Detection of Climate Transitions in Asia Derived from Speleothems

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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,

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

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). Typical measures of complexity for recurrence analysis use recurrence probability or the histogram of the lengths of the diagonal or vertical lines, like

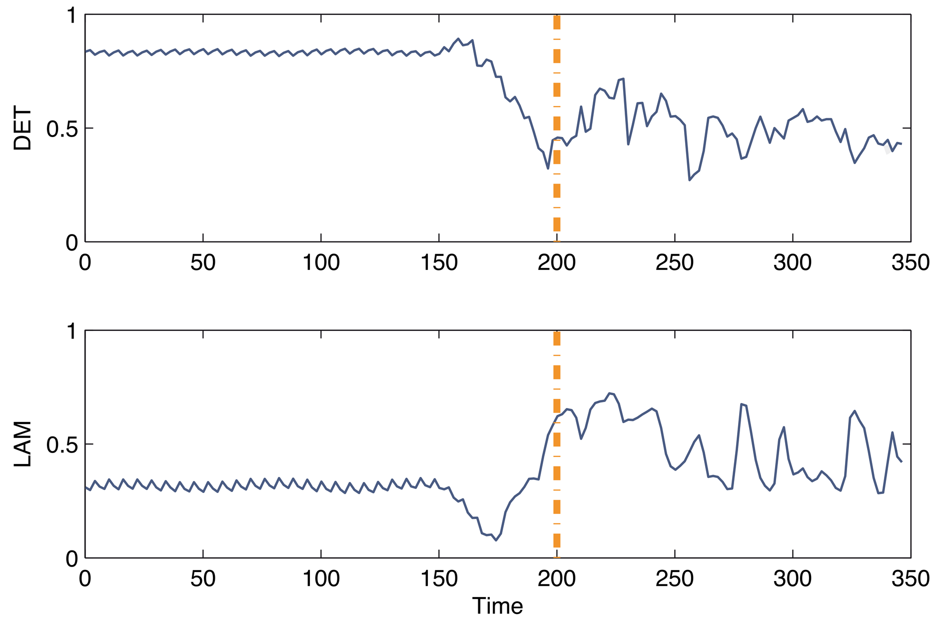
determinism

$$DET = \frac{\sum_{l=l_{min}}^{N} P(l)}{\sum_{i,j} \mathbf{R}_{i,j}}$$

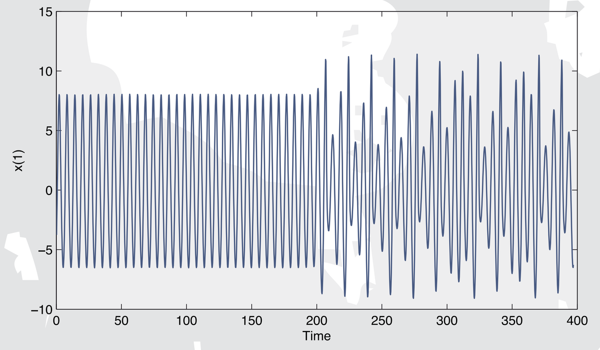
or laminarity

$$LAM = \frac{\sum_{v=v_{min}}^{N} P(v)}{\sum_{i,j} \mathbf{R}_{i,j}}$$

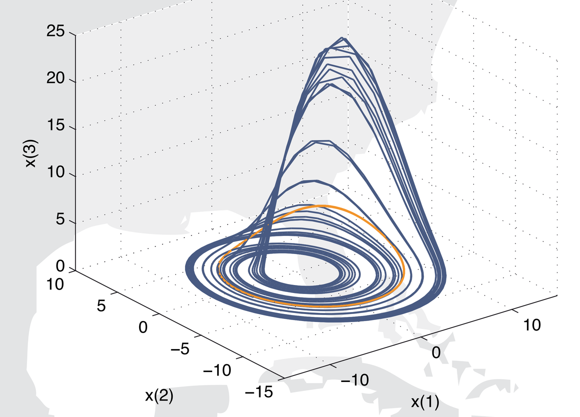
A time dependent quantification of the recurrence structure can reveal dynamical transitions in the system.



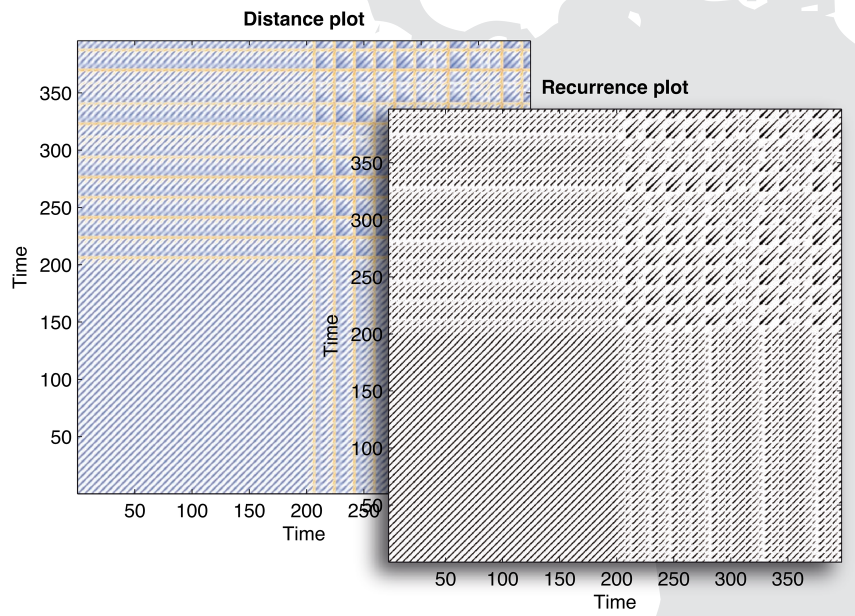
Recurrence quantification of the Rössler system, clearly indicating the transition from a regular (periodic) phase to a non-regular (chaotic) one around time t=200.



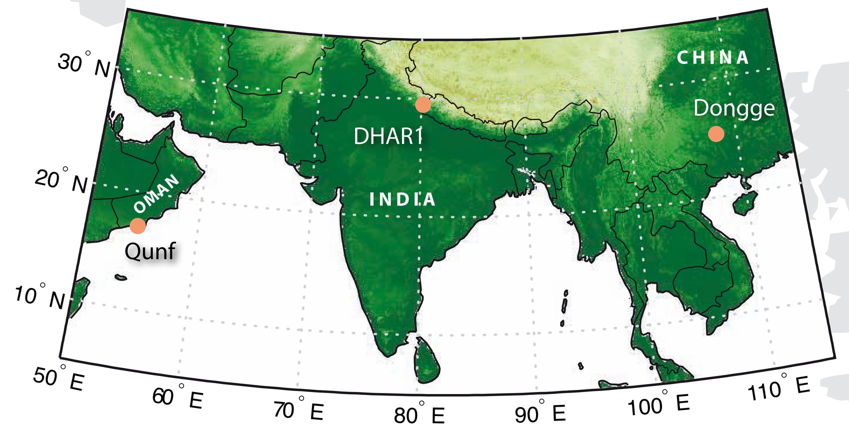
First component of the Rössler system, revealing a transition from periodic to chaotic behaviour (change from b=0.7 to b=0.2 and c=3.6 to c=5.7; a=0.2 in both segments).



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

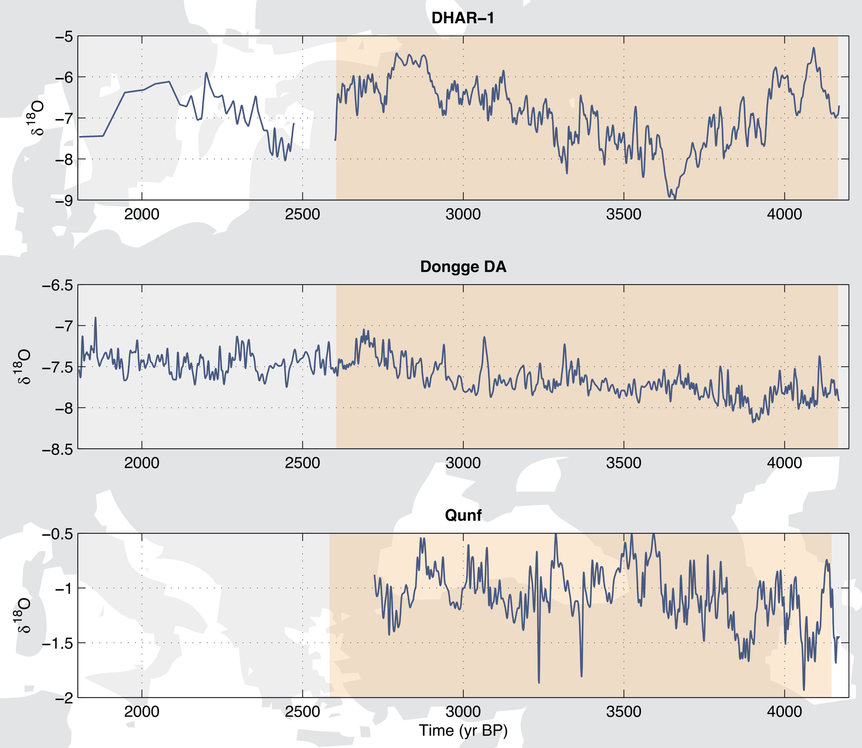


Distance plot (left) of the Rössler system. In order to construct a recurrence plot from a phase space trajectory, a threshold is applied on the distance plot. Corresponding recurrence plot (right) of the consideredsystem. The transition from periodic to chaotic behaviour is obvious.



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. Due to the different regional (local) monsoonal influences, different δ^{18}O regimes in these different regions are expected and were confirmed by measurements. However, changes in the monsoonal circulation system could have impact at all places, although not obvious in the data, and perhaps after some delay (between ISM and EAM).

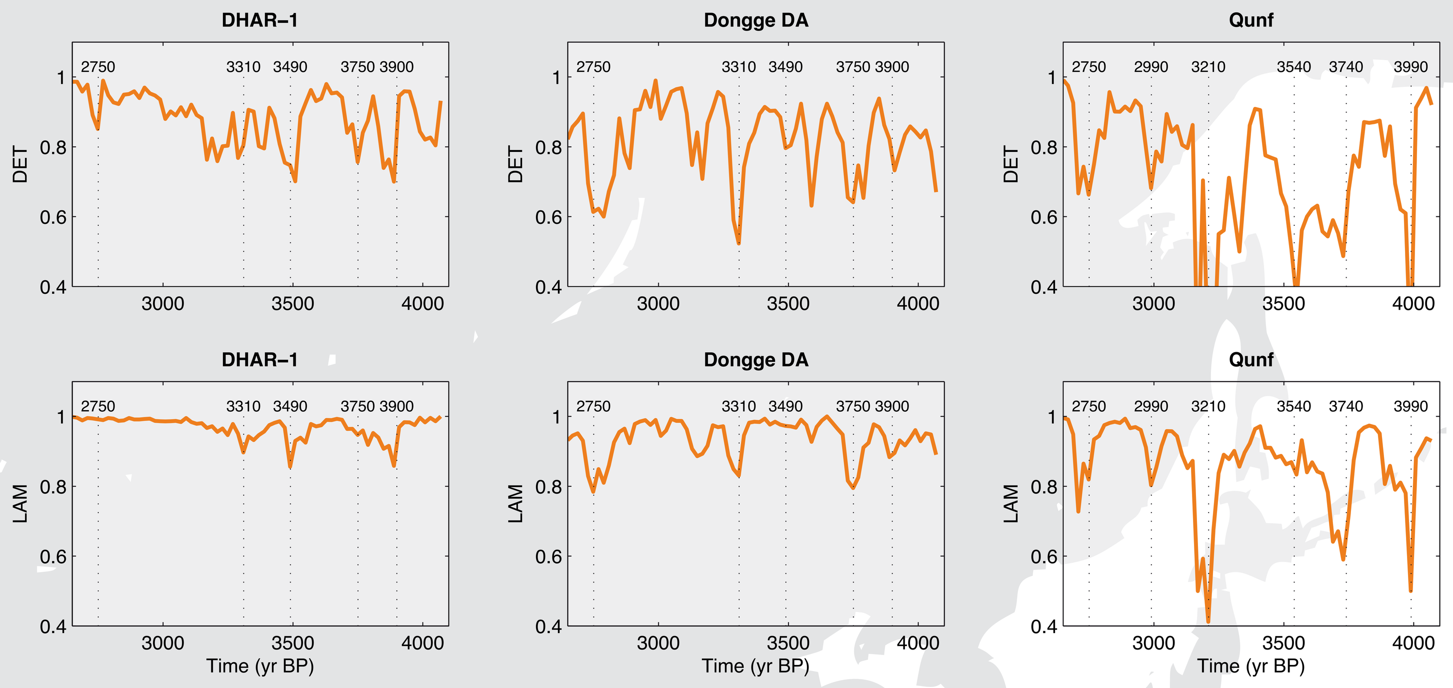
Stalagmite DHAR-1 from the cave Dharamjali (Himalaya).



δ^{18}O records derived from stalagmites of three different caves: Qunf (Oman), Dharamjali (India, Himalaya) and Dongge (China). In our study we focused on the time range between 2600 and 4100 yr BP (orange overlay). The data were low pass filtered (0.6 yr^{-1}). Although the data show regions with some correlation, most parts seems to be uncorrelated.

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

Note that this study is a methodological work and the results are preliminary.

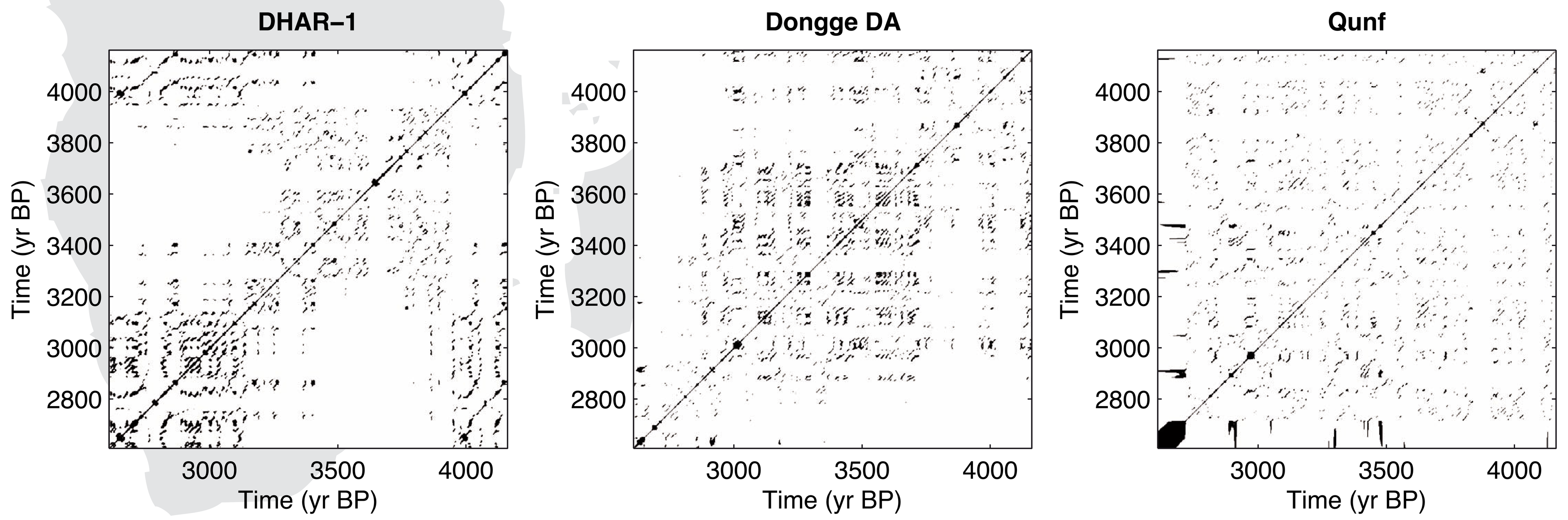


Recurrence quantification of the δ^{18}O records. Despite the differences in the recurrence structure, the measures DET and LAM reveal transitions at almost the same times for the locations in Oman and Himalaya. The record from China shows delayed transitions (10-160 yrs).

The recurrence analysis clearly reveals transitions in the monsoonal dynamics for the Oman and Himalayan stalagmites at 2750, 3310, 3490 and 3900 yrs BP. Despite the meaning of these years, this suggests rather rapid changes in the ISM. The Chinese stalagmite record reveals transitions at other times (2990, 3210, 3540, 3740, 3990 yrs BP), indicating different monsoonal dynamics of the ISM and the EAM.

Although the type of monsoonal influence is different at the Oman and Himalayan locations, the simultaneous occurrence of the transitions in the δ^{18}O records confirms the influence of the ISM on both locations. However, the record from the more eastern region (China) does not reveal the same transitions. This region is influenced by the EAM, whose changes are not in coincidence with or are delayed regarding the ISM.

Moreover, this results confirm that it is not possible to conclude from one stalagmite record for the dynamics of the entire monsoonal circulation system.



Recurrence plots of the δ^{18}O records. The recurrence structure differs in all three plots, revealing the different nature of the impact of the monsoon and thedifferent source of the monsoon

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.

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

Poster XY0655: N. Marwan et al.: Can nonlinear data analysis help to conclude climate changes in Asia during the Holocene?

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