

A Conceptual Model of Avalanche Hazard

Statham G, Haegeli P, Greene E, Birkeland K, Israelson C, Tremper B, Stethem C, McMahon B, White B, Kelly J (2018) A conceptual model of avalanche hazard. Natural Hazards 90: 663-691.

ESTABLISH CONTEXT

Operational Application	Objective				
Commercial backcountry operations	To keep clients safe, while providing a high quality guided backcountry experience				
Public backcountry ecreation	To provide accurate avalanche information that enables the public to safely enjoy backcountry recreation				
ki areas	To provide safe access to as much in-bounds ski/snowboard terrain as early as possible each day				
ransportation corridors	To keep roads/rails and travellers safe, and to minimize the frequency and duration of closures				
Vorksites	To keep workers safe, and enable work objectives by minimizing the frequency and duration of closures				
Nobile workers	To provide accurate avalanche information that enables workers to safety accomplish backcountry work objectives				
Itilities	To minimize the frequency and duration of service interruptions				
Occupied structures	To keep occupants safe and prevent or minimize damage to infrastructure				

Terrain

of avalanche problem is located

Specific terrain features

Spatial Extent	Description	Examples	Scale			
Terrain Feature	Individual geographic features contained within a larger slope	Convex roll, gully or terrain trap				
Slope	Large, open, inclined areas with homogenous characteristics bounded by natural features such as ridges, gullies or trees	Typical avalanche starting zone or wide open area on a ski run	Micro < 1 km²			
Path or Run	Multiple interconnected slopes and terrain features running from near ridge crest to valley bottom Full length avalanche paths with a start zone, track and runout zone or typical long backcountry ski run					
Mountain	An area rising considerably above the surrounding country with numerous aspects and vertical relief running from summit to valley bottom	Ski resort area or typical single operating zone in a snow cat skiing area 4	Meso > 10 ² km ²			
Drainage	An area with a perimeter defined by the divide of a watershed the divide of a watershed Typical single operating zone in a helicopter skiing area					
Region	A large area of multiple watersheds defined by mapped boundaries Typical public forecasting area or public land jurisdiction					
Range	A geographic area containing a chain of geologically related mountains	Mountain ranges or sub-ranges	> 10 ⁴ km ²			

Time Span	Description	Example Final, on-the-ground decision to enter or avoid a terrain feature Daily, or twice daily assessments of avalanche hazard that are common in most operational forecasting programs			
Now	Assessments with immediate consequence				
Hours	Assessments that are valid for a matter of hours, or portion of a day up to 24-hours				
Days	Assessments that are valid for more than 24-hours but less than a week	Two to three day outlooks common with publi avalanche forecasts			
Weeks	Assessments of seasonal trends and patterns that emerge in the course of a single winter season	Avalanche problems that remain a concern for weeks to months; sometimes for an entire winter season			
Years	Assessments that are valid beyond a single winter, often for many years	Land-use planning based on a long-term analysis of avalanche frequency and magnitude			

TYPE OF AVALANCHE PROBLEM

Name	Description	Formation	Persistence	Typical Physical Characteristics					Typical Risk Mitigation
	Description		i ciolocilec	Weak Layer Type	Weak Layer Location	Slab Hardness	Propagation Potential	Relative Size Potential	
Dry Loose	Cohesionless dry snow starting from a point. Also called a sluff or point release.	Surface layers of new snow crystals that lack cohesion, or surface layers of faceted snow grains that lose cohesion.	Generally lasts hours to days when associated with new snow, and longer when associated with facets.	~	~	~	Downslope entrainment	R1-2	Avoid terrain traps where avalanche debris can concentrate, exposure above cliffs where small avalanches have consequence, and steep terrain overhead where sluffs can start.
Net Loose	Cohesionless wet snow starting from a point. Also called a sluff or point release.	Snow becomes wet and cohesionless from melting or liquid precipitation.	Persistence correlates with warm air temperatures, wet snow or rain, and/or solar radiation.	~	~	~	Downslope entrainment	R1-3	Avoid gullies or other confined terrain features when water from melting or precipitation is moving through the snowpack.
Storm Slab	Cohesive slab of soft new snow. Also called a direct-action avalanche.	Cohesive slab of new snow creates short-term instability within the storm snow or at the old snow interface.	Peaks during periods of intense precipitation and tends to stabilize within hours or days following.	DF, PP	In new snow or at new/old snow interface	Very soft to medium (F-1F)	Path	R1-5	Avoid avalanche terrain during periods of intense precipitation, and for the first 24-36 hours following. Assess for crack propagation potential in all avalanche terrain during and in the days following a storm.
Wind Slab	Cohesive slab of locally deep, wind-deposited snow.	Wind transport of falling snow or soft surface snow. Wind action breaks snow crystals into smaller particles and packs them into a cohesive slab overlying a non-persistent weak layer.	Peaks during periods of intense wind loading, and tends to stabilize within several days following. Cold air temperatures can extend the persistence.	DF, PP	Upper snowpack	Soft to very hard (4F-K)	Terrain feature to path	R1-4	Identify wind-drifted snow by observing sudden changes in snow surface texture and hardness. Wind erodes snow on the upwind side of an obstacle, and deposits it on the downwind side. They are most common on the lee side of ridge tops or gullies and are most unstable when they first form and shortly after.
Persistent Slab	Cohesive slab of old and/or new snow that is poorly bonded to a persistent weak layer and does not strengthen, or strengthens slowly over time. Structure is conducive to failure initiation and crack propagation.	Weak layer forms on the snow surface and is buried by new snow. The overlying slab builds incrementally over several storm cycles until reaching critical threshold for release.	Often builds slowly and then activates within a short period of time. Can persist for weeks or months but generally disappears within six weeks.	SH, FC, FC/CR combo	Mid to upper snowpack	Soft to hard (4F-P)	Path to adjacent paths	R2-4	Complex problem that is difficult to assess, predict and manage. Typically located on specific aspects or elevation bands but sometimes widespread. Identification and tracking of weak layer distribution and crack propagation propensity is key, along with a wide margin for error and conservative terrain choices.
Deep Persistent Slab	Thick, hard cohesive slab of old snow overlying an early-season persistent	Weak layer metamorphoses within the snowpack forming facets adjacent to an early-season ice crust, depth hoar at the base of the snowpack, or facets at the snow-glacier ice interface. The overlying slab builds incrementally over many storm cycles until reaching critical threshold for release.	Develops early in the winter and is characterized by periods of activity followed by periods of dormancy, then activity again. This on/off pattern can persist for the entire season until the snowpack has melted.	DH, FC, FC/CR combo	Basal or near-basal	Medium to very hard (1F-K)	Path to adjacent paths	R3-5	The most difficult avalanche problem to assess, predict and manage due to a high degree of uncertainty. Low probability/high consequence avalanches. Triggering is common from shallow, weak snowpack areas, with long crack propagations and remote triggering typical. Weak layer tracking and wide margins for error are essential, with seasonal avoidance of specific avalanche terrain often necessary.
Wet Slab	Cohesive slab of moist to wet snow that results in dense debris with no powder cloud.	Slab or weak layer is affected by liquid water which decreases cohesion. Crack propagation occurs before a total loss of cohesion produces a Wet Loose Avalanche Problem.	Peaks during periods of rainfall or extended warm air temperatures. Persists until either the snowpack refreezes or turns to slush.	FC or DH	Any level	Soft to hard wet grains (4F-P)	Path	R2-5	Rainfall, strong solar radiation, and/or extended periods of above-freezing air temperatures can melt and destabilize the snowpack immediately. Timing is key regarding slope aspect and elevation, and overnight re-freezing of the snow surface can stabilize the snowpack.
Glide Slab	Entire snowpack glides downslope then cracks, then continues to glide downslope until it releases a full-depth avalanche.	Entire snowpack glides along smooth ground such as grass or rock slab. Glide crack opens, slab deforms slowly downslope until avalanche release results from a failure at the lower boundary of the slab.	Can appear at any time in the winter and persists for the remainder of the winter. Avalanche activity is almost impossible to predict.	WG, FC	Ground	Medium to very hard (1F-K)	Path	R3-5	Usually localized, visible and easy to recognize, the presence of a glide crack does not indicate imminent release. Predicting a glide slab is almost impossible, so avoid slopes with glide cracks and overhead exposure to glide slabs.
Cornice	Overhanging mass of dense, wind-deposited snow jutting out over a drop-off in the terrain.	Wind transport of falling snow or soft surface snow develops a horizontal, overhanging build out of dense snow on the leeward side of sharp terrain breaks.	Persists all winter on ridge crests, and tends to collapse spontaneously during periods of warming, or following intense wind loading events.	~	~	~	Path	R1-5	Avoid overhead exposure to cornices whenever possible, particularly during storms or periods of warmth and/or rain. Cornices are heavy and can trigger slabs on the slopes below. Use great care on ridge crests to stay on solid ground, well away from the root of the cornice.

