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Multi-fractal scaling comparison of the Air Temperature and the Surface Temperature over China

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HIGHLIGHTS

- There exist different multi-fractal phenomena in AT and ST.
- The diversity features of geographic distribution in multi-fractal behaviors.
- Some differences and similarities between AT and ST are successfully detected.

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ABSTRACT

The spatial and temporal multi-scaling behaviors between the daily Air Temperature (AT) and the Surface Temperature (ST) over China are compared in about 60-yr observations by Multi-fractal Detrended Fluctuation Analysis (MF-DFA) method. The different fractal phenomena and diversity features in the geographic distribution are found for the AT and ST series using MF-DFA. There are more multi-fractal features for the AT records but less for ST. The respective geographic sites show important scaling differences when compared to the multi-fractal signatures of AT with ST. An interval threshold for 95% confidence level is obtained by shuffling the AT records and the ST records. For the AT records, 93% of all observed stations shows the strong multi-fractal behaviors. In addition, the multi-fractal characteristics decrease with increasing latitude in South China and are obviously strong along the coast. The multi-fractal behaviors of the AT records between the Yangtze River and Yellow River basin and in most regions of Northwest China seem to be weak and not significant, even single mono-fractal features. However, for the ST records, the geographical distributions of multi-fractal phenomenon seem to be in disorder which account for 81% of the stations. The weak multi-fractal behaviors of the ST records are concentrated in North China, most regions of Northeast China.

1. Introduction

As is known to all, there exist Long Range Correlations (LRCs) for the temperature time series [1–7]. Many studies focused on the scaling behaviors of the Air Temperature (AT) and there is only a little research on the scaling behaviors of the Surface

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Temperature (ST) [8]. In fact, the temperature time series show the complex self-similar structures governed by different physical processes containing a variety of temporal–spatial scales. Therefore, it is quite necessary to compare and analyze the multi-fractal scaling behaviors of AT and ST records.

The Detrended Fluctuation Analysis (DFA) method has been introduced to qualify scaling behaviors due to some limitations of traditional methods such as Fourier transform and spectral analysis. The DFA method is established by Peng et al. [9], and extended by Bunde et al. [10]. LRCs have been detected and determined using DFA [11,12]. Kalauzi et al. [13] compared trends and rhythms of complexity climate trends of rainfall data series using fast Fourier transform and fractal dimension. Chelani [14] found the observed extreme CO and NO_2 concentrations are significant in two time scaling regions and the persistence is related with the property of self-organized criticality. Vindel and Polo [15] investigated the relations between the scaling exponents and the orders in the structure functions for the clearness and transmittance indexes. Zhang and Zhao [16] unraveled asymmetric upward and downward long-term persistence analysis in SSTA.

An approach based on the DFA method, called Multi-Fractal Detrended Fluctuation Analysis (MF-DFA), was extended since a mono-fractal scaling behavior cannot fully describe uneven multi-fractal characteristics [17,18]. Multi-fractal theory is a complex self-similar behavior that describes quantitatively the nonlinear evolution and multi-scale characteristics of the system. The MF-DFA method has been successfully applied in many fields [19–21]. Feng et al. [22] analyzed non-universal multi-fractal behaviors of wind speed at four stations over China. Zhang et al. [23] employed three methods to analyze scaling properties of numerically generated series and observed streamflow series. The results show that the average removing method performed reasonably better than the Fourier-based detrending method and adaptive detrending algorithm. Gao and Fu [24] found strong multi-fractal characters over some stations located in the Yunnan, Guangdong, and Inner Mongolia regions by studying the multi-fractal scaling of relative humidity over China.

There are also many studies on multi-fractal characters of temperature time series. Lin et al. [25] characterized different multi-fractal behaviors of temperature over China using a universal model. Du et al. [26] applied the MF-DFA method to determine the thresholds of extreme low minimum and high maximum temperature events. Moreover, the extreme temperature indices are proposed to reflect the severity ranks of extreme temperatures in order to find serious areas of extreme temperature events over Northeast China. Jiang et al. [27] analyzed multi-fractal scaling of four ST records over China and found strong persistence features and different multi-fractal behaviors of ST. In addition, Yuan et al. [28] analyzed the multi-fractal scaling of diurnal temperature range over China. Different multi-fractal characters are found over China taking Yangtze River as the roughly dividing line according to some criterions. Burgueño et al. [29] found that there are no clear spatial distributions for the multi-fractal spectrum parameters of the daily extreme temperatures in Catalonia (NE Spain), but depending on complex self-similar behaviors.

The first aim of this Letter is to study and compare the multi-fractal behaviors and detect the geographical distribution of the scaling law. The paper is organized as follows. In Section 2, the acquisition of the AT and ST records and the MF-DFA method are described. In Section 3, the results of MF-DFA and the multi-fractal spectrum and geographical distributions of multi-fractal strengths are investigated. We summarize the results and draw our conclusions in Section 4.

2. Data and method

2.1. Data records

The high-quality daily surface climatic records including 412 weather stations during the time 1951–2009 are from the Chinese National Meteorological Information Center (NMIC). Many studies have applied the long data records in recent years [25,28]. The daily AT and ST time series are used to study the different scaling behaviors in this paper. The seasonal cycles are removed from the raw data x_i by calculating the AT and ST anomaly $\Delta x_i = x_i - \langle x_i \rangle_d$, $i = 1 \ldots N$, where N is the length of the time series and $\langle x_i \rangle_d$ denotes the average value for a given calendar day.

2.2. The method

The MF-DFA method is mainly described by the following steps [30]. Firstly, the anomaly time series $\{\Delta x_i\}$ are integrated to get the profile. Secondly, the so-called profile is divided into segments of equal length s, and local polynomial fits of order N are computed respectively for each segment υ. Polynomial detrending of order N is capable of eliminating trends up to order $N - 1$. Then calculate the corresponding variance $F^2(\upsilon, s)$ for each segment length s from polynomial fits and take the qth root of the average fluctuation function $F^2(\upsilon, s)^{q/2}$ over all segments. If the time series is long-range power-law correlated, the fluctuation function $F_q(s)$ increases asymptotically with s as power-law: $F_q(s) \sim s^{h(q)}$, where the exponent $h(q)$ describes the scaling behavior of the qth-order fluctuation function. In this Letter, the fourth-order polynomials are used to eliminate cubic trends in the raw data. For stationary series, the exponent $h(2)$ is the well-defined Hurst exponent. For a mono-fractal time series, which can be characterized by a single scaling exponent over all scales, $h(q)$ is independent of the index q, whereas for a multi-fractal time series, $h(q)$ varies with q, which are characterized by more than one scaling exponent indicating multi-fractal behaviors [30].

The singularity spectrum $f(\alpha)$ is also used to characterize multi-fractal scaling behaviors [31,32]. The generalized Hurst exponent $h(q)$ and the scaling exponent $\tau(q)$, the singularity exponent α and the singular spectrum $f(\alpha)$ in multi-fractal