Seismic localization and dynamical characterization of snow avalanches and slush flows of Mt. Fuji, Japan

Image source: Mount Fuji Research Institute, Japan

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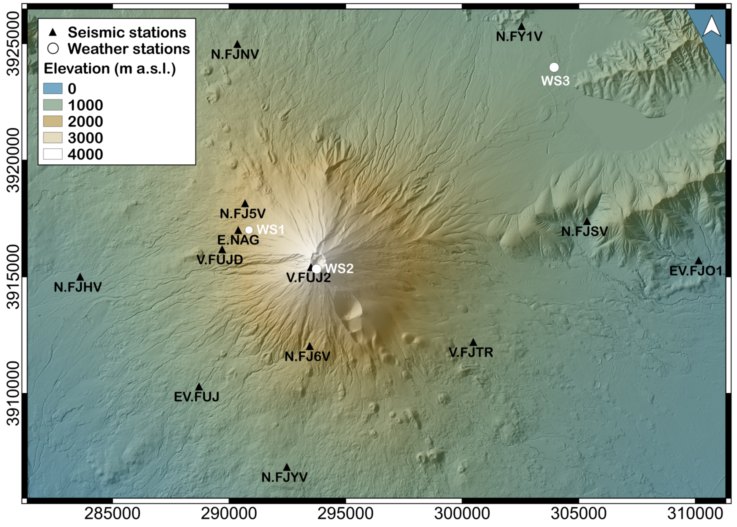
Snow avalanches of Mt. Fuji, Japan

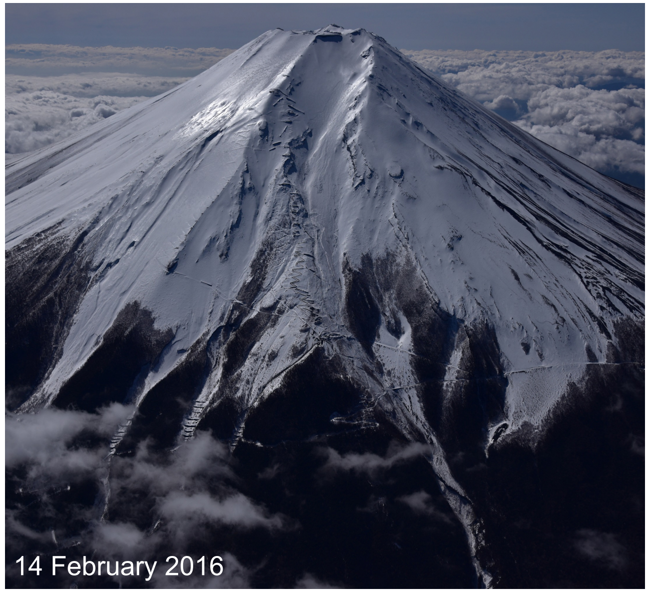
Introduction

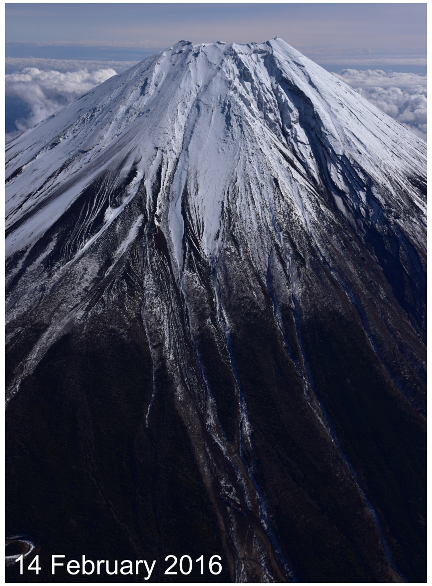
We detected and located large avalanches and slush flows released at Mt. Fuji, Japan using the local seismic network:



Snow avalanches and slush flows at Mt. Fuji

These flows represent a major natural hazard as they may attain run-out distances up to 4 km, destroy parts of the forest, and sometimes damage infrastructure:





Sources of the images: Asahi Shimbun Digital (https://www.asahi.com, left picture) and Mount Fuji Research Institute, Japan.

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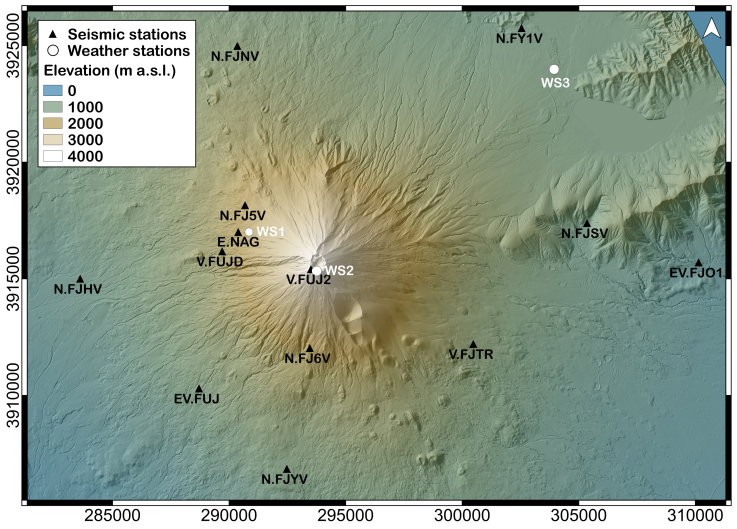

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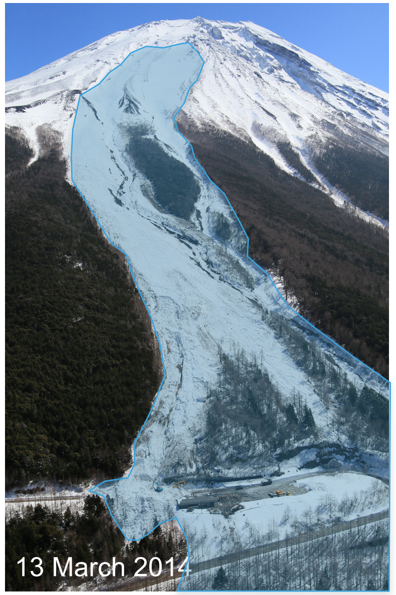

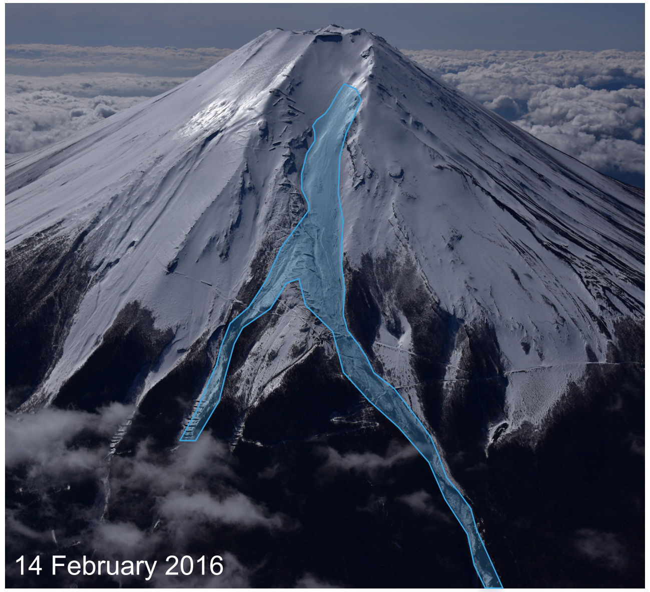

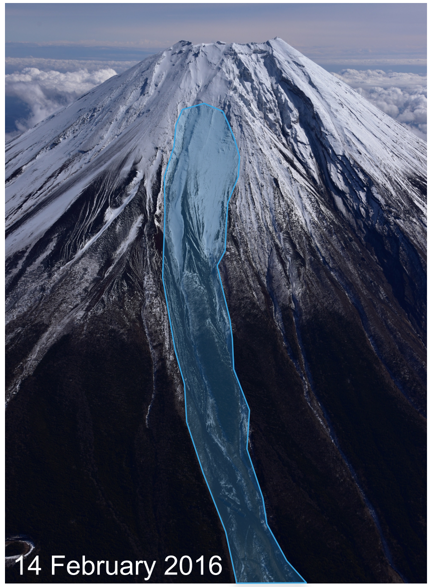

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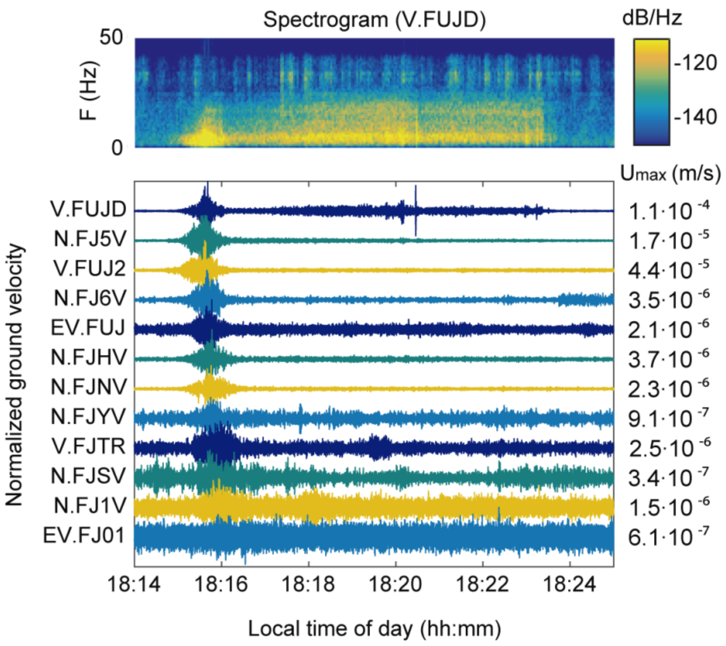
Seismic method to locate avalanches

Avalanche seismic data



Spectrogram and seismic signals generated by the large avalanche #1 (13 March 2014) and recorded by 11 stations at a maximum distance of 15 km.

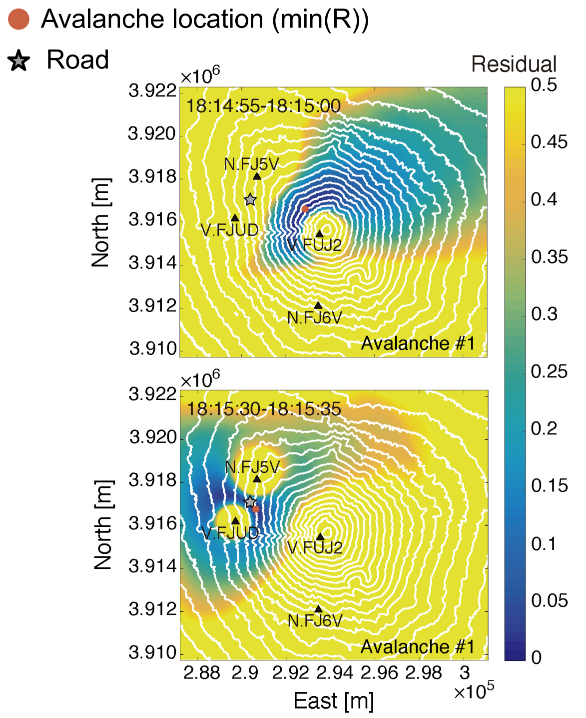
ASL location method

To track the flows, we used the amplitude source location (ASL) based on the decay of the amplitudes with distance. The locations are estimated by minimizing the residual (see Pérez-Guillén et al., 2019 for details), R:

$$R = \frac{\sum_{j=1}^{N} \left\{ u_j^o(t_s + r_j/\beta) - \overbrace{A_0 \frac{e^{-Br_j}}{r_j}}^{\text{Attenuation law of amplitudes}} \right\}^2}{\underbrace{\sum_{j=1}^{N} \left\{ u_j^o(t_s + r_j/\beta) \right\}^2}_{\downarrow}}$$

Amplitudes recorded and corrected by the site amplification factors estimated

Grid search



Maps of the spatial distribution of the residuals estimated in a grid for avalanche #1 showing the flow location at the release (up) and run-out (down) areas.

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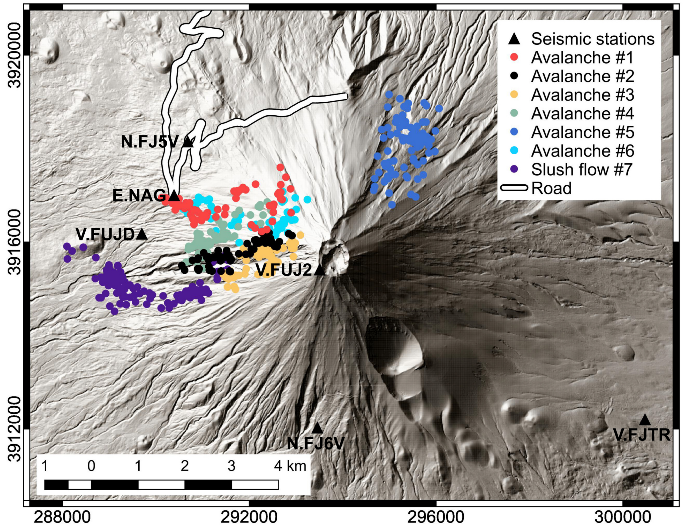
Seismic locations & Numerical simulations

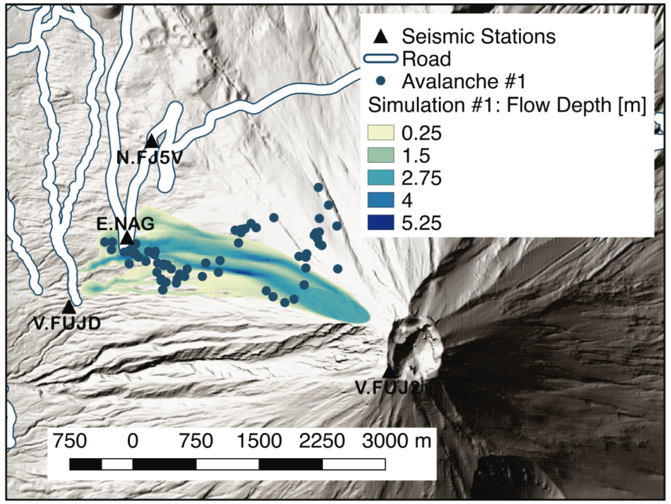
Avalanche locations

Map showing the seismic locations of the seven detected flows as estimated by the ASL method:



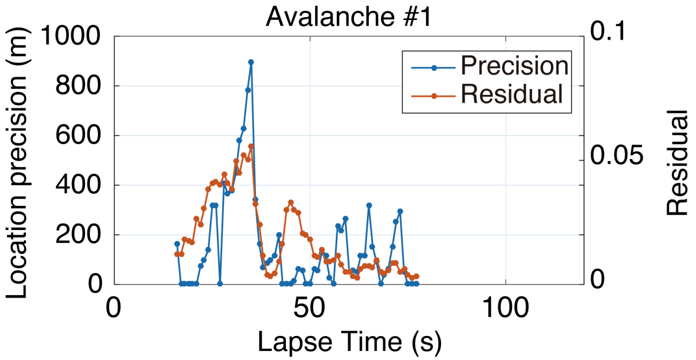
Numerical simulations

We conducted numerical simulations of the flows with the numerical model Titan2D and we compared them with the seismic locations:



Precision of seismic locations

The precisions of the seismic locations as a function of time are deduced from the comparison with the numerical simulations:



Location precisions and residuals estimated as a function of lapse time from the simulation start time.

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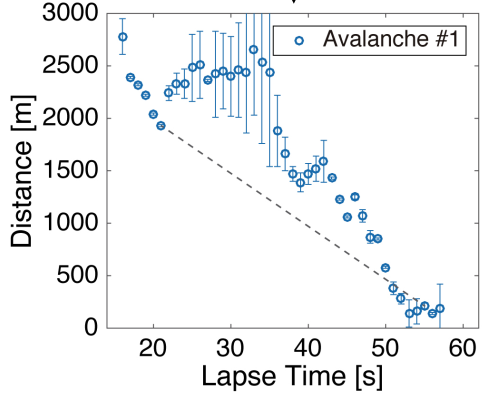
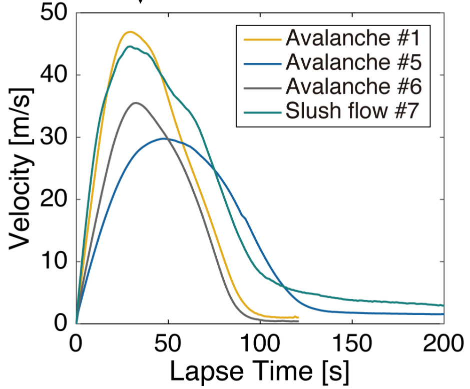
Dynamical characterization

Average front speeds

To estimate the average speeds, we computed the ratio of the distance traveled versus time. These speeds are consistent with the numerically predicted speeds:

$v_1(seism.) = 51\, m/s$ $\qquad$ $v_1(num.) = 47\, m/s$



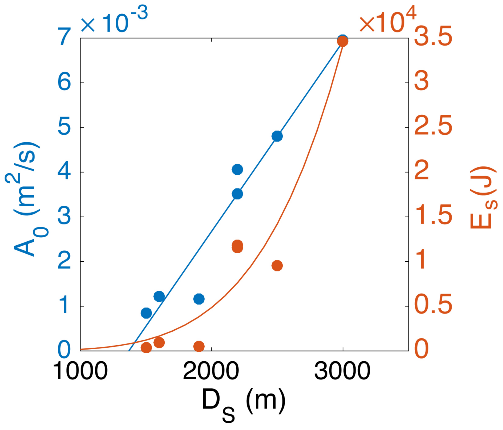


Distance of ASL locations of avalanche #1 from the run-out area as a function of lapse time (left) and numerically predicted speeds of four avalanches (right).

Flow size

We classified avalanche size according to the approximate run-out distances (D_s) and correlated them with two seismic parameters, the maximum source amplitude, A_0 and the maximum radiated seismic energy, E_s estimated by (see Pérez-Guillén et al., 2019 for details):

$$E_s = \int_{t_i}^{t_f} 2\pi\rho\,\beta A_0^2(t')\,\mathrm{d}t'$$



Maximum A_0 (left in blue) and E_s (right in orange) versus the approximate run-out distances, D_s. The lines show the fitting of source amplitudes vs. distance ($R^2 = 0.95$) and the power-law fit of the seismic energy vs. distance ($R^2 = 0.92$).

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Conclusions

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- We successfully detected seven large avalanches and slush flows released at Mt. Fuji using the local seismic network at distances up to 10-15 km.
- We localized them applying for the first time the ASL method to avalanches.
- Our results show feasibility of tracking the flow paths with reasonable precision (in the order of magnitude of 100 m), and to infer additional flow properties such as the average speeds and the run-out distances, which would be unknown otherwise.
- The scaling relationships presented here will be useful to establish an empirical method for qualifying the size of the flows.
- Developing highly effective methods for automatically detecting and tracking avalanche events in the seismic data in near-real time will be major implementation challenge.

Acknowledgments

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References

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