PERIODIC PATTERNS IN SNOW STABILITY

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Introduction

The art and science of snow avalanche prediction is built around saving lives. This study is based upon 181 avalanches which occurred during a 23-year period in which 157 people died and brings out the fact that most of these fatalities occurred at periodic and predictable times. Therefore, the assumption can be made that future avalanches are likely to occur at periodic and predictable times. This is borne out in recent avalanche accidents. With the tables described, and risk periods given, similar efficacy in avalanche forecasting can be obtained.

No claim is made as to the cause of the correlation of the data given. Many interesting and plausible ideas have come from people who are familiar with this data. It is the belief of the authors that these concepts will remain unproven for many years to come. However, the fact that the exact causality of these events is unknown does not refute their existence. This paper describes what happens, not why. We have put these remarks in because the unknown nature of the causality of events has been very disturbing to many readers, especially those in the scientific community.

Background

At Alta, Utah, in 1971, the problem of avalanches which ran after the end of a storm, sometimes days later in clear weather, was of particular concern to Snow Rangers B. Sandahl, J. Head, and P. Lev. Discovery of seemingly periodic avalanches of this type lead to correlation with tide tables. Trial and error methods eventually led in the late 1970's to a workable avalanche forecast methodology which incorporated this data--by P. Lev at Blue River, B.C., helicopter skiing with the support of O. Wieringa and B. Sandahl at Alta.
This paper is the result of a statistical study of post-precipitation avalanches which supports and enhances the experience-based findings at Blue River and Alta.

Selection of Avalanches

The avalanches sampled for this study met the following criteria:

1. There was no precipitation occurring at the time of the avalanche. This is to eliminate the primary contributory factor in avalanche release, which is generally accepted to be direct precipitation overload, and to focus on the avalanche which falls after the cessation of precipitation.

2. The selection of only dry snow slab avalanches maintained the consistency of the essential character of the avalanche data. It is assumed that loose snow avalanches and wet snow avalanches exhibit characteristics significantly different from dry snow slabs. They are, therefore, excluded from the data.

3. Only avalanches which run a track distance of 50 metres or longer are included in the data. Avalanches which run less than 50 metres are not included in order to eliminate probable small-scale micro-climate effects.

4. Only avalanches which release naturally or are triggered by unsuspecting skiers, climbers, and others are included in the data. The event of a skier going skiing is considered to be random in relation to the sample space. This is because the event of a skier arriving at any given terrain can happen at any time within the sample space with equal probability.

The 181 avalanches in this study occurred over a span of 23 years (1958 to present) and on three continents (North America, Europe, and Asia). Of the 181 avalanches, 48 were natural releases. The remaining avalanches were triggered by the victims themselves which resulted in 157 deaths and 145 injuries.

The following is an example of the data compilation.
<table>
<thead>
<tr>
<th>Event #</th>
<th>Reference</th>
<th>Location</th>
<th>Weather</th>
<th>Avalanche Class.</th>
</tr>
</thead>
<tbody>
<tr>
<td>179</td>
<td>Wieringa</td>
<td>Days Fork Alta, UT</td>
<td>Clear, 2 days after snow</td>
<td>SS-AS-3</td>
</tr>
</tbody>
</table>

**Additional Data**

<table>
<thead>
<tr>
<th>Date</th>
<th>Killed</th>
<th>Buried/Injured</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/8/81</td>
<td>2 dogs</td>
<td>2 persons</td>
</tr>
</tbody>
</table>

**Solunar Tables**

The readily available Solunar Tables were developed in the 1930's for use as a "forecast of the daily feeding times of fish and game". These tables appear to be tide tables calculated on the Standard Meridians of the time zones. Four times are given in the Solunar Tables, two AM times and two PM times, each approximately six hours apart. One AM time and one PM time are listed under the heading "Minor", and one AM time and one PM time are listed under the heading "Major". The correlation between the avalanche data and the Solunar Tables is calculated in the following way:

**Example from Solunar Tables - March, 1981.**

<table>
<thead>
<tr>
<th>Date</th>
<th>Day</th>
<th>AM Minor</th>
<th>AM Major</th>
<th>PM Minor</th>
<th>PM Major</th>
<th>Moon Phases</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>Sunday</td>
<td>6:25</td>
<td>12:15</td>
<td>7:00</td>
<td>12:45</td>
<td>2 days after new moon</td>
</tr>
</tbody>
</table>

(Longitude correction for Alta, Utah, add 25 minutes)

6:50   12:40 7:25   1:10

(Round off to nearest hour)

7:00   1:00 7:00   1:00
Example of the data compilation.

<table>
<thead>
<tr>
<th>Event#</th>
<th>Date of Avalanche</th>
<th>Time of Avalanche</th>
<th>Nearest Major Solunar Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>179</td>
<td>3/8/81</td>
<td>2:00 PM</td>
<td>1:00 PM</td>
</tr>
</tbody>
</table>

The hour and day are the coordinates of this event in the sample space.

The Sample Space

The sample space, in Figure 1, is defined as the solunar time daily trend (ordinate) and lunar phases monthly trend (abscissa). The ordinate and abscissa are independent because at any lunar phase time, one can ski at any daily time.

A uniform distribution of events over the sample space would demonstrate a null hypothesis, meaning there is no correlation between times of avalanche release and solunar time and lunar phases. In contrast, heavy grouping of events demonstrates correlation. The greater ratio of densities of grouped events versus surrounding areas defines the risk or likelihood ratio, of an avalanche within the sample space. The sample space, and distribution of avalanche events therein, is taken to be a representation of post-precipitation avalanche occurrence in the natural world.

Ideally, the period of new and full moon is identical; thus they are treated the same in this study. This results in an idealized lunar half-month of 14 days, seven days before new/full moon, and seven days after. The new/full moon point on the horizontal axis (abscissa) of the graph is "0". Ideally, the period of AM and PM major solunar time is identical; thus they are treated the same in this study. This results in a 12-hour half-day, six hours before AM/PM major solunar time, and six hours after. The AM/PM major solunar time point on the vertical axis (ordinate) of the graph is "0". In summary, the data has been "folded", full moon onto new moon and AM major solunar time onto PM major solunar time.
The Event Densities

Figure 1 displays the avalanche event densities in the sample space. In group 1 there are 86 events, in group 2, 66 events, and in the exterior area, there are 29 events, giving a total of 152 events in groups 1 and 2 versus 29 in the exterior area. The total area of groups 1 and 2 is 83 day/hour spaces versus 85 day/hour spaces in the exterior area, giving a total sample space area of 168. Therefore, the vast majority of events occur in less than half the total area, or the vast majority of events occur in less than half the sample space time period. From the data in Figure 1, the density of events is as follows (where the density of events is defined as the number of events which happen in a single day-by-hour period):

<table>
<thead>
<tr>
<th>Group</th>
<th>Events per Day/Hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>2.39</td>
</tr>
<tr>
<td>Group 2</td>
<td>1.40</td>
</tr>
<tr>
<td>Exterior Area</td>
<td>0.34</td>
</tr>
</tbody>
</table>

The density of points for the null hypothesis is given by:

\[
\text{Density} = \frac{\text{total number of events}}{\text{total area}} = \frac{181}{168} = 1.08
\]

Therefore, the null hypothesis is outweighed by a ratio of 2.21:1 (2.39/1.08) in group 1. The depletion of events in the exterior area is also significant with a ratio of 1.08/0.34 = 3.18. The more that 2:1 ratio between the null hypothesis and the data in both groups supports acceptance of the alternative hypothesis: post-precipitation avalanche release is statistically dependent on lunar phase and major solunar time.

Risk factors (likelihood ratios) can now be established between time periods by taking the ratio between group densities. They are:
Group 1 + Group 2 over exterior area = \( \frac{152}{83} = 5.38 \), or
\[
0.34
\]
53.8% denser than surrounding area.

\[
\begin{align*}
\text{Group 1} & \quad \text{Exterior area} = 7.0 \\
\text{Group 1} & = 1.7 \\
\text{Group 2} & \\
\text{Group 2} & = 3.3 \\
\text{Group 1} & \quad \text{Group 2 and exterior area} = 4.1
\end{align*}
\]

This means, for example, that it is 7 times more likely for an avalanche event to occur in the group 1 period over the exterior group period. The events outside groups 1 and 2 can be considered statistically random events in terms of this sample space. This is because there are no groups in the data in this area which can give a statistically significant statistic which overrides the null hypothesis.

Conclusion

Avalanche release, which occurs after the cessation of precipitation, is likely to occur at periodic and predictable times. The density values of avalanche events in the sample space confirm this conclusion. For want of another term, even though it may be a misnomer, the phenomenon has been termed "tidal effect".

Using Solunar Tables and Figure 1, high risk periods can be defined. While it appears that a large portion of the month indicates significant avalanche hazard in terms of tidal effect risk factors, it must be remembered that avalanches are the result of a combination of conditions.

Tidal effect can be considered an addition to other contributory factors currently accepted in stability evaluation. However, the tidal effect concept encourages an avalanche forecast methodology based on the consideration that tidal effect risk periods can be determined in advance,
anticipating potentially hazardous times, as well as potentially safer times. In this way, tidal effect risk periods provide a framework, or matrix, through which the other contributory factors are evaluated. This methodology has been used successfully in the avalanche forecasting program at Alta, Utah to time and reduce explosive control, and in helicopter skiing at Blue River, B.C. to predict subtle and dangerous avalanche hazard periods which might otherwise have been erroneously forecast.

In summary, tidal effect forecasting can be an auxiliary tool for wide-ranging, and rapid-paced activity such as helicopter skiing, and for reducing and improving timing of artillery and explosives use in ski areas and highway avalanche programs.

References

Solunar Tables, Mrs. Richard Alden Knight, P.O. Box 207, Moutoursville, Pennsylvania, 17754.


Schaerer, P. Personal communication.


Williams, K. Personal communicaition.

Avalanche personnel in Colorado, Utah, Wyoming, Alberta and British Columbia.
Table 1  Risk Calculation Table Using Solunar Table

**Group 1 - High Risk Tidal Effect Period**

A. From 2 days before new or full moon (0) until 5 days after
B. From major solunar time
- At -2 days, from 4 hours to 5 hours later
- At -1 day, at 4 hours after
- At 0 day, from Major time to 4 hours after
- At +1 day, from 2 hours before to 3 hours after
- At +2 days, from 2 hours before to 3 hours after
- At +3 days, from 2 hours before to 3 hours after
- At +4 days, from 2 hours before to 1 hour after
- At +5 days, from 4 hours before to 1 hour after

**Group 2 - Moderate Risk Tidal Effect Period**

A. From 6 days before new or full moon (0) until 7 days after
B. From major solunar time
- At -6 days, at 3 hours after
- At -5 days, from 3 hours after to 6 hours after
- At -4 days, from 3 hours after to 6 hours after
- At -3 days, at 5 hours before and from 3 hours after to 6 hours after
- At -2 days, from 2 hours after to 6 hours after
- At -1 day, from Major time to 5 hours after
- At 0 day, from Major time to 4 hours after
- At +1 day, from 3 hours before to 4 hours after
- At +2 days, from 3 hours before to 4 hours after
- At +3 days, from 3 hours before to 4 hours after
- At +4 days, from 3 hours before to 4 hours after
Table 1 cont'd

- At +5 days, from 5 hours before to 2 hours after
- At +6 days, from 5 hours before to 2 hours after
- At +7 days, from 6 hours before to 2 hours before

Exterior Area - Low Risk Tidal Effect Period

A. All times outside Group 1 and Group 2 time periods.
FIGURE 1

THE SAMPLE SPACE

GROUP 1

GROUP 2

EXTERIOR AREA

LUNAR PHASES MONTHLY TREND (DAYS)

SOLUNAR TIME DAILY TREND (HOURS)
Discussion

LaChapelle:

In your data base did you include post control releases and, if so, how do they correlate?

Lev:

Yes, there are several in there. About half were in the group 1 area and the rest were scattered throughout the graph.

Bleuer:

Somebody has touched on the importance of tidal forces and gravitational forces on our lives and nature. They must affect the snowpack. Have you any idea of the importance of the effects of the contributing factors that you talked about in relation to other factors precipitating avalanche release? In other words, how important are tidal effects in forecasting?

Lev:

Tidal effects should be considered only in combination with other meaningful contributory factors. In other words, tidal effect by itself is presumably not going to do anything if you are out in the middle of Kansas. First you have to have a structural weakness in the snowpack, then I think you can weigh tidal effects as being of some considerable importance. I have used tidal effects as a kind of background or matrix against which I judge the other factors. By doing so, a certain extra meaning is given to the other factors such as weak substratum and a slab build-up on a weak substratum. It allows you to get a sense of timing as to when a slab is in question or the area that you are concerned with might be entering or leaving a period of instability.

LaChapelle:

I am thoroughly convinced from the evidence Peter has gathered from all these studies, which are very nicely assembled in a statistical analysis, that, in fact, people do get involved in dry snow slab avalanches more often at
certain times of the lunar and solunar cycles. I think this is very convincing evidence. I wanted to make public a little running argument I have with Peter on this point however. This is that the statistics don't tell us whether the effect is on the people or on the snow. What we need is another study like this done just as carefully with natural releases, not with ones that have been triggered by people.

Lev:

The assemblage of data that I just presented was carefully arranged with just this argument in mind because Ed brought it up last time when I did not have it organized in quite the same way. It looked a lot like there was a greater effect around full moon time and so naturally several people jumped up and said "mysticism or psychological effects". The statistics this time were done so as to try to eliminate this sort of bias. The period in Figure 1 covers the entire month so it doesn't throw any weight on the full moon. It is evenly distributed over the months, so we like to think that the passage of the skiers is random if the avalanches are not. There are skiers out every day of the month, and they were not out just because of the full moon. In fact, only one skiing event occurred in moonlight skiing. I took all the group 1 events and laid them out against the new moon and the full moon to see where they would fall. It turns out that there were almost twice as many events at the full moon as at the new moon time, but by the rules of statistical method I was using we couldn't include that. But on a practical level of forecasting, I do include it. I find, for myself, for reasons that I don't know, that there does seem to be more sensitivity in the period of full moon and three days after.

Wiegele:

In general, we have developed a system for hazard forecasting in which we have confidence about 70% of the time. For the 30% of the time, during which we have difficulty forecasting we have sought other contributory factors. One such possibility is the relation to tidal effects which Peter Lev has introduced.