A hydroclimatological approach to predicting regional landslide probability using Landlab

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Motivation

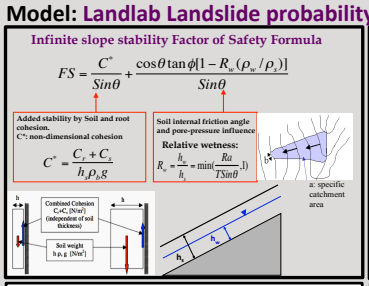
- Steep elevations dominantly erode by mass-wasting which form major source of sediment input to streams. Where landslide intersect with human development, they cause damage and life loss.
- Existing models focus on **research applications** in small watersheds with **detailed landslide inventories**.
- **Tools** are needed that can combine **regional gridded soil, vegetation, climate, and hydrologic model products** to develop landslide hazard models without the need for detailed calibration.

A regional landslide hazard model shall:
(1) be flexible to incorporate changes in intrinsic and extrinsic conditions, such as vegetation and climate;
(2) account for spatial variability in model parameters and forcings
(3) integrate spatial and temporal dimensions of uncertainty to quantify landslide probability.

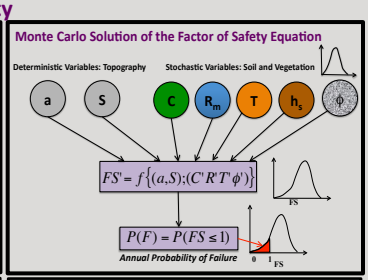
Strauch R., Istanbulluoglu E., Nudurupati S.S., Bandaragoda C., Gasparini N.M., and G.E. Tucker (2018). A hydro-climatological approach to predicting regional landslide probability using Landlab. **Earth Surf. Dynam., https://doi.org/10.5194/esurf-6-1-2018.**

Reproducibility: On Hydroshare, code and example available on landlab.github.io/#/.

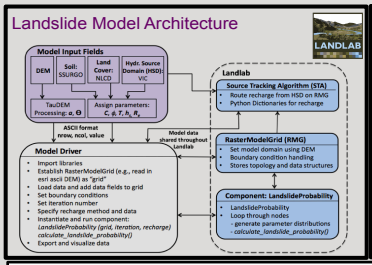
Model: Landlab Landslide probability



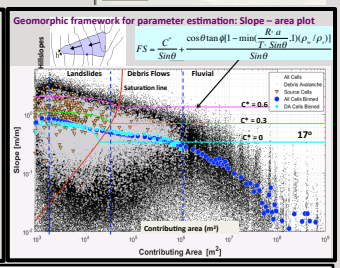
Shallow landslide initiation is modeled using the infinite slope stability factor of safety (FS) equation.



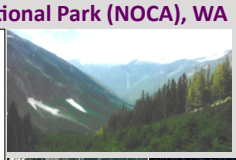
A Monte Carlo solution is used for the FS equation. Outcome is local annual Probability of Failure, P(F).



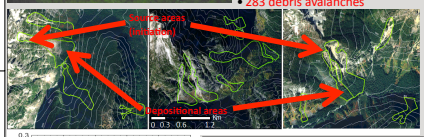
Model is developed in Landlab (Hobley et al., 2017). Parameter fields are derived from gridded data, uncertainties added. Recharge is used from VIC for subsurface flow. Parameter ranges are evaluated against observations on slope-area domain.

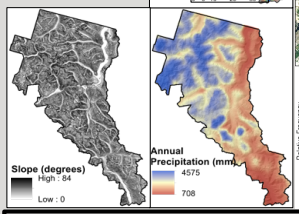


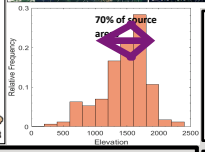
Field Site: North Cascades National Park (NOCA), WA



- Area: 2,700 km²
- Elevation range: 100-2,800m
- Slopes up to 84°
- MAP: 708 – 4,575 mm
- ~1,700 mass wasting mapped by the National Park Service.
- 283 debris avalanches



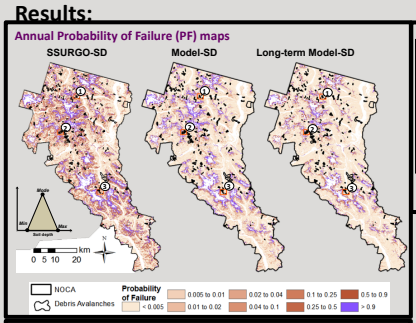


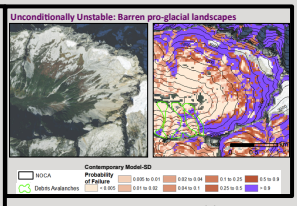


70% of the source areas of the mapped landslides are located in intermediate elevations in NOCA.

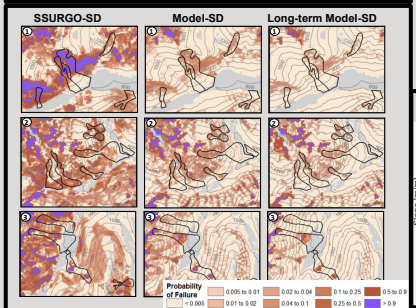
Question:
How do hydro-meteorologic, vegetation, and soil variability control the spatial patterns of landslides?

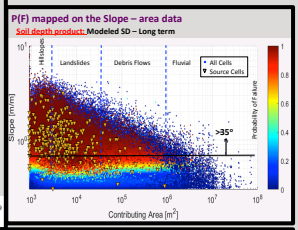
Results:





- All models give relatively higher P(F) at the location of observed landslides.
- Among the soil depths maps used, P(F) is higher across the landscape with SSURGO Soil Depth, which gives discontinued soil depth in space.
- Representing the long-term soil depth uncertainty gives the lowest P(F).
- Intermediate slopes where landslide source areas are located have higher P(F).
- Lack of soil in high elevations lead to reduced P(F).



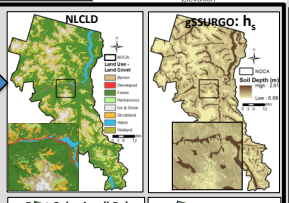


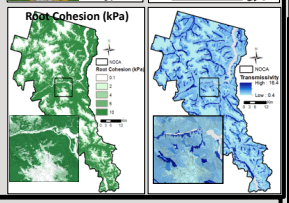
Parameter Fields:

- **Vegetation types:** US National Land use Land Cover (NLCD):
- **Soil parameters:** USDA gSSURGO data base

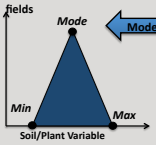
Parameter values from literature

→ Landlab Fields





Modes of a Triangular distribution from Landlab fields

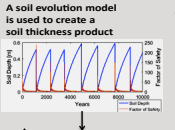


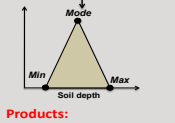
How was the model run?

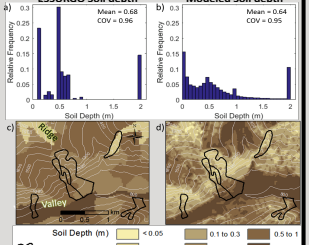
- Annual maximum upslope Recharge (R_m) for each model grid is obtained from regional VIC model runs (1916 to 2006), forced by gridded meteorology.
- A non-parametric distribution is used for R_m.
- Triangular distribution is assumed for all model parameters.
- At each grid cell 3,000 samples were generated for each parameter and P(F) is calculated.

Alternative soil depth product:

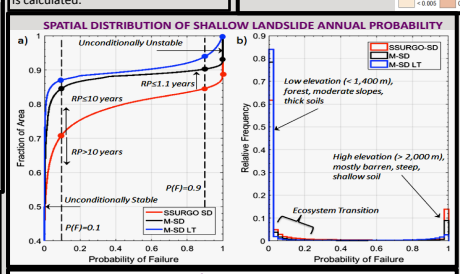
A soil evolution model is used to create a soil thickness product

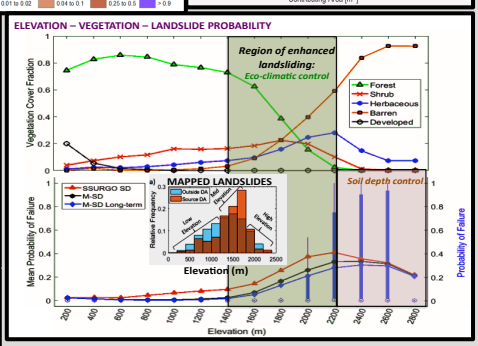


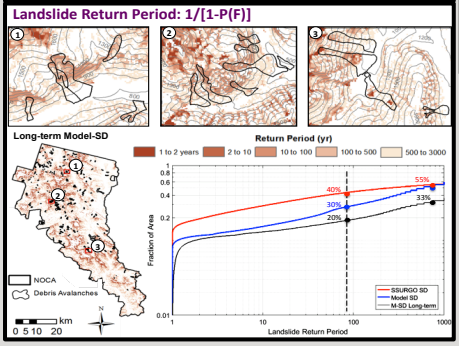




Products:
- Modeled SD (contemporary)
- Modeled SD-Long term







Conclusions:

- Soil depth (SD) and its uncertainty control P(F) in space.
- Using the SSURGO-SD provide a relative P(F) map for short term landslide risk, causes overestimation of landslide return periods.
- Considering long-term soil evolution in SD uncertainty gives landslide RP and denudation rates consistent with the literature.
- Forests stabilize landscape at low elevations, loss of forest increase landslide risk in mid-elevations (1400 – 2400 m), and soil limitation in high alpine elevations reduce landslide risk.

Results Reproducible on HydroShare.org

Regional landslide hazard using Landlab - NOCA Observatory

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Funding: NSF, CBET-1336725, OAC-1450412, 1450409, 1450338, ICER 1663859

Hobley, D. E. J., et al. (2017): Creative computing with Landlab: an open-source toolkit for building, coupling, and exploring two-dimensional numerical models of Earth-surface dynamics, ***Earth Surf. Dynam.*** **doi:10.5194/esurf-5-21-2017**.