Automatic characterisation of Dansgaard-Oeschger events in palaeoclimate ice records

Susana Barbosa[1], Maria Eduarda Silva[1], Nuno Dias[1], Denis-Didier Rousseau[2,3]

[1] INESC TEC, Porto, Portugal
[2] Geosciences Montpellier, University of Montpellier, CNRS, France
[3] Silesian University of Technology, Gliwice, Poland

Abstract

The automatic identification of abrupt transitions in paleoclimate records is a relevant task for the study of past climate variability. Here the Matrix Profile approach is applied for the identification of Dansgaard-Oeschger (DO) events in the NGRIP δ^{18} O ice core record and its classification in terms of shape of the transition.

Introduction

Dansgaard-Oeschger (DO) events are abrupt transitions identifiable in Greenland ice core records. DO events are characterised by episodes of rapid warming (~ decades) followed by a slower cooling. Data-driven methods have the potential to foster the identification of abrupt transitions in palaeoclimate time series in an objective way (e.g. Bagniewski et al, 2021), complementing the traditional identification of transitions by visual inspection of the time series.

In this study we apply an algorithmic time series method, the Matrix Profile approach (e.g. Yeh et al, 2016; 2018), to the analysis of the NGRIP Greenland ice core record, focusing on the detection of abrupt transitions and on the classification of the DO events in terms of similarity of the corresponding warming/cooling temporal pattern.

Data

Figure 1 shows the NGRIP δ^{18} O time series on the Greenland Ice Core Chronology 2005 (GICC05) time scale back to 60 ka b2k (years relative to A.D. 2000), with 20-year resolution (Rasmussen et al, 2014). Also shown are the start and end times of DO events that were identified from transitions from warm climate Greenland Interstadials to cold climate Greenland Stadials.

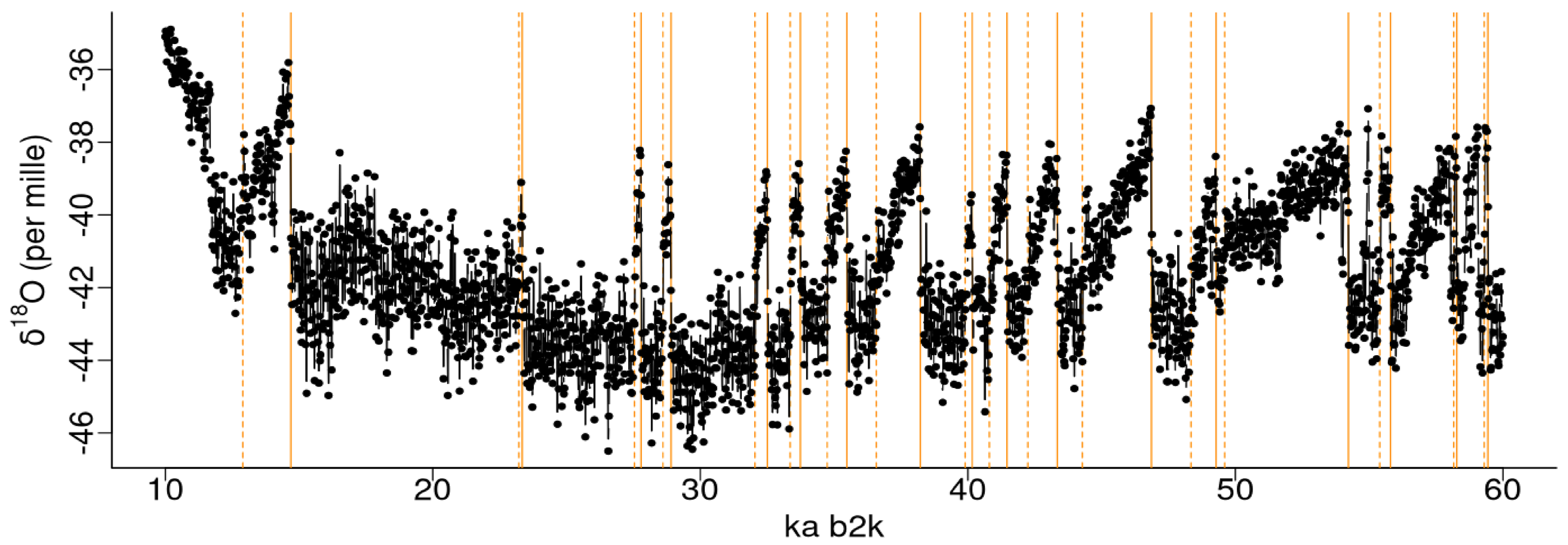

Figure 1: NGRIP record and expert-based identification of DO events (— indicates the start and ---- the end of the DO event).

Methodology

The matrix profile (MP) is a time series data structure that annotates a time series. The aim is not to characterise the global properties of a time series, but rather local features from subsequences of the time series. The matrix profile contains the distance between all possible subsequences of a time series to its nearest neighbour in terms of z-normalized Euclidean distance. From the computational point of view, available algorithms allow to retrieve the matrix profile of a time series in a scalable and efficient way. The approach has the advantage of being simple and parameter-free (depending only on the prescribed subsequence length) and efficient even for very large time series.

Palaeoclimate records are notorious by their shortness, given the challenges inherent to the retrieval of past climate information by painstaking field and laboratory work. The small size of palaeoclimate series is a major hindrance for any time series method, and in this case it also limits the ability to use the matrix profile approach for the direct identification of DO events, as their duration is quite variable. Still, since DO events are a recurring feature in the NGRIP record, the matrix profile is a particularly apt tool.

Results

The matrix profile analysis is performed using the R-package tsmp (Bischoff et al, 2022). Figure 2 shows the matrix profile results for a prescribed subsequence length of 100 (corresponding to 2000 years).

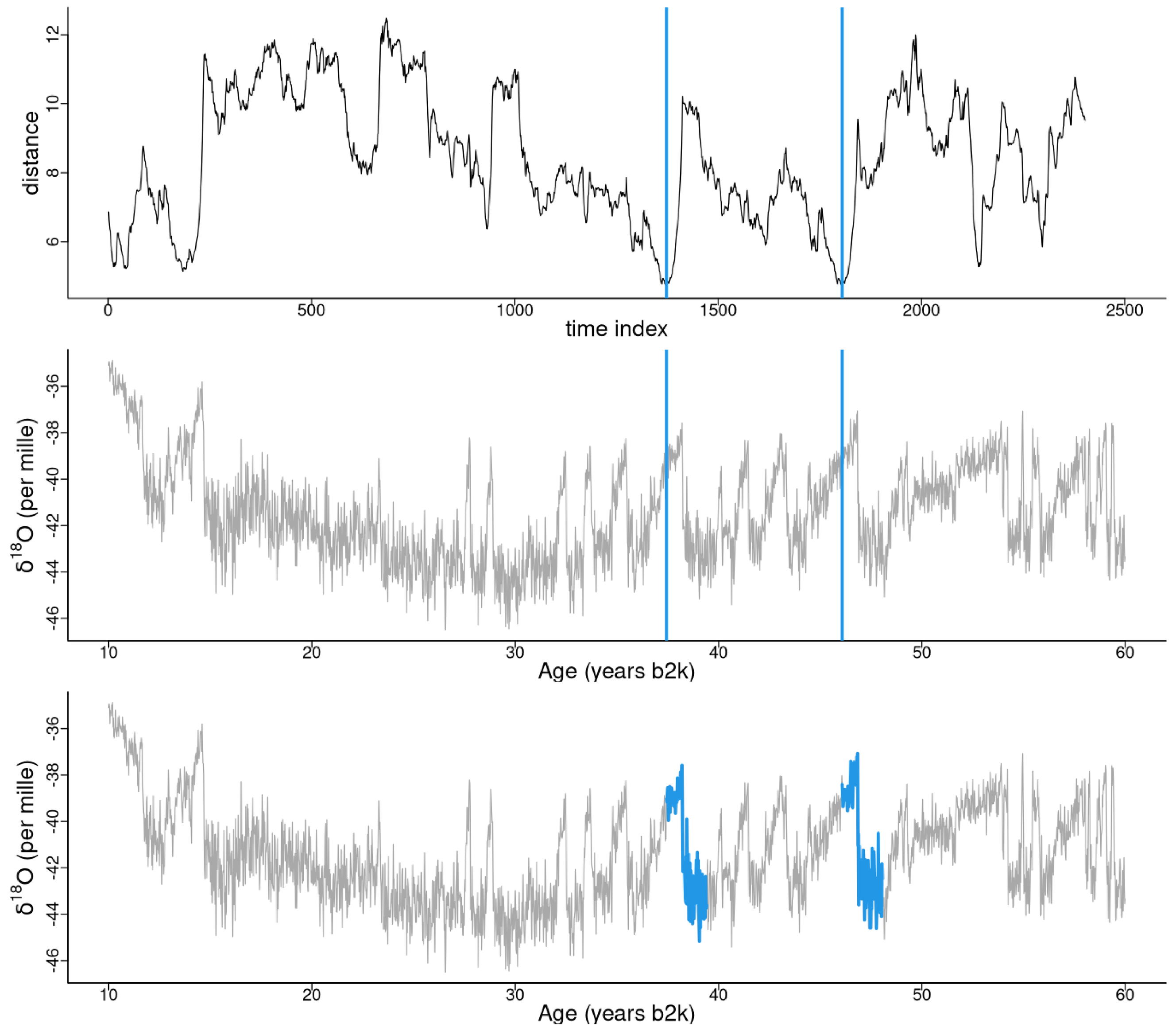

Figure 2: Matrix profile for the NGRIP record (top) and corresponding motifs (bottom).

The matrix profile can be used to identify reoccurring patterns ("motifs"). The pair of lowest values of the matrix file correspond to the dominant motif. Similar subsequences to this dominant motif are given by its nearest (distance-wise) neighbours. Figure 3 shows the top motif in the NGRIP record and its neighbours. The main motif in the NGRIP time series corresponds to a longer period (~1200 years) of stable values followed by a sharp increase in the proxy value (Figure 4).

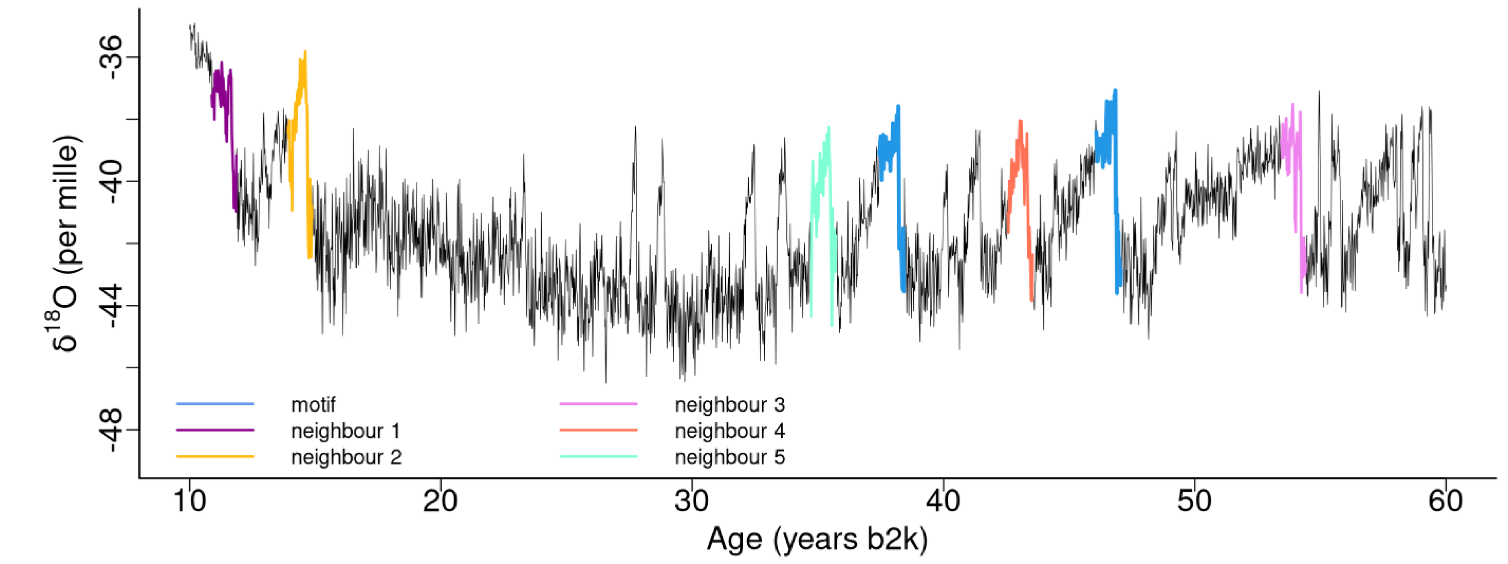

Figure 3: Dominant recurring pattern in the NGRIP time series.

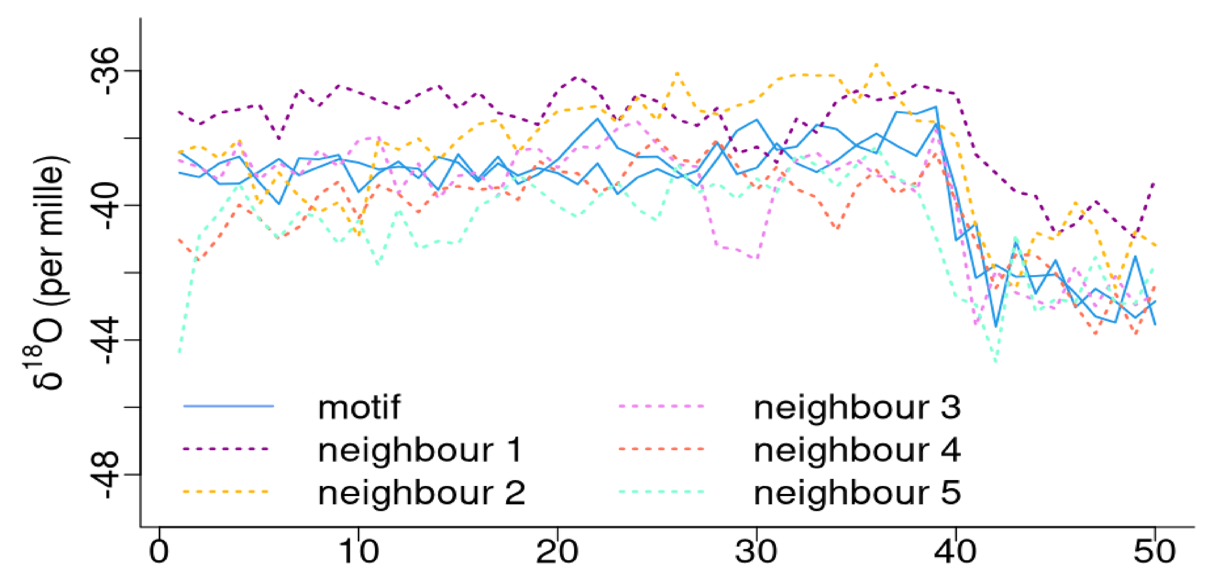

Figure 4: Top motif of length 100 (2000 years) in the NGRIP record.

Conclusions

The matrix profile approach is strongly determined by the fixed subsequence length, and thus is unable to characterise all the DO events in the NGRIP record. However, it is able to pinpoint reoccurring patterns in the NGRIP ice record reflecting similar transitions from cold to warm climate. Thus the matrix profile can be an useful tool for the automatic characterisation of reoccurring patterns in palaeoclimate time series.

References

Bagniewski, W., Ghil, M. and Rousseau, D.D., 2021. Automatic detection of abrupt transitions in paleoclimate records. Chaos: An Interdisciplinary Journal of Nonlinear Science, 31(11), p.113129.ts

Bischoff F., 2022. tsmp: Time Series with Matrix Profile. R package version 0.4.15, https://github.com/matrix-profile-foundation/tsmp.

Rasmussen, S.O., et al, 2014. A stratigraphic framework for abrupt climatic changes during the Last Glacial period based on three synchronized Greenland ice-core records: refining and extending the INTIMATE event stratigraphy. Quaternary Science Reviews, 106, pp.14-28.

Yeh, C.C.M., Zhu, Y., Ulanova, L., Begum, N., Ding, Y., Dau, H.A., Silva, D.F., Mueen, A. and Keogh, E., 2016, December. Matrix profile I: all pairs similarity joins for time series: a unifying view that includes motifs, discords and shapelets. In 2016 IEEE 16th international conference on data mining (ICDM) (pp. 1317-1322).

Yeh, C.C.M., Zhu, Y., Ulanova, L., Begum, N., Ding, Y., Dau, H.A., Zimmerman, Z., Silva, D.F., Mueen, A. and Keogh, E., 2018. Time series joins, motifs, discords and shapelets: a unifying view that exploits the matrix profile. Data Mining and Knowledge Discovery, 32, pp.83-123.

INESCTEC

EU Horizon 2020 project - grant agreement No. 820970