REMOTE SENSING FOR NATURAL HAZARD STUDIES

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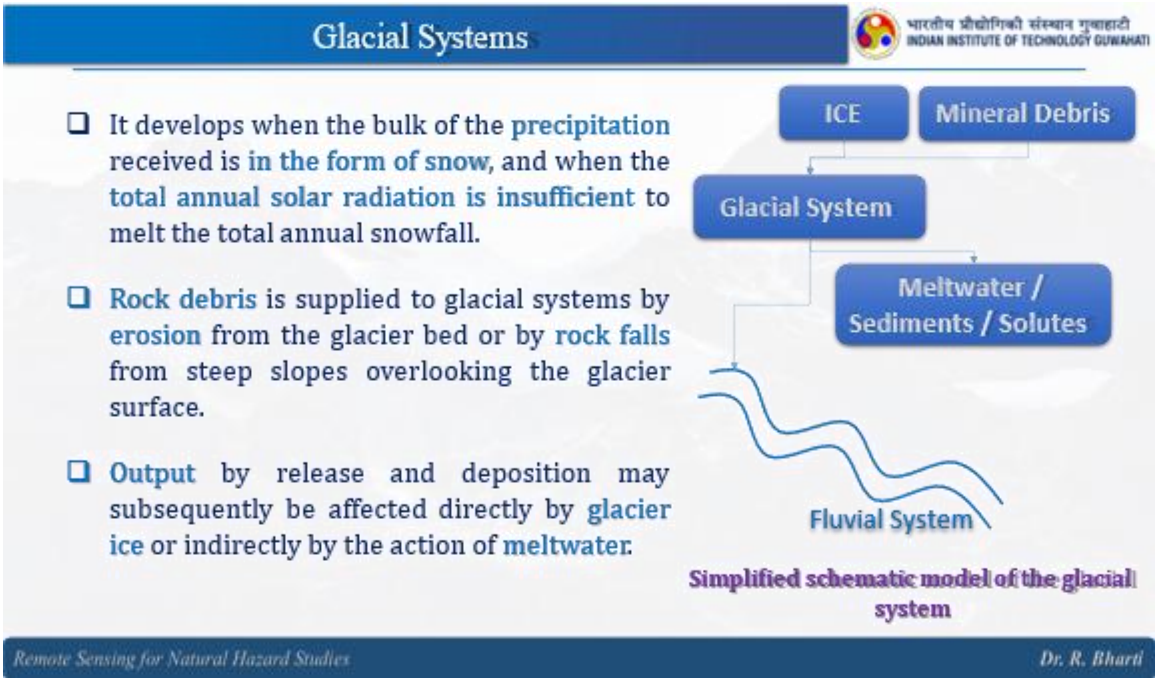
Lec 20a: Introduction to Cryosphere Hazards Part A

Hello everyone, welcome to Lecture 20. This is the second lecture of Module 6, which is on Cryosphere Hazard. So, today we will see more details about the cryospheric hazards. So, before we get into the hazard part, let us understand why exactly this glacier study or cryospheric studies are needed. So, we will start with the importance of glaciers and glacier study. So, if you see here, glaciers play a crucial role in ensuring a stable year-round water supply. So, basically, we are dependent on the glacier-fed rivers, and some of them are purely glacier-fed; some of them are rain-fed. So, it is mixed with both, but if you see the year-round supply that is coming from the glacier-fed rivers. So, for example, Gangotri is responsible for the Ganga River and the glacier near Lake Mansarovar that is responsible for the Brahmaputra River.

Rapid deglaciation is a potential consequence of evident climate change because if there is a change in temperature or atmospheric pressure, any changes in atmospheric components directly impact the glaciers. Understanding the progenesis of glaciers requires knowledge about their mass change. So, if you want to see how they will be in the future, what their status will be, then you need to have a very good understanding of the mass balance. So, coming back to this again, the importance of these glaciers. So, it is basically the year-round water supply that we need to sustain life on this particular planet. So, before we get into the hazardous part again, let us see some of the more basic components.

So, let us see the details of the glacier system. So, here you can see the ice and the mineral debris that are coming into the glacier system. So, what happens? It starts with solid precipitation and slowly, because of metamorphism, it turns into glacier ice, and due to the influence of gravity, it starts to move and during the movement, what happens is that the rock debris is supplied to this glacier system by erosion from the glacier bed or by rock falls, and that is coming into this glacier system here, and slowly they are coming to the zone where it starts melting correctly.



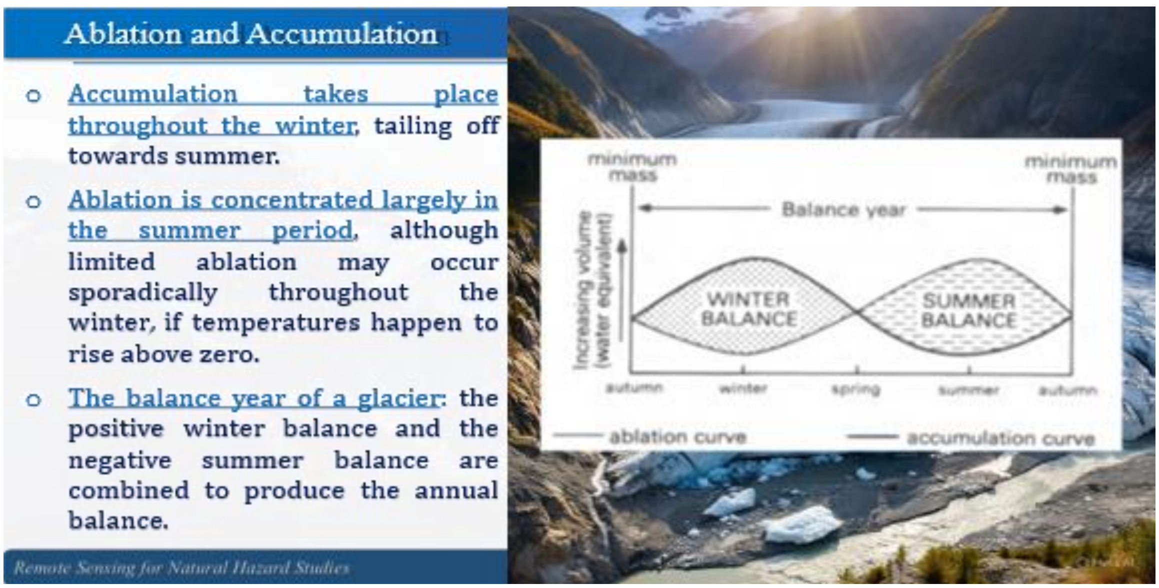
So, the meltwater will again link to the fluvial system, which is downstream, and that will feed this particular river, which is coming to our region. So, output by release and deposition may subsequently be affected directly by glacier ice or indirectly by the action of meltwater.

So, whatever changes we see here are because of the meltwater, sediment, and how this glacier system is being affected by climate change. If you see the glacier and the environment, the development of glaciers depends on the complex interaction of climatic, topographical, and geographical factors, of which precipitation and temperature are the most important controlling climatic factors, because this will decide whether you will have a positive mass balance or a negative mass balance.

For glacier development, high annual precipitation is required in the solid form, which is snow. The proportion of precipitation received as snow, which is the ratio of snowfall received in water equivalent to total precipitation, is basically how we measure the snowfall in water equivalent. So, what happens? Let us see if this is a mountain, and here the climatic conditions support the snowfall, the solid precipitation. So, this is the line from where you have solid precipitation. Now, what happens? The first few years, let us say in winter, it accumulated maybe 1 meter, and then comes the summer season. Again, you have the accumulation. So, the melting was less correct. So, after the winter, the summer season will come, and maybe because of the temperature change, there will be some melting.

So, initially the accumulation was 1 meter, but there is a melting of 30 cm. So, 1 meter minus 30 cm will be your mass change or the mass balance of this particular area. So, this is how slowly this gets accumulated, and because of the temperature and pressure, it gets metamorphosed and comes up with this kind of glacier ice. The annual snow budget is greatly influenced by solar radiation because solar radiation is the only source from which we get the energy to melt these glaciers. So, the geographic location plays a very critical role here in determining whether this region will have a high temperature.

The low temperature will be decided by the location. Then the distance to the ocean will also play a role in determining or influencing the total amount of precipitation. So, whether this particular area will receive high solid precipitation or low solid precipitation will be defined by the distance from the ocean. Then comes the topography, which plays an important role on the regional scale. So, on the regional scale, the topography has. A very good impact on the glacier system. So now we have learned what the glacier system is, what its environment is, and what the controlling factors are.

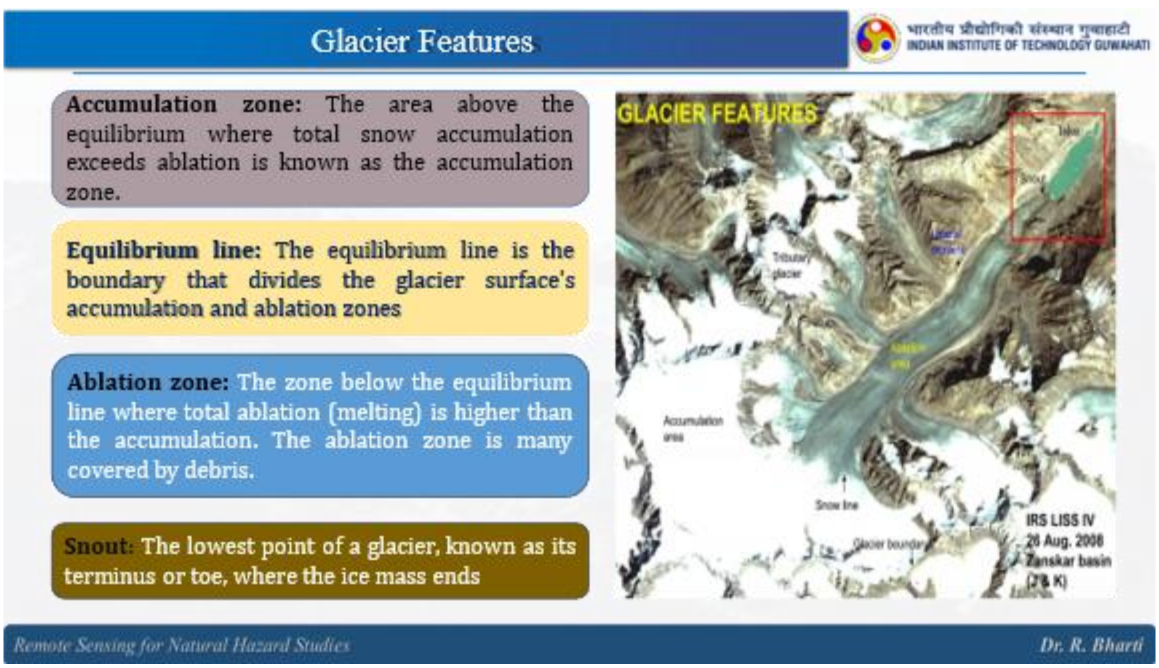


Now, let us learn about ablation and accumulation. So, we know that the solid precipitation accumulates more and gets deposited on this surface, and we say this is accumulation. But what is ablation? It is simply melting. So, the accumulation takes place throughout the winter, tapering off towards summer. In the summer, what will happen is that melting will start. So, the accumulation can be seen largely in the winter season. Ablation is concentrated largely in the summer. Although limited ablation may occur sporadically throughout the winter, if the temperature happens to rise above 0, the balance year of a glacier is very, very important. The positive winter balance and the negative summer balance are combined to produce the annual mass balance. So, as I said, if you draw the graph, let us say this is the solid precipitation; here it is. In meter water equivalent, let us say this is 1 meter. Now this winter, let us put this summer here again. So, in summer, it melts. So, this will be the accumulation for winter; it is melting or ablation. So, if you see, the melting is only this much.

So, this has a positive mass balance. This is what we have here in this graph. So, if you see this kind of behavior where ablation and accumulation are both equal to each other, then we call it mass balance or the balance year. If the ablation and accumulation are both equal in a given year, then we call it a balanced year. So, this is winter balance; this is summer balance. Together, there is no change in the mass. So, that is why we are calling it a "balance" year.

If the area under both the accumulation and ablation curves is equal, then the budget is balanced, and the glacier is in equilibrium. If accumulation is in excess, then the glacier has a positive budget and is growing. This is what we discussed in the previous slides. If the budget is negative, that means melting is greater than accumulation; then the glacier is shrinking. Accumulation is greater at higher altitudes because, if you observe the accumulation, solid precipitation occurs at higher altitudes, where ablation processes are more limited due to lower temperatures.

So, here, because of the low temperature, accumulation will be greater compared to ablation or melting. That is why you can see that the accumulation is greater at higher altitudes. Ablation dominates accumulation in the lower part of the glacier. So, here, when it comes to the low-lying areas or those at a relatively lower altitude, ablation will dominate over accumulation. The point at which ablation and accumulation are balanced is the equilibrium line. So, there will be a line where both are equal; that will be your equilibrium line. Let us see the different features of glaciers.



So, here you have an accumulation zone. So, here you can see that the accumulation zones are basically at higher altitudes; the area above the equilibrium where total snow accumulation exceeds ablation is known as the accumulation zone. Then we have the equilibrium line; the equilibrium line is the boundary that divides the glacier surface accumulation and ablation zones. So, if you see, this is the ablation area, and there will be some accumulation area. So, if this line divides these two zones, we will call it the equilibrium line. The ablation zone, the zone below the equilibrium line where total ablation is higher than the accumulation, is mainly covered by debris. Then we have the snout; this is the mouth of the glacier, the lowest point of a glacier known as its terminus or toe, where the ice mass ends. So, if you see here, this may be the snout of this glacier; from there, it will start melting.

So, here you can clearly see that the snouts are marked. So, here, if you look at 1780, the Gangotri glacier had its snout up to this location. Then in 1935, this was shrunk, and it is here; then in 1956, we have this note; then in 1964, it is here; 1971. This was here in 2001, it is currently here, and maybe in 2025, I do not have the actual data, but it is probably shrinking again. So, you can see how the snouts change over time because of the changes in the climatic conditions.

So, one of the important aspects of this melting is to generate or develop a new glacier system. So, here you see this glacier, and here at the toe of this, we have this glacier lake. So, slowly, what will happen if there is more input?

So, there will be more melting, so there will be a negative mass balance. Negative mass balance. So here the water will rise, and then, probably because of the capacity of this particular lake, the excess amount of water will breach, and it will go downstream. So that is why these glacier lakes are very, very important, and we need to have a very good understanding of the mass balance and development of any new glacier lakes.

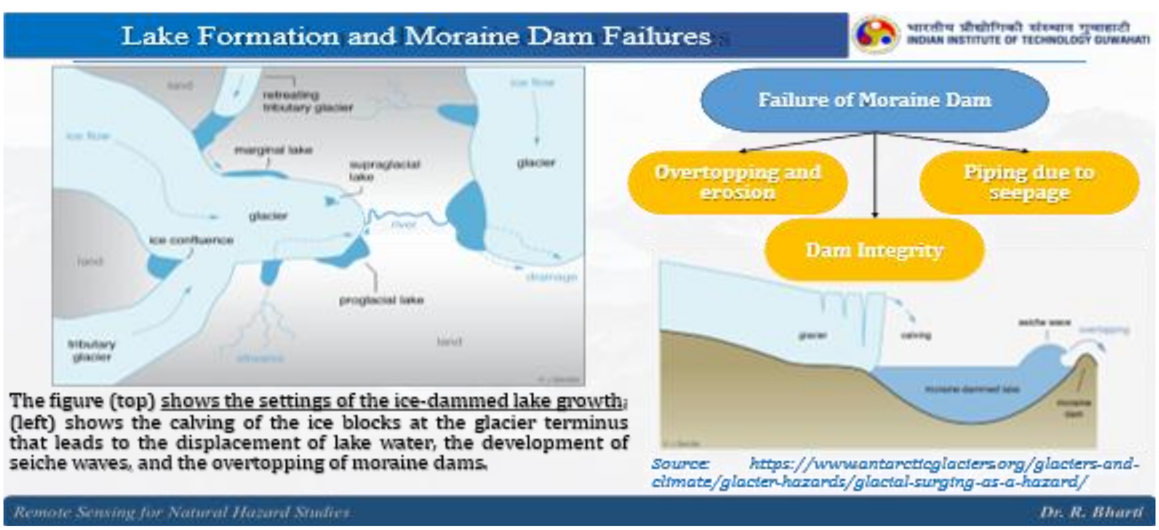
So, here you can see that this beautifully shows the development of a system. Glacial Lake here, slowly at the depression, just next to the snout, there is an accumulation of water, and what will happen in the future, suppose it is shrinking further, this area will also be available for this Glacial Lake. So, for this reason, there will be a new development of Glacial Lake, and slowly, this might take this kind of form. So, here you can see some glaciers. So, a rock and ice avalanche struck the glacier lake at the base in eastern Nepal, triggering a 5-meter surge that overtopped the natural dam.

So, because of that, there was an overtopping, and this extra water caused the GLOF. Then here you can see the lake surrounded by steep slopes below the glacier that feeds the lake and threatens it with floods and avalanches. So, such glacial lakes are very, very important to study and monitor continuously. So, here you can see the basics of glacial lakes: how they are generated and what their importance is. So, a glacial lake is a body of water that originates from glacier activity. They are formed when a glacier erodes the land and then melts.

Filling the depression created by the glacier. As we discussed in the previous slide, this depression was created by the meltwater. Glacial lakes are often dammed by moraine or ice. So, here you will see the moraine that is accumulating and storing this water. In the Indian Himalayan region, most glacial lakes are formed due to retreating glaciers as a result of climate change.

Over 5,000 glacial lakes have been identified in the Indian Himalayan region. Primarily in Sikkim, Himachal Pradesh, Uttarakhand, and Jammu and Kashmir. The majority are in the upper reaches of river basins such as the Indus, Ganges, and Brahmaputra. This is from the ICIMOD report of 2011, and here you can see clearly that we have marked the accumulation zone, and these are the regions. This is where the melting starts.So, this is what we call the ablation zone. This is the lake. I hope all the components are clear to you. Here, you can also see the glaciers coming, and this is the snout; further, we have the formation of glacial lakes. So, the accumulation of glacier meltwater behind ice dams, bedrock barriers, or moraines to prevent the water's natural flow is what we call glacial lakes.

So, the moraine dam lakes formed when the glacier debris creates a natural dam that obstructs the flow of meltwater, and then there will be a formation of a glacial lake. Then we have ice dam lake results due to the temporary blocking of a river impounding meltwater by the glaciers. Then we have a glacier erosion lake formed by the depression caused by erosion as the glacier sculpts. Other glacial lakes are fed by the direct melting of glaciers within the glaciated valleys. So, we have different types of glacial lakes, and there are different types of moraine present, and depending on that, the stability will be defined.



So, here you can see that this particular figure shows the setting of the ice dam lake growth. So, here you have supraglacial lakes, then a marginal lake, and because of the retreat, you have the formation of new lakes here. And then, if this is connected to a river system, there will be snowmelt-fed rivers Failures of the Moraine Dam are due to two major reasons: overtopping and erosion, and then piping due to seepage and the dam's integrity. So, this figure beautifully explains what happens if there is a calving effect in this lake.

So, what will happen if this mass comes to this system is that there will be a seiche wave generation, which causes the overtopping, and this water may or may not remove this moraine. Because of this water, there will be a GLOF event downstream. If you see the breach in season when the flowing water erodes some moraine channel, a positive feedback loop is created; this is when a breach in season occurs. If you see, this location is the moraine bridge location, and here we have the glaciers that feed this particular glacial lake. The increased water flow accelerates erosion, thereby causing the failure of the dam. The process can then lead to rapid moraine dam lake drainage and potential GLOF.

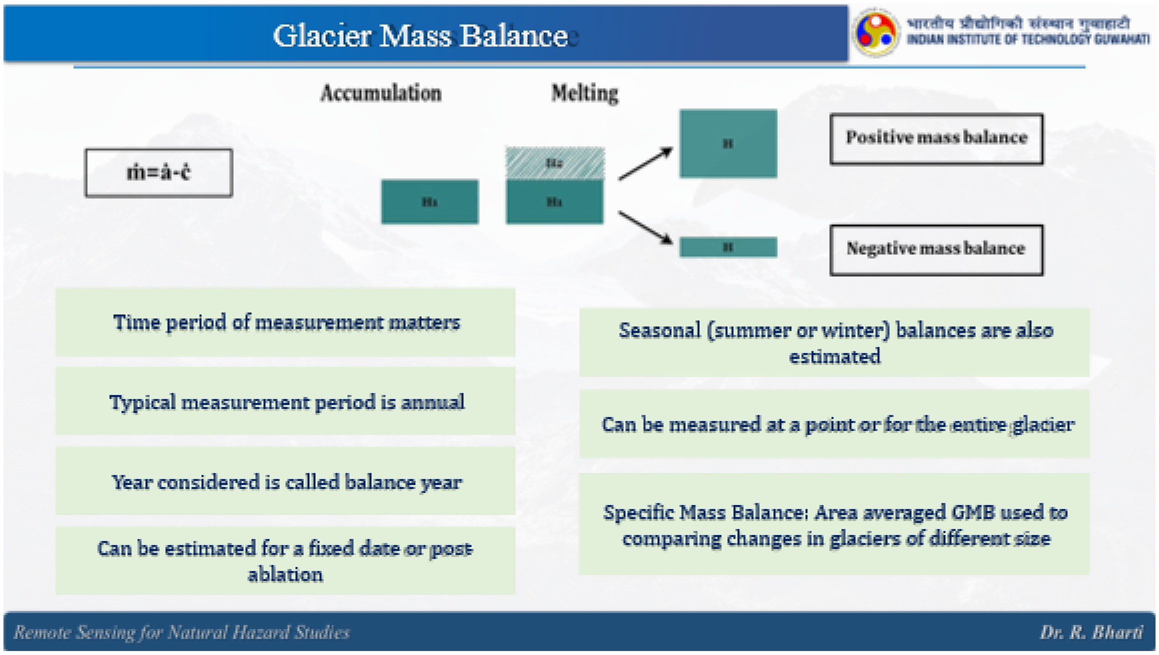
Because of this, it may cause the GLOF event downstream. This particular image was created by NASA. So, here you can see the Bishop Glacier Lake of Canada and how it is growing over time. So, you see this particular time frame. So, starting from 1984, how is this changing with time? Then we have the South Lhonak Glacial Lake from India.

So, if you see here, this is 1967, how the lake was there, and if you see the latest 2022 image, there is a drastic change in the area. So, we have also created a video here; you can see how this video is changing with time. So, recently we had a GLOF event in the South Lhonak Glacial Lake, and it experienced the calving effect. Because of this calving, there was overtopping of the water, which caused the glacial lake outburst flood downstream. So, the importance of the Glacial Lake is that it is a freshwater source.

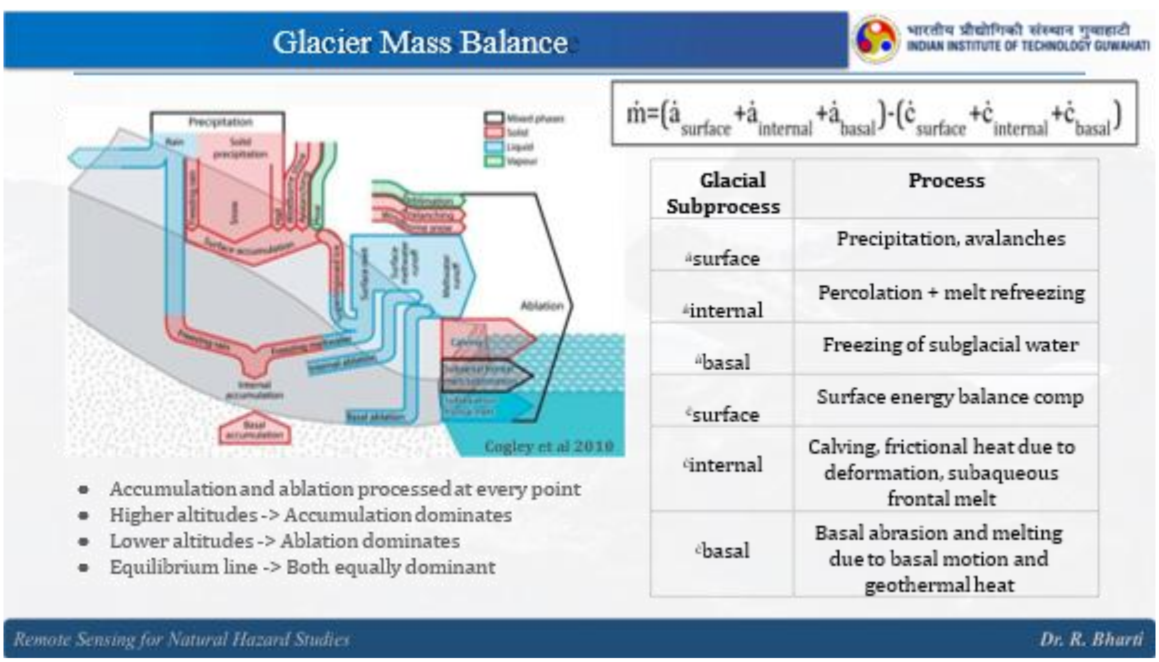
Then we have a very good climate change indicator; it also attracts tourism, improves the livelihood of that particular area, and it also has a very good role in the ecological balance. Then we have the potential for hydroelectric power. The disaster risk is one of the things we are most worried about because it can affect the lives and property of the people living in that particular region or downstream. The water that is coming from the melt is right.

So, basically, it is causing the mass balance change. If there is a negative mass balance, you have more water in the glacial lakes, and then you have more vulnerability to glow events. So, the annual mass balance is the difference between the snow accumulation during winter and the ablation during summer over a year. Thus, the glacial health can be measured with mass balance. Glaciers are affected by variations in temperature and snowfall.

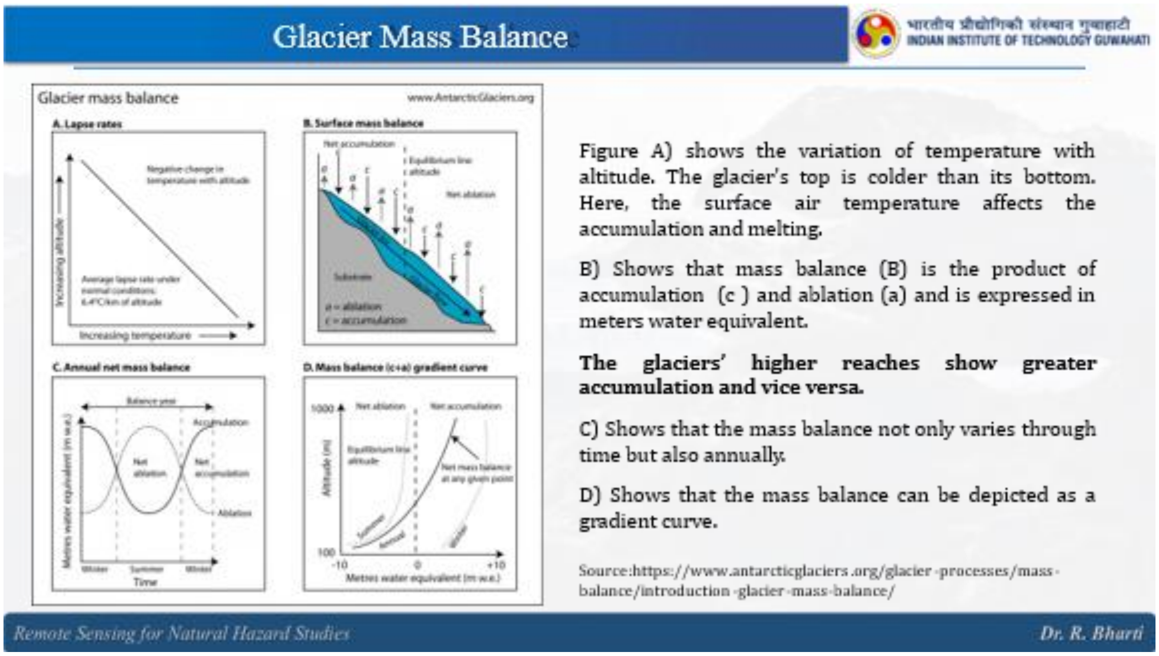
This is what we discussed. The study of mass balance serves as the system that accounts for the loss or gain of ice and snow in response to climatic change. So, this figure shows the Himalayan region in different colors, and the glacier boundaries are shown in purple.



So, if we talk about the glacier mass balance, here you can see that you have two things: accumulation and melting; this is basically ablation. So, if there is an increase in the mass balance, then it is positive. If it is decreased in the mass balance, then it is a negative mass balance.



So, until now, I hope you have understood that if you have a negative mass balance, you have more supply to the glacier lakes, and you have more vulnerability to the GLOF kind of disaster. So, here you can see that this is the mass balance we can calculate. So, here at higher altitudes, accumulation dominates, while at lower altitudes, ablation dominates, and the equilibrium line has both equal proportions.



So, here you can see figure A, which shows the lapse rate, and the glaciers' higher reaches show greater accumulation, and vice versa. So, you can see, and we will have a separate discussion on the glacier mass balance.

So, this is just for your information that glacier mass balance is one of the major parameters that we need to study to see the status of glacier lakes as well as the glaciers. So, if you see the different cryospheric hazards that are related to this glacier system. So, the various events caused by the cryospheric processes can threaten human lives and affect the surroundings. The cryospheric disasters are a result of changing global climatic conditions.

Here, you can see some examples. I have provided. So, if you talk about the different cryospheric hazards, the major ones are glacier lake outburst floods, ice avalanches and landslides, river ice jams and flooding, sea ice loss and maritime hazards, snow avalanches, permafrost degradation and slow failure, and rapid glacier retreat and instability. And just to show you the impacts of the cryospheric hazard, you can see that if we talk about sea level rise, it is related to the mass balance of the glacier system. So, this report was published by NASA, and you can see. Starting from the 1990s to date, there has been a change of 100 millimeter in sea height.

So, this was very evident from the satellite image study. Then we have glacier surges; you can see that the surges can impact the downstream. Then, rock, snow, or ice avalanches are the major problems at high altitude. Then seasonal floods due to snowmelt, then glacial lake outburst floods, then we have debris flows; you can see downstream how devastating it could be if there is a sudden release of water. Mass wasting due to permafrost degradation. So, there are several studies available that talk about mass waste due to permafrost degradation.

Then we have snow or glaciers melting. So, particularly, this glacial lake outburst flood is very, very dangerous, and these incidents have increased in the past few decades. So, we will talk about these in the next part of this lecture.

Thank you. Thank you very much.