Geofísica Internacional (2004), Vol. 43, Num. 2, pp. 271-279

Rainfall cycles with bidecadal periods in the Brazilian region

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Received: March 31, 2002; accepted: August 31, 2002

RESUMEN

Se consideran datos sobre precipitación líquida en tres estaciones meteorológicas de Brasil (Pelotas: 31°45'S, 52°21'W; Campinas: 22°53'S, 47°04'W; Fortaleza: 3°45'S, 38°31'W) durante 1849–2000. Estas estaciones cubren prácticamente todo el rango latitudinal de Brasil. El análisis del nivel anual de lluvia en Pelotas y Fortaleza muestra una periodicidad bidecenal muy pronunciada a lo largo de 100-150 años con una gran variación de amplitud de aproximadamente 90%. Se observan altas correlaciones/anticorrelaciones con el ciclo magnético solar: en Fortaleza los coeficientes son -77%±4% durante 1849–1940 y +80.0±4% durante 1952-2000, en Pelotas son 60%±13% en 1893-1920 y -84 %±4% durante 1929 - 2000. La correlación de la variación de la lluvia con periodos de 24 años, característica de modelos acoplados de océano-atmósfera independientes del ciclo solar, es de +54%±6% en Fortaleza durante 1849-2000. Se buscaron correlaciones de corto plazo entre el nivel de lluvia y el cruce terrestre con el sector magnético del medio interplanetario, con eventos de partículas de ráfagas y con decrementos Forbush durante ~ 50 años de observaciones. Los resultados se pueden usar para predicción a largo plazo en la región de Sur América y otras partes y para contribuir a resolver el problema de la relación sol-clima.

PALABRAS CLAVE: Correlaciones Sol-Tierra, clima, lluvia, ciclo solar, América del Sur, acoplamiento océano-atmósfera.

ABSTRACT

Precipitation in Brazil for three meteorological stations (Pelotas: 31°45'S, 52°21'W; Campinas: 22°53'S, 47°04'W; Fortaleza: 3°45'S, 38°31'W) from 1849 up to 2000 were considered. Periodic analysis of annual rainfall in Pelotas and Fortaleza shows bidecadal periodicity over 100-150 years with variation amplitude of about 90%. High correlation/anticorrelation coefficients with the 22-year solar magnetic field cycle in Fortaleza are -77%±4% during 1849–1940 and +80.0±4% during 1952-2000, and in Pelotas 60%±13% in 1893-1920 and -84 %±4% during 1929-2000. Correlation with 24-year periodicity is +54%±6% in Fortaleza during 1849-2000. Short term correlations of Brazilian rainfall level with magnetic sector boundary of interplanetary magnetic field crossing by Earth, with solar flare particle events, and with Forbush decreases in cosmic rays during ~ 50 years of observations were negative.

KEY WORDS: Solar-terrestrial connections, climate, rains, solar cycle, South America, ocean-atmospheric coupling.

INTRODUCTION

Decadal and bidecadal periodicities in climatic parameters are often considered as evidence of influence of solar activity on climate. Correlations with short-lived events such as solar flares and with the 11-year, 22-year and longer solar radiation changes (both electromagnetic and corpuscular) have been suggested (Herman and Goldberg, 1978). In some geographic regions solar cycles correlate, and in other they anti-correlate, with meteorological parameters such as precipitation or thermal patterns. No convincing physical mechanism causing this correlation has been proposed.

Evidence of long-term decadal and bidecadal variations of climate parameters has been observed in annual rainfall level in South Africa, Adelaide (Australia), and Fortaleza (Brazil). The same cycles were observed in droughts in the Middle West (USA) and in floods, in seasonal temperature in various states of USA, in annual average atmospheric pressure at middle and high latitudes in Europe, and in lightning frequencies (King, 1975). The amplitudes of variations may reach 100%. These significant effects could be used for long-term forecasting in agriculture, in flood prediction and fire control where frequencies may also vary with decadal and bidecadal cycles. However if these variations are caused by 11-, 22-year solar cycles one needs to assume an existence of correlation phase change that makes it difficult to use for forecasting of weather parameters. These changes were found both in the north (50°-60° latitudes in North America) and in the southern hemisphere (Brazil, Australia). Herman and

Goldberg (1978) noted that a relatively rapid change of sign of the correlation phase or a slow correlation phase change during tens of years was reported practically in all publications considering a correlation of solar activity with climate parameters. Instability of solar-climate relations was studied in the past (see chapter 3.3 in Herman and Goldberg, 1978, and Georgieva and Kirov, 2000).

Space weather impact on climate is less well researched in the southern hemisphere. We present new evidence of long-term bidecadal rainfall variations in the southern hemisphere, and their possible connection with solar cycles or with ocean-atmospheric coupling.

BIDECADAL RAINFALL VARIATIONS IN BRAZIL

The study of influence of 22-year solar magnetic cycle on climate parameters at low geographic latitudes in tropical countries and in particular in Brazil continues many years. The most comprehensive review in this relation was made by King (1975). It was shown there that the annual rainfall level at Fortaleza, Brazil, was correlated with double sunspot cycle from 1865 up to 1925. In Fortaleza the amplitude of 22-year variation amounted to about 35%. It was also noted that after 60 years the relationship between the rainfall and double cycle at Fortaleza changed phase. Today we have rainfall statistics from 1849 up to 2000 in Fortaleza, from 1890 in Campinas and from 1893 in Pelotas which cover practically whole latitude range of Brazil (equatorial, tropical and most south point of Brazil).

The annual rainfall data smoothed with 11-point filter are plotted in Figures 1, 4 jointly with adequately smoothed annual sunspot numbers. The latter is present in conventional form of "double sunspot cycle" when the spot numbers are multiplied by -1 in each odd cycle. If one multiplies them by -1 in each even cycle, phase of correlation will be inverted. It means that a phase of correlation is conventional, but a phase change is an absolute characteristic.

Figure 1 presents data on rainfall level in Fortaleza extended to 1849 and 2000 years in comparison with the data of 1860-1925 period previously analyzed by King. Fourier analysis (Figure 2) shows a distinguished 23±3-year periodicity. This bidecadal periodicity is clearly observed during seven periods. Characteristic feature of the cycle is a great amplitude of rainfall variations reaching ~90%.

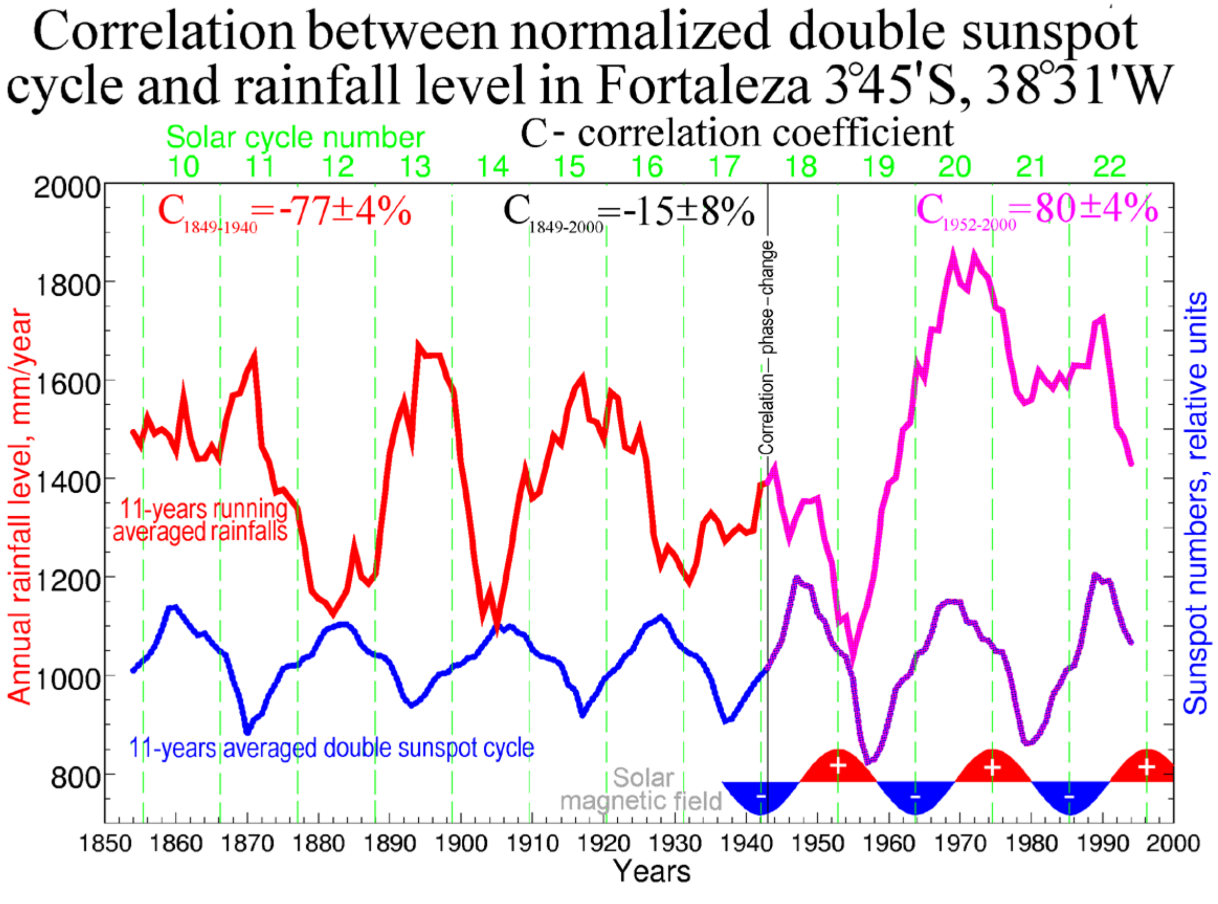

Fig. 1. The 11-year running averaged rainfall variations in Fortaleza and sunspot numbers from 1849 up today; "+", "-" are signs of a solar magnetic field polarity. The vertical line marks an approximate year of the phase change.

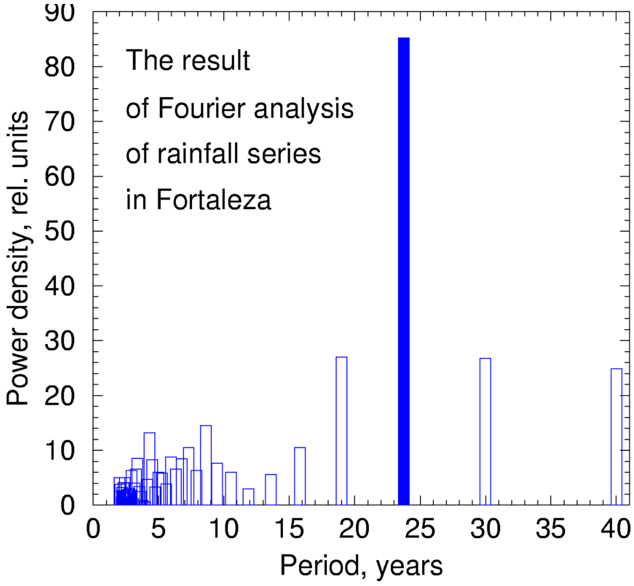

Fig. 2. The result of Fourier analysis of rainfall variations in Fortaleza from 1849 up to 2000.

One can clearly see an anti-correlation from 1849 until ~1949 and a correlation after 1949 until 2000 between double sunspot cycle and rainfalls. The correlation coefficient for 1849-1940 period is –77.2%±4.4% and for 1952-2000 is +80%±4% for normalized amplitudes. A confidence level is 99.9%. For the complete data set from 1849 up to 2000 the correlation coefficient between the rainfall level and the double solar cycle is –15.3%± 8%.

To check the fact of the phase change on quantitative base we selected a subseries with the left boundary fixed in 1920 and shifting the right boundary from 1939 to 1952 obtained the correlation coefficient drop from -43%±4% to -7% (see Figure 3). The same was made for a subseries with the right boundary fixed in 1970 and the left boundary shifting from 1952 to 1939. In this case the correlation coefficient decreased from +80%±4% to +60%. Years when the absolute values of the correlation coefficients decrease by one error are chosen as the boundaries of the time interval of the correlation phase change. As a result we obtained that the correlation with 22-year solar cycle changed its phase in

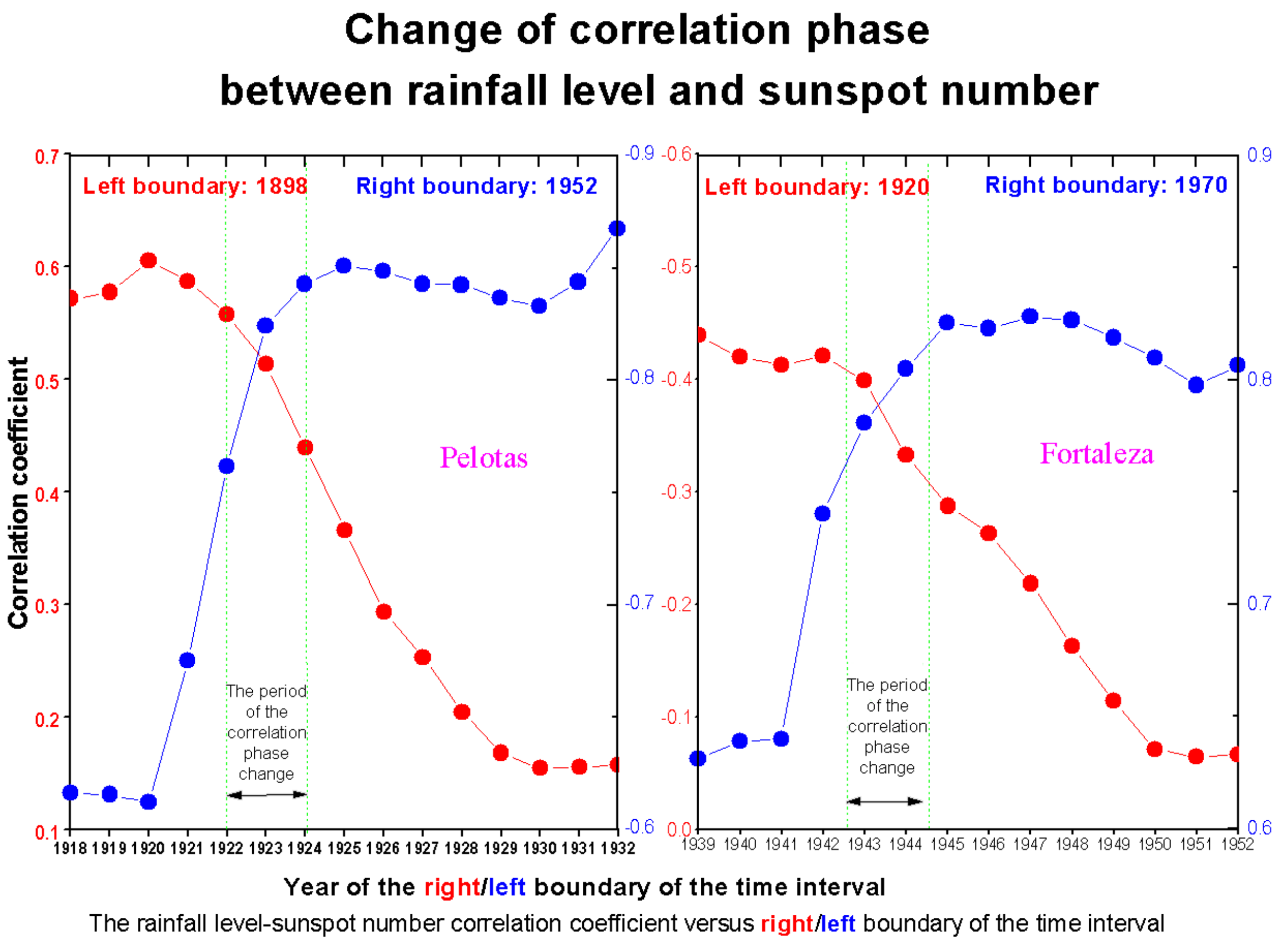

Fig. 3. The dependence of the correlation coefficient on a position of the right boundary (closed circles, the left scale) and left boundary (open circles, the right scale) of a subseries.

Fortaleza during 1942-1945, *i.e.* between maximum of 17 and 18 solar cycles when IMF had negative polarity sign.

Figure 4 presents the rainfall data of Pelotas. One can see an apparent bidecadal cycle in rainfall variations. The maximal variation amplitude of about 40% was observed between 1937 and 1942 year. Taking into account that inundation on the South of Brazil brings huge damage to national economy and threaten to population of the region, the knowledge and forecasting an increase of rainfalls in the region is very important. It is interesting to note that minimum rainfall level observed during this secular interval (1893 - 2000) is practically the same, in the range of 1100 to 1180 mm/year, *i.e.* it changes on ~7-8%.

A positive correlation between the rainfalls and annual sunspot numbers lasted from 1893 to 1920th, when correlation phase changed to negative and this new phase continues until nowadays. Using the same procedure as for Fortaleza data we got the time interval of phase change between 1922–1924 (Figure 3). This period corresponds to the arising phase of the 16th solar cycle with negative IMF sign. The correlation coefficient between the normalized rainfall amplitudes and the sunspot numbers is very high -84%±4.0% during 1929–2000 and +60%±13% during 1893–1920 with a confidence level 99.9%. For the complete date set of rainfall data in Pelotas, 1893–2000, a correlation coefficient is -50.62%±7.5%. A similar analysis for annual temperature and sunspot numbers in tropical region distinguishing a correlation phase change from negative in 1813-1920 to positive after 1920 was performed earlier by Troup (1962). More examples of this approach one can find in the review of King (1975).

A rainfall-solar cycle correlation was observed in the northern hemisphere at the latitudes of 50°-60° of North America with a sign change around the maximum of 14th cycle, *i.e.* 22-years earlier that in Pelotas (King, 1975). Does it mean that the phase change happens first at high latitudes?

A reason for correlation change is still not clear. It may be related both to some secular variations of the solar activity (see for example Georgieva and Kirov, 2000) and to local or global meteorological factors, independent of it.

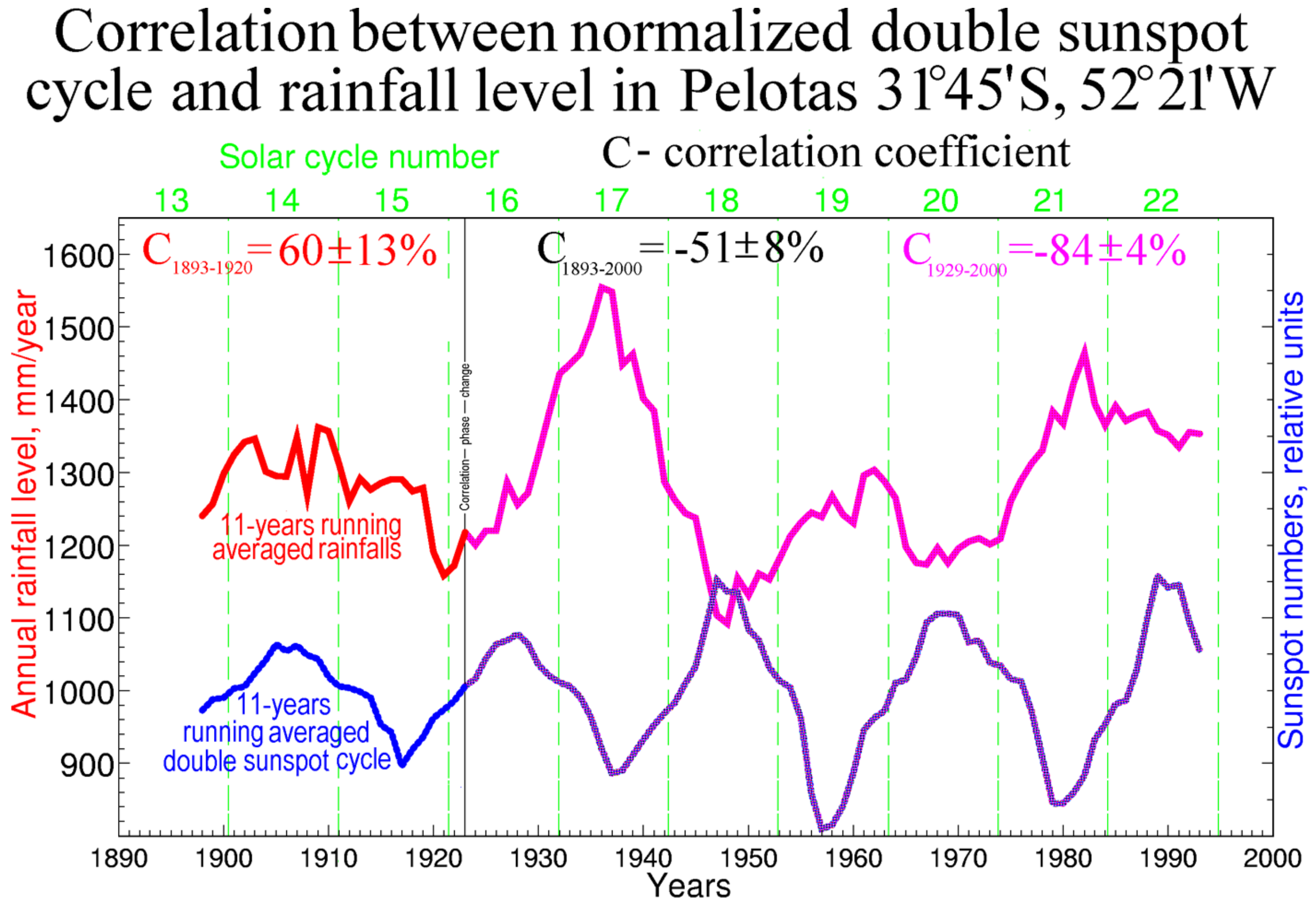

Fig. 4. The 11-year running averaged rainfall variations in Pelotas and sunspot numbers from 1893 up to 2000. The vertical line marks an approximate year of the phase change.

In Figure 5 one can see that a bidecadal rainfall periodicity is absent in Campinas. The amplitude of 11-year running rainfall level there is less than ±10% and it could be one of the reasons why 22-year cycle is not pronounced there. A possible reason of distinguished bidecadal variation of rainfalls in Fortaleza and Pelotas in comparison with Campinas is a littoral position of the formers. We checked this hypothesis using data of three other littoral stations in Ubatuba (23° 25' S 45° 05' W), in Caragua (23° 38'S 45° 26'W) and in Sao Sebastian, (23° 50'S 45° 33'W), and stations located far from the ocean coast in Bauru (22°19'S 49°02'W) and Aracatuba (21°12'S 50°27'W) for a period ~1950 up to 2000. Fourier analysis revealed 22.2, 20.9 and 22.44 year periodicity with 95% confidence level for Ubatuba, Caragua and São Sebastian respectively. Data of Bauru and Aracatuba don't demonstrate a bidecadal periodicity.

Of course, simply to establish a fact of a correlation does not mean to establish a dependence of rainfall variations on solar magnetic cycle. But at least it is a reasonable justification for looking for a possible mechanism connecting these two phenomena.

We checked also a suggestion that the bidecadal variation observed in rainfalls in Brazil may be provoked by climate cycle unrelated to solar activity. In Figure 6 we compared the data of the longest time series of Fortaleza with a 24-year sinusoidal curve with a maximum phase placed at 1871. A corresponding correlation coefficient is sufficiently high: +54%±6% with a confidence level >99%. This interpretation does not have a phase change problem and certainly fits to Fourier analysis of Figure 2 where a periodicity of 23 ±3 years is distinguishable.

Paying attention that the bidecadal variations are observed only in a littoral region, it is possible that a natural periodicity of 24±1 years in atmosphere-ocean coupling observed in northern hemisphere (Hurrell, 1995) influences on the rainfall variations registered in Brazil.

A reciprocal correlation coefficient of Fortaleza and complete Pelotas time series is 33%±11%, but with a +8 year time shift of Pelotas data the correlation increases up to +56%±9%. The 8 years time shift between rainfall variation in Pelotas and in Fortaleza supposes that the decadal varia-

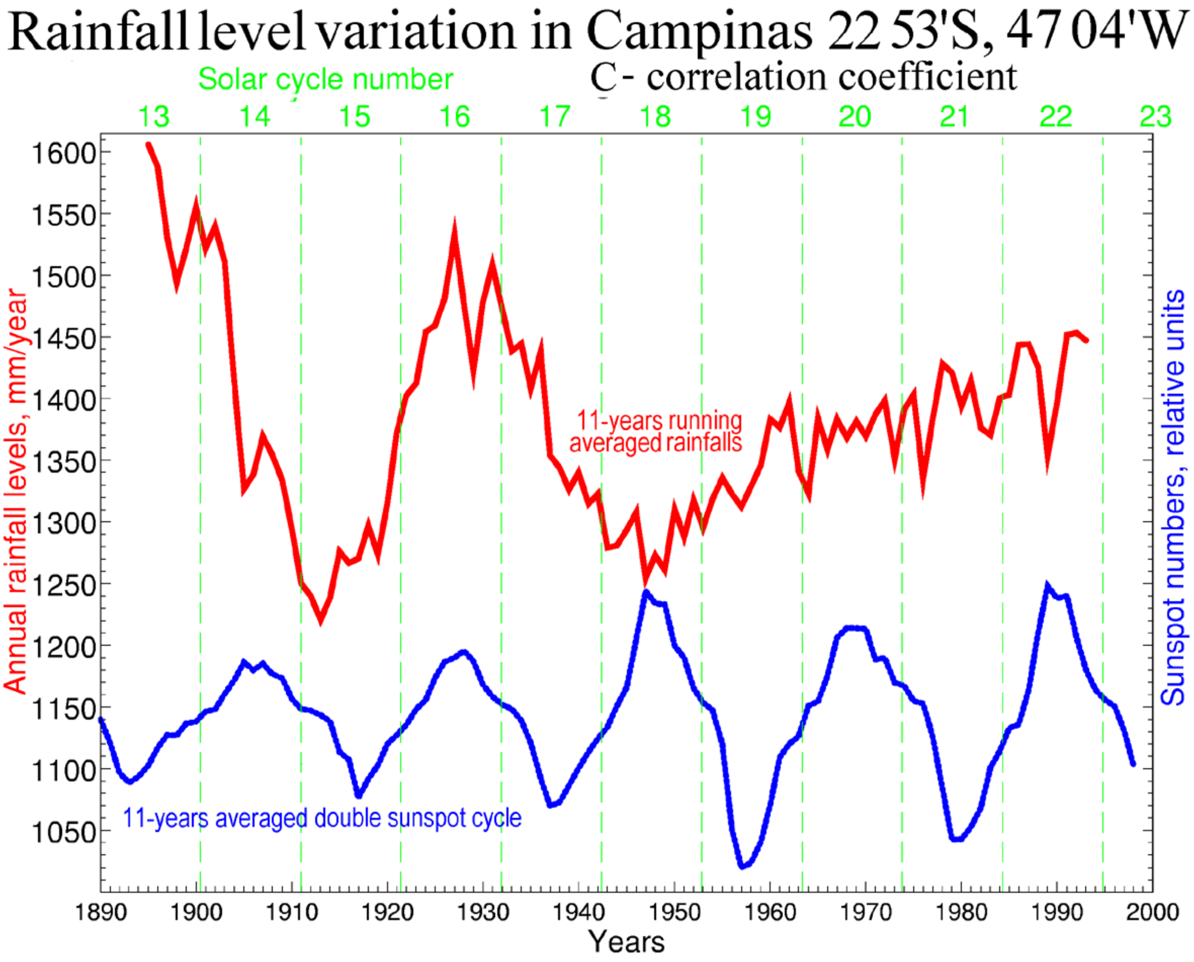

Fig. 5. The 11-year running averaged rainfall variations in Campinas and sunspot numbers from 1890 up today.

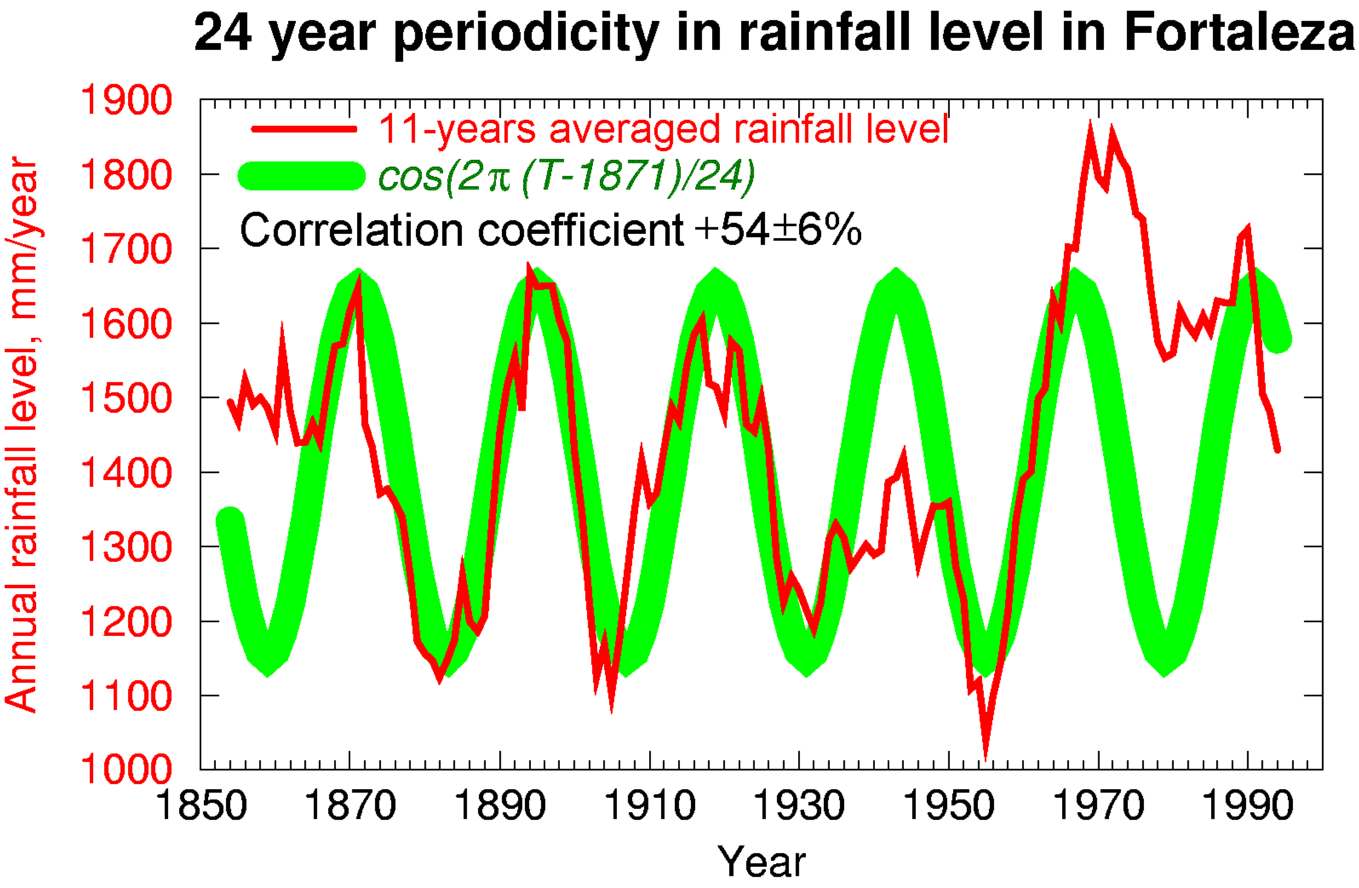

Fig. 6. The 11-year running averaged rainfall variations in Fortaleza and 24-year sinusoidal curve normalized on the Fortaleza data in 1871.

tions observed may be related to a rather inertial mechanism with a period of the same order. A possible candidate for this is the ocean-atmospheric coupling which characteristics in southern hemisphere is still poorly studied.

The results of analysis of bidecadal variation of the rainfall level in Brazil demonstrate that without phase change assumption the better correlation (+54%±6%) is obtained for 24-year periodicity independent of solar cycles in comparison with 22-year solar cycle (–15.3%± 8%). In the same time a higher correlation (-77%±4% and +80%±4%) with a solar cycle was obtained when we supposed an existence of the phase change in the rainfall variations. Nevertheless basing only on those results we can not prefer one of the hypotheses. It is also worth to mention that these two hypotheses do not necessarily exclude one another considering that 24±1 year periodicity in ocean-atmosphere coupling is amazingly close to 22±1 year of solar cycles.

SHORT TERM RAINFALL VARIATIONS IN BRAZIL

Decadal cycles (of 11 and 22 years) are observed practically in all manifestations of the solar activity itself (irradiation, sunspot numbers, solar flare frequency, transient fluxes etc.) and in various magnetospheric and atmospheric phenomena provoked by it (magnetic storms, ionospheric currents, aurora etc). A possible mechanism of solar activity-weather relations responsible for this could be revealed through the study of short term weather response to isolated solar or magnetospheric events like solar flares, ground level enhancements (GLE) of energetic particle fluxes during solar flare, Forbush decreases of cosmic rays, and crossings of magnetic sectors boundary (MSB) by the Earth. Tinsley (1991, 1996) found examples of that in variations of atmospheric pressure at ground level, of liquid precipitation, of an atmosphere Earth's electric current, of thunderstorm frequencies during and/or after strong solar flares. Influence of MSB on atmospheric electric field, vorticity index and other meteorological parameters was also studied (Herman and Goldberg, 1978).

The influence of charged particle fluxes on atmospheric transparency was studied by Pudovkin and Raspopov (1992) and by Svensmark and Friis-Cristensen (1997). They supposed that atmospheric transparency is affected by galactic and solar cosmic rays with the energy greater 1 GeV which permits them to penetrate into middle atmosphere. It was found that the transparency varies when solar cosmic ray fluxes increase in the atmosphere during solar flares and cosmic ray decrease during so-called Forbush-effects. Their findings are valid for middle and high latitudes where magnetic cut-off rigidity is low enough to permit a penetration of the cosmic rays into the magnetosphere. At low latitudes effects of this type could be found only for very powerful manifestation of solar flare resulting in GLE events.

The energies of the solar flare protons are mostly in the range of 1-100 MeV and their spectra are almost exponential with the characteristic energy ~30 MeV which could not reach low latitudes. But a small part of the great solar flares such as February 23, 1956; October 6, 1960; August 4, 1972; October 19-24, 1989; February 16, 1984 has flaccid spectra with significant fluxes of even >10 GeV protons. To find the solar flare events with high energy proton fluxes reaching low latitudes we used a data base of GLE with the rigidity of 2-5 GV, from 1942 until now (Gentile, private communication, 2000). The data base includes 57 GLE events (Table 1).

The superposed epoch method was used to analyze an influence of GLE events on rainfalls in Pelotas. We plot the 15 days before and 15 days after the key day of each GLE event. The daily relative mean deviations from five day smoothed daily rainfalls during these 31 days were determined. No evidence of solar flare particle flux-rainfall relation that could manifest in increase of the relative mean deviation in the key day was found.

We selected also 73 greatest Forbush decreases from 1956-1996, which coincided with the rainy season in Pelotas (March-May). Only Forbush decreases with the amplitudes more than 100 counts per hour according to Washington neutron monitor with cut-off rigidity 1.24 GV were selected.

Table 1

Ground level enhancements date

Event date	Time start - end (UT)	Event date	Time start - end (UT)
28 February 1942	-	22 November 1977	090000 - 100000
07 March 1942	-	07 May 1978	020000 - 030000
25 July 1946	-	23 September 1978	090000 - 100000
19 November 1949	-	21 August 1979	050000 - 060000
23 February 1956	020000 - 030000	10 April 1981	150000 - 160000
31 August 1956	110000 - 120000	10 May 1981	060000 - 070000
17 July 1959	220000 - 240000	12 October 1981	050000 - 060000
04 May 1960	090000 - 100000	26 November 1982	020000 - 030000
03 September 1960	230000 - 240000	07 December 1982	220000 - 230000
12 November 1960	120000 - 130000	16 February 1984	080000 - 090000
15 November 1960	010000 - 020000	25 July 1989	070000 - 080000
20 November 1960	190000 - 200000	16 August 1989	230000 - 240000
18 July 1961	090000 - 100000	29 September 1989	100000 - 110000
20 July 1961	150000 - 160000	19 October 1989	110000 - 120000
07 July 1966	230000 - 240000	22 October 1989	160000 - 170000
28 January 1967	010000 - 020000	24 October 1989	160000 - 170000
28 January 1967	060000 - 070000	15 November 1989	050000 - 060000
29 September 1968	150000 - 160000	21 May 1990	210000 - 220000
18 November 1968	090000 - 100000	24 May 1990	190000 - 200000
25 February 1969	080000 - 090000	26 May 1990	190000 - 200000
30 March 1969	020000 - 030000	28 May 1990	030000 - 040000
24 January 1971	220000 - 230000	11 June 1991	000000 - 010000
01 September 1971	180000 - 190000	15 June 1991	070000 - 080000
04 August 1972	110000 - 120000	25 June 1992	180000 - 190000
07 August 1972	140000 - 150000	02 November 1992	020000 - 030000
29 April 1973	200000 - 210000	06 November 1997	100000 - 110000
30 April 1976	200000 - 210000	02 May 1998	-
19 September 1977	090000 - 100000	06 May 1998	-
24 September 1977	050000 - 060000		

The amplitudes of Forbush decreases observed by equatorial Huancayo neutron monitor (cut-off rigidity 13 GV) at the same days were 3 % greater. The superposition epoch method did not reveal any dependence of rainfall variations on the selected events.

The absence of correlation between rainfalls and GLE and Forbush events together with the phase change of rain-sunspot number correlation and a different phase of the correlation for different geographical places prove that the local variation of an ionization produced by charged particle flux variations are not able to produce an immediate effect to a local at least in the tropical region. Hence this mechanism can not also be responsible for the long time correlation discussed above.

Using the same method we also studied a correlation of rainfalls with the Earth's crossing magnetic sector boundaries. MSB days were taken from NASA data center (nssdc.ngdc.gov). From rainy season in Fortaleza for a period of 1 January 1947 up to 31 July 1993 the date were selected when the Earth crossed only two boundaries during one solar rotation period (27 days). Superposition was made for time intervals beginning 10 days before and terminating 10 days after a key day of MSB crossing. It was separately done for IMF sign changes from "–" to "+" and from "+" to "–". For each interval a daily rainfall level averaged over 10 days before the key day was found and all daily rainfall levels were normalized on this value.

Figure 7 demonstrates a 2-2.5 times greater rainfall level after the key day, especially on 8th-10th days, compared with the mean level before MSB both for "+/-" and "-/+" crossings. A statistical reliability of the results is greater than 3 standard deviations.

In the same time the observed short term correlation of the rains with MSB crossing suppose an existence of a mecha-

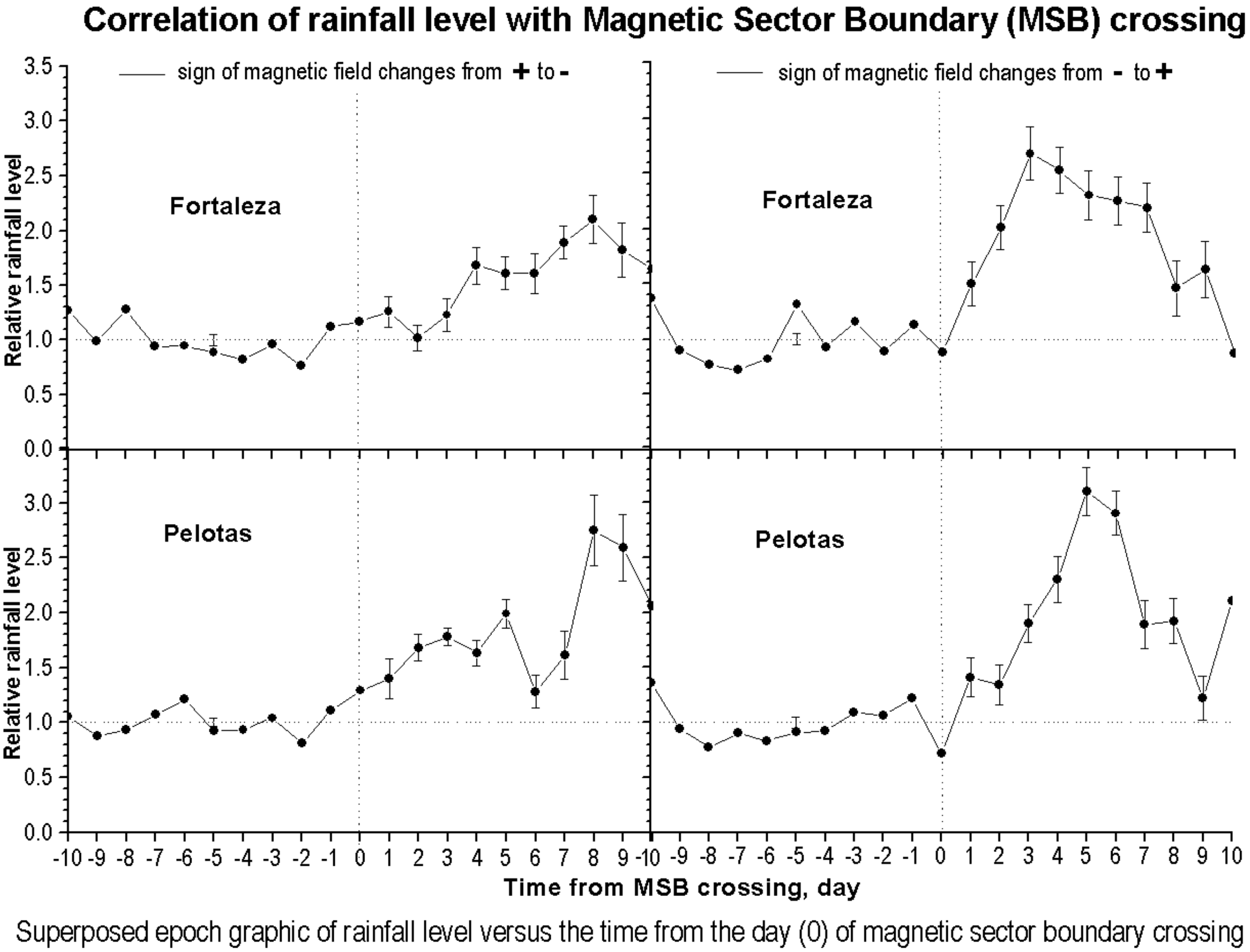

Fig. 7. A superposition of relative rainfall variation in Fortaleza and Pelotas for 21-day interval with a key day (0) in a day of MSB "+/-"crossing and "-/+"crossing. Horizontal dashed line marks relative mean level of rainfalls before key day.

nism linking the latter with weather parameters for example, through the magnetospheric disturbances. The delay time between MSB crossing and the rainfall level increase is close to a time of propagation of cold fronts from the polar region to the lower latitudes. So far as magnetospheric-atmospheric connections are especially pronounced in the pole region one can suppose that magnetospheric disturbances provoked by MSB crossing facilitate the cold front formation, responsible for a part of liquid precipitation in Brazil. A frequency of the MSB crossing depends on solar cycle that might provide the 22-year periodicity observed in rainfalls.

CONCLUSION

A bidecadal periodicity in annual rainfalls was found for several littoral regions of Brazil. The amplitude of the variation reaches ~80%, that makes this result important not only from a scientific point of view, but for forecasting aim also. The best correlation with a 22-year solar magnetic filed cycle is obtained with the assumption that the phase of the correlation is changed once during the whole 150 years of observations at Fortaleza and during the 100 year's observations at Pelotas. The phase of the correlation is different and even opposite for various regions. The phase change occurred mostly during even 16th and 18th solar cycles, first at higher latitudes, later in the equatorial region.

In the same time this result can not be considered as a definitive proof that bidecadal variations are really caused by solar phenomena. The rainfall series considered also demonstrate sufficiently high correlation with a 24-year periodicity probably connected with the atmosphere ocean coupling and without suggestion about phase change.

Analysis of short-term rainfall variations also shows a significant increase in rainfall level several days after MSB crossing that is an argument in favor of relation of rainfall variations with the solar cycle. The analysis did not show CR or solar CR influence on rainfalls at low latitudes.

ACKNOWLEDGMENTS

Drs. G. Pugacheva and A. Gusev thank the CNPq for the award of fellowships to work at INPE. The financial support by FAPESP-SP (93/4978-0) is acknowkledged.

BIBLIOGRAPHY

GEORGIEVA, K. and B. KIROV, 2000. About the instability of solar-climatic relations, submitted to *J. Atm. Sol.-Terr. Phys.*

HERMAN, J. R. and R. A. GOLDBERG, 1995. Sun, Weather, and Climate, NASA, Washington D.C. pp. 318.

HURRELL, J. W., 1995. Decadal trend in the North Atlantic Oscillation and relationship to regional temperature and precipitation. *Science, 269,* 676-679.

KING, J. W., 1975. Sun-Weather Relationships, Aeronautics and Astronautics, 13, 10-19.

PUDOVKIN, M. I. and O. M. RASPOPOV, 1992. A mechanism of influence of solar activity on conditions in middle atmosphere and climate parameters. *Geomagnetism and Aeronomy, 32,* 1-21.

SVENSMARK, H. and E. FRIIS-CRISTENSEN, 1997. Variation of cosmic ray flux and global cloud coverage – a missing link in solar-climate relationship. *J. Atm. Sol-Terr. Phys, 59,* 1225-1232.

TINSLEY, B. A. and G. W. DEEN, 1991. Apparent Tropospheric Response to MeV-GeV Particle Flux Variations: A Connection Via Electrofreezing of Super-Cooled Water in High-Level Clouds? *J. Geophys. Res., 36,* 22283-22296.

TINSLEY, B. A., 1996. Correlation of atmospheric dynamics with solar wind-induced changes of air-earth current density into cloud tops. *Geophys. Res., 101,* 29701-29714.

TROUP, A. J., 1962. A secular change in the relation between the sunspot cycle and the temperature in the tropics. *Geophys. Pure Appl., 51,* 184.

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