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Hypersensitivity of climate response to solar activity output during the last 60 years

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Abstract. Historical sunspot and climate records were analyzed by means of nonlinear tools to study long-term trends and relationships with the solar activity variations. Cross Wavelet technique and Recurrence Plot analysis were applied to the data to find their similarities and phase coherence at different time and time-scale. It is shown that solar cycle signal is more evident in climatic data during the last 60 years. This result is discussed in conjunction with the problem of unprecedented high level of sunspot activity and climate warmth in the late 20th century.

Key words. Solar activity – Climate change

1. Motivation

Sunspot and climate time-series result from natural dynamical processes at the Sun and the Earth. Both the solar activity and climate exhibit significant interannual variations and changes. Solar impact on climate (if exists) is essentially nonlinear. Relatively new techniques as Recurrence plot (RP) and Wavelet analyses display hidden behavior and similarities between different time-series. We try to use these tools to find the solar signal in the climatic proxies.

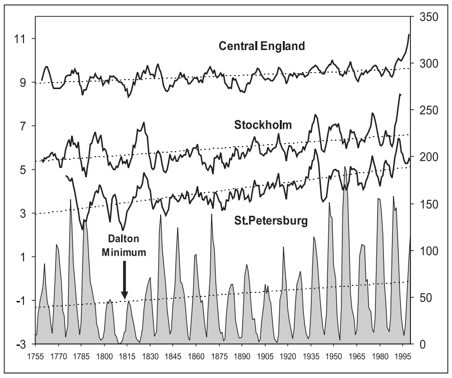

Fig. 1. Long-term mean annual temperatures (five-year running averages) for CET, Stockholm and St.Petersburg stations, the Wolf sunspot numbers (from the top to bottom).

2. Data and Methodology

The data used here are presented in the Figure 1. The panel displays smoothed time-series of annual averages of air-surface temperature in Central England (CET), Stockholm, St.Petersburg, and sunspot numbers. We used also reconstructions of Northern and Southern Hemisphere mean surface temperature over the past two centuries Jones & Mann (2004).

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2.1. Recurrence and Cross-recurrence plot tools

Recurrence is fundamental property of dissipative dynamical systems typical in real world. Recurrence plots (RP) simply display recurrent behavior of natural processes in phase space Eckmann et al. (1987). Recurrence of a state at time i at a different time j is pictured within a two-dimensional squared matrix with black and white dots, where black dots mark a recurrence, and both axes are time axes. This analysis is particularly useful in finding locations in the data where underlying dynamics change.

The structure of RP is characterized by *typology* and *texture* Eckmann et al. (1987). The *typology* determines large-scale global characteristics of the patterns. The *texture* displays small scale features of the dots distributions. Single isolated points correspond to infrequent states or if they fluctuate; diagonal lines occur when evolution of states is similar at different times; vertical and horizontal lines marks the time length, when state does not change or change slowly (laminar states).

Extension of RP to visualize coupling between two dynamical systems is called *cross recurrence plot* Marwan & Kurths (2004). CRP simultaneously displays two time series in the same phase space.

Visualization of CRP help to reveal hidden nonlinear interrelations between time series. Especially informative for this purpose is so called *line of synchronization* (LOS).

The RP *main diagonal* denotes the line when $\mathbf{R}_{i,i} = 1$ ($i = 1 \ldots N$) and thus is called *line of identity*. While analyzing two different time series coupling between systems often means some changing delay, so the line of identity is replaced by the line of synchronization $\mathbf{CR}_{i,i}$ ($i = 1 \ldots N$) (if exists). Usually it is disrupted, bowed and doesn't lay an angle of $\pi/4$.

2.2. Wavelet and Cross-wavelet analysis

Discovered in late of 1980's wavelet transforms are well suitable in detection of localized and quasiperiodic fluctuations using limited time span of the climatic data. Wavelet analysis involves a transform from a one-dimensional time-series to a diffuse two-dimensional time-frequency image Torrence & Compo (1998).

Cross-wavelet analysis is an extension of wavelet transforms to examine relationships in time-frequency space between two time series Grinsted et al. (2004). However, the wavelet cross spectrum appears to be not suitable for significance testing the interrelation between two processes. Instead, one should rather apply wavelet coherency Maraun & Kurths (2004).

3. Results and Discussion

Figure 2 displays similar topological patterns and near simultaneous changes of the *texture* in climatic data. These transitions indicate surprisingly different behavior of the climate just before and after 1930's. Results of wavelet transforms applied to the same period are presented in the Figure 3. Particularly, quasi 11-year periodicity is evident in the second half of the 20th century Ponyavin (2004). Solar cycle signal can be clearly seen in St.Petersburg, Stockholm series and in the CET data. Cross-wavelet spectra show high level of coherence between time series in the vicinity of 11-year period. Interesting is that the different behavior before and after 1930's is observed also when applying the CRP analysis to the Northern and Southern mean temperatures series (Figure 4). To summarize, the climate at the Earth show unprecedented behavior during the last 60 years that may be related to the unprecedented warmth at global scales Jones & Mann (2004). The second half of 20th century demonstrates unusual response of climatic system to the solar signal. If so, one can estimate too low the level of the solar activity in the past when reconstructing the history of solar activity from linear models and geophysical proxies Solanki et al. (2004).

4. Conclusions

Recurrence plots and wavelet patterns show similarities and coherence between regional temperature data revealing their global origin. Nonlinear analysis demonstrates different dynamical behavior of the global climatic system

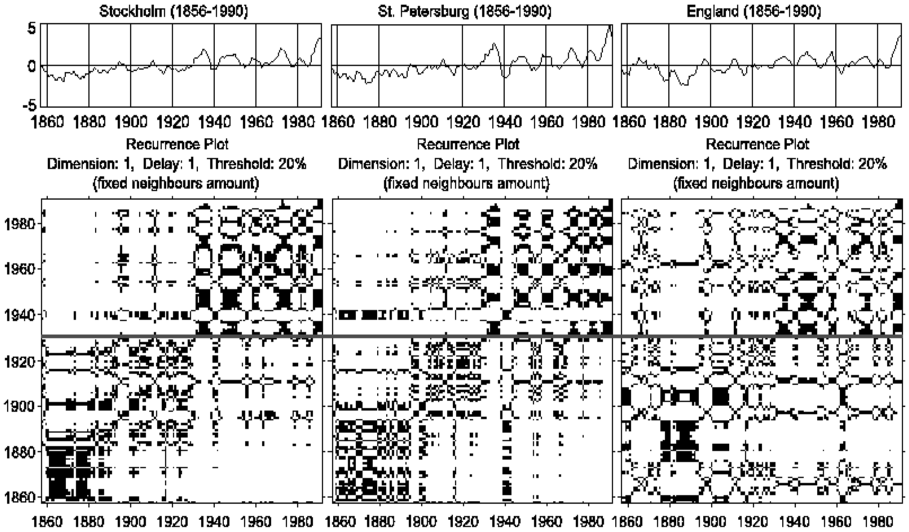

Fig. 2. Recurrence plots of the air surface temperature in Stockholm, St.Petersburg and Central England versus time from 1856 to 1990. Note the near-simultaneous phase transitions observed in late of 1930's. Patterns just before and after this time are different denoting different recurrent behavior of underlying dynamical systems. The demarcation line corresponding to structural changes is marked by horizontal line.

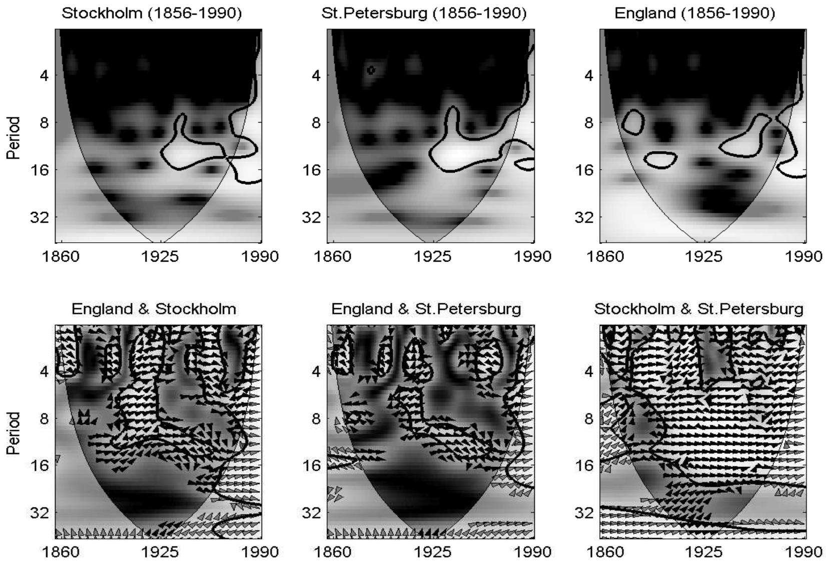

Fig. 3. Wavelet transforms of the standardized time series. The 5% significance level against red noise is shown as a thick contour. Cross-wavelet spectra are displayed at the bottom of the panel. The relative phase relationship is shown as arrows (with in-phase pointing right, anti-phase pointing left, and one set of data leading another by 90 pointing straight down).

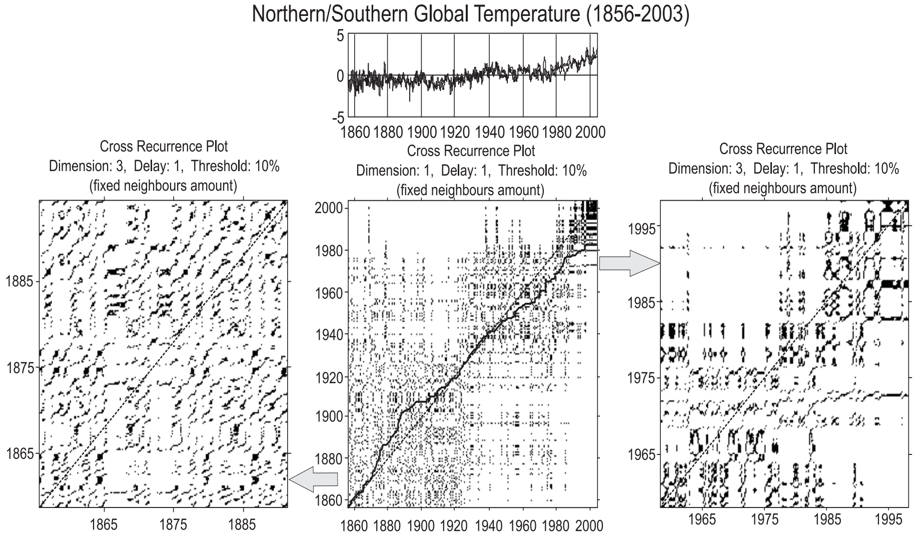

Fig. 4. Cross Recurrence Plots demonstrate synchronous changes in the monthly mean temperatures of the Northern and Southern Hemispheres. However, the density of plots is asymmetrical denoting a slight bowing of the *line of synchronization* (solid line) relative to the main diagonal (dashed line). The texture of CRP is significantly different in the late of last decades of 19th and 20th centuries.

in the second half of the 20th century to compare with the other epochs. Solar cycle signal is more evident in climatic data during the last 60 years.

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