Dansgaard–Oeschger events: bifurcations in the climate system.

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Introduction

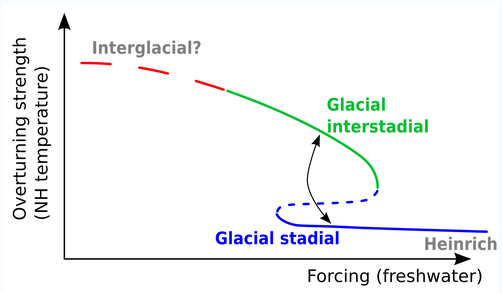
Dansgaard–Oeschger events represent the largest variability during last glacial age:

- Fast warming in the North Atlantic region (5–10°C in few decades)
- Slow cooling lasting hundrends to thousands of years
- Periodicity of approximately 1500 years

Common hypothesis:
connection with thermohaline circulation (THC).

Multiple equilibria

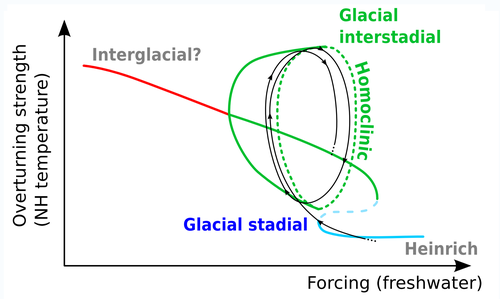
Response of THC (double saddle node structure) to an external forcing (noise+periodic component):



The basic mechanism is that of stochastic resonance [1].

Periodic orbits

Interplay between THC and ice dynamics:



In connection with the presence of a fold-Hopf bifurcation, the system can undergo series of DO-events cycling close to a Homoclinic orbit [2].

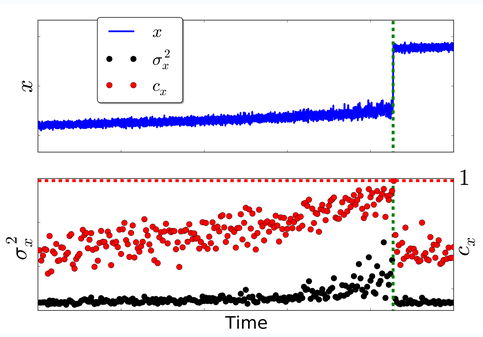
From *early warnings*...

An approaching bifurcation can be associated with critical slowing down [3, 4].

- Slower decay of fluctuations = Increased autocorrelation c and DFA exponent α
- Larger fluctuations = Increased variance σ^2

...to *noise signatures*...

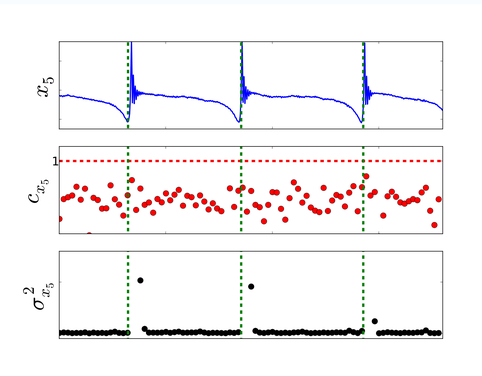
For a slowly changing parameter forcing a system to undergo a fold bifurcation we have a clear signature in the c, α and σ^2:



No such signal would be detected in the case of stochastic resonance!

...or no *noise signatures*

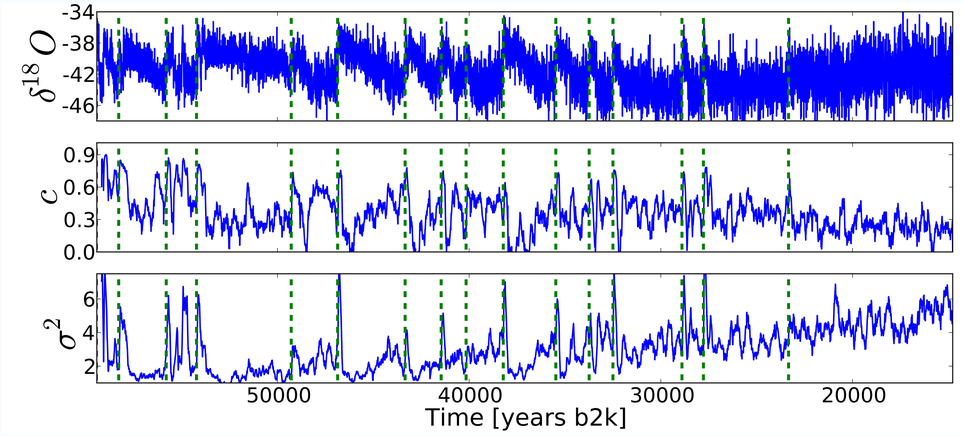
Abrupt transitions can take place with no early warning signal, for instance in the case of motion close to a homoclinic orbit (CD model [5]):



Consistent results with other "prototype models".

Early warnings in ice core data

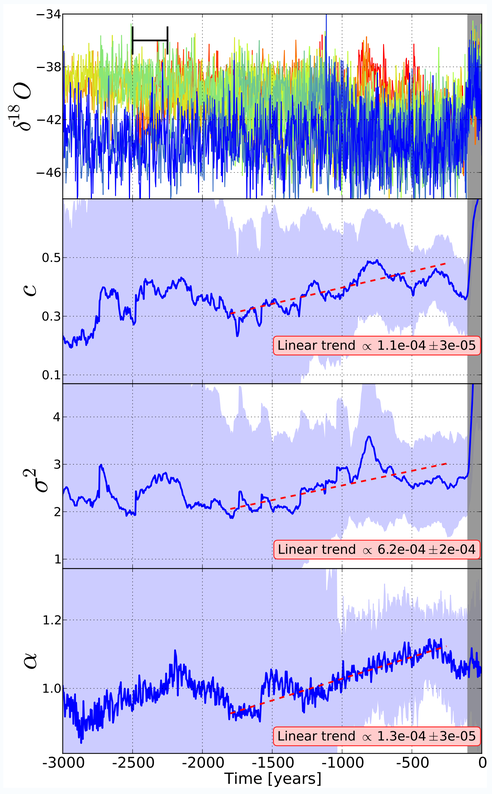
Noise signatures are computed for a high resolution $\delta^{18}O$ paleoclimatic time series [6]:



Green lines mark DO events: *early warning signals are visible only for some of the events.*

Ensamble behaviour

More reliable information is obtained when the ensamble of DO events is considered:



Conclusions and Open Questions

*Statistical properties of fluctuations **in the ensemble of DO events** are consistent with the crossing of a (fold?) bifurcation point by climate system.*

- What is the forcing mechanism?
- Can we confirm these findings on other time series from last glacial age?
- Can we link the bifurcation to thermohaline circulation instability?

References

[1] A. Ganopolski and S. Rahmstorf Abrupt Glacial Climate Changes due to Stochastic Resonance Phys. Rev. Lett. 2002, **88**:038501
[2] A. Timmermann *et al.* Coherent resonant millennial–scale climate oscillations triggered by massive meltwater pulses J. Clim 2003, **16**:2569
[3] C. Kuehn A mathematical framework for critical transitions. arxiv:1101:2899
[4] M. Scheffer *et al.* Early–warning signals for critical transitions. Nature 2009, **461**:53
[5] D. Crommelin *et al.* A mechanism for atmospheric regime behavior J. Atm. Sci. 2004, **61**:1520
[6] A. Svensson *et al.* A 60,000 year Greenland stratigraphic ice core chronology Clim. Past 2008, **4**:47

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