Improving age models for abrupt climate changes during the last glacial by pattern recognition

Mark Turner and Sandy P. Harrison (University of Reading)

Abstract

Quaternary records provide an opportunity to examine how regional climates and vegetation reflect global climate changes comparable in magnitude and velocity to those expected during the 21st century. The Dansgaard-Oeschger (D-O) cycles of the last glacial period provide the best documented examples of such rapid climate warmings (Greenland interstadials, GIs). However, the age models of pollen records that document regional responses to D-O events are, in general, poorly constrained beyond the radiocarbon timescale. Here we use a pattern-recognition approach, based on matching oscillations in palaeoclimate records to a template of D-O events seen in the Greenland record, to provide better constrained age models. We create a series of templates of Greenland Interstadials (GIs) and compare these to a normalised and detrended time series from a target record using a sliding window and measuring goodness-of-fit using Euclidean distance. We show that this approach can identify D-O events in well-dated records, including reproducing the Greenland record itself. We then apply this approach to the less well-constrained pollen records from the last glacial period from southern Europe. The re-aligned age models permit a more robust comparison of the reconstructed vegetation and climate changes through time and across sites, allowing for regional differences in the response to individual GIs to be identified.

Introduction

- Dansgaard-Oeschger events (D-Os) are abrupt warmings, initiating Interstadials, during the last glacial period (~123-11 ka) that are well documented in the Greenland ice core record [Figure 1].

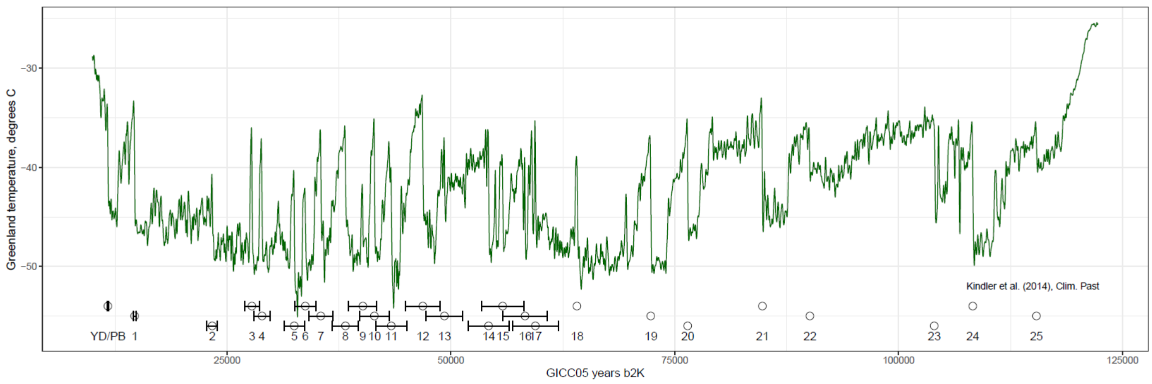

Figure 1. Greenland NGRIP temperature (green line) from Kindler et al. (2014). The black points, bars and labels show the initiation of Greenland Interstadials (D-Os), with age uncertainties where available (± maximum counting error, equivalent to 2σ), on GICC05modelext timescale.

- D-O events are clearly registered in long pollen records from southern Europe; however the age control on some of these records is poor, particularly before ca 40 ka.
- The poor radiometric age control has led to a reliance of assumed correlations with D-O events during the early part of the glacial, precluding objective correlations between records, the investigation of geographic differences in the magnitude of the response during individual D-Os, or the identification of lags in the vegetation response to climate.
- Given the distinctive form of D-O events, it should be possible to use pattern-recognition approaches to provide a more secure way to identify them in pollen records.

- We test this idea using pollen-based quantitative climate reconstructions, since these integrate the signals from the whole pollen assemblage. The pollen records, and their age models, are taken from the ACER database. The climate variables we use are mean temperature of coldest month (MTCO), growing degree days above 0 °C (GDD0) and the square root of Moisture Index (sqrt(MI)).

Method/results

- D-Os have a highly distinctive pattern around the sudden warming [Figure 2]. We search for that pattern in the reconstructed climate variable, by sliding a D-O template along the climate reconstruction and recording the distance between the two as it moves. D-O-like events are at the points in the reconstruction which are most similar to the template, that is, have the lowest distances.

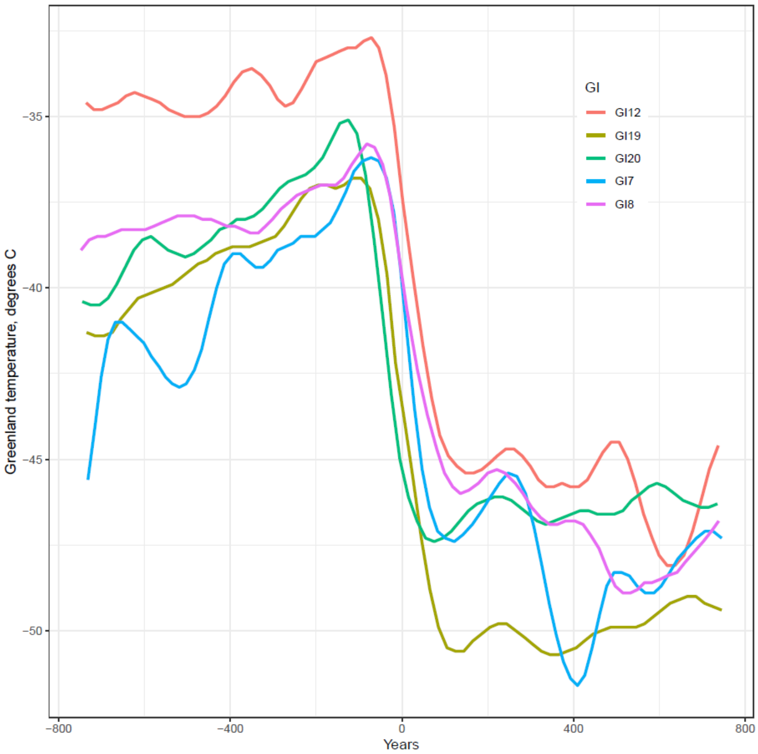

Figure 2. 1 500 year sections of the Kindler et al. (2014) NGRIP temperature series, overlaid by placing the initiation of selected Greenland Interstadials (GIs) at 0 years.

- **Step 1**: Pollen samples are not regularly distributed in time, so the reconstructed climate values are linearly interpolated to the higher-resolution 50-yr interval timescale of the ice core record.
- **Step 2:** We calculate Z-scores for both the template and the reconstruction, and detrend the reconstruction by subtracting a LOESS curve (span = 0.1) [Figure 3]. This avoids artificial distances or artificial changes in distances over the series because of an offset or a trend. (We use the core from Lagaccione as an example throughout; similar results are obtained with other cores.)

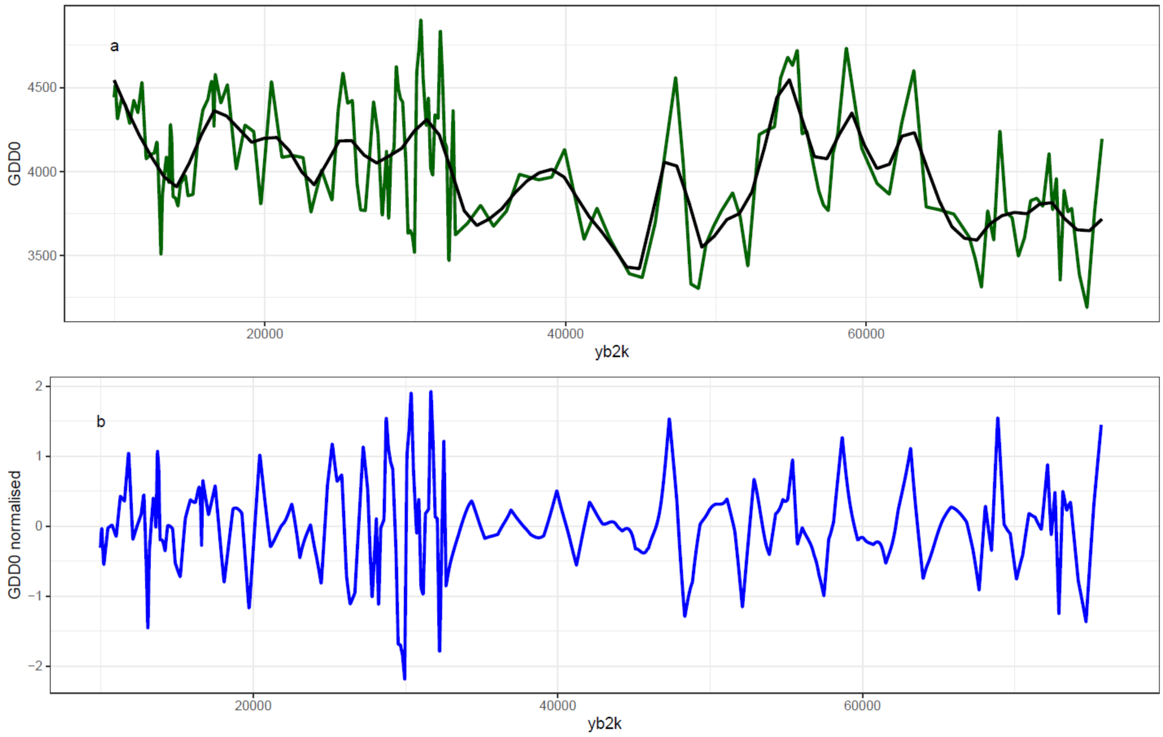

Figure 3: Progressive detrending and normalising of a reconstructed climate variable. a: Green line: original reconstruction of growing degree days above 0 °C (GDD0) at Lagaccione; black line: loess curve identifying trend. b: blue line: reconstruction with trend subtracted and then normalised.

- **Step 3**: By sliding a window the same width as the template (1 500 years) along the detrended z-score curve, we can calculate the Euclidean distance between the climate value in the window and the normalised temperature in the template (sqrt(sum((x_i - y_i)^2))) at each step. This is recorded at the centre point of the window (i.e. the point of warming in the template) and used to produce a curve of distances between the reconstruction and the template.
- **Step 4**: The troughs in the Euclidean distance curve are the most likely D-O points in the reconstruction. In [Figure 4a] we use a single D-O template and compare reconstructed GDD0 with the Greenland temperature, since both reflect approximately annual temperature values. [Figure 4b] shows that different GI templates give highly similar curves and identify D-O like events at the same points.
- [Figure 4c] shows that in fact all three climate variables locate the great majority of most-D-O-like points in the same places.

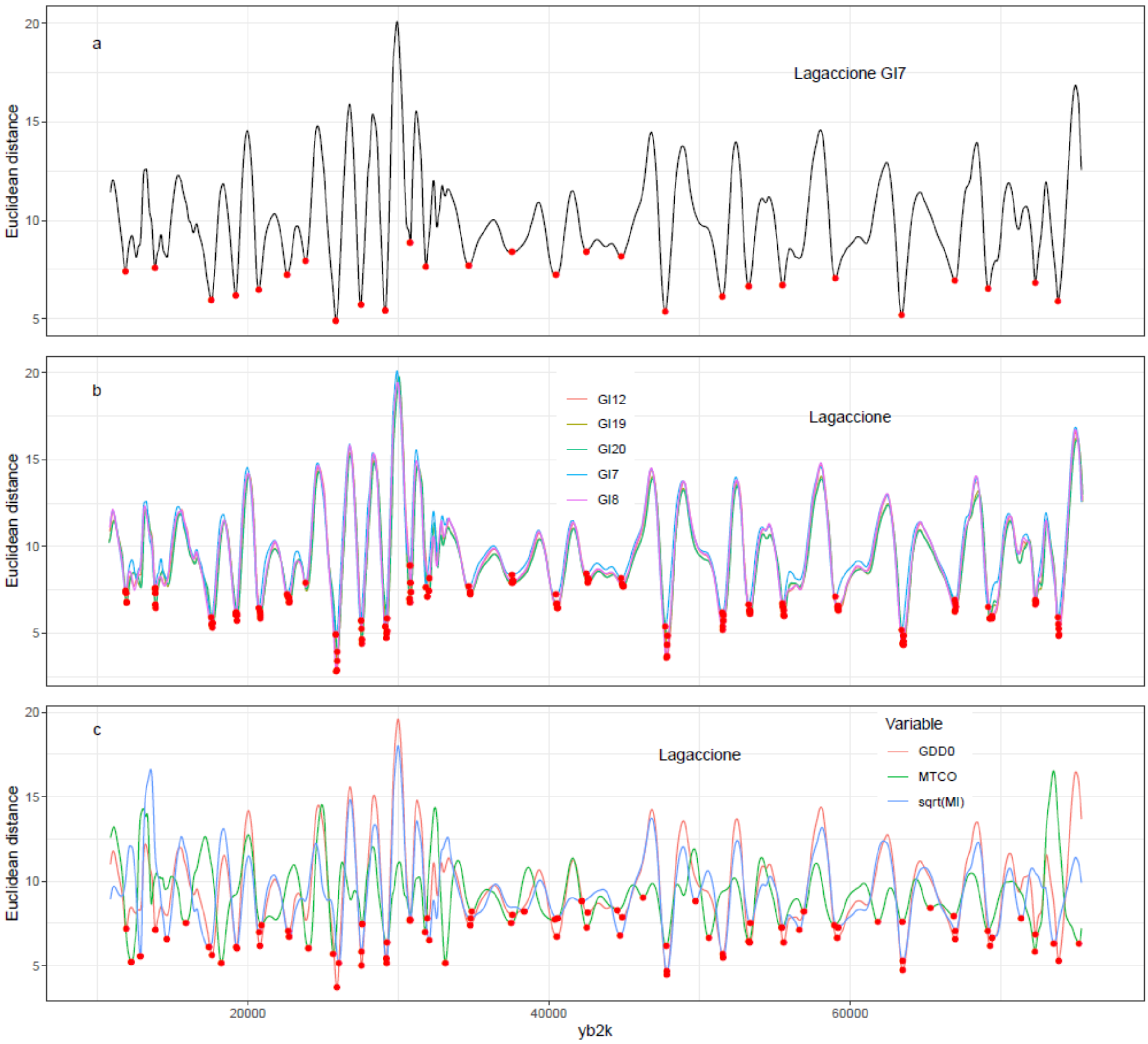

Figure 4. Distance curves for Lagaccione. Red points identify points most like D-Os. **a**: comparing one climate variable (GDD0) and one D-O template (GI 7). **b**: comparing many templates with GDD0. **c**: for the three climate variables, each averaged across all GIs used.

- By applying templates for several D-Os to all 3 climatic variables, a composite picture and a mean distance which captures information from all the climatic variables and all the templates is obtained [Figure 5].

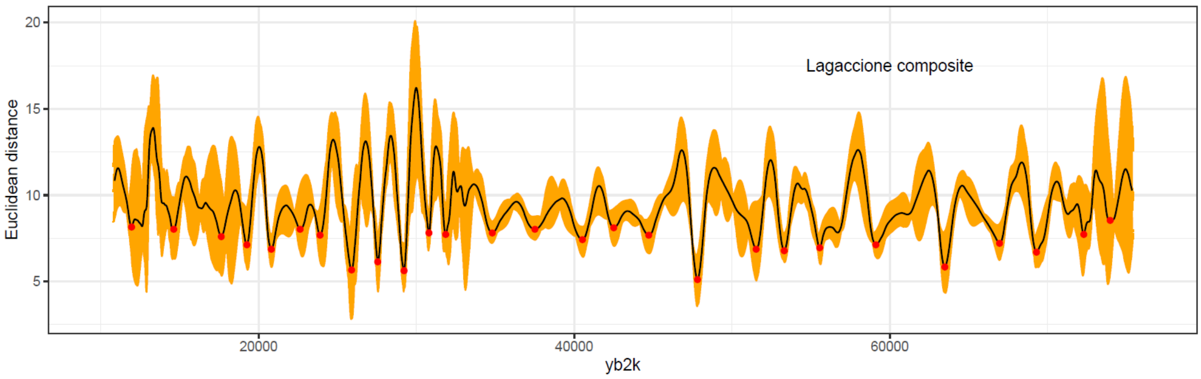

Figure 5. Composite distance curve for Lagaccione. Orange ribbon: range of distances, obtained by combining distances for all combinations of templates and climatic variables. Black line: mean of all such distances. Red points: trough points, i.e. points most similar to D-Os.

- As a check [Figure 6] shows that the D-O-like events identified at Lagaccione appear properly located within the climate reconstructions.

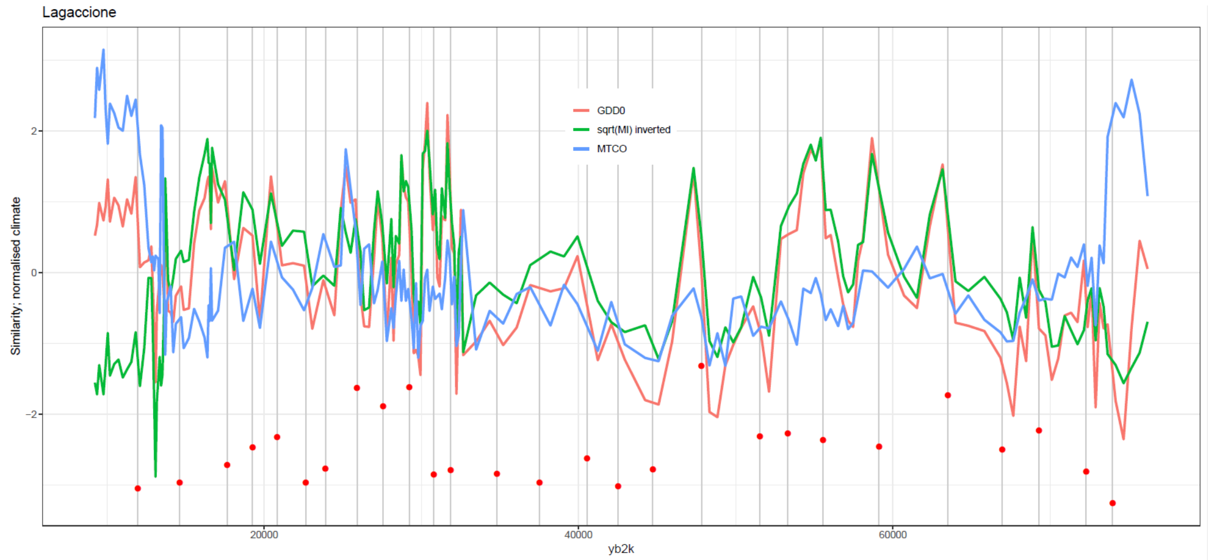

Figure 6. D-O-like events identified at Lagaccione, compared with normalised reconstructed climatic variables: mean temperature of coldest month (MTCO), growing degree days above 0 °C (GDD0) and the square root of Moisture Index (sqrt(MI); inverted for ease of comparison). Grey vertical lines: points identified as D-O-like by composite distance curve; red points: similarity of D-O-like events (distance), higher = more similar.

- **Step 5**: The most-similar (lowest) points along the mean composite distance curve are then allocated to the most probable D-Os. The simplest approach is to allocate each identified D-O event in the record to the nearest D-O event on the GICC05 timescale. The degree of similarity (Euclidean distance) can be taken into account if there are multiple candidates. There may be no secure match for some D-Os [Figure 7]. In the Lagaccione core, some strongly D-O-like events have no apparent counterpart in Greenland, and some GIs appear missing (e.g. perhaps 6, 10 and 16).

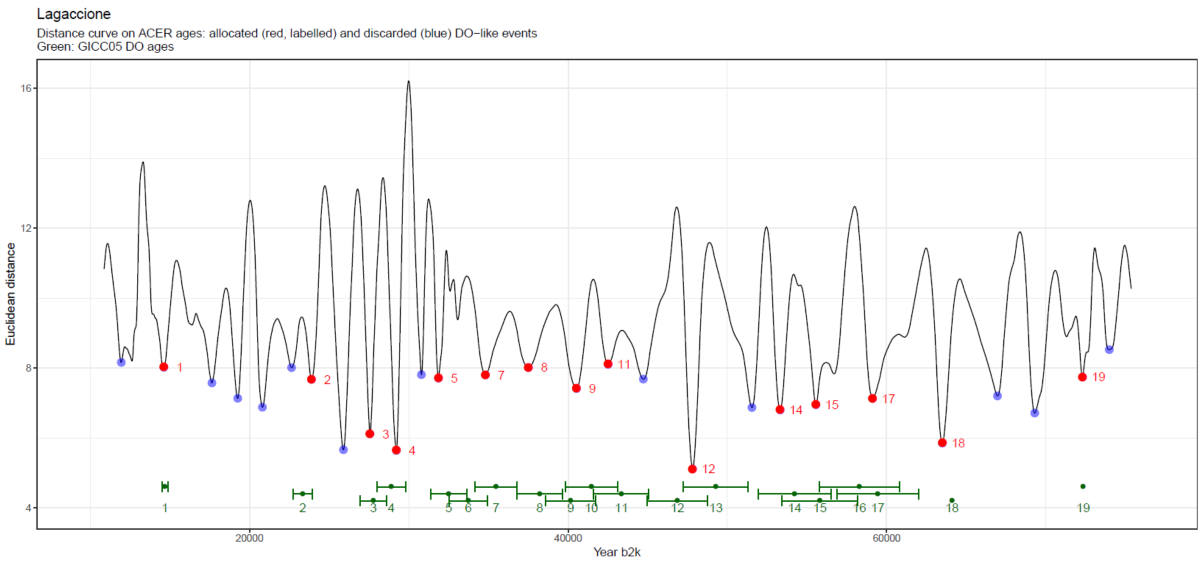

Figure 7. Composite distance curve for Lagaccione, identifying troughs i.e. most D-O-like events. Red points: events provisionally considered to match D-Os, with number; blue points: events not allocated; all on original age model timescale. Green points, bars and labels: Greenland GI initiations with age uncertainties, on GICC05modelext timescale.

- **Step 6**: Apply the GICC05modelext ages to the core depths of the identified D-O-like events to rebuild the age-depth model [Figure 8], assuming a linear sedimentation rate between events.

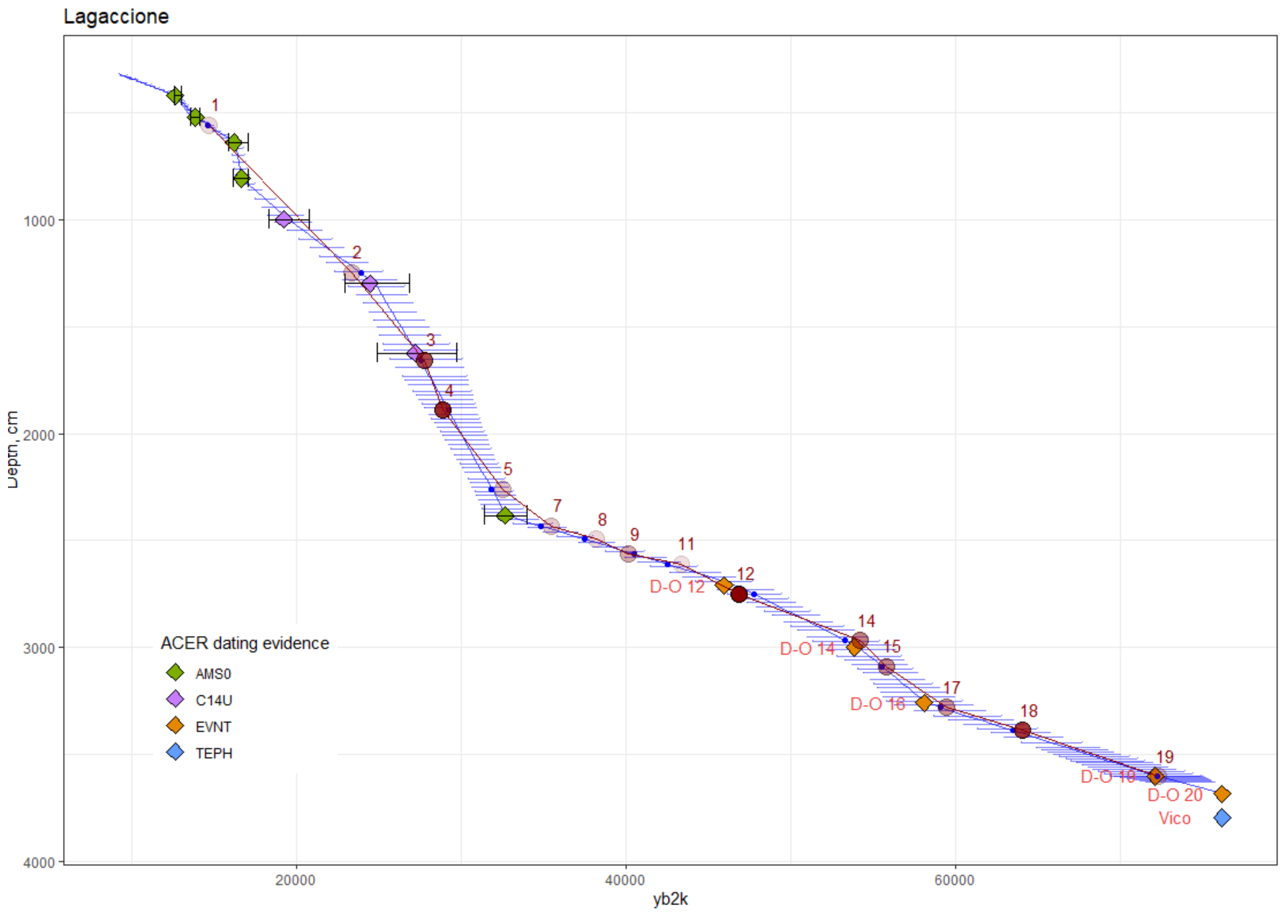

Figure 8. Revised age-depth model for Lagaccione. Blue line/uncertainties: original ACER model; blue points: location in ACER model of newly identified D-O-like points. Diamonds and black error bars: dating points quoted in ACER; brown: "events" (EVNT), subjective matches used in the construction of the ACER model. Red line, simple restated age model using only D-O-like points; red points and labels: newly identified D-O-like points, alpha ~ similarity.

Testing

- We apply the method to the original Kindler et al. (2014) series from which the templates were extracted and show it can identify the D-Os in the original series [Figure 9]. Note it also finds e.g. 19.1, not typically labelled as a "full" GI, as well as 4 other small events not so recognised.

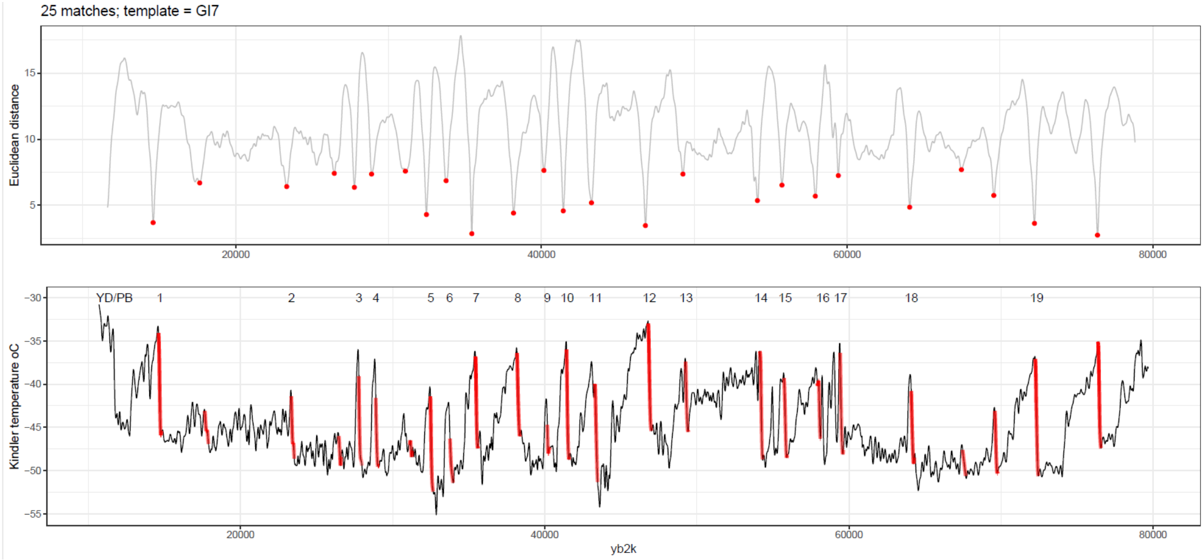

Figure 9. Identifying D-Os in the original series from which the templates were extracted. Upper panel: distance curve (low = more similar) for GI 7, with most D-O-like points in red. Lower panel: original Kindler et al. (2014) series, with identified stretches highlighted in red, alpha ~ similarity.

- As a second test, we apply Superposed Epoch Analysis (SEA), which examines the consistency of an apparent repeating pattern. In SEA, windows centred on repeating events in a time series are superimposed and averaged, and then compared with randomly chosen windows from the same series to find the probability that the averaged pattern would emerge by chance. As an example, [Figure 10] shows a consistent shape of warming and cooling across different GIs in the Greenland data, which is very unlikely to arise by chance.
- Only if the age model were in line with the GICC05 dates would the shapes of the GIs in the reconstructions line up and a consistent pattern emerge. To test this, we apply SEA to the reconstruction dated using (a) using the original age model and (b) the restated model, centring windows on the GICC05 dates of GI initiation in both cases.
- In [Figure 11b] we use the revised age model, and the GI shape is consistently found, confirming that we identified warmings well. In [Figure 11a] we use the original age model, and the absence of a clear GI shape shows that the dates originally attributed to the reconstruction do not identify warmings well, and that our revised age model is an improvement. The underlying sampling resolution of the core is less than that of the Greenland series, so the warming appears less sharp than in [Figure 10].

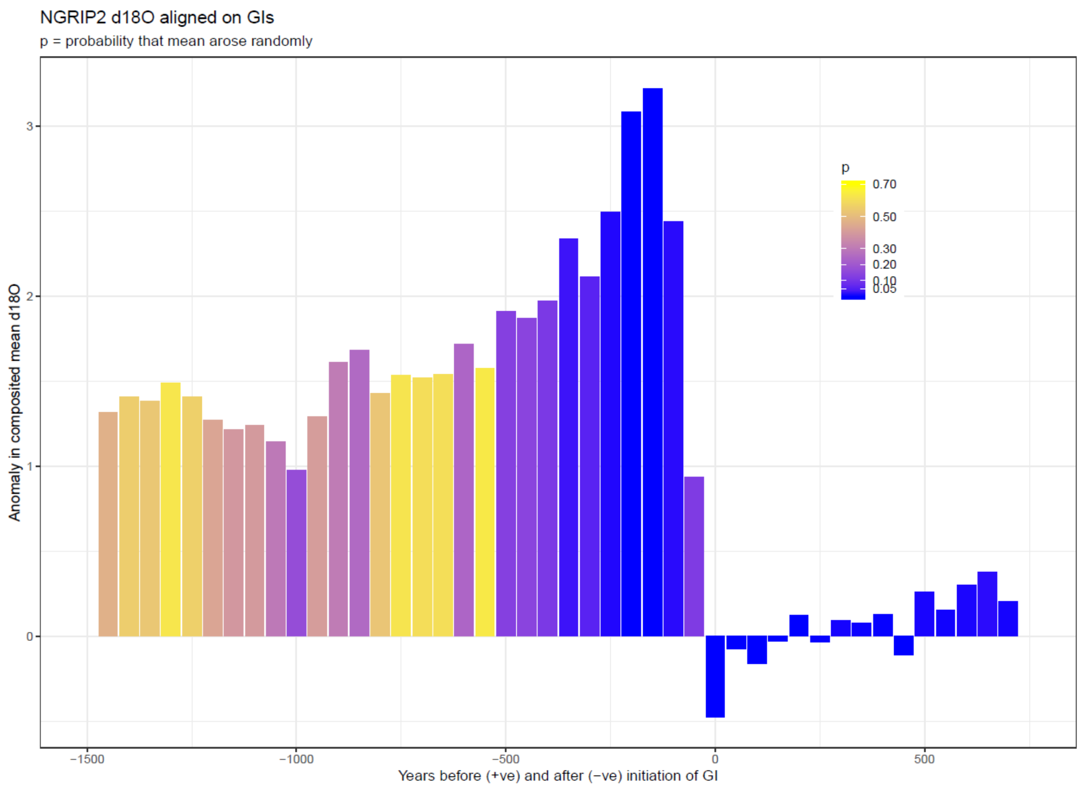

Figure 10. Superposed Epoch Analysis of NGRIP $\delta^{18}O$ series, showing strong pattern centred on warming, and low probability of it arising by chance, with less certainty in "tail" as temperatures decline, since GIs differ in their duration. Resolution and bin width is 50 years.

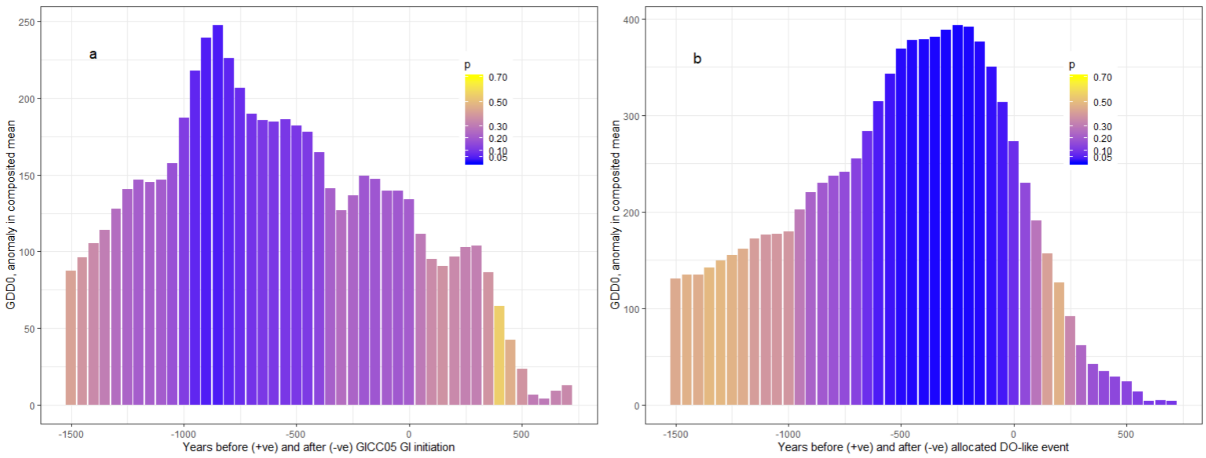

Figure 11. Superposed Epoch Analysis of GDD0 at Lagaccione. Windows are centred on GICC05 dates of GI initiations: **a**: using the original age model; **b**: using the restated age model.

Conclusions

- Using pattern matching, D-Os can be identified in pollen-based reconstructions of the climate of the last glacial period using pollen cores from S Europe.
- These D-Os can be plausibly aligned with Greenland events and revised age/depth models developed.
- However, (1) not all Greenland-evidenced D-Os are sufficiently well registered in the pollen cores to be clearly identified, and (2) there are rapid climate changes evidenced in the pollen cores that do not seem to match recognised Greenland events.

References

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Contact

m.g.turner@pgr.reading.ac.uk