Characterizing Snow Structure and Meteorological Parameters of Wet Slab Avalanches along the Going-to-the-Sun Road, Glacier National Park, MT

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Why study wet slab avalanches?

Most avalanche fatalities occur due to dry slab avalanches. However, wet snow avalanches are also dangerous and can be particularly difficult to predict. The rate of change from safe snow conditions to dangerous snow conditions occurs rapidly in a wet snowpack, often in response to water production and movement within the snowpack. Wet snow avalanches impact recreationists, transportation corridors, and ski areas. The manner in which water flows through a snowpack has many implications for avalanche hazard. Forecasting wet slab avalanches requires considering the complexities of water percolation through the stratified snowpack, and the interaction of that water with various snowpack layers. The first component of this research focuses on the relationship between snow stratigraphy and water movement in an inclined snowpack. The second portion examines meteorological conditions associated with wet slab avalanche cycles. These two concepts comprise a major part of the wet slab avalanche problem. Increasing global mean temperatures may increase the frequency of wet snow avalanches of all types, so a better understanding of the processes involved is important. As snow may be precipitated at warmer temperatures, rain-on-snow events might become more frequent, and the snowpack itself might trend toward a wetter one.

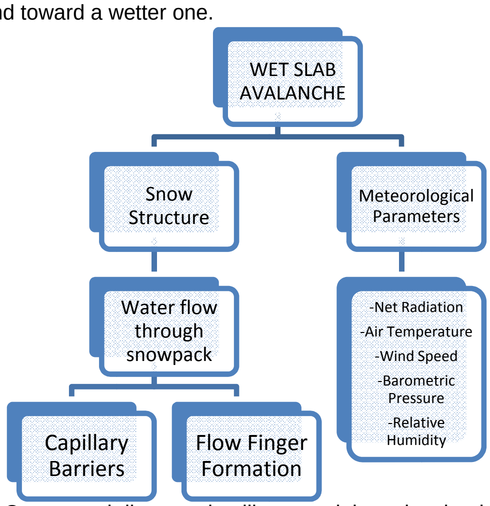

Figure 1: Conceptual diagram detailing wet slab avalanche theory that forms the basis of this research.

Where do we study wet slab avalanches?

The study site for this research project includes slopes within Glacier National Park (GNP) along the Going-to-the-Sun Road (GTSR), a two-lane, 80-kilometer roadway traversing through Glacier that is closed each winter because of avalanche hazards, inclement weather, and heavy snowfall. Extensive wet slab activity has been documented on roads in GNP, as well as several wet slab avalanche accidents in 71 seasons of clearing and opening of Going-to-the-Sun Road, including a 1964 wet slab that carried a bulldozer and an operator off the road. Wet slab avalanches continue to plague spring opening operations along the GTSR. However, the occurrences of this type of avalanche as well as access to avalanche prone slopes and the weather stations located along the GTSR corridor provide a prime research site for studying wet slab avalanches. This research allows for a better understanding of wet slab avalanche processes along the GTSR, and will aid in avalanche forecasting operations for the spring opening of the GTSR.

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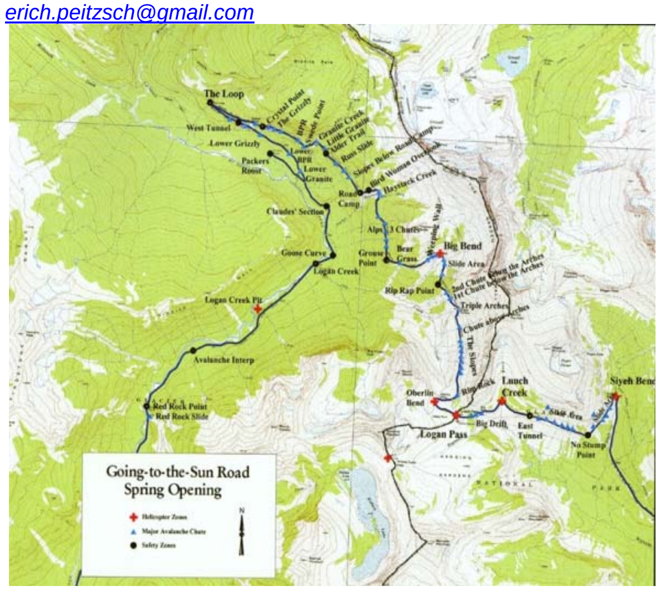

Figure 2: Map showing the 40+ avalanche paths that affect the GTSR.

How does water flow affect wet slab avalanches?

The "water factory" (a term coined by former USGS avalanche forecaster Blase Reardon) is important in wet slab avalanche processes. The capillary barrier effect involves a change in the infiltration rate of water within a snowpack due to a textural difference between two layers. In a wet slab avalanche context, water is impeded at the interface between two layers. It then accumulates and flows along this interface. When water moves throughout a weak layer, a structural disintegration occurs which might cause a collapse that initiates a wet slab avalanche. This illustrates the importance of snow stratigraphy as a factor in wet slab avalanche formation.

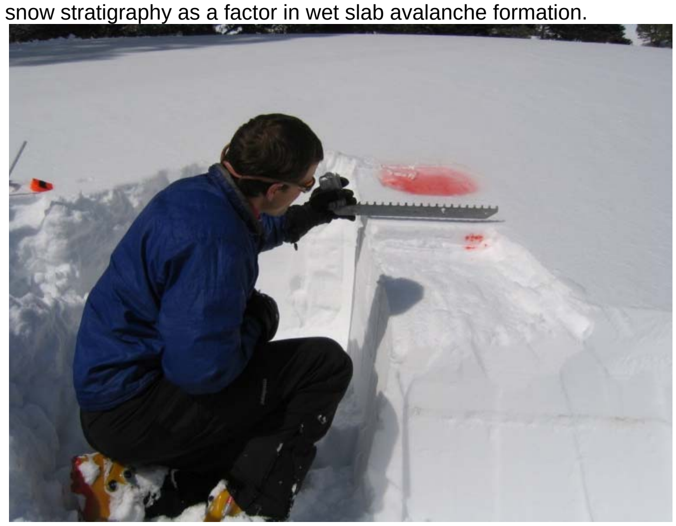

Figure 3: Researcher investigating water flow through the snowpack by using red dye tracer. Photo: Karl Birkeland

Concentrating on the capillary barrier effect and flow finger formation within the snowpack, dye tracer was mixed with water and applied to a stratified snowpack to observe and measure the movement of water in various snow grain types, sizes, densities, and temperatures. We utilized red food coloring to determine timing events of water flow and creation and persistence of capillary barriers and preferential flow paths. We mixed the dye with water, and then applied it with a spray bottle to simulate rain or meltwater production within the snowpack. Experiments show that even a slight textural change within dry snow grains produce a capillary barrier. This is important because the introduction of water to a dry snowpack drives wet slab avalanche processes. The amount of water needed to produce flow fingers depends on the snow structure. Both capillary barriers and flow finger formation may play a large role in wet slab avalanche formation.

More work is needed to better understand the complexities of capillary barriers and their role in wet slab avalanche formation. While we applied varying amounts of water in our experiments, it was constructed as a test plot, not a slope-scale experiment. The amount of water flow on a large scale might also be critically important as to whether or not a capillary barrier will form at specific interfaces. Therefore, it is a complex problem with no simple answers, but this work provides a start for understanding capillary barriers in the inclined snowpack and aids practitioners and researchers alike in identifying the location where free water within the snowpack may move downslope laterally and identify potential failure layers in a wet slab avalanche scenario.

How does weather play a role in wet slab avalanches?

Meteorological data (air temperature, snow surface energy balance, wind speed, barometric pressure, and relative humidity) is measured from three locations at the study site in Glacier National Park. The Garden Wall (7440' a.s.l.) and Logan Pass (6675' a.s.l.) weather stations provide high altitude data from our avalanche start zones, while Flattop SNOTEL site (6300' a.s.l.) provides mid-elevation meteorological parameters. Energy balance measurements are the focus of this research. A radiation sensor that measures both incoming and outgoing radiation allows for a better understanding of radiation conditions necessary for wet slab avalanche production.

Radiation drives the "water factory" in the snowpack through melting at the snow surface, which is the reason we are interested in energy balance measurements. We are currently investigating any patterns or relationships between radiation values and wet slab avalanche cycles. Of note thus far is a piece of anecdotal data from avalanche researchers and practitioners that suggests a time lag between peak radiation values for the day and wet slab avalanche occurrence. We are also currently investigating energy balance patterns leading up to wet slab avalanche occurrences. We are compiling a database of wet slab avalanches occurring throughout western North America, including GNP, and examining meteorological factors associated with all wet slab cycles.

The results of this work will help assist avalanche professionals by providing information about the contributory factors for wet slab avalanche formation, as well as specific information about free water production and flow in the stratified snowpack. For instance, it will aid avalanche forecasters for the GTSR and, inherently, allow for more precise forecasts for the GNP Road Crew during spring opening operations. Other outcomes of this research include an article profiling the progress on this project in *The Avalanche Review* (26(4), April 2008), and a scientific paper and presentation at the 2008 International Snow Science Workshop in Whistler, B.C.

Figure 4: Researcher monitoring meteorological measurements at the Garden Wall Weather Station. The GTSR is located ~2000 vertical feet below and in the clouds in this photo.

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Figure 5: Wet slab avalanche in Big Bend slide path along the Going-to-the-Sun Road in Glacier National Park. Photo: Karl Birkeland
For more information on the USGS/GNP Avalanche Forecasting program visit http://www.nrmsc.usgs.gov/research/gtsr_aval.htm