Ecohydrological Drivers of Vegetation Patterns and Landscape Evolution

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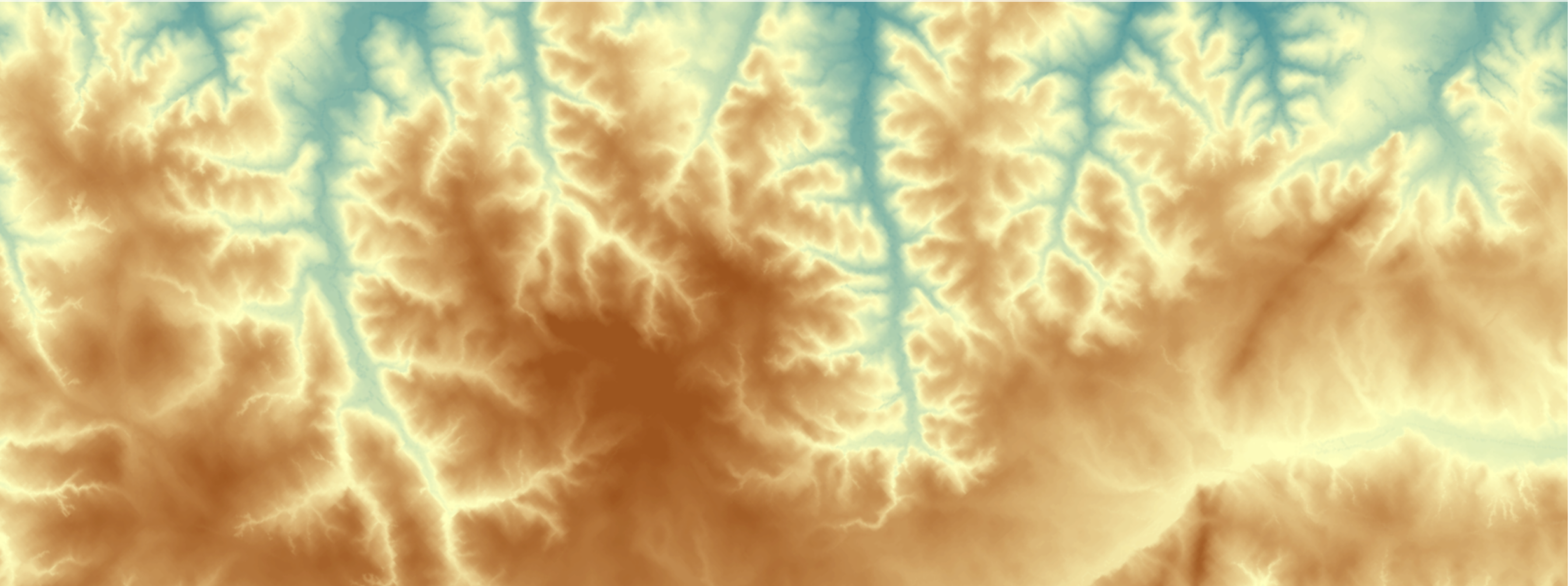
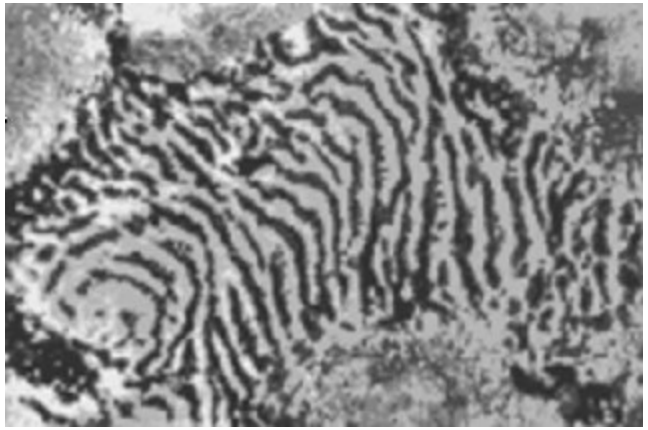


A labyrinth of green biomass observed in the northern **Negev** (200 mm annual rainfall). Distance between green patches is ~ 15 cm.



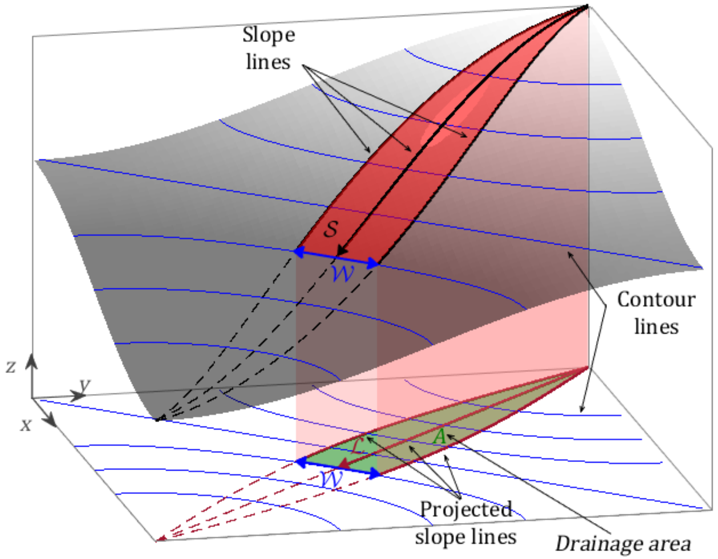
Vegetation bands on hillslopes near Niamey, **Niger**

Outline

- Stochastic dynamics of plant water stress

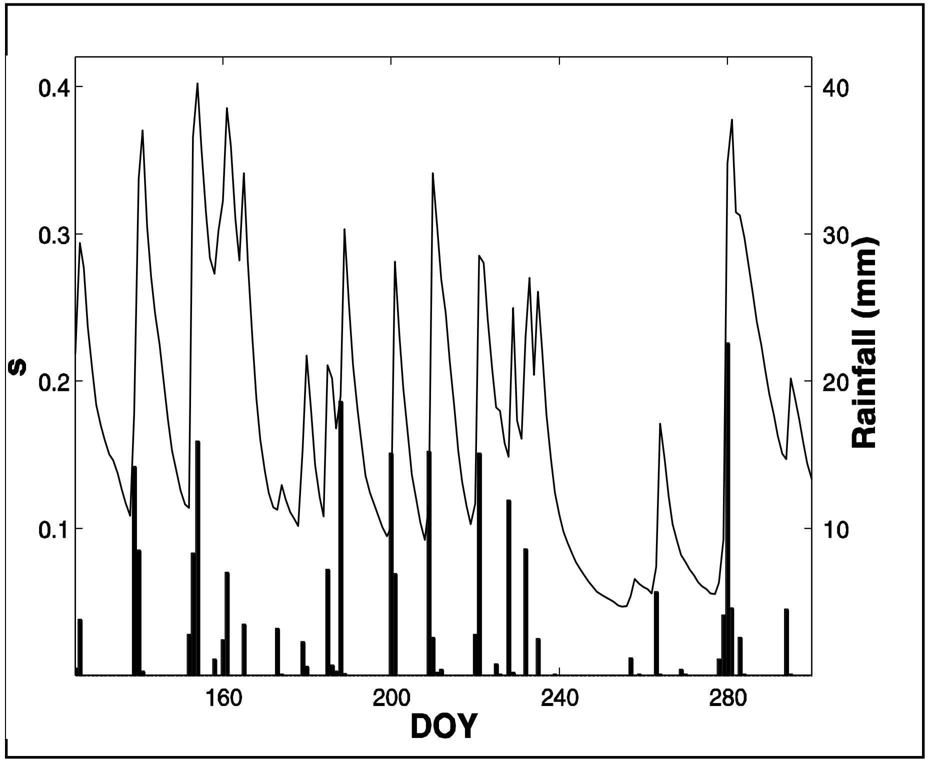
- Erosion thresholds and land degradation

- Landscape evolution
  (preliminary)



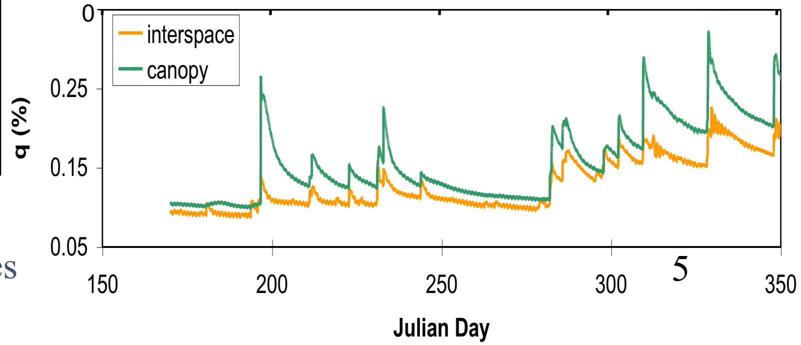
Stochastic soil moisture dynamics

Daly et al. WRR 2006

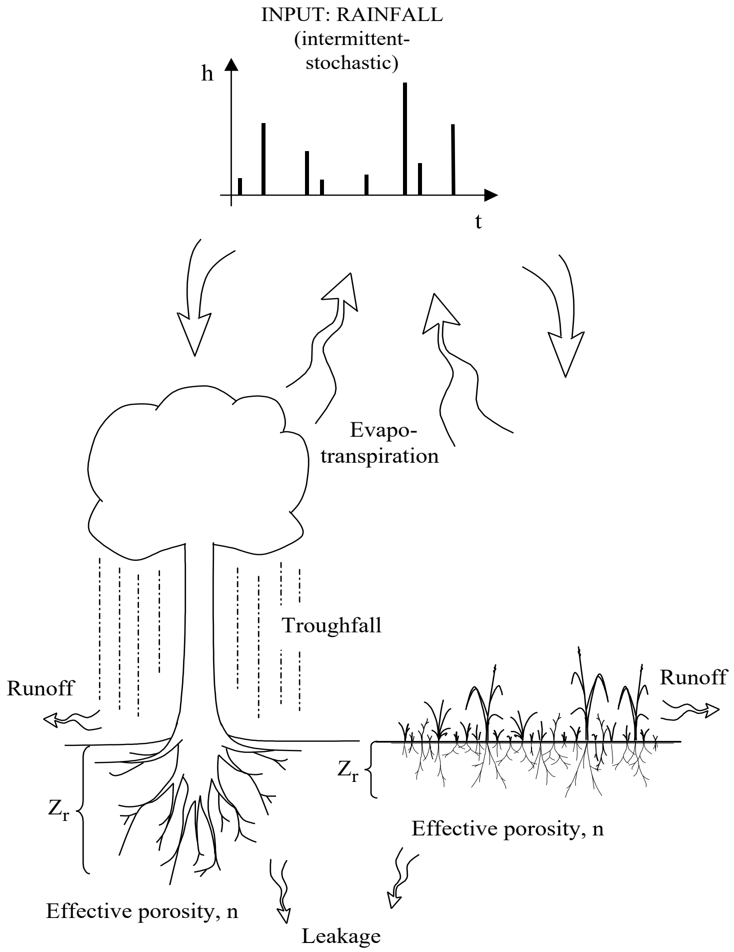


Daily Rainfall and Soil moisture in the Duke forest site (soil moisture is the average of the measurements from 4 TDR probes located over 30 cm

Loblolly pine (*Pinus taeda*) and surrounding hardwood forest at the CO2-enriched atmosphere (FACE) experiment) at Duke



The Soil Water Balance



secondary role of vegetation

primary role of vegetation

$$nZ_r \frac{ds(t)}{dt} = \underbrace{R(t) - I(t) - Q[s(t),t]}_{Y[s(t),t]} - E[s(t)] - L[s(t)]$$

n = porosity

Z_r = active soil depth

$s(t)$ = relative soil moisture

$R(t)$ = rainfall rate

$I(t)$ = canopy interception

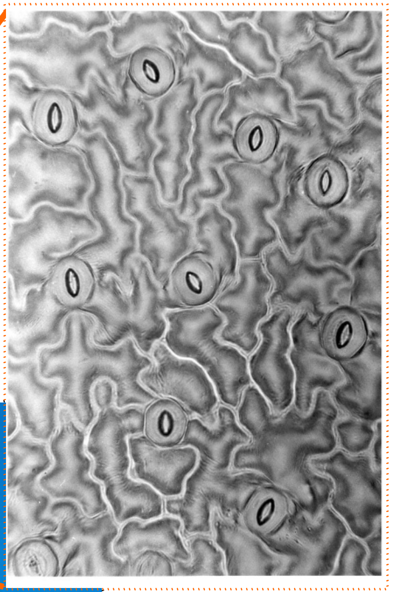
$Q[s(t),t]$ = runoff

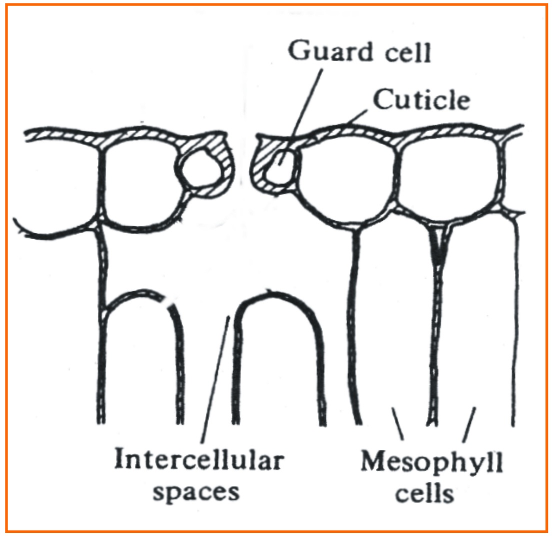
$E[s(t),t]$ = evapotranspiration

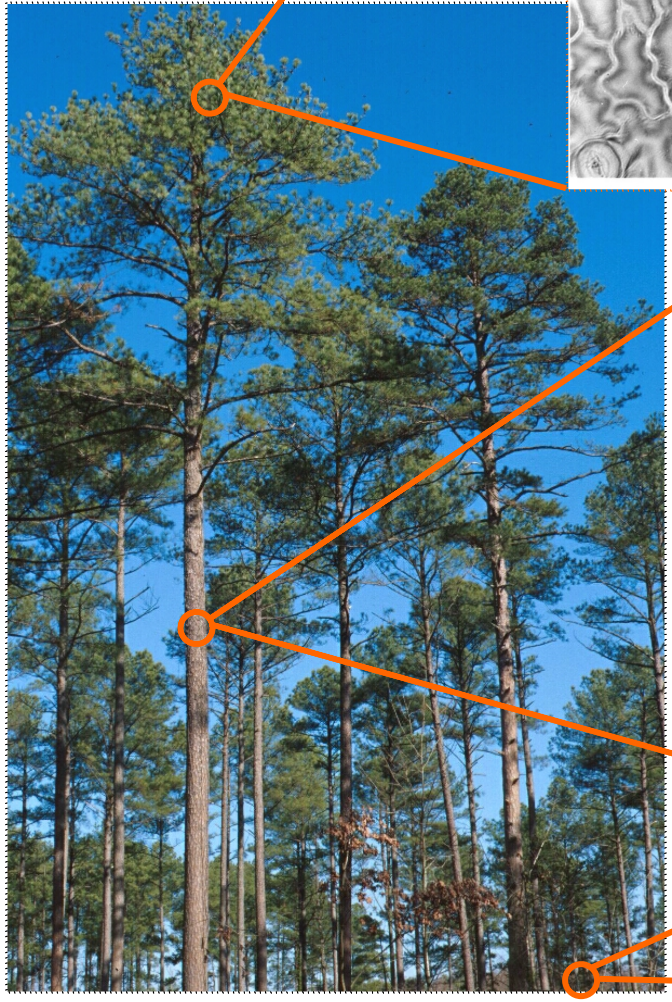
$L[s(t),t]$ = leakage

- Daily time scale
- Vertically averaged over the root zone
- Negligible topographic effects

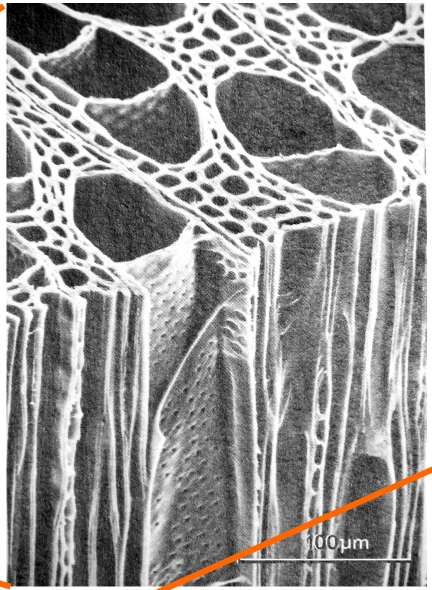
stomata



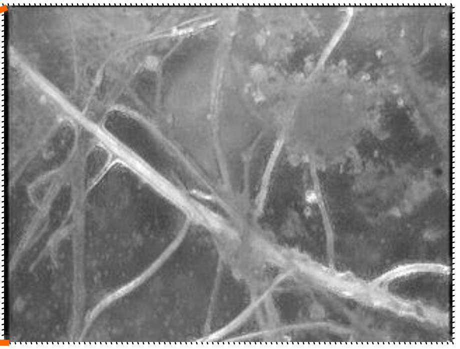




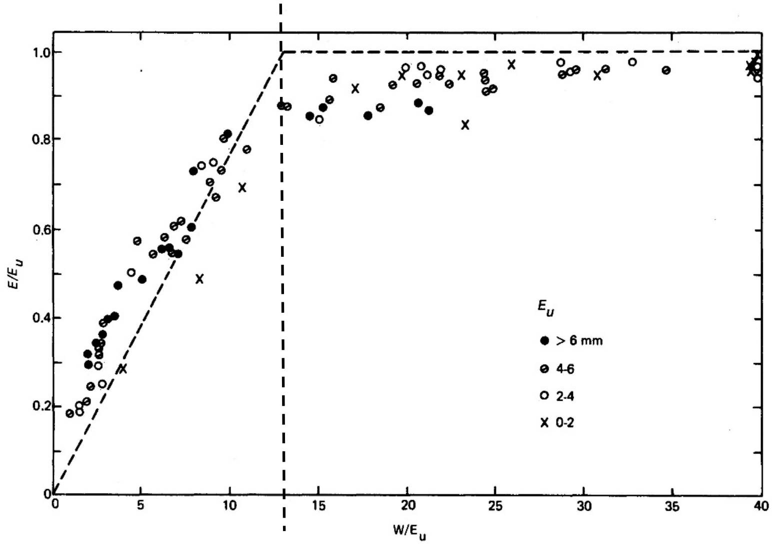
xylem vessels



soil-root interface



onset of stress

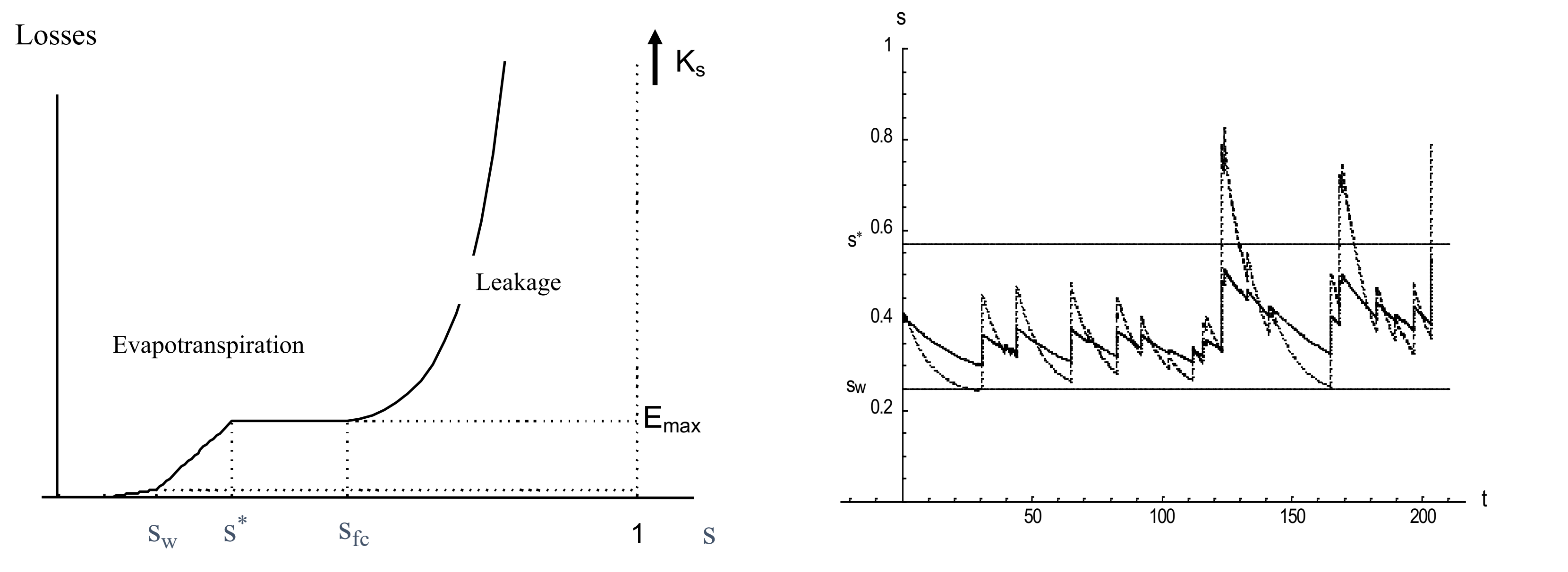


wilting point

After: Federer, *Water Resour. Res.*, 15 (3), 555-561, 1979.

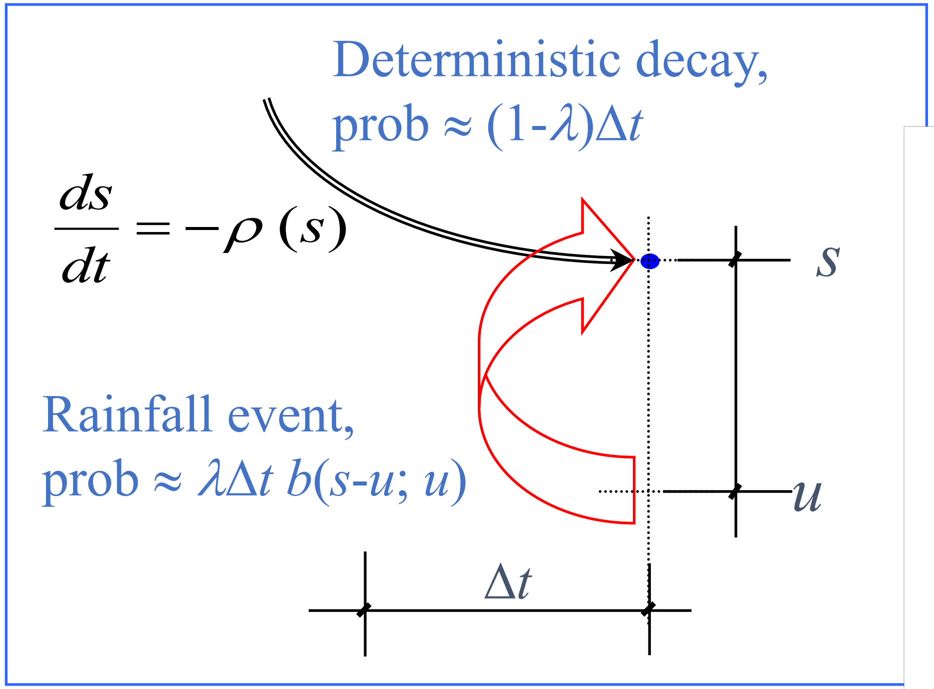
1-D Non-linear (stochastic) differential equation driven by a state-dependent Poisson noise

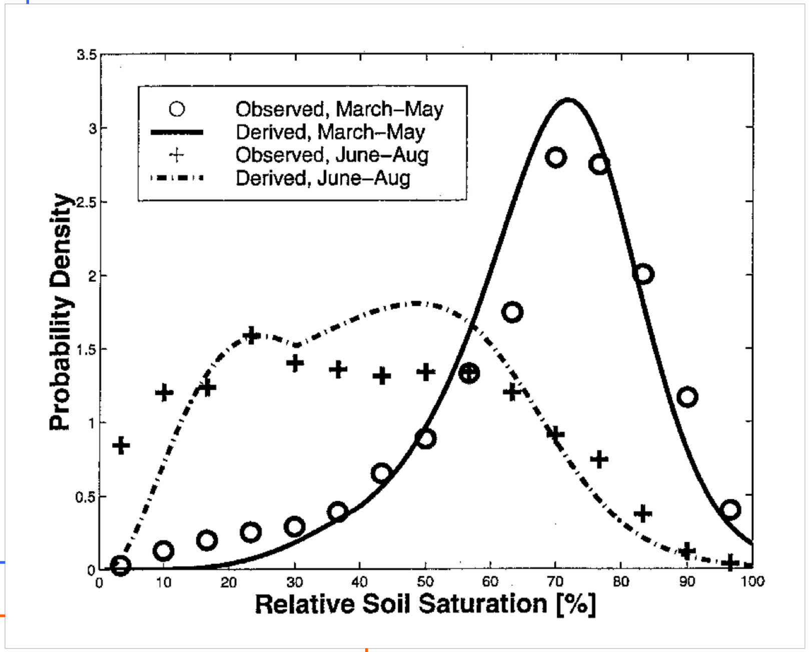
$$\frac{ds}{dt} = -\rho(s) + F(t,s)$$



Chapman-Kolmogorov eq. (Bartlett & Porporato PRE 2018)

$$p(s,t+\Delta t) = \underbrace{(1-\lambda\,\Delta t)\,p(s+\Delta s,t)\,\mathrm{d}(s+\Delta s)}_{\text{det.decay}} + \underbrace{\lambda\,\Delta t\int_0^s p(u+\Delta u,t)\,b(s-u;u)\,\mathrm{d}(u+\Delta u)\,\mathrm{d}s}_{\text{jumps}}$$

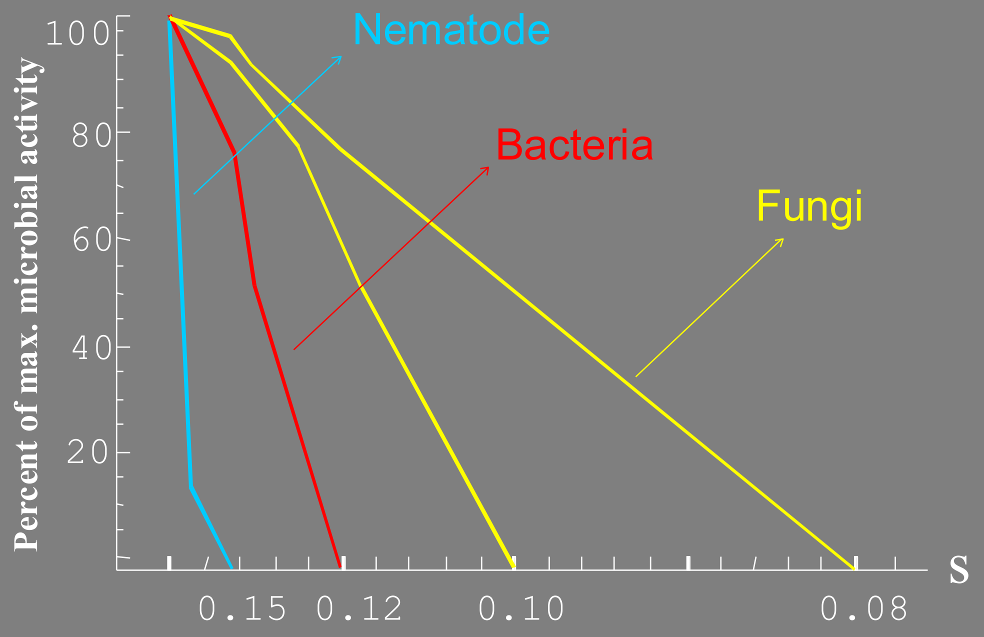


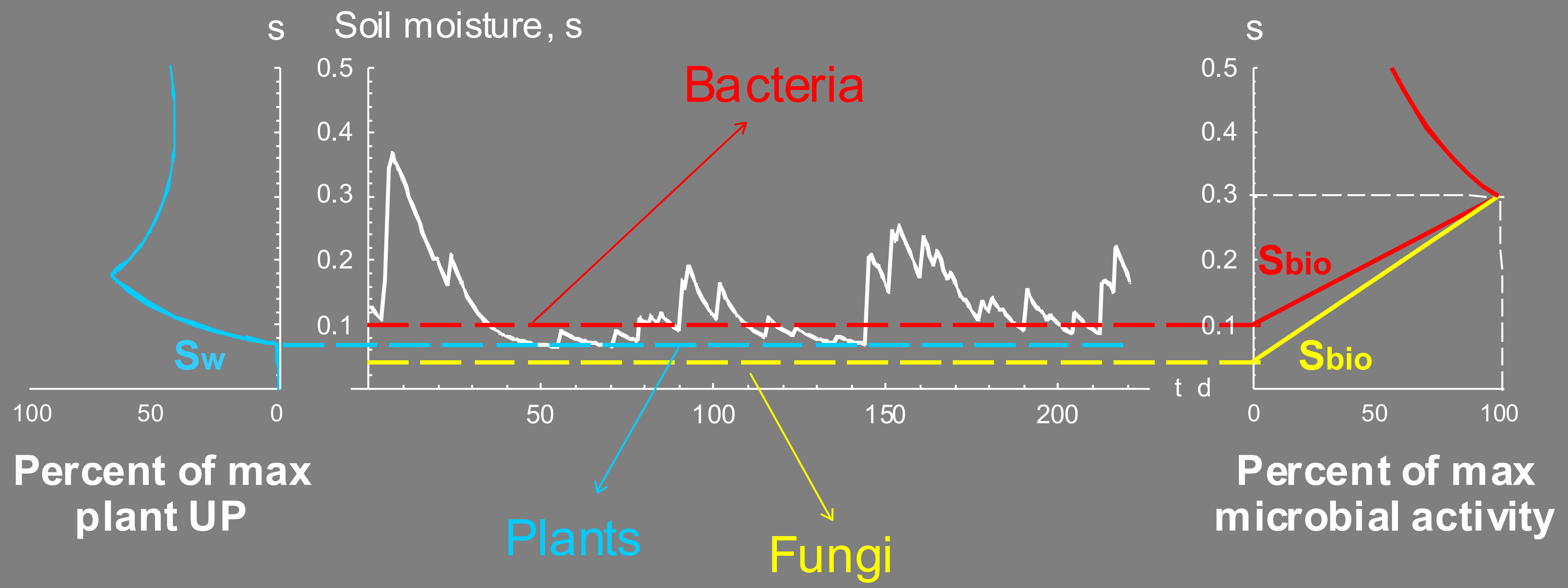


frequency of crossing

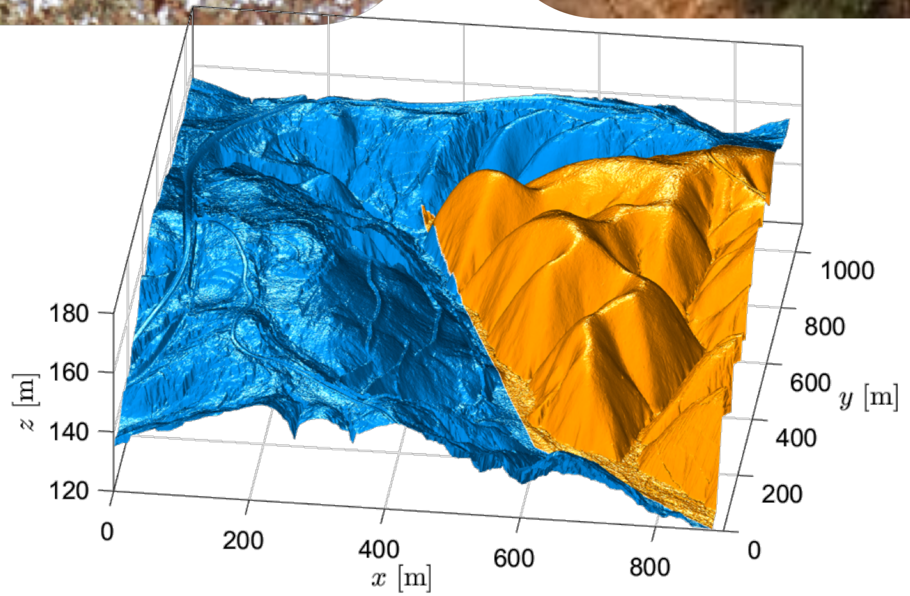
$$\frac{\partial}{\partial t}p(s,t) = \frac{\partial}{\partial s}\left[p(s,t)\rho(s)\right] - \lambda\,p(s,t) + \lambda\int_0^s p(u,t)\,\gamma\; e^{-\gamma(s-u)}du$$

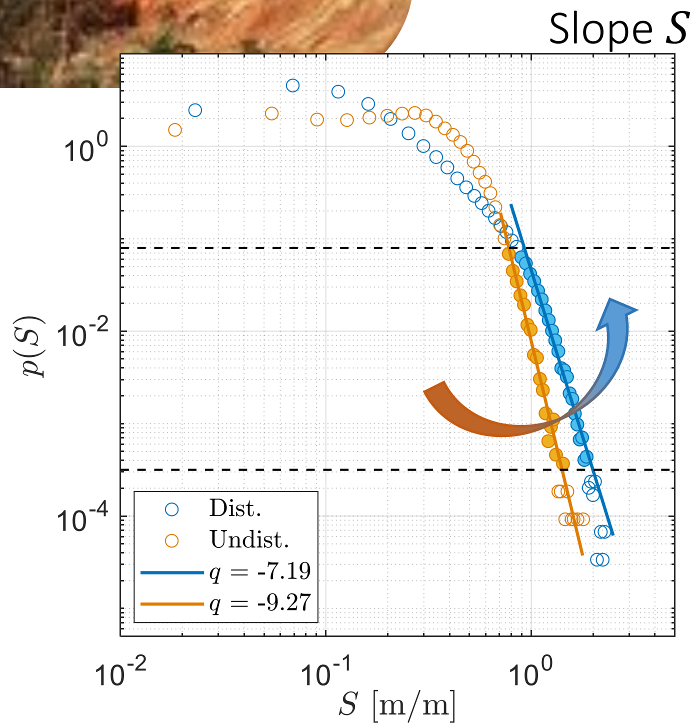
Crossing of stress points





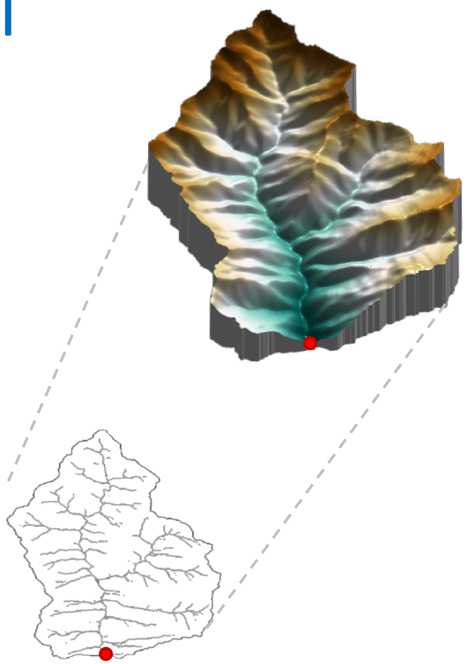
Vegetation ‘disturbances’ and landscape morphology



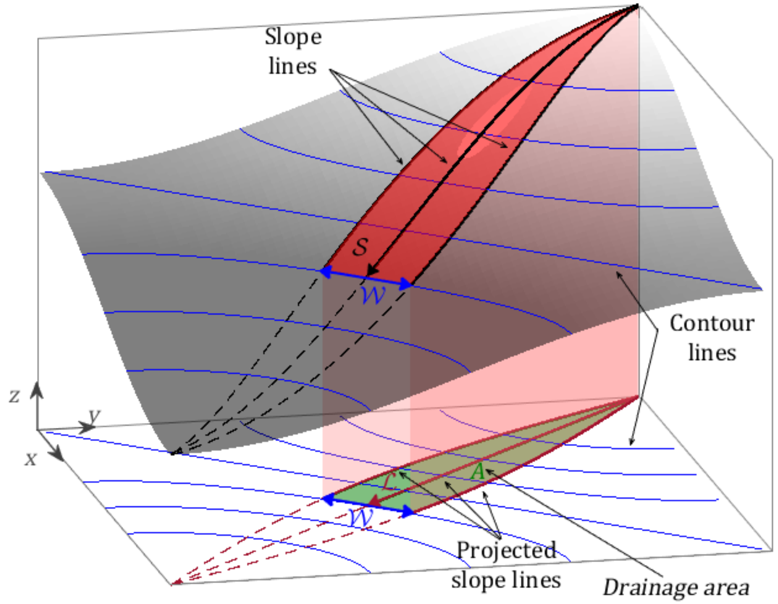


Minimalist Landscape-Evolution Model

$$\frac{\partial z}{\partial t} = D\nabla^2 z - K a^m |\nabla z|^n + U$$



Theoretical definition of **drainage area**



- Contour lines
- Slope lines (direction given by $-\nabla z$)
- Drainage area A [L^2]
- Specific drainage area a [L]

$$a = \lim_{w \to 0} \frac{A}{w}$$

- Local slope $|\nabla z|$

Bonetti et al., PRSA (2018)

Mathematical model

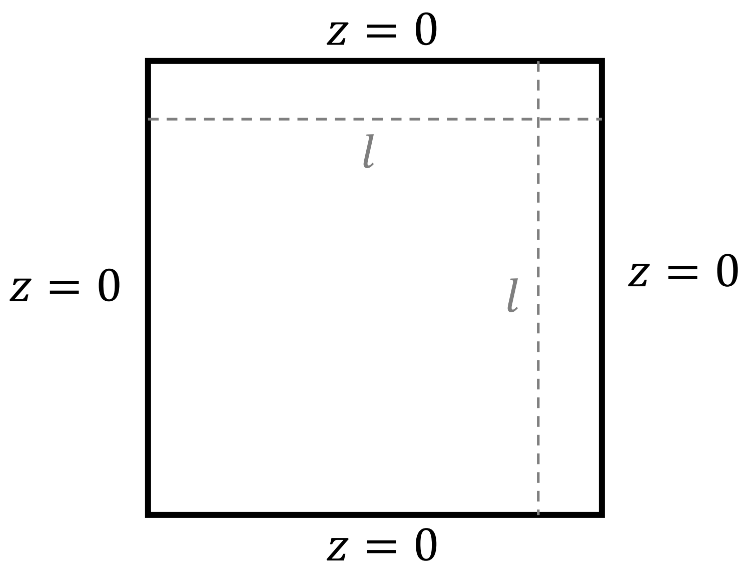
$$\frac{\partial h}{\partial t} = R - \nabla \cdot (q\mathbf{n})$$

$$\frac{\partial z}{\partial t} = D\nabla^2 z - K q^m |\nabla z|^n + U$$

$$\mathbf{n} = \frac{\nabla z}{|\nabla z|} \qquad q = h v_0$$

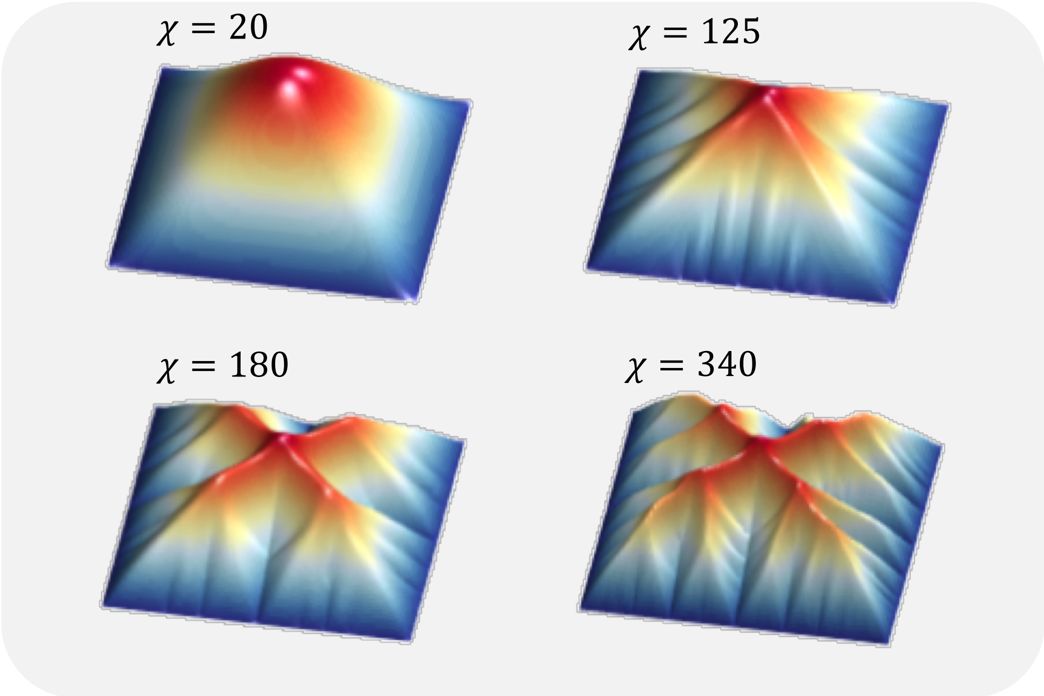
$$-\nabla \cdot \left(a \frac{\nabla z}{|\nabla z|}\right) = 1$$

$$\frac{\partial z}{\partial t} = D\nabla^2 z - K a^m |\nabla z|^n + U$$



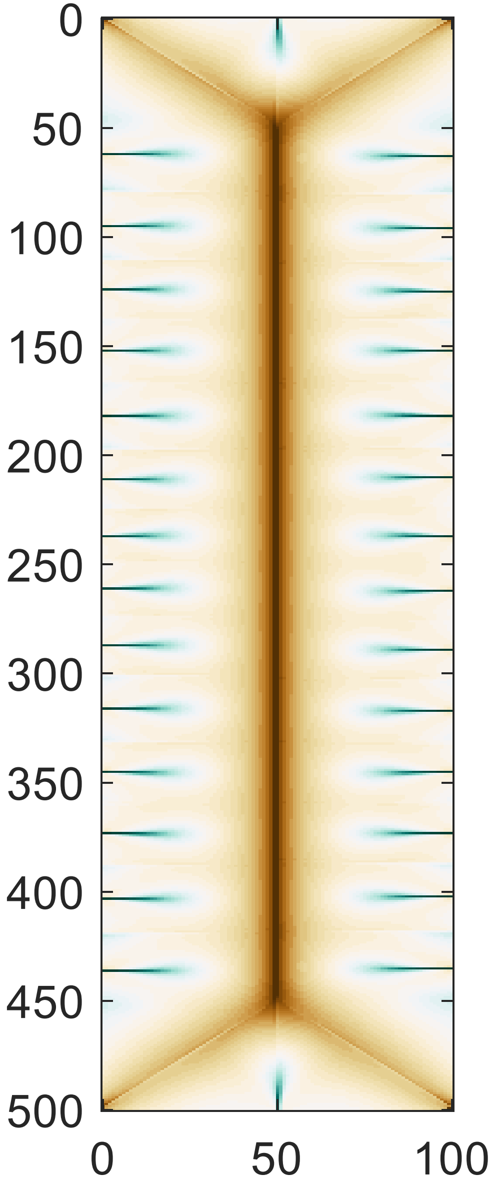
$$\chi = \frac{K\, l^{m+n}}{D^n U^{1-n}}$$

role of vegetation?

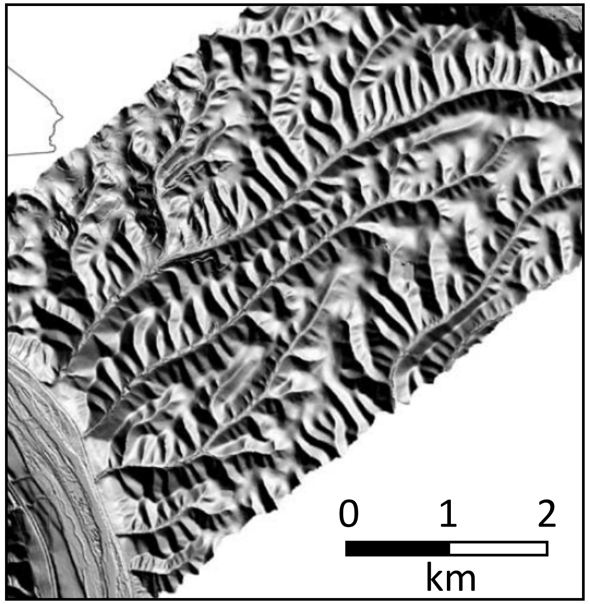


Bonetti et al., PRSA (2018) ; Bonetti et al. 2019 (submitted)

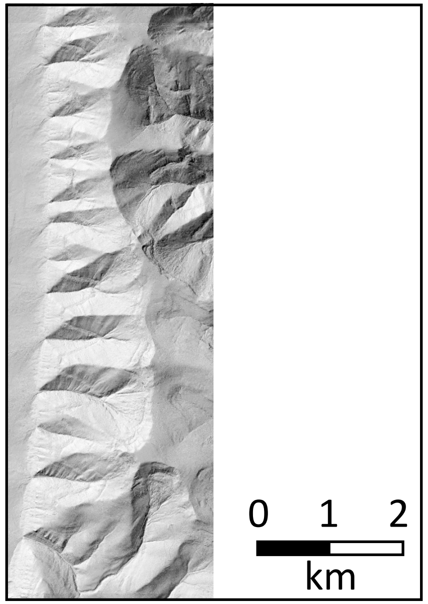
Evenly-spaced valleys



Orland, CA (Perron et al., 2008)

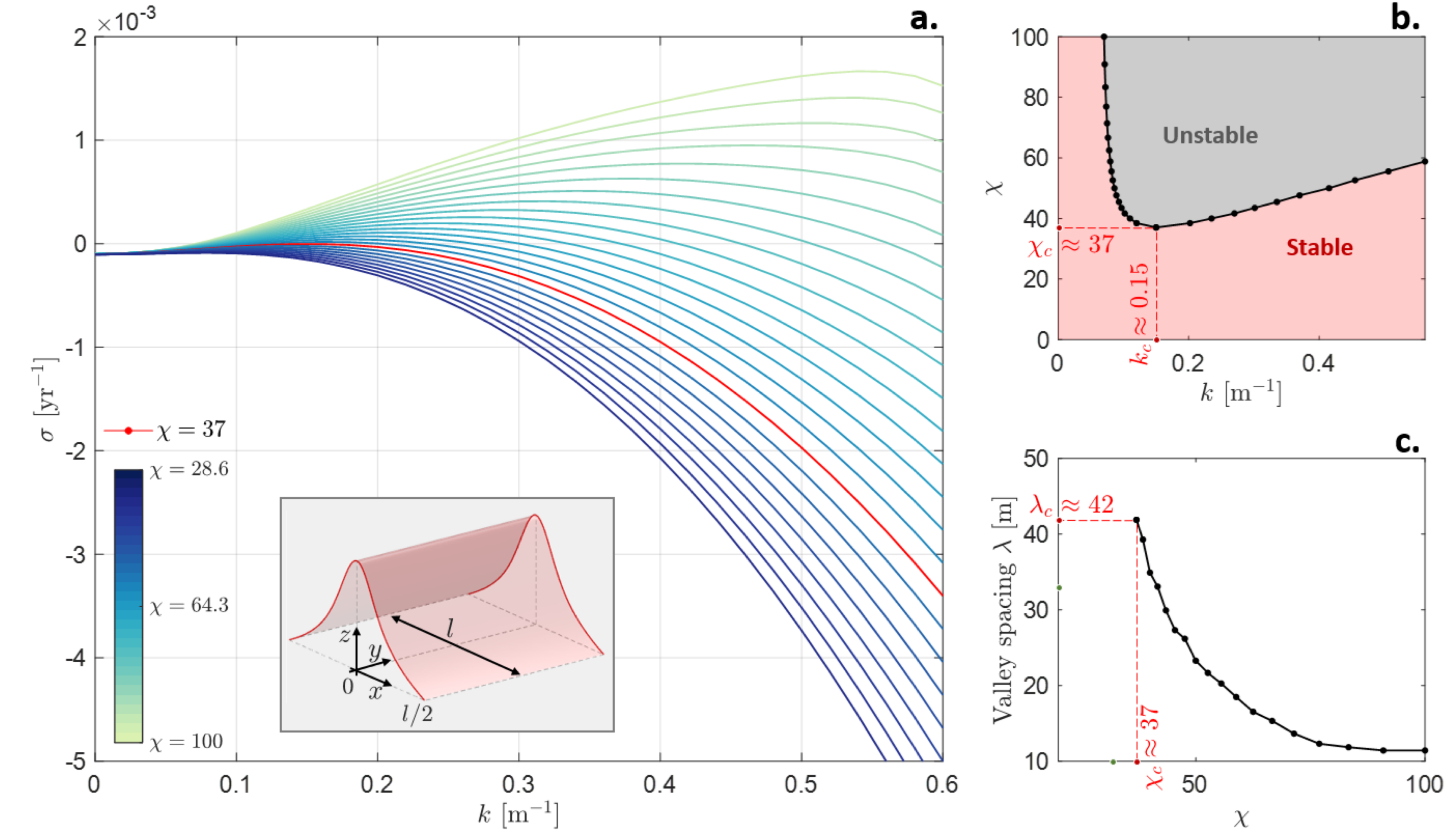


Gabilan Mesa, CA (Perron et al., 2008)

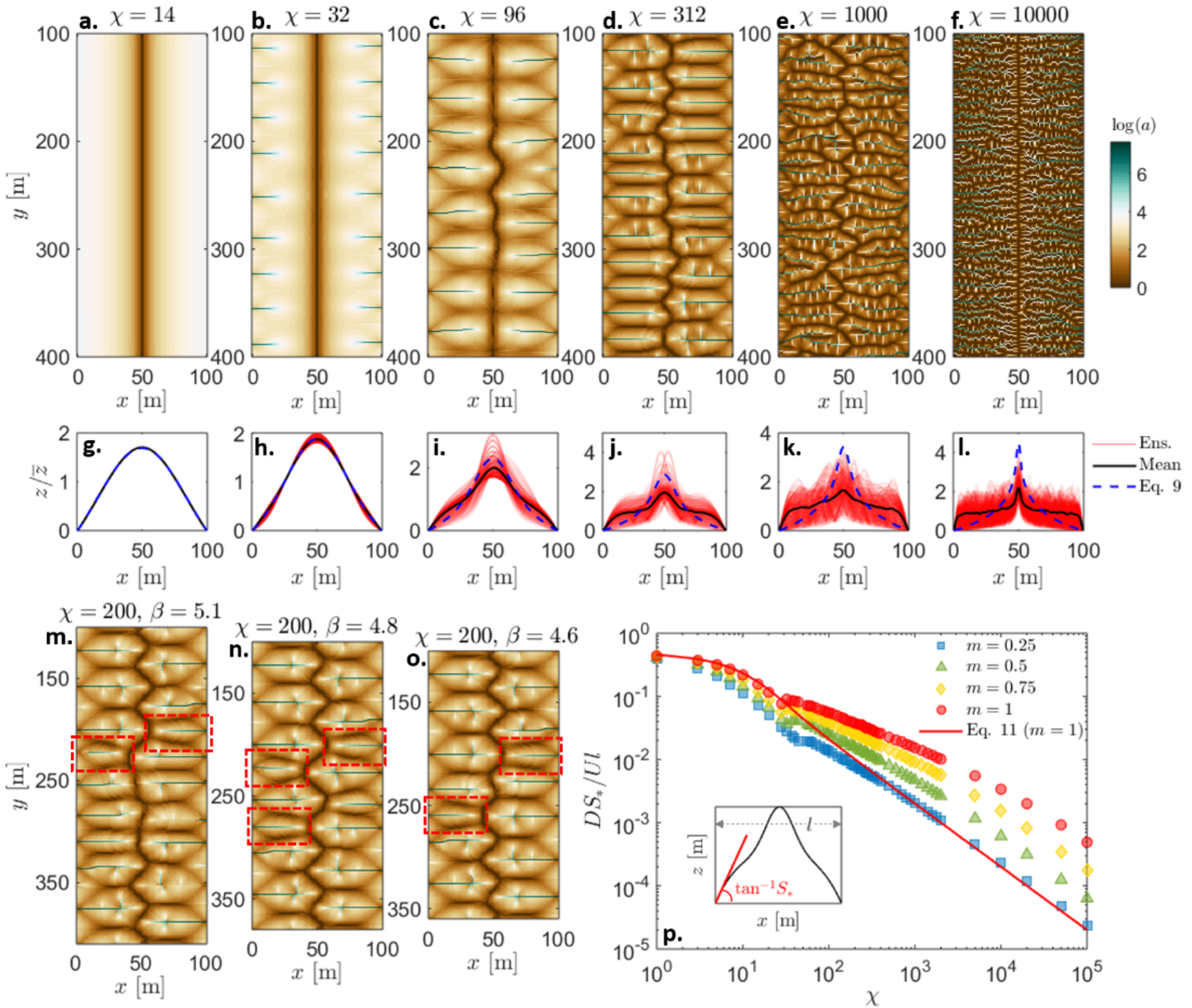


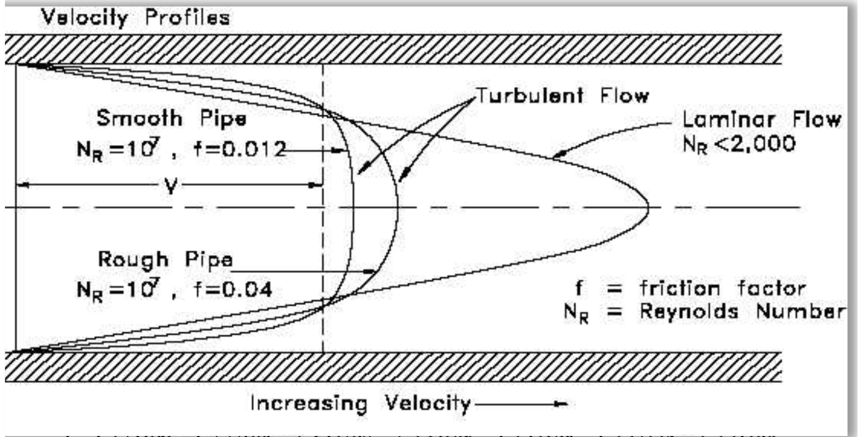
Manti-La Sal National Forest, UT

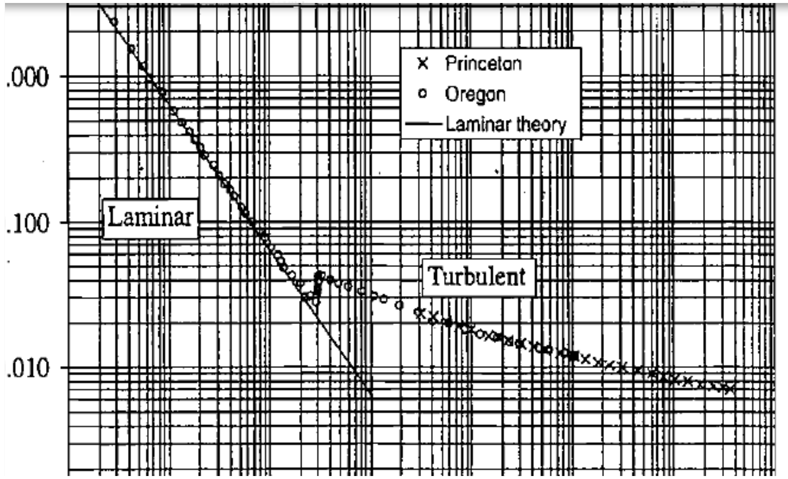
Linear Stability Analysis



χ increases complexity

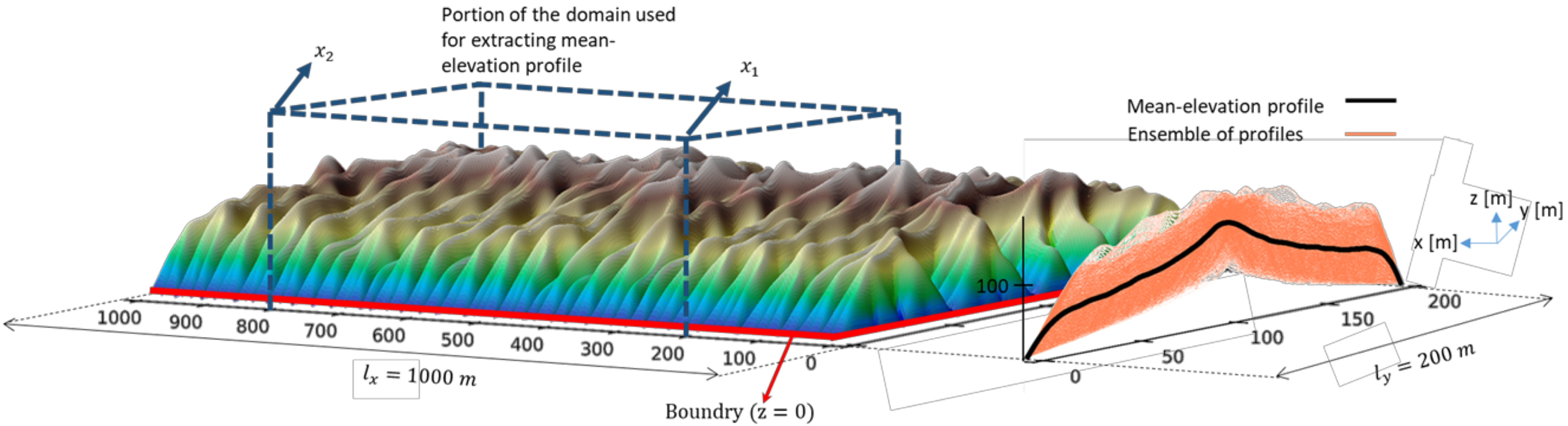




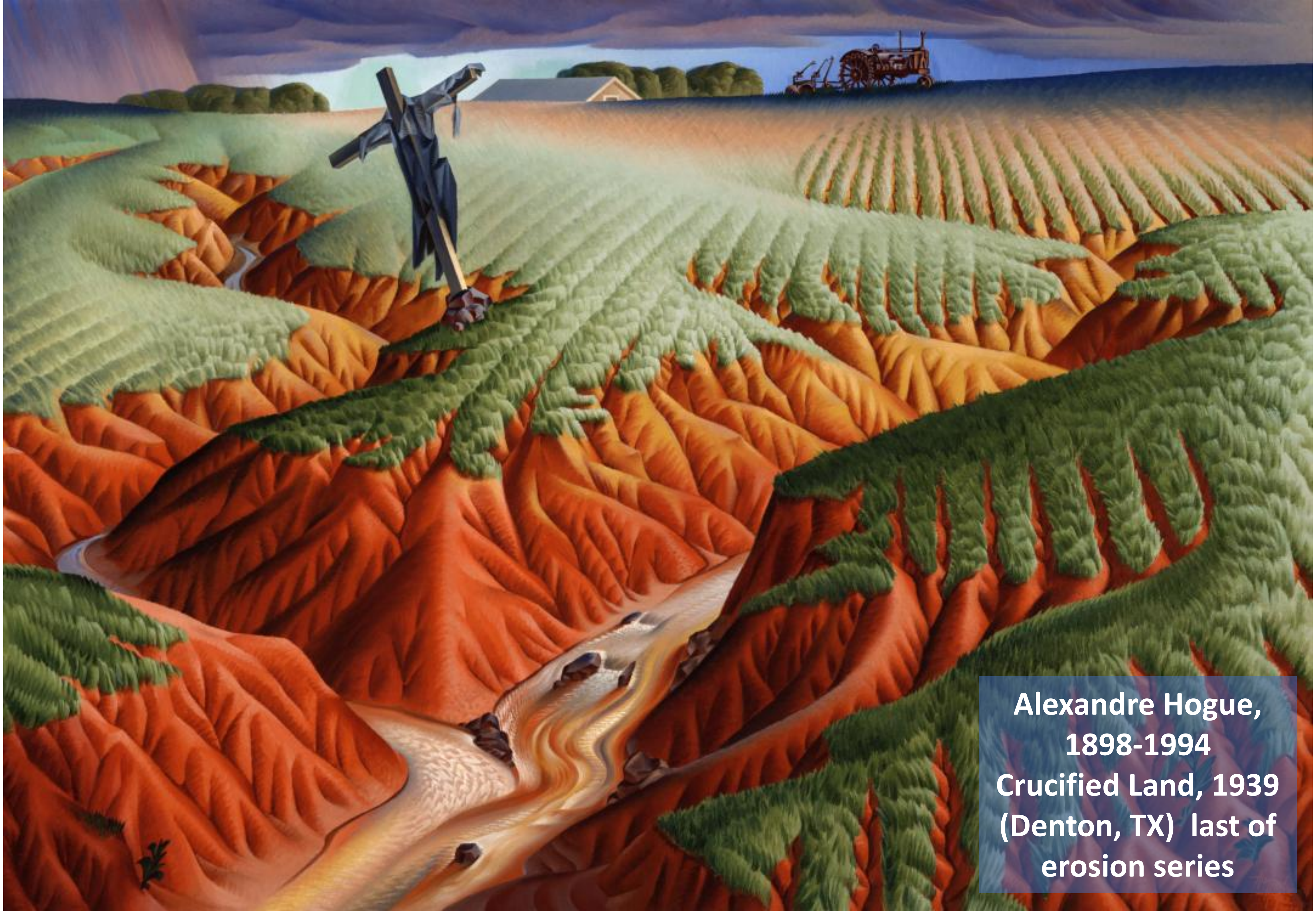


Logarithmic elevation profile

Hooshyar et al. (poster Wed evening)




Thank you!



Alexandre Hogue,
1898-1994
Crucified Land, 1939
(Denton, TX) last of
erosion series