ABSTRACT: April of the 2006 helicopter ski season in the Valdez Alaska Chugach Mountains is characterized by numerous skier triggered avalanches. Preliminary data confirms at least six involvements in April including two full burials and three injuries. Investigations revealed that these avalanches were caused by buried surface hoar and near-surface facets.

This paper reviews the snowpack and meteorological conditions prior to these involvements, outlines known involvements, and suggests a method of pro-active sharing of weather, snowpack, and avalanche information between the industry operations of the Chugach.

Keywords: buried surface hoar, skier triggered, Chugach, helicopter ski

1. INTRODUCTION

April of the 2006 helicopter ski season in the Valdez Alaska Chugach Mountains is characterized with persistent surface hoar and faceted layers that caught skiers off guard, leading to avalanche involvements. This paper will describe commercial helicopter skiing in the Valdez Chugach, review the snowpack and meteorological conditions prior to the April involvements, outline each known involvement, and suggest a method of pro-active sharing of weather, snowpack, and avalanche information between helicopter ski operators in the Chugach to facilitate more effective forecaster and guide decision making.

2. LOCATION

The Valdez Chugach is situated on the north coast of the Gulf of Alaska in a high-latitude maritime climate. The region experiences an average of twenty-eight major storms a winter (AMSC, 2003). The usual synoptic weather patterns are similar to those recognized by Scheler et al. (2004): 1) Onshore (coastal) flow, 2) Offshore (northerly) flow, and 3) Split flow. Warm, moist onshore storms track inland bringing precipitation and southerly winds to the area. High-pressure blocks sink down from the Arctic, spill over the coastal mountains and replace the coastal flow with strong outflow winds. Split flow is the transition period between onshore and offshore activity, producing unstable air packages that can be responsible for heavy snowfalls to lower elevations. All three weather patterns are channeled and convoluted by topography, glaciation, and coastal inlets. The combination of unique geography and variable weather leads to disparate snow conditions and dramatic spatial variability within the range.

The avalanche winter regime for the region is most commonly direct-action events, the result of intense precipitation and wind loading. Less common, but prevalent, are persistent buried weak layers such as surface hoar and/or near-surface facets. More research is needed to fully categorize the Valdez region’s regime.

Thompson Pass is the corridor through the Valdez Chugach for the Trans-Alaska Pipeline and the Richardson Highway. Located at 61º north latitude and 145º west longitude, fifty-five kilometers inland from the nearest salt water and 167 kilometers from open ocean, the 864m Thompson Pass is critical to several Valdez helicopter ski operators vis-à-vis transportation, fueling, and baseline weather observations.

The most snowfall recorded over a winter by the Alaska Department of Transportation is 2474cm. The average seasonal snow accumulation is 1400cm. Onshore weather will typically bring rain to start zone elevations at least twice each winter. In general, heavy precipitation events decrease snow stability; however, given time,
the relatively warm snowpack strengthens weaknesses. Further distance from coastal waters changes the meteorological climate from maritime toward continental. Less precipitation, cooler temperatures and more clear weather create persistent buried weak layers and occurrence of delayed action avalanche conditions.

3. BACKGROUND AND METHODS

Commercial mechanized skiing in the Valdez area has existed since 1990. In 2006 six companies were flying out of bases near Valdez and Cordova, Alaska. Much of the helicopter skiing in the range is exploration, pioneering, and reconnaissance. Limited continuous documented data exists for weather, snow, and avalanche observations. Each company has their own database consisting mostly of field observations, but to date, information sharing has been a proprietary and reactive exercise, not a daily exchange of standard observations.

The restricted amount of daylight during Alaskan winter forces the Chugach helicopter skiing season to be short; beginning in February and running through April, or early May. This means the majority of forecasters and guides who work the season do not live and experience the winter in the area until February. Becoming familiar with the season’s weather and snowpack history is a difficult task as each operation sets up for commercial guiding. Using the internet and local contacts, many guides who work in the region have become adept at piecing together the weather and snowpack history before venturing out onto the slopes. Short weather windows allowing abbreviated periods for monitoring snowpack conditions exacerbate these challenges. As helicopters are the primary access to start zones, the compressed season can add stress to operations with the pressure of skiing every “bluebird” day, leaving less than optimal time for extensive snowpack stability analyses or avalanche risk assessment.

The Chugach terrain has much to offer commercial helicopter skiing. Coastal mountains rising to 4250 meters stretch 100-150 kilometers inland from Prince William Sound. A large portion of the skied terrain hosts steep alpine chutes, walls, and ridges leading to glaciated faces and valleys. Most skiing occurs between 500 and 2000 meters elevation. Forecasters utilize elevation zones to describe snowpack activity: upper (above 1300m), mid (1300-700m), and lower (below 700m) zones. Treeline is either below 300 meters or non-existent from glaciation.

The land is managed by several public agencies including the U.S. Bureau of Land Management, U.S. Forest Service, Alaska Department of Land Management (DNR), Alaska State Parks, the Municipality of Valdez, and Alaska Department of Transportation. Each agency has its own permitting and land use terms. Provided the operators satisfy each agency’s requirements, more than 2000 square kilometers of terrain is available for helicopter accessed remote backcountry guiding. Unlike some helicopter operations in North America, the Valdez operators do not have long-term tenure on their land base. The U.S. Forest Service seasonally provides the only exclusive land use. Operators ski a cobbled together potpourri of lands slated multi-use, some of which is too remote to be economically viable, and vie for the same areas at the same time. The modus operandi is first come, first served. The combination of limited historical data, a short operating season, and a patched together land base a daily challenge for forecasters and guides working in the Valdez Chugach mountains.

3.1 Research in High-latitude Maritime Climates

With the growing number of industry operations in the Chugach Mountains, opportunity exists for significant snow science research. Published research in high-latitude maritime climates is limited. Two studies near Juneau, Alaska at 58º-north latitude monitored surface hoar and near-surface faceted layers during the winters of 2002-2004 (Hood et al. 2005, Scheler et al. 2004). This work demonstrated buried surface hoar and near-surface faceted layers can be responsible for snowpack instabilities in high-latitude maritime environments. Surface hoar and near-surface facets are prime candidates for such focused research because the burial of these layers is commonly associated with widespread avalanche activity (Hood, 2005).

Faceted crystals form near the surface of the snowpack in low-density snow when subjected to diurnal temperature cycling or solar radiation inputs (Colbeck, 1989). Strong vapor pressure gradients drive rapid kinetic metamorphism developing a layer of weak,
poorly bonded crystals. Hood et al. (2005) confirmed this process in a high-latitude maritime environment, recording temperature gradients in the upper 25cm of the snowpack (density 220kg/m$^3$) exceeding a diurnal change of 7°C. Although the physical processes are entirely different, near-surface facets can form at the same time surface hoar forms above.

The meteorological processes contributing to the formation of surface hoar and its mechanical properties have been the subject of a sizable body of research in lower latitude and less maritime affected environments than Valdez. Colbeck (1988) showed theoretically that it is necessary to have turbulent transfer, mixing, for surface hoar to grow. He theorized that molecular diffusion of water vapor from the air to the snow surface is not sufficient alone to grow surface hoar and that wind must aid in the process. Hachikubo and Akitaya (1997) later confirmed Colbeck’s findings; dispelling the theory that surface hoar forms only on nights with no perceptible wind. They showed the importance of measuring the wind speed when looking at surface hoar formation, concluding that wind speeds of 1 - 2 m/s at a height of 1m above the surface are necessary for maximum surface hoar formation.

Given what we know about how surface hoar forms, the next logical question is “where?” Avalanche practitioners observe and learn spatial distribution. Jurg Schweizer, of the Swiss Federal Institute for Snow and Avalanche Research in Davos, published a study (2004) on the variation in surface hoar formation and destruction from daily measurements made at twenty locations with different aspect and wind exposure within the same square kilometer. Different wind regimes had a stronger influence on growth conditions than any other meteorological or topographic parameter. For both surface hoar formation and surface hoar destruction, wind conditions proved to be most important variable for explaining spatial variation.

Avalanche forecasters must monitor the evolution of a persistent weak layer such as buried surface hoar (Jamieson and Schweizer 2000) and near-surface facets. Tracking the formation and destruction of the surface hoar and near-surface facets buried April 2$^{nd}$ 2006 (herein called the April 2$^{nd}$ surface hoar) proved a formidable task. Field observations were limited to ski-able days and other available data was not always representative of the slopes skied.

Wind is presumed the main factor in the distribution and destruction of the April 2$^{nd}$ surface hoar. Of the contributing variables, wind was the most difficult to track due to the convoluted nature of the ski terrain; adjacent valleys had different wind effect due to channeling, shelter, and/or aspect exposure. Standardized daily sharing of documented observations would assist track weak layers and map spatial variability. The larger the database, the more evident patterns and trends of variables like wind will become.

3.2 Data Collection

Due to the transitional and mobile nature of the heli ski operations, few Valdez avalanche forecasters monitor their own weather plot daily creating a lack of baseline data. Much of the information collected is from the field. Heavy reliance is placed on guides’ ability to quickly observe and record accurate information at landing zones, on-slope, and at pick up zones.

Valdez avalanche forecasters access a variety of websites containing meteorological models and weather product to facilitate their daily forecasts. The primary local weather resource in the Valdez area is the National Weather Service (NWS) in the port town of Valdez.

Another resource is the highway avalanche program at the road maintenance camp located one kilometer inland and 100m below Thompson Pass at milepost 27. The highway program records weather observations at mileposts 10 and 19 on the seaward side of the Pass, at the summit of the Pass, and mileposts 27, 29, 37, and 45 on the inland side of the Pass. Observations include barometric pressure, precipitation type, rate, and quantity, temperature, humidity, depth of new snow, depth of storm snow, depth of snowpack, wind speed and direction, and solar radiation. Information and camera images from mileposts 19, 26, 27, and 45 are posted on the internet. A remote automated weather station is being installed at 1480m above milepost 44.

4. WEATHER SUMMARY

The significant snowfalls recorded at Thompson Pass during the 2005-2006 winter are depicted in Figure 1. By mid-February the 2006 heli ski season started with less snow than usual, with 150-180cm observed above 1000m.
The weak layer to watch at that time was 5-10cm of buried facets that formed near the surface during a severe cold clear period in January. A major natural avalanche cycle occurred February 6th to 9th on the January facets. The first report of heli skier triggered avalanches on this layer was February 14th.

By mid-March the January facets gained sufficient strength to be less of a concern. During the first two weeks of March, the Valdez Chugach endured strong to extreme outflow winds across the heli ski operating areas. Much of the snow available for transport was blown, forming pencil hard windslab. Sublimation was also observed to be substantial during this windy period. As a result, much of the moisture in the upper meter of the pack exited, leaving irregular pockets of hard windslab over hollow facets.

![Figure 1: Significant snowfalls during the 2005-2006 winter recorded at Thompson Pass.](image)

At the end of March, the Chugach saw convective weather with large diurnal temperature fluctuations of the snow surface, ≤Δ20°C, caused by a combination of clear, cold nights with strong radiative cooling and relatively warmer, sunny days. The weather at Thompson Pass was clear March 24th through April 1st with overnight low temperatures near -10.0°C and daytime highs near 7.0°C. Light northeast to east winds were consistent during this period. The humidity was found to rise at night to 40-50% and drop during the daytime, resulting in an inverse humidity/temperature relationship. If net radiation were measured, the snow surface energy balance would have been very interesting to observe during this period.

The meteorological conditions were similar to the recipe cited by Birkeland et al. (1996) producing large temperature gradients, strong vapor pressure gradients, and the rapid formation of faceted snow near the surface. As a result of diurnal recrystalization, surface hoar and near surface facets grew larger with each consecutive clear night. Hood et al studied a similar high-latitude maritime event with a snowpack temperature probe used to track and measure the temperature gradients near the surface. That research found near-surface faceted crystals responsible for snowpack weaknesses in the high-latitude maritime environment near Juneau, Alaska. It was noted the collection of more spatially distributed field data could allow further evaluation of the extent of the weakness. Similarly, in the Valdez Chugach, the surface hoar and near-surface facets were reported as being inconsistent and sporadic across the operating area, with more data needed to determine the distribution of the weakness. Guides and forecasters found surface hoar to 15mm with 2-10cm of facets to 4mm below and reported temperature gradients of 10°C between the surface and 25cm below the surface. The photograph in Figure 2 shows the faceted snow that provided excellent skiing in late March.

![Figure 2: Six mm surface hoar at 1200m ASL forty km from Thompson Pass (buried April 2nd).](image)

The weather pattern changed on the last day of March as the high-pressure block began to break down and a storm from the southeast moved in. Light to moderate wind blew onshore at the beginning of the storm. A snow water equivalent of 13mm fell in spits April 1st to 4th.
April 5th brought rising temperatures and rain at sea level. Due to orographic lifting and topography, start zones closest to the ocean received more snow with higher water content. After the surface hoar and near-surface facets layer was buried April 2nd, there were three more short clear periods alternated with onshore storms with water equivalents of 30mm, 4mm, and 64mm respectively. The last significant storm of the heli ski season was April 22nd to 25th with 75cm of storm snow in the upper elevation zone.

5. INVOLVEMENT SUMMARY

Limited test results on April 5th showed easy failure at the surface hoar/storm snow interface, 30-40cm from the surface. At 10am on a 40° NNW slope at 1460m, thirty-four km from Thompson Pass, a skier was hit by a small pocket of slab triggered by a cornice dropped by skiers on the ridge 75m above. The avalanche with the destructive potential of burying, injuring, or killing a person (D2) and of medium size relative to the path (R3) injured the skier. The slab was 35cm deep, 30m wide, and ran 250m. The bed surface was the April 2nd surface hoar 2-4mm in size. The same day a natural D2 ran to the edge of the highway at milepost 15. The next day, during the warmest period of the afternoon, widespread natural point releases were observed to step down to the April 2nd surface hoar throughout the Thompson Pass highway corridor. A natural D3 avalanche reached within 100m of the highway at MP 51.

Guides found easy to moderate results on April 7th with shear quality 1 and 2, sudden planar, down 18-45cm on the April 2nd surface hoar. At 1pm on a 30° NW slope at 1550m, forty-one km from Thompson Pass, a skier triggered a soft slab that broke 20m above. The skier was not entrained but injured. The skier was the seventh to ski the slope, on a slightly more westerly less steep slope than previous skiers. The slab was 30cm deep, 50m across, and ran 500m, sized R3, D2. There was a second incomplete report that day from another operation of a skier-triggered slab failing on the April 2nd surface hoar.

On April 10th, at 1130am on a 26° NW slope at 1095m, seventy-one km from Thompson Pass, a skier triggered soft slab 30cm deep that propagated 100m over a roll and onto a 40° slope. The avalanche entrained a different skier 30m below. That skier was carried 320m, injured, and buried 60cm deep. The avalanche was sized R2, D2. The weak layer was the April 2nd surface hoar layer ≤5cm thick.

On April 13th, on a 31° NNW slope at 1225m, thirty-seven km from Thompson Pass, the last skier of twenty-two skiers skied just left of tracks in an open alpine bowl and triggered a wind affected soft slab avalanche sized R3, D2. The slab fractured 50m above the skier and 40cm deep. The skier was entrained and buried 1.2m deep 300m below without injury. The crown was 200m across. The avalanche ran 350m on 5-6mm April 2nd surface hoar. Compression tests in the area were rated moderate; shovel shear tests were rated easy. Also that day, another skier triggered avalanche, sized R2, D2, released on a 35° NNW aspect at 1350m. The fracture depth was 40cm to the April 2nd surface hoar.

Beginning April 14th, new snow, afternoon warming and moderate northerly windloading triggered an avalanche cycle. Natural avalanches to size D3 on most aspects along the highway corridor near Thompson Pass released on the April 2nd surface hoar. Guides reported shear quality 1, sudden planar results on the April 2nd surface hoar as deep as 65cm on north aspects. That day a heli ski operator reported a natural release sized R4, D2.5 on a north aspect at 1350m thirty-seven km from Thompson Pass.

On April 15th, at 1pm on a 40° NW slope just off a ridge at 1740m, seventy-four km from Thompson Pass, a skier triggered a soft slab 30cm deep and 30m across that ran 170m on 5mm April 2nd surface hoar. The skier was caught, funneled into a chute, and diverted into a secondary chute, and narrowly missing being carried over 20-30m cliffs. The skier was carried 150m without injury or burial in an avalanche sized R2, D2.

Between April 15th and April 19th several skier-triggered avalanches were reported with few details other than the weak layer being the April 2nd surface hoar. Most were on northerly aspects near 1500m with fracture depths between 25cm and 60cm.

---

1 Direction from Thompson Pass is not included to protect operators concerned with competition.
2 The term skier includes snowboarding and without distinction between guide and client.
3 Avalanches sized in accordance with the 2004 Snow, Weather, and Avalanches: Observational Guidelines for Avalanche Programs in the United States.
On April 19th, at 2:30pm on a 41st NW slope at 1740m, thirty-eight km from Thompson Pass, a 240 lb. skier was the thirty-seventh skier on slope. Skiing well within that day’s tracks, the skier triggered a soft slab 60cm deep that fractured 190m across and ran 325m. The skier was entrained, buried to the neck, and recovered without injury. The bed surface was 5mm April 2nd surface hoar. The avalanche, sized R4, D3, occurred when the peak air temperature of the day reached 7.0ºC. A natural release was observed shortly after one kilometer away on a slope with similar aspect and elevation.

6. DISCUSSION

Across much of the Valdez Chugach during April 2006, the surface hoar buried April 2nd was observed to form on top of a ≤10cm layer of near-surface facets. Birkeland (1996) affirmed this is common, “often near surface faceted snow is topped off with surface hoar, a well documented weak layer”. Once this surface hoar/near-surface faceted layer was buried it was not consistently reactive in tests and ski cuts. Skiers triggered avalanches on slopes that had been skied repeatedly. Also, slopes were deemed safe adjacent to slopes with similar aspect, elevation, and slope configuration as slopes that had avalanched. Of the factors attributed to the inconsistency (wind, temperature, solar exposure, slab stiffness), wind is the likely source of the high spatial variability.

While difficult to draw conclusions from limited data, most of the heli skier triggered avalanches on the April 2nd surface hoar occurred on northwest slopes. Part of the reason may be because in April operators avoid south aspects when seeking dry snow and managing risk. The average elevation of the avalanches triggered and/or observed to have failed on the April 2nd surface hoar was 1500m. The involvements were triggered by the skier or a nearby skier less than 50m down from a ridge, usually not the first to ski the slope, and as late as the thirty-seventh skier.

After the April 22nd to 25th storm, no further avalanches triggered by light loads were reported on the April 2nd surface hoar. Several large natural releases to size D3.5 observed in the last week of April appeared to have stepped down to the April 2nd surface hoar after initially failing at a newer storm snow interface.

All operators in the Valdez Chugach encountered and observed the April 2nd surface hoar and made decisions to avoid and/or manage the exposure to this buried weak layer. One operation decided to ski only runs their operation had compiled historic records from. By repeatedly using “the exact route over and over again” they were able to avoid surprise encounters with the weak layer. Another emphasized the use of terrain such a ridges, spines, and low angle terrain to lower the risk of being caught in a slide. It follows that collective observations of weather and snowpack conditions specific to a buried weak layer can aid predicting where a weak layer remains intact and continues to be reactive.

Observations of the April 2nd surface hoar in the Valdez Chugach led some to believe that slope failure was more a function of shear resistance rather than the presence of the surface hoar and/or near-surface facets. Louchet and Duclos (2006) cite a series of four rupture mechanic phenomena that need to occur before an avalanche releases: basal crack nucleation, basal crack propagation, crown crack nucleation, and crown crack expansion with avalanche release. This concept may explain why it took between the seventh and thirty-seventh skier to trigger avalanches during the 2006 heli ski season. When the basal layer (surface hoar/slab interface) is affected by pressure from skiers, a basal crack nucleation takes place, but it may take several skiers to apply enough stress to expand the basal crack. Louchet and Duclos (2006) observed gradual damage to the basal crack may cause the failing slab to extend “step-by-step in an area around the skier’s path.” This was often observed in the Valdez Chugach during April 2006. The soft slab failed following the curves of ski tracks.

Louchet and Duclos (2006) also reference subcritical and supercritical triggering. Subcritical triggering being when the avalanche starting zone is limited roughly to the area damaged by the skier. Supercritical triggering being when the crown crack opening occurs at a large distance from the skier. Both subcritical and supercritical triggering occurred in the Valdez Chugach involvements. Supercritical triggering describes almost all of the involvements in which the skier was caught and/or buried.

Spatial variation of the April 2nd surface hoar was observed across the Valdez Chugach during April. Triggering the weak layer was highly spatially variable in terms of the presence.
or absence of the weakness. Some slopes reacted; some slopes didn’t, even when the slopes tested had similar aspect, elevation, and terrain configuration. Schweizer (2004) concluded the standard method to assess snowpack instability is to do local observations of snow stratigraphy and perform a stability test. “However”, Schweizer noted, “the extrapolation of the test results is hindered by spatial variability, which is usually not known. It is therefore crucial to understand the nature and causes of spatial variability, but not only for one scale but across the scales relevant for avalanche release and forecasting.” This being said, the vagaries of spatial variability warrant further data communication and research in the Valdez Chugach.

Valdez area forecasters and guides do not have the luxury of accessing information from an avalanche-forecasting center; there is not a daily bulletin for reference. The decisions made are based on their own observations, their own experience, and ad hoc “after the fact” emailed and faxed communication regarding involvements.

Communicated observations of neighboring operators, forecasters, and guides could be utilized more fully to support effective decision-making. Ski guiding mountains from the top-down is difficult, particularly so on new or rarely used routes. Sharing daily observations between operators is regarded by some as an unnecessary disclosure of “company secrets”. In an industry where technology, techniques, and methodology is ever improving, this practice is not industry standard.4 Jamieson (2003) emphasized the importance of taking time each day to analyze the observations and information from other operations and communicate unexpected observations with others who work in the area. Standard observations, shared in the same format using the same language and symbols, has the potential to show trends and patterns applicable not only to daily operation, but would also provide data for further research and understanding in the region.

The avalanche industry in the United States recently adopted a standard for observing and recording observations, Snow, Weather, and Avalanches: Observational Guidelines for Avalanche Programs in the United States, as the first necessary step toward formalizing communication networks between avalanche workers. The six helicopter ski operations in Valdez and Cordova, the Cordova ski area, the Thompson Pass and Cordova avalanche programs are one such network. At the other end of the Chugach in Turnagain Arm and Turnagain Pass, heli ski, cat ski, ski area, railroad, and highway operations have teamed together to build remote automated weather stations with the information available on the internet. Also for that end of the Chugach, the U.S. Forest Service operates an avalanche information center and posts a public advisory. The next step could be a regional information-sharing forum.

This forum may emulate the system used in Canada where the Canadian Avalanche Association manages the InfoEx program instrumental in aiding avalanche risk management, education, and research. This model could help Chugach industry operators become pro-active and further the goals of snow safety.

Chris Stetham, avalanche educator, states, “Greater uncertainty requires a greater margin of safety.” Sharing daily information, analyzing it, and applying it to their complex decision making matrix could increase the margin of safety for forecasters and guides in the Alaska Chugach. While forecasting a thirty-seventh skier on a slope will trigger an avalanche weeks after a storm remains far fetched, operational decisions regarding terrain choices based on information from more sources, may help avoid exposure to, and risk from, buried weak layers such as the 2006 April 2nd surface hoar. Sharing information amongst operators will not solve all problems, but it is one step toward managing avalanche risk in the Alaska Chugach.

7. ACKNOWLEDGEMENTS

We are grateful to all colleagues, forecasters, guides, and operators in the Valdez Chugach who contributed to the collection of snow, weather, and avalanche information including the Valdez National Weather Service, Valdez Heli-Camps, Alaska Backcountry Adventures, Valdez Heli Guides, H2O Guides, Rendezvous, and Points North. Thanks to the field observations and/or photos of Dan Starr, Dan Vandermullen, Gabe Monroe, Alex Eaton, Joel Serra, and Chad Colby. Special thanks to Dr. Eran Hood, Mark Newcomb, Dave Rintala, and Kelly Gray.

4 Bay Street judgement: Ochoa v. CMH.
8. REFERENCES


NOAA Cooperative Institute for Regional Prediction. Last visited 19 July, 2006. www.met.utah.edu/cgi-bin/droman/time_mesowest.cgi


Ochoa v. CMH. 1996. Supreme Court of British Columbia, Canada.
