STORM STATISTICS AND HELI-SKI USE IN THE CHUGACH AND KENAI MOUNTAINS, ALASKA

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ABSTRACT: Heli-skiing operations face a unique challenge in avalanche hazard forecasting in that the areas in which they operate are very large and infrequently visited by other users. Meteorological data is an important factor for heli-skiing operations in assessing the avalanche risk in the area they plan to ski. It is common to keep track of meteorological variables that will affect the snowpack stability throughout the season, but long-term statistical analysis of these factors is rarely used. This paper aims to investigate the relationship between precipitation variables, or storm statistics, and heli-skiing use in different areas. Using snow water equivalent values from three SNOTEL sites, yearly storm statistics were calculated and correlated with frequency of use in different areas by Chugach Powder Guides in the Chugach and Kenai mountains in south-central Alaska. Although few statistically significant results were found, suggestions for refined future research are proposed. These techniques can be used by heli-skiing operations to assess their use of different areas based on seasonal storm statistics.

KEYWORDS: Helicopter skiing, Alaska, storm cycle, snow climate, historical snow records

1. INTRODUCTION

Forecasting for heli-skiing operations presents a unique challenge, in that the area in which they operate is typically much larger than a ski resort or forecast center. Heli-ski operations are also operating in areas that are not frequented by other users and the meteorological data they rely on is often remote sensors as opposed to manual observations. Also due to the limited number of users in the area used by heli-ski operations, there is a very limited set of avalanche observations, during periods when operations cease during no-fly periods.

Much effort over the years has gone into developing avalanche hazard forecast tools. Meteorological data is an important factor in these tools. Atwater (1954) proposed a list of 10 factors contributing to avalanche hazard, including snowfall depth, previous snow depth, precipitation rate, air temperature, and wind speed. Most avalanche forecast models have been developed for ski areas or highways and are thus concerned with avalanches occurring during or immediately after a storm (Jones & Jamieson, 2000). Heli-ski groups are often on slopes that have been loaded during a storm but have not been accessed by any users for several days or weeks. The avalanche hazard can thus be a concern not just during and immediately post storm, but also in the clear intervals between storms (Jones & Jamieson, 2000).

Jones and Jamieson (2000), Jamieson (1995), and Woodmency and Shick (1994) looked at forecast factors used in heli-ski operations. All note the large area for which is being forecasted and the relatively sparse meteorological and avalanche data. Jones and Jamieson (2000) and Jamieson (1995) compared data on the largest skier triggered avalanche for the day and several forecasting variables. The best variables predicting the size of skier-triggered avalanches on a given day were the size of skier-triggered avalanches in the previous day or two days. The next best predictors were the height of new snow in the previous 24 hours, the precipitation for the previous day, and the cumulative snowfall for the storm interval (defined as the amount of snow since the last day with less than .3mm of precipitation) (Jones & Jamieson, 2000).

There has been much research into the decision making process for mechanized ski guides as to where it is safe to ski. Many of these papers look at the human factors in that process (e.g. Stewart-Paterson, 2004). Descriptions of the process used by heli-skiing operations in developing an avalanche forecast for the day cite the use of meteorological data (e.g. Weigele, 2012 & Woodmency, 1994). However, there has been little research into the usefulness of statistical analysis of meteorological variables in the decision making

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process. This paper aims to investigate the relationship between storm statistics and heli-skiing use in different areas. Strong correlations will be examined with an eye towards the usefulness of statistical analysis as a decision making tool for a heli-skiing operation.

2. DATA COLLECTION

Snow water equivalent (SWE) data was used from the Alyeska, Turnagain, and Grandview SNOTEL stations. SWE values for water years 1999 through 2013 were used, coinciding with the operation years of Chugach Powder Guides. For yearly storm interval data, the period from December 1 to April 30 was used. Daily SWE values were obtained from the NRCS report generator. All SNOTEL data had been quality controlled by NRCS staff, however, SNOTEL stations are remote and do not receive daily maintenance and thus there are some minor gaps in the data sets where an instrument was not reading correctly.

Heli-ski use data was obtained from Chugach Powder Guides for the time period 1999-2013. Each season's data set included the number of "fly days" and "no fly days" and the number of times each run was skied per year. Runs are grouped into areas based on the SNOTEL site which best represents them (Fig. 1). Runs that fell into the overlap between the Turnagain area and Grandview area were included in the analysis of both areas. Storm statistics were calculated for each area using the corresponding SNOTEL site data.

3. METHODS

3.1 Storm Statistics

For each area data was divided into storm intervals using the criteria of any day with zero new SWE as the start of a new storm interval. The total SWE added during each storm interval was calculated by subtracting the minimum SWE value from the storm interval from the maximum value for that storm interval. Since SWE is recorded as a cumulative number for the water year, this accounted for any time, often in late spring, where a small amount of SWE would be lost, likely due to melting. Duration of each storm interval was defined as the number of days when there was measurable SWE added.

Storm statistics were calculated for each heli-ski season as well at the December through April winter period. The heli-ski season was defined as one day prior to the first fly day until the last fly day. The variables included seasonal SWE, the number of storm intervals, the number of storm intervals depositing more than 2.5 cm of SWE, the number of days with more than 2.5cm of SWE and the number of days with any new SWE. The statistics were calculated for each year at each of the three SNOTEL sites. See Table 1 for definitions of storm statistics and time intervals used.

Tbl. 1: Definitions of storm statistics.

Storm Statistic	*Definition*	*Time Period*
Storm Total SWE	Total amount of SWE added during a storm (cm)	1 December -30 April
Duration	Length of a storm interval (days)	1 December -30 April
Total SWE	Total accumulated SWE for the water year (cm)	1 October- Last fly day of heli-ski season
In Season SWE	Amount of SWE added during the heli-ski season (cm)	Heli- ski season
Storms	Number of storm intervals	Heli- ski season
Storms >2.5	Number of storm intervals with more than 2.5 cm of SWE added	Heli- ski season
Days>0	Number of days with any measurable SWE added	Heli- ski season
Days >2.5	Number of days with more than 2.5 cm of SWE added.	Heli- ski season
Snow Climate	Estimation using Mock & Birkeland (2000) decision tree	1 December- 31 March

3.2 Relationships Between Sites

Relationships between sites were measured with Student's t-tests for each variable between each possible pair of areas.

3.3 Correlations with Heli-Ski Use

Using the Shapiro-Wilk test, it was determined that all variables were normally distributed with the exception of the run data for the Turnagain area. This was due to the extremely high numbers of runs in this area during 2012 and 2013 seasons. To achieve normality these seasons were excluded from analysis. Relationships between variables were calculated with Pearson Product-Moment correlations.

Correlations were determined at the yearly level between each of the storm statistics and for an area and the percentage of runs skied in that area each year (Fig. 1). Using the percentage of runs skied in an area out of the total runs skied accounted for the total increase of number of runs skied each year, a result of a growing business, not changing weather.

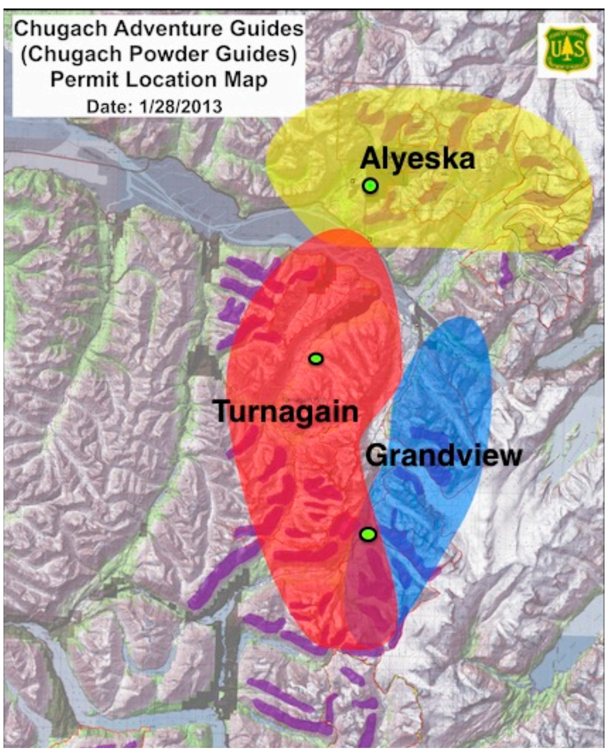

Fig. 1: Locations of the SNOTEL stations and areas used in correlations by area.

3.4 Snow Climate

The snow climate for each area was estimated using the decision tree developed by Mock and Birkeland (2000). This methods uses five parameters: (1) seasonal rain, (2) average air temperature, (3) December average temperature gradient, (4) snow water equivalent, and (5) snowfall. December temperature gradient was calculated using the daily average temperature and snow depth, assuming the ground-snow interface was 0˚C. SNOTEL data does not provide information on rainfall and thus the seasonal rain parameter could not be used. Also, snowfall data is only available from 2008 to the present so this parameter was only used in half of the calculations. This lack of data makes the use of the decision tree more of an estimation of snow climate.

4. RESULTS

4.1 Storm Statistics

Figures 2 and 3 represent quartile ranges for the total amount of SWE added in a storm interval (Figure 2) and the duration of a storm interval (Figure 3) at each of the three SNOTEL sites. There were calculated with data from all storm intervals from between 1 December and 30 April with more than 2.5cm of SWE added. A t-test showed that the average SWE added in a storm interval to be significantly different between Alyeska and Turnagain but not between any other pair of sites. The average duration of a storm interval in Alyeska was significantly less in Alyeska than Turnagain and Grandview, but no significant difference was observed between the latter two.

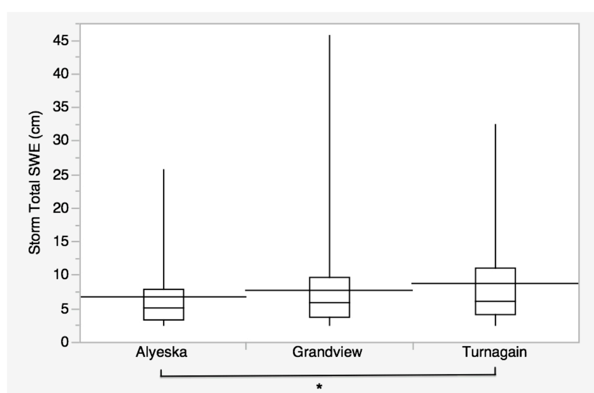

Fig. 2: Quartile box plots for storm total SWE for each site using storms with more than 2.5cm of SWE between 1 December and 30 April. Horizontal lines represent means. *p>.05 for Wilcoxon test between sites.

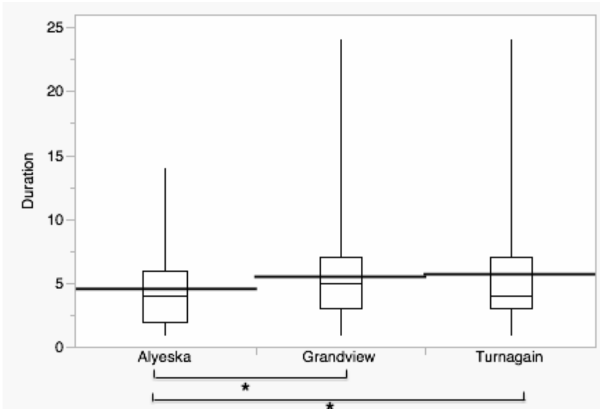

Fig. 3: Quartile box plots for storm duration at each site using storms with more than 2.5cm of SWE between 1 December and 30 April. Horizontal lines represent means. *p>.05 for Wilcoxon test between sites.

4.2 Relationships Between Sites

The difference between sites was determined for each of the storm statistics used. The only significant differences observed were between Alyeska and Turnagain in total SWE for the year and the number of days with any SWE accumulation. For both variables Turnagain was significantly higher than Alyeska. There were no significant differences observed between Grandview and either of the other sites, or between sites by any of the other variables. All means and p-values are presented in Table 2.

4.3 Correlations With Heli-ski Use

The relationship between each storm statistic and the proportion of runs in each year that was skied in each area was examined looking for weather variables that could indicate a greater or lesser likelihood of skiing in that area. Most correlations were weakly negative, except in the Alyeska area where most were weakly positive. The only two relationships that achieved significance were the number of storms adding more than 2.5cm of new SWE in the Alyeska area and the number of days with any new SWE added in the Turnagain area. Both of those correlations were positive. Pearson Product-Moment correlations and their level of significance for each storm statistic by area are shown in tables 3, 4, and 5 for Alyeska, Grandview, and Turnagain respectively.

Tbl. 3: Correlations with runs in the Alyeska area. *p<.05

Variable	*Correlation*	*p*
Total SWE	0.2775	0.3368
In Season SWE	0.4607	0.0973
Storms	-0.1069	0.7161
Storms>2.5	0.6004*	0.0232
Days>0	0.4683	0.0913
Days>2.5	0.5193	0.057

Tbl. 2: Means and p-values for storm statistics between areas. *p<.05

Site 1 / Site 2	*Turnagain*	*Alyeska*	*p-value*	*Turnagain*	*Grandview*	*p-value*	*Grandview*	*Alyeska*	*p-value*
Total SWE	*114.60*		*0.04**	*114.60*		*0.12*	*98.32*		*0.60*
		92.86			*98.32*			*92.86*	
In Season SWE	*39.73*		*0.40*	*39.73*		*0.56*	*41.48*		*0.78*
		36.04			*41.48*			*36.04*	
Storms	*11.06*		*0.65*	*11.06*		*0.75*	*10.73*		*0.90*
		11.2			*10.73*			*11.2*	
Storms >=1	*4.4*		*0.24*	*4.4*		*0.43*	*4.66*		*0.69*
		5.2			*4.66*			*5.2*	
Days>0	*41.2*		*0.02**	*41.2*		*0.20*	*36.8*		*0.30*
		33.26			*36.8*			*33.26*	
Days >=1	*5.4*		*0.40*	*5.4*		*0.60*	*4.33*		*0.75*
		4.733			*4.33*			*4.73*	

Tbl. 4 Correlations with runs in the Turnagain area. *p<.05

Variable	*Correlation*	*p*
Total SWE	-0.1654	0.5719
In Season SWE	-0.178	0.5427
Storms	-0.2088	0.4737
Storms>2.5	-0.0784	0.79
Days>0	0.5821*	0.029
Days>2.5	-0.1961	0.5017

Tbl. 5 Correlations with runs in the Grandview area. *p<.05

Variable	*Correlation*	*p*
Total SWE	-0.0778	0.7915
In Season SWE	-0.313	0.2759
Storms	0.1004	0.7327
Storms>2.5	-0.2328	0.4231
Days>0	-0.3061	0.2872
Days>2.5	-0.3017	0.2945

4.4 Snow Climate

According to Wagner (2012) the snow climate of Turnagain Pass varies from year to year and spans all three of the commonly described snow climates: coastal, intermountain, and continental, and also that the snow climate can differ from that of nearby areas in the same year. All three areas exhibited characteristics of each of the three snow climates across the time period examined. Most years the snow climate was different between sites.

For each site the correlation between yearly snow climate and the percentage of total runs skied in that area was calculated but no significant correlations were found. The yearly snow climate and run percentage for each area can be seen in Table 6.

5. DISCUSSION

While few statistically significant results were found from this research, there is still interesting and valuable information to be had. All statistics examined in this work were at the yearly level. Since at this level, there was little difference between areas, it is not surprising that there were relatively weak correlations between storm statistics and run usage.

Most of the significant differences between sites set Alyeska away from the other two. Alyeska was significantly lower than both Turnagain and Grandview in storm duration and significantly less

Tbl. 6 Estimated snow climates and percentage of total runs by year and area.

	Turnagain		*Alyeska*		*Grandview*		
Year	*Snow Climate*	*Run Percent*	*Snow Climate*	*Run Percent*	*Snow Climate*	*Run Percent*	*Total Runs*
2013	Continental	38%	Continental	39%	Continental	22%	2513
2012	Coastal	39%	Intermountain	49%	Continental	12%	2006
2011	Intermountain	23%	Intermountain	42%	Continental	34%	1564
2010	Coastal	26%	Coastal	68%	Coastal	5%	1065
2009	Continental	14%	Intermountain	66%	Continental	20%	1372
2007	Continental	11%	Intermountain	40%	Continental	49%	1920
2006	Intermountain	9%	Intermountain	52%	Coastal	39%	1169
2005	Intermountain	29%	Coastal	47%	Intermountain	24%	1044
2004	Coastal	15%	Intermountain	64%	Intermountain	20%	669
2003	Continental	26%	Coastal	56%	Intermountain	18%	852
2002	Coastal	25%	Intermountain	34%	Coastal	41%	1374
2001	Coastal	13%	Coastal	57%	Coastal	30%	1297
2000	Coastal	21%	Coastal	48%	Coastal	31%	1170
1999	Continental	9%	Intermountain	41%	Coastal	49%	649

than Turnagain in average Storm Total SWE. Alyeska significantly less total yearly SWE and days with any measurable SWE than Turnagain did. From these numbers one would hypothesize that Alyeska was in general “less snowy” than other areas.

However, looking more closely at the storm statistics we notice that Alyeska did have the lowest average number of days with any snow, but also the highest number of storms and storms with more than 2.5cm of SWE. While only the difference in average number of days with any snow was significant, this could show that Alyeska tends to have larger storms with more clear days in between. Since one of the main factors that will keep a heli-skiing operation on the ground is current snowfall, the amount of clear days could be an important distinction.

Analysis in this paper compares run usage only with meteorological variables when in reality there are other factors that go into the decision about where to ski. The Chugach Powder Guides hangar as well as the guest lodging are in the Alyeska area and would thus be logistically easier ski there whenever possible. For the Alyeska area, the only correlation with moderate strength was a positive correlation with the number of storms adding more than 2.5cm of SWE. There was also a moderate positive correlation between days with any SWE added and runs skied in the Turnagain area.

It is worth noting that in the early stages of this research correlations were calculated using the number of runs in an area per year as opposed to the percentage of the total runs for the year skied in that area. Using these numbers the correlations were quite different. The authors determined that the percentage was a more accurate number since each year the total number of runs skied increased, which was far more likely due to a growing business than any weather variables.

Lastly, most of the correlations between run usage and storm statistics in each area are negative. This is expected since if it is snowing, heli-ski operations are likely on the ground. Although this paper did not yield many significant or profound results, the techniques could be refined to be more useful and hopefully reveal important patterns.

6. FURTHER RESEARCH

There are many options for storm statistics that could be correlated with run usage. The storm statistics used in this paper were based on accepted standards for significant snowfall (2.5 cm of SWE) and the author’s estimation of variables affecting run usage.

In any year and in any area there are going to be days that are skiable and days that are not. This determination is largely affected by the preceding days weather and snowfall. This paper looked at run usage and storm statistics only at a yearly level which doesn’t allow for examination of daily or weekly storm statistics and how they affect run usage and even whether or not a day is a fly day or a no-fly day. Over the course of the year there will be fly days and no-fly days in all areas, but they may not coincide across areas. The scope of this paper does not account for this and further research should delve into a shorter time scale and examine these differences.

7. CONCLUSIONS

The most meaningful results uncovered in this work are the differences between areas. Alyeska seems to be significantly different from the other two sites based on storm statistics. While few significant correlations between these storm statistics and heli-skiing usage were found, with some refining of methods, the authors believe that storm statistics could be used effectively as part of the decision making process in a heli-skiing operation. As previously stated, these results are only looking at correlations at the yearly level. Since conditions can vary greatly over the course of one season, strong correlations that may exist at the storm interval level are likely muted over the course of the whole season.

Additionally, there are more factors than weather that are influencing where a heli-ski operation choses to ski on any given day or how many runs are skied over the course of a season, such as client preference. Refining of the statistical methods used in correlating heli-ski usage and storm statistics to account for these differences would likely yield more significant and also, more useful results. While many factors play in to the decision making process of a heli-ski operation, a solid statistical tool based on previous use data could be a valuable addition to the process.

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