Journal of Atmospheric and Solar-Terrestrial Physics
Volume 71, Issues 8–9, June 2009, Pages 923-930

Phase-coherent oscillatory modes in solar and geomagnetic activity and climate variability

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https://doi.org/10.1016/j.jastp.2009.03.012
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Abstract

Oscillatory modes with the period of approximately 7–8 yr were detected in monthly time series of sunspot numbers, geomagnetic activity aa index, NAO (North Atlantic Oscillation) index and near-surface air temperature from several mid-latitude European locations. Instantaneous phases of the modes underwent synchronization analysis and their statistically significant phase coherence, beginning from 1950s, has been observed. Thus the statistical evidence for a coupling between solar/geomagnetic activity and climate variability has been obtained from continuous monthly data, independent of the season, however, confined to the temporal scale related to oscillatory periods about 7–8 yr.

Introduction

Possible influences of the solar activity on the terrestrial climate, in particular, possible manifestations of the solar variability in the climate change have been investigated for many years (see Friis-Christensen and Svensmark, 1997; Friis-Christensen, 2000; Rind, 2002; Haigh, 2005; Kane, 2005; Lean et al., 2005; Bard and Frank, 2006; Tinsley, 2008 for reviews). Therefore, relationships between the solar activity, or quantities closely related to the solar activity, and climate data have been sought. Besides the well-known sunspot numbers, the aa index characterizing the geomagnetic activity provides the longest data set of solar proxies which goes back to 1868 (Mayaud, 1972). Some relations during the last century and especially during the last 60 yr have been observed between the geomagnetic activity and the near-surface air temperature (Cliver et al., 1998; Bucha and Bucha, 1998; Ponyavin, 2004; Le Mouel et al., 2005; Valev, 2006). Possible connections between the Earth's magnetic field and climate were proposed by Courtillot et al. (2007) and critically discussed by Bard and Delaygue (2008). Dependence relations have been sought between the geomagnetic activity and indices describing the dominant pattern of the tropospheric circulation variability in the extratropical Northern Hemisphere, known as the North Atlantic Oscillation (NAO) (Hurrell et al., 2001). Bucha and Bucha (1998) have found correlations between the geomagnetic activity and circulation indices similar to NAO for the period 1970–1996. Thejll et al. (2003) observed correlations between the geomagnetic Ap index and the NAO index after 1970, Lukianova and Alekseev (2004) have found a correlated behavior between the NAO index and the aa index after 1940. The observed correlations are based on the winter NAO index. This seasonal restriction leads to relatively small numbers of data samples (due to the yearly sampling used), making the statistical significance of the observed correlations extremely vulnerable to small changes in the analyzed number of samples and to the choice of preprocessing (e.g., filtering or smoothing) parameters. Bard and Delaygue (2008) discuss this kind of problems in relation to analyses presented in Courtillot et al. (2007). Another example of the problems caused by a limited number of samples and data smoothing is the correlation between the global air temperature and lengths of the solar cycles (Friis-Christensen and Lassen, 1991; Lassen and Friis-Christensen, 1995). Damon and Peristykh (1999) and Laut (2003) assert that the correlated curves of the global temperature and solar cycle durations during last several decades were probably obtained due to a smoothing procedure applied by Friis-Christensen and Lassen (1991) and Lassen and Friis-Christensen (2000) rather than due to an actual dependence.

In this paper we focus on possible scale-dependent relationships between the solar/geomagnetic activity and the climate variability represented by the NAO index and near-surface air temperature. Since several studies (Gleisner and Thejll, 2003; Veretenenko and Pudovkin, 2000; Usoskin et al., 2004) have observed latitudinal dependence of tropospheric responses to the solar/geomagnetic variability, we have focused on temperature records from mid-latitude European stations. Following our previous studies (Paluš and Novotná, 1998, Paluš and Novotná, 2004, Paluš and Novotná, 2006, Paluš and Novotná, 2007), we first identify oscillatory modes on various temporal scales (frequencies) in the monthly solar, geomagnetic and climate data. Then, for the detected oscillatory modes we extract their instantaneous phases and test a possible presence of phase synchronization in pairs of the modes from different source data. We have found statistically significant phase coherence from 1950s for oscillatory modes with the approximate period of 7–8 yr.

Section snippets

Methods

The singular system analysis (SSA) is a well-known method for the detection and extraction of trends and oscillatory modes from noisy time series such as long-term records of meteorological variables or measurements from other complex geophysical processes (Vautard et al., 1992; Elsner and Tsonis, 1996; Golyandina et al., 2001; Ghil et al., 2002). Allen and Smith (1996) introduced the Monte Carlo SSA (MCSSA), a statistical approach in which eigenvalues (variance) of the SSA modes are tested…

Data

The monthly mean values of the near-surface air temperature from the Czech stations of Prague–Klementinum (longitude $14^\circ 25' \mathrm{E}$, latitude $50^\circ 05' \mathrm{N}$, the measurement period 1775–2006) and Milešovka ($13^\circ 55' \mathrm{E}$, $50^\circ 33' \mathrm{N}$, 1905–2005), as well as from several other European stations: Bamberg ($10^\circ 53' \mathrm{E}$, $49^\circ 53' \mathrm{N}$), Basel ($07^\circ 35' \mathrm{E}$, $47^\circ 33' \mathrm{N}$), De Bilt ($05^\circ 11' \mathrm{E}$, $52^\circ 06' \mathrm{N}$), Potsdam ($13^\circ 04' \mathrm{E}$, $52^\circ 23' \mathrm{N}$), Vienna ($16^\circ 21' \mathrm{E}$, $48^\circ 14' \mathrm{N}$), and Zurich ($08^\circ 34' \mathrm{E}$, $47^\circ 23' \mathrm{N}$), from the period 1901–1999 (Klein-Tank et al., 2002) were…

Results of EMCSSA

A number of oscillatory modes have been detected in the analyzed data. Paluš and Novotná, 2004, Paluš and Novotná, 2006 give a detailed description of EMCSSA of the atmospheric data (near-surface air temperature, NAO index). Paluš and Novotná, 2007, Paluš and Novotná, 2008 extend EMCSSA to the aa index and the sunspot data.

The common occurrence of the oscillatory modes with the periods of approximately 11, 5.5, and 2.2 yr and in the range 7–8 yr in the sunspot numbers, the aa index, the…

Results of synchronization analysis

In order to assure the precise temporal localization of the modes and their phases, in the following we study the instantaneous phases $\varphi_i(t)$ and phase differences $\Delta\varphi(t)$ obtained by using CCWT.

Fig. 4 demonstrates the initial steps of the synchronization analysis. The oscillatory mode with the approximately 8 yr period is obtained from the sunspot data residuals (after previously removed modes related to the 11 yr cycle), by using CCWT with the central wavelet frequency giving the period 96 months. …

Discussion and conclusion

We used the EMCSSA (Paluš and Novotná, 1998, Paluš and Novotná, 2004) in order to identify oscillatory modes in the solar (the sunspot numbers) geomagnetic (the aa index) and climate (the NAO index, the near-surface air temperature) variability. Existence of some common oscillatory modes (i.e., the modes with the same average period) gives the possibility to apply the synchronization analysis (Pikovsky et al., 2001; Paluš, 1997; Paluš and Novotná, 2006) in order to find a possible dependence…

Acknowledgments

This study was supported by the Grant Agency of the Academy of Sciences of the Czech Republic Project no. IAA300420805, and in part by the Institutional Research Plans AV0Z10300504 and AV0Z30420517.…

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Haigh, 1996; Shindell et al.,1999), the solar wind modulation of the global-electric circuit (Tinsley, 2000), and the galactic cosmic ray flux (e.g. Tinsley and Deen, 1991; Pudovkin and Veretenenko, 1995; Marsh and Svensmark, 2000; Pallé-Bagó and Butler, 2000; Usoskin et al., 2004; Svensmark, 2007). After finding a good correlation between cloud cover changes and galactic cosmic rays (CR) along 1983–1994 Svensmark and Friis-Christensen (1997) suggested that CR modulate the production of clouds on time scales of decades and longer.…

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