Power-law persistence and trends in the atmosphere: A detailed study of long temperature records

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We use several variants of the detrended fluctuation analysis to study the appearance of long-term persistence in temperature records, obtained at 95 stations all over the globe. Our results basically confirm earlier studies. We find that the persistence, characterized by the correlation $C(s)$ of temperature variations separated by s days, decays for large s as a power law, $C(s) \sim s^{-\gamma}$. For continental stations, including stations along the coastlines, we find that γ is always close to 0.7. For stations on islands, we find that γ ranges between 0.3 and 0.7, with a maximum at $\gamma = 0.4$. This is consistent with earlier studies of the persistence in sea surface temperature records where γ is close to 0.4. In all cases, the exponent γ does not depend on the distance of the stations to the continental coastlines. By varying the degree of detrending in the fluctuation analysis we obtain also information about trends in the temperature records.

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I. INTRODUCTION

The persistence of weather states on short terms is a well-known phenomenon: A warm day is more likely to be followed by a warm day than by a cold day and vice versa. The trivial forecast, that the weather of tomorrow is the same as the weather of today, was in previous times often used as a "minimum skill" forecast for assessing the usefulness of short-term weather forecasts. The typical time scale for weather changes is about 1 week, a time period that corresponds to the average duration of so-called "general weather regimes" or "Grosswetterlagen," so this type of short-term persistence usually stops after about 1 week. On larger scales, other types of persistence occur. One of them is related to circulation patterns associated with blocking [1]. A blocking situation occurs when a very stable high pressure system is established over a particular region and remains in place for several weeks. As a result the weather in the region of the high remains fairly persistent throughout this period. It has been argued recently [2] that this short-term persistence regime may be linked to solar flare intermittency. Furthermore, transient low pressure systems are deflected around the blocking high so that the region downstream of the high experiences a larger than usual number of storms. On even longer terms, a source for weather persistence might be slowly varying external (boundary) forcing such as sea surface temperatures and anomaly patterns. On the scale of months to seasons, one of the most pronounced phenomena is the El Niño southern oscillation event which occurs every 3–5 years and which strongly affects the weather over the tropical Pacific as well as over North America [3].

The question is, *how* the persistence that might be generated by very different mechanisms on different time scales decays with time s. The answer to this question is not easy. Correlations, and in particular long-term correlations, can be masked by trends that are generated, e.g., by the well-known urban warming. Even uncorrelated data in the presence of long-term trends may look like correlated ones, and, on the other hand, long-term correlated data may look like uncorrelated data influenced by a trend.

Therefore, in order to distinguish between trends and correlations one needs methods that can systematically eliminate trends. Those methods are available now: both wavelet techniques (WT) (see, e.g., Refs. [4–7]) and detrended fluctuation analysis (DFA) (see, e.g., Refs. [8–11]) can systematically eliminate trends in the data and thus reveal intrinsic dynamical properties such as distributions, scaling and long-range correlations very often masked by nonstationarities.

In a previous study [12], we have used DFA and WT to study temperature correlations in different climatic zones on the globe. The analysis focused on 14 continental stations, several of them were located along coastlines. The results indicated that the temperature variations are long-range power-law correlated above some crossover time that is of the order of 10 days. Above the crossover time, the persistence, characterized by the autocorrelation $C(s)$ of temperature variations separated by s days, decayed as

$$C(s) \sim s^{-\gamma}, \tag{1}$$

where, most interestingly, the exponent γ had roughly the same value $\gamma \cong 0.7$ for all continental records. Equation (1) can be used as a test bed for global climate models [13].

More recently, DFA was applied to study temperature correlations in the sea surface temperatures [14]. It was found that the temperature autocorrelation function $C(s)$ again decayed by a power law, but with an exponent γ close to 0.4, pointing towards a stronger persistence in the oceans than in the continents.

In this paper, we considerably extend our previous analysis to study systematically temperature records of 95 stations. Most of them are on the continents, and several of them are on islands. Our results are actually in line with both earlier papers and in agreement with conclusions drawn from independent type of analysis by several groups [15–17]. We find that the continental records, including those on coastlines, value of the exponent is close to 0.65, in agreement with earlier calculations based on different methods [12,15–17].

(ii) On islands, the exponent shows a broader distribution, varying from 0.65 to 0.85, with an average value close to 0.8. This finding is in qualitative agreement with the results of a recent analysis of sea surface temperature records, where also long-term persistence with an average exponent close to 0.8 has been found [14]. Since the oceans cover more than 2/3 of the globe, one may expect that also the mean global temperature is characterized by long-term persistence, with an exponent close to 0.8.

(iii) In the vast majority of stations we did not see indications for a global warming of the atmosphere. Exceptions are mountain stations in the Alps [Zugspitze (D), Säntis (CH), and Sonnblick (A)], where urban warming can be excluded. Also, in half of the islands we studied, we found pronounced trends that most probably cannot be attributed to urban warming. Most of the continental stations where we observed significant trends are large cities where probably the fast urban growth in the last century gave rise to temperature increases.

When analyzing warming phenomena in the atmosphere, it is essential to employ methods that can distinguish, in a systematic way, between trends and long-term correlations—in contradistinction to a number of conventional schemes that have been applied in the past. These schemes run the risk of mixing up the correlatedness of natural climate system variability with entire regime shifts enforced by anthropogenic interference through greenhouse gas emissions. The fact that we found it difficult to discern warming trends at many stations that are not located in rapidly developing urban areas may indicate that the actual increase in global temperature caused by anthropogenic perturbation is less pronounced than estimated in the last IPCC (Intergovernmental Panel for Climate Change) report [24].

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