Tipping points and early warning signals

Summer School on Biogeodynamics and Earth System Sciences
Venice, June 2011

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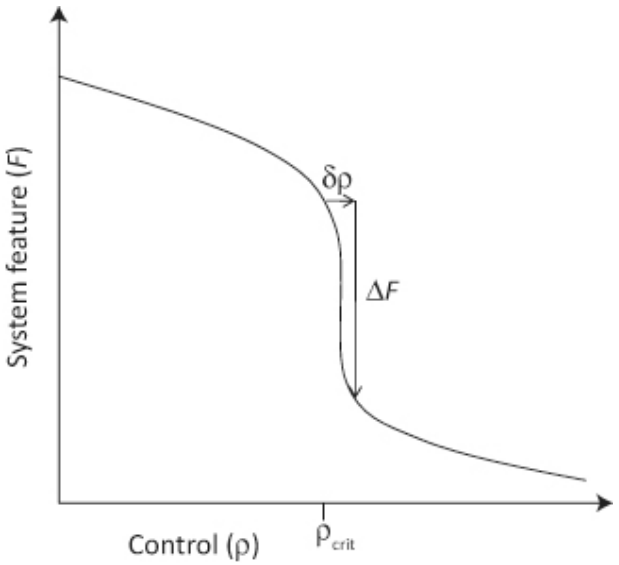
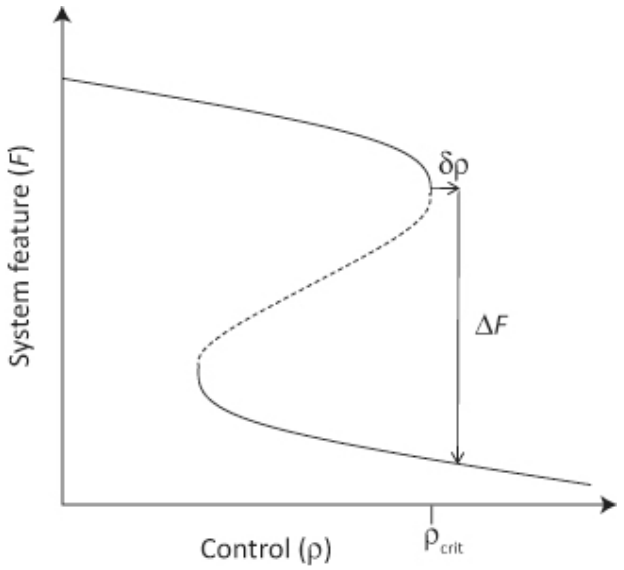
What is a tipping point?



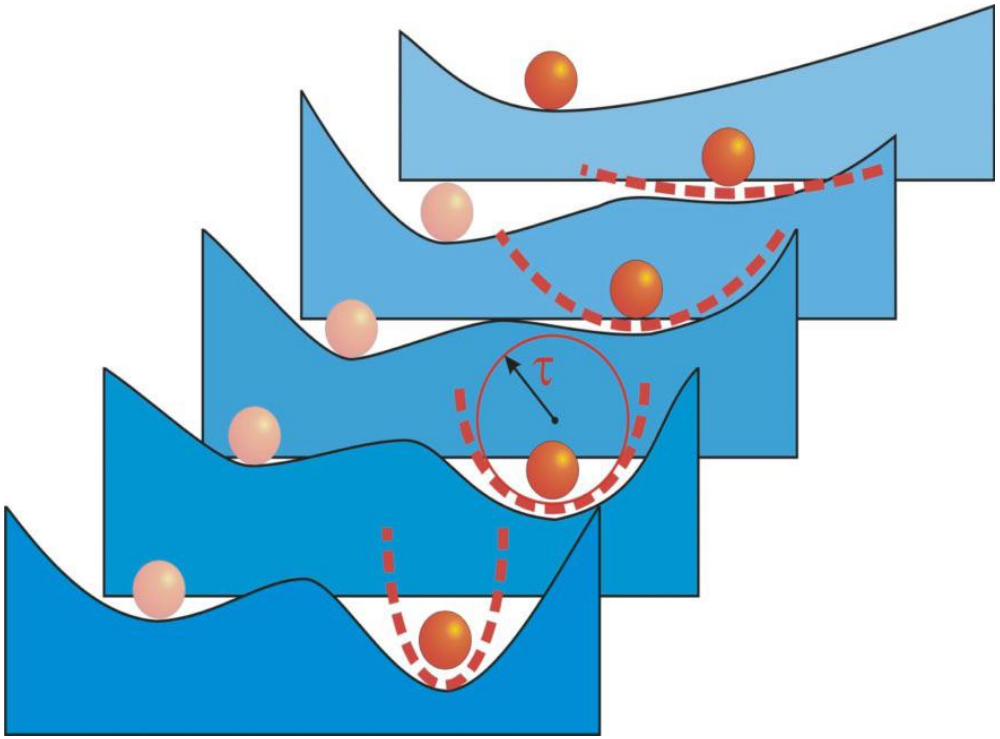


Lenton (2011) BESS Lecture 4

Where are tipping points?

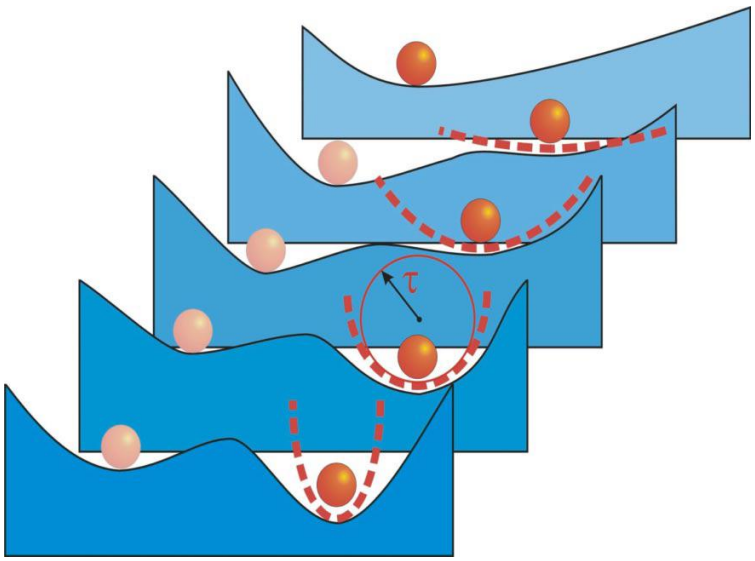
- Everywhere

What happens near a tipping point?



Lenton et al. (2008) *PNAS* 105(6): 1786-1793

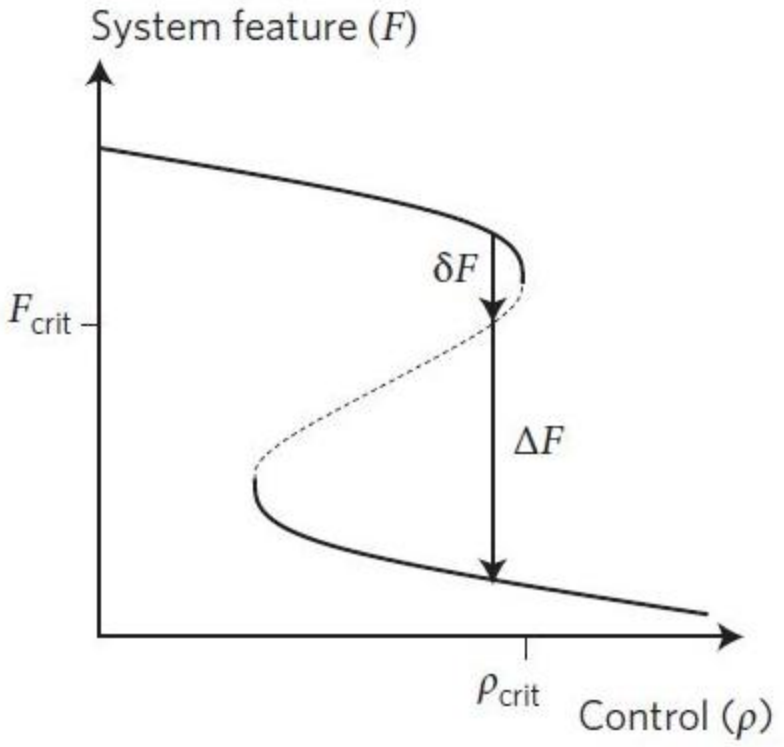
What happens near a tipping point?



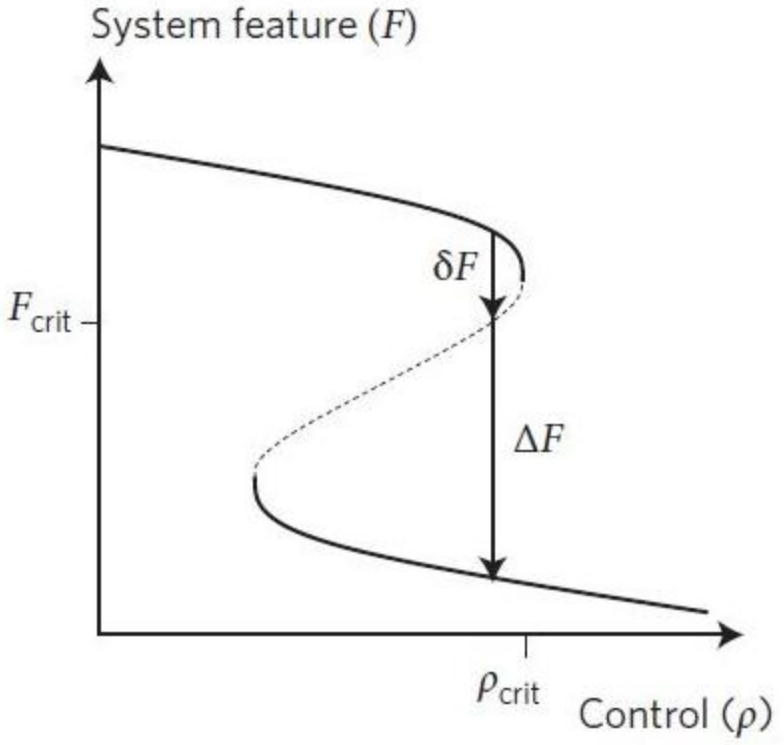
- slowing down recovery from perturbations
- increasing memory, i.e. autocorrelation
- shift of power to lower frequencies
- increasing variance
- increasing skewness

Lenton et al. (2008) *PNAS* 105(6): 1786-1793

But: Noise induced transition



But: Noise induced transition



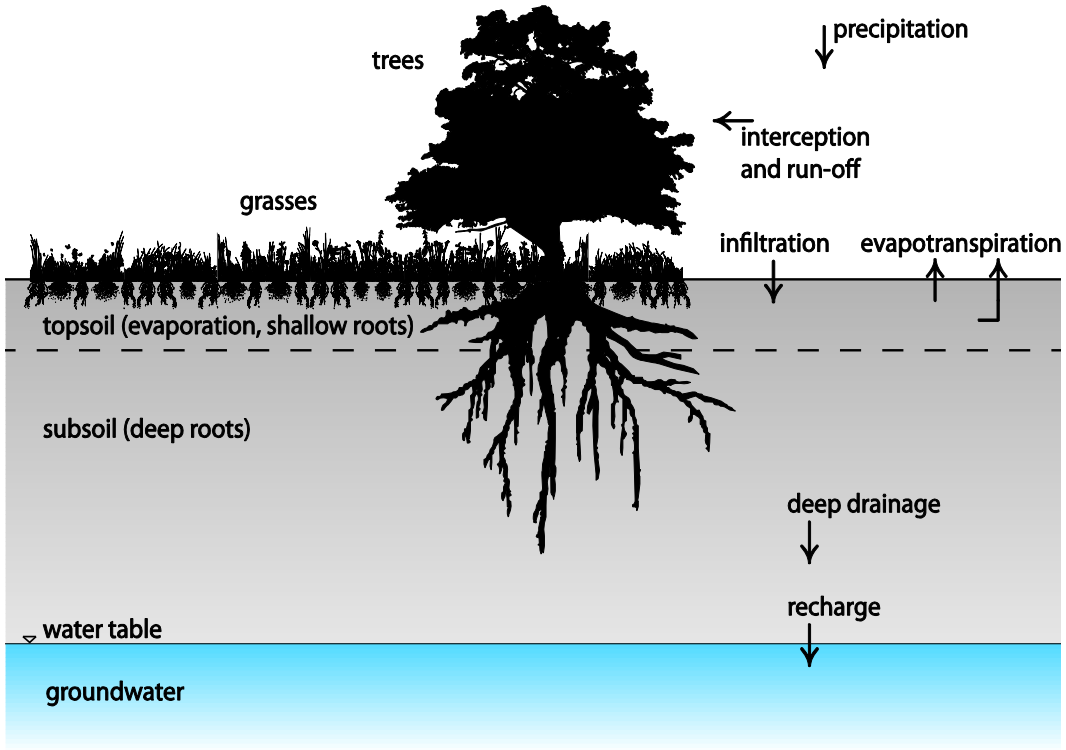
fundamentally

unpredictable

Can we detect an early warning signal for a greening desert?

Can we detect an early warning signal for a greening desert?

- model of vegetation dynamics of arid ecosystems
- involves positive feedback between vegetation and soil water availability



Kefi et al. (2010) Theor Ecol 3:257–269

Model equations

$$\frac{\partial O}{\partial t} = R - \alpha O \frac{P + k_2 W_o}{P + k_2} - l_o O$$

surface water

$$\frac{\partial W}{\partial t} = \alpha O \frac{P + k_2 W_o}{P + k_2} - g \frac{W}{W + k_1} P - r_w W$$

soil water

$$\frac{\partial P}{\partial t} = cg \frac{W}{W + k_1} P - dP$$

plant density

Kefi et al. (2010) Theor Ecol 3:257–269

Model equations

rainfall

$$\frac{\partial O}{\partial t} = R - \alpha O \frac{P + k_2 W_o}{P + k_2} - l_o O$$

surface water depth

infiltration

runoff/evaporation

$$\frac{\partial W}{\partial t} = \alpha O \frac{P + k_2 W_o}{P + k_2} + g \frac{W}{W + k_1} P - r_w W$$

soil water

infiltration

uptake

drainage

$$\frac{\partial P}{\partial t} = cg \frac{W}{W + k_1} P - dP$$

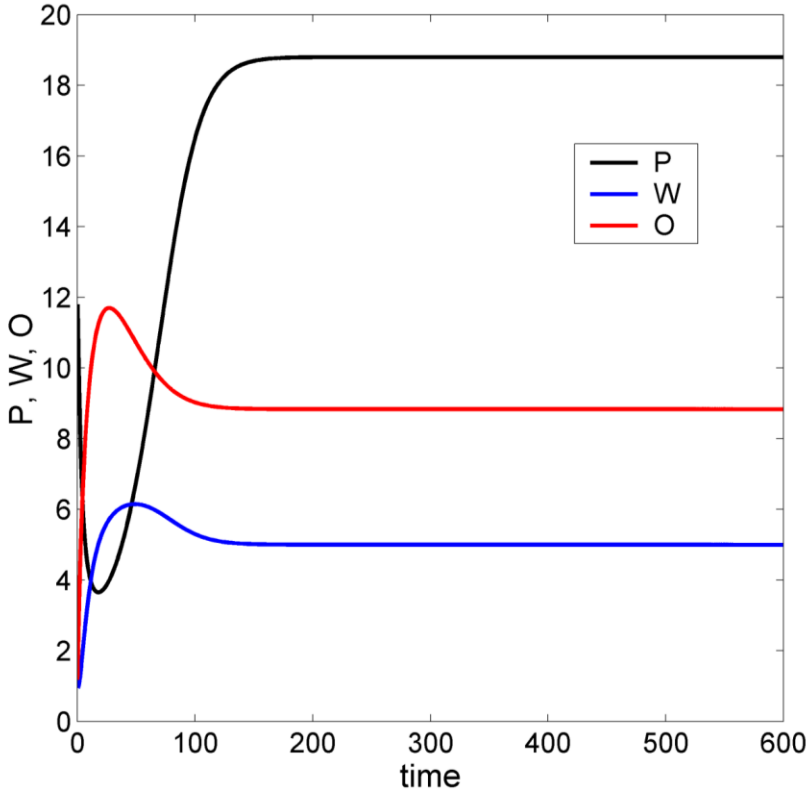
plant density

uptake

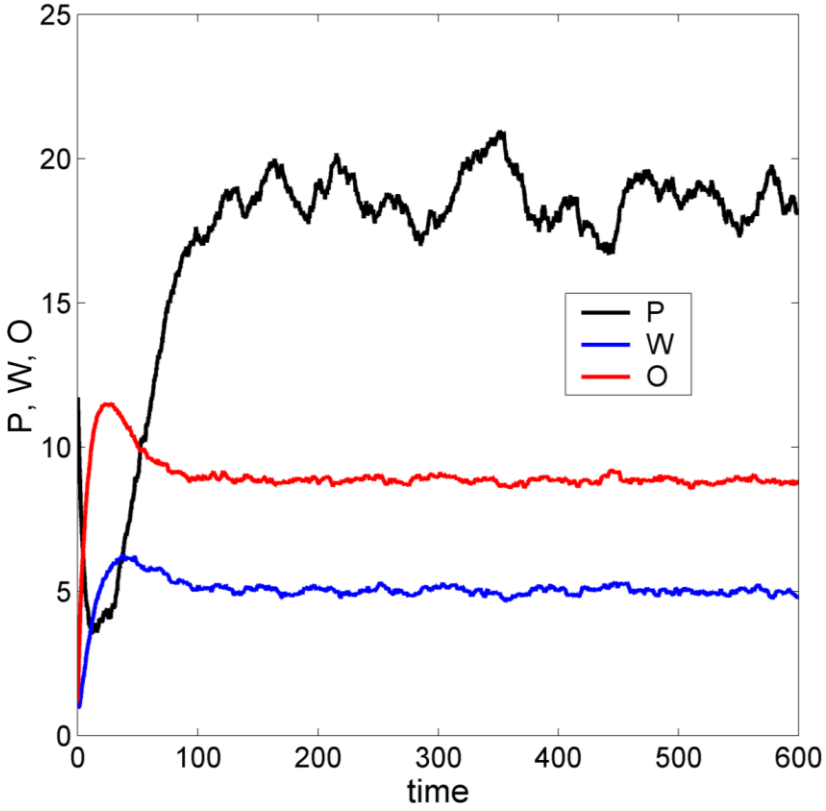
mortality

Kefi et al. (2010) Theor Ecol 3:257–269

sample simulation

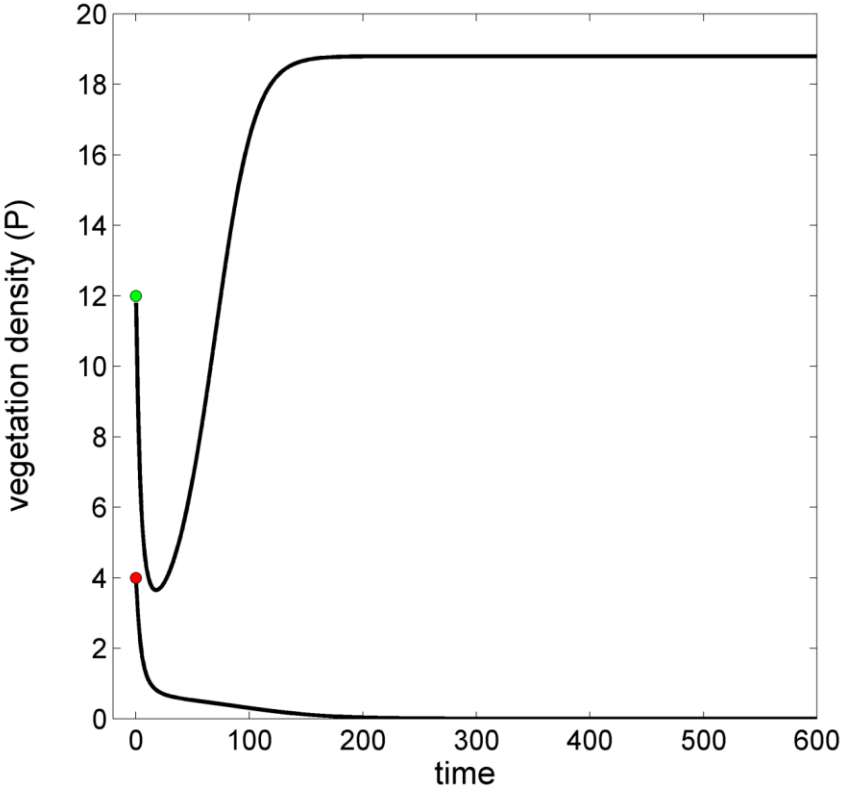


…with noise

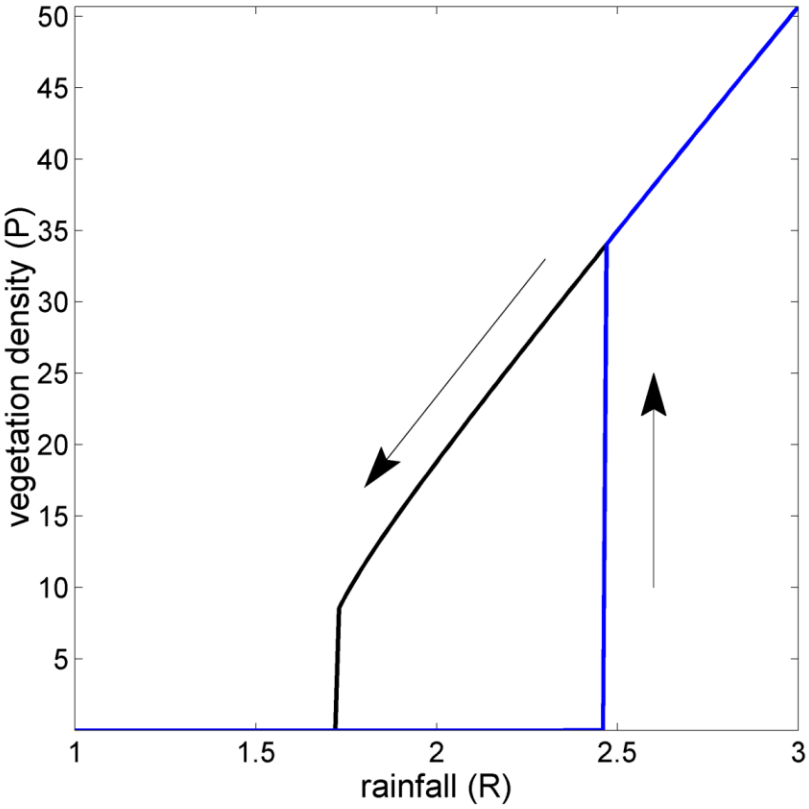


bistability

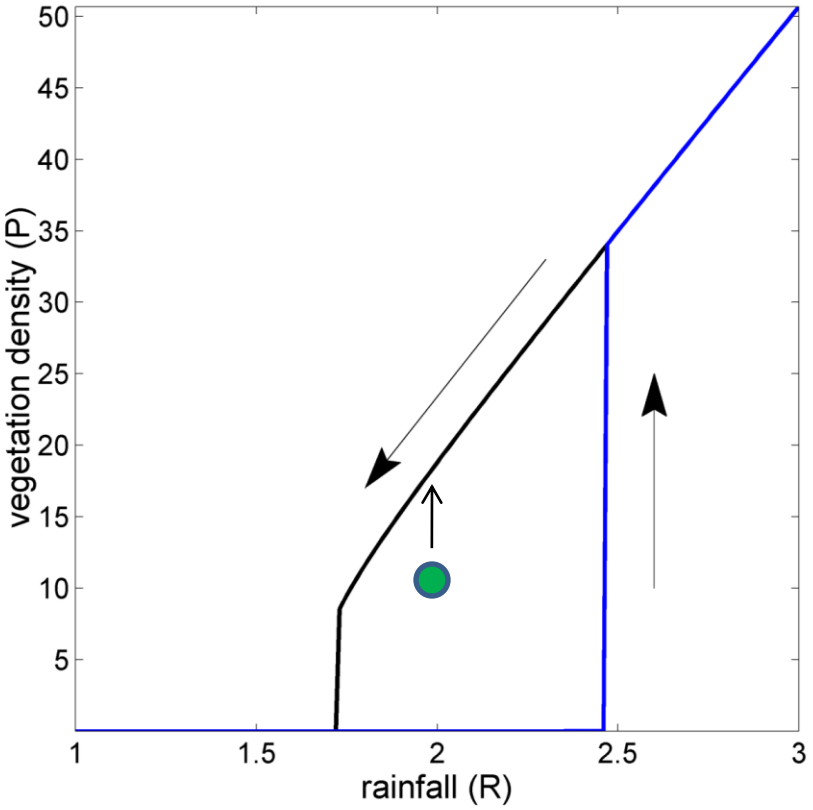
(same parameters, different initial condition)

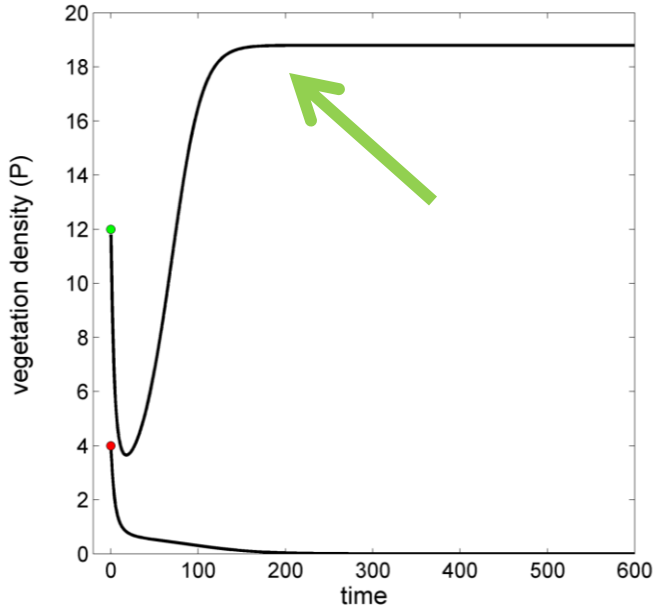


hysteresis diagram

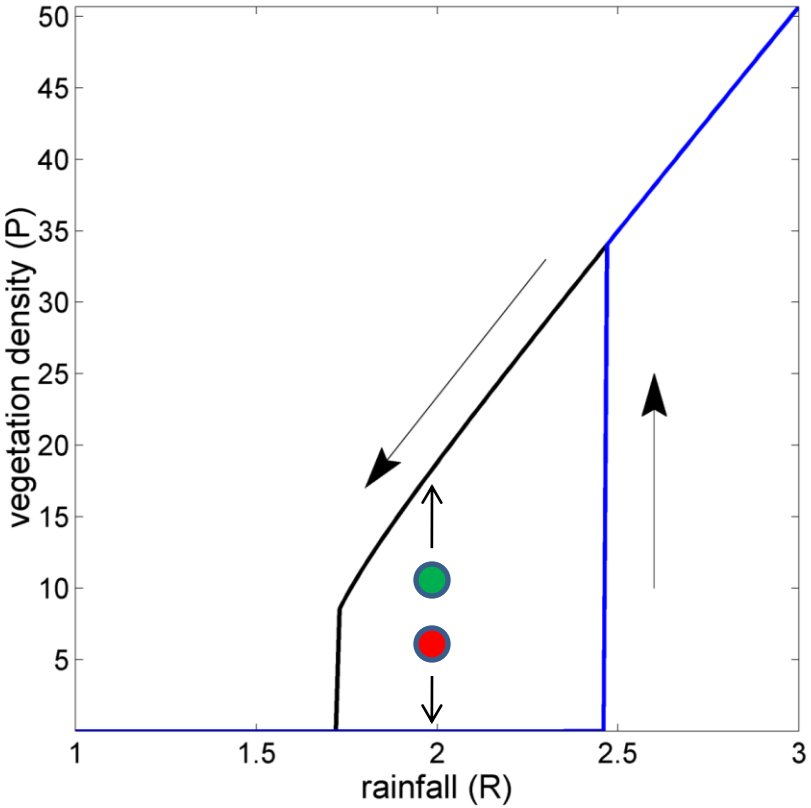


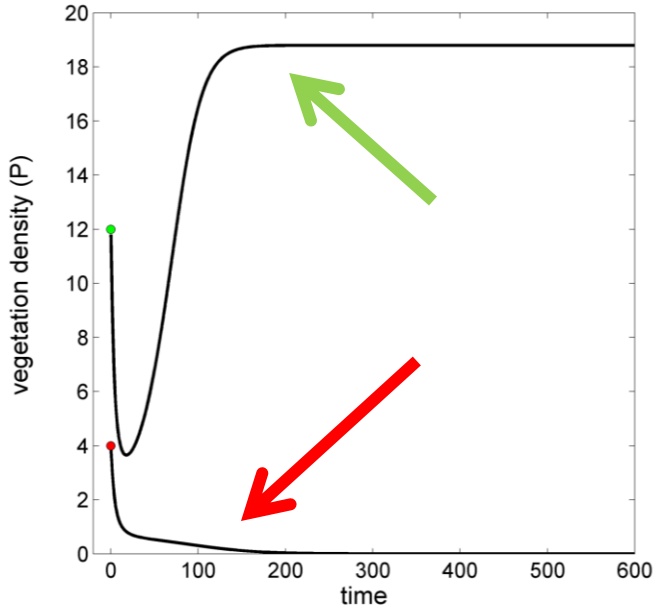
hysteresis diagram, bistability



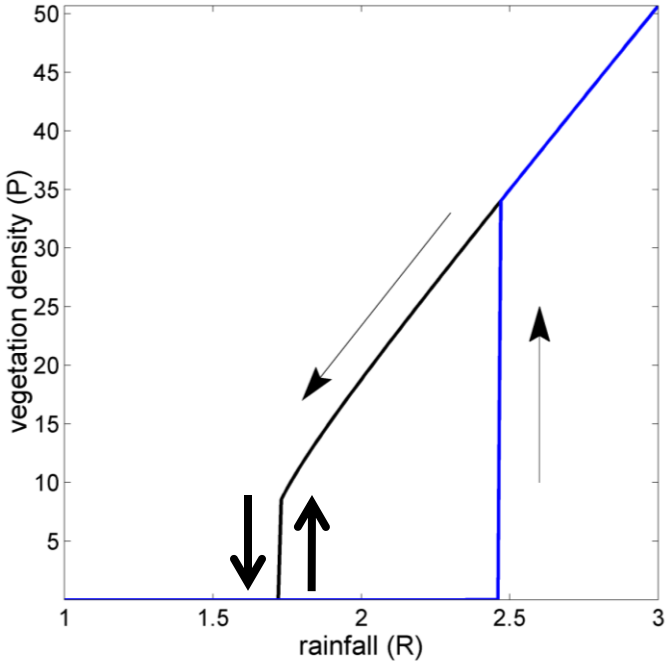


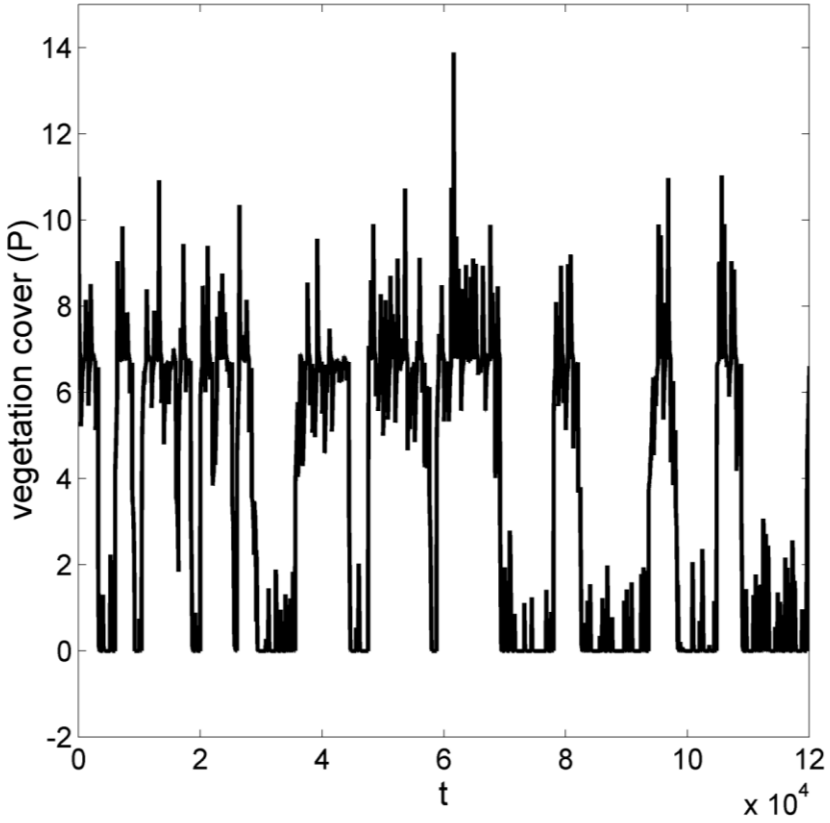
hysteresis diagram, bistability



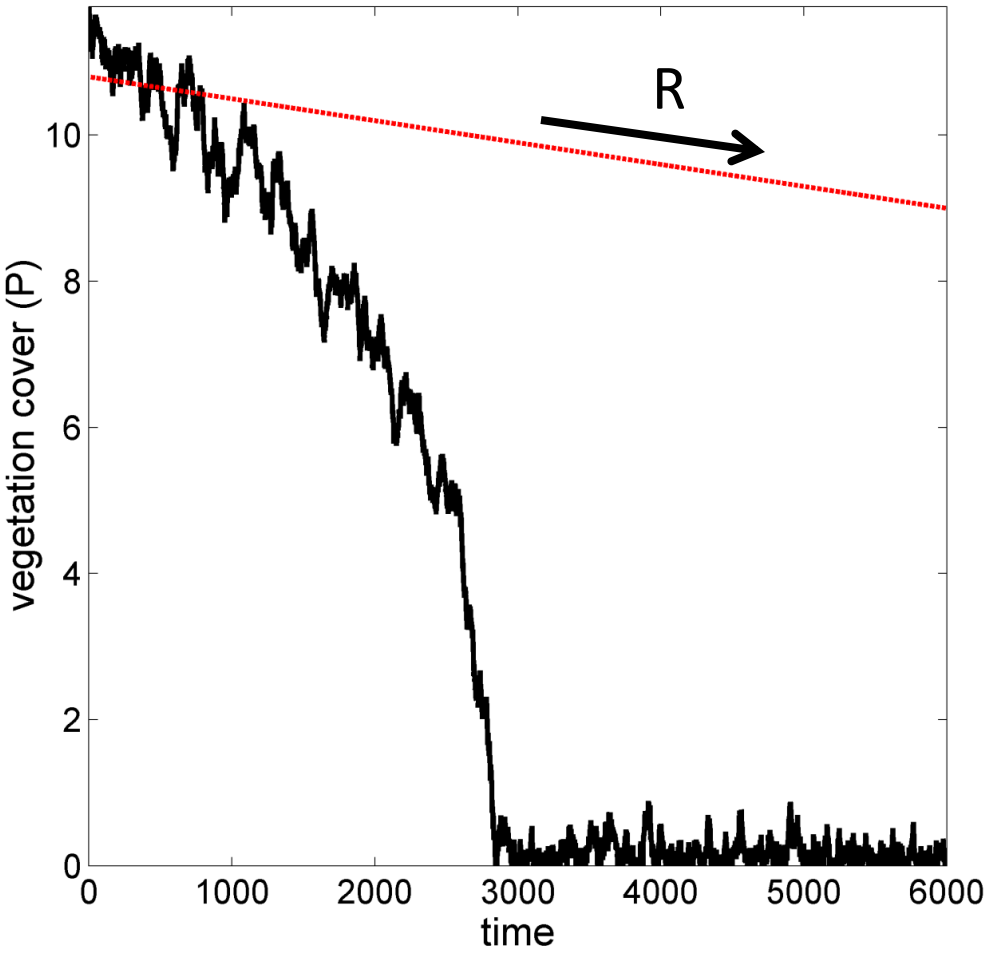


effect of noise near transition

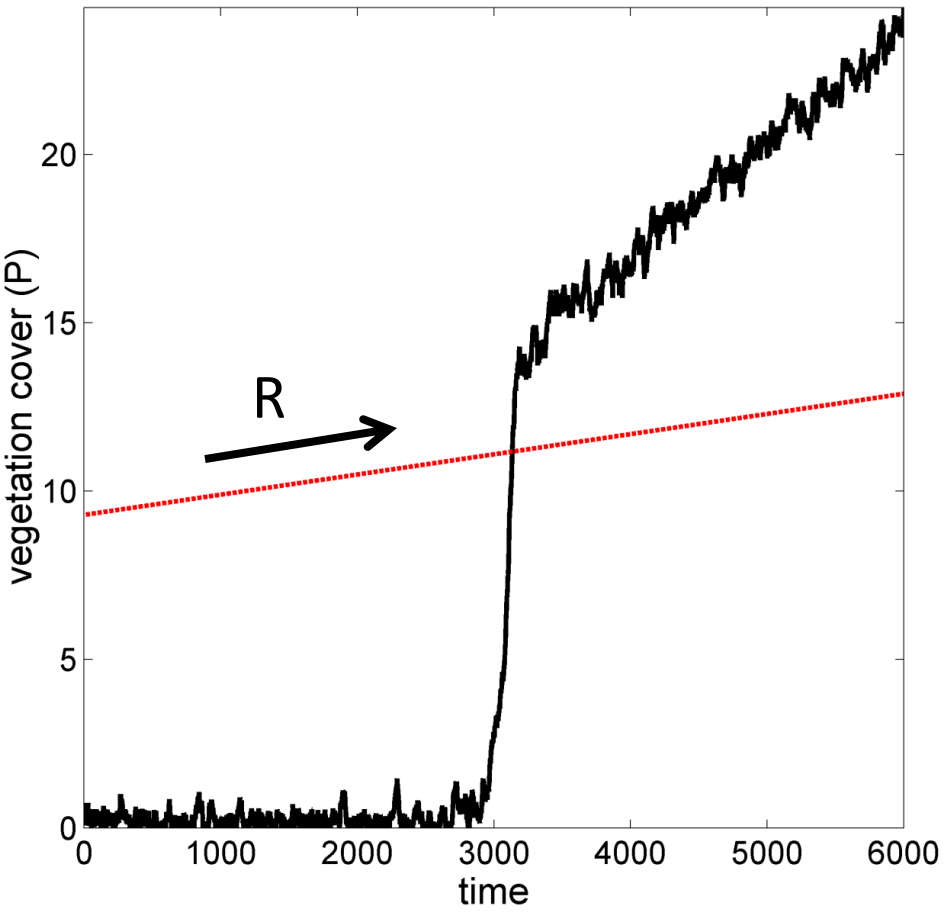




driving the system over the edge

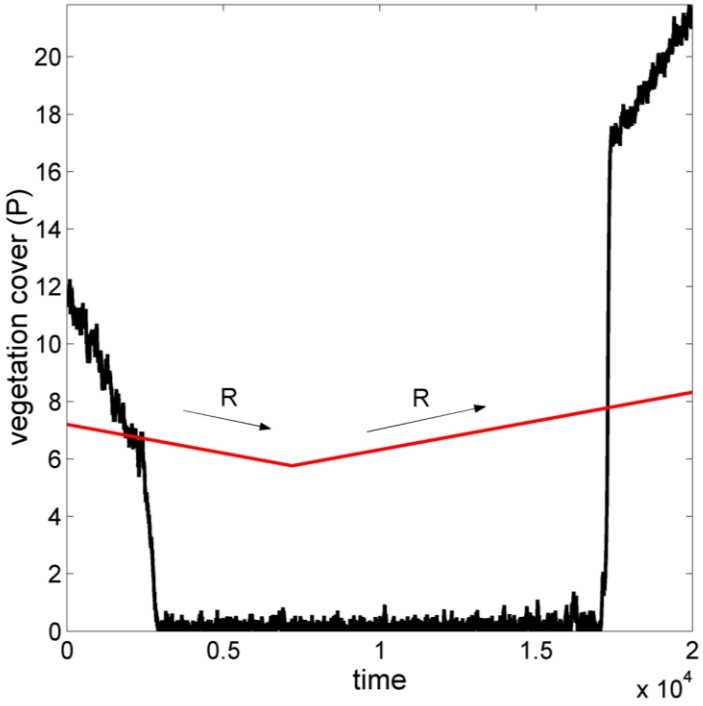


driving the system over the edge



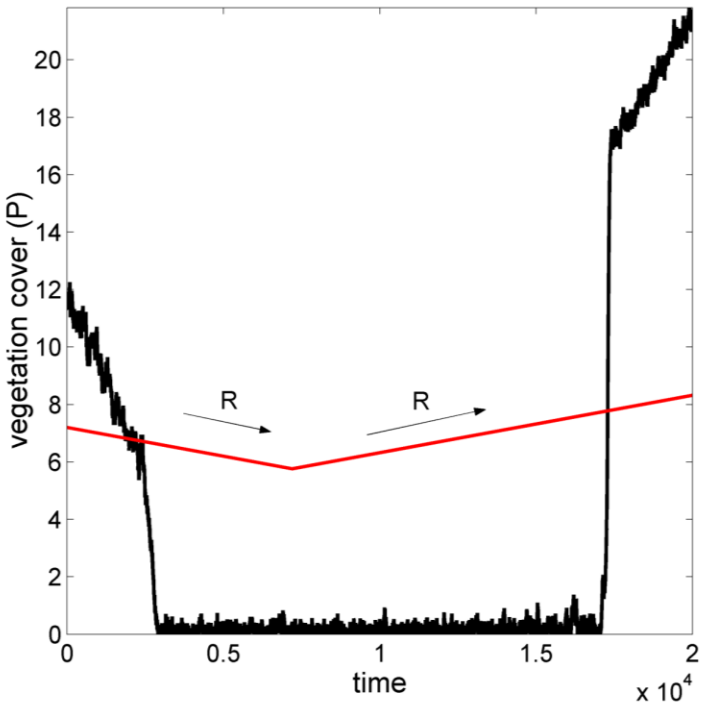
hysteresis

time domain

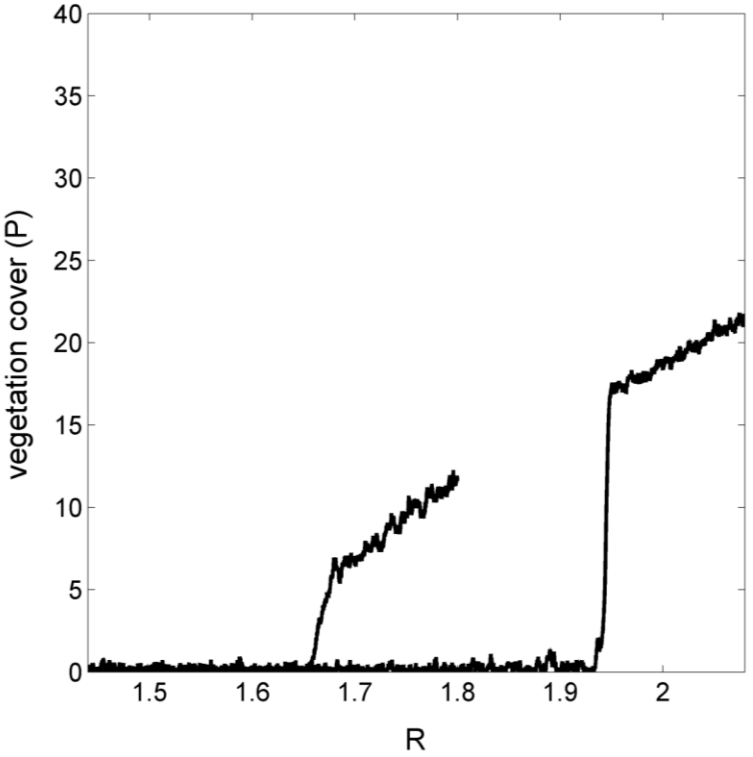


hysteresis

time domain

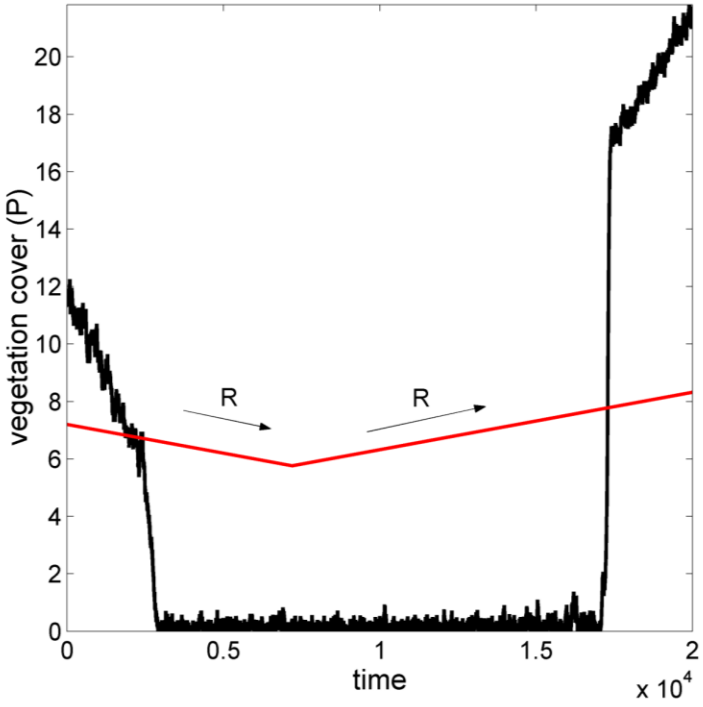


phase space

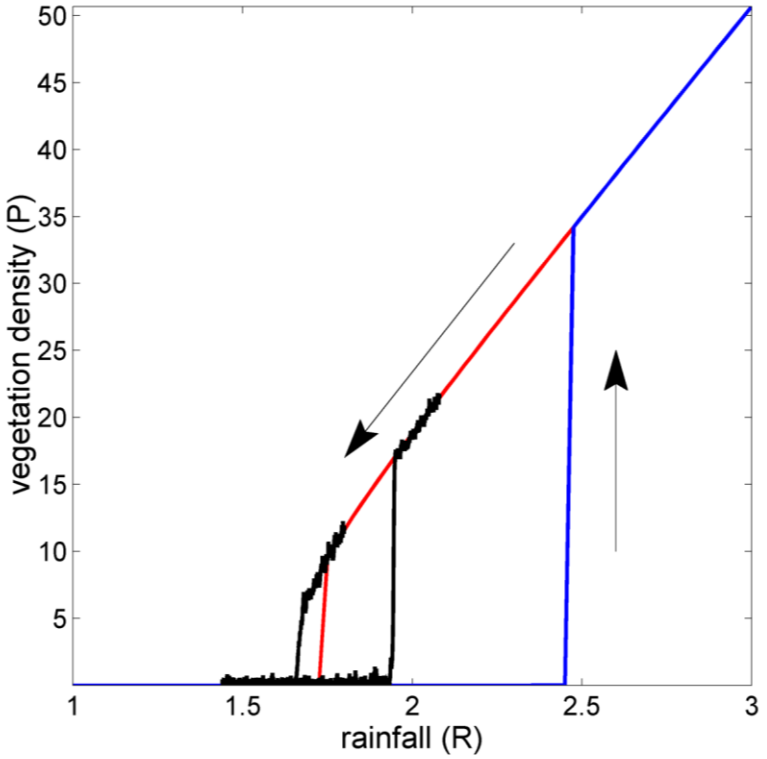


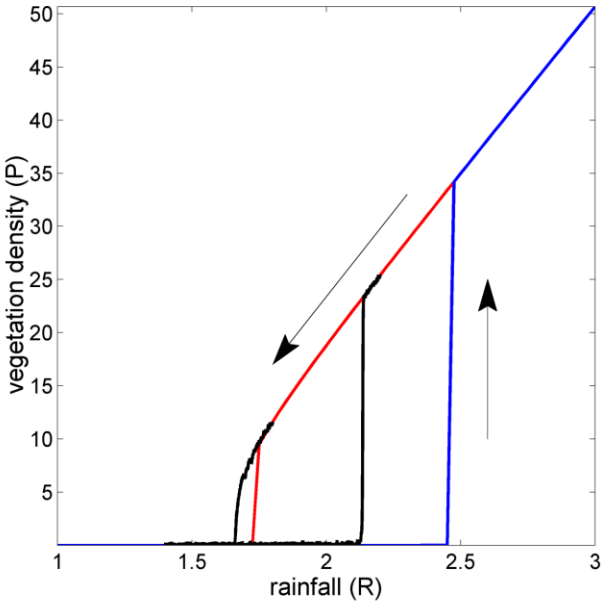
hysteresis

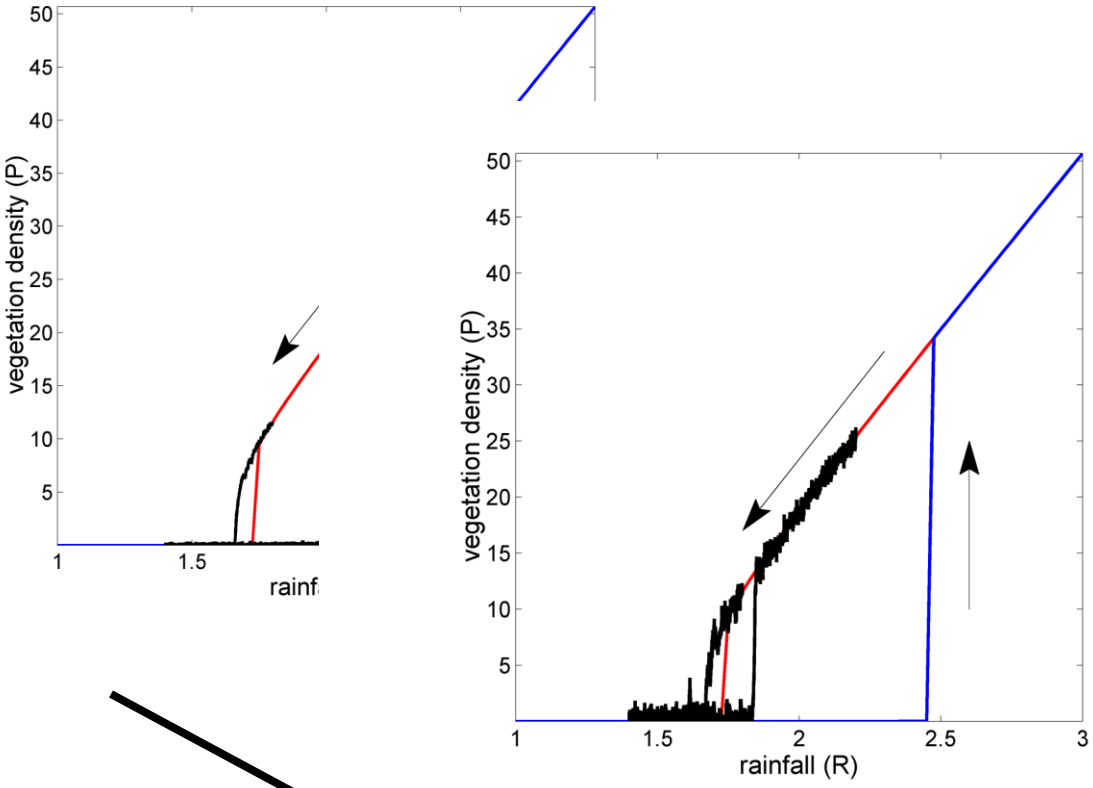
time domain

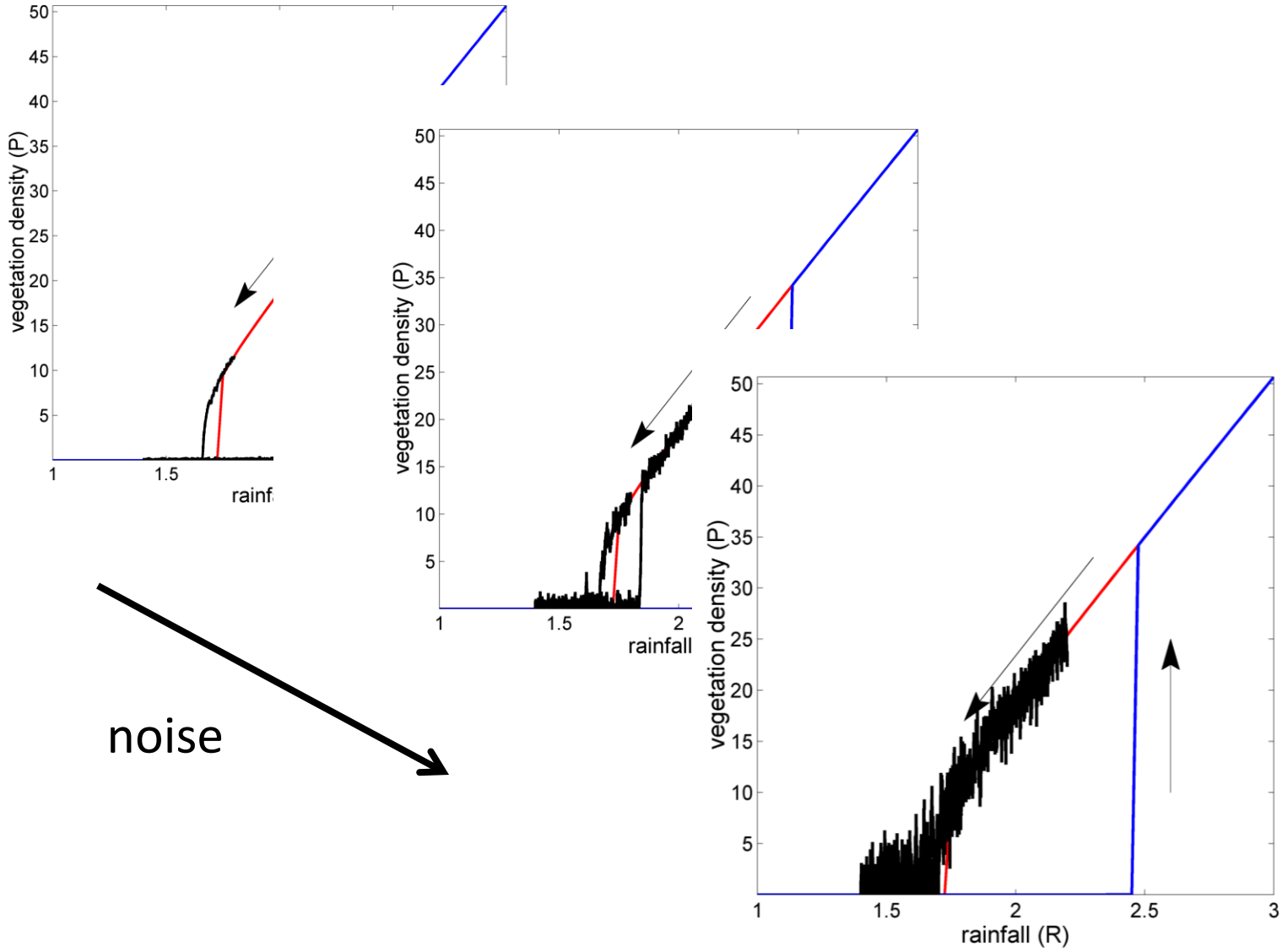


phase space




vegetation density (P)
rainfall (R)
50
45
40
35
30
25
20
15
10
5
1
1.5
2
2.5
3

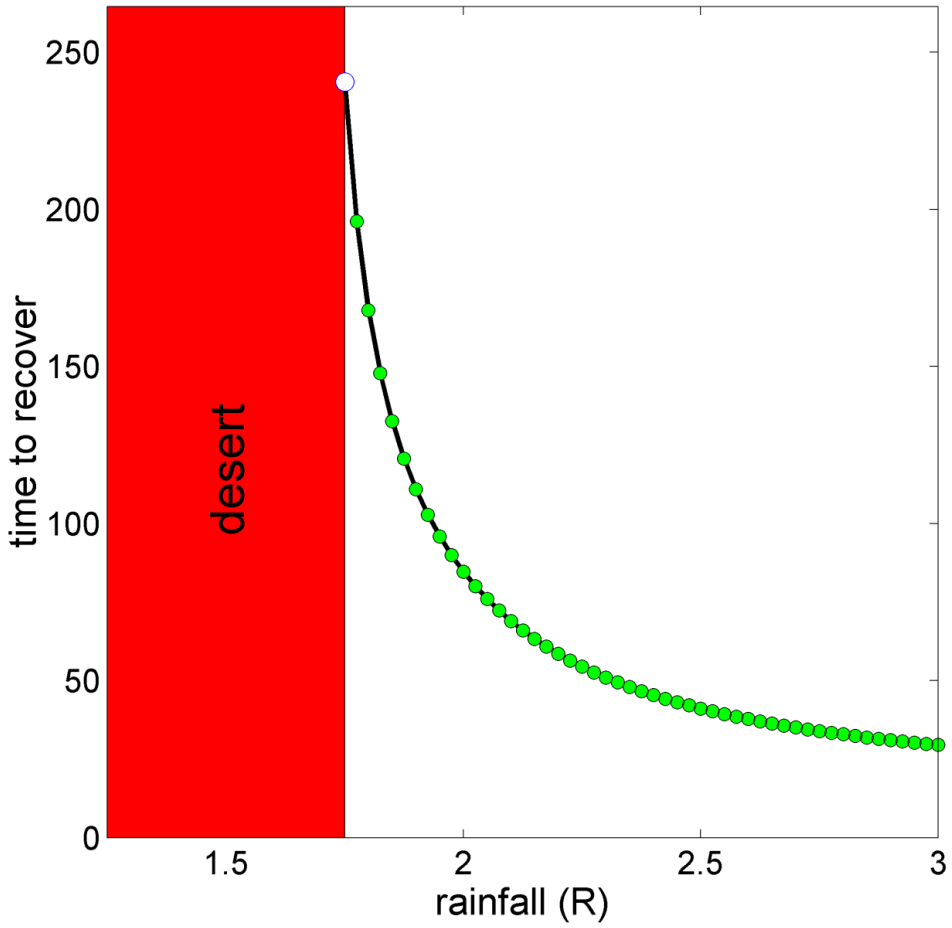

vegetation density (P)
rainfall (R)
noise


vegetation density (P)
rainf
rainfall
vegetation density (P)
rainfall (R)
noise

EARLY WARNING SIGNALS OF CRITICAL TRANSITIONS

Slowdown

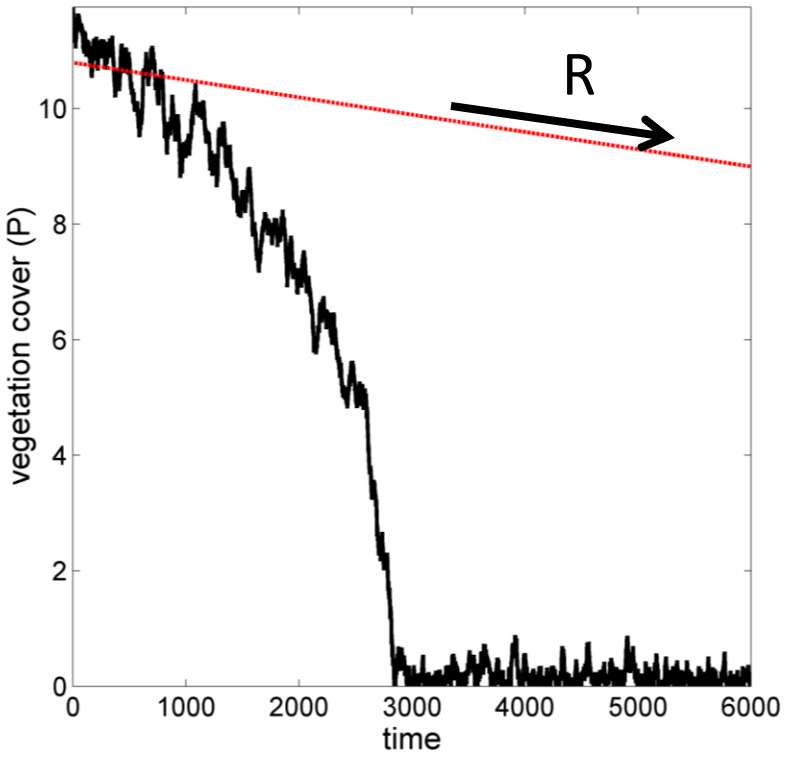
Time to recover 10% reduction in P



EARLY WARNING SIGNALS OF CRITICAL TRANSITIONS

Time series analysis

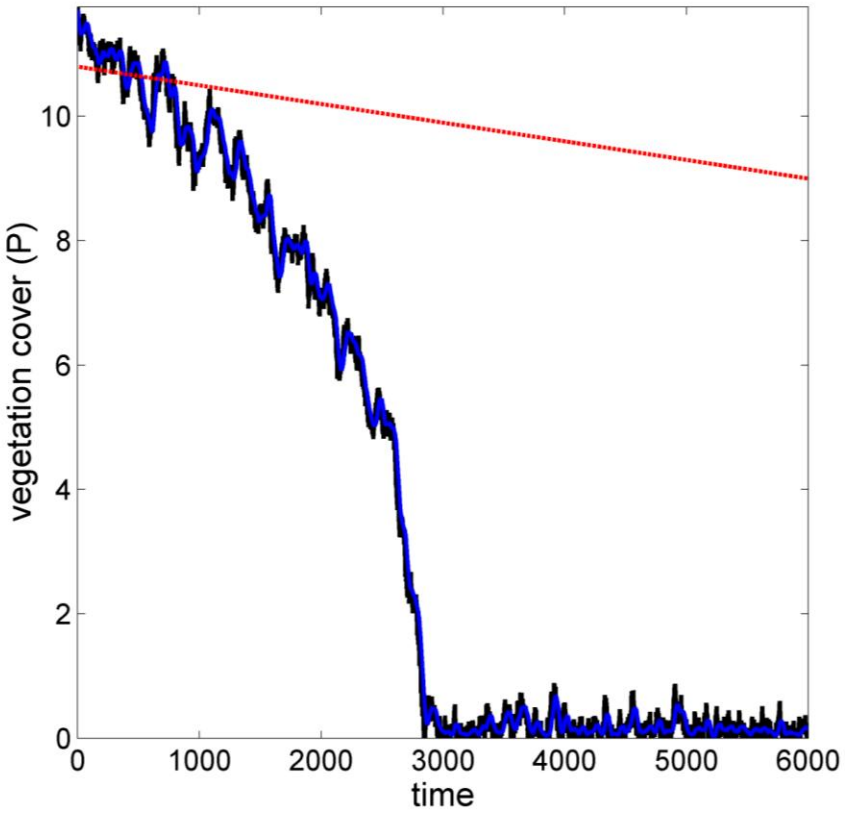
variance, autocorrelation…



EARLY WARNING SIGNALS OF CRITICAL TRANSITIONS

Time series analysis

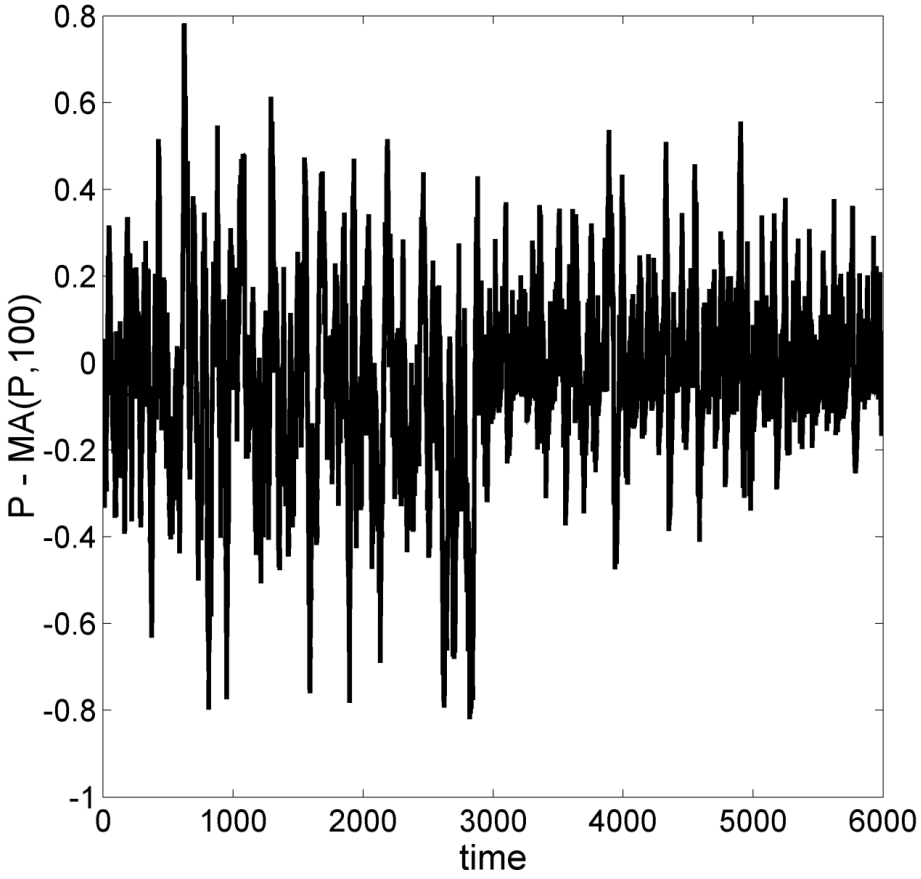
detrend with moving average



EARLY WARNING SIGNALS OF CRITICAL TRANSITIONS

Time series analysis

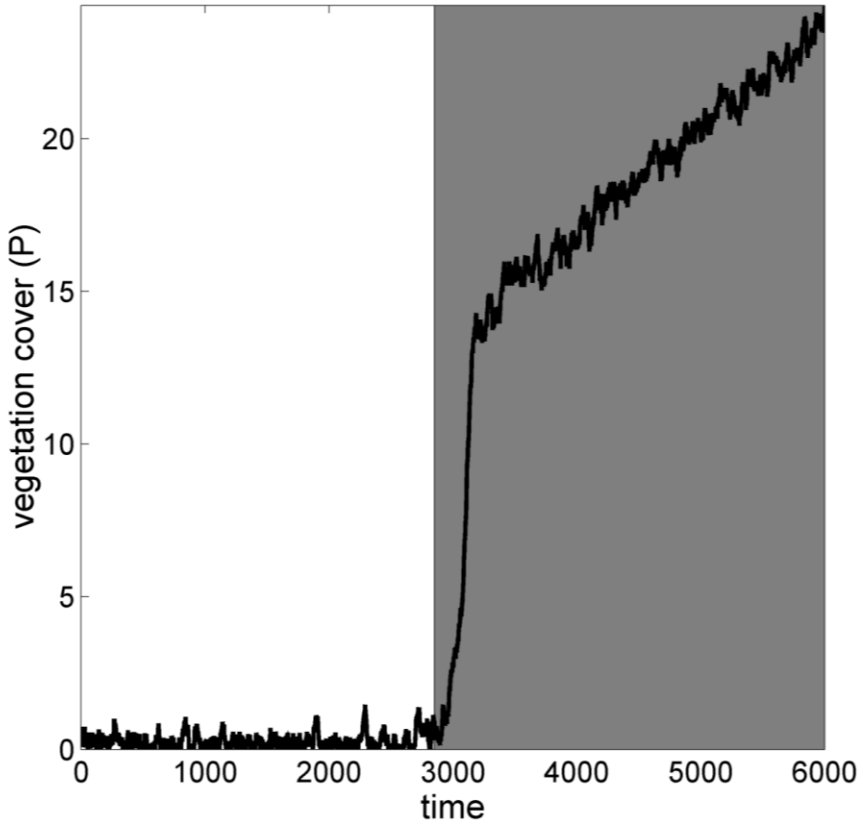
detrend with moving average

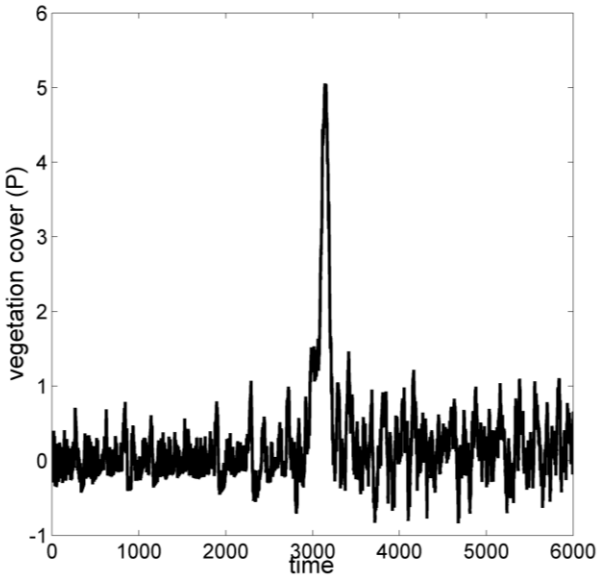


EARLY WARNING SIGNALS OF CRITICAL TRANSITIONS

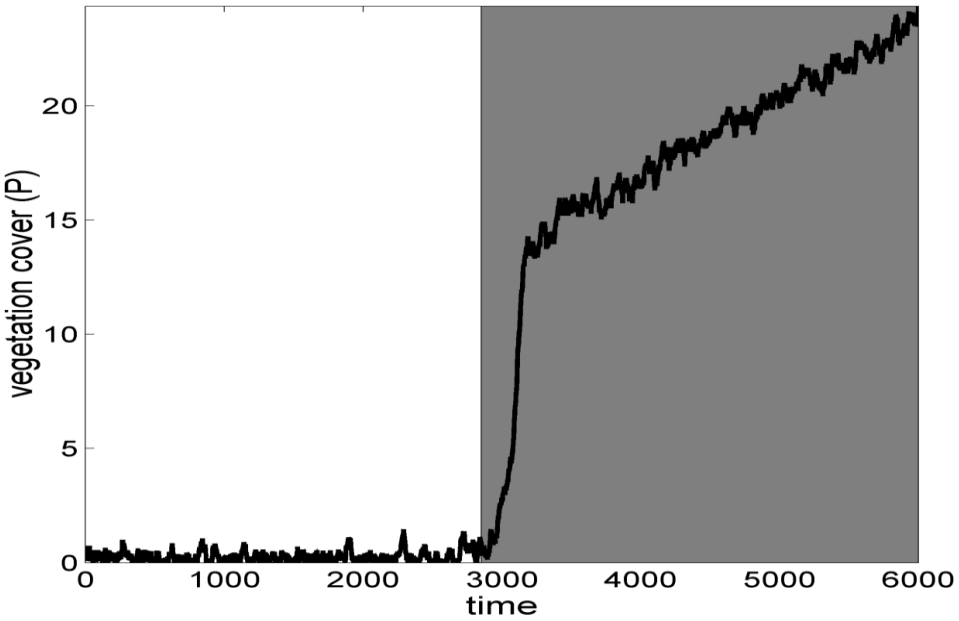
Time series analysis

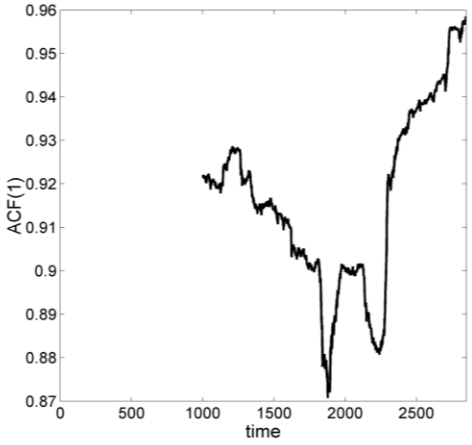
Is the system moving towards a cliff?





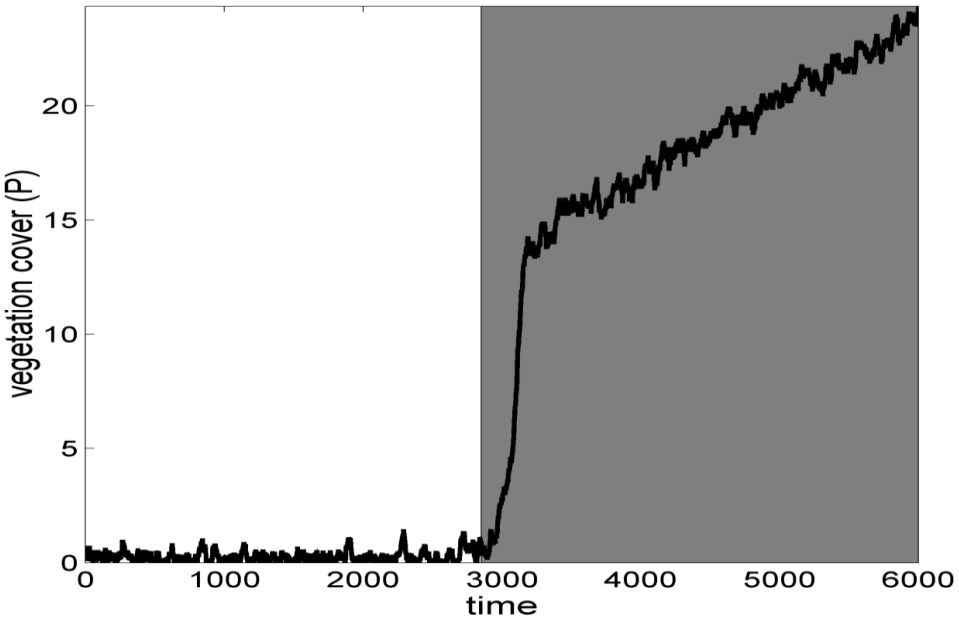
EARLY WARNING SIGNALS OF CRITICAL TRANSITIONS

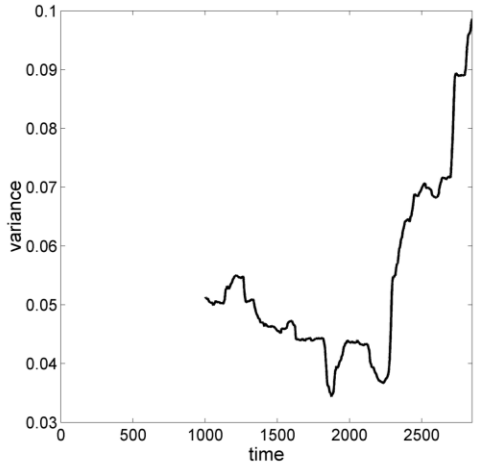




autocorrelation

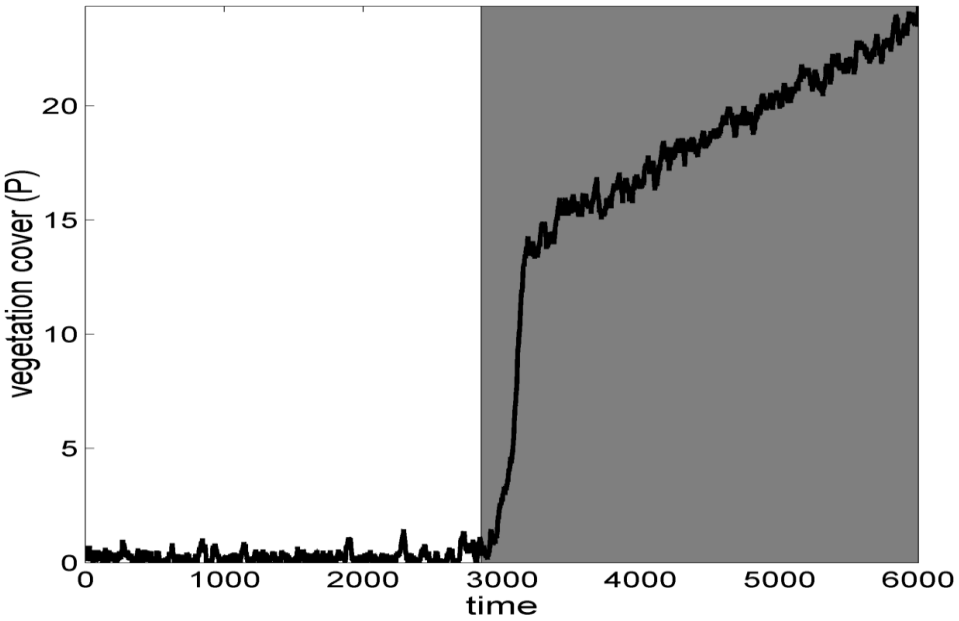
EARLY WARNING SIGNALS OF CRITICAL TRANSITIONS

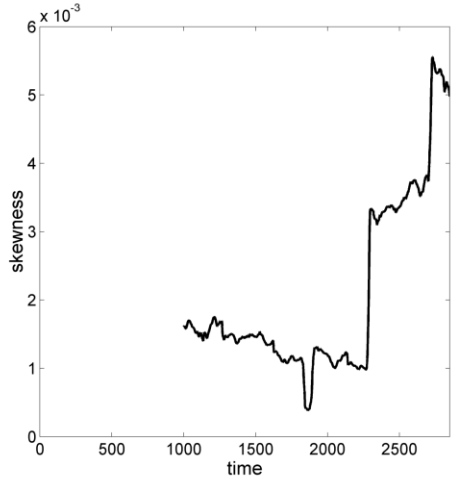




variance

EARLY WARNING SIGNALS OF CRITICAL TRANSITIONS

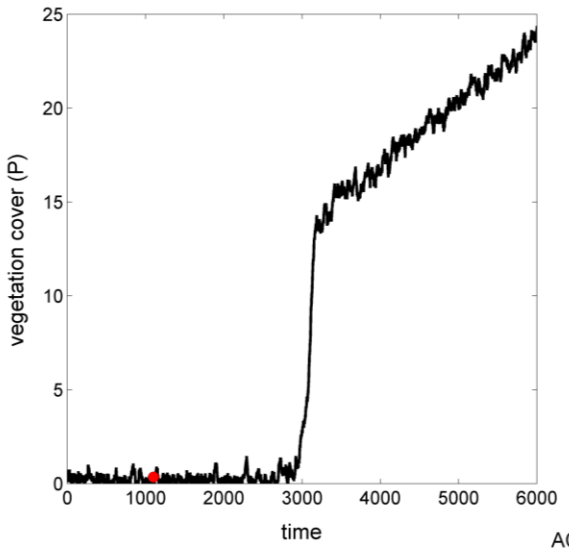


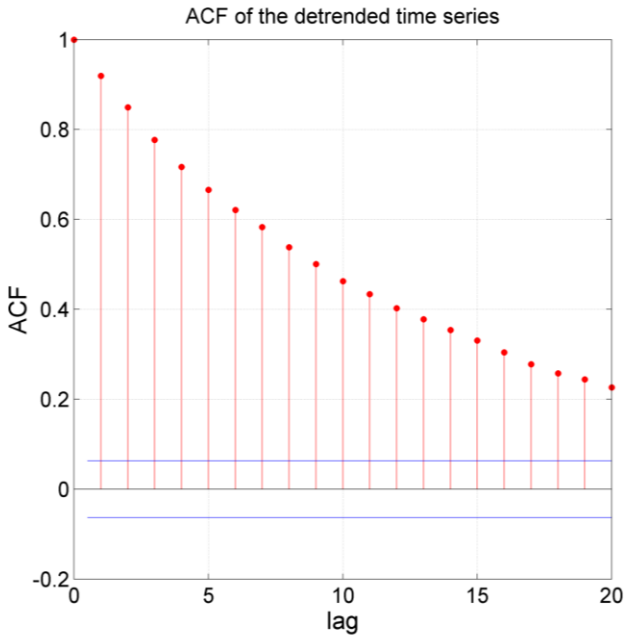


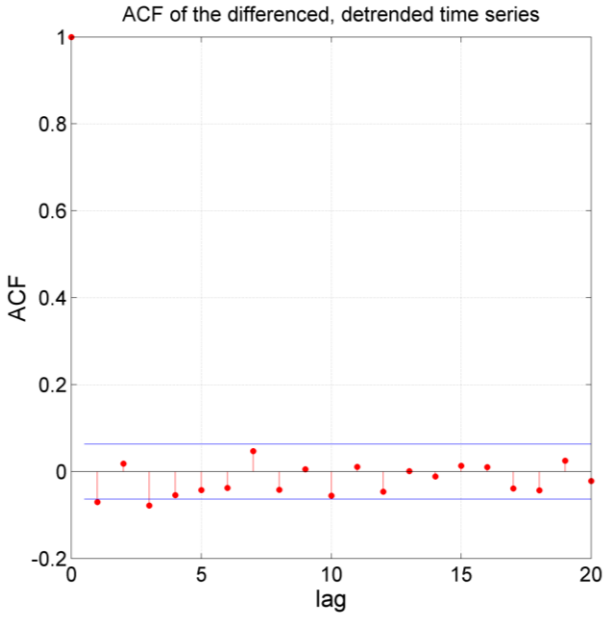
skewness

Yes, we can!!!

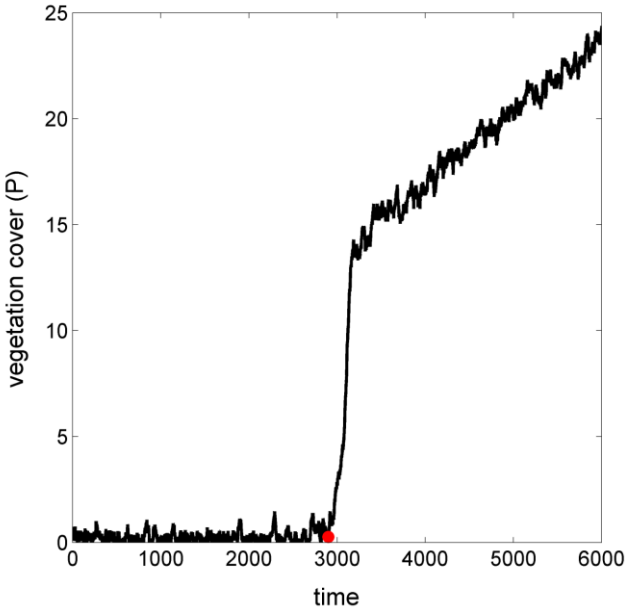
…can we?

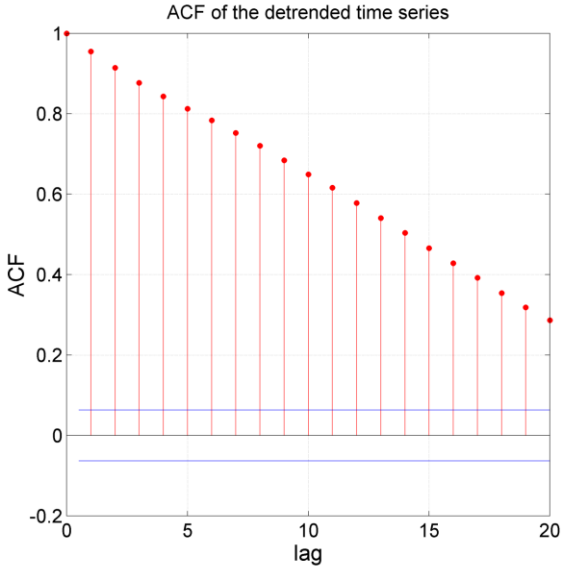


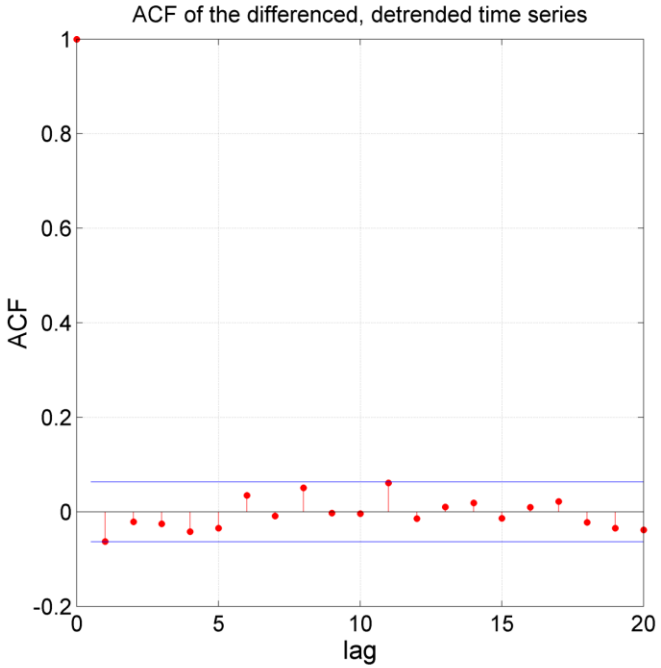


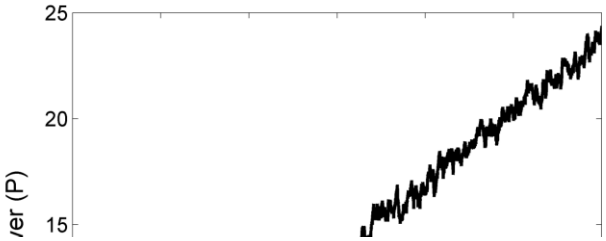


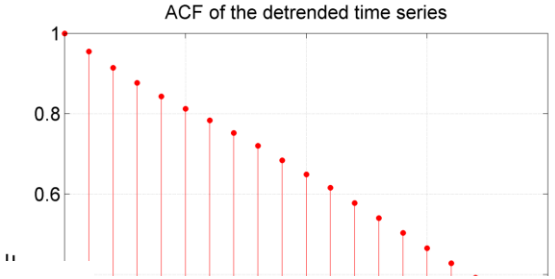
Looks like a random walk!
…be careful

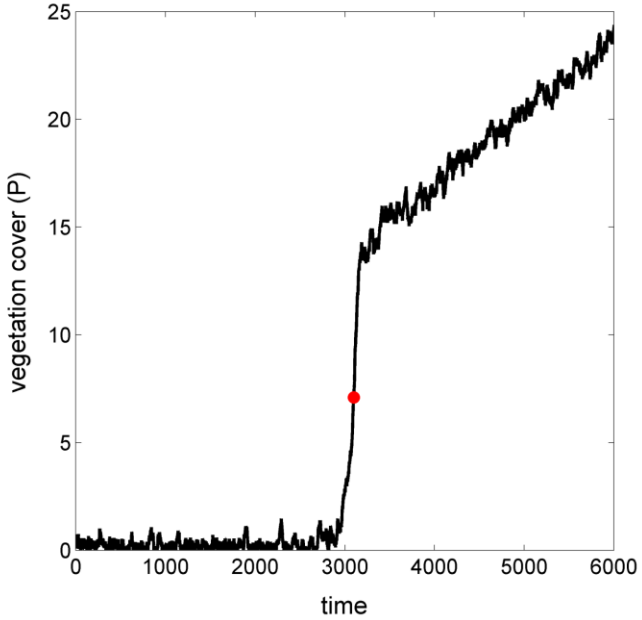

vegetation cover (P)
time
0
5
10
15
20
25
0
1000
2000
3000
4000
5000
6000

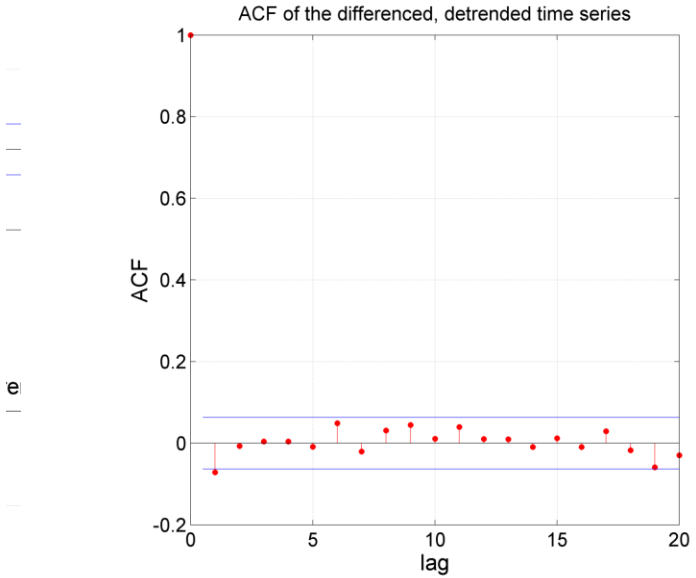

ACF of the detrended time series
ACF
lag
1
0.8
0.6
0.4
0.2
0
-0.2
0
5
10
15
20

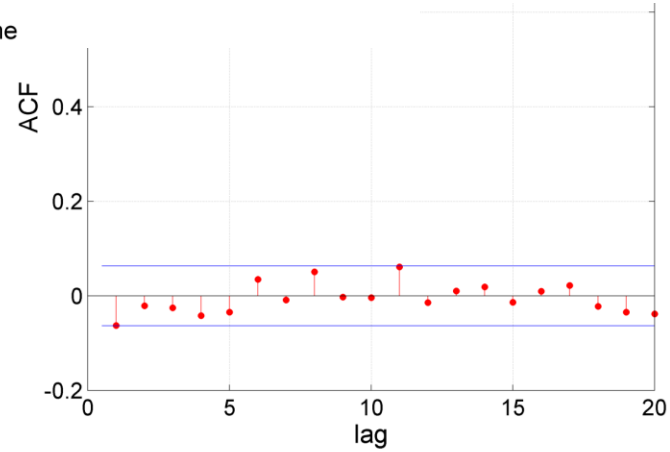

ACF of the differenced, detrended time series
ACF
lag
1
0.8
0.6
0.4
0.2
0
-0.2
0
5
10
15
20

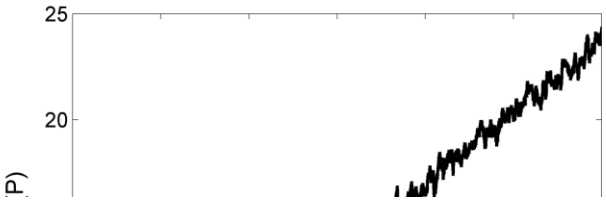

25
20
15
er (P)

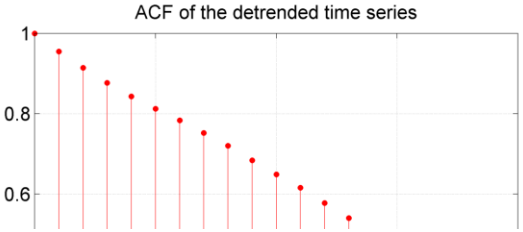

ACF of the detrended time series
1
0.8
0.6

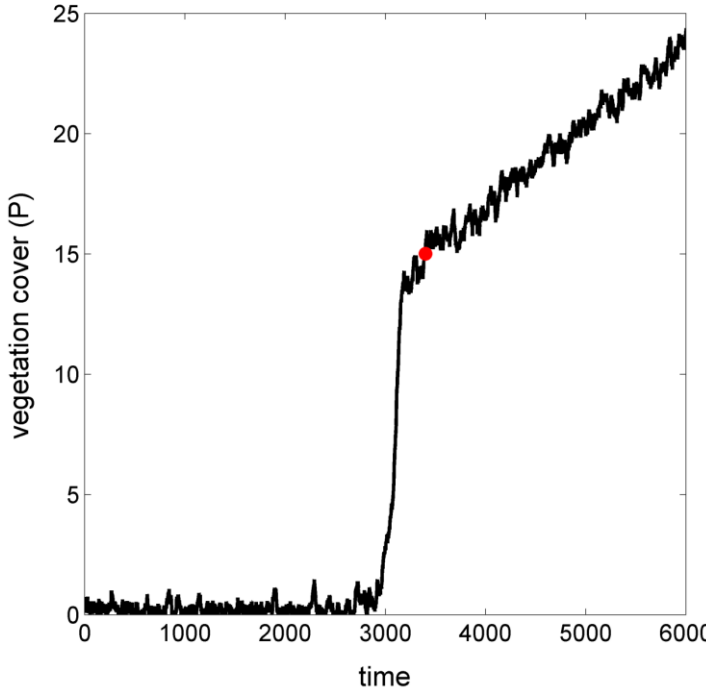

25
20
15
10
5
0
vegetation cover (P)
0
1000
2000
3000
4000
5000
6000
time

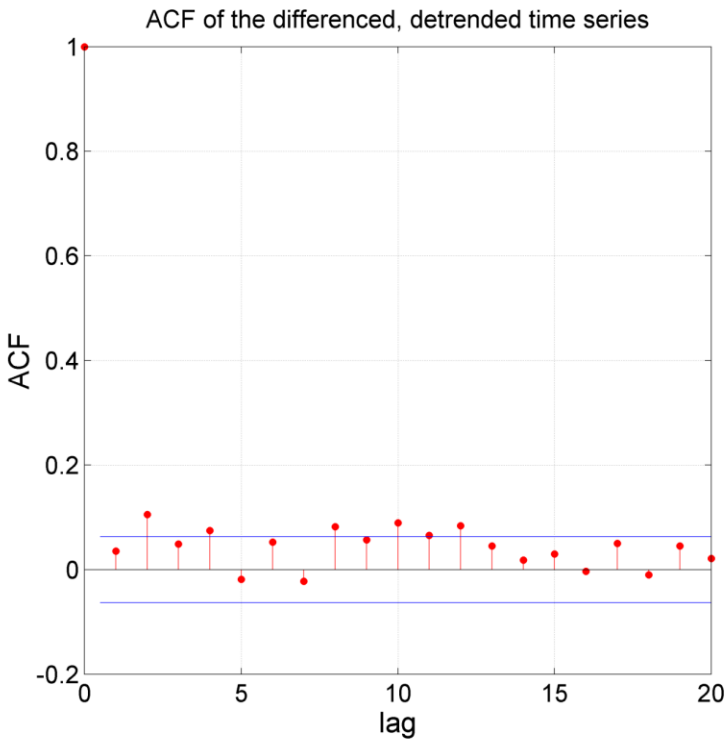

ACF of the differenced, detrended time series
1
0.8
0.6
0.4
0.2
0
-0.2
ACF
0
5
10
15
20
lag

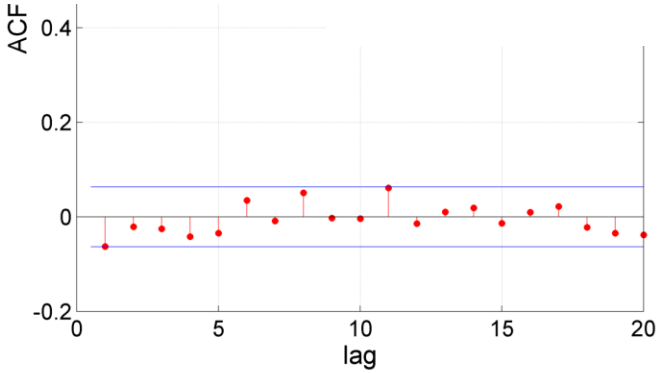

0.4
0.2
0
-0.2
ACF
0
5
10
15
20
lag


25
20
P)


ACF of the detrended time series
1
0.8
0.6


25
20
15
10
5
0
vegetation cover (P)
0
1000
2000
3000
4000
5000
6000
time


ACF of the differenced, detrended time series
1
0.8
0.6
0.4
0.2
0
-0.2
ACF
0
5
10
15
20
lag


0.4
0.2
0
-0.2
ACF
0
5
10
15
20
lag

EARLY WARNING SIGNALS OF CRITICAL TRANSITIONS

Can we forecast a regime shift?
Maybe…

EARLY WARNING SIGNALS OF CRITICAL TRANSITIONS

Can we forecast a regime shift?

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…probably not for this model

EARLY WARNING SIGNALS OF CRITICAL TRANSITIONS

Can we forecast a regime shift?
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Need to develop robust indicators