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Possible evidence of the resonant influence of solar forcing on the climate system

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Abstract

An assumption of the existence of natural climatic oscillations driven by solar activity enables an explanation of phase differences between variations in solar activity and rainfall level in Fortaleza, Brazil. Decadal and interdecadal variations in rainfall level can be reproduced using a forced oscillation equation with a driving force term that describes the variation in the sunspot number and with the assumption of the existence of 31.7-year interdecadal and 12.96-year decadal natural climatic oscillations. This equation satisfactorily reproduces the periodicity with a length of approximately 22 yr in the interdecadal rainfall variation before and up to the middle of the past century as well as the subsequent phase inversion, period and amplitude increase in the variation that followed the corresponding increases in the interdecadal sunspot number variation. The equation accurately reproduces the irregular phase shifts between decadal variations in rainfall level and in sunspot number over the entire 160 yr of recorded observations.

Highlights

► The long-term SSN and rainfall variations were bound through a casual mathematical equation. ► Simultaneous presence of both external forcing and natural oscillations is a necessary condition. ► The yearly rainfall data for Fortaleza (Brazil) from 1849 up to 2010 were used for the analysis. ► Phase inversion in the interdecadal rainfall component is due to a period increase in SSN after 1950. ► Irregular phase shift in the decadal rainfall component is due to anharmonic character of SSN.

Introduction

The scientific and political relevance of the problem of long-term (i.e., more than several years) variability in climate is universally recognized (see, for example, the last report of the IPCC, 2007) and needs no further corroboration here. In spite of the fact that the phenomenon of long-term changes has been thoroughly established, its character (quasi-periodic oscillations or a stable trend) and its origin (intrinsic dynamics or external forcing) remain vague.

Because of the fundamental impossibility of any active experiment in studies of long-term climatic changes, the only possible approach for studying of the problem is through an analysis of existing instrumental records, proxy data, and historical evidence within the frameworks of physical/mathematical models of various degrees of sophistication. Unfortunately, the quality and number of the observational meteorological data available today and in the near future (a list of parameters measured, the duration and continuity of measurements, and the geographic distribution of the stations) hinder the substantial progress of research in this area..

Periodic forcing related to solar activity is one of the hypotheses aimed at explaining long-term climatic variations as a result of an external influence. Like other hypotheses of the origin of climatic variation, this hypothesis is still in a stage of development of qualitative scenarios rather than the formulation of a physical mechanism.

Most assumptions about the relationships between a given meteorological parameter and solar activity are based on the presence of ≈22-year (the Hale cycle) or ≈11-year (the Schwabe cycle) periods in a frequency expansion of the variation in the climatic parameter and/or on the correlation of a given meteorological parameter's profile with that of the corresponding solar parameters (e.g., Palle et al., 2004, Fadnavis and Beig, 2006, Kasatkina et al., 2007 and references therein). Evidence of the existence of tropospheric cycles with periods of lengths close to those of the Hale and Schwabe cycles has been also found through statistical analyses of paleodata (e.g., Evans et al., 2001, Garric and Huber, 2004, Dima et al., 2005) and gridded climate datasets (e.g., Venegas et al. (1997)) assimilating data on long-term direct meteorological observations (NOAA, 2008).

Some general circulation models (GCM) not considering external forcing reproduce similar periodicities (James and Gray, 1986, Liang et al., 1995, Grötzner et al., 1998, Wainer and Venegas, 2002). These results are often used as an argument against the hypothesis of solar forcing (James and James, 1989; Geller, 1989; Burroughs, 2003, Pittock, 2009). Attempts to incorporate solar activity into the GCM models have not resulted in a coherent conclusion about the influence of this activity on the Earth's climate (Matthes et al., 2003, Langematz et al., 2005, Schimanke et al., 2008).

The main shortcoming of direct meteorological observation data is their insufficient duration. According to Pittock (2009), at least 4–5 sequential cycles must be demonstrated for a statistically justified assertion of the presence of a periodicity. This requirement amounts to 100yr for the Hale cycle. Among the available data of this length, only a few are of the quality sufficient for analysis.

The hypothetical mechanisms of solar signal transmission to the troposphere are based on one of two assumptions: a solar signal is transmitted directly to the troposphere through the ionization of atmosphere by high-energy cosmic rays modulated by solar activity (Svensmark and Friis-Christensen, 1997) or indirectly (e.g., Hameed and Lee, 2005, Langematz et al., 2005) through the propagation and amplification of stratospheric variations caused by solar ultraviolet, X- and gamma-rays, and various interactions of solar wind and charged particle fluxes with the magnetosphere and atmosphere. Some parameters that undoubtedly correlate with the solar activity include stratospheric temperature, geopotential height, and ozone (see Labitzke (2006), and references therein).

Both of these hypotheses of the mechanisms by which a solar signal is transmitted to the atmosphere consider the climatic system as having neither inertia nor resilience, implying, as a result, a constant phase of a solar signal during the course of its interaction with the atmosphere. An assumption of inertia and resilience naturally leads to the possibility of natural oscillations.

There are only a few publications that consider the possible relationship between external forcing and the intrinsic dynamics of the climate system. To address the problem of the insufficient power of the external forcing, Tobias and Weis (2000) considered the possibility of a nonlinear climate system "flipping" between two quasi-stable states in response to triggering by a weak external signal. Similarly, a phase inversion in the tidal variation component (i.e., the lunar component with an 18.6-year period) of the drought area rhythm (Cook et al., 1997) may be also a reaction of a non-linear system to a small external signal. Tree-ring frequency spectra were interpreted by Raspopov et al. (2004) in terms of simple harmonic generation producing multiples of the fundamental frequency in a nonlinear medium. Gusev et al. (2004) put forward the hypothesis that changes in the pattern of rainfall variation in the Brazilian Fortaleza may be explained as a natural climate oscillation driven by solar activity.

The existence of natural (i.e., resulting only from intrinsic climate dynamics) oscillations may distort an external signal by, for example, changing its phase. This effect may be used to explain a varying phase difference between solar activity and climatic parameters (e.g., Xanthakis, 1973, King, 1975, Gusev et al., 2004). This phase difference is one of the main arguments (Pittock (2009) and references therein) against the reported correlation between solar variations (and cosmic rays) and climate variability. The effect may add to the evidence of a sun–weather relationship, but it may also obstruct (if not make impossible) the detection of such a relationship with traditional filtering-correlation methods.

In the present work, an attempt was made to find climate phenomena that could be treated as a result of the interaction of solar activity with inherent climate dynamics. This was achieved not through a filtering-correlation procedure but through a causative mathematical equation, which simulates a climatic variation from the observed solar variation.

The rainfall level (RL) variation was selected as a climatic parameter for this study. This is the most traditional meteorological parameter used in this kind of study, the results of which have been actively discussed (Xanthakis (1973), Pittock (2009), Dobrica et al. (2009), Bal and Bose (2010) and the references therein).

Section snippets

Data and methods

The forced oscillation equation describes a simple physical process with a controlled (as opposed to a nonlinear chaotic system) phase shift. In the simplest linear case, the equation describes oscillation $y(t)$ of a system responding to an external forcing $F(t)$: $y''(t) + \omega_0^2 y(t) + \Gamma y'(t) = F(t)$ where ω_0 is the natural (resonant or eigen) frequency of the oscillator and Γ is a damping coefficient.

In the case of zero damping (Γ=0) and a harmonic driving force with frequency ω_F and amplitude F, the…

Results

Using running average smoothing and fast Fourier transform filtering, the components containing periods of <7 (interannual), 7–16 (decadal), 16–70 (interdecadal) and >70 (secular) years were extracted from the total SSN and RL variations. Because of the rather wide frequency bands used, the results obtained with the two methods are practically identical.

The filtering procedure revealed the presence of interdecadal and decadal components with amplitudes of 10% or more of the total variation in…

Discussion

Our findings serve an example of a climatic variation that can be interpreted in terms of the simultaneous presence of two phenomena: a natural oscillation in the climate system and an external (i.e., solar) quasi-periodic forcing with a characteristic frequency close to that of the climate one. Thus, the hypotheses treating climatic variations as a manifestation of intrinsic dynamics of the climate system or as a result of an external forcing are considered here as complementary rather than an …

Acknowledgments

The data on liquid precipitation are from the Research Data Archive (RDA) which is maintained by the Computational and Information Systems Laboratory (CISL) at the National Center for Atmospheric Research (NCAR). NCAR is sponsored by the National Science Foundation (NSF). The original data are available from the RDA (http://dss.ucar.edu↗) in dataset number ds570.0. The data on RF in Fortaleza were updated with information from the site of the National Institute of Meteorologia, Brazil (//www.inmet.gov.br/html/observacoes.php↗…

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2004; Gusev and Martin, 2012; Heredia and Elias, 2013; Hernández et al., 2010; Mauas et al., 2011), as well as in tree rings (Nordemann et al., 2005; Perone et al., 2016; Prestes et al., 2011; Rigozo et al., 2007, 2008a, 2008b). Variability in the Peru-Chile upwelling appears also to be influenced by solar activity changes, especially by the solar Gleissberg cycles with a periodicity of 80–100 years (Agnihotri et al., 2008; Guiñez et al., 2014)....

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