Simulating dryland cliffs evolution in response to extreme rainstorms

Shmilovitz, Y.[1], Rossi, M.[2], Tucker, G.[2], Campforts, B.[3,4], Pederson, J.[5], Morin, E.[1], Armon, M.[6], Enzel, Y.[1], and Haviv, I[7]

[1]The Hebrew University of Jerusalem, The Fredy & Nadine Herrmann Institute of Earth Sciences, [2]University of Colorado, CIRES, Boulder, [3]University of Colorado, INSTAAR, [4]Vrije Universiteit Amsterdam, Department of Earth Sciences, [5]Utah State University, Geosciences Department, [6]ETH Zurich, Department of Environmental Systems Science, [7]Ben-Gurion University of the Negev, Department of Earth and Environmental Sciences, Be'er Sheva, Israel

EGU23-9185

This presentation participates in OSPP

Outstanding Student & PhD candidate Presentation contest

Motivation and challenges

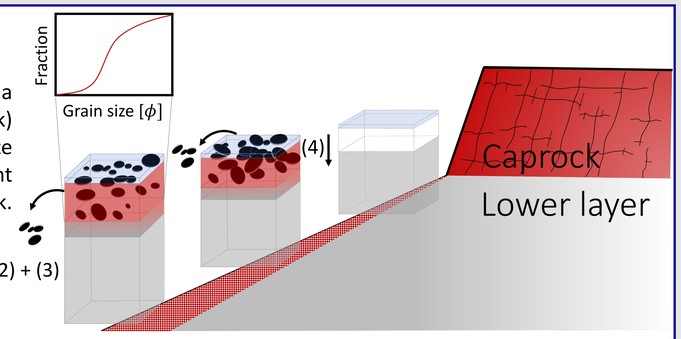
A key element in landscape evolution is the response of hillslopes to hydroclimatic forcings. Dryland rocky hillslopes are often positioned along cliffs and their evolution is greatly influenced by rainstorms. However, because rainstorms are short and hard to scale up to geologic time, models describing the evolution of hillslopes in response to rainstorms are lacking, and topographic imprints of intra-storm hydrological and erosional processes were rarely examined. To bridge this gap, we developed a landscape evolution model (1-D, Landlab-based) and a modeling approach for dryland hillslopes, including explicit representations of rainstorm forcing and hydrology.

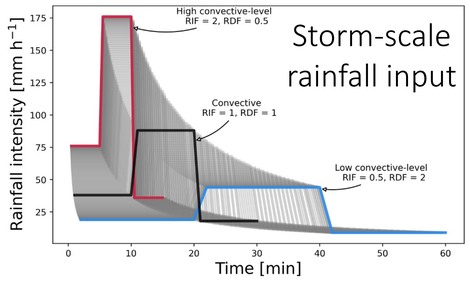
Research Questions:

-Under what rainstorm intensities and grain sizes are cliffs preserved?
-What are the effects of rainstorm convective level on hillslope processes?
-Is there a relation between rainstorm regimes and hillslope morphology?
-How do alternating storm regimes affect hillslope morphology?

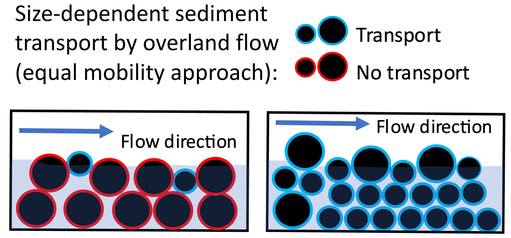
Modeling approach

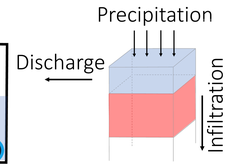
We view dryland hillslopes as an evolving landform under short-duration (<daily) severe rainstorms. We run the model in a **storm-based framework**. The model distinguishes between two main lithological units, a resistant layer on top (caprock) that overlies a softer layer (lower layer) and an additional mobile debris layer that honors heterogeneous grain-size distributions. Topography is updated according to: (1) production and run-out of debris from bedrock; (2) sediment transport by diffusion processes; (3) sediment transport by overland flow, and (4) incision, by overland flow, into bedrock. The model tracks the water volume accounting for rainfall, infiltration, and overland flow routing.

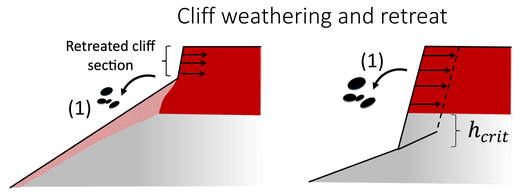




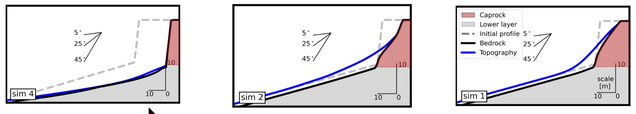
Size-dependent sediment transport by overland flow (equal mobility approach):



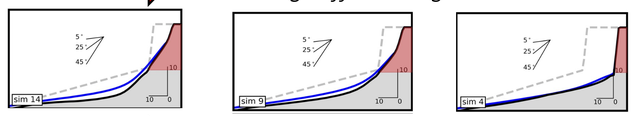




The role of rainstorm magnitude and cliff debris grain size

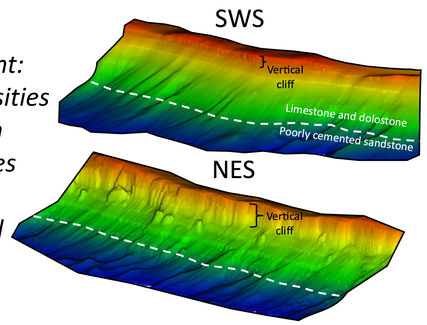


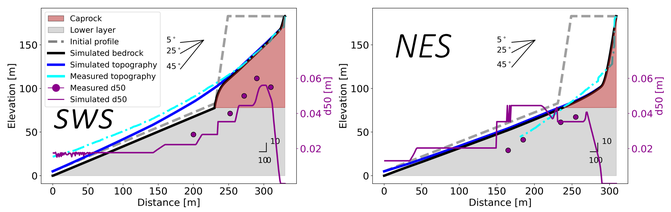
Increasing cliff-debris grain size



Increasing storm intensities

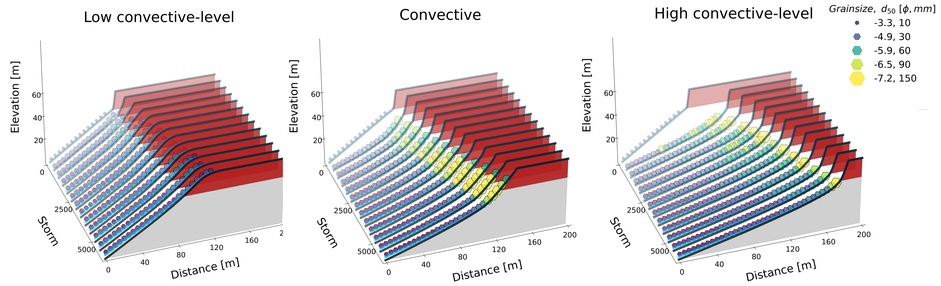
Data-driven experiment: Could rainstorm intensities and grain sizes explain topographic differences along a 40-km escarpment in the arid Negev?



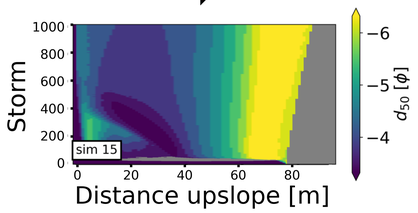


Intra-storm intensity pattern impacts on hillslope morphology

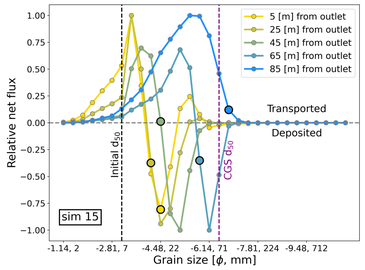
Constant storm regime. Storm convective-level (intensity temporal pattern) differ between the simulations. Total rainfall depth is constant



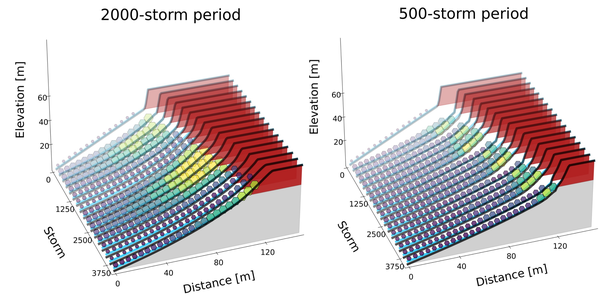
Increasing storm convective-level

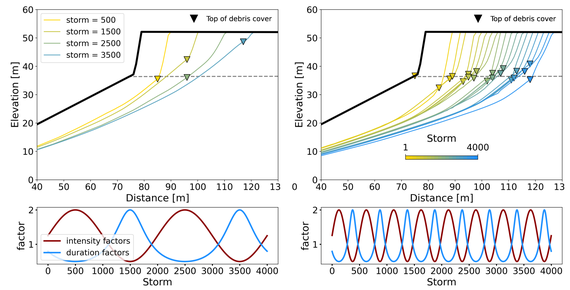


Downslope decrease in grain size induced by size dependent selective transport



Changes between rainstorm regimes





Key points

- Cliffs are buried when debris grain size > 100 mm or rainstorm intensities <~40 mm h^{-1}
- Intra-storm sediment transport can help explain observed topographic trend
- Grain size decreases downslope in response to size-dependent runoff transport
- High convective storms enhance lateral cliff retreat and vertical cliff persistence
- Alternating rainstorm regimes with different convective-levels impacts the extent of the debris cover and leads to complex caprock profiles
- Changes in rainstorm regime induce geomorphic transitions even if the total rainfall remain the same

Future work

Based on the modeling tools and approach presented here, we aim to investigate how spatiotemporal rainstorm properties affect the development of channel networks below cliffs and identify the conditions required to form hillslope remnants (talus flatirons).

Acknowledgments

This study was partially funded by BSF (2020664) and fellowships to YS from the Hebrew University Advanced School for Environmental Studies and the Keren Kayemeth LeIsrael-Jewish National Fund.

yuval.shmilovich@mail.huji.ac.il