Cross Recurrence Plot
Based Rescaling of Geological Time Series

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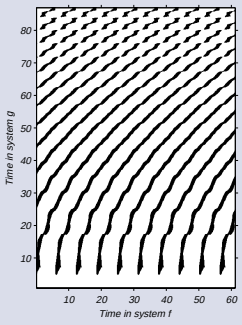
The method of recurrence plots (Eckmann et al., 1987) is extended to the cross recurrence plots (CRP), which enables the study of synchronization or time differences in two time series (Marwan et al., 2002). In principal, the CRP visualizes times, when phase space trajectories of two dynamical systems are very close to each other:

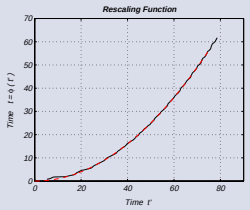
$$CR(i,j) = \Theta(\varepsilon - |x_i - y_j|),$$

where x and y are vectors, which can be formed from multivariate data sets, Θ is the Heaviside function, ε a predefined cut-off distance and $|\cdot|$ is a norm.

If x and y are the same, the CRP will have a straight black diagonal – the line of synchronization (LOS); differences in the time domains of x and y (e. g. one time series is stretched or compressed) causes a distrortion of this black line. A nonparametrical fit of this LOS can be used to rescale the time axis of the two data series so that they are synchronized.
Using this method, the synchronization and time-rescaling of geological data to a given time scale is much easier, objective and faster than by hand. The application to geophysical borehole data shows the potential of this

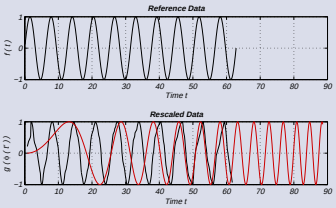
An illustration with two sine functions $f(t)=\sin(\varphi\, t)$ and $g(t)=\sin(\psi\, t^2)$.





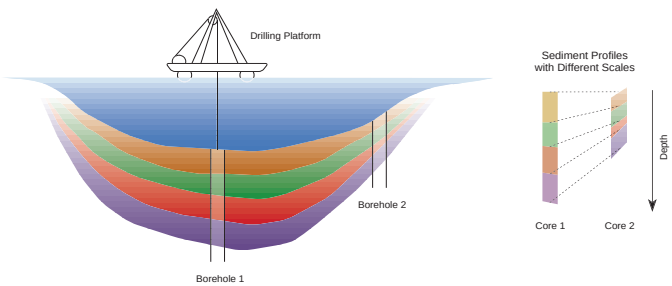
The rescaling function (black) determined from the CRP shows the expected parabolic shape. In red the square function.

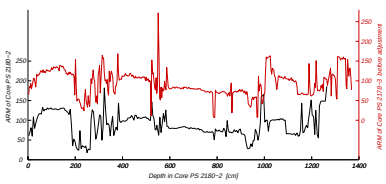
Reference data series f (upper panel) and second data series g before (red) and after (black) time-rescaling by using the LOS (lower panel).



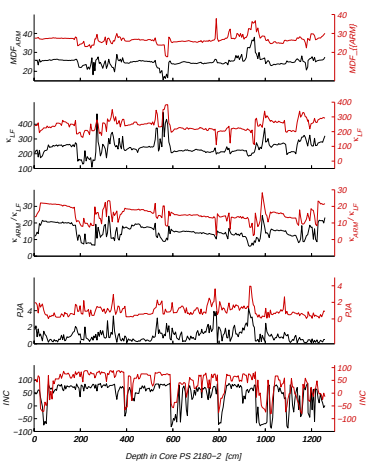
The CRP for two sine functions which is the base for the determination of the rescaling function (LOS) between both data series ($m = 2$, $\tau = 1$, $\varepsilon = 0.2$). The differences in the time domain cause a distorted LOS in the form of the parabolic function $\phi \sim t^2$.

The adjustment of the time scales of geological data series to a geological reference time series is of major interest in many investigations, e. g., geophysical borehole data should be correlated to a given data series whose time scale is known in order to achieve an age-depth function or the sedimentation rate for the borehole data. Instead of using the *wiggle matching* by eye, we suggest a new method based on techniques from nonlinear time series analysis, the method of cross recurrence plots.
In the following example we adjust the scales of two different sediment cores from the Makarov Basin, central Arctic Ocean, PS 2178-3 and PS 2180-2, by using palaeo- and rock magnetic data.

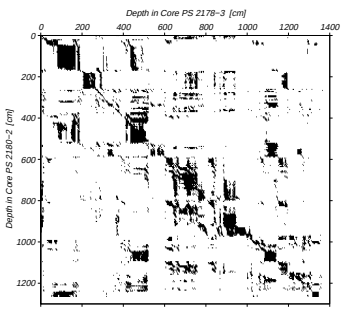




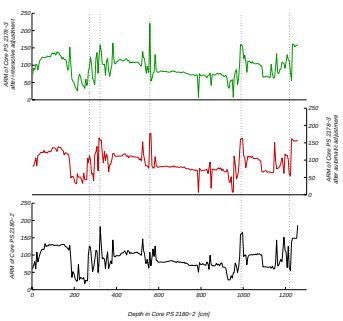
ARM data as an examplary data set of the boreholes PS 2178-3 GPC and PS 2180-2 GPC in the Central Arctic Ocean before adjustment.



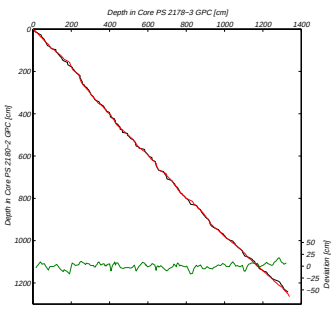
The adjusted marine sediment parameters. The construction of the CRP was done with the normalized parameters. In this plots we show the parameters, which are not normalized.



Cross recurrence plot based on six normalized sediment parameters (κ_{LP}, ARM, κ_{ARM}/κ_{LP}, PJA, MDF_{ARM}, INC) and an additional embedding dimension of $m = 3$ ($\tau = 1$, $\varepsilon = 0.05$).



Comparison between the interactive wiggle matching (top) and the automatic CRP adjustment for ARM data. The bottom figure shows the reference data.



Depth-depth-curves gained with the LOS. In black the curve gained with the CRP, in red the manually matching result. The green curve shows the deviation between both results.

References

Eckmann, J.-P., S. O. Kamphorst, D. Ruelle: Recurrence Plots of Dynamical Systems, Europhysics Letters 4, 1987

Nowaczyk, N. R., Frederichs, T. W., Kassens, H., Nørgaard-Pedersen, N., Spielhagen, R. F., Stein, R., Weiel, D.: Sedimentation rates in the Makarov Basin, Central Arctic Ocean – A paleo- and rock magnetic approach, Paleoceanography, 2001

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