Can nonlinear data analysis help to understand climate changes in Asia during the Holocene?

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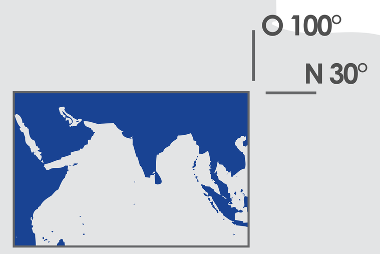


Recurrence is a fundamental property of dynamical systems. Recent developments in nonlinear data analysis have focused on recurrences in order to successfully analyse and understand processes in different scientific fields (physiology, economy, astrophysics etc.).

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

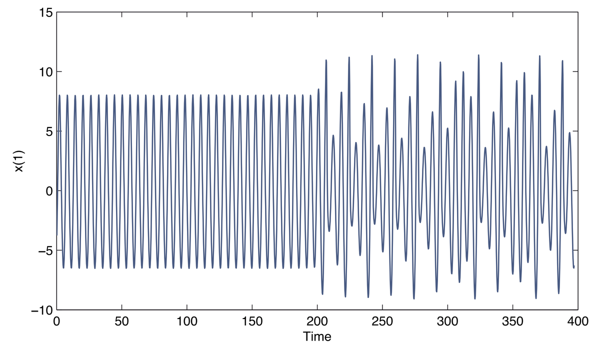
$$\mathbf{R}_{i,j} = \Theta\left(\varepsilon - \left\|\vec{x}_i - \vec{x}_j\right\|\right), \quad i, j = 1, \ldots, N$$

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

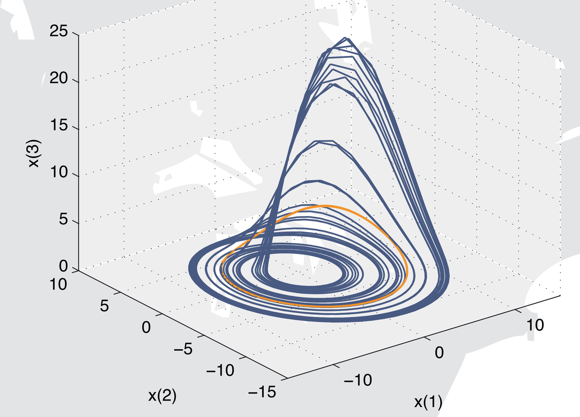
Recurrence plots exhibit typical large- and small-scale structures, which can be interpreted and quantitatively analysed (cf. Marwan et al., 2007). Diagonal lines indicate such epoches where states evolve in a similar manner as in the past (or future) and are a sign of some determinism or auto-correlation in the system. Vertical lines mark states which do not change for some time or change very slowly and are typical for laminar behaviour. White bands reveal times with rather rare states or transitions.

For illustration of a transition from a periodic to chaotic behaviour, we apply the recurrence plot on the Rössler oscillator, whose parameters change after a certain time: change from b=0.7 to b=0.2 and c=3.6 to c=5.7; a=0.2 in both segments.

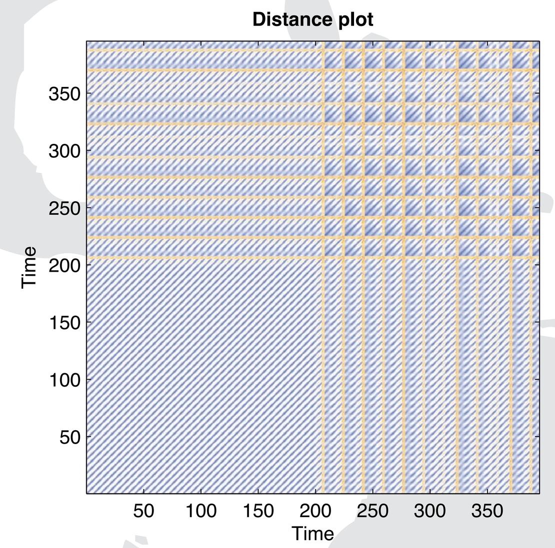
$$\begin{aligned} \dot{x} &= -y - z, \\ \dot{y} &= x + a y, \\ \dot{z} &= b + z(x - c) \end{aligned}$$



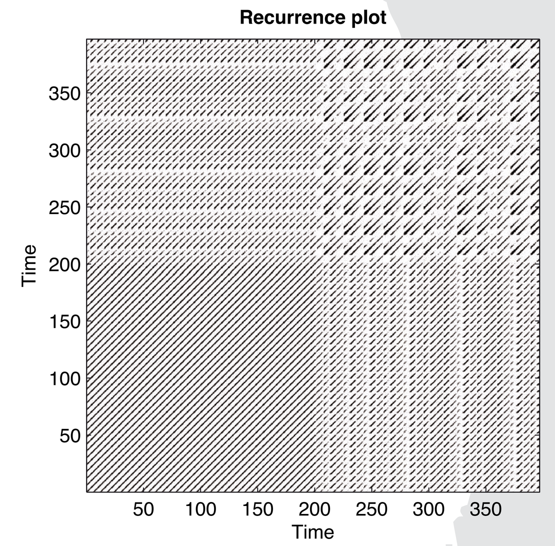
First component of the Rössler system, revealing a transition from periodic to chaotic behaviour (change from b=0.7 to b=0.2 and c=3.6 to c=5.7; a=0.2 in both segments).



Phase space trajectory for the Rössler oscillator. *Orange:* periodic part, *blue:* chaotic part.

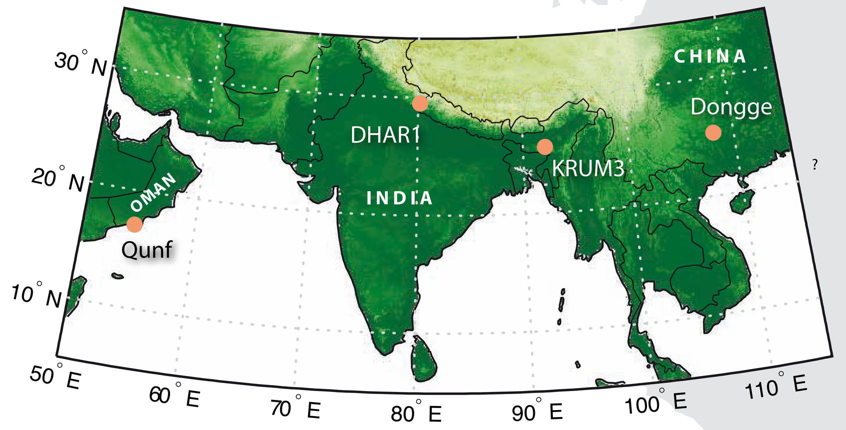


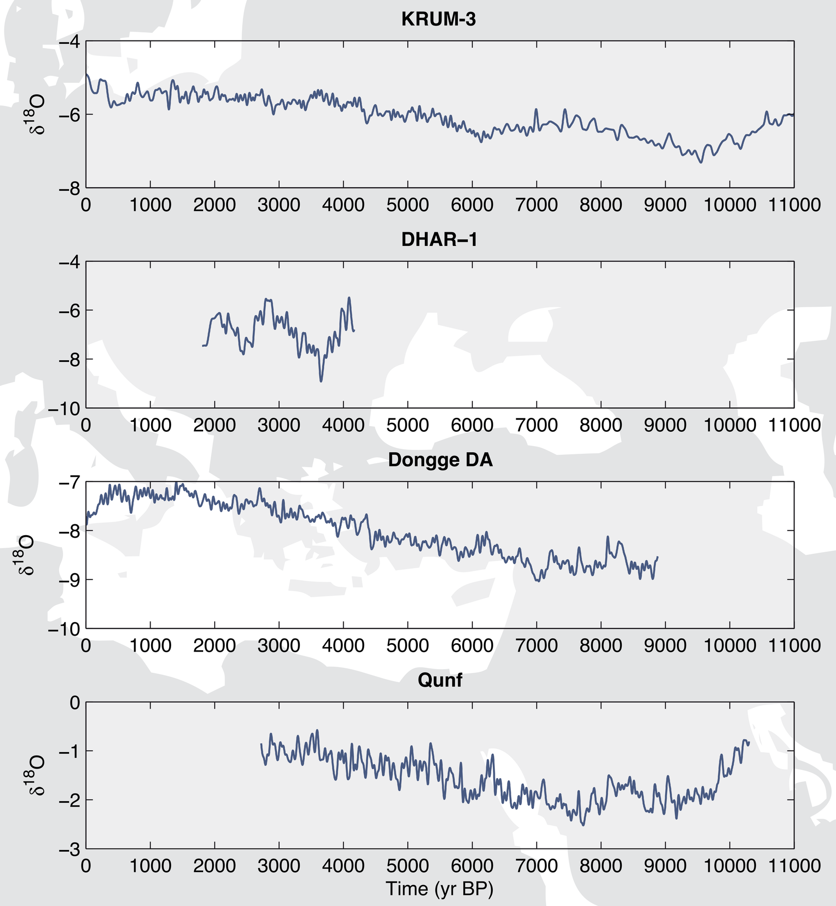
Distance plot of the Rössler system. In order to construct a recurrence plot from a phase space trajectory, a threshold is applied on the distance plot.



Corresponding recurrence plot of the consideredsystem. The transition from periodic to chaotic behaviour is obvious.

Asian speleothem records of δ^{18}O provide past continental monsoonal variability. The few available stalagmites from Asia cover a region in western, central and eastern Asia, where the Indian Summer Monsoon (ISM) and the East Asian Monsoon (EAM) are active. The isotope records are used in order to reconstruct and understand the monsoon circulation system. Are there correlations between the stalagmite records, can interrelations with climatic teleconnections detected?





δ^{18}O records derived from stalagmites of four different caves: Qunf (Oman), Dharamjali (India, Himalaya), Krem Umsynrang (India, Meghalaya) and Dongge (China), representing different monsoons: ISM and EAM.

Location of the stalagmite KRUM-3 in cave Krem Umsynrang (India, Meghalaya). At this place, several measurements (like drip water rate, cave climate) are still going on.

The recurrence quantification is applied on the δ^{18}O stalagmite data and on δ^{18}O GISP2 data in order to compare them with the special focus on dynamical transitions.

The data was low pass filtered with 1/50 yr^{-1} cut off frequency. The isotope record KRUM-3 is still under measurement. Therefore, the data presented here are of lower time resolution and the results are preliminary.

Note that the focus of this study is on the method.

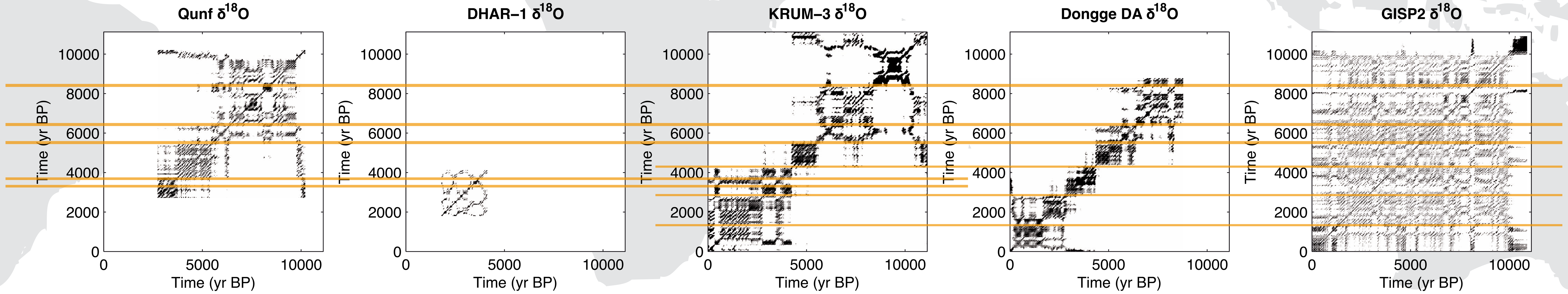
Using a simple comparison of recurrence plots, we have found certain transitions in the ISM (e. g. 3500 yr BP) and further transitions in the EAM (e. g. 4300, 5700, 8300 yr BP). Some of these transitions coincide with rapid changes in the global mean temperature (represented by GISP2 δ^{18}O). Very distinct transitions have occured around 9800-9000 and 5500-4200 yr BP and me bay important for the climatic interpretation.

References:

D. Fleitman et al.: Holocene Forcing of the Indian Monsoon Recorded in a Stalagmite from Southern Oman, Science 300, 2003.

N. Marwan et al.: Recurrence plots for the analysis of complex systems, Physics Reports 438, 2007.

D. Yuan et al.: Timing, Duration, and Transitions of the Last Interglacial Asian Monsoon, Science 3004, 2004.



Recurrence plots of the δ^{18}O records derived from stalagmites of the four different caves and of the δ^{18}O record from GISP2. The records Qunf and DHAR-1 reveal some similarities, indicating that both are in the same influence region of the ISM. The other two records show many similar recurrence patterns, mainly exhibited by the white bands. Both are in the influence region of the EAM. The found corresponding transitions are marked (orange lines) and seem to have some corresponding white band structures in the recurrence plot of the GISP2 data. The longest record KRUM-3 reveals a strange clustering of recurrence points around 9000 and 9800 yr BP, suggesting an anomaly in the record or in the monsoonal circulation.

For data description and further background information see also Poster A0499:

S. Breitenbach et al.: North Atlantic cold events pushed ITCZ southward and weakened Indian summer Monsoon in northern India

Further results of the recurrence analysis are presented on the poster A0496:

N. Marwan et al.: Detection of Climate Transitions in Asia Derived from Speleothems

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