VERY LONG TIME SCALE SIGNATURE OF INTERMITTENCY IN THE ATMOSPHERIC FLOW

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The climate of the Earth is the long term mean of the state of the atmospheric – and oceanic flows. As a practice, more or less arbitrarily, 30 years averages defines climate. Is this long term mean at all influenced by the much shorter time – and spatial scale turbulence of the underlying dynamical system? The answer to this provocative question is that some indications that it does can be found in paleoclimatic records. Detailed timeseries of climatic proxies have been obtained from cores drilled in the Greenland ice-sheet [1]. These records have a temporal resolution of about 1–5 years from present to 90 kyrs B.P. This enables us to separate, by spectral filtering, dynamics of long timescales changes (climate) and short timescales (atmosphere/ocean fluctuations). The analysis of the isotope temperature proxy shows that the state of the fast timescale flow was different in the glacial climate in comparison to the present climate [2]. Figure 1 shows the $\delta^{18}O$ temperature proxy signal. (a) is the full signal while (b) is the 100 years running mean and (c) is the residual. The envelop of the residual is proportional to the degree of glaciation. This indicates that the atmosphere was in in a more stormy and turbulent state in the glacial climate.

A higher temporal resolution parameter is the content of dust in the ice-core [3]. Dust taken up from the continents is passively advected in the atmosphere and deposited with precipitation on the ice. The dust record is an indirect proxy for the state of the climatic system and wind strengths in the atmosphere.

Standard models (stochastic climate models [4]) of the climatic changes are that they are noise triggered, where the noise is the fast atmospheric fluctuations forcing the climate from one stable state to another. This type of dynamics is described by a Langevin equation, $dy = -(dU/dy)dt + \sigma dL$.

This model can be tested against the dust record. Here the requirement that the drift-term can be neglected in comparison to the diffusion-term from one measurement point to the next is fulfilled. It turns out that this

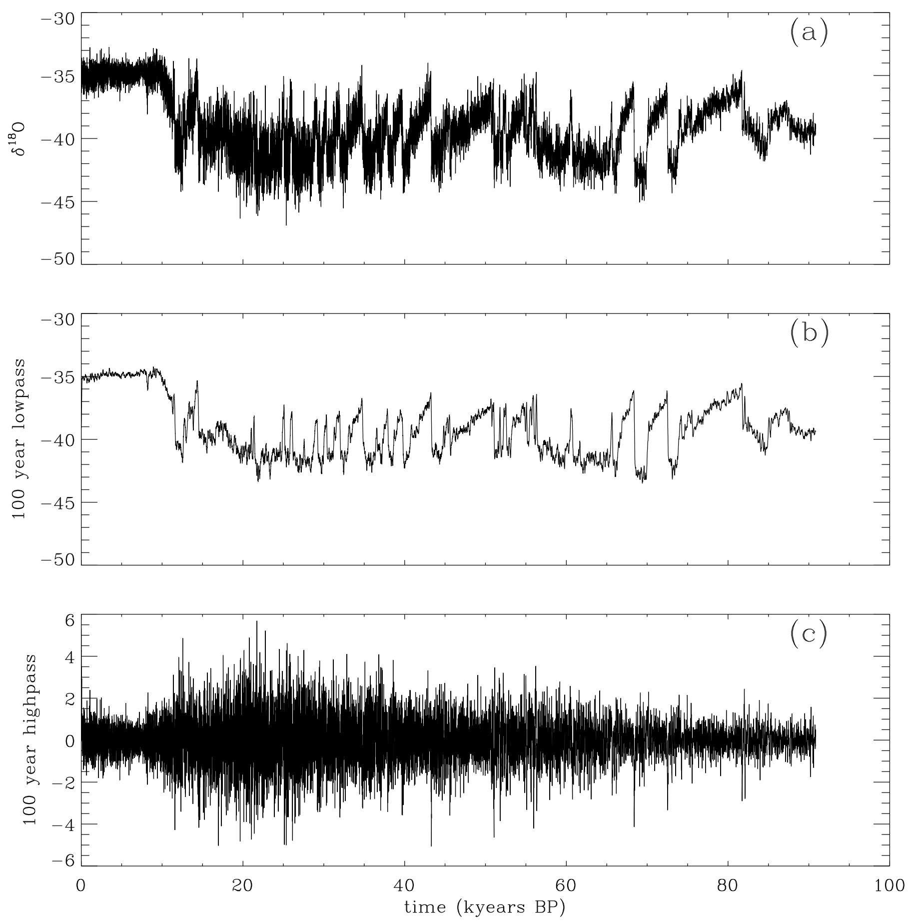

Figure 1. (a) The $\delta^{18}O$ in per mil deviation from standard mean ocean water. This is a paleo-temperature proxy. (b) is the 100 years running mean representing the slowly varying components of the climate. (c) is the residual ((a)–(b)) representing the fast components of the climate including the atmospheric temperature variations. The envelop indicates a more variable atmosphere in the glacial climate.

dynamics is consistent with the dust record. However, for this to be true, the noise is not gaussian white noise but a compound noise with an α-stable white noise component with $\alpha = 1.75$ [5]. The α-stable distributions are characterized by power-law tails, such that only moments of order less than α exists ($\langle |x|^\beta \rangle = \infty$ for $\beta \geq \alpha$). These distributions fulfill a generalized version of the central limit theorem, namely that sums of α-stable stochastic variables are again α-stable, with the same value of α.

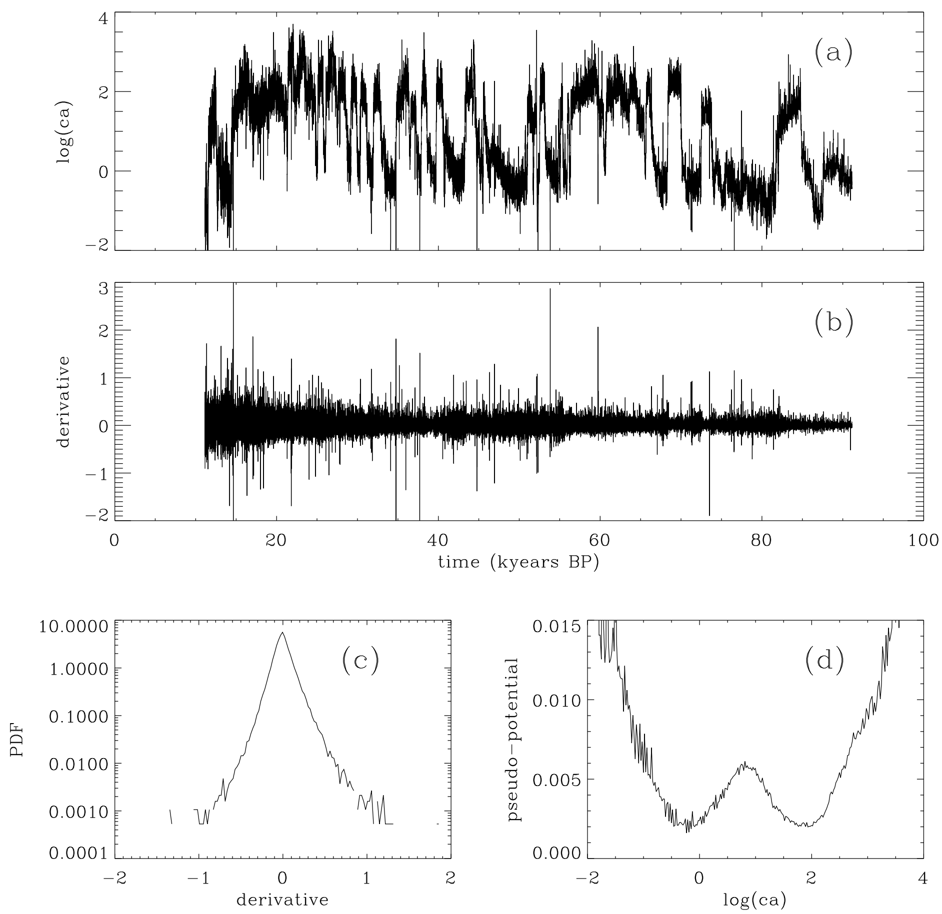

Figure 2. (a) The logarithm of the calcium record from the GRIP ice-core. This record only covers the glacial period. The calcium originates from dust transported through the atmosphere and deposited with snow onto the ice-sheet. The resolution is roughly annual down to 90 kyr BP. (b) is the derivative of log(ca), represented by the annual increments. (c) is the probability density of (b), which is strongly intermittent. (d) is the climate pseudo-potential. The two climatic states represented by the minima are the full glacial state and the interstadials. They are clearly seen in figure 1 (b).

Figure 2 shows the log(ca) record and its derivative which approximates the noise component in the Langevin equation. Figure 2 (c) shows that this noise is very intermittent. The record has a bimodal distribution, with shifts between a cold glacial climate and warmer interstadials. Figure 2 (d) shows the climate pseudo-potential U. This is derived using the Fokker-Planck equation. The two stable states probably represents two states of the Atlantic ocean circulation. The ocean circulation is forced by the wind shear and the wind induced evaporation. The consistency of the analysis has been tested by simulation of the Langevin equation where an excellent statistical agreement with data is obtained.

The α-stable distribution for the fast atmospheric fluctuations originates from the dynamics of the flow. A hypothesis is that it is a result of the turbulent nature of the flow which manifests itself on these very long timescales. For this record the fast timescales are annual means. This is still an extremely long timescale in comparison to the turbulent flow. The direct measurements of the state of the atmosphere covers a period of roughly 100 years which is short on climatological time scales. We know that the atmospheric flow on other planets are rather different from the flow on the Earth, so we might expect that a different climate, like the glacial, could lead to a different state of the atmospheric flow. The only evidence we have for that is through these admittedly very indirect paleoclimatic records. It is therefore important to increase our understanding of the relationship between these records and the underlying climate dynamics.

If the interpretation presented in this analysis is correct it questions the validity of any of the present day climate models. All general circulation models, used for assessing climate change scenarios, are coarse resolution models for which all effects of turbulence have been smoothed out and parametrized by large scale eddy diffusion. No extreme event will ever be captured in these models. The findings here indicates that these extreme events actually can play a role in triggering climatic changes.

References

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