Re-alignment of Geological Time Series
Using the Cross Recurrence Plot Toolbox

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The method of recurrence plots (Eckmann et al., 1987) was extended to cross recurrence plots (CRP), which enables the study of time transformations (e. g. dilatation) in two time series (Marwan et al., 2002 and 2005). In principal, the CRP visualizes times, when phase space trajectories of two dynamical systems are very close to each other:

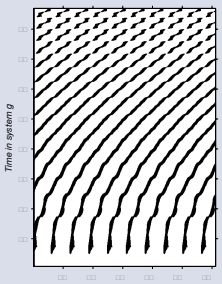
$$\mathrm{CR}(i,j) = \Theta(\varepsilon - |\mathbf{x}_i - \mathbf{y}_j|),$$

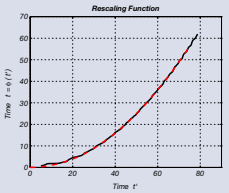
where $\mathbf{x}$ and $\mathbf{y}$ are vectors, which can be formed from multivariate data sets, Θ is the Heaviside function, ε a predefined cut-off distance and $|\cdot|$ is a norm.

If $\mathbf{x}$ and $\mathbf{y}$ are the same, the CRP will have a straight black diagonal – the line of synchronization (LOS); differences in the time domains of $\mathbf{x}$ and $\mathbf{y}$ (e. g. one time series is stretched or compressed) causes a distortion of this LOS. A non-parametrical fit of the LOS can be used to re-adjust the time axes of the two data series so that they are matched.

Using this method, which is provided in the CRP toolbox, the alignment of time axes of geological data to a given time scale is much easier, objective and faster than by hand.

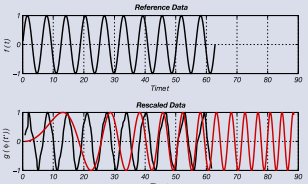
An illustration with two sine functions $f(t)=\sin(\varphi\, t)$ and $g(t)=\sin(\psi\, t^2)$.





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

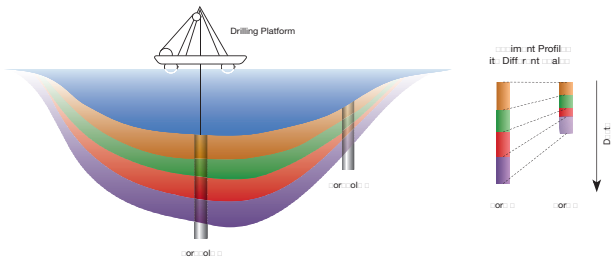
Reference data series f (upper panel) and second data series g before (red) and after (black) time-alignment by using the LOS (lower panel).

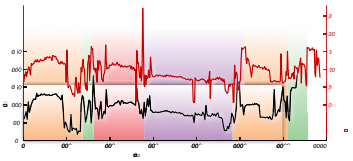


The CRP for two sine functions which is the base for the determination of the rescaling function (LOS) between both data series ($m = 2$, $\tau = 1$, $\varepsilon = 0.2$). The differences in the time domain cause a distorted LOS in the form of the parabolic function $\phi \sim t^2$.

The alignment 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. Instead of using *wiggle matching* (alignment by eye), we suggest a method based on techniques from nonlinear time series analysis, the method of cross recurrence plots.

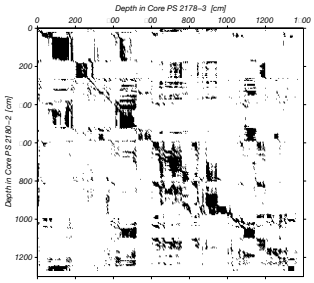
In the following example we adjust the scales of two different sediment cores from the Makarov Basin, central Arctic Ocean, PS 2178-3 and PS 2180-2, by using palaeo- and rock magnetic data and the CRP toolbox, available from tocsy.agnld.uni-potsdam.de.

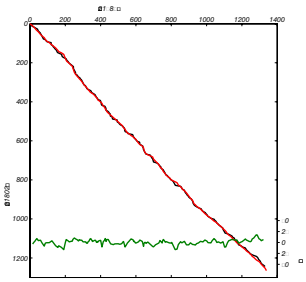




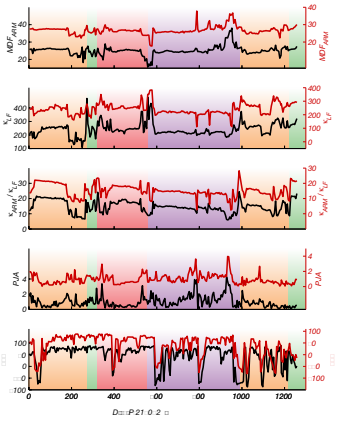
ARM data as an examplary data set of the boreholes PS 2178-3 GPC and PS 2180-2 GPC in the Central Arctic Ocean before alignment.

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

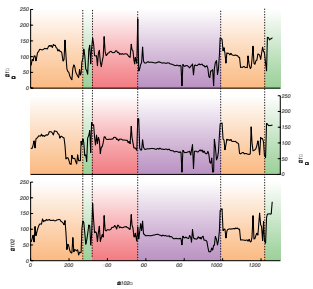




Depth-depth curves obtained from the LOS (black) and using wiggle matching (red). The green curve reveals the deviation between both results.



The aligned 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.



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

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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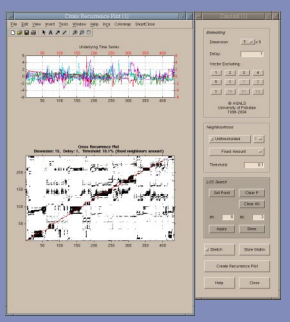

The CRP toolbox contains MATLAB® routines for computing recurrence plots, cross/ joint recurrence plots and their quantifications. Further useful tools for data preparation and nonlinear data analysis are also included.

Norbert Marwan, http://www.agnld.uni-potsdam.de/~marwan, September 2005