HISTORICAL ANALYSIS OF AVALANCHE FATALITIES IN DENALI NATIONAL PARK

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ABSTRACT: Since the first mountaineering avalanche fatality in Denali National Park (DNP) in 1976, at least 45 climbers have been killed by avalanches in the mountains surrounding Mt. McKinley. The avalanche problems are different in many cases than recreationists encounter in smaller and lower elevation mountains. Specific problems include crevasses, glacier icefall, and exposure to large cliffs in the runouts. We looked at the historical avalanche related fatalities in DNP to refine our education methods and drive future research. This paper includes a statistical look at fatal incidents as well as a case study of a recent fatal avalanche event.

1. INTRODUCTION

Denali National Park and Preserve is a 24,584 square kilometer area managed by the National Park Service (NPS) originally established in 1917. The Park's main attractions include abundant wildlife and the majestic views of the high mountains of the Alaska Range. For mountaineers, Mt. McKinley (locally known as Denali) is a sought after climbing objective, with a peak of 6,194 meters (20,320 ft.) and recognition as the tallest mountain in North America. Each year approximately 1800 climbers travel into the glaciated mountains of the Alaska range in DNP, with 2/3 of climbers focused on Denali. The geology of the region has produced monumental granite walls, mountain faces with up to 4200m (14,000 ft.) of vertical relief, and expansive glaciers up to 58 km. (36 miles) in length.

1.1 Alaska Range climate

The climate zone of the Denali region is difficult to classify. Large temperature and precipitation variation occurs within the Alaska Range both laterally and vertically. Annual snowfall can be significant, winter temperatures are severe, and the mountains are heavily glaciated. Climate zone maps typically classify this region as continental, but large snowfall amounts, high latitude, and permanent glacial ice can force different considerations from a typical continental snowpack problem. The summit of Denali lies only 193 km from the ocean to the south, easily within reach of violent storms from the north Pacific. The arctic circle is 386 km to the north, making it a high latitude and cold environment. The high variation in elevation (glaciers within the Park range from less than 300m above sea level to over 6000m), causes elevational differences in the snow climate. Low elevations often produce a deep transitional snowpack (1.5 to 3m), with complete melting during the summer, and continental to arctic temperatures. Mid elevations (1500 to 4000m) can have maritime snow totals (3m+) but still see very cold temperatures with only the southern aspects melting completely. High elevations (above 4000m) are relatively dry, receive most snowfall in summer months, and have below freezing temperatures year round. Extreme cold temperatures are common with temperatures at 5,700m recorded as low as -73° C and -30° C in December and July, respectively (International Arctic Research Center 2010). Glacial equilibrium (zone separating accumulation and ablation) averages near the 1800m elevation. All incidents within this study occurred well above treeline (600m) and far from any significant vegetation.

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1.2 National Park Service climbing program

The NPS places a high priority on visitor safety. Denali National Park has a long standing mandatory registration and education program which serves to advise climbers of the inherent dangers of climbing Denali and Foraker and help them choose appropriate climbing objectives based on experience and abilities. A discussion of avalanche hazard is an integral part of these orientations. A study in 2008 found the risk of death while climbing Denali to be decreasing over the years and the measures imposed by the NPS have contributed to a safer climbing

experience. (Macintosh 2008) The considerable effort to educate climbers on potential hazards includes safety guides published in eight different languages. The orientation requirement does not apply to climbers on peaks outside of Denali or Foraker, although climbing rangers are available year-round to give advice and answer questions about climbing in the Park.
There is no public avalanche forecast for this region of Alaska. The remote location, extreme altitude, lack of remote sensing equipment, and lack of resources make macro scale avalanche forecasting inaccurate and impractical. Alaska Range climbers must rely exclusively on their own skills and avalanche assessment resources to stay safe in these mountains.

1.3 Previous research
There has never been a comprehensive study of avalanche incidents in Denali National Park except for a section of Jonathan Waterman's book "Surviving Denali" from 1983. Many of the incidents within this report have never been included in national statistics compiled by the Colorado Avalanche Information Center.

1.4 Limitations
This paper does not look at non-fatal avalanche incidents. There are many avalanche events with injuries in NPS records, but the records cannot be considered complete due to poor reporting from the public. Typically these were only recorded if the National Park Service was involved in a rescue capacity.

Several cases of missing climbers included within this paper are not proven to be avalanche related, but the investigators of the disappearances believe avalanche to be the most likely cause of the teams going missing. Several other mysterious disappearances of climbers were not included in the study even though avalanche may have been the cause of death and disappearance. In these cases we classified the cause according to the investigator's conclusions. The statistical conclusions derived from this information can be assumed to have a degree of error because of this uncertainty.

This paper looks only at the snow and ice avalanche fatalities within the mountaineering scope of DNP. There have been at least 4 recorded avalanche fatalities in the more easily accessed, low elevation peaks inside DNP. One was a ski tourer, the other 3 were snowmobilers. The scope of this study covers only mountaineering related avalanche fatalities and omits these other incidents.

Some ambiguity exists on classifying certain fatalities as primarily caused by avalanche. 3 incidents included within this study were originally classified by the NPS as death due to climbing falls. In all of these cases a significant failure of snow caused the initiation of the fall which caused the fatal injuries. It is possible that many of the fatalities recorded as climbing falls were caused by a small snow slab failure. Certain places on Denali, such as the Orient Express, with many cases of entire teams being killed in falls may have had a slab failure component to the fall initiation. In most cases we have no evidence to confirm or deny this possibility and these cases were not included in this paper.

Only basic avalanche information was recorded by investigators prior to 2005. We have few details regarding: avalanche size, weak layer, slab, bed surface, trigger, preceding weather events, exact elevations, alpha angles, start zone angle, or other technical information. Even in modern times it can be impossible to access the sites to record these details because of safety concerns or logistical challenges.

2. METHODS

The National Park Service holds an exclusive jurisdiction over the land in DNP and is the primary agency responsible for search and rescue, law enforcement, and death investigations. Denali National Park keeps mountaineering records on file starting in 1903 and an electronic database beginning in 1976 for all events involving search and rescue or a fatality. Case incident records include expedition information, search and rescue efforts, medical treatment, witness interviews, media reports, maps of accident sites, and accident analyses. In some cases photos or videos are available with the reports.

This paper is based on reviewing records in the NPS database as well as interviews with Rangers involved in the rescue efforts. Both authors of this paper are current mountaineering rangers of Denali National Park and personally worked as rescuers and investigators since 2005.

3. RESULTS

Since the first mountaineering fatality in 1932, 164 people have died climbing in DNP. 120 (73.1%) were on Denali, and 44 (26.8%) were on other peaks. Out of these, avalanche accounted for a total of 45 people killed (27.4%), in 22 separate incidents. 13 climbers in 5 avalanche incidents died on Denali, 32 climbers in 17 avalanche incidents died on other peaks.

We looked at Denali separately from the other peaks because 95% of Denali climbers use the West Buttress route, which did not have a fatal avalanche incident until 2012. We can assume that Denali's trade route has less avalanche risk than other popular climbs in the region.
10.83% of climbers killed on Denali, and 6.4% of fatal incidents were from avalanche.
72.72% of climbers killed on other peaks, and 70.83% of fatal incidents were from avalanche.

YYYY	MM	DD	PLACE	Fatal	Avalanche type	Notes
2012	6	13	DENALI, West Buttress, Motorcycle Hill	4	Slab	crevasse
2011	4	28	BEAR TOOTH, Ruth Gorge, Root Canal.	1	Serac	icefall
2011	5	23	MT FRANCES, West face	2	WL	cliff terrain
2010	5	29	WEREWOLF, Ruth Gorge, Freezy Nuts	2	WL	cliff terrain
2007	5	16	BARRILL, Ruth Gorge, Japanese Couloir	2	Slab	cliff terrain
2005	2	15	MT HUNTINGTON, West face	1	Slab	crevasse
2002	6	13	MT FORAKER SE ridge	3	Slab	steep terrain
2000	5	25	MT JOHNSON	1	Serac	icefall
1997	6	6	MT HUNTER, North Buttress	1	Cornice mushroom	cornice
1997	5	29	DENALI , Orient Express	1	Slab	steep terrain
1996	6	24	MT HUNTER, NW spur of West ridge	2	Unknown	cliff terrain
1996	5	13	MT HUNTER, Rattle and Hum	2	Slab or slab triggered by debris	steep terrain
1992	6	18	MT FORAKER, Pink Panther	2	Slab	steep terrain
1987	7	21	DENALI, NE fork Kahiltna	1	Unknown	Missing persons
1987	5	22	MT HUNTER, West face below summit	1	Slab	burial
1987	5	6	MT FORAKER, SE ridge	4	Slab	steep terrain
1981	7	1	DENALI, E fork Kahiltna	3	Unknown	Missing persons
1980	6	1	DAN BEARD	2	Cornice Collapse	cornice/steep terrain
1980	8	3	DENALI, NE fork Kahiltna	4	Unknown	Missing persons
1979	5	9	MT HUNTER, West Ridge	1	Cornice Collapse	crevasse
1978	5	30	MT FORAKER, SE ridge	2	Slab	crevasse
1976	8	6	MT FORAKER, NE basin	3	Serac	crevasse/icefall
			Total	45		

Mt. Mckinley climbing fatalities – through 2012
120 total climbing fatalities (Figure 1)
13 avalanche fatalities
10.83% avalanche

78 total fatal climbing incidents
5 fatal avalanche incidents
6.4% avalanche

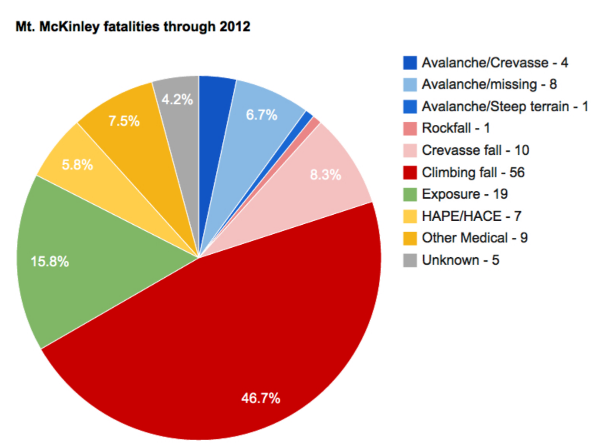


Figure 1

<u>All Other DNP peaks fatalities – through 2012</u>
44 total climbing fatalities (Figure 2)
32 avalanche fatalities
72.72% avalanche

24 total fatal climbing incidents
17 fatal avalanche incidents
70.83% avalanche

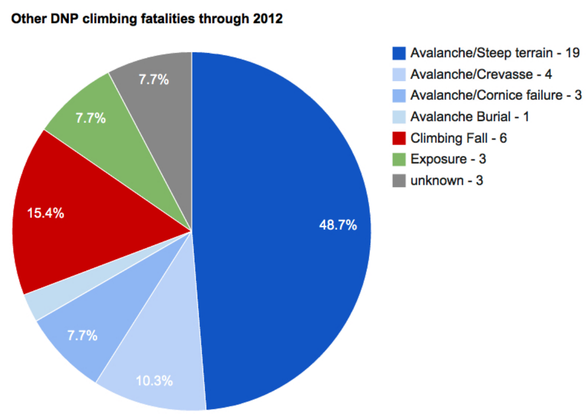


Figure 2

4. DISCUSSION

4.1 <u>Multiple fatalities per incident</u>
A significant aspect of avalanches in DNP is multiple people getting killed in most fatal incidents. We found the average number killed per fatal incident to be 2.04 people, compared to a national average (excluding Alaska) of 1.25 people (CAIC database). A couple of reasons cause this unusually high number. Roped climbing accounts for the majority of the multiple fatality incidents. Of the 19 incidents in which the mechanism is known, 14 (74%) were roped together at the time of the incident. Climbing roped together with one or more partners is the accepted way to mitigate other mountaineering hazards including crevasse danger and protecting against falls in steep terrain. Unfortunately, climbing roped has distinct disadvantages in avalanche terrain. First, the rope creates a bond between partners. Second, it forces close proximity to teammates. Both of these make it almost impossible to limit exposure of avalanche danger to one person at a time. Even if climbers were able to climb safely without a rope, the size of the avalanche paths can make it impractical to expose only one person at a time, and many alpine routes force long durations of exposure to avalanche hazard from above.

4.2 <u>Terrain Exposure</u>
Exposure to serious terrain traps was a common scenario in many of the incidents. The enormous consequences encountered in the Alaska Range are probably one of the most underestimated aspects of climbing there. The result of getting knocked off a stance, even in non-technical climbing terrain with cliff exposure or other terrain traps below has proven to be fatal in many instances.

In at least 9 of the incidents we examined, victims were killed by trauma in extended falls after the avalanche. Many popular alpine routes in the Alaska range travel through hanging snow fields with the bottom edge terminating over steep cliff faces. The consequences of even very small avalanches in such terrain are inevitably fatal. Evaluating snow conditions while on these routes can be extremely challenging, and retreat may not be possible. A couple circumstances have recurred in these cases: 1. Wet avalanches during the heat of the day in lower elevation zones (below 10,000 ft.) (avalanches on Frances 2011, Werewolf 2010), 2. The topout where poorly bonded wind slab may be present only close to the crest of a ridge. In one incident a survivor suspected that “the avalanche came from an isolated pocket of wind-deposited snow... The 5 inches that fell over the 48 hours before the accident had given us little cause for concern.” (Coombs 1992) The team likely triggered a thin windslab on steep terrain as they got close to the ridge on the upper snowfield. (avalanche on Foraker 1992)

In another incident, investigators found tracks leading into a small storm slab crown just before the ridge crest and the victims were located thousands of feet lower beneath a cliff face. (avalanche on Barrill, 2007) Using climbing protection in the form of ice screws, pickets, or rock protection may have prevented some of these tragedies. Climbing roped but without protection is common practice with experienced and confident teams in this kind of moderate but high consequence terrain. However, in numerous cases in the Alaska Range, this practice of climbing roped together without protection has resulted in a fatal outcome.

4.3 <u>Ski descents</u>
Ski descents of the high peaks have become increasingly popular in recent years. Many skiers coming to the Alaska range for the first time don’t realize that snow coverage on the upper mountain is very poor until mid summer. Skiers arriving in

April or early May to attempt to ski above 4000 meters will usually find a firm, wind scoured surface or ice. Seasonal snowfall at this elevation increases by late May through the rest of the summer. Skiers find that the lack of snow makes steeper slopes very unforgiving in the event of a fall, but slab avalanche concerns may be less. As the summer progresses, the hazards associated with falls are traded for better skiing, but at the expense of increased slab avalanche danger.

4.4 Crevasses

At least 5 of the 22 incidents we examined had a component of crevasse fall adding to the lethality of the incident. In 2 recent cases the victims were carried for only short distances before being pushed into a crevasse and buried deeply. None of these victims were recovered despite search efforts and a high degree of certainty as to their location. The glacial crevasse hazard proves to be one of the most deadly terrain traps, pushing the victims into a vertical fall before burying them deeply by subsequent debris. The consequences of crevasse hazard combined with avalanche slopes should be considered nearly as dangerous as a precipitous cliff face. Large open crevasses below avalanche slopes will collect some of the debris, and likely any people who are caught with it. Picture 1 shows the 2012 fatal avalanche and crevasse in which the 4 victims were caught and buried.

Picture 1: Motorcycle Hill avalanche 2012

Open crevasses cutting across a steep snow field may also make the slope more likely to slide due to a lack of compressive strength that is typically provided by the adjoining lower snowpack (Smith 2005).

4.5 Icefall

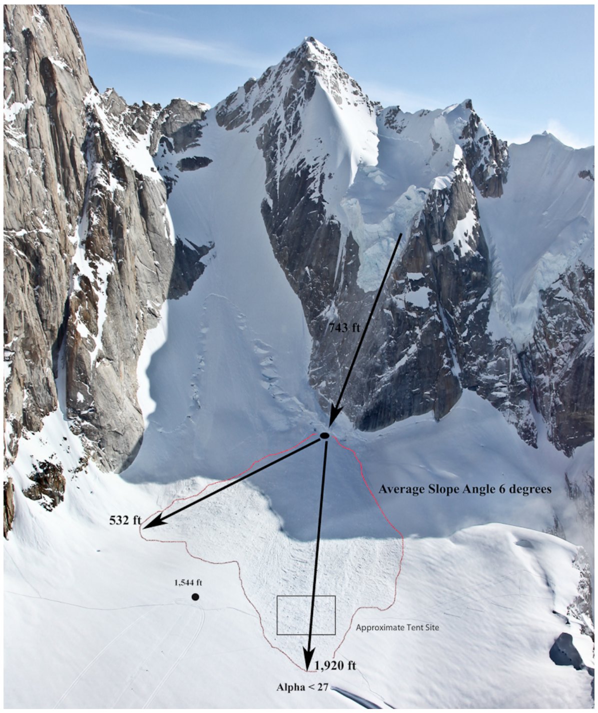
Icefall accounted for 3 of the incidents, and is likely the culprit for the missing climbers in 1980, 1981, and 1987. The dangers and patterns of icefall avalanches are poorly understood, especially by climbers who spend limited time around large glaciers. A belief that higher daytime temperatures can destabilize hanging seracs is prevalent among climbers, but some research suggests that nighttime cooling can actually cause the highest frequency of icefall. (Pinchak 1968) The standard practice in the Alaska Range is to limit exposure under these dangerous features regardless of the time of day or ambient temperature. On steep routes sun exposure will cause increased rockfall and weakened cornices. The larger scale hanging glaciers with significant mass will fail when the underlying glacial stress becomes too great. Temperature changes likely play a minor role compared to the glacial forces. Many potential routes are widely considered to be death traps because the overhead icefall hazard cannot be avoided. The northeast basin of Mt. Foraker is a good example of a route with high objective hazard, and the death of 3 Japanese climbers in 1976 is a good reminder of that assessment. The northeast fork of the Kahiltna glacier has earned the name “the valley of death” for its reputation of icefall hazard and missing climbers in 1980 and 1987.

It is common to hear of alpinists who observed a specific route for an extended period of time to learn the icefall frequency and patterns before setting foot on the climb. When informed climbers choose to travel underneath icefalls it is with an acceptance of the risk and a hope that the odds remain in their favor. There is still no escaping the reality that such decisions rely on a gamble, which sometimes ends tragically.

Minimizing exposure to icefall avalanches requires that campsites (where climbers will spend a great deal of time) must be chosen well away from icefalls and snow slopes above. The incident in the Root Canal in 2011 is a poignant reminder of this requirement. Measuring alpha angles may be a quick and effective way of staying beyond theoretical runouts, and using defensive terrain features to divert debris flows is a proven effective strategy even when in close proximity to avalanche areas. No research into a standard alpha angle in the Alaska range has yet been done, and conservative decisions when estimating runouts and choosing campsites should be emphasized.

5. CASE STUDY

On April 28, 2011 at approximately 0120 hours an ice avalanche released off the West face of the Bear’s Tooth and struck two guided climbing parties camped below on the Root Canal glacier. All five climbers were struck by the avalanche, two were partly buried while three remained on the surface. One of the two buried victims was found to be unconscious with shallow respirations. Shortly after the avalanche, the unconscious victim succumbed to traumatic injuries. The victim was evacuated at 0600 and Ranger medics confirmed he was deceased. A site investigation was completed on 05/06/11.



Picture 2: Bear Tooth 2011

Ice avalanches (serac falls) result from tensile failure within the ice due to ice flow creep within the ice mass and/or glide at the bed surface. It is inherently difficult to predict the timing of this type of failure. Unlike snow avalanches there is very little correlation to time of day, aspect, elevation or weather. This leaves few tools available to the practitioner for use in the field. Avoidance and limiting the time of exposure continue to be the best practice.

The runout distance for an avalanche is the farthest point to which debris can reach. Currently the best methods for determining runout distance are "(1) long-term observations of avalanche deposits; (2) observations of damage to vegetation, ground or structures; or (3) searches of the historical record as preserved in newspapers, old aerial photos, or other written material" (McClung and Schaerer, 2006). Unfortunately very few of these are available for the mountains of the Alaska Range so we must use other methods.

A field method used by practitioners to estimate maximum runout distance for snow avalanches is to measure the alpha angle of a given slope. Alpha angle values range anywhere from 15-50 degrees (McClung and Schaerer, 2006). These values are compiled from statistical analysis of "the historical record of avalanche runout in a given mountain range" (McClung and Schaerer, 2006). Because alpha angle values are specific to, mountain range, avalanche path, snow density, snow climate and terrain configuration they vary greatly from location to location. The use of alpha angle values derived from statistics for snow avalanches are not necessarily representational for ice avalanches. The alpha angle from the camp placement was approximately 27 degrees. To be beyond a 15 degree alpha angle (safe) it would be difficult to camp anywhere in the "Root Canal". More important than using an alpha angle for runout avoidance is the ability to read terrain and use defensive features within the terrain.

Defensive features deflect, stop or dissipate the flow of ice and snow. Terrain configurations that are most suitable as defensive features are: a rapid gain in elevation such as a knob or ridge, large crevasse features that can swallow debris, and extremely long shallow angled or flat runouts. The debris from this event traveled 1,920 feet out from the point of impact on an average slope angle of 6 degrees. This is a substantial distance on a shallow slope angle, yet the avalanche retained enough energy to hit the camp with impressive force. A subtle depression channeled the majority of the debris (estimated at up to 4 feet deep) and deposited it directly through the area of the campsite.

In addition to this small depression, another significant terrain feature that contributed to this event is the nearly vertical avalanche path. The vertical fall of approximately 743ft allowed for an almost free-fall environment for the ice to travel, increasing the speed at which it fell. This appears to have created an explosive type of impact that broke the ice into small pieces allowing them to travel greater distances, also resulting in a substantial air blast that traveled in front of the debris. The air blast hit with such force that it ejected all five climbers from their tents. It sent them ahead of the debris, accounting for their position mostly on top or only shallowly buried in the debris.

The return frequency of this icefall is unknown. We have very little information in the Alaska Range to estimate icefall frequency. The only good historical information on this particular icefall is: the fatal event in 2011, a Google Earth image from 2006, and a photo from 1977 that shows similar avalanche debris.

5.1 Decision making

An additional component to this fatality was the guides' decision to place their camps in this location. Historically, camps on the Root Canal glacier have been used on both sides, up and down the entire air strip. The approximate campsite location where the accident occurred is a popular area often used by many climbers each year for its view of the entire "Ham and Eggs" climbing route and proximity to airplane access. Interviews indicate that there were previous campsites from this season in this location and none in other locations. Choosing safe camping locations in this area is difficult due to the large scale of terrain and multiple potential hazards (rock fall, snow avalanches, weather, and serac fall) that threaten the basin. At times you may trade one for the other, making decisions difficult even for experienced guides.

Professionals often rely on experience to help guide their decision making process. However experience based decisions are not always flawless. Studies have shown that novices and professionals make decisions using "heuristics" or mental shortcuts. These shortcuts allow for quick decisions during complex tasks and are based on limited information. Two heuristics that professionals are especially prone to are "social proof" and "familiarity". In this case the existing campsites and historical use of this area may fall into McCammon's "social proof" category. "The social proof heuristic is the tendency to believe that a behavior is correct to the extent that other people are engaged in it" (McCammon, 2002). One of the two guides had also been to the area many times and camped in a similar location on seven previous trips without incident. His decision may fall into the "familiarity" category. "The familiarity heuristic is the tendency to believe that our behavior is correct to the extent that we have done it before" (McCammon, 2002).

Complex terrain in the Alaska Range demands attention to detail every step of the way and timing will always be a part of it. Using all of our tools to avoid and reduce exposure will help to reduce the risk but cannot take away all of the risk. The decision to camp in this location worked for many people for many seasons but did not this time. Based on this tragic event, we can conclude that the hazard of camping in this location is greater than previously assumed and we cannot recommend it for future climbers.

6. CONCLUSION

The Alaska Range presents some avalanche problems that do not exist in non-glaciated and lower elevation mountains. Climbers need to tune their senses to the different problems and higher risks found in these areas. Terrain traps including crevasses and cliffs carry high consequences. Icefalls are unpredictable and poorly understood. Besides the obvious hazards associated with big avalanches, the Alaska Range is an inherently hostile environment. Surviving a traumatic avalanche is unlikely, and rescue is even less likely. Most climbers fly 45 minutes from the nearest town of Talkeetna to the glaciers of the Alaska Range to start their expeditions. The remote location makes rescue and recovery extremely difficult. Out of 45 climbers killed in avalanches only 17 were recovered. The remaining 28 bodies were lost in the accumulation zone of the glacier. Even in instances where the whereabouts are known, the benefits of recovery or a rescue attempt may be outweighed by the risk to rescue teams.

6.1 Future Research

Icefall alpha angles and avalanche frequency are poorly understood. The high alpine zone of DNP holds numerous hanging glaciers, in some cases above common climbing routes. The dished nature of glacial valleys creates a very steep transition from steep or vertical terrain to relatively flat ground below. In addition, the chunky and high density of icefall may behave differently than standard snow slab avalanches. Regression analysis of alpha angles on large avalanche events has not been done, but may shed some light on icefall behavior in the Alaska Range.

A detailed study including hazard mapping of the 14,200 ft. basin on the West Buttress of Denali (advanced basecamp) could help prevent a mass casualty avalanche in the future. The large slopes hanging above the traditional camp zones have created avalanches that dusted camp and left debris close to tents. The destructive potential of a 50 or 100 year event is poorly understood in a place where upwards of 200 climbers can be camping.

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