Climatological temperature records: persistence at asymptotic time-scales (EMS2008-A-00149)

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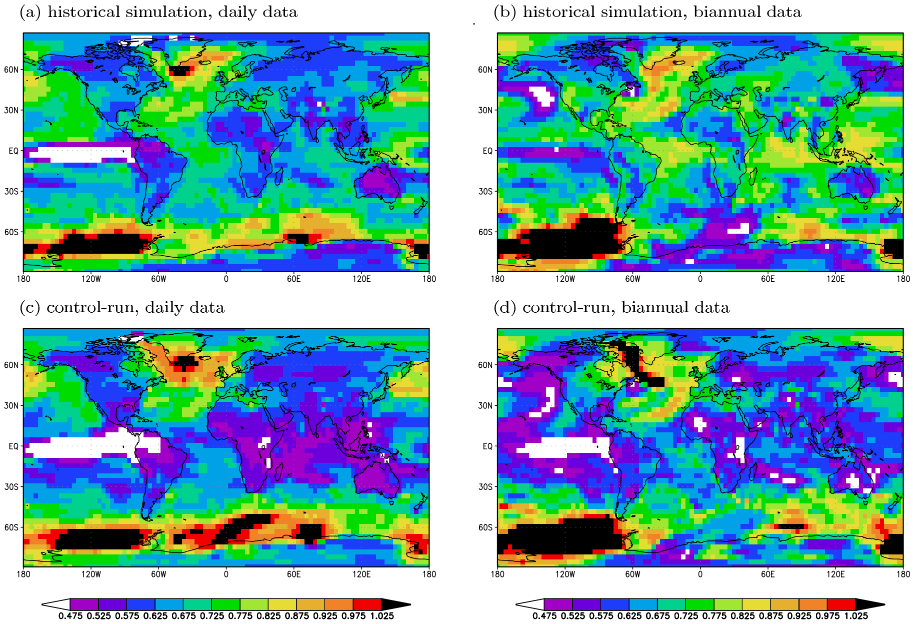

Figure 2

We study the temperature records obtained from a historical simulation (with greenhouse gas, solar, and volcanic forcing) performed with the global coupled general circulation model ECHO-G for the years 1000-1990. Applying Detrended Fluctuation Analysis (DFA) we quantify the long-term behavior with respect to asymptotic correlations. As comparison, we also analyze a 1000-year control run with constant external forcings. We consider daily data as well as their biannual averages in order to suppress 2-year oscillations appearing in the model records for some sites near the equator. In the case of the historical simulation we find that most continental sites have correlation exponents between 0.8 and 0.6, which substantially confirms earlier studies of (considerably shorter) instrumental data. In the control run the long-term correlations are less pronounced and show a more pronounced latitude dependence, visible also at continental sites. Where available, we compare with instrumental records. In addition, we have analyzed six recently reconstructed records of the Northern Hemisphere (NH) temperatures and found that all are governed by long-term persistence, even on millenial scale such as in the case of the Moberg et al. 2005 record (years 1-1979).

Climate Model Simulations

We consider the global coupled general circulation model ECHO-G, which consists of the atmosphere model ECHAM4 (approx. 3.75°×3.75°, 19 vertical leels) and the ocean model HOPE-G (2.81°×2.81°, 20 vertical levels). Constant, zero-average flux correction of heat and freshwater is applied in order to avoid climate drift in such a long simulation.

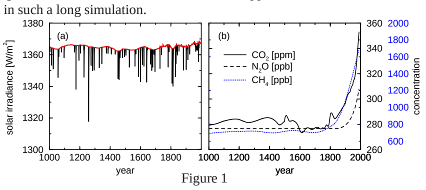

Figure 1

Here we analyze the 2m-temperature records of all $96 \times 48 = 4608$ gridpoints for two runs of this model, both extended over almost 1000 years.

1. historical simulation: forced with reconstructions of solar, volcanic activity, and greenhouse gas concentrations during the last millenium [Fig. 1], period 1000-1990 A.D. (991 years).
2. control-run: constant driving factors, i.e., solar insolation (with an annual cylce), as well as aerosol and greenhouse gas load.

Analysis of temperature records

We first subtracted the annual cycle of each daily temperature record

$$\tau_i = T_i - \overline{T}_i$$

and then applied DFA0-DFA3 [1–2]. To obtain the fluctuation exponent α, we fitted a power law to the fluctuation function between 2 and 200 years. α is related to the correlation exponent $\gamma = 2 - 2\alpha$ $(0 < \gamma < 1)$.

In some areas, especially in the Equatorial Pacific, almost regular biannual cycles occur, which cannot be subtracted completely. Therefore we also consider time series of biannual temperatures (i.e., averaged over two years of daily data). With this renormalization (aggregation) we also verify that scaling in the daily data is not due to a short-term process with a correlation length below two years.

Figure 2 shows the results for the fluctuation exponents obtained by DFA2.

- Values of α below 0.475 (white) and above 1.025 (black) are not discriminated, since we are only interested in stationary long-term correlated data $(0.5 < \alpha < 1.0)$.
- Values of α between 0.475 and 0.525 indicate white noise behavior and are in violet, while α-values between 0.975 and 1.025, which indicate $1/f$-noise, are in red.

In Fig. 2 we find large violet and white areas where $\alpha \leq 0.5$ close to the Equator, and red and black areas where $\alpha \geq 1.0$ close to the Antarctica or Greenland. These findings will be discussed separately below.

historical simulation

- Over land mainly exponents between 0.6 and 0.7 for *daily data*.
- For Europe the α-values of about 0.65 are well reproduced [4].
- Over the oceans, the long-term correlations are more pronounced (northern part mainly exponents between 0.7 and 0.85, [6]).
- There is a weak dependence of α on the latitude (reduced values at the Equator, raised values at the Arctic Circles).
- Also some ocean currents can be identified (Kuroshio current, South Equatorial current).

control-run

- Considerably smaller fluctuation exponents.
- Larger areas with $\alpha \leq 0.5$ (white) or $\alpha \geq 1.0$ (black).
- Latitude dependence is more pronounced.
- Weaker correlations at grid-points far from the oceans.

This indicates that the forcings of the historical simulation represent important contributions to the strength of the long-term correlations (see also [7]).

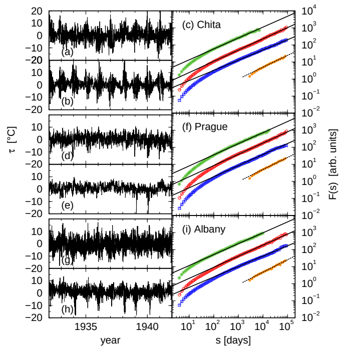

Figure 3

Figures 3 and 4 show, on the right hand side, examples of DFA2 fluctuation functions of the historical simulation (**circles**), of the control-run (**squares**) and, if available of instrumental (**asterisk**) or reconstructed (**plus**) records. They also show, the fluctuation functions of the biannual records of the historical simulation (**filled circles**). On the left hand side of each figure, ten years of the deseasoned records from the historical simulation and of the corresponding instrumental record (if available) are shown.

Figure 3 presents examples for the vast majority of fluctuation functions (continental grid-points close to the meteorological stations of Chita, Prague, and Albany).

- excellent scaling behavior, apart from a crossover at short time scales.
- fluctuation functions are straight lines for large scales.
- control-run underestimates the long-term persistence.
- seasonal trend in the standard deviation (still after deseasoning), slightly exaggerated in the model (left hand side of Fig. 3), exponents remain unchanged.

Principally the west-coast of Southern America and the complete Equatorial Pacific regime are influenced by *ENSO*. Exceptionally warm (El Niño) and cold (La Niña) sea surface temperatures occur irregularly on a time scale of 3 – 8 years (almost periodic behaviour with a period of 2 years by the model). We inspect Central Africa [Fig. 4(a,b)], the Pacific on the latitude of the Equator [Fig. 4(c,d)], and Central Australia [Fig. 4(e-g)] [9].

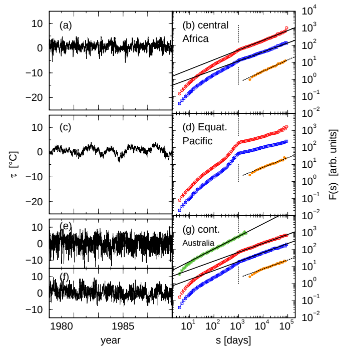

Figure 4

- fluctuation functions exhibit a hump at a period of about two years (misleading conclusion that the data are like white noise).
- exponents α considerably smaller than 0.5 seems to suggest long-term anti-correlations in the Equatorial Pacific.
- certainly an artefact as the real underlying temporal correlation structure is masked by the (irregularly occuring) ENSO.
- fluctuation functions for the biannual data [bottom curves in Figs. 4(b,d,g)] show exponents α slightly above 0.5.
- instrumental data exists for *Central Australia* [Fig. 4(e), Charleville].
  - again small humps in the fluctuation functions of the model-runs.
  - pattern of two years in the temperature record of the historical simulation.
  - instrumental record: $\alpha \simeq 0.74$ (on scales $40 < s < 2000$ days).
  - simulation records: $\alpha \simeq 0.5$ (on scales $850 < s < 70000$).

Reconstructed NH temperatures

Applying DFA2, in Fig. 5 we analyzed six reconstructions of Northern Hemisphere (NH) temperature [10].

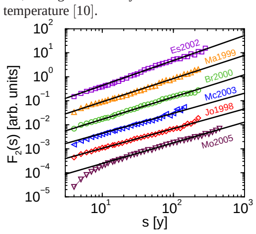

Figure 5

We obtained (from top to bottom):

- Esper et al. (2002), years 831-1992: $\alpha \simeq 1.04$
- Mann et al. (1999), years 1000-1980: $\alpha \simeq 0.97$
- Briffa (2002), years 1000-1993: $\alpha \simeq 0.93$
- McIntyre and McKitrick (2003), years 1400-1980: $\alpha \simeq 0.83$
- Jones et al. (1998), years 1000-1991: $\alpha \simeq 0.82$
- Moberg et al. (2005), years 1-1979: $\alpha \simeq 0.86$

Thus, we found fluctuation exponents roughly between 0.8 and 1. Even the longest reconstruction by Moberg et al. 2005 comprises pronounced long-term persistence on centennial time-scales.

Discussion

We could neither verify the claim that the long-term correlations vanish in the middle of the continents nor that the strength of these correlations increases from the Poles to the Equator (our outcome indicates the opposite). The exponents obtained for continental sites from the historical run are rather in agreement with the values found by [5], who report $\alpha \simeq 0.6 \ldots 0.7$ with a maximum at 0.65, and by [8], who find $\alpha \simeq 0.63 \ldots 0.75$ with a maximum at approximately 0.69.

We have found, however, that these long-term correlations hold at least up to 200 years in the historical run, considerably extending the largest scales for instrumental records of typically 50 years. The comparison between control-run and historical simulation shows, that the forcings are essential for the long-term correlations in the temperature records. The findings are supported by the analysis of NH temperature reconstructions exhibiting long-term correlations on centennial scales, such as the Moberg et al. 2005 record with $\alpha \simeq 0.86$.

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