Dynamics of the deadly snow avalanche of January 18, 2017 at Rigopiano (Central Italy)

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November 23, 2022

Abstract

On January 2017, a snow avalanche devastated a Resort-hotel in the municipality of Rigopiano in Abruzzo (Central Italy), unfortunately, burying alive 40 people. In a dramatic rescue operation only 11 people could be recovered. Due to the bad weather conditions, no visual observation was made, thus making it impossible to determine the exact moment of the avalanche and to report necessary observations of the dramatic event. Many are the questions and hypotheses around this tragic event. On-site inspections revealed that the hotel was horizontally cut by shear forces and dislocated by 48 m in 70°deg;N direction, once the increasing avalanche pressure exceeded the structural shear strength of the building. Analyses of phone calls revealed that the avalanche struck sometime before 16:40, when the first emergency call was received, while the last phone call from Hotel Rigopiano before the avalanche was taken at 15:30. Subsequent inspections of the victims' mobile phones indicates the latest possible event time as 15:54 (all times in UTC). Within this eligible 24 min time window, we scanned regional seismograms for any "suspicious" signal that could have been generated by the avalanche and found three weak seismic transients, starting at 15:42:38 UTC, recorded by the nearest operating station GIGS located in the Gran Sasso underground laboratory at a distance of approximately 17 km from Rigopiano. Particle motion analysis of the strongest seismic avalanche signal, as well as of the synthetic seismograms match best when assuming a single force seismic source, attacking in direction of 120°deg;N. Hundreds of simulations of the avalanche dynamics – calculated by using a 2D rapid mass movement simulator – indicate that the seismic signals were rather generated as the avalanche flowed through a narrow and twisting canyon directly above the hotel. Once the avalanche enters the canyon it is travelling at maximum velocity (37 m/s) and is twice strongly deflected by the rock sidewalls. These impacts created a distinct linearly polarized seismic "avalanche transient"; that can be used to time the destruction of the hotel. Our results demonstrate that seismic recordings combined with simulations of mass movements are indispensable to remotely monitor snow avalanches.

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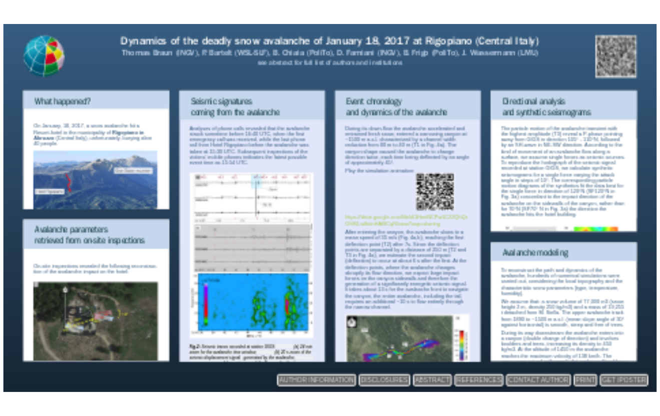

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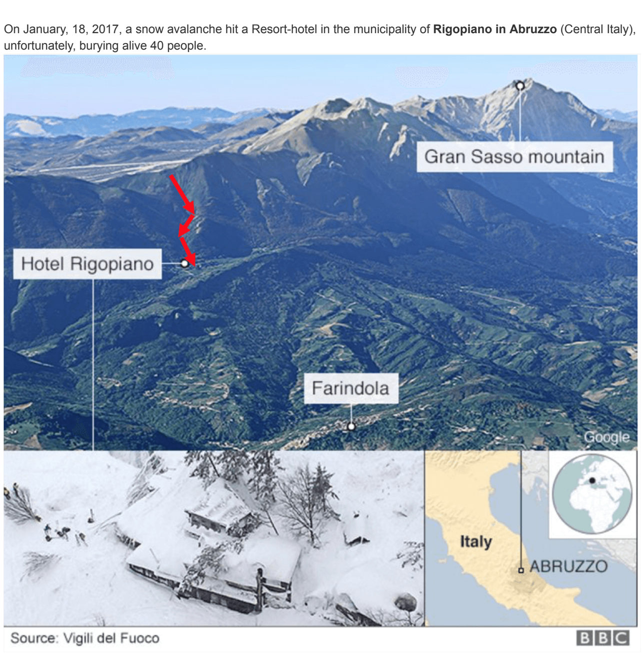
WHAT HAPPENED?

On January, 18, 2017, a snow avalanche hit a Resort-hotel in the municipality of **Rigopiano in Abruzzo** (Central Italy), unfortunately, burying alive 40 people.



Aerial photograph of the Rigopiano area (Abruzzo)

In a dramatic rescue operation only 11 people could be recovered. Due to the bad weather conditions, no visual observation was made, thus making it impossible to determine the exact moment of the avalanche and to report necessary observations of the dramatic event. Many are the questions and hypotheses around this tragic event.

A brief cold period lasting from January 15 - 19, 2017, caused abundant snowfall in Central Italy, reaching a snow depth of about 2 m at altitudes above 1,000 m a.s.l. in the Sibillini and Gran Sasso Mountains.

In the morning of January 21, 2017, three days after the avalanche, the Meteo-Service Agency estimated a fresh snow depth of 2 m near Hotel Rigopiano and even more on top of Mt. Siella (2,027 m a.s.l.).

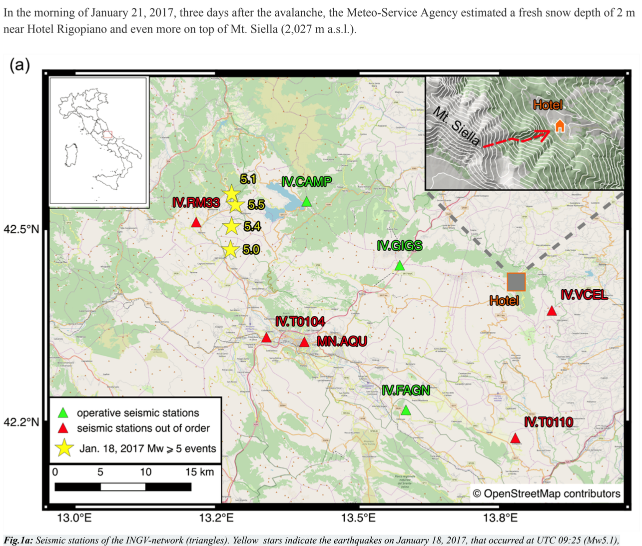


Fig.1a: Seismic stations of the INGV-network (triangles). Yellow stars indicate the earthquakes on January 18, 2017, that occurred at UTC 09:25 (Mw5.1), 10:14 (Mw 5.5), 10:25 (Mw 5.4), and 13:33 (Mw 5.0).

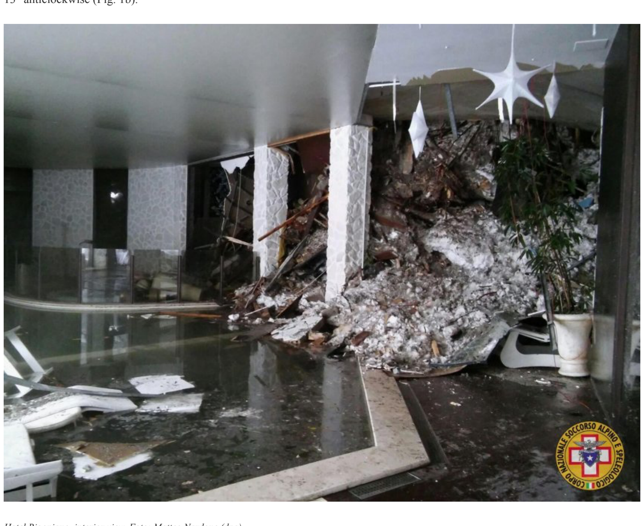
On January 18, 2017, between 09:25 and 13:33 UTC four seismic events of magnitude M > 5 occurred at a distance of circa 45 km W off the location of Hotel Rigopiano (yellow stars in Fig. 1a) causing tremors perceptible as far as Rome and Naples. As those earthquakes were distinctly felt also at Rigopiano, spreading panic among the hotel residents, the question arose, whether the avalanche could have been seismically triggered. Given the large epicentral distance and a minimum 2 hours time offset between the latest M5 event and the snow mass detachment, we consider it as very unlikely that the avalanche was released by ground oscillations from those events, while temperature increase in the course of the day may, however, play an important role for triggering the avalanche.

AVALANCHE PARAMETERS
RETRIEVED FROM ON-SITE INSPECTIONS

On-site inspections revealed the following reconstruc-tion of the avalanche impact on the hotel:

Fig.1b: The avalanche dislocated the hotel's upper floor by 48 m in 70°N direction including a 13° anticlockwise rotation

The westernmost portion of the building, which was constructed at the end of the 60's, along the upstream side was facing the frontal impact of the flow, with an angle of incidence approximately orthogonal (less than ± 20° with respect to the perpendicular) and (minimum) height of the second floor above ground. Once the increasing pressure of the mass of snow and debris exceeded the structural shear strength of the building, the hotel's upper floor was shifted approximately 48 m downstream, rotating it slightly by 13° anticlockwise (Fig. 1b).



Hotel Rigopiano, interior view. Foto: Matteo Nardone (dpa)

SEISMIC SIGNATURES
COMING FROM THE AVALANCHE

Analyses of phone calls revealed that the avalanche struck sometime before 16:40 UTC, when the first emergency call was received, while the last phone call from Hotel Rigopiano before the avalanche was taken at 15:30 UTC. Subsequent inspections of the victims' mobile phones indicates the latest possible event time as 15:54 UTC.

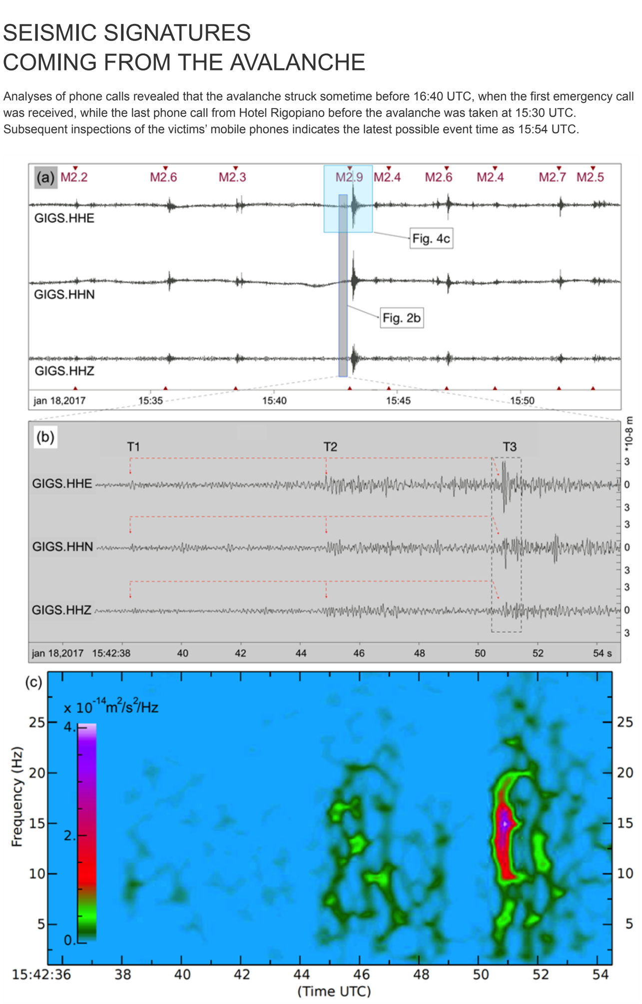


Fig.2: Seismic traces recorded at station GIGS. (a) 24 min zoom for the avalanche time window, (b) 20 s zoom of the seismic displacement signal generated by the avalanche, (c) spectrogram of the E-comp for the time window of Fig.2b

Within this eligible 24 min time window, we scanned regional seismograms for any "suspicious" signal that could have been generated by the avalanche.

We found three weak seismic transients, starting at 15:42:38 UTC, recorded by the nearest operating station GIGS located in the Gran Sasso underground laboratory at a distance of approximately 17 km from Rigopiano. The absence of any coincident signals at the other running stations of the network (triangles in Fig. 2a) indicates that they had not been generated by the Central Italy seismic sequence.

The "avalanche-signal" lasts approximately 15 s and is composed by three distinct onsets (called hereafter avalanche transients T1 – T3). T1 (first red arrow in Fig. 2b) weakly starts at 15:42:38, followed by an amplitude increase 7 s later (T2 – second arrow) and culminating in the very sharp high-frequency (~14 Hz) transient (T3 – third arrow).

T3 lasts for less than 0.5 s and is particularly evident on the horizontal-components, indicating an SH-wave. The peak ground velocity reaches a value of 3.2·10-6 m/s, and a corresponding peak ground displacement of 3·10-8 m. The spectrogram in Fig. 2c shows the three distinct patterns as spectral energy in the frequency band of 1 – 20 Hz, with continuously increasing seismic energy at 38 s (T1), 45 s (T2) and 51 s (T3), respectively, the latter showing a distinct maximum at ~14 Hz (violet).

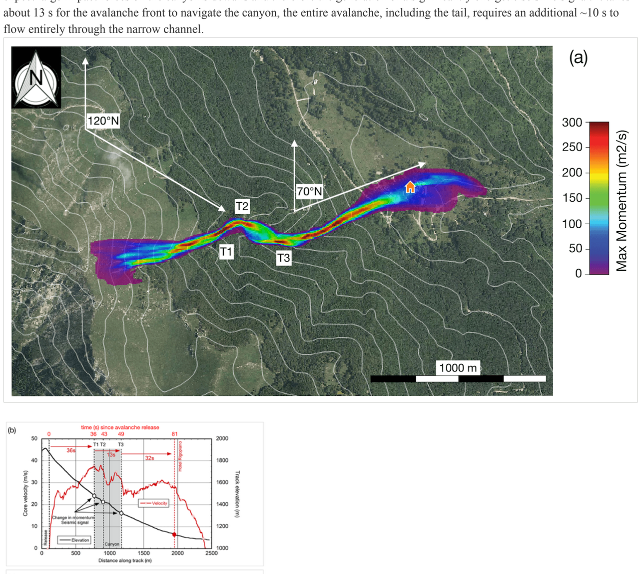
EVENT CHRONOLOGY
AND DYNAMICS OF THE AVALANCHE

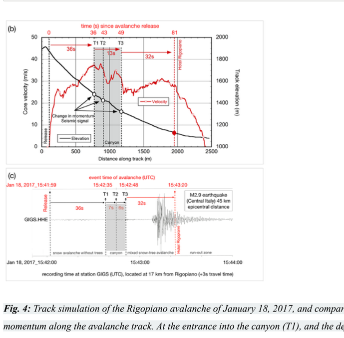
During its down-flow the avalanche accelerated and entrained fresh snow, entered a narrowing canyon at ~1500 m a.s.l. characterized by a channel width reduction from 80 m to 40 m (T1 in Fig. 4a). The canyon shape caused the avalanche to change direction twice, each time being deflected by an angle of approximately 45°.

Play the simulation animation:

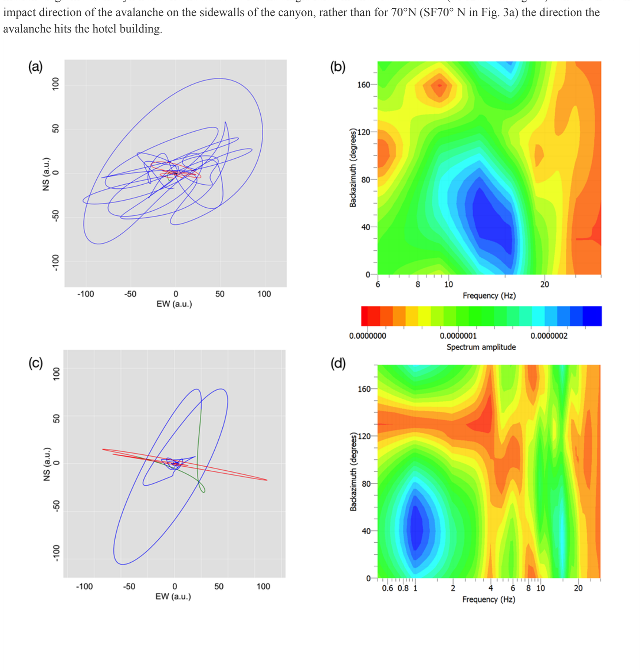
https://drive.google.com/file/d/1HenNCPw1C2ZQhQrGSfVLw8zmHAf9CqR/view?usp=sharing

After entering the canyon, the avalanche slows to a mean speed of 35 m/s (Fig. 4a,b), reaching the first deflection point (T2) after 7s. Since the deflection points are separated by a distance of 250 m (T2 and T3 in Fig. 4a), we estimate the second impact (deflection) to occur at about 6 s after the first. At the deflection points, the avalanche changes abruptly its flow direction, we expect large impact forces on the canyon sidewalls and therefore the generation of a significantly energetic seismic signal. It takes about 13 s for the avalanche front to navigate the canyon, the entire avalanche, including the tail, requires an additional ~10 s to flow entirely through the narrow channel.





DIRECTIONAL ANALYSIS
AND SYNTHETIC SEISMOGRAMS



AVALANCHE MODELING

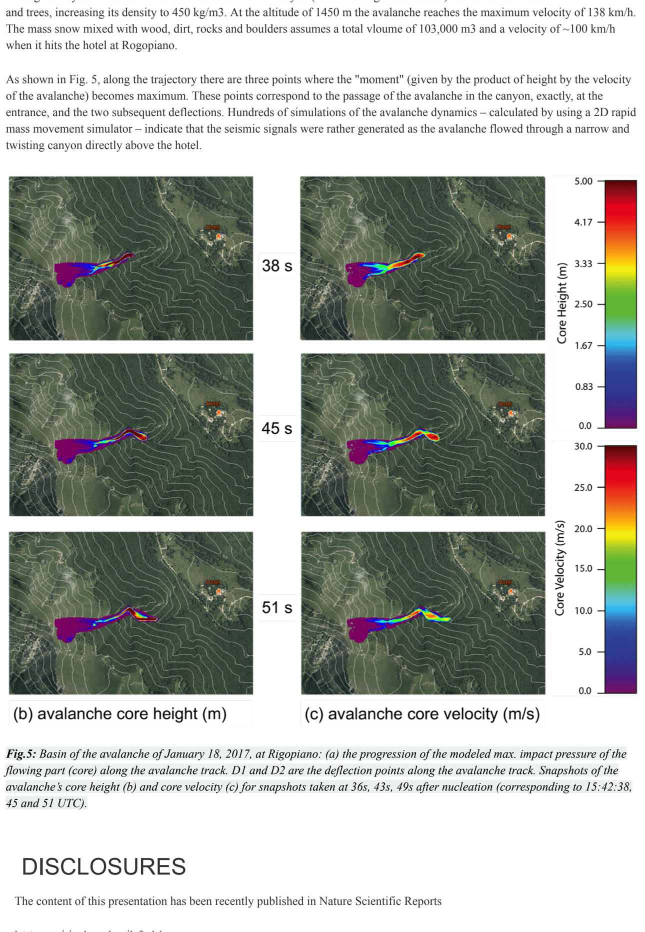


Fig.5: Basin of the avalanche of January 18, 2017, at Rigopiano: (a) the progression of the modeled max. impact pressure of the flowing part (core) along the avalanche track. D1 and D2 are the deflection points along the avalanche track. Snapshots of the avalanche's core height (b) and core velocity (c) for snapshots taken at 36s, 43s, 49s after nucleation (corresponding to 15:42:38, 45 and 51 UTC).

DISCLOSURES

The content of this presentation has been recently published in Nature Scientific Reports

https://rdcu.be/b9qbh

Braun, T.; Frigo, B.; Chiaia, B.; Bartelt, P.; Famiani, D. & Wassermann, J.
Seismic signature of the deadly snow avalanche of January 18,2017, at Rigopiano (Italy)
Scientific Reports, 2020, 10, 10
https://doi.org/10.1038/s41598-020-75368-z

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ABSTRACT

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