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

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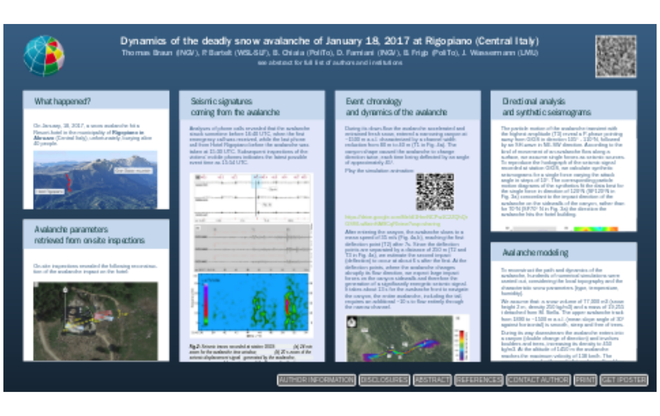

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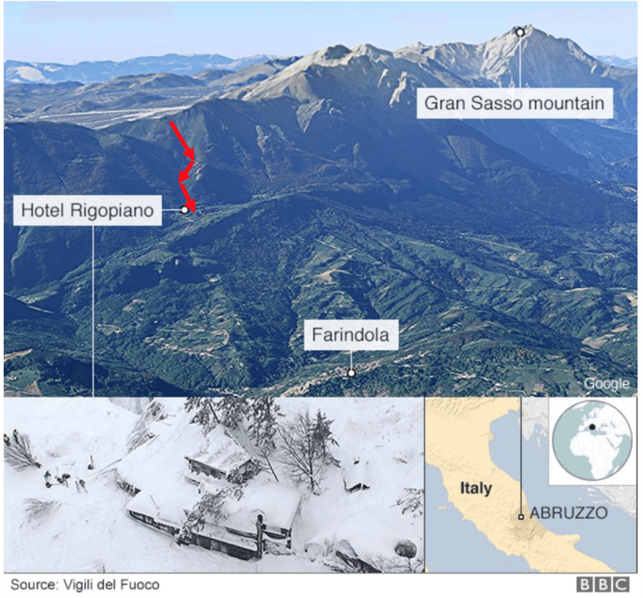
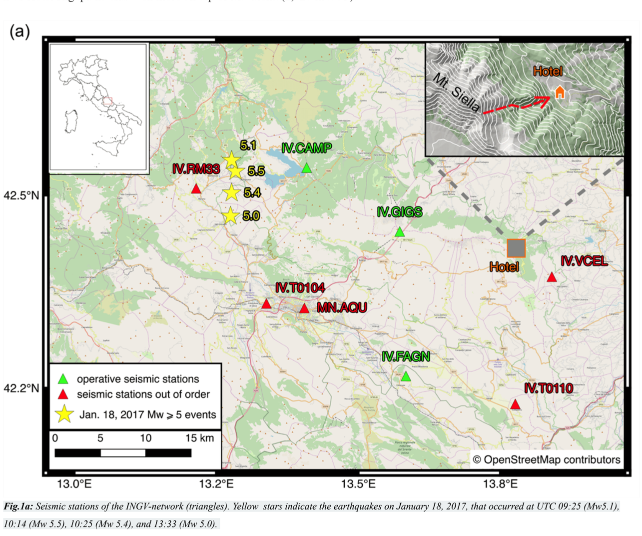
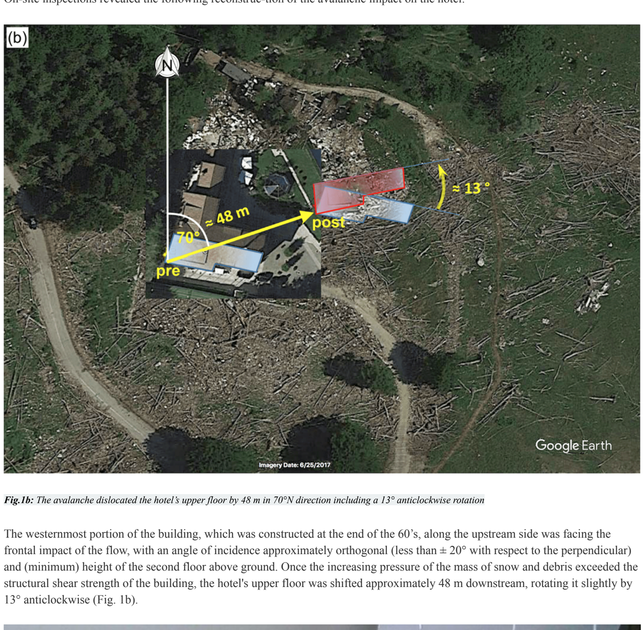
PRESENTED AT: AGU Fall Meeting

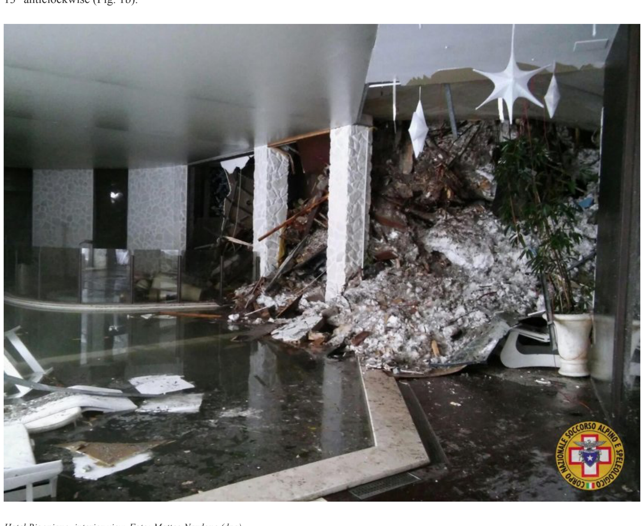
WHAT HAPPENED?



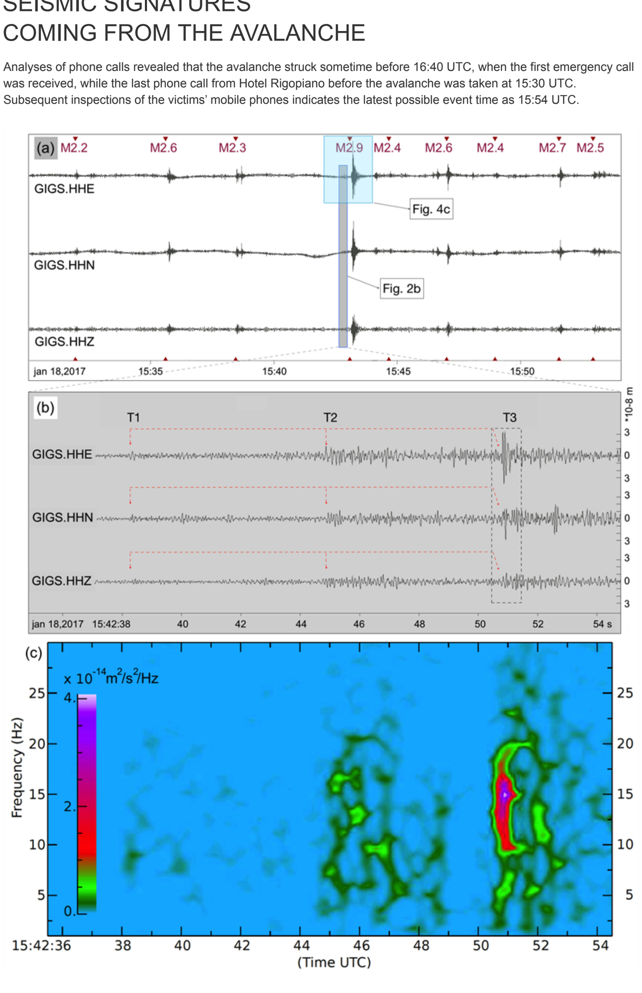


AVALANCHE PARAMETERS RETRIEVED FROM ON-SITE INSPECTIONS

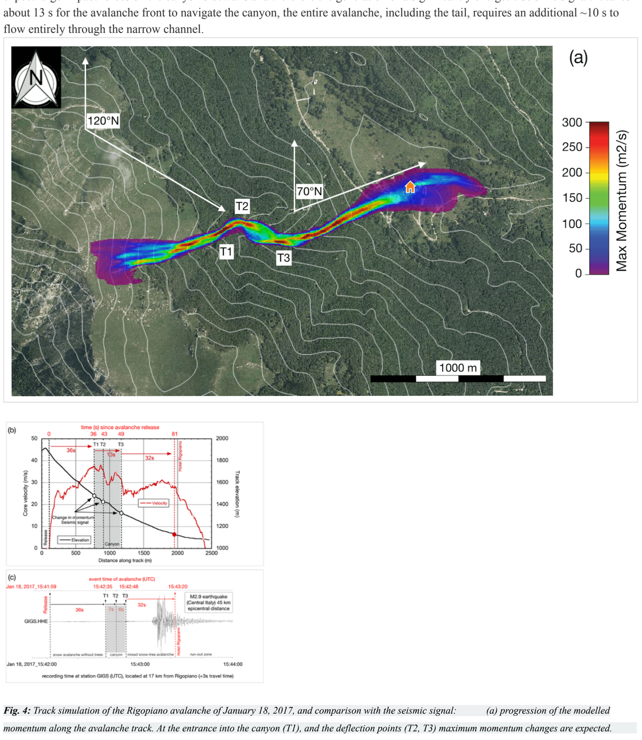




SEISMIC SIGNATURES COMING FROM THE AVALANCHE



EVENT CHRONOLOGY AND DYNAMICS OF THE AVALANCHE



The question is, whether shearing and dislocation of the hotel building's upper floor is capable to generate a seismic signal strong enough to be recorded by a seismic station located at a distance of 17 km? We are convinced that the answer is "NO".

To generate a seismic signal by an avalanche, a land slide or a rock fall, a strong force coupling between the mass flow and the ground is needed. Especially in the case of a snow avalanche, when the involved densities of the moving mass are relatively small, this coupling can arise either by the avalanche hammering onto the ground in the perpendicular direction of the flow, or when the avalanche impacts sidewalls, thus significantly changing its slope-parallel flow direction. As the slope-parallel velocities can reach 150 km/h, more seismic energy is generated by impacting sidewalls or buildings (obstacles). The main force of the avalanche is exerted downhill in the slope-parallel direction, while forces in the slope-perpendicular direction remain comparatively small. In fact, these forces are usually taken to be close to hydrostatic, and therefore depend on the height and density of the flowing snow. Sidewalls are thus ideal, because the large slope-parallel momentum of the avalanche is transferred directly into ground. When an avalanche flows on a smooth slope (without obstacles) almost no seismic energy couples to the ground, requiring seismic sensors to be installed in the near vicinity to measure any potential avalanche induced ground shaking.Coming back to the question about the exact timing we compare the variation of the simulated track elevation and avalanche velocity (Fig. 4b) with the temporal evolution of the avalanche recorded by the seismogram (Fig. 4c). As the seismic recordings of events occurring at Rigopiano take about 3 s travel time to reach station GIGS 17 km away, Fig. 4c indicates two different time scales: in red, the Time (UTC) shifted by the travel time correction of 3 s and in black, the UTC-timing for the seismogram.

- 15:41:59 ± 2.5 s: avalanche release

- 15:42:35 ± 0.5 s: T1 is avalanche enters the canyon

- 15:42:42 ± 0.5 s: T2 first deflection

- 15:42:48 ± 0.5 s: T3 second deflection

- 15:43:20 ± 5.0 s: the avalanche reaches the hotel.

The uncertainty in the definition of the release time (± 2.5 s) is associated with the break-up of the fracture slab into smaller fragments. This process determines the transition from the motion of a solid block to a granular fluid and therefore the initial speed of the avalanche. Once the granularization process is complete, the uncertainties in the model calculations decrease significantly to ± 1.0 s.

We calculated that the theoretical onset time of a hypothetical seismic signal caused by the impact of the avalanche with the hotel, has to be expected at ~81 s ± 5 s after the avalanche release. This instant falls exactly in the eligible time window when station GIGS recorded a M2.9 earthquake from the Central Italy seismic sequence, thus masking in its S-wave coda any hypothetical signal caused by the detachment of the hotel's upper floor due to the avalanche (see Fig. 4c).

DIRECTIONAL ANALYSIS AND SYNTHETIC SEISMOGRAMS

The particle motion of the avalanche transient with the highest amplitude (T3) reveal a P-phase pointing away from GIGS in direction 105° - 110°N, followed by an SH-wave in NE-SW direction. According to the kind of movement of an avalanche flow along a surface, we assume single forces as seismic sources. To reproduce the hodograph of the seismic signal recorded at station GIGS, we calculate synthetic seismograms for a single force varying the attack angle in steps of 10°. The corresponding particle motion diagrams of the synthetics fit the data best for the single force in direction of 120°N (SF120°N in Fig. 3a) concordant to the impact direction of the avalanche on the sidewalls of the canyon, rather than for 70°N (SF70° N in Fig. 3a) the direction the avalanche hits the hotel building.

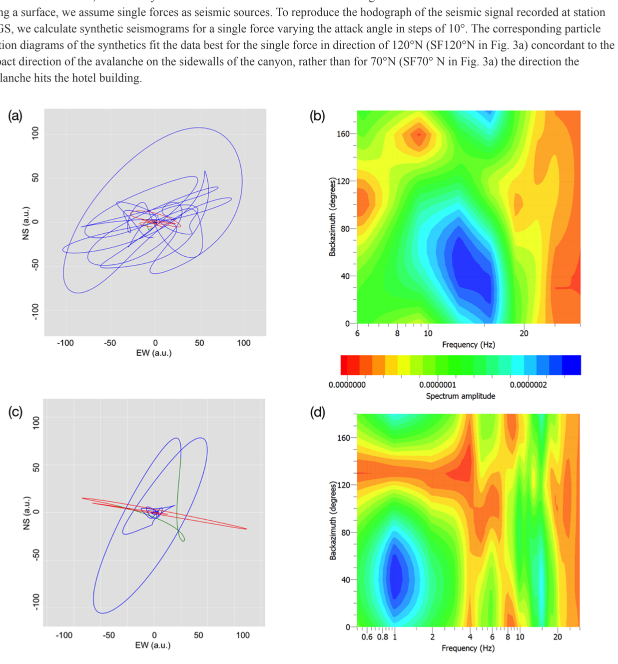


Fig.3: *Directional analysis of the avalanche signal: (a) Particle motion of the data and (c) of the synthetic seismograms (arbitrary units).Rotated frequency spectra calculated from combining the horizontal components of station GIGS for a time window of (b) 0.3 s and (d) 1.0 s around AT.*

AVALANCHE MODELING

To reconstruct the path and dynamics of the avalanche, hundreds of numerical simulations were carried out, considering the local topography and the characteristic snow parameters (type, temperature, humidity).

We assume that: a snow volume of 77,000 m3 (snow height 2 m, density 250 kg/m3) and a mass of 19,255 t detached from M. Siella. The upper avalanche track from 1890 to ~1500 m a.s.l. (mean slope angle of 30° against horizontal) is smooth, steep and free of trees.

During its way downstream the avalanche enters into a canyon (double change of direction) and involves boulders and trees, increasing its density to 450 kg/m3. At the altitude of 1450 m the avalanche reaches the maximum velocity of 138 km/h. The mass snow mixed with wood, dirt, rocks and boulders assumes a total vloume of 103,000 m3 and a velocity of ~100 km/h when it hits the hotel at Rogopiano.

As shown in Fig. 5, along the trajectory there are three points where the "moment" (given by the product of height by the velocity of the avalanche) becomes maximum. These points correspond to the passage of the avalanche in the canyon, exactly, at the entrance, and the two subsequent deflections. 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.

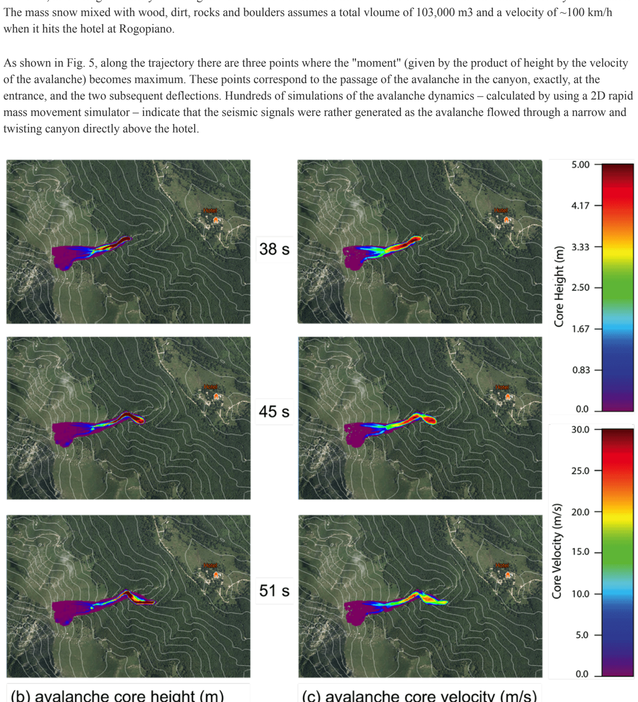


Fig.5: *Basin of the avalanche of January 18, 2017, at Rigopiano: (a) the progression of the modeled max. impact pressure of the flowing part (core) along the avalanche track. D1 and D2 are the deflection points along the avalanche track. Snapshots of the avalanche's core height (b) and core velocity (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

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ABSTRACT

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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°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°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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