REMOTE SENSING FOR NATURAL HAZARD STUDIES

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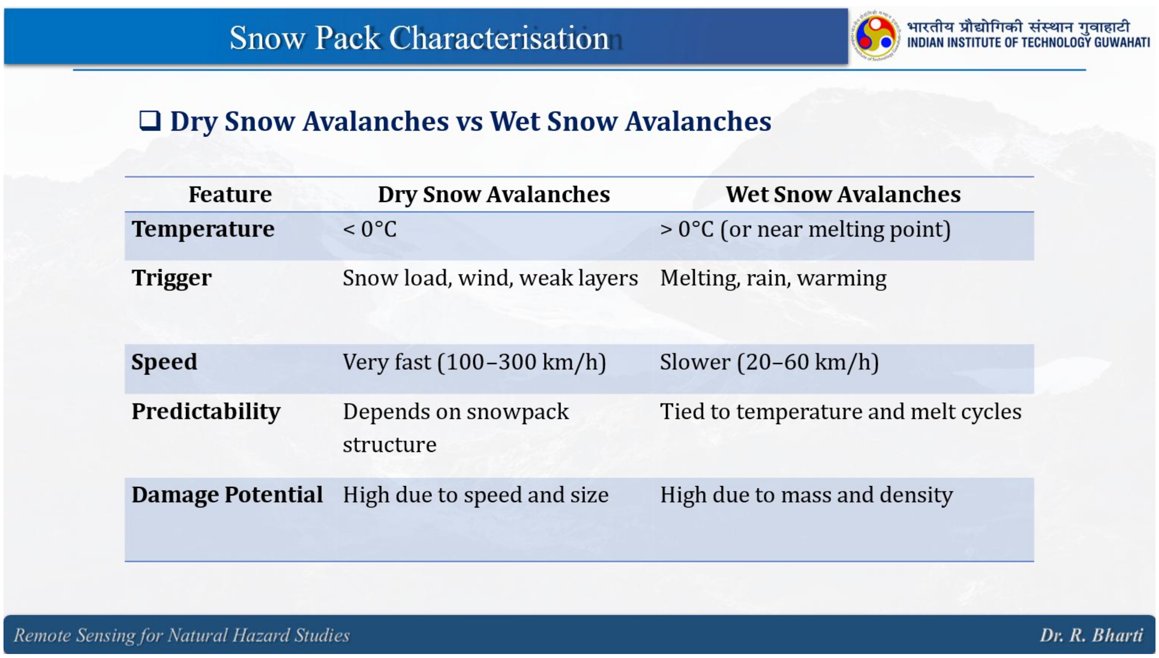
Lec 27 a: Snow Avalanche Studies Part A

Hello, everyone, welcome to Lecture 27. So, today we will talk about the snow avalanche studies, and this is part of module 7. In module 7, we have this avalanche and glacial lake hazard. So, let us start this lecture. So, before we go into the details, let us first try to understand what we exactly mean by the avalanche, or particularly the snow avalanche. So, it is a rapid flow of snow down a slope, like from a hill or a mountain. So, here you can see that many of you might have seen this kind of figure or the videos on news channels. So, this is a very dangerous scenario, and if it happens, it may cause the loss of lives at higher altitudes. So, to understand snow avalanches, we need to understand snowpack characteristics so, the changes in the snow grain size and liquid water content are important parameters for avalanche forecasting. So, here there are two terms: snow grain size and liquid water content. So, here you can see that these are the grains of the snow. So, here you can easily understand that this looks like wet snow. So, albedo is also an important parameter for assessing the snowpack stratigraphy and avalanches. So, if there is a sudden change in the albedo during the winter, it can cause the formation of an ice layer, and fresh snowfall will cause an avalanche. So, what is happening? Let us say this is the area, and here you are experiencing snowfall. So, depending on the grain size, and the type of snow. So, whether it is dry snow, wet snow, or contaminated snow, the albedo that is reflected from this surface will be different. So, let us say here that if you consider this particular snow, it is bright, but if you consider this part, it looks like dirty snow.

So, assuming these are two different types of snow, here the albedo will be less, but their albedo will be very high. So, if there is a change in the albedo, what will happen? There will be a change in the absorption of energy. So, energy will be absorbed by the target. So, that will change the temperature of this particular snowpack, and because of that, this dry snow will become wet, and then slowly it will start melting. This is one part of the story. Now, albedo is also an important parameter to assess the snowpack stratigraphy and avalanches. So, what we mean by stratigraphy is that we need to understand. Snowpacks are often characterized by a number of distinct stratigraphic layers. So, these are the stratigraphic layers. So, you can see there is a boundary. I have another image that will help you understand these layers. So, here in these static graphic layers, the properties are very different. So, it will vary vertically, and the properties will be density, crystal shape, grain size, and hardness.

So, these will vary across this depth. That will help you understand how they have been formed and how consistent or stable they are in this particular area. This is another example; here you can see these are the distinct layers, so these are the stratigraphic layers. They have been formed at different times, and between this and this, there was a gap in the accumulation. So, here you can easily see the 8 layers. This is what I mean by the stratigraphy, and I have a few examples for the fresh snow and dirty snow. So, here you can see that you can easily understand that I mean to refer to this particular location as fresh snow; even here, if you see, these are the fresh snow, but here these are the dirty snow or the contaminated ones.



Feature	Dry Snow Avalanches	Wet Snow Avalanches
Temperature	< 0°C	> 0°C (or near melting point)
Trigger	Snow load, wind, weak layers	Melting, rain, warming
Speed	Very fast (100–300 km/h)	Slower (20–60 km/h)
Predictability	Depends on snowpack structure	Tied to temperature and melt cycles
Damage Potential	High due to speed and size	High due to mass and density

So, obviously, when you have contaminated snow, the energy coming from the sun in terms of solar radiation will be absorbed here because this will not work as a Lambertian surface. So, here the reflectance amount will be, let us assume, 10%, but when we talk about this particular layer, it may be 95%. So, you see the difference. So, here you will have less energy available for changing the temperature of the system, but when we have contaminated snow, we have more energy to change the system's temperature. Dry snow and wet snow play distinct roles in avalanche studies due to their different properties. So, this is dry snow and wet snow. Understanding the properties and behavior of both dry and wet snow is crucial for avalanche forecasting, hazard assessment, and mitigation strategies. So, here you can see the different types of snowfalls. So, here you have wet snow, normal snow, and dry snow. And, I have one example of wet and dry snow. So, here you can see this is the wet snow, and the top layer is basically your dry snow. So, if you want to make a snowball out of this dry snow, you will not be able to do so. But, if you are able to make these snowballs, then that is the wet snow. This is the simple way of understanding dry earth and wet snow. This is another example: sometimes when we have snowfall, we can easily make snowballs, but sometimes it is not possible. So, that is because of the wet and dry snows. So, if there is dry snow here and if there is a change in the temperature, we have more solar radiation; then this will change to wet snow. And then wet snow will subsequently melt if the temperature is still rising. Dry snow avalanches often form from newly fallen low-density snow or wind-deposited snow. The bonds between crystals are relatively weak. The characteristics can be fast-moving and create a large cloud of snow dust. They often involve cohesive slabs of snow breaking off during the sliding. The snowpack structure is studying layers of different snow densities and crystal types that can create weak layers. Wind loading analyzes how wind deposits snow unevenly, creating dangerous cornices and wind slabs. Fracture propagation involves researching how cracks initiate and spread through the snowpack. So, this is how we need to understand dry snow avalanches.

Now, we have a wet snow avalanche. So, the formation occurs when liquid water is present in the snowpack, typically due to warming temperatures, rain, or melting. Water lubricates the snow crystal, reducing friction and weakening the bond because of the saturation. Then we have a characteristic; it tends to be slower moving and heavier than a dry snow avalanche. They often involve the entire snowpack sliding down to the ground. So, here we have the liquid water content, melt-freeze cycle, and hydrodynamic processes. So, in liquid water content measuring, we monitor the amount of water in the snowpack. In melt-freeze cycle studies, how repeated melting and freezing or refreezing affects snowpack stability is examined. In hydrodynamic processes, understanding how water flows through the snowpack and influences its strength is essential. So, let us try to understand the dry snow avalanche versus the wet snow avalanche. So, here you can see the temperature in dry snow; it is less than 0 degrees Celsius.

So, that is why there are fewer chances of having liquid water here. And, when we talk about the wet snow avalanche, the temperature is greater than 0 degrees or near the melting point; that is why this dry snow will become wet snow and will move towards melting. They trigger snow load, wind, and weak layers can trigger this avalanche here when we have wet snow; the melting rain and warming can affect the process, and the speed here is very fast because of the dry snow and you can see the velocity correctly, but in wet snow this is slower at 20 to 60 kilometer per hour, whereas here it is 100 to 300 kilometer per hour. The predictability depends on the snowpack's structure. Tied to temperature and melt cycle. So, here the atmospheric parameters are very important. Damage potential in both cases indicates a high potential for damage.

Now, let us try to understand the application of remote sensing in avalanche studies, particularly in snow avalanche studies. So, let us take the example of optical remote sensing in avalanches. Avalanche debris and its surroundings are typically made of the same material, which is the biggest obstacle to avalanche detection utilizing electromagnetic snow properties. So, what is happening here? Since we are talking about the avalanche, here you have the snow cover, and one part is getting avalanched. So, why is it happening? We have understood that it has many other parameters, including the snow property and meteorological parameters that affect this process, but ultimately the property of this snow and the other snow are the same. So, it is very difficult to identify or monitor this using optical remote sensing because both appear similar in optical. Due to its high and consistent reflectance, dry snow appears brighter in the visible range. This reflectance diminishes as albedo drops in older or dirty snow or in snow with larger grain size. So, if there is contamination or a change in the grain size, the albedo will change. Avalanche activity is monitored using automatic time-lapse photography, which offers accurate near-real-time data and will help you model this disaster. Structure from Motion (SFM) photogrammetry facilitates the creation of detailed 3D models from an array of overlapping images. It is a low-cost, easy-to-learn, and extremely portable optical remote sensing approach that competes with LIDAR scanning in terms of spatial resolution and accuracy. So, earlier we had only this lidar scanning, but nowadays we also have the portable optical remote sensing approach, which provides very good spatial resolution and accuracy. So, here you can see some examples; these images will explain the process and the location we are discussing regarding the avalanche activity. Here with optical remote sensing in an avalanche, this particular image is the visualization of the RPAS flight path, and a 3D model of avalanche debris generated using the structure from motion technique; this particular image is the orthophoto of avalanche debris with its outline interpreted in red. So, this is the boundary of the avalanche. Now, let us talk about TLS terrestrial laser scanning. So, a scan of the slope with TLS in both snow-free and snow-covered situations detects mass loss in the starting zone and the slide pathways of released avalanches, as well as mass gain in the run-out zone. So, this TLS can give you very beautiful images of this location that can be used as input in your study. By measuring snow depth with a TLS before and after a controlled avalanche release, the snow depth of the avalanche debris was obtained. So, here you have a few components: monitoring snowpack changes, then pre and post avalanche surface comparison, then avalanche volume estimation, and finally hazard assessment and mitigation. So, when we talk about monitoring snowpack changes, we have to detect small-scale snow accumulation, settling, and compaction. For the pre- and post-avalanche surface comparison, it helps you detect this snow erosion and deposition zone. When we say avalanche volume estimation, it calculates the snow volume displaced by the avalanche. So, that will help you understand the impact of it in the later part, which is the hazard assessment and mitigation. It identifies terrain features influencing avalanche behavior.

So, here you can see the output of TLS scanning of mass gain and mass loss in the snow cover induced by avalanches. Now, you might be wondering how it is different from a landslide because in both processes, it is the mass that is coming down the hillslope under the influence of gravity. So, how is it different? So, both involve rapid downslope mass movement of materials under the influence of gravity. So, here you can see this is the avalanche, and this is an example of a landslide. Landslides involve rock, earth, or debris that we have seen in the landslide module. But when we talk about avalanches, it involves snow and ice. So that is why there is a difference in the material. So, the basic difference is the type of material they have and the type of environment they are in, these are the locations that were reported in 1987, and these are possible locations of avalanche activities. Around the globe, and this is from India. So, we have Karakoram, Western Himalaya, Central Himalaya, and Eastern Himalaya; these are the possible locations for avalanches. So, let us try to understand the anatomy of avalanches. So, first, we have this crown line.

So, in the figure, you can see the crown line.

So, the crown will always be on the top. So, that is why we have this crown here and the name "crown line" we are using. So, this is the crown line or the fracture line. So, the uppermost point where a slab avalanche separates from the snowpack is identified. So, here this will be stagnant, but this whole mass will come down. Then we have flanks. The two arms connected by the crown have a downslope orientation, while the orientation of the crown is across the slope. So, the flank is here; even this will be the flank. This is flank, and here you can see that post-avalanche, the debris will be coming in this direction. And this is the bed surface of the avalanche. Then we have the bed surface that we have understood there, so this is another avalanche where we have the bed surface here. Inside this, this is the bed surface. And here you have the flank, here you have the crown, and the debris will be here in the downstream or in the downslope. Any material collected by the avalanche in its path may contain timber or rocks if we are talking about large-scale avalanches. Then, Stauchwall. So here you can see it beautifully shows you this Stauchwall. It is the downslope boundary of a slab avalanche. It is the lowest point of the fracture line where the slab releases and slides over the underlying snow. So, this is the Stauchwall. The avalanche path consists of three zones. So, here you can see the size; the size of the avalanche also matters, whether it is small scale or large scale. So, that is very important.

So, in the first zone, the release area where the avalanche begins. So, this is the release area. The second zone is the track where the avalanche reaches its maximum velocity. So, here is the track where it will have the maximum velocity. The third zone is the run-out area where the moving snow slows down and stops. So, this is the run-out area. So, here you can see the features of avalanches. So, avalanches are mostly triggered spontaneously by factors like snow or rain due to the change in temperature during rainfall, as raindrops also carry a certain temperature that will change the temperature of the glacier system or snow system. Avalanches can also be triggered artificially by things like skiers and explosives. So, here you can see this particular video I am going to play, and here this particular gentleman was skiing, and then because of that movement, this avalanche got triggered, and you see the scale of this avalanche. So, the explosive triggers that is also possible. So, here hunting down the cornices is. So, cornices are overhanging ledges of snow that form on the leeward side of ridges or mountain edges. Here you can see that these are the cornices. So, this is a mass that is hanging, formed because of this snowfall or the accumulation over time. They are created by wind transporting and depositing snow, which then builds up over time. It refers to identifying and assessing the risks associated with snow cornices, which are overhanging masses of snow that can break off and cause avalanches.

So, here we are going to do the manual blasting to remove this one. So, you can see that we have the Wyssen Tower. So, here you can see this particular video; this is just to explain it to you, and these are very nicely created videos. So, that will help you understand. So, these Wyssen avalanche towers use remote control blasting to proactively cause avalanches. The control center sends a coded command to the deployment box control system to start blasting explosive are available in that particular box in order to cause an avalanche. Then we also have artillery methods. So, manually we are firing and then triggering these avalanches as and when required. So, there are three main forms of avalanche release. So, the first one is the loose snow avalanche, then we have the slab avalanche, and then the gliding avalanche. So, you can see the loose snow avalanche; they are very loose. So, they are not very dangerous, you can see. But the slab avalanche will be a major chunk of mass causing this particular disaster. Then, gliding avalanche, here you can see it is gliding; there are multiple fractures available here and they are causing. So, the loose snow avalanche, also known as point release or sluff avalanches, begins at a single point or fracture line on a slope and spreads out in a cone as it moves downhill. So, they are moving down the hill. Loose snow avalanches start with a small mass of cohesionless snow falling on the surface. The initial mass in a loose snow avalanche entrains more snow as it moves downhill. So, this will keep accumulating, and then the masses will increase. Then we have a slab avalanche; it involves the release of a large cohesive layer of snow. Slab avalanches occur when an extended weak layer buried within the snowpack fails. It is often triggered by scares, heavy snowfall, or temperature changes, making it more dangerous than a loose snow avalanche. This is what we discussed in the previous slides.

Then, we have a gliding avalanche release of the entire snow cover as a result of gliding over the ground. The risk of a gliding avalanche can easily be identified by the typical fish mouth cracks. So, these are the fish mouth cracks. Gliding avalanches fail where the underlying ground is smooth, typically on grassy slopes. So, what happens on this grassy slope is that the more accumulation of snow and the subsequent change in temperature will lead to the failure of this particular slab. Cannot be artificially triggered, and the steepness is greater than 27 degrees; often at low and mid-elevation, it is found gliding on a film of water, most often on steep meadow slopes, which very rarely cause fatalities. So, to understand the avalanche problem, we have divided this into different categories based on the characteristics. So, from that, the potential and behavior of avalanches can be understood; the four main problems are character, size, location, and likelihood. This is what we are going to see. So, this is a very nice diagram related to the avalanche problem. So, here are the 4 elements: character, size, location, likelihood. So, you can see that the avalanche problem the character plays a very, very important role here. Then we have the location; what is the location of the avalanche? Then, the likelihood, what is the probability, and then finally the size of the avalanche will help you to understand the disaster or the fatalities caused by this particular avalanche. So, here you can see the different elements of the character. So, here you have loose wet, wind slab, storm slab, gliding, cornices, and loose dry, all listed. So, with this, I will end part 1 of this lecture. We will continue this. Thank you.

Thank you very much.