FLUCTUATIONS AND SPECTRAL ANALYSIS OF CLIMATIC VARIABLES IN SALVADOR, BAHIA, BRAZIL

Amin BASSREI[1]
Alberto Brum NOVAES[2]
Francisco Carlos Pataro de QUEIROZ[3]

[1] Engenheiro Eletricista, Doutor em Geofísica Aplicada, Professor Associado, Departamento de Geologia e Geofísica Aplicada, Instituto de Geociências e Centro de Pesquisa em Geofísica e Geologia, Universidade Federal da Bahia – IGEO-CPGG/UFBA. E-mail: bassrei@ufba.br
[2] Bacharel em Física, Mestre em Geofísica Nuclear, Doutor em Física da Atmosfera. Professor Associado, Departamento de Física da Terra e do Meio Ambiente, Instituto de Física – DFTMA/IF/UFBA e CPGG/UFBA. E-mail: albrum@ufba.br.
[3] Bacharel em Física, Mestre em Geofísica Nuclear. Professor Adjunto, DFTMA/IF/UFBA e CPGG/UFBA. E-mail: fapataro@ufba.br

RESUMO. Flutuações e análise espectral de variáveis climatológicas em Salvador, BA, Brasil. Neste trabalho é estudada a periodicidade da precipitação, temperatura média, pressão, umidade, insolação, temperatura mínima, temperatura máxima e evaporação na cidade de Salvador, Bahia, Brasil. As séries temporais utilizadas têm amostras mensais durante um período de 30 anos, portanto resultando em 360 amostras. O estudo é feito através da análise espectral, importante conjunto de ferramentas para a descrição de fenômenos periódicos. A análise espectral indica uma forte tendência para uma base de variação anual, ou seja, de um ciclo por ano, para todas as oito variáveis. A componente semestral, de dois ciclos por ano, também é forte em todos os casos.
Palavras-chave: Nordeste do Brasil, Salvador (Brasil), análise espectral, clima.

ABSTRACT. *We study here the periodicity of precipitation, average temperature, pressure, humidity, solar radiation, minimum temperature, maximum temperature and evaporation in the city of Salvador, Bahia, Brazil. The available time series have monthly samples during a period of 30 years, thus resulting in 360 samples. The study is mainly done through spectral analysis, which is an important set of tools for the description of periodic phenomena. The spectral analysis indicates a strong trend for the year basis variation (1 cycle per year) for all eight variables. The six month component (2 cycles per year) is also strong in all cases.*
Keywords: *Brazilian Northeastern, Salvador (Brazil), spectral analysis, climate.*

INTRODUCTION

For a long time the science of Climatology considered the normal climatic conditions, that is, the variation standards were normal. Then it was considered the variation from the normal conditions. This was done mostly with statistical analysis. In this work, through basic spectral analysis, we try to identify some periodicity in these variations from normal conditions.

In early works about the climatology of the Brazilian Northeastern precipitation was the most studied climatic variable. Markham (1974), for instance registered a periodicity of 13 years in the town of Fortaleza, Ceará. Hastenrath and Kaczmarczyk (1981), showed that the precipitation variation in the Brazilian Northeastern was concentrated in different regions and preferably within the ranges of 2.5; 5; 10; e 13-21 years. This variability was considered as a result the great scale circulation patterns variation in Brazilian Atlantic Tropical Sector.

Kane (1998), showed that the rain characteristics between the Septentrional Brazilian Northeastern and the Oriental Brazilian Northeastern were close, but different from the Meridional Brazilian Northeastern. The Septentrional Northeastern showed periodicities of 2.03 and 2.45 years, the Oriental Northeastern showed periodicities of 2.26 and 2.60 years, while the Meridional Northeastern showed significant quasi-annual oscillations.

Kane (1998), also states that these quasi-annual oscillations, as well as, the precipitation and humidity characteristics of the Brazilian Northeastern are related Atlantic Ocean parameters, like, sea surface temperature, pressure and winds.

Salvador is a picturesque city at the Brazilian coast. It is the capital of the State of Bahia, and now the third city of Brazil in terms of population. Salvador like the major portion of the Northeast region is classified as the **Aw** type according to Koeppen system (GRIFFITHS, 1966, p. 29; HENDERSON-SELLER; ROBINSON, 1986, p. 213). The letter **A** means that the average temperature of the coolest month is 18 ^{o}C or higher. This is quite true for Salvador since the minimum average temperature is always higher than 22 ^{o}C for the period from 1961 to 1990.

In this work we study the spectrum analysis of precipitation, average temperature, pressure, humidity, solar radiation, minimum temperature, maximum temperature and evaporation. In reality we have six different variables since we consider the temperature in three forms: average, minimum and maximum.

SPECTRAL ANALYSIS

In the development of this work we have used data collected by the Instituto Nacional de Meteorologia (INMET). The data was acquired at the INMET Fourth District, and was collected at the Salvador Station, which is located at coordinates 13^o 01' south latitude and 38 ^{o} 31' west longitude, and the station height is 51.41 *m*.

The available data are: precipitation (*mm*), average temperature (^oC), pressure (*hPa*), humidity (%), solar radiation (W/m^2), minimum temperature (^oC), maximum temperature (^oC) and evaporation (*mm*). All the data is in form of monthly values, during a period of 30 years, from 1961 to 1990, that is, each data set has 360 samples. The data without any treatment can be seen in Figure 1 (precipitation), Figure 3 (average temperature), Figure 5 (pressure), Figure 7 (humidity), Figure 9 (solar radiation), Figure 11 (minimum temperature), Figure 13 (maximum temperature), and Figure 15 (evaporation).

The time series are analyzed at the frequency domain through the Fourier transform. Consider that a given time series is represented by a generic time function *f(t)*. Then its Fourier transform is given by

$$\Im\{f(t)\} = F(\omega) = \int_{-\infty}^{+\infty} f(t)e^{-i\omega t}dt \qquad (1)$$

The available time series are not continuous functions but rather a set of discrete values. Thus we have to make use of the Discrete Fourier Transform, or from the computational point of view we can use the Fast Fourier Transform (FFT).

The total number of samples for the period of 30 years is $N = 360$. Each time series has 12 samples per year, so that $\Delta t = 1/12$ year. The frequency interval is thus

$$\Delta f = \frac{1}{N\Delta t} = \frac{1}{360\cdot(1/12)} = 0.0333 \quad cicle/year,$$

being the Nyquist frequency given by

$$f_N = \frac{1}{2\Delta t} = \frac{1}{2\cdot(1/12)} = 6 \quad cicles.$$

The Nyquist frequency, which is also called folding frequency is the frequency which value is half of the sampling frequency. The frequencies which are higher than f_N are aliased, that is, are mixed with the lower frequencies, becoming not distinguishable, characterizing the ambiguity situation.

Applying the FFT in the time series, we obtain the amplitude spectrum, given by

$$A(\omega) = \sqrt{\mathrm{Re}\{F(\omega)\}^2 + \mathrm{Im}\{F(\omega)\}^2},$$

where *F* is a complex function and the Fourier transform of the same series given by *f(t)*, given by equation (1).

The amplitude spectra of the time series can be seen in Figure 2 (precipitation), Figure 4 (average temperature), Figure 6 (pressure), Figure 8 (humidity), Figure 10 (solar radiation), Figure 12 (minimum temperature), Figure 14 (maximum temperature) and Figure 16 (evaporation).

DISCUSSION

In all cases we see that two components are prominent: the annual and the semestral. The annual component is always stronger that the semestral, with one exception, in the humidity the semestral component was larger than the annual one.

These prominent features can also be noticed without using Fourier transform. Figure 17 shows the time series of precipitation, for 1990. It is possible to see two maxima, one in May and the other in October, thus resulting in a quasi-semestral periodicity. The maximum of October is more intense than the maximum of May, in this case suggesting an annual periodicity. For the minima in this figure the semestral periodicity is less evident since there are three values of minima: February, April and November. But this just a single year and again the two minima of April and November result in a quasi-semestral periodicity. Figure 18 shows the time series of average temperature, again for 1990. Here the maximum of April and the minimum in August define the quasi-annual periodicity. The quasi-semestral periodicity can be attested if one considers August and December as two minima and April and November as two maxima.

Our approach in order to establish other periodicities was as follows. In each amplitude spectrum diagram, we choose an ad-hoc threshold or cut-off. Then we counted for which frequencies the amplitude spectrum was equal or higher the cut-off.

In Figure 2 (precipitation) we noticed 5 prominent frequencies. Considering a cut-off for amplitude equal to 3000, we have that: (i) amplitude 3542, frequency 4.29 years; (ii) amplitude 3279, frequency 1.76 year; (iii) amplitude 9268, frequency 1 year; (iv) amplitude 6335, frequency 6 months; and (v) amplitude 3367, 4 months.

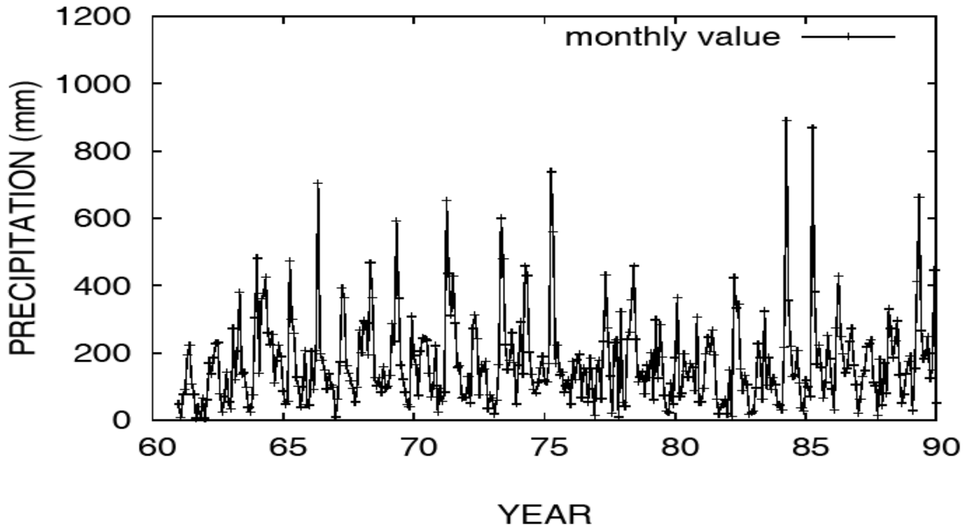

Figure 1. Monthly values of precipitation (*mm*) in Salvador, Bahia, Brazil, in the period 1961-1990.

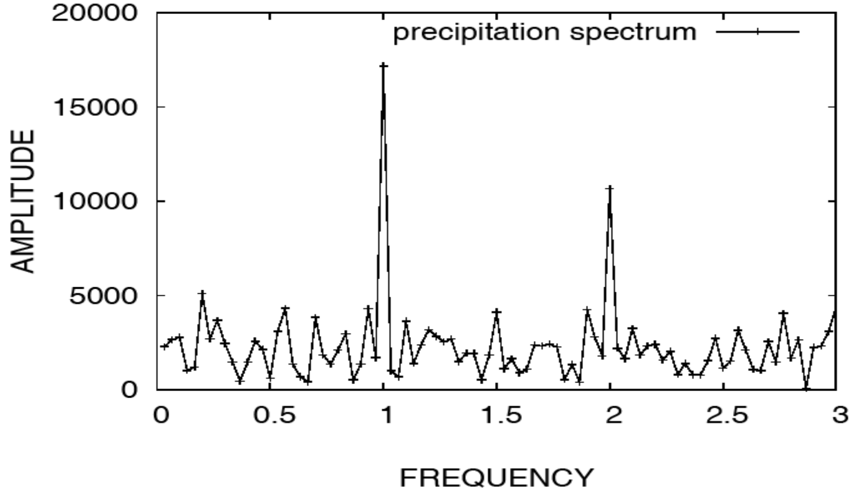

Figure 2. Precipitation spectrum in Salvador, Bahia, Brazil, in the period 1961-1990.

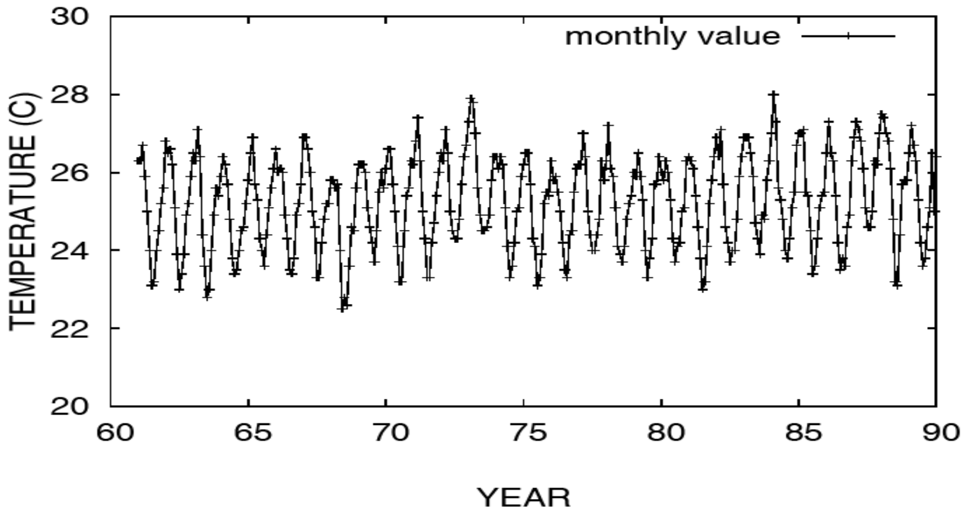

Figure 3. Monthly values of average temperature (^{o}C) in Salvador, Bahia, Brazil, in the period 1961-1990.

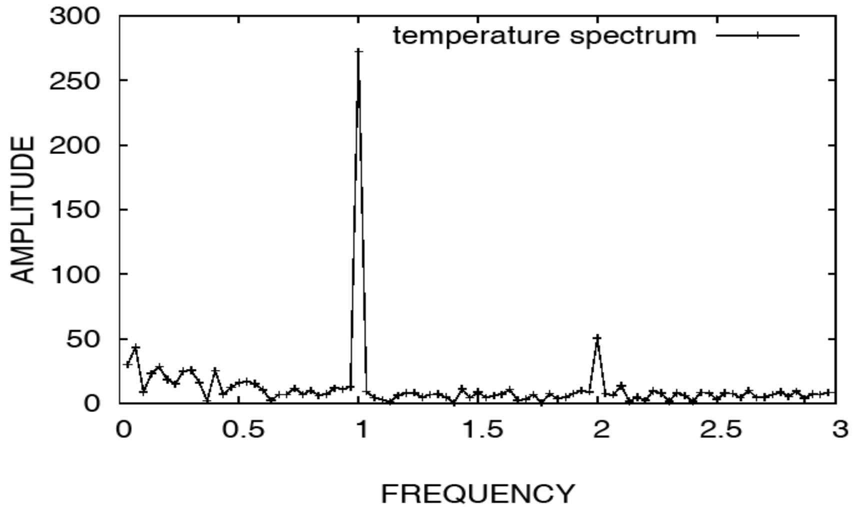

Figure 4. Average temperature spectrum in Salvador, Bahia, Brazil, in the period 1961-1990.

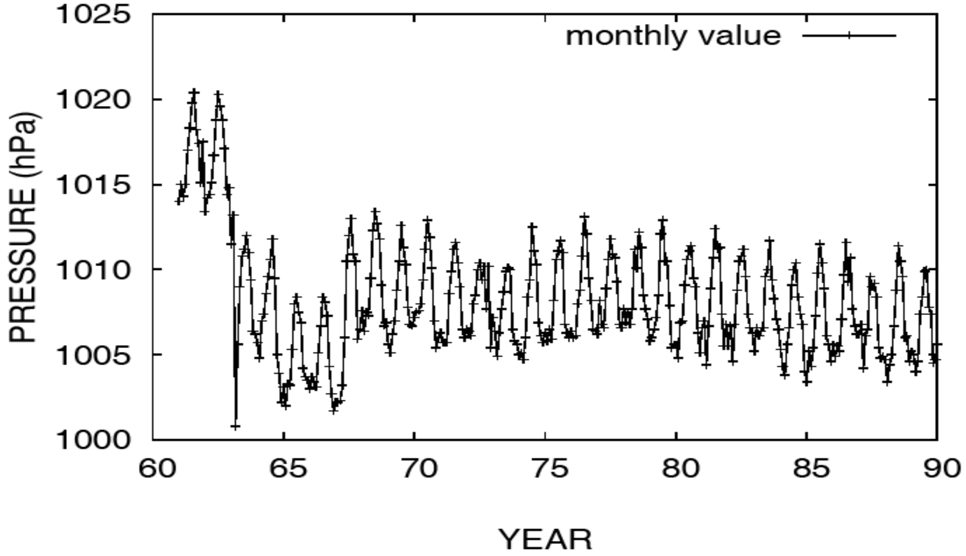

Figure 5. Monthly values of pressure (*hPa*) in Salvador, Bahia, Brazil, in the period 1961-1990.

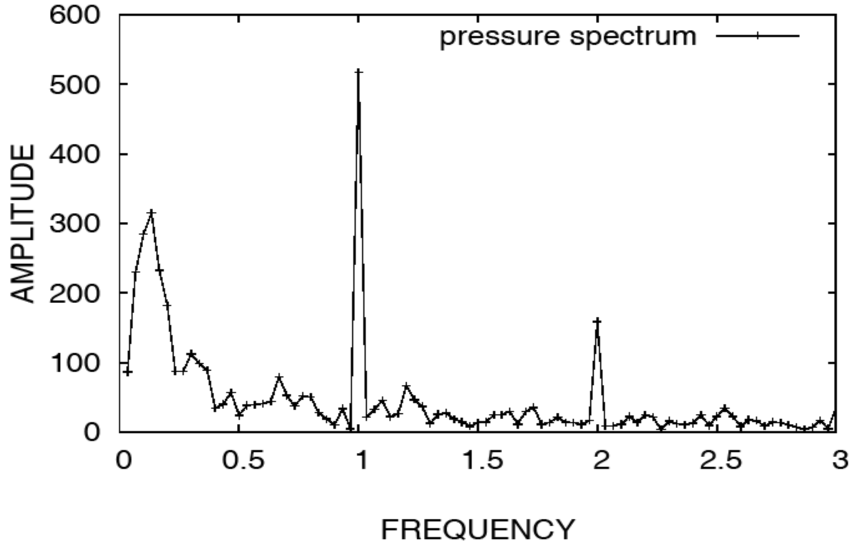

Figure 6. Pressure spectrum in Salvador, Bahia, Brazil, in the period 1961-1990.

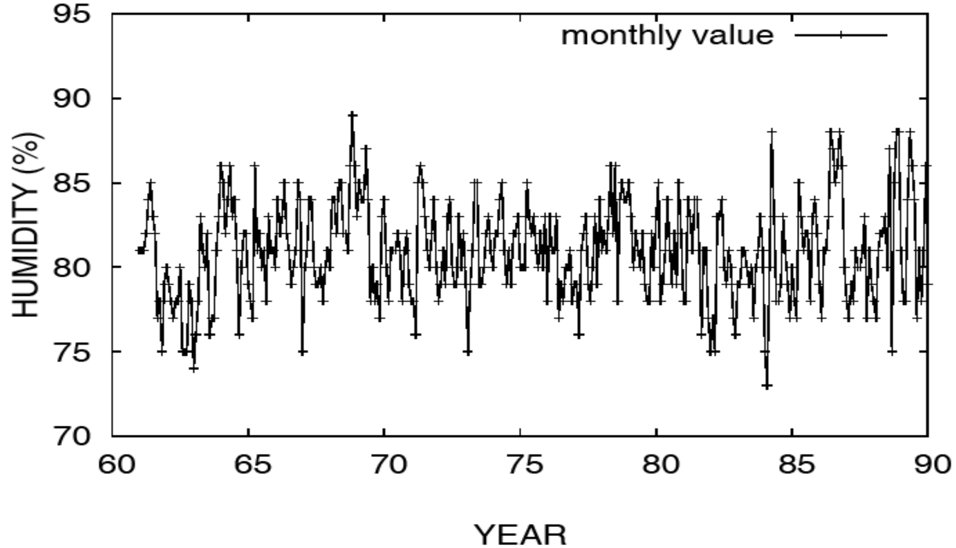

Figure 7. Monthly values of humidity (%) in Salvador, Bahia, Brazil, in the period 1961-1990.

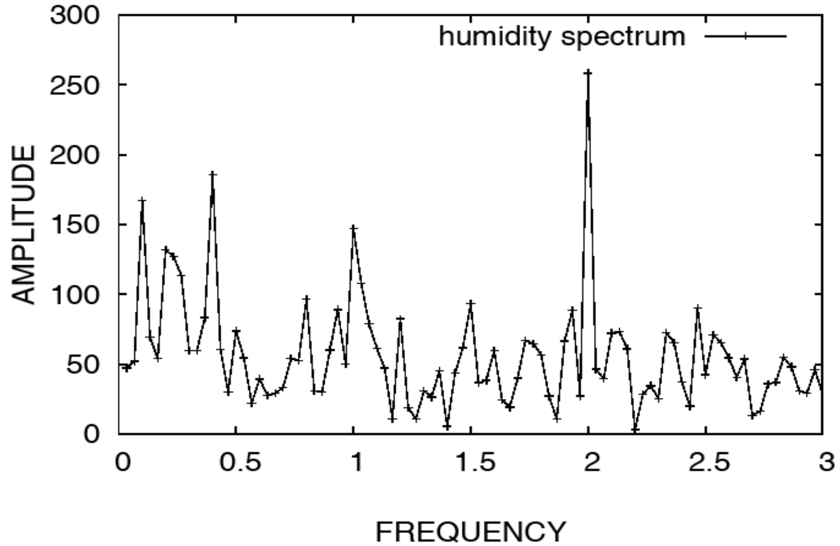

Figure 8. Humidity spectrum in Salvador, Bahia, Brazil, in the period 1961-1990.

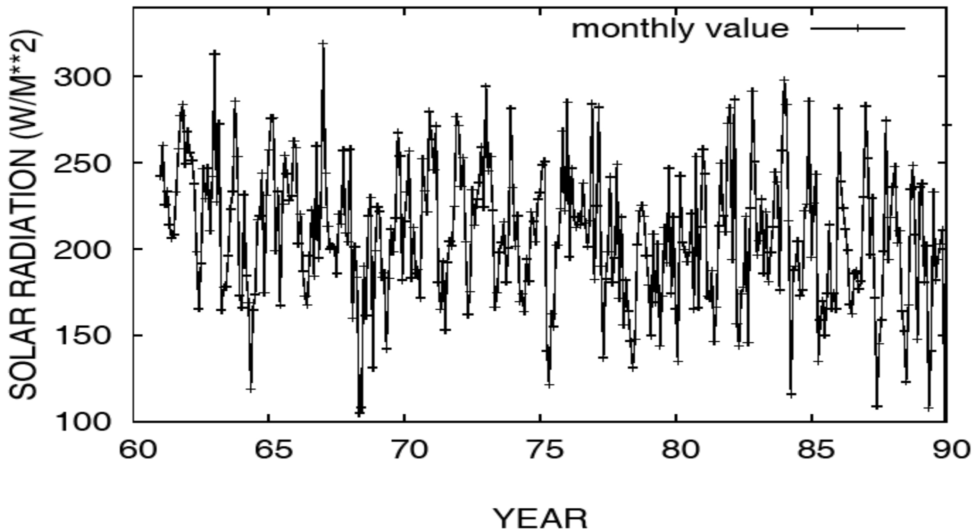

Figure 9. Monthly values of solar radiation (*W/m²*) in Salvador, Bahia, Brazil, in the period 1961-1990.

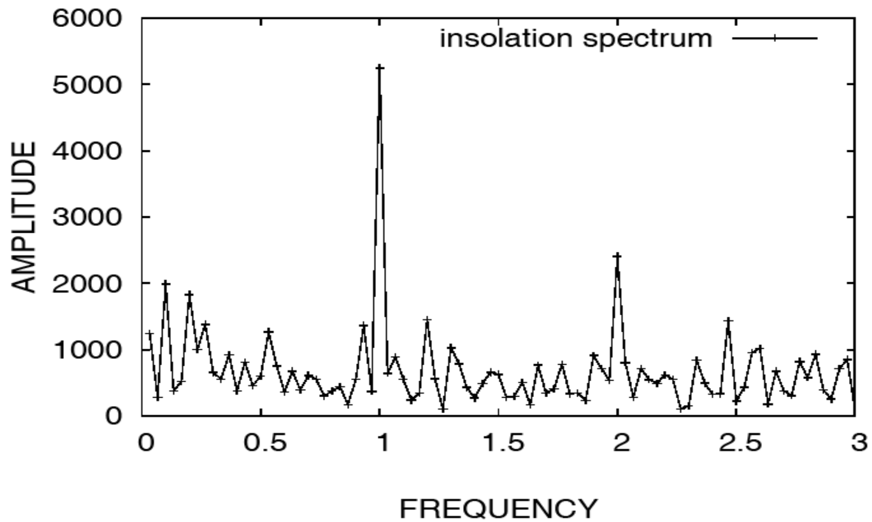

Figure 10. Solar radiation spectrum in Salvador, Bahia, Brazil, in the period 1961-1990.

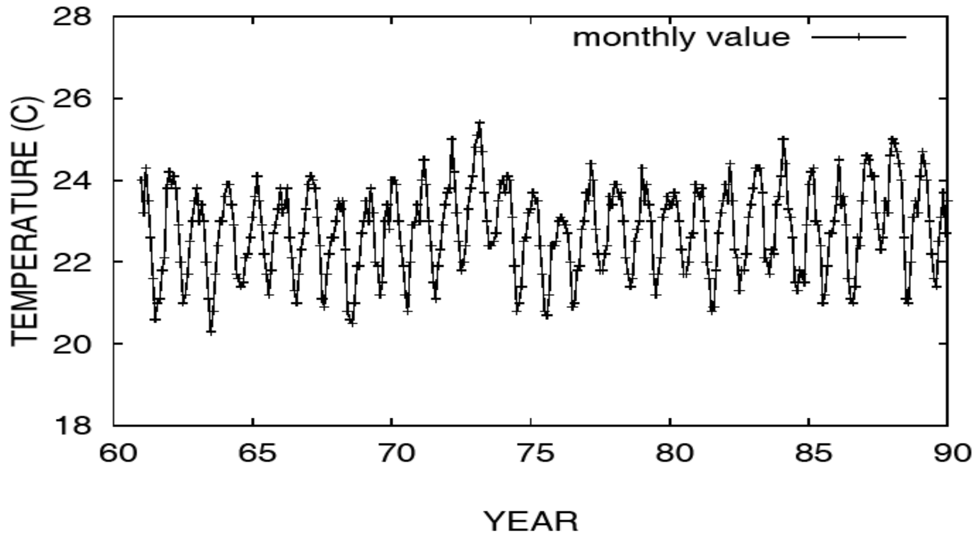

Figure 11. Monthly values of minimum temperature (*°C*) in Salvador, Bahia, Brazil, in the period 1961-1990.

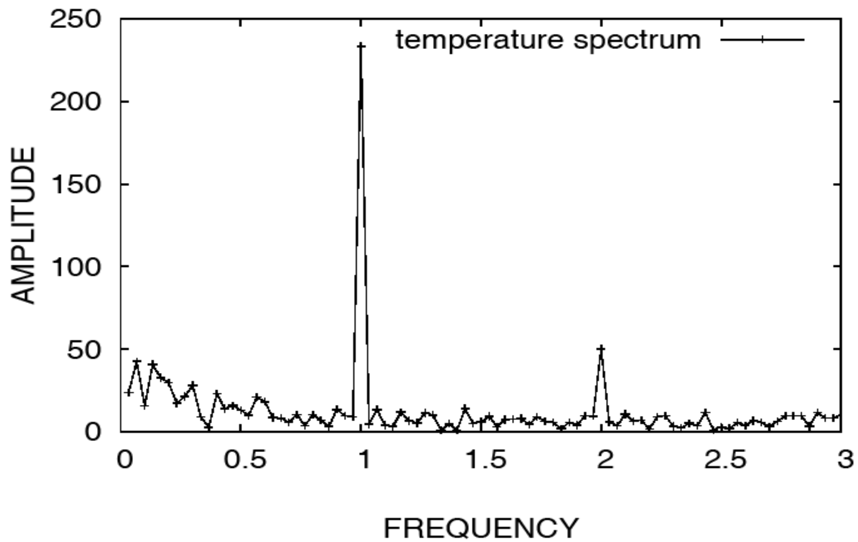

Figure 12. Minimum temperature spectrum in Salvador, Bahia, Brazil, in the period 1961-1990.

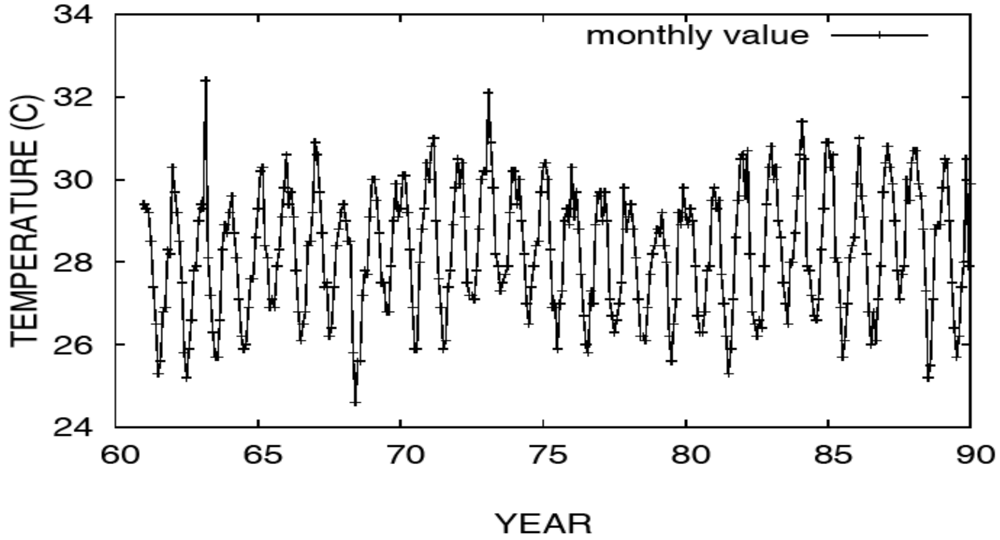

Figure 13. Monthly values of maximum temperature (^oC) in Salvador, Bahia, Brazil, in the period 1961-1990.

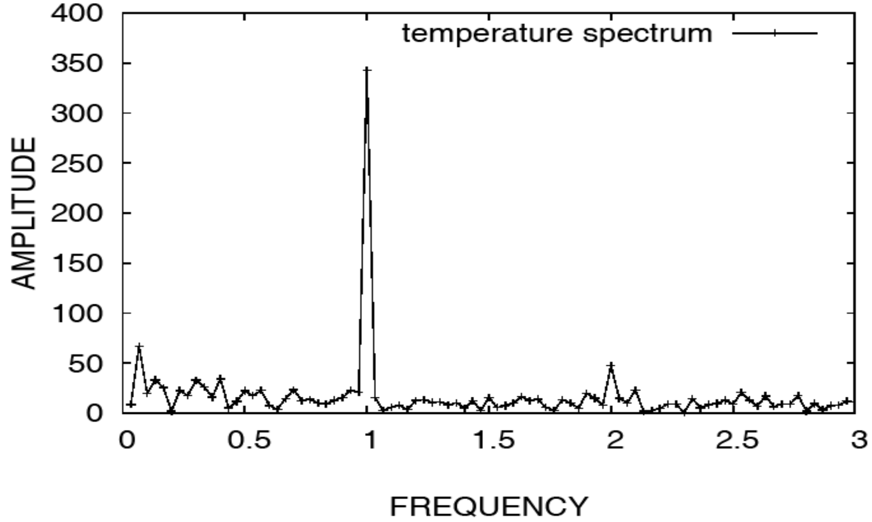

Figure 14. Maximum temperature spectrum in Salvador, Bahia, Brazil, in the period 1961-1990.

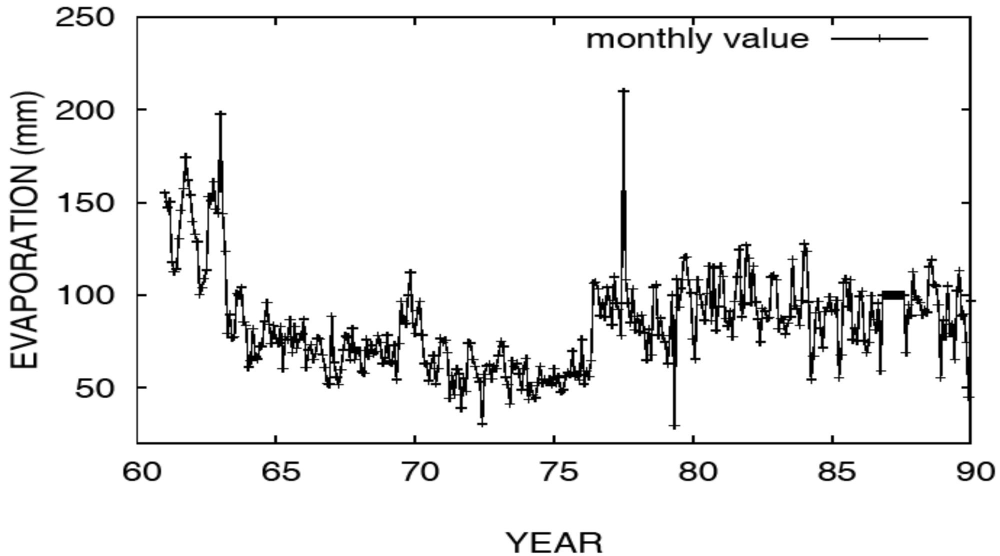

Figure 15. Monthly values of evaporation (*mm*) in Salvador, Bahia, Brazil, in the period 1961-1990.

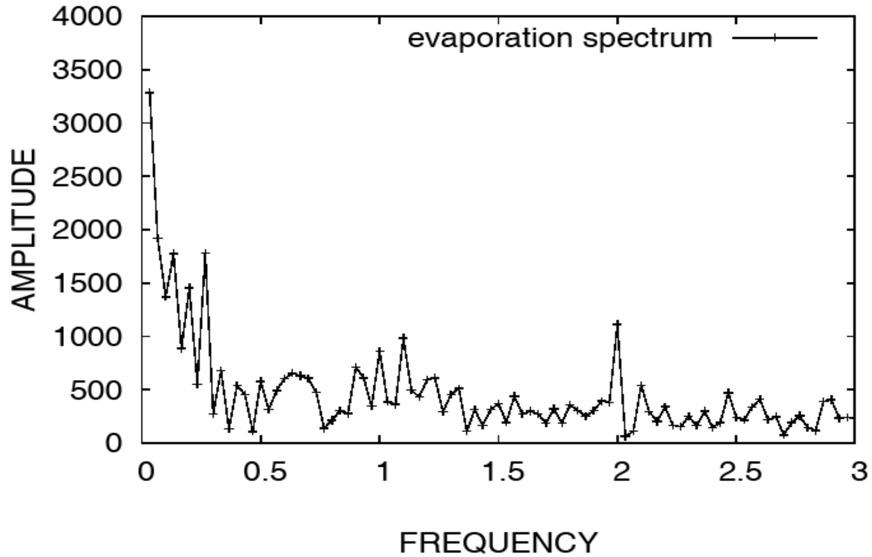

Figure 16. Evaporation spectrum in Salvador, Bahia, Brazil, in the period 1961-1990.

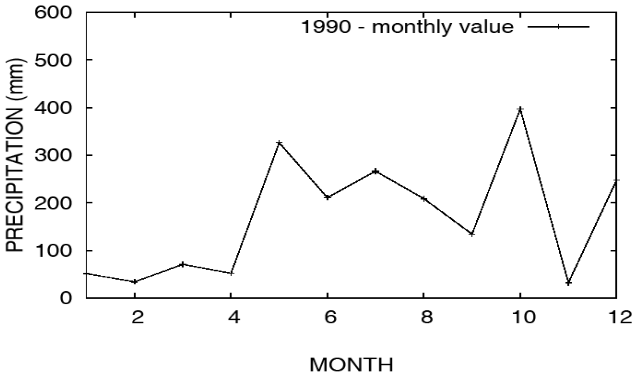

Figure 17. Monthly values of precipitation (*mm*) in Salvador, Bahia, Brazil, for the year 1990.

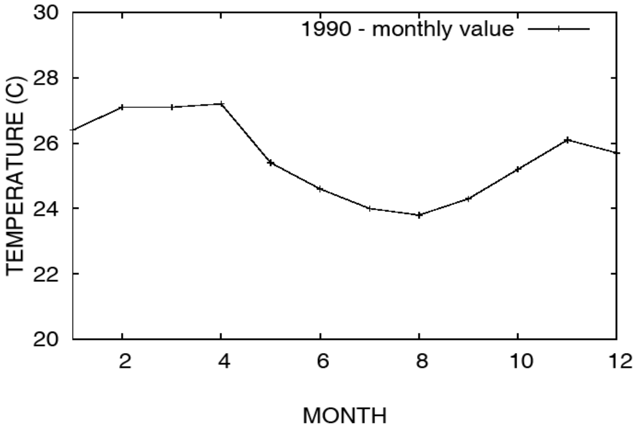

Figure 18. Monthly values of average temperature (^{o}C) in Salvador, Bahia, Brazil, for the year 1990.

In Figure 4 (average temperature) we noticed 3 prominent frequencies. Considering a cut-off for amplitude equal to 25, we have that: (i) amplitude 31, frequency 15 years; (ii) amplitude 142, frequency 1 year; and (iii) amplitude 29, frequency 6 months.

In Figure 6 (pressure) we noticed 3 prominent frequencies. Considering a cut-off for amplitude equal to 80, we have that: (i) amplitude 287, frequency 7.5 years; (ii) amplitude 265, frequency 1 year; and (iii) amplitude 86, frequency 6 months.

In Figure 8 (humidity) we noticed 5 prominent frequencies. Considering a cut-off for amplitude equal to 100, we have that: (i) amplitude 114, frequency 10 years; (ii) amplitude 125, frequency 4.28 years; (iii) amplitude 129, frequency 2.5 years; (iv) amplitude 113, frequency 1 year; and (v) amplitude 148, 6 months.

In Figure 10 (solar radiation) we noticed 4 prominent frequencies. Considering a cut-off for amplitude equal to 1000, we have that: (i) amplitude 1241, frequency 30 years; (ii) amplitude 1304, frequency 4.28 year; (iii) amplitude 2876, frequency 1 year; and (iv) amplitude 1341, frequency 6 months.

In Figure 12 (minimum temperature) we noticed 4 prominent frequencies. Considering a cut-off for amplitude equal to 30, we have that: (i) amplitude 31, frequency 15 years; (ii) amplitude 34, frequency 6 year; (iii) amplitude 120, frequency 1 year; and (iv) amplitude 29, frequency 6 months.

In Figure 14 (maximum temperature) we noticed 3 prominent frequencies. Considering a cut-off for amplitude equal to 30, we have that: (i) amplitude 41, frequency 15 years; (ii) amplitude 180, frequency 1 year; and (iii) amplitude 30, frequency 6 months.

In Figure 16 (evaporation) we noticed 5 prominent frequencies. Considering a cut-off for amplitude equal to 800, we have that: (i) amplitude 3255, frequency 10 years; (ii) amplitude 2465, frequency 3.75 years; (iii) amplitude 1649, frequency 1.67 year; (iv) amplitude 926, frequency 1 year; (v) amplitude 828, frequency 6 months.

CONCLUSIONS

We analyzed the amplitude spectra of time series for precipitation, average temperature, pressure, humidity, solar radiation, minimum temperature, maximum temperature and evaporation. This dataset, for the period from 1961 to 1990, was collected by INMET at its Fourth District - Salvador Station. For each one of these eight time series, we generated the amplitude spectrum, as well as a filtered amplitude spectrum. In the case of temperature we noticed a significant component with a periodicity of 15 years, eventually related to sunspots. It is interesting that this result was consistent with two other results displayed in this work: minimum temperature and maximum temperature. Further studies are necessary in order to provide a physical interpretation for the other prominent values, for all climatic variables. We stress that we did not apply any data correction, that is, we did not neglect any data point with irregular behavior.

REFERENCES

GRIFFITHS, J.F. **Applied climatology:** an introduction. London: Oxford University Press, 1966.

HASTENRATH, S.; KACZMARCZYK, E.B. On spectral and coherence of tropical climate anomalies. **Tellus**, v. 33, p. 453-462, 1981.

HENDERSON-SELLER, A.; ROBINSON, P.J. **Contemporary climatology**. Harlow (UK): Longman, 1986.

KANE, R.P. Quasi-biennial and quasi-triennial oscillations in rainfall of Northeast Brazil. **Revista Brasileira de Geofísica**, v. 16, p. 37-52, 1998.

MARKHAM, C.G. Apparent periodicities in rainfall Fortaleza, Ceará - Brazil. **Journal of Applied Meteorology**, v. 13, p. 176-179, 1974.