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A short journey through long-term climatic variability

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Outline

- Introduction
- How long is “long-term”?
- Why we look into large temporal scales?
- How we look into large temporal scales?
- What do we see in these scales?
- How can we determine natural variability?
- What do these methods suggest for…
  - temperature?
  - precipitation?
  - drought?
- Conclusions

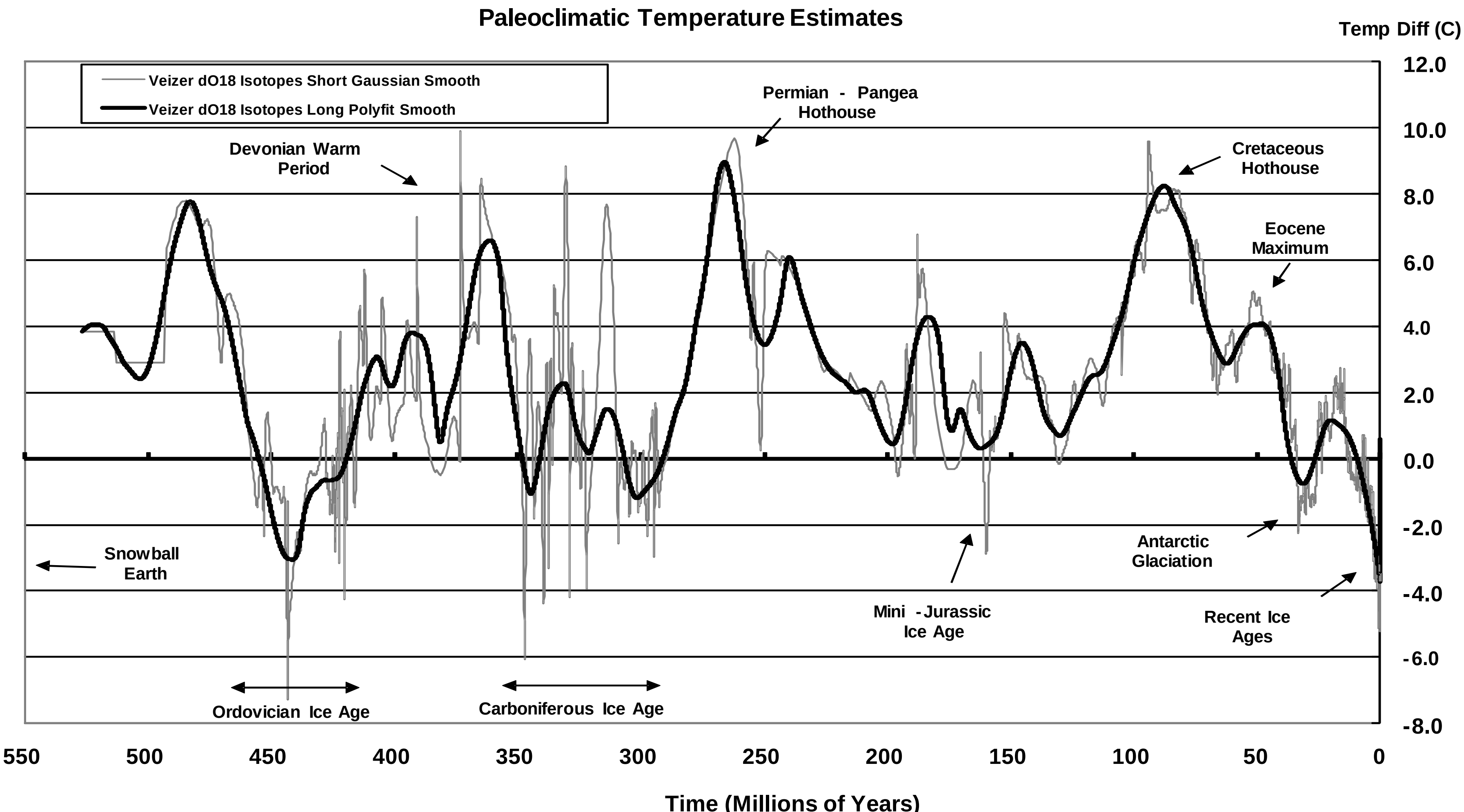
Introduction

Let me introduce myself:

- Diploma/Msc in environmental engineering [TUC]
- PhD in stochastic hydroclimatology [NTUA]

Koutsoyiannis [2015]

How long is "long-term"?



Adapted from Veizer *et al.* [2000]

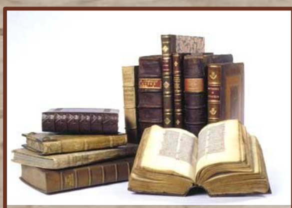
How long is "long-term"?

Age of Earth: 5 By

1000 tomes

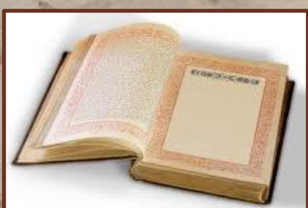
Climate Data:
500 My

100 tomes



Permian Hothouse:
250 My

50 tomes



Last Glacial
Epoch: 2.5 My

Half tome

Previous
Interglacial:
100 Ky

5 pages

Holocence:
10 Ky

Half page

Industrial
Revolution:
200 years

3 words

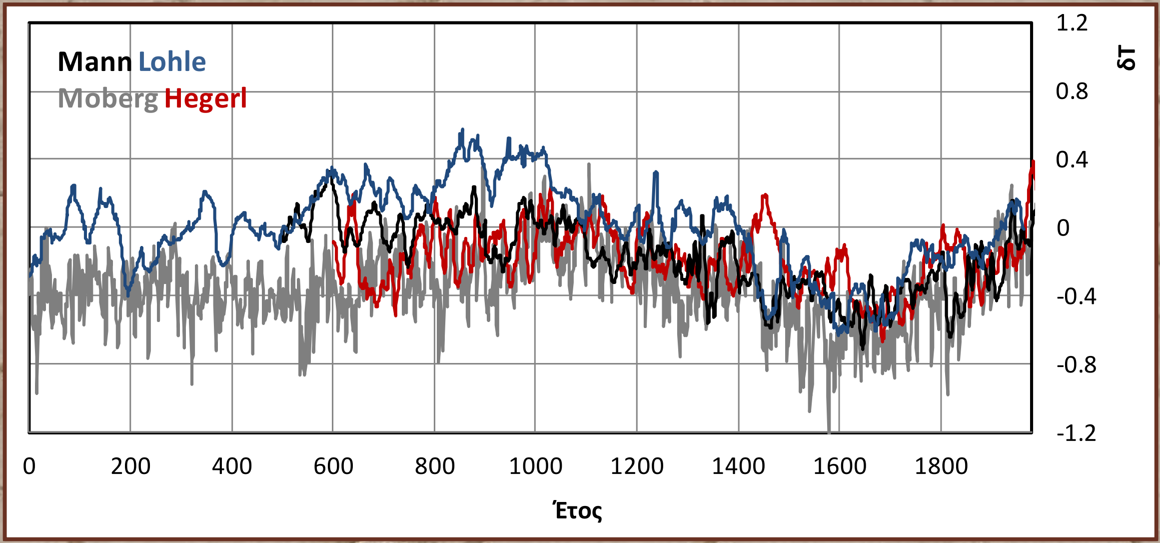
Why we look into large temporal scales?

Before the theory of anthropogenic global warming:

- To understand how the climate evolved in time

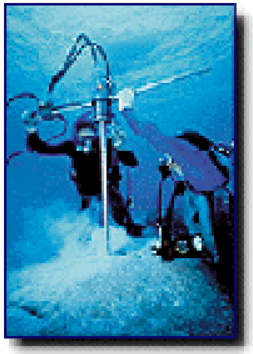
After the theory of anthropogenic global warming:

- To determine the statistical significance of the recent warming
- To estimate the magnitude of natural variability
- To validate physical-based models
- To understand how the climate evolved in time
- To understand climate in general



How we look into large temporal scales?

Ocean Sediments



Corals

Lake Sediments

Tree-rings

Ice cores

Boreholes

Caves

Source: *NOAA*

How we look into large temporal scales?

Variables:
- Temperature
- Precipitation
- Drought, floods, atmospheric pressure, wind, atmospheric composition and other

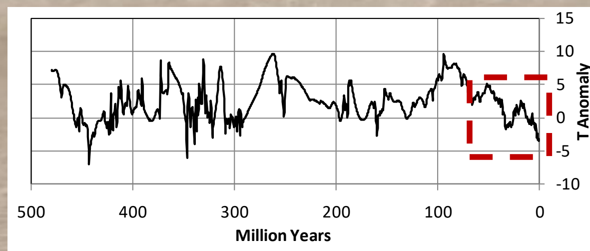
Common problems:
- Transfer function uncertainty
- Artificial biases
- Age model calibration
- Resolution issues

Solutions:
- Multi-proxy reconstructions
- Physical-based models
- Better statistical methods

Source: *NOAA*

What do we see in these scales?

a.



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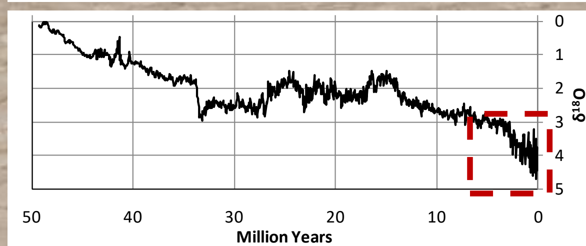

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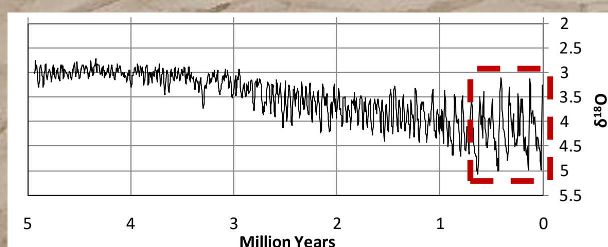

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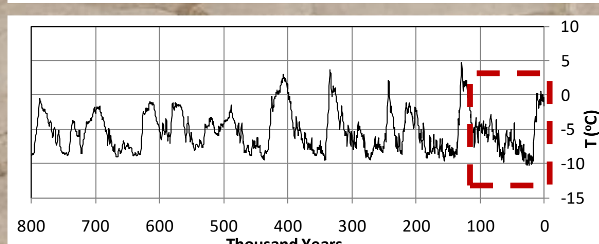
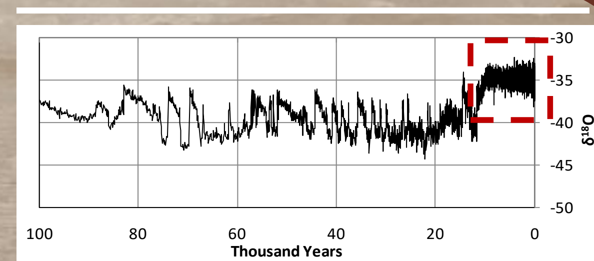


e.



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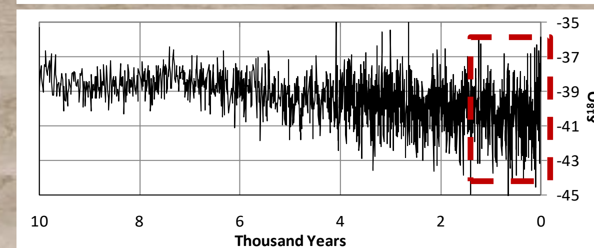
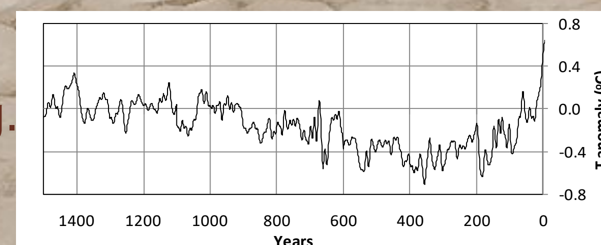


g.



a. Ve00, b. Zα01, c. Hu07, d. EPICA, e. GRIP, f. Taylor, g. Ma09

Markonis et al. [2010]

How can we determine natural variability?

*Climate in a narrow sense is usually defined as the average weather, or more rigorously, as the **statistical description** in terms of the mean and variability of relevant quantities over a period of time ranging **from months to thousands or millions of years**.* [IPCC, 2013]

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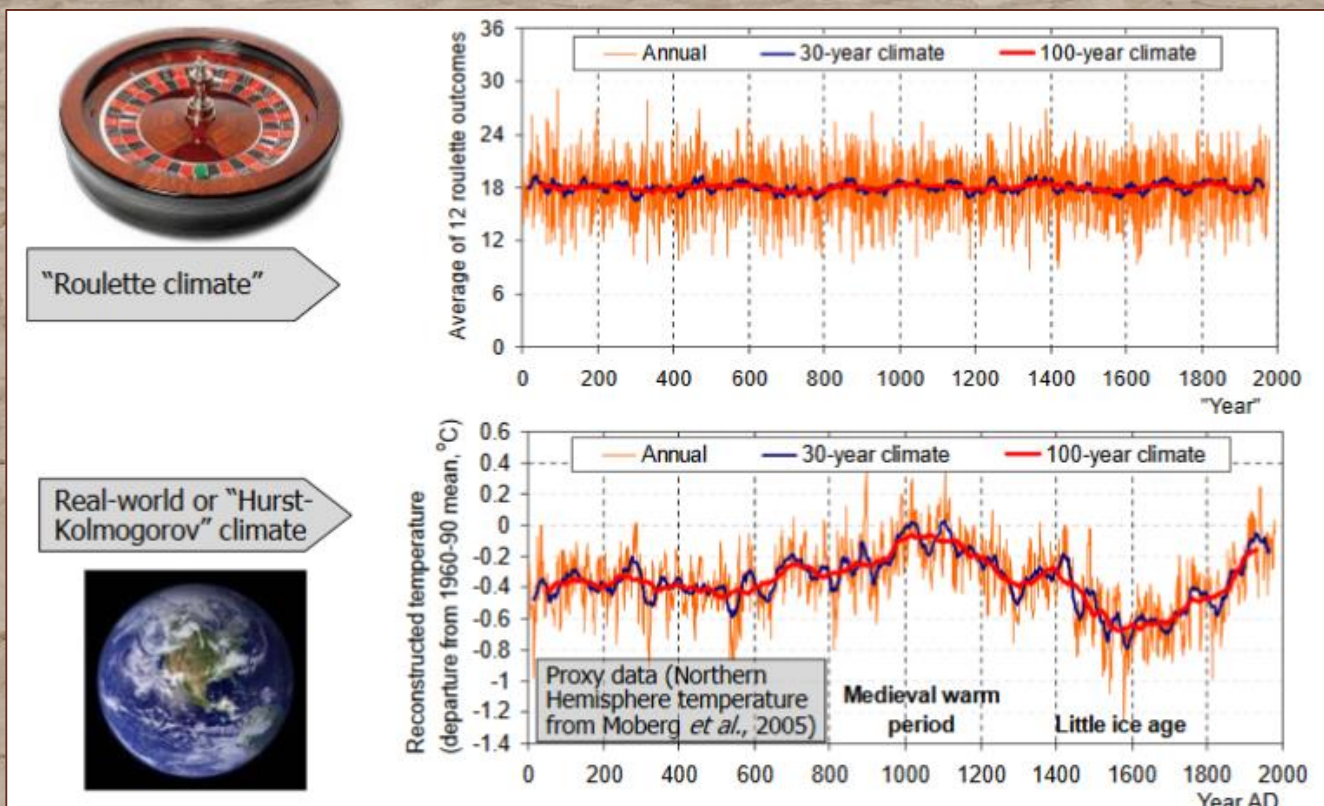


Koutsoyiannis [2013]

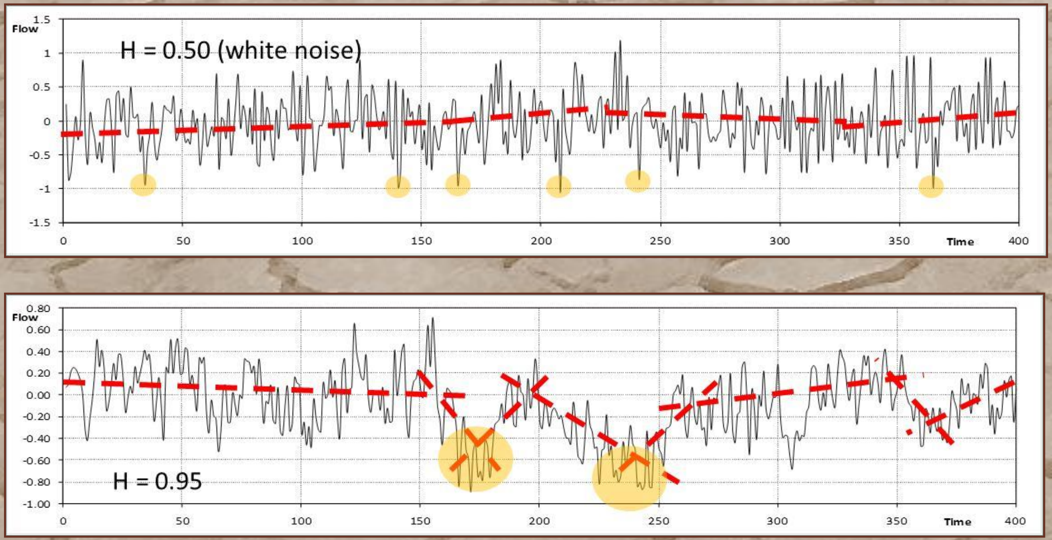
How can we determine natural variability?

Hurst [1951]

Nile's high level values have the tendency to be succeeded by high values as well, while low values usually follow the lowest values; hence the extreme values manifest in clusters.

Kolmogorov [1940] (from Koutsoyiannis [2002])

1. $\sigma^{(\kappa)} = \kappa^{H-1}\sigma, \quad 0 < H < 1$
2. $c_T^{(\Delta)}(j) = \lambda\left(\frac{\alpha}{\Delta}\right)^{2-2H}\left(\frac{|j-1|^{2H}+|j+1|^{2H}}{2} - |j|^{2H}\right)$
3. $s_T(\omega) \coloneqq 2T\gamma(T) + 4T\sum_{j=1}^{\infty} c_T(j)\cos(2\pi\omega j)$



Markonis and Koutsoyiannis [2010]

Bloomfield and Nychka [1992]:
Thus in order to evaluate the observed trend in the temperature series it is necessary to understand the natural variability of global temperatures within this range. (…) This article studies the impact of several stochastic models for variability in the global temperature series.

Smith [1993]
Koutsoyiannis [2002]
IPCC [2013]

How can we determine natural variability?

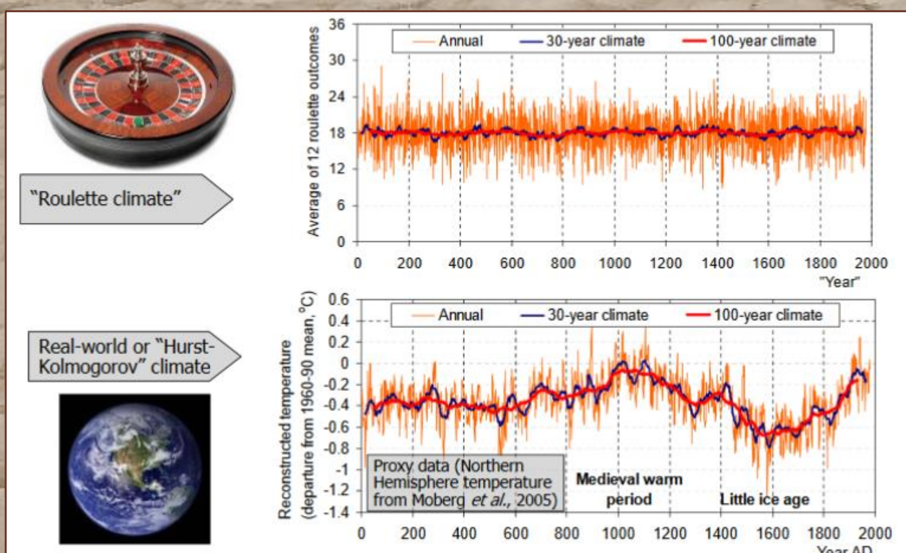
Popular methods to determine LTP include:

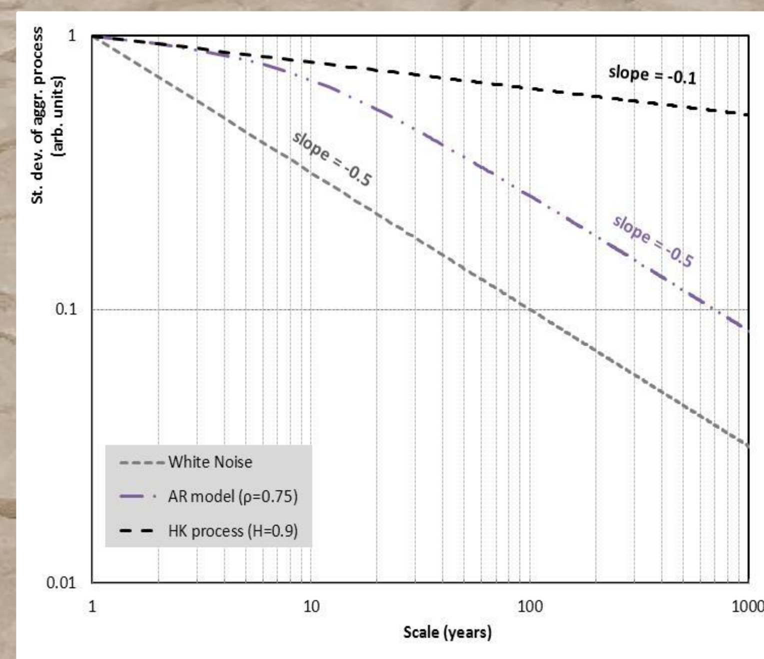
- Power spectrum
- Autocorrelation function
- Detrended Fluctuation Analysis [DFA]
- Maximum Likelihood Estimation
- The climacogram [Aggregated Variance]

The climacogram:

$$\sigma^{(\kappa)} = \kappa^{H-1}\sigma, \quad 0 < H < 1$$

$$H = 1 + \log(\sigma^{(\kappa)}) / \log(\kappa\,\sigma)$$





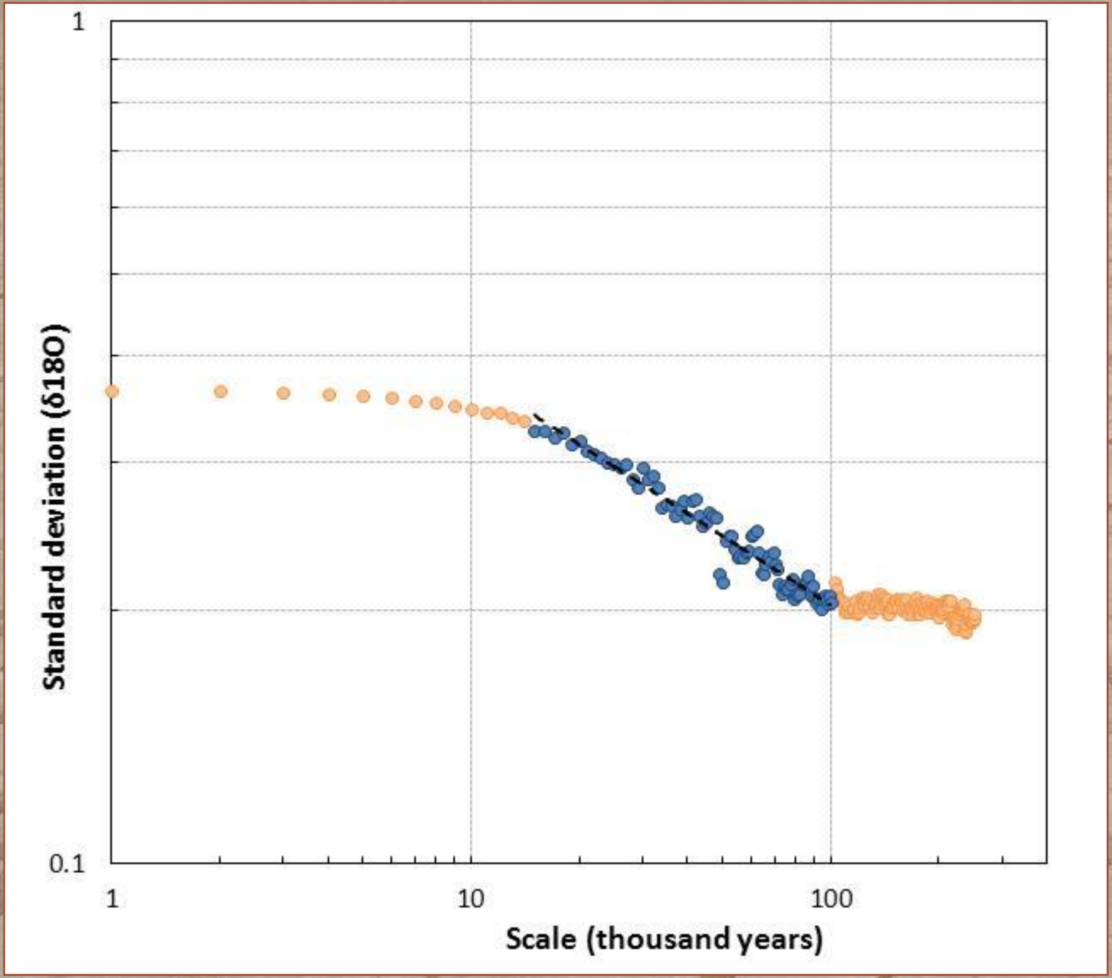
How can we determine natural variability?

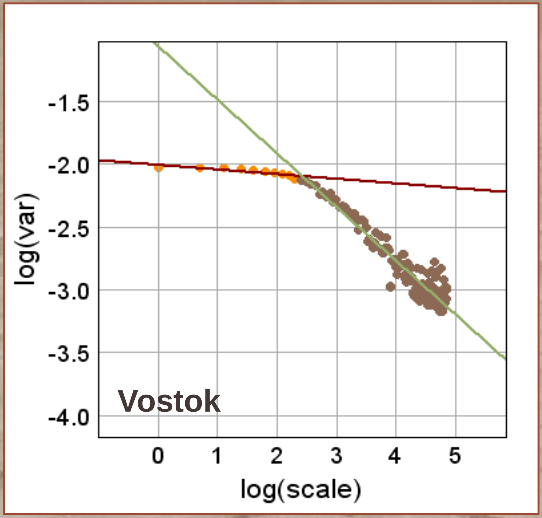
True values ⟶	Mean, μ	Standard deviation, σ	Autocorrelation ρ_l for lag l
Standard estimator	$\underline{\bar{x}} := \frac{1}{n} \sum_{i=1}^{n} \underline{x}_i$	$\underline{s} := \sqrt{\frac{1}{n-1}} \sqrt{\sum_{i=1}^{n} (\underline{x}_i - \underline{\bar{x}})^2}$	$\underline{r}_l := \frac{1}{(n-1)\underline{s}^2} \sum_{i=1}^{n-l} (\underline{x}_i - \underline{\bar{x}})(\underline{x}_{i+l} - \underline{\bar{x}})$
Relative bias of estimation, CS	0	≈ 0	≈ 0
Relative bias of estimation, LTP	0	$\approx \sqrt{1 - \frac{1}{n'}} - 1 \approx -\frac{1}{2n'}$	$\approx -\frac{1/\rho_l - 1}{n' - 1}$
Standard deviation of estimator, CS	$\frac{\sigma}{\sqrt{n}}$	$\approx \frac{\sigma}{\sqrt{2(n-1)}}$	
Standard deviation of estimator, LTP	$\frac{\sigma}{\sqrt{n'}}$	$\approx \frac{\sigma \sqrt{(0.1\,n + 0.8)^{\lambda(H)}(1 - n^{2H-2})}}{\sqrt{2(n-1)}}$ where $\lambda(H) := 0.088\,(4H^2 - 1)^2$	
Note: $n' := n^{2-2H}$ is the "equivalent" or "effective" sample size: a sample with size n' in CS results in the same uncertainty of the mean as a sample with size n in HKS (Koutsoyiannis, 2003; Koutsoyiannis & Montanari, 2006).			

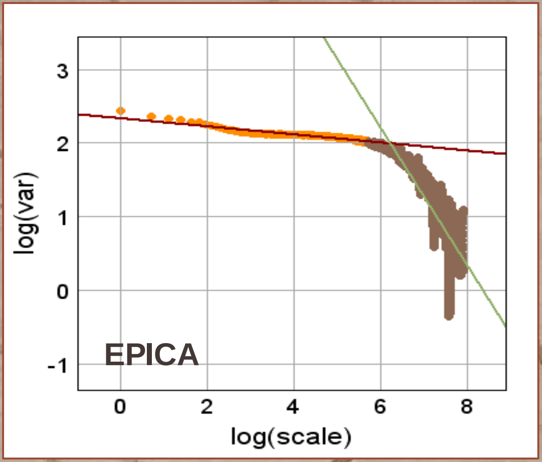
Markonis and Koutsoyiannis [2010]

Investigating natural variability

Huybers global T reconstruction [2.5 My]:

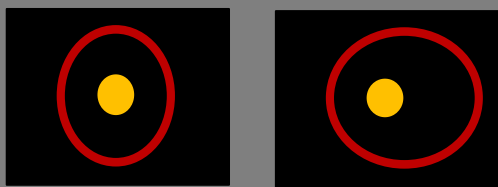


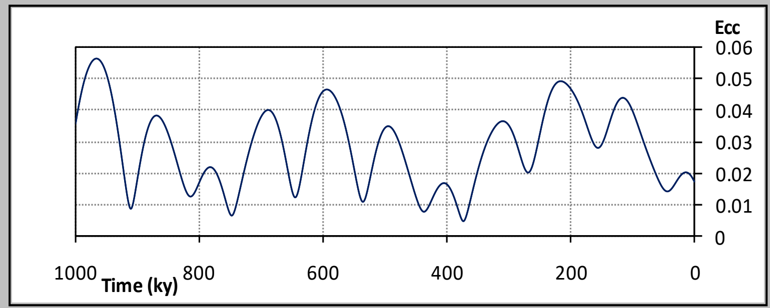




Investigating natural variability

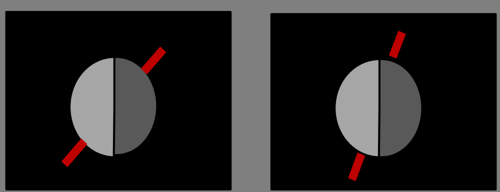
Eccentricity

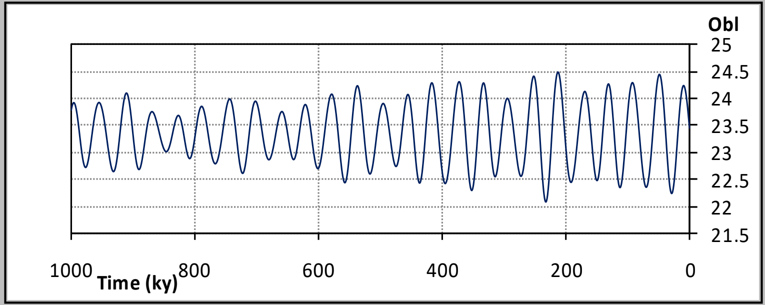




Cycles: 100 ky & 400 ky

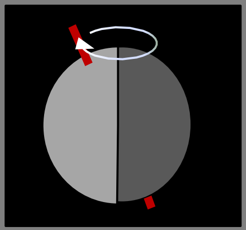
Obliquity

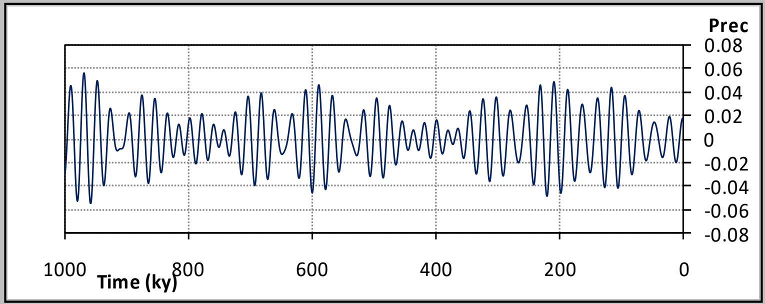




Cycles: 41 ky

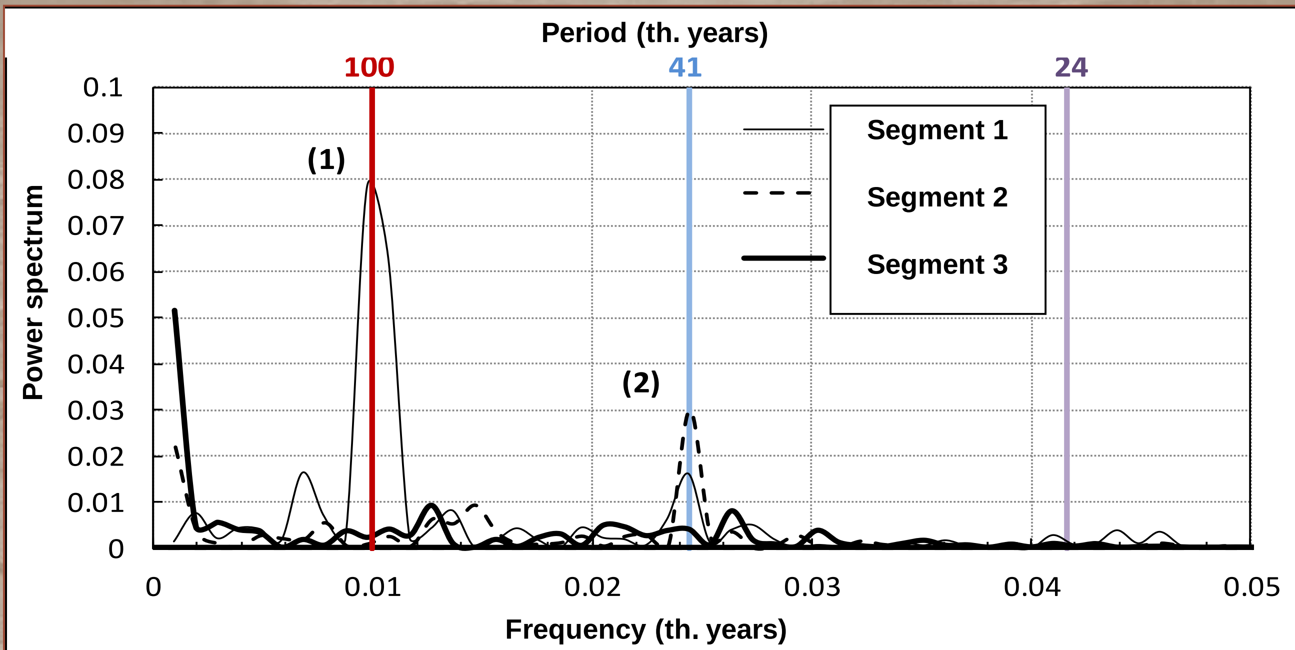
Precession

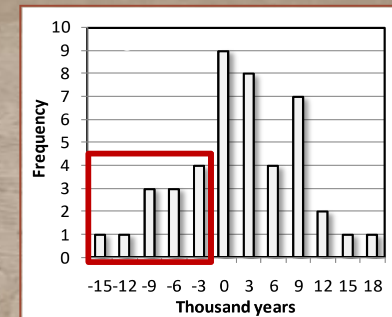


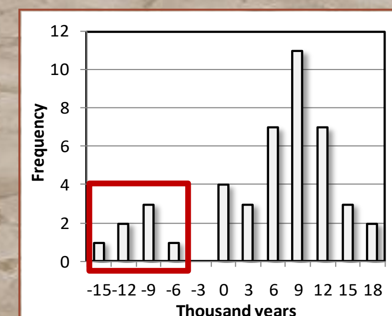


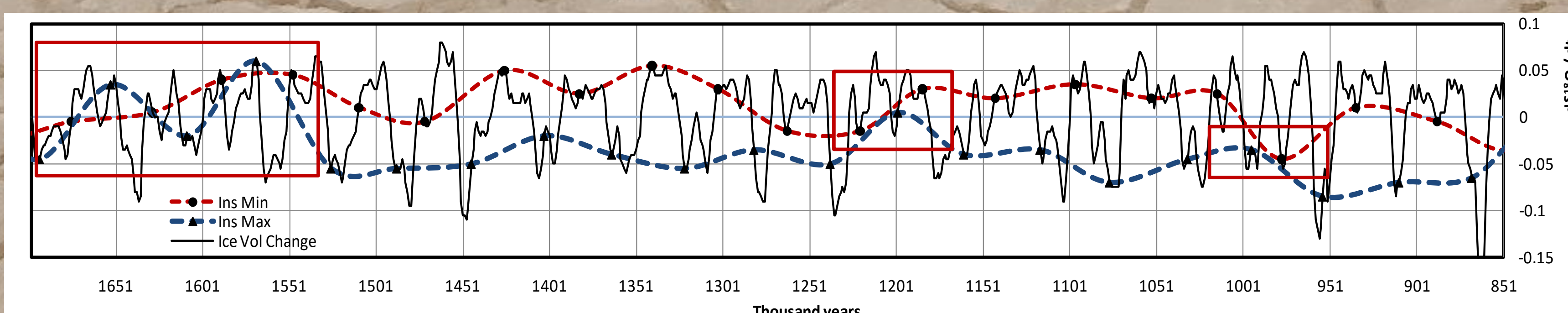
Cycles: 19 ky & 23 ky

Investigating natural variability



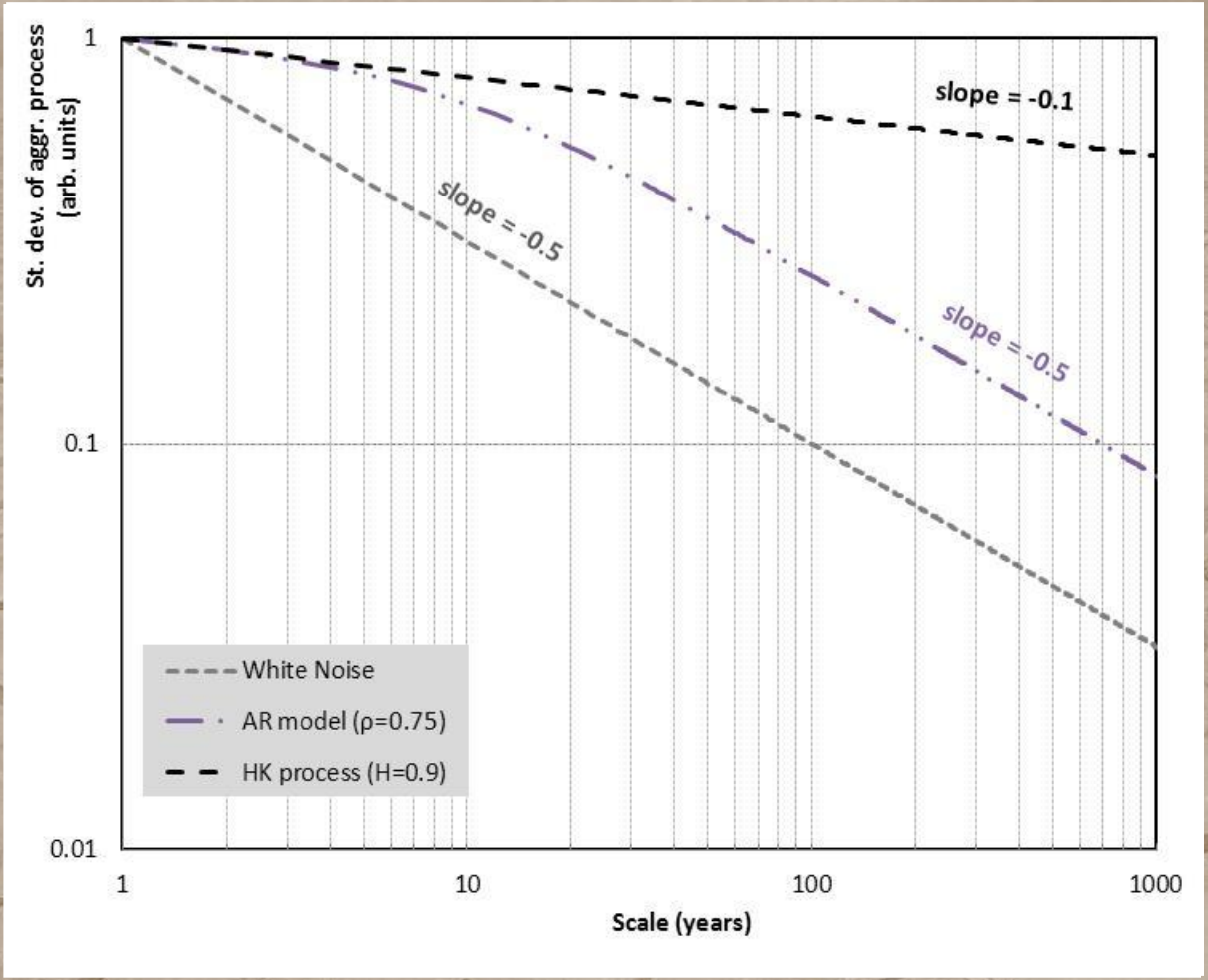






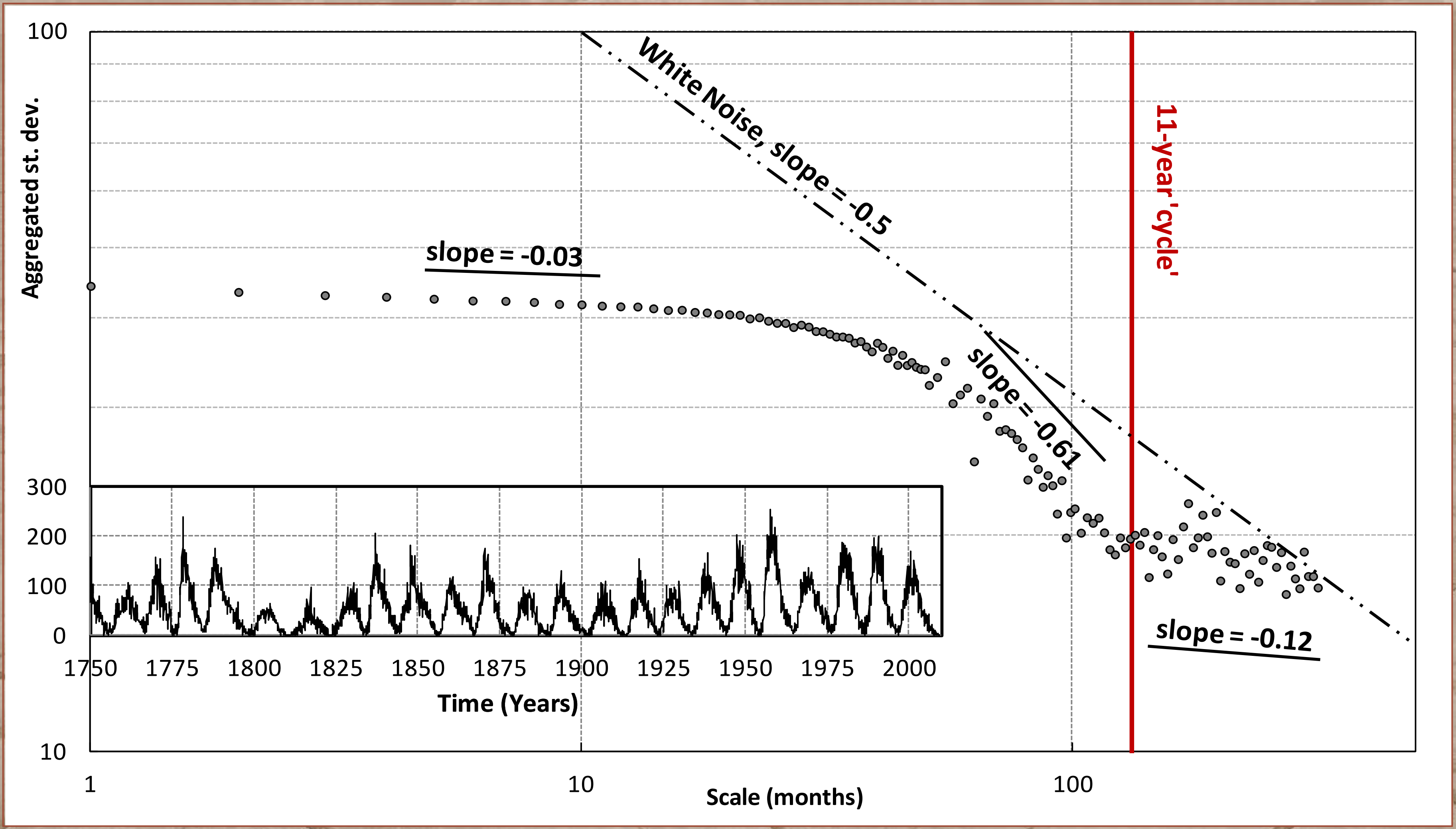
Markonis *et al.* [2011]

Investigating natural variability



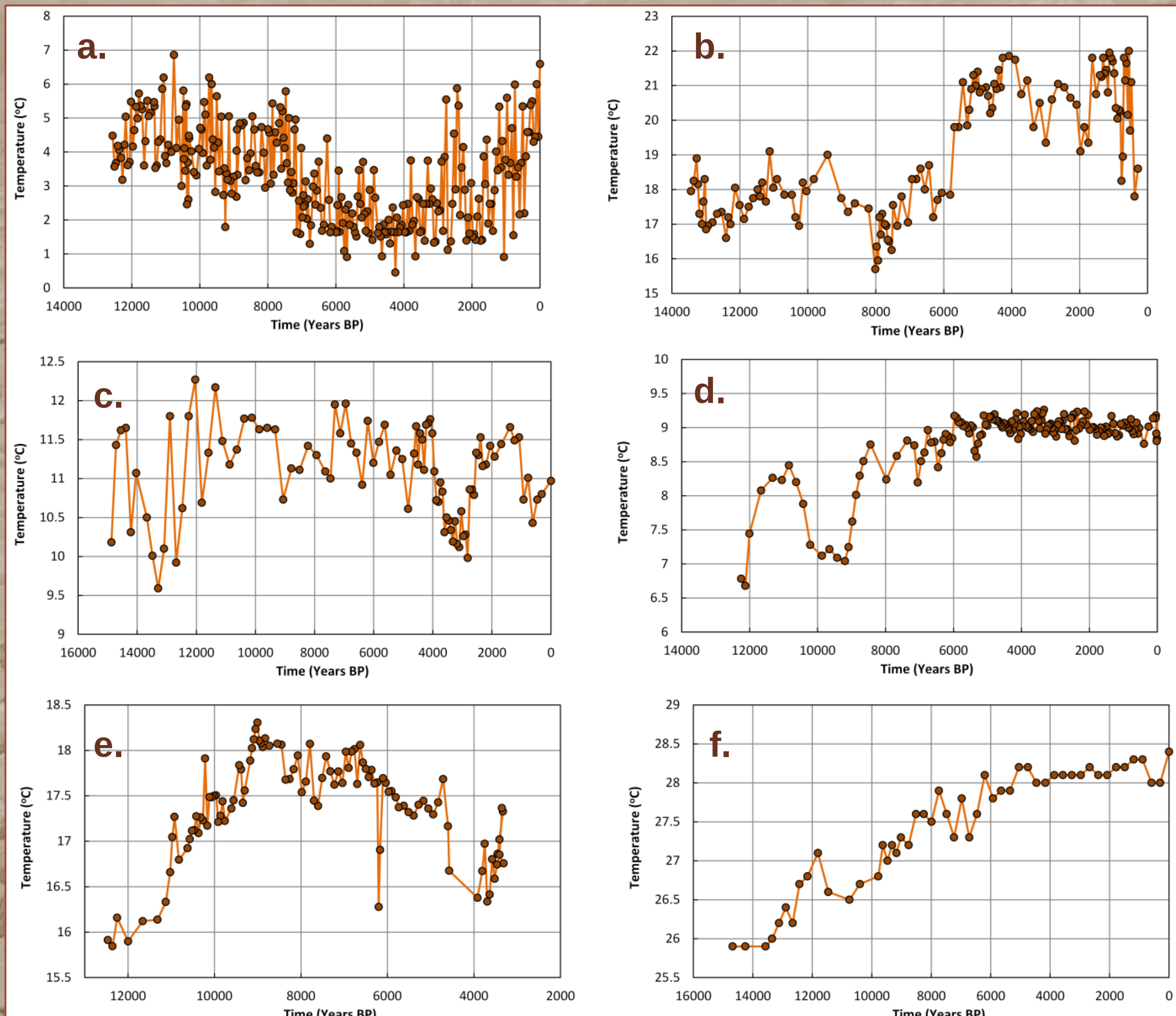
Markonis and Koutsoyiannis [2013]

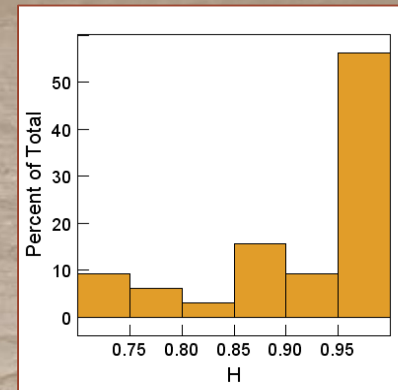
Investigating natural variability

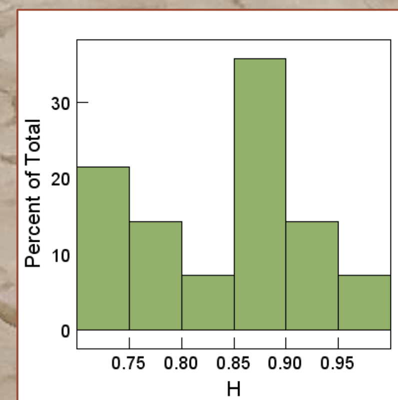


Markonis and Koutsoyiannis [2013]

Investigating natural variability



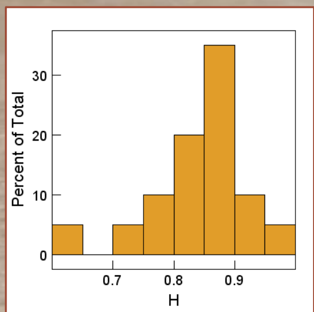


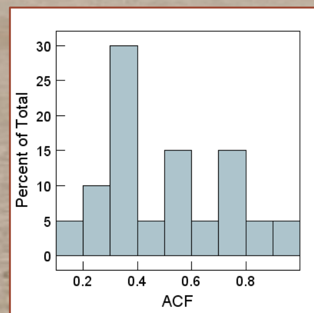


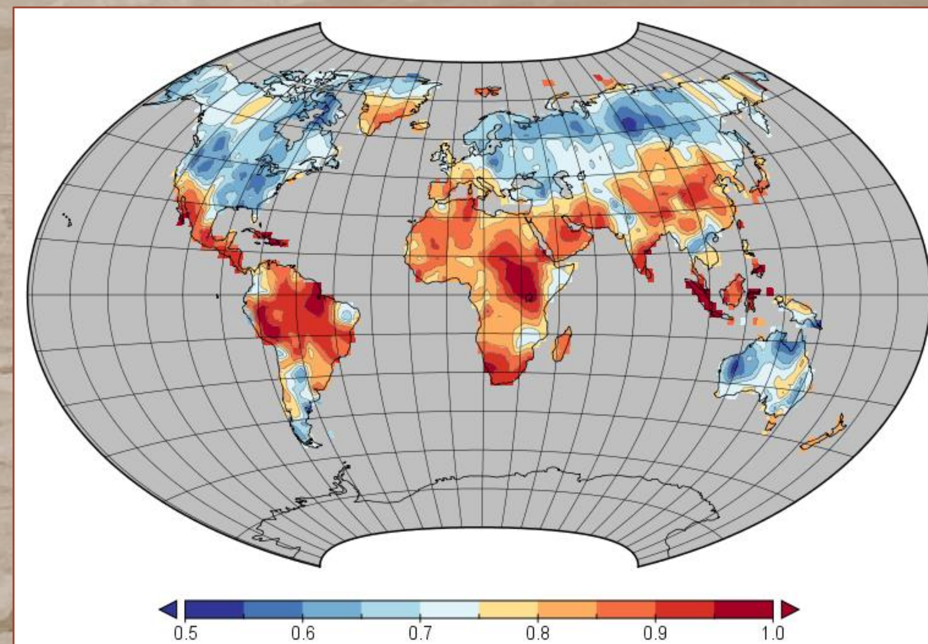
58 local reconstructions ($\rho < 0.6$): $\overline{H} = 0.88$

Markonis [2016]

Investigating natural variability







Palaeoclimatic data

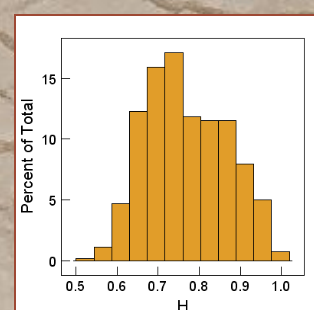
20 local reconstructions: *H* ∈ (0.6 , 1)
6 continental reconstructions:
H ∈ (0.8 , 1)
9 hemispheric reconstructions:
H ∈ (0.9 , 1)

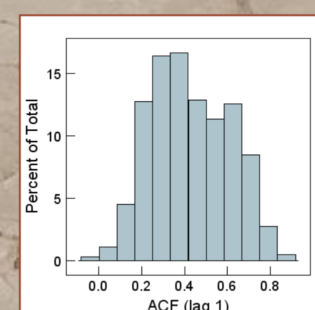
Instrumental data

CRU TS3.22 - 2.5° (sample size 10 368 time series): $\overline{H}$ = 0.77
Global and hemispheric means H ∈ (0.76 , 0.99)

Satellite data

Global and hemispheric H ∈ (0.93 , 0.98)

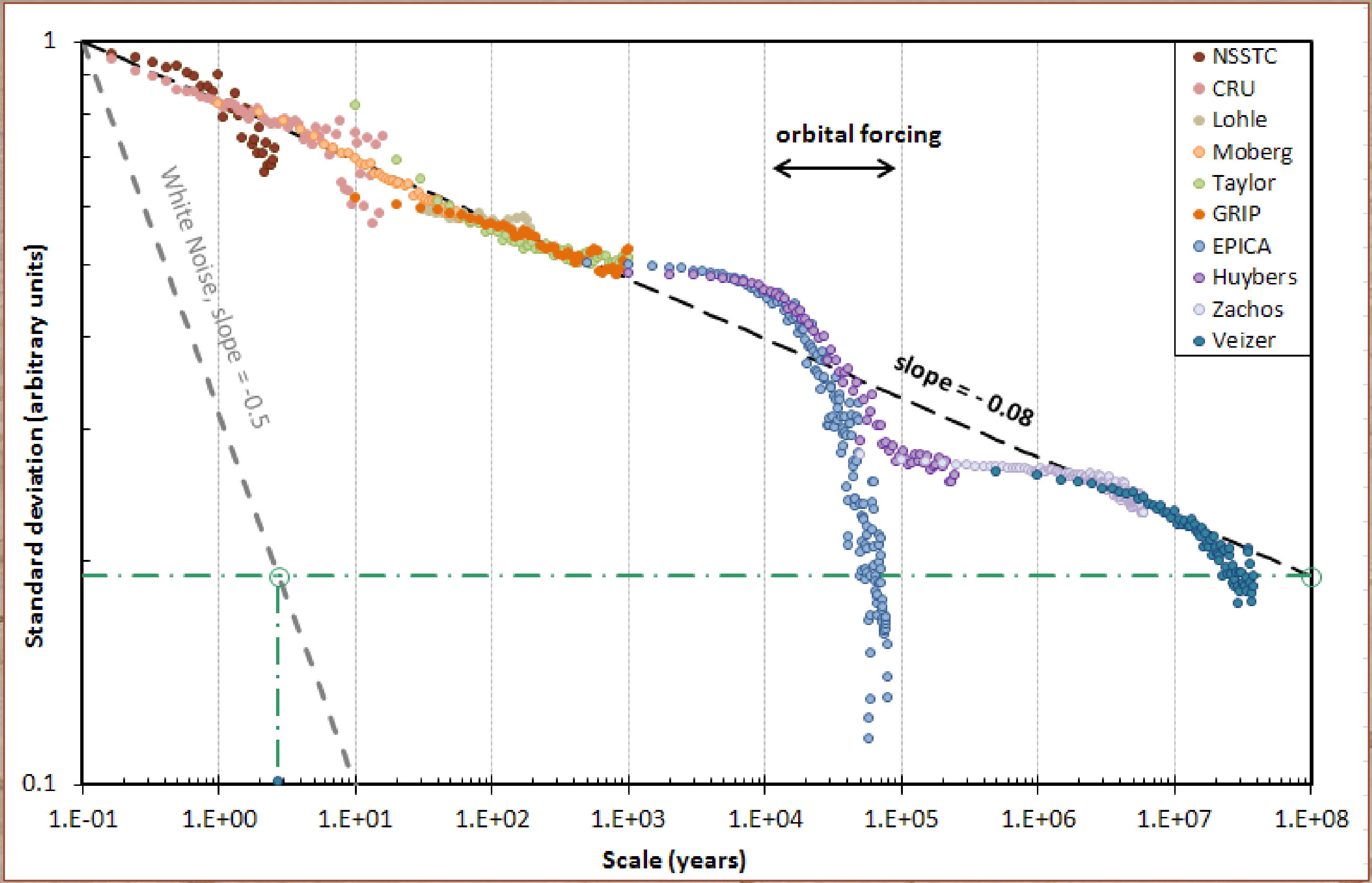




Markonis [2016]

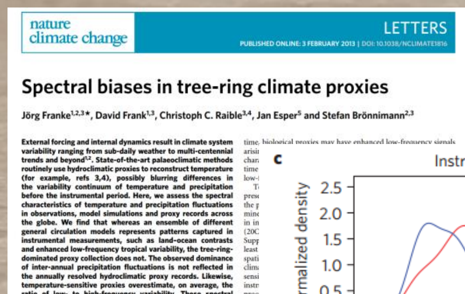
Investigating natural variability

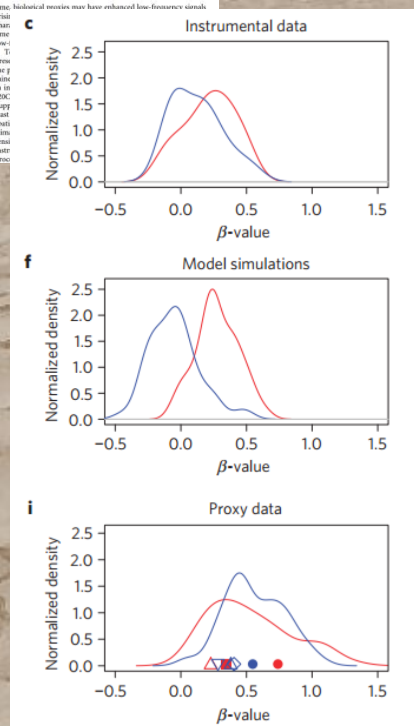
An overview of global temperature variability for 9 scales of magnitude [H>0.92]



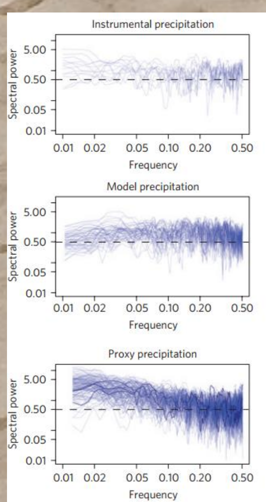
Markonis and Koutsoyiannis [2013]

Investigating natural variability

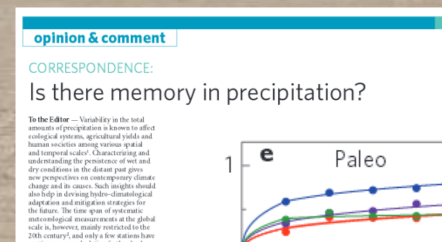

nature climate change
LETTERS
Spectral biases in tree-ring climate proxies
Jörg Franke, David Frank, Christoph C. Raible, Jan Esper and Stefan Brönnimann

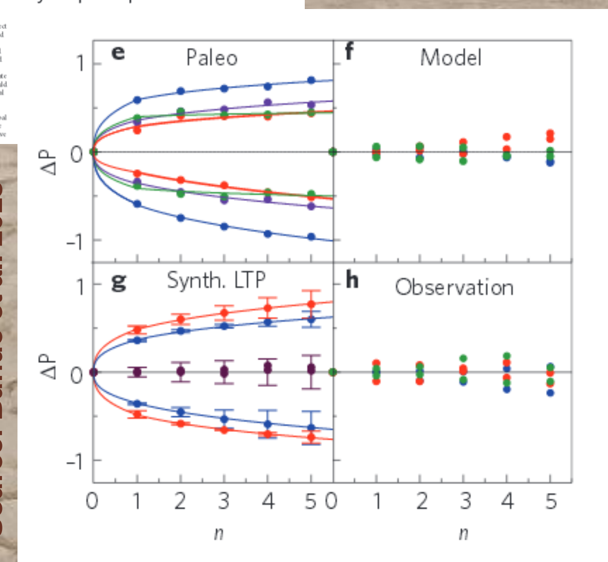


Instrumental: CRU TS3 grid
Tree rings: 128 individual
Models: ECHO-G, COSMOS, CCSM3, HADCM (500 years)



Source: Franke et al. 2013

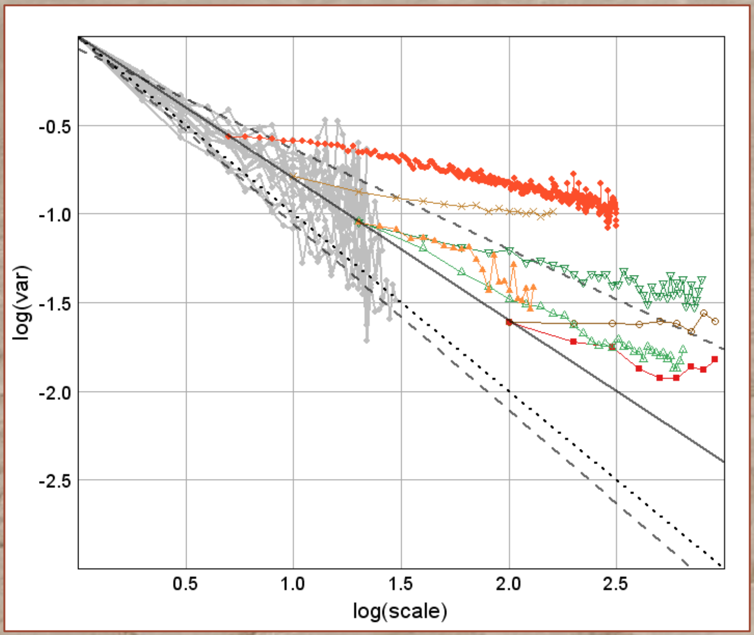

opinion & comment
CORRESPONDENCE:
Is there memory in precipitation?

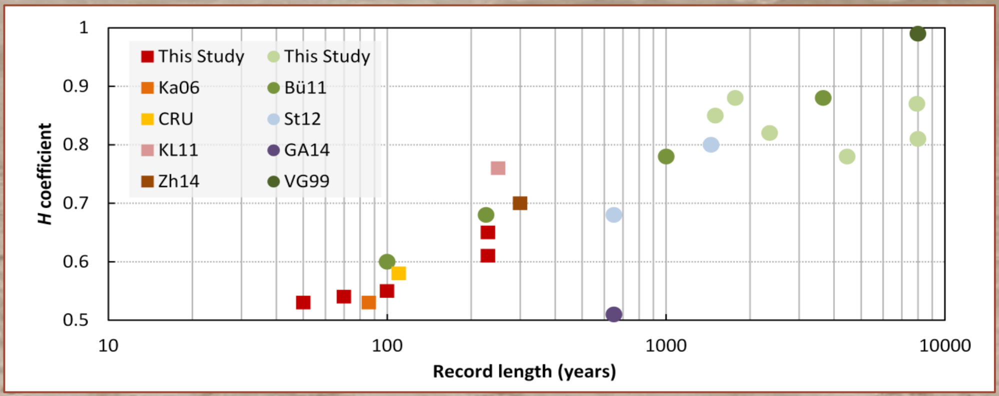


Source: Bunde et al. 2013

Instrumental: 3 indiv. ~100-year stations
Tree-rings: 3 sets Central Europe (1000–2000), North America (1000–1988) and High Asia (1000–1998)
Model: ECHAM6 (850–1850)

Investigating natural variability



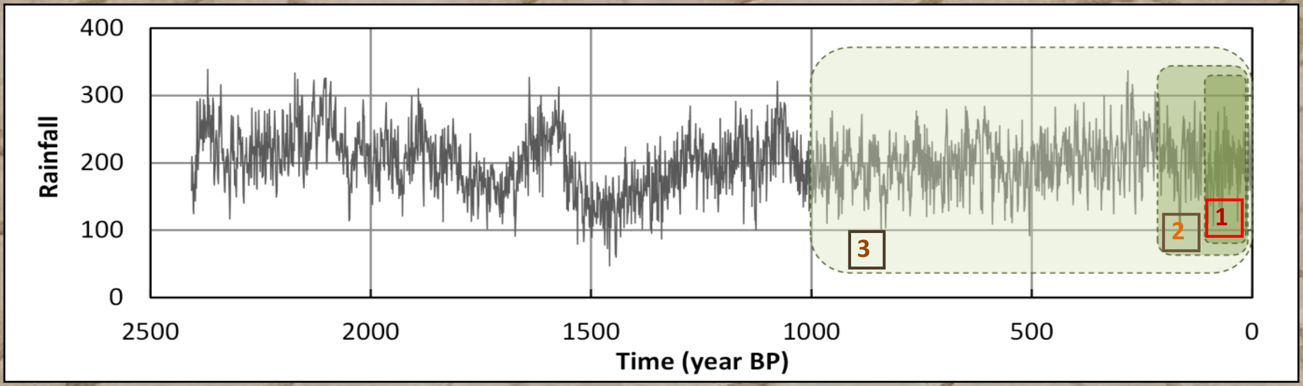


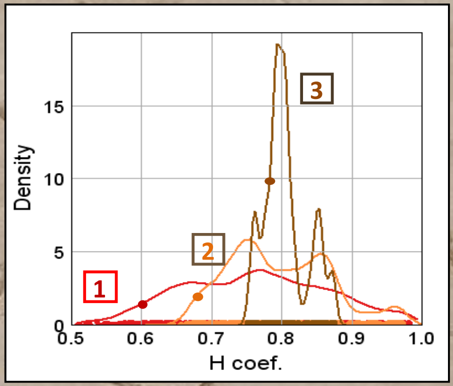
Instrumental Data

17 Time series in central and northern Europe

Palaeoclimatic Data

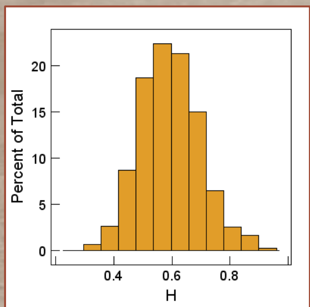
9 reconstructions of different proxy data

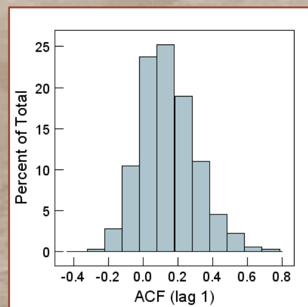


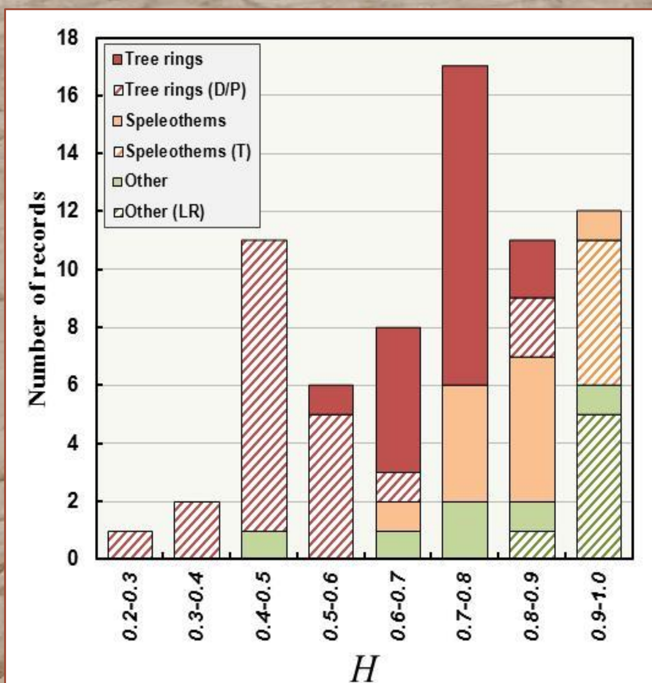


Markonis and Koutsoyiannis [2015]

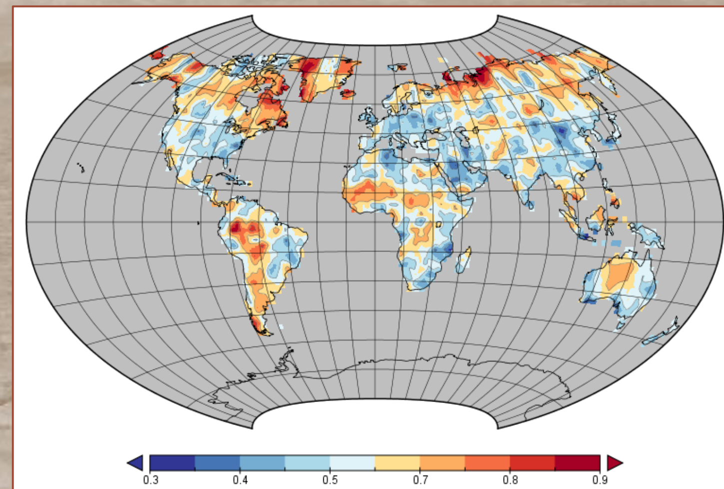
Investigating natural variability







Iliopoulou *et al.* [2016]



Instrumental data

CRU TS3.22 - 2.5°
(sample size: 10 368 time series)

Palaeoclimatic data

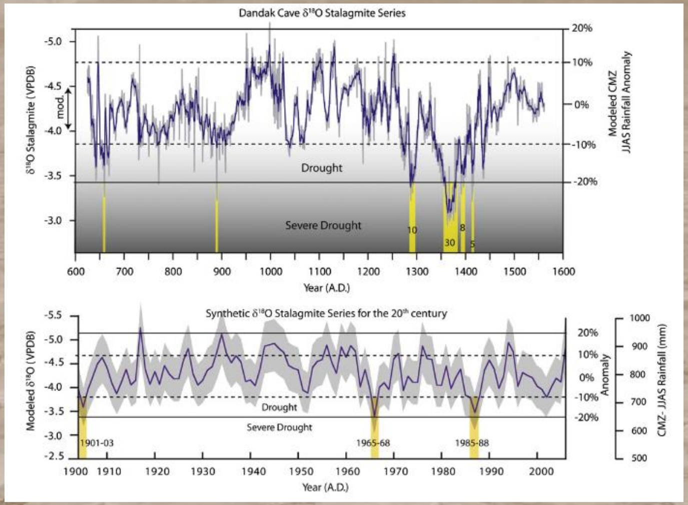
40 tree-ring reconstructions
16 speleothems reconstructions
12 other reconstructions

Underestimation:
Tree-rings
Overestimation: *Speleothems and low-resolution reconstructions*

Markonis and Koutsoyiannis [2015]

Investigating natural variability

Single site proxies



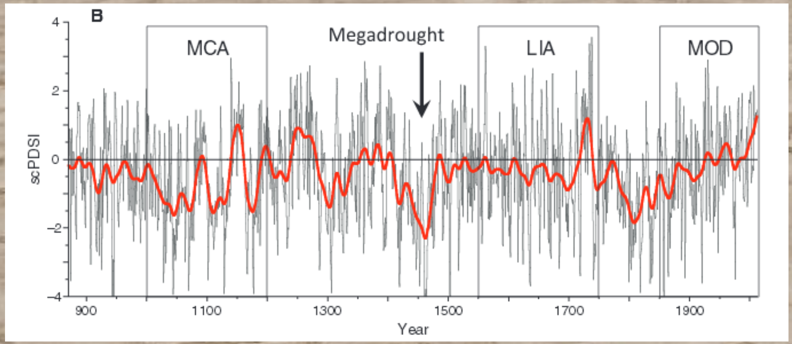
Monsoon Asia

Source: Sinha et al. 2011

Evidence of LTP in drought reconstructions:

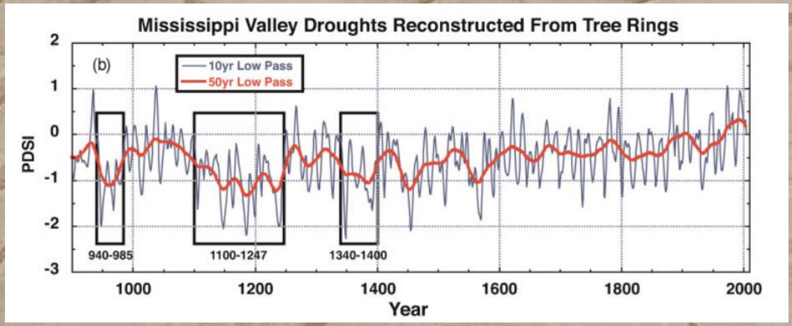
Spatial PDSI reconstructions

Europe



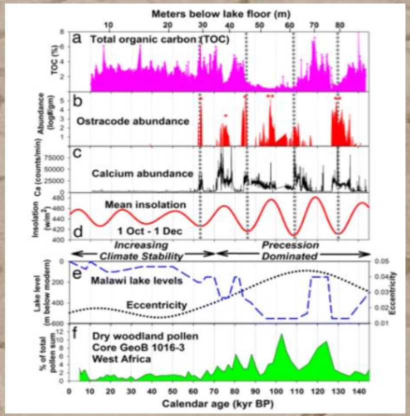
Source: Cook et al. 2015

N. America



Source: Cook et al. 2009

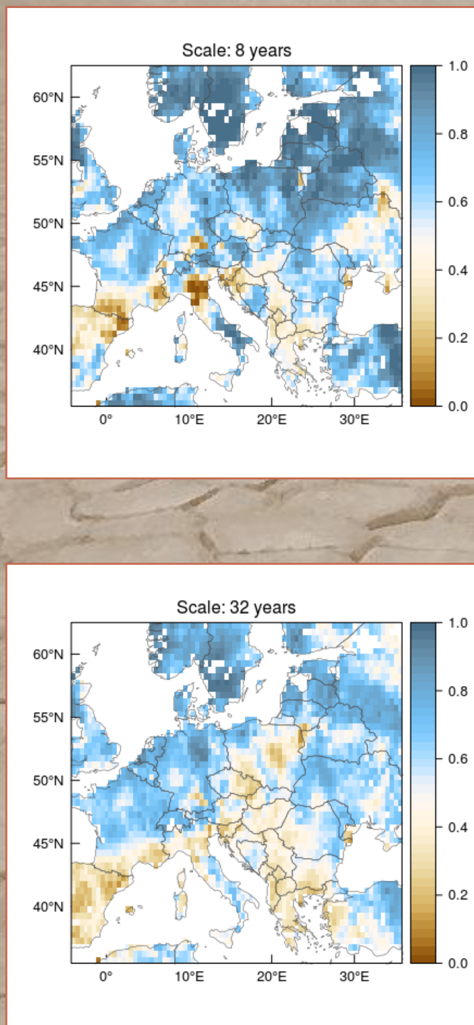
Eastern Africa



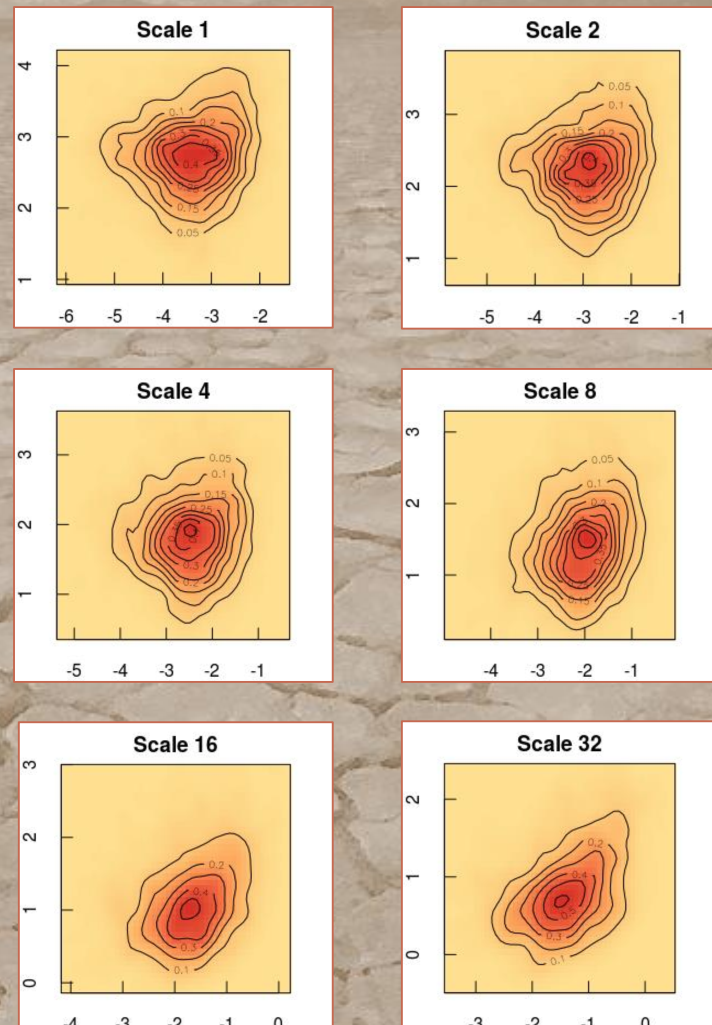
Source: Cohen al. 2007

Investigating natural variability

Empirical quantiles



0.05 vs 0.95 quantiles



Are there any conclusions?

- Climate changes.
- Climate changes a lot.
- Climate changes a lot in different scales.
- Climate changes a lot in different scales and this could imply LTP.
- Climate changes a lot in different scales and this could imply LTP, but there is a debate on this.
- Climate changes a lot in different scales and this could imply LTP, but there is a debate on this, because the magnitude of LTP has enormous impact to the statistical significance of recent warming.

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