

REMOTE SENSING FOR NATURAL HAZARD STUDIES

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Lec 27 b: Snow Avalanche Studies Part B

Hello everyone, welcome to Lecture 27; this is part 2 of Lecture 27. So, today we will continue these avalanche studies. So, this is just to maintain continuity. So, on the basis of the characteristics of the snowpack, avalanche problems are characterized. From that, the potential and behavior of avalanches can be understood, and we have seen that there are four different types of problems. So, the first one is the character, then we have size, location, and likelihood, and we were discussing these avalanche problems one by one.

Avalanche Problem

- On the basis of the characteristics of the snowpack, Avalanche problems are categorized.
- From that, the potential and behaviour of Avalanche can be understood.
- The four main problems are:-

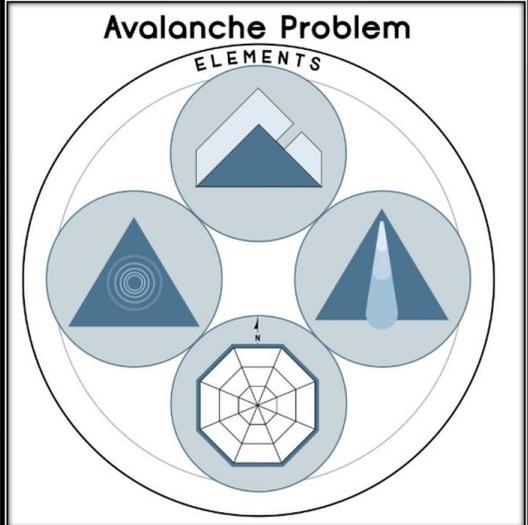
1. Character
2. Size
3. Location
4. Likelihood



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Avalanche Problem

ELEMENTS



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So, to see that character to start with, we will watch this particular video, and you will be able to understand what exactly we mean by character. So, just see the loose wet, wind slab, storm slab, glide, and so on; these are the different types of characteristics for avalanches, particularly snow avalanches. So, the first one is this storm slab release of a soft cohesive layer, which is a slab of new snow that breaks within the storm snow or at the interface between the new and the old snow. So, if this is the new snow and this is the

old snow, this is the position. Then comes the wind slab release of a cohesive layer of snow.

Formed by the wind, drifted snow. So, here you can see the example, and this is for the storm slab; then comes the wet slab. So, the name itself is unclear. So, you will be able to understand the release of a cohesive layer of snow caused by meltwater weakening the bond between the slab and an underlying weak layer. So, you can see that this weak layer has been detached from the main mass because of the wet slab.

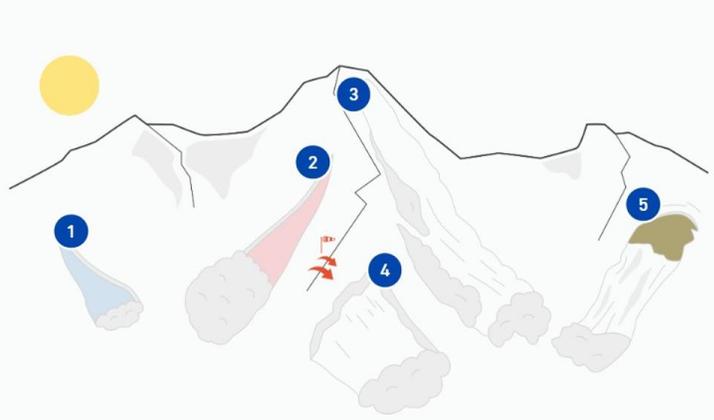
Then comes the loose, wet release of unconsolidated damp or wet snow. So, here you can see these are on a very small scale. Then comes the cornice. The release of an overhanging mass of snow formed by wind deposits occurs. So, here you can see the cornices and the glide release of the entire snow cover as a result of gliding over the ground.

So, it is because of the precipitation that this precipitation will bring temperature to this ice mass and if there is a surface that has a high melt water content, then this entire mass will slide like this one. Then the persistent slabs release a cohesive layer of snow when the bond to an underlying persistent weak layer break. So, here you can see this layer. Deep persistent slab release occurs when a thick cohesive layer of hard snow becomes a slab, and the bond breaks between the slab and an underlying persistent weak layer deep in the snowpack or near the ground. So, here you can see that this is the deep, persistent slab.

At a glance...

Types of Avalanches

1. "Dry" loose snow avalanche
2. "Wet" loose snow avalanche
3. Powder avalanche
4. Slab avalanche
5. Gliding avalanche



<https://www.ortovox.com/uk-en/safety-academy/training/avalanche-courses>

Then comes the loose, dry release of dry, unconsolidated snow. So, here you can see that dry loose avalanches can act as a trigger for slab avalanches on a larger scale. Dry loose avalanches are the simplest problem to manage because of their predictable behavior and

relatively smaller size. So, these are manageable, and it would not cause any loss of life or property. Now, we can see the different types of avalanches here: first, the dry loose snow avalanche, which you can see as an example; then comes the wet snow or wet loose avalanche, which is the second; and finally, the powder avalanche, which is the third.

These are the different types of avalanches. Then we have a slab avalanche, so here you can see this is an example of a slab avalanche, then a gliding avalanche. So, this is the right one. So, now comes the location and how it is important. So, you see this video here; the location will be highlighted. So, here you can see that the north, south, east, and west have been marked, and then we have to relate them to the topography of how they appear.

So, this video will slowly explain how the locations and the directions are important. So, here comes the topography. So, in the topography, you can see that the direction has been matched; both directions can be seen, and this side is basically your eastern side. All these hills are on the eastern side. Now comes the location, slope aspect, and elevation, and how they play a significant or critical role here.

So, avalanche release generally requires a slope angle greater than 30 degrees. The curvature and aspect of the slope also influence the size of the release area. The steeper the slope, the more dangerous it becomes. So, because of the steepness, you will have a higher velocity that can be achieved by the avalanche. The north-facing slopes are very, very important.

The fact that most accidents occur on north-facing slopes could be because settling takes longer due to the reduced exposure to sunlight and because more weak layers form. Powder snow also lasts longer on the north-facing slopes, which generally means that they are frequented more often. However, there are situations in which south-facing slopes are more dangerous than north-facing slopes. So, the south-facing slopes are more dangerous. So, here you can see on this side, it is more dangerous than the north-facing slopes.

Now comes the likelihood, so you will be able to understand how this particular likelihood hill is susceptible to avalanches. So, whether it is highly susceptible, less susceptible, or very certain that it is going to happen, we can describe it using the likelihood. So, the size that also plays a major role here; you can see this is a relatively small size. When it is a large one or the biggest one, it will have more impact on the downstream area, and it has been observed that after an avalanche, there is a flash flood condition in the downstream. So, the factors responsible for the avalanche are the higher temperature, seismic activities, and the movement or vibration produced by machines and explosives that we have seen in some areas where we are using artificial vibration to clear the avalanches.

So, when we talk about the higher temperature, the surface layer of the snowpacks melts because of the high temperature, and the accumulated snow will become highly susceptible to sliding down. Then come the seismic activities; they are one of the important factors that lead to the triggering of the layers of accumulated snowpack because earthquake-generated seismic waves cause the ground to vibrate and trigger avalanche activities. Then the vibration during the development activities of the terrain vehicles in regions with unstable layers of snow can dislodge the layers from the surface and cause them to slide down under the influence of gravity. Then we have heavy snowfall. So, when a higher rate of snowfall occurs, leading to the accumulation of snow on the mountain slope, it triggers the weaker layer of snow in the snowpack of unstable areas of the mountain, causing an avalanche.

Now, we have wind direction; the direction of the wind determines the pattern of the snowfall as well as snow accumulation on the mountain slope. If the strong wind blows, then the upward direction of the winds might trigger the steep slope, which could cause an avalanche and the deforestation we all know that the plants or the vegetation help to restore the area; it also reduces the intensity and frequency of the hazards. So, the trees and plants always protect the land against natural disasters like floods, tidal waves, strong winds, and also avalanches. So, if we see the avalanche hazard triangle, it refers to the three key elements: snowpack, terrain, and weather.

The weather, terrain, and snowpack have different impacts, and they can be studied together to find the avalanche hazard in a given area. So, continuing with the factor responsible for the avalanches. So, the layering of snow also helps to trigger the gradual snowfall that creates layer-by-layer accumulation of snow, which hypersensitizes the snowpack; if a catastrophic event happens, these layers of snow fall down, leading to avalanches, and steeper slopes are more responsible for such events. An avalanche is also caused by the influence of gravity. If gradual snowfall accumulated on the slope of the mountain, then it is prone to rush down the slope at greater speed.

Then the winter sports activity that can also trigger avalanches is something we have seen examples of in the previous part of this lecture, where I showed you some videos of how skiing can trigger an avalanche. So, the avalanche conditions refer to the interplay between factors like weather and snowpack. Snowpack can consist of multiple layers of snow, each one formed by a different snowfall. that becomes compacted under the weight of the subsequent layer that lies on top right. Then comes the weather: we have wind, temperature, snowfall, and rain; together, they can impact and trigger avalanche activities.

So, the weather and snowpack are very, very important. So, let us try to understand the recipe for an avalanche. So, the snowflakes generally have 6 arms formed by the accumulation of water molecules: 2 hydrogen atoms and 1 oxygen atom. Sometimes

the snowflakes stay separate, creating a weak pillow layer. If another hard layer is forced on top of the snowpack, the millions of snowflakes within it have set the stage for one of the most deadly faces on earth.

We have a strong layer, then a slightly weaker layer, and then another strong layer on top of it. They are faster than other snowflakes, which can create a continuous hard layer of snow that can stretch across an entire mountain side. So, here you might have seen this particular video, and it explains how this accumulates, how it triggers, and what the resultant of an avalanche is. So, when we talk about the weather, it plays a crucial role here. So, the precipitation creates and influences the snowpack over the course of winter.

A new snow layer often poorly bonds with the old snow layer. Therefore, the possibility of an avalanche typically increases during or shortly after snowfall. Rain also constitutes an additional load and warms and soaks the snowpack. During a period of precipitation, the amount of new snow, the temperature, and the wind are the main factors for the development of an avalanche. An unfavorable combination of these factors leads to what is called critical new snow depth, and the avalanche danger level can be expected to increase.

Here you can see that this is the lee side and this is the windward side, so on the lee side it will be more. So, the wind is said to be the architect of the avalanche. The wind is responsible for the formation of snow slabs; the slab can only slide away if it is on top of a weak layer; then only will it slide. These are also known as wind slabs and are predominantly found on the untouched lee aspect of the steep slope behind terrain breaks, so this side is right. The temperature influences the snowpack, the transformation processes within it, and in particular the top 30 to 50 centimeter of the snow layer.

Cold and warm air both influence the snowpack. Cold air leads to a grainy non-cohesive layer that, when later covered in snow, can become a weak layer. Heat initially leads to settling, but it can also destabilize if the snow starts to melt and soak the snowpack. So, we have an example from Uttarakhand; from March onwards, the temperature was higher than in the previous year. So, the melting started early and the snow became wet.

The liquid water content also increased, and because of the fresh snowfall over this wet snow, it will result in an avalanche. So, you see here, this is the area that I was talking about. A critical amount of new snow that is also very important. So, the critical amount of new snow refers to how much new snow accumulates, which signals a considerable rise in the risk of an avalanche. During new snowfall, the wind generates drifted snow, which leads to enormous brittle snow slabs.

Low temperatures slowed the process of new snow sintering with the existing snow surface. So, here you can see the unfavorable conditions and the favorable conditions that are listed. Then comes the rain, as we all know, the rain also brings temperature to the

snow, and then the snow can be wet snow, which will slowly lead to the avalanche. For instance, it adds a lot of heat to the snowpack, which makes it unstable; second, it also adds mass. So, it increases the load; rain causes the top area of the snowpack to become heavier, perhaps overstressing the weak layer beneath, and that will lead to the avalanche.

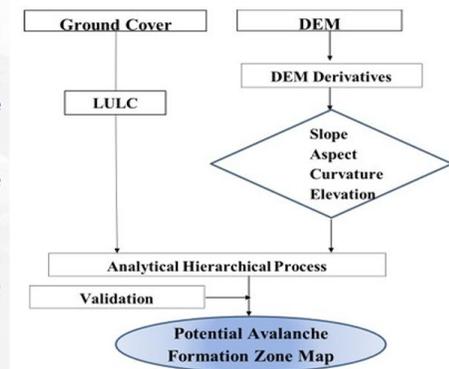
Avalanche occurrence is dependent on both static and dynamic conditions; favorable terrain conditions for avalanche occurrence are examples of static conditions. characteristic. Terrain conditions that remain constant over time are known as static conditions. Avalanche occurrence requires favorable terrain circumstances; otherwise, favorable dynamic parameter conditions are irrelevant. So, here you can see that the ground cover, land use land cover, and the digital elevation model have been used.

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GIS Based AHP Approach

Methodology adapted for Potential avalanche formation zone

- Avalanche occurrence is dependent on both static and dynamic conditions.
- Favourable terrain conditions for avalanche occurrence are examples of static characteristics.
- Terrain conditions that remain constant over time are known as static conditions.
- Avalanche occurrence requires favourable terrain circumstances; otherwise, favourable dynamic parameter conditions are irrelevant.



Source: Vardan Singh, M. Tech -WRD, IIRS 2018; Singh et al., ISPRS 2018

From the digital elevation model, slope, aspect, curvature, and elevation information have been extracted, and at the same time, you have the land use and land cover, and together they are going into the AHP. Then, from the field, we are gathering the information to validate, and then we can proceed with the potential avalanche formation zone mapping. This example is from the Rishiganga Valley. So, in the western Himalayas, the Rishiganga catchment is composed of an area of about 690 square kilometers. There are several large valleys and hanging glaciers, such as Changband, Hanuman, Trisul, Bethartoli, and Ronti glaciers.

The region falls into the category of rugged topography with elevations ranging from 1,200 to 7,800 masl. The catchment is enclosed by eight peaks, with Nanda Devi being the second highest peak rising to about 7,846 m asl. The region is prone to avalanches due to the presence of hanging glaciers, as the slopes are sufficiently steep, leading to ice calving from the terminus of the glacier. And we had an incident in the past you might

have heard about, the Chamoli disaster; it was because of the ice waves detachment, It was here in the location.

I will share the details now. So, this is the position of the detached wave. So, it was on 7th February 2021 that a major rock mass and glacier ice dissociated from the northern slope of Trisul Mountain, resulting in an avalanche, and the velocity ranged downstream from around 127 to 134 miles per hour. The studies revealed that the 60 million metric tons of mass that crashed over the Ronti consisted of 80 percent rock and 20 percent metamorphosed ice. So, here you can see the same area we studied using the physical prototype of this triangular wedge, and subsequently, we used the satellite images to study the reason behind this rock ice wedge failure. So, this is the methodology that we have adopted for this particular work.

So, we use the Sentinel-1 GRD data. Then we also had input from the field investigation, and the optical satellite dataset and the digital elevation models were used. The Sentinel-1 GRD data that was used to measure or estimate the glacier mobility. However, the digital elevation model and the field information, such as rock type, slope, and wedge geometry. So, that was used for the probabilistic analysis of this slope. Also, we have done the rockfall simulation, and subsequently, we concluded that this particular rock-ice wedge failure was not due to glacier mobility, as the glacier was moving at a very constant rate and there was no abnormality that we have seen.

Avalanche Studies from Himalayan Ranges

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DATASETS USED

Sentinel-1A Level-1 Datasets									
Timeline	Master Data	Slave Data	Microwave Band/ Frequency	Data Type	Beam /Polarization	Mode	Spatial Resolution/ Width	Frame/Path/ Flight Direction	Temporal Baseline (Days)
Pre-Monsoon	16 Mar 2020	2 July 2020	C-Band/ 5.405 GHz	GRD	IW/VV+VH		5m*20m/ 250 Km	92/129/ Ascending	108
Monsoon	2 July 2020	18 Oct 2020							
Post-Monsoon	18 Oct 2020	3 Feb 2021							
Annual (2020-2021)	16 Mar 2020	3 Feb 2021							324

ALOS PALSAR Dataset							
Data	Date	Spatial Resolution	Microwave Band/ Frequency	Polarization	Beam Mode/Path	Frame/Flight Direction	Off-Nadir Angle
			L-Band/ 1.27 GHz	HH+HV	FBD/520	590/ Ascending	34.3°

Sub-pixel Intensity Offset Tracking

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graph TD
    MI[Master Image] --> APOF[Apply Precise Orbit File]
    SI[Slave Image] --> ASPOF[Apply Precise Orbit File]
    APOF --> CR[Co-registration]
    ASPOF --> CR
    CR --> S[Subset]
    S --> SPO[Sub-pixel Offset Tracking]
    SPO --> CVC[Compute velocities for GCPs]
    CVC --> LA[Local average & fill holes]
    LA --> CVO[Compute velocity & offset]
    CVO --> CGC[Compute GCPs]
    CGC --> VM[Velocity Map]
    TC[Terrain Correction using DEM] --> CVC
    
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So, here you can see the list of data sets that have been used in this particular study, and for the glacier mobility, we have used the sub-pixel intensity offset tracking, which was used to measure the velocity, and based on that, we have determined that for this given area, the maximum mobility observed is 5.84 meter per year and for this mobility, we

have also studied all along the glaciers and at different positions in the glacier, and then we tried to study whether it was consistent throughout the glacier or whether it varied at different locations. So, maximum annual surface displacement is seen towards the end of the glacier flanks, ranging between 150 and 185 centimeters, which is reduced to less than 10 centimeters near the snout. It is to be noted that the surficial displacement of the Ronti glacier body is comparatively less than that of the other glacier bodies such as Trisul and Bethartoli in the Rishiganga valley.

Avalanche Studies from Himalayan Ranges

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Datasets Used				
Pre-Avalanche Data	Post-Avalanche Data	Band/ Sub-swath	Path/ Frame	Polarization
13 th January 2021	25 th January 2021	C-Band/IWI	121/496	VV+ VH
DEM (ALOS-PALSAR)				
Data	Path/Frame	Absolute Orbit	Band/Polarization	
10 th March 2009	512/560	16653	L-Band/HH	

Methodology Adopted:

Read

↓

TOPSAR Split

↓

Apply Orbit File

↓

Radiometric Calibration

↓

TOPSAR Deburst

Write

↑

Range-Doppler Terrain Correction

↑

LinearToFromdB

↑

Multilook

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Minimum surface displacement registered by satellites is in the post-monsoon period, and maximum displacement is observed in the pre-monsoon period. Then we have also studied the Annapurna mountain range avalanche because this is one of the very popular reasons why we experience avalanches very frequently. So, the incident occurred at an altitude of around 3,230 meter, close to the base camp of Annapurna, one of the highest peaks in the Himalayas. So, using the satellite images and this particular adopted methodology. We have tried to map the avalanches in the Annapurna region, and here you can see all the glaciers marked with this particular color and combination.

So, the avalanche activation zone, the possible reason behind such a pattern, can be attributed to the backscattered response due to the sloping mountain surface lying underneath the snowpack. So, here you can see the backscattering intensity that has been calculated. As the topographic gradient of these regions is comparatively greater than 30 degrees, freshly precipitated dry snow can slide more easily than in other areas. This led to less deposition of dry snow, giving dominance to the backscatter response from the underlying ground surfaces. So here you can see the temporal classification of avalanches.

So here we have identified the different locations that have avalanche activity. So red color is used to mark the recent avalanches, and the old avalanches can be seen in blue color and the uncertain reason it is in white color. So, in the Indian Himalayas, the Indian Army and DRDO have jointly installed the avalanche monitoring radar in North Sikkim; rapid detection is possible with this radar, which can also work in different weather conditions, and the coverage area is 2 square kilometers around the area. The sensor and the technology used here are microwave pulses to scan and detect avalanche activities in the surrounding area.

Other than the snow avalanches, this radar can also detect landslides, increasing its utility in hilly terrains. So, the effects of avalanches are listed here. So, for example, flash floods can cause disasters in low-lying areas due to debris from avalanches that accompany them. So, it also disrupts transportation, harms property, and the communication failure at higher altitudes is very, very common. So, you have seen the different aspects of the avalanches, and this particular slide explains the number of affected people and loss of lives in different countries because of the snow avalanches.

So, with this, I will end this lecture, and then you can refer to these references if you want to understand more about snow avalanches.

Thank you very much.