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Flow and Bed Conditions jointly control Debris-Flow Erosion and Bulking

Link to paper

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Abstract and conclusions

Debris flows can grow greatly in size and **hazardous** potential by **eroding** bed and bank materials. However, **erosion mechanisms** are poorly understood because debris flows are **complex hybrids** between a **fluid flow** and a moving mass of **colliding particles**, bed erodibility varies between events, and field measurements are hard to obtain. Here, we identify the **key controls on debris-flow erosion** based on a field dataset of the Illgraben (CH) that combines information on **flow properties**, **bed conditions**, and bed and bank **erosion**. The Illgraben is the most active channel of the European Alps, experiencing 5-10 debris flows per year (Figs. 1-2).

We show that:

- **Flow** conditions and **bed wetness** jointly control debris-flow **erosion** (Fig. 3, Table 1).
- Flow conditions describing the **cumulative forces** exerted at the bed during an event **best** explain **erosion** .
- **Cumulative rainfall** over a **2-3** hr period is **strongly** correlated to **erosion** (Fig. 4, Table 1).
- **Shear forces** and **particle-impact forces** are strongly **correlated** and act in **conjunction** in the erosion process.
- A **shear-stress approach** accounting for bed erodibility may be best **applicable** for **modelling** and **predicting** debris-flow **erosion**.

1. Study site: Illgraben (CH)

Fig. 1: Overview of the Illgraben catchment and fan, and examples of debris flows. Flow measurements are performed at the toe of the fan. Here we compare flow properties with erosion and deposition in the lower 800 m of the channel.

2. Drone-based erosion measurements

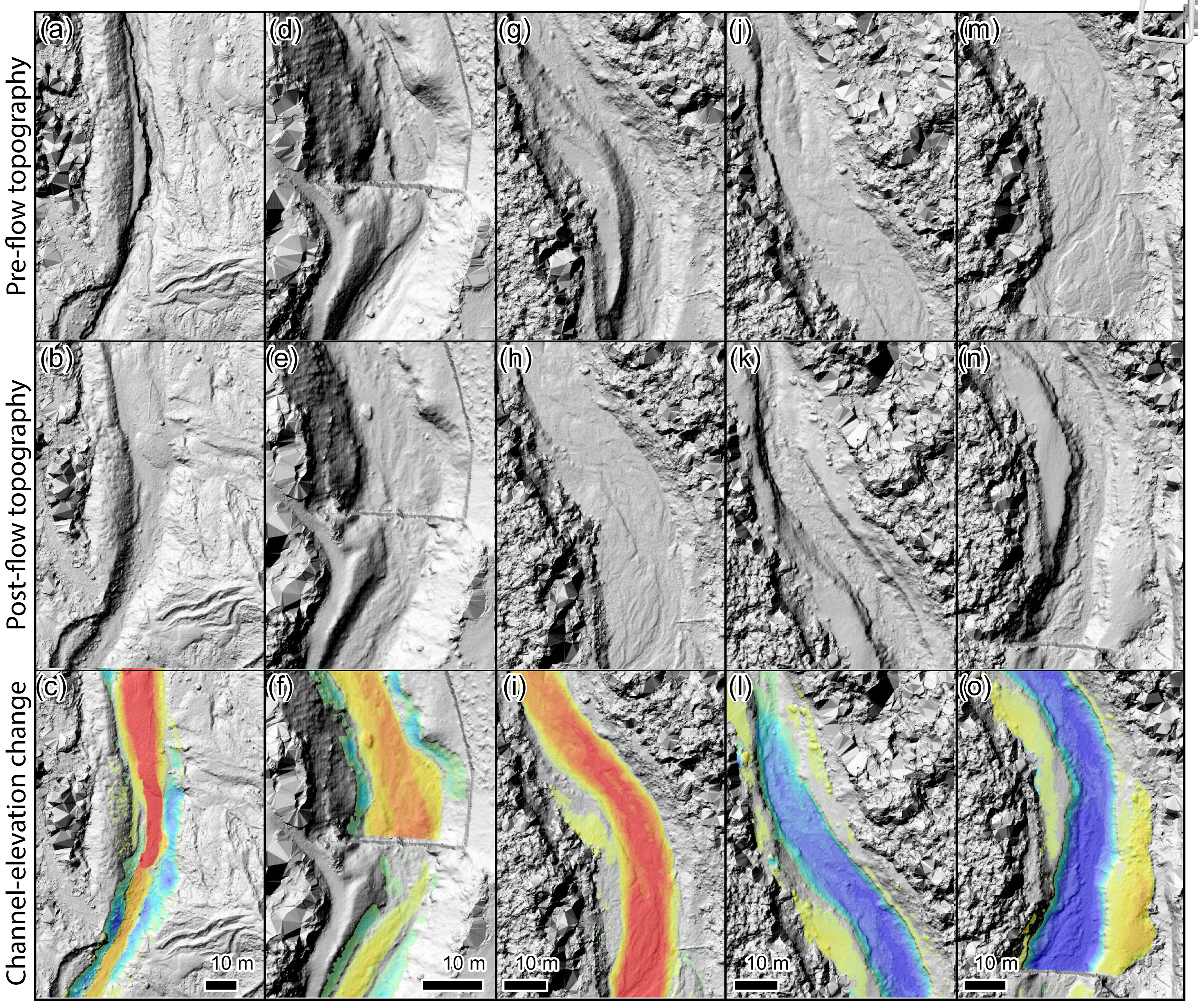

Fig. 2: Examples of erosion and deposition patterns. Panels show hillshaded DEMs, for the channel-elevation change panels overlain by the DEM of difference, on which warm colours denote erosion and cold colours denote deposition. Value range from red to blue is -3 to 3 m channel-bed elevation change.

3. Relation between debris flow and erosion

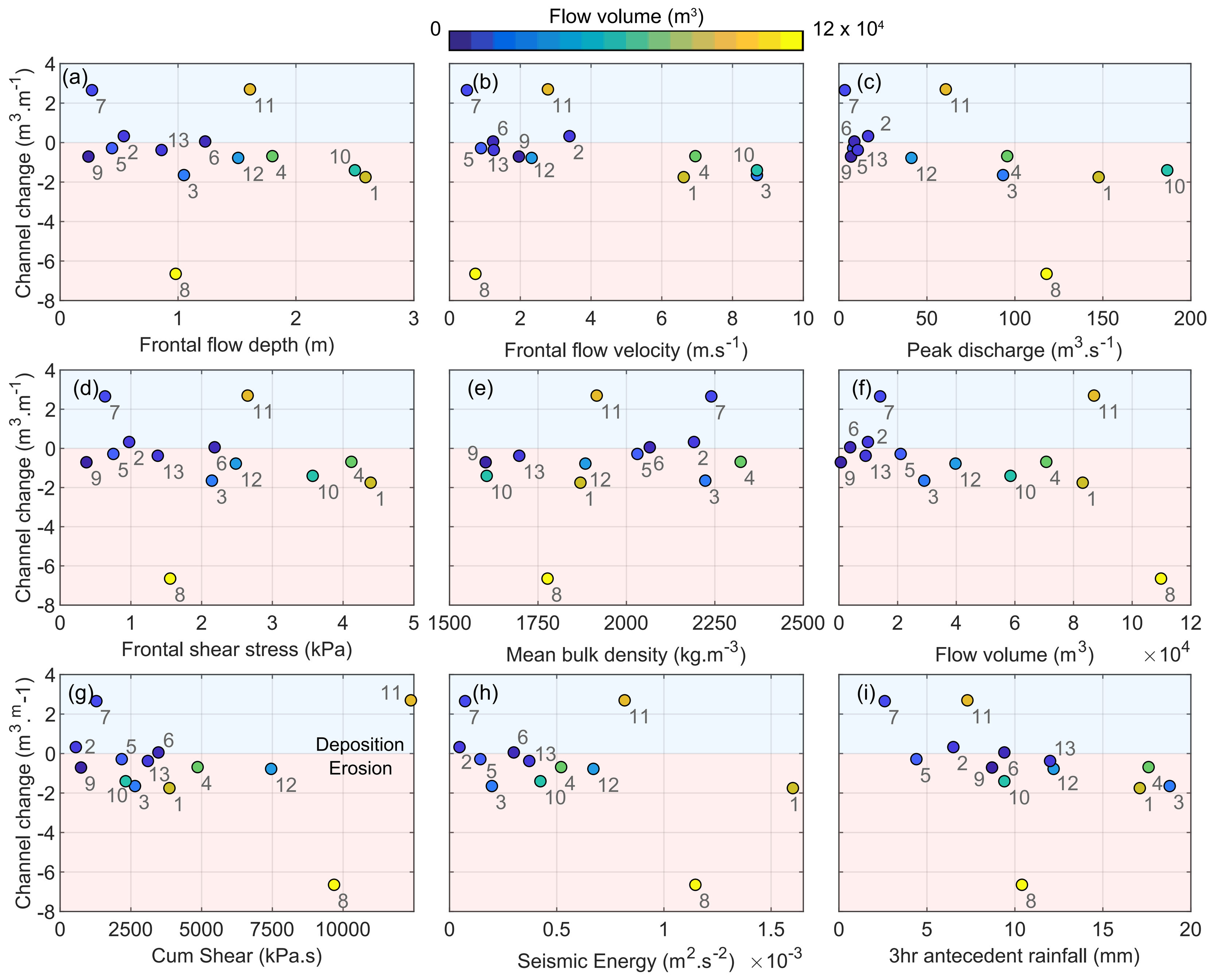

Fig. 3: Flow properties and 3hr antecedent rainfall versus and channel-bed elevation change. See Table 1 for correlation coefficients. Cumulative forces are most strongly correlated (Volume; Cumulative shear; Seismic Energy).

4. Relation between antecedent rainfall and rainfall

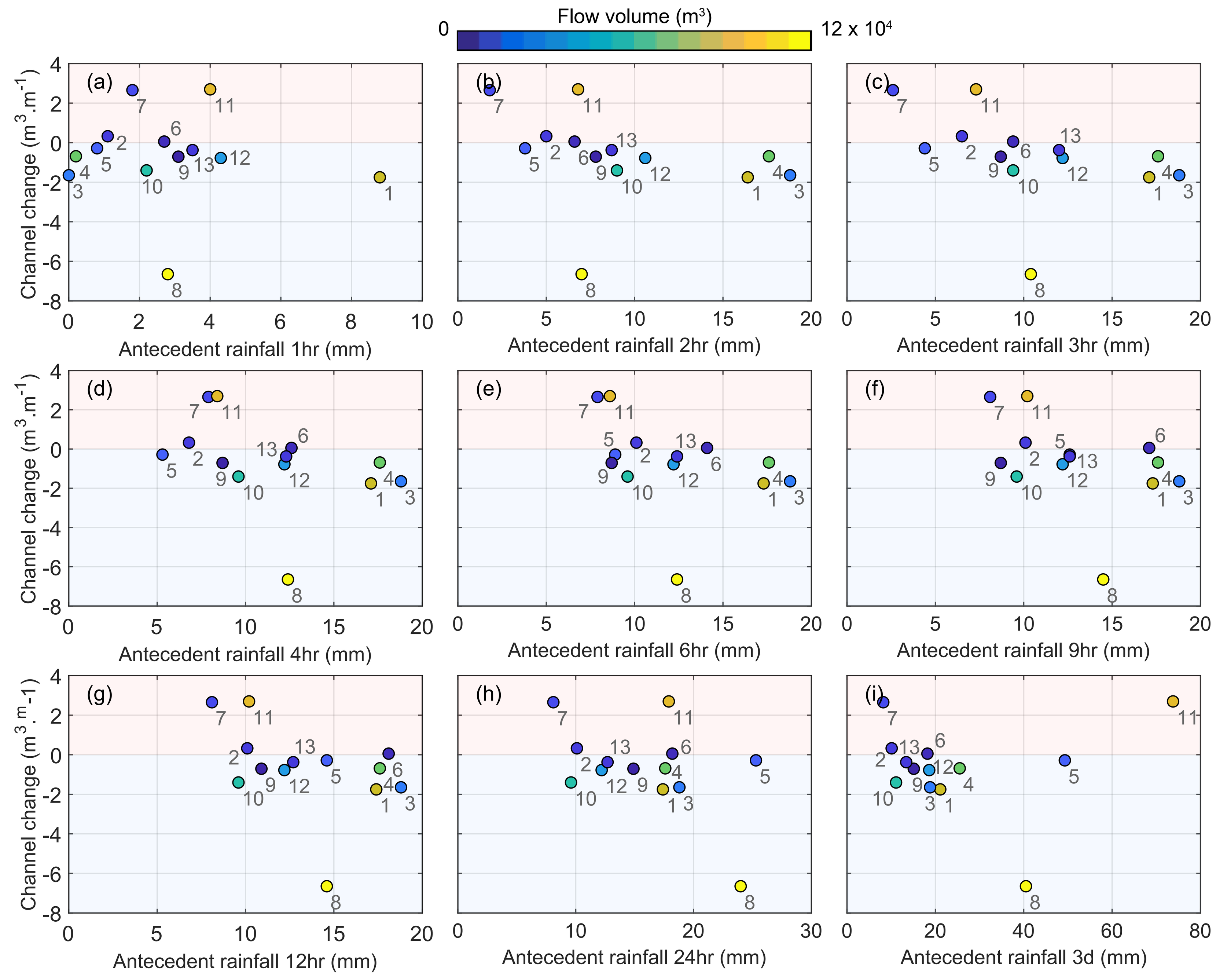

Fig. 4: Antecedent rainfall over various time periods versus and channel-bed elevation change. See Table 1 for correlation coefficients. Antecedent rainfall over a 2-3hr period shows he strongest correlation with erosion.

5. Correlation coefficients

Debris flow	H_{front}[a] [m]	U_{front}[a] [m s^{-1}]	Q_{front}[a] [m^3 s^{-1}]	τ_{front}[a] [kPa]	ρ_{mean}[a] [kg m^{-3}]	Volume[c] [m^3]	cum. τ[c] [kPa.s]	Seismic E[c] [m^2 s^{-2}]	
R^2	0.39	0.46	0.42	0.35	0.16	0.58	0.55	0.41	
p-value	0.04	0.02	0.03	0.06	0.23	0.01	0.01	0.03	
Ant. rainfall	1hr[b] [mm]	2hr[b] [mm]	3hr[b] [mm]	4hr[b] [mm]	6hr[b] [mm]	9hr[b] [mm]	12hr[b] [mm]	24hr[b] [mm]	3d[b] [mm]
R^2	0.01	0.45	0.48	0.30	0.37	0.29	0.31	0.04	0.16
p-value	0.72	0.02	0.01	0.06	0.04	0.07	0.06	0.53	0.19

Table 1: Pearson's correlation coefficient and p-values for the relations of debris-flow characteristics and antecedent rainfall with net erosion/deposition. Significant trends with p-values < 0.05 are highlighted in dark green and marginally significant trends with p-values < 0.10 are highlighted in light green.