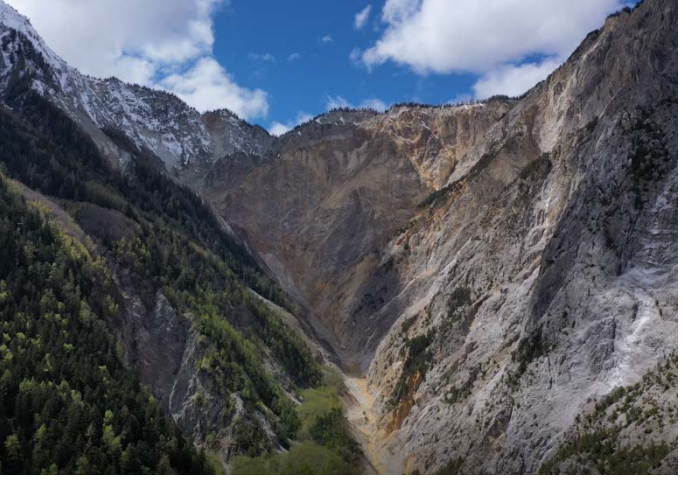


Linking Characteristics of Debris Flows to Their High Frequency Seismic Signature: insights from field measurements and model predictions

Zhen Zhang[1,2], Fabian Walter[2,3], Brian W. McArdell[3], Tjalling de Haas[4], Michaela Wenner[2,3], Małgorzata Chmiel[2,3], and Siming He[1]

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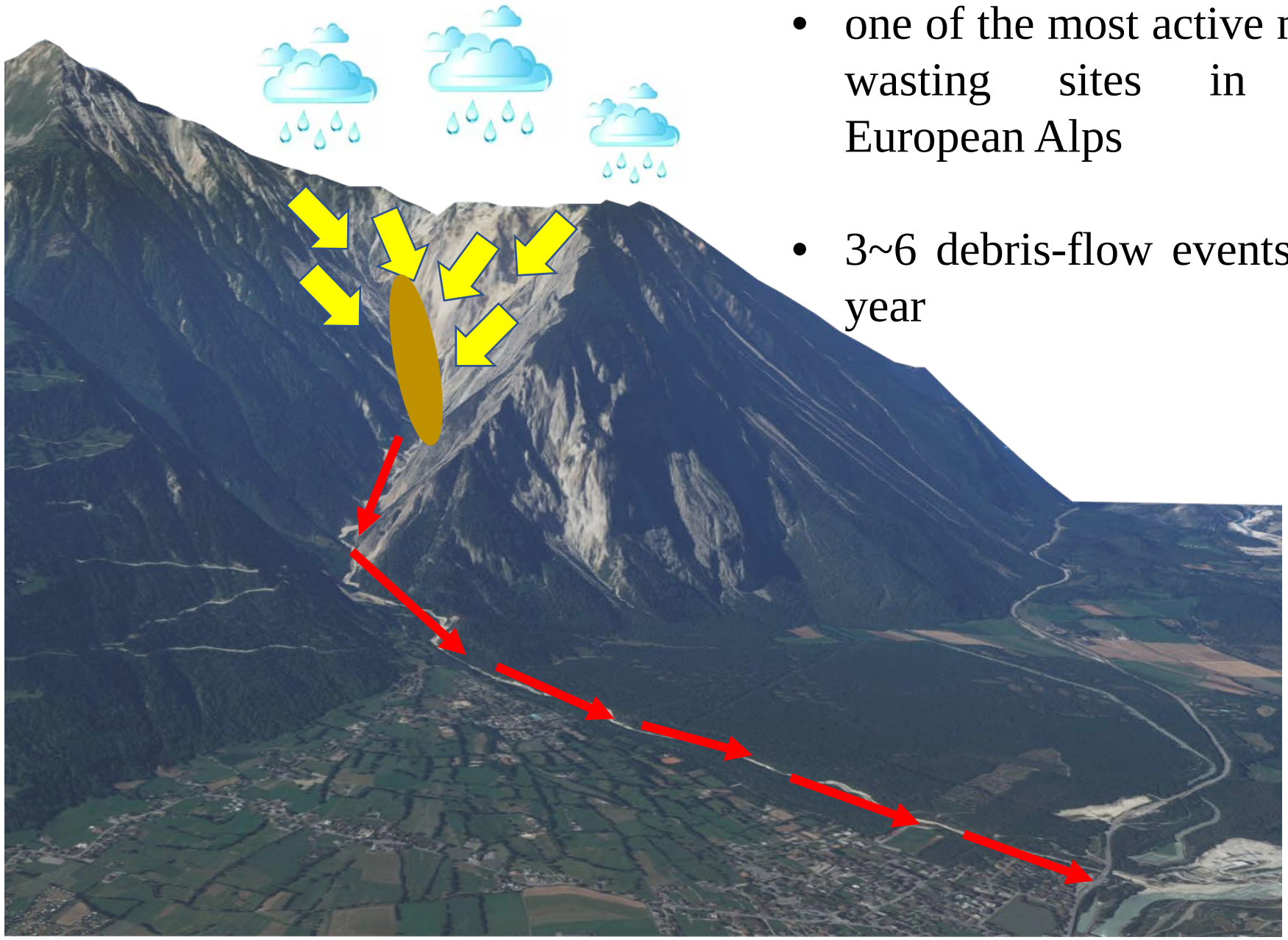
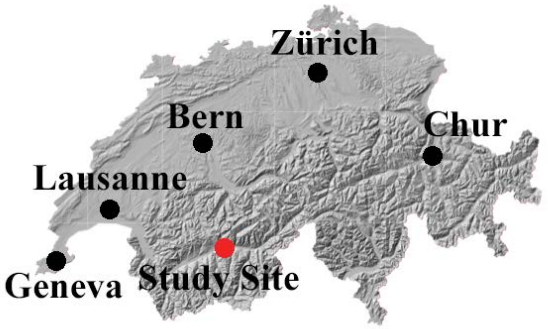
Study site – Illgraben, Switzerland

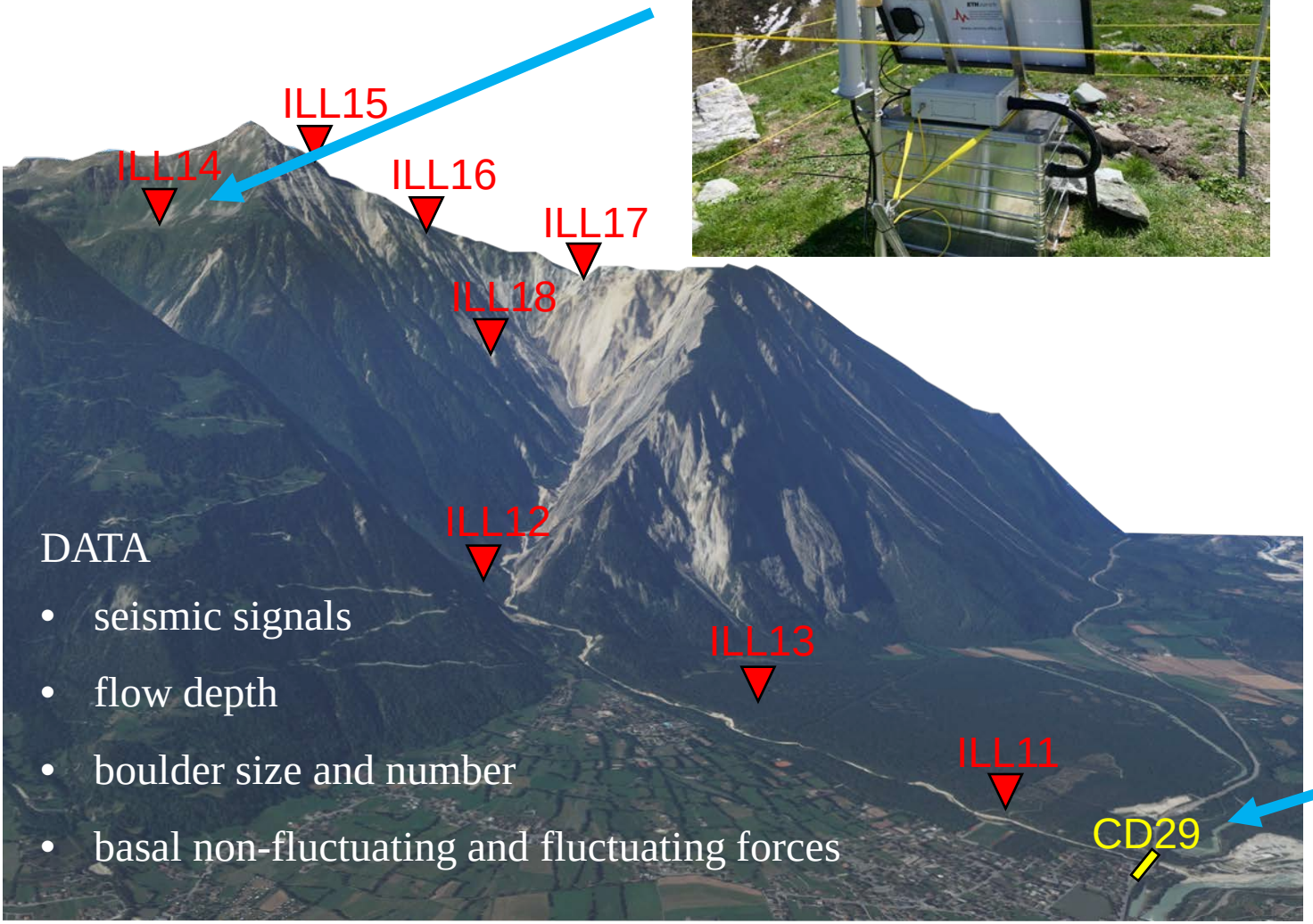


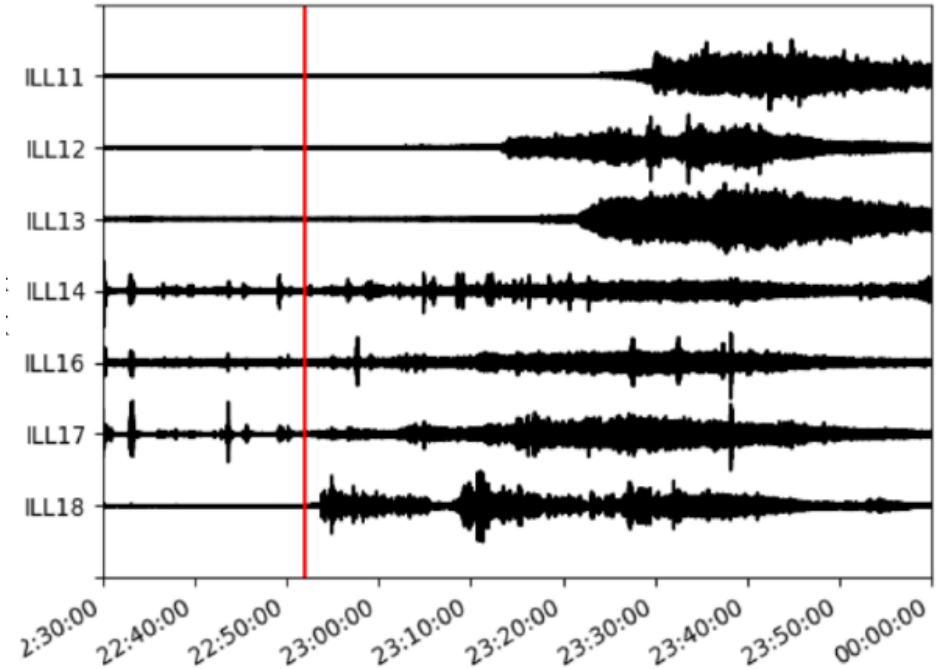


- one of the most active mass wasting sites in the European Alps
- 3~6 debris-flow events per year

- slope failures provide the source sediment material
- transform into debris flows during heavy summer precipitation

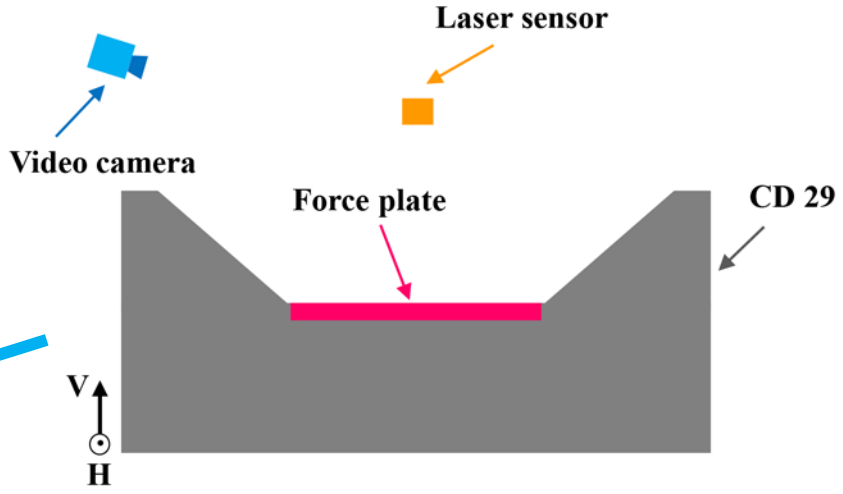
Study site – Illgraben, Switzerland





DATA

- seismic signals
- flow depth
- boulder size and number
- basal non-fluctuating and fluctuating forces

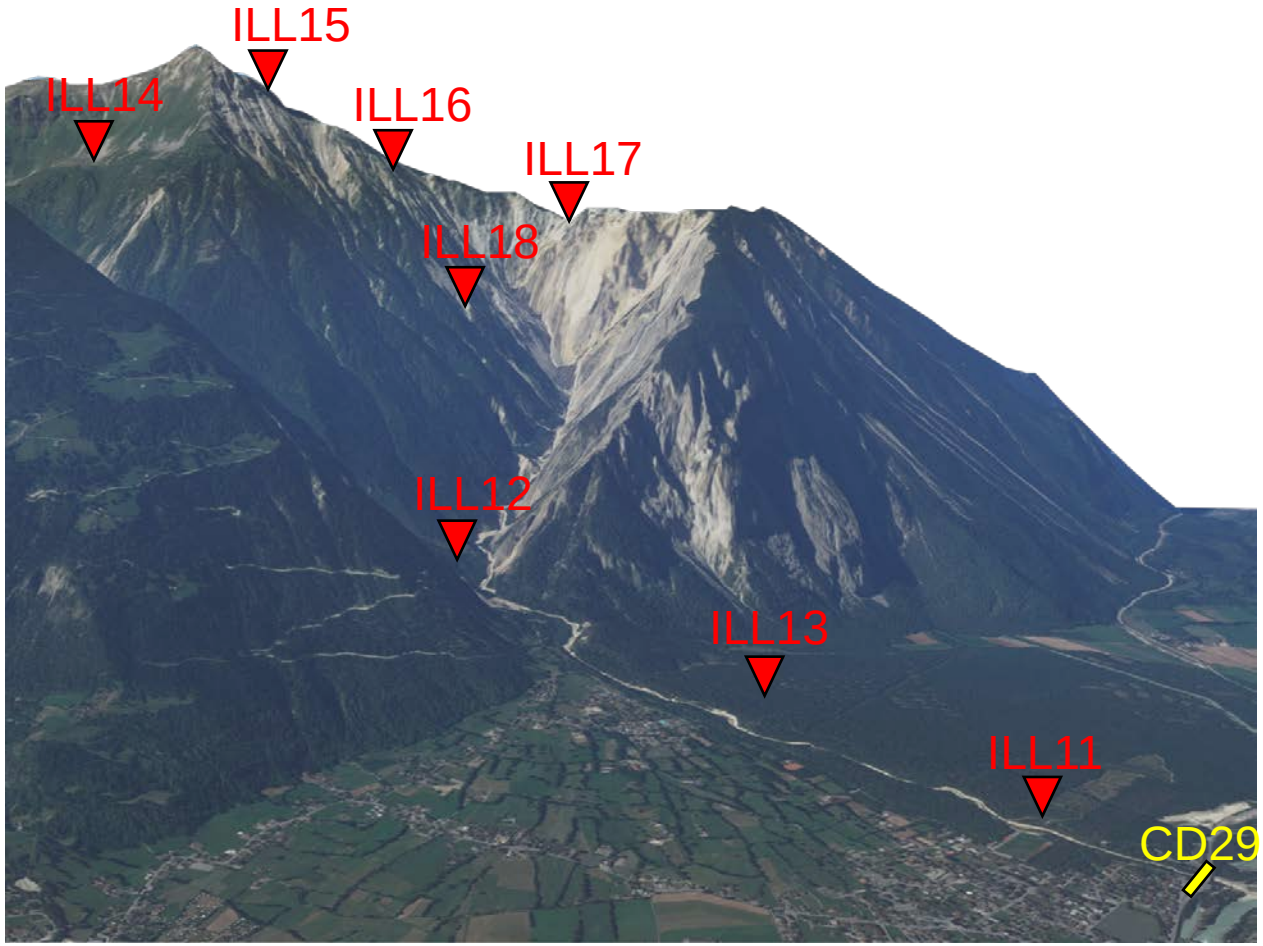


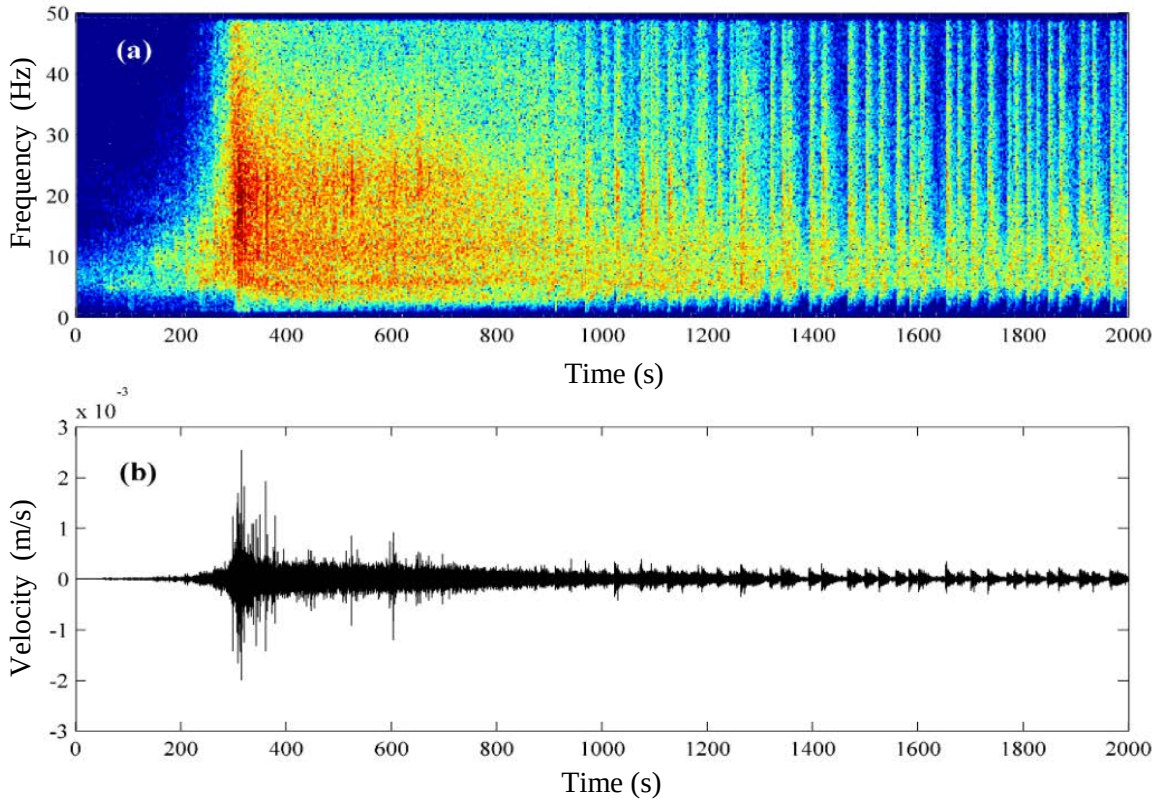
Debris-flow seismic signals

Seismic Signals = Path Effects * Source

high frequency (>1Hz) seismic ground models basal fluctuating forces

empirical Green's functions





Debris-flow dynamics

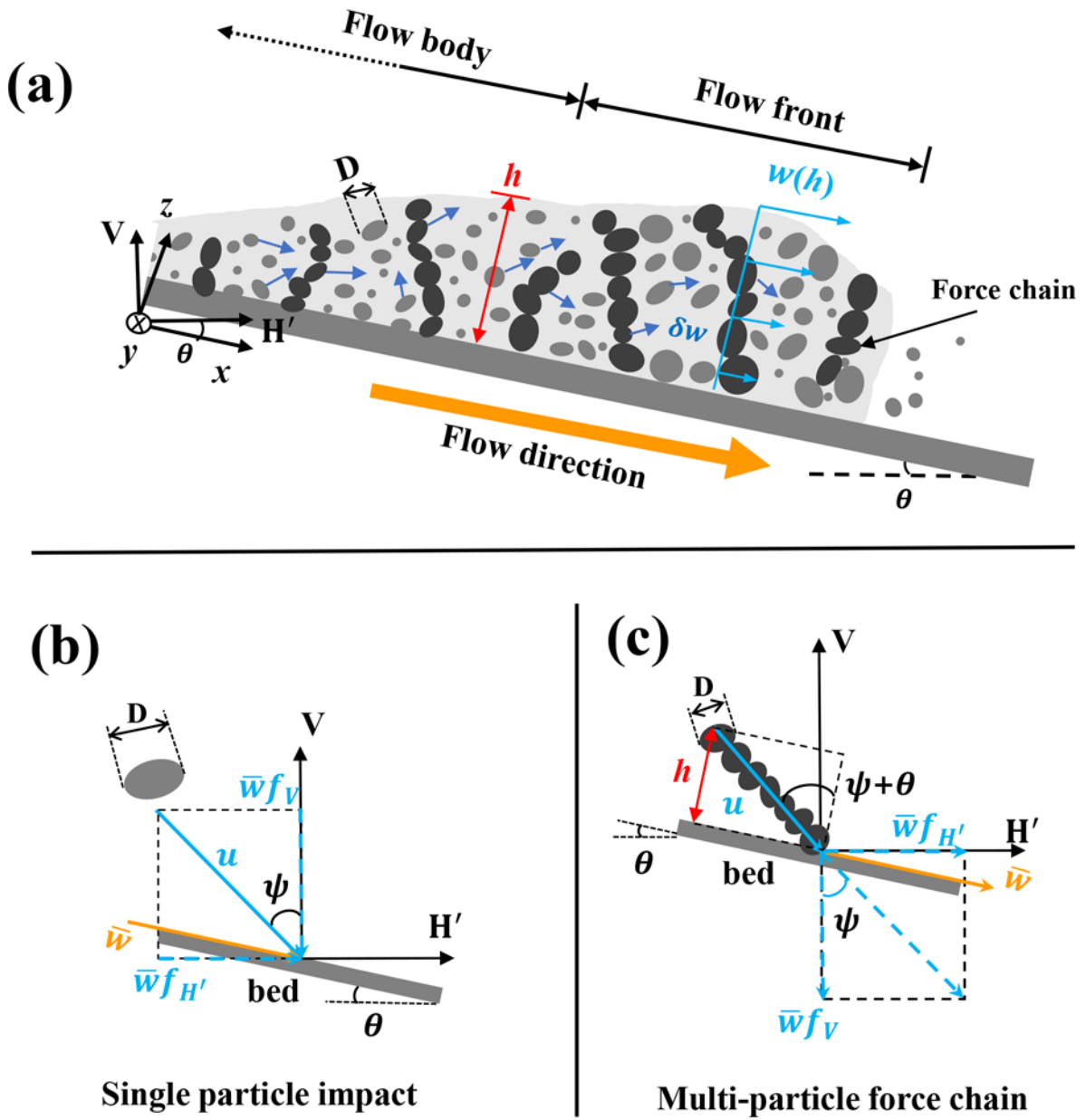
Basal fluctuating forces:

- single-particle impact
- multi-particle force chain: a distributive network of filamentary force-accommodating chains

$$\left|\tilde{F}_i^t(f,t)\right| \approx \frac{\pi(1+\lambda)\rho_s \Lambda^{1.5}\sqrt{\bar{\phi} S_{bed}}}{6\left(\cos\frac{\pi}{6}\right)^{\eta}} {D_e}^{1.5-\eta} h^{1.5\alpha+\eta} f_i$$

Ignore

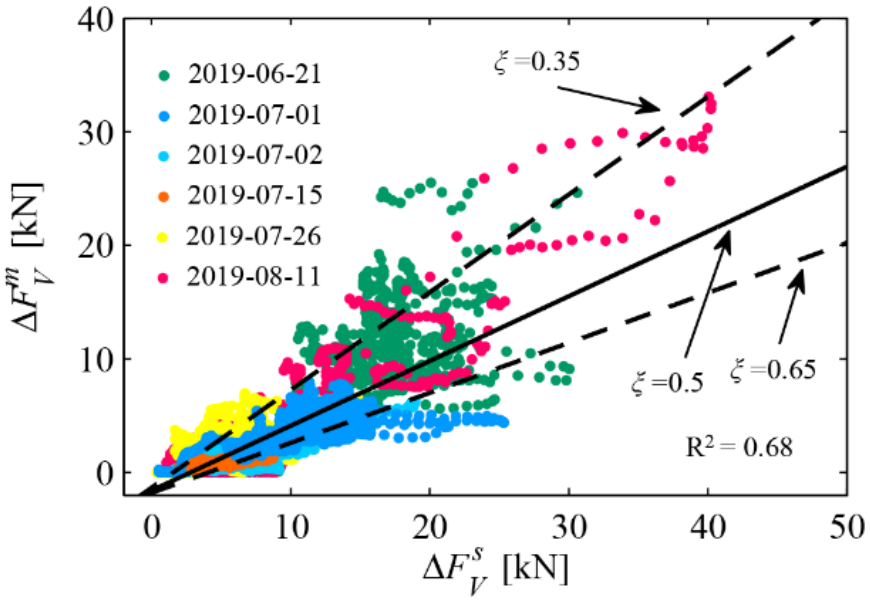
- interactions of particle clusters with the bed
- dynamic pore-pressure fluctuations
- changes in debris-flow bulk properties

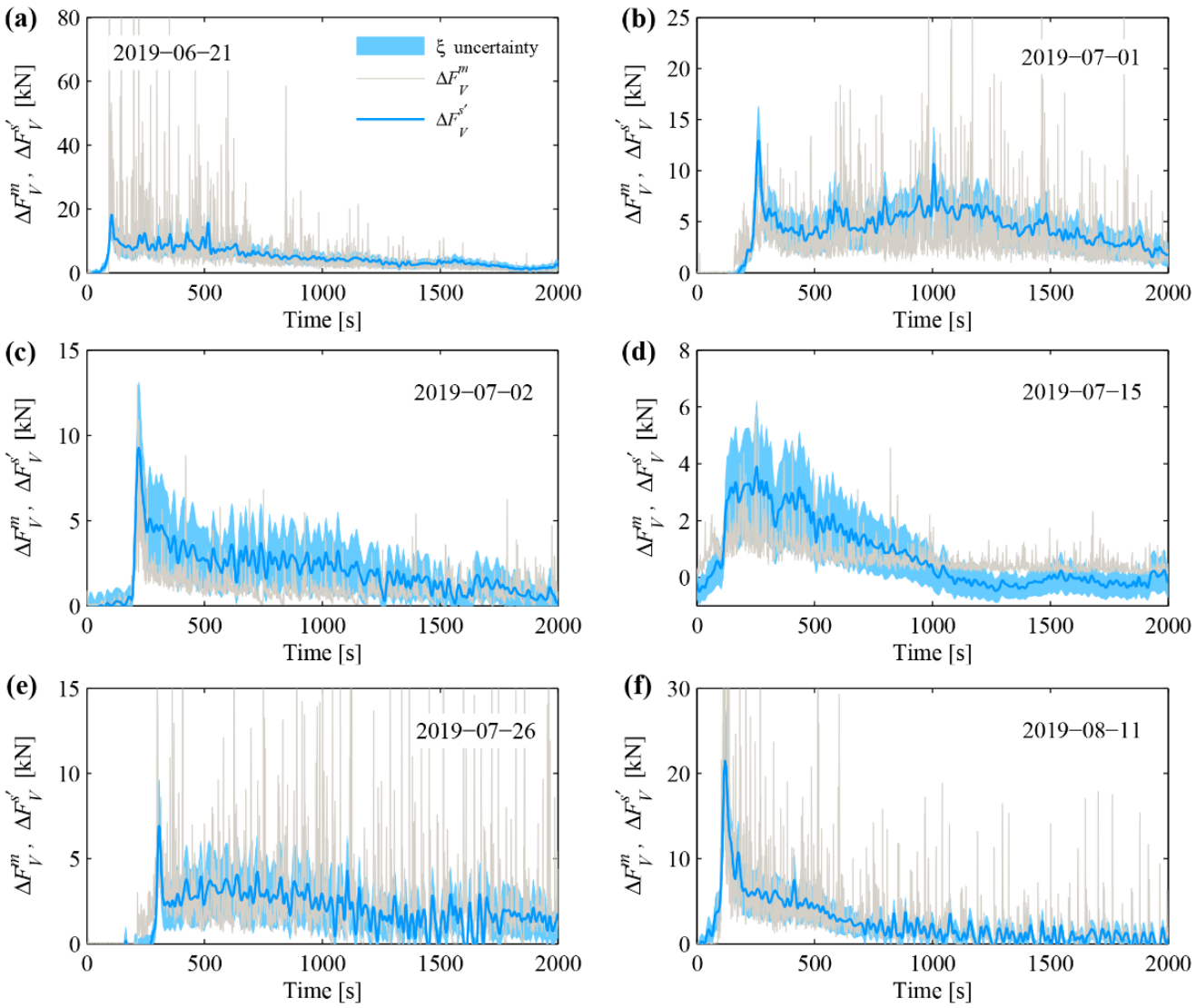


Seismically derived basal fluctuating forces

absolute magnitude of basal force fluctuation from seismic signals

- difference in area of seismic source and of force plate
- simplification in seismic ground model





ΔF_i^m: Measured basal fluctuating forces; ΔF_i^s: Seismically inverted basal fluctuating forces

Basal fluctuating forces

➢ Flow body

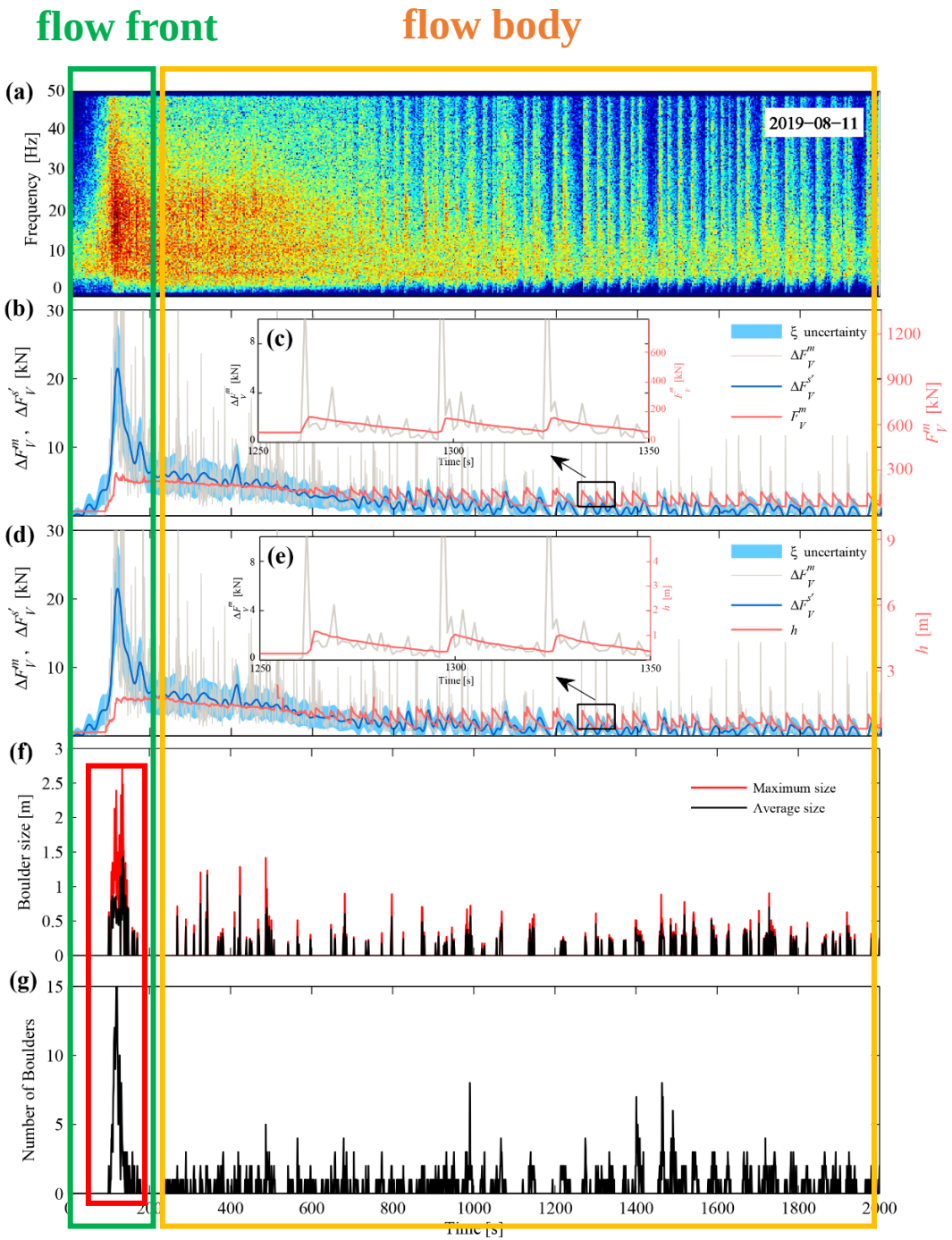
measured basal force and flow depth correlate with envelope of basal fluctuating forces

➢ Flow front

measured basal fluctuating forces and seismically derived basal fluctuating forces exhibit distinct peaks.

It is because large particles are transported to flow front due to size segregation.

h: flow depth
F_V^m: basal vertical forces
ΔF_V^m: measured basal fluctuating forces
$\Delta F_V^{s\prime}$: seismically inverted basal fluctuating forces



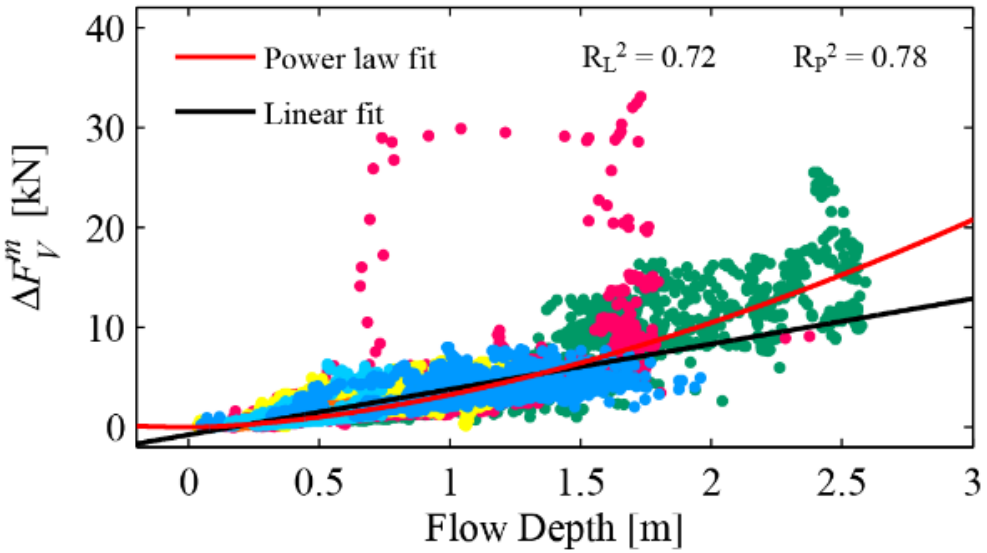
Correlations between basal force fluctuations and flow depth

- a power law relation better explains the relation between basal force fluctuations and flow depth

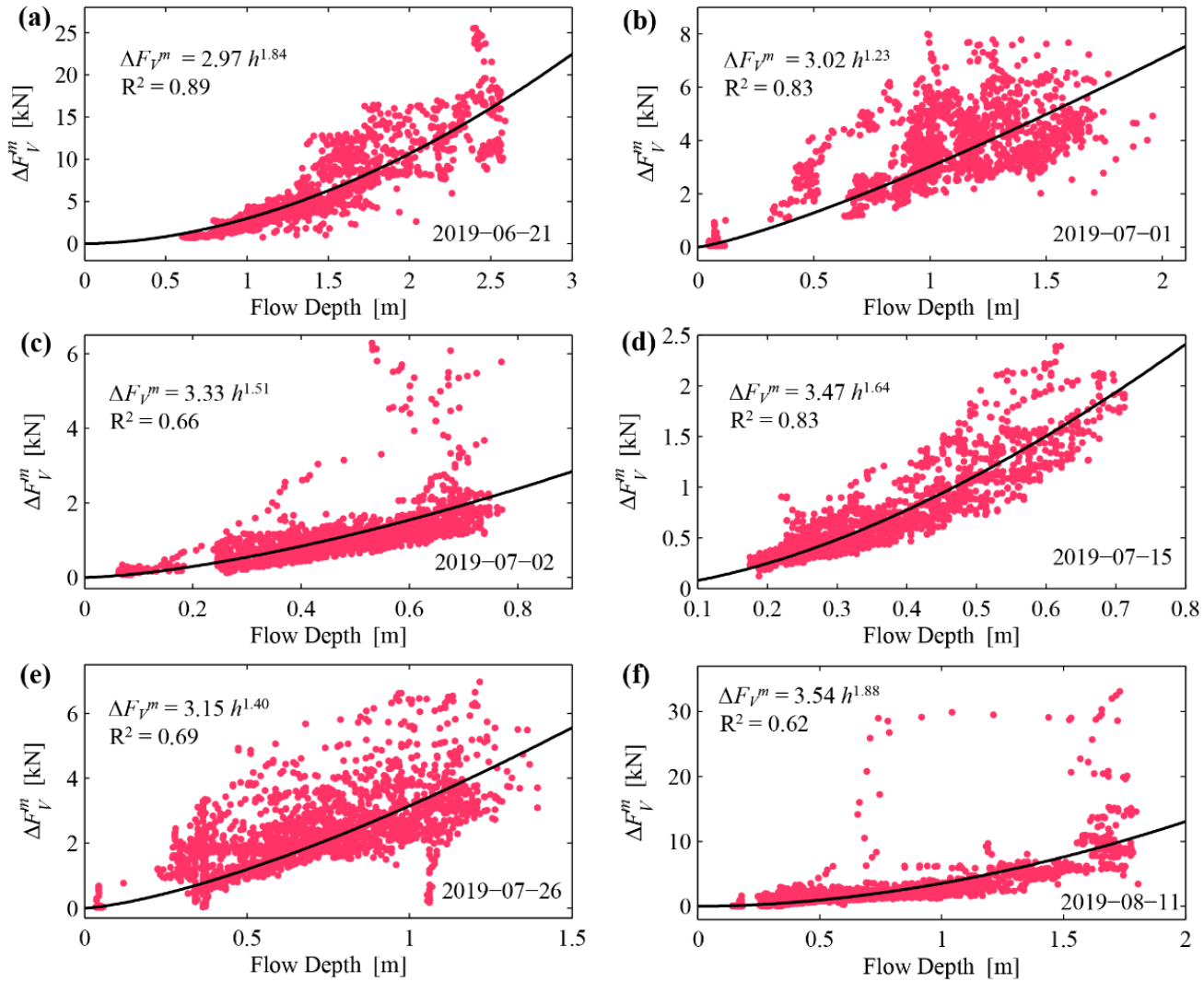
$$\Delta F_V^m \propto h^{1.69}$$

- flow-depth dependence of basal fluctuations varies between events

relative contributions of single impacts and of multi-particle force chains on basal fluctuations is different in each event



h: flow depth
ΔF_V^m: measured basal fluctuating forces



Theoretical basal fluctuations

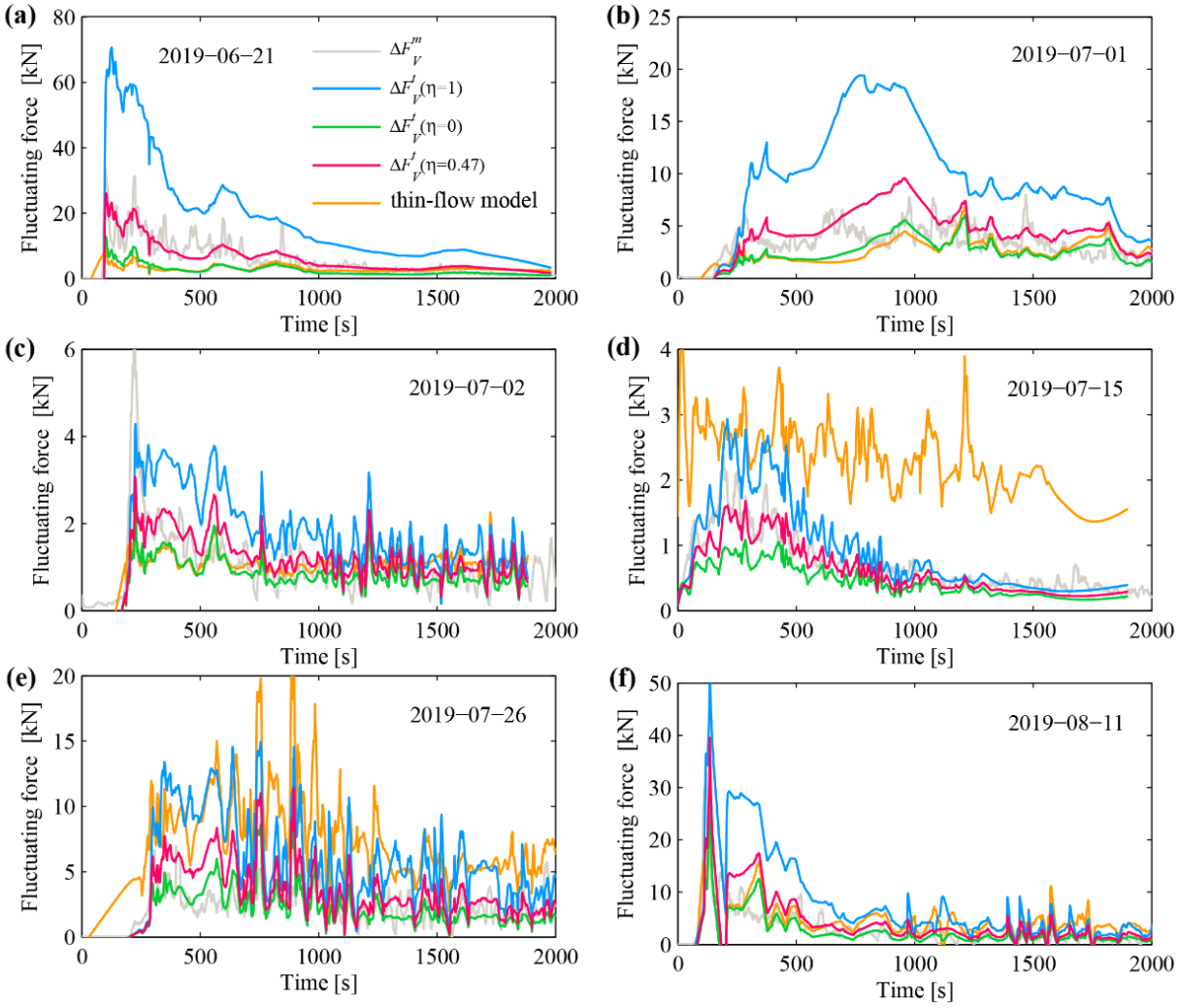
h: flow depth
ΔF_i^t: theoretical basal fluctuating forces

$$\Delta F_i^t(t,\eta,D_e) \approx 21.8 f_i \left(\cos\frac{\pi}{6}\right)^{-\eta} {D_e}^{1.5-\eta} h^{1.22+\eta}$$

- $\eta = 0$: all impacts on force plate result from single particles.
$$\Delta F_i^t \propto h^{1.22}$$

- $\eta = 1$: all basal fluctuating forces are transmitted to force plate via force chains.
$$\Delta F_i^t \propto h^{2.22}$$

- $\eta = 0.47$: $\Delta F_V^t(\eta = 0.47)$ can better predict basal fluctuations.
$$\Delta F_i^t \propto h^{1.69}$$

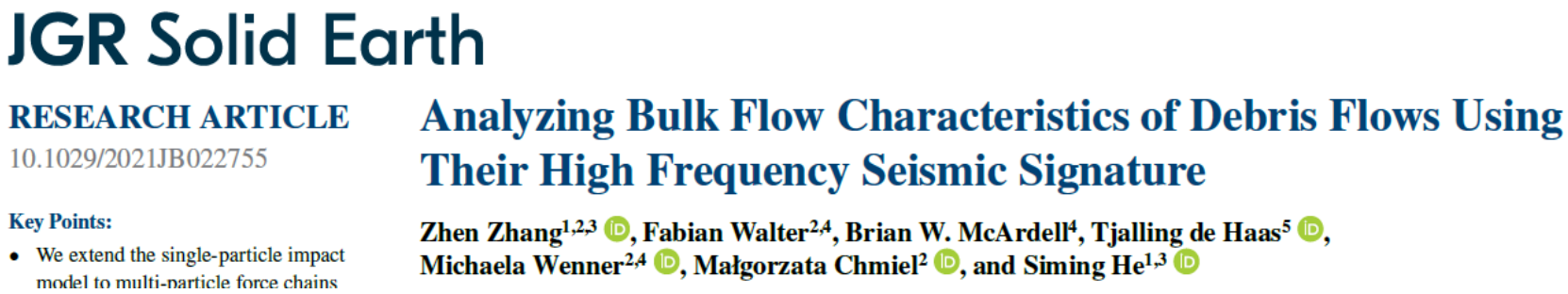


- **basal fluctuations are controlled by single-particle impacts and multi-particle force chains**
- **flow depth dependence of basal fluctuations has an exponent between 1.22 and 2.22**

Summary

- Seismically derived basal fluctuations correlate with the bulk flow properties.
- An extended physical model consisting of both single-particle impacts and multi-particle force chains is proposed.
- The relative contributions of single particles and of multi-particle force chains may vary significantly for different events and flow position.

More detail:



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Key Points:

- We extend the single-particle impact model to multi-particle force chains

Analyzing Bulk Flow Characteristics of Debris Flows Using Their High Frequency Seismic Signature

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