

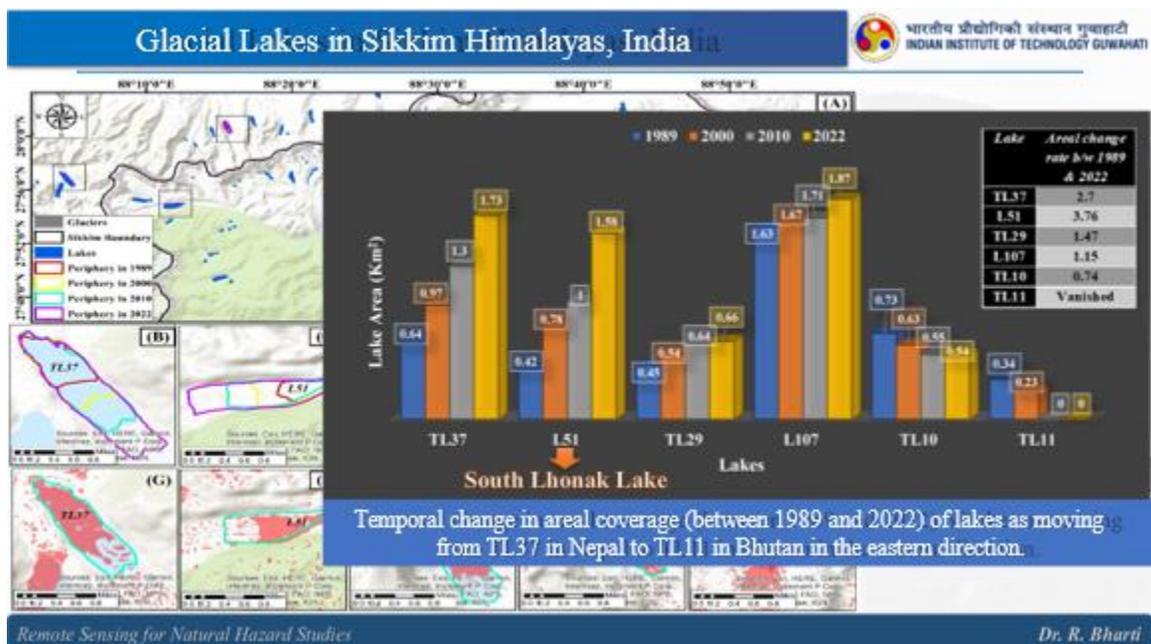
## REMOTE SENSING FOR NATURAL HAZARD STUDIES

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### Lec 20b: Introduction to Cryosphere Hazards Part B

Hello everyone, welcome back to Part 2 of Lecture 20. So, we were discussing the different types of cryospheric hazards. So, we will continue that discussion about the GLOF, Glacial Lake Outburst Floods. So, it is basically the sudden release of extensive water present in the glacial lake as a result of slope failure, breaching, overtopping, or other mechanisms. So, you can see there is a sudden release of water that is causing the glacial lake outburst floods. So, what are the different causes of GLOFs? So, it could be because of the heavy rainfall, not the solid precipitation.

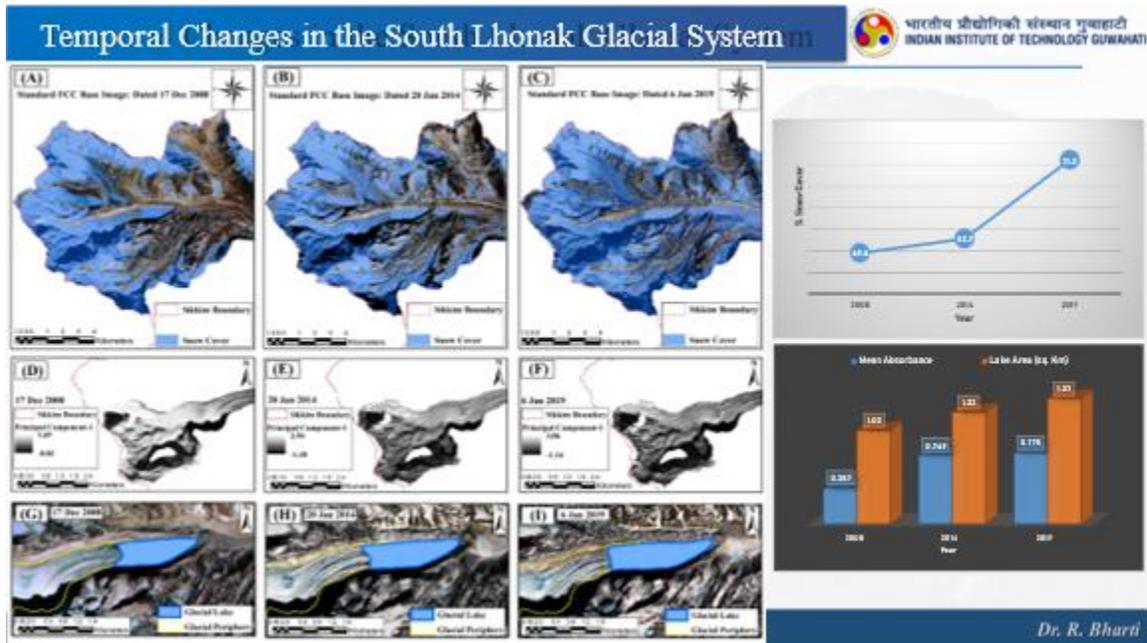
Failure of a moraine dam or ice dam might occur due to volcanic activity, rapid glacier melting, and avalanches, which may cause overtopping.



So, if we refer to the glacial lakes in the Sikkim Himalayas, you can see we have conducted several field investigations, and here, these are the different glacier lakes that

we have visited, and then we have tried to see how the lake area is changing over time. So, you can see that from 1989 until 2022, the area has been changing.

So, some areas of the lakes are changing drastically. So, that is our major concern if you look at this particular graph. So, this is showing the temporal change in aerial coverage of lakes from 1989 to 2022, moving from TL 37 in Nepal to TL 11 in Bhutan in the eastern direction, and here you can see this is particularly true for South Lhonak Lake, how it is changing over time.



So, this is the temporal change study, particularly for South Lhonak Glacial Lake, and here you can see how it changes over time: in 2008, in 2014, and in 2019, and if you see the snow cover in that particular area, it is increasing.

So, here you see the mean absorbance and the lake area that are given here over time. So, it is also showing an increased tendency. So, this is what we experienced on October 3rd, 2023. So, here is the image. Prior to this GLOF event, and this is after the GLOF.

So, because of the overtopping, this excess water came into the fluvial system, which has caused excessive problems downstream. So, here you can see the disaster during the South Lhonak glacial lake event.

## Kedarnath Disaster of 2013



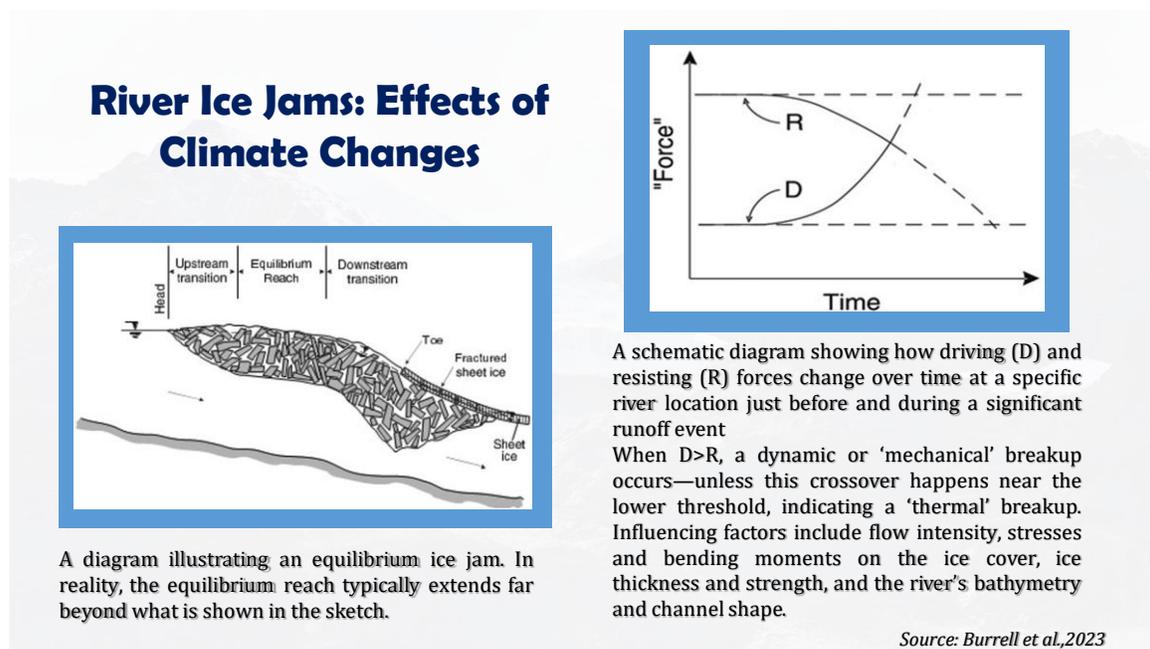
The images show the increase in the settlements from 1965 to 2011 (a and b). The event of 2013 caused complete (53%) and partial damage (22%) to the structures (c and d). The circle in the image is the Kedarnath temple, which remained unharmed post-flood event. Here, A, B, and C denote completely damaged, partially damaged, and slightly/unaffected structures, respectively.

Similarly, for the Kedarnath disaster that occurred in 2013, you can see some of the photographs available in several papers. So, this is a post-event, except for this temple, all the areas on 17th June 2013, an outburst flood from Chorabari Lake, which was formed by the lateral moraine, caused extensive damage to the northwestern flanks of Kedarnath village. Kedarnath lies within a kilometer of the termini of the Chorabati and companion glaciers. So, here you can see this is the Kedarnath settlement, and this is how this flow has come to this particular location. This is from another paper where they have significantly marked the affected areas. So, the image shows the increase in the settlement from 1965 to 2011, A and B; these are the two images you have to refer to. The event of 2013 caused complete damage of 53% and partial damage of 22% to the structure. And here you can see that this is the marked location for the Kedarnath temple. So, the circle in the image is the Kedarnath temple, which remained unharmed after the flood event. Here, A, B, and C did not completely damage, partially damage, and slightly affect structures, respectively.

Then we have one example of a Shisper Glacial Lake outburst flood. So, here you can see this is located at this particular location and has multiple sources of glacial lake meltwater. So, this happened on May 7, 2022, and because of that, you can see there was massive damage in this particular location. So, a community hall and houses show signs of damage after a glacial lake outburst flooding incident at the nearby Shisper glacier. So, this is another report from the down-to-earth perspective. So, they have published about the glacial lake outburst flood in the Karakoram Himalayan region. So, you can see there are many locations that have been marked as the potential or historical glacial lake outburst floods.

Then we have the evidence from the Kashmir Himalayas, so here we have studied the period from 1972 to 2019, and you can see how it is changing, or how the area is changing with time. So, the frontal retreat of the glacier and the changes in the area from 1972 to 2019 are depicted in this image. The data seen here are planet Cubesat imagery of the year 2019, the base image the but we have studied this since 1972. Then another type of disaster related to the cryosphere is the ice avalanche and landslides. Ice avalanches occur when the overhanging ice breaks off.

The glacier that flows over a cliff forms an icefall. These ice blocks, when they fall, trigger an ice avalanche. An ice landslide occurs due to the weakening of the ice and is a slow, gradual movement of a large chunk of ice moving downslope.

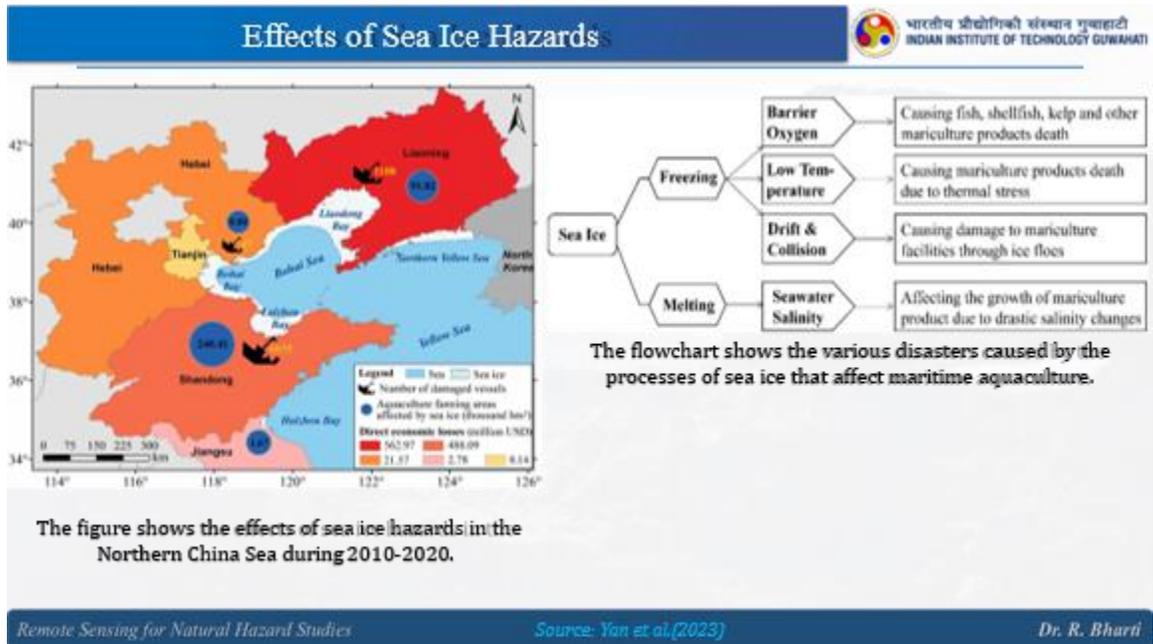


So, then we have the river ice jam; river ice jams lead to flooding due to the obstruction of the river flow and cause the water level to rise upstream. Suppose it is flowing in this direction, and because of the ice, there is an obstruction in the flow.

So, what will happen is that the level of the water will go up in this region. The river ice jam effects of climate change; you can see here a diagram illustrating an equilibrium ice jam. The equilibrium reach typically extends far beyond what is shown in the sketch. So, here you can see how the forces and the time are interacting. Here, this is another example; you can see the distance downstream and the forces.

So, a schematic shows how driving and resisting forces change downstream over time, with broken ice blocked by intact cover forming an ice jam. Then, sea ice loss is the result of sea ice, which is the frozen water that forms, grows, and melts in the ocean. Sea ice affects both global ocean temperature and the global movement of ocean waters.

Significant ice loss is seen in the Arctic in a few decades, and if there is a loss of sea ice, what will happen? The level will rise. The figure shows the sea ice in the Arctic Ocean and the maritime hazard risk.



So, there is an immediate risk of amalgamation of sea ice hazards and human activities such as shipping. Then, long-term hazards are the rapid reduction of ice extent in summer, unpredictable conditions such as drifting ice, flows, as well as sudden changes in weather. Then we have navigation-related hazards, and we have near-term hazards increased coastal erosion due to changes in the sea ice dynamics and extent. This is an example of the global sea ice in the Arctic and Antarctica. So, the figure shows the extent of sea ice in the Arctic and Antarctica, and the y-axis does not start at 0.

So, this is not on the scale. The 5-year rolling average is observed. So, you can see how it is changing. Ice mass variation since 2002 shows the changes in Antarctica and Greenland. So, both are changing drastically.

So, there are different satellite images and satellite missions that are dedicated to this kind of problem. So, one of them is the GRACE-FO; then we have NASA's IceBridge and the IceSat-2, which can be used to study this kind of phenomenon. Effects of sea ice hazards. So, we have seen some examples; this further explains that particular problem. So, the flowchart shows the various disasters caused by the process of sea ice that affects maritime aquaculture. So, here you have sea ice freezing and melting. So, how is it affecting what is given here? Rapid glacier retreat and instability are occurring. So, if you refer to the glacial retreat, it refers to the rapid shrinking of glaciers as the rate of melting increases and ablation exceeds snow accumulation. So, here we have two different

domains: one is water availability decreasing, and that will cause an ecosystem problem. Then we have increased hazards, such as glaciers, and that will lead to a rise in sea level.

So, this instability is the biggest problem nowadays related to the cryosphere. Here again, we are referring to the Gangotri glacier. It is the moraine representing the retreat of the glacier from 1780 to 2001. And we have seen how this snout is changing, which is basically a reduction or the shrinkage of this glacier system. The melting of Greenland glaciers, which flow into Arctic waters through the steep-sided fjords, is a major source of global sea level rise that is occurring due to climate change.

Here, you can see that this particular photograph was captured during a specific project. So, the OMG project dropped probes by plane into the abyss along Greenland's coast to measure water depth and salinity. Then we have the glacier retreat. So, these are some photographs that show the impact of the glacier's retreat. So, in the left image, is the Muir Glacier in 1941, while the image on the right shows how the tidewater glacier retreated 12 kilometers by the year 2004.

So, you can see both are from the same area, but here there is a formation of a glacial lake because of the retreat of the glaciers. So, this remains the same; this is the glacier. Then let us talk about the Chamoli disaster. So, this is one of the disasters that we will never forget. So, a massive rock and ice avalanche originated from the 6,063-meter height of Ronti Peak on 7 February 2021.

The event triggered a series of events that led to the death or disappearance of more than 200 individuals. It caused extensive damage to infrastructure, including two hydropower projects located in the valleys of Risiganga and Dhauliganga. So, this is one of our papers explaining the reasons why it happened. So, if you are interested, you can refer to this paper.

Here you can see the A. This particular image shows the geographical location of the affected area. So, with DEM and satellite images, you can now see how beautifully we can identify the location, and we can also see the topographic variation. The B, which is from the Sentinel-2 satellite image, shows the pre-event. So, this is the pre-event. Here you can see there is a mark. You can see. So, the site of the collapsed rock and glacier block is seen where the red arrow indicates the fracture, which became the landslide headscarf.

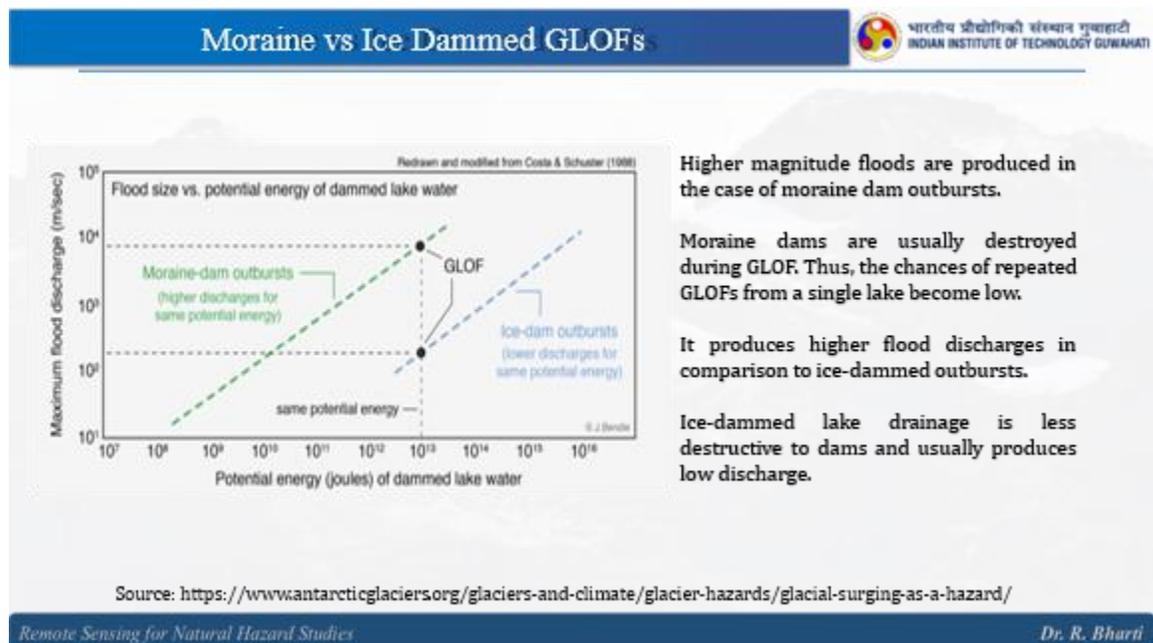
So, if I remove these red dots, you can easily see that the fractures have developed, and slowly they are getting detached from the main mass. So, in the D image, you can see the post-event satellite imagery where the remaining portion of the lower eastern glacier is depicted. So, you can see the comparison. E is the 3D rendering of this area; this is 500 meters. The permafrost degradation and slope failure, along with the permanent thawing of frozen ground, can cause an increasing risk of slope failure. So, how does permafrost

degradation lead to slope failures? So here you have slope instability, increased pore water pressure, reduced soil strength, and ground subsidence.

So, these can be studied. Then we have snow avalanches, rapid, gravity-driven snow masses that move down the slope of a mountain. Here we have the loose snow avalanche and the snow slab avalanche, and here you can see how dangerous it is to imagine your presence here during an avalanche. So, different types of avalanches we have are dry slab avalanche, loose snow avalanche, two-wet slab avalanche, powder cloud, and a few more that include glided avalanche. Then, flow path erosion and deposition are caused by wet avalanches.

Dry snow deposit and wet snow deposit. So, these are the further implications of the avalanches. Then, let us talk about glacier surging. The sudden movement of ice over a short period during rapid glacier advance is known as glacier surging. You can see this particular image. The surging activity is illustrated here, showing Panama and Chatkoi glaciers and the surrounding tributaries.

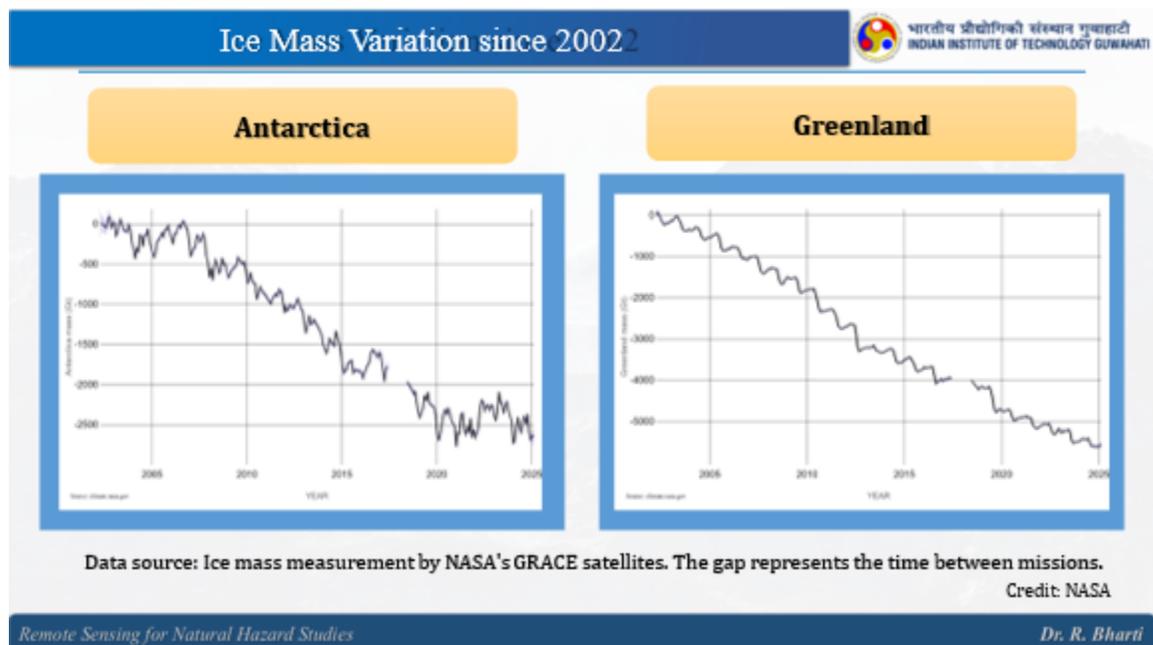
Then we have another example from the Kayagar Glacier, located in Karakoram, which has resulted in globs due to glacier surging since 1880. You can see that the history is very long. Since 1880, we have had glaciers surging in this Karakoram region. So, the figure shows the formation of an ice-dammed lake due to glacier surging that blocked the flow of the river from right to left at the Kayagar glaciers.



Then, Moraine versus ice dam GLOF. So, here you can see these are the examples. So, here on the x-axis, we have the potential energy of dammed lake water and the maximum flood discharge, and this particular graph is presented. High-magnitude floods are

produced in the case of a moraine dam outburst. Moraine dams are usually destroyed during GLOFs; thus, the chances of repeated GLOFs from a single lake become low. It produces a higher flood discharge in comparison to an ice dam outburst.

Ice dam lake drainage is less destructive to dams and usually produces low discharge. So, the moraine discharge is higher. When we talk about the permafrost thawing and the thermokarst development, we mean that the permafrost is a mixture of organic matter, soil, or sediment that remains completely frozen for at least 2 consecutive years. According to the National Snow and Ice Data Center, 9 million square miles of the Northern Hemisphere are covered with permafrost. The natural ecosystem is affected by permanent thawing. So, the development of thermokarst, the release of greenhouse gases, the risk of wildfires, and areas of sagging ground damaging infrastructure are the post-disaster risks. The seasonal snowmelt and runoff impacts are explained here. So, the primary issues are accelerated glacier retreat, shifted timing of snowmelt and runoff, increased rain or snow events, and reduced snow cover due to snow darkening effects. Here, if you remember, I have also used this particular image in the previous lecture. So, it beautifully illustrates the key components and changes between the cryosphere and the ocean, and the global exchange of water, heat, and carbon dioxide between the systems.



So, here you can see the loss of ice sheet mass in Greenland and Antarctica, permafrost decline, the extent of Arctic sea ice, decreasing extent of snow cover, and glacier mass loss; these can be explained with such a schematic diagram. The anthropogenic influences on global warming, along with anthropogenic activities, cause a significant portion of glacier mass loss, and a shift in the timing and intensity of snowmelt is observed. Increased warming periods of winter are associated with rain or snow events

that increase the risk of snow avalanches and cause permafrost degradation. When we talk about the second component, the deposition of light-absorbing aerosol, black carbon, and dust. Anthropogenic activity causes black carbon and dust to be deposited on the surface of snow.

This reduces the snow albedo, causing more absorption of incoming radiation in the snowpack, and as a result, our energy balance will be disturbed. So aerosol forcing can save this snowmelt timing, increasing snowmelt, thereby decreasing snow cover. So that will be the ultimate impact of this component. Here you can see the feedback mechanism in the cryosphere.

So, this is a change in the Arctic cryosphere. So, it is explained here. Then we have changes in the Arctic cryosphere. Now, the monitoring part, cryosphere monitoring, is important. So, monitoring cryosphere changes can be done using satellite images. So you have optical data, synthetic aperture radar data, a SAR data set, and the LIDAR can also be used here.

Then you can go for assessing the hazard risk, avalanche hazard, glacier-related hazards, and permafrost-related hazards. and then developing mitigation strategies. So, we can develop an early warning system, water resource management schemes, and planning for infrastructure building according to the expected hazards and the satellite data, which are popular in this area: Landsat, MODIS, and Sentinel. So, these three data sets are widely used; apart from that, you have many sources. So, when we talk about the risk and the hazard. So, what is the difference between risk and hazard? So, hazards are potential sources of harm, like glaciers and avalanches, in terms of the cryosphere.

When we talk about risk, it is the probability of the hazard causing harm or damage that will affect the surroundings, and here, the affected will be people and the environment. So, when we try to evaluate the risk. We need to have hazard, vulnerability, and exposure, and the intersection will be your risk. So, with real-time observation, we have a remote sensing data set, meteorological data, and hydrological data; with that, you can go for susceptibility mapping and identify high-risk zones. You can also have modeling and simulation. Here, you can identify the likelihood of the event, the severity of the event, and then the socio-economic impacts of a particular hazard.

So, with this, I will end this lecture, and you can see that some of the references are listed here. You can read this for further understanding these cryosphere hazards.

Thank you. Thank you very much.