Stochastic effects of forest canopies on extreme precipitation events and initiation of shallow landslides

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Objectives

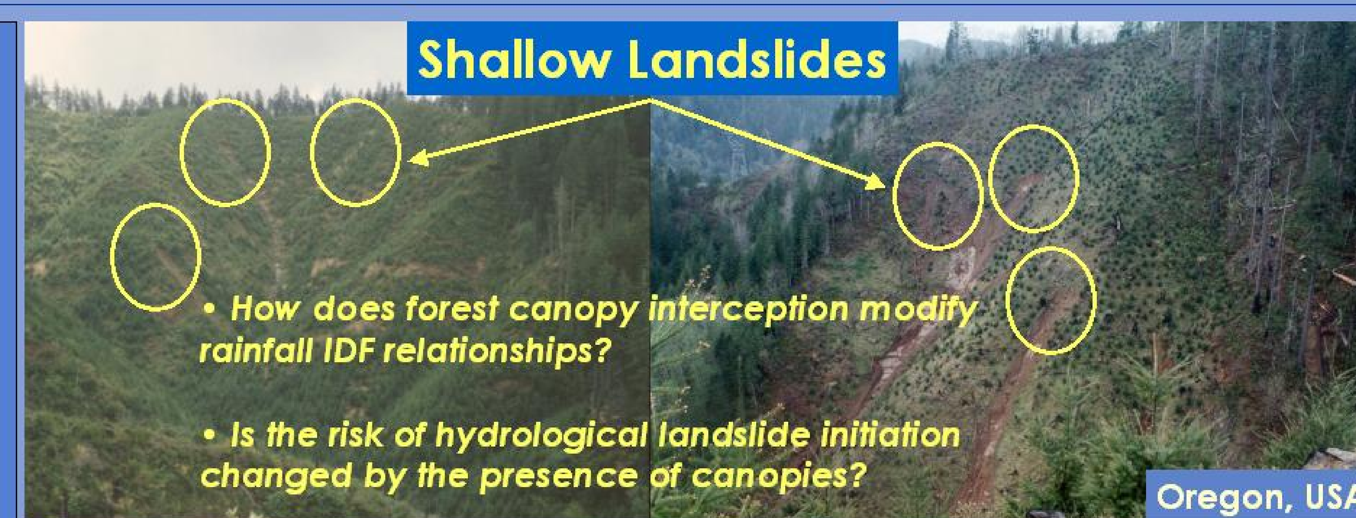
Initiation of shallow landslides depends on intensity-duration-frequency (IDF) of extreme precipitation events.

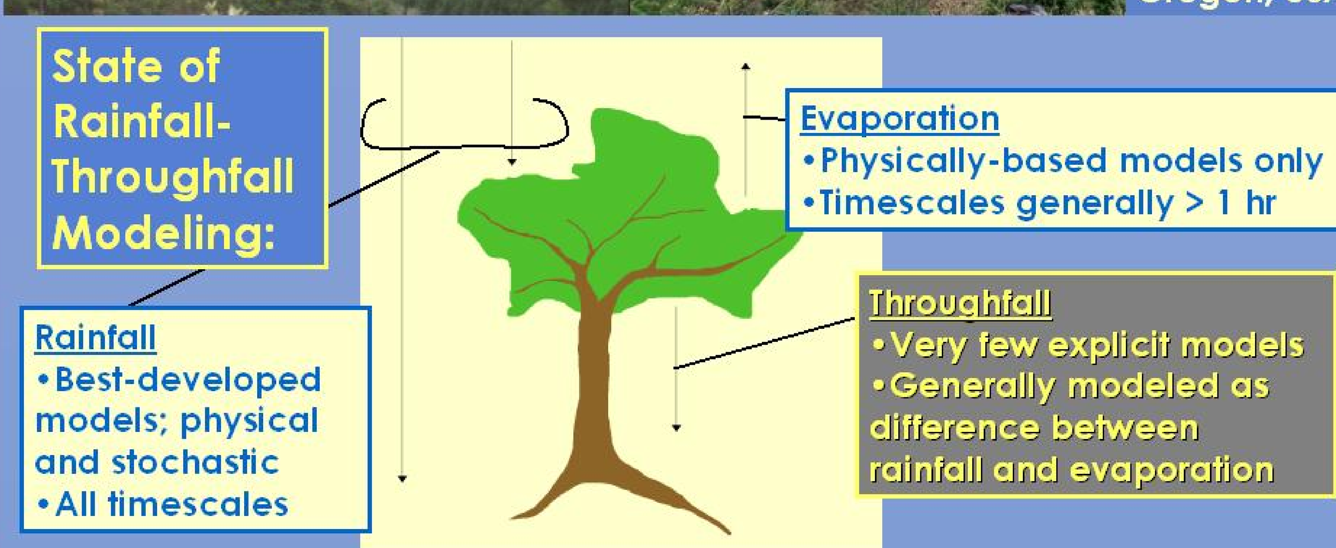
What is the effect of canopies on rainfall IDF curves? How is landslide initiation affected?

Temporal stochastic models of rainfall may be poor tools in forested watersheds because canopy affects the amount and timing of precipitation.

Long time series of throughfall data of high temporal resolution do not exist to parameterize models of throughfall directly, especially for short durations.

We ***develop a stochastic model of throughfall*** using rainfall-throughfall relationships to modify a stochastic model of rainfall.





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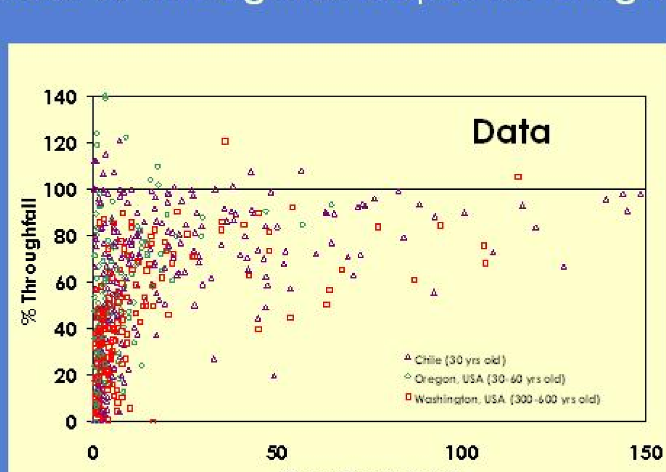
Model Components

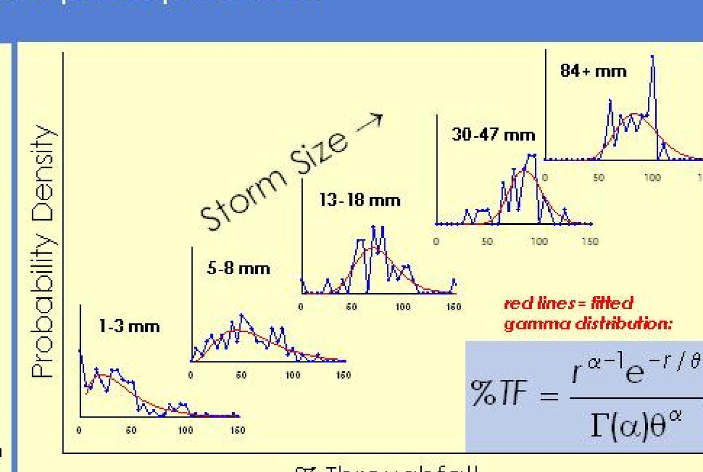
i Stochastic 6-Hourly Rainfall

Random cascade with calibrated, scale-dependent splitting probabilities (Rupp et al., 2000).

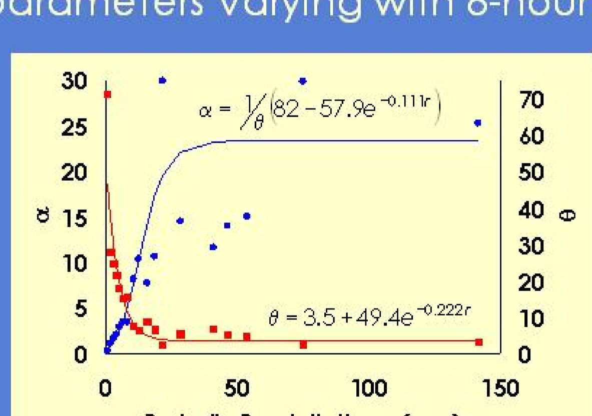
ii Stochastic 6-Hourly Evaporation

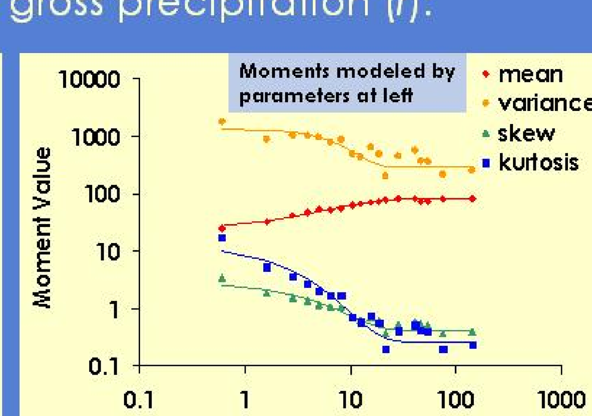
6-hour % throughfall depends on gross precipitation:





We modeled the PDFs of 6-hour % throughfall using a gamma distribution with parameters varying with 6-hour gross precipitation (*r*):





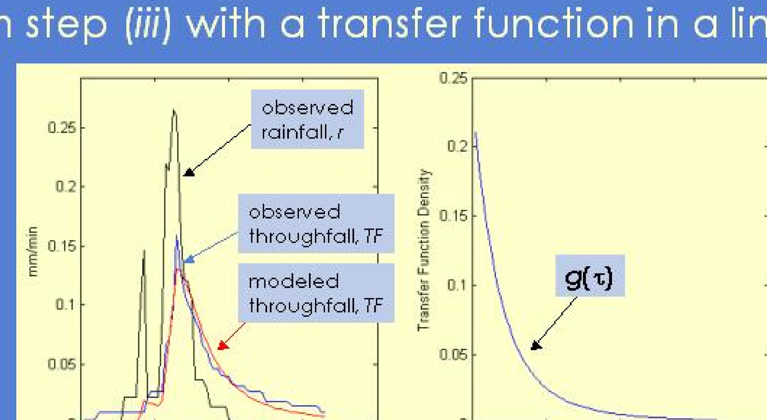
iii Stochastic Sub-6-Hour Downscaling

Downscale 6-hourly throughfall (obtained in step *ii*) by continuing random cascade (as step *i*) to 5-min data.

iv Stochastic Intensity Smoothing

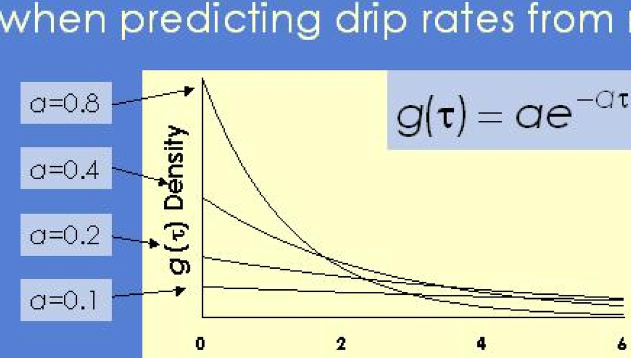
Convolve simulation from step (*iii*) with a transfer function in a linear model:

$$TF(t) = \int_0^t r(t-\tau)g(\tau)\,d\tau$$

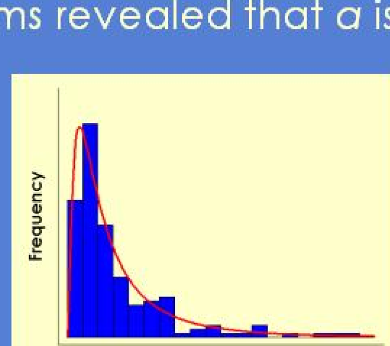


where $r(t-\tau)$ is rainfall occurring at time shift τ before *t*, and g is the transfer function defining response of throughfall to a unit input of rainfall.

We have found simple exponential drainage is a useful form of transfer function when predicting drip rates from rainfall rates:



Optimizing fit of the linear system to observed rainfall/throughfall data for natural storms revealed that *a* is log-normally distributed:

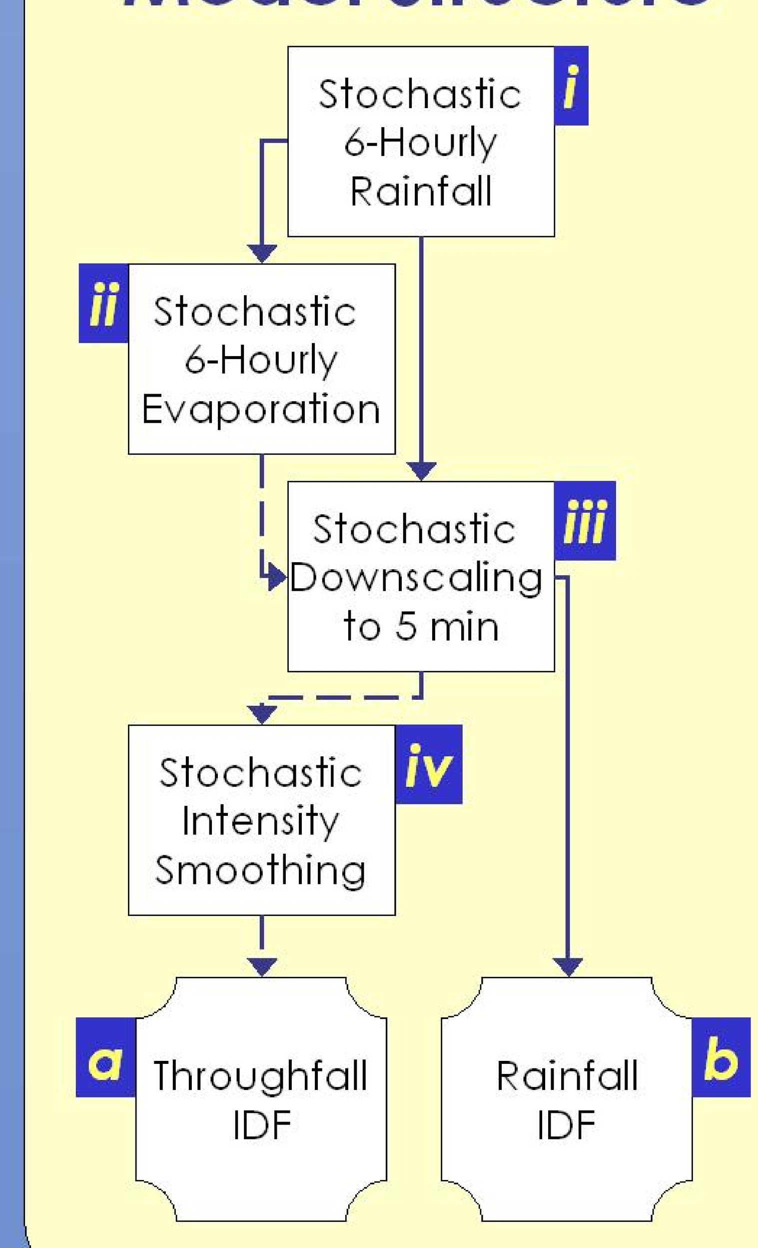


Mean Residence Time = 1/*a*

Our data:
median *a* = 0.10
median MRT = 10 minutes

The model operates by choosing *a* from this distribution, and smoothing throughfall intensity by convolving the sub-6-hour rainfall with *g*.

Model Structure

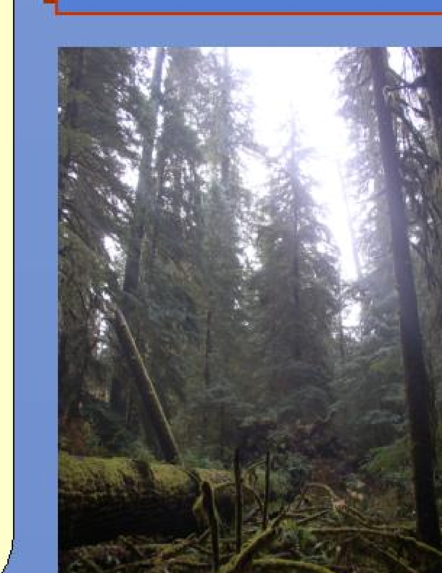


Conclusions

1. Reduction of intensities by evaporation and intensity smoothing in the canopy ***increase return interval of landslide-triggering storms by 10 years or more***.

2. The ***highest intensities are proportionally most reduced*** by canopies.

3. At durations ≥ ***1 hour, canopy effects limited to evaporation***. Additional ***intensity smoothing effects at shorter durations***.



Literature Cited

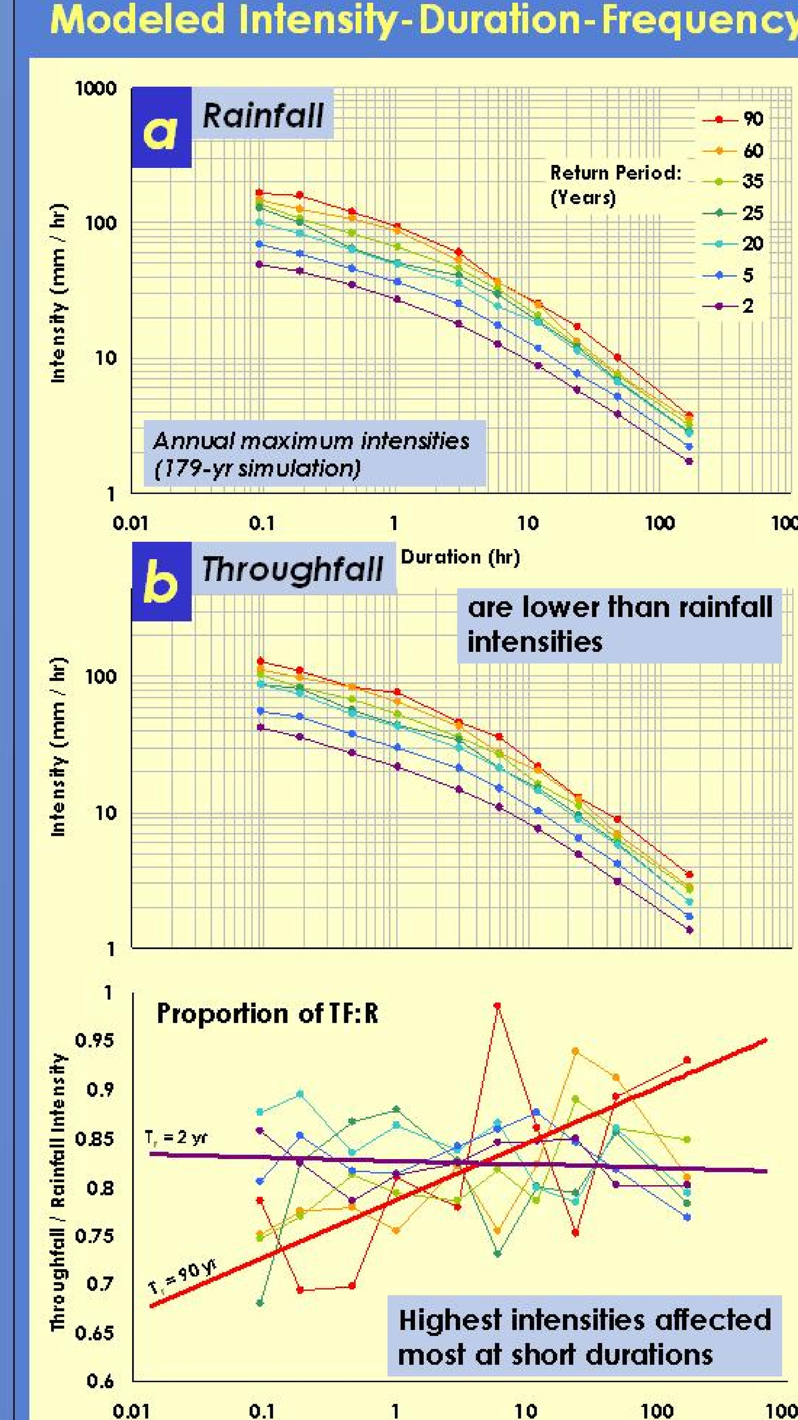
Caine, N. 1980. The rainfall intensity-duration control of shallow landslides and debris flows. *Geografiska Annaler* 62A:23-27.

Iverson, R.M. 2000. Landslide triggering by rainfall infiltration. *Water Resources Research* 36:1897-1910.

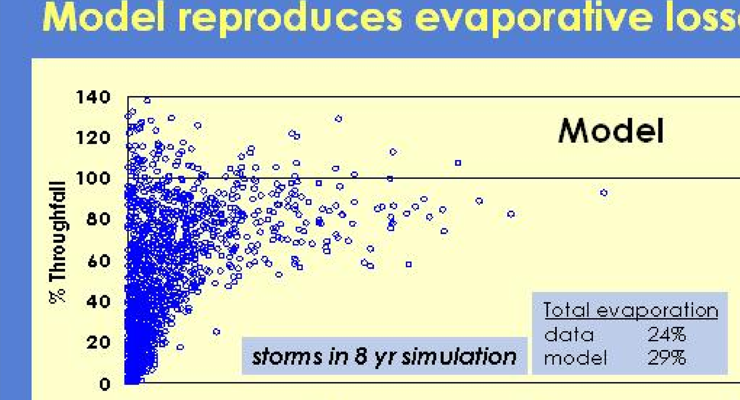
Rupp, D.E., R.F. Keim, M. Brugnach, M. Ossiander, and J.S. Selker. 2000. A scale-variant random cascade model of temporal rainfall. *Eos*, Trans. AGU, 81(48), Fall Mtg. Suppl., Abstr. NG71B-09.

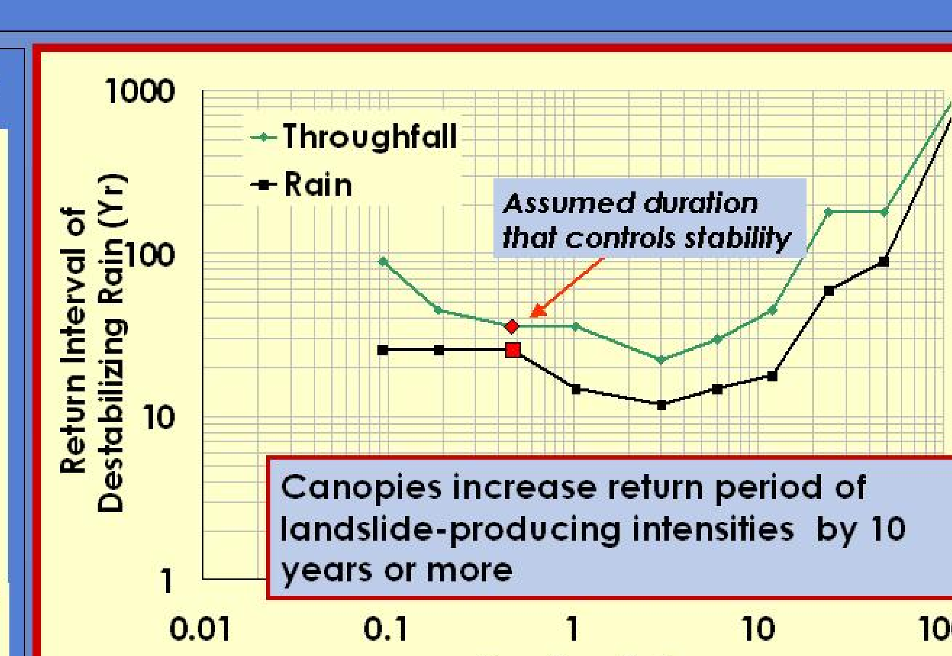
Results

Modeled Intensity-Duration-Frequency



Model reproduces evaporative losses





Probability of Landslide-Triggering Intensities

To modify Caine's (1980) intensity-duration threshold for hydrological landslide triggering to assess slope stability our sites, we assumed:

1. Pore-pressure responses respond to infiltration at ~20 min timescale at our sites (Iverson 2000); other timescales are less important for hydrological triggering of landslides.

2. Landslide-producing storms occur at 25-year return periods.

Thus, we modified the threshold to predict failure at a 25-yr return period at 0.5-h duration: