



Climate Influences on Large-Magnitude Natural Snow Avalanches in John F. Stevens Canyon, Montana

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Objectives:

- To investigate whether large-scale patterns of climate variability influence natural avalanche frequency and magnitude

- To compare historic and dendrochronological records of natural avalanche activity

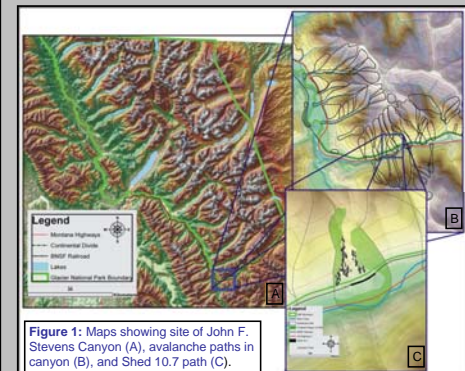


Figure 1: Maps showing site of John F. Stevens Canyon (A), avalanche paths in canyon (B), and Shed 10.7 path (C).

Study Site - John F. Stevens Canyon

- Located at the southwest corner of Glacier NP in northwest Montana, U.S.A (Figure 1)

- One of few year-round transportation corridors in the northern Rockies
 - Burlington-Northern-Santa Fe Railroad (Completed 1891)
 - U.S. Highway 2 (Completed 1930; maintained year-round -1945)

- Railroad and highway cross the run-outs of 40 avalanche paths in -16km (Figure 2)

- Railroad partially protected by 9 snowsheds; highway unprotected

- No explosive avalanche control; BNSF forecasting program started 2005

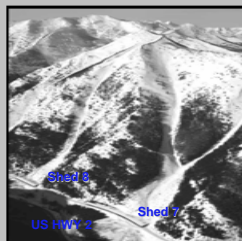


Figure 2: Avalanche paths and snowsheds in Stevens Canyon.

Historic Record

- 96 winters (1910-2004)

- Compiled from variety of primary sources

- Great Northern Railway records
- Glacier NP ranger logs
- Montana Dept. of Transportation logs
- Local newspapers

- No consistent period of record or data recording

- Focus on natural avalanches that damaged railroad or highway infrastructure, injured or killed workers, or disrupted traffic in canyon.

- Bias towards large-magnitude avalanches - those that exceeded normal run-out or breached snowsheds

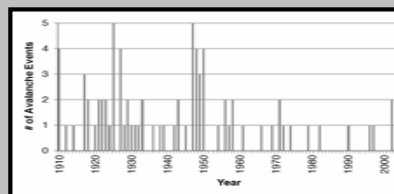


Figure 3: Winters with traffic disruptions or accidents caused by natural avalanches for the entire John F. Stevens Canyon (Reardon et al., 2004).

Historic Record and Climate Variability

- Natural avalanches in Stevens Canyon result primarily from synoptic-scale weather events (Reardon et al., 2004)
 - Arctic air followed by advection of warm, moist Pacific air
 - Sustained snowfall (~100mm over 8 days)
 - Rapid warming (up to 20°C/hour).

- Synoptic-scale weather reflects patterns of climate variability

- Regionally, inter-annual variations in Snow-Water Equivalent (SWE) associated with Pacific Decadal Oscillation (PDO) and Nino 3.4 (McCabe and Dettinger, 2002)

- Stevens Canyon snowfall correlates most strongly w/ PDO (Figure 4)

- March 1 SWE anomalies at Pike Creek Snow Course (1934-2004)

- Mean DJF PDO indices

- Strong inverse relationship (r=-.585)

- Cool phase PDO associated w/ greater snowfall

- Natural avalanches also show an association w/PDO. (Figure 5)

- Avalanche events that disrupted traffic in Stevens Canyon more common in winters w/ cool phase PDO (66% than neutral or warm phase (52%))

- Multiple avalanche events that disrupt traffic far more common in winters w/ cool phase PDO (40%) than neutral (24%) or warm phase (15%) winters.

- Association likely due to:

- More frequent storms

- Deeper snow in avalanche tracks, allowing for greater run-outs

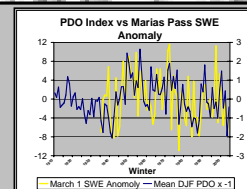


Figure 4: Comparison of PDO indices to Stevens Canyon SWE anomalies

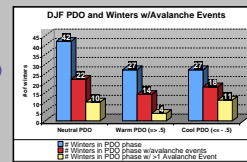


Figure 5: Comparison of PDO indices to Stevens Canyon avalanche events in historic record.



Figure 6: Cross-section from in-situ dead tree w/ GPS recording location

Tree-Ring Record

- Intensive survey of avalanche damaged trees in one path (Figure 6)
 - Collected over 100 cross-sections from in-situ dead trees w/in path
 - Sampled cores of 17 living trees w/in and along margins of path
 - Primarily Douglas Fir (*Pseudotsuga menziesii*)
 - Recorded GPS coordinates for each sample

- Processed and dated samples according to standard procedures (Stokes and Smiley 1968)

- Rated avalanche-induced injuries and growth responses (Figure 7):

- Clear avalanche scar associated w/ obvious reaction wood or growth suppression
 - Clear scar, but no reaction wood or suppression of growth. OR, obvious reaction wood or growth suppression that lasts for three years
 - Obvious reaction wood or growth suppression that only occurs for 1-2 successive growth years
 - Reaction wood or growth suppression is present, but occurred when tree was young and more susceptible to damage from various environmental and biological conditions. OR, the reaction wood is not obvious
 - Same as 4 except reaction growth is even less obvious and may result from soil or snow creep
- Trees w/ avalanche damaged were mapped to produce estimates of minimum avalanche extent (Figure 9).

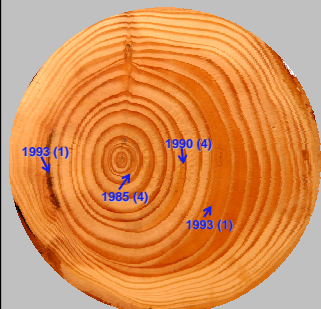


Figure 7: Dated cross section taken from avalanche path Shed 10.7. Note the scarring, reaction wood and years - with response ratings - that correspond to injuries and growth anomalies.

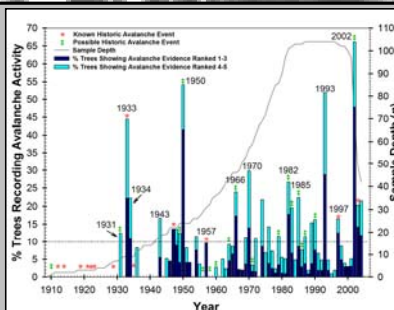


Figure 8: Graph showing sample depth by year and years avalanches recorded by trees in Shed 10.7 avalanche path.

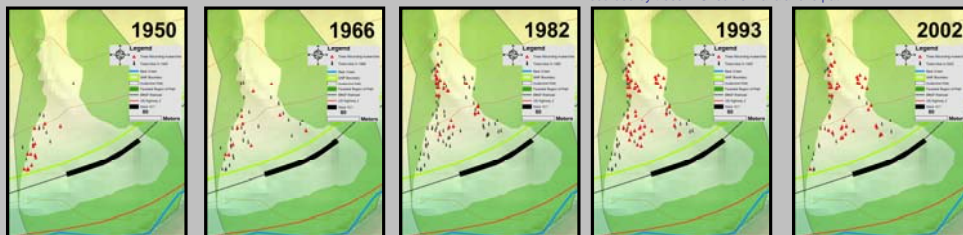


Figure 9: Annual maps of minimum avalanche extent in Shed 10.7 as estimated using by tree-ring analysis. Some years (1950, 1982 and 2002) match known or possible events in historic record. Two years (1966 and 1993) do not.

Discussion

- Most of the known or possible avalanche events from the historic record appear in the tree-ring record.
- The tree-ring record captures more events than the historic record for the same period.
- Several confounding factors - notably wildfires and large-magnitude destructive avalanches - make it difficult to compile long-term tree-ring chronologies of natural avalanches.
- Due to the short tree-ring based record we were not able to correlate PDO or Nino 3.4 with natural avalanche frequency in the tree-ring record.
- Correlation of synoptic climate patterns with avalanche magnitude was difficult and likely the result of the geometry of the Shed 10.7 path - an abrupt transition between lower track and upper run-out - which results in limited variability in avalanche runout distance.
- An avalanche path with a more gradual transition between track and runout may show more variability in avalanche magnitude that could be correlated with climate variability.
- An avalanche path with no human disturbance in the lower run-out would allow sampling of trees that might show lower-frequency, high magnitude avalanches.
- Mapping of trees showing avalanche-related growth response helps to evaluate the quality of data with a relatively small sample depth.
- Sampling additional paths in the canyon might allow better comparisons with patterns of climate variability.

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