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

T. Alberti[1], F. Lepreti[1], A. Vecchio[2], and V. Carbone[1]

[1] *Dipartimento di Fisica, Università della Calabria, Ponte P. Bucci Cubo 31C, 87036 Rende (CS), Italy*
[2] *LESIA-Observatoire de Paris, 5 place Jules Janssen, 92190 Meudon, France*

HS7.4: Change in climate, hydrology and society
EGU General Assembly 2016

1. Introduction: Climate variability

1. Introduction: Climate variability
2. Data & Methods: Paleoclimate records and EMD

1. Introduction: Climate variability
2. Data & Methods: Paleoclimate records and EMD
3. Results: Short/Long timescale dynamics and cross-correlation analysis

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

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

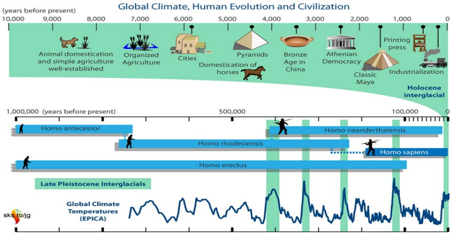
1. Introduction: Climate variability
2. Data & Methods: Paleoclimate records and EMD
3. Results: Short/Long timescale dynamics and cross-correlation analysis
4. Statistical analysis: climate equilibrium states
5. Conclusions

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",
Clim. Past, 10, 1751-1762, 2014, doi:10.5194/cp-10-1751-2014

> "For a very long time, something of contention and debate in the U.S. had been whether or not a lot of climate change has in fact been induced by human activities, while many scientists around the world, Europe especially, have been more convinced that this is the case."
>
> *NASA report*

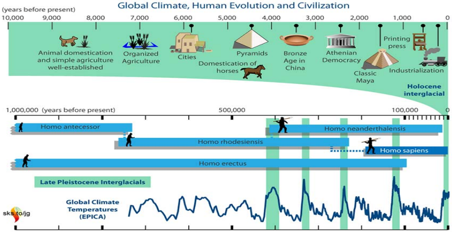
"For a very long time, something of contention and debate in the U.S. had been whether or not a lot of climate change has in fact been induced by human activities, while many scientists around the world, Europe especially, have been more convinced that this is the case."

NASA report



"For a very long time, something of contention and debate in the U.S. had been whether or not a lot of climate change has in fact been induced by human activities, while many scientists around the world, Europe especially, have been more convinced that this is the case."

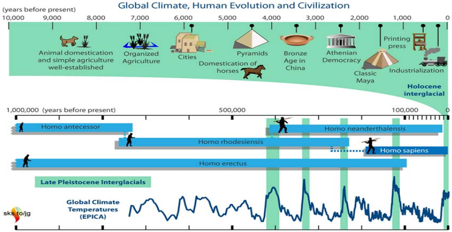
NASA report



- An important question:

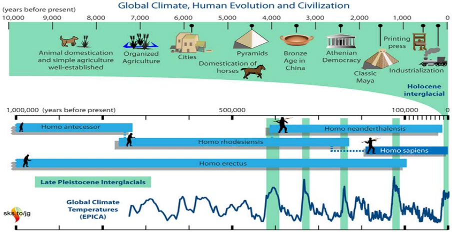
"For a very long time, something of contention and debate in the U.S. had been whether or not a lot of climate change has in fact been induced by human activities, while many scientists around the world, Europe especially, have been more convinced that this is the case."

NASA report

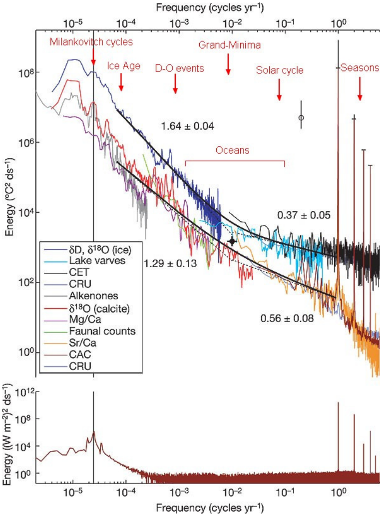


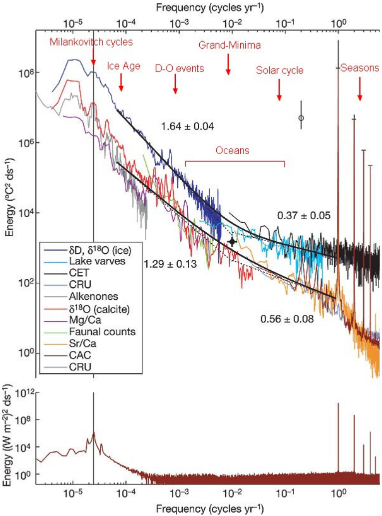
- An important question:
  1. "Are there recurrent cycles in climate variability?"

> "For a very long time, something of contention and debate in the U.S. had been whether or not a lot of climate change has in fact been induced by human activities, while many scientists around the world, Europe especially, have been more convinced that this is the case."
>
> *NASA report*

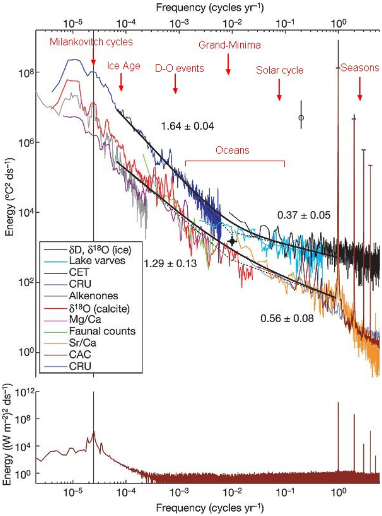


- An important question:
    1. "Are there recurrent cycles in climate variability?"
- The answers is ...

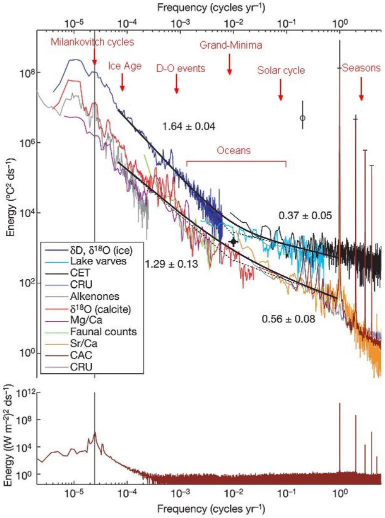

Frequency (cycles yr−1)
Milankovitch cycles
Ice Age
D-O events
Grand-Minima
Solar cycle
Seasons
Oceans
1.64 ± 0.04
0.37 ± 0.05
1.29 ± 0.13
0.56 ± 0.08
Energy (°C² ds−1)
δD, δ18O (ice)
Lake varves
CET
CRU
Alkenones
δ18O (calcite)
Mg/Ca
Faunal counts
Sr/Ca
CAC
CRU
Energy ((W m−2)2 ds−1)
Frequency (cycles yr−1)



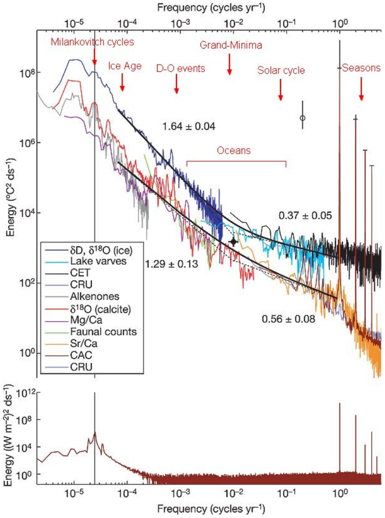
- Existence of the climate variability at all timescales [P. Huybers, Nature (2006)]



- Existence of the climate variability at all timescales [P. Huybers, Nature (2006)]
- Clear peaks in the Fourier spectrum:
  1. Annual/Seasonal variations
  2. Milankovitch cycles



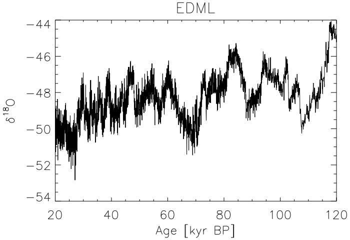
- Existence of the climate variability at all timescales [P. Huybers, Nature (2006)]
- Clear peaks in the Fourier spectrum:
  1. Annual/Seasonal variations
  2. Milankovitch cycles
- Continuous spectrum
  - Solar cycles
  - DO events



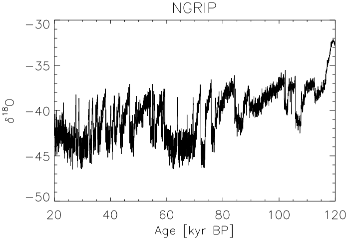
- Existence of the climate variability at all timescales [P. Huybers, Nature (2006)]
- Clear peaks in the Fourier spectrum:
  1. Annual/Seasonal variations
  2. Milankovitch cycles
- Continuous spectrum
  - Solar cycles
  - DO events
- Our analysis focused on the continous part of the spectrum

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

- South Pole



- North Pole

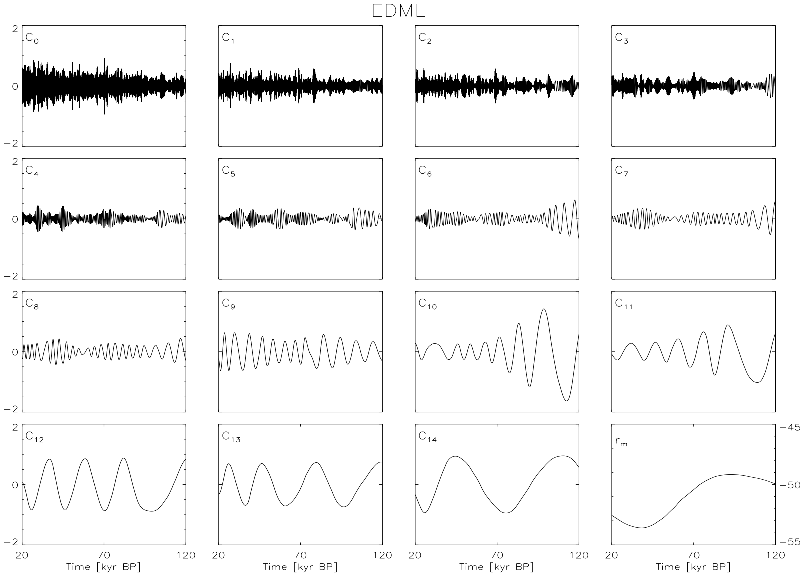


- A posteriori decomposition method useful for nonlinear and non-stationary datasets [Huang et al., 1998]

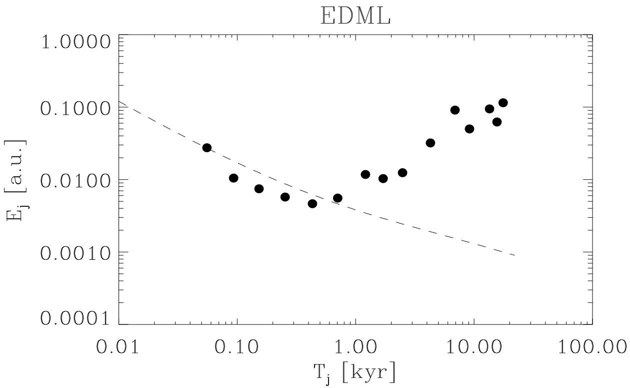
$$X(t) = \sum_{j=0}^{m-1} C_j(t) + r_m(t) \quad (1)$$

- $C_j(t)$ 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

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

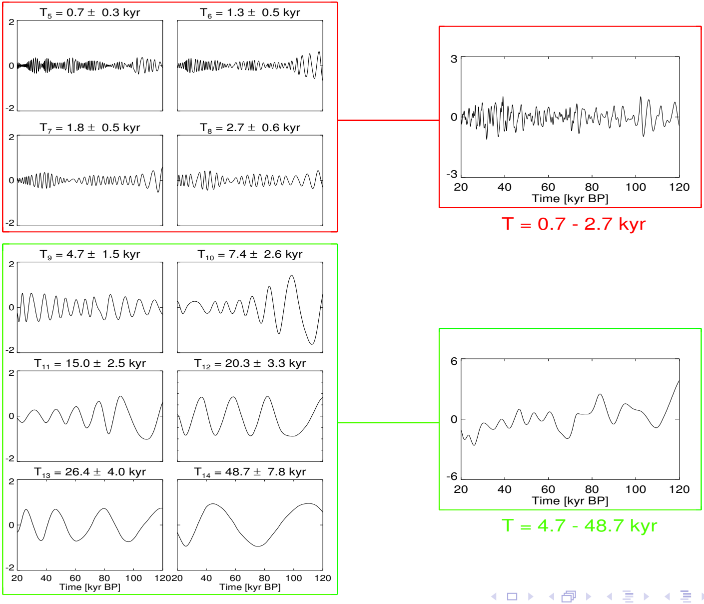


- The statistical significance test [Wu et al., 2004] is useful to discern the IMFs containing information at a given confidence level from purely noisy IMFs.

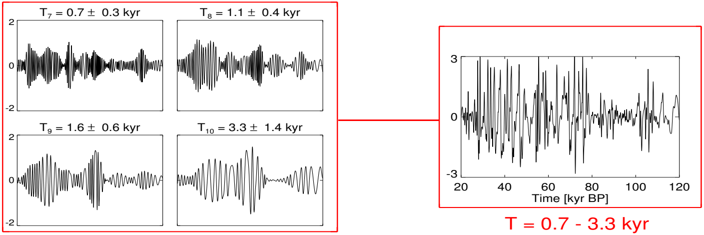


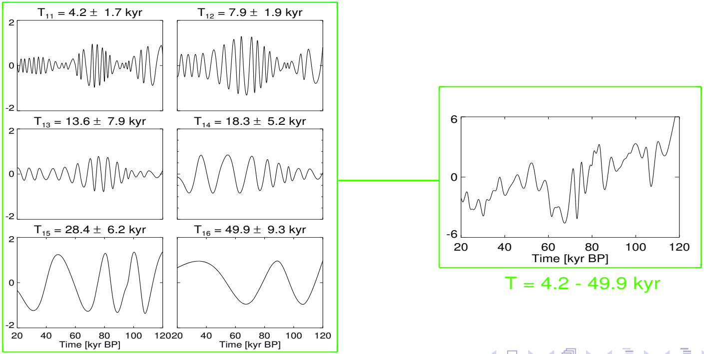
- The dashed line represents the 99*th* percentile, while black dots represent the mean square amplitude of each mode

- EDML analysis



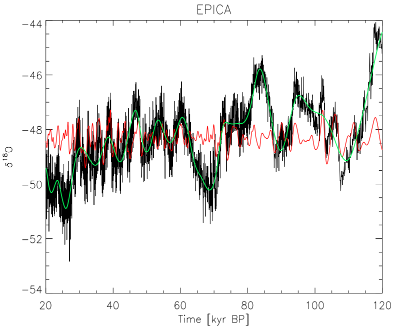
- NGRIP analysis

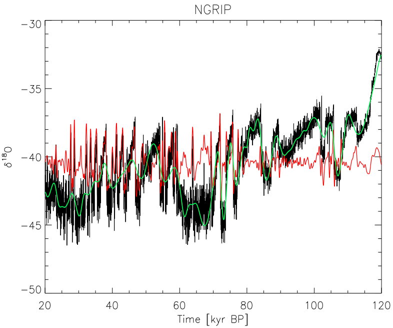




- A timescale separation is found through EMD technique

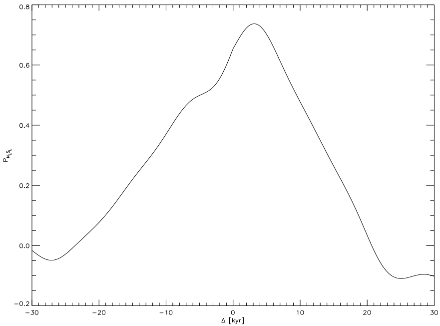
  - South Pole
  - North Pole





- Short-term reconstruction ⇒ D-O events
- Longer timescale dynamics ⇒ cooling/warming cycles

- 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]

- 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 $U(z)$

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

Stationary solution of F-P equation

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

Potential function

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

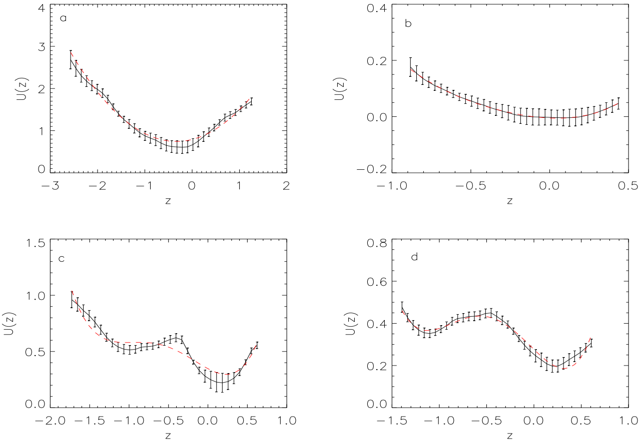
where ρ_d is the empirical probability density function.

Functional form of $U(z)$

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

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



- 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

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

1. "Are there recurrent cycles in climate variability?"

- Yes, there are recurrent cycles in the continous part of the spectrum of the climate variability. This cycles are not connected to DO events or to Milankovitch orbital variations ($\sim 10^5$ yr) but are related to a variability on time scales between 5 and 50 kyr.

Thanks for the attention!