Predicting past tipping points: The Dansgaard-Oeschger events of the last glacial period

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Summary

- The last glacial period has been frequently interrupted by abrupt warming events, the cause of which is still debated
- Due to their repeated occurrence, they can be analyzed statistically and compared with several dynamical mechanisms associated with tipping points, such as noise-induced transitions or bifurcations.
- Here, we present a novel analysis of Greenland ice core records, which reveals that the timing of the abrupt transitions can be predicted from gradual, linear trends preceding the individual events
- As a consquence, the events cannot be purely noise-induced. A deeper understanding of the proxy trends identified here will help to solve the puzzle of the cause underlying these abrupt climate changes.

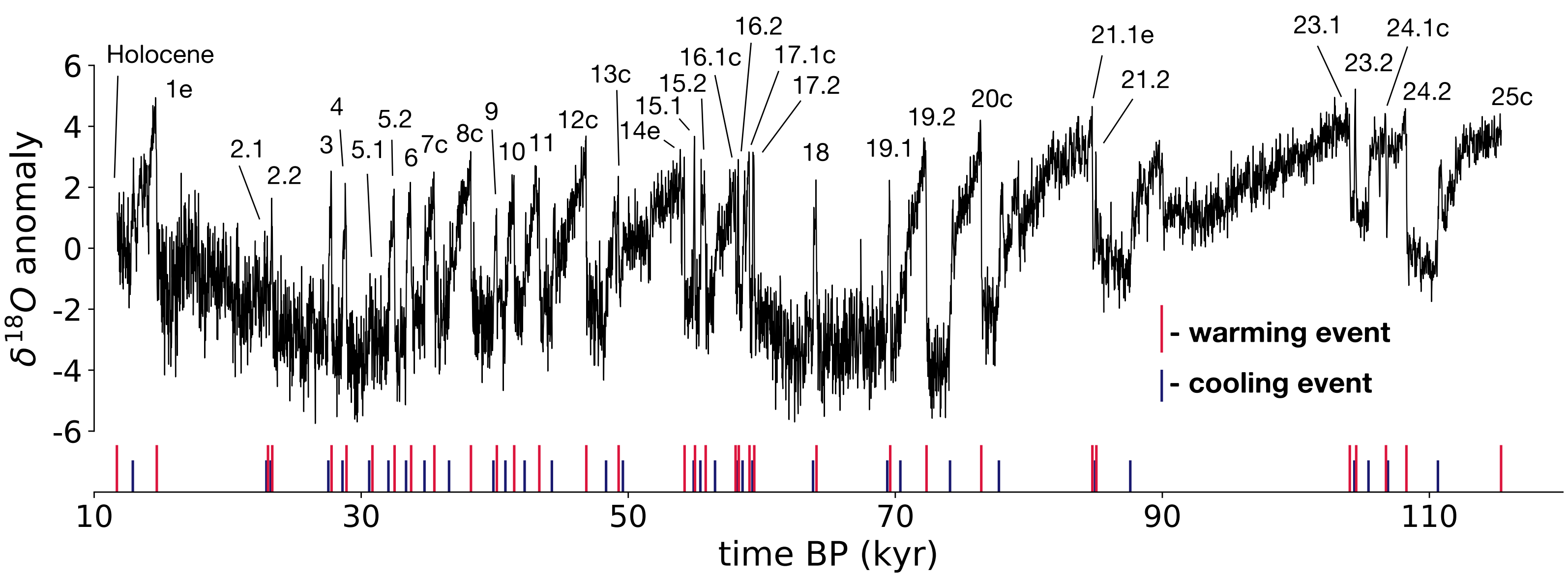

Fig. 1: Temperature proxy record of the last glacial period from a Greenland ice core, featuring abrupt warming and cooling events in a complex temporal pattern

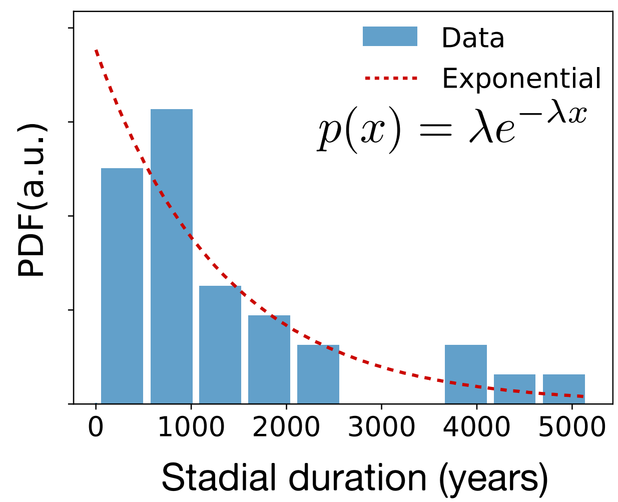

Fig. 2: The distribution of escape times before an abrupt warming is consistent with an exponential, and thus with noise-induced transitions.

Linear trends of temperature in interstadials and of dust in stadials

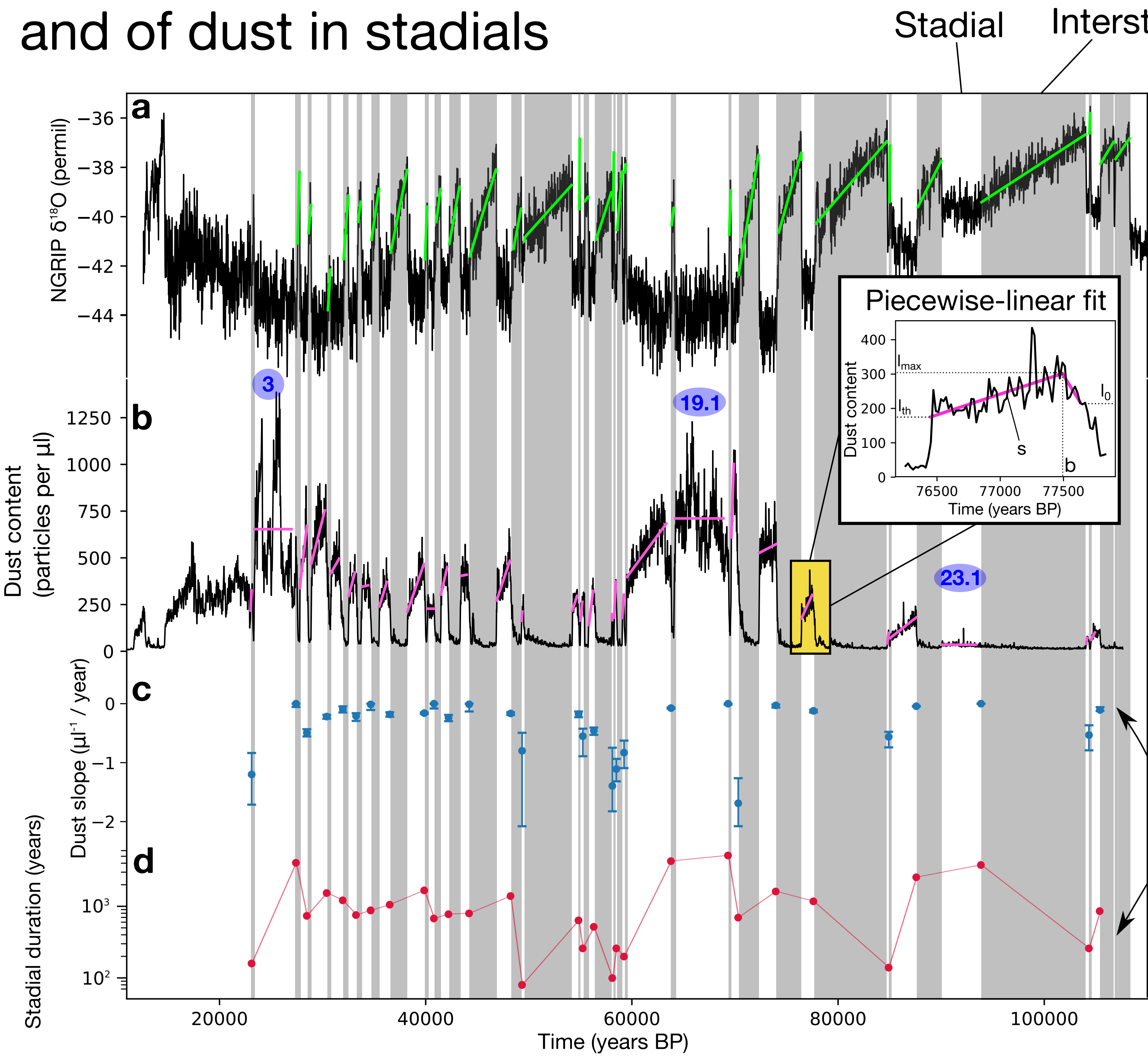

Fig. 3: **a** Temperature proxy from the NGRIP ice core, with gradual, linear downward trends in the interstadials (green). **b** NGRIP dust content record, with linear downward trends in the stadials (pink). **c** Linear dust slopes estimated by a piecewise-linear fit (see inset in b). **d** Duration of the stadials, indicated at the respective times of onset.

= Outlier

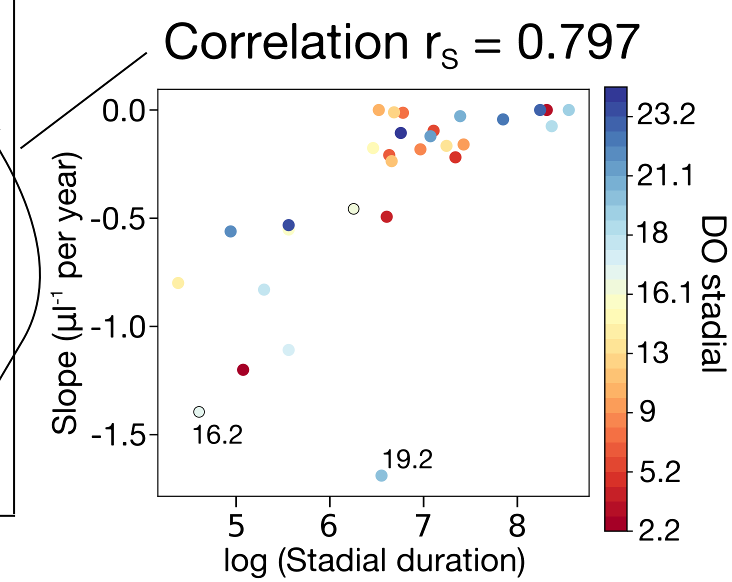

Fig. 4: Significant correlation of stadial dust trends and stadial durations

Methods: Prediction of the DO onsets from the stadial dust record via two empirical findings

1. The dust slope s is well-defined from a data interval shortly after stadial onset, yielding significant information about the stadial duration D. We choose a slice length of 320 years.

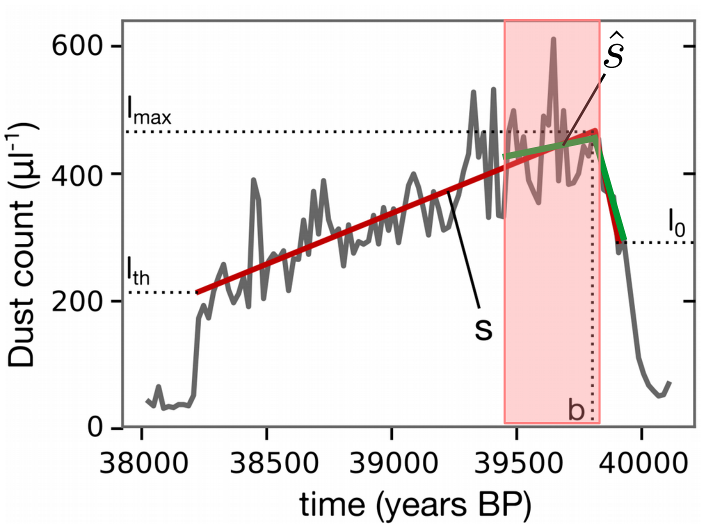

Fig. 5: Data slice starting at a stadial onset b (red shading), and estimated slope ŝ and maximum l_{max} from piecewise-linear fit (green).

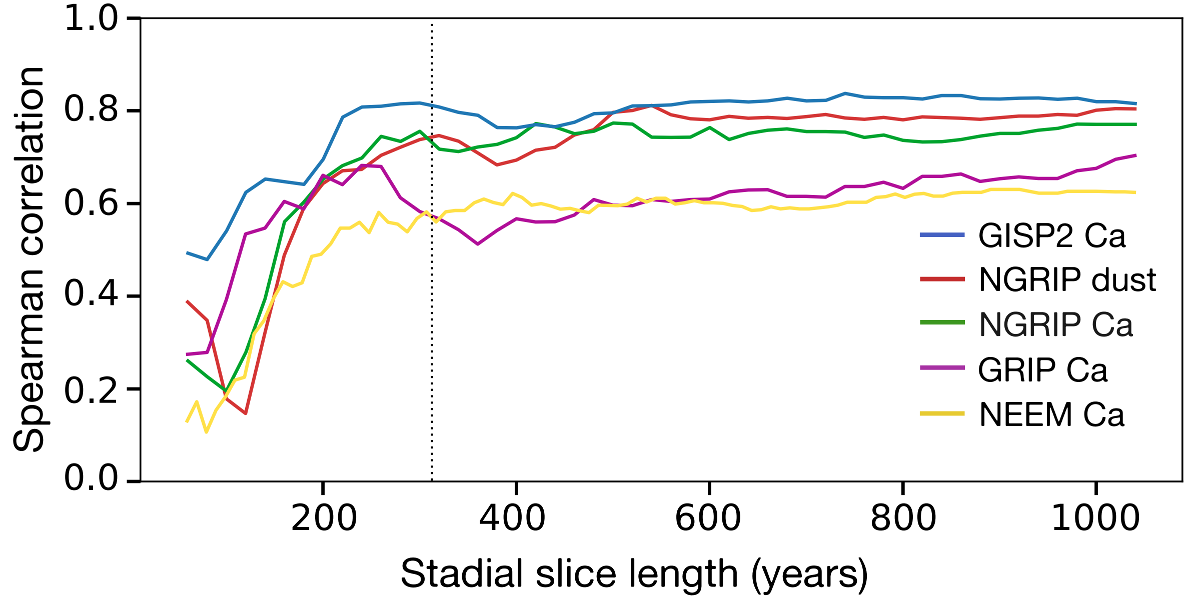

Fig. 6: Correlation of stadial duration D and dust slope s estimated from slices starting at the stadial onset as a function of the length of these slices. Five different ice core recods are shown.

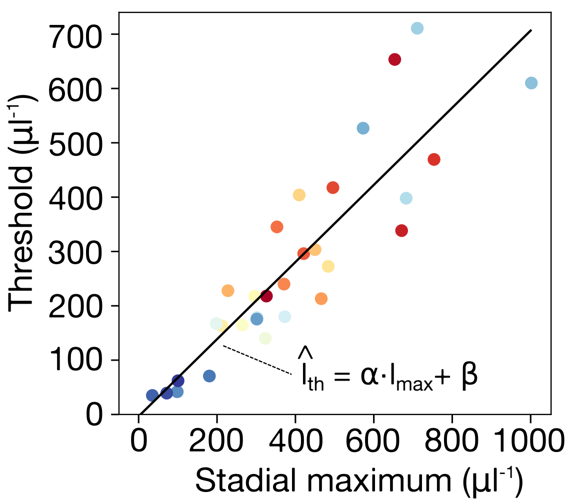

Fig. 7: Dust threshold l_{th} vs. stadial maximum l_{max}. The linear fit is used to estimate l_{th} from a given observed l_{max}.

2. The dust value l_{th} at the following DO warming can be estimated from the maximum after stadial onset (Fig. 7)

Since by definition:

$$D = \frac{l_{th} - l_{max}}{s}$$

we can predict the duration by:

$$\hat{D} = \frac{\hat{l_{th}} - l_{max}}{\hat{s}} = \frac{(\alpha - 1) l_{max} + \beta}{\hat{s}}$$

Results: Prediction of DO stadial durations and statistical significance

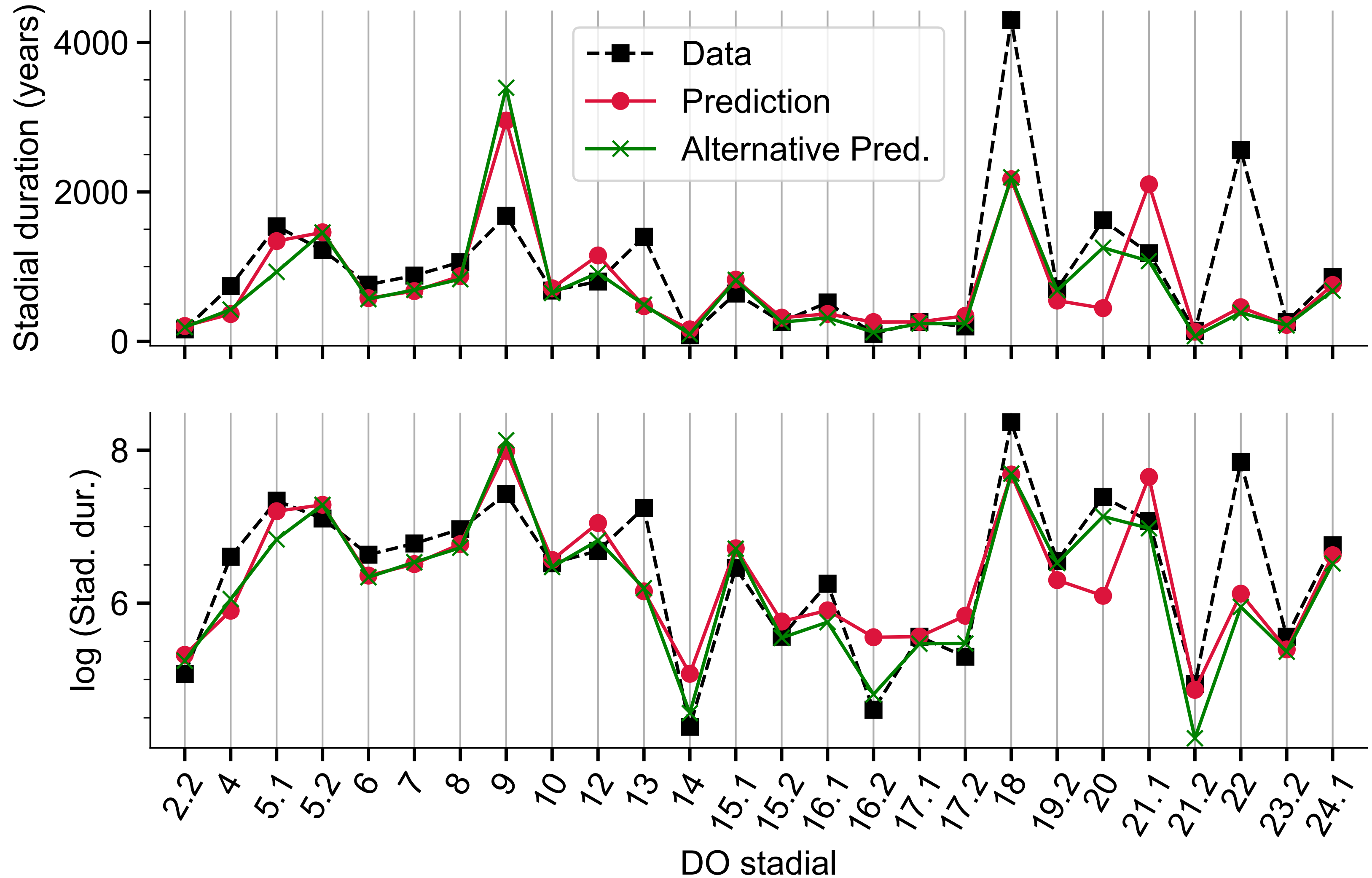

Fig. 8: Predicted and observed stadial durations. The lower panel shows the logarithm of the stadial duration to show that the prediction is able to capture the different orders of magnitude of observed durations. Whereas the red dots indicate a prediction where only information from past stadials is used, the green crosses show a leave-one-out prediction of the entire ensemble of stadials in the last glacial.

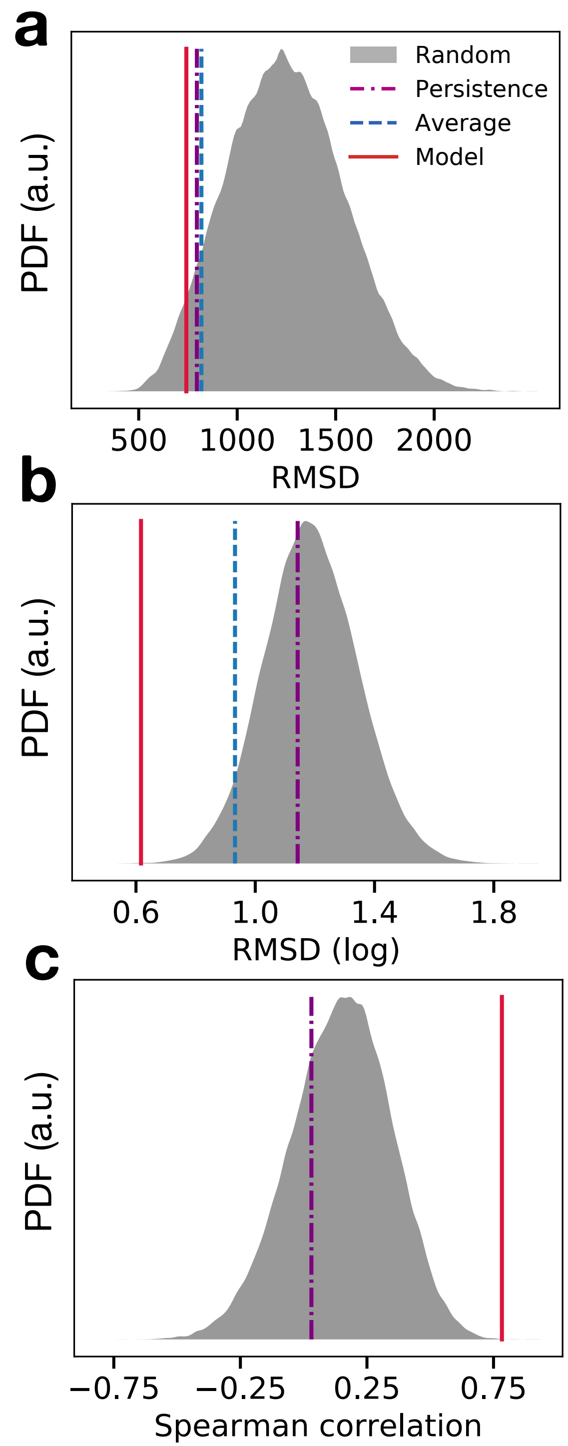

Fig. 9: Comparison of **a** RMSD, **b** RMSD of the logarithm, and **c** correlation of data and prediction against three different null hypothesis models

Conclusion and outlook

- Our prediction of DO warming onsets is significantly better than typical null models.
  The results presented here can be found in the publication:
  Johannes Lohmann: "Prediction of Dansgaard-Oeschger Events From Greenland Dust Records"
  Geophys. Res. Lett. **46** (21), 12427-12434 (2019)

- Still, the prediction is not perfect and there remains room for other (potentially stochastic) triggers to influence the timing of the events

- We performed a similar analysis for interstadial trends, which also indicates predictability for the DO cooling transitions
  See: Johannes Lohmann, Peter D. Ditlevsen: "Objective extraction and analysis of statistical features of Dansgaard-Oeschger events" Clim. Past, **15**, 1771-1792 (2019)

Future research should investigate:

1. What physically drives the proxy trends underlying the predictability
2. How to reconcile their strong variation from event to event with their determinism