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ABSTRACT

We study the influence of solar activity phenomena on the modulation of solar radiation at the earth level. On basis to some definite solar activity indeces, it is established the correlation between solar radiation and solar activity. The relevant modulation is paradigmatized for the case of Mexico, Moscow and Vilnius.

1. INTRODUCTION

Within the frame of the ecological programs related to atmospheric pollution, a long term experiment of solar radiation measurement was undertaken in three different cities of high interest and prejudice for ecologists: Mexico City, Moscow and Vilnius. Taking into account estimations about the contribution of anthropogenic activities (dust emissions, combustion products, and other atmospheric pollution effects) it is attempted to study the possible modulation of the solar radiation (as observed at the earth surface level) by the solar activity (**SA**).

It must be reminded that solar radiation at the earth surface level is characterized by both, diurnal and seasonal variations due to the rotation and translation motions of the planet. In addition, there is the influence of the geographic location of the place of observation. In fact, the geographic environment is of fundamental importance for the regulation of the radiation fluxes at the earth surface. In large cities, with important sources of atmospheric pollution, the climatological behavior of those fluxes is different from that in rural zones. This difference is due not only to the direct interferences of gas and particles to solar radiation passage (Muhlia et al., 1989) and the formation of diffuse radiation fluxes with very *sui generis* spectral and angular properties, but also due to modifications of the cloud field by particles, as has been hypothesized by Twomey (1976), taking into account that the cloud field is the more important modulator of solar radiation at the tropospheric level.

In this work we attempt to determine the importance of an external influence in the modulation of the radiation flux on the earth surface, as this is measured in three sites that are characterized by environmental conditions of the urban type: the cities of Mexico, Vilnius and Moscow. The goal of this research is to determine the importance of the influence of the natural factors, relative to anthropogenic factors, in the conditions of illumination and heating of the earth surface, under the present conditions of industrial development.

2. SOLAR ACTIVITY INDECES

In the works of Pérez-Peraza et al., (1996a,b) it was established the existence of a frequence relation between the temperature oscillations and the level of two lakes in Mexico and Russia with solar activity. Therefore, it entails the need of chose and index (or a combination of indeces) of solar activity able to describe adequately the variations of the electromagnetic conditions in the interplanetary space. Since in the previously mentioned works the Wolf number does not give the adequate correlations, so the sunspot surface S was used as solar activity index.

The analysis of the relations between the 11 years variations of the cosmic ray intensity and the different indeces of solar activity [the sunspot number (W), the intensity of the coronal green line (λ =5303 Å), the number of sunspots groups and solar radio-emissions] shows that the variation of the solar activity characteristics, considering the cyclic variations of the distribution of the solar activity centers, is directly correlated with similar variations of cosmic rays, the earth temperature and the hydro-meteorological parameters (Gushchina et al., 1992).

In the case of cosmic rays, the problem of the selection of the adequate indeces has been solved long ago (e.g. Gushchina et al., 1992). The existence of a clear correlation between the long-period variations of cosmic ray intensity and the parameters of solar activity, previously mentioned, is not a casual one, since each index describes general properties of the solar activity periodicity. Although is clear that in certain cases the direct use of solar activity indeces is not adequate, because the plasma fluxes of the solar wind proceeding from different helio-latitudes have different efficiencies to modulate cosmic rays and solar radiation at the earth level, on the other hand, for global parameters, such as the climatic and hydrologic ones, the use of solar activity indeces (or their combinations) is completely vindicated.

Concerning the measurement of cosmic ray intensity or solar radiation, the properties of the modulation from any active zone of the sun are determined not only by its activity level and its helio- coordinates, but also by the angular extension of the solar wind flux. For this reason, in the work of Gushchina and Dorman (1970), it is proposed an index which considers the terrestrial helio-longitude at the time of the measurement (solar radiation in the present case), the difference in degrees of the active centers, between north and south solar hemispheres and the latitude variation of sunspots during the solar activity cycle:

$$HL(\Theta_{\overset{+}{o}},\Theta_o,t) = a \int_{-\pi/2}^{\pi/2} K_i(\Theta,t)\ \exp\left(-\left|\frac{\Theta - \Theta_{\overset{+}{o}}}{\Theta_o}\right|\right) d\Theta \qquad (1)$$

where $K_i(\Theta,t)$ is the parameter that characterizes the solar activity at the time t and helio-latitude Θ; Θ_o is a parameter that characterizes the angular half-amplitude of solar wind fluxes, and $\Theta_{\overset{+}{o}}$ is the earth helio-latitude, which introduction allows to eliminate the effects produced by the inclination of the earth orbit relative to the equatorial plane on the cosmic rays and solar radiation fluxes. It should be mentioned that in the case of climatological data, the index HL is only slightly sensitive to the parameter $\Theta_{\overset{+}{o}}$; a is a normalization factor determined from the condition

$$a \int_{-\pi/2}^{\pi/2} \exp\left(-\left|\frac{\Theta - \Theta_{\overset{+}{o}}}{\Theta_o}\right|\right) d\Theta = 1 \qquad (2)$$

so that

$$a = \{2\Theta_o[1 - \cosh(\Theta_{\overset{+}{o}}/\Theta_o)\exp(-\pi/2\Theta_o)]\}^{-1} \qquad (3)$$

In the work of Gushchina and Dorman (1970) the index HL was calculated for the solar activity cycles 18 and 19: the parameter of activity $K_i(\Theta,t)$ considered in that work was the sunspot surface (S) and the sunspot number (W). In the work of Gushchina et al. (1992) the values of the index HL were calculated for the 20th activity cycle. Besides, the series of monthly mean values of the index HL, for a period longer than two solar activity cycles, give the possibility of accomplish the correlational and spectral analysis between the sunspot surface (S), the index HL and the solar radiation, in spite that all these processes are not of a strictly steady-state nature (Pérez-Peraza et al., 1996b); in those works it is shown that such a time-dependence behavior does not introduce variations in the dephasage of the analyzed processes with respect to solar activity, and so, the application of the spectral analysis is widely permissible, and even better the application of the ARMA (Mathematical autoregression) model. In table 1a and 1b, we present the normalized monthly mean values of the index HL (for $\Theta_o = 30^\circ$ and $\Theta_o = 50^\circ$ respectively) for the period 1952-1984.

3. RESULTS AND DISCUSSION

In a previous work (Pérez-Peraza et al., 1996a) we have performed an auto-regressive bidimensional spectral analysis of the sunspots integrated surface and the temperature in Mexico, Russia and Estonia. This method was used for the analysis of the solar activity index HL, the sunspots and the solar radiation, and was done with monthly yearly mean values during the period 1952-1990.

In Figs.1(a)-(c) we show the reciprocal amplitude spectra of the index HL and the solar radiation in Vilnius, for the years 1955-1987. In Figs. 1(d)-1(e) we present the coherence spectra for the analyzed solar activity cycles. Analogous spectra for the measurements of solar radiation in Mexico are given in Figs. 2(a)-(c). In Figs. 3(a)-(c) and 4(a)-(b) we show the reciprocal amplitude spectra (a), the phase spectra (b) and the coherence spectra (c), for Vilnius and Mexico respectively, on basis to annual data. Calculation for another different region with the minimum values of the remaining dispersion are shown in Figs. 5(a)-(d). Similar spectra were obtained for Moscow: the coherence coefficient for the peaks in the reciprocal spectra of Moscow and Vilnius reach values of 0.89 for oscillations with periods of 3 months up to 0.96 for a period of 11 years.

From the previous figures it can be seen a wide frequency interval in the solar radiation data: at the level of the earth surface, we found oscillations with periods of 3 months, 11-12 months, 4-5 years and 11 years, closely related to solar activity. The comparison of the obtained results with other similar investigations about the influence of solar activity on the superficial temperature, the lakes level and the magnitude of pluvial precipitations (Pérez-Peraza et al., 1996 a,b,c) show not only a good qualitative agreement, but also a good temporal coincidence (with precision up to the magnitude of the dephasage). Of particular importance are the results concerning the behavior of the coherence coefficient and the remaining dispersion of the analyzed processes by modeling with solar activity, i.e. by the use of the index HL and the sunspot surface. The results are displayed in Table 2, where it can be seen that the employment of the index HL as indicator of solar activity gives more precise results than with the use of the index S. The employement of the index HL instead of the index S is justified not only from the physical point of view , but also statistically. In Figs. 5(a)-(d) we present the ARMA reciprocal spectra of the solar activity HL-S. The obtained results not only confirm the presence of the peaks (2 ~ 3, 5 and 12 months, and 2, 3.8, 5.3 and 11 years) in the series of different cycles of the solar activity, but they also present a high statistical coherence of both indexes (Fig. c). Nevertheless, when using the index HL, the remaining dispersion of the process is 2 ~ 2.5 times lower than with the use of the index S [Figs. 6(a)-(b)].

4. CONCLUSIONS

The obtained results in this work require still of further precision. It is necessary to introduce corrections for meteorological conditions (Libin, 1987) and human activity, in the solar radiation data: for the anthropogenic activity it should be excluded the low frequency tendency related to the gathering of dust in the atmosphere. At any event, the obtained results confirm, in a definitive form, the existence of narrow solar-terrestrial relations in the behavior of the solar radiation observed on different sites of the earth surface.

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Table 2.

Variation of the spal parameters ρ, σ with the change of solar activity index.

		Moscow, RUSSIA				Mexico, MEXICO			
		3	12	5~6	11	3	12	5~6	11
		[monnths]		[years]		[months]		[years]	
ρ	S	51	68	25	77	49	69	34	80
	HL	72	84	48	90	72	82	83	82
σ	S	34	25	48	28	40	27	51	32
	HL	26	11	40	11	28	22	28	19

ρ: correlation coefficient between the solar activity and solar radiation (x 100).

σ: remaining dispersion of solar radiation according to the auto-regressive amplitude model [ARMA] (in %).

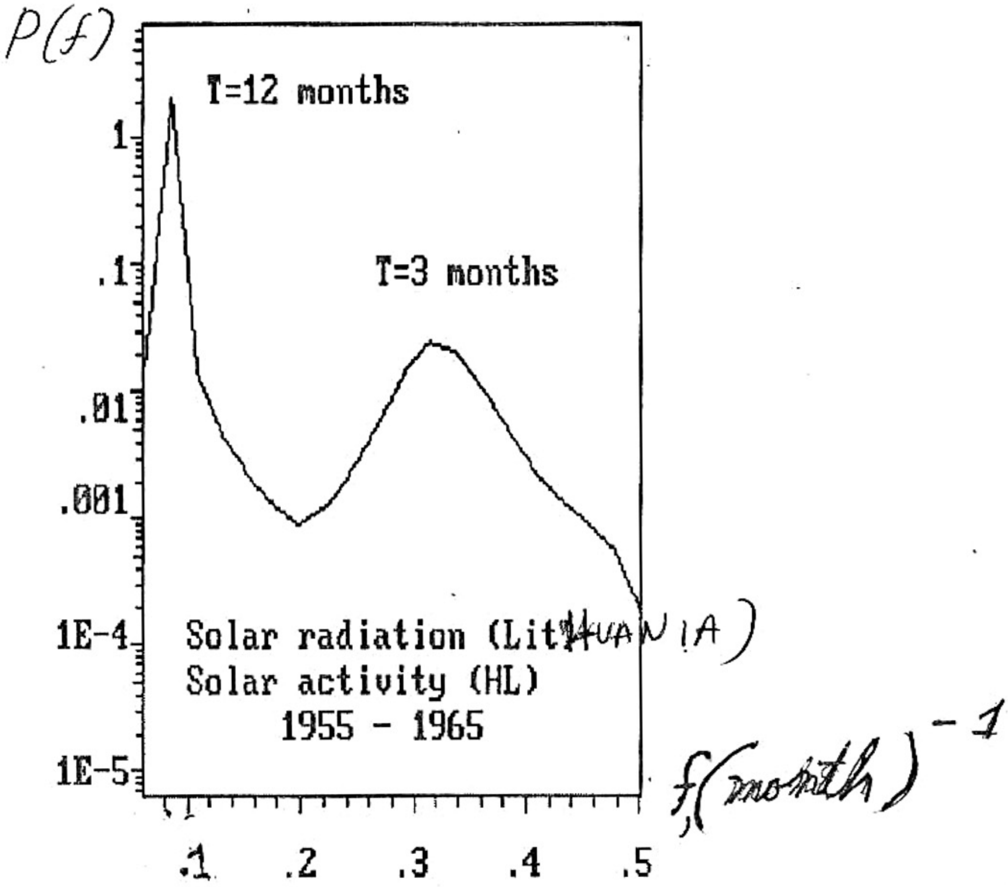
Tabla 1a. Valores normalizados del indice HL (30 grados)

	ENE	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SEP	OCT	NOV	DIC
1952	174.7	113.7	77.5	156.0	143.2	165.6	294.9	370.4	162.3	175.8	186.4	233.4
1953	147.7	4.4	27.1	174.4	77.0	79.6	35.4	137.7	71.8	15.0	5.0	1.5
1954	0.0	0.2	89.1	0.8	0.4	0.0	4.1	18.3	0.0	3.3	14.9	25.1
1955	124.1	67.3	13.4	15.9	69.9	112.6	40.6	147.2	123.0	263.7	416.8	282.2
1956	296.1	695.3	487.9	338.4	635.6	444.1	523.9	836.6	633.6	655.3	1050.5	1034.9
1957	714.9	301.2	582.1	680.7	886.3	1207.1	908.5	712.3	1552.7	1290.0	944.9	1224.0
1958	992.0	827.2	1261.9	1075.1	929.0	729.0	1068.8	997.2	1007.5	872.2	533.7	1146.2
1959	1337.7	550.5	947.2	681.8	854.6	1057.4	966.7	1331.4	909.6	713.1	772.0	850.5
1960	935.8	546.5	444.2	675.6	775.3	540.7	817.9	832.0	493.6	406.1	476.4	334.9
1961	222.3	134.4	237.5	269.9	225.0	474.0	584.1	229.0	434.7	126.1	133.7	180.7
1962	216.6	278.2	242.6	192.2	272.4	147.6	136.4	65.2	286.7	162.4	119.9	76.5
1963	64.5	59.9	44.8	114.0	113.9	137.1	71.6	148.8	254.3	187.2	99.1	25.9
1964	30.5	29.0	11.1	8.4	51.0	28.2	23.6	4.2	40.7	45.6	28.6	45.2
1965	30.5	29.1	11.1	9.4	50.8	28.2	23.7	4.2	40.8	45.7	28.7	45.3
1966	65.4	31.9	108.4	133.2	119.1	77.3	183.5	179.9	333.2	239.5	236.5	168.0
1967	479.0	234.7	466.9	152.3	364.3	235.6	307.7	589.1	242.2	327.7	370.6	504.4
1968	596.1	439.4	282.0	208.2	438.8	507.3	487.9	430.9	387.4	323.7	325.5	444.3
1969	458.0	317.2	626.4	476.1	440.7	400.1	342.0	392.9	247.3	600.7	474.6	371.5
1970	515.7	627.4	461.2	696.5	739.5	492.8	626.6	522.4	443.4	482.6	582.6	449.2
1971	755.7	525.4	278.7	319.7	237.1	156.4	443.7	347.9	227.7	437.1	329.6	418.4
1972	210.9	432.0	494.1	144.2	529.9	584.1	362.2	416.4	284.7	343.3	213.7	184.5
1973	164.5	171.1	348.9	302.2	201.4	199.7	239.9	100.4	379.8	151.2	122.3	114.7
1974	110.3	92.9	68.5	211.9	190.3	120.5	267.8	155.7	273.1	312.3	152.5	89.3
1975	57.7	33.1	29.4	6.9	31.8	51.6	36.0	50.7	30.5	43.5	111.4	14.2
1976	48.3	6.2	124.3	160.8	42.4	35.9	3.0	111.4	57.8	56.1	37.0	71.0
1977	21.9	53.8	14.3	33.6	25.4	157.0	68.7	72.8	275.0	138.6	75.5	158.7
1978	166.3	398.4	323.4	307.5	363.1	313.9	261.9	122.8	514.0	397.0	401.1	656.4
1979	793.2	563.8	458.2	485.1	422.7	777.9	452.8	632.6	648.4	912.2	703.0	575.3
1980	707.4	942.3	457.1	688.4	975.4	714.2	618.7	531.7	746.6	640.1	981.3	909.4
1981	460.6	754.7	714.6	693.5	619.9	361.8	1015.1	804.1	811.3	924.0	582.0	766.0
1982	502.7	1163.1	1168.0	496.4	449.6	919.7	599.7	753.9	507.7	462.2	559.4	1039.5
1983	411.1	292.2	314.8	350.1	600.0	511.0	399.5	305.6	242.6	365.1	133.5	167.8
1984	474.8	658.1	432.0	653.7	666.6	269.7	194.3	140.4	120.9	114.3	159.1	137.4

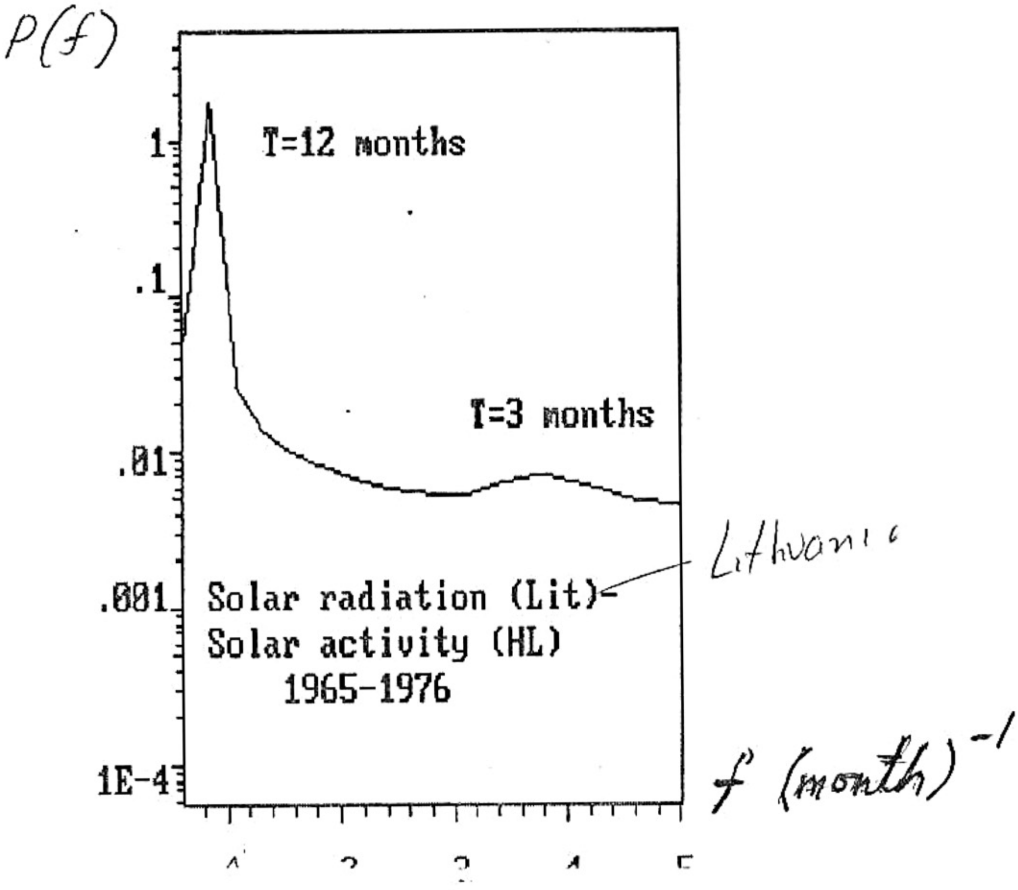
Tabla 1b. Valores normalizados del indice HL (50 grados)

	ENE	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SEP	OCT	NOV	DIC
1957	118.7	128.5	106.3	131.8	116.6	134.7	134.3	147.0	163.9	164.0	154.8	154.8
1958	166.1	136.2	102.7	127.3	131.1	143.1	146.9	161.4	161.0	163.3	176.7	176.9
1959	143.4	154.8	117.5	126.1	113.1	100.3	136.3	132.7	128.8	117.0	105.2	105.6
1960	111.3	114.2	101.4	93.1	111.3	95.6	100.8	95.5	102.2	94.9	74.5	75.1
1961	99.9	84.4	87.9	61.3	63.8	75.7	74.7	82.3	62.7	57.0	52.5	51.7
1962	47.5	48.7	47.3	56.7	43.5	46.4	47.9	47.6	48.8	40.0	37.3	37.4
1963	24.8	33.2	26.5	28.4	41.3	23.7	31.5	36.8	36.7	34.3	34.2	33.5
1964	28.5	34.9	39.0	26.5	25.2	20.5	22.0	17.5	19.8	24.1	22.6	22.6
1965	23.5	31.1	17.0	19.0	24.7	33.3	24.8	23.8	21.0	20.0	23.6	23.8
1966	20.9	20.5	35.7	23.7	39.0	55.3	49.5	56.8	41.4	39.1	57.4	55.8
1967	75.0	53.3	93.5	84.1	61.0	67.0	86.4	77.0	72.7	76.3	88.8	89.2
1968	98.9	82.2	85.2	78.6	78.8	79.3	82.6	78.8	97.5	57.3	63.1	63.0
1969	81.6	64.7	55.2	59.4	65.0	91.2	103.7	42.9	30.9	82.2	63.0	63.7
1970	57.1	65.8	91.8	85.5	109.9	99.6	93.0	121.2	68.6	87.4	63.7	63.7
1971	61.5	95.5	72.7	54.9	59.1	81.3	76.5	42.8	42.2	45.8	62.0	61.5
1972	75.7	55.9	45.6	61.4	74.0	62.9	97.8	67.4	55.3	61.1	45.4	45.6
1973	88.7	51.5	69.4	46.3	60.3	54.5	40.9	55.9	38.1	54.1	35.8	36.1
1974	91.6	88.2	117.7	65.1	72.2	104.2	110.8	115.2	115.6	117.0	113.1	85.8
1975	79.2	65.8	72.8	74.5	41.5	48.1	88.1	106.8	106.3	90.0	91.2	79.9
1976	74.2	62.2	59.0	54.9	67.7	67.7	52.7	54.7	85.1	76.5	109.4	73.7
1977	51.5	46.2	85.2	93.6	96.9	143.4	125.3	111.5	111.5	154.5	165.7	175.9
1978	209.8	182.7	200.8	203.3	183.7	179.2	181.1	168.2	190.9	176.3	264.4	253.3
1979	253.5	239.0	269.6	214.2	296.9	254.9	219.5	325.6	262.7	266.5	260.7	292.0
1980	248.0	268.4	272.2	248.2	228.5	277.1	315.4	259.5	290.7	282.7	245.5	235.6
1981	225.1	232.0	244.7	288.0	233.9	215.0	204.2	229.1	276.3	259.8	273.3	286.5

1 (a)


P(f)
T=12 months
T=3 months
1
.1
.01
.001
1E-4
1E-5
Solar radiation (LitHUANIA)
Solar activity (HL)
1955 - 1965
f (month)$^{-1}$
.1
.2
.3
.4
.5

1 (b)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T=3 months
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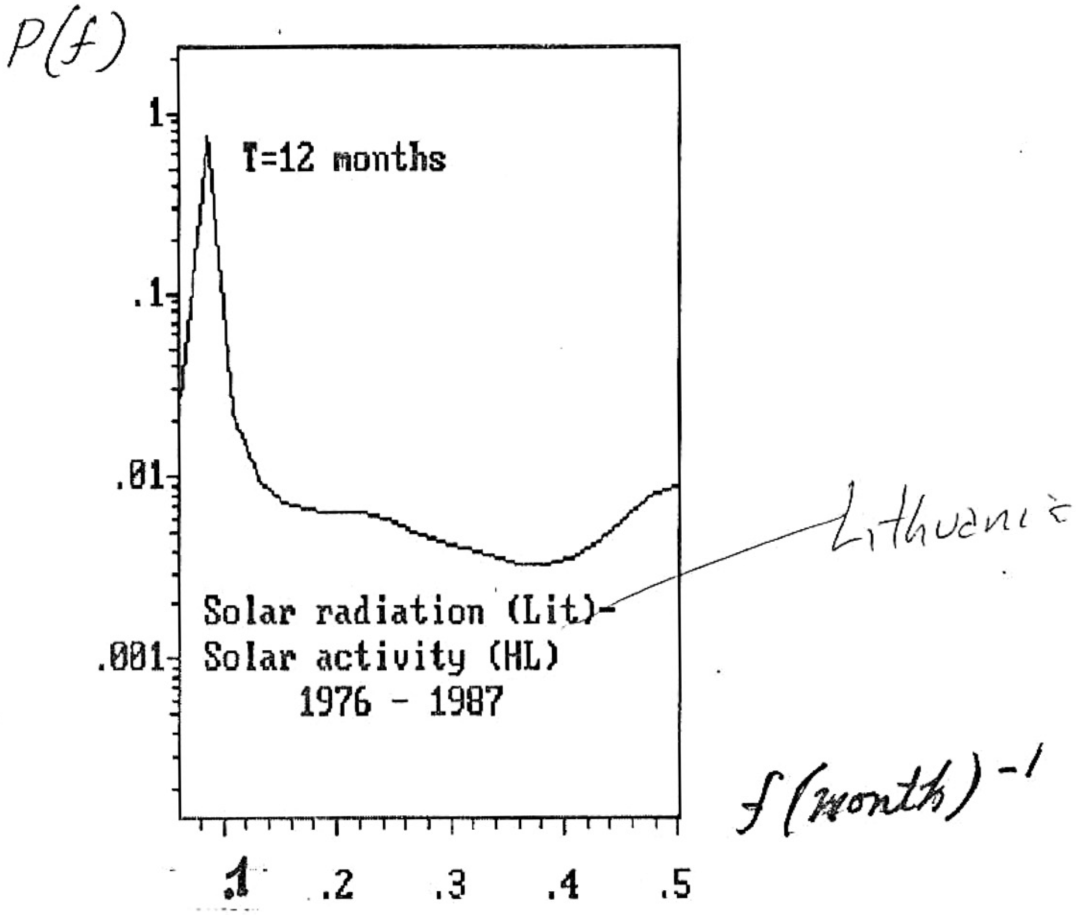
Solar radiation (Lit)
Lithuania
Solar activity (HL)
1965-1976
f (month)$^{-1}$

1(c)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T=12 months
Solar radiation (Lit)-
Solar activity (HL)
1976 - 1987
Lithuania
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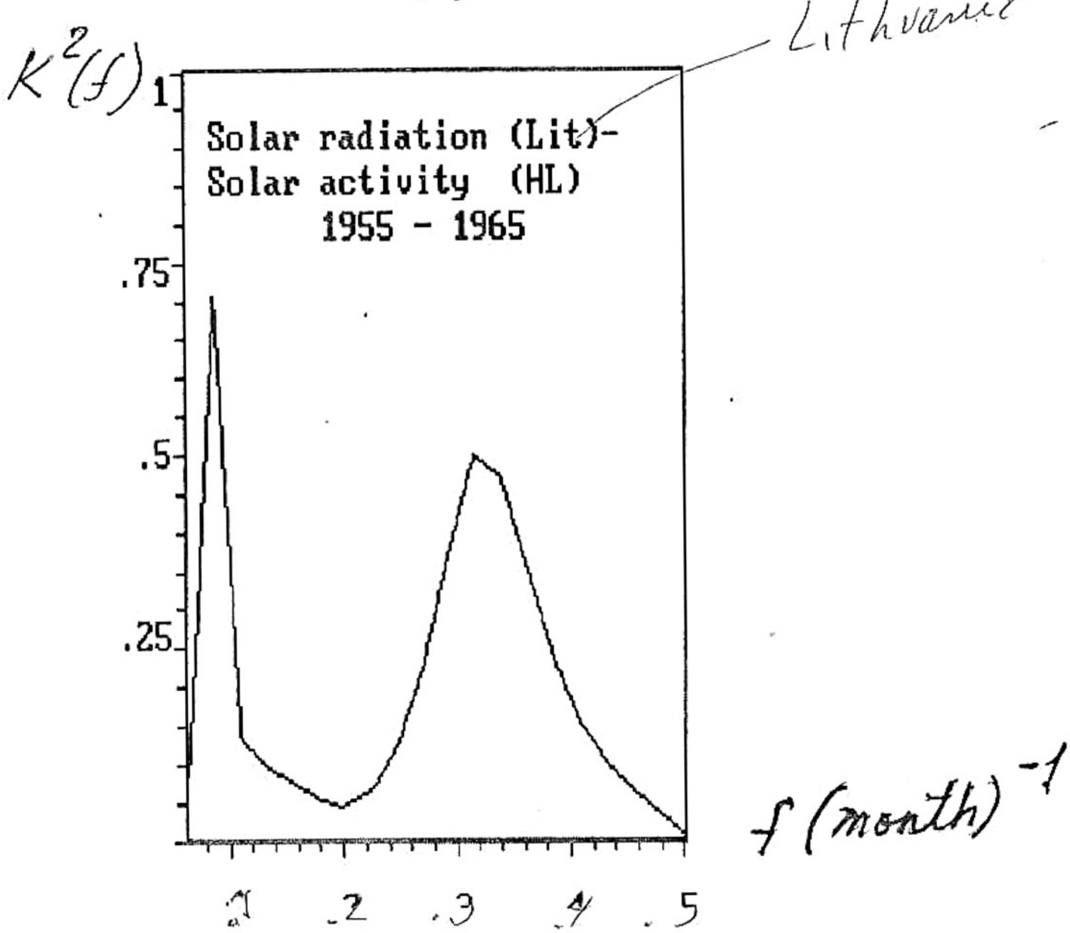
.2
.3
.4
.5

1(d)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1
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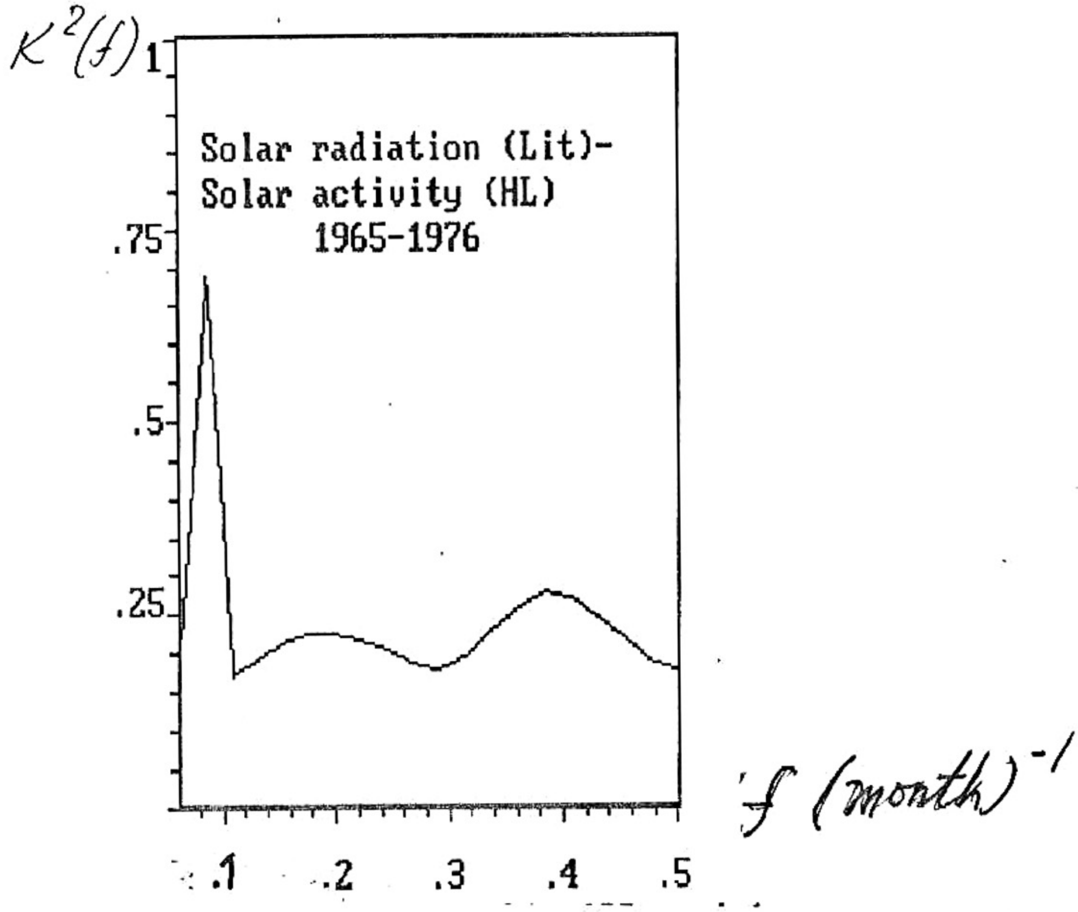
.25
Solar radiation (Lit)-
Solar activity (HL)
1955 - 1965
Lithuania
f (month)$^{-1}$
.1
.2
.3
.4
.5

1(e)


K²(f)
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.5
.25
Solar radiation (Lit)-
Solar activity (HL)
1965-1976
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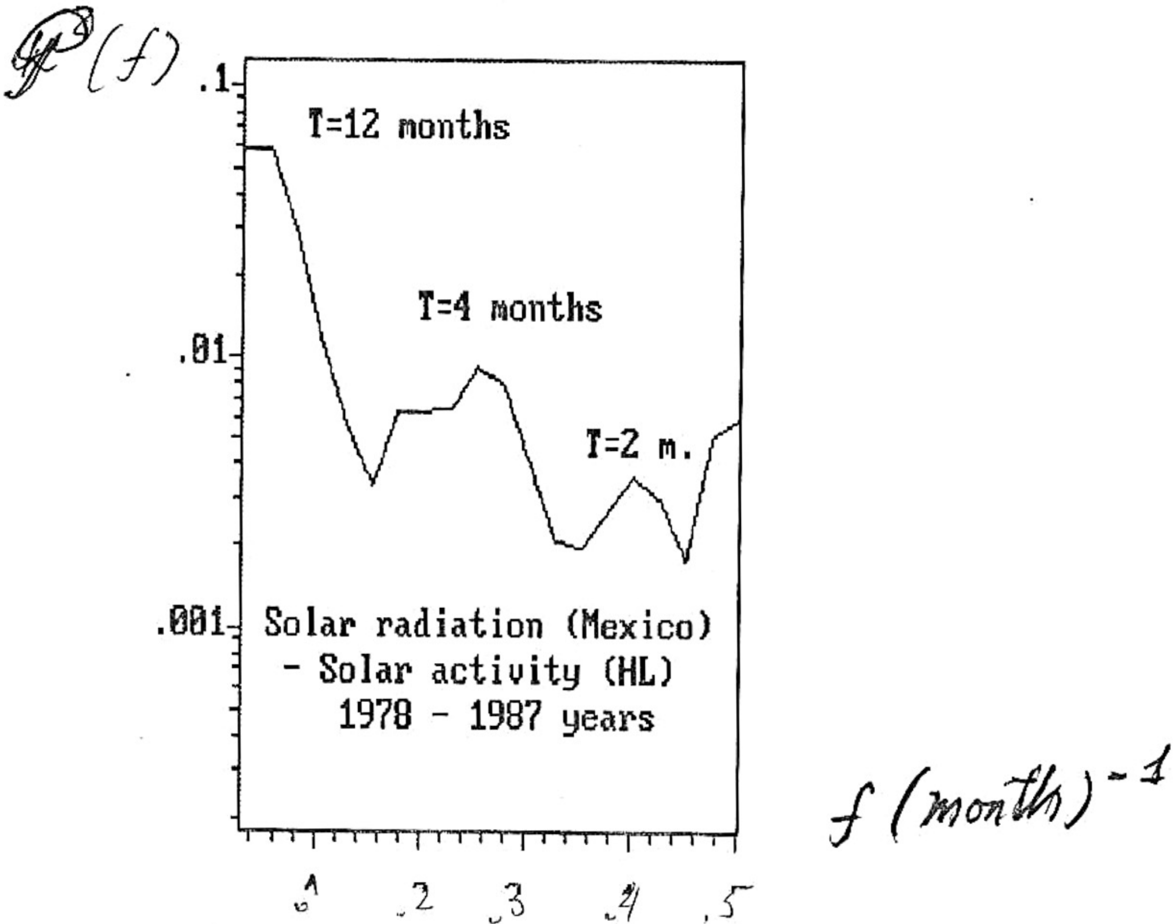
.5
f (month)⁻¹

2(a)


(f)
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.01
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T=12 months
T=4 months
T=2 m.
Solar radiation (Mexico)
- Solar activity (HL)
1978 - 1987 years
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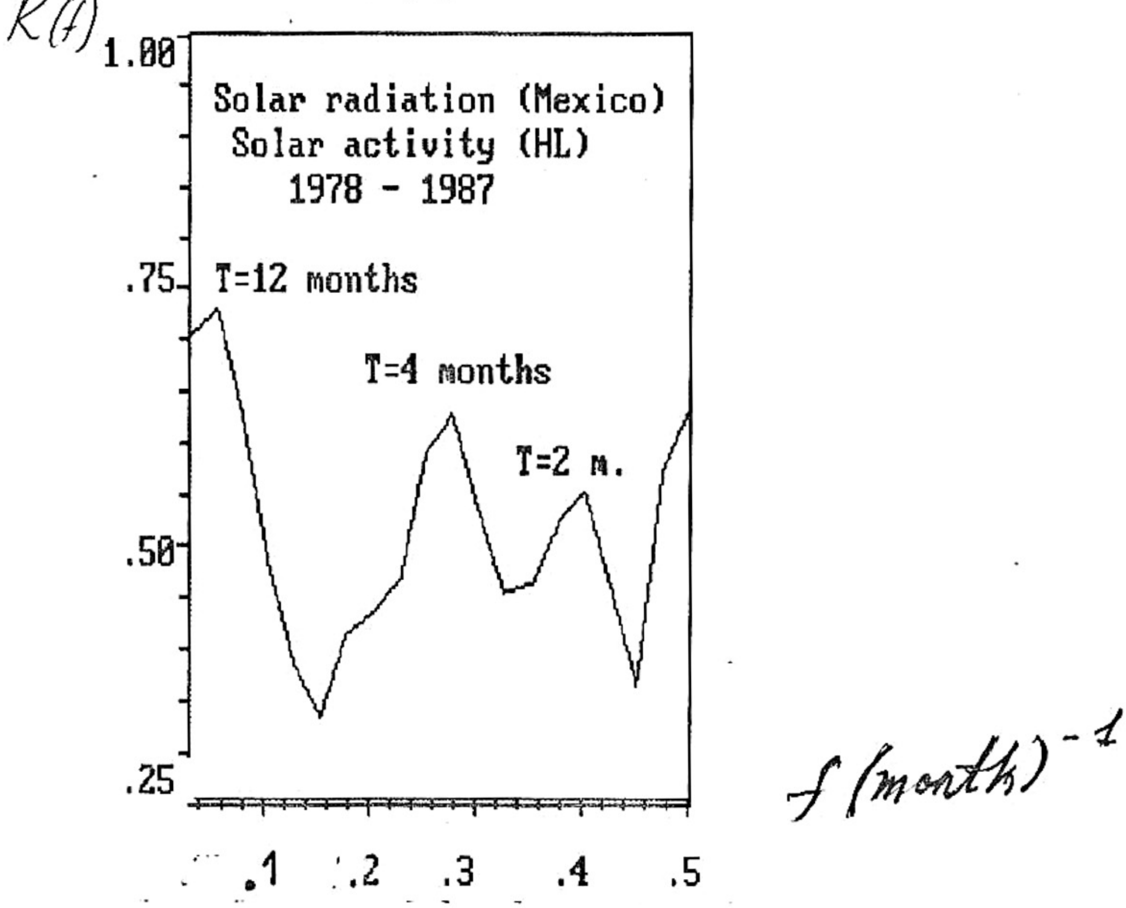
.4
.5
f (months)⁻¹

2(b)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Solar radiation (Mexico)
Solar activity (HL)
1978 - 1987
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T=4 months
T=2 m.
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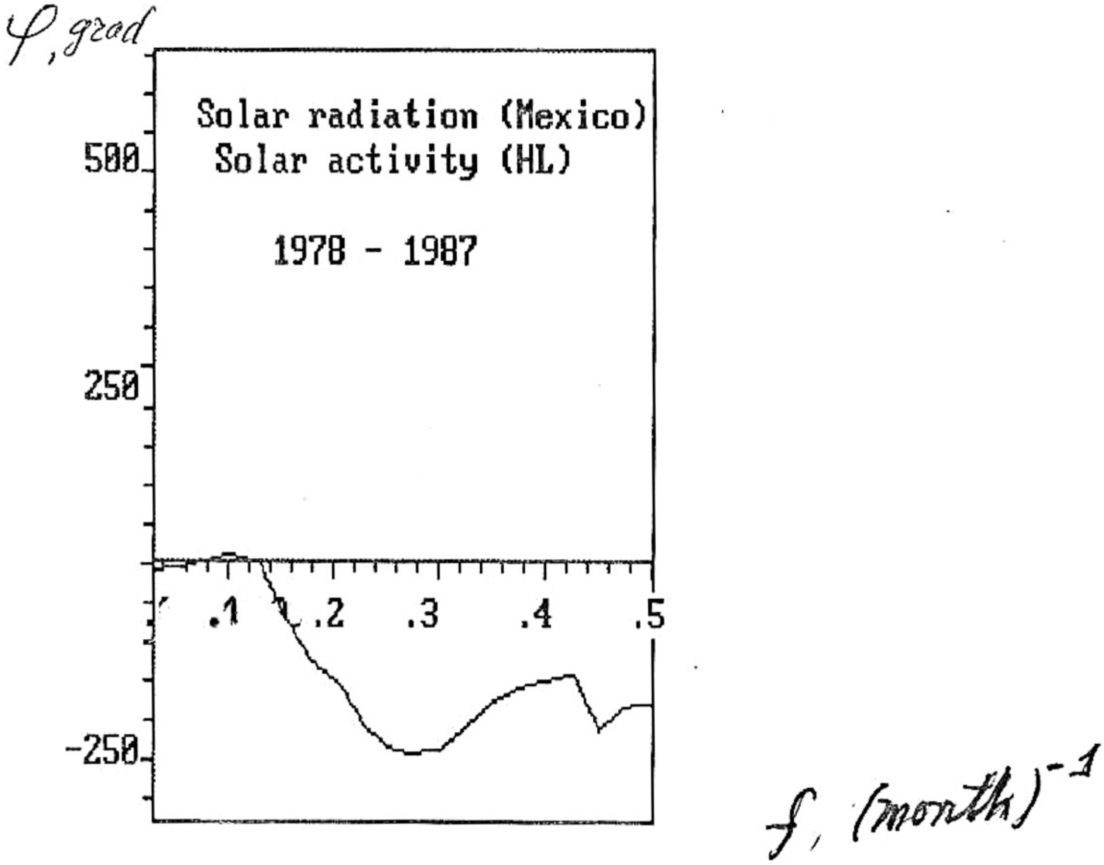
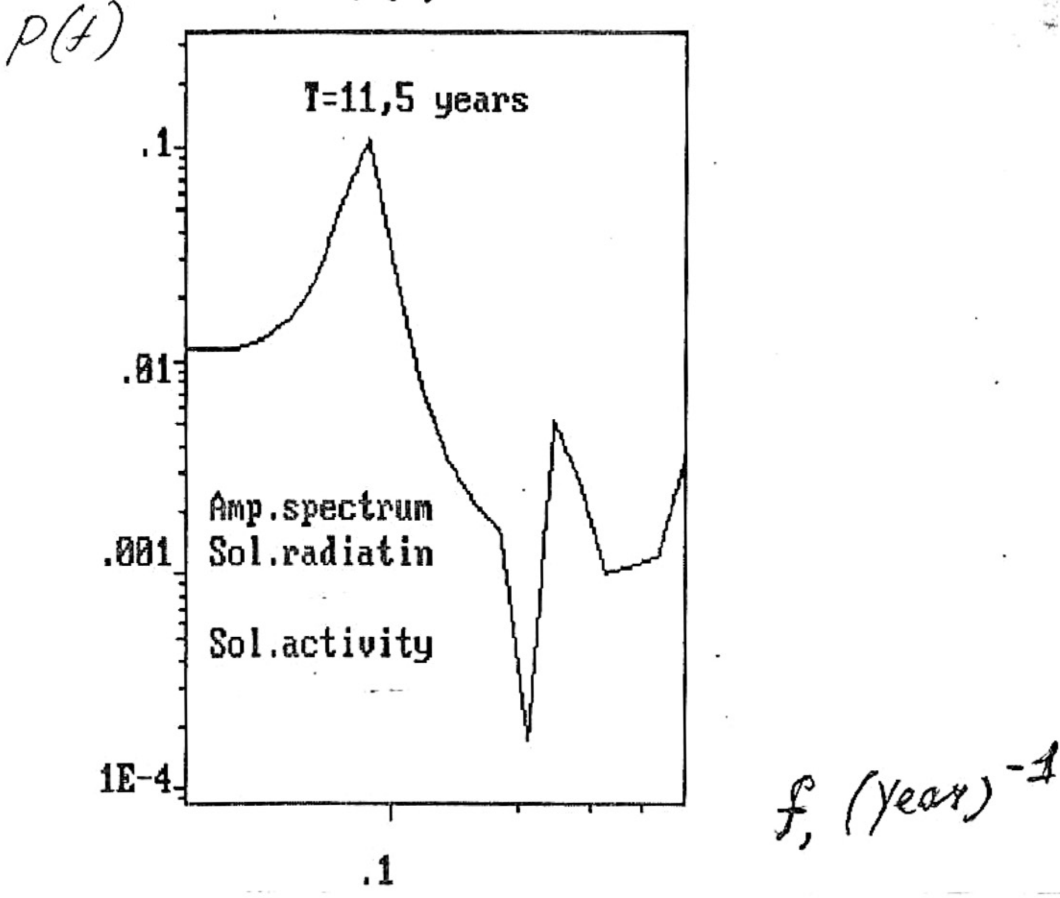
.2
.3
.4
.5
f (month)$^{-1}$

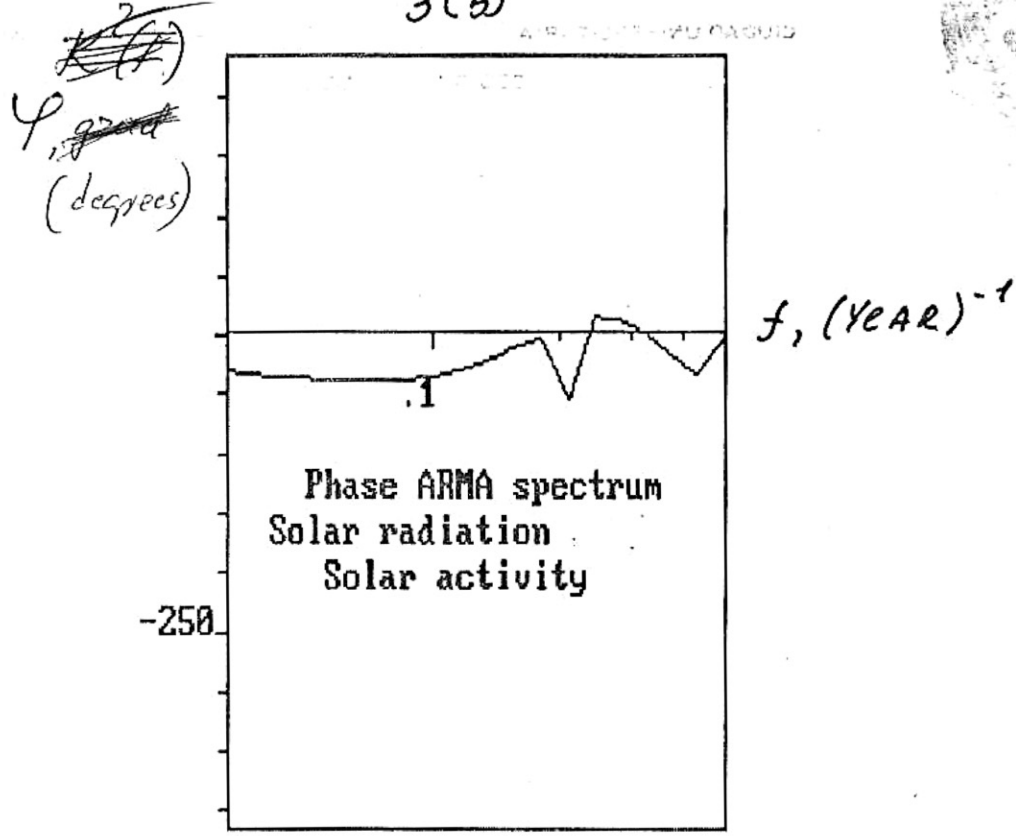
2(c)


φ, grad
500
250
-250
Solar radiation (Mexico)
Solar activity (HL)
1978 - 1987
.1
.2
.3
.4
.5
f, (month)$^{-1}$

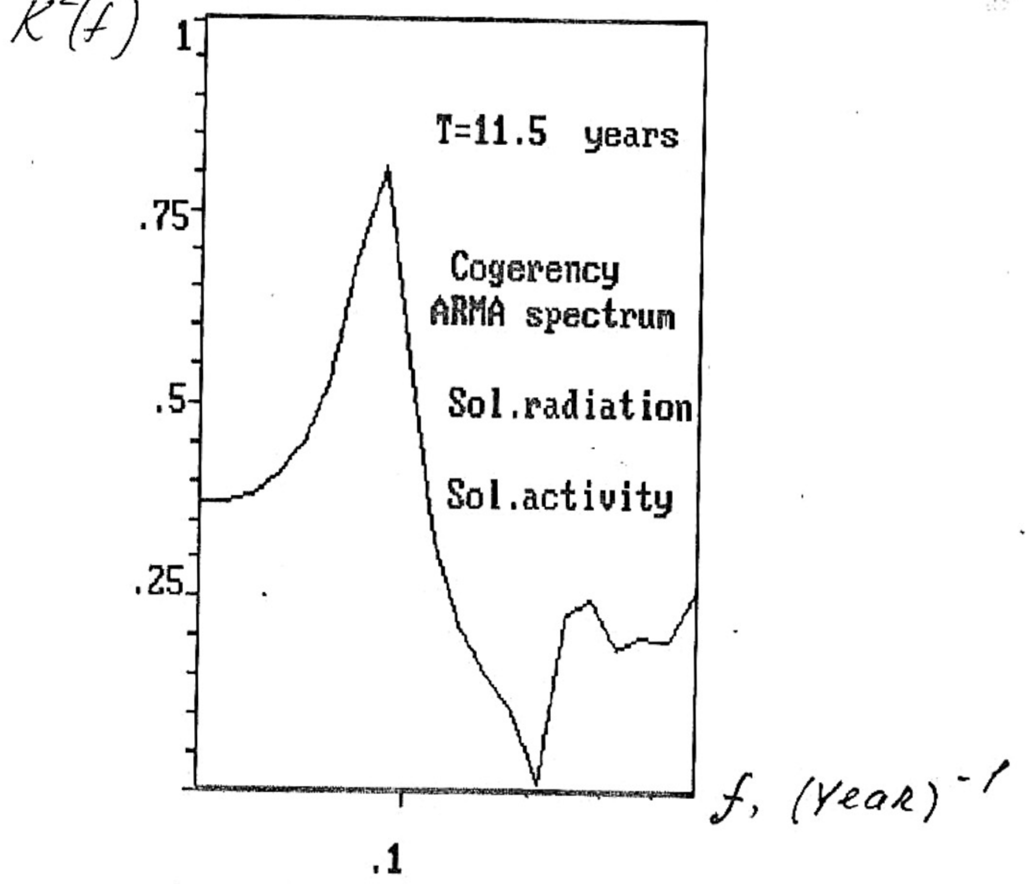
3(a)


P(f)
T=11,5 years
.1
.01
.001
1E-4
Amp.spectrum
Sol.radiatin
Sol.activity
.1
f, (year)$^{-1}$

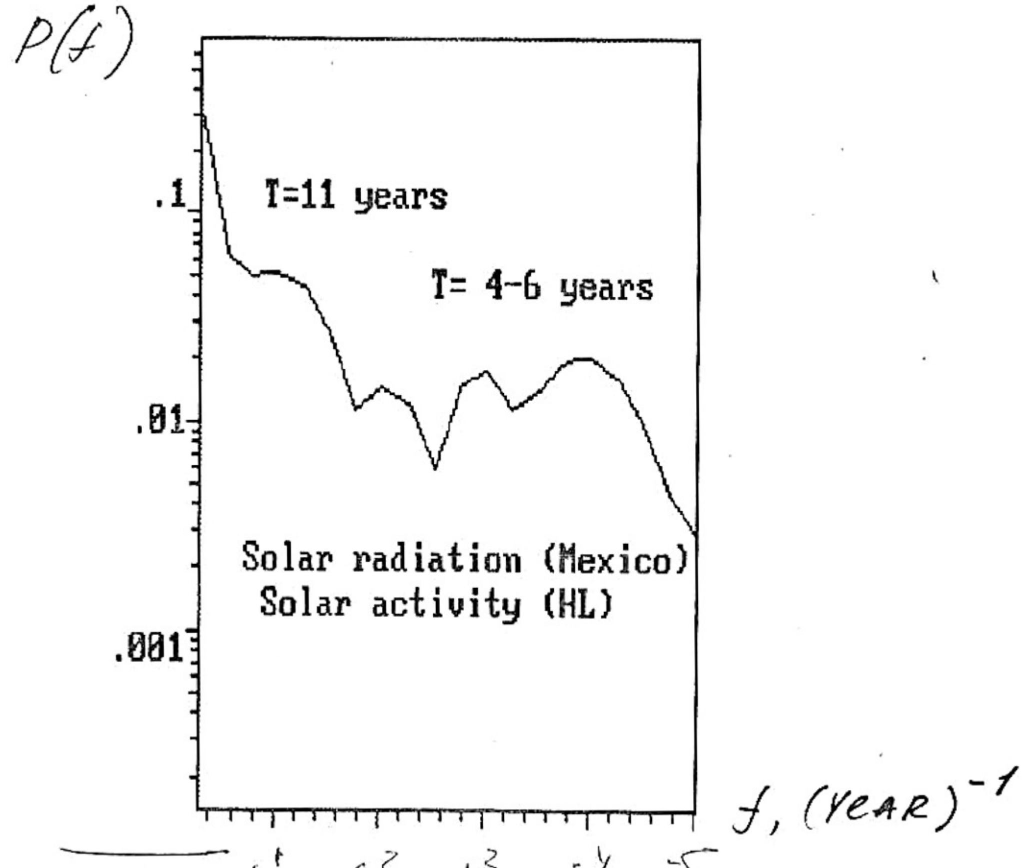
3(b)


~~K²(f)~~
φ, ~~grad~~
(degrees)
f, (YEAR)$^{-1}$
.1
Phase ARMA spectrum
Solar radiation
Solar activity
-250

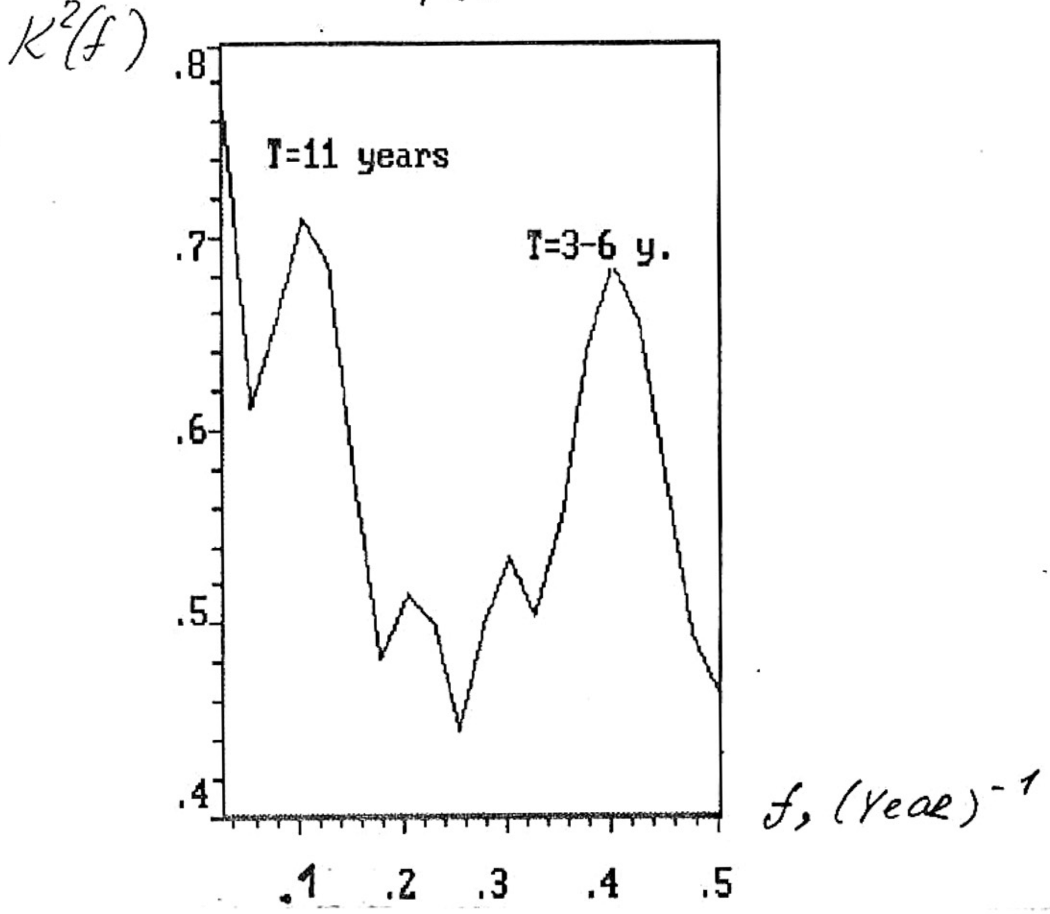
3(c)


$K^2(f)$
1
.75
.5
.25
T=11.5 years
Cogerency
ARMA spectrum
Sol.radiation
Sol.activity
.1
f, (YEAR)$^{-1}$

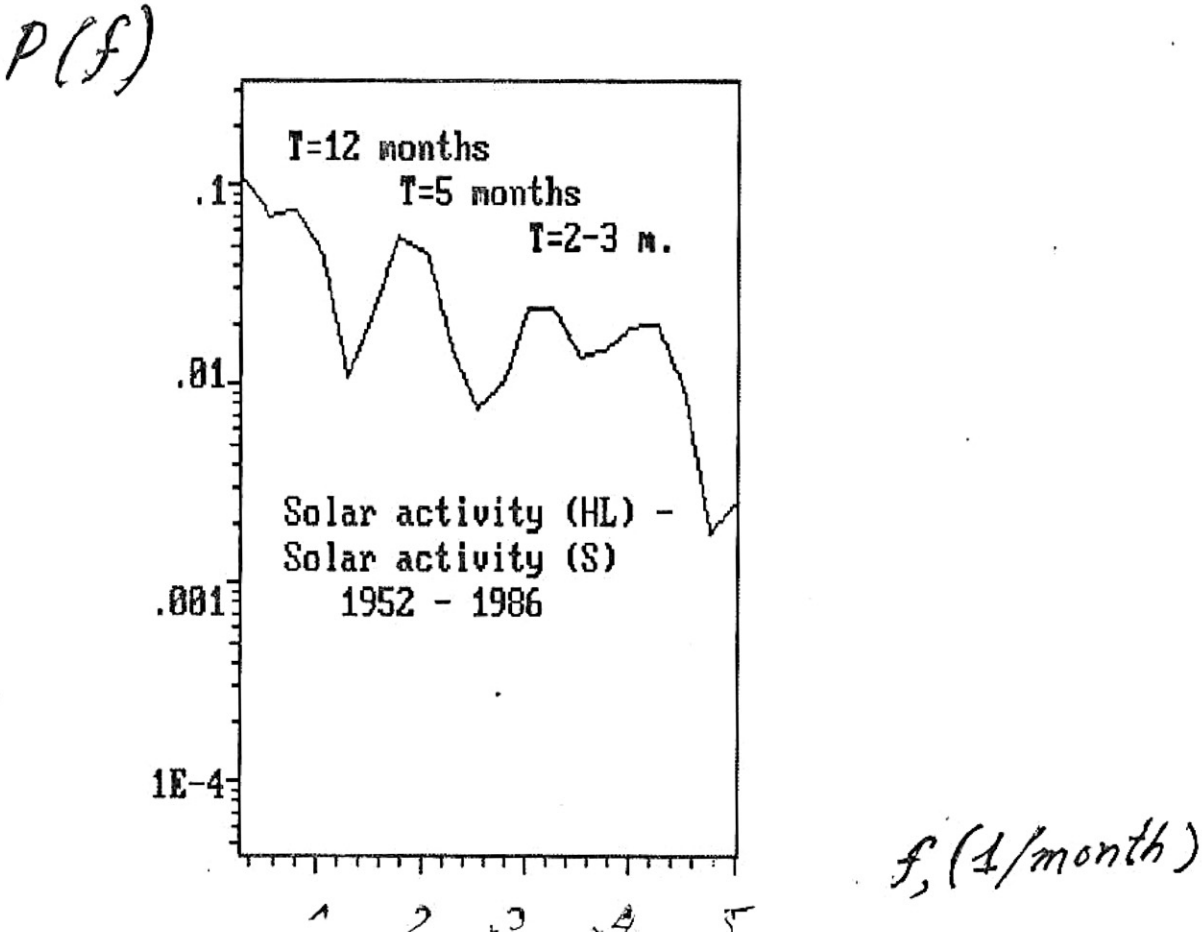
4 (a)


$P(f)$
.1
.01
.001
T=11 years
T= 4-6 years
Solar radiation (Mexico)
Solar activity (HL)
f, (YEAR)$^{-1}$

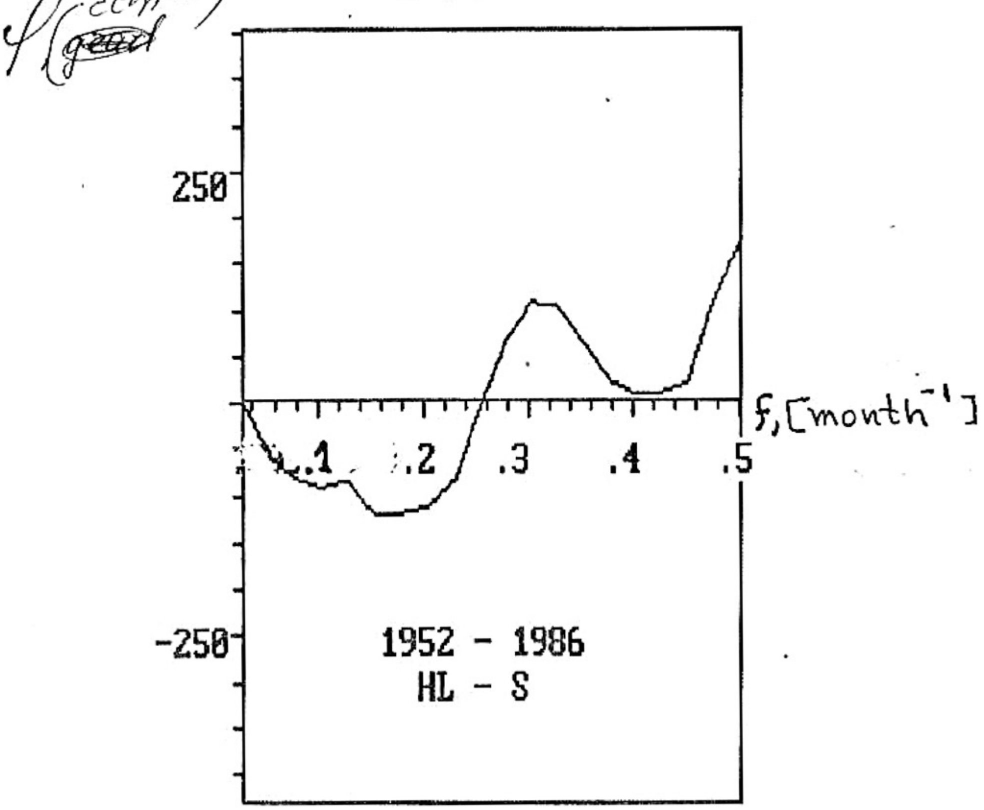
4(b)


$K^2(f)$
.8
.7
.6
.5
.4
T=11 years
T=3-6 y.
.1
.2
.3
.4
.5
f, (year)$^{-1}$

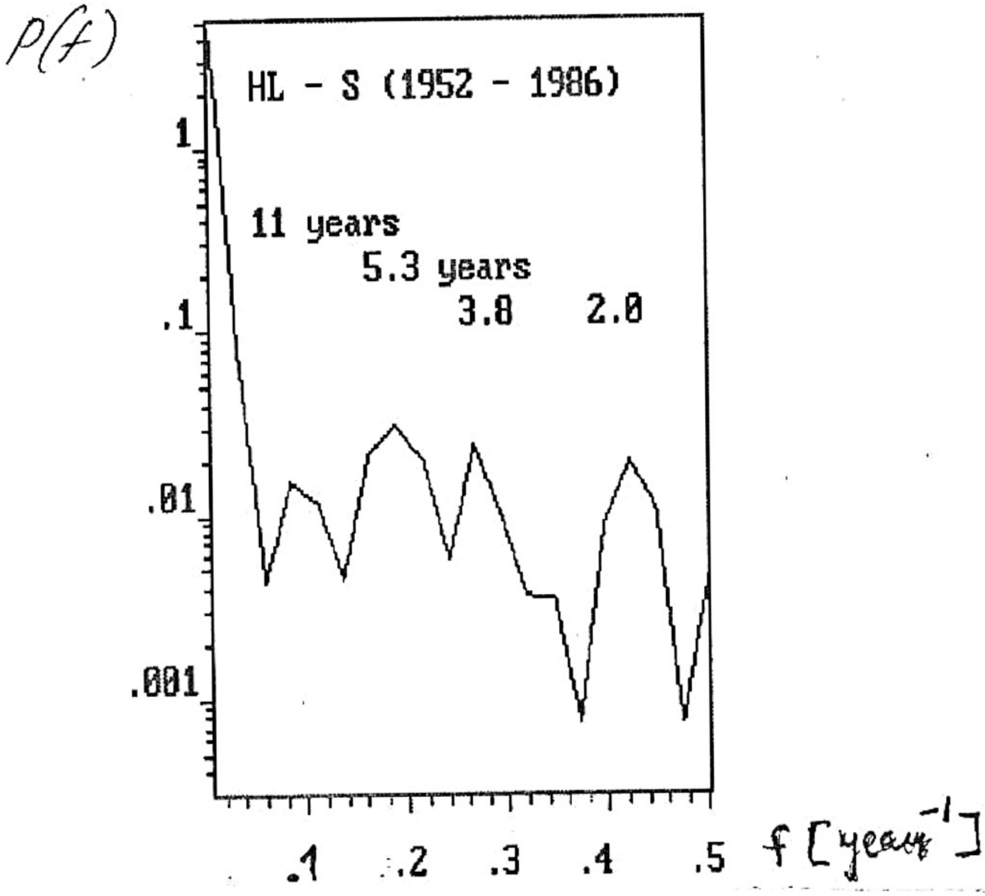
5(a)


P(f)
.1
.01
.001
1E-4
T=12 months
T=5 months
T=2-3 m.
Solar activity (HL) -
Solar activity (S)
1952 - 1986
f, (1/month)

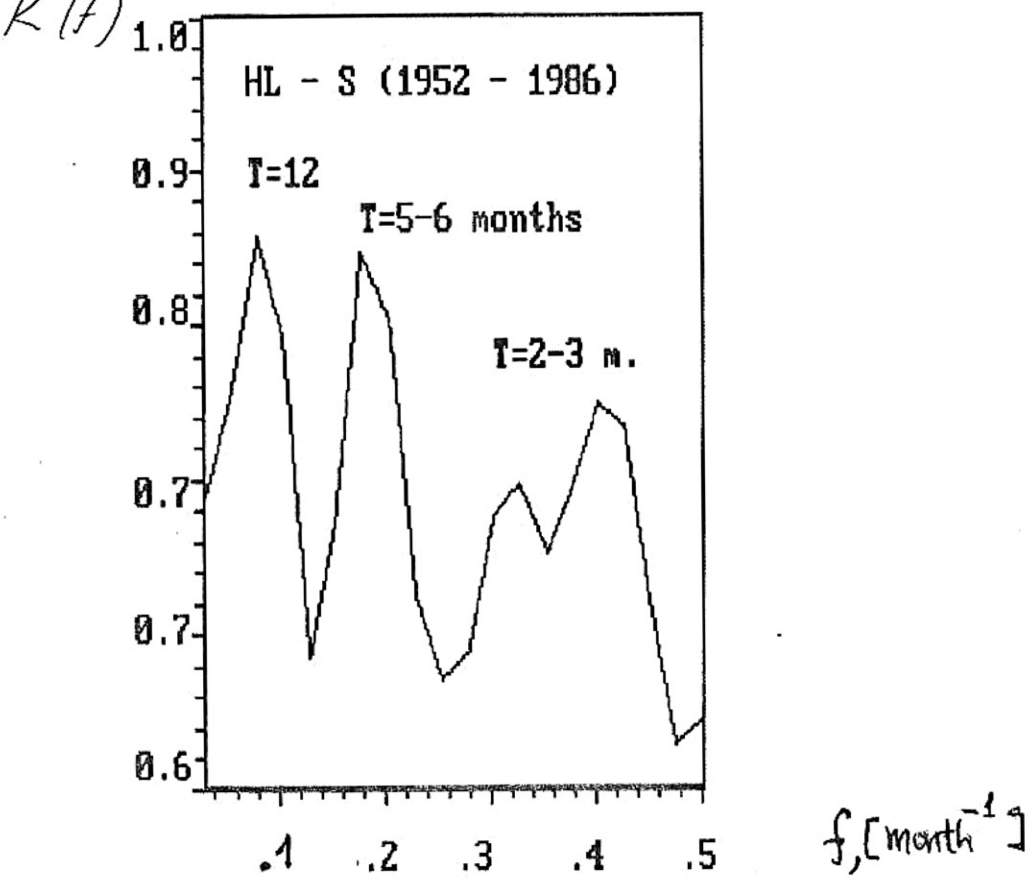
5(b)


φ(~~year~~ degree)
250
-250
f, [month^{-1}]
.1
.2
.3
.4
.5
1952 - 1986
HL - S

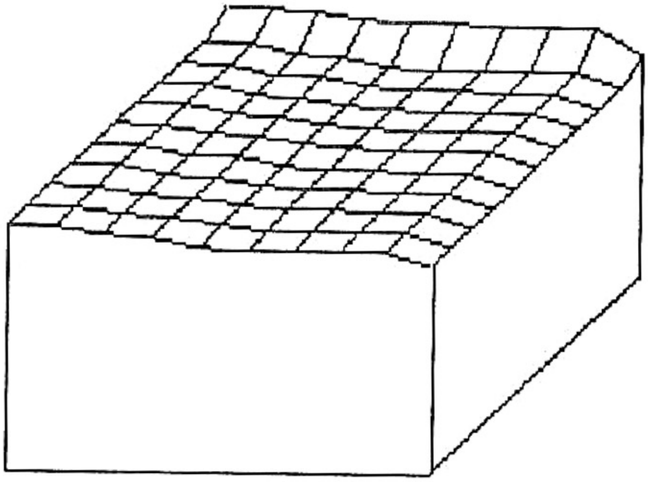
5(c)


p(f)
HL - S (1952 - 1986)
1
.1
.01
.001
11 years
5.3 years
3.8
2.0
.1
.2
.3
.4
.5
f [year^{-1}]

5 (d)

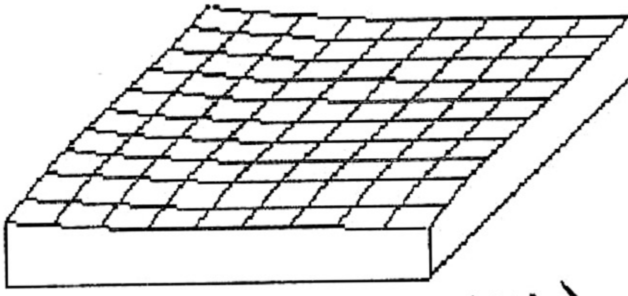


6 (a)



Noise dispersion (**S**)

6 (b)



Noise dispersion Sola (HL)

FIGURE CAPTIONS

Fig. 1.- Amplitude (a-c) and coherence (d-e) spectra of the monthly data series of Vilnius solar radiation and HL-solar activity index. The used ARMA model orders (in parenthesis) are: (a) (1-5,4) and (2-5,3) for the 1955-1965 period, (b) (1-5,3) and (2-5,3) for the 1965-1976 period, (c) (1-4,3) and (2-5,3) for the 1976-1987 period, (d) (1-5, 4) and (2-5,3) for the 1955-1965 period, (e) (1-5,3) and (2-5,3) for the 1965-1976 period.

Fig. 2.- Amplitude (a) and coherence (b) and phase spectra (c) of the monthly data series of Mexico City solar radiation and HL-index, for the 1978-1987 period, with ARMA model orders of (1-8,7) and (2-7,6).

Fig. 3.- Amplitude (a) and coherence (~~b~~c) and phase spectra (~~c~~b) of the annual data series of Vilnius solar radiation and HL-index, for the 1978-1987 period, with ARMA model orders of (1-8,7) and (2-7,6).

Fig. 4.- Amplitude (a) and coherence (b) of the annual data series of Mexico City solar radiation and HL-index, for the 1978-1987 period, with ARMA model orders of (1-8,7) and (2-7,6).

Fig. 5.- Co-spectra of Hl and S solar activity indeces, for monthly (a-b) and annual (c-d) data series, during the 1952-1986 period: (a) amplitude spectrum with ARMA model orders (1-7,8) and (2-9,6), (b) phase spectrum with ARMA model orders (1-7,8) and (2-9,6), (c) amplitude spectrum with ARMA model orders (1-10,8) and (2-10,7), (e) coherence spectrum with ARMA model orders (1-7,8) and (2-9,6).

Fig. 6.- Residual dispersion of the modeled processes (a) S-index and (b) HL-index, by using AR (autoregressive) and MA (mathematical) orders from 1 to 10 in both cases.