Ergodic to non-ergodic transitions and hysteresis in ecosystem models

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The Ergodic Principle

The ergodic principle states that the temporal average state of a system equals the average of singles states of an ensemble of the system. Formulated to describe the physics of an ideal gas (Boltzmann, 1871), it is also applied in in the growth series concept of whole ecosystems.

Data

Field data came from Gabon (W-Congo basin along) along a W-E gradient in precipitation (Pietsch and Gautam, 2013):

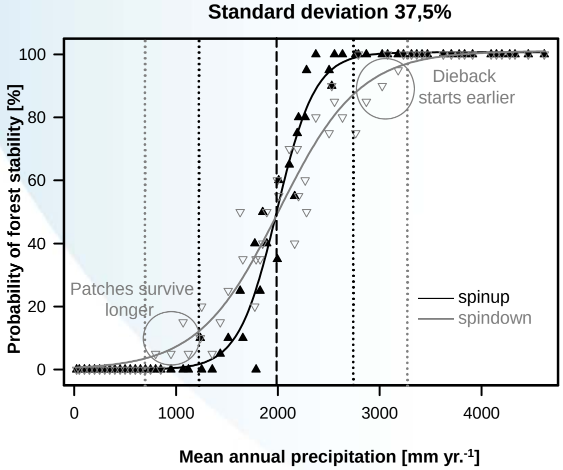
- 34 angle count plots from a forest refuge (Mts. Birougou)
- 27 savannah plots from a forest savannah mosaic

Analysis

Artificial climate with known interannual variation in precipitation ranging from 10 % to 40 % (standard deviation) was used to simulate forest establishement on non forest sites (spinup, black triangles). For 37.5% interannual variation in precipitation forest may not establish below 1250 mm mean annual precipitation. Stable limit cycles do not occur below 2800 mm mean annual precipitation.

The same climate was used to simulate the effects of climate change on a stable forest established at 3500mm mean annual precipitation (spindown, open triangles). The pathway of transition from stable limit cycles to 100% forest dieback differs from the spinup and hysteresis is evident! The mean of the transition phase is equal, but the length of the transition phase differs.

Standard deviation 37,5%



Hysteresis

Hysteresis on the other hand is the observable contrary of the ergodic principle, i.e. that the current state of a system strictly depends on the individual temporal development steps – or – that individual history is unequivocally important.

Methods

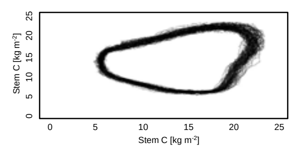
The Biogeochemistry model Biome-BGC 4.1.2 (Thornton et al, 2002) with dynamic mortality (Pietsch and Hasenauer, 2006) parameterized for the Congo Basin (Gautam, 2012) was used, for long term simulation of forest dynamics.

Attractors of model behaviour were reconstructed using Poincaré sections mapped onto themselves (Pietsch and Hasenauer, 2005). Embedding delay was 50 years.

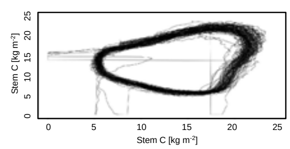
Simulation Results

Attractors of aboveground stem C content reconstructed from 100.000 simulation years exhibited limit cycles.

stable for the forest refuge!
(var. in prcp. 13%)



unstable for the mosaic!
(var. in prcp, 29 %)



In case of a stable limit cycle the ergodic principle holds and the growth series concept remains valid. In case of unstability, with frequent patch level forest dieback events, the ergodic principle does not hold!

Conclusion

Ergodic to non-ergodic transitions are evident, with ergodic model behavior when stable limit cycles occur and non-ergodic behaviour when frequent forest dieback events occur! Such transitions are sometimes referred to as catastrophic shifts (Scheffer et al., 2001). The phase transition differs depending on the initial state, i.e. forest establishement follows a different pathway than large scale dieback of established forests. This helps explaining transistions from forest to savannah and back, observable in the Congo basin over the Holocene (Maley, 2001)

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