From flames to flux: how wildfires alter soil formation and sediment dynamics

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1. Introduction

Wildfires occur across diverse terrestrial landscapes and are widely studied for their socio-economic consequences. It is well known that geomorphic processes respond to fire (McGuire et al., 2024), as it can reduce vegetation and soil infiltration capacity, thus increasing erosion by runoff and fluvial incision. Wildfire-induced erosion can change soil depth, possibly exposing less weathered material and increasing soil production rates. Despite the knowledge on the effects of fire on hydrological and geomorphic processes, studies examining how wildfire-induced changes in soil production rates influence catchment-wide sediment fluxes are still lacking. Here, we propose to use the Landlab modeling framework to explore how wildfire regimes and soil production interact to control sediment mobilization in a landscape. Our preliminary results show that over a centennial timescale, sediment flux peaks occur after high magnitude fires. However, there is a decrease in sediment flux peaks over a millennial timescale, suggesting that erosion is outpacing soil production.

2. Methods

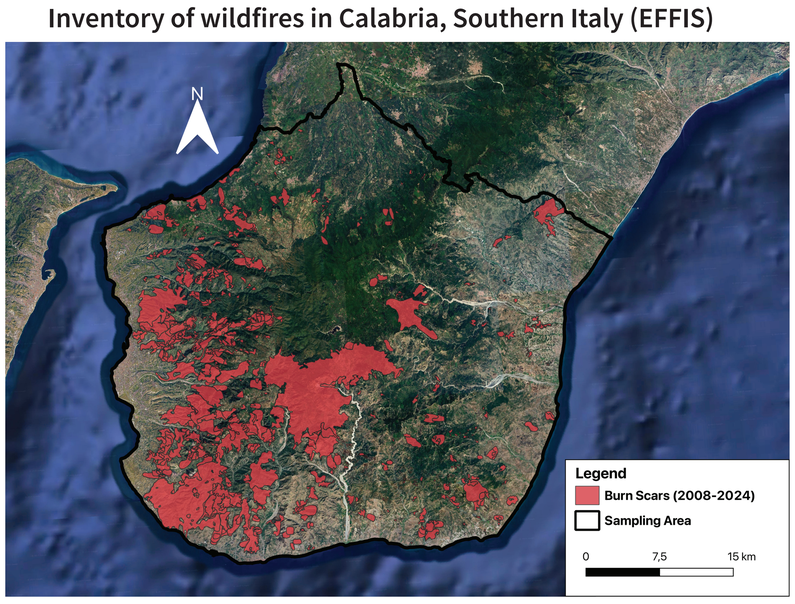
Model driver

- Import Python libraries and Landlab components
- Creating raster grid and defining size, resolution, and boundary conditions
- Adding random topography and noise
- Evolving topography to steady state
- Adding soil layer and defining bedrock elevation
- Components parameterization
- Run iterations, keeping track of fire occurrence and sediment fluxes for every catchment
- Export and visualize outputs

Parameterization

- Parameterizing SpaceLargeScaleEroder, ExponentialWeatherer, DepthDependentDiffuser, Burner, and ErodibilityStepper
- Defining how much erodibility and maximum SPR increase after a fire
- Defining fire frequency and erodibility decay time
- Defining total runtime and timestep

Inventory of wildfires in Calabria, Southern Italy (EFFIS)



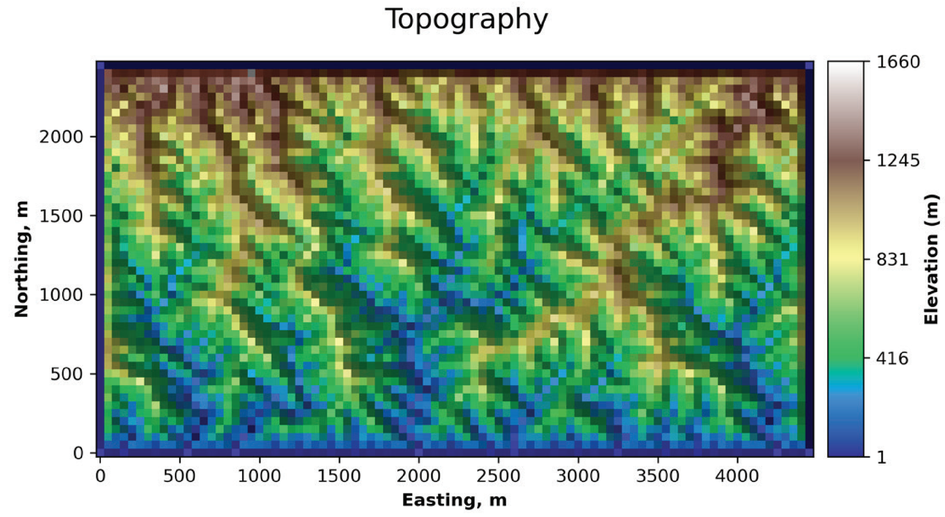
Wildfire simulation

- Modification of available python modules to generate fires at random locations within a the grid (Burner and ErodibilityStepper)
- Fires are generated based on a frequency-area distribution dataset
- Fire sizes are sampled from this distribution
- Fires are generated based on a defined fire frequency (number of fires/year)

If a fire occurs

- Sediment erodibility increase
- Soil production maximum rate increase
- Erodibility goes back to original after 3 years

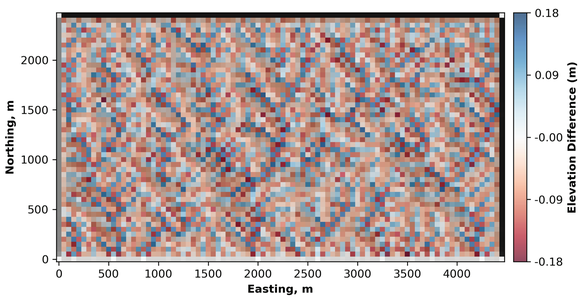
Topography



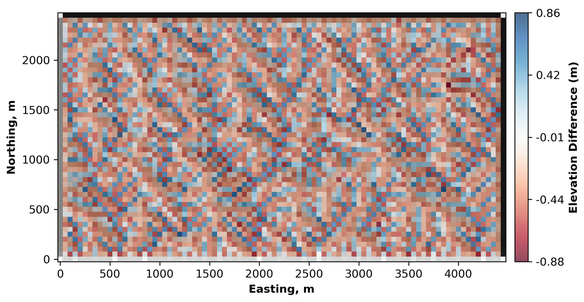
3. Preliminary results

Enhanced soil production after a fire

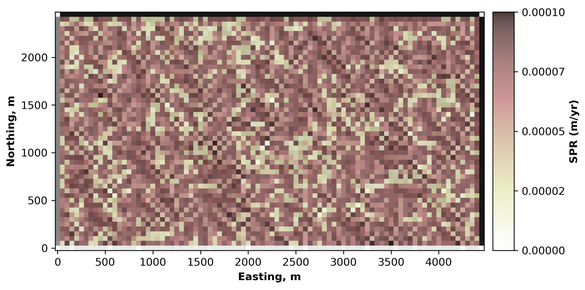
Changes in elevation (m) after 100 years



Changes in elevation (m) after 1000 years



Soil Production Rates (SPR) after 100 years



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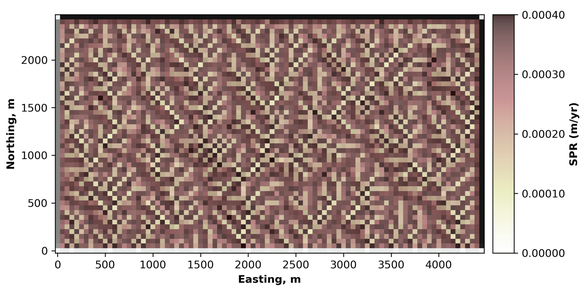
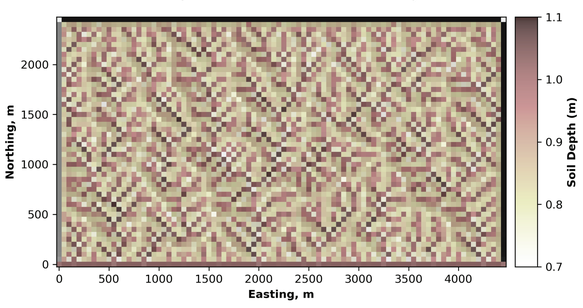
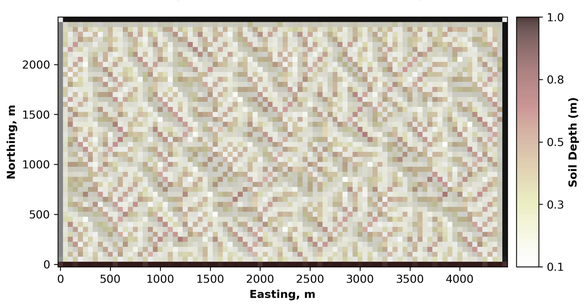


Soil Depth Distribution after 100 years

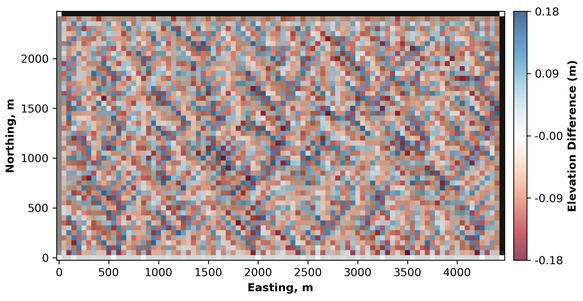


Soil Depth Distribution after 1000 years

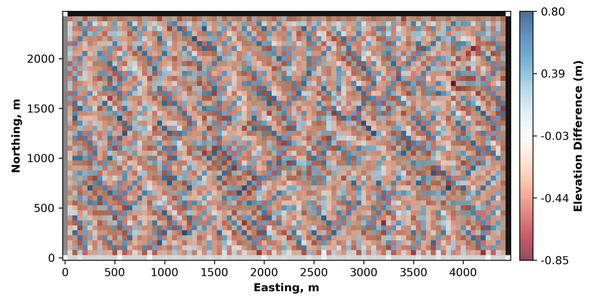


Soil production invariant after a fire

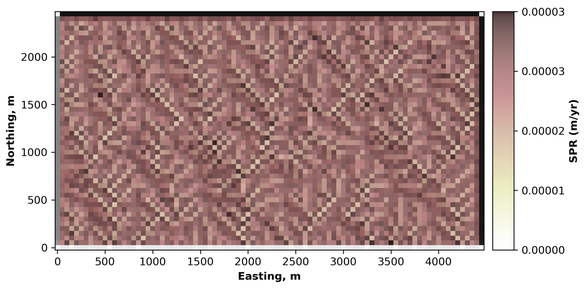
Changes in elevation (m) after 100 years



Changes in elevation (m) after 1000 years



Soil Production Rates (SPR) after 100 years



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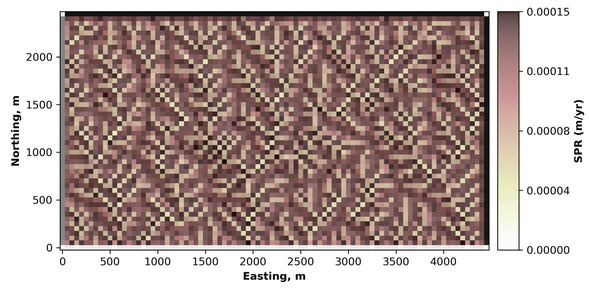

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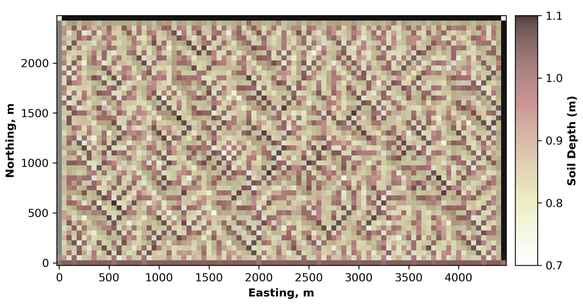
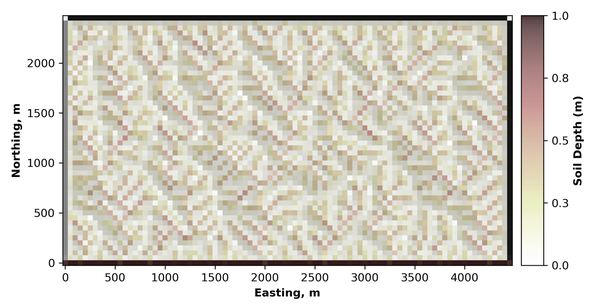
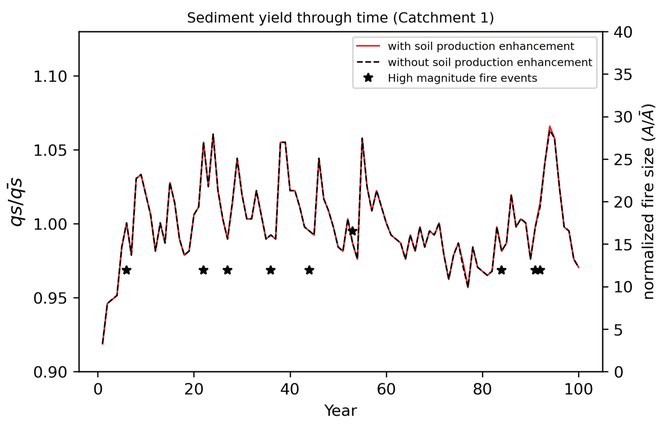


Soil Depth Distribution after 1000 years

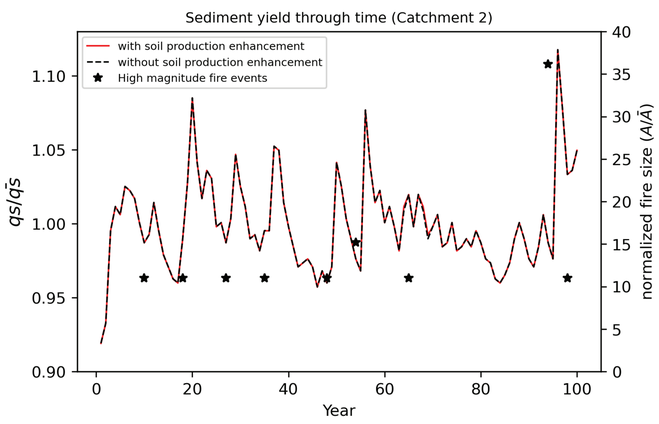


Tracking sediment yield over time (100 and 1000 years)

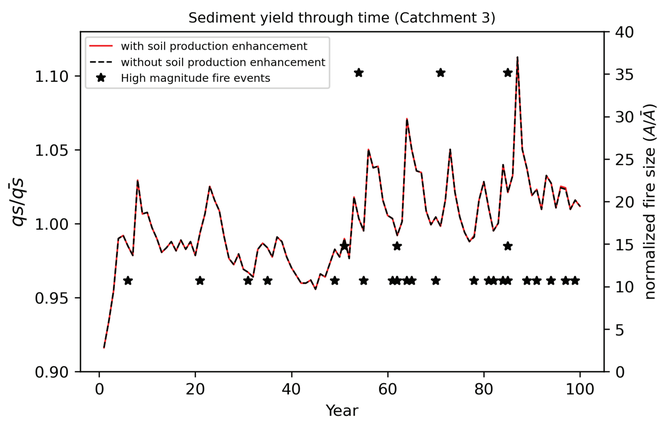
Sediment yield through time (Catchment 1)



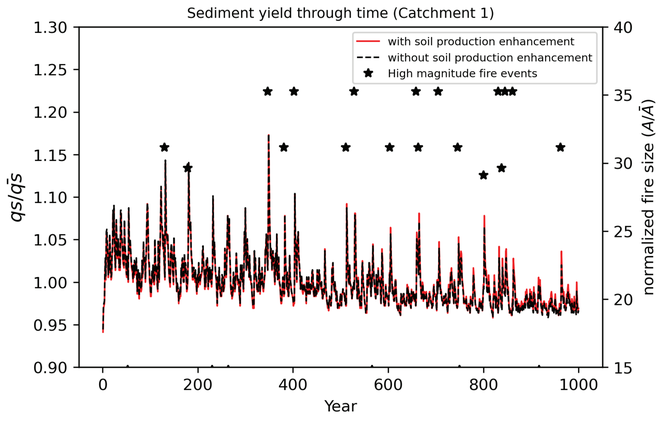
Sediment yield through time (Catchment 2)



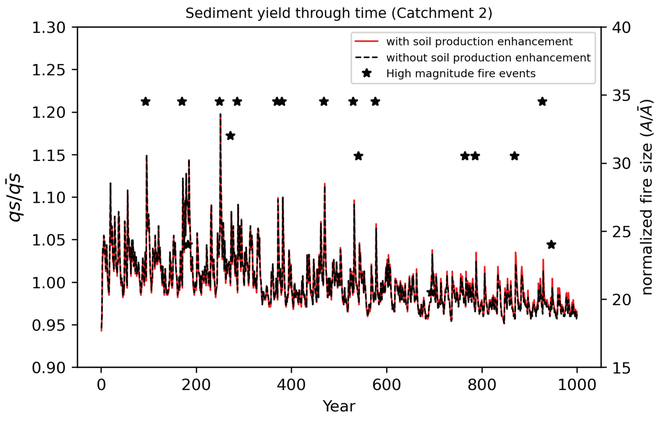
Sediment yield through time (Catchment 3)



Sediment yield through time (Catchment 1)



Sediment yield through time (Catchment 2)



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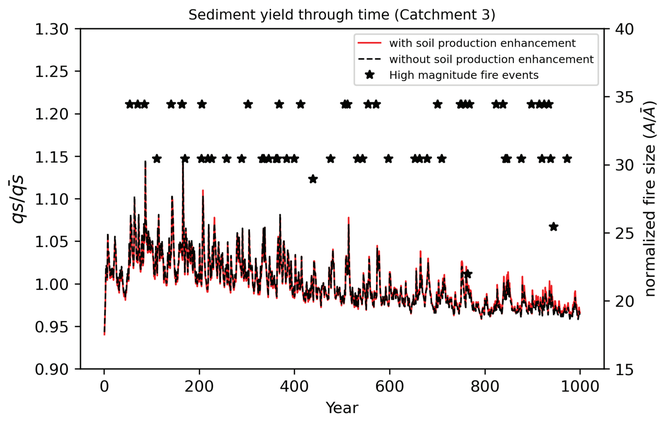

4. Conclusions

- The 100 year scenario shows that frequent fires can set a higher baselevel of catchment-average sediment fluxes, with peaks after high magnitude fires
- The 1000 year scenario shows a decreasing trend in sediment flux peaks, suggesting that erosion is outpacing soil production in these conditions
- Changes in soil production rates are not being reflected in soil depth and sediment export over a centenial timescale
- Changes in soil production will only be reflected over millennial timescales, with an increase in sediment availability

Follow up question:
What is necessary to represent soil mantled landscapes that are historically affected by frequent fires?