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Enjoy the Sunshine

MOST OF MY DAYS are spent in the office (albeit staring longingly at the Monashee skyline across the valley), so it can feel a bit out of touch from those of you who spend your days in the snow. That's why it was great to once again spend time with many of you at the CAA spring conference in Penticton, talking about your season, pitching articles, and listening to case study and research presentations.

In this issue, outgoing president Aaron Beardmore gives his final president's message and looks back on the progress towards the self-regulatory model that has been achieved during his tenure on the Board of Directors.

Andrew Jones gives us an update on the evolution of data management in Rogers Pass and how the Avalanche Control Section's Avalanche Forecasting System continues to progress.

CAA Software Developer and IT Systems Manager Luke Norman wrote an article about his trip to northern BC this winter, visiting several operations to help increase his understanding of how InfoEx is used by practitioners and operations in order to guide development. He saw some real value in meeting face-to-face with operators both during that trip and during the CAA spring meetings and asks that anyone with a suggestion contact their IAG representative.

James Blench provides some background about the CAA Avalanche Operations Level 3 and its progression over the years. Look for articles from Level 3 graduates in coming issues - it might encourage you to take the plunge.

Martina Halik bravely shares the barrage of thoughts and emotions one can go through when caught in an avalanche, and then deciding how to share that experience with others. Fortunately for us, she created a video case study about her avalanche to help people learn, and then wrote about that for this issue.

Thanks to Avalanche Canada Communications Director and former editor of *The Avalanche Journal* Mary Clayton for her thoughtful review of Bruce Kay's book *Autonomy, Mastery and Purpose in the Avalanche Patch*, which she says will likely "make you think hard about how you approach your next day in the field." Do you have a book or piece of gear that you'd like to review? Send me a pitch, I'd love to hear it.

Summer is a great time to write an article about your season, or about new changes to your program for the upcoming winter. Please email editor@avalancheassociation.ca with any ideas, comments or questions. Enjoy the sunshine.

Karilyn Kempton

Contributors

ANDREW JONES

Andrew Jones has worked in Mount Revelstoke and Glacier National Parks since 2008, where he has cleaned washrooms, sold park passes, trapped bears, and triggered avalanches. Prior to joining Parks, he was a proud member of the Kicking Horse Ski Patrol. Andrew has a MSc in Environment and Management and is currently working as the avalanche technologist in the Rogers Pass Avalanche Control Section. Andrew lives and plays in Golden BC with his wife and baby girl.

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LUKE NORMAN

Luke Norman is a Revelstoke-based software developer who maintains InfoEx for the CAA. Outside of the office he enjoys exploring and playing in the mountains.

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MARKUS ECKERSTORFER

Markus 'Max' Eckerstorfer grew up in the Austrian Alps where he received a MSc degree in Cartography. He then moved to Svalbard where he did a PhD in avalanche science. Now he works and lives with his family in Tromsø, Northern Norway.

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MARY CLAYTON

Mary Clayton has been the Communications Director at Avalanche Canada since 2004. She lives in beautiful Revelstoke, BC, where she's currently recovering from knee surgery and looking forward to getting back on her skis next season, after a lousy winter being injured.

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JAMES BLENCH

James Blench is a mountain guide living in Canmore, AB. This May he received a CAA Service Award for his outstanding contributions to the CAA's Industry Training Program.

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MARTINA HALIK

Martina Halik works for Avalanche Canada in the South Rockies. She has a knack for looking stylish wearing recently deployed airbag packs.

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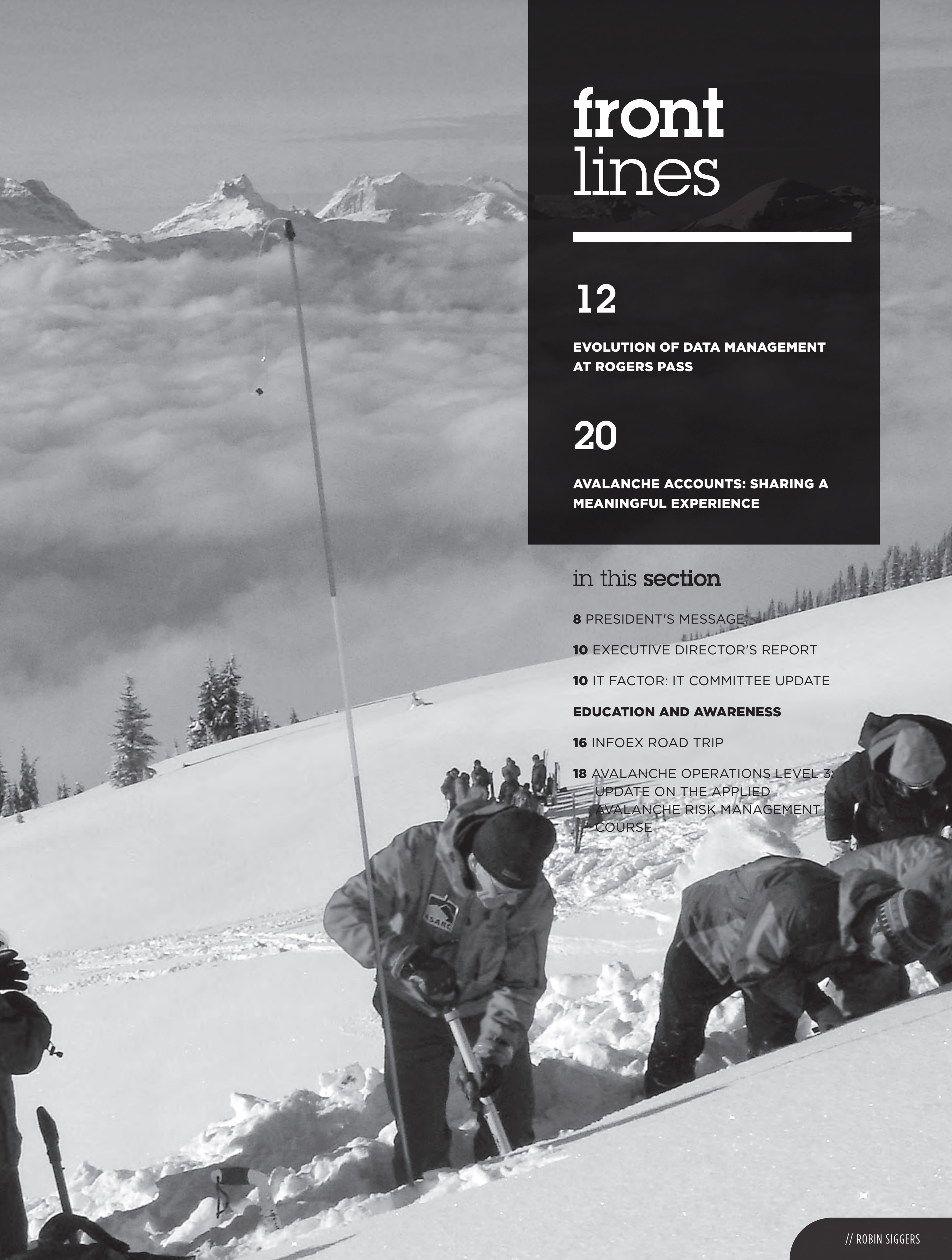

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// ROBIN SIGGERS

Outgoing CAA President's Message

Aaron Beardmore
CAA Past President

AS I REFLECT ON THE PAST six years as a member of the CAA Board of Directors, the last two as president, I am overwhelmed by the diligent work ethic and patience of the board, committees and staff. I am also grateful and honoured to have been entrusted by the membership with the leadership of the CAA. These factors have enabled the CAA to make great strides on our journey toward achieving our vision: *"The Canadian public has the highest degree of confidence in the avalanche safety programs and services delivered by CAA members."* While we are quite a way down the road, our journey is not over yet. With my final message as president I would like to draw attention to the path we have undertaken as an organization, where I think we should go in the future, and give thanks to some of the great people I have worked with along the way.

WORK WE HAVE DONE

During my time on the Board of Directors there has been a move to ensure the CAA remains relevant as a professional organization well into the future. To do so, the board identified the need to create a self-regulatory approach, which suits the needs of the public. When I became president I refocused the efforts to align with our strategic plan and began working on deliverables. George Bryce, our legal counsel, assisted by helping provide some visual clarity to self-regulatory model we were trying to design. The figure below has helped the Board remain focused despite temptations to be pulled in different directions. You might laugh, but when the complexity of self-regulatory models began to seem mystifying, I came back to this picture for clarity and simplicity. I encourage you to do the same.

The map has been drawn. While elements of the self-regulatory model change and as our association has evolved, the following have been completed:

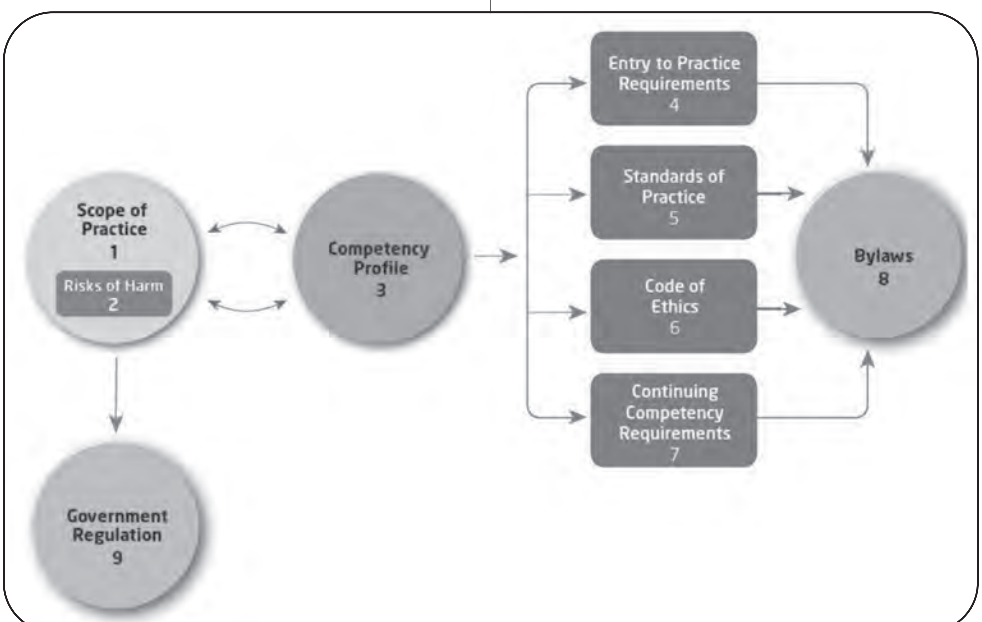
- Competency Profile
- Scope of Practice Statement
- The Code of Ethics
- Bylaws that enforce a scrupulous complaint investigation and discipline process

STILL ON THE TO-DO LIST

Our self-regulatory model lacks the following elements:

- Risks of Harm Analysis
- Practice Standards and Guidelines
- Entry to Practice
- Continuing Competency Management

While the remaining to-do list may look daunting, I'm happy to say we have started on most of this work. A variety of committees



and working groups have been tasked with completing these parts. Specifically, a working group of staff and CAA members completed a gap analysis between the competency profile and ITP, setting the stage to both restructure the ITP program and produce future entry to practice requirements. Also, the Ethics and Standards committee has been tasked with providing a plan to the board to develop continuing competency requirements as well as investigating what practice standards and guidelines will look like. The last piece, the Risk of Harm Analysis, has yet to be initiated; however it should be on the next president's agenda in the near future.

WHAT THE RESULTS SHOULD LOOK LIKE

When we complete the final elements, our organization will be in a strong position to attain our vision. Avalanche professionals will work under a model similar to other respected professions like engineers, doctors, nurses, and geologists. While we have accomplished many things that help us get closer to our goal there is still work to do. To this end, I encourage future presidents and the board of directors to work tirelessly to see this through.

My plan is to work towards helping the CAA achieve its vision from a different position but with no less conviction. While I will no longer be serving you as president I will continue to serve the membership as a committed member of the Ethics and Standards Committee. In the same spirit, I ask all CAA members to consider what contribution you can make and reach out to the board, staff or committees to help us build a strong CAA. And, before I sign off, I would like to thank Joe Obad and his staff immensely. Joe has demonstrated exceptional leadership and initiative that we can attribute to the CAA's successes for the past four years.

Aaron Beardmore, CAA Past President

The New Board of Directors

Walter Bruns
CAA President

WELCOME TO OUR NEW CAA President Walter Bruns, who was elected on May 3, 2016. Walter is well known to many of you. He started in the avalanche community as an assistant heli-ski guide around 1980. His first CAA course was through BCIT in Creston/Kootenay Pass with instructors Peter Schaerer and Willi Pfisterer.

Walter worked as a CMH heli ski guide through the 1980s, becoming operations manager in the 1990s before being the President of CMH from 2001 to 2010. Walter resides in Banff, where he's now semi-retired, though he remains an occasional ITP instructor. He anticipates now being much busier with the CAA Board of Directors. His other hobbies include blues harmonica, sailing and growing food.

Lisa Porter
Director-At-Large

LISA PORTER BEGAN WORKING as an avalanche forecaster at Mt. Norquay in Banff, AB while completing her MSc at the University of Alberta. She then moved on to work with BC's Ministry of Transportation and Infrastructure as an Avalanche Technician in the North Cascades. Over the last few years, Lisa has also worked her way through the Thompson Rivers University courses to become an ACMG certified Hiking and Apprentice Ski Guide.

In the winters, Lisa currently works as a ski guide and teaches avalanche courses, for which she has a particular passion. She is a CAA Professional Member, a member of the CAA's Complaint and Investigation Committee, and chair of the ACMG's Communication Committee. Lisa lives in Canmore, AB where you can find her skiing, biking, climbing, hiking, and more.

Lisa wanted to join the CAA Board of Directors to help shape the future of professional avalanche practice in Canada through work on the next strategic plan and practical implementation of the competency profile.

Joe Obad
CAA Executive Director

CAA Executive Director's Report

COMING TOGETHER, MOVING AHEAD

IT IS HARD NOT TO LOOK BACK on the year to tease out patterns or trends. The themes that jumps out after this season are sidestepping some serious challenges for now, and moving from uncertainty to clarity in other areas.

Sidestep what, you ask? Coming into the year, dire speculations about El Niño pervaded most conversations within the industry in Western Canada. A weak season of snow and business following the poor 2014-15 would have a negative effect on industry and support for avalanche practitioners. Fortunately, freezing levels were just good enough to give most recreational operations strong years. In a similar stoke of good fortune, the weak Alberta economy did not take down the the recreational snow industry with it. With the Alberta economy taking more hits and climate change looming generally, there may have been significant impacts on industry and practitioners if not for this past season. So the CAA must take a cautious approach, knowing CAA members are vulnerable to these large trends.

While we are limited in addressing these large macro forces, we can address much of the fate that rests in our hands, and have tried to do that this year. Where we've made strides the general theme has been bringing a broad array of voices together. It warrants looking at a few of these steps forward in that light.

On the Membership/Association file, we can look at the year as a mix of achievements and steps along the road. The biggest achievement is the completion of *Technical Aspects of Snow Avalanche Risk Management – Resources and Guidelines for Avalanche Practitioners in Canada (TASARM)*. These practice guidelines draw from the earlier *Risk Determination Guidelines (2002)*, but lay out a broader view of practice, incorporating widely used tools like the Conceptual Model of Avalanche Hazard and the Avalanche Terrain Exposure Scale, along with a framework to define risk management for planning and operations.

Many thanks to Principal Investigator Cam Campbell and his team of subject matter experts for completing this resource, which we hope will help everyone from the program leader defining risk for management down to the frontline practitioner heading out to make observations.

The board also pushed staff to help the working groups focus on two critical tasks related to competency. If the competency profiles released in 2015 show the way towards new entry-to-practice standards, then this past year has been about taking steps down that path. The Competency Working Group and Education Committee worked with Emily Grady to define and analyze the gap between ITP's current curriculum and assessment and what may be needed to support entrance-to-practice requirements for Active and Professional members in the future. Based on this analysis the Competency Working Group developed an initial model for assessing the entrance-to-practice competencies for active members. We will follow up this work with model to assess the entrance-to-practice competencies for professional members.

On the terrain front, John Kelly led another working group closer to developing terrain guidelines for CAA members teaching avalanche courses. For what one might consider the equivalent to AST 1 courses, the working group drew from the P1 (similar to active member) proficiency scale to propose a model based on terrain restrictions. For the P2 proficiency scale (similar to professional member) the group developed a model that defines parameters for familiarity to both enable and limit professional members teaching AST 2 courses. These models have a way to go but we are getting closer to providing practical terrain guidelines to CAA members teaching the public.

With InfoEx, the CAA and the InfoEx Advisory Group have really hit our stride over the past year. The IAG was consulted as we engaged Sweden as a new revenue source. We also worked through establishing a baseline of where InfoEx is, from the standpoint of technology and development. This provides the IAG and the IT Committee with a common reference point to prioritize development into the future.

This cooperation has been good practice for the summer's biggest task—revamping the InfoEx Subscriber agreement. We've all recognized that the current subscriber agreement needs work to address InfoEx as it exists today. IAG Chair Brad Harrison along with Karl Klassen and Niki Lepage have worked with CAA staff to create a framework upon which we hope to build a new agreement that works for subscribers and the CAA. We have wrestled with different approaches to ensure fairness to subscribers while ensuring InfoEx is financially sustainable. We look forward to moving this work forward through the summer.

On the Industry Training Program front the Education Committee and instructors helped us achieve several key successes this year: developing and rolling out the AvSAR course, and stepping up to get courses taught when we lost instructors to illness or other factors. The board has been concerned with the financial margins of ITP and has pushed the staff toward ensuring we retain enough earnings from ITP to reinvest in curricula going ahead.

The sustainability bell has also been rung by our member Auditors Albi Sole (AB) and Mark Vesely (BC). Their reports have pushed the board to revisit timing of the fiscal year versus the AGM. Currently we are barely completing the year-end financial statements prior to the AGM with no margin for error. Beyond the risk of arriving at the AGM without statements, Mark and Albi both point out the lost opportunity to review finances for greater efficiency. Staff and Board have already started to look at options.

This summary has a lot of models, frameworks and initiatives started. All these efforts must advance before the snow flies in the fall. It promises to be a busy summer! Many thanks in advance to all the CAA members we will call on to contribute to moving ahead on these fronts.

Joe Obad, CAA Executive Director

The IT Factor: IT Committee Update

Scott Garvin

THE IT COMMITTEE wrapped up its second season since forming in January 2014, with a solid foundation in both IT management and a variety of sector representation from within the avalanche community. With several committee members also volunteering with the InfoEx Advisory Group, we feel that the IT committee is well balanced to provide IT expertise with a sound knowledge of what the key issues are to not only the staff, but the membership as well. The committee members include Tanya McKinney, Krissy Boucher, Brad Harrison, Josh Milligan, Eirik Sharp, Andrew Grasmuck and Mike Smith.

Our work over the past year has involved tackling some significant IT issues related to InfoEx. As well, we continue to plan towards building a road map to help guide the CAA's IT management for future planning. Some of the key InfoEx issues the committee has been working on over the past year include a mapping replacement, automated testing and technological lifecycle planning, and recommendations for prioritizing future works

The committee provided its recommendations to the BoD/CAA staff regarding the InfoEx mapping resolution. We continue to work on providing feedback related to the automated testing project and lifecycle planning, as well as prioritizing future fixes required for InfoEx.

We are currently working with the CAA IT staff to provide potential avenues for professional development opportunities for the staff. These include mentoring and resource opportunities with other IT professionals. The committee has also helped to resolve outstanding IT issues not related to InfoEx and is currently planning to help design an IT roadmap to aid and guide the IT staff with planning future IT initiatives.

The committee is still in its nascency and is trying to figure out the extent of its role. We continue to learn and look forward to providing our guidance and feedback to the CAA IT staff in the coming year as the need arises.

UPGRADING WEATHER TELEMETRY COMPONENTS AT MACDONALD WEST SHOULDER STATION, 2016 // PARKS CANADA, RYAN BUHLER PHOTO

The Evolution of **Data Management at Rogers Pass**

Andrew Jones

ON DECEMBER 29, 1968, THE THERMOMETER at the Mount Fidelity research station (1,910m) dropped to -41.1°C, the coldest temperature in 51 years of records. The record height of snow (HS) for the Rogers Pass weather plot (1,320m) was 319cm on March 2, 1972. Eight days later on March 10, 1972, the HS stake at Mount Fidelity peaked at 493cm. Data collection of this kind has been a key component of the avalanche control program in Glacier National Park since the initial stages of highway planning through Rogers Pass. Modern weather telemetry equipment and database software have contributed to an evolution in weather and avalanche data management that continues to address the needs of the Rogers Pass Avalanche Control Section (ACS).

IN THE BEGINNING: THE EARLY YEARS OF DATA COLLECTION AT ROGERS PASS

In the winter of 1953-54, the Department of Public Works assigned Noel Gardner the task of observing avalanche occurrences in Rogers Pass. Once or twice a month, Gardner traveled the proposed route of the soon-to-be-built highway on skis, documenting the number and location of downed avalanches. At the same time, Parks Canada wardens in Glacier National Park recorded daily air temperatures and height of snow. In 1956 Peter Schaerer expanded the data collection program to include daily weather readings at Rogers Pass Summit and Mount Abbott, daily avalanche occurrence observations, weekly snow profiles and various snow studies. These early efforts laid the foundation for a data collection program that would influence every aspect of highway construction through Rogers Pass and guide the development of the largest mobile avalanche control program in North America.

AVALANCHE FORECASTING SYSTEM: THE PATH TO AFS

Careful data collection has remained a cornerstone in the ACS at Rogers Pass. Precise data collection methods developed by early forecasters at Rogers Pass eventually formed the foundations for the Canadian Avalanche Association's Observation Guidelines and Recording Standards. Today, hundreds of field books containing

THE GLACIER STUDY PLOT, ROGERS PASS SUMMIT CIRCA 1957 // REVELSTOKE MUSEUM ARCHIVES, PETER SCHAERER COLLECTION

weather, snowpack and avalanche occurrence data beginning in the early 1960s line the shelves of the computer server room in the Rogers Pass ACS offices. The books are kept for posterity, as all the data has been meticulously entered into a modern, secure, searchable database that is housed on the computer servers in the same room. The Avalanche Forecasting System (AFS) is an active data repository for over 56,100 standard weather plot observations, 89,337 avalanche occurrences, and 17 years of weather data taken every 10 minutes from nine remote weathers stations. Data is continually entered into AFS and can be viewed through a custom graphical user interface.

Realizing the operational benefits of a robust database, Rogers Pass avalanche forecasters past and present have contributed to the development of AFS. Over the years, AFS has evolved to include several important features. Graphing capabilities facilitate quick summaries of weather and avalanche occurrence data, as well as easy comparisons between avalanche conditions and occurrences of past winters. Cell phone callout alarms can be configured with real-time weather telemetry, allowing forecasters to know when preset wind, temperature or snowfall thresholds have been reached. A complete avalanche atlas linked to avalanche control records, avalanche observations and photos allows for the quick study of tricky avalanche problems, such as the timing of springtime glide crack releases. Parks Canada Senior Avalanche Officer Jeff Goodrich identified a strong linear correlation between the size of springtime glide crack releases in the Mounds avalanche path on Mount Tupper and height of snow values at Mount Fidelity and the summit of Rogers Pass. With ongoing data collection, the predictive power of AFS is expected to grow.

DATA SHARING AND RESEARCH

Databases containing 50-plus years of mountain weather and avalanche occurrences are rare outside of Europe, making the AFS database particularly useful to avalanche and climate researchers. Rogers Pass has long been an area of interest for avalanche research in Canada and researchers routinely request data from the AFS database to support their projects. Most recently, in early 2016, researchers from the Applied Snow and Avalanche Research University of Calgary (ASARC) group published a thorough analysis of long-term weather, snow and avalanche data at Glacier National Park, studying the influence of climate change on avalanches (Bellaire et al. 2016). Currently, researchers from the University of Sherbrooke are using ACS weather data to enhance the representation of snow cover in the Canadian regional weather models and improve remote sensing techniques. Past data-sharing agreements have led to published papers in the fields of glaciology, ecology, and wildlife management.

Data-sharing agreements have been established with a wide variety of partners ranging from government agencies (Environment Canada), crown corporations (BC Hydro), and private contractors. The longest standing partnership has been with Environment Canada, for whom Parks Canada has been an official weather observer since 1965. BC Hydro uses daily weather observations from Mount Fidelity and

Rogers Pass in algorithms for predicting spring runoff and water availability. Engineering and geotechnical firms are currently studying historical avalanche occurrence and weather data to inform the placement of avalanche mitigations in the highway corridor. Internally, Parks Canada ecosystem and social scientists have used AFS data for various applications from studying winter trail use to research on white-nosed syndrome in bats.

THE ONGOING EVOLUTION OF AFS

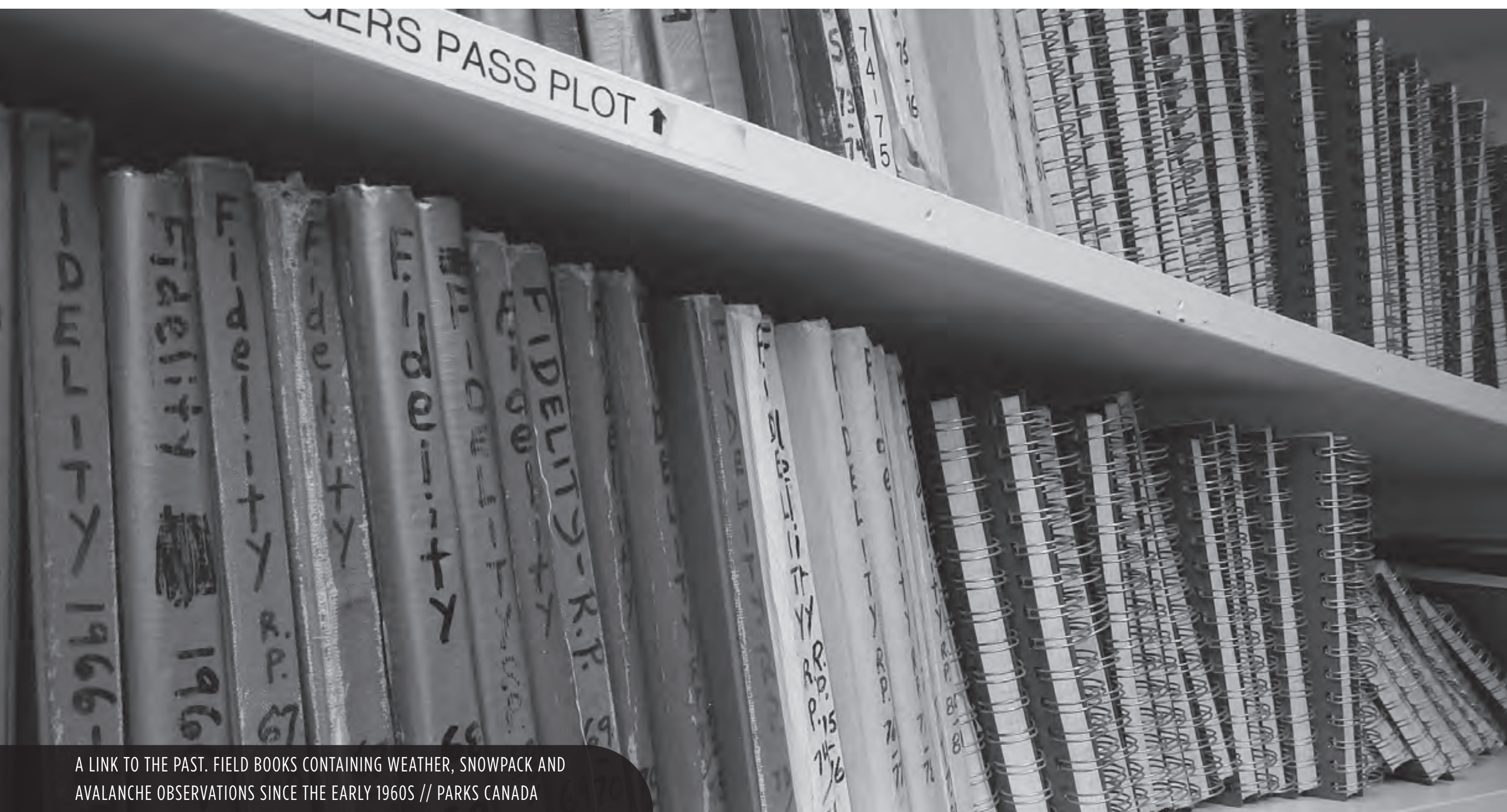
In the summer of 2015, AFS was again upgraded, this time to include a snow profile visualizer component. For the first time, Rogers Pass snow profile data, including heading information, layer characteristics and stability tests, is now being stored in a searchable database. Snow profile data entered in a tabulated interface can be outputted to a graphed profile and exported as a PDF or PNG file. From an avalanche forecasting perspective, the addition of a snow profile visualizer is a key step in the evolution of AFS. Significant weak layers identified in the snowpack are easily tracked among profiles allowing for quick comparison of weak layer characteristics across space and time. With upwards of 100 snow profiles per winter being observed and recorded by ACS, this component of AFS will quickly develop into a useful tool for avalanche forecasters as well as a new data source available to the research community.

The goal for the next phase of AFS development is to integrate recently developed decision support tools for avalanche forecasting into the AFS user interface in the form of a "predictive dashboard." Avalanche researchers have developed a series of analysis tools for avalanche forecasters including threshold sum for deep-slab forecasting (Conlan and Jamieson, 2015), the SWarm model for solar warming (Bakermans and Jamieson, 2008), Operational Decision Tree Avalanche Forecasting (Rosenthal et al. 2002), and nearest neighbour models for forecasting likelihood of triggering avalanches (Zeidler and Jamieson, 2004). In the future, we hope to incorporate the functionality of these models to AFS, thereby creating a truly predictive avalanche forecasting system. The development goal for AFS is to trend towards a streamlined system where the power of real-time and historic data is easily leveraged to assist avalanche forecasters with their hazard assessments.

REFERENCES

Bellaire, S., B. Jamieson, S. Thumlert, J. Goodrich, G. Statham 2016. "Analysis of long-term weather, snow and avalanche data at Glacier National Park, B.C., Canada." *Cold Regions Science and Technology* 121: 118-125.

Conlan, M., B. Jamieson 2015. "Improved forecasting of persistent deep slab avalanches with a decision support tool." *Paper presented at Disaster Prevention Speciality Conference of the Canadian Society for Civil Engineering Speciality Conference, Canadian Society for Civil Engineering*, Regina, Saskatchewan, Canada (2015)

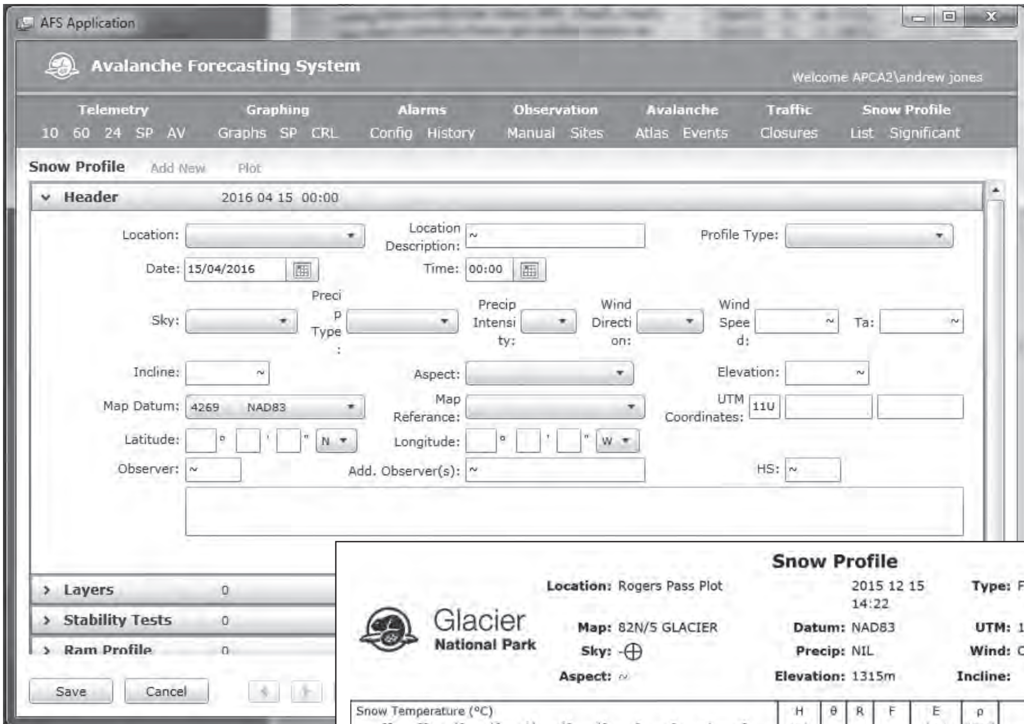


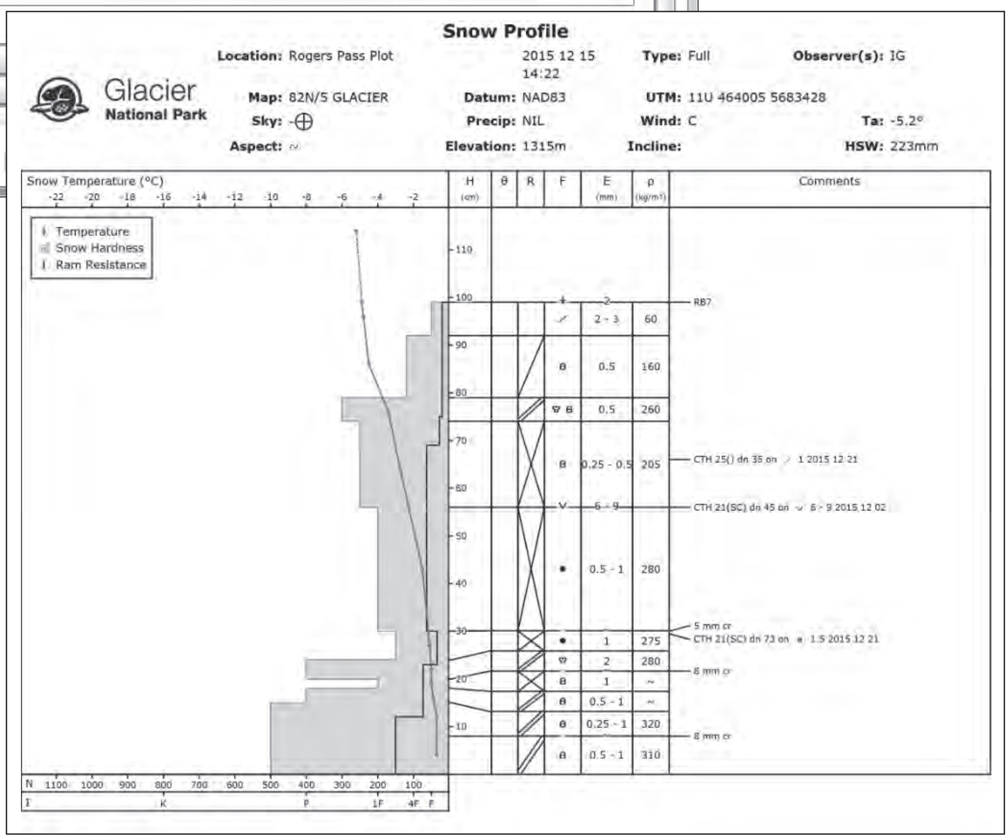
A LINK TO THE PAST. FIELD BOOKS CONTAINING WEATHER, SNOWPACK AND AVALANCHE OBSERVATIONS SINCE THE EARLY 1960S // PARKS CANADA

Bakermans, L., B. Jamieson 2009. "A solar warming model (SWarm) to estimate diurnal changes in near-surface snowpack temperatures for back-country avalanche forecasting." *Proceedings of the 2008 International Snow Science Workshop*, Whistler, BC, Canada: 306-314

Rosenthal, W., K. Elder, R. E. Davis 2002. "Operational Decision Tree Avalanche Forecasting." *Proceedings of the 2002 International Snow Science Workshop*, Penticton, B.C: 152-159.

Zeidler, A., B. Jamieson. 2004. "A nearest-neighbour model for forecasting skier-triggered dry-slab avalanches on persistent weak layers in the Columbia Mountains." *Canada Annals of Glaciology* 38: 166-172.





AFS Software

AFS snow profile entry screen (above) and the snow profile graphed by AFS software (right).

InfoEx Road Trip

Luke Norman

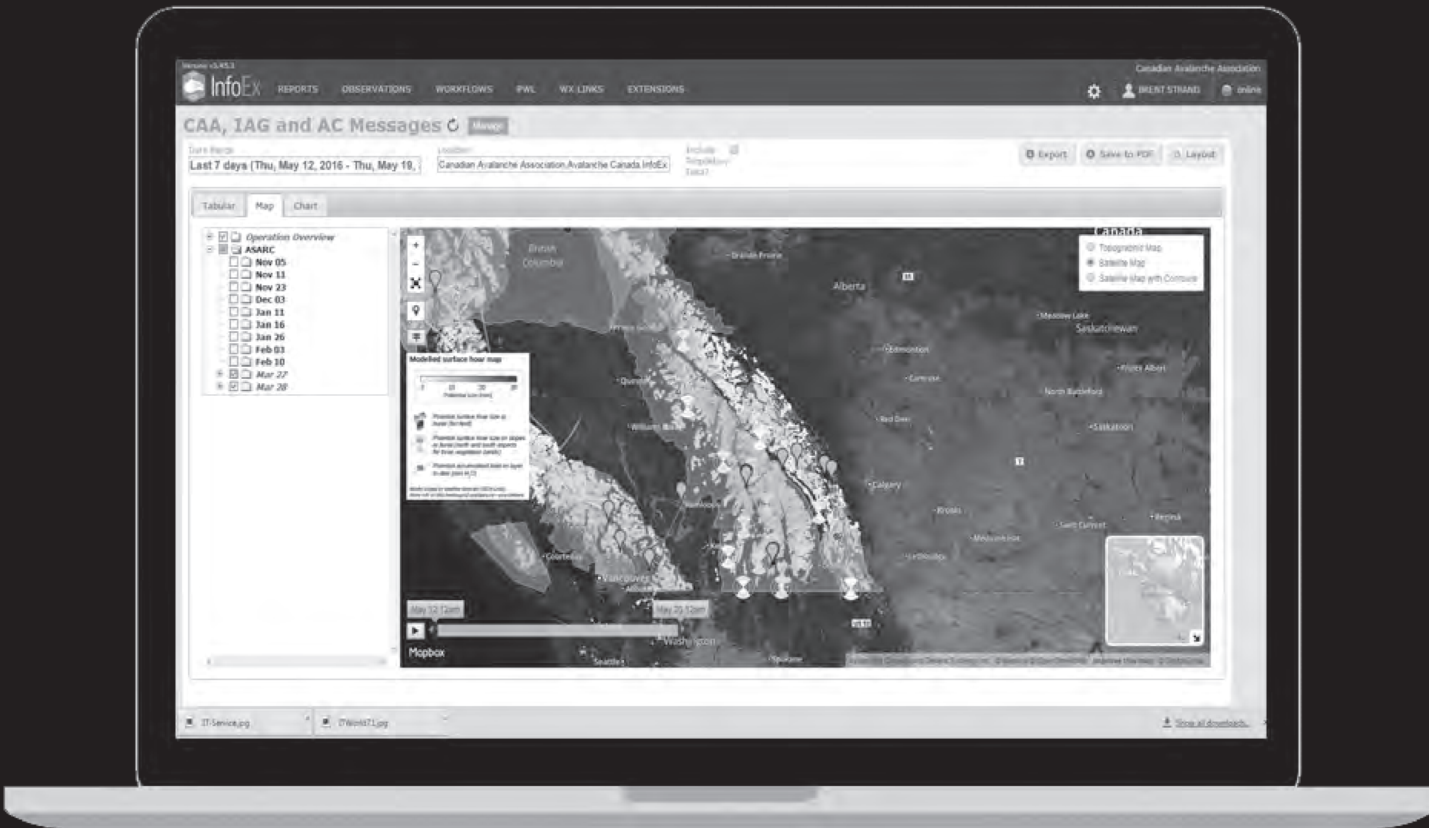
UNDERSTANDING HOW INFOEX is used by practitioners is a challenging aspect of developing the application from the Revelstoke CAA office. Throughout the season we get questions and bug reports via phone and email, but it doesn't compare to being in an operation's morning meeting at 6:00am, seeing in real time how the design decisions we make impact our users. We believe that there is so much value to these experiences that in January I spent a week in Terrace, BC, meeting with InfoEx subscribers in a range of different fields, and accompanying them throughout their day. The folks at Northern Escape Heli Skiing, White Wilderness Heliskiing, Northwest Avalanche Solutions and the BC Ministry of Transportation and Infrastructure were kind enough to let me shadow their operation for a day and to share their experiences.

My aims were to experience how InfoEx is used in varied operational settings, suggest better ways for subscribers to use InfoEx, gain feedback on frustrations and desired future development, and demonstrate the new mapping functionality within InfoEx. Some details of the new mapping functionality are below, and I also ran a more detailed hands-on training session at the AGM in Penticton.

The visit to Terrace was eye-opening, providing some excellent first-hand experiences of some of our successes over the last few years. The visit also shed light on some of the frustrations experienced by subscribers. Some operations had really made the most of workflows, using an InfoEx workflow to guide the whole morning meeting, recording proprietary data such as logistics or strategic mindset with the Freeform module, and using a range of reports to filter out noise and quickly find relevant information. On the other hand, it is clear there are still issues around observation submission/validation within a workflow, and confusion around the limited feedback provided to users when submission errors occurred. I hadn't realised that some operations would use a different conceptual model of avalanche hazard than the model we use in InfoEx, and would need to convert between the two.

I was surprised about how little was known about some InfoEx functionality, and the improvements that could be made to a morning meeting with a few InfoEx tweaks. There is a wealth of functionality in the reporting module that is often either overlooked or misunderstood, and some users were surprised by the power available once you start to dig down. I was pleased by how much progress could be made by spending just a couple of hours working with an operation, understanding their needs, and suggesting improvements. Stuart Smith and I held some very productive one-on-one training sessions during the AGM in Pencticton, and I would encourage any InfoEx user who has ever thought "InfoEx would be so great if it could do ..." to come and talk with us, to see what we can suggest.

We have a long list of InfoEx work to do, compiled mainly from user suggestions over the last 3 years. Feedback on how InfoEx is or isn't working in your operation is crucial to our success in further development. I would really encourage anyone who has a problem or issue to let us know. If you have suggestions for future InfoEx development then please contact your IAG representative and make your feelings known. I look forward to our continued success together, and to working with subscribers in the winters ahead.



INFOEX UPDATES THIS PAST SEASON AT A GLANCE

We made changes to the base mapping platform throughout the application. The clunky Google Earth plugin is gone, replaced by a faster, more reliable 2D map which is much quicker to load. There are multiple map layers, including topographic and satellite. The drawing and editing tools have been replaced with a more intuitive toolset, and we have made improvements to the overall stability of the platform.

It is now much easier to select a location or draw a polygon when entering an avalanche or snowpack observation, and we have made a wealth of improvements to the map report view as well, so it's simple to view and understand this information. We have added a mini-map and full screen options to the map view, as well as a legend explaining all of the icons and symbols. The window has been redesigned with more space for data and less menu clutter. We fixed numerous small bugs, resulting in a stable mapping platform that loads very quickly.

Avalanche Operations Level 3: Update on the Applied Avalanche Risk Management Course

James Blench

SINCE MY FIRST COURSE IN THE 1980S, I have regarded teaching on the ITP programs both as a privilege and a gift. The courses provide an opportunity to interact and collaborate with other avalanche professionals who often work outside of my sphere and broaden my outlook in avalanche work. Curious students ask well thought-out and challenging questions that help keep me fresh. The Avalanche Operations Level 3 course (Applied Avalanche Risk Management–AARM) has been no different and the learning and interaction has been outstanding.

On the first few iterations of the Level 3 course, the "students" included many of the elder statesmen of the Canadian avalanche patch, many with 20 to 30 years of avalanche work behind them and representing almost every sector of our community. A significant number of the participants had either developed or had been instrumental to many of the current avalanche programs in western Canada. Chris Stethem piloted the ship on the first few courses as we navigated our way through a sea of new vocabulary and concepts, since quite a lot of the material was as new to us as to the students. Much of the current course content was a result of the first two beta courses and feedback from the participants. The Conceptual Model of Avalanche Hazard from the ADFAR project was relatively new for the first course in 2010. Some folks found it controversial, and test driving the model's utility was a primary focus of the course. We had no idea that snow stability was so near and dear to many people's hearts! Discussions were lively—sometimes heated—and often the students would pursue an interesting topic in directions the instructor team had never considered. It was great to be part of that.

> The now-defunct QAP designation was a key motivator for the initial courses, and I am pleased that the course content has proven its value and merit beyond the need for paper qualification.

Now, ten or so courses later, the student demographic has changed somewhat. Most are just reaching senior positions in their respective organizations (with about 10 years of experience) and have been groomed through well-established programs. We have had students from the US, Sweden, Switzerland and Germany, and good representation from both practitioners and the academic community. Sector wide participation has also been good with highways, ski areas, guiding, and industry generally well represented.

Course content has evolved as well. The current iteration is framed by IS0 31 000: Risk Management – Principles and Guidelines (2009). This provides us with common language, concepts and structure to describe, manage and communicate risk issues, like how OGRS keeps us all on a similar page with snowpack and weather. Application of ISO 31 000 is highlighted through a series of case histories (some as long as four hours of class time) that usually have breakout work and student analysis embedded in the lesson. Student teams are assigned a small avalanche project to work through during the course, and create a short presentation for the last day. This project provides an opportunity to use the new language and concepts, apply ISO 31 000 to a hypothetical example, and discuss issues of scope of practice. Feedback has been very positive to this instructional approach, and the international students in particular provide insights through a different cultural context, which adds overall value.

Common to all the courses has been the assessment process. It is a two-stage process consisting of a written report and subsequent oral presentation. There is a well-documented guideline to frame the report around, which is essentially a year-end recap of the student's avalanche season and an opportunity to demonstrate his or her understanding of the AARM terms, concepts and principles. I often find the reports quite insightful, and they provide useful views into facets of avalanche work I am not involved with. The oral presentation is an opportunity to expand upon the written report. The best orals take an interesting topic from the written content and delve into more detail. There is a question and answer to finish the oral presentation, and we frequently run over time due to interesting discussions. The common feedback regarding the assessment process is that while it is difficult and challenging (as many of us do not write reports routinely), it is simultaneously the best element of the course as it provides a structured approach to reflect upon a season of work.

To wrap things up, some historical context and acknowledgment of individuals is in order. My involvement started in 2006 with Randy Stevens and some training we did for the Icelandic Meteorological Office in Reykjavik. An invitational beta course was held in Canmore in 2008, and many of the initial lessons were developed in that 2008 session. The now-defunct QAP designation was a key motivator for the initial courses, and I am pleased that the course content has proven its value and merit beyond the need for paper qualification. The official inaugural course was held in 2010, and two were run that season. Credit is due to Chris Stethem for his vision and leadership, particularly for the first courses, along with Larry Stanier, Grant Statham, Mark Veseley, Robin Siggers and Dave Smith. Phil Hein provided valuable insights at the planning stages of the program. Later on, Brian Gould, Bruce Jamieson, Iain Stewart Patterson, Colin Zacharias, Brad White, Scott Davis, Mark Klassen and Conny Amelunxson all have made (and continue to make) significant contributions to the AARM course.

I am sure I speak for the entire Level 3-AARM team when I say we are looking forward to this year's batch of reports and oral presentations.

// DAVE SCOTT

Avalanche Accounts:
Sharing a Meaningful Experience

Story Martina Halik, Photos Raven Eye Photography

IT'S AMAZING HOW MANY THOUGHTS RUN THROUGH YOUR HEAD IN THE SECONDS WHEN YOU SUDDENLY FIND YOURSELF HELPLESSLY CAUGHT IN A MASS OF MOVING SNOW, HURTLING HEADFIRST TOWARD A STAND OF TREES.

*OhS**t-OhF**k-ThisIsActuallyHappening-PullYourAirbag-ProtectYourAirway-Nononono!* My head was pushed under the snow, I heard my airbag inflate, and I lost sight of the world. With one hand I tried to cover my airway and the other I stretched forward to brace for impact with old growth spruce. Seconds later came relief; I'd come to a stop, unburied in a stand of trees, as the rest of the debris continued for another 80m. Somehow I'd slalomed through the trees without hitting a single one, and came to a gentle stop when the snow piled up into a tree ahead of me. I pushed up out of the snow, began to hyperventilate as the adrenaline wore off, and shouted up to my co-worker Matt that I was okay.

I started berating myself immediately. *What the hell was I thinking? Why didn't I ski cut first? Why did I ski this slope when it was obviously safer to ski the skin track down? There were so many signs—shooting cracks and loud naturals rumbling in the unseen alpine. How could I have been so stupid?* The list of hindsight questions and exclamations continued as Matt and I searched for my missing ski and poles in the debris. Then came the really scary thought: I'm actually going to have to tell people about this. In that moment, it was the last thing I wanted to do. I just wanted to find my gear, get the hell out of there, and crawl into the safety of my bed. I started imagining the disapproving comments I was going to get from my supervisor, my coworkers, my friends and family. *I work for Avalanche Canada! We're not supposed to get caught in avalanches! It was only a size 1.5; it probably couldn't have buried me. Maybe no one even needs to know?*

Then I regained some professional composure, realizing I had a real opportunity to share a meaningful experience. If even one person could learn from my mistakes and it would help keep them safe, then it was worth the shame of owning up to some of my decisions leading up to this incident. It's my job to promote education and awareness to the avalanche community, so it would be hypocritical of me not to share. What I've learned in the last three and a half years of working in public safety is that simply telling someone how to be safe is only a fraction as powerful as a real life story—particularly with details, video, photos, and context from the accident. So that's how I bullied myself into standing in front of the camera barely ten minutes after getting caught in the avalanche. My airbag was still inflated and I mustered up an oddly cheery face despite the terror and flood of emotions I had felt moments before. Currently, the five-minute case study video I produced has had over 10,500 views through blogs, forums, Facebook and other media venues. In our little world of avalanche outreach, we call that viral. Typically, our most successful blog videos reach less than half as many viewers. Surprisingly, feedback has been overwhelmingly positive. I've heard from sledders, skiers, AST providers, guides, and avalanche professionals telling me how much they appreciated that I

TELL US YOUR STORY
If you have been involved in an avalanche and want to share your story, email us at: editor@avalancheassociation.ca

SIZE 1.5, 25M WIDE X 125M LONG, 5-10CM DEEP SOFT SLAB ON SURFACE HOAR WEAK LAYER

shared my incident. The negative feedback I had feared so much in those early moments after the accident never really happened. My supervisors did not berate me for the decisions I made, my friends supported me, and my family did not beg me to stop going into the backcountry.

I understand how difficult it can be to share as a professional. Speaking with recreationists, I don't believe the majority feel like they have as much to lose by sharing their mistakes in public. We work in a very competitive industry where we spend years building a reputation. Each day we maintain a careful balance of staying safe in a volatile environment, keeping the boss or clients happy, and also enjoying the incredible mountains we are lucky to call our office. There aren't many other professions where our environment often has more control over our work than we do. After hearing about my accident, my friend framed it well: as an accountant, if she misinterprets an income tax rule it means her supervisor will write a note on how to fix it, not throw her down a mountain in a mass of thundering snow hoping she pulls her airbag. Sharing and learning from mistakes is something done in all industries, just not always those with such serious consequences.

> I don't kid myself; I'm sure *someone* out there watched my video and thought I was an idiot.

I don't kid myself; I'm sure *someone* out there watched my video and thought I was an idiot. Despite any isolated negativity, I think it's important as a community we continue to encourage disclosure and support the people who make it a priority to share their experiences. Since I first entered the avalanche industry, I have witnessed great steps forward to becoming an open and transparent culture, but I also think there is always room to grow. In the end, all my accident cost was a $25 airbag canister refill, and getting the living daylights scared out of me, but Avalanche Canada and the public got an effective case study video in return. It wasn't easy, but sharing my experience was a worthwhile process.

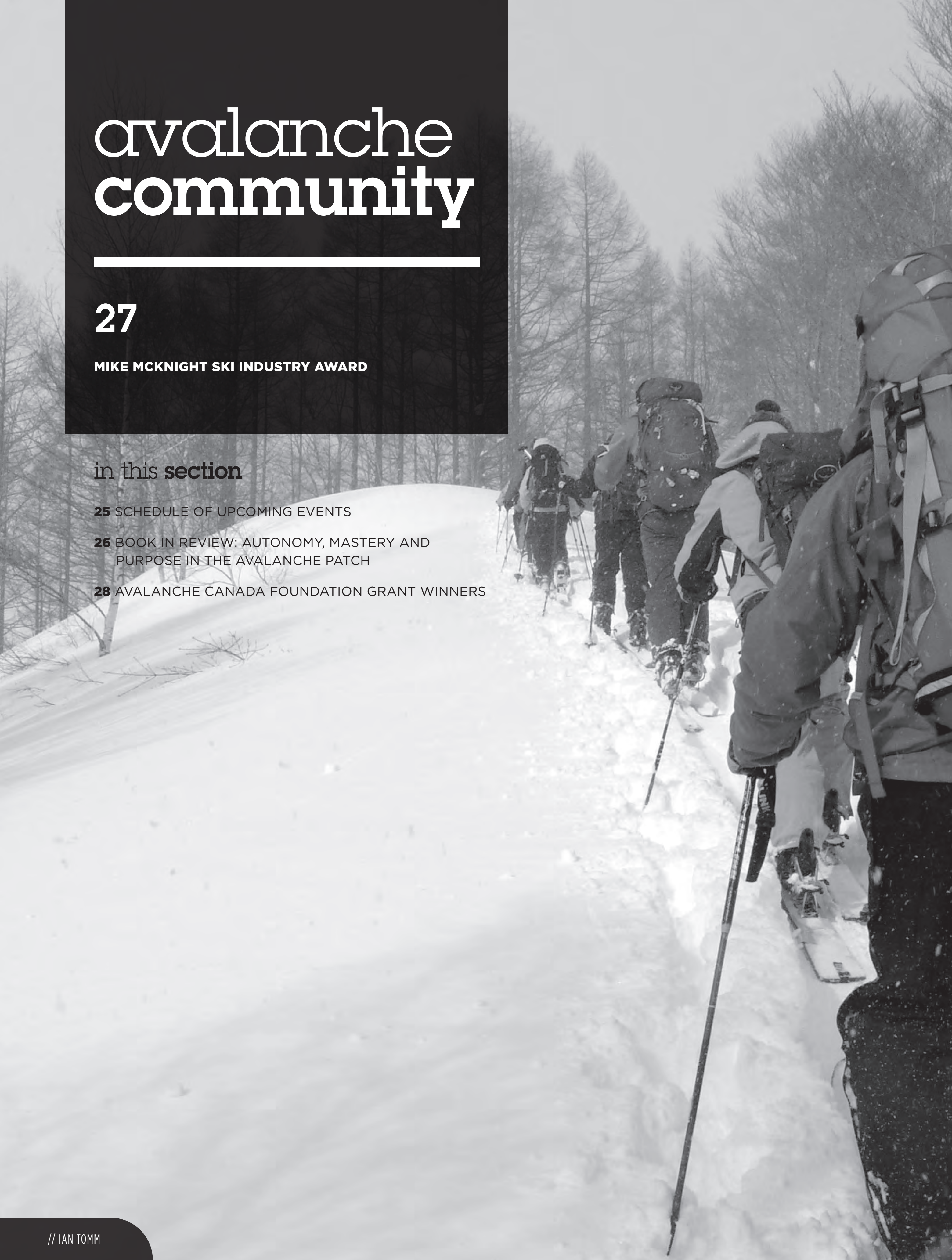
You can view the case study here: vimeo.com/152304534.

Flakes

ROB BUCHANAN

avalanche **community**

in this **section**



// IAN TOMM

Schedule of Upcoming **Events**

INTERNATIONAL CONFERENCE ON SNOW ENGINEERING
June 14-17, 2016
Nantes, France
Bringing together research and operational communities to discuss scientific, engineering and operational issues related to snow and ice.
For more information: snoweng2016.org

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

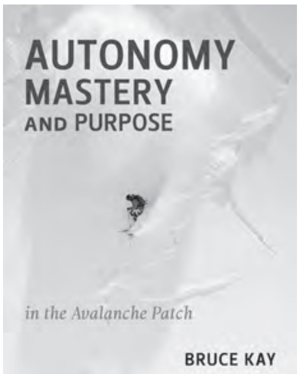
ISSW 2016
October 3-7, 2016
Breckenridge, Colourado
Facilitating the interdisciplinary exchange of ideas and experiences between snow science researchers and practitioners.
For more information: issw.net

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

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

Book in **Review**

AUTONOMY, MASTERY AND PURPOSE IN THE AVALANCHE PATCH
$35.00
AVALANCHEPATCH.COM



Mary Clayton is Communication Director for Avalanche Canada.

IT'S NOT A NEW QUESTION. How do people with training, sometimes very advanced training, still manage to get caught and even killed in avalanches? Ian McCammon introduced the concept of heuristics to the avalanche patch in the early 2000s. While not the first to explore the effect of human factors on decision making in avalanche terrain, McCammon certainly brought the term to the forefront. His ideas have been hugely influential over the intervening years and have gained increasing traction across many boundaries.

In this new book, *Autonomy, Mastery and Purpose in the Avalanche Patch*, author Bruce Kay dives deeply in to this question. He builds on McCammon's concepts and more, bringing in work from Nobel Prize-winning cognitive psychologist Daniel Kahneman and research psychologist Gary Klein, famous for his work in decision making. If this sounds like advanced-class thinking, that's because it is. Kay cautions the reader that his book will take some commitment, and even gives a guide to "the best bits" for those who don't want to tackle the whole book.

The warning is overly modest; this is a very good read. Kay's writing is conversational and engaging as he skilfully guides the reader through an understanding of how the varied research he uses to develop his thoughts applies to the "wicked learning" environment of the avalanche patch. Personal stories, some hair-raising, others heart-breaking, are peppered throughout the book, illustrating the points being made and underlining the assertion that education in the mountains is never really completed. There's always something more to learn, both about the snowpack and ourselves.

As the title suggests, this book is not for the backcountry neophyte. Kay speaks from long experience in avalanche risk mitigation and his lessons are aimed at those who have a serious interest in this field, whether as a professional or an advanced recreationist. As a skier and climber Kay speaks solely to this user group, which I found needlessly exclusionary. There are plenty of snowmobilers in his target audience but they'll likely have trouble with the dismissive way Kay describes their sport.

Despite the occasional judgmental tone, *Autonomy, Mastery and Purpose in the Avalanche Patch* is highly recommended. The way Kay applies Kahneman's theories, which are based on decision making in economics, to the natural world of avalanches is fascinating and thought provoking. With this book, Kay has taken us to the next level in understanding the complex world of how we make decisions in avalanche terrain. I am sure that reading it will make you think hard about how you approach your next day in the field.

GOLDEN & DISTRICT COMMUNITY FOUNDATION'S RYAN WATMOUGH CONGRATULATES GOLDEN AND DISTRICT SEARCH AND RESCUE'S SHAUNA SPEERS, THE 2015 RECIPIENT OF THE MIKE MCKNIGHT SKI INDUSTRY AWARD // GADSAR

2015 **Mike McKnight Ski Industry Award**

THE GOLDEN DISTRICT and Community Foundation awarded Shauna Speers the 2015 Mike McKnight Ski Industry Award. The award was created in 2009 to honour the memory of one of Golden's community builders, Mike McKnight.

The award is granted to an institution or training organization for a nominated student of their choosing, who must be a Golden resident with a history of community involvement and who is entering or continuing a training program for employment in the ski industry. This year it went to the Golden and District Search and Rescue (GADSAR) for Speers to take a CAA Introduction to Weather course.

Speers volunteers a lot of time to GADSAR as a SAR manager. Speers has also been a Kicking Horse Mountain Resort employee since 2007 in a variety of roles, including mountain safety dispatcher and ski patroller. She has lived in Golden for ten years.

Avalanche Canada Foundation **Grant Winners**

THE AVALANCHE CANADA FOUNDATION IS PLEASED TO HAVE AWARDED TWO SCHOLARSHIPS RECENTLY.

The Foundation would like to thank everyone who donates to these memorial funds. For more information please visit their website at avalanche.ca/foundation/programs#memorialFunds.

The Foundation granted $1,000 from the Al Hodgson Memorial Fund to Mark Hillary of Invermere, BC, to help pay for his CAA Level 1 course which he completed in the winter of 2015-16. Mark is an active search and rescue volunteer and works as a snowmobile guide for Toby Creek Adventures.

Anna Victoria Bourelle of Nelson, BC also received $1,000 from the Craig Kelly Memorial Scholarship Fund to assist her with her Level 2 courses, which she completed this winter. Anna says "Thanks to Craig Kelly for the life he led and for being such a positive role model to Snowboarders in the backcountry and guiding world. I am proud to be a small part of his legacy and very grateful to have been awarded this scholarship."

research

in this **section**

// CHRIS BORSTAD

Educating Future Avalanche Professionals in the High Arctic

Markus Eckerstorfer,
Earth Observation,
Norut (Northern
Research Institute)
Hanne H. Christiansen
& Alexander Prokop
Arctic Geology
Department, UNIS,

IMAGINE A SNOW AND AVALANCHE course at a university campus surrounded by a stunning mountain winter landscape. From the lecture room window, one could observe and discuss snow drifting, cornices accreting, and slab avalanche release. Within a few minutes, these processes could then be directly approached and studied on site.

The University Centre in Svalbard (UNIS), located in the Svalbard archipelago's main settlement Longyearbyen, offered such a course for the first time in the winter of 2015. Now offered on a yearly basis, AG-346 Snow and Avalanche Dynamics is an intense, masters-level course, offering European credit transfer and accumulation system points for qualified students enrolled in snow and avalanche science Masters programs worldwide. With no tuition fees, UNIS is a popular study location for international students interested in Arctic natural sciences. UNIS' geographical position in the High Arctic gives it a unique advantage to use nature as a laboratory for observation, monitoring, and data collection. The UNIS safety and logistics department offers year-round field support, and field safety courses for students and researchers.

Field safety courses are of importance for UNIS due to the imminent polar bear danger, danger of travelling on sea ice, on glaciers, and in avalanche terrain. No student or researcher has ever been injured severely or killed; however, fatalities amongst the local population and tourists occur. The majority of deaths in the last decade have been the result of avalanches. Just recently, on December 19, 2015, a slab avalanche released from a valley side in Longyearbyen with a maximum crown height of 4m, moving and destroying ten houses and killing two people who were inside these houses.

Avalanche activity is controlled by low-pressure activity leading to direct action avalanching and topography, leading to the accretion of cornices and their consequent collapse. The snowpack has continental characteristics in that it is thin, spatially highly variable, and underlain by a persistent weak basis. The snowpack also exhibits maritime characteristics in the form of ice layers and melt forms from mid-winter rain on snow events, leading occasionally to destructive wet avalanche cycles.

An important part of AG-346, and inherent to all UNIS courses, is to learn about natural processes in Svalbard and other parts of the High Arctic. Nevertheless AG-346 focuses on the science of the key snow and avalanche processes influenced by meteorological and topographical conditions. The theoretical part of the course introduces snow science basics, the physical, mechanical, radiative, and thermal properties of the snowpack. The largest emphasis is of course on snow avalanche mechanics and avalanche dynamics, avalanche hazard mapping, runout modeling, hazard mitigation and forecasting. Besides the focus on the physical science of avalanches, we also discuss human factors in avalanche accidents as well as good avalanche terrain travel behavior. The anticipated course learning outcomes are detailed knowledge on methods and data acquisition within snow and avalanche science, as well as knowledge of the newest theoretical approaches. We also focus on teaching the ability to critically analyze existing theories and research papers, and to plan fieldwork and research projects using appropriate, safe field methods.

Common to all UNIS courses, different main course topics are taught by international guest lecturers as well as internal UNIS research staff. Besides Eckerstorfer, Chris Borstad, Michael

FIELD LAB 1 ON THE WEST FACING VALLEY SIDE OF LONGYEARDALEN, IN WHICH THE SETTLEMENT LONGYEARBYEN IS LOCATED. UNIS IS PARTLY VISIBLE IN THE FAR LEFT CORNER OF THE IMAGE. DURING FIELD LAB 1, THE STUDENTS LEARNED AND PRACTICED EFFICIENT SNOWPIT TECHNIQUES

FIELD LAB 5 ON A MOUNTAIN PASS WITH A DISTINCT CONTINENTAL SNOWPACK DUE TO THE HIGHER ELEVATION. WE REACHED THIS PASS WITH SNOWMOBILES PROVIDED BY THE UNIS SAFETY AND LOGISTICS DEPARTMENT. DURING FIELD LAB 5 THE STUDENTS LEARNED AND PRACTICED MEASURING THE VARIABILITY OF SNOW DEPTH AND SWE AT DIFFERENT SPATIAL SCALES.

FIELD ASSESSMENT DAY ON A MOUNTAIN PASS JUST OUTSIDE OF LONGYEARBYEN. IN TEAMS OF TWO, THE STUDENTS HAD TO DIG AND ANALYSE A FULL SNOW PIT, EXECUTE TWO DIFFERENT STABILITY TESTS OF CHOICE, AND RATE THE LOCAL AVALANCHE DANGER, BASED ON THE SNOW PIT AND OTHER OBSERVATIONS.

Schirmer and Karsten Müller taught in the first AG-346. UNIS PhD student Wesley Farnsworth and external UNIS MSc student Holt Hancock tutored both in the field and during exercises. This spring, the main guest lecturer will be Michael Lehning from SLF.

The first AG-346 course lasted 21 intense days, of which nine days were spent in the field close to UNIS. The field labs offer a rich setting for field based lectures and demonstrations. In the field we developed skills to efficiently collect robust data to a prescribed standard. Each field lab was followed up by a written group field report. The course curriculum was developed by Jordy Hendrikx from Montana State University in Bozeman and Markus Eckerstorfer, who held a 20% position at UNIS running and teaching the course in spring 2015. Eckerstorfer, Hendrikx and Christiansen also organized an international snow expert workshop in 2013, where a snow and avalanche course and a full position in snow science was recommended (Eckerstorfer et al., 2013).

Alexander Prokop is the Associate Professor of snow science in the Arctic Geology department at UNIS. He is therefore responsible for running AG-346 in the coming years, as well as tutoring PhD and MSc students, and developing snow and avalanche science in Svalbard.

We hereby encourage Canadian and North American students to apply for AG-346 in spring 2017. Deadline for the spring 2017 semester will be 15 October 2016. Applications can be sent to UNIS online via: unis.no/studies/regulations-and-routines/how-to-apply. More information about the course requirements, academic content, and learning outcomes of AG-346 are provided here: unis.no/course/ag-346-snow-and-avalanche-dynamics. UNIS is interested in offering course packages to MSc students combing for example AG-346 with a glaciology and/or a permafrost course for example. Admission to AG-346 and UNIS courses in general is competitive. In 2015, over 80 students applied for AG-346, from which 17 female and two male students from eight different countries were chosen to participate.

REFERENCES:

Eckerstorfer, M., J. Hendrikx and H. H. Christiansen 2013. "Avalanche research, education and forecasting in Svalbard, Norway – A roadmap provided by an expert workshop in Longyearbyen, April 2013", *Proceedings of the International Snow Science Workshop 2013*, Grenoble - Chamonix, Mont Blanc, France, pp. 562-566.

ASARC Retrospective
Sequel to the Prequel

Dr. Bruce Jamieson

"SO WHAT IS THE RISK?" I ASKED.

It was 1998 and ASARC's first two graduate students, Greg Johnson and Crane Johnson, were on the Connaught Creek trail with me, ready to cross the Grizzly Slide runout. One said "low" and the other said "very low."

"But is it 1 in 1,000? 1 in 100,000? What is the probability of one of us getting hit or killed crossing this runout?" None of us knew the answer, but it signalled ASARC's interest in risk-based decisions and quantifying backcountry avalanche risk. The closest we came to answering that question was in an ISSW 2009 paper (Jamieson et al., 2009). However, that paper simplified terrain so much that the results only applied to "centre-punching" start zones. (The associated video is called: "Considerable avalanche danger – How much riskier is it?") Nevertheless, the risk framework in that paper remains useful. Alexandra Sinickas, Pascal Haegeli and I are currently using it to analyze data from backcountry skiing operations.

In March 2000, a volunteer travelling with ASARC staff was caught in an avalanche. He was not injured but it identified shortcomings in our risk control procedures, both in the field and in our morning meeting. Soon after, I was fortunate to be part of the CAA committee re-working the Avalanche Operations Level 2 curriculum. I soaked up lots of ideas from the committee and other operations and implemented many changes that improved ASARC's risk control plan. In addition to restricting our use of volunteers, we implemented some changes which made a difference:

1. At the morning meeting, it was not good enough to thoughtfully review the recent and forecast weather, snowpack observations and recent avalanches. We needed to specifically identify low risk routes ("green" routes) under the forecasted conditions. If any individual had concerns about a route, we rejected it. If we dismissed a route that was later recognized to be low risk, that was an important and acceptable part of making consistent, cautious decisions.
2. When we arrived back at the trailhead at the end of each field day, we would ask three questions (adapted from other operations): What was our best decision? (Start with a positive pat on the back!) What was our biggest risk? Was that risk adequately mitigated? Most days the biggest risk was either driving or skiing down to the valley bottom, and was considered low or negligible.
3. In the early years, ASARC staffers had a few epic drives, some of which occurred while driving to one of the field stations on the last of several days off. The changed policy was: if anyone, for any reason, had concerns about the road conditions or their alertness, stop. Call the others at the field station to say you'd be late; get a motel room. Even if the person was on his or her last day off, start charging expenses to ASARC. This was radical, effective and cheap! This only happened about once per winter and typically cost about $100. Aside from being very inexpensive, it sent a strong message about our low-risk culture to those new to ASARC.
4. Peer Incident Narratives: We needed to share—without blaming—the narratives, including the human factors that contributed to the incident or close call (Jamieson, 2008). We recognized that people get better at sharing the human factors days, weeks or months after the event. During December training we would review incidents and close calls from previous winters, including those that occurred during recreation, along with the 2000 incident that involved the volunteer.

These and other changes were very effective. Nevertheless, in the following 15 years we did experience several mostly minor injuries, including a few knee injuries from skiing—one of which required surgery—and a couple of tweaked backs while getting sleds unstuck.

Rule-based approaches (such as *no travel in complex terrain today because the regional danger is rated considerable*), would also have reduced the avalanche risk. Certainly, there was some

DEEP PIT WITH GREG JOHNSON (UPSTAIRS) AND CRANE JOHNSON (DOWNSTAIRS) // ASARC

pressure to implement rule-based decisions. Although we later introduced rules as a check, around 2002 we chose to implement knowledge-based decisions initially because that is what other operations were doing. Later, we were also early adopters of the Conceptual Model of Avalanche Hazard Forecasting. Keeping the research technicians and graduate students involved with forecasting the daily avalanche hazard and selecting low-risk routes contributed to their success after working for ASARC. Also, the practice of knowledge-based decisions—within a structured framework—added to the relevance of our research.

Fracture propagation and weak layer collapse were recurring topics in ASARC field studies. In fall 1998, Crane Johnson selected whumpfs and remote triggering as the topic for his MSc research. As part of his studies, he wanted to measure the speed of a propagating fracture. In the February 2000, we got a call from Marc Ledwidge in Banff National Park saying people were triggering whumpfs around Bow Summit. A couple of days later Crane picked up a seismic recorder from an exploration company in Calgary and met Greg Johnson and Tom Chalmers at Bow Summit. For two days, they walked around the meadows on touring skis and snowshoes. When they triggered a whumpf in one meadow, they threw a rock attached to a cord across the adjacent meadow (high tech!), then used the cord to pull a climbing rope with a string of geophones across the meadow. Once the seismic recorder was recording the string of geophones, one of them would snowshoe into the meadow. For two days, they did not trigger a whumpf while the geophones were recording. They decided on a third and final day of experiments, by which time I had arrived. Our experiments the next morning were also unsuccessful. We decided on one more in the afternoon before accepting that we had missed the cycle of whumpfs. In that last attempt we triggered a whumpf in a meadow and set up the string of geophones in the adjacent meadow. With the recorder collecting data, Tom stomped into the meadow. We all heard and felt a whumpf and froze in silence while Crane checked the recorder. When he called out "We got it," we whooped! We sounded like the Ghostbusters getting their first call. To get a photo of the scene, Greg climbed a tree in what may likely be the only time someone climbed a tree to study fracture propagation in the snowpack.

The fracture speed was about 20m/s in sharp contrast to the 100s of, or even 1000, metres per second proposed for shear fractures by previous theoretical studies. While this result didn't prove that weak layer collapse was a different and important mechanism of fracture propagation, it came to form part of the argument. Crane's paper about this surprisingly slow fracture involved an unusual experimental method and an unexpected result. The paper was initially rejected by one journal but we persisted. We re-wrote the methods section and submitted the paper to a different journal, which accepted it (Johnson et al., 2004). The paper has since been widely cited. I mention the publication difficulty to encourage others with unorthodox experimental methods or unexpected results.

There are many other stories behind ASARC's field studies, which I encourage ASARC folks to write. To keep this retrospective short, here is a list of topics with key contributors (the folks in italics were collaborators): snowpack tests and fracture propagation (Crane Johnson, Cam Campbell, Colin Johnston, Alec van Herwijnen, Dave Gauthier, Cameron Ross), spatial variations of snowpack properties and stability (Kyle Stewart, Cam Campbell), stability of non-persistent weak layers (Catherine Brown, Dave Gauthier), effects of warming (Adrian Wilson, Laura Bakermans, *Jürg Schweizer*, Thomas Exner), vulnerability and risk in backcountry travel (Alan Jones, Cora Shea, *Jürg Schweizer*), climate trends (Sascha Bellaire, Alexandra Sinickas, Scott Thumlert), penetrometers (James Floyer), runout estimation (Alan Jones, Donna Delparte, Katherine Johnston, Alexandra Sinickas), thermal imaging of snow surfaces (Cora Shea, Michael Schirmer, *Karl Birkeland*), improved forecasting for deep slab avalanches (Torsten Geldsetzer, *Chris Stethem*, Dave Tracz, Mike Conlan), quick field observations and localizing avalanche danger (Cam Campbell, Alan Jones, *Pascal Haegeli*, Dave Gauthier, Shane

Haladuick), stress below skiers and sledders (Thomas Exner, Scott Thumlert), formation, properties and evolution of surface hoar and facets (Greg Johnson, Alec van Herwijnen, Thomas Chalmers, Paul Langevin, *Sam Colbeck*, Antonia Zeidler, Cora Shea, Simon Horton), formation, properties and evolution of melt-freeze crusts (Mike Smith, Ryan Buhler, Simon Horton), modelling the snowpack with weather data (Sascha Bellaire, *Charles Fierz*, Simon Horton, Michael Schirmer). Those contributions are summarized in over 100 conference papers, about 75 papers in ISI journals and about 50 videos, all listed or linked at ucalgary.ca/asarc.

Over the years, ASARC received many compliments from practitioners about our presentations and videos. There were at least two factors. In the latter years, I was only accepting about one in 10 applications for graduate studies, i.e. the graduate students were bright and diligent. Secondly we practised each presentation in front of the ASARC team, critiqued it, revised it to better communicate to the target audience and then repeated the cycle. Often we developed two versions of a presentation: one for practitioners at training sessions or CAA spring meetings and one for researchers at scientific conferences. Our effort to “drink with any tinker in his own language” improved the impact of the research, the communication skill of ASARC staffers, and likely contributed to their subsequent employment success.

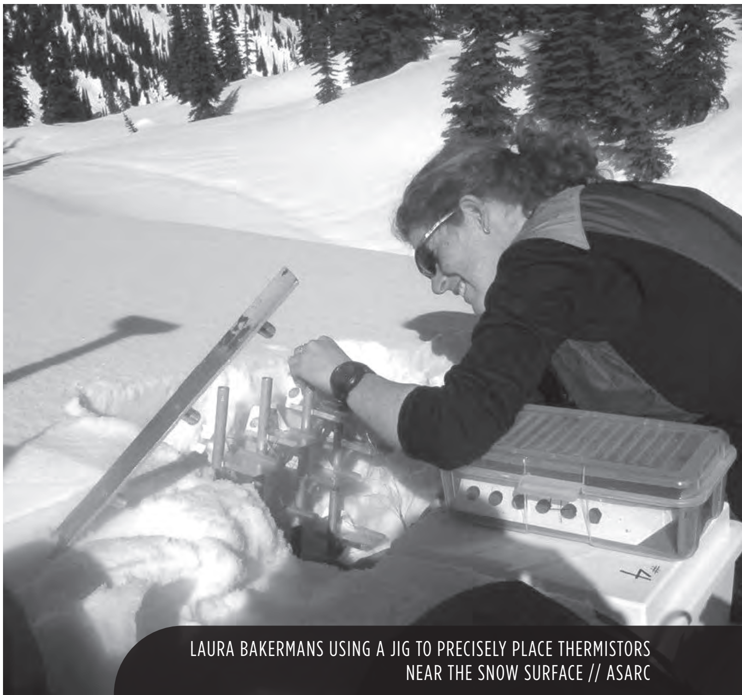
I like to think the ASARC program also contributed expertise to the avalanche profession. Following a couple of winters with their heads and hands in the snow, many of the research technicians have gone on to become guides, avalanche technicians, forecasters and operations managers. Many of the graduate students and post docs now work as consultants, engineers, geoscientists, forecasters, guides, and researchers. A few are now supervising graduate students. I believe their years with ASARC contributed to their subsequent success and impact.

In many cases, there were two versions of our papers: one for practitioners and one for scientific journals. Both were extensively revised, reviewed by fellow ASARC staffers and revised again. Dave Gauthier’s article "Puzzling over Propagation Propensity" is a fine example of writing for practitioners—former editor of this journal Mary Clayton called it “A thing of beauty.”

If you were in a tree and looking down at two ASARC staffers touring uphill or in a pit, you could not distinguish a grad student from a research technician. ASARC’s research technicians were inquisitive, experienced ski tourers and great workers! Some of the ones that, I think, worked at least two winters include: Leanne Allison, Deanna Andersen, Sebastian Balerin, Ken Black, James Blench, Aaron Cooperman, Joe Filippone, Michelle Gagnon, Ryan Gallagher, Torsten Geldsetzer, Brian Gould, Sue Gould, Jason Guptil, Ali


TO TRACK THE RELATIVELY FAST CHANGES IN NON-PERSISTENT WEAK LAYERS, WE MADE SOME MEASUREMENTS AT NIGHT // ASARC


BRUCE REPLACES A TEMPERATURE SENSOR ON A WEATHER STATION NEAR VALEMOUNT // CURTIS PAWLIUK


LAURA BAKERMANS USING A JIG TO PRECISELY PLACE THERMISTORS NEAR THE SNOW SURFACE // ASARC

SOME ASARC FOLKS, INCLUDING THE FIRST AND LAST GRADUATE STUDENT, GATHERED AT THE ISSW 2014 BANQUET. BACK ROW FROM LEFT TO RIGHT: SCOTT THUMLERT, RYAN BUHLER, CAM CAMPBELL, ALEC VAN HERWIJNEN, MIKE CONLAN. MIDDLE ROW: GREG JOHNSON, SASCHA BELLAIRE, MICHAEL SCHIRMER, JAMES FLOYER, DAVE TRACZ, SIMON HORTON, ALEX SINICKAS. FRONT ROW: MIKE SMITH, BRUCE JAMIESON, SHANE HALADUICK. // ASARC

Haeri, Jill Hughes, Mark Kolasinsky, Spencer Krkosky, Paul Langevin, Lydia Marmont, Ken Matheson, Greg McAuley, Rodden McGowan, Gord Ohm, Jennifer Olson, Willy Rens, Braden Schmidt, Lucas Shubin, Mark Shubin, Michael Shynkaryk, Jordan Stiefvater, Mike Wheater. Apologies to those I have forgotten to include.

In addition to those who worked with ASARC, it is important to recognize some "movers" in the supporting organizations, including Jack Bennetto, Colani Bezzola, Mike Boissonneault, Walter Bruns, Jeff Goodrich, Brad Harrison, Phil Hein, Clair Israelson, Mark Kingsbury, Karl Klassen, Bruce McMahon, Jon Neufeld, Joe Obad, Rob Rohn, Jimmie Spencer, Ian Tomm, Bob Sayer, Dave Skjonsberg, Grant Statham, Chris Stethem and Mike Wiegele. They provided advice on grant applications, funding through their respective organizations, and stuck with ASARC through numerous challenges.

Why did I choose to not apply for another term of an industrial research chair in 2014 (and consequently retire in 2015)? My desire to be a hands-on supervisor of field studies combined with academic responsibilities like teaching undergraduate courses resulted in too many six and seven day weeks between September and April. In 2013 I was in my early sixties and didn't want to work so hard for another five-year term of a research chair. Sure, my work-life balance would have improved if the research group discontinued the field studies and focussed on modelling or reanalyzing existing field data, but my passion was for field studies, which could no longer be combined with growing academic demands of the office and classroom. After 25 years and 25 graduate students, it was time for a change. Over the 25 years, ASARC staff conducted over 6,000 person-days of field measurements, shovelled over 8,000 tonnes of snow (not including shovelling to extricate "misaligned" snowmobiles), observed over 5000 snow profiles, did more than 20,000 snowpack tests, and ate more than 10,000 chocolate bars.

Did ASARC start with a long term plan? Well no, but I came to realize that if you put inquisitive people in the mountains in winter, and sprinkle with advice from operational folks who manage avalanche risk, those inquisitive people will produce useful—sometimes important—applied research.

I'll finish with the formative advice that Peter Schaerer gave me around 1998 (at least as I remember it): "Field studies are slow, expensive … and the results are often worthwhile."

REFERENCES

Gauthier, D. 2006. "Puzzling over propagation propensity." *Avalanche News* 76, 44-46.

Jamieson, B. 2008. "ASARC's experience with incident peer narratives". *Avalanche.ca - The Journal of Canada's Avalanche Community,* Canadian Avalanche Association, Revelstoke, BC, Canada, 48-49.

Jamieson, B., J. Schweizer and C. Shea 2009. "Simple calculations of avalanche risk for backcountry skiing", *Proceedings of the 2009 International Snow Science Workshop* in Davos Switzerland, 336-340. (The associated video is called "Considerable avalanche danger - How much riskier is it?" vimeo.com/50900661).

Johnson, B.C., B. Jamieson and R.R. Stewart 2004. "Seismic measurement of fracture speed in a weak snowpack layer". *Cold Regions Science and Technology*, 40(1-2), 41-45.

The quote "drink with any tinker in his own language" is from Shakespeare, W., Henry IV, Part 1. Act 2, Scene 4.

Monitoring Snow Avalanches From Space: **Why is it possible, and what is it good for?**

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Tromsø, Norway

AVALANCHE ACTIVITY IS an important sign of snow instability. Schweizer (2003) related avalanche activity to the avalanche danger level and showed that there is a correlation between increasing danger level and the occurrence of both artificially released and natural avalanches. The relationship between avalanche activity and avalanche hazard is, however, not always obvious if avalanche observations are missing, e.g., due to bad visibility or lack of resources (Schweizer et al., 2003)

Missing avalanche observations are due to critical limitations in our traditional, field-based approach to monitoring avalanche activity. In any given avalanche forecasting region, only some safely accessible areas can be monitored. Moreover, on a temporal scale, poor to zero visibility and high avalanche danger may limit consistent monitoring throughout a winter. Given the high value of avalanche activity observations in constructing the avalanche forecast, this lack of a complete observational record significantly impacts our ability to accurately forecast avalanches. Furthermore, the large data gaps may in fact represent the pivotal data required for a more in-depth understanding of the avalanche phenomena, particularly the relationship between avalanche release and triggering meteorological and snowpack factors.

REMOTE SENSING OF AVALANCHES

Remote sensing of avalanches is a young and quickly developing scientific field where ground, air and spaceborne platforms are used. The operational capabilities of optical sensors and LiDAR systems in monitoring the spatio-temporal avalanche activity in a given forecasting region is, however, highly limited due to their short range and limited capabilities in darkness and cloudy/ snowy conditions (Eckerstorfer et al., 2015).

RADAR (RAdio Detection and Ranging) sensors utilize the microwave portion of the electromagnetic spectrum, with synthetic aperture radars (SAR) actively emitting and receiving energy, thereby measuring the amount of energy backscattered by a target. The large advantage hereby lies in the radar's abilities to "see" both through clouds and darkness. Launched in 2014, the Sentinel-1A (S1A) radar satellite from the European Space Agency (ESA) provides freely available data from any place on Earth repeatedly every 12 days, with high spatial resolution (5x20m) and large ground swaths (150x250km). Given these specifications, S1A provides—for the first time in satellite history—data that has the potential to be used in operational avalanche activity monitoring and mapping.

ELECTROMAGNETIC BACKSCATTER OF SNOW IN AVALANCHE DEBRIS

In the case of undisturbed dry snow (Fig. 1a), the largest contribution of the backscattered radar wave stems from scattering at the snow-ground interface. In Fig. 1b we exemplify detected avalanche debris with the perimeter visualized with a dotted line. Surrounding the avalanche debris, undisturbed dry snow exhibits comparably low backscatter, visible by the dark grey pixel colours. The histogram in Fig. 1b shows the distribution of the backscatter amplitude for the undisturbed dry snow, with a median backscatter of -16 decibels (dB). The backscatter distribution of the avalanche debris has a higher population peak of 10dB, thus is somewhat distinguishable from undisturbed snow. However, there is also considerable overlap between both populations since the spread in backscatter values of each population is significant, making false detection possible. In Fig. 1c we explain the reason for the higher backscatter from dry avalanche debris, which is mainly due to an increased contribution of scattering at the air-snow surface interface. This increase is due to a higher surface roughness in avalanche debris. Additionally, greater snow volume and higher snow densities also contribute to increased backscatter from avalanche debris.

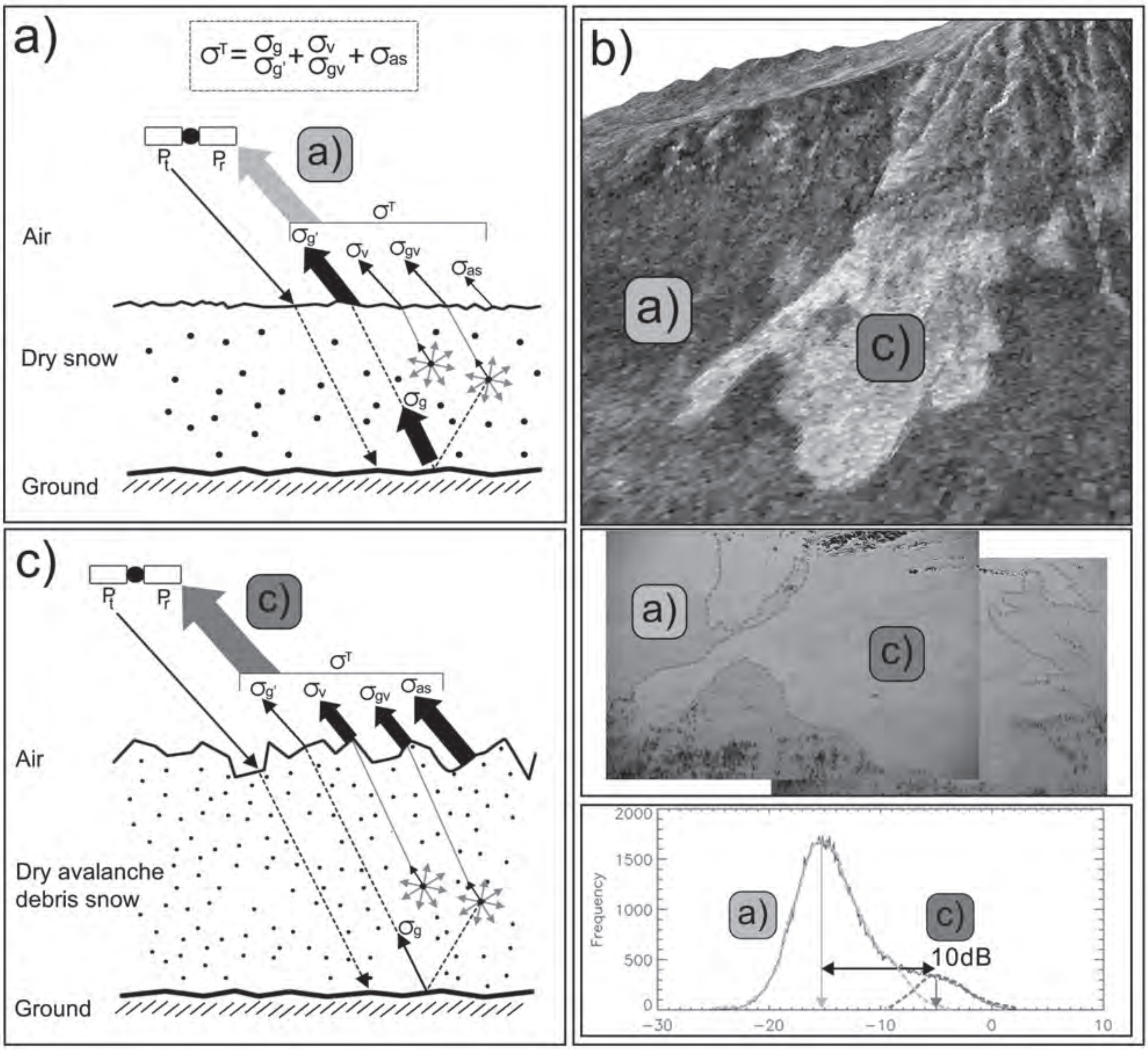

FIG. 1: PHYSICAL MODEL OF ELECTROMAGNETIC BACKSCATTER FROM a) UNDISTURBED SNOW (ULABY ET AL., 1986), AND c) SNOW IN AVALANCHE DEBRIS (ECKERSTORFER AND MALNES, 2015). C-BAND MICROWAVES ARE NOT ABLE TO PENETRATE WET SNOW SIGNIFICANTLY. THUS IN THE CASE OF WET SNOW, SCATTERING AT THE AIR-SNOW SURFACE INTERFACE DOMINATES. b) EXAMPLE OF AN AVALANCHE DETECTION USING SENTINEL-1A DATA. THE HISTOGRAMS OF BACKSCATTER FREQUENCY FROM UNDISTURBED SNOW (a) SURROUNDING AVALANCHE DEBRIS (c) SHOW TWO POPULATIONS WITH A DIFFERENCE IN POPULATION MEAN OF 10dB, AND AN OVERLAP OF 6dB. WE ALSO SHOW A FIELD PHOTOGRAPH OF THE AVALANCHE DEBRIS AS VERIFICATION.

Wiesmann et al. (2001) were the first to show the potential of spaceborne SAR for detecting avalanches. Using ERS 1/2, C-band SAR data, they utilized the increased backscatter of rough, compacted avalanche debris snow for detection of a single avalanche. A more comprehensive study was carried out by Eckerstorfer and Malnes (2015) who collected 12 Radarsat-2 Ultrafine SAR images during an avalanche cycle in March 2014 in the county of Troms, Northern Norway. They manually detected 467 avalanches in single backscatter images. Of these 467 avalanches, 37% were validated by fieldwork and auxiliary remote sensing data.

A COMPLETE AVALANCHE ACTIVITY RECORD FROM TAMOKDALEN, NORTHERN NORWAY

Study area

Tamokdalen is one of 23 avalanche forecasting regions in Norway. It extends over an area of roughly 1600km^2, encompassing four major valleys, of which Tamokdalen ("dalen" means valley) is one. The alpine topography rises from sea level to a maximum elevation of approximately 1,600m a.s.l. The snowpack is mainly continental in character, however maritime influence in the form of mid-winter rain on snow events can occur.

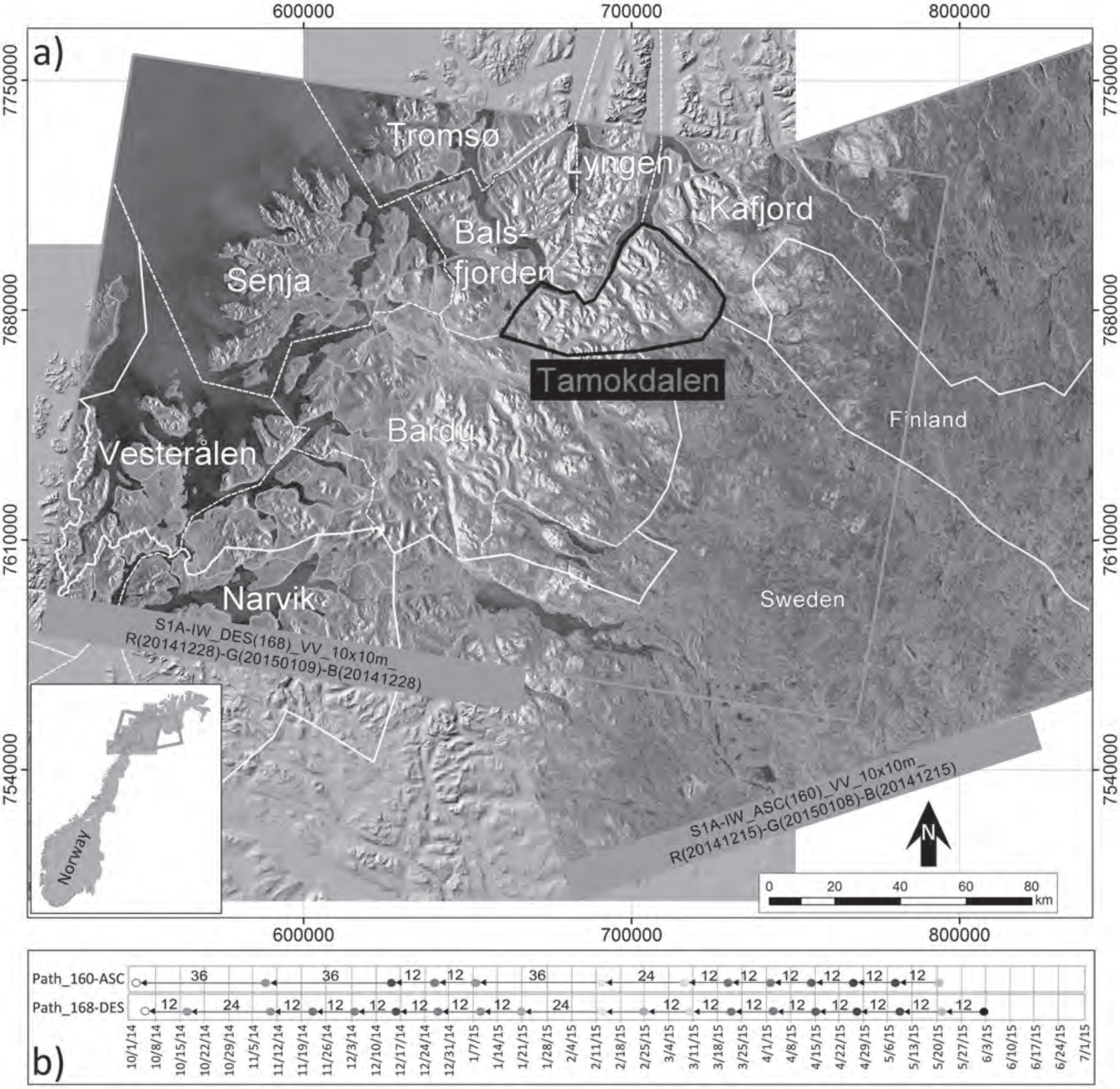

FIG. 2: a) TOPOGRAPHIC MAP OF THE COUNTY OF TROMS, NORTHERN NORWAY. TWO RGB COMPOSITES COMPRISED OF BOTH ASCENDING PATH 160 AND DESCENDING PATH 168 BACKSCATTER IMAGES ARE SUPERIMPOSED. BOTH S1A IMAGES COVER THE AVALANCHE FORECASTING REGION 'TAMOKDALEN', OUTLINED IN BLACK. THE OTHER EIGHT NORTH-NORWEGIAN AVALANCHE FORECASTING REGIONS ARE ALSO VISUALIZED. b) S1A IMAGE ACQUISITION DATES FOR BOTH ASCENDING PATH 160 AND DESCENDING PATH 168 USED IN THIS STUDY. THE REPEAT PASS INTERVALS ARE MARKED, WITH A MINIMUM OF 12 DAYS, AND A MAXIMUM OF 36 DAYS.

SAR image acquisition and processing

We acquired a total of 31 Sentinel-1A (S1A) images covering the period between October 1, 2014 and June 6, 2015. We used images from the ascending path 160 (coming from the south) and descending path 168, both covering Tamokdalen every 12 days. In Fig. 2a we exemplify the spatial coverage (ground swath) of both image geometries, covering Tamokdalen outlined in the centre.

The combination of ascending and descending path images allowed for avalanche debris detection on all slope aspects. This is due to the radar satellite emitting energy sideways to its right, rather than straight down. In ascending path images, layover effects due to the mountain topography occur on the west sides, while radar shadow effects occur on the east sides and vice versa for descending path images. These areas are mostly areas of no information.

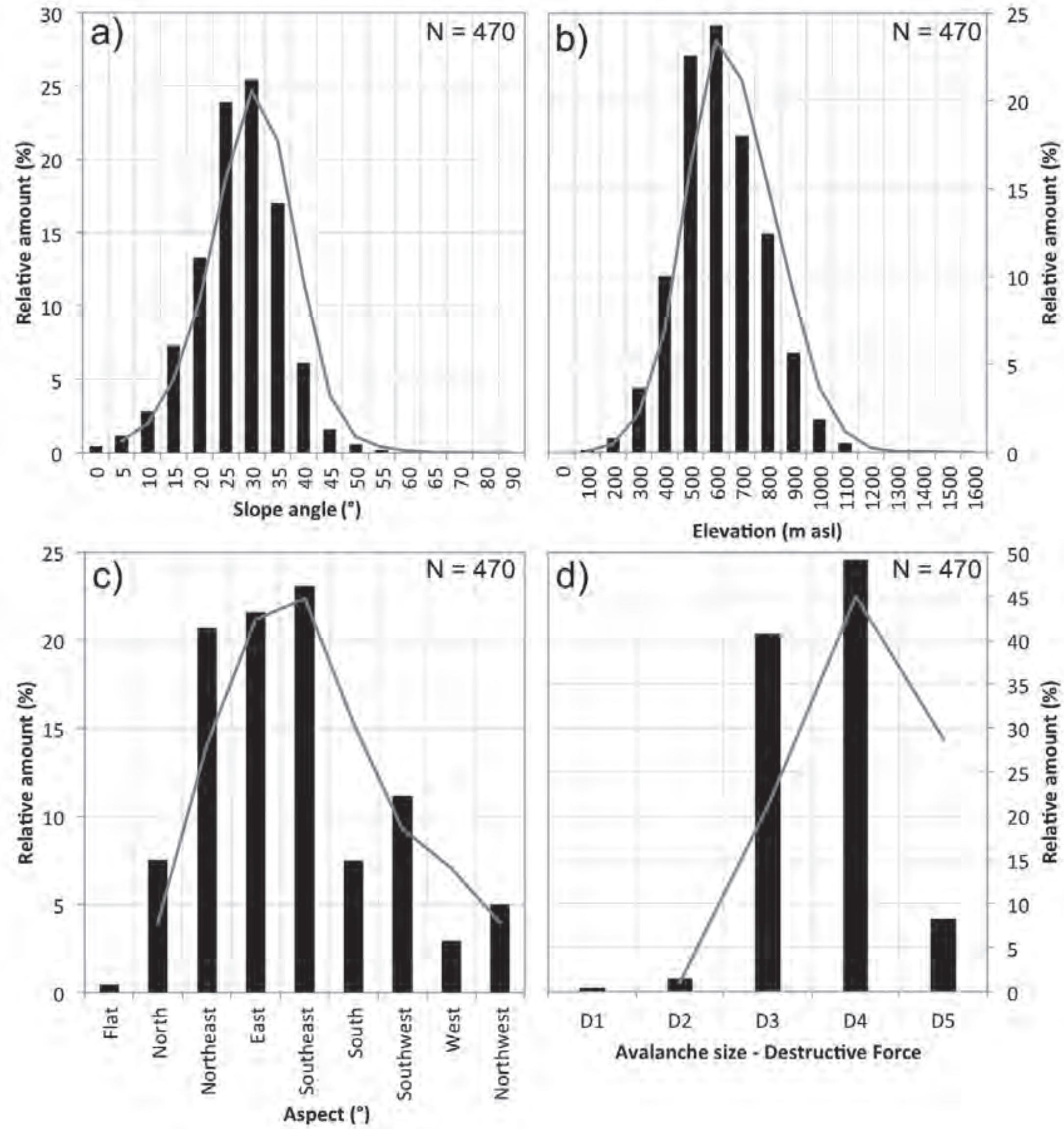

FIG. 3: SUMMARY STATISTICS OF TOPOGRAPHIC CONDITIONS (a-c) AND AVALANCHE SIZE (d) FOR ALL 470 DETECTED AVALANCHE DEBRIS. A MOVING AVERAGE TREND LINE IS IMPOSED IN GREY.

Unfortunately, we encountered some periods during the winter where the repeat pass was more than the usual 12 days later. The acquisition dates for both image geometries and their repeat passes are shown in Fig. 2b.

Manual avalanche debris detection using change detection images

Using SAR images, only the avalanche debris zones are detectable by radar, since this part of the avalanche corresponds to increased surface roughness and increased snow density. For manual avalanche debris detection, we used a SAR change detection method which was inspired by Wiesmann et al. (2001). We constructed a change detection image, which is simply the difference between two single backscatter images of similar geometry and path (either path 160 or path 168), with a minimum temporal baseline of 12 days. Of these single backscatter image pairs, one image was used as the reference image without avalanche activity, while the temporarily subsequent one was used as the activity image with avalanche activity. The SAR difference images then show the change in backscatter amplitude between two instances in time, and can be used to identify avalanche debris which typically correspond to an increase in backscatter. If both single backscatter images have similar surface snow conditions (without avalanches having occurred), no backscatter change is observed.

Spatio-temporal characteristics of detected avalanche debris

In total, avalanche debris was visually identified 282 times in ascending images, and 188 in descending images, for a total of 470 occurences when both image geometries are combined. Several avalanche cycles were visible, mostly towards the end of the season. However, the avalanche cycle with the largest number of releases occurred in the first week of January 2015. In the ascending and descending images from January 8 and 9, 2015, we detected avalanche debris a total of 221 times. The wet snow avalanche cycle occurred due to a severe low-pressure system around New Year 2015, which brought mild temperatures, large amounts of precipitation and high winds to the entire region.

The spatial characteristics of avalanche activity during the entire 2015 winter season in Tamokdalen are a product of the local topography and the local climate conditions. Most avalanche activity took place in the parts with pronounced alpine topography, especially in the Tamokdalen, Signaldalen and Kitdalen valleys. There exists a marked climate difference across the avalanche forecasting region with minimum precipitation in the north-eastern part. The Skibotndalen valley is one of the driest places in Norway, with a precipitation average four times lower than in the Tamokdalen valley. Avalanche activity seems to also have been higher in areas with close proximity to the fjords.

Morphological and topographical characteristics of detected avalanche debris

The delineation of each manually detected avalanche debris allowed us to compile statistics on avalanche morphology and the topographic conditions in which these avalanches occurred (Fig. 3). The avalanches stopped on average at a slope angle of 25°, with 1.6% of all avalanches reaching a runout inclination of 0-5°, which is effectively the valley bottom (Fig.3a). About 2.5% of all avalanches stopped at slope angles steeper than 45°, which hints at loose snow avalanche activity. The median elevation band in which the detected avalanches stopped was 560m a.s.l., which is in the lower third of the mountains reaching a maximum of 1,600m a.s.l. in the study area (Fig. 3b). It is also the highest treeline in the wider area. The most active slope aspects were the sector northeast to southeast, where over 60% of all detected avalanches occurred. This is logical, since there are many north-south trending valleys in the eastern part of the avalanche forecasting region, with easterly facing slopes. Lastly, over 98% of all detected avalanches were at least size D3 avalanches. The average measured lengths of the polygons delineating the avalanche debris were 745m; the average measured avalanche debris area was 2.5 hectares.

What we can and cannot do: part 1

The complete spatio-temporal avalanche activity dataset from the winter 2014-15 from the forecasting region Tamokdalen in northern Norway is the first of its kind. The database was collected using the Sentinel-1A radar satellite to detect avalanche debris every 12 days throughout the winter. The collected avalanche activity database provides an overview of avalanche cycles, their magnitude and spatial distribution, as well as a quantification of avalanche sizes, their elevation and slope angle as well as aspect of deposition. All of these data are vital information for avalanche forecasting services, as well as for avalanche science. However, there are currently still a handful of challenges before the detection of avalanches using radar satellite can become operational:

- Sentinel-1A takes a radar image every 12 days at any location on Earth. This means that we do not have any knowledge of when exactly the detected avalanches released within any 12-day window. As S1A is in a polar orbit, it covers higher latitudes more frequently, with Tamokdalen effectively being covered every three to four days by combining all possible paths of the satellite. In this study, however, we only chose to use two image geometries. In spring 2016, Sentinel-1B will be launched, decreasing the revisit time to six days for any location on Earth.
- The spatial resolution of S1A of 5-20m, resampled to 10m, limits the smallest detectable avalanches to size 2 avalanche debris. Smaller avalanche debris cannot be resolved by the radar at this resolution.
- Other natural features can be mistaken for avalanche debris. Using the change detection method, the majority of these features are not visible. Moreover, we use a simple topographic model which eliminates areas where avalanche debris are unlikely to occur, based on slope angle and forest cover masks.
- Field validation of detected avalanche debris at large scale is not possible. We rely on observations from backcountry users who send their data into www.regObs.no, which is an open crowdsourcing platform for avalanche related observations operated by the Norwegian Avalanche Centre.
- Manual detection is too time consuming to use in an operational context. Moreover, manual detection as a scientific method is problematic, as it is difficult to quantify errors of false detection and bias by the person carrying out the detections. An automatic avalanche detection algorithm is thus needed.

AUTOMATIC AVALANCHE DEBRIS DETECTION

Method

We have developed an automatic avalanche debris detection algorithm that we are currently testing by comparing its results to manual detection results. A detailed technical explanation is not the scope of this paper, thus we only give a short summary. The algorithm first eliminates areas where avalanche debris is unlikely to occur. The algorithm then applies a backscatter threshold value that identifies potential areas containing avalanche debris from areas of only undisturbed snow. As we show in Fig. 1, there is a distinct difference in backscatter amplitude between these two populations, which is utilized by the algorithm. Based on the thresholding, the difference or change detection image is classified with pixels being assigned to one of two classes, these corresponding to "avalanche debris" and "no-avalanche debris." The "avalanche debris" pixels are transferred onto a digital elevation model as a last step.

Case study: Tamokdalen wet snow avalanche cycle

Fig. 5 shows a comparison between manual (green) and automatic (pink) avalanche debris detections in an ascending path with 160 images from January 8, 2015 (activity image), where a total of 70 individual avalanche debris features were manually identified by an expert. In terms of the number of avalanche pixels, 62% were identified both manually and automatically at the same locations, which is roughly in agreement with the number of detected features. The correctly-detected avalanche debris appear to include both smaller and large sized debris. However, we can see that in general the avalanche debris areas that were missed by the automatic detection algorithm seem to correspond to smaller-sized avalanche debris. This is consistent with settings in the algorithm where false alarms are avoided by imposing a minimum threshold on the size of the avalanche debris.

The lower panel in Fig. 5 shows field photographs for validation purposes acquired from www.regObs.no. All the database reported avalanches were manually detectable.

Fig. 6 shows the corresponding descending geometry (path 168) from January 9, 2015, where the manual detections are in blue and the automatic detections are in red. We see that the automatic detection performed slightly poorer in relation to the manually identified debris, even though the correct automatic detections did well at representing the size and morphology of the manual detections.

The results of the comparison between manual and automatic avalanche detections are shown in Table 1. The true positive detection rate lies at 61.2%, achieved with the current version of the algorithm. Error of commission (misclassified pixels) is high, also at slightly over 60%, and error of omission (missed pixels) is close to 40%. These are promising first results, especially as the commission error is higher than the omission error. This allows for further fine-tuning of the algorithm to interpret fewer pixels incorrectly as avalanche debris. Note that Table 1 compares the number of pixels detected manually and automatically. If we only look at how many areas of avalanche debris were correctly detected, we find a better agreement, currently between 75 and 85%. This means that the automatic avalanche debris detection algorithm replicates the manually delineated avalanche debris correctly in 60% of all cases; however, it correctly detects features as avalanche debris for an average of 80% of all cases.

What we can and what we cannot do: part 2

The automatic avalanche debris detection algorithm's true positive detection rate of 61.2% when compared with manual detections is too low for operational avalanche activity monitoring. The algorithm currently struggles to replicate the exact morphology of the avalanche debris; however, it does fairly well in finding the locations of avalanche debris. This is of importance in terms of quantifying the magnitude of avalanche cycles and their spatial extent.

There are a few parameters that can be tuned in order to improve the true positive detection rate, for example changing the backscatter threshold value that distinguishes avalanche debris from undisturbed snow, or the choice of the reference images for constructing change detection images. Moreover, an error source is also the manual detection and the manual delineation of avalanche debris, which is especially difficult for the uphill part of the avalanche debris. This also means that misclassifications (commission and omission) could be due to the algorithm detecting avalanche debris that manual detection has missed.

CONCLUSION

The snow and avalanche research group at Norut currently has three research projects dealing with SAR detection of snow avalanches. What started with initial detections of very large avalanches in single case studies has transformed into trying to collect complete spatio-temporal avalanche activity data sets for given avalanche forecasting regions. To our knowledge this have never been done before, and we are committed to provide such datasets in the near future

TABLE 1: COMPARISON OF MANUAL AND AUTOMATIC AVALANCHE DEBRIS DETECTION. VALUES ARE NUMBER OF PIXELS IN TOTAL AND IN PERCENTAGE OF THE TOTAL.

Threshold	Missed	%	Misclassified	%	Correct	%
6dB	2273	38.7%	3537	60.2%	3596	61.2%

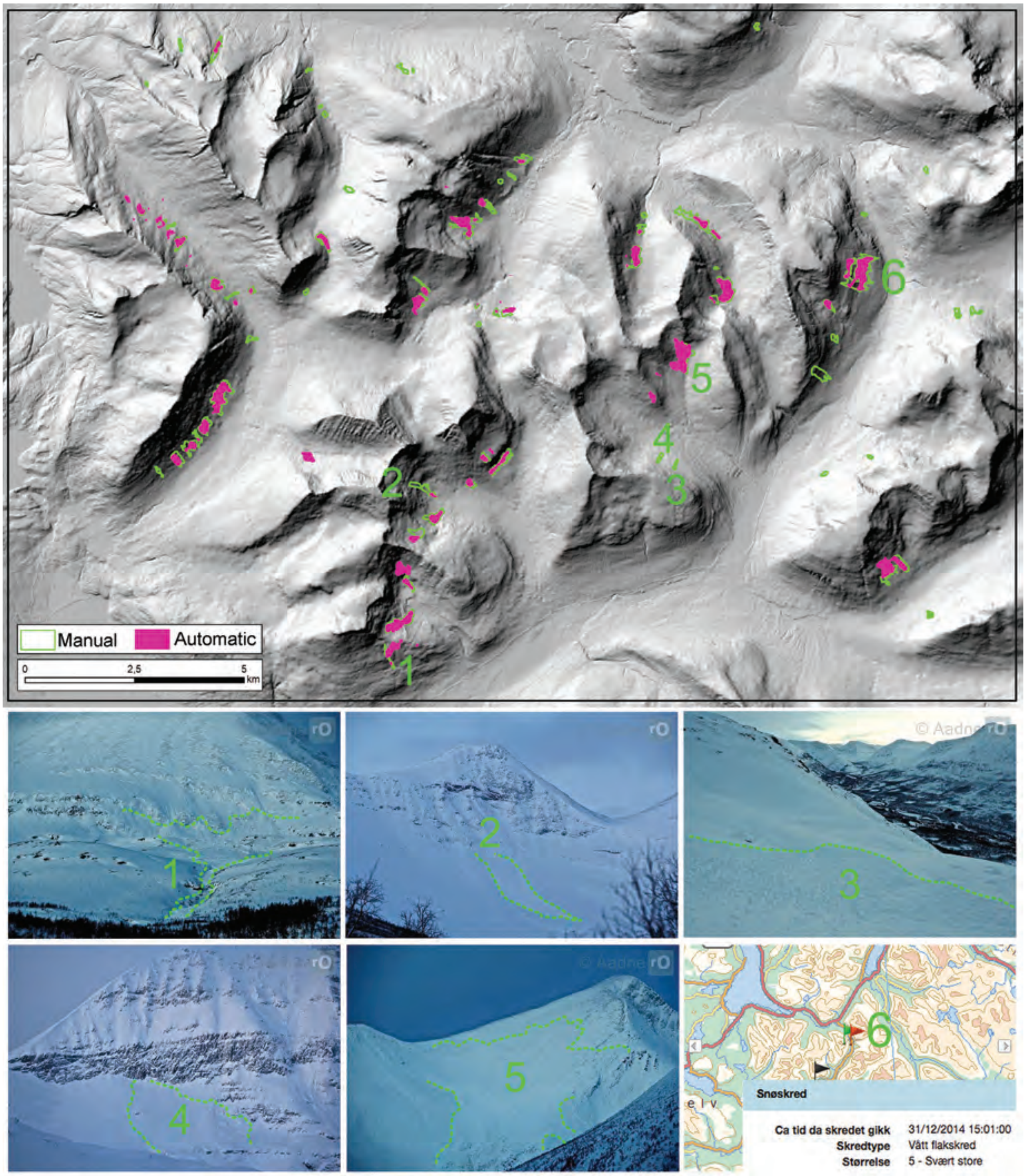

FIG. 5: COMPARISON BETWEEN MANUAL (GREEN OUTLINES) AND AUTOMATICALLY DETECTED AVALANCHE DEBRIS (PINK AREAS) FOR TAMOKDALEN. BOTH MANUAL AND AUTOMATIC DETECTION WAS CARRIED OUT IN THE ACTIVITY IMAGE FROM JANUARY 8, 2015 WITH REFERENCE IMAGE FROM DECEMBER 15, 2014, BOTH WITH SIMILAR GEOMETRY FROM ASCENDING PATH 160. THE NUMBERING CORRESPONDS TO OBSERVED AVALANCHES IN THE FIELD. ALL IMAGES ARE FROM THE CROWD-SOURCING PLATFORM WWW.REGOBS.NO.

to the Norwegian Avalanche Centre (www.varsom.no). With the use of Sentinel-1A and its sister satellite Sentinel-1B, operational from mid-2016, any avalanche forecasting region on Earth can be monitored for avalanche activity every six days throughout a winter. With increasing latitude, the repeat pass intervals shorten even more due to the polar orbit of the satellites. Until then, we hope to further improve our understanding of the electromagnetic backscattering from snow in avalanche debris, important for the backscatter thresholding we use in our automatic detection method.

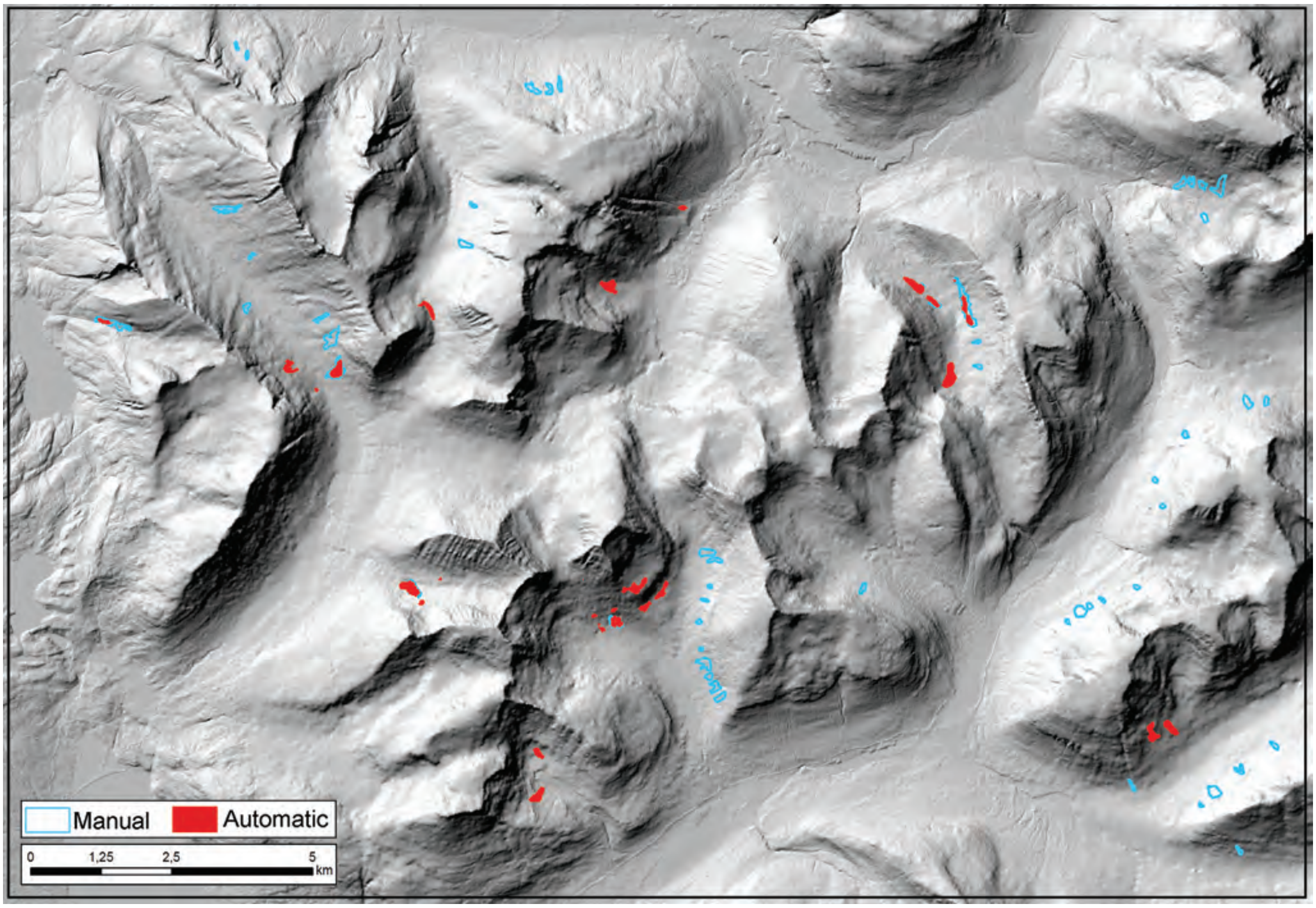

FIG. 6: COMPARISON BETWEEN MANUAL (BLUE OUTLINES) AND AUTOMATICALLY DETECTED AVALANCHE DEBRIS (RED AREAS) FOR TAMOKDALEN. BOTH MANUAL AND AUTOMATIC DETECTION WAS CARRIED OUT IN THE ACTIVITY IMAGE FROM JANUARY 9, 2015 WITH REFERENCE IMAGE FROM DECEMBER 16, 2014, BOTH WITH SIMILAR GEOMETRY FROM DESCENDING PATH 168.

ACKNOWLEDGEMENTS

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REFERENCES

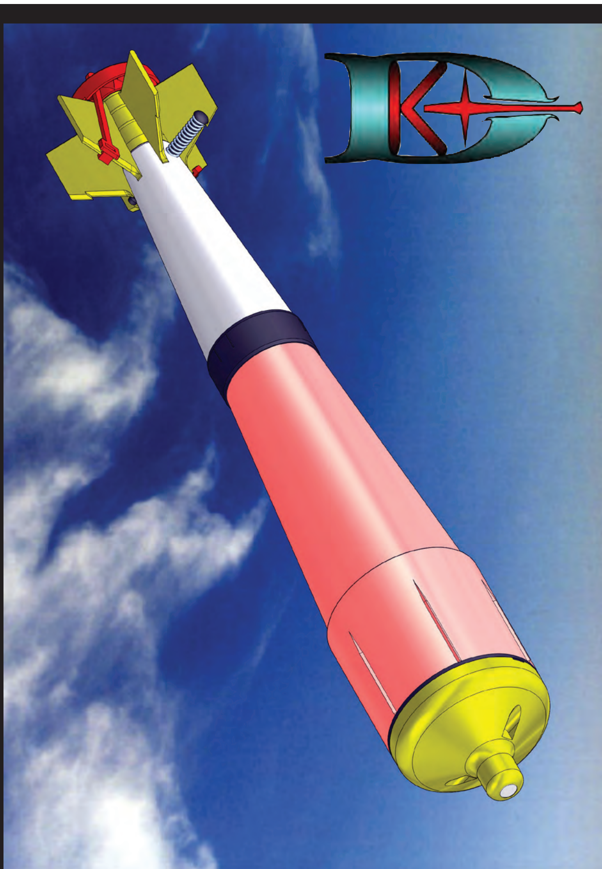
Eckerstorfer, M., Malnes, E., 2015. "Manual detection of snow avalanche debris using high-resolution Radarsat-2 SAR images". *Cold Regions Science and Technology*, 120, 205-218.

Schweizer, J., 2003. "Rutschblock 73 - Verifikation der Lawinengefahr". *Bergundsteigen - Zeitschrift für Risikomanagement im Bergsport*, 12(4), 56-59.

Schweizer, J., K. Kronholm, and T. Wiesinger, 2003. "Verification of regional snowpack stability and avalanche danger". *Cold Regions Science and Technology*, 37(3), 277-288.

Ulaby, F.T., R.K. Moore, and A.K. Fung, 1986. *Microwave remote sensing: Active and passive; from theory to applications*. Artech House, Norwood, pp. 1065-2162.

Wiesmann, A., U. Wegmueller., M. Honikel, T. Strozzi and C.L. Werner, 2001. "Potential and methodology of satellite based SAR for hazard mapping"., *IGARSS 2001*. IEEE, Sydney, Australia.



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