Natural periodicities and Northern-Southern Hemisphere connection of temperature changes during the last glacial period: EPICA and NGRIP data sets revisited

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Summary

1. Introduction: Climate variability
2. Data & Methods: Paleoclimate records and EMD
3. Results: Short/Long timescale dynamics and cross-correlation analysis
4. Statistical analysis: climate equilibrium states
5. Conclusions

T. Alberti et al.,
"Natural periodicities and Northern Hemisphere–Southern Hemisphere connection of fast temperature changes during the last glacial period: EPICA and NGRIP revisited",
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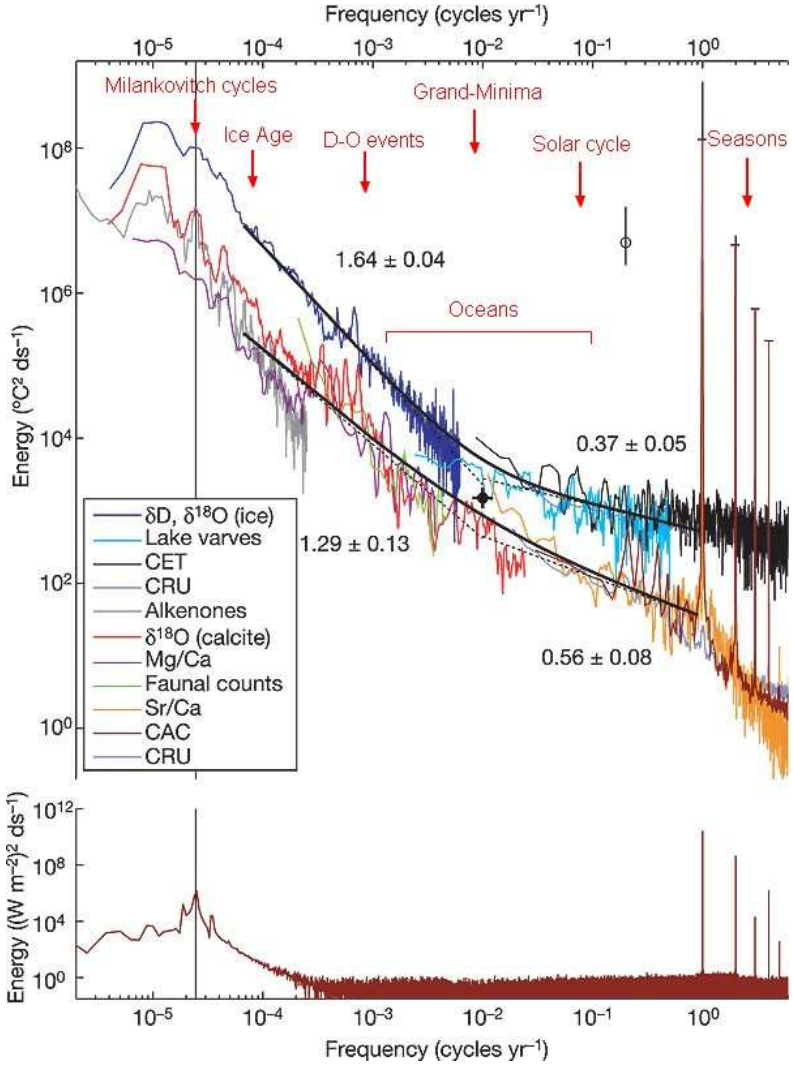
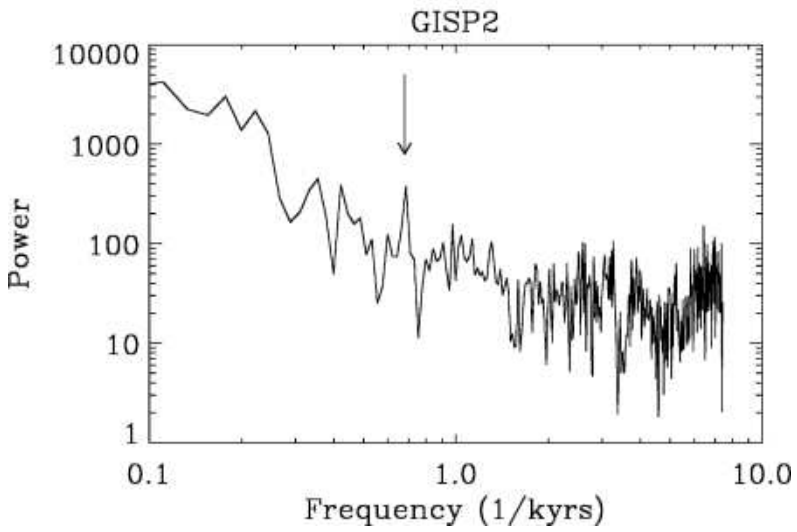
Introduction



- Existence of the climate variability at all timescales [P. Huybers, Nature (2006)]
- Two clear peaks in the Fourier spectrum:
  1. Annual/Seasonal variations
  2. Milankovitch cycles
- Continuous spectrum
  - Solar cycles
  - Dansgaard-Oeschger events
- Analysis of paleoclimatic time series

Dansgaard-Oeschger events

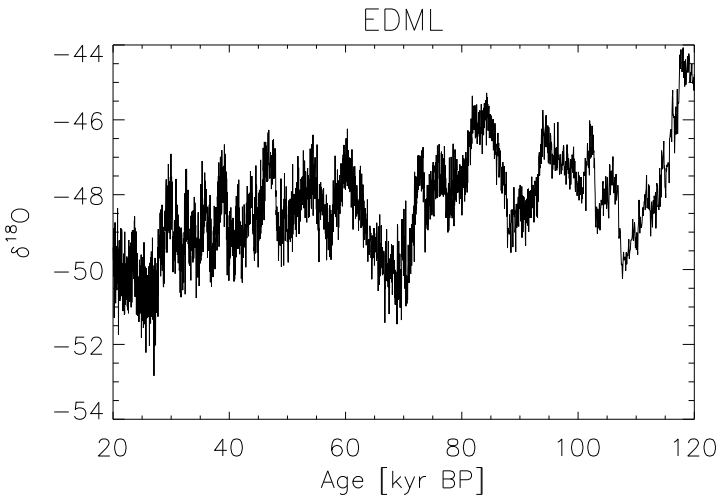


- Rapid climate fluctuations [W. Dansgaard et al., Nature (1993)]
- Mean period $\sim$ 1470 years [S. Rahmstorf, GRL (2003)]
- Causes
  - Solar forcing?
  - Thermohaline circulation?
  - Atmospheric circulation?
  - Changes in sea-ice cover?

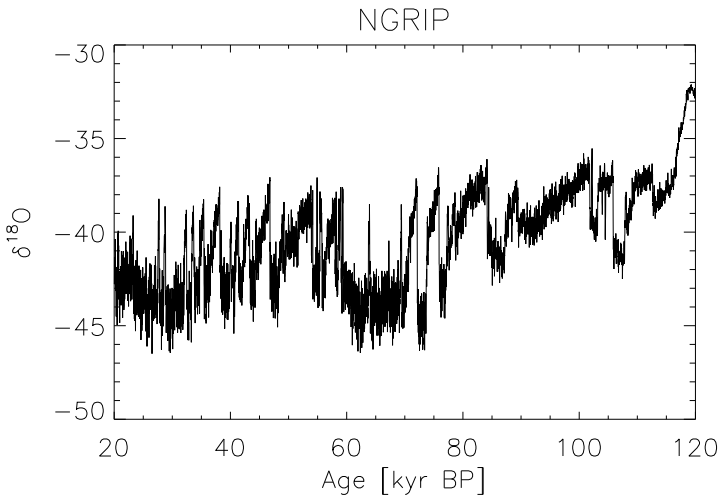
Paleoclimatic records

- Analysis of $\delta^{18}O$ time series
- Direct connection with temperature variations

- South Pole



- North Pole



Empirical Mode Decomposition (EMD)

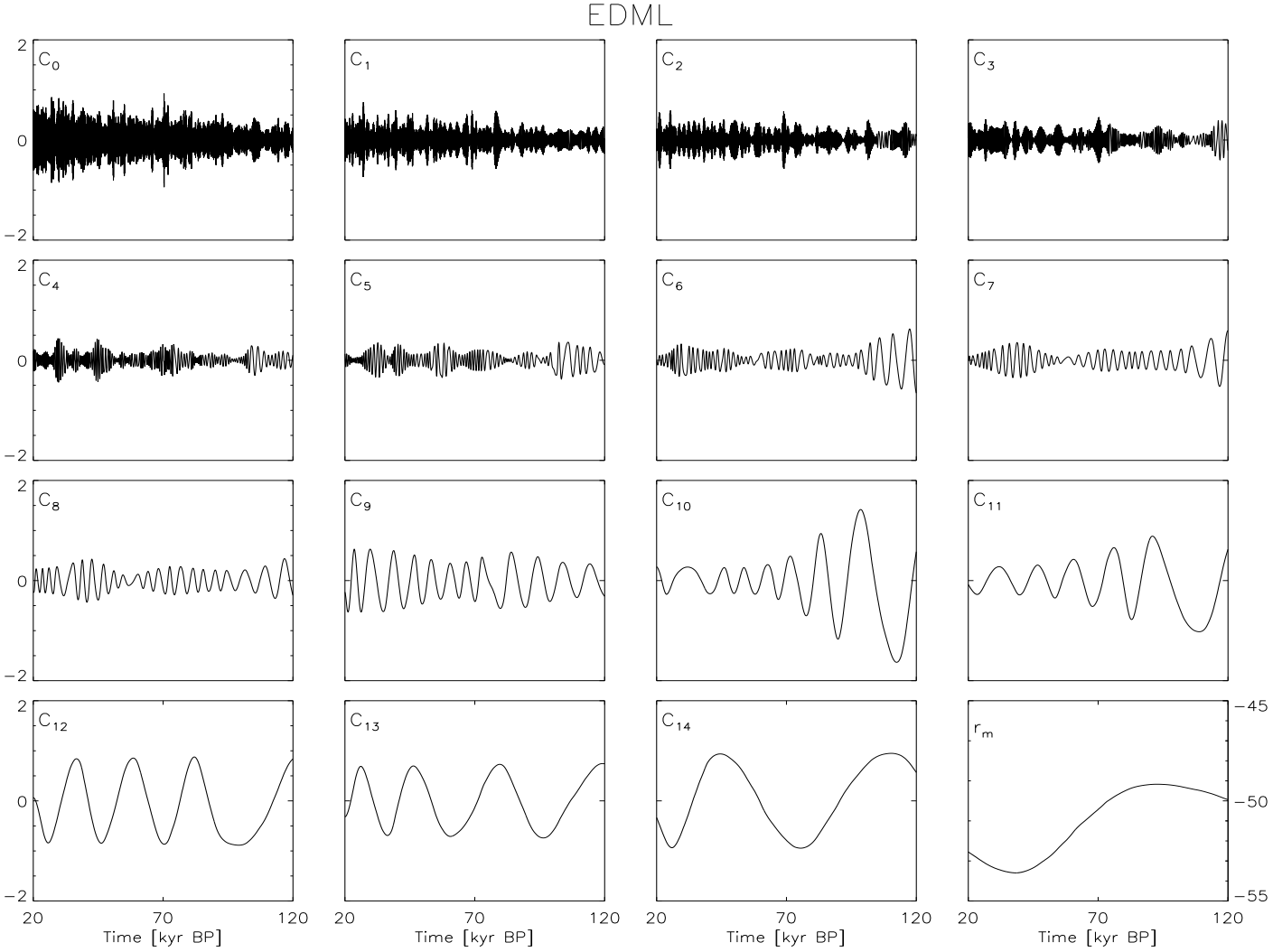
- A posteriori decomposition method useful for nonlinear and non-stationary datasets [Huang et al., 1998]

$$X(t) = \sum_{j=0}^{m-1} C_j(t) + r_m(t) \tag{1}$$

- $C_j(t)$ is called Intrinsic Mode Function (IMF) and $r_m(t)$ is the residue of the decomposition
- Through the Hilbert Transform, it is possible to write $C_j(t) = A_j(t)\cos[\Phi_j(t)]$
- Instantaneous frequency can be derived as $\omega_j(t) = d\Phi_j(t)/dt$.
- For each IMF, we can obtain a characteristic mean period as $T_j = \frac{2\pi}{<\omega_j(t)>}$
- The set of m IMFs (or empirical modes) is local, complete and orthogonal in all practical sense

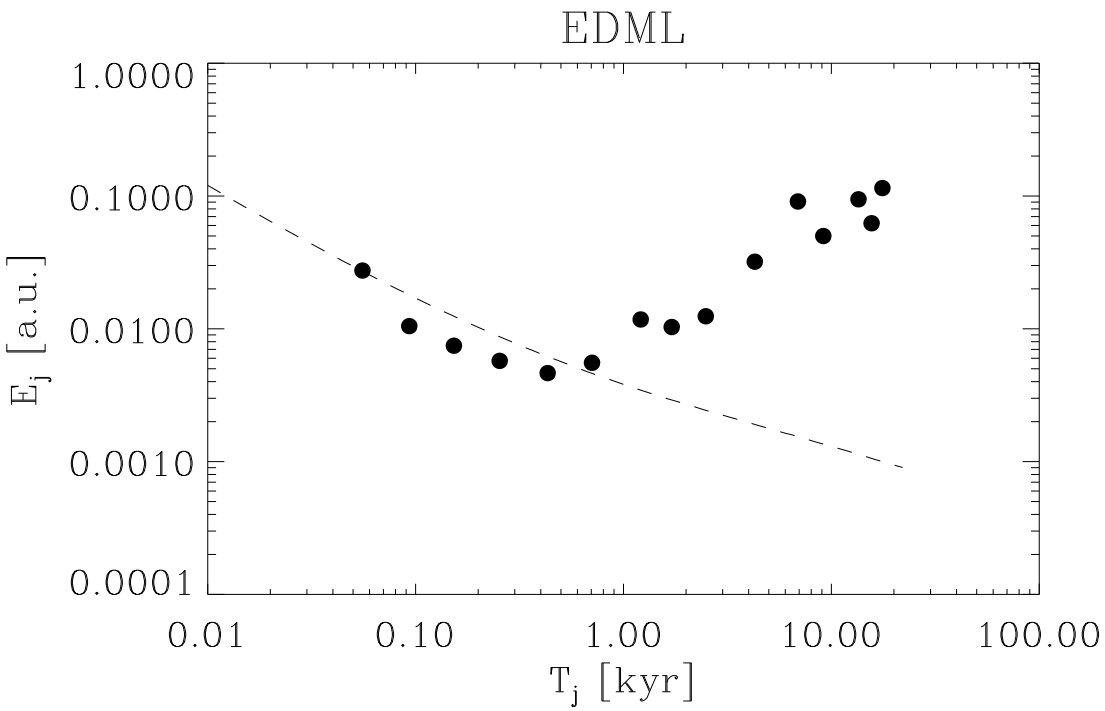
EMD results: EDML dataset

- We obtain a set of $m = 15$ empirical modes



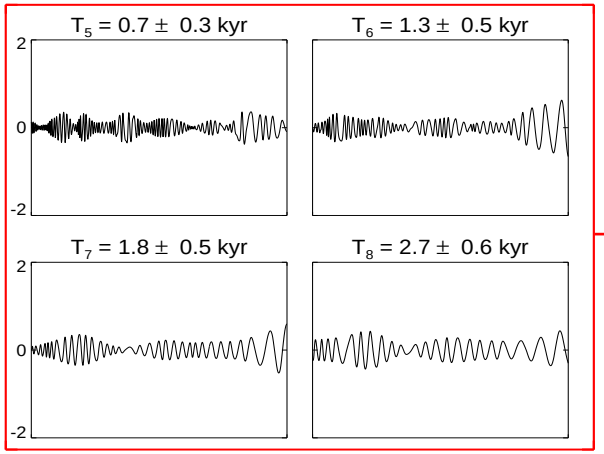
Statistical Significance Test

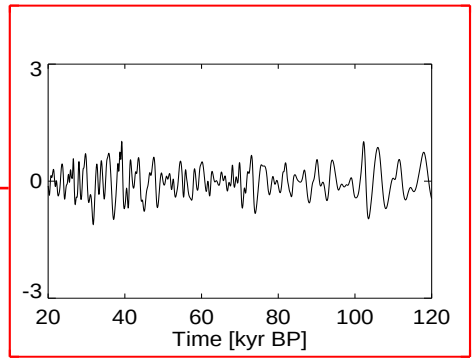
- The statistical significance test [Wu et al., 2004] is useful to discern the IMFs containing information at a given confidence level from purely noisy IMFs.



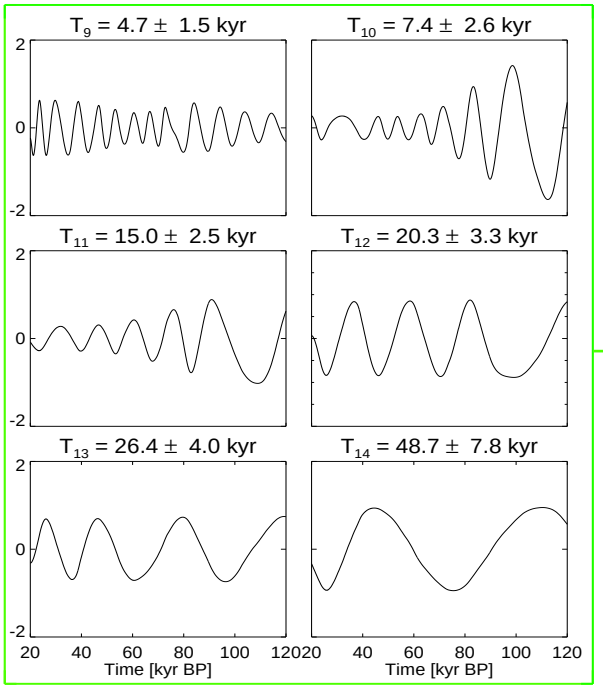
- The dashed line represents the 99*th* percentile, while black dots represent the mean square amplitude of each mode

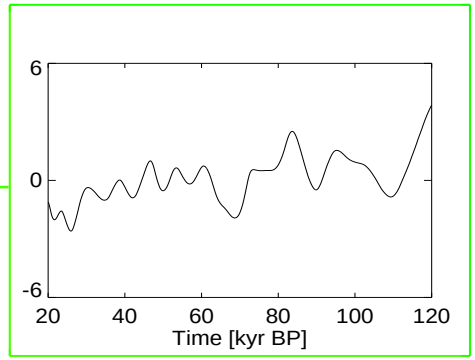
EMD results: Two different contributions





T = 0.7 - 2.7 kyr



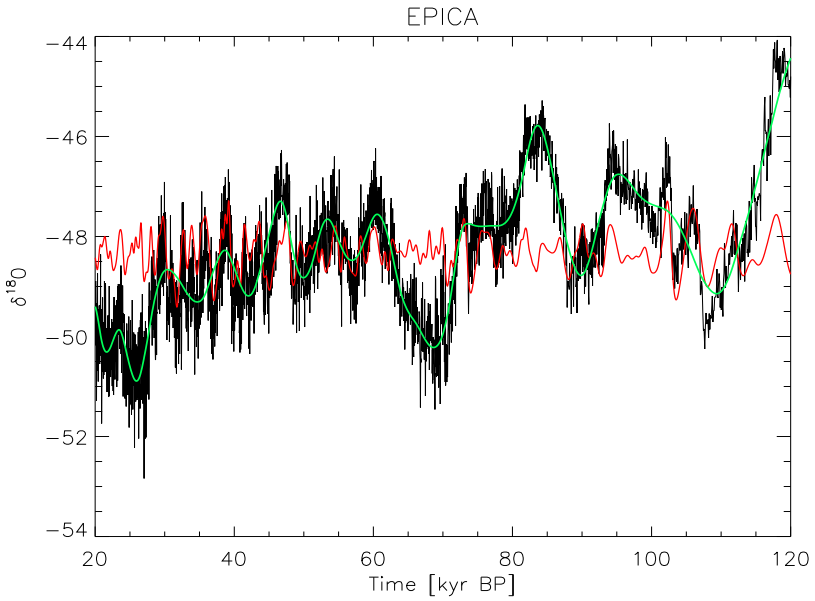


T = 4.7 - 48.7 kyr

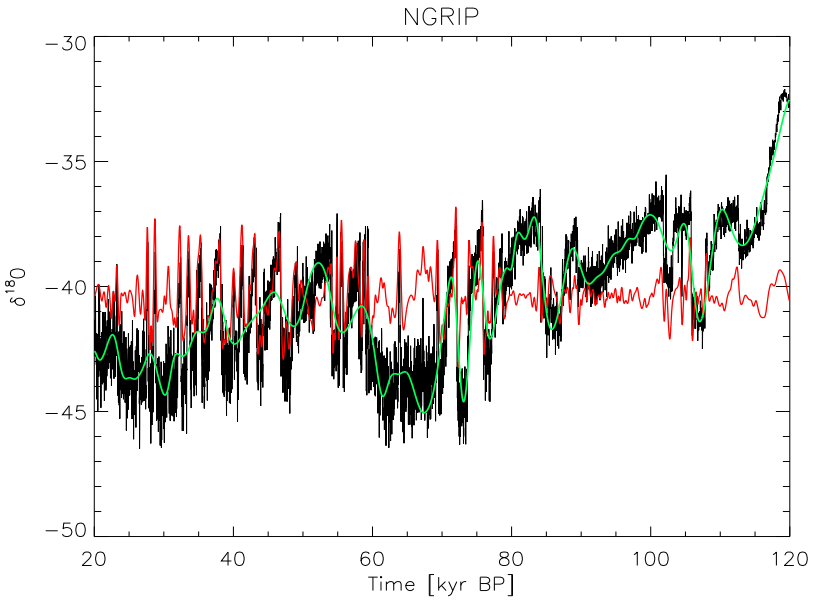
Partial reconstructions

- The same timescale separation is made for NGRIP EMD results

- South Pole



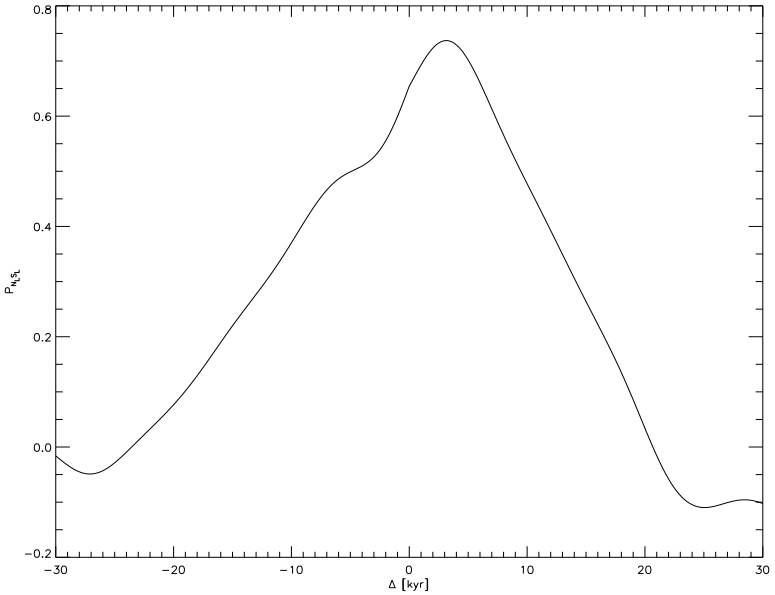
- North Pole



- Short-term reconstruction ⇒ D-O events
- Longer timescale dynamics

Cross-correlation analysis

- How Earth's hemispheres have been coupled during past climate changes? [Blunier et al., 1998]
- Study of the cross-correlation coefficient between the EDML and NGRIP longer timescale reconstructions



- Existence of a North-South asynchrony
- A maximum value of ~ 0.73 and $\Delta = 3.05 \pm 0.19$ kyr
- The Antarctic climate changes actually lead those of Greenland, but on a longer timescale than previously reported [Blunier et al., 1998]

Climate system equilibrium states

- The climate system is described in terms of a nonlinear system with many dynamical states [Livina et al., 2010]
- Transitions among states are triggered by a stochastic forcing

1-D Langevin model

$$dz = -\frac{\partial U(z)}{\partial z} dt + \sigma dW \tag{2}$$

where z is a large-scale climate variable (e.g. $\delta^{18}O$), $U(z)$ is potential function, σ is the noise level and W is a Wiener process.

Fokker-Planck equation

The F-P equation relates the probability density function $\rho(z,t)$ to $U(z)$

$$\frac{\partial \rho}{\partial t} = \frac{\partial}{\partial z}\left[U'(z)\rho(z,t)\right] + \frac{1}{2}\sigma^2 \frac{\partial^2}{\partial z^2}\rho(z,t) \tag{3}$$

Potential function

Stationary solution of F-P equation

$$\rho(z) \sim exp\left[-\frac{2U(z)}{\sigma^2}\right] \tag{4}$$

Potential function

$$U(z) = -\frac{\sigma^2}{2}\ln\rho_d \tag{5}$$

where ρ_d is the empirical probability density function.

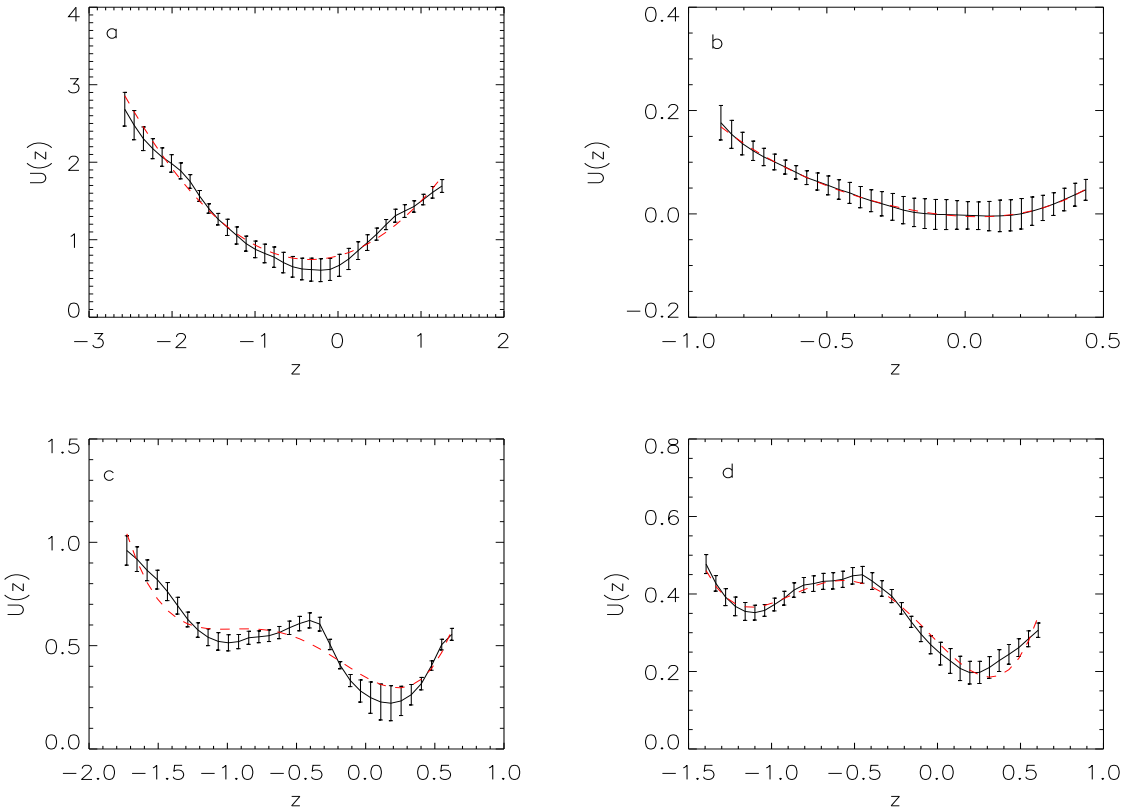
Functional form of $U(z)$

$$U(z) = \sum_{i=0}^{L} a_i z^i \tag{6}$$

where

- L is related to the number of climate states which is $L/2$
- $a_L > 0$ is a necessary condition for the existence of the stationary solution

Extrapolation of the potential



- Short-term dynamics is characterized by a single-well potential function: $L^{D-O} = 2 \Rightarrow 1$ climate state
- Longer timescale dynamics has a double-well potential function: $L^{stad} = 4 \Rightarrow 2$ climate states

Summary & Conclusions

Two range of periods into paleoclimate variability are present

1. Dansgaard-Oeschger events are related to short-term variability
2. Stadial/interstadial switch is representative of climate evolution at longer timescales

Applying cross-correlation analysis between long-term reconstructions we found a clear North-South asynchrony by which Antarctic climate changes lead those of Greenland with a characteristic time delay of ~ 3 kyr

Using a 1-D Langevin model we found that the occurrence of DO events can be described as excitations of the system within the same climate state, while longer timescale dynamics appear to be due to transitions between two different climate states

Thanks for the attention!