies included in this issue, which I hope you find valuable. Two of those, Julie McBride's "Avalanche at Marmot on page 24 and Christoph Dietzfelbinger's "Close Call at the Burnie Glacier Chalet" on page 28 dive into what goes through our heads after accidents or close calls, and how to productively address those emotions (or attempt to).

A few updates from the public avalanche safety front include a new avalanche forecasting service in Sweden utilizing InfoEx, an update from Avalanche Canada on how their Youth Outreach Coordinator Shannon Werner targets youth, and a breakdown of some statistics from the Mountain Information Network, which I hope many of you are using or recommending.

I hope you enjoy the issue. Feedback is always welcome at editor@avalancheassociation.ca, as well as suggestions or pitches for upcoming articles.

I also hope you had a rejuvenating summer and feel healthy and happy about the coming winter. Welcome back, snow.

Karilyn Kempton

THE INSIDE LOOK

Glide Cracks and Cornices: Whistler 2015-16 Season Recap

LAST YEAR'S 2015-16 EL NIÑO WINTER BROUGHT A LOT OF SNOW TO WHISTLER, BC, including significant weather events which came with mid-mountain freezing levels and occasionally substantial rainfall to approximately 2,000m. Whistler Mountain records snowfall at the Pig Alley weather plot, located in a sheltered location at an elevation of 1,650m. The 2015-16 winter brought our maximum snow height to 375cm, our fifth highest on record. The elevation at the top of our highest lift is 2,180m.

A number of significant avalanche events occurred on Whistler Mountain during the course of the winter. In January 2016, we had a glide crack release in a start zone named Robertson's. Following this event, we observed significant cornice growth due to the mild temperatures and consistent SE storm winds. Most of these significant storm cycles had a cooling trend in their wake.

Story and Photos by Tim Haggerty

ROBERTSONS NATURAL SIZE 3.5 GLIDE CRACK/WET SLAB AVALANCHE

ROBERTSON'S

Sometime between the evening of January 28 and the early morning of January 29, a natural size 3.5 glide crack/wet slab avalanche released in the Robertson's slide path. This slope had not seen an avalanche of this magnitude in 36 years.

Robertson's is a steeply treed start zone above a green road traverse that sees heavy traffic when this zone is open. It is also an egress route for groomers on the night shift when avalanche clearance is given. It is an ESE/SE slope which averages 38 degrees at a tree line elevation of 1,875m, and is undercut by a cat road below.

Glide cracks often form here in periods of extended warm weather or during heavy rain events. However, no matter how much explosives testing we have done over the years, we have never had one release.

The creep and glide over the years have pulled most of the rock anchors and stumps out of the ground, and adjacent trees are sometimes uprooted as well. When the snow finally melts, the rocks and stumps tend to roll or slide on the wet surface down and over the lower road. The end result is one of our few start zones that can be at threshold when we have a height of snow of not greater than 50cm.

The last big event on this slope happened on February 20, 1979, and claimed the life of a local skier. This zone was outside of the operational ski area boundary at the time. The fracture line measured 1,200 meters across, affected multiple start zones and averaged one metre deep. The contributing factors were a shallow, below average snowpack with a 40cm thick depth hoar basal layer. A mid-February storm cycle dropped 130cm of snowfall over this base, and was accompanied by strong SE winds. The trigger was determined to be skier accidental, but multiple groups were on the ridgeline that day and the fracture line was so long that it was hard to determine who actually triggered it. A fellow named Robertson was buried at the very end of the ridge close to where the road is now cut. This incident can be found in *Avalanche Accidents in Canada III.*

The snowpack this season was dramatically different from that of the winter of 1979, with above average snowfall accumulation and an above average height of snow at 1,650m. We also had four significant rain events that played a factor in this climax avalanche.

The first significant rain event happened on November 12, 2015. We had a height of snow of 87cm at Pig Alley weather plot (1,650m). A storm cycle brought 35cm of snow followed by 21mm of rain to as high as 2,000m elevation. The HS then settled to 73cm. On November 17 we received another 18cm of new snow, again followed by 19mm of rain to 2,050m. The freezing level quickly lowered to the valley bottom by 5:00 pm, forming a crust that, once buried, would become our first persistent weak layer (PWL) of the season.

During this rain event we witnessed our first natural wet slab cycle of the year, running on the previous crust. Glide cracks in a nearby basin named Sunbowl were observed. Our second rain event happened on December 3 through December 4. We received 65mm of rain to 1,800m. A brief lull in the systems allowed us to observe various natural wet slab releases, including a size 2.5 on Cowboy Ridge. This terrain feature is located just outside our boundary toward Singing Pass. The following storm cycle brought cool temperatures, another 90cm of new snow and strong SE winds. On December 8, toward the end of this cycle, an additional 21mm of rain fell to 1,950m, resulting in a saturated, upside down upper snowpack.

Temperatures again began to cool as 90cm of low density new snow fell over the next six days. Our height of snow had now doubled to 184cm. Our coldest temperatures of the season set in around Christmas break, where we saw average temperatures of -10°C for a week.

The third significant rain event happened on January 21 and 22. The freezing level fluctuated between 1,700m and 2,000m. We received 25cm of snow followed by 25mm of rain on January 21, and 10mm of rain followed by 7cm of snow on January 22. The freezing level lowered on January 23 as temps cooled to -3.0°C at 1,830m.

On January 24, cornices became brittle and we had our first skier accidental cornice failure in Flute Bowl (resulting in an injury, but no burial). Small glide cracks were observed opening up in Robertson's in the usual place: the upper skier's right start zone.

The fourth and most critical rain event happened on January 27 and 28. Rainfall totals of 78mm fell to 2,000m in a 24-hour period, followed by a rapid cooling that finished with 10cm of snow falling on the newly-formed crust. Our alpine terrain would remain closed on January 28 until the saturated snowpack stabilized.

On January 29, with the cooling trend and limited explosive testing results, we were well on our way to a full opening in the alpine. The groomers were given avalanche clearance in the morning to make their way through Burntstew Traverse, the green road under Robertson's. One of our drivers nonchalantly called in "some larger debris" on the road below Robertson's and asked if he could clean it up. The answer was yes. We normally see size 1.5 to small size 2 wet loose avalanches release naturally and cross the traverse with these rain events.

The first control team who came across the debris were a couple of junior patrollers who called in a size 3 avalanche that failed and stepped down to a basal layer. The radio was silent with doubt. Our head forecaster Anton Horvath went to look and confirmed a size 3.5 wet slab failure. My route partner and I were doing explosives cornice work in Flute



ROBERTSON'S PATH WINTER AND SUMMER


HIRO OKAZAKI DEPLOYING A CORNICE SHOT IN THE CIRQUE

TYPICAL MORNING IN THE BOMB SHACK

CONTROL SHOOT ON MAIN 2 CLEAVE

HIRO OBSERVING MAIN 2 CLEAVE

Bowl at the time, so we were next on scene. Both of us were thoroughly impressed with what we witnessed and began documenting. We were instructed to lap around to conduct a fracture line profile. The refreeze had already taken place and the site was safe to approach from the top. We determined that the slide had taken place at some point during the night since there were two to four centimetres of snow on the bed surface. The glide crack I had observed in the previous weeks was gone.

The fracture line measured 18m wide and ran for 250m, the lower 150m of which ran through mature timber, breaking branches up to seven metres off the ground and taking out some 30-year-old trees as well as some larger 40cm diameter trees. The deposition was up to four metres deep. The trees adjacent to the slide had marks on them from the 1979 event, but had 30-year-old trees spaced between them.

The fracture line profile revealed that the bed surface was the November 17 MFcr, laminated and approximately 35cm thick. The failure plane was roughly 30cm of wet 3mm facets which had started the rounding process. The fracture was between one and two metres deep, the top 40cm of which had already dried out with the rapidly cooling temperatures while the mid-pack became progressively wetter until water started running freely on the bed surface.

The facets we found would have been formed during the mid-December outflow event. With the slope situated predominately windward and the east aspect causing the relatively thin snowpack to see quite a bit of solar effect, even in early and mid-winter, Robertson's sees frequent rapid snow temperature changes and strong temperature gradients. Average grain size in this area is bigger than anywhere else in our tenure.

The fracture line ran predominately where the ground cover changed from treed and rocky to smooth and grassy, allowing for a significant decease in the downslope friction when combined with the likelihood of free running water/slush on the laminated bed surface. As the snow at the surface began to refreeze and contract, it would have increased the tensile stresses rapidly and allowed for a full depth slab to release and propagate widely.

This combination, though different than 1979, resulted in a similar climax avalanche on Robertson's. It would be hard to repeat this as a dry snow climax avalanche in this day and age due to the amount of daily skier compaction this area receives from early December onwards. We will definitely be more vigilant when major rain events are forecast in the future, especially when we have a significant basal crust.

CORNICE INCIDENTS AND MITIGATION

On Whistler Mountain we have approximately 1.3km of cornice lines along our ridgetops. On a big control day, up to 13 control route teams are utilized to deal with these and other smaller isolated cornice features, as well our many other slide paths in our upper elevations.

Almost all of these cornice lines have an intermediate groomed run in close proximity. This allows easy access for our valued customers with no mountain knowledge to go "sightseeing" and take beautiful pictures from the edge of the world. We mitigate these cornice lines with a combination of signage and rope fences, sometimes to no avail.

Our above average precipitation amounts, average temperatures of -3.0°C at ridge top, and moderate to strong SSE winds accompanying each storm cycle combined to allow for substantial cornice growth starting in January and continuing on into April.

January 24 was the first sunny day after a seven-day storm cycle that brought us 90cm of HST and moderate to strong SSE winds. The temps had cooled from 0.0°C to -7.5°C. We conducted avalanche control throughout this storm cycle producing size 1 to size 3 storm slab results, but only size 1-1.5 cornice results.

Flute Bowl reaches an elevation of 1,990m and faces NE through NW. Cornice control was done that morning in the Flute area on Main 1 and Main 2. Around 11:00 am, a 27-year-old snowboarder walked out past the cornice signs on Main 3. The cornice released behind him and he fell approximately four metres, losing his board and riding on top of the debris and coming to rest on the staunchwall. He strained his lower back and was tobogganed out. The cornice that released was a size 2.5 that also released a small soft slab on the underlying slope.

That afternoon we proceeded with cornice clean up in the Flute area with larger two and three-kilogram Emulex shots producing a few more size 2.0 cornice falls.

The next cornice incident followed a month later in the same area. February 22 was a scattered cloud-cover day and the temperature had dropped from -4.0°C the previous day to -8.5 °C that morning. We had received another 150cm in February and the last storm that rolled through brought moderate but steady SSE winds. The height of snow had maxed out at 265cm and had begun to settle and stabilize over the previous 24 hours. We had not done avalanche control or cornice work since February 20, since all the slopes had since been skied and were mostly well compacted.

At 11:20 am, a 26-year-old snowboarder walked out past the cornice signs onto Flute Main 1 to the apex of the cornice line to get a better look. He promptly fell through as he approached the edge, triggering a size 2.0 cornice fall, which released a

ANTON HORVATH IN THE DEBRIS OF MAIN 1 CONTROL WORK

PROBE LINE IN SUNBOWL, APRIL 2016

storm slab on the slope below. He fell approximately five metres and slid down on top of the debris. The whole event was witnessed and called in by an Extremely Canadian backcountry guide with precise and accurate information. No one was injured. The site was quickly cleared by one of our CARDA dog teams.

A cleave in the Flute cornice that began opening up the previous week started to show signs of widening. We did cornice clean up work around Main 1 on February 23 with only size 1 results, but decided to hold off on the cleave until we came back with bigger charges. We were worried that two-kilogram shots would be ineffective, but could destabilize the cleave. We came back on the February 24 with two bags of ANFO and a couple of singles to make holes for the ANFO to rest in. As it turns out, the cleave had become quite fragile and a one-kilogram shot did the trick and pulled out a big size 3.0 that caused the immediate slope below it to release to ground.

March came in like a lion with 280cm of new snow falling in the first two weeks. On March 13, our height of snow reached 375cm, our highest HS in four years and fifth highest since 1972. These storms were accompanied by strong SSE winds and an average temperature of -3.0°C. Cornices had grown to very large sizes, despite our team's daily trimming.

Billy Goat Rock is a west aspect at 2,015m, located in Whistler Bowl directly under the Peak Chair. We had done cornice control here with significant size 3.0 results on February 9. We continued to place charges on it during the March storm cycles, but it was being stubborn to unreactive and continued to grow.

On this day we had overcast skies in the morning for avalanche control. Cornices' bellies were being stubborn but touchy fresh tabs continued to grow. At 2:00 pm a report came in of a female snowboarder who was injured after colliding with debris from an unwitnessed cornice failure in a high traffic traverse area of Whistler Bowl. The injured guest said that she was carrying speed in limited visibility across the traverse because the debris was not there the run before.

Ski tracks witnessed during the investigation led us to believe that the cornice failure was a Sa or Sr triggered from someone skiing on the cornice beyond the warning signs. Due to limited visibility it went unreported. It was a size 2.5 cornice release with size 2 loose snow entrainment. It did not run far but there was up to 1.5 meters of debris over a 20m by 20m area. The scene was cleared with spot probing and a CARDA dog team.

By March 13 temperatures had began to cool, falling to -10°C on March 15. Another cleave had formed behind a cornice on the south end of Flute Main 2. A two-kg shot managed to release the whole cleave, which was about the size of a tour bus, a size 3.5. Further cornice cleanup resulted in multiple size 2 to 3 cornice releases.

On April 3 the remaining mature cornice on Flute was made vertical following a good crust recovery after several days of max temperatures reaching +10 °C. This was another size 3.5 cornice result that gouged the slope below to ground and entrained the loose wet snow below. At least we got to it before the public did!

Last but not least, on April 11 at 1:00 pm an unwitnessed natural cornice released in the Sunbowl in an area called Vail East. It was reported as a size 2.5 cornice failure with loose wet entrainment by a passing patroller. Vail has an east aspect at 2,015m that loads with southerly winds. Intermediate skiers tend to traverse into this slope from below, so an involvement could not be ruled out.

Control work was done on this cornice during the previous weeks with size 2 results. It was mainly vertical leading up to its natural release. We were in a spring diurnal cycle and temperatures reached as high as +13 °C at 1,830m with a gradual cooling trend in the past 48 hours. We had seen the most significant crust recovery that morning with air temperatures of –1 °C.

By early afternoon the broken cloud cover produced a strong greenhouse effect and the crust had broken down to mashed potatoes, but foot penetration was holding steady at 20cm. Control work that afternoon resulted in more size 2 stubborn cornice chunks. The car-sized chunks entrained the lower slope to bare rock in the upper 40m.

At Whistler Mountain we tend to do limited clean-up control on cornices during the morning in any areas that affect grooming and make a mess of the skiing product. We tend to schedule any clean up in the afternoon after the terrain is swept. Obviously this cannot routinely be done during storm cycles, so by the time the dust had settled this season, we threw close to 300 percent more cornice shots during morning control work compared to the previous year. We found that as cornices grew bigger, two-kilogram shots worked best when placed on top while cornices were fragile. If we missed that short window, then buried linked charges were the best way to produce clean vertical walls. Unfortunately, this technique is much more time- and labour-consuming compared to surface shots, but it is often our tool of choice as conditions dictate.

Looking back on it, that was a good season of snow safety! Mother Nature definitely proved to us that cornices become brittle as warm snow is affected by cooling air temperatures. But the most important lesson learned was don't let the familiarity of your own terrain dictate your choices. Cleaves do sometimes go and glide cracks can slide!

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Where Should The Canadian Avalanche Society Be Registered?

John Martland

IN MAY 2015, the BC Legislature passed the new Societies Act (2015), which takes effect on November 16, 2016. It replaces the former BC Society Act (1996), under which the CAA has been registered since 1981 as a not-for-profit society. The CAA is also registered in Alberta under the Societies Act, 2000. However, we also qualify for registration under the Canada Not-For-Profit Corporations Act (2009) and if we choose to do so could become a federal society. The CAA Board of Directors formed a Jurisdiction Committee to analyze which option is best. The Committee compared the choices and consulted with appropriate outside experts. Here is what we found about our various options.

REMAIN REGISTERED IN BRITISH COLUMBIA

The new BC legislation makes a number of new demands on current societies like the CAA. To remain in BC, the CAA is required to transition from the old act to the new act. Much of the work to transition is technical and/or legal in nature and, while time consuming and involving legal cost, those changes are not difficult to implement. Examples of such changes are filing a new constitution, filing new conforming bylaws, approving the new bylaws at a general meeting, and preparing a consolidated legislation package.

The concern we have identified is this: under the new Societies Act, the CAA logically would declare itself as a "member funded society," but unfortunately we may well be prevented from doing so due to the government funding that the CAA receives. There may be an argument that the particular government funding we get is not covered, but there is no certainty to that position and it would require either a bureaucratic ruling or a court order to sort out. This would be expensive and time consuming.

If we are not a "member funded society" then other restrictions apply, including: 1) disclosing all remuneration paid to directors, employees and contractors; 2) restrictions on the number of directors who could be employed by, or work under contract with, the CAA; and 3) providing public access to the CAA financial statements.

In summary, the BC option is not particularly attractive as it involves considerable legal work, expenses and uncertainties down the road.

REMAIN REGISTERED IN ALBERTA AND DISSOLVE BC SOCIETY

The Alberta Act, while recently revised, is far less restrictive than BC, but there may be changes similar to those in BC (and Ontario) coming in due course. The CAA is much more connected to BC and we would have to register in BC as an extra-provincial company. This option would also require dissolving the BC society with attendant costs and consequences. Overall, there appears to be little advantage to making this move.

REGISTER UNDER THE CANADA NOT-FOR-PROFIT CORPORATIONS ACT

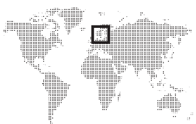
The CAA is in an excellent position to come under the Federal legislation. Our society is truly national in scope with members in BC, Alberta, Quebec, Newfoundland and the Territories. We can continue to keep our head office in BC but subject to federal requirements. While it is relatively straightforward to become incorporated, there are a few requirements we would face (including specific voting classes of members, annual audits and extra provincial registration in BC). The CAA would fall under an act that has been in place since 2009. The act is based on the long standing Canada Business Corporation Act, which at this point has a good history as to interpretation and meaning in past court cases. This means that difficulties understanding certain sections of the act can be understood in the light of past review in court.

A move to the federal statute would mean discontinuing the BC and Alberta registrations, and assigning the BC assets and liabilities from the BC society to the new Canada not-for-profit society. There would be legal costs involved in making the switch. The annual audit requirement would involve some additional accounting fees, more than is currently involved in having a review engagement under the BC legislation.

THE RECOMMENDATION

Whatever jurisdiction we choose, there will be some work and costs involved. In considering the best position for the CAA, it appears at this point that a move to register under the Canada Not-For-Profit Act is our best course of action. It should be noted that while there will be some bylaw amendments required as a result of changes to the membership categories caused by the Competency and Professional initiatives, these changes can as easily be done under the federal legislation as in BC . The board will complete its review of the situation and move ahead in the next few months to implement the best possible path forward.

Establishing Sweden's **First Public Avalanche Forecasting Service**



Per-Olov Wikberg and Petter Palmgren, Swedish EPA

INTRODUCTION

Sweden's launched its first public avalanche forecasting service in the winter of 2015-16. Initiated by the Swedish government's Environmental Protection Agency (SEPA), it's a milestone for public safety in the country. The first avalanche bulletins were published in January 2016, and daily bulletins were issued for three regions. The forecasting service was reliable and worked well, and we felt it has succeeeded in reaching the main user groups. Over the next three years, the forecasting service hopes to cover up to eight regions, encompassing most of Sweden's mountainous areas. The main goals of the Swedish avalanche service are to reduce the number and severity of avalanche incidents and to provide visitors to the mountains with good information for decision making, leading to safer mountain experiences.

Unlike other European countries, Sweden chose to follow international standards with the North American Danger Scale and the Canadian Conceptual Model of Avalanche Hazard. Over the past fifteen years, Sweden's avalanche education system has been heavily influenced by Canadian avalanche education standards, and Sweden is also the first country in Europe to use the InfoEx observation exchange platform based on OGRS inputs.

BACKGROUND

Over the past ten years, 29 people from Sweden have died in avalanches either in Sweden or outside the country. Like many parts of the world, the use of avalanche terrain is increasing, leading to more accidents.

Avalanche incidents in Sweden primarily involve winter recreationists; the Swedish mountains see approximately one million visitors each winter. Backcountry users like skiers and snowmobilers put themselves at varying degrees of avalanche risk, and the need for reliable public avalanche information has long been discussed. The need for a public avalanche service was first investigated in the 1950s, and has been requested by the Swedish skiing and snowmobiling public several time since.

Two important trends during the last decades have highlighted the need for avalanche forecasts in Sweden. The first is evolving terrain use in the mountains, with more recreationists travelling in steep or complex terrain and thus exposing themselves to more avalanche risk.
The other is the globalization of winter recreation. Swedish skiers are likely to ski not only in Sweden but also abroad, and Swedish mountains are increasingly popular among international visitors. Both of these factors highlight a need for avalanche information in Sweden that conforms to international standards.

Since 2001, there have been 39 Swedish citizens killed in avalanches—mostly in other countries. Swedes have been overrepresented in avalanche fatalities abroad, and there is an assumption and hope that if Swedish skiers get more accustomed to accessing public avalanche information for informed decision-making, they may seek out avalanche conditions and adapt to conditions when skiing abroad, as well as at home.

SEPA's mandate to provide an avalanche warning service includes three components: establishing the avalanche forecast and warning service for Swedish mountains in cooperation with other relevant actors; taking on principle operational responsibility for the operations (outsourcing some operational duties to relevant sectors as required); and being responsible for governance and funding.

Managers and forecasters are based in the city of Östersund, while area managers and field observers are on the ground in the forecasting regions. Three regions were established for the first winter of operations: Åre/Bydalen/Storulvån, Hemavan/Tärnaby and Abisko/Björkliden/Riksgränsen. When choosing forecast areas, priority was given to popular winter recreation areas. Other factors included areas with a history of many avalanches, and availability of local avalanche expertice. The intent was also to spread the regions around geographically to ensure widespread relevance.

SEPA has taken on the operational responsibility for the avalanche warning service and important parts of the daily operational work has been outsourced. The 2015-16 forecast service was funded with approximately $3.5 million Swedish kroner.

GEOGRAPHY

The Swedish mountain range stretches 1,200km along the Norwegian border in the northern half of the country. The mountain range is old; in most areas it is comprised of simple avalanche terrain abundant with access to plateaus, broad valleys and broad ridges. Avalanche accidents involve, with few exceptions, people who have sought out steep terrain, and they are a mix of recreationists and workers.

The network of automated weather stations is relatively sparse, especially at higher altitudes. Most of the area is sparsely populated with few roads. Villages and tourism is concentrated around major roadways. This means few visitors in a large portion of the mountainous terrain during low season, which, in the northern part, extends well into February when the sun returns.

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THE 2015-16 SEASON

The SEPA published the avalanche forecasts on a standalone website at lavinprognoser.se. The goal was to offer clear, concise, simple information that was easy to receive and read, and would be easily recognizable and understandable to visitors who read avalanche bulletins in other countries.

The SEPA aimed to make the main message understandable to those with limited avalanche knowledge. The simple avalanche danger scale comes first, followed by a more technical description of the avalanche danger.

ORGANIZATION

The organization aims to balance central coordination with effective local management of daily work using area managers. The area managers are responsible for coordinating the daily collection of field observations, making twice daily hazard assessments, evaluating the forecast products and transferring all of this information to the forecasters in Östersund.

The main daily staff consists of a forecaster who issues daily forecasts for the three regions; an area manager in each region who evaluates the issued bulletin and makes an avalanche hazard assessment twice a day, and prioritizes and coordinates observations in the region; a varying number of field observers; and a meteorologist from SMHI who delivers weather forecasts and weather support, as well as offers a daily telephone/video conference.

A total of 25 people were contracted as observers, area managers and writers for the season, as well as a large network of paid observers and an even larger network of voluntary contributors. Decisions and assessments are often made at the local level, while forecasters are responsible for all the regions. Although the organization is small, it was designed to have more than one person involved in assessments.

PRODUCTION

During the season, daily avalanche forecasts were issued daily at 17:00 for three regions. Some forecasts were also updated in the morning. Forecasts extend for three days. The forecast has been based on three principle sources of information:

- A contracted local network.
- Weather information, forecast and automated weather data from the Swedish Meteorological and Hydrological Institute (SMHI) and other sources.
- Cooperation with local actors such as ski areas, tourist companies and the public.

Sweden has few weather stations and we presumed that public reports would be sporadic due to recreational public's irregular use of terrain. Therefore, we concluded that a successful avalanche program in Sweden would need to compensate for that data sparsity by organizing a professional network of observers to ensure a reliable information flow. Information flows through two main channels: daily conferences between local networks and forecasters, and InfoEx for exchanging technical information.

Area managers in each region made a hazard assessment twice a day during the season. The area managers and observers used Canada's Observation Guidelines and Recording Standards for Weather, Snowpack and Avalanches (OGRS) as the standard. During the first year, more than 300 observations of avalanches and snow cover information were collected. Close to 1,000 manual weather observations were delivered, in addition to SMHI's automatic weather observations.

THE SWEDISH USE OF INFOEX

In December 2015 CAA Executive Director Joe Obad and InfoEx Manager Stuart Smith visited Sweden to give us a great introduction to the CAA's InfoEx software.

In 2016, SEPA purchased a license to use InfoEx software as the platform for technical information exchange between observers and forecasters. InfoEx is largely perceived as reliable, and was proven to be an effective tool to organize, structure and document data and as decision support. InfoEx was also used to document the work of consultants, their risk analysis before field trips, and for reporting risks or incidents during the work. InfoEx places relatively high demands on specialist knowledge in order to be fully utilized and probably has a slightly higher entry threshold than some other similar programs.

SEPA intends to find an alternative method to increase interactivity between public users and the forecast service. This is for a few reasons: SEPA's assessment is that organizations and companies tend to report less if their reporting system is completely open to the public, and InfoEx is not a suitable platform for collecting public avalanche reports.

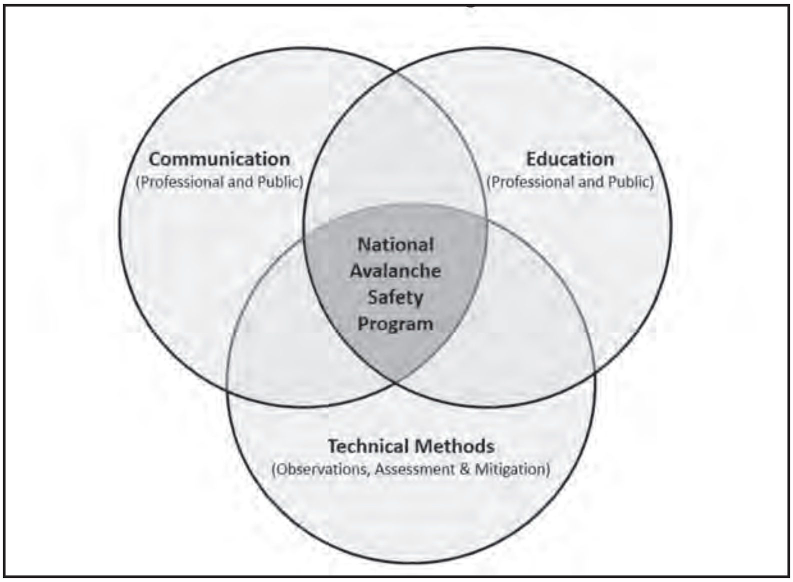

FIG. 1: THE THREE STRATEGIC COMPONENTS OF AVALANCHE SAFETY PROGRAMS, AND HOW HARMONIZATION BETWEEN THEM CAN INTERSECT FOR NATIONAL LEVEL PREVENTION PROGRAMS.

TRAINING STANDARDS AND COMPETENCE REQUIREMENTS

Professional-level avalanche training and proof of experience is required for most assignments as forecast writer, area manager or observer. Since 2001, Swedish avalanche professionals have taken their professional training in Canada through the CAA's Industry Training Program. These programs offer a staged, apprenticeship style of training founded upon teaching consistent and standardized methods for avalanche forecasting. Forecast writers and area managers must have accomplished at minimum the CAA's Avalanche Operations Level 2, and observers must have taken at least a CAA Avalanche Operations Level 1 or similar. Pre-season training focuses primarily on skills specific to the task of creating national avalanche forecasts.

EVALUATION

SEPA used an online survey for users, the general public and professionals to evaluate the first season of the avalanche forecasting service. Canada's Grant Statham visited in April to provide an international evaluation of the program, as did the 25 participating avalanche technicians.

The results of the evaluation process were positive. The program is considered to have been established well, and is well-regarded compared to other countries' forecasting services. The participating evaluators provided constructive suggestions to refine work processes and methodology.

Statham offered a number of recommendations, including the establishment of an incident reporting system, in order to eventually evaluate the effectiveness of preventive work; expanding the number of forecast areas slowly and making sure there is local expertise in each new area; continuing work on Sweden's avalanche training program, because educating professional and recreationists is crucial to the future success of the avalanche forecasting service; and increased cooperation with the Norwegian avalanche forecast service in terms of communicating comparable forecasts.

DISCUSSION: THE FORECASTING MODEL

In the absence of a national avalanche service in Sweden, avalanche forecasting and managing avalanche risk has happened at the local level at ski areas over the past 15 years. Local forecasting has also been used in guiding, in transportation and by the Swedish armed forces. This means that avalanche forecasts were introduced in a context where certain established industrial standards already exist. Those standards are primarily learned in professional avalanche courses, and the national Swedish avalanche courses have, in general, been based on the CAA's ITP course system for 15 years.

During that time, a Swedish version of the North American danger scale has been used, along with adoption of OGRS as a national standard. More than 150 people have taken the an Avalanche Technician course, similar to CAA Avalanche Operations Level 1. Nearly 3,000 people have taken shorter recreational avalanche courses.

Although we consider avalanche forecasting an important part of preventive work, it is not the only factor and so Sweden has been implementing a Canadian approach to structuring its avalanche industry for 15 years. As most readers probably know, the two variations of the international avalanche danger scale are European and North American. In SEPA's assessment, the differences between the scales do not have much effect on the recreational public. However, their underlying structural differences have practical implications in the professional setting.

While geography was a strong argument for Sweden to use the European danger scale, we took a broader look at the avalanche industry as a whole. Avalanche education is key, and we are convinced that our decision to base our course system on the CAA's Industry Training Program is right. From that followed the choice to keep using OGRS, along with the Conceptual Model of Avalanche Hazard. That said, we encourage work to bring the two existing standards together to create one international avalanche danger scale in the future.

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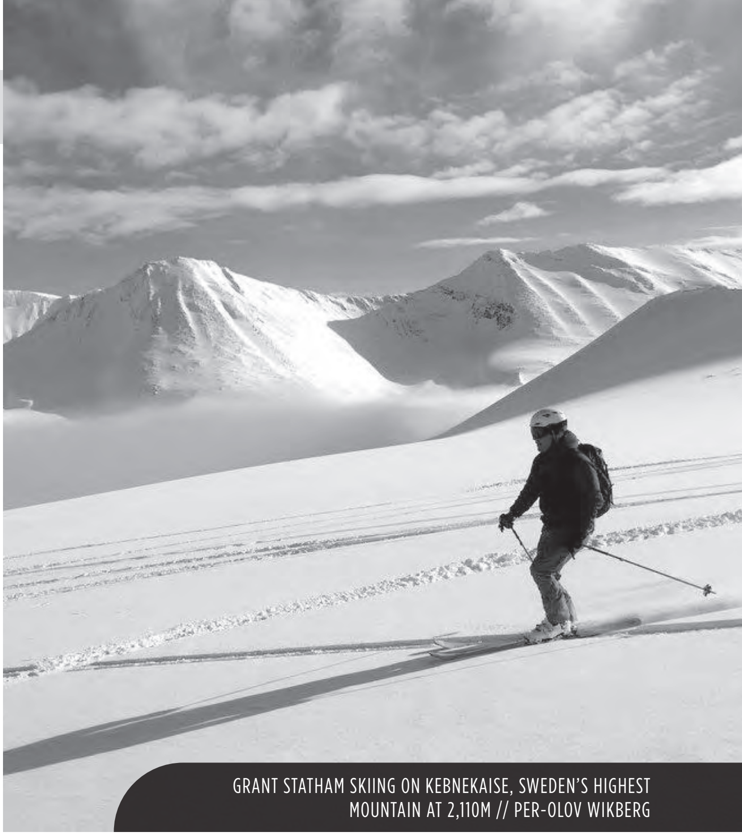

GRANT STATHAM SKIING ON KEBNEKAISE, SWEDEN'S HIGHEST MOUNTAIN AT 2,110M // PER-OLOV WIKBERG

PER-OLOV WIKBERG WITH GRANT STATHAM ON THE PEAK OF ÅRESKUTAN, 1,424M // GRANT STATHAM COLLECTION

AVALANCHE AREA OBSERVER JENNY RÅGHALL, GRANT STATHAM, UIAGM GUIDE ANDERS BERGWALL, AVALANCHE AREA MANAGER MATTIAS HELLGREN AND PETTER PALMGREN FROM THE NATIONAL FORECAST SERVICE // PER-OLOV WIKBERG

A SA IN CHUTE 6 AT MARMOT BASIN // JASON RECHNER

Avalanche at **Marmot Basin**

Julie McBride

FOR MARMOT BASIN, Friday, January 29, 2016 marked the end of a nearly two-month drought. Although November blessed us with a dump of snow during our opening week, December and January had forsaken us. Our last appreciable snowfall had been seven weeks prior on December 9. The arrival of the much anticipated storm was also the harbinger of a human-triggered avalanche cycle from the Icefields Parkway to McBride, BC. A total of five separate events involving avalanche professionals as well as recreationists all occurred within a 200km radius of Marmot Basin. It was a busy day in the avalanche world near Jasper, one that would ultimately cast a sombre shadow over our operation for the remainder of the season.

During the drought, temperatures had ranged from just below –20°C to just above freezing with a week of sustained cold. With less than 90cm of snow on the ground, Marmot's was a textbook continental snowpack—shallow and weak, facets throughout, sitting on a base of depth hoar. Although the "storm" delivered only 8cm of snowfall in 24 hours, it was accompanied by moderate to extreme southerly winds, that formed a new storm slab. Friday, January 29 was our first avalanche control morning in weeks.

As the forecaster that morning, my first priority was an Avalauncher shoot that produced results from size 1 to 2.5, with the larger releases initiating in the storm slab and then stepping down to a layer of facets and depth hoar, 50-70cm down. Satisfied with these results, I turned my attention to Charlie's Bowl.

A northeast to southeast-facing alpine bowl with a series of steep, rocky chutes below its entrance adjacent to the Knob area, Charlie's Bowl had not yet opened for the season. In mid-November, Chutes 5 through 7 had released to ground during a natural cycle. A week later, Chutes 5 and 6 failed to ground with explosive control work. With more explosives in December, Chutes 6 to 9 released to ground for a third time. By mid-January, ski cuts produced only small results in isolated pockets of thin wind slab. We began ski compacting and waited for more snow to open Charlie's to public. Late in the afternoon on Thursday, January 28, with over 100 sets of tracks around me, I stood at the top of the Chutes, snow and wind obliterating my visibility, hopeful that we might be getting close.

The first two one-kilogram hand charges in Charlie's Bowl on the morning of the 29th produced no results. Two more 1kg charges, deployed simultaneously at either end of a broad apron above the Chutes, also failed to produce a result. With no more explosives, I proceeded to ski cut from my position at the top of Chute 8. Once I was clear, my partner, one of our avalanche technicians, did the same in Chute 5. While ski cutting we both noted a 10-15cm thick, 1F slab that was penetrable on skis, but no signs of fracture propagation or releases other than small fist-sized slab cookies. Then I decided: the avalanche tech would take two patrollers and continue ski cutting in Charlie's to break up the slab, while I moved on to another area with a third patroller.

Minutes after we'd parted ways, I got a call over the radio from one of the two patrollers in the Chutes: "We've had a deployment; he's on top…" *Oh shit*. The tech had gone for a ride. Then a second call from the tech: "I'm ok." *Thank God*.

As the tech skied into Chute 6, a small pocket of wind slab had propagated into the rocks above him and then stepped down to ground. With no escape, he'd deployed his air bag and was swept by a size 2 for nearly 200m to the flats at the base of the chutes. Spotting from above, his partners reported that he'd been on top of the slide the entire time and that when it came to a stop, he appeared to be sitting upright in the debris, his legs buried to the hip. He had lost both skis and one pole but was able to self-extricate. By the time his partners had made their way to him, he was free and clear of the runout zone, a bit shaken but understandably so. Although he had tweaked his lower back while twisting to release from his skis, he had somehow managed to otherwise emerge physically unscathed from a rather nasty ride through some very thin, bony terrain.

No stranger to ski cutting, it was the tech's third involvement during his seven-year tenure at Marmot. His propensity for triggering avalanches was already well established. At 6'8" and 260lbs, he has been known to trigger slopes where even large explosives have failed. His skis sink deep into the snowpack and he has a knack for finding the sweet spot.

In addition to his formidable stature and reputation, his pursuits outside of work invoke similar images of unbreakable nerve and strength: base jumping, parachuting and backcountry sledding. This is someone who had been hired as an avalanche tech not only for his knowledge and experience, but also for his ability to remain stolid and clear-headed in stressful situations. It came as no surprise that after debriefing with the control team he was ready to get back on the horse, so to speak.

Back at the top of Chute 6, he gladly volunteered to place a 6.75kg sack of explosives into the hangfire. The shot cleaned out what was left, taking Chute 7 to ground along with it and releasing the thin storm slab in Chutes 8 and 9, which ran over top of the ski cuts in Chute 8 from a few hours earlier.

That afternoon, details of other larger events to the south and to the west of Marmot began to circulate on the news and within industry channels. A Visitor Safety Officer from Jasper National Park had been involved in a skier-accidental size 3 that deposited nearly two metres of debris on the Icefields Parkway near Parker Ridge, closing the highway. And at least 15 snowmobilers from three separate groups were involved in a size 3 machine accidental near McBride that resulted in the deaths of five snowmobilers.

Amidst these rumours and half reports I went home that night and

AERIAL SHOT OF MARMOT BASIN // MARMOT BASIN contemplated the decisions I had made that day: where I had failed, what I could have done differently, what I had learned, what I would do differently now, what I would do in the future. My head reeled from the cerebral merry-go-round.

As avalanche professionals we spend a great deal of time talking about avalanche problems and avalanche hazard, and how things like variability, uncertainty and confidence play into our analysis of what the problem or hazard actually is. We also talk about human factors: nebulous sub-conscious phenomena thata can sometimes lead us to miss or misinterpret pieces of information, or bias our intuition and instincts.
Even though we employ various tools, decision aids, methods and procedures to avoid mistakes of both the analytical and the human kind, sometimes unexpected or unlikely things happen. Sometimes we get caught in slides. That is just the nature of snow on steep slopes. And it is why we also practice and teach avalanche rescue skills. There is always uncertainty and sometimes we get it wrong.

While I knew that my decision to continue ski cutting that morning had turned out to be a bad one, the reality is that the possibility of going for a ride exists every time I or someone else ski cuts a slope. Still I couldn't help feeling that I'd let the team down, in particular the tech who had been the victim of my decision. An element of complacency had crept in during the drought. Having seen little change from day to day for seven weeks, I'd underestimated the effect of a little bit of new snow and some wind on our deep persistent layers and what a light trigger in the right spot could do, even in worked terrain. My confidence was rattled. Our snowpack was weak and unpredictable, and the head forecaster and I resolved to punctuate future control missions with larger explosives.

In the week that followed, it was obvious that the tech who'd been involved was clearly struggling to deal with how he had been affected. He was having trouble sleeping, he was having nightmares, his hands trembled, his head just wasn't in the game and the pain in his lower back had worsened. We sent him to a doctor, a physiotherapist and a critical incident stress counsellor. We filed a workers' compensation claim and he was placed on light duties.

The physiotherapy sessions continued, the counselling sessions continued. Weeks passed, then months. His mood and progress seemed to ebb and flow. Every day was a different day, each with possibly a different challenge. He started experiencing panic attacks. He was frustrated.
With no manual, tools or methods guiding us in supporting him, we—his supervisors—were frustrated. We

CHARGES LARGE AND NUMEROUS // MARMOT BASIN PATROL talked, we talked with him, we talked with our managers, we talked with WCB, then we talked some more. I suggested that perhaps some time completely away from the work environment would help. He opposed; he felt that his anxiety was something he had to face head on and that stress leave would be counterproductive to learning how to overcome it. I was skeptical but conceded. After all, I was no expert and I admired his dogged determination. He was doing everything right. And while he struggled, the rest of us carried on, not for lack of compassion but for lack of other options.

The season continued much as it had begun, with little snowfall and low confidence in our snowpack. We opened most of our avalanche terrain eventually. Large and numerous explosives continued to produce large avalanches running on deep persistent weaknesses. We were cautious and conservative. Temperatures remained above freezing throughout most of April. An impressive iso-cycle ripped out moguled runs down to the basal depth hoar; our suspicions were vindicated. As we packed up our gear on our final day of the season, the tech was clearly still struggling. I watched the panic wash over his face when someone deployed an avalanche airbag for summer storage, triggering a flashback and the anguish of his trauma. My heart broke. *It's the last day, what happens now?*

The tech has since been diagnosed with an adjustment disorder. Over the summer worked with a team of professionals (a psychologist, occupational therapist and a physio/personal trainer) overseen by a specialist in traumatic psychological injuries. It is still a long road ahead but one that he is facing with courage and optimism. He is Hercules to me, and like all parables his trials hold a lesson for us.

When avalanche professionals talk about human factors, we need to talk not only about what goes on in the subconscious prior to our decision of whether or not to ski into a slope, but also potential consequences of that decision at the psychological level as well. Although we find it easy to casually discuss the physical consequences of an avalanche with euphemisms such as "raked through the trees" or "cheese-grated over the rocks," we rarely discuss how the same event might affect one's mental health. Or if we do, it is often in hushed voices, behind closed doors: "Why can't she just deal with it?"

That is because psychological or mental health issues of any kind have a stigma in society in general. It's not polite to talk about the elephant in the room or the crazy uncle in the attic, so to speak. And this is precisely the reason why we need to talk about it, because the patroller who goes to a wreck or the tech who goes for a ride or the guide whose guest gets buried might not be able to. They might not even recognize that they've suffered a traumatic psychological injury, never mind have the strength to admit it to themselves and ask for help. As their supervisors, we need to build our knowledge and understanding of "mental health first-aid" and have these tools in our proverbial tool-boxes when we start the conversation.

JULIE AND THE TECH INVOLVED // JASON RECHNER

NW SIDE OF TOM GEORGE MOUNTAIN

Close Call at the Burnie Glacier Chalet

Story and Photos by Christoph Dietzfelbinger

INTRODUCTION

Close calls and accidents are just a step apart. While close calls do not have the serious consequences of an accident, they still demonstrate that risk management has at least partially failed. While the organization behind the Burnie Glacier Chalet is very modest, consisting essentially of me, sometimes another guide, and a cook, I try to operate as a highly reliable organization. In this article, I have used Reason's Swiss cheese model to explore where my organization failed and which layers in it—combined with a healthy dose of luck—were able to prevent catastrophe.

One of the key challenges in guiding is putting the large volume of available information into a structure that serves to keep an operation in its acceptable risk band. In this article I attempt to illustrate where problems can lie for a small organization. In February of 2010, I had a close call with my guests on a ski trip based out of the Burnie Glacier Chalet in the Coast Mountains of northwestern British Columbia. I remotely triggered a size 3.5 and a size 3 avalanche simultaneously on terrain I was considering for guiding. Since I had operated there for ten years at the time, and guided for over 35 years, I remain chastened by my failure to recognize the relevant problem that day.

Guides very often experience accidents and close calls as personal failure. Guides' self image is closely tied to their ability to prevent accidents and close calls. When this fails, guides often react with denial, withdrawal, or aggression. Being a guide, I understand how deeply my self image is challenged when I have made mistakes that could kill my guests and myself. This large emotional investment makes it hard to debrief close calls—let alone accidents—in a non-judgmental way that allows a clear analysis of the event and shows ways to improve risk management.

This article analyzes the close call using James Reason's Swiss cheese model for my small organization.

It explains the multiple failures at several levels of the operation, and what led to the conclusion of the incident without involvement. It integrates the technical aspects of observation, record keeping, and structured decision making with social and personal issues such as motivational bias on my part, which can be found across the guiding industry. It closes with reflections on mental mechanisms that influence decision making.

THE SETTING

The winter of 2009-10 had a long cold, clear period in December which formed a thick and widespread layer of surface hoar. While this is not really rare, these layers are usually destroyed by wind or sometimes rain—particularly early in the season—before they are buried. The lodge only starts operating by New Year's, so we do not have weather or snowpack data for this period. When Ken Bibby and I arrived to teach a CAA Avalanche Operations Level 1 in early January 2010, the slab on the buried surface hoar was extremely touchy. It was 30 to 40cm thick at the time. When I set the first uptrack of the season, I remotely triggered numerous slides on this layer. There was no perceptible whumpfing, but the failures travelled up to 200m.

There were no bookings for a month after this course and we shut the lodge down. I worked and taught in different areas with different snow packs. No data was collected at the Burnie Glacier Chalet. It was not possible to keep informed via the InfoEx as the operation has no nearest neighbours. I returned on February 12 with a group of very competent, strong guests who ski with me every year.

The relationships that grow between a guide and their loyal, competent and generous guests are a guide's most valuable asset. Guides will go to great lengths to cultivate these relationships. The guide's input is good skiing or climbing, and they will strive to make sure that each guest experience is at least as good or preferably better than the last one. This easily leads into motivational bias where guides push the operational risk band to make sure these special guests are satisfied and will want to return.

Throughout the week, the ski quality deteriorated. We had found the surface hoar in a sheltered location in the high alpine at 2,300m, which limited our alpine options. At treeline and below, a short sunny period had crusted the solar aspects while cold aspects still had good snow. By Tuesday, we were casting about for good snow. Visibility was poor in the alpine. In terms of ski quality, the north side of Tom George Mountain was desirable. This is a 500-vertical-metre run to which all the bad words of avalanche terrain apply. It's north facing. It's steep, uniform and cold. It's wind-loaded, and a massive cornice sits over top. But at least it ends in a nasty terrain trap. And the skiing can be excellent.

REASON'S SWISS CHEESE MODEL

Reason considers an accident or mishap to be caused by failures on all levels of an organization. He expressly rejects the concept of human error, stating that the term is meaningless in the context. I had indeed not planned to stare down a bed surface on my intended run that day. The question is how I got to that place.

Reason understands the hierarchy of an organization as management layers that each manage risk in their own specific way. There is the management level where corporate culture and mission are determined. There is the operations level where workplace decisions are made and data is collected. There is the front line worker who drives the train, wields the scalpel or sets

ROB ORVIG BELOW FRACTURE LINE ON EAST SIDE

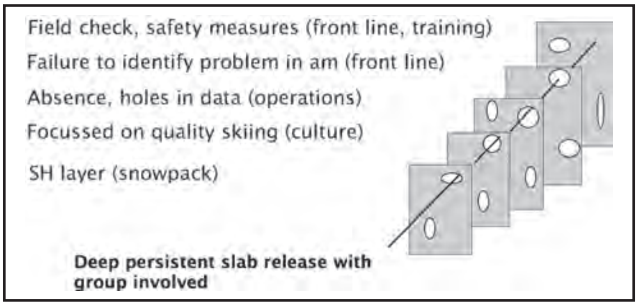

FIG. 1: REASON'S MODEL APPLIED TO THE INCIDENT

the track. And finally, there are mechanisms that try to contain or reverse damage once all else has failed. That could be the level of recovery and rescue skill in our avalanche world, for example, or a spill response in the mining industry. Each organization exists in its specific environment, which determines the dangers it faces; snow avalanches and alpine hazards are ours. Infections or wrong diagnoses are some of the dangers in hospitals, and so on. I'm using the term danger deliberately here; it is what's "out there" and what could happen. Whatever is there becomes risk once something of value is exposed to it. And an accident happens when the trajectory of an event is able to pass through each management layer.

In my organization, for better or for worse, I am on all its levels. I have a certain vision and mission for how things should be happening. Most of the time I run the operation in the field, deciding what happens every day and collecting observations to support those decisions. I also set the uptrack, kick steps and place protection, and when something goes wrong, I am the first responder as well as the rescue coordinator.

In Reason's model, an accident happens when a threat, such as a snow avalanche, penetrates all the layers of risk management in the organization. The holes in the Swiss cheese slices have to line up. Fig. 1 shows how I interpret the layers for this case study.

The environment is what it is: it contains snow that is at times unstable and terrain steep enough to slide. In backcountry ski guiding, few operations use methods of avalanche control to modify this layer. At the management level, there certainly is a focus on quality skiing. This is a necessary focus for a guiding operation. However, in this case it led to a partial blindness, or a bias in the interpretation and weighing of information. We use the term operational risk band, determined for itself by each organization. If the accepted risks are too high, then accidents are more likely and the organization might fail. But if the acceptable risks are set very low, then the organization might also fail because guests come for quality skiing, and good backcountry skiing happens in avalanche terrain. A general lowering of the acceptable risk may not be the best strategy.

The closing of the lodge and the absence of data are also conditions beyond my control. When there are no bookings, it is impossible to keep someone at the lodge to collect data and maintain records. Incomplete data is therefore part of the framework that is outside my control.

BIASES, HEURISTICS AND INTUITION

However, the failure to recognize the problem is not. How did I, after the events a month previous, and with all the guidance, training and experience I've had, come to ignore the possibility that the surface hoar would still be active in this site? I had no record of it releasing. It's true that the summit of Tom George Mountain is highly wind exposed, and that it is uncommon for surface hoar to be preserved there. However, we had found surface hoar in less exposed alpine locations earlier that week and abandoned a summit climb because of it. So there was an obvious breakdown in my information gathering process as well as in the decision making.

There is quite a bit of research on motivational and confirmation bias. Confirmation bias is usually defined as "the tendency to favour information that confirms one's own preconceptions. Under the influence of a given desire or emotion, the arguer tends to focus on the evidence that seems to confirm his claim and, conversely, to overlook the evidence that seems to disconfirm it" (Correira, 2011). The bias applies to both evidence gathering and its evaluation. So quite clearly, I had disregarded relevant information and then evaluated this information in a way that confirmed my desire to ski this run with my guests.

However, some researchers argue that biases are not always necessarily a bad thing. Like heuristics, they serve as important mental shortcuts. Biases allow for consistency in a person's cognition and can help in keeping objectives in focus. And, going further, here is a question that I have not seen asked very much: where is the boundary between intuition, which we value highly in expert decision making, and biases and heuristics? Structurally, they are similar—they are all mental mechanisms that allow us to select the information we deem relevant, and to process that information much faster than we could through a formal analysis of all the factors. If we define intuition as the ability to understand something immediately and without conscious reasoning, the only aspect that differentiates intuition from a bias is that we usually understand intuition to be the result of experience tempered by study, while biases are understood to be unreflected. Most of us would agree that unchecked and unreflected biases lead to poor decisions. But that seems to be an argument after the fact; if it led to bad outcomes, the decision making process must have been flawed. This does not address the real issue, because at the time the decision is made the outcome is not known.

Biases seem to be unavoidable. Within a rational framework, we can do a lot to mitigate their effects. The structured joint decision making that Canadian avalanche workers use is a great help, although it is subject to group-specific biases such as group think and the tendency to side with the majority. However, the ubiquity and pervasiveness of biases require strategies to address them. The formal joint decision making framework used in Canada provides considerable guidance, but it is, as shown here, by no means foolproof. There is research that argues encouraging dissent in group decision settings can liberate the group's thinking.

LOOKING DOWN THE EAST FLANK AFTER THE RELEASE

I'll close with a concept that is more philosophical or religious than scientific: mindfulness. I think that mechanistic and structural approaches to decision making need a spirit that fills them with vibrancy and meaning. The concept of mindfulness is relatively new in positivist science, and I like to think that it can supply the spark that keeps the concepts, processes, and structures fresh. Here is a definition: "The word sati or mindfulness derives from a root meaning 'to remember,' but as a mental factor it signifies presence of mind, attentiveness to the present, rather than the faculty of memory regarding the past. It has the characteristic of not wobbling, i.e. not floating away from the object. Its function is absence of confusion or non-forgetfulness. It is manifested as guardianship, or as the state of confronting an objective field. Its proximate cause is strong perception (thirasaññā) or the four foundations of mindfulness." (Bodhi 2012) While the concept's origins are in Buddhist teachings, mindfulness is now regarded as "paying attention in a particular way: on purpose, in the present moment, and nonjudgementally" (Kabat-Zinn, 1994).

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Strategies for Improving **Avalauncher Accuracy**

John Brennan

THE WORLD'S MOST TECHNICAL SNIPER RIFLE isn't going to make marksmen out of Mr. or Mrs. Average. The most skilled Avalaucher gunner can't hit the broad side of a barn at 1,500m with a crooked projectile, a flimsy gun deck or a poorly designed launcher. Long range accuracy and target repeatability require astutely designed projectiles with strict quality control and properly engineered Avalaunchers and firing platforms.

One way to check if your existing mount is to blame for poor accuracy is to video the machine in action. Kevin Powell, the developer of the Delta K Avalauncher projectile, recommends using at least 1,000 frames per second. By reviewing the footage frame by frame, if your projectile leaves the barrel before your mount allows significant deformation to your launcher's resting position then your accuracy issues likely lie elsewhere. By having a perpendicular object framed in the background of your launcher video you can more easily note displacement. What may appear a stout launcher deck may actually be allowing quite a bit of deflection when the Avalauncher fires.

Alan Jones, principal at Dynamic Avalanche Consulting, reports excellent accuracy and target repeatability with their Falcon GT Avalauncher mounted on their customized trailer. Alan is quick to point out that heavy duty jacks, positioned at the four corners of their trailer, make stabilizing their trailer a quick and easy job. It is very important to level the trailer as well. Dynamic Avalanche Consulting monitors a launcher-mounted bubble level as they raise their trailer completely off the ground. Alan notes that that standard trailers lack adequate bracing to be sufficiently rigid: "We were surprised how much movement we got when we filmed in HD, slow motion video."

Colin Mitchell of the Pimenton Mine in Chile has both a fixed-mounted and a mobile-mounted Falcon GT Avalauncher. They use a backsighting exercise for some of their mobile firing positions. They park their trailer in routine positions on their missions, trying to mimic as closely as possible their previous alignments. Then they fabricate simple cross hairs on the end of their barrel and bore sight on the same nearby fixed objects every mission. By using simple math and their launcher's 360 degree azimuth plate they are able to dial in their shot charts in short order. To add an additional level of precision, Alaska DOT utilizes a fixed rifle scope on their Falcon GT.

Misconceptions have lingered for many decades about Avalauncher accuracy. With modern engineered projectiles and Avalaunchers, excellent accuracy and target repeatability can be achieved with proper mount design. Please contact me with any questions or comments: jb@avalanchemitigationservices.com.

1. MOBILE MOUNT AT THE PIMENTON MINE, CHILE // COLIN MITCHELL
2. RIFLE SCOPE FOR PRECISE BACKSIGHTING // ALASKA DOT
3. EL MAULE GEOTHERMAL PROJECT, CHILE // MAGMA ENERGY CORP.
4. DYNAMIC AVALANCHE CONSULTING'S CUSTOM TRAILER // ALAN JONES
5. BC HYDRO JOB SITE // ALAN JONES

In The Pursuit Of Standards:
The Next Step In Canada's Avalanche Risk Management Guidelines

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Brian Gould,
Pascal Haegeli,
Bruce Jamieson,
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Canadian Avalanche Association,
Revelstoke, BC

THIS ARTICLE IS THE FIRST IN A SERIES EXPLORING TECHNICAL ASPECTS OF SNOW AVALANCHE RISK MANAGEMENT (TASARM).

Editor's note: To view the figures in colour, please visit avalancheassociation.ca/in-the-pursuit-of-standards.

RECOGNIZING THE NEED TO STANDARDIZE new and innovative Canadian avalanche risk management practices and respond to increasing demand from regulatory bodies, the Canadian Avalanche Association recently embarked on a two-year project to revise and update its best practice guidelines for avalanche risk management. This paper provides highlights and practical examples from the first of two new publications, which covers the technical aspects of avalanche risk management. The centerpiece of this publication are guidelines for planning and operational risk management for common avalanche terrain land-use activities in Canada.

1 INTRODUCTION

The *Guidelines for Snow Avalanche Risk Determination and Mapping* and *Land Manager's Guide to Snow and Avalanche Hazards*, both published by the CAA in 2002 (CAA, 2002a, 2002b), provided an important reference for technical and engineering practices related to the assessment and mitigation of avalanche risk. However, the period between 2002 and 2016 has seen remarkable change and growth in Canadian planning and operational avalanche risk management practices. With support from the National Search and Rescue Secretariat's New Initiatives Fund and our sponsor organization, Parks Canada, the CAA was able to fund a two-year project involving leading industry experts to update and revise our guideline documents to reflect current practice.

The recently published *Technical Aspects of Snow Avalanche Risk Management (TASARM)* (CAA, 2016) is the first of two documents and the focus of this paper. It presents technical guidelines for avalanche risk assessment and mitigation that is intended to inform practice, from the planning of avalanche risk management to day-to-day operational work. This 125-page, comprehensive avalanche risk management resource includes new and innovative content in areas such as:

- A risk assessment process that applies to both planning and operational activities.
- Uncertainty in avalanche risk management.
- Guidelines for avalanche terrain identification, classification and mapping.
- An overview of avalanche risk assessment and decision aids.
- Modern avalanche risk mitigation techniques.
- Up-to-date guidelines for avalanche terrain land-use in Canada.

2 THE AVALANCHE RISK MANAGEMENT PROCESS

As shown in Fig. 1, the avalanche risk management process aligns with the ISO 31000 risk management process (CSA, 2010), and has a parallel sequence of steps for the planning (Section 2.1) and operational (Section 2.2) stages. Each stage consists of establishing the context, risk assessment, then risk treatment. The steps followed in each stage are not fundamentally different; however in operations the distinct step of avalanche forecasting may comprise the endpoint of an operational objective or may lead to mitigation activities. Fig. 1 also shows that monitoring and review as well as communication and consultation apply to all stages of the risk management process.

This process applies to avalanche hazard management as well as risk management. Avalanche hazard is defined in terms of the likelihood of avalanche release and avalanche magnitude. Avalanche risk includes the components of avalanche hazard as well as the exposure in space and time of elements at risk and their vulnerability.

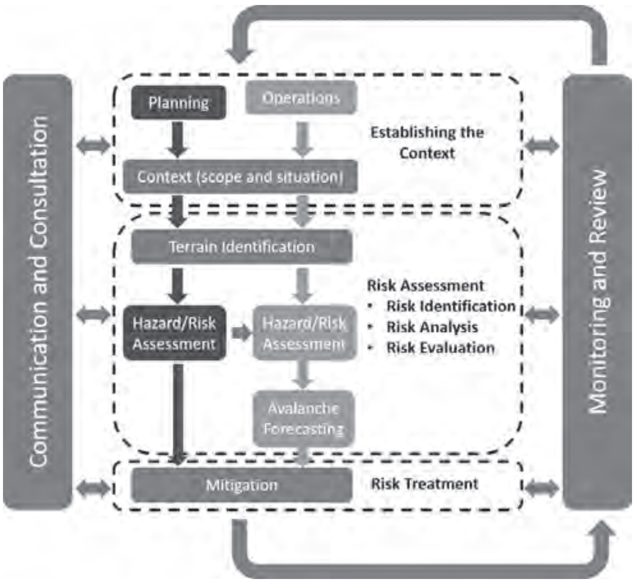

FIG. 1: THE AVALANCHE RISK MANAGEMENT PROCESS. THE CENTRE OF THE DIAGRAM ILLUSTRATES THE PARALLEL PATHS THAT FOCUS ON EITHER PLANNING OR OPERATIONAL ACTIVITIES AND IDENTIFIES HOW THIS STRUCTURE ALIGNS UNDER THE ISO 31000 UMBRELLA.

2.1 Planning

Avalanche planning involves the analysis of avalanche hazard and risk, and proposed mitigation for specific objectives. The focus of the specific objectives is long-term (possibly permanent), and typically results in maps, plans and reports. Avalanche hazard and/or risk assessments for planning may lead to the design of long-term engineered mitigation measures, or the description of operational measures to mitigate risk, or a combination of these two approaches.

2.2 Operations

Operational avalanche risk management includes avalanche forecasting tasks and the implementation of short-term mitigation measures in order to achieve specific organizational objectives. It is often a real-time activity in the immediate proximity of the avalanche hazard, though selected steps may be undertaken at a time before assessment and mitigation activities are conducted.

Operational avalanche hazard and/or risk assessments occur in a number of different contexts, from office-based forecasters relying on incoming data from numerous sources, to individual or teams of professional guides and forecasters working in the field. It usually follows a structured workflow that assesses both hazard and risk, usually done as a sequential, two-step process. The conceptual model of avalanche hazard (Statham et al., forthcoming) is regularly used as a component of the hazard assessment sub-step. It can also be a less structured process, when considered in the context of real-time slope-scale risk management in the field (e.g. guiding a heliski group through complex terrain by managing exposure and vulnerability).

2.2.1 Avalanche Forecasting

Avalanche forecasting is the prediction, over a specified scale of terrain, of current and/or future (e.g. with the range of a weather forecast) avalanche hazard and/or risk based on the expected likelihood of triggering, avalanche size and runout. In keeping with the definition of risk, operational avalanche forecasting typically involves assessment of avalanche hazard and risk separately and in sequence. Forecasters normally assess avalanche hazard first, followed by a risk assessment focusing on the effects of the avalanche hazard on the element at risk.

2.3 Uncertainty in planning and operations

Consistent with engineering definitions, uncertainty is partitioned into aleatoric uncertainty and epistemic (knowledge source) uncertainty. Aleatoric uncertainty pertains to natural variability over time and space, and should be considered in assessments because it cannot be reduced. Examples of aleatoric uncertainty include variations in snowpack height over terrain or the variable number of vehicles on a road crossing an avalanche path. Epistemic (knowledge source) uncertainty arises from limited knowledge or understanding and can potentially be reduced by gathering more information. The most common way of reducing epistemic uncertainty is to identify knowledge gaps and seek targeted information to reduce the uncertainty.

The following steps are used to deal with uncertainty in planning and operations:

1. Acknowledge the existence of uncertainty.
2. Reduce epistemic uncertainty when practical.
3. Include natural variability and residual epistemic uncertainty in assessments.
4. Communicate the unreduced uncertainty to those responsible for the risk.

In avalanche operations, uncertainty is rarely quantified, and qualitative safety margins such as “stay well away from slopes over 40 degrees” are common in the mitigation of avalanche risk. As an example of qualitative uncertainty being included and communicated in an avalanche hazard assessment, Fig. 2 shows the uncertainty in avalanche likelihood and magnitude (size) for two scenarios: a wind slab avalanche and a deep slab avalanche.

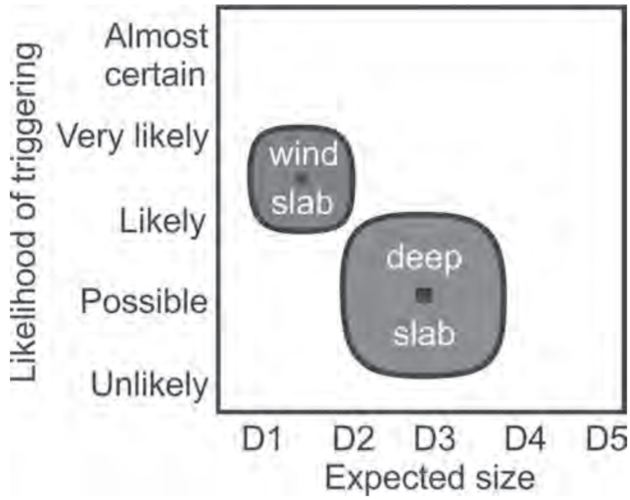

FIG. 2: FOR A GIVEN FORECAST AREA, DAY, AND CHARACTER OF AVALANCHE, THIS AVALANCHE HAZARD CHART DISPLAYS THE QUALITATIVE UNCERTAINLY AND VARIABILITY IN EXPECTED AVALANCHE SIZE (D1 TO D2 FOR WIND SLABS AND D2 TO D4 FOR DEEP SLABS) AND IN THE LIKELIHOOD OF TRIGGERING (LIKELY TO VERY LIKELY FOR WIND SLABS AND UNLIKELY TO LIKELY FOR DEEP SLABS) (CAA, 2016) (AFTER STATHAM ET AL., IN PREP.).

2.4 Assessment and Decision Aids

Assessment/decision aids are support tools that explicitly help decision makers combine multiple observations or factors to produce an assessment and/or decision regarding risk mitigation. These aids can capture advanced avalanche knowledge or operational risk management expertise and make it broadly accessible. Chapter 7 of TASARM (2016) describes numerous types of assessment and decision aids including risk matrices, assessment tables, checklist sums, snowpack evolution models, and decision trees. While most of the currently available assessment and decision aid are unable to replace the judgement of an experienced forecaster, they can be used as 'second opinions' to help reduce uncertainty. If the decision aid and expert decision give similar results (e.g., both put risk in the acceptable range) uncertainty is reduced. If assessments diverge, the decision maker can either choose to mitigate according to the more conservative assessment or gather additional targeted information to reduce uncertainty.

3 TERRAIN IDENTIFICATION

Avalanche terrain identification involves the analysis of topography and vegetation, observations and records of avalanche activity, snow supply and climate characteristics, and/or numerical runout modeling (e.g., Jamieson and Sinickas, 2015) to identify the location and extent of avalanche terrain. In general, avalanche terrain identification methods can be categorized as those that take place either in an office (i.e., a desktop study) or in the field.

Desktop investigations during both the planning and operational stages often begin with analysis of terrain photographs and imagery, topographic maps, oral and written avalanche activity records, and/or snow supply and climate data. Google Earth or other GIS-based digital terrain models are helpful tools to gain a general impression of terrain during the initial stages, or for advanced analysis when required. In most cases, a preliminary desktop investigation is conducted in preparation for field investigations.

Avalanche terrain identification often requires verification and supplementary observations from the field since not all avalanche paths, particularly those in forests or in steep northerly quadrants, can be accurately identified on photographs or maps. Furthermore, field observations often provide information helpful for assessing the frequency of previous avalanches. Aerial views allow expert observers to quickly interpret terrain from several angles. Often patterns and clues emerge from aircraft that otherwise would not be evident from a ground-based survey. Ground-based survey includes investigation of vegetation, including clues from dendrochronology, as well as measurement of topographical parameters, including slope angle and shape, surface roughness and dimensions of the avalanche terrain.

TABLE. 1: TERRAIN SURVEY LEVELS OF EFFORT (TSLE) RECOMMEND THE EXTENT TO WHICH TERRAIN IDENTIFICATION AND MAPPING SHOULD BE CHECKED FROM THE FIELD (AFTER BCMOFLNRO, 1999).

TSLE	*Preferred map scale*	*Typically assessment scale*	*% of aval. terrain field surveyed*	*Method of surveying*	*Field progress per day*
A	1:1,000 to 1:10,000	Terrain feature- to slope-scale	50-100	Ground surveys by foot traverses.	20-100ha
B	1:20,000 to 1:50,000	Slope- to path-scale	20-50	Ground surveys by foot traverses, supported by vehicle and/or flying.	500-1,200ha
C	1:20,000 to 1:50,000	Path- to mountain-scale	1-20	Vehicle and flying with selected ground observations, supported by desktop investigations.	1,200-5,000ha
D	1:20,000 to 1:50,000	Path- to mountain-scale	0	No field surveys. Desktop investigations only.	n/a

3.1 Level of Effort

The level of effort put into an avalanche terrain identification depends on the amount of detail required to meet the objectives, which is influenced by the stage of assessment (i.e., planning or operational), along with size of the study area or assessment scale, complexity of the terrain, and element(s) at risk, including exposure-time characteristics. The level of effort can be determined by the preferred map scale using Terrain Survey Level of Effort (TSLE) scale (Table. 1) (after BCMoFLNRO, 1999). The four-level TSLE scale represents the extent of field surveying from A to D (most to least effort) recommended for adequate avalanche terrain identification at the preferred map scale.

4 TERRAIN CLASSIFICATION

Terrain classification systems are intended to categorize avalanche terrain into areas with common characteristics. These characteristics may be topographical (e.g. slope angle and/or forest density), related to avalanche exposure (e.g. degree of interaction of the element at risk with starting zones) (Table. 2) or they can include some elements of avalanche hazard (e.g., frequency-magnitude relationships) (Fig. 3). The two main types of classification systems used in Canada include impact-based classification and terrain exposure classification.

4.1 Impact Based Classification

Impact-based classification results from a detailed assessment of hazard or risk that considers avalanche magnitude in terms of impact. This type of terrain classification is most common for fixed (unmoving) facilities during the planning stage of risk assessment.

A hazard zone model for occupied structures is shown in Fig. 3. Red, blue and white hazard zone classes are defined by the expected impact pressure and return period of an avalanche within an avalanche path. This is an impact-based classification system that often leads to maps (Fig. 4) with associated zoning recommendations for development of occupied structures (Section 7.1).To see these figures in colour, visit avalancheassociation.ca/in-the-pursuit-of-standards.

4.2 Terrain Exposure Classification

Terrain exposure classification categorizes avalanche terrain according to severity with respect to the exposure of an element at risk. This type of terrain classification is most common for backcountry travel activities (e.g. roving workers, recreationists) where the element at risk is mobile. Terrain exposure classifications are generally applied as a single overall rating for a defined area or route (e.g. Statham et al., 2006), or as multiple classified zones within a defined area or along a particular route (e.g. Campbell and Gould, 2014) (Fig. 5).

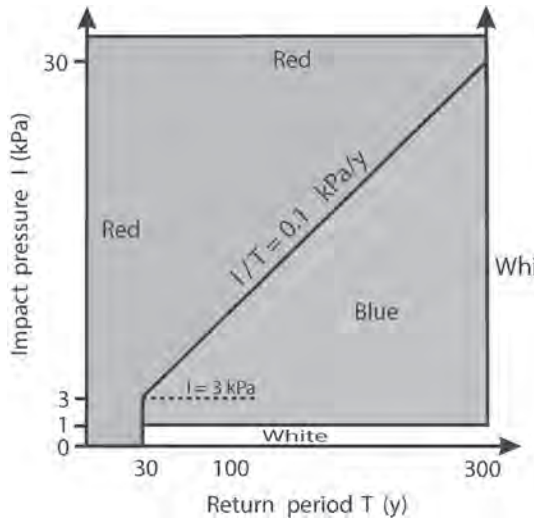

FIG. 3: HAZARD ZONES FOR OCCUPIED STRUCTURES IN CANADA (CAA, 2016).

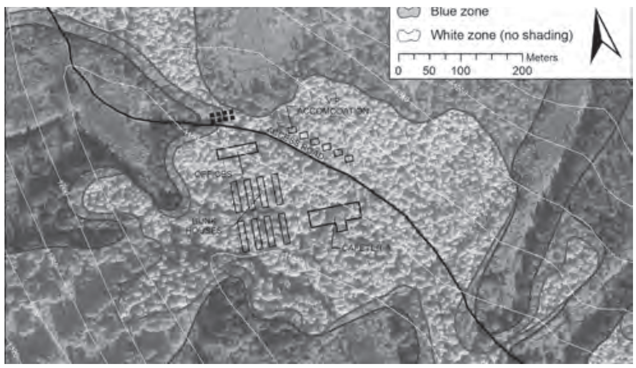

FIG. 4: EXAMPLE HAZARD MAP FOR OCCUPIED STRUCTURES. THIS MAP SHOWS COLOUR-CODED ZONES CLASSIFIED ACCORDING TO AN IMPACT-BASED CLASSIFICATION SYSTEM SUCH AS THE SYSTEM FOR OCCUPIED STRUCTURES (FIG. 3) (CAA, 2016).

FIG. 5: EXAMPLE OF ATES ZONE MAPPING (TBL. 2) FOR AN ENERGY CORRIDOR. ATES CLASSES ARE INDICATED BY COLOUR (CLASS 1), (CLASS 2), (CLASS 3), (CLASS 0) (CAMPBELL AND GOULD, 2014).

The Avalanche Terrain Exposure Scale (ATES) (Statham et al., 2006) is one example that includes three models: technical, communication (Table. 2) and zoning. Independent analysis of specified terrain parameters leads to terrain classification through default or weighted thresholds, which can involve expert judgement (Campbell and Gould, 2014). This is a terrain exposure classification system that is often used as an input to a risk matrix for procedure and policy based risk controls (Section 7.2).

TABLE. 2: COMMUNICATION MODEL FOR THE AVALANCHE TERRAIN EXPOSURE SCALE (ATES) (AFTER STATHAM ET AL., 2006; AND CAMPBELL AND GOULD, 2014).

Class	*Description*
0	Non-avalanche terrain.
1	Exposure to low-angle or primarily forested terrain. Some forest openings may involve the runout zones of infrequent avalanches. Many options to reduce or eliminate exposure.
2	Exposure to well defined avalanche paths, starting zones or terrain traps; options exist to reduce or eliminate exposure with careful route finding.
3	Exposure to multiple overlapping avalanche paths or large expanses of steep, open terrain; multiple avalanche starting zones and terrain traps below; minimal options to reduce exposure.

5 HAZARD, RISK AND TERRAIN CLASS MAPS

Hazard, risk and terrain class maps are a detailed representation of avalanche hazard, risk or terrain class often used for risk control based on procedure and policy, planning transportation corridors and pedestrian areas, as well as hazard zoning for occupied structures. Figs. 4 and 5 show example maps for impact and terrain exposure based classification respectively.

Maps typically display hazard, risk or terrain class in one of two formats:

- Linear (e.g. for a transportation corridor, transmission line or ski run).
- Polygonal (e.g. for occupied structures or a backcountry recreation area).

6 MITIGATION MEASURES

Avalanche risk mitigation, also referred to as "avalanche protection" or "risk control", may involve single or multiple layers of systems or techniques to reduce or eliminate avalanche risk. Often an integrated approach to mitigation is used and is incorporated at various stages and scales. For example, the avalanche risk to roads is reduced by:

1. Location planning (e.g., reducing the length of a road exposed to avalanches during the design phase).
2. Static defenses (e.g., snow sheds, diversion dikes and retarding mounds).
3. Warning signs to reduce the number of vehicles stopping in avalanche paths.
4. Short-term measures (e.g. forecasting, road closures and artificial triggering) to reduce the likelihood of avalanches reaching open roads.

As another example, avalanche risk to a ski lift could be reduced by:

1. Locating the towers and terminal stations where avalanche frequency and/or impact pressures are low.
2. Reinforcing the lift towers to withstand expected impact pressures.
3. Compaction of the snowpack and artificial triggering of avalanches on the slopes above the exposed towers.

CAA (2016) categorizes measures according to the strategy for intervening with the avalanche process (direct versus indirect) and the duration in which the intervention occurs (short term versus long term). Direct intervention strategies act on the avalanche hazard, whereas indirect intervention strategies adjust the exposure and vulnerability of the element at risk. Long term is considered effective over periods of several years, while short term is effective for hours to a winter season, depending on the context. Long-term measures are specified during the planning stage, while short-term measures are applied during the operational stage (and typically outlined during the planning stage). See table. 3 lists example mitigation measures by strategy (direct vs. indirect) and duration (short vs. long term).

TABLE. 3: AVALANCHE MITIGATION MEASURES CATEGORIZED BY THE STRATEGY FOR INTERVENING WITH THE AVALANCHE PROCESS (DIRECT VS. INDIRECT) AND DURATION IN WHICH THE INTERVENTION OCCURS (LONG TERM VS. SHORT TERM). MANY SHORT TERM MITIGATION MEASURES REQUIRE AVALANCHE FORECASTING TO BE EFFECTIVE.

	Short term	*Long term*
Indirect	• Precautionary evacuation • Restricted access. • Backcountry trip planning • Backcountry route finding • Backcountry group management • Avalanche safety equipment • Risk communication	• Location planning. • Zoning (e.g., Section 7.1) • Reinforcement and design of structures
Direct	• Artificial triggering • Snowpack compaction	• Snowpack support structures • Protection forest. • Tunnels • Snow sheds • Retarding mounds, breakers or arresters. • Reinforced concrete walls • Diversion dikes or berms • Catchment basins and benches • Splitting wedges • Catching nets

6.1 Example: Terrain Coding

A common strategy for operational risk evaluation and mitigation relies on detailed terrain identification (Section 3), classification (Section 4) and mapping maintained as an inventory of ski runs and/or operational zones. This list is used as a reference point to systematically evaluate risk on a run-by-run (or zone-by-zone) basis, and then track and communicate the status of each run for purposes of trip planning and access restriction. Typically accomplished by a team of avalanche forecasters or guides before going into the field, terrain coding follows a specific analysis of avalanche risk considering forecasted avalanche hazard and exposure points in the terrain.

Each run or zone is subsequently coded as either open (green) if the risk is acceptable, or closed (red) if it isn't (Fig. 6). If there are identified knowledge gaps, some operations will conditionally open a run or zone pending a set of prescribed conditions, typically illustrated with yellow coding. For example, a run can be conditionally open if the large cornice above the landing in absent. If the cornice is in fact determined to be absent after field investigations then the run can be opened after discussions with the avalanche forecaster, but if the cornice continues to threaten the landing zone then the run must remain closed.

Run List: Friday 2015/03/13	
Crystalline Drainage	
Crystalline Glacier	Sun Light
Crystalline High Right	Sundance
Crystalline Low Right	Thierry's
Crystalline Boulder	Vertigo[3]
Crystalline High Left[1]	White Out
Tequila Sunrise[2]	Billy Goat
Crystalline Low Left	Kid Goat
Crystalline Moraine	Noble Chute
Tetragon	Blue Rudi
Tetragon Low	Rudi's Revenge[4]
Twilight	Hoya Hoya
Twilight Shoulder	Up Yours

(dark grey)	Green run – open for guiding by consensus decision
(light grey)	Yellow run – potentially open for guiding using a set of conditions that must be recorded in footnote and then met with consensus in the field
(black)	Red run – closed for guiding, consensus not required.

FIG. 6: AN EXAMPLE OF A RUN LIST FOR A HELICOPTER SKIING OPERATION (COURTESY OF CANADIAN MOUNTAIN HOLIDAYS).

7 AVALANCHE TERRAIN LAND-USE GUIDELINES

CAA (2016) provides thresholds for avalanche size and/or impact pressure and return periods to initiate avalanche planning for most activities and corresponding elements at risk in avalanche terrain. It also provides guidance for typical hazard/risk assessments for new developments or activities, and for mitigation strategies during both the planning and operational stages of avalanche risk management.

7.1 Example: Occupied Structures

Typical thresholds specified for occupied structures in municipal, residential, commercial and industrial areas include impact pressures of ≥ 1 kPa with a return period of ≤ 300 years. If an initial hazard assessment determines that avalanches with impact pressures ≥ 1 kPa have the potential to affect the area proposed for development once every 300 years or more frequently, then a risk assessment must be undertaken and mitigation considered.

During the planning stage, a risk assessment should be carried out at the avalanche path-scale for an exposure time scale of decades. The level of effort for avalanche terrain identification should be TSLE: A (Table. 1), and include numerical runout modelling and frequency-magnitude analysis. Impact-based classification (Fig. 3) should be displayed on a hazard zone map (Fig. 4) and used for zoning according to the following recommendations:

- White zone (low hazard) – Construction of occupied structures is normally permitted.
- Red zone (high hazard) – Construction of occupied structures should not be permitted.
- Blue zone (moderate hazard) – Construction of occupied structures may be permitted with specified conditions.

Considerations for development of occupied structures in a blue zone include:

- Number of occupants.
- Timing of occupancy.
- Whether the structure is a place of refuge during a storm.
- Whether the occupants are aware of, and accept the risk associated with avalanches.
- Whether the structure is critical infrastructure for essential and/or emergency services.
- Whether access can be effectively restricted to allow for occupancy only during periods deemed to be safe as determined by a qualified person.
- Whether an effective precautionary evacuation plan can be implemented that can quickly evacuate the entire structure during high hazard periods.

Conditions that may be specified for the development of occupied structures in a blue zone include: structures reinforced to withstand avalanche impact; structures protected by long-term runout zone mitigation measures (e.g., diversion dikes or catchment basins); restricted access and evacuation plans; or a combination of these.

Sufficient mitigation for occupied structures in municipal, residential, commercial and industrial areas is typically achieved at the planning stage. Otherwise, operational risk management with short-term mitigation measures (e.g., avalanche forecasting, precautionary evacuation, temporary curfew and restricted access) are used to reduce the residual risk to an acceptable level.

7.2 Example: Backcountry Travel for Non-Avalanche Workers

Typical thresholds specified for non-avalanche related roving backcountry work (e.g. exploration and survey crews) include avalanches large enough to harm a person with an expected return period of 30 years or less. If there is any concern for worker avalanche safety, then a planning risk assessment should be conducted. "If [the] avalanche risk assessment indicates that a person working at the workplace will be exposed to a risk associated with an avalanche, a written avalanche safety plan is developed and implemented" (WSBC, 2014).

Avalanche safety plans for backcountry travel will typically include operational risk management techniques such as policy for avalanche safety equipment and training and procedure for safe travel, including pre-trip planning. Fig. 7 is an example backcountry fieldtrip planning matrix that outlines daily requirements to field workers. The matrix combines the operational avalanche hazard rating with the terrain exposure class (Section 4.2) of the intended field site, and work requirements for field crews.

Hazard Rating	Backcountry Travel Work Requirements		
5	Work plan approval	On-site guidance	On-site guidance
4	Work plan approval	On-site guidance	On-site guidance
3	Safety equipment Rescue training	Work plan approval	On-site guidance
2	Safety equipment Rescue training	Work plan approval	On-site guidance
1	Safety equipment Rescue training	Safety equipment Rescue training	Work plan approval
	Class 1	Class 2	Class 3
	Terrain Exposure Class		

FIG. 7: EXAMPLE OF BACKCOUNTRY FIELD TRIP PLANNING MATRIX FOR NON-AVALANCHE WORKERS. OPERATIONAL AVALANCHE HAZARD RATINGS, APPROVAL, GUIDANCE AND TRAINING MUST COME FROM A QUALIFIED PERSON.

8 LAND MANAGERS GUIDE

Management of avalanche risk also depends on human competency, the regulatory environment and societal tolerance of risks. A forthcoming companion document: *A Land Managers Guide to Law, Ethics and Human Resources for Addressing Snow Avalanche Risk in Canada* (CAA, in prep), will assist land managers and risk owners working with avalanche professionals. It is intended to help decision makers, including those who are legally accountable for avalanche-associated risks, understand their responsibilities and how to carry them out. In particular:

- Social context and the non-regulatory environment, including societal risk tolerances, corporate responsibility, communications and ethics and accountability.
- Avalanche-specific regulations, as well as general application regulations and non-regulatory policy that apply to avalanche risk management.
- Professional regulation and best practice in human resources, including competency profiles, scope of practice and training programs.

ACKNOWLEDGEMENTS

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Changes to Industry Training Program **Tuition Fees**

Emily Grady

SINCE 2009, THE AVERAGE FINANCIAL MARGIN for the CAA's Industry Training Program (ITP) has been approximately 3%. The CAA's Board of Directors has been concerned with these margins and has tasked staff with ensuring that the CAA retains enough earnings from the ITP to reinvest in curricula going forward.

Tuition fees are scrutinized on an annual basis. The fees are a tight balance between delivering quality courses using instructors from a variety of avalanche sectors and keeping courses affordable to future and current avalanche workers. One of the biggest issues is estimating yearly tuition due to the significant variability in running courses in many of places. Each location has its own set of associated costs such as accommodations, travel time for instructors, and food expenses.

Until now, tuition costs have been standard across the board (e.g., all CAA Avalanche Operations Level 1 courses cost the same, regardless of location). As a result, students attending a course based in Revelstoke or Golden are subsidizing courses in more expensive locations such as Lake Louise or Whistler. In order to address that variability and to meet the objectives set out by the Board, course costs have been determined based on course location. Course registrants will now see a breakdown of their course costs as follows:

- Tuition fee
- Registration fee
- Course materials
- Location fee
- Helicopter/snowcat (refundable if not used during the course)

In addition to these changes the Avalanche Operations Level 2 Module 2 has an additional two days added to account for the Avalanche Search and Rescue (AvSAR) Practical Skills assessment and the prep day required to set up the AvSAR scenarios. Also, the Introduction to Weather has an additional half day of preparation for instructors to account for the actual time taken to prepare for the course.

// @BRENMACKENZIE

Mountain Information Network
(MIN) Statistics

Ryan Buhler, photos submitted by users

IN JANUARY 2016, AVALANCHE CANADA released an updated version of the Mountain Information Network (MIN) data sharing platform. The MIN allows backcountry users to submit real time observations, which are geotagged and displayed on an interactive map on Avalanche Canada's homepage (avalanche.ca).

The latest release has added four new reporting options to the pre-existing "Quick Report" option. These new report options target advanced recreationists, and allow detailed avalanche, snowpack, weather and incident reports to be submitted. Users can choose exactly what they want to submit and there is no requirement to fill in all of the report options. A report can be as simple as a short line of text, or a detailed avalanche report with supporting weather and snowpack observations.

As a public avalanche forecaster, the MIN has become an integral part of my daily workflow. These user-submitted posts help fill in data gaps, especially in data sparse regions. Each morning the forecasters scour the map for new posts. For me, the real highlight of the MIN is the photos. Good photos can transport me from my desk in Revelstoke into your mountain range and give me a sense of the local weather, riding conditions, and potential signs of instability.

During the 2015-16 winter season, we received a total of 1,309 user submitted posts, up from 397 the previous season. The observations from 2015-16 included 1,221 quick reports, 122 avalanche reports, 132 snowpack reports, 122 weather reports, and 34 incident reports. Over 1,100 photos were also uploaded during the season.

The real strength of the MIN is that the data is geotagged and map based. Public forecasters can immediately put the observations into context within our forecast regions. Because many of the forecast regions are huge, one of the difficulties in public forecasting is interpreting variability within forecast regions. User submitted observations helps forecasters to better understand how conditions vary across a region, especially when the posts come from areas where professional observations are scarce.

Looking at where MIN submissions are coming from gives us a detailed look into where our target audience is actually recreating within a region. Some of the most visited recreational areas include Whistler, the Duffey Lake road, Terrace, Banff and Lake Louise Parks, Kananaskis Country, Rogers Pass, Kootenay Pass, Nelson, Fernie, and White Pass in the Yukon. Looking at the data by forecast region, this past season saw the greatest number of posts come from the South Coast Inland, North Rockies, and Banff regions. This dataset also provides us with insight into where users are recreating outside of forecast regions. The greatest number of posts not within forecast regions came from Haines Pass, Kootenay National Park, and the Rocky Mountains outside National Parks.

The primary purpose of the MIN is real-time information sharing amongst backcountry users as well as with public avalanche forecasters at Avalanche Canada. However, the MIN also provides a powerful dataset that allows us to better understand how and when users are travelling in the backcountry in various conditions. The following are examples of some basic statistics pulled from the 2015-16 season:

- 33% of reported avalanches were wind slabs, 21% were storm slabs, and 15% were persistent slabs. 53% were human-triggered and 47% were natural.

- Twice as many reports were submitted on weekends (1.7 reports/day) compared to on weekdays (0.9 reports/day).
- 50% of submissions reported powder snow conditions, 39% reported wind affected conditions, and 23% reported crusty conditions.
- The weather was reported to be cloudy in 50% of reports, sunny in 48% of reports, warm in 29% of reports, and windy in 26% of reports.
- On days when whumpfing or shooting cracks were observed, 81% of users reported avoiding convex slopes and 68% of users reported avoiding steep slopes. On the same days, 72% of users reported riding mellow slopes and 66% of users reported riding open trees.
- On days reported as having stormy weather, 66% of users reported avoiding convex slopes and 59% of users reported avoiding steep slopes. On the same days, 74% of users reported riding open trees and 72% of users reported riding mellow slopes.
- On days when users reported riding steep slopes, 56% of reports said the weather was sunny and 50% of reports said it was cloudy. On the same days, 71% of reports said the surface conditions were powder and 42% said the conditions were wind affected.

The stats listed above are just a small sample of potential information that can be extracted for the MIN dataset.

The next step is to couple the MIN dataset with Avalanche Canada's public forecasting dataset. The public forecasting dataset includes daily hazard ratings for three elevation bands as well as up to three unique avalanche problems. This analysis will be completed for the 2016 International Snow Science Workshop (ISSW) in Breckenridge, Colorado.

Due to the relatively high number of Quick Reports compared to other report types, Quick Reports are the current focus for this research. As we move a few years into the future and the MIN dataset continues to grow, I foresee this dataset becoming an invaluable source of information for public forecasting and avalanche research.

SHANNON WERNER DEMONSTRATING THE CT // AGATE BERNARD

Reaching Out to Youth About Avalanche Safety

Shannon Werner, Avalanche Canada Youth Education Coordinator

AVALANCHE CANADA'S (AVCAN) YOUTH PROGRAM continues to evolve and expand through western Canada, and its success is due to support from many organizations, passionate youth educators and engaged students of all ages.

Over the past two years, Avalanche Canada received significant support from the Columbia Basin Trust for youth education. Over the 2015-16 winter season, AvCan youth educators spoke/presented to over 3,820 students with youth-specific outreach programs on winter safety and backcountry awareness. AvCan youth educators traveled to over 26 different communities and more than three dozen schools, reaching students from kindergarten to grade 12. These programs included in-class, grade-specific curriculum and outdoor hands-on rescue training.

Additionally, this funding allowed us to subsidize and collaborate with Girls Do Ski, providing a Youth AST 1 course in Revelstoke. Students in Fernie and Trail also received an AvCan-certified AST 1 course. We held Companion Rescue training courses in Fernie, Kimberley and Valemount, BC. We added an additional course in direct response to the tremendously positive feedback received from our trial courses in the 2014-15 winter season. Older students from grade 10-12, including gap year students, felt that these courses were good stepping stones to prepare them for introductory decision making before heading into the backcountry. I have had students and teachers contact me specifically hoping for a course in their school for the 2016-17 winter season.

The Parks Canada Avi Smart program funds AvCan each year and targets grades 7-10 in the Bow Valley, Exshaw and the Columbia Valley regions. During 2015-16, presenters reached 1,500 youth from grades 7 to 10. Outdoor rescue training sessions and a new toolbox of rescue training gear was also added to the program last season, for which we received positive feedback. This program is entering its sixth season with hopes of expanding east to students in the Calgary area.

For the second season in a row, the RBC Foundation contributed $10,000 for backcountry awareness outreach in Northern Alberta schools and in Okanagan schools last

// AGATE BERNARD

winter. We visited seven different schools in Hinton, Edson, Grande Prairie and Grande Cache and reached over 700 students. We integrated more snowmobile awareness into our curriculum to accommodate the increasing number of snowmobile families in those areas. We hope to continue this program and strive to reach more schools over the next several years.

On the BC coast, thanks to funding support from the Whistler Blackcomb Foundation, we held youth "Shreducation" sessions in Pemberton, Whistler and Squamish schools and saw over 700 students. New "Know Before You Go" video material was an important component of our in-school curriculum season, offering students new media utilizing avalanche professionals and professional athletes promoting backcountry and avalanche safety messaging.

Social media has been a fast growing, useful and successful tool for Avalanche Canada's youth program. The Behind The Lines Facebook page has almost 1,300 likes, up from 1,038 at the end of 2014-15. Avalanche Canada has more than 2,100 Instagram followers, up from 651 in the previous season, and the youth-specific Behind The Lines Instagram account (@behind_thelines) has 175 followers. We found that younger users are using platforms like Instagram rather than Facebook, so we are adjusting to those demographics. Encourage youth you know to follow Avalanche Canada and Behind the Lines.

During the winter, we encouraged youth to send in photos related to snow, gear, backcountry and avalanches and held three contests, each with a different backcountry-related theme. Three winners each received new avalanche rescue gear including a probe, shovel and digital transceiver with support from BCA and Mammut, and support from the Avalanche Canada Foundation's Hugh and Helen Hincks Memorial Fund.

The AvCan Youth Program continues to evolve and grow in the classroom and learning objectives in the field. Our toolbox program sends avalanche safety equipment throughout Alberta and BC schools to assist teachers and instructors with rescue training. New last season was a Youth Educators page on the AvCan website full of resources to assist in avalanche education programs (find it at avalanche.ca/youth#resources). We also offer direction on grade-specific curriculum.

I would thank the hard-working AvCan youth educators who travel throughout BC and deliver the classroom and outdoor training sessions: Colin Adamson, Alison Cardinal, Jen Coulter, Megan Kelly, Deanna Andersen, Madeleine Martin-Preney, Curtis Pawliuk and Dave Quinn, as well as funders, educators, school districts and students. We look forward to another year of youth avalanche education.

avalanche community

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SCHEDULE OF EVENTS

// TROY GRANT

Schedule of Upcoming **Events**

GEOVANCOUVER 2016
October 2-6, 2016
Vancouver, BC
This year's theme is "History and Innovation," recognizing historical achievements and highlighting new innovations.
For more information: geohazardassociation.org/event/geovancouver-2016

ISSW 2016
October 3-7, 2016
Breckenridge, Colorado
Facilitating the interdisciplinary exchange of ideas and experiences between snow science researchers and practitioners.
For more information: issw.net

WILDERNESS RISK MANAGEMENT CONFERENCE
October 12-14, 2016
Salt Lake City, Utah
An outstanding educational experience to help you mitigate the risks inherent in exploring, working, teaching, and recreating in wild places.
For more information: nols.edu/wrmc

SARSCENE 2016
October 12-17
Edmonton, Alberta
SARscene offers a variety of topics related to SAR in Canada.
For more information: publicsafety.gc.ca/cnt/mrgnc-mngmnt/rspndng-mrgnc-vnts/nss/srscn-2016/index-en.aspx

ICAR CONFERENCE 2016
October 19-22, 2016
Borovets, Bulgaria
Registration is now open for ICAR 2016.
For more information: alpine-rescue.org

AVALANCHE CANADA ANNUAL GENERAL MEETING
November 12, 2016
Vancouver, BC
9:00 AM at the MEC North Vancouver Store. Immediately following the AGM, Avalanche Canada will be presenting at the MEC Snowfest event in the store.
For more information: avalanche.ca/events/V9By4yYAACgAz0Ni/agm-save-the-date-2016

research

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ANALYSIS OF LONG-TERM WEATHER, SNOW AND AVALANCHE DATA AT GLACIER NATIONAL PARK

// JORDY SHEPHERD

Analysis Of Long-Term Weather, Snow and Avalanche Data At Glacier National Park

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LONG-TERM CHANGES OF THE GLOBAL climate system have been observed. However, the effect of long-term changes in the climate system on avalanche hazard in mountainous areas remains inconclusive. For this study we analyzed long-term weather, snow cover, and avalanche data from Glacier National Park (GNP), BC, Canada. Weather and snow cover data were measured at two sites (1315m and 1905m a.s.l.). The avalanche data were observed along the section of the Trans-Canada Highway within the park. Meteorological data were analyzed by winter season, i.e., early, mid and late winter, represented by three-month periods between September and May. Increasing trends were found for the mean seasonal air temperature at both stations during the mid-season. Trends for the solid precipitation rate were not significant, indicating no trend towards more rain events. Decreasing trends of the maximum snow depth were only found for the lower elevation station at Rogers Pass for the mid and late season, which is consistent with decreasing trends for all seasons of the mean 24-hour new snow amounts at the lower elevation and for the mid-season at the higher elevation station at Mt. Fidelity. Due to uncertainty arising from changes in explosive control, we draw no conclusions regarding the regional change of avalanche activity. However, the weather and snowpack trends observed in GNP are consistent with longer time series from mountains with similar latitudes and elevations in France and Switzerland.

1 INTRODUCTION

Trends in avalanche activity, if they exist, could be used in planning for avalanche hazard management for transportation corridors, pipe- or powerlines, and ski areas, as well as for commercial winter recreation in the backcountry. Trends in avalanching, snow cover or weather could be indicators of climate change. Several long-term studies of avalanche activity have not found significant trends (e.g. Fitzharris, 1987; Föhn, 1992; Laternser and Schneebeli, 2002; Schneebeli et al., 1997). However, Germain et al. (2009) found an increase in avalanche activity in eastern Canada during the last 30 years using tree-ring analysis. Based on 41 winters of records, Teich et al. (2012) found a significant decrease in potential avalanche days in forested areas of the Swiss Alps. For the French Alps, Eckert et al. (2010a, 2010b, 2013) found an upslope retreat of the run-out distance for avalanches with a 10-year return period, as well as a decrease in the frequency of powder snow avalanches.

In two of six avalanche-prone sections of highways in western Canada, Sinickas et al. (2015) found a decrease in the number of avalanches reaching highways. They also found a weak increase in the number of wet-snow avalanche deposits at highways with low elevation and low latitudes. The studies by Eckert et al. (2010a, 2010b, 2013), Castebrunet et al. (2012) and Sinickas et al. (2015) might indicate a change of avalanche type, size or runout rather than a trend towards more or less avalanches.

It is particularly difficult to relate trends in avalanche activity to climate change since many avalanche safety operations with good records of avalanches use explosives to trigger avalanches, which are subject to technological and human-induced changes. As examples, new technologies for triggering avalanches, (e.g., fixed exploders), have been developed and installed in some mountain passes in western Canada, increases in exposure such as the number of vehicles on transportation corridors may promote more frequent explosive triggering; decreasing societal tolerance for risk at ski areas or on public roads as well as decreasing tolerance for closures may also promote more explosive triggering. Increases in explosive triggering, and may decrease the frequency of large natural (spontaneous) avalanches (e.g., Sinickas et al., 2015).

Trends in snowpack properties such as depth and structure, as well as snowfall trends, may be

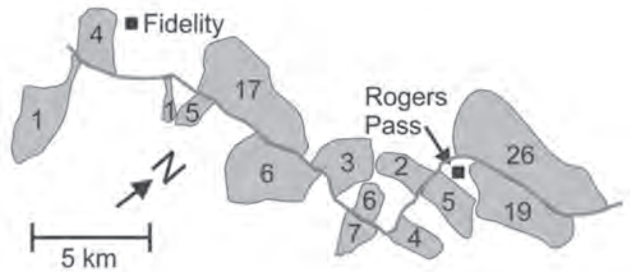

FIG. 1: MAJOR AVALANCHE AREAS (SHADED GREY) IN GNP. THE NUMBER IN EACH AREA IS THE NUMBER OF MAJOR PATHS THAT REACH THE HIGHWAY (BLUE LINES). IN ADDITION TO THE PATHS IN THE SHADED AREAS, AVALANCHES IN A SMALLER NUMBER OF PATHS THAT INFREQUENTLY AFFECT THE HIGHWAY OR RAILWAY WERE RECORDED AND USED IN THE ANALYSIS. WEATHER STATIONS AT MT FIDELITY, 1,905M, AND ROGERS PASS, 1,315M, ARE MARKED BY BLACK SQUARES. BASE MAP FROM ROGER PASS SNOW AVALANCHE ATLAS, GNP, BRITISH COLUMBIA, CANADA (SCHLEISS, V.G., 1989).

more indicative of climate change. Marty and Blanchet (2011) applied extreme value statistics to long-term time series of snow depth and snowfall for 25 Swiss stations between 200m and 2500m. They found decreasing trends of extreme snow depth for all elevations and a decrease in extreme snowfall for the low and high elevations. Snowfall trends for the mid-elevations were not significant. Weather patterns and climate have been related to avalanche activity In combination with regional topography, Birkeland et al. (2001) related anomalous atmospheric troughs to heavy snowfall and increased regional avalanche hazard. Castebrunet et al. (2012) analyzed an index of observed, mostly natural, avalanches and an instability index from a snow cover model from 1959 to 2009 in France. When smoothed, the indices show a peak in activity during a cold snowy period around 1980 and subsequently exhibit a gradual increase between 1975 and 2000 that correlated with warming, notably at 3,000m.

Ocean oscillations have also been related to avalanche activity. Keylock (2003) showed that an increase in the cumulative North Atlantic Oscillation correlated with an increased number of avalanche cycles in Iceland. McClung (2013) showed that La Niña winters produced more snow, more avalanches and a higher percentage of dry than wet-snow avalanches in two mountain areas of British Columbia. Snowfall and accident data from Chile suggest the opposite behavior—more avalanches in El Niño winters. Thumlert et al. (2014) found larger and more frequent dry-snow avalanches during the Pacific Decadal Oscillation negative phase and during La Niña winters. Conversely, wet-snow avalanches increased during the Pacific Decadal Oscillation positive phase and during the El Niño winters. Since the present study will focus on linear trends over the period from 1965 to 2014, our results should not be strongly influenced by decadal and shorter oscillations.

For western Canada there are few studies of long-term trends of weather or snowpack. For the Cariboo Mountains, roughly 250km northwest of GNP, Beedle et al. (2015) found that all glaciers receded during the period 1952–2005 and that areal retreat averaged –0.19 ± 0.05% per year. Over the 54 year period air temperature at McBride (733m) and Barkerville (1,283m) weather stations increased by +0.38°C during the ablation season and +0.87°C during the accumulation season, and average precipitation decreased, particularly in the accumulation season by 32mm (–3.2%). Using a gridded data set of climate variables for the Cariboo Mountains, Sharma and Déry (2015) found that the minimum and maximum air temperature increased by 1.9°C and 1.2°C, respectively, from 1950 to 2010. At elevations above 2,000m, the annual minimum air temperature increased by an average of 0.5°C per decade. Although the total annual precipitation did not show a significant trend, year-to-year annual precipitation varied by ±30% from its long-term mean.

TABLE 1: SUMMARY STATISTICS (SIMPLE LINEAR REGRESSION) FOR MEAN AIR TEMPERATURE (TA_{MEAN}), THE SOLID PRECIPITATION RATIO (SPR), MEAN AND MAXIMUM 24-HOUR NEW SNOW AMOUNTS ($HN24_{MEAN}$ AND $HN24_{MAX}$) AS WELL AS THE MAXIMUM SNOW DEPTH (HS_{MAX}). STATISTICS ARE GIVEN FOR EACH WINTER SEASON AND STUDY SITE LOCATION. GIVEN ARE P-VALUES, THE COEFFICIENT OF DETERMINATION (R^2) AS WELL AS THE OVERALL TREND OVER THE INVESTIGATED TIME PERIOD (T.O.P.), I.E. 49 YEARS. SIGNIFICANT TRENDS (P<0.05) ARE HIGHLIGHTED IN BOLD.

Variable	Season	Rogers Pass (1315 m a.s.l.)			Mt. Fidelity (1905 m a.s.l.)		
		p-Value	R^2	T.o.P.	p-Value	R^2	T.o.P.
Ta_{mean} (°C)	Sep.–Nov.	0.51	0.01	−0.45	0.45	0.01	0.55
	Dec.–Feb.	**0.04**	**0.09**	**1.89**	**0.01**	**0.13**	**2.1**
	Mar.–May	0.38	0.01	−0.51	0.59	0.01	0.35
SPR (–)	Sep.–Nov.	0.65	0	−0.020	0.16	0.05	−0.07
	Dec.–Feb.	0.53	0.01	0.010	0.76	0.00	0
	Mar.–May	0.08	0.06	−0.090	0.11	0.06	−0.08
$HN24_{mean}$ (cm)	Sep.–Nov.	**<0.01**	**0.16**	**−1.43**	0.22	0.03	−0.82
	Dec.–Feb.	**<0.01**	**0.52**	**−4.53**	**<0.01**	**0.33**	**−3.7**
	Mar.–May	**<0.01**	**0.06**	**−3.53**	0.09	0.06	−0.8
$HN24_{max}$ (cm)	Sep.–Nov.	0.96	0	−0.21	0.96	0	0.32
	Dec.–Feb.	**0.03**	**0.09**	**−9.55**	**0.05**	**0.08**	**−9.36**
	Mar.–May	0.6	0	2.09	0.95	0	−0.24
HS_{max} (cm)	Sep.–Nov.	0.6	0.01	−6.21	0.86	0	−4.14
	Dec.–Feb.	**0.02**	**0.12**	**−42**	0.21	0.03	−35.83
	Mar.–May	**0.02**	**0.03**	**−40.36**	0.26	0.03	−31.45

In view of the limited studies of long term avalanche records (Fitzharris, 1987; Sinickas et al., 2015) as well as of

TABLE 2: SUMMARY STATISTICS (SIMPLE LINEAR REGRESSION) FOR THE CHANGE OF FREQUENCY WITH TIME OF NATURAL AVALANCHES (NATURALS) SEPARATED BY AVALANCHES WHERE THE MOISTURE CONTENT OF THE DEPOSIT WAS FOUND AS EITHER DRY OR MOIST/WET. IN ADDITION GIVEN ARE THE SUMMARY STATISTICS FOR NATURAL AVALANCHES THAT AVALANCHED ON PATH WITH START ZONES ABOVE TREE LINE (ATL) AND BELOWTREE LINE (BTL). STATISTICS ARE GIVEN FOR EACH WINTER SEASON. SAME STATISTICAL MEASURES AND HIGHLIGHTING AS IN TABLE 1.

Variable	Season	Dry			Moist/wet		
		p-Value	R^2	T.o.P.	p-Value	R^2	T.o.P.
Naturals	Sep.–Nov.	0.89	0	1	0.34	0.02	−7
	Dec.–Feb.	0.69	0	11	**0.01**	**0.13**	**−72**
	Mar.–May	0.05	0.08	21	**0.02**	**0.08**	**−59**
		ATL (>2000 m)			BTL (<2000 m)		
Start zone	Sep.–Nov.	0.58	0.01	−6	0.4	0.02	−3
	Dec.–Feb.	**0.03**	**0.09**	**−58**	**0.02**	**0.1**	**−30**
	Mar.–May	0.06	0.08	−47	0.85	0.08	−2

TABLE 3: CORRELATION COEFFICIENTS (KENDALL'S TAU) DERIVED BY SIMPLE CORRELATION OF AVALANCHE COUNTS (DRY OR MOIST/WET) AND MEAN AIR TEMPERATURE (TA), SOLID PRECIPITATION RATE (SPR), MEAN AND MAXIMUM 24-HOUR NEW SNOW AMOUNTS AS WELL AS THE MAXIMUM SNOW DEPTH (HS). CORRELATION WAS PERFORMED FOR EACH STATION AND WINTER SEASON. MODERATE AND STRONG CORRELATIONS, I.E. CORRELATION COEFFICIENTS <0.3 ARE HIGHLIGHTED IN BOLD.

Rogers Pass (1315 m a.s.l.)						
Variable	Dry			Moist/wet		
	Sep.–Nov.	Dec.–Feb.	Mar.–May	Sep.–Nov.	Dec.–Feb.	Mar.–May
Ta_{mean}	−0.06	0.08	0.07	−0.01	−0.16	0.05
SPR	0.06	−0.22	−0.05	0.13	0.02	0.11
$HN24_{mean}$	**0.42**	0.13	0.12	**0.47**	0.17	**0.44**
$HN24_{max}$	**0.41**	0.22	**0.45**	**0.42**	0.18	**0.32**
HS_{max}	**0.56**	**0.31**	0.16	**0.52**	0.05	**0.33**
Mt. Fidelity (1905 m a.s.l.)						
Ta_{mean}	−0.14	−0.07	−0.14	−0.12	0.22	−0.22
SPR	0.01	0.18	−0.01	0.02	**−0.34**	0.14
$HN24_{mean}$	0.29	0.21	**0.31**	**0.59**	0.23	**0.51**
$HN24_{max}$	**0.33**	0.18	**0.40**	**0.40**	0.22	**0.37**
HS_{max}	**0.44**	**0.35**	0.15	**0.57**	0.12	**0.32**

weather and snowpack variables from elevations relevant to avalanche forecasting in the interior of British Columbia, we sought to identify long-term trends in weather, snowpack and avalanches in GNP that are relevant to avalanche forecasting. Specifically, in the GNP records, are there trends over 1965 to 2014 in the weather, snow cover data from weather stations at 1,315m and 1,905m, or in the avalanche records? Trends, especially if consistent with large-scale trends such as global climate change, are likely to influence avalanche forecasting in the region in the future.

2 DATA AND METHODS

In this section, data sets of long-term meteorological and avalanche observations from GNP, Canada as well as the corresponding applied methods are introduced. The winter was partitioned into an early winter season from September to November, a mid-winter season from December to February, and finally the late winter season from March to May.

2.1 Study area

For this study we analyzed long-term meteorological, snow and avalanche data from the Rogers Pass area (Fig. 1) located within GNP. Rogers Pass, a mountain pass with the highest point at 1330 m, is used by the Canadian Pacific Railway and the Trans-Canada highway (TCH) and is therefore the main transportation corridor in Western Canada. Rogers Pass is located in a transitional climate with a strong maritime influence (Haegeli and McClung, 2003). Tree-line in this area is located around 2,000m. For this study we therefore consider starting zones higher than this threshold as above tree-line (ATL) and lower as below tree-line (BTL).

Skilled observers frequently patrol the TCH and observe avalanche occurrences. Since the TCH is the main transportation corridor in western Canada, avalanche control work is a necessity along the highway during wintertime. The Avalanche Control Section at GNP has routinely observed avalanches along the TCH since 1965; individual avalanche paths have been partly controlled by explosives. Nevertheless, numerous natural avalanches have been observed on the same path that have been controlled in this area since 1965 roughly between Mt. Fidelity station and 10km east of the Rogers Pass station, a distance of about 30km from east to west. The starting zones of approximately 140 avalanche paths range from about 800m to 2,800m a.s.l. with vertical falls of up to 1,800m (Fig. 1). The majority of the starting zones are north- or southfacing, (i.e., both sides of the east–west oriented TCH).

2.2 Meteorological and snow cover data

We used snow as well as meteorological data from two study plots located at Rogers Pass and Mt. Fidelity, respectively. The Rogers Pass station, is located at 1,315m a.s.l. and the Mt. Fidelity, station is located at 1,905m a.s.l. We analyzed meteorological data, (e.g., air temperature and precipitation), from these two stations between 1965 and 2014.

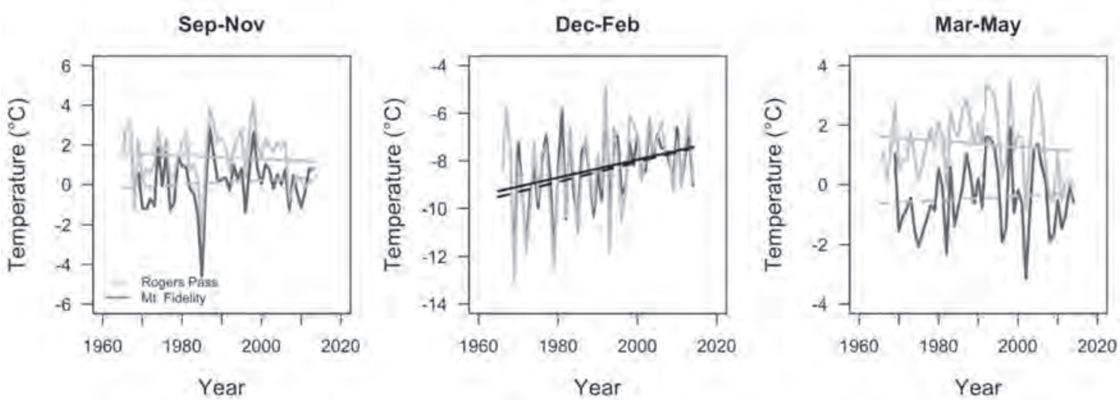

FIG. 2: MEAN SEASONAL AIR TEMPERATURE MEASURED AT ROGERS PASS (LIGHT GREY LINE) AND MT. FIDELITY (DARK GREY LINE) FOR SEPTEMBER–NOVEMBER (LEFT) DECEMBER–FEBRUARY (MIDDLE) AND FOR MARCH–MAY (RIGHT) PER YEAR. TREND LINES FOR ROGERS PASS (SOLID) AND MT. FIDELITY (DASHED) ARE GIVEN; WHEREAS A GREY LINE INDICATES A NON-SIGNIFICANT TREND AND A BLACK LINE A SIGNIFICANT TREND (P<0.05).

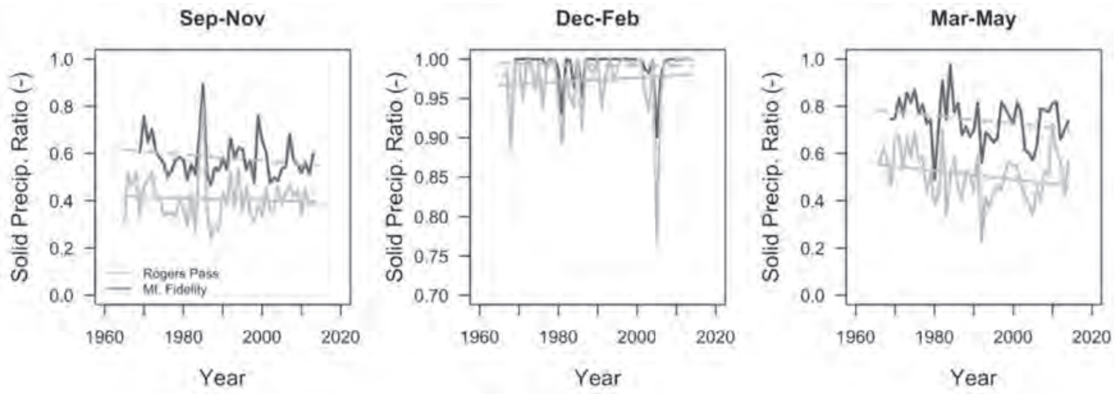

FIG. 3: MEAN SEASONAL SOLID PRECIPITATION RATIO (SOLID/TOTAL) AT ROGERS PASS AND MT FIDELITY. COLOR-CODING AS WELL AS TREND LINES AS IN FIG. 2.

Monthly mean air temperature at Rogers Pass and Mt. Fidelity was calculated by averaging the daily observed minimum and maximum air temperature. Precipitation was measured at both stations with a precipitation gauge. At Mt. Fidelity precipitation measurements were only available since 1969. For comparison, corresponding trends at Rogers Pass were only calculated for the time period between 1969 and 2014.

In the event of precipitation falling as snow, the snow water equivalent (SWE) was calculated based on measured snow density. Density was measured using a sampling tube pushed vertically through the new snow collected on a storm board. The sample was then weighed. In absence of a measured snow density, we assumed 100kg m−3. Using snow density, the solid precipitation ratio, (i.e., the fraction of the solid precipitation in the total precipitation) can be calculated. However, for some years the solid precipitation ratio could not be calculated due to missing monthly precipitation measurements. In addition, mixed precipitation, (i.e., snow and rain), was not considered specifically and therefore treated as snowfall.

Throughout the study period, the manual measurement of new snow height (HN24) at the Rogers Pass study plot has not changed. However, at Mt. Fidelity the daily new snow height was initially measured manually, whereas in recent years, on days without observers on site HN24 is estimated from manual measurements on adjacent days with guidance from hourly measurements from a precipitation gauge and ultrasonic snow depth sensor at the same site as the manual measurements.

2.3 Avalanche data

We used all avalanches observed along the TCH with a qualitative size of medium and large. The qualitative size (small, medium, large) is not a standard observation and was introduced by the Avalanche Control Section at Rogers Pass and is therefore not comparable to the relative size introduced by the American Avalanche Association (Greene et al., 2010). It represents the size of an avalanche in relation to the maximum avalanche that can occur in the particular path where the avalanche was observed. A medium qualitative size avalanche at Rogers Pass can be classified as an avalanche with a destructive size (CAA, 2014) of about 2 to 3 depending on the size of the avalanche path. An avalanche classified as large might reach a destructive size of 3 to 4, also depending on the size of the avalanche path.

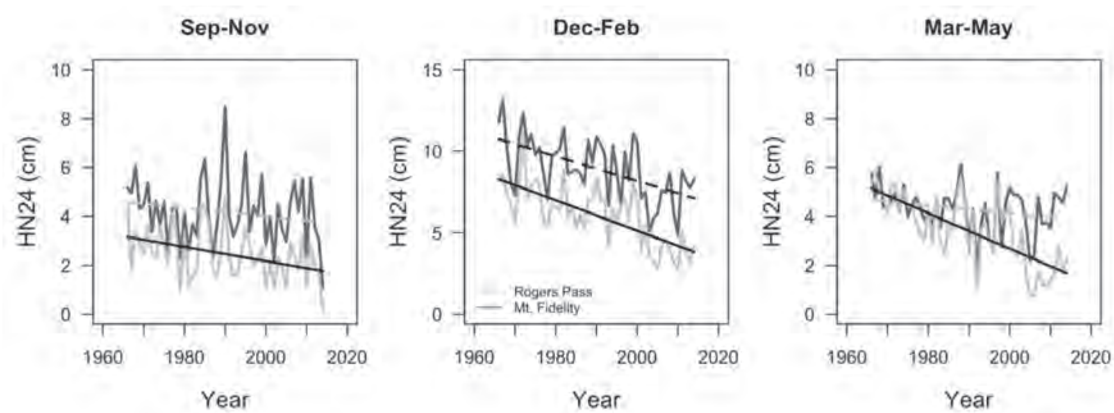

FIG. 4: MEAN 24-HOUR NEW SNOW AMOUNTS (HN24) PER YEAR AND SEASON AT ROGERS PASS AND MT FIDELITY. COLOR-CODING AS WELL AS TREND LINES AS IN FIG. 2.

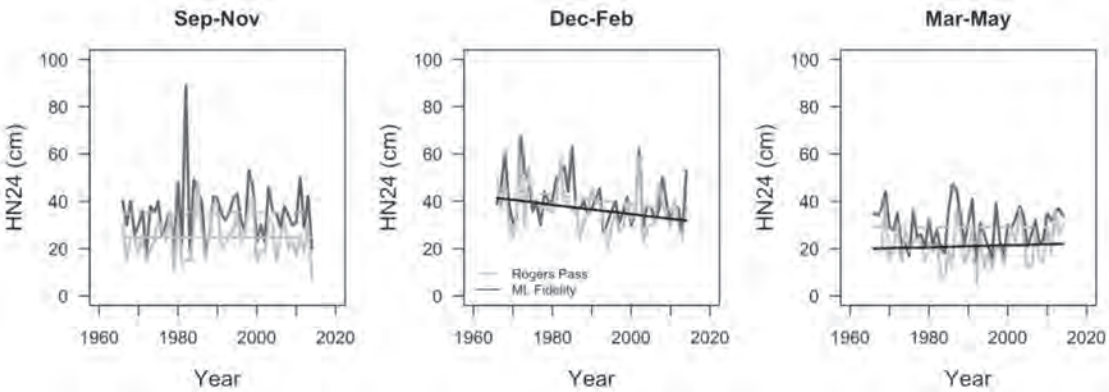

FIG. 5: MAXIMUM 24-HOUR NEW SNOW AMOUNTS PER YEAR AND SEASON OBSERVED AT ROGERS PASS AND MT FIDELITY. COLOR-CODING AS WELL AS TREND LINES AS IN FIG. 2.

This size selection leaves a total number of 27,330 avalanches observed at 140 avalanche paths between 1965 and 2014 for the analysis. About two-thirds of these avalanches released naturally (N = 18,238) and one third were triggered by explosive (N = 9,092).

For each of these avalanches, skilled observers classified the moisture content of the avalanche deposit in dry, moist, or wet deposits. For this study we grouped moist and wet avalanches into one group (moist/wet) since it is often difficult to clearly distinguish between moist and wet avalanche deposits.

2.4 Manual snow cover observations

Manual snow cover profiles recorded in a flat experimental site at Mt. Fidelity were used to assess whether or not early season rain crusts formed more often in recent years. Therefore, manual profiles recorded in early December between 1959 and 2014 were searched for the presence or absence of crusts. For this study we define a crust as a distinct layer thinner than 10cm consisting of ice or melt-forms with a hardness greater than one finger or a ram resistance of 400N and higher (Fierz et al., 2009).

2.5 Statistical analysis

For this study we used simple linear regression to estimate trends or long-term changes of meteorological, snow and avalanche observations. Trends were judged to be statistically significant based on a significance level of 5% (ANOVA, F-Statistic, p-value b 0.05).

In addition, a breakpoint analysis, (i.e., a segmented linear regression (Bai and Perron, 2003)), was used to determine significant breaks or changes in a time series. This method was used to determine whether or not a significant change in melt-freeze crust occurrence took place during the investigated period. For our breakpoint analysis we assume that the change in our data (crust occurrence; no/yes or 0/1) is not a logistic transition but a step function. Therefore we perform a breakpoint analysis with two segments, separated by a breakpoint, in which each segment has a significantly different intercept. The breakpoint between the segments was varied to find the value that maximized the fit to the preceding and following segments.

Simple correlation (pairwise, complete) was used to analyze relations between avalanche count (dry or moist/wet) and meteorological as well as snow parameters. We define a rank correlation coefficient (Kendall's tau) of smaller than 0.3 as weak correlation, larger than 0.3 and smaller than 0.7 as moderate correlation as well as correlation coefficients of larger 0.7 as strong correlation.

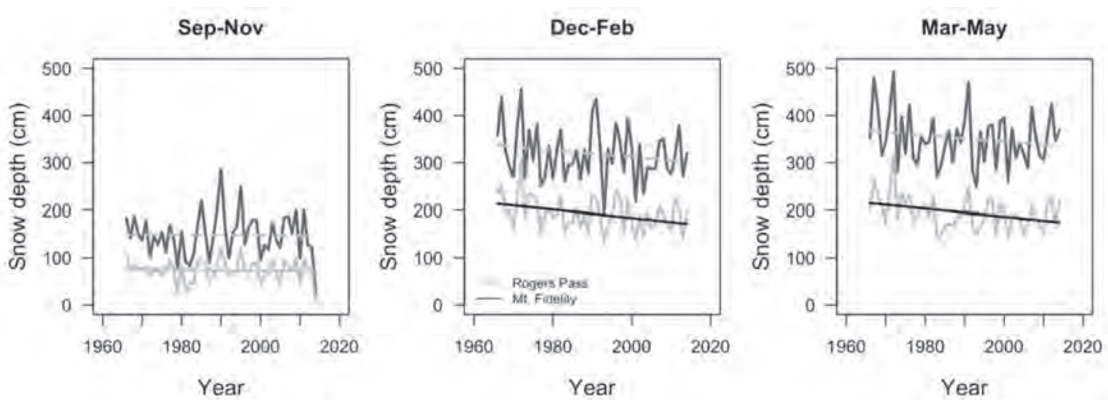

FIG. 6: MAXIMUM SNOW DEPTH PER YEAR AND SEASON MEASURED AT ROGERS PASS AND MT. FIDELITY. COLOR-CODING AS WELL AS TREND LINES AS IN FIG. 2.

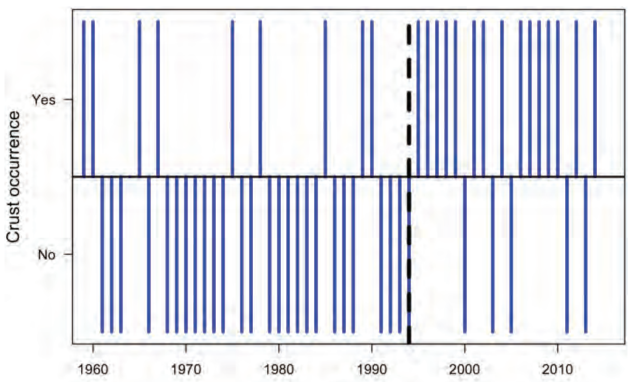

FIG. 7: CRUST OCCURRENCE (YES OR NO) DERIVED FROMMANUAL SNOW COVER OBSERVATIONS RECORDED BETWEEN MID NOVEMBER ANDMID DECEMBER FROM 1959 TO 2014 IN THE NEAR VICINITY OF THE MT. FIDELITY STUDY SITE. DASHED VERTICAL LINE SHOWS THE LOCATION OF THE BREAKPOINT (1994) DERIVED FROM A SEGMENTED LINEAR REGRESSION.

3 RESULTS

In the following sections, we summarize the results of the statistical analysis for the seasonal air temperature, precipitation, snow or snow cover as well as avalanche characteristics. Statistical measures are summarized for each parameter, research site and winter season in Tables 1 to 3, respectively.

3.1 Air temperature

The mean air temperature (winter season: September–November, December–February, and March–May) measured at Rogers Pass and Mt. Fidelity is shown in Fig. 2. Significant positive trends, (i.e., increasing seasonal air temperature), were found for the mid season between December and February at both stations (Table 1). No significant trends were found for the mean seasonal air temperature at Rogers Pass, or Mt. Fidelity during the early (Sep.–Nov.) and late (Mar.–May) winter seasons.

3.2 Precipitation

3.2.1 Solid precipitation ratio—SPR

No significant trends were found for the seasonal solid precipitation ratio (SPR), (i.e., the ratio between solid and total precipitation amounts), at both stations Rogers Pass and Mt. Fidelity based on a significance level of p b 0.05 for the time period between 1969 and 2014 (Fig. 3, Table 1). Note that this time period is four years shorter than used for the other parameters due to missing precipitation measurements at Mt. Fidelity (1965–1968).

3.2.2 New snow amounts—HN24

Highly significant (p b 0.01) decreasing trends of the 24-hour mean new snow amounts were found for all seasons at Rogers Pass and the mid winter season at Mt. Fidelity (Fig. 4, Table 1). The analysis revealed a significant decreasing trend of the 24-hour maximum new snow amounts at both study sites during mid-winter (p-values 0.03 and 0.05, respectively). No significant trends were identified for the early and later winter season (Fig. 5, Table 1).

3.3 Snow cover

Significant decreasing trends of the maximum snow depth were found for the mid and late season at Rogers Pass (Fig. 6, Table 1). Trends at Mt. Fidelity as well as early winter trends at Rogers Pass were not significant. No significant trends (Rogers Pass p = 0.28; Mt. Fidelity p = 0.66) were found for the day of the year when the study site at Rogers Pass and Mt. Fidelity became snow free for the first time, (i.e., snow height equals zero).

The analysis of the manual snow profiles observed between 1959 and 2014 showed that early season rain crusts formed more often during the last two decades (Fig. 7). A segmented linear regression using one breakpoint showed a significant breakpoint in 1994 (p b 0.001), (i.e., significant change in crust occurrence was found for the winter season after 1994/1995).

3.4 Avalanches

3.4.1 Deposit moisture content

The frequency distribution of the deposit moisture content (dry or moist/wet) for all natural avalanches observed at Rogers Pass per season is shown in Fig. 8. No significant trends were found for natural avalanches with dry deposit for all seasons. A negative significant trend, (i.e., less moist/wet deposits), was found for the mid and late winter season between December and May.

3.4.2 Avalanche start zones

Natural avalanche releases per start zone—above tree-line (ATL) and below tree-line (BTL)—was found to show significant negative trends for the mid-winter season from December to February, indicating a general trend towards less avalanches during this period. All other trends in both elevation bands were found to be not significant (Figs. 8, 9; Table 2).

3.4.3 Correlations—avalanches, snow, precipitation and temperature

Counts of dry and moist/wet-snow avalanches were correlated with the mean air temperature, the solid precipitation ratio, mean and maximum 24-hour new snow amounts as well as the maximum snow height per avalanche season and station. Correlation coefficients are shown in Table 3. Weak to moderate positive correlation was found for almost all snow parameters, (e.g., new snow amounts and snow height), for the early and late winter season, but not for the mid winter season. No correlation was found between avalanche counts, dry or moist/

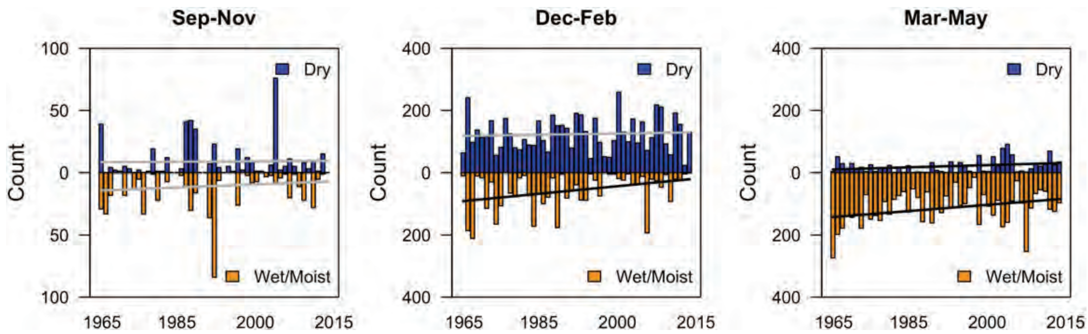

FIG. 8: FREQUENCY DISTRIBUTION OF ALL NATURAL AVALANCHES OF SIZE MEDIUM AND LARGE WITH DRY DEPOSIT (BLUE BARS) AND MOIST/WET DEPOSIT (ORANGE BARS) OBSERVED IN THE ROGERS PASS REGION BETWEEN 1966 AND 2014 SEPARATED BY SEASON. SOLID LINES INDICATE CORRESPONDING TREND LINES, WHEREAS GREY LINES INDICATE NON-SIGNIFICANT ($P<0.05$) TRENDS AND BLACK LINES SIGNIFICANT TRENDS ($P<0.05$).

wet, for the mean air temperature at both stations. A weak negative correlation was found for the solid precipitations rate (SPR) suggesting a link between rain events, (i.e., decreasing SPR), and increasing wet snow avalanche activity.

4 DISCUSSION

For Rogers Pass (1,315m) and Mt Fidelity (1,905m) study sites, four and three of the weather and snowpack parameters in Table 1 show significant trends for at least one avalanche season. When the avalanche seasons are considered separately, seven of the 15 trends for Rogers Pass and three of the 15 for Mt Fidelity are significant. Each of the significant trends is consistent with expectations for climate warming, i.e. warmer temperatures and less snowfall over monthly or longer periods. Also, greater effects (or in this study more trends that are significant) at lower elevations (Rogers Pass 1,315m) than at higher elevations (Mt. Fidelity 1,905m) are consistent with climate change. Further the increase in the number of early winter rain crusts shown in Fig. 7 is consistent with climate change. Trends towards greater or more frequent extremes are not apparent in Figs. 1 to 6, 8 or 9. However, the shortest period displayed is three months, so extremes on the scale of days or multi-day storms would not be apparent. Analyzed trends, even when significant, show low coefficients of determination (Tables 1, 2). This can partly be explained by the large interannual variations of the data and use of a simple linear regression.

However, applying more robust methods (e.g., Mann–Kendall Test, not shown) exhibited similar results. Therefore, we believe that applying an easily interpretable method such as a linear regression is justifiable.

Long-term time series of meteorological and avalanche observations in mountainous terrain are rare in Canada. However, the Avalanche Control Section at GNP has been recording these data systematically since the early 1960s leaving a data set of about 27,000 avalanches with a relative size of medium and larger. ACS does avalanche control work in the Rogers Pass area ensuring safe public transportation. This control work, (i.e., avalanche release by explosive), might have biased our data set. However, a strong positive correlation of 0.72 was found between counts of natural avalanches and explosive controlled avalanches suggesting that explosive control in the Rogers Pass area does not strongly reduce natural avalanche activity. Hence, apparent trends are not likely to be highly biased, which is also shown by the fact that almost two-thirds of all analyzed avalanches were natural releases. In addition, Sinickas et al. (2015) found no substantial difference in natural avalanche activity between paths in British Columbia outside of GNP that were frequently controlled by explosives and paths with more than 75% natural avalanches.

During the early years of the avalanche program at Rogers Pass, meteorological data were manually observed routinely at least twice daily and automatically during the last two decades. Homogenization of long-term meteorological data is typically required prior to analysis. However, homogenization for both stations was not possible since this typically requires at least a few other stations with similar geographical location or characteristics. Neither station has moved during the investigated time period, and observational methods—except for new snow amounts—were similarly applied to both stations, (i.e., should show the same trends). In addition, Venema et al. (2012) showed that absolute homogenization methods could make the data even more inhomogeneous if the data shift or error is unknown. However, trend comparisons, although similar to trends found outside the Park (e.g., Sharma and Déry, 2015) need to be interpreted cautiously.

Understanding and quantifying the effect of climate change on the environmental system is one of the main aims of the climate science community. However, linking climate change to avalanche activity remains challenging. For example increasing air temperature might stabilize the snow cover; on the other hand warmer air can hold more moisture, which might result in larger precipitation amounts, and therefore increase avalanche activity.

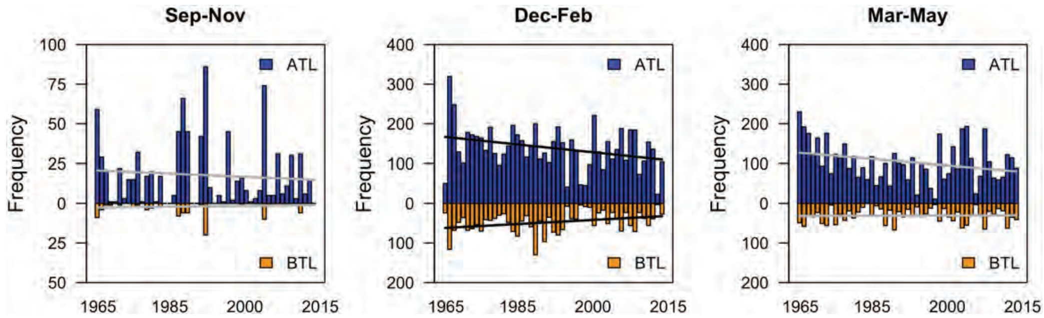

FIG. 9: FREQUENCY DISTRIBUTION OF ALL NATURAL AVALANCHES OF SIZE MEDIUMAND LARGEWHICH AVALANCHED ABOVE TREE-LINE (ATL; START ZONE N 2000M) OR BELOWTREE-LINE (BTL; START ZONE B 2,000M) IN THE ROGERS PASS REGION BETWEEN 1966 AND 2014 SEPARATED BY SEASON. SOLID LINES INDICATE CORRESPONDING TREND LINES, WHEREAS GREY LINES INDICATE NON-SIGNIFICANT (P<0.05) TRENDS AND BLACK LINES SIGNIFICANT TRENDS (P<0.05).

However, the latter might not be the case since our analysis showed decreasing significant trends for the mean 24-hour new snow amounts at Rogers Pass station for all seasons and at Mt. Fidelity station during the mid season. In addition, we found significant decreasing trends of the maximum 24-hour new snow amounts for the mid season at Rogers Pass and Mt. Fidelity station, suggesting less intense storms.

Consequently, reduced 24-hour new snow amounts result in decreasing maximum snow depth. However, a significant decrease was only found for Rogers Pass (1,315m a.s.l.) for the mid and late season. No changes were found for Mt. Fidelity station (1,905m a.s.l.). No trends were found at both stations for the day of the year when the experimental site became snow free for the first time.

Marty and Blanchet (2011) found similar results for long-term time series of snow depth and snowfall for 25 Swiss stations between 200m and 2,500m. They found decreasing trends of extreme snow depth for all elevations and a decrease in extreme snowfall for the low and high elevation. Snowfall trends for the mid-elevation were not found to be significant. Their chosen category mid-elevation (between 800m and 1,500m) corresponds to the elevation of Rogers Pass station, which showed highly significant results for selected snow parameters in our study. This might show the effect of different geographical location with regard to climate change. However, different statistical methods were used, which makes comparing the studies difficult.

In the Swiss Alps, Marty and Meister (2012) found a significant decreasing trend in the solid precipitation rate (SPR), (i.e., the fraction of solid to total precipitation). Based on a significance level of 5% our data suggests no significant trends of the solid precipitation rate at either station. However, we included mixed precipitation with solid precipitation, which might partly explain our non significant trends.

During the last two decades, early season rain crusts occurred more often in manually observed snow profiles at Mt. Fidelity. A segmented linear regression showed a significant breakpoint in 1994, (i.e., a significant change in crust occurrence after the winter season of 1994/1995). Nevertheless, the existence of the crusts suggests more rain events, i.e. a decreasing SPR during the early season, although no significant trends in the solid precipitation rate were found.

A moderate negative correlation of moist/wet avalanche counts with the solid precipitation rate during the mid season (Table 3) might suggest more avalanches triggered by rain events during this period. Alternatively, this could be due to moist or wet snow being entrained along the avalanche path in lower elevations.

Avalanche formation is clearly related to atmospheric conditions including precipitation rate, duration, and type as well as wind, air temperature, and radiation. All these driving agents for avalanche formation changed in recent years as stated by the Intergovernmental Panel on Climate Change (IPCC, 2013). Therefore, avalanche activity should also be affected by changing atmospheric conditions in a changing global climate. However, avalanche cycles are caused by short-term weather systems (days) rather than long-term climate trends (decades). In addition, avalanche formation is rather a combination of snow cover structure in combination with preceding and current weather conditions. This is supported by correlating avalanche counts with snow parameters (Table 3). Although the correlations are not highly significant, Table 3 suggests that an increase in new snow amounts and consequently snow heights correlates with increasing counts of avalanches or simply put more snowfall results in more avalanches.

Therefore, snow cover structure should be introduced into analysis of long-term avalanche records especially when linked to climate change scenarios as suggested by researchers such as Haegeli and McClung (2007).

Nevertheless, in our large data set of observed natural avalanches we found significant change in avalanche characteristics. A significant decreasing trend for natural avalanches with moist or wet deposits was found for the mid and late avalanche season from December to May. This seems counter-intuitive since one would expect more moist/wet deposits or avalanches in a warming climate. However, as stated above warming, (i.e., settling or melting and refreezing), can also stabilize the snow cover and hence, less natural avalanches might release. Furthermore, our data set suggests fewer avalanches, (i.e., decreasing trends), during the mid season from December to February for avalanches releasing below and above tree-line, which is in alignment with increasing air temperature and decreasing new snow amounts for the same period. However, due to the intense explosive triggering during this period in the area, the avalanche data set might be biased and the trends, even when significant, have to be interpreted carefully.

5 CONCLUSIONS

We analyzed long-term meteorological and avalanche data from two weather stations by season: early avalanche season (September to November), mid season (December to February), and late season from (March to May). Based on a significance level of 5%, increasing trends were found for the mean seasonal air temperature at both stations during the mid-season consistent with global climate change. No significant trends were found for the solid precipitation rate indicating no trend towards more rain events. Decreasing trends of the maximum snow depth were only found for the lower elevation station at Rogers Pass for mid and late season. Consequently, we found significant decreasing trends for all seasons of the mean 24-hour new snow amounts at the lower elevation and for the mid season at the higher elevation station Mt. Fidelity. Furthermore, decreasing trends for the maximum 24-hour new snow amounts were found for the mid season at both stations.

Only seven of the 15 possible weather or snowpack trends for Rogers Pass and four of the 16 for Mt. Fidelity (including a change in the number or early season crusts) are significant. Each of the significant trends is consistent with warmer temperatures and less snowfall. The limited number of significant trends suggests that further studies involving longer time series—when they become available—and more sophisticated analyses would be worthwhile. We found no graphical indications of greater extremes or more frequent extremes in the weather, snowpack or avalanche records from Glacier National Park. However, our analysis is insensitive to changes at time scales shorter than three months. Due to a potentially biased avalanche data set, the conclusions on the regional change of avalanche activity remain inconclusive.

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Flakes

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