Landslide and flood early warning possibility with seismic study (Fluvial Seismology)

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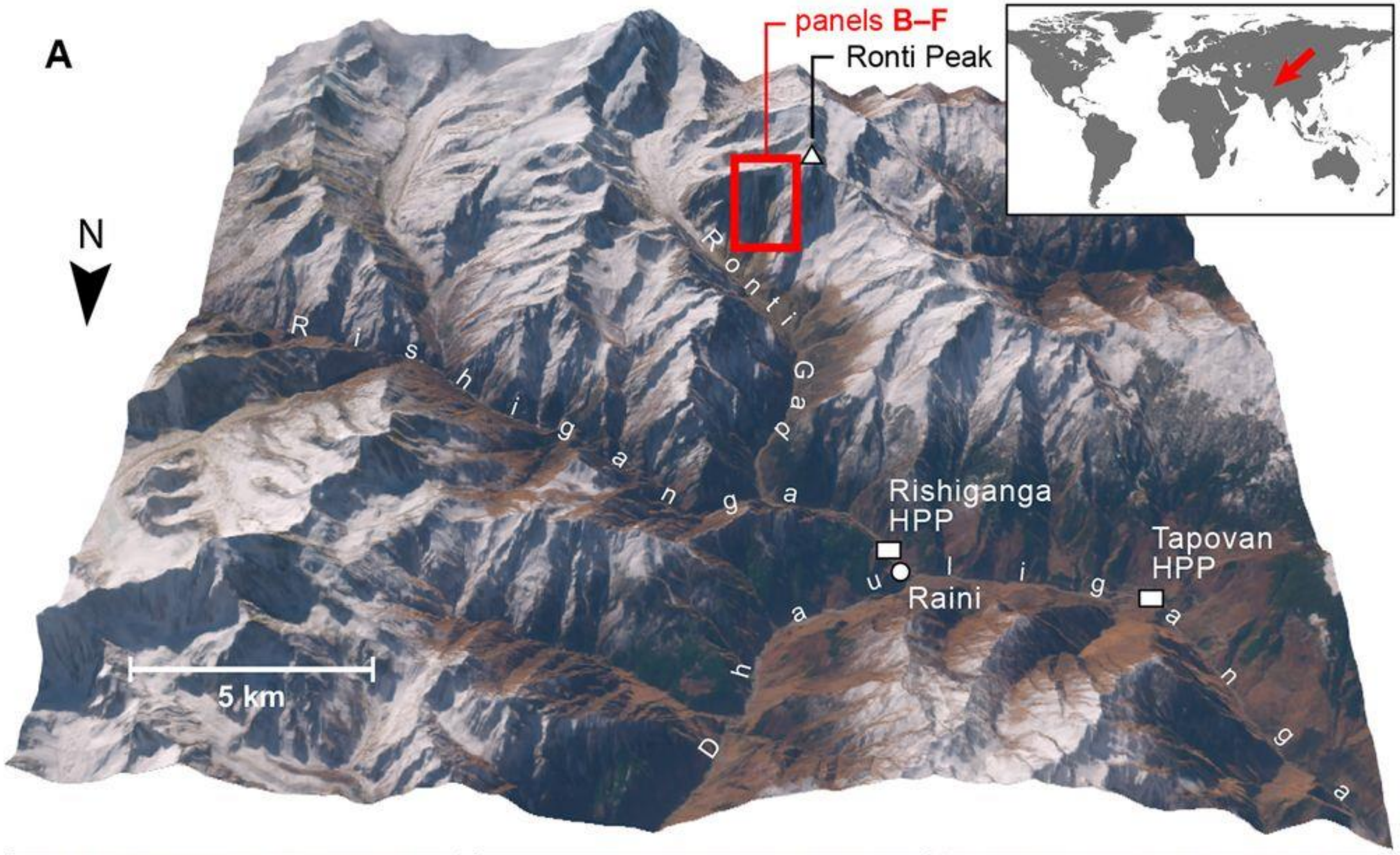
Chamoli Disaster, Himalayas
7 Feb 2021 by massive ice and rock avalanche

D. H. Shugar et al. 2021

This disaster severely damaged two hydropower projects and over 200 people were killed or are missing.

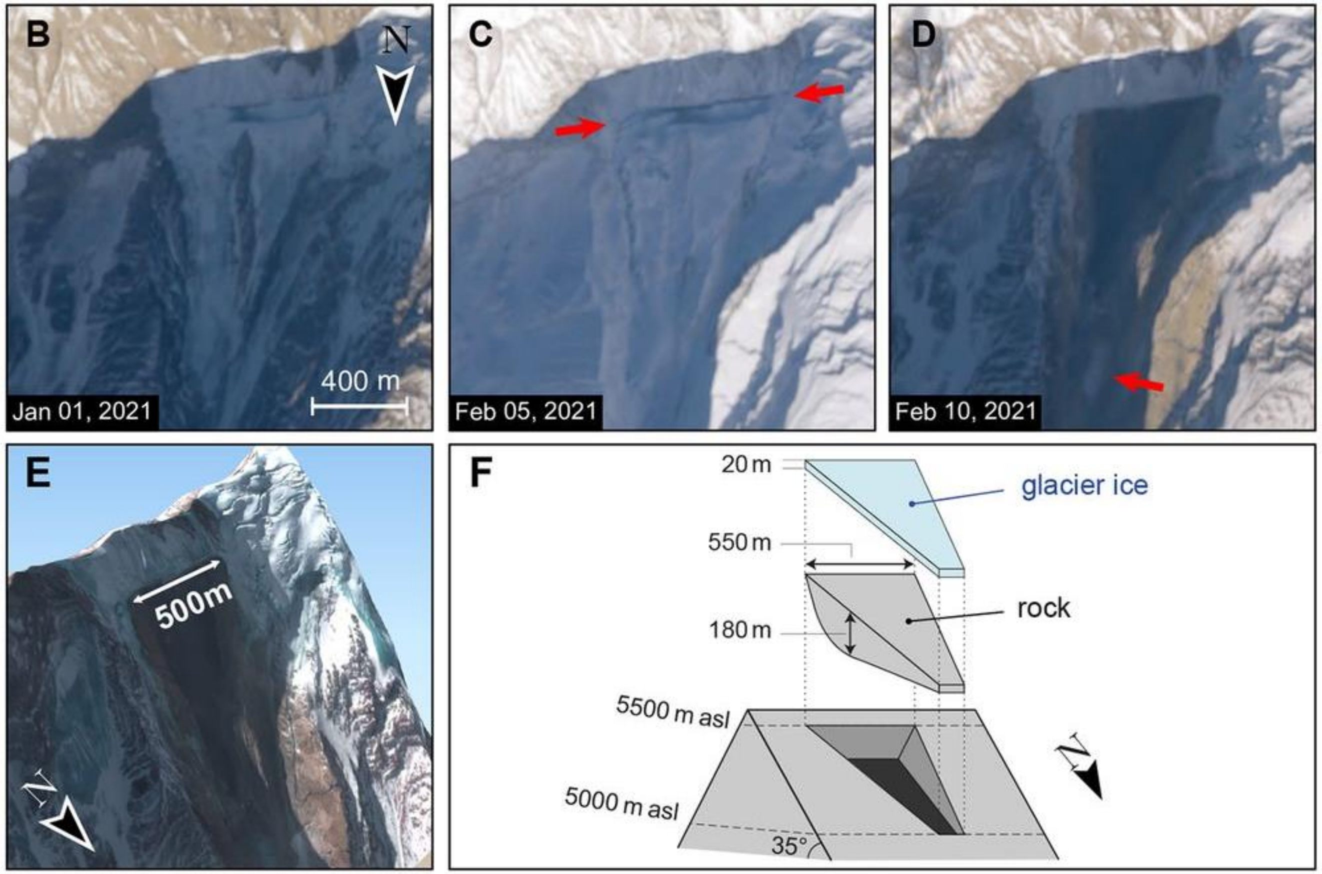


Overview of the Chamoli disaster, Uttarakhand, India.
3D rendering of the local geography, with labels for main place names mentioned in the text. HPP=hydropower project.

1. Origin events
2. Debris mass flow components
3. Effects in far areas
4. Seismic analysis results
5. Its causes
6. Its physics
7. Warning system
8. Conclusion

Optical feature tracking detected movement of the failed rock block as early as 2016, with larger displacements in 2017 and 2018.

The fig B, C, D shows the crack before and after incident.



- Geodetic analysis showed that in total rock-ice broken part - 80% ~ rock and 20% `~ ice by volume.
- DEM images revealed failure scar has vertical difference of up to 180m and slab width approx. 550m.
- Analysis of satellite imagery and eye witness videos showed that total volume of ice-rock that was broken from scar was nearly equal to 26.9e6 cubic meter, i.e., 26.9e9 liters.

If we imagine this much volume of water, then One month water supply of whole Bengaluru city was poured down in the valley in few minutes.

Acc to the Bangalore Water Supply and Sewerage Board (BWSSB) wiki page, BWSSB currently supplies approximately 900 million liters of water to the city per day, i.e., 9e8 liters per day.

- 29.9e9 / 9e8 = 29.88 days.

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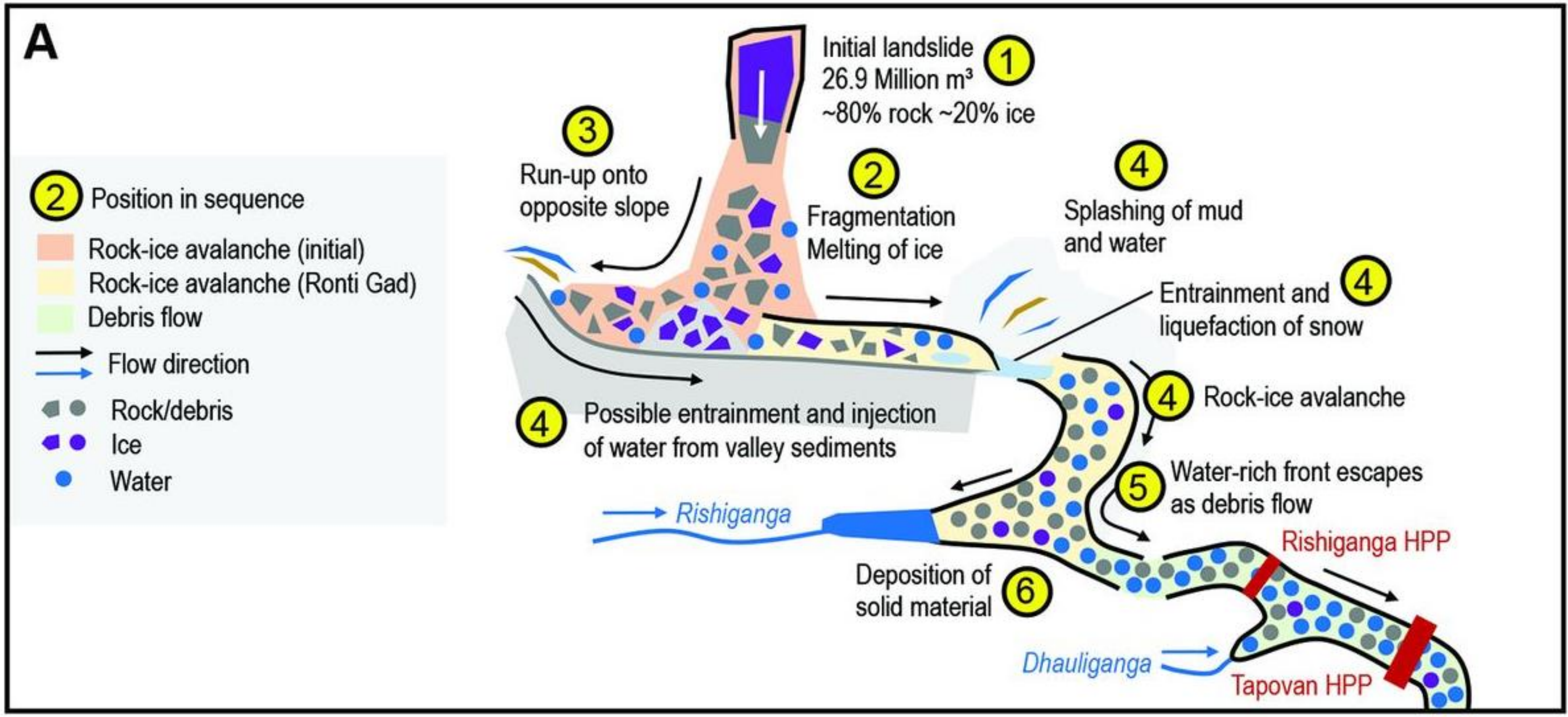
- The catastrophic **mass flow** was divided into four main component-

  1. Main Rock and Ice Avalanche from Ronti Peak.

  2. Splash deposit- Relatively fine grained, wet sediments that become airborne as the mass flow ran up the adjacent slopes upto 220m.



3. Airborne dust deposition- smooth layer of debris, estimated from satellite imagery to be only few cm thickness was deposited upto 500m above valley floor.

4. Debris flow through river.

❑ **Deposition** of debris
-At junction of Ronti Gad and Rishi Ganga river, a 40m thick deposit of debris blocked the Rishi Ganga Valley.
-Due to deceleration of mass flow at sharp turn
-lake of 700m formed behind these deposits in Rishi Ganga valley upstream of its confluence with Ronti Gad. DEM images estimate deposit volume ~ 8e6 cubic meter.
-It require careful monitoring as there is now risk of GOLF, if ice melt.
- A flood warning system has been installed 400 m upstream of Raini Village.

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- A substantial fraction of the fine-grained material involved in the event was transported far downstream.
- 24 hrs later- 150km downstream- sediment plume was visible in hydropower project's reservoir on the Alaknanda River at Srinagar.
- 8 days later- officials of Delhi water quality board reported unusual spike in suspended sediment 80 times the permissible level, from the canal drawing directly from Ganga river.
- 2.5 weeks later- ~900km downstream- turbidity was observed in Ganga waters at Kanpur.
- Water level also was high in river ganga for many days.
- From eye-witness, the farmers in plains using Ganga's water for irrigation reported that this summers the water was much muddy than it usually is during this time of year.

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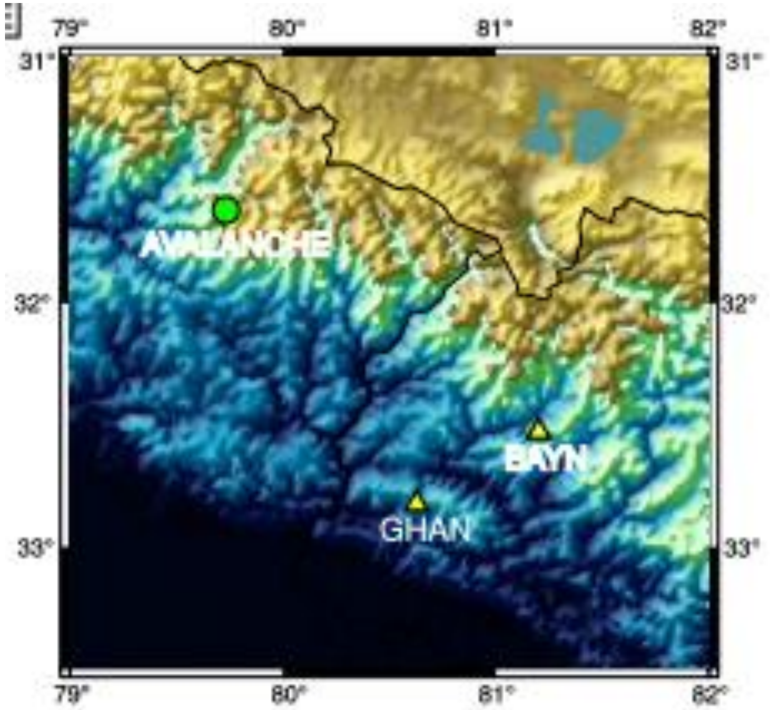
Continuous seismic data was observed from 6th and 7th Feb from two seismic stations from Nepalese seismic network (DMG/NEMRC). (location shown in fig)

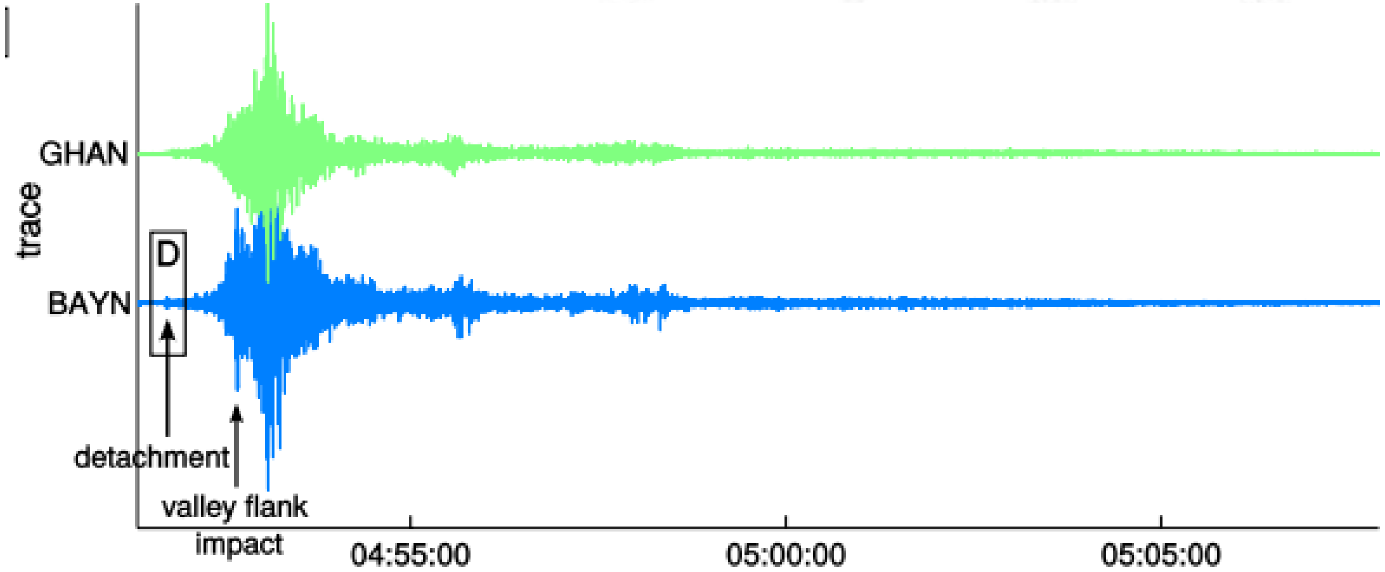
1. BAYN- Bayana - vertical sensor (ZM 500) – 174 km
2. GHAN- Ghanteshwar - 3 component broadband – 160km



No earthquake was observed before avalanche that may have dynamically triggered the rock slope failure. It showed that the block detached in one piece.

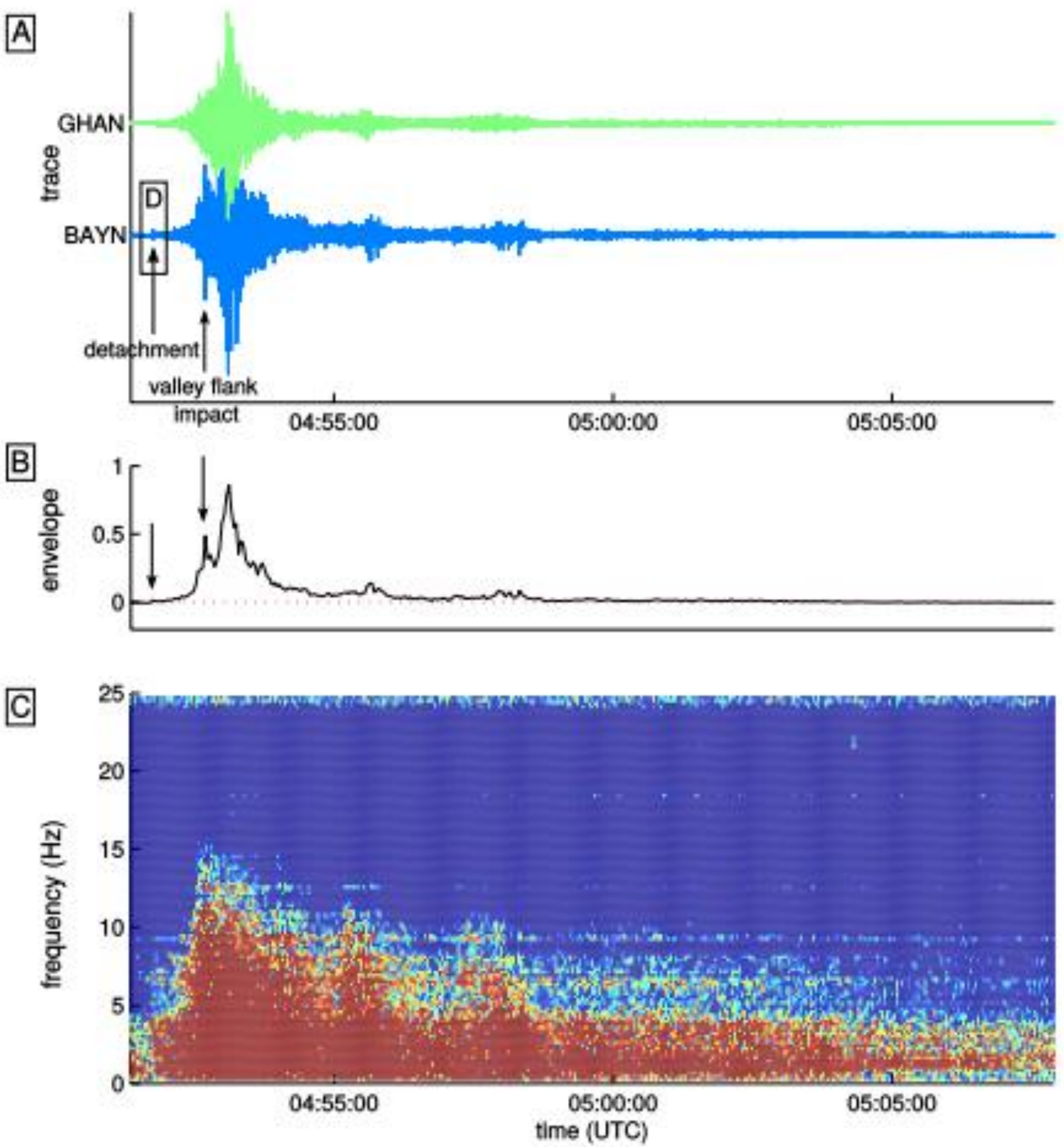
First pulse is seen in BAYN but not in GHAN due to higher noise of the traces.

The time zone on x-axis is in UTC.
The rock failure [rectangular D] occurred at 4:51 UTC = 10:21 IST



- ❑ The time shifts between these two stations provided mean wave apparent velocities between 5.8 – 7.2 km per sec.
- ❑ These values are consistent with P-wave velocity estimates of the crust and upper mantel in high Himalaya region.

<u>This shows that P-wave dominate the high frequency content of the signal</u>.



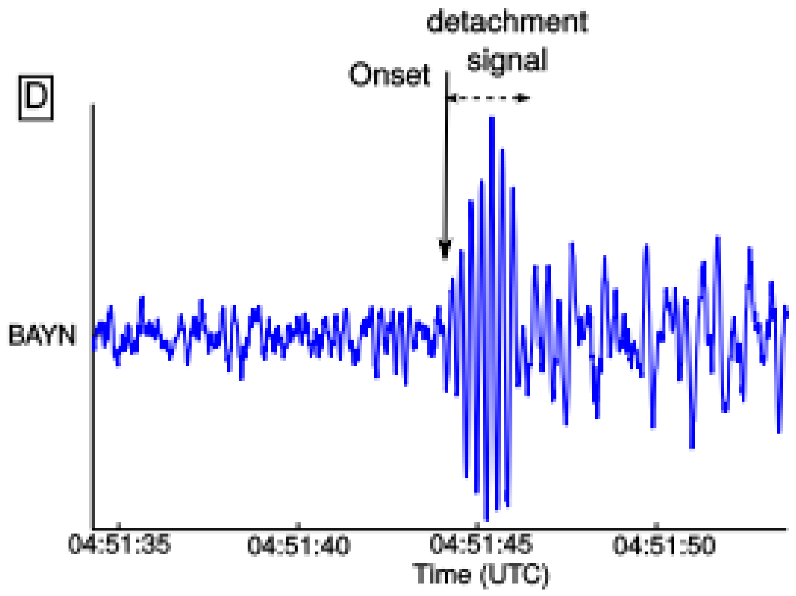
<u>The frequency spectrogram-</u>

- ❑ The triangular asymmetrical shapes on the spectrogram of about 5 mins – due to large rockslide sources.
- ❑ The main frequency content for 5 min is 15 Hz.
- ❑ Then followed by long coda of at least 10 mins with frequency – below 5 Hz.

The wave propagation travel time is consequently estimated at between 24.2 and 30.3 seconds at station BAYN

- So, the onset time of the rockslide detachment between 4:51:13 UTC and 4:51:21 UTC
- i.e., 10:21:13 IST to 10:51:21 IST

* Error on the physical origin of the detachment signal included.



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- Geologic features that contributed-
  - Slope is extremely steep and high relief of Ronti Peak
  - Rock type- schist and gneiss [these rocks are soft and platy and disintegrate into fine materials easily]
  - The large expanding crevasse at the head scarp may have allowed liquid water to penetrate into bedrock, which would have enhanced freeze-thaw weathering.
  - No other source of water or glacial lake was found near peak.

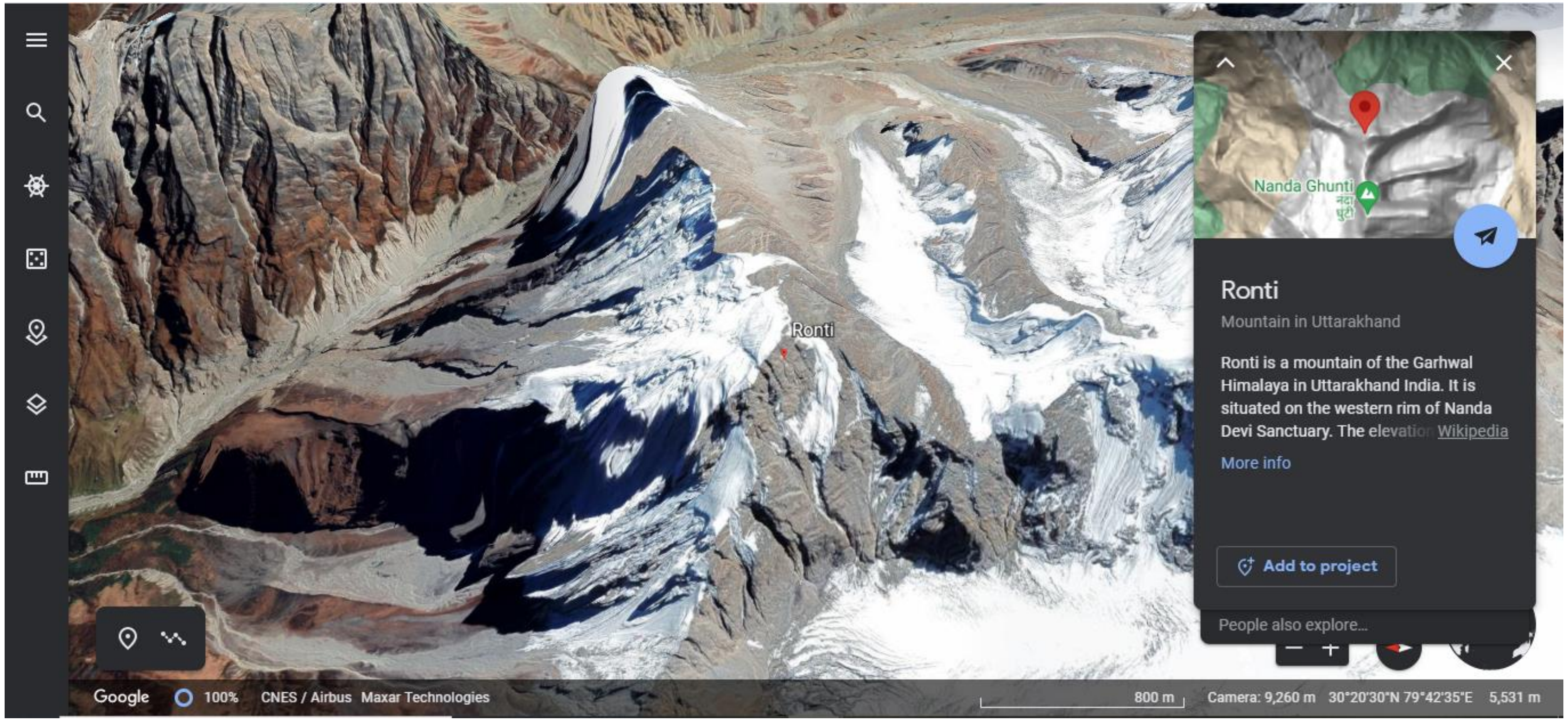
- Combination of ~20:80 ice:rock ratio and large fall height of the rock ice avalanche helped in faster melting of ice which in turn contributed in easy flow of debris downstream.

- Climatic cause-

Climate change cannot be directly claimed to be the cause of Chamoli disaster. It may be seen in the context of change in geomorphological sensitivity-
Glacier shrinkage uncovers mountain flanks making them destabilized. It strongly alters the hydrological and thermal regimes of the underlying rock.

Thermal reason- According to Gruber et al 2017, most of the south faces in central and eastern Hindu Kush Himalaya are permafrost free due to radiation.

- South face of Ronti Peak is certainly warmer with rock temperature around or above zero degree Celsius.
- Rock on the north face of Ronti peak likely contains cold permafrost with rock temperature several degrees below zero degree.
- This causes strong south to north lateral heat flow.



Google earth maps

- Increase in ground temperature would have reduced strength of the frozen rock mass by altering the rock hydrology and the mechanical properties of discontinuities and the failed rock mass.

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Early warning System

- Similar mass failures have occurred on north face of Ronti peak in Jan 2000, Sep 2016 and now in Feb 2021.
- Considering this repeated failures from same slope in past two decades, there should be monitoring of this area for early warning system. But the people at direct risk had no warning.

- **If we had dense seismic network near landslide, it may have provided up to 20 min of warning before arrival of debris flow at Tapovan Project.**

Along with good monitoring instrumentation, Remote sensing, seismology and climate check, we also require public education, which would increase awareness of potential hazards and improve ability to take action when disaster strike.

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Summarizing :
3 primary drivers for the severity of Chamoli disaster –

1. Extraordinary fall height, which increased gravitational energy
2. The ice:rock ratio ~ 20:80 which resulted in complete melting of ice and enhanced mobility of debris flow.
3. Unfortunate location of hydropower plants.

My opinion:
There are many glaciated peaks in direct vicinity of population that either direct affects people down the valley or affect the level of water in tributaries and rivers in valley. These peaks and glaciers should be continuously monitored, especially those which had some catastrophic history and are posing threat in near future.
Such peaks should be identified and rather than studying them for small time, there should be continuous monitoring system and effective pre-warning system.

References

- Shugar, Dan & Jacquemart, Mylène & Shean, D. & Bhushan, Shashank & Upadhyay, K. & Sattar, Ashim & Schwanghart, W. & McBride, Sara & Vries, M. & Mergili, Martin & Emmer, Adam & Deschamps-Berger, C. & McDonnell, M. & Bhambri, Rakesh & Allen, Simon & Berthier, Etienne & Carrivick, Jonathan & Clague, John & Dokukin, M.D & Westoby, M.. (2021). A massive rock and ice avalanche caused the 2021 disaster at Chamoli, Indian Himalaya. Science. 373. eabh4455. 10.1126/science.abh4455.