On Possible Relation between Inter-Tropical Convergence Zone Location and the Solar Cycles

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Abstract. Yearly rainfall amounts (RA) in Brazilian Fortaleza and Quixeramboim were used to study variation in position of the Inter-Tropical Convergence Zone (ITCZ). Using a forced oscillation equation with a driving force term describing the variation in the sunspot number it proved to be possible to simulate decadal and interdecadal variations of RA in the both sites. The equation satisfactorily reproduces the periodicity close to the Hale one before and up to the middle of the past century as well as the subsequent phase inversion, period and amplitude increases in the interdecadal component of RA variation that followed the corresponding increases in the interdecadal sunspot number variation if a period of 31.7-year is assumed for a natural oscillation. The equation also accurately reproduces the irregular phase shifts between decadal variations in RA and sunspot number with assumption of a of 12.96-year period for the decadal natural climatic oscillations.

Keywords: Solar cycles, climatic cycles, Solar-climate connection, rainfall, forced oscillation

Introduction

Despite the fact that the reality of the long-term (i.e., more than several years) variability in climate has been thoroughly established (IPCC, 2007), its character (quasi-periodic oscillations or a stable trend) and its origin (external forcing or intrinsic dynamics) remain unclear. 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.

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 the 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.

Both of these hypotheses consider the climatic system as having neither inertia nor resilience, thus implying 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 and phase shift between the solar signal and a corresponding climate variation. Accounting for the latter effect may probably explain a varying phase difference between solar activity and climatic parameters (e.g., Xanthakis, 1973; King, 1975; Gusev et al., 2004). Thus 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.

Correlation with solar activity is reported for numerous local phenomena (see Burrouth (2003) and references herein) and for such global phenomena as Earth's cloud cover (Svensmark, H., Friis-Christensen, E., 1997), averaged sea surface temperature (SST) Reid (1987) and Pacific monsoon (e.g. Lihua et al., 2002).

One more of such large scale phenomena is the Inter-Tropical Convergence Zone (ITCZ): a low pressure zone encircling the earth near the equator where northeasterly and southeasterly trade winds come together. The ITCZ is characterized by intensive rainfall activity. The position of the ITCZ varies throughout the year responding seasonal variations in the temperature difference between the northern and southern hemispheres.

Paleoclimatic proxies indicate a possibility that position if the ITCZ is controlled by variation of the solar irradiance at least on century time-scale (Haug et al., 2001; Poore et al., 2004). For searching variations of shorter periods one can use the data on rainfalls in localities where the major part of the precipitations is determined by seasonal coming of the ITCZ. Fortaleza (3.7°S, 38.6°W) and Quixeramboim (5.2°S, 39.3°W) are on of these places: in February-May the ITCZ shifts maximally southward covering them and bringing practically all the total yearly amount of precipitations (Hewitt and Jackson, 2003). The both sites are practically the only ones for which data exists of the length and quality required for analysis.

In the present work the attempt was made to find a linkage between variations in solar activity and the rainfalls in the Fortaleza region not through the traditional filtering-correlation procedure but through a causative mathematical equation, which simulates a climatic variation from the observed solar variation.

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 $F(t)$:

$$y''(t) + \omega_0^2 y(t) + \Gamma y'(t) = F(t) \qquad (1)$$

where ω_0 is the natural (resonant) 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 solution is also a harmonic function with the same frequency ω_F and the amplitude

$$F/(\omega_0^2 - \omega_F^2) \qquad (2)$$

Varying the driving force frequency ωF near the natural ω_0 allows for the changing of the sign of the amplitude, i.e., inverting the phase of the oscillation (see the example in Gusev (2011)). A non-zero Γ results in phase shifts within $\pm\pi/2$.

When null initial conditions are applied, the amplitude of the natural oscillation is zero, and the resultant oscillation is controlled only by the external driving force. With non-null initial conditions, the solution is a superposition of the natural and the forced oscillations.

In our case, y(t) is the variation in yearly rainfall amount RA and F(t) is the yearly mean sunspot number (SSN) characterizing solar activity.

The equation was solved over the period from 1750 to 2010 for which a continuous set of direct SSN observations exists. The initial conditions and the equation parameters were varied until the best likeness of the solution y(t) with a selected RA set was reached.

The main block of the data is taken from NCAR (2010). For the period after 2000, the data of the Brazilian National Institute of Meteorology (INMET, 2010) were used. For the instances of missing data (<1%) the records of the Quixeramboim meteorological station (WMO#825860, FUNCEME (2010)) were used both for Quixeramboim and Fortaleza. In the last case the data were normalized for the ratio of the RA climatologists of Fortaleza and Quixeramboim (INMET, 2010). A comparison of the data from Fortaleza and nearby Quixeramboim shows that they are strongly correlate (Kane and Trivedi,1988), thus indicating the absence of erroneous records in the datasets.

Results

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

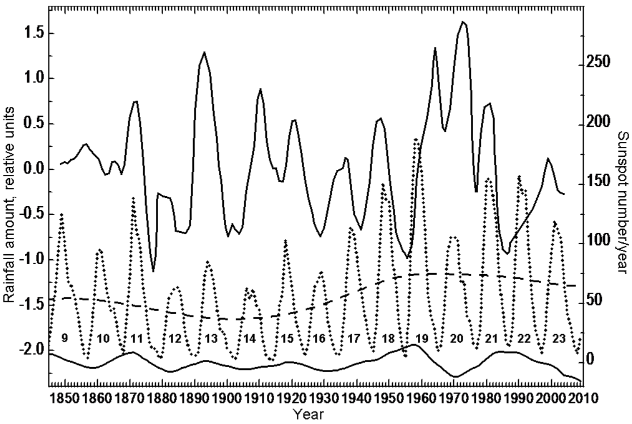

Figure 1. The total Fortaleza RL variation (upper solid curve) compared with the SSN variation components: total variation – dotted curve (the numerals mark Schwabe cycle numbers), interdecadal variation – lower solid curve, secular variation – dashed curve. The relative units means standard deviation from the mean value.

Figure 1 illustrates the result obtained for Fortaleza. The total variation curves in the figure are the result of smoothing of the annual data with a threefold sequential two-year running average. One can see that the total RA variation is a superposition of components with approximately ten-year (decadal) and more than twenty-year (interdecadal) periods. The decadal RA variations include the same number of cycles as the SSN one, but the irregular phase difference between the corresponding RA and SSN variations results in a non-significant correlation value.

The interdecadal SSN component

The limits of the frequency bands for the interdecadal components were set such that for the SSN variation, a profile close to a 22-year sinusoid is to be expected. This profile is a commonly used pattern for the interdecadal solar variation component. However, the actual interdecadal component depicted in Fig. 1 demonstrates a rather different profile[i]. The reason for this is that the interdecadal SSN variation is determined by amplitudes of sequential Schwabe cycles, whereas the Hale cycle is determined as the period of the reversal of the magnetic polarity of sunspot pairs. The approximately 22-year SSN cycles are a result of the regular alternations of the amplitudes in pairs of sequential Schwabe cycles. The 9-10, 11-12, 13-14, and 15-16 cycles shown in Fig. 1 (represented by the dotted and the lower solid curves) indeed form such a sequence. However, this regularity is violated beginning with cycle 17. As a result, rather than a sequence of Hale cycles, two approximately 40 year cycles develop (formed of the 16-20 and 20-23 cycles). In the present work, for the first time, a variation of a climate parameter is compared with the real interdecadal component of solar activity (the lower solid curve in Fig. 1) rather than with the classic Hale cycle.

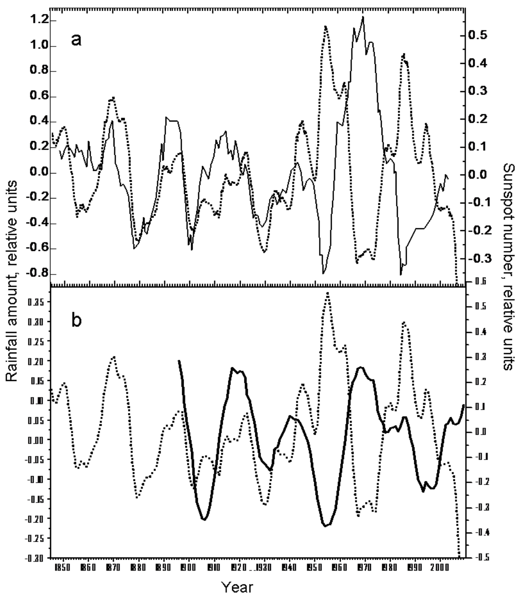

Figure 2. Interdecadal components of the RL variations (solid curves) in Fortaleza (a) and Quixeramboim (b) compared with the interdecadal component of the SSN variation (dotted curve).

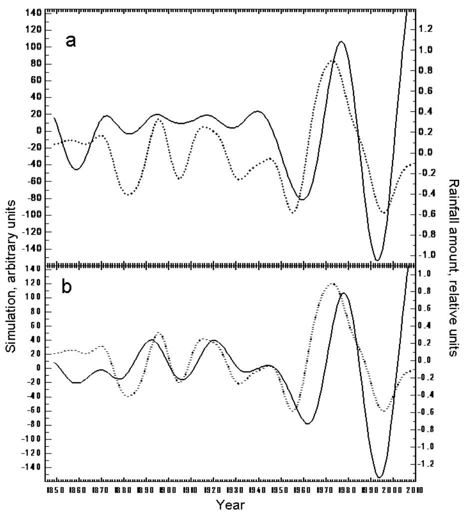

Figure 3. Comparison of the observed interdecadal RL variation in Fortaleza (dotted curves) with solutions of equation 1 (solid curves) **a** – with zero natural oscillation component, **b** –with non-zero natural oscillation component

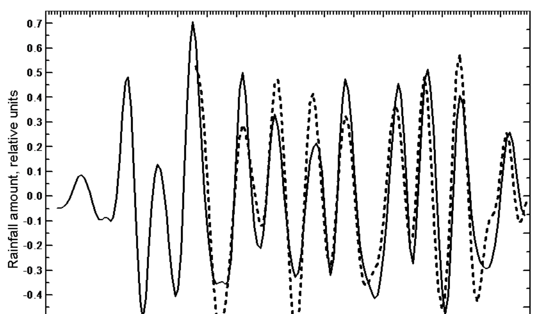

Figure 4. The decadal RA variations in Fortaleza (solid curve) and Quixeramboim (dashed curve)

The interdecadal RA component

The interdecadal RA curves for Fortaleza and Quixeramboim shown in Fig. 2 were obtained with the smoothing of the yearly mean values with an 11-year running average, thereby eliminating the decadal variation. A comparison of the curve with the corresponding SSN variation reveals characteristics likely related to solar activity:

a. Between 1850 and 1950, both components become in phase.

b. Starting from 1940-1950, the period and amplitude of the RA variation approximately doubles, repeating the same increases in the SSN variation.

c. The doubling of the period of the RA variation is accompanied by a 180° phase change

(phase inversion) against the SSN variation.

The effect of a phase inversion in the RA variation in Fortaleza has been known for several decades (King, 1975) and was examined in detail by Gusev et al. (2004). It was demonstrated that an artificial inversion of the RA curve after 1945 increases the correlation between the interdecadal RA and SSN components to be close in value to 80%.

Taking into account the existence of the phase inversion effect (Eq. 2), we can relate the period increase and the phase inversion of the interdecadal RA variation to the simultaneous increases in the period of the corresponding SSN variation, assuming the latter as the driving force.

Numerical solutions to Eq. 1 are compared in Fig. 5 with the Fortaleza interdecadal RA variation obtained from a thirty-fold two-year running average of the yearly means. The total (non-smoothed) SSN variation (the dotted curve in Fig. 2) was used as a driving force. The effect of phase inversion is shown in Fig. 3a in its pure state, i.e., without damping and with null amplitude of the natural oscillations. The best likeness is obtained with a natural frequency ω_0 =0.198 1/year (31.7-year period). The observational and the calculated curves show a close phase coincidence; however, the calculated amplitude before the phase inversion is several times lower than the observed amplitude. The coincidence of the curves considerably improves with the addition of a natural oscillation with amplitude of a 25 units (Fig. 3b).

The solution obtained does not significantly change if the natural oscillation period only varies within 0.1 year, which is most likely the result of using only one natural frequency harmonic to fit all those composing the driving force, which obviously reduces the range of permissible variation of the natural oscillation frequency.

The decadal RA component

Unlike the interdecadal RA variation, the decadal variation in Fortaleza and Quixeramboim (Fig. 4) has no characteristics indicating its potential relation with solar activity (Fig. 5a). In addition, the existence of the decadal variation itself does not seem to be well-grounded because its amplitude is comparable to that of white noise. Due to that, the observed approximately 11-year periodicity could be simply a result of a narrow band of the frequency filter used.

In spite of being well known, the RA decadal variation in Fortaleza has not previously been considered in the context of a solar-climate relation. This fact may be attributed to the presence of irregular phase shifts between the decadal RA and SSN variations, which reduces the correlation between them down to a non-significant and impedes the ability to prove the existence of a periodicity close to that of the Schwabe cycle using standard statistical methods. For example, the period corresponding to the maximum in the FFT frequency spectrum is 12.9 years for the decadal RA variation in Fortaleza and 10.8 years for the SSN variation.

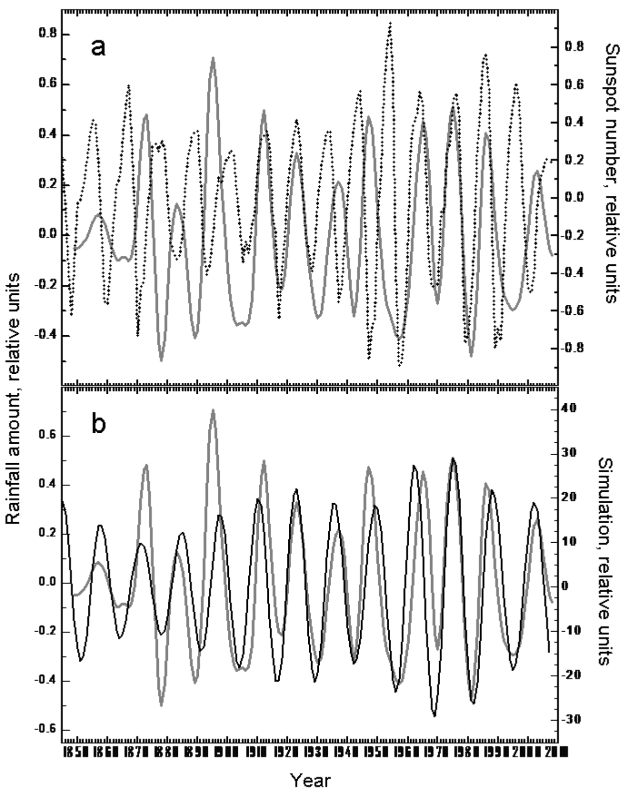

Figure 5. Decadal RA variation component in Fortaleza (gray bold curve) compared with the corresponding SSN variation (dotted curve in panel **a**) and with the equation solution (solid black curve in panel **b**)

Nevertheless, using Eq. 1 with the driving force described by the total SSN variation, it is possible to obtain a solution that almost perfectly matches the decadal RA variation. Figure 5 demonstrates the result with a natural frequency period of 12.96 years and null damping. The agreement between the curves remains close even when the amplitude of the natural oscillation component increases up to 0.3 units (i.e., comparable with the amplitude of purely forced oscillations) and the phase varies within ±90°.

What is unexpected is the extended period of the natural oscillation, which was presumed to be within the range of the variation of the length of the solar Schwabe cycle. In that case the result could be explained as a phase inversion caused by variations of the driving force frequency near the frequency of the natural oscillation. However the best fit period (12.96 years) exceeds the maximal Schwabe period (12.5 years) over the considered period from 1849 to 2010. It means that in this case, there is a continuous transient process caused by an inharmonic external force with a characteristic frequency slightly above the resonant frequency. The profile of the solution most likely is a result of an amplitude variation in the SSN interdecadal component ranging widely from 60 years to 200 1/year (Fig. 1). Such an effect clearly could not be predicted through an analytical consideration.

As with the interdecadal variation, the optimal value of the natural frequency must be maintained with a precision a few tenths of a year. For example, if the period of the natural frequency changes from 12.5 to 13.2 years, the phase changes by 90°. The best coincidence between separate cycles was obtained for periods varying from 12.7 to 13.2 years, which likely define the possible range of variation of the natural oscillation period.

Discussion

Basing on the forced oscillation equation it proved to be possible to associate the decadal and interdecadal variations in ITCZ position with the corresponding solar variations through a causative mathematical relation rather than a statistical correlation. The variations were simulated from the total SSN variation with the same equation and with only one free parameter: the natural frequency ω_0. No filtering procedures other than detrending of the SSN variation were applied.

Our findings serve an example of a large scale 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 the intrinsic dynamics of the climate system or as a result of external forcing are considered here as complementary rather than alternative evidencing the existence of both the phenomena.

As with other hypotheses on the causes of long-term climatic variations, our result cannot currently be definitively confirmed or refuted. In addition, the possibility that the Fortaleza region is a unique place on Earth where the described effect is observed cannot be excluded. In the same time the detection of 5 to 15 periods and a 160-year time span during which it proved to be possible to reproduce the variations are evidences in favor of a non-casual character of the effect described in this work. In addition, an interdecadal RA variation profile similar to that of Fortaleza was found in Charleston, United States (Gusev, 2011) as well in the air and the ocean surface temperature difference, although with a delay of several years, (Fig.6).

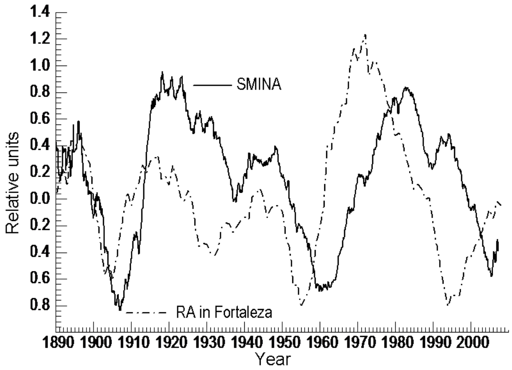

Figure 6. Interdecadal variation of the difference in air and ocean surface temperature (SMINA) in comparison with corresponding variation of RA in Fortaleza.

The approach used in this work, in spite of being purely mathematical, indicate some characteristics of the potential mechanism providing a linkage between the observed climatic variation and the solar activity. The absence of a delay (within the time resolution of the data used) between SSN and RA variations and null dissipation may indicate the rapid and nearly direct mechanism similar to a factor such as the modulation of the cloudiness through cosmic ray ionization (Svensmark and Friis-Christensen, 1997; Palle et al., 2004; Kristjansson et al., 2008; Erlykin et al., 2009 and references therein).

In connection with the delayed correlation presented in Fig. 6 it is of interest to note the hypotheses of Soon (2009) relating Arctic temperature variation with that of the total solar irradiance through a multilink mechanism including such classic climatic phenomena like atmospheric, thermohaline, and gyre circulations, modulation of ITCZ etc. The hypotheses predicts a 5- to 20-year delay in the tropical Atlantic sea surface temperature relative to the initial solar variation. As one can see from Fig. 6 the delay between the two curves with a similar characteristic profile falls within the predicted range over the most of the time sample considered that is a possible evidence in favor of the proposed mechanism.

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