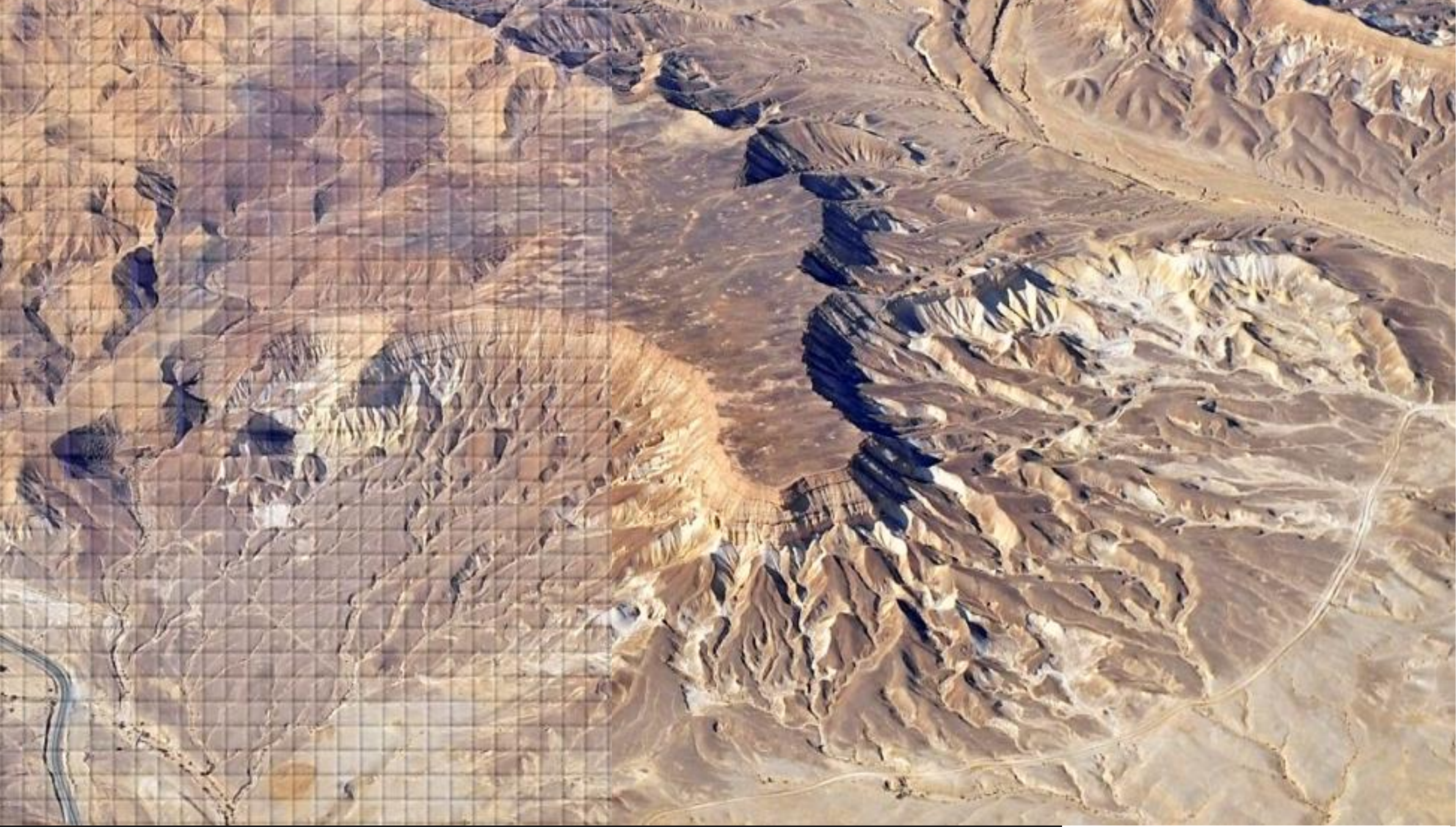

Linking frequency of rainstorms, runoff generation and sediment transport across hyperarid talus-pediment slopes

Shmilovitz Y., Morin E. , Rinat Y., Carmi G. , Haviv I., Mushkin A., and Enzel Y.

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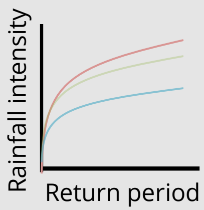
الجامعة العبرية في اورشليم القدس

Shmilovitz et al., : ESPL

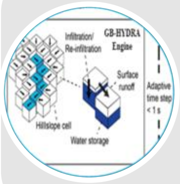
- EGU 2020 -

Contents

Key points (click on title to skip)

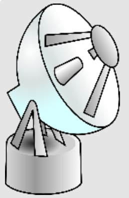


IDF-based designed storms



Fully distributed hydrological modeling (GB-HYDRA)

The frequency of full extent hillslope overland flow



Remote-sensed analyses of runoff-generating storms

Which storm could erode the slope surface?

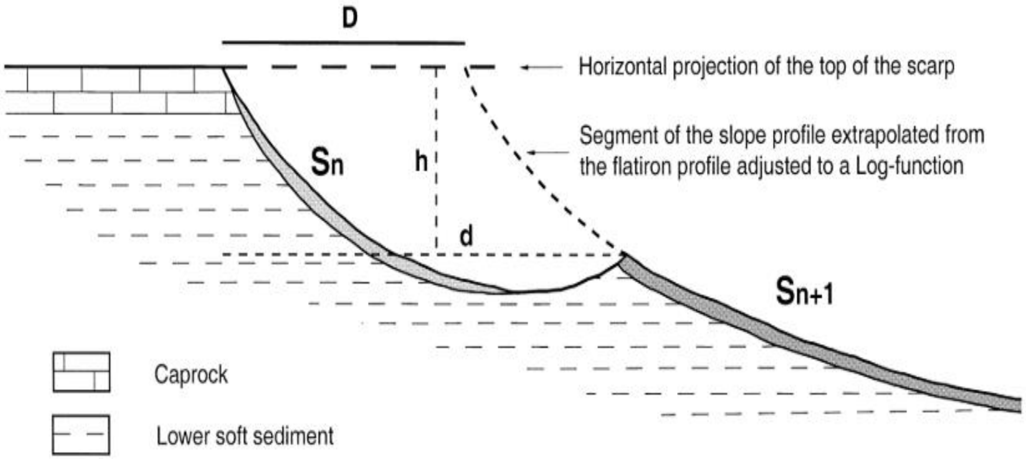
Summary

In short: we provides quantitative analyses of runoff-generating rain cells and their geomorphic impact on hyperarid talus-pediment slopes. Full extent of hillslope runoff occurs only under rainstorms with ≥100-years return interval. Sheetwash efficiency rises with downslope distance; ≥100-years return interval storms are capable of transporting surface clasts. The erosion efficiency of these discrete rare events highlights their potential importance in shaping the landscape of arid regions.

Talus slopes

dominant geomorphic elements and primary runoff and sediment contributors

(e.g., Pinheiro et al., 2017, Duszyński et al., 2019)



Modified from Gutiérrez et al., (1998)

Talus flatirons

considered as geomorphic evidence of climate oscillations (e.g., Schmidt 2009, Gutiérrez et al., 1998)

Spain Elorza and Martinez (2001)

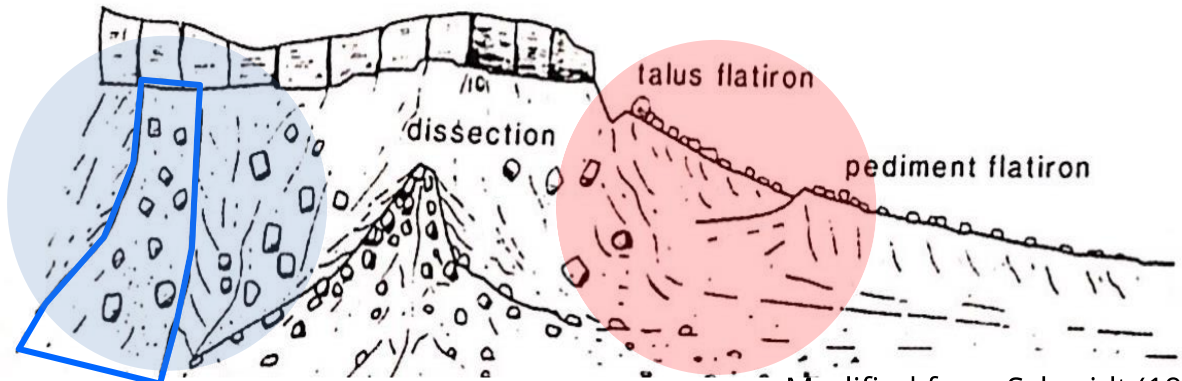
Colorado plateau Pinheiro (2017) a

Book cliffs (Utah)

Two-phase conceptual model

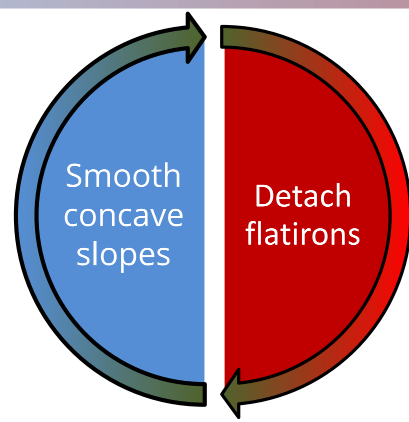
(e.g., Schumm and Chorley 1966, Gerson, 1982, Schmidt 1989b,2009)

Flatiron evolution was hypothesized to be associated with glacial-interglacial climatic cycles



Modified from Schmidt (1989b)

Wet



Dry

In wet conditions: caprock-derived material accumulates within the lower scarp slope. The slope is consider as stable

In arid conditions: dissection and gullying lead to the separation of the slope from the cliff

However

In arid areas, many previous arguments linking the evolution of such landforms with climate were actually based on inferences; relevant landforms were never dated to support this notion

- In dry regions, a shift toward a climate characterized by more frequent **extreme storms** can significantly increase erosion, even when the mean climatic conditions do not become wetter
- Only a few previous studies focused on evaluating and quantifying the link between extreme rainstorms, runoff, and erosion on arid hillslopes

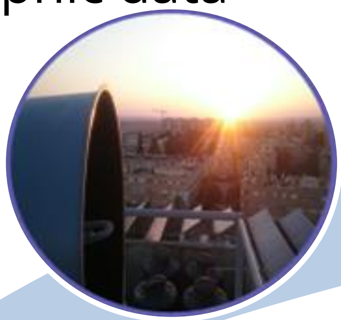
We ask :

How often runoff is generated over the slopes?

Which extreme rainfall events, if at all, drive the evolution of talus-pediment sequences?

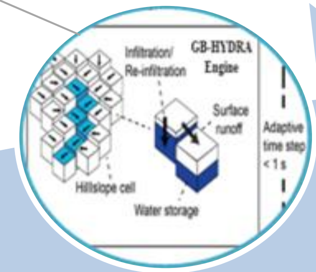
How can we get long-term implications about short-term processes ?

1 . Collecting rainfall\topographic data

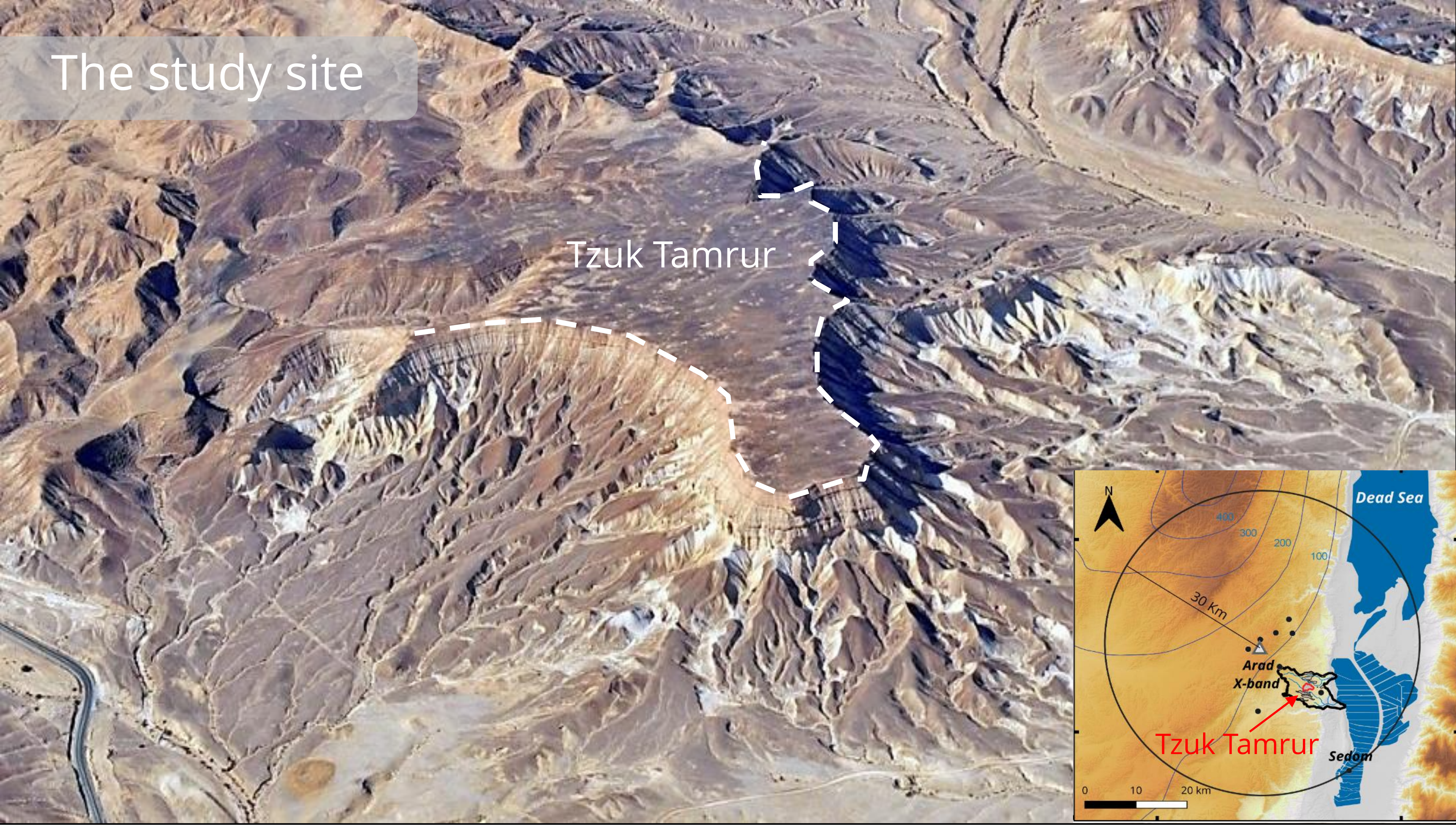


2. Construct field rainfall simulator experiments of **IDF-based designed storms** on a plot scale ($2\ m^2$)

3. Simulate the **designed storms** with gird-based numerical modeling on slope scale



The study site



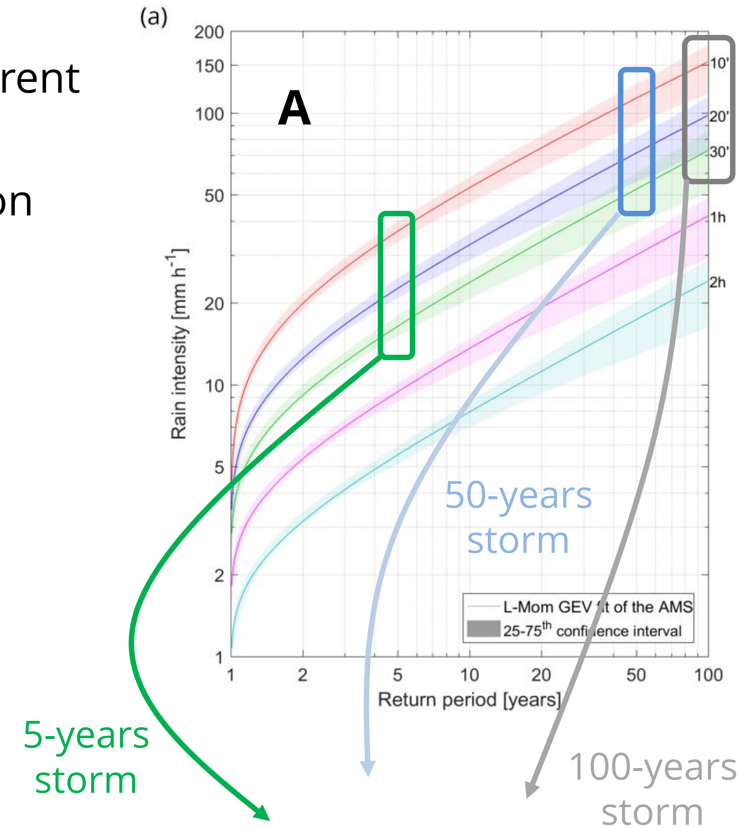
Mean annual precipitation < 80 mm

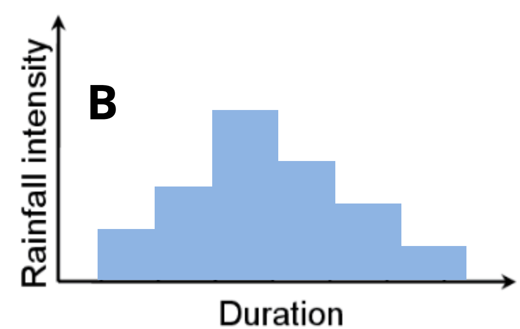
Convective rain environment

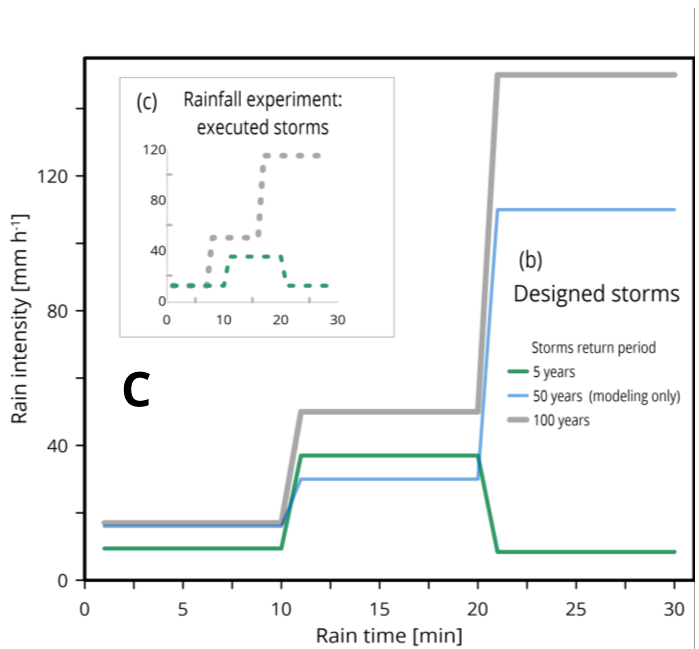
Complex hydrological response

What is IDF-based designed storms?

- **A** IDF curve relate the maximal rain intensity for different durations with a given return period **(A)**
- **B** A design storm is a theoretical storm event based on rainfall intensities associated with frequency of occurrence **(B)**
- **C** Three synthetic storms (30-min) were designed, representing 5- (20%), 50- (2%) and 100-years (1%) return periods **(C)**

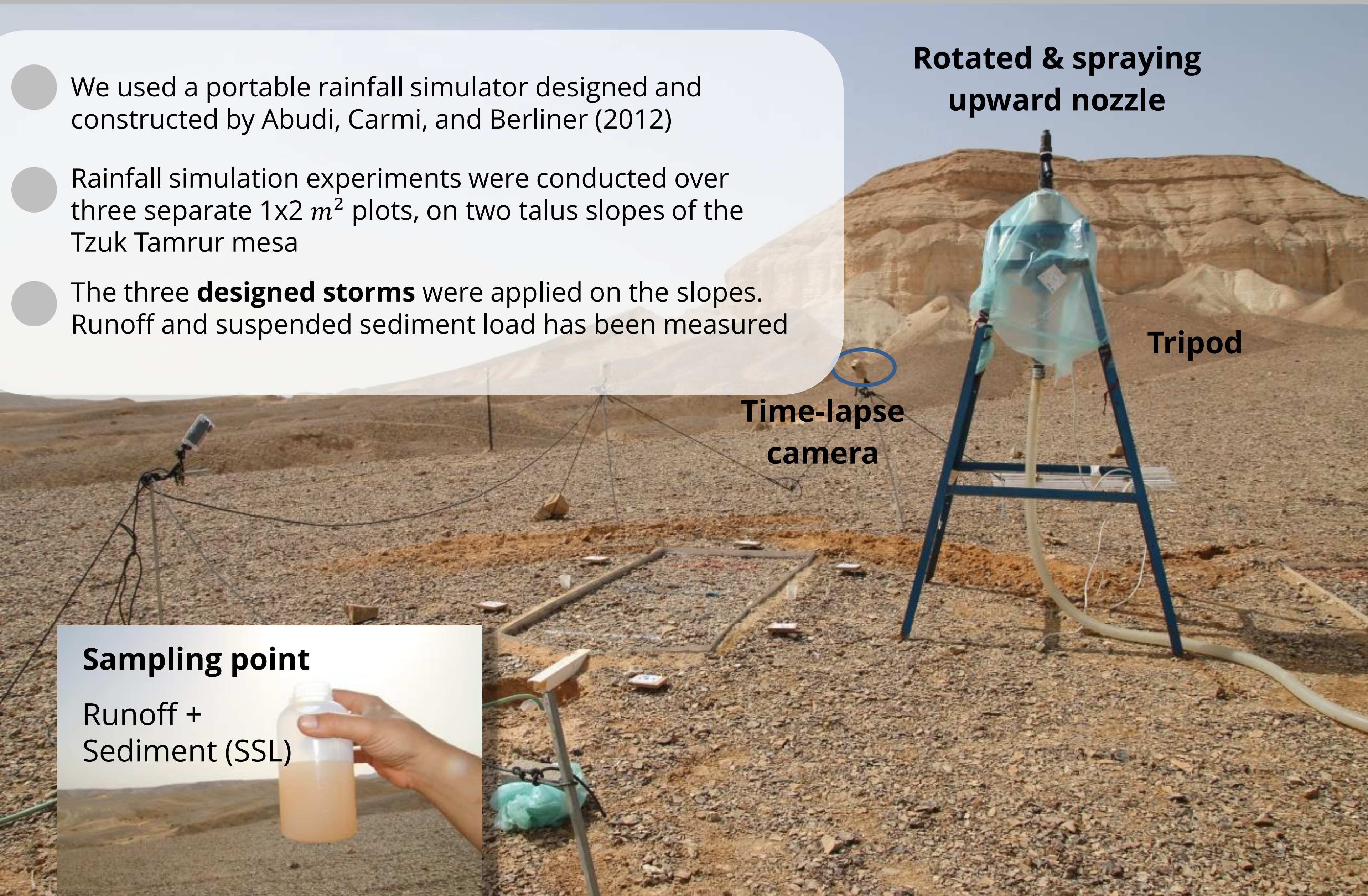






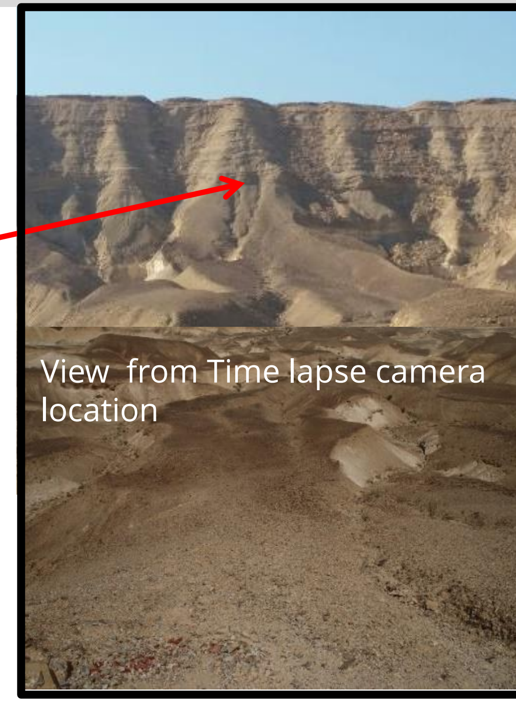
Field rainfall simulator experiments

- We used a portable rainfall simulator designed and constructed by Abudi, Carmi, and Berliner (2012)
- Rainfall simulation experiments were conducted over three separate 1x2 m^2 plots, on two talus slopes of the Tzuk Tamrur mesa
- The three **designed storms** were applied on the slopes. Runoff and suspended sediment load has been measured



Monitoring the 2017\18 hydrological season

Field installed
time lapse cameras (TLC)
used to monitor selected
slopes during rainstorms
(click here for camera view).
In each video, we searched
for runoff generation and
feedbacks concerning
sediment transport.



1-min resolution rain gauge network

X-band mini weather radar
(60 x 60 m^2, 1 min)
Allegretti et al., (2012)

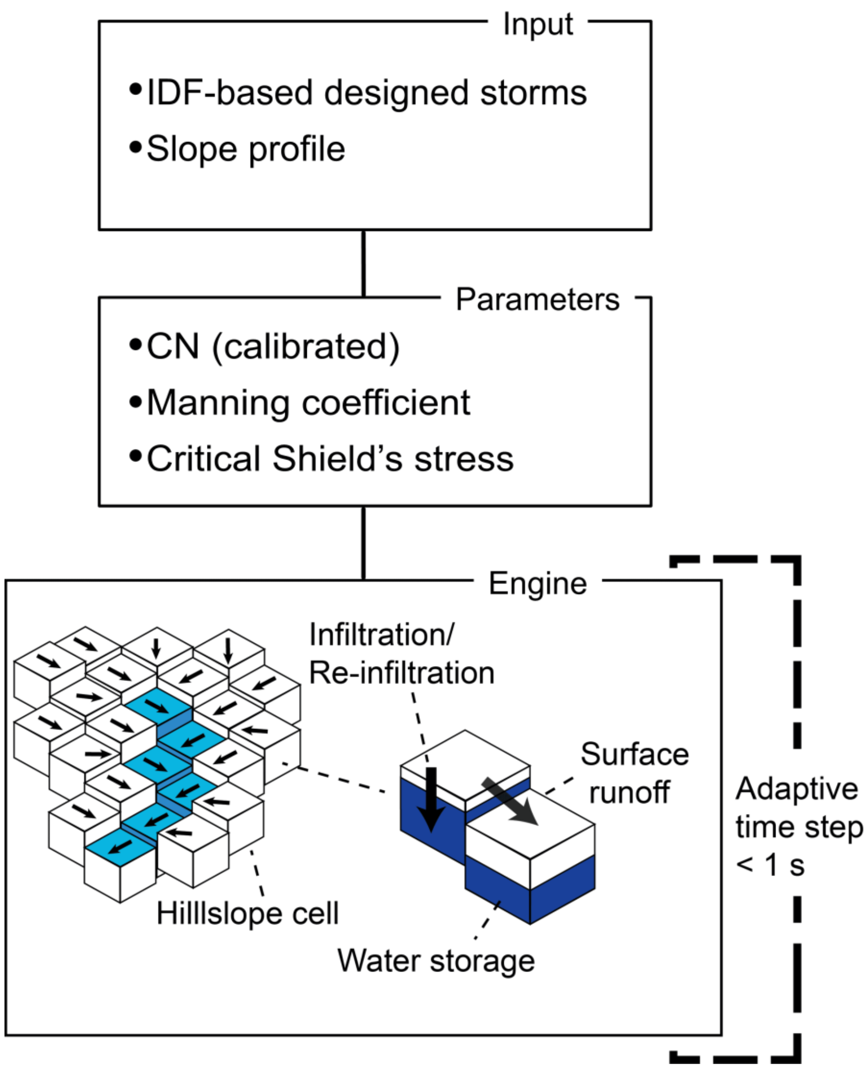
GB-HYDRA (Rinat et al., 2018)

GB-HYDRA model which is an event-scale, physically-based, fully distributed hydrological model

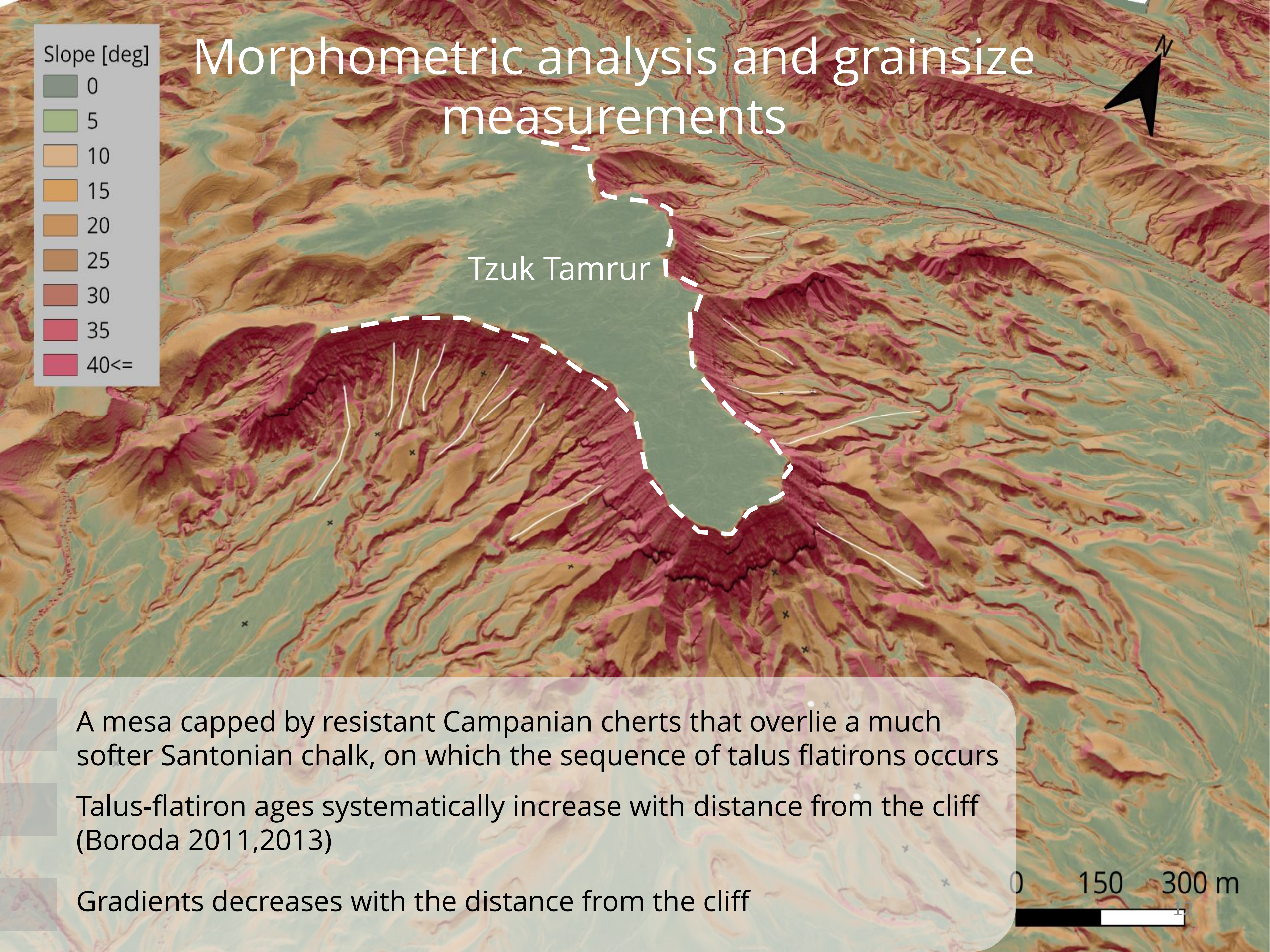
Here we used the GB-HYDRA to **simulate the designed storm in slope-scale**

We used the hillslope-runoff module that was specifically designed to calculate at a high-resolution the water budget, infiltration, runoff generation and its routing down the slope and, maximum shear stress on a **pixel-by-pixel basis**

Infiltration and local runoff generation is computed by a **specifically modified version** of the Soil Conservation Service (SCS) conceptual method (Chow, Maidment, & Mays, 1988)



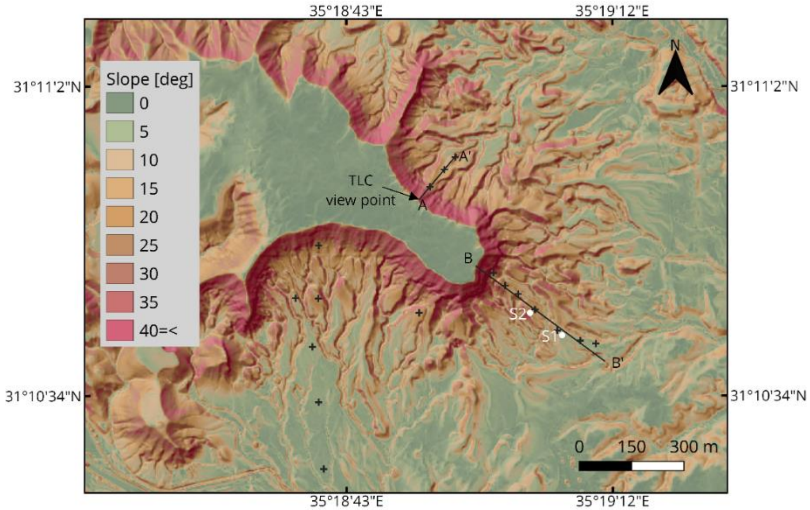
Morphometric analysis and grainsize measurements



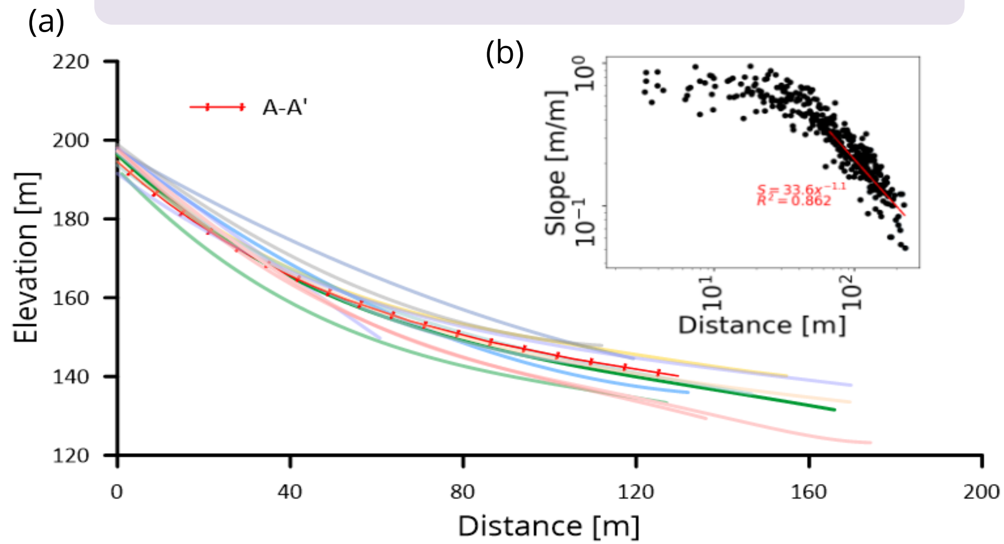
A mesa capped by resistant Campanian cherts that overlie a much softer Santonian chalk, on which the sequence of talus flatirons occurs

Talus-flatiron ages systematically increase with distance from the cliff (Boroda 2011,2013)

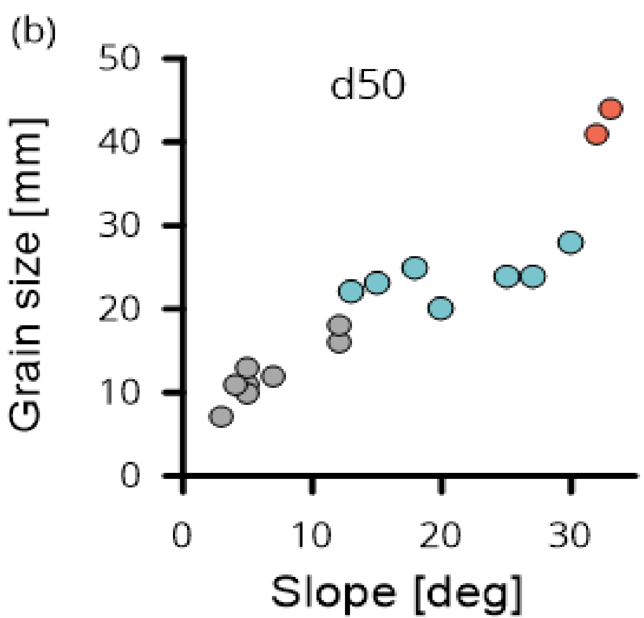
Gradients decreases with the distance from the cliff

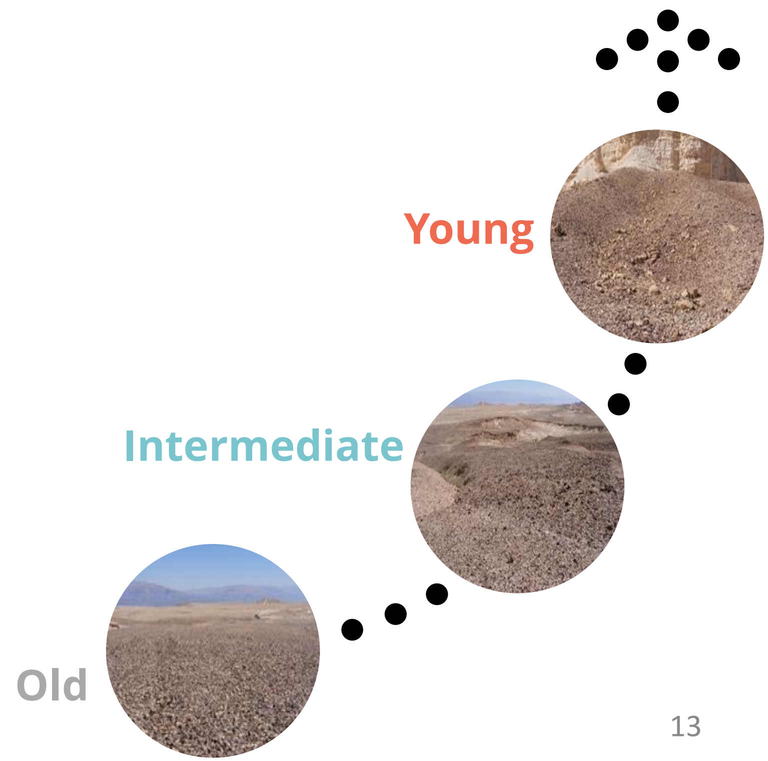


Concave upward slopes



Grainsize trend with talus gradient and age



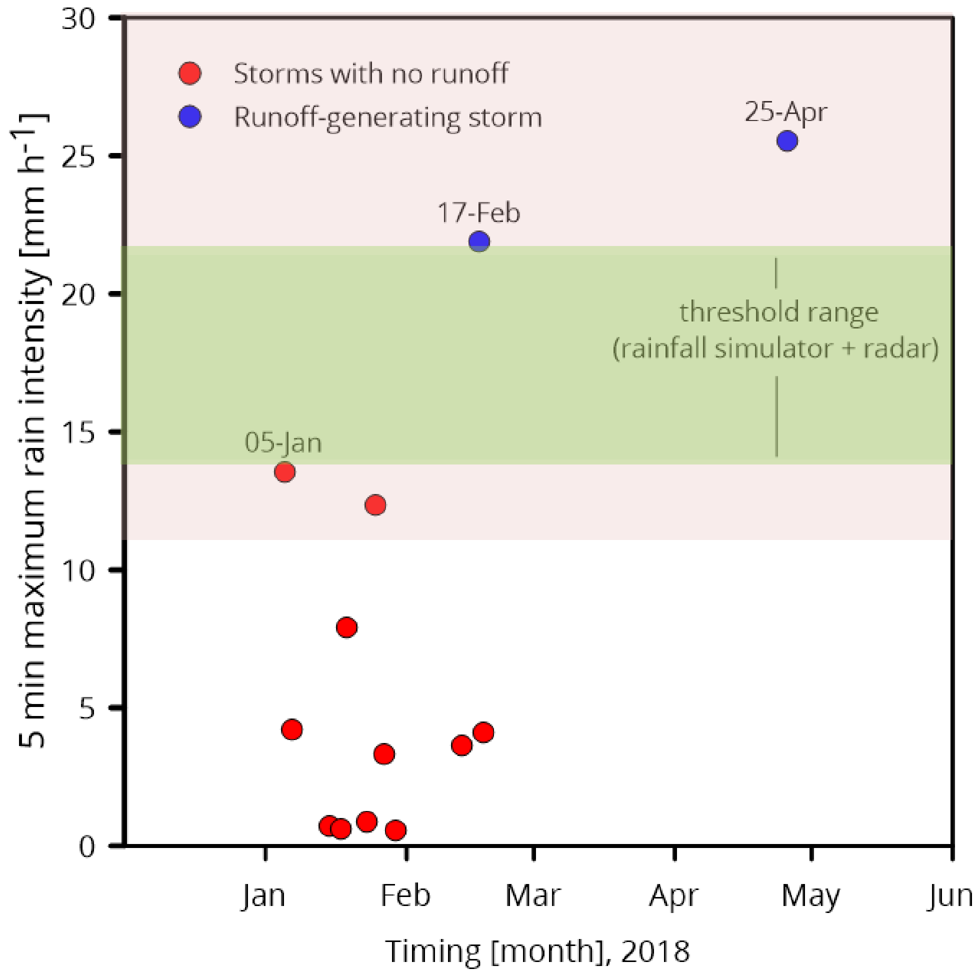


Threshold for runoff generation

From the Rainfall simulator result:
No runoff is observed for rain intensify <12 mm h^{-1} for a duration of 5 min

Radar analysis and filming:
No runoff is observed for storms with rain intensity <22 mm h^{-1} for a duration of 5 min

Suggested **rainfall threshold:**
5-min rain with intensity exceeding **14-22 mm h^{-1}**

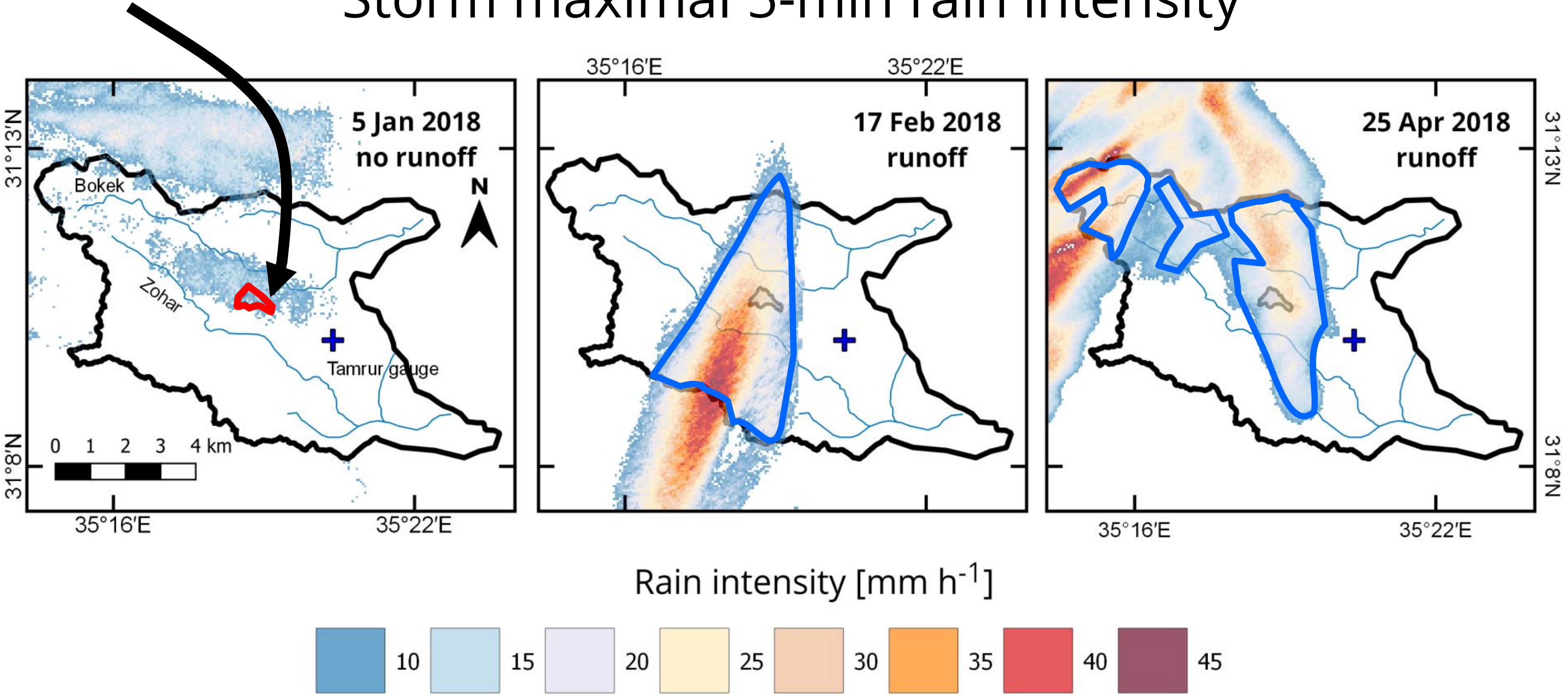


Considering the above threshold, it is possible to examine the runoff contribution area within a watershed during a storm (next slide)

Runoff contributing areas

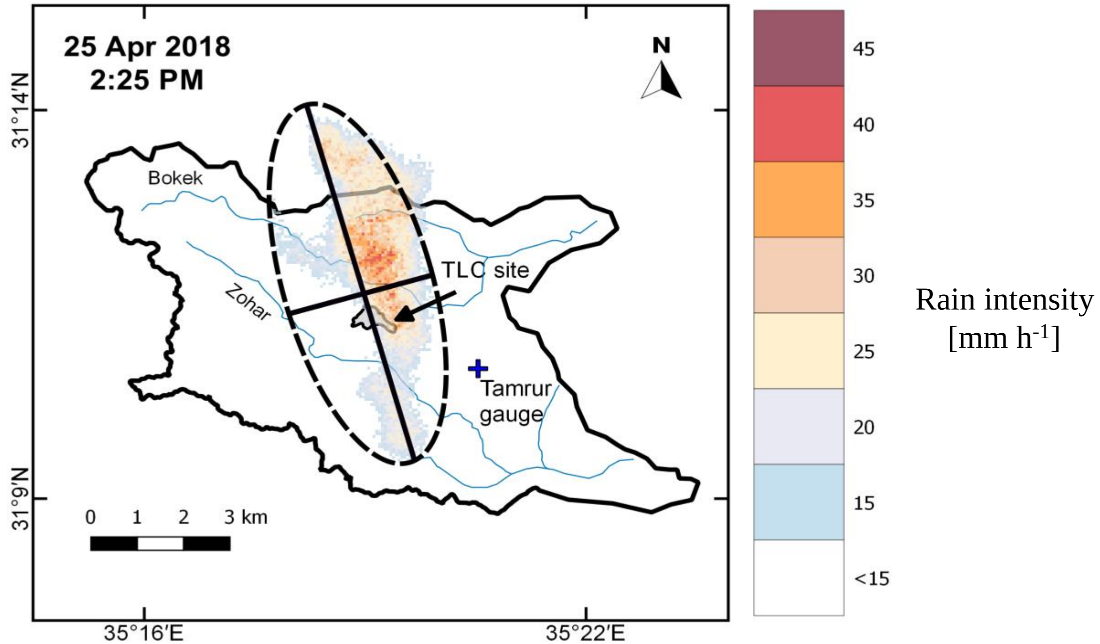
Tzuk Tamrur

Storm maximal 5-min rain intensity



For the most intense storms in our database, covering only a portion of the watershed, local runoff is generated (3%-0%, 41%-30%, 39%-20% , from left to right respectively)

Properties of runoff generating rain cells



Maximal rain intensity gradient of 11% over a distance of 100 m

Low rain cell velocity (8-10 m/s)

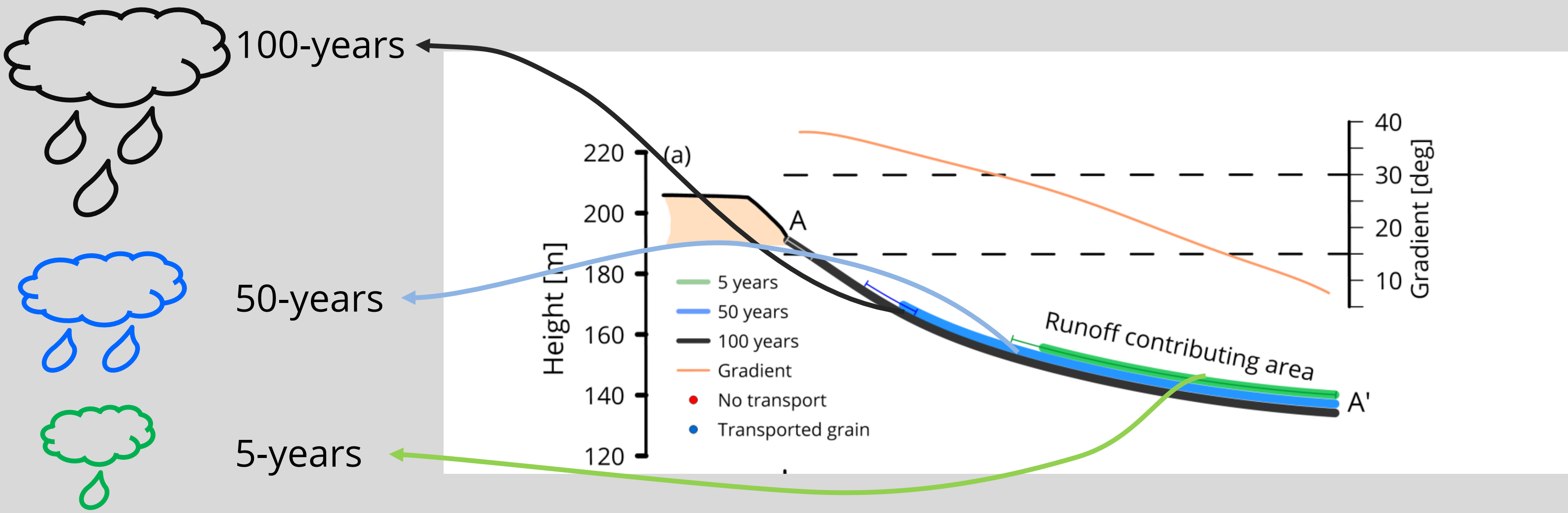
Relatively small cell area (20-35 km^2)

Based on 52 years gauges record :

1-3 events per year generate **local runoff** at the study site

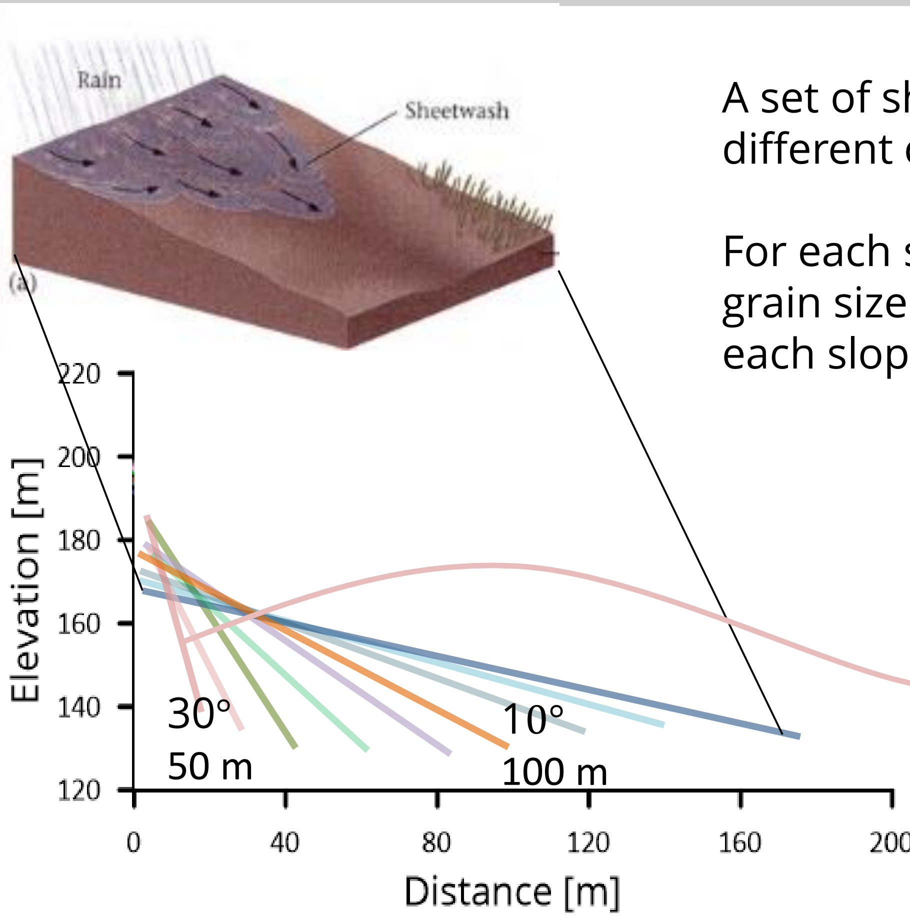
The frequency of full extent hillslope overland flow

Hydrological simulations were performed for 5,50 and **100** years return period synthetic storms.



Runoff contributing area of the **100-year (1%)** rainstorm is the entire slope area (**100%** contributing area). under the 5- and 50-years storms, runoff generated in the uppermost part of the slope does not reach the base of the slope due to infiltration (83% and 43% contributing area, respectively)

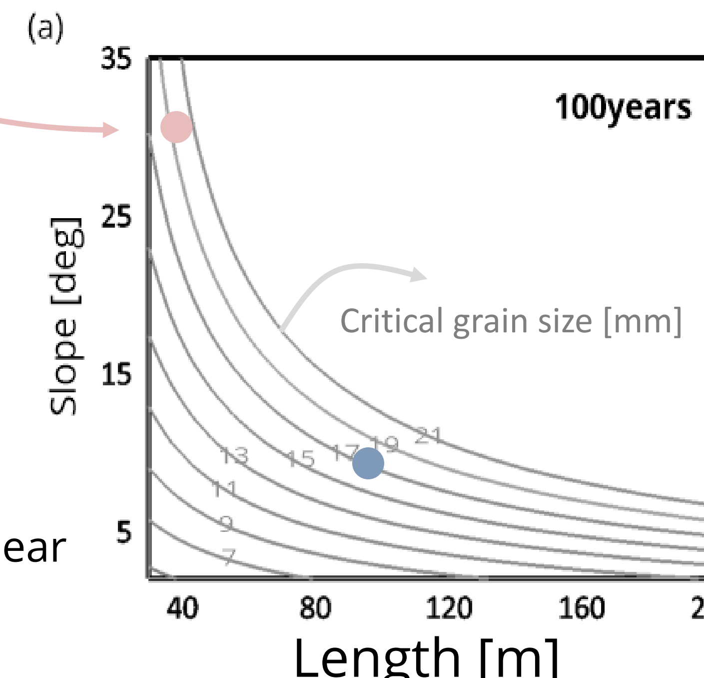
Which storm could mobilize clasts on the slope surface?



A set of shear-stress simulations was applied to different combinations of gradients and slope lengths

For each simulation, we calculated the transportable grain size using the maximal shear stress generated in each slope-length combination

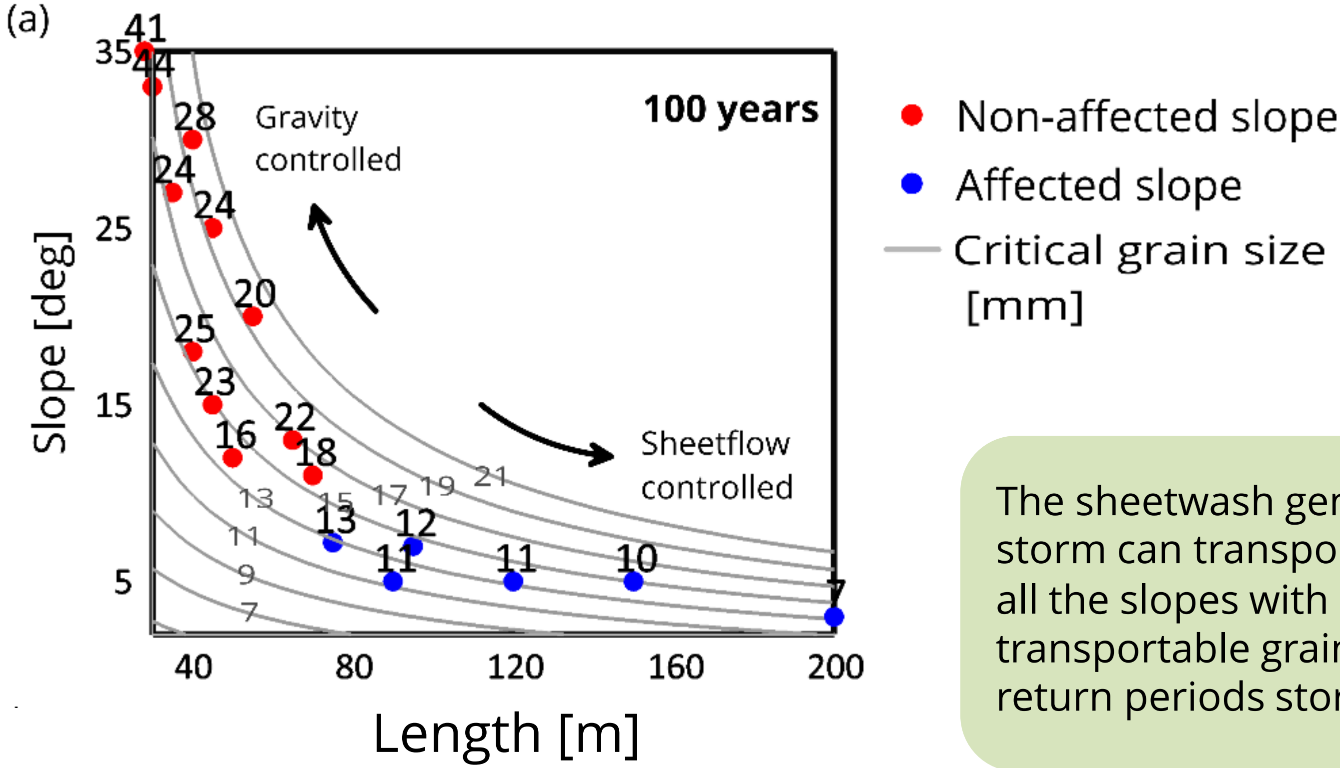
The results of **100-years storms** are summarized in the contour figure



For example, for 30° and 50 m slope, the maximal shear stress exert by the 100-years sheetwash is capable transport clasts of 19 mm (D50) or smaller

Which storm could mobilize clasts on the slope surface?

We compare the model simulations results (gray contours) with field grainsize measurements (filled colored circles).

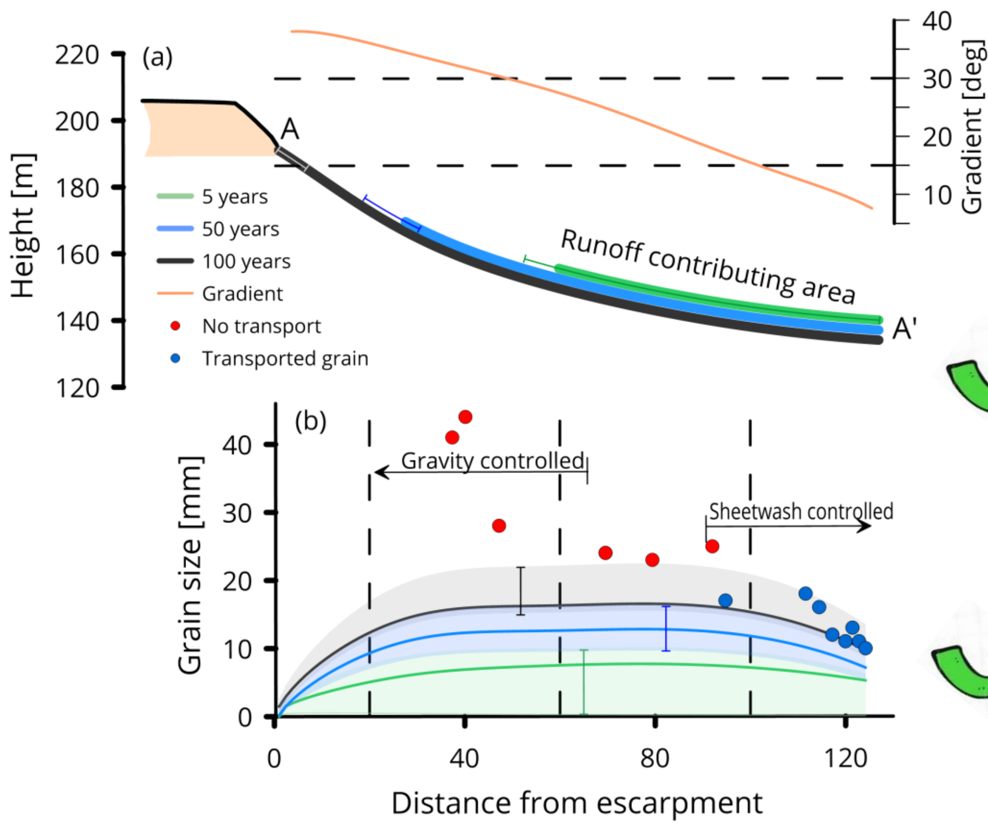


The sheetwash generated by the 100-year storm can transport the observed clasts on all the slopes with low gradients. ***No** transportable grainsize for 5- and 50-years return periods storms

Blue and red circles denote transport and no-transport, respectively (we consider sheet flow is able to transport sediment where the calculated (gray contour) value is greater than the measured clasts size (filled colored circles).

Which storm could erode the slope surface?

We also calculated the potential transported grain size for the 5, 50 and 100-years storm **along a characteristics concave up slope**:

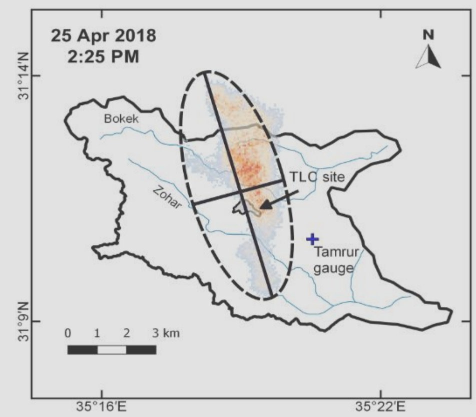


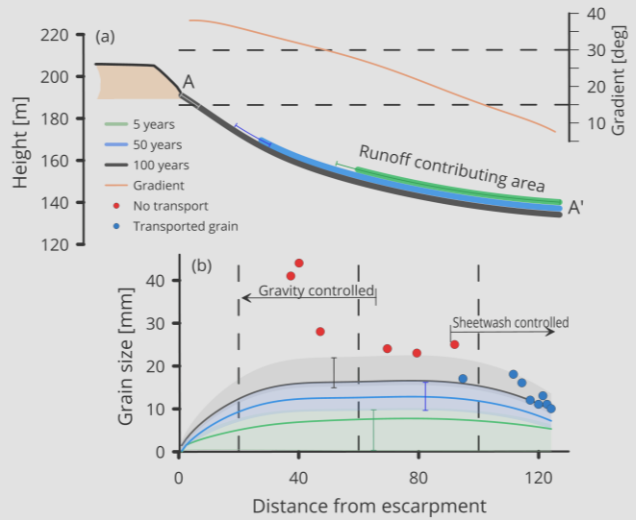
The return period for runoff generation over the entire length of talus-pediment slopes is at least **100 years** (hillslope runoff from more frequent storms includes only part of the slope).

100-years storm (**black curve**) can produce runoff and sheetwash with shear stress that is high enough to trigger clast mobilization at a distance of ~80 m from the cliff

Summary and conclusions

- Frequency of local runoff generation over the study site (1-3 times per year)
- The frequency of full extent hillslope runoff is 1 in 100-years. The contributing area for hillslope runoff from more frequent storms declines dramatically and includes only part of the slope.
- 100-years storm (and rarer) can potentially trigger clast mobilization over the lower part of the slope.
- 100-years storms and rarer are most probably responsible also for forming the observed rills, which eventually disconnect the slopes from the cliff
- The erosion efficiency of these discrete rare events highlights their potential importance in shaping the landscape of arid regions





Questions?

Check out our paper in ESPL or
contact directly by email: yuval.shmilovich@mail.huji.ac.il

Appendix 1. Runoff generation over Tzuk Tamrur slopes during the 25 Apr 2018 rainstorm. (a) TLC image captured 4-min after the beginning of the rainstorm and (b) image captured 6-min later.

(a)

(b)

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