Cellular Automata for tropical forests prone to fire

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(Dynamical Systems & Analysis)

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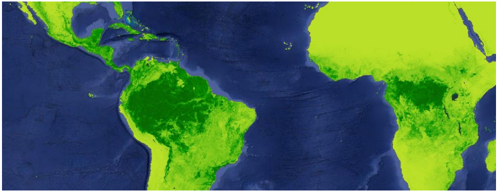
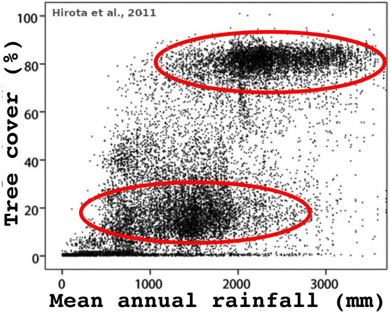
Background

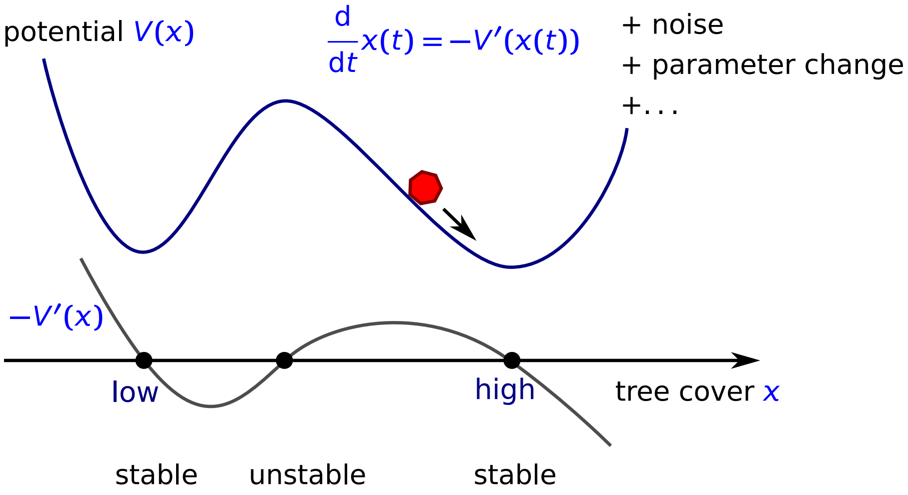
MODIS VCF data

Bimodality
Bistability?





Common tipping mechanism



Fire feedback

- fire ignites and spreads in grassland
- trees block fires but get damaged
- **fast** fire spread (hours-days)
- **slow** tree spread (years-decades)

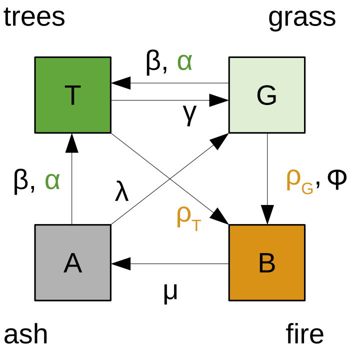
Models have **threshold parameter** for effect of fire ($\sim 40\%$ tree cover)

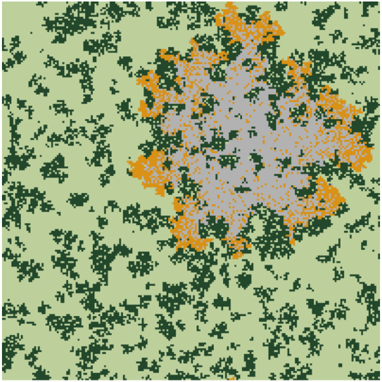
Motivation: percolation theory

Staver and Levin (2012); Schertzer et al. (2014); Patterson et al. (2021)

Cellular automaton — Hébert-Dufresne *et al.* 2018

- Square Lattice (each cell $\sim 30\text{m} \times 30\text{m}$), $N = 100$
- 4 Species: Tree, Grass, Burning, Ash

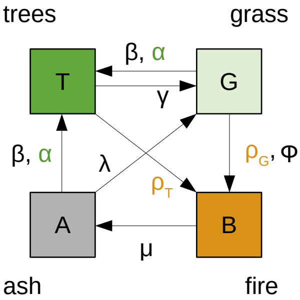


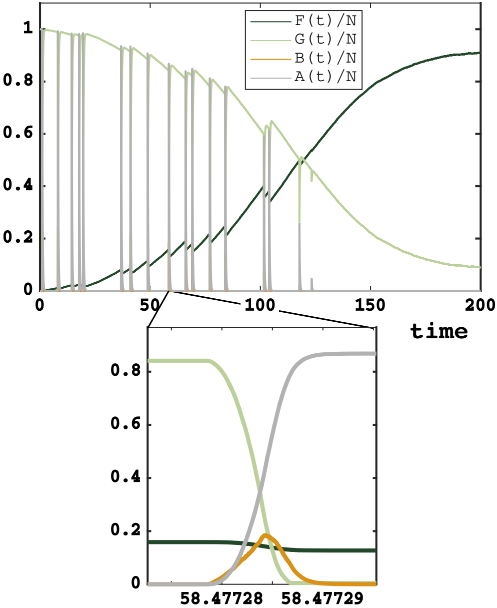


Intuition: SIS on slow timescale ⟷ SIRS on fast timescale

Hébert-Dufresne et al. (2018)

Cellular automaton simulation

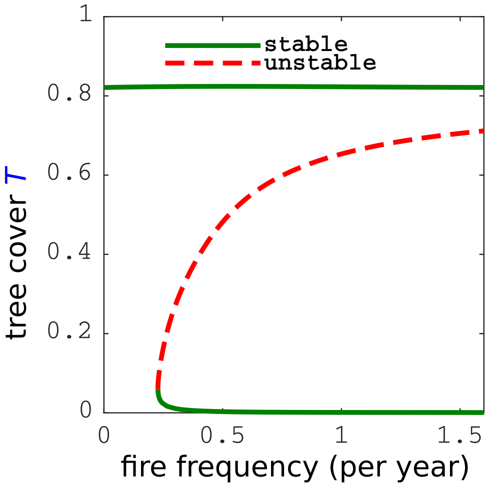




video

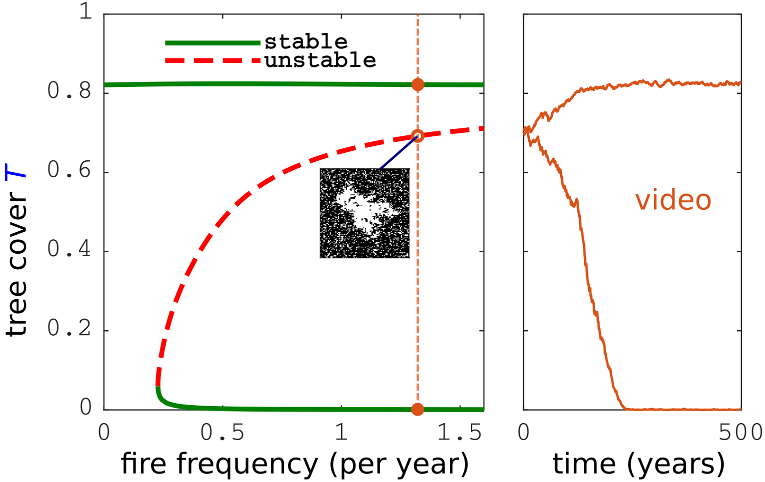
Wuyts and Sieber (2023)

Cellular automaton — bistability



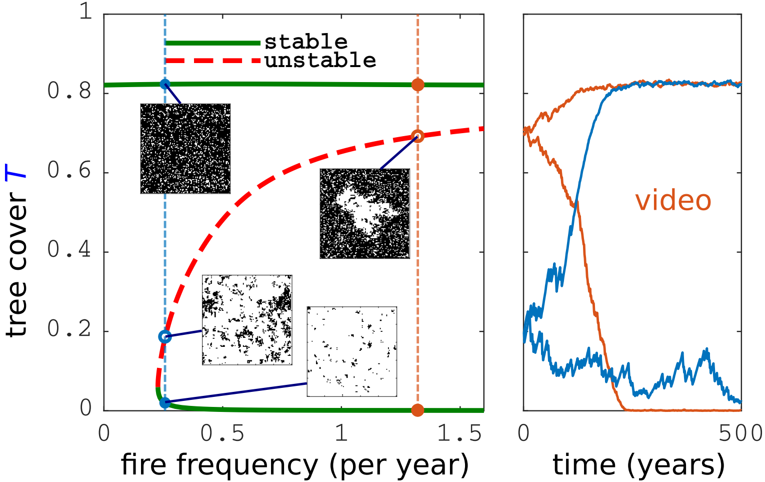
Wuyts and Sieber (2023)

Cellular automaton — bistability



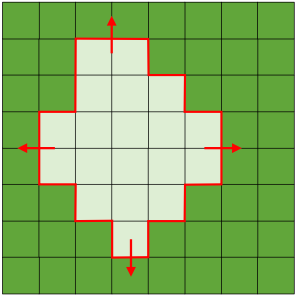
Wuyts and Sieber (2023)

Cellular automaton — bistability



Wuyts and Sieber (2023)

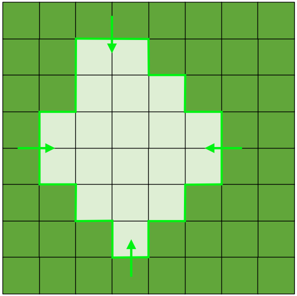
Potential $V(T)$



forest **loss** by repeated fires

$\langle TG \rangle_{cg} :=$

length of forest boundary, each cell weighted by size of adjacent grass patch



forest **gain** by growth

$[TG] :=$

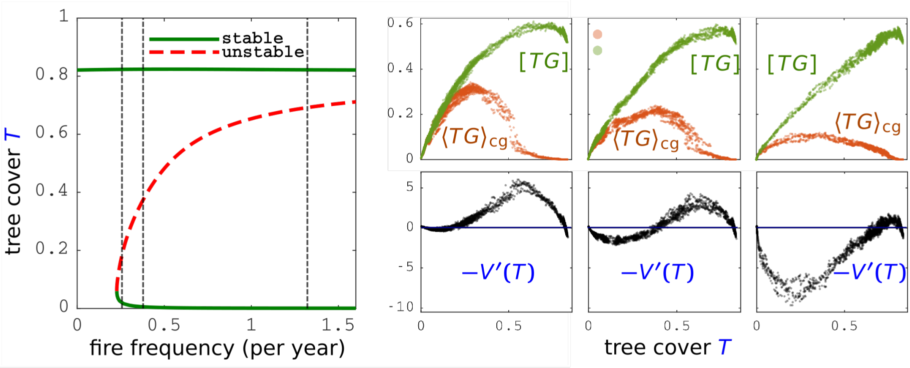
length of forest boundary

$\Rightarrow$ violate assumptions of percolation theory

Wuyts and Sieber (2023)

Potential $V(T)$

$$\frac{\mathrm{d}}{\mathrm{d}t}T = -\mu T + \alpha_+[\mathrm{TG}] - \alpha_-(1-T)\langle TG\rangle_{\mathrm{cg}} =: -V'(T)$$



$[TG]$ forest boundary

$\langle TG\rangle_{cg}$ adjacent grass weighted forest boundary

Wuyts and Sieber (2023)

Summary & implications

- adjacent grass cells cooperate by burning down

  $\Rightarrow$ long-range correlations

  $\Rightarrow$ violation of assumptions behind mean fields & percolation theory

- Quantities determining tipping potential $V(T)$:
  - gain: forest boundary $[TG]$
  - loss: grass-weighted forest boundary $\langle TG \rangle_{\mathrm{cg}}$

- Implications:
  - tropical forest change and resilience can be empirically estimated from its spatial structure.
  - determine where tropical forest bistable