Recurrence in climate variability – a comparison of modern climate data from Nakuru, Kenya, with Early Holocene palaeo-climate records

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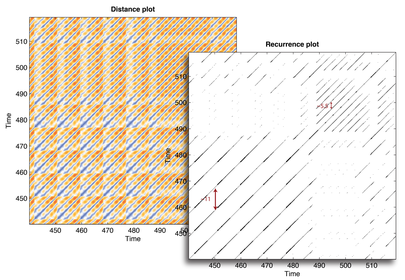
Recurrence is a fundamental property of dynamical systems. Recent developments in nonlinear data analysis have focused on recurrences in order to analyse and understand processes in different scientific fields (physiology, economy, astrophysics etc.).

An appropriate tool for a recurrence analysis is the recurrence plot,

$$\mathbf{R}_{i,j} = \Theta\left(\varepsilon - \left\|\vec{x}_i - \vec{x}_j\right\|\right), \quad i, j = 1, \ldots, N$$

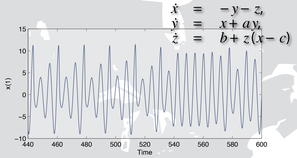
which visualises such times in the past or the future, when a state of the system (at a certain time) recurs.

Recurrence plots exhibit typical large- and small-scale structures, which can be interpreted and quantitatively analysed (cf. Marwan et al, 2007). The vertical distance between recurrence points in such a plot reveal the recurrence times. A recurrence time spectrum can be an additional interesting measure in order to study time relations in a system.

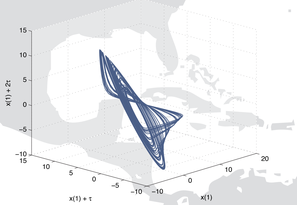


Distance plot (left) of the Rössler system. In order to construct a recurrence plot from a phase space trajectory, a threshold is applied on the distance plot. Corresponding recurrence plot (right) of the Rössler system. The vertical distances between the recurrence points correspond with characteristic periods of the oscillator.

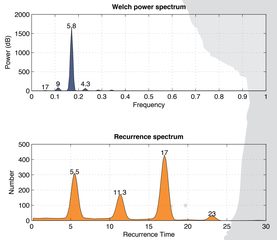
$$\begin{aligned} \dot{x} &= -y - z, \\ \dot{y} &= x + ay, \\ \dot{z} &= b + z(x - c) \end{aligned}$$



First component of the Rössler system.

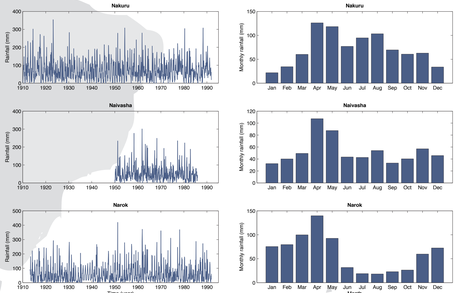


Phase space reconstruction for the Rössler oscillator based on its first component.



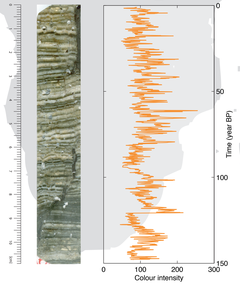
Power spectrum (top) and recurrence times spectrum (bottom). The periods due to the unstable periodic orbits in the Rössler oscillator are better detected by the recurrence times spectrum.

Today, complex rain-shadow effects cause one, two or even three rainy seasons per year in the tropical East Africa. The three stations Nakuru, Naivasha, Narok (Kenya) represent these three modes of intra-annual rainfall variability. Moreoever, past climate changes could have caused shifts in the relative influence of equatorial vs. northern hemisphere insolation and, hence, a change in the relative importance of monsoonal moisture-bearing winds and equatorial convection caused by the seasonal migration of the ITCZ. Second, the strength and regional influence of ENSO is also a matter of debate. If ENSO was active between 17-16 kyr ago, the influence of this climate anomaly on rainfall in Kenya might have been different from today.

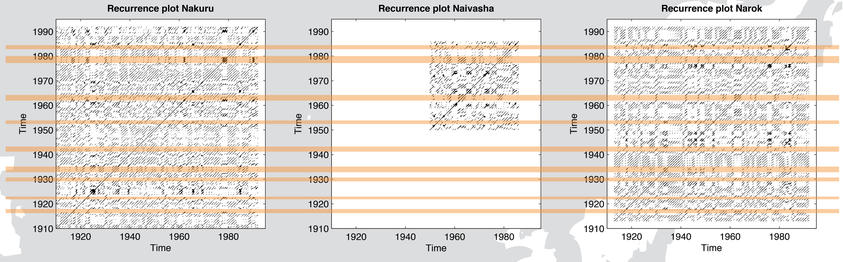


Rainfall of the three closest stations (Nakuru, Naivasha and Narok). Due to the location near the Equator, the ITCZ crosses twice this region, leading to two well pronounced rainfall seasons in Nakuru and Naivasha.

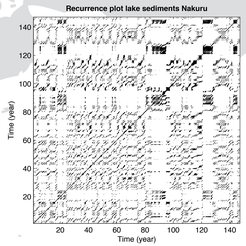
Data from layered lacustrine sediments derived from the lake Nakuru, Kenya, provides an insight into the rainfall variability of tropical Africa 17-16 kyr BP. A recurrence analysis may help to answer the questions, whether two rainfall seasons were persistent during this period, and whether the rainfall variability had have the similar reason than today (e. g. ENSO).



Lake sediments from the lake Nakuru. The colour intensity is supposed to be linked with rainfall variability. 17-16 kyr BP.



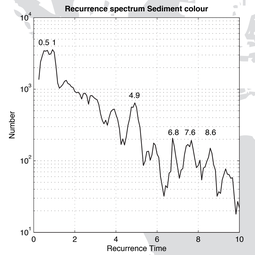
Recurrence plots of the modern rainfall in Nakuru (left), Naivasha (middle) and Narok (right). The vertical distance between the diagonal lines correspond with characteristic period lengths (i. e. recurrence times; e. g. 1 yr, 5 yrs, 7 yrs). White bands in the recurrence plots indicate epochs of non-regular (or rare) states (overlayed by the red bars).



Recurrence plot of the lake sediment's colour intensity. Similar patterns as for the modern rainfall are present: diagonal lines with certain vertical distances (recurrence times) and wite bands of non-regular states.

The found recurrence times in the sediment data of around a half and one year suggest two rainfall seasons per year as today. The longer recurrence times coincide with typical periods of the ENSO.

The recurrence structures as provided by the recurrence plots are similar for the modern rainfall and the colour variation of the sediments.



Recurrence times spectrum for the lake sediment's colour intensity, revealing recurrence times of 0.5, 1, 4.0, 6.8, 7.6 and 8.6 years.

This suggests a similar climatic regime 17-16 kyr BP and today. However, this results are preliminary and needs a further justification by other data sets.

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