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A nonlinear method for detecting climate mutation

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A nonlinear method for detecting climate mutation: a case study for summer climate change in China

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Abstract

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In this paper, we explored the dynamical mechanism of anomalous summer climate late 1970s in China applying a new method, i.e., a dynamics index-Q based on phase-space reconstruction. The interesting results show that different climate variable have
5 the similar dynamics property in different regions, they reflect an intrinsic dynamics interior climate system, which may be associated with the teleconnection wave trains mainly triggered by the Tibetan Plateau, and reveals some of causes making North China drought indirectly. However, the Phenomena are hardly possible found via any statistic methodology.

10 1 Introduction

Climate mutation is a specific representation of the dynamical structures of climate system, its dynamical processes or mechanisms are largely unknown (Feng et al., 2001, 2004; Li and Chou, 2003; Li and Wang, 2003). Statistical techniques, such as low pass filtering, moving *t*-test, Cramer method (Fu and Wang, 1992), Yamamoto
15 method (Yamamoto et al., 1985, 1986), and M-K method (Goossens and Berger, 1986), etc., are still the main tools for diagnosing the climate mutation. These methods have advantages to certain extent, but can't show confidence level due to certain subjectivity involved sometimes (Fu and Wang, 1992). Furthermore, most of these methods can't be used to deal with complicated time series.

20 Although the climate mutation studies based on the statistical techniques have indicated that under the background of global climate changes, many climate elements jumped late 1970s, however, the property and mechanism associated with the climate jump remain to be established (Shi, 1996; Shi et al., 2000, 2003; Dai et al., 2003). Aiming at exploring the question, the dynamics index-Q (Li and Pei, 2003), which has
25 the superior performance in distinguishing different dynamics and is suitable for the cases of small sample (Feng et al., 2005, 2006), is introduced in this paper to iden-

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tify the nonlinear dynamics climate system. In present paper, we use the dynamics index-Q to diagnose climate mutation in the summer climatic elements. The data sets and methodology are exposed in Sect. 2. Results of the analyses on temperature and precipitation in China are given in Sect. 3. Reconstruction of climate dynamical backgrounds is shown in Sect. 4. Conclusions and discussion appear in Sect. 5.

2 Data and methods

2.1 Daily weather observations

Daily precipitation and temperature in mainland China for the period 1960–2000 was obtained from a recent developed comprehensive daily meteorological dataset (Feng et al., 2004). The dataset contains 729 stations that have long-term precipitation and temperature observations. The data had been subjected to a series of quality control, which includes homogeneity testing and adjustments to assure their reliability (Feng et al., 2004). The 1960–2000 complete summer (JJA) daily data at 547 stations without any missing value selected (Fig. 1) and divided into 1960–1977 and 1983–2000 groups in order to avoid the influence of the mutation periods (Shi, 1996) (namely the 5 years of 1978–1982 were not included).

2.2 The optimizing algorithm

In this section, we introduce the methodology for the application of Q-index. The Q-index method is designed to detect dynamical structures of time series recorded at various locations, based on phase-space reconstruction. The dynamical reconstruction of a nonlinear time series with the size $N\{x(t_i), i=1, 2, \dots, N\}$ can be performed according to the following expression:

$$X_i = \{x(t_i), x(t_i + \tau), \dots, x(t_i + (m-1)\tau)\} \quad (1)$$

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where the lag time $\tau=\alpha\cdot\Delta t$, α is a lag parameter, Δt the sampling interval, and m the dimension number of the embedding space (Sauer, 1994). Thus a vector matrix of $(N-\alpha(m-1)) \times m$ dimensions is constructed,

$$\vec{X} = \{X_i, i=1, 2, \dots, N-\alpha(m-1)\} \quad (2)$$

- and its self-correlation function is defined as (Grassberger and Procaccia, 1983)

$$C_{xx}(\epsilon) = P(\|X_i - X_j\| < \epsilon) = \frac{2}{(N-\alpha m)(N-\alpha(m-1))} \times \sum_{i=1}^{N-\alpha m} \sum_{j=i+1}^{N-\alpha(m-1)} \Theta(\epsilon - \|X_i - X_j\|) \quad (3)$$

which denotes the probability of finding an adjacent point within distance ϵ in the reconstructed space (Grassberger and Procaccia, 1983). Θ denotes the Heaviside function. $C_{xx}(\epsilon)$ has certain ability to distinguish potential dynamics for chaotic signals (Provanzale et al., 1992), however, it is far from the most important standard for discerning the closeness of chaotic time series (Grassberger and Procaccia, 1983; Grassberger, 1990).

- Then, how to identify the dynamical differences of chaotic time series? Let $x(i)$ and $x(j)$ be two points of discrete series $x(n)$ (n is size of samples), when $|x(i) - x(j)| \leq \epsilon$, the probability $s_m = C_{xx}^{m+1}(\epsilon) / C_{xx}^m(\epsilon) \leq$ for $|x(i+1) - x(j+1)|$ has stronger forecast ability than self-correlation (Savit and Green, 1991; Manuca and Savit, 1996). Similarly, for two time series $\{x_i\}$ and $\{y_i\}$, the dynamical self-correlation factor can be defined as (Li and Pei, 2003)

$$Q_{xy} = \lim_{\epsilon \rightarrow 0} \left| \ln \frac{C_{xx}(\epsilon)}{C_{yy}(\epsilon)} \right| \quad (4)$$

- which means that when Q_{xy} is statistically small enough, series $\{x_i\}$ and $\{y_i\}$ at least have a close dynamical structure, otherwise, they do not have close dynamical characters. It can directly measure the “distance” of different chaotic time series (Grassberger, 1990), i.e., when $Q_{xy} \approx 0$, it represents that two series originate from the same dynamics system.

3 Results

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Researches based on the statistical techniques indicated that under the climate background of global changes, climate elements in China jumped late 1970s. Shi (Shi, 1996; Shi et al., 2003) investigated the climate change in China in terms of annual temperature, annual precipitation and characteristic quantities of the Northern Hemispheric general circulation, and pointed out that the regional characters of the precipitation and temperature in the 1980s in China are as follows: north China was warm and dry, southwest China cold and dry, northeast China warm and wetter, and the Yangtze River valley cold and wet; while the intensities of teleconnection patterns including the WA and PNA had jumped, respectively, in the early 1980s and the middle 1970s; The discontinuous change of the subtropical high happened in 1976 and the early 1980s. Recently, Dai (Dai et al., 2003) pointed out that the interdecadal dry/wet subrogation occurred in most areas of China, and north China has been severely dry in the 1980s–1990s. To sum up, the climate jump late 1970s in China has been well established. However, what property and physical meaning do the mutations have? Those questions were rarely addressed in past studies.

3.1 Dynamical mutation of precipitation and temperature

Generally speaking, jump of climatic elements are firstly reflected in their mean values. The difference of average summer (JJA) total precipitation between 1983–2000 and 20 1960–1977 over China is displayed in Fig. 2a (mutation areas are shaded). It is obvious that the results are consistent with those of previous studies, such as floods in the Yangtze River valley and droughts in north China (Dai et al., 2003; Shi et al., 2003, 2000; Shi, 1996). However, whether the jump of mean-value means the change in the dynamics of the governing system or not? This is the key issue to be analyzed 25 and solved in this paper by using the latest research achievement of the nonlinear dynamics. The dynamics index-Q calculated via Eq. (4) suggests that the dynamical mutation areas (shaded) generally do not accord with the mean-value jump areas, but

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both coincide well in north China (C1 in Fig. 2b). namely, remarkable mean-value jump and dynamical mutation both occur in North China. Although the mean-value jump in the lower-middle reaches of the Yangtze River is more notable than that in North China, there is no evidence for dynamical mutation to appear in this region (Fig. 2b).

Similarly, the distributions of the mean-value and dynamical mutation of temperature are shown in Fig. 2c and d, respectively. It is clear that there was a warming in North China and a cooling in the Yangtze River valley for mean temperature (Shi, 1996; Shi et al., 2003) and the situation of temperature is in agreement with that of precipitation for dynamical mutation. The contrast analysis shows that the mean-value jump centers for precipitation and temperature do not coincide with each other (Fig. 2a and c) while the dynamical mutation centers (including eastern Tibetan Plateau, North China and north Northeast China) of precipitation and temperature coincide well (A1, B1 and C1 coincide basically with A2, B2 and C2, respectively).

Figure 3 is summer (JJA) total precipitation at Shanghai (Fig. 3a), Wutaishan (Fig. 3b), respectively. Figure 3a shows that although the first and second segments of the precipitation series at Shanghai (located in the Yangtze River valley) differ greatly in the mean value, they are very similar in the shape, indicating that the mean value jump of precipitation in the middle and lower reaches of the Yangtze River results from the different phases (namely wave peak and trough scenarios) of the same system. That is to say, the dynamical structure of precipitation in Shanghai does not change. The boreal spring SAM (Southern Hemisphere annular mode) variation provides a potential valuable signal for predicting the summer precipitation in the lower-middle reaches of the Yangtze River valley. However, situations in Wutaishan (Fig. 3b, located in North China) is different from that in Fig. 3a. Two segments of the precipitation series differ in the shape, amplitude, even period, reflecting the difference in the dynamical structure of the two segment curves. Therefore, the mean-value jump does not mean any change in dynamics.

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3.2 Possible mechanism for climate mutation

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- 25 It has been mentioned above that the mean value jump of precipitation and temperature can't be superimposed spatially, but all of the dynamical mutation are basically uniform.

4 Reproducibility of the climate dynamical backgrounds

What essence does it reveal?

As well known, the climate system is a complicated dynamical system, it can be described by differential equations of different variables such as potential height, pressure, temperature, or precipitation etc. meteorological elements. Each of them can 5 reproduce the climatic backgrounds. The nonlinear research outcomes of the 1970s reveal that the dynamics of a climate variable is the sub domain of the climate system, which can reflects the character of the governing system. That is to say, after the reconstruction of phase space, whether precipitation or temperature can reveal the 10 character of the dynamical structure and the evolution of climate system, namely the climate dynamical backgrounds can be reconstructed via various weather elements respectively.

5 Discussion and conclusions

Based on the phase reconstruction of precipitation and temperature, the characteristics 15 of the dynamical structure of climate system are revealed. The similar phenomena are found between precipitation and temperature, indicating that they are governed by the same dynamical system. This insight can not be provided by conventional statistical techniques.

As a source center, the Tibetan Plateau is sensitive to the abnormality of the global 20 climate system and might play an important role as the heat source over the Philippines, which induces teleconnection pattern. It becomes a key part making the climate system abnormal in the Northern Hemisphere.

The anomalous climate in North China is not an isolated point, but is closely related 25 with the anomaly of the northern circulation. Researches indicated that some serious drought periods in North America in history are in agreement with those in North China plain (Namias, 1983; Stockton and Meko, 1983). For example, the severe droughts of about 10-year happened both in the Great Plains and North China plain in the 1930s and 1960s. In 1980 and 1983, severe droughts occurred in both areas (Namias, 1983).

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This synchronous drought is possibly associated with the fact that the two plains are in the propagation path of the Tibetan Plateau wave trains. However the further studies are needed to find out the mechanisms responsible for the links.

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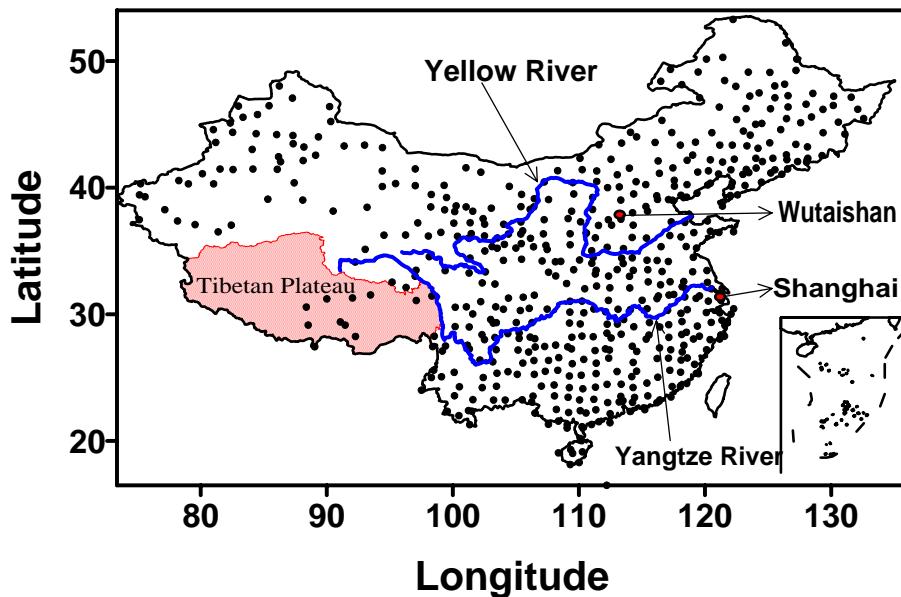


Fig. 1. Geographical distribution of the 547 meteorological stations in China (dots).

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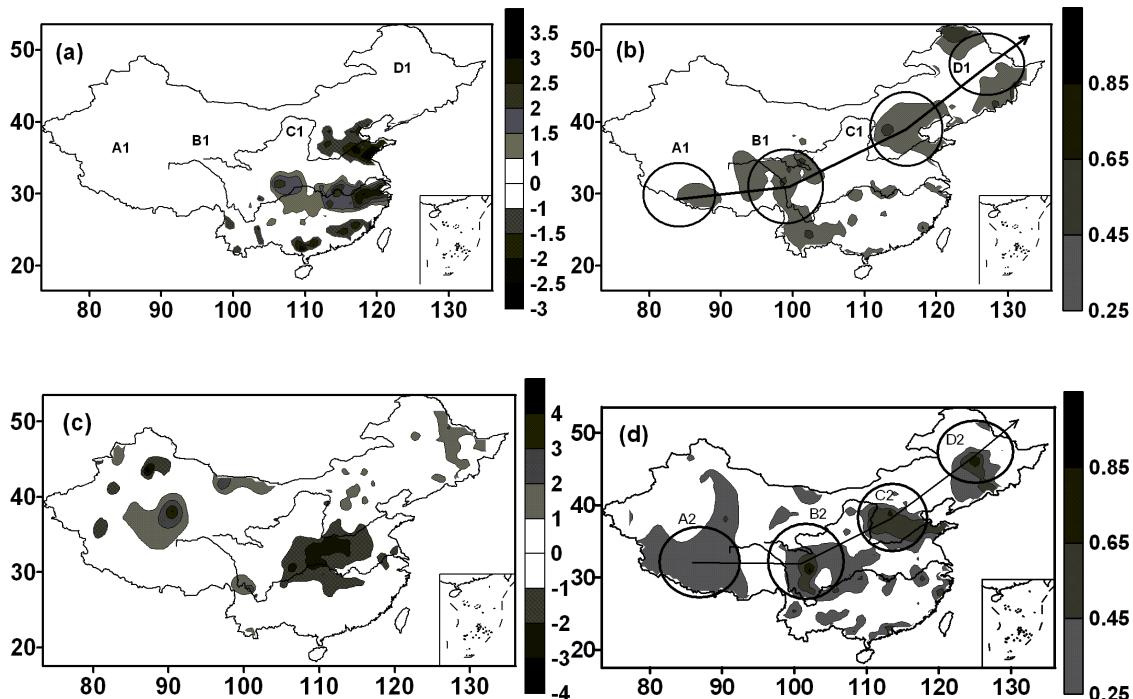


Fig. 2. Regions (shaded) for the Mean values jump **(a), (c)** and the dynamical mutation **(b), (d)** for precipitation and temperature in China respectively.

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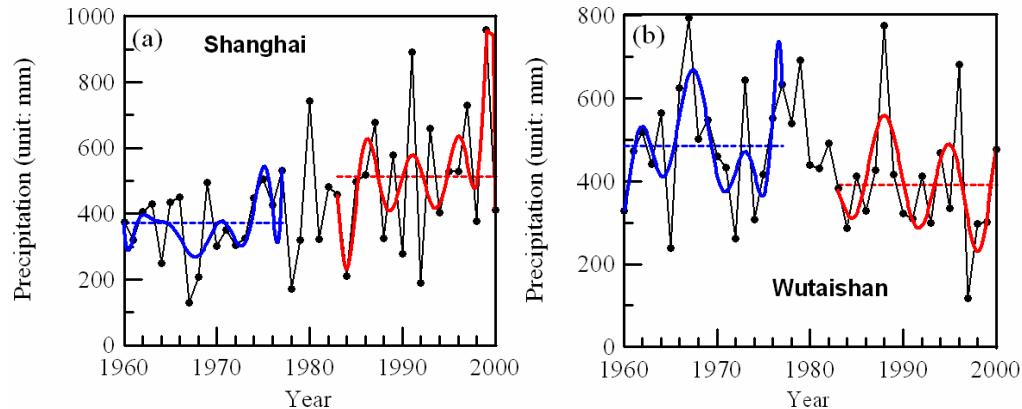


Fig. 3. Summer total precipitation at Shanghai **(a)** and Wutaishan **(b)**. The dash lines denote mean values for the first (1960–1977) and second (1983–2000) periods, respectively, and the smooth thick lines the 10-order polynomial fitting.

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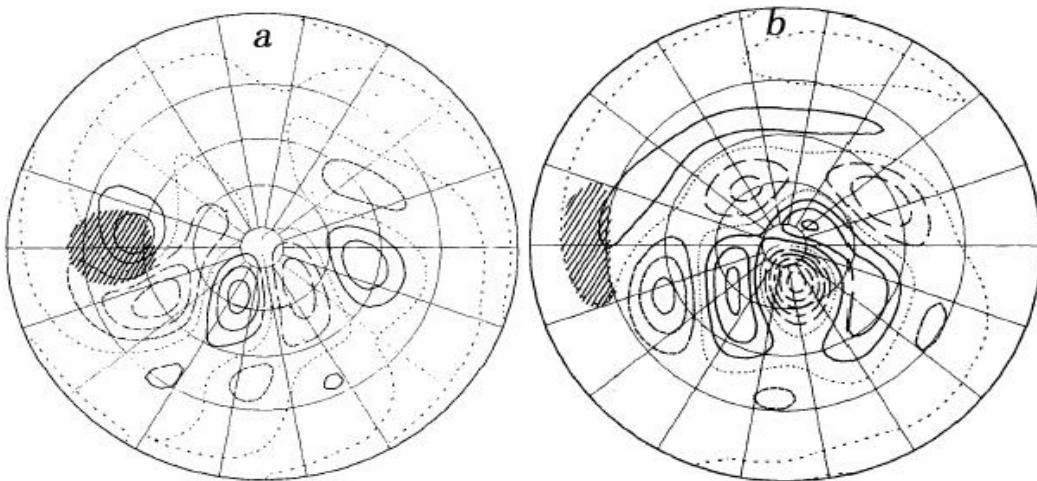


Fig. 4. The remote response situations of 300-hPa geopotential heights triggered by a circular mountain (30° N) **(a)** and an elliptic heat source (15° N) **(b)** under a Northern winter zonal flow (Hoskins and Karoly, 1981).

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