Synoptic Scale Storm Tracks With Specific Density Trends, Leading to Natural Avalanches on HW 210, Little Cottonwood Canyon, Utah

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Abstract: A review of historical avalanche and meteorological data for Little Cottonwood Canyon, Utah allowed a relationship to be found between synoptic scale storm tracks, density trends, and natural avalanching on Utah State Road 210 (SR). It is thought that specific synoptic scale storm tracks produce specific density trends within the new snow during a storm. These density trends have importance to the avalanche forecaster when evaluating the likelihood of instabilities within the new snow. In order to find relationships of events, density trends were divided into three cases. Case 1- Decreasing density trends throughout the storm (>2% decrease in density during storm). Case 2- Similar density throughout storm (No greater than 2% fluctuation in density). Case 3- Increasing density throughout the storm (>2% increase in density during storm). 500 mb geopotential height analysis were constructed and grouped for each of the above cases. Similarities between these groupings were found, and average 500 mb geopotential height analysis for each of the cases were constructed. The results of these findings will be identified in the following paper.

Keywords: Natural avalanches, density trends, synoptic scale storm tracks, historical weather data, historical avalanche data.

1. Introduction

Utah State Road 210 (SR) provides the sole access to the town of Alta, Alta and Snowbird ski resorts, and the surrounding public land in the Wasatch-Cache National Forest. This highway is renowned to have one of the highest avalanche hazards in North America. Presently, the Utah Department of Transportation Highway Avalanche Safety Program is responsible to mitigate this hazard and provide safe public access on SR 210.

Little Cottonwood Canyon is oriented in a west to east direction, with the town of Alta at its terminus at the eastern end. When one reaches Alta by vehicle, they have traveled under 36 avalanche paths (many have secondary starting zones named separately) that have historically reached the highway (Lev 1986). Natural avalanches have accounted for numerous “close calls” and one fatality of a state road worker in march of 1950. All slide paths (with the exceptions of Coalpit and the Blackjack area) are on the north side of the highway with starting zone aspects ranging from southeast to southwest. Vertical fall distances vary from 1000' to 4000'.

The avalanche paths vary from being steep, narrow, and rocky from low in the canyon to Snowbird, to open snowfields above the town of Alta. The Highway Avalanche Safety Program uses a variety methods to control the avalanche hazard above the highway. These include: military weapons, avalaunchers, helicopter control, and a hand charge route. The primary method of mitigating the avalanche hazard above the highway is with the use the military weapons.

Artillery has proven to be the only practical method that can be used under all conditions to mitigate this hazard. Currently, three military weapons are used. These include: One 105 mm recoilless rifle stationed at Alta (Peruvian Ridge Gun), One 106 mm recoilless rifle stationed at Snowbird (Willows Gun), and One 105 mm howitzer stationed at Snowbird (Valley Gun). These weapons can allow the whole canyon to be shot during road closures in a relatively short amount of time, minimizing the time road closures are in effect.

Yearly averages of snowfall and water at the Alta Guard Station yield 505"/47.11" respectively. The predominant storm track comes from the Northwest with higher pre-frontal snow densities at the onset of the storm, to lower snow densities associated with the post-frontal environment. Though decreasing density trends during snowfall events are the majority, it is not uncommon to have storms with either sustained densities, or increasing densities throughout the event. It is for this reason there is an interest in how these varying trends affect avalanche formation in the canyon.

2. Data Formulation

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Avalanche databases in Little Cottonwood Canyon allow for the use of over 50 years of accurate data relating to avalanches crossing SR 210. Of these 50 years of data, 30 years have had canyon-wide, active control work with the use of military weapons. Due to this, both natural and explosives induced avalanches are on record.

For this study on how storm tracks with specific density trends affect avalanche formation in Little Cottonwood Canyon, questions arose on what the use of military artillery had on the frequency of avalanches crossing HW 210. It is impossible to determine whether or not a controlled avalanche would have occurred naturally. Therefor, the frequency of avalanches prior to and since the introduction of the use of military weapons is probably different.

For these reasons, and for the purposes of this study, only natural avalanche events occurring between the winter of 1972-73 and the present date will be used.

3. Data Acquisition

It was necessary to acquire both natural avalanche data (post 1972-73) and meteorological data to find similarities between density trends, storm tracks, and natural avalanches.

Natural avalanche events reaching SR 210 were acquired by combining the UDOT data base, the Alta Center For Snow Science's database, and the Snowbird Snow Safety's database. This ensured that all natural avalanche events were accounted for. Natural avalanche events post 1972-73 were filtered, sorted, and grouped by chronological date.

Meteorological data needed would be both in the form of sampled snow and water data (to find density trends of storms that produced natural avalanches), and synoptic scale meteorological data (to find patterns between individual storms). Snow and water measurements have been taken daily at four sites during the time period applicable to this study. These sites include; the Snowbird snow safety study plot (8,000'), the Alta snow safety study plot (8,600'), and the UDOT Atwater and Guard Station study plots (8,740'/8,680'). Due to little vertical variation between the Alta site and the UDOT sites, only the Snowbird and UDOT sites were used to find density trends. Synoptic scale meteorological data was acquired by creating analyses using the Climate Diagnostic Center's website(www.cdc.noaa.gov). It was decided that the best method for finding synoptic scale storm patterns would be to use atmospheric height analysis, and that an average atmospheric height should be chosen. Therefor, 500 mb geopotential height analyses were constructed for the dates of each natural avalanche event. Analyses with height levels > 500 mb could run the risk of being less accurate due to the complex terrain found in the intermountain west, and height levels < 500 mb could detract from smaller short waves and smooth some amplification of the waves out. These reasons would make the analysis harder to decipher and group.

In all, 227 natural avalanche events reaching the highway occurred in Little Cottonwood Canyon from December 1973 - March 2002. These events were spread over 90 separate days (12 of these occurred during the same storm and hours after one from the previous day, therefor these were not considered a separate avalanche day, giving 78). For each of the 78 avalanche days, densities from the onset of the storm causing the natural avalanche to the event itself were found, and 500 mb geopotential height analysis were constructed.

4. Methods

In order to find patterns between density trends and storm tracks for 78 avalanche days, a method to differentiate a decreasing density trend, a constant density trend, and an increasing density trend was needed.

Decreasing density trend storms and increasing density trend storms would be easy to interpret once a trend for the constant density storm was found. It was thought that a 2% or less fluctuation in density could account for any errors in measurement, wind affects, and small subtleties within a storm. Therefor, any storm that had a 2% or less fluctuation in density leading up to a natural avalanche would be considered a constant density storm. Any storm with a fluctuation greater than 2% in the positive direction would be considered an increasing density storm and any storm with a fluctuation greater than 2% in the negative direction would be considered a decreasing density storm.

Avalanche dates were then grouped by density trend and compared to the 500 mb geopotential height analysis for the same natural avalanche event.

5. RESULTS

5.1 Decreasing Density Trend Storm Track

Evident from figures 1and 1.1-1.2 (Appendix1), is the development of a deep trough over Utah. This trough develops over the great basin and dives through Utah from the northwest. This is the predominant storm track for midwinter storms in Little Cottonwood Canyon.

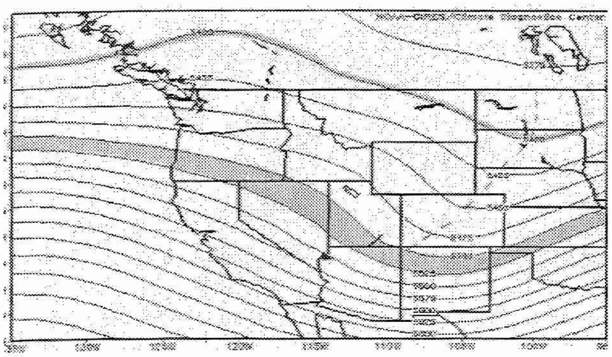

Figure 1: Average 500 mb geopotential height analysis for decreasing density trend storms. Dates include 12/22/81, 3/30/82, 1/31/83, 1/15/91, 1/11/97, 2/26/98, 11/26/01.

Though this is the predominant storm track for winter storms in Little Cottonwood Canyon, only 7 avalanche days accounted for 17 total natural avalanches from storms with a decreasing density trend throughout. This number, though low (7.5% of the total number of natural avalanches), is consistent with prior publications on this trend being a more stable solution (Mueller, 2000).

The 500 mb trough axis (see dotted line in figure 1) has passed through Utah at the time of the natural avalanches, and is consistent with a well developed low pressure system. One could interpret that a strong cold front, with sufficient moisture both with the cold front, and in the post frontal environment occurs. Winds predominantly from the northwest enhance precipitation with orographic lift, and heavy snowfall can persist.

This synoptic pattern is very similar to Sharp Trough Big (STBs) storm tracks, derived from a study of big vs. super snow storms for Salt Lake City, UT by the Salt Lake City National Weather Service Forecast Office (Hogan et al 1994).

Figure 2 shows a 500 mb analysis of 11 STBs carried out by the Weather Service in their study. Both figures 1 and 2 have sharp troughs, well-defined trough axis, on shore flow at the US Canadian border, and rapid progression.

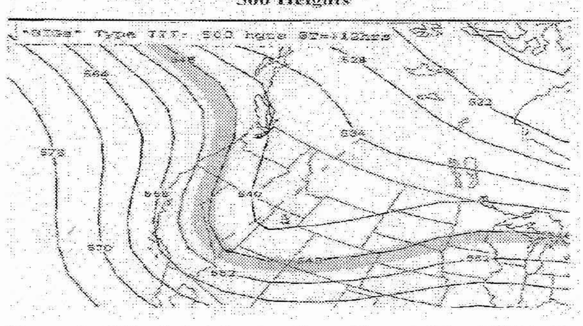

Figure 2: 500 mb heights for Sharp Trough Bigs (STBs), 12 hours after snowfall began in Salt Lake City. Analysis generated by Salt Lake City WSFO. (Hogan et all 1994)

It is important to note that figure 2 is valid for 12 hours after the onset of snow in Salt Lake City and figure 1 is valid for the time the natural avalanches occurred (all cases are >12 hours from onset of snowfall). This could explain the variance in trough axis location between figures 1 and 2.

5.2 Constant Density Storm Track

Constant density trend storms accounted for 26 avalanche days in which 111 natural avalanches occurred. This pattern has accounted for the greatest percentage (49%) of natural avalanche activity in Little Cottonwood Canyon.

Two synoptic scale patterns were found upon reviewing the 500 mb height analyses. The first pattern, 5.2.1, occurs predominantly both early in the winter, and late in the winter. The second pattern, 5.2.2, occurs predominantly during the mid winter months. Both of these cases show initial development and progression from the Gulf of Alaska.

5.2.1 Early and Late Winter, Constant Density Trend

The main feature of the 500 mb geopotential heights (figures 3 and 3.1-3.2 in Appendix 1) is the development of a closed low over the Great Salt Lake at the 500 mb level. It appears that this scenario occurs during the transition periods associated with both early winter and late winter. This closed low pattern has an early average of December 8, and a late average of March 25 (both were found by averaging the date of occurrence).

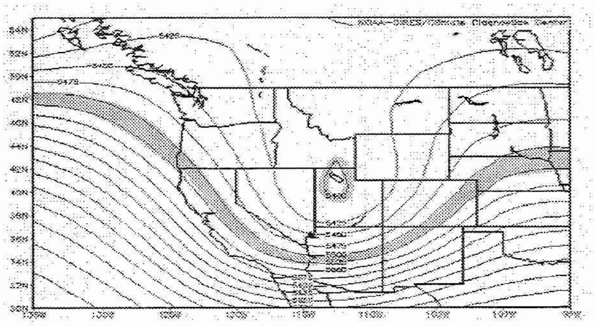

Figure 3: 500 mb geopotential heights for early and late winter, constant density storms. Dates include 4/10/74, 12/13/74, 3/23/75, 12/1/82, 3/25/83, 4/3/83, 2/17/84, 4/1/84, 4/20/84, 3/3/85, 12/26/88, 11/23/92

500 mb geopotential heights over the Great Salt Lake have an average fall of 1550m in a 48 hour period. This creates a very deep, intense low pressure creating strong synoptic scale dynamics.

This synoptic pattern is almost identical to that of Closed Low Supers (CLSs), derived from the same study of big vs. super snow storms for Salt Lake City, UT by the WSFO in Salt Lake City. Figure 4 is an average 500 mb height analysis for CLSs storms.

Figure 4 shows the direct relationship spring CLSs (defined from march-may) have with constant density trend storms that occurred either early or late in the winter, and lead to natural avalanches reaching SR 210. All three cases, spring CLSs, early winter constant density storms producing natural avalanches reaching SR 210, and late winter constant density storms producing natural avalanches reaching SR 210, have the same 500 mb height pattern.

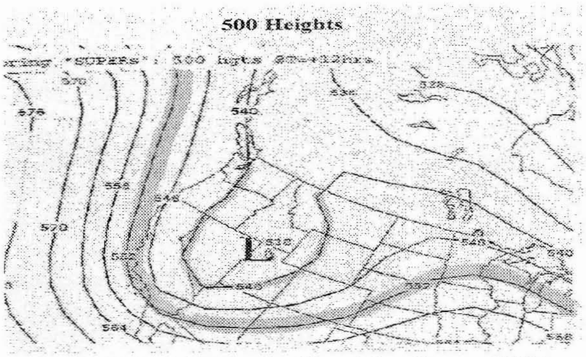

Figure 4: 500 mb heights for Closed Low Supers (CLSs), 12 hours after snowfall began in Salt Lake City. Analysis generated by Salt Lake City WSFO. (Hogan et all 1994)

5.2.2: Mid Winter, Constant Density Trend

As evident from figures 5 and 5.1-5.2 in Appendix 1, mid winter constant density storms that caused natural avalanches to reach SR 210 have a much different 500 mb height pattern than the preceding early/late winter pattern.

Rather than having a closed low over the Great Salt Lake, the mid winter case has a broad trough over the west, making it difficult to differentiate from the 500 mb analysis of decreasing density storms in section 5.1 (Figure 1). The main differences between figure 5 and figure 1 are the slight difference in wavelength of the troughs (differentiates between broad and sharp), and the difference in the upstream flow pattern.

Figure 5 shows a similar synoptic scale pattern as one a Broad Trough Super (BTSs) storm exhibits (Figure 6). The term Broad Trough Super also comes from the same study of big vs. super snow storms for Salt Lake City, UT by the WSFO in Salt Lake City.

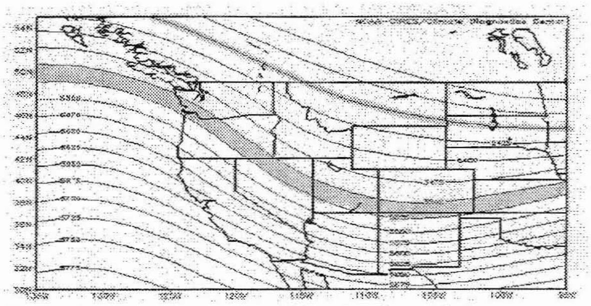

Figure 5: 500 mb geopotential heights for midwinter, constant density storms. Dates used were 2/1/82, 1/23/73, 2/11/83, 3/9/83, 2/4/85, 1/27/95, 3/13/02, 1/17/95, 2/19/83, 2/5/74, 1/22/82, 2/3/85, 2/3/82, 1/6/94, 1/17/96.

Figure 6 is a 500 mb height analysis from the WSFO's study. The similarities figures 5 and 6 include; wavelength, upstream flow, trough depth, and downstream flow. The location of the trough axis, however, differs between the two analyses. This discrepancy can be explained by the time lag between the two figures. Figure 6 is valid for 12 hours after the onset of snow in Salt Lake City and figure 5 is valid for the time the natural avalanches occurred (all cases are >12 hours from onset of snowfall).

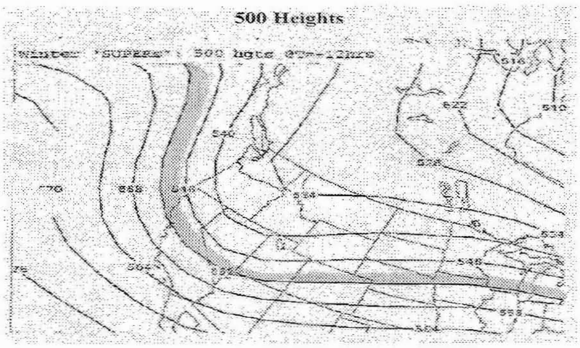

Figure 6: 500 mb heights for Broad Trough Supers (BTSs), 12 hours after snowfall began in Salt Lake City. Analysis generated by Salt Lake City WSFO. (Hogan et all 1994)

5.3 Increasing Density Storm Track

Increasing density trend storms accounted for 44 % of the natural avalanches reaching SR 210. Although increasing density storms account for fewer avalanches reaching the highway than constant density trend storms, they account for the greatest number of days natural avalanches reached the highway (56%).

In the previous 500 mb analyses, the general storm track was one that originated from off the northwest coast. Increasing density trend storm tracks, on the other hand, each have a much stronger zonal component in the upstream flow. Strong zonal, moist onshore flow from the Pacific ocean typically is associated with hard-to-forecast, very progressive short waves for the intermountain west. These progressive shortwaves typically follow one another very closely both spatially, and temporally . A storm can be comprised of separate short waves progressing through an area, giving fluctuating atmospheric conditions throughout the storm. These fluctuations of atmospheric conditions seem to be responsible for the increasing density trend events that occur in Little Cottonwood Canyon.

In all, 44 avalanche days were found, analyzed and grouped into 4 differing cases. Three of the cases were similar in that 500 mb heights varied little over the days preceding natural avalanching. The other case, however, has a small variation in 500 mb heights, and is discussed separately.

5.3.1 Increasing Density Trend, Sustained 500 dm Levels

Figures 7 and 7.1-7.2 in Appendix 1, show little change in the overall 500 mb geopotential height pattern over a three day period. One variation that could be of importance, though, is the subtle increase of 500 mb heights over Utah. This could be indicative of a slight warming trend of the airmass below 500 mb. This slight height rise (and possible warming trend) over Utah could have contributed to the increasing density trend indicative of each of these storms.

The 5000 m height level remains around the Great Salt Lake throughout, a possible indicator height level for identifying such events.

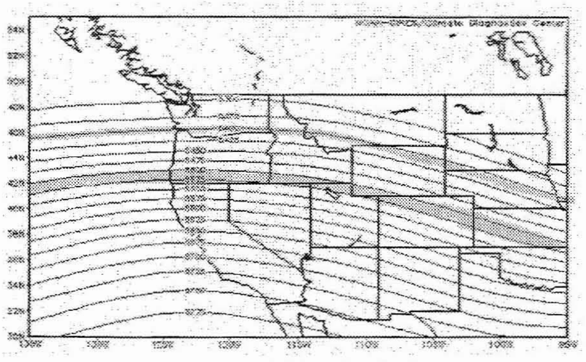

Figure 7: 500 mb geopotential heights for increasing density storms with sustained heights. Dates include 12/7/83, 12/24/83, 12/27/73, 12/29/73, 12/27/81, 1/12/80, 1/15/98, 2/7/83, 2/13/86

Figures 8 and 8.1-8.2 in Appendix 1, also show little variance in 500 mb geopotential height in a three day period over the Great Salt Lake. Strong onshore flow is once again evident along the west coast.

As with the first case, 5000 m heights are oriented over the Great Salt Lake throughout, a possible indicator for this case also.

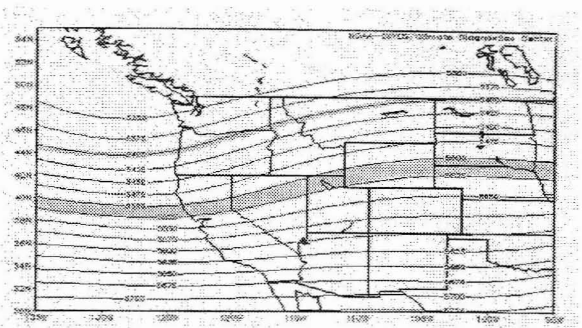

Figure 8: A second 500 mb geopotential height analysis for increasing density trend storms with sustained heights. Dates include 2/21/80, 2/22/80, 12/23/82, 1/28/83, 12/26/83, 3/5/83, 11/25/85, 2/8/85, 2/15/86, 2/15/87, 12/22/87, 3/4/95, 2/22/96.

Figure 9 and 9.1-9.2 in Appendix 1, once again show little change in 500 mb geopotential height over the three day period. The onshore flow however, is evident more in the northwest coast, rather than along the majority of the west coast as with the previous increasing density storm cases. This puts Utah under a more northwesterly onshore flow at 500 mb.

The 5000 m height level can once again be used as a possible indicator level. In this case it bisects the state of Wyoming from NW to SE.

5.3.2 Increasing Density Trend, Sagging Long Wave Trough

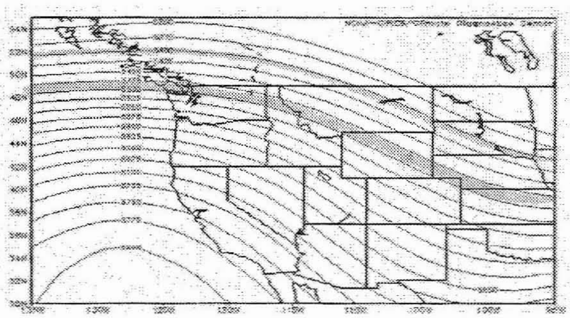

Figure 9: A third 500 mb geopotential height analysis for decreasing density trend storms with sustained heights. Dates include 2/6/79, 1/11/79, 2/7/79, 12/13/83, 1/25/84, 12/20/74, 2/11/95, 1/10/88, 1/25/75, 1/24/74, 1/12/78, 3/6/96, 2/10/88.

Figures 10 and 10.1-10.2 in Appendix 1, represent the fourth increasing density trend storm track found. This case varies from every other increasing density case in that the 500 mb geopotential heights decrease over Utah during the period preceding natural avalanche formation. The decrease is due to the slow settlement of a long wave trough over the intermountain west. The overall pattern, however, still shows onshore flow along the west coast. This helps stand to reason that a strong component of onshore flow is the main contributor to increasing density trends in Little Cottonwood Canyon.

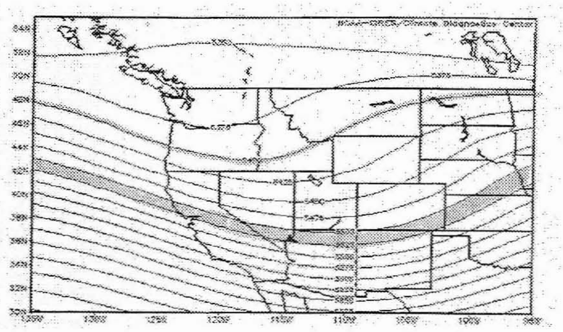

Figure 10: 500 mb geopotential height analysis for midwinter increasing density trend storms. Dates include 3/26/83, 4/9/95, 4/2/74, 3/25/83, 2/25/00, 1/9/93, 12/4/83, 2/25/93, 1/10/80

6. Discussion

When one is at a card table, holding five cards, it would be nice to know what card game is being played before placing a bet. This holds true for avalanche forecasting also. When the possibility of a large storm exists it would be nice to know what density trend will occur within the new snow. Density trends are important to the avalanche forecaster when evaluating the likelihood of instabilities within the new snow.

The percentages of natural avalanches over the last 30 years in Little Cottonwood Canyon for each density trend were briefly discussed in section 5. It has been found that constant density trend storm tracks have caused the greatest number of natural avalanches crossing the highway, increasing density storm tracks have caused the most natural avalanche days, and decreasing density storm tracks (the majority LCC) have lead to very few incidents of natural avalanches reaching SR 210.

It has also been found that specific storm tracks (with their associated density trends) tend to alter both size and location of the natural avalanches within the canyon. Figure 11 shows a breakdown of natural avalanche class size and occurrence, versus new snow density trend.

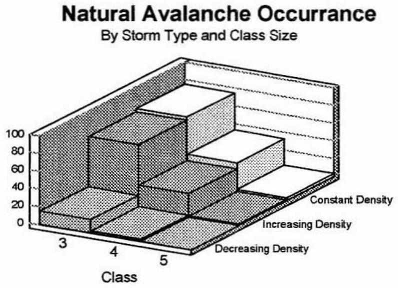

Figure 11: Natural avalanche occurrence by storm type and class size.

It can be seen that the majority of natural avalanches are during either a constant density trend storm or increasing density storm, and of class 3 of 4. There have been very few cases of any class 5 natural avalanches (4 events), or of decreasing density trends producing natural avalanches on the highway (17 events).

When natural avalanches occur it was also found that the average location varied with storm type. To aid with avalanche forecasting, Little Cottonwood Canyon has been separated into five areas. These are (From west to east): Mid canyon slide paths, Snowbird area slide paths, Blackjack slide paths, Hellgate / Superior slidepaths, and the town of Alta slide paths. Figure 12 shows a breakdown of natural avalanches and their location within the canyon.

In this figure, the four areas; Mid Canyon (MC) and Hellgate / Superior (HS) (combined due to similar reactions to new snow loading), Snowbird paths (SB), Blackjack paths (Bypass), and paths above the town of Alta (Alta), show drastic differences . Clearly, most of the natural avalanches that have reached the highway have occurred either in the mid canyon or Hellgate / superior areas. This was expected because these areas are, more often than not, the most active.

When one moves up canyon, from the mid canyon slide paths, to the snowbird slide paths, and onto the town of Alta slide paths, average slope angle profiles decrease, and the terrain associated with them change from rock lined chutes to open snowfields. Figure 12 shows the affect this has on natural avalanches reaching the Highway. Both decreasing and constant density trend natural avalanche occurrences decrease as one moves up canyon. Increasing density trend natural avalanches decrease initially and then remain relatively constant above Alta and Snowbird. Therefor, it could be stated that as density trends increase from a decreasing trend to an increasing trend, the likelihood avalanches becomes more uniform throughout the canyon.

7. Conclusion

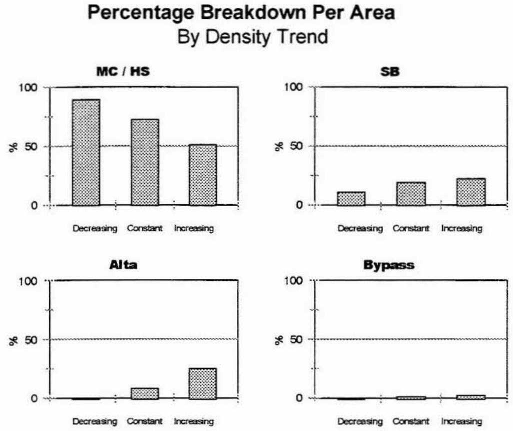

Figure 12: A percentage breakdown of natural avalanching by location

Seven storm tracks have been identified to produce specific density trends within the new snow in Little Cottonwood Canyon, UT. One decreasing density trend storm track, two constant density trend storm tracks, and four increasing density trend storm tracks were discussed.

It was found that both decreasing and constant density trend storm tracks that lead to natural avalanching on SR 210 originated in the northwest. The trough (broad, sharp, or closed low) would then push / settle over Utah for the event.

It was also found that increasing density trend storm tracks that lead to natural avalanching on SR 210 however, had a strong onshore or zonal flow pattern in which short waves rippled through Utah at a fast pace and high frequency, typically from the west.

In some cases, relationships were found between storm tracks causing natural avalanches to reach SR 210 and a National Weather Service Study on big versus super snowstorms for Salt Lake City.

These storm tracks, with their associated density trends, have been found to produce varying results of natural avalanche activity both in class size and location within the canyon. In general, as density trends increase from a decreasing trend to an increasing trend, the likelihood of natural avalanches reaching SR 210 becomes more uniform throughout the canyon. On the flip side, as density trends decrease from an increasing density trend to a decreasing density trend, the likelihood of natural avalanches reaching SR 210 becomes confined to the mid canyon and Hellgate / Superior areas.

Of special note, this study does not factor in the preexisting snowpack for these cases, nor did it attempt to decipher the precise meteorological conditions that were occurring at the time of the natural avalanche (ie, precipitation rate, snowfall rate, wind speed, wind direction, etc). For a complete and more precise study, both the snowpack and the atmosphere would have to be studied more thoroughly.

8. Appendix 1

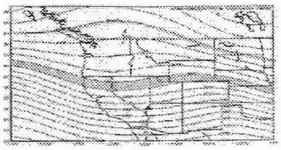
Figure 1.1: One day prior to Avalanche

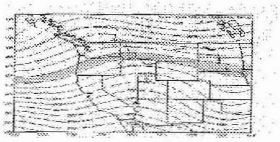
Figure 1.2: Two days prior to Avalanche

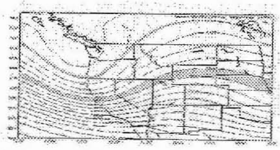
Figure 3.1: One day prior to avalanche

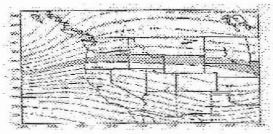
Figure 3.2: Two days prior to avalanche

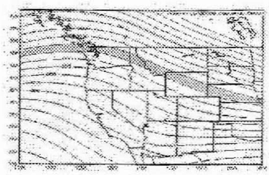
Figure 5.1: One day prior to avalanche

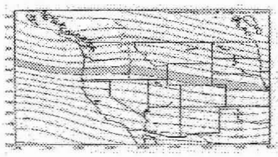
Figure 5.2: Two days prior to avalanche

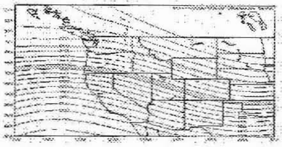
Figure 7.1: One day prior to avalanche

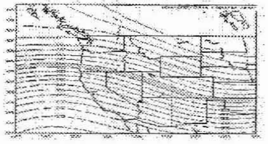
Figure 7.2: Two days prior to avalanche

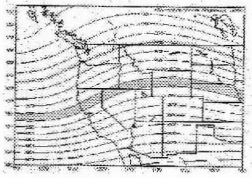
Figure 8.1: One day prior to avalanche

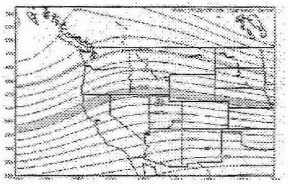
Figure 8.2: Two days prior to avalanche

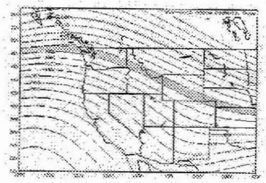
Figure 9.1: One day prior to avalanche

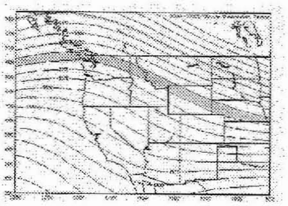
Figure 9.2: Two day prior to avalanche

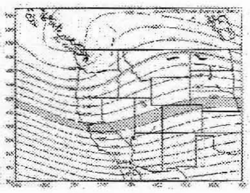
Figure 10.1: One day prior to avalanche

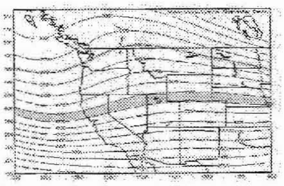
Figure 10.2: Two days prior to avalanche

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