MANAGING THE PHYSICAL RISK FROM AVALANCHES IN A HELICOPTER SKIING OPERATION—MERGING AND CONTRASTING TERRAIN USE DATA WITH THE OPERATIONAL GUIDING PERSPECTIVE

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ABSTRACT: In the backcountry, physical risk from avalanches is managed by 1) assessing the nature, severity and spatial distribution of the local hazard based on weather, snowpack and avalanche observations and 2) carefully choosing terrain and travel procedures to mitigate that hazard. While extensive research has been conducted to improve our understanding of avalanche hazard, there is increasing interest in developing a better quantitative understanding of the subsequent risk management process with the goal of developing evidence-based decision aids for avalanche professionals and recreationists. While some studies have attempted to address this challenge, their approach has generally been reductionist and the resulting insights have been limited. The objective of this paper is to provide a more integrated perspective by comprehensively recording and visualizing an entire operating season at CMH Galena—a helicopter skiing operation located in the Selkirk Mountains of British Columbia. In addition to the operational data collected on hazard conditions, the skiing program and operational constraints, we equipped guides with passive GPS tracking units to capture the full range of terrain choices at an unprecedented level of detail. We suggest that heuristics have evolved to deal with the high number of required decisions in mechanized skiing and that terrain selection involves two processes—habitual patterns combined with targeted adjustments in response to specific hazard conditions and operational needs. Our visualization of the 2015/16 winter season illustrates a number of these patterns. While the comprehensive and detailed recording of terrain choices at participating operations provides the necessary tangible foundation for this collaborative work, we stress that the extraction of meaningful terrain use patterns with the potential to be used for developing decision aids requires a close collaboration between researchers and local guides who are familiar with the intricacies of their operational practices. We are confident that the results of this line of research will offer valuable benefits for both professionals and recreationists travelling in avalanche terrain.

KEYWORDS: Helicopter skiing, decision-making, risk management, terrain choices, GPS tracking.

1. INTRODUCTION

In the backcountry, physical risk from avalanches is managed by 1) assessing the nature, severity and spatial distribution of the local hazard based on weather, snowpack and avalanche observations and 2) carefully choosing terrain and travel procedures to mitigate that hazard. For decades, academic avalanche safety research has primarily focused on understanding of avalanche hazard. However, there is an increasing interest in improving our quantitative understanding of the risk management process. Central questions of interest are: what are suitable terrain choices under different types of avalanche conditions, how are the choices made and what are the residual risks associated with these choices?

Public avalanche safety programs have considerable interest in these questions. Klassen (2012) highlighted that our ability to further improve the quality of avalanche hazard forecasts might be limited, but integrating evidence based terrain guidance with avalanche hazard information will create new learning opportunities and improve avalanche safety for recreational backcountry users. The general popularity of online trip planning tools that offer suggestions for suitable backcountry trips under present conditions (e.g., http://www.skitourenguru.ch) indicate that recreationists are thirsty for this type of information.

The big challenge is, however, how do we best build the necessary foundation for developing evidence based decision aids for terrain use guidance both professionals and recreationists?

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Avalanche accident analyses have been one of the primary approaches for examining decision-making in avalanche terrain, particularly for identifying flaws in this process. McCammon (2002, 2004) introduced the concept of heuristic traps. In psychology, heuristics refer to simple rules or mental shortcuts often used to make decisions in complex situations by focusing on individual aspects of the situation and ignoring others (Gigerenzer, Todd, & ABC Research Group, 1999). Due to the cognitive simplicity of heuristics, many decisions in our daily lives rely on this basic approach. However, these rules of thumb can lead to dangerous situations if applied incorrectly or in an inappropriate context. While McCammon's work was a landmark development in avalanche safety education as it provided a tangible perspective on the so-called 'human factors', it provides a biased perspective of the decision making process since it focuses exclusively on heuristics that have been associated with avalanche accidents, completely ignoring the possibility that many positive heuristics might facilitate good decision-making when travelling in avalanche terrain. The concept of 'ecological rationality' (Todd, Gigerenzer, & ABC Research Group, 2012) highlights that the key to success is to have a toolkit of heuristics, be aware of their limitations and know under what circumstances they can be applied effectively.

Professional mountain guides have a tremendous wealth of expertise in terrain selection and risk management in uncontrolled backcountry terrain. While the in-depth knowledge of the guiding community offers a unique source of information for examining the risk management process, there are numerous hurdles for extracting tangible patterns for the development of terrain guidance.

It is well-known that it is difficult for experts in complex decision environments to explicitly articulate their decision rules (Klein, 1998) because their process has become highly intuitive. To avoid this challenge, Haegeli et al. (2010) and Haegeli and Atkins (2010) used online surveys that included realistic, but hypothetical decision situations to capture the decision expertise of professional guides by forcing them to make a choice and indirectly draw conclusions about their expertise. While online surveys have the advantage that researchers have full control over the experimental setup, hypothetical decision scenarios are unable to comprehensively represent the complexity of real-world decision situations. While these types of studies can provide valuable insights into general patterns, caution should be used when applying the results outside of the experimental setup.

Most recently, Hendrikx et al. (2013) introduced the use of handheld GPS devices to record terrain preferences of recreationists and avalanche professionals at an unprecedented level of accuracy. Hendrikx et al. (2016) used GPS devices to record terrain preferences and associated demographics, avalanche and group information for 18 days of client guiding by heli-ski guides at Majestic Heli-Ski in Alaska. Their analysis primarily focused on the relationships between incline and aspect of the terrain skied and the hazard rating and avalanche problems present. The results of these analyses were somewhat limited as they did not find statistically significant relationships between avalanche hazard and incline and aspect, and only weak relationships between the most extreme values of incline (i.e., 90^{th}, 95^{th} and 100^{th} percentile) and avalanche hazard.

While we believe that the approach of GPS tracking has great merit for capturing the ultimate end product of the assessment and decision process, we suspect that the limited results are partially a reflection of the much too simplified perspective on the operational environment in helicopter skiing. We see four main reasons that make the intended analysis challenging:

First, terrain choices at a helicopter skiing operation are affected by a multitude of factors that can be represented by a decision hierarchy (Israelson, 2015). Grounded in the available terrain inventory, the final terrain choices are the result of risk management considerations, weather and flying conditions (i.e., accessibility), flight economics, skiing quality and guest preferences. To isolate the relationship between avalanche hazard and terrain choices, it is critical to document these other contributing factors and integrate them in the analysis.

Second, the analysis of the relationship between avalanche hazard and terrain choices is further complicated by the fact that the objective of helicopter skiing operations is not to provide skiing at a target risk value, but rather to offer clients exciting skiing at an acceptable level of risk. In other words, the relationship that lower hazard conditions equal steeper or more serious terrain choices cannot necessarily be expected to hold true under all circumstances because the operational target variable is exciting skiing. The fact that heliskiing is performed in an inherently hazardous environment where it is not possible to completely eliminate risk is well illustrated by the lower limit of the operational risk band (McClung, 2002)

Third, personal preference of individual guides, the configuration of the guiding team and local culture at operations result in particular terrain use patterns that further complicate the analysis and make the outside application of the extracted rules questionable.

Fourth, the guides' small scale knowledge of past terrain use and avalanche activity history—both within the current season and historically—allows them to make nuanced choices that cannot be captured by correlating hazard ratings with basic terrain characteristics.

All of these factors combined make the use of GPS tracking data for studying the relationship between avalanche hazard and appropriate terrain choices highly challenging. An insightful interpretation of the data depends critically on an in-depth understanding of operational practices, properly controlling for confounding factors and finding meaningful metrics for representing avalanche and terrain characteristics. We believe that this type of work requires comprehensive, multi-year data collection efforts and a close collaboration between the data analyst and guides who understand the intricacies of the local operation.

The purpose of this paper is to present ideas that facilitate a more comprehensive approach for capturing and interpreting terrain choices in backcountry skiing operations to improve our understanding of avalanche risk management in heliski operations and to develop meaningful applications of this information. Using the 2015/16 winter season at CMH Galena as a case study, we will illustrate the challenging objective by presenting two complementary perspectives:

- A data perspective that depicts the season based on terrain use observations and observations and assessments collected for operational purposes.
- A guide's perspective that describes the nature of the choices based on an intimate familiarity of the season and the operational procedures.

2. STUDY SITE

CMH Galena, one of 11 helicopter skiing lodges operated by Canadian Mountain Holidays, is located in the Selkirk Mountain Range in western Canada near Revelstoke, BC. The skiing terrain at CMH Galena consists of approximately 1150 km^2 and 280 established runs. The operation is well known for abundant snowfall and steep tree skiing. The lodge can host up to 44 guests, which are usually serviced in groups of 11 by a single helicopter. The operating season typically runs from late December to the end of March.

3. THE BASIC RISK MANAGEMENT PROCESS

The management of the physical risk from avalanche at CMH Galena follows generally accepted industry best practices, which can be described with the following main features:

- It is an iterative process starting the first day of the season and continuously updated as new information becomes available (LaChapelle, 1980).
- Each morning, the guiding team identifies and characterizes the relevant avalanche problems for the day based on field observations from the previous day, changes in the weather conditions overnight and relevant observations from neighboring operations. See Statham et al (under review) for a more detailed description of the hazard assessment process.
- The guiding team then collaboratively establishes an operational mindset. The concept of "strategic mind-set" (Atkins, 2014) aims to facilitate the explicit articulation of a shared attitude towards the day that provides the backdrop for all subsequent decisions.
- The morning guides meeting concludes in the "run list", where runs that are considered open for guiding are coded green (i.e., open) and unacceptable runs are coded red (i.e., closed). This consensus-based run list represents a binding foundation for any subsequent terrain choices in the field (first level of terrain selection).
- While each group of skiers is led by their own guide, it is generally the guide of the first group serviced by the helicopter (known as the lead guide) who decides which drainage to visit and which runs are skied (second level of terrain selection).
- The guides of the subsequent groups either ski the same runs or runs close-by that fit with flying logistics. Each guide is responsible to safely lead their group down the chosen ski runs (third level of terrain selection).
- At the end of the day, the guiding team reconvenes and shares their observations to produce an updated hazard assessment which becomes the foundation for the following day.

4. DATA PERSPECTIVE

4.1 Data collected

CMH has been using SnowBase, a comprehensive database system, to store operational data since 1995. Daily data records relevant for our study include:

- Weather observation from fixed sites
- Field observations
- Avalanche observations
- Avalanche hazard assessment according to the Conceptual Model of Avalanche Hazard (Statham et al., under review)
- Strategic mind-set (Atkins, 2014)
- Run list codings
- Run use

To get a more in-depth perspective on terrain use and choices, we equipped guides at CMH Galena with passive GPS tracking devices during the 2015/16 winter season. GPS trackers were configured to record their location at 4 sec intervals. We collected tracks for a total of 237 guiding days during 113 days of operation (Dec. 4, 2015 to Mar. 31, 2016). During this period, we tracked three guides on 47 days, two guides on 30 days and only a single guide during 36 days. An effort was made to ensure that the lead guide would be tracked on all days.

A comprehensive geodatabase system and a series of R packages (Haegeli et al., in prep.) were developed to process the raw GPS files, store the extracted tracks and supportive information and allow researchers to interact with the data. The extraction algorithm identified a total of 1782 individual ski runs (between 1 and 36 per day) based on 775,539 individual location observations. After initial processing, individual ski runs were stored as line geometries and information on terrain characteristics along these ski lines (e.g., incline, aspect, elevation, convexities and vegetation density) were extracted from terrain rasters freely available at http://geogratis.gc.ca (0.75 arc sec resolution). Terrain characteristics were extracted from all cells within a 20 m buffer around the ski run track. The first and last 200 m of the track were eliminated to avoid including information about irrelevant pieces of terrain (e.g., steep cliffs adjacent to a ridgetop landing opposite of the ski run).

To capture additional constraints on terrain choices we also collected information on flying conditions as it limits terrain accessibility and skiing quality as poor snow conditions are avoided regardless of hazard conditions.

4.2 Visualization of 2015/16 season

To provide a meaningful foundation for the discussion of terrain choices and the influencing factors, we animated the 2015/16 winter season to illustrate the richness of the day-by-day evolution of avalanche conditions and terrain choices. While it is not possible to present full complexity of this evolution in this paper, we provide a summary chart (Fig. 1) to describe the charts and highlight 'stepping out' periods of improving conditions (Dec. 10 to 20; Jan. 28 to Feb. 4; Feb. 18 to 27). Fig. 1 consists of the following panels (top to bottom and left to right):

a) *Snow conditions:* Solid line indicates the height of the snowpack at the lodge and the red 'v' indicate the formation of surface hoar. The bars indicate daily snowfall (in cm, grey) and rain (in mm, black).
b) *Hazard conditions*: The three bands at the top indicate the evening hazard ratings for the three elevation bands (alpine, treeline, below treeline) with the standard colors. The rows of colored dots indicate the presence of avalanche problems of the various types (Statham et al., under review).
c) *Strategic mindset:* The rows of colored dots display the progression of the strategic mind set throughout the season.
d) *Run list:* Shows the daily percentages of runs open for guiding (green), conditionally open for guiding (yellow), closed for guiding due to avalanche hazard concerns (red) and other concerns (grey).
e) *Types of runs skied*: Shows the types of runs skied on individual days classified according to how often they were coded red during the season (<5%: green; 5-20%: light green; 20-40%: yellow; 40-60%: orange; 60-80%: red; >80%: dark red)
f) *Progression of runs skied and locations of available GPS tracks* during an example 'stepping out' period (Jan. 28 to Feb 4). Each color indicates the runs skied on a particular day. The dots indicating the available GPS tracks are colored according to their unit identifier.
g) *Quantiles of inclines skied*: Daily quantiles (99%, 95%, 90%, 75% and 50%) of inclines skied derived from incline raster values extracted along the available GPS tracks.

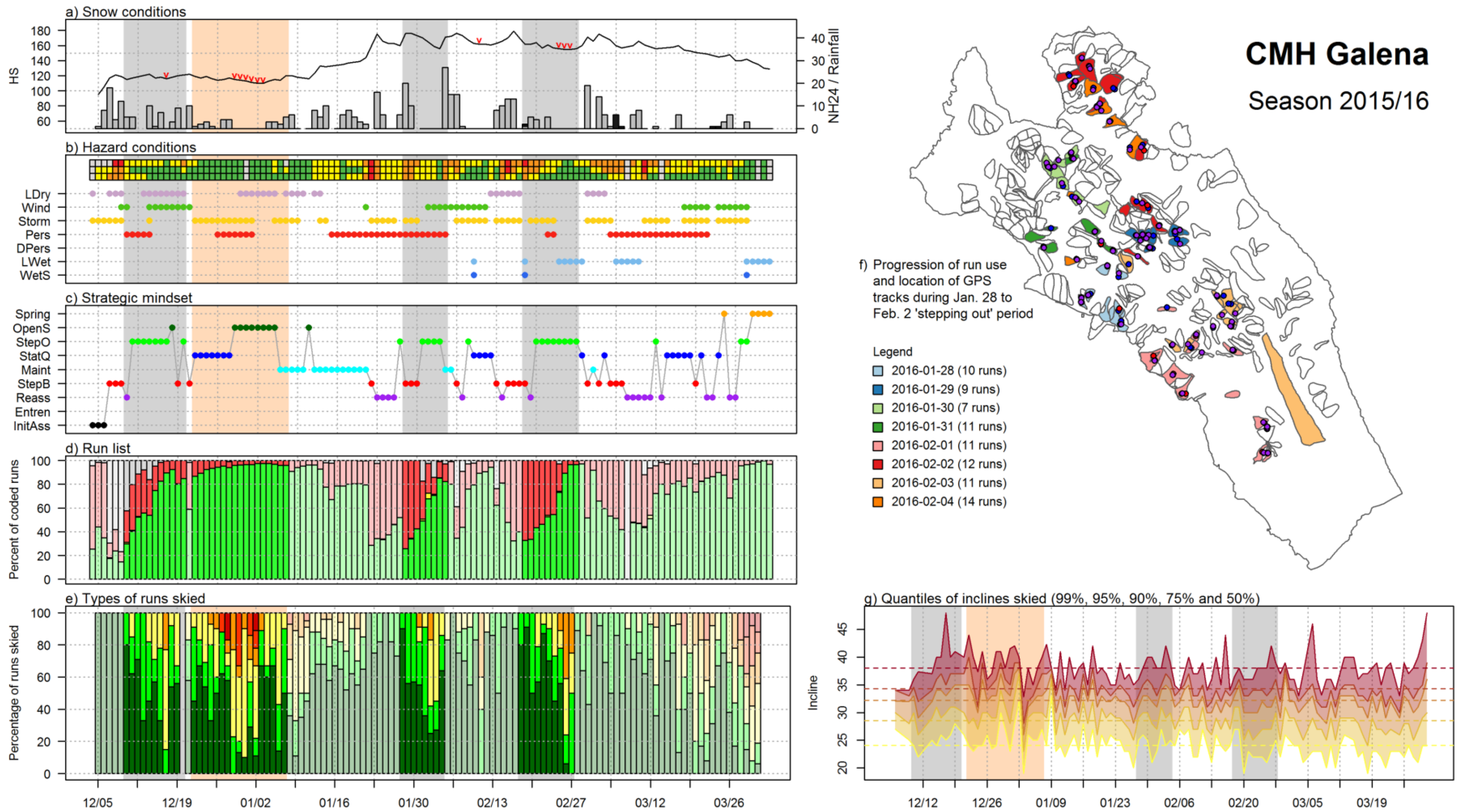

Fig. 1: Overview chart for avalanche conditions and terrain choices during the 2015/16 winter season at CMH Galena. Highlighted are three periods of 'stepping out' (light grey) and one sequence of 'stepping out', 'open season' and 'maintenance mode' (light orange). See text for detailed descriptions of individual charts. Description of abbreviations: Panel a: HS (height of snowpack), NH24 (24hr new snow); Panel b: LDry (loose dry avalanches), Wind (wind slabs), Strom (storm slabs), Pers (persistent slabs), DPers(deep persistent slabs), LWet (loose wet avalanches), Wet (wet slabs); Panel c: Spring (spring diurnal), OpenS (open season), StepO (stepping out), StatQ (status Quo), Maint (maintenance mode); StepB (stepping back), Reass (Reassessment), Entren (Entrenchment), InitAss (initial assessment).

5. GUIDE'S PERSPECTIVE

Helicopter ski guides are confronted with a constant stream of critical decisions with an overwhelming number of possibilities. Operational practices have developed to reduce the resulting potential for "decision overload". Some practices are deliberate while others, which we may not even be aware of, evolve automatically without conscious effort.

There are two main aspects of our terrain choices: habitual patterns and variations from those patterns. The majority of our decisions repetitively follow historically successful patterns—consistently cycling through the ski terrain in response to changing conditions. Based on particular details of our hazard assessment, we adjust our habitual behavior. Both aspects are equally important—the combination allows us to operate successfully. This patterned and adaptable behavior is an iterative type of anchoring and adjustment heuristic (Kahneman, 2011) that simplifies our decisions. Well considered adjustments can avoid the heuristic traps inherent in habitual behavior. Each level of decision making (i.e., run list, run selection, how an individual run is skied) exhibits habitual patterns, and individual guides have their own unique habitual preferences within the general context of the guiding team.

Terrain use patterns evolve as a guiding operation gains experience and as the guiding team changes. The guiding team is most comfortable operating in established patterns of terrain use, suggestions to deviate significantly from these patterns are usually met with skepticism, regardless of merit.

5.1 *Hierarchy of runs*

It is not surprising that we tend to ski safer terrain during higher avalanche hazard and venture into more aggressive terrain when avalanche hazard is lower, but the relationship between terrain selection and avalanche hazard is complex. Historic terrain use data show a hierarchy of run use, with certain runs regularly used under higher avalanche hazard and other runs typically used as avalanche hazard decreases. It is difficult to relate the run use hierarchy to physical terrain characteristics alone. Classifying runs according to the percentage of time they are closed for skiing (i.e., coded 'red') is a way to identify this hierarchy that provides a more comprehensive perspective that includes operational considerations as well.

The time profile shown in Fig. 1e provides meaningful depiction of when skiing was limited to runs we consider guidable under most conditions and periods when we visited runs less frequently open for guiding. The observed pattern is probably more easily related to snowfall and the presence of persistent weak layers than to the avalanche hazard rating. Periods of higher precipitation intensity generally correspond to periods of increased avalanche activity. These periods also correspond to increased opportunity for untracked skiing and decreased accessibility to remote terrain. During these periods, our skiing concentrates on frequently used local terrain and habitual patterns dominate our terrain decisions. The converse is true for periods of clear weather, which correspond to increasing use of runs infrequently considered open for guiding and increased accessibility to remote terrain. During these periods, there is incentive to travel to less frequently skied terrain and the reliance on hazard assessment increases.

5.2 *Examples of patterns and adjustments*

Although each year has unique aspects of terrain use, there is a typical repeatable seasonal progression of patterns. Normally, a small common subset of safer terrain is used to start the season (initial assessment). As confidence is gained in the stability assessment, the terrain selection expands through a fairly repeatable hierarchy of run choices (stepping out). The early season snowpack is often relatively simple without persistent weak layers, which may lead to a honeymoon period when almost all terrain is considered for guiding (open season). As the season progresses, periods of deteriorating stability associated with storms alternate with periods of improving stability associated with stable weather; the terrain selection correspondingly contracts to a repeatable selection of runs (stepping back) and expands through a repeatable hierarchy of runs (stepping out). Toward the end of the season, avalanche activity often follows the daily freeze/thaw cycle, which is reflected in spring terrain use patterns (spring diurnal).

The 'stepping out' phase is the most critical period. Three stepping out periods are highlighted in the time profiles on Fig. 1 with a grey background. While venturing into more aggressive terrain as hazard conditions improve, the speed of stepping out through the terrain hierarchy and the terrain that we choose are adjusted according to specific conditions. Persistent weak layers or complex snowpacks cause us to step out much more cautiously and limit the overall extent of terrain that we use. Well established persistent instabilities can cause us to restrict all skiing to a very small number of runs for extended periods (entrenchment mode).

The ‘maintenance’ phase is another example of an adjustment where terrain choices are altered independent of consistently low hazard conditions. The light orange highlight in Fig. 1 marks an extended period of low and moderate hazard in late December and early January. While many infrequently considered runs were skied during the earlier part of this period (highlighted by the larger percentage of orange and red in Fig. 1e), the end of this period is characterized by a marked return to commonly skied runs (i.e., larger percentage of dark green) in anticipation of the potentially developing surface hoar problem. This helps us to continue skiing these runs through unstable periods by deliberately managing skier traffic on potentially problematic terrain features to disturb weak layers and release small loose dry avalanches.

The terrain we ski during times of elevated hazard is often quite steep. This is somewhat counter-intuitive, but there are two distinct reasons for it. First, we purposely ski these areas during the maintenance phase to actively keep the local hazard low during periods of high hazard. Furthermore, steep terrain of certain characteristics naturally avalanches frequently and can be safer on more days than moderate terrain where hazard persists between avalanche cycles because it avalanches infrequently and therefore has the potential to harbor protected weak layers. These two factors often allow us to ski consistently steep terrain even during periods of elevated hazard.

6. DISCUSSION

Physical terrain characteristics and avalanche hazard rating alone are insufficient to predict terrain use, but analysis of terrain use data in context of conditions combined with the guide’s perspective give insight into patterns of terrain use and the basis on which those patterns evolve. At any time, terrain selection depends on many factors including the character and spatial distribution of the avalanche hazard, snowpack conditions specific to particular terrain features, uncertainty regarding the avalanche hazard assessment, phase of avalanche cycle, strategic use of terrain, numerous operational considerations unrelated to avalanches, and more.

Because of the many confounding factors affecting the relationship between avalanche hazard and terrain selection, using a reductionist bottom-up approach for finding meaningful predictive relationships between avalanche hazard and physical terrain characteristics seems highly limited. This study takes a more holistic and integrated ‘top-down’ approach by analyzing actual terrain use in the context of avalanche conditions combined with the guide’s perspective to gain insight into patterns of terrain use and the basis on which those patterns evolve. The identified patterns can then provide the foundation for more detailed qualitative and quantitative analyses of individual aspects of terrain use.

For the analyst, the GPS data collected in this study is just data, but the tracks are extremely fascinating for the guides of the involved operations. The data is rich and is associated with past experiences and our perception of the terrain. Maps of GPS tracks and time profiles of terrain use clearly show familiar patterns. Some individual tracks recall specific conditions or events while the overall collection of tracks represents our habitual behavior. We can often infer which guide’s track we are viewing because of our familiarity with each other’s habits. The data captures a remarkably detailed record of our travels.

7. CONCLUSIONS

The objective of this collaborative study between a researcher and a guides was to comprehensively capture and present the nature of the risk management process at a helicopter skiing operation for an entire winter season.

We believe that much of the decision making at a mechanized skiing operation is heuristics based (habitual patterns combined with targeted adjustments in response to particular hazard conditions and operational needs), which is a way to deal with the high number of required decisions. Heuristics can be a very useful and effective approach when applied under the correct circumstances. While our illustrations primarily focus on the large scale run choice, our dataset of GPS tracks show similar patterns for how individual runs are skied. Identifying these heuristics together with the conditions when they are appropriate is the primary objective our future research program.

While the study was not yet able to identify explicit heuristics or decision rules, the collaborative qualitative exploration produced numerous ideas and strategies for future research directions. While ideas such as the Conceptual Model of Avalanche

Hazard (Statham at al., under review) and Strategic Mindset (Atkins, 2014) do a good job of capturing avalanche conditions and operational mindset, we need to develop a more holistic classification of avalanche terrain beyond the pure terrain characterization (e.g., incline, aspect, convexities). Only a more integrated perspective that includes operational aspects will allow us to extract insightful patterns. Detailed records of GPS tracks provide the necessary platform for these collaborative discussions. Furthermore, we believe that analysis approaches with a grounding in cognitive psychology will likely be more successful at identifying meaningful heuristics and decision rules than uninformed statistical analyses.

The benefits of the proposed research direction are many-fold. The long-term collection of terrain use data at mechanized guiding operations can benefit the local guiding team by explicitly capturing and illustrating their risk management expertise, helping them to better understand the implications of their own patterns of behavior and facilitate communication about those patterns within the guiding team, with new guides or with other operations. In the mechanized skiing industry in Canada, there has been continuous interest in finding better ways to effectively communicate comfort with terrain choices. While it might be possible to develop meaningful decision aids to facilitate terrain choices at operations in the future, we caution against the tendency to view them as 'silver bullets' for streamlining the operational process of terrain selection. Using them as an evidence-based second opinion will likely be a much more meaningful and accepted use of these types of tools.

If we are able to properly isolate the relationship between avalanche hazard and terrain use from other operational factors, the results of this research will also have tremendous benefits for the recreational avalanche community, as it will provide the foundation for evidence-based terrain guidance tools. However, differences in the recreational and professional approach to avalanche terrain use will have to be considered carefully.

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