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Periodicity of About 27 Days in the Cosmic-Ray Intensity and Kp Data During the Solar Cycle N? 18

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The quasi-periodical variations of the cosmic-ray intensity, with a period of about 27 days, have been studied in the data recorded through shielded ionization chambers at Huancayo and at Cheltenham during the solar cycle N? 18 (1944-53). The same investigation has been extended to the contemporary variations of the geomagnetic index Kp. The results obtained by the periodical analysis through the Vercelli's method (amplitudes and periods) and by the calculation of the correlation coefficients among the data of different variables are reported and discussed. Perticularly, a detailed diagram is reported on the behaviour of the single oscillation amplitudes, extended also to the following solar cycles N? 19 (1954-64) and N? 20 (1965-74), which have previously been analysed; this diagram has been compared with a similar one obtained by Baziilevskaya et *al.* in other place, in the interval 1957-73. The amplitude behaviour of the solar cycle N? 18 validates a discrepancy versus the sunspot Wolf number, already realized through another statistical procedure by Venkatesan.

A variação quase periódica de intensidade da radiação cosmica, com período de cerca de 27 dias, foi estudada nos dados registrados por meio de câmaras de ionização protegidas em Huancayo e em Cheltenham durante o ciclo solar N? 18 (1944-53). Conjuntamente foram estudadas as variações contemporâneas do indice geomagnético Kp. Neste trabalho são relatados e discutidos os resultados obtidos com a análise de periodicidade segundo o método de Vercelli (amplitudes e periodos) e com cálculo de coeficientes de correlaçao entre os dados das diferentes variáveis. Em particular é aqui apresentado um diagrama detalhado do andamento das amplitudes das sucessivas oscilações, estendido tambem aos

ciclos solares N? 19 (1954-64) e N? 20 (1965-74), que foram por nós analisados precedentemente. Este diagrama é comparado com um análogo apresentado pqr Bazilevskaya et *al.* com dados obtidos em outra localidade (Deep River) no intervalo 1957-73. O andamento das amplitudes no ciclo solar N? 18, confirma uma discordância de comportamento do mesmo em relação ao andamento do número de Wolf das manchas solares, já evidenciada com outro procedimento estatistico por Venkatesan.

The analysis of the quasi-periodical variations of the cosmic-ray intensity, with period of 27 days, carried out for the solar cycles N? 19 (1954-64)[1,2] and N? 20 (1965-74)[3], has been extended to the solar cycle N? 18 (1944-53). As before, the behaviour of the daily mean values of the cosmic-ray intensity recorded through shielded ionization chambers at Huancayo (Peru) and at Cheltenham (Maryland, USA) in the years 1944-53, has been analysed. (The Cheltenham station, during the N? 19 cycle, on the 5th October 1956, was replaced by Fredericksburg station (Virginia)). In the same time interval, the daily sums of the international geomagnetic index Kp have been examined. The data have been analysed through the periodical method of Vercelli[4,5]: this method lends itself quite well to evidence the time history and the dynamics of quasi-periodical variable, which shows variations both of amplitude and of period and sudden changes of phase, making it unsuitable to be analysed by a procedure assuming fixed periods. In fact such variations would damp the importance of the variable in an uncontrollable way and would fade its contribution in a given frequency interval (with possibility of misunderstandings in the evaluation of the results).

Really, the studied variations of the cosmic-ray intensity are related to a modulation process of solar origin which, whilst bound to a sun rotation period around its own axis of about 27 days (in the solar equatorial zone), otherwise stems from rising, development and fading processes of disturbed areas of solar discus: a possible shift of the barycentre of the active regions during a solar cycle can result in a period variations in respect of the sun rotation period.

Here, the results referring only to the variation of about 27 days of the N? 18 cycle are reported and compared with the ones obtained for the other two following cycles N? 19 and N? 20.

PERIODS

As to the periods for the 27-day variation and for the three solar cycles under examination, the following are the mean data:

	cosmic-ray at Huancayo	cosmic-ray at Cheltenham-Fredericksburg	Kp
solar cycle N? 18			
solar cycle N? 19 [1]	28.5		27.0
solar cycle N? 20 [2]	27.5	27.5	27.2

The annual means of the periods don't show a characteristic behaviour in the whole time interval considered and their variations are held in a quite limited range.

AMPLITUDES

The detailed behaviours of the oscillation amplitude with a 27-day period, both for cosmic-ray intensity at Huancayo and at Cheltenham-Fredericksburg, and for the Kp index, are reported in fig. 1, for the three cycles 18, 19 and 20; the behaviour of the annual average values of the amplitude are superimposed. The detailed diagrams point out a remarkable variability of the amplitude, particularly noticeable when in relation to the larger Forbush decays, whose time position is plotted in the diagram as well (arrows).

The agreement between the general behaviour of the diagrams for H and C-F is quite good in the cycles N? 18 and N? 19 and fairly good in the cycle Nº 20. As regarding the single details, the best agreement happens for the cycle N? 19 (except, at most, the last years of the cycle: 1962-64), the agreement is still satisfactory for the cycle N? 18 whilst it is poor for the cycle N? 20.

The correspondence between the two diagrams of the cosmic ra-

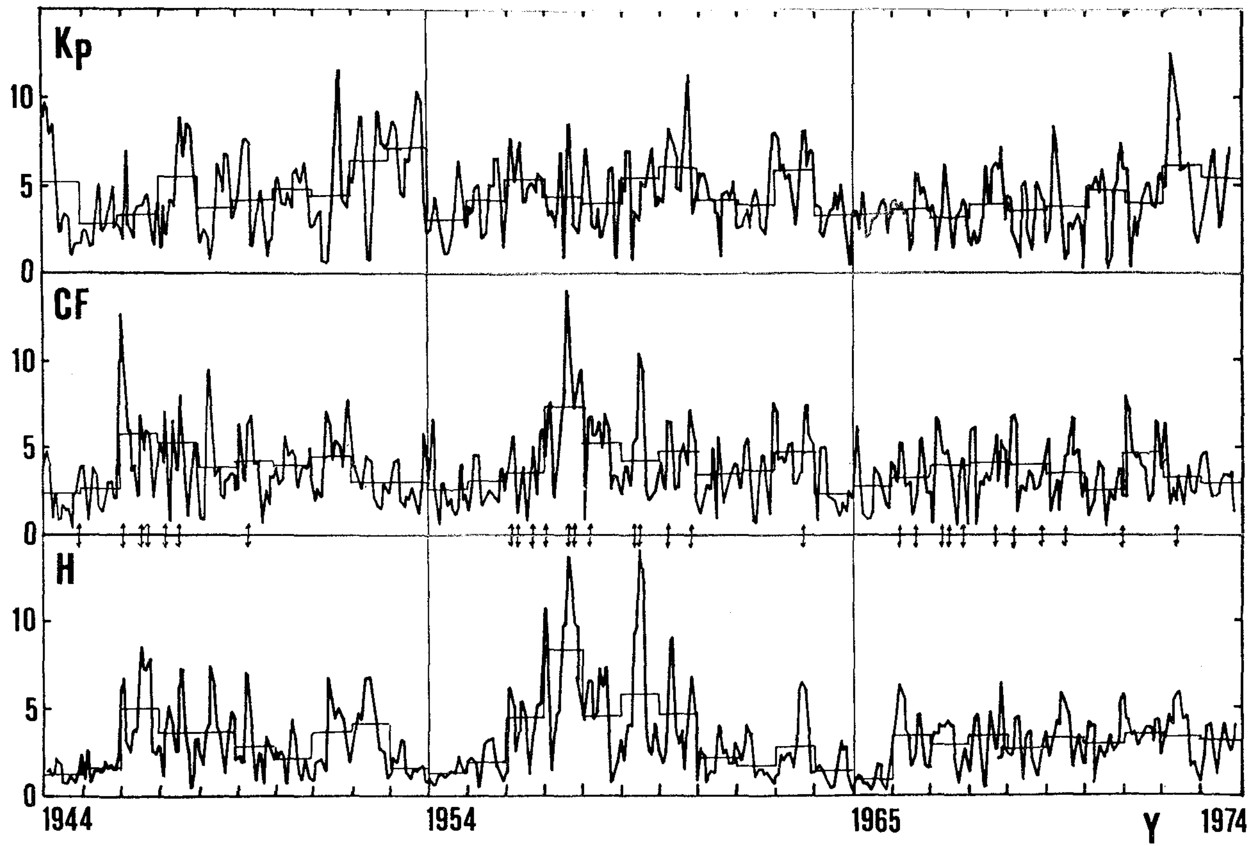

Fig.1 - Amplitudes versus time of 27-day variations: H: cosmic-ray intensity at Huancayo; C F: cosmic-ray intensity at Cheltenham-Fredericksburg; Kp: geomagnetic index.

diation and that of Kp is quite scanty, what is not amazing because the Kp index relates to the geomagnetic activity, in connection with the interaction of the solar wind with the earth magnetosphere, while the modulation process, which the cosmic-ray-intensity variations are related to, reflects the interplanetary space situation.

An analysis like the present one has been recently performed by G.A. Basilevskaya et *al.*[6] on the daily data of the cosmic-ray-intensity, measured both on the ground at some stations with neutron monitórs and in stratosphere over Murmansk and Mirynyi, and on data of some parameters characterizing the solar activity. That investigation, related to the time interval 1957-73, was carried out with an analysis process similar to ours to take the variation of about 27 days (with a selective filter somewhat different from the used here one (see[5]) but with a frequency response curve quite close to ours).

In fig.5 of that paper a graphic in reference to the present fig.1, is reported showing the detailed behaviour of the amplitude for the the 27-day variation of cosmic-ray intensity measured at Deep River, of the Kp index and moreover of three parameters related to the solar activity (sunspot Wolf number, sunspot total area, solar radio emission flux at 2800 MH frequency). In the time interval which is common to the two analysis a very good agreement is observed in the general behaviour between the cosmic-ray intensity diagram at Deep River and those ones at Huancayo and Fredericksburg and even a good concordance in the details, for the cycle N? 19, particularly between Deep River and Huancayo The curves obtained for Kp both in that paper and in the present one, are in full agreement, indication of the equivalence of the analysing schemes used. The temporal variation of the annual means of the amplitude, for the 27-day oscillation of the cosmic-ray intensity at Huancayo, velidates the disagreement in the behaviour of that amplitude versus the Wolf numbers R of the sunspot, which has already been pointed out and discussed by Venkatesan[7] and confirmed with another procedure by Lovera[8], although with a more limited analysis than the present one.

In fact, in the solar cycle N? 18, R shows a maximum in 1947 and a hint to a secondary maximum in 1949, while the average amplitude of the 27-day oscillation of the cosmic radiation at Huancayo has the main maximum in 1946 and a secondary maxirnurn, quite evident, in 1952 (in 1951 for Cheltenham).

This discrepancy is justified by reference to the results of Gnevyshev[9], who has shown that the behaviour of many factors attaining to the solar activity presents, in every solar cycle, two maxima, the latter related to the solar equatorial area and the former to higher soiar latirudes.

On the contrary, in the behaviour of R which includes all the sunspots without discrimination of the heliolatitudes, the two maxima are not generally resolved (a hint of resolution turns out, for R, just in the cycle N? 18).

Besides, this behaviour has been pointed out and discussed in the solar cycle N? 19 [1].

In table I, the annuai average amplitudes are reported for the oscillation of 27 days in the solar cycle N? 18 (section a) (with comparison for the cycles N? 19 and N? 20, sections b) and c)). The amplitudes of the cosmic-ray intensity are given in millesimal of the mean intensity in the considered interval.

The recorded errors are the standard deviation of the amplitudes in each year. As criterion of reliability of the recorded oscillation, we refer the one deduced by G.A. Gazilevskaya et a ~[6]. and described in the paragraph 2nd of their paper. In our case, the ratio between the average amplitudes and the standard deviations of the analysed data is about 0,7 for the Huancayo data, is 0.6 for the Cheltenham-fredericksburg ones, is 0.5 for the Kp index data and therefore quite higher than tne reliability limit (0.3 ÷ 0.4) proposed by Bazilevskaya:

CORRELATIONS

The correlation coefficients both among the experimental data (from which the annual variation of the cosmic-ray intensity has been

Table Ia

Average amplitudes of the oscillation of 27 days in the solar cycle N? 18 (H: Huancayo; C: Chetenharn; Kp: geomagnetic index).

Year	CH	C	Kp
1944	1.3 ± 0.1	2.2 ± 0.3	5.3 ± 0.9
1945	1.7 ± 0.2	2.7 ± 0.3	2.8 ± 0.3
1946	4.9 ± 0.7	5.6 ± 0.9	3.2 ± 0.4
1947	3.4 ± 0.5	4.3 ± 0.6	5.2 ± 0.7
1948	3.7 ± 0.5	3.9 ± 0.7	3.3 ± 0.6
1949	2.7 ± 0.5	3.5 ± 0.5	4.1 ± 0.6
1950	2.0 ± 0.3	4.0 ± 0.3	5.0 ± 0.3
1951	3.4 ± 0.6	4.6 ± 0.5	4.4 ± 1.0
1952	4.3 ± 0.6	3.1 ± 0.4	6.1 ± 0.7
1953	1.6 ± 0.2	3.0 ± 0.6	7.2 ± 0.6

Table Ib

Average amplitudes of the oscillation of 27 days in the solar cycle N? 19 (H:Huancayo; C-F: Cheltenham-Fredericksburg; KP: geomagnetic index).

Year	H	C-F	Kp
1954	1.3 ± 0.1	2.4 ± 0.4	3.0 ± 0.5
1955	1.8 ± 0.3	2.7 ± 0.3	3.9 ± 0.4
1956	4.2 ± 0.5	3.3 ± 0.4	5.4 ± 0.3
1957	8.2 ± 1.0	7.0 ± 1.0	4.1 ± 0.6
1958	4.6 ± 0.6	5.1 ± 0.6	3.6 ± 0.5
1959	5.6 ± 1.2	4.3 ± 0.8	4.8 ± 0.5
1960	4.1 ± 0.7	4.4 ± 0.5	6.3 ± 0.6
1961	2.2 ± 0.3	3.0 ± 0.4	4.1 ± 0.3
1962	1.9 ± 0.4	3.3 ± 0.6	3.8 ± 0.5
1963	2.9 ± 0.5	4.9 ± 0.4	5.9 ± 0.4
1964	1.5 ± 0.3	2.5 ± 0.4	3.1 ± 0.3

Table Ic

Average amplitudes of the oscillation of 27 days in the solar N? 20 (H: Huancayo; F: Fredericksburg; Kp: geomagnetic index).

Year	H	F	Kp
1965	1.0 ± 0.2	2.8 ± 0.5	3.2 ± 0.2
1966	3.5 ± 0.5	3.3 ± 0.3	3.6 ± 0.4
1967	2.8 ± 0.3	3.5 ± 0.6	3.1 ± 0.4
1968	3.3 ± 0.4	4.0 ± 0.5	4.3 ± 0.6
1969	2.7 ± 0.3	4.0 ± 0.5	3.2 ± 0.5
1970	3.4 ± 0.4	3.6 ± 0.5	3.4 ± 0.6
1971	3.1 ± 0.4	2.4 ± 0.3	4.4 ± 0.6
1972	3.6 ± 0.2	4.5 ± 0.5	3.9 ± 0.5
1973	3.4 ± 0.5	3.0 ± 0.3	6.2 ± 0.9
1974	3.0 ± 0.3	3.0 ± 0.4	5.3 ± 0.5

removed) and among the data of the oscillation of about 27 days are reported in Table II - a), b), c): they refer to simultaneous data taken in the time. The relative errors[10] are reported as well.

The correlation coefficients between the cosmic-ray intensities are all positive and have quite higher values in the central part of each cycle, between the years 1946 and 1952 for the cycle N° 18.

Generally, except for a few cases, they exceed at least three times the values of the error. Anyhow, the probability that the interested variables be linearly correlated is <1% if $|r| \geqslant 0.135$ and <1/1000 if $|r| \geqslant 0.171$ (Ref.11).

The coefficients relating the geomagnetic Kp index to the cosmic-ray intensity indicate a negative correlation, but of poor statistic importance, as has been said above in relation to the comparison between the amplitude diagrams. Anyhow, apart from the comparison with

Table IIa

Correlation coefficiencts - Solar cycle Nº 18

Year	H - C		Kp - H		Kp - C	
	Experim. data	27-day waves	Experim. data	27-day waves	Experim. data	27-day waves
1944	0.18 ± 0.05	0.02 ± 0.05	-0.32 ± 0.05	-0.60 ± 0.03	-0.09 ± 0.05	0.21 ± 0.05
1945	0.33 ± 0.05	0.48 ± 0.04	-0.06 ± 0.05	-0.17 ± 0.05	-0.23 ± 0.05	-0.36 ± 0.05
1946	0.78 ± 0.02	0.81 ± 0.02	-0.41 ± 0.04	-0.38 ± 0.05	-0.36 ± 0.05	-0.38 ± 0.04
1947	0.63 ± 0.03	0.86 ± 0.01	-0.34 ± 0.05	-0.36 ± 0.05	-0.30 ± 0.05	-0.42 ± 0.04
1948	0.68 ± 0.03	0.90 ± 0.01	-0.20 ± 0.05	-0.40 ± 0.04	-0.21 ± 0.05	-0.30 ± 0.05
1949	0.54 ± 0.04	0.64 ± 0.03	-0.32 ± 0.05	-0.54 ± 0.04	-0.28 ± 0.05	-0.61 ± 0.03
1950	0.43 ± 0.04	0.79 ± 0.02	-0.26 ± 0.05	-0.39 ± 0.04	-0.24 ± 0.05	-0.48 ± 0.04
1951	0.51 ± 0.04	0.67 ± 0.03	-0.27 ± 0.05	-0.51 ± 0.04	-0.17 ± 0.05	-0.35 ± 0.05
1952	0.49 ± 0.04	0.83 ± 0.02	-0.25 ± 0.05	-0.26 ± 0.05	-0.17 ± 0.05	-0.26 ± 0.05
1953	0.18 ± 0.05	0.30 ± 0.05	-0.01 ± 0.05	0.08 ± 0.05	-0.12 ± 0.05	-0.25 ± 0.05

Table IIb

Correlation coefficients - Solar cycle Nº 19

Year	H - CF		Kp - H		Kp - CF	
	Experim. data	27 - day waves	Experim. data	27-day waves	Experim. data	27-day waves
1954	0.06 ± 0.05	0.08 ± 0.05	-0.04 ± 0.05	-0.18 ± 0.05	-0.05 ± 0.05	-0.12 ± 0.05
1955	0.28 ± 0.05	0.51 ± 0.04	-0.10 ± 0.05	-0.16 ± 0.05	-0.11 ± 0.05	-0.14 ± 0.05
1956	0.47 ± 0.04	0.53 ± 0.04	-0.24 ± 0.05	-0.27 ± 0.05	-0.18 ± 0.05	-0.07 ± 0.05
1957	0.80 ± 0.02	0.92 ± 0.01	-0.30 ± 0.03	-0.60 ± 0.03	-0.23 ± 0.05	-0.52 ± 0.04
1958	0.68 ± 0.03	0.78 ± 0.02	-0.30 ± 0.05	-0.37 ± 0.04	-0.26 ± 0.05	-0.15 ± 0.05
1959	0.78 ± 0.02	0.95 ± 0.01	-0.31 ± 0.05	-0.31 ± 0.05	-0.27 ± 0.05	-0.25 ± 0.05
1960	0.67 ± 0.03	0.80 ± 0.02	-0.44 ± 0.04	-0.56 ± 0.04	-0.40 ± 0.04	-0.41 ± 0.04
1961	0.33 ± 0.05	0.39 ± 0.04	-0.26 ± 0.05	-0.29 ± 0.05	-0.18 ± 0.05	-0.07 ± 0.05
1962	0.34 ± 0.04	0.47 ± 0.04	-0.23 ± 0.05	-0.14 ± 0.05	-0.13 ± 0.05	-0.16 ± 0.05
1963	0.36 ± 0.04	0.67 ± 0.03	-0.14 ± 0.05	-0.35 ± 0.05	-0.17 ± 0.05	-0.52 ± 0.04
1964	0.18 ± 0.05	0.05 ± 0.05	-0.01 ± 0.05	-0.03 ± 0.05	-0.08 ± 0.05	-0.19 ± 0.05

Table IIc

Correlation coefficient - Solar cycle Nº 20

Year	H - F		Kp - H		Kp - F	
	Experim. data	27-day waves	Experim. data	27-day waves	Experim. data	27-day waves
1965	0.15 ± 0.05	0.35 ± 0.05	-0.07 ± 0.05	-0.21 ± 0.05	-0.15 ± 0.05	-0.21 ± 0.05
1966	0.38 ± 0.04	0.37 ± 0.05	-0.23 ± 0.05	-0.43 ± 0.04	-0.17 ± 0.05	-0.44 ± 0.04
1967	0.47 ± 0.04	0.72 ± 0.03	-0.22 ± 0.05	-0.34 ± 0.05	-0.20 ± 0.05	-0.36 ± 0.05
1968	0.56 ± 0.04	0.58 ± 0.03	-0.30 ± 0.05	-0.49 ± 0.04	-0.24 ± 0.05	-0.58 ± 0.03
1969	0.46 ± 0.04	0.59 ± 0.03	-0.20 ± 0.05	-0.12 ± 0.05	-0.18 ± 0.05	-0.18 ± 0.05
1970	0.48 ± 0.04	0.70 ± 0.03	-0.21 ± 0.05	-0.23 ± 0.05	-0.23 ± 0.05	-0.35 ± 0.05
1971	0.32 ± 0.05	0.43 ± 0.04	-0.23 ± 0.05	-0.47 ± 0.04	-0.11 ± 0.05	-0.21 ± 0.05
1972	0.50 ± 0.04	0.75 ± 0.02	-0.35 ± 0.05	-0.31 ± 0.05	-0.22 ± 0.05	-0.12 ± 0.05
1973	0.37 ± 0.04	0.45 ± 0.04	-0.30 ± 0.05	-0.46 ± 0.04	+0.01 ± 0.05	-0.04 ± 0.05
1974	0.41 ± 0.04	0.56 ± 0.03	-0.07 ± 0.05	-0.26 ± 0.05	-0.09 ± 0.05	-0.07 ± 0.05

the pertinent errors, it is statistically significant the sign persistente (except one case, statistically not reliable). The total correlation coefficient of Kp versus the cosmic-ray intensity at Huancayo and at Cheltenham-Fredericksburg has been taken into consideration too. Within a multiple linear correlation of a variable x with two other variables y and z, the total correlation coefficient $\rho_{x;y,x}$ of x versus y and z is defined by the well known relation:

$$\rho^2_{x;y,z} = \frac{1}{1 - r^2_{yz}} (r^2_{xy} + r^2_{xz} - 2r_{xy}\, r_{xz}\, r_{yz})$$

which gives the squared modulus of $\rho_{x;y,z}$; r_{xy}, r_{xz}, r_{yz} are the correlation coefficients among the three variables, taken two by two.

Table III and fig.2 report the absolute values of the total correlation coefficient of Kp with the two cosmic-ray. intensities in the three cycles N? 18, N? 19, N? 20 for the experimental data and for

Table IIIa

Total correlation coefficient-Solar cycle N? 18

Year	Experim. data		27-day waves	
1944	0.32	0.05	0.64	0.04
1945	0.23	0.05	0.36	0.04
1946	0.41	0.02	0.40	0.02
1947	0.35	0.03	0.42	0.02
1948	0.22	0.03	0.42	0.04
1949	0.35	0.03	0.64	0.02
1950	0.30	0.04	0.48	0.02
1951	0.28	0.04	0.51	0.03
1952	0.26	0.04	0.28	0.02
1953	0.12	0.05	0.30	0.06

Table IIIb

Total correlation coefficients - Solar cycle Nº 19

Year	Experim. data	27-day waves
1954	0.07 ± 0.05	0.21 ± 0.05
1955	0.13 ± 0.04	0.17 ± 0.04
1956	0.26 ± 0.04	0.29 ± 0.05
1957	0.30 ± 0.03	0.61 ± 0.02
1958	0.31 ± 0.03	0.43 ± 0.05
1959	0.32 ± 0.02	0.34 ± 0.04
1960	0.46 ± 0.02	0.56 ± 0.02
1961	0.28 ± 0.04	0.35 ± 0.06
1962	0.24 ± 0.04	0.18 ± 0.04
1963	0.20 ± 0.04	0.52 ± 0.03
1964	0.08 ± 0.05	0.20 ± 0.05

Table IIIc

Total correlation coefficients - Solar cycle Nº 20

Year	Experim. data	27-day waves
1965	0.16 ± 0.05	0.26 ± 0.04
1966	0.25 ± 0.04	0.53 ± 0.03
1967	0.25 ± 0.04	0.38 ± 0.02
1968	0.32 ± 0.03	0.61 ± 0.02
1969	0.22 ± 0.04	0.18 ± 0.04
1970	0.26 ± 0.03	0.35 ± 0.03
1971	0.23 ± 0.04	0.47 ± 0.04
1972	0.35 ± 0.04	0.35 ± 0.05
1973	0.32 ± 0.05	0.49 ± 0.05
1974	0.12 ± 0.04	0.37 ± 0.06

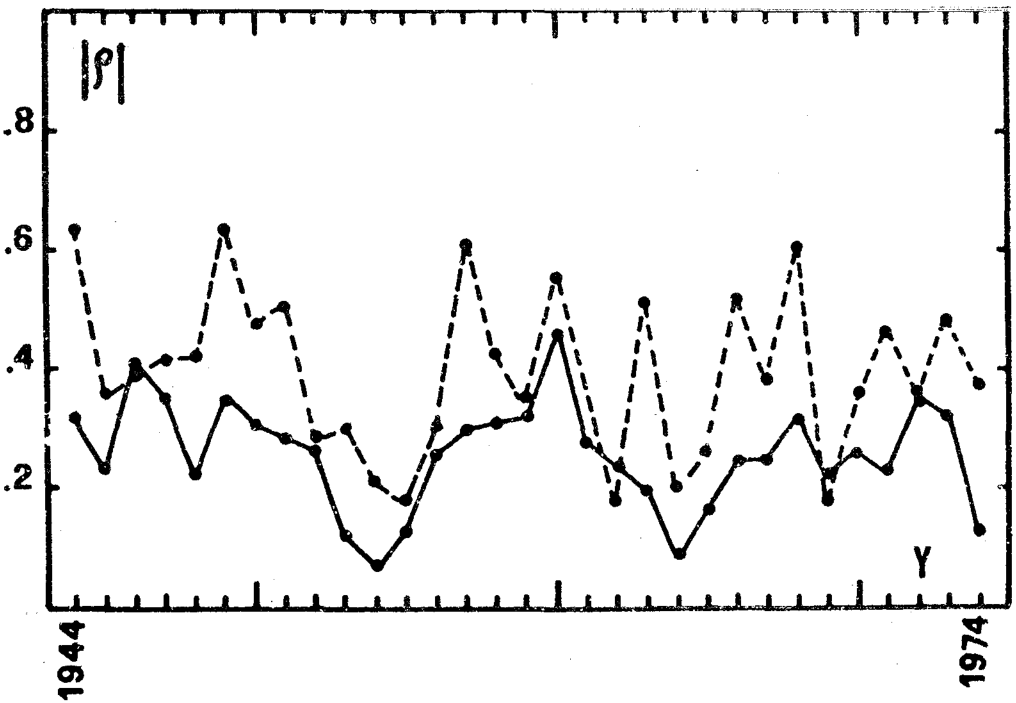

Fig.2 - Total correlation coefficient |ρ|: experimental data: solid curve; 27-day waves: dashed curve.

the 27-day oscillations (the correlation is negative as it is seen in the present Table (I, and in the Table IV of the reference[2]). The errors have been computed obviously following the law of error propagation. The average values of $|\rho|$ are slightly higher in the cycie N? 18; anyhow the differences among the three cycles are not remarkable.

There is some trend to higher values of $|\rho|$ in thè central part of each cycle, according to the behaviour of each r_{ij}.

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