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ABSTRACT

An autoregressive model of 7th order is used for the forecast to one year of the level of lakes. By using data from previous years of the levels of the Tchudskoe (Russia) and Patzcuaro (México) lakes, temperature, precipitation and solar activity, the obtained prediction is within an error of 25%.

1. INTRODUCTION

It has been known long ago that the terrestrial climate oscillations have a polycyclic nature, with characteristic periods (in years) such as 2 ~ 3 (the quasi-biennial cycle), 4 ~ 7, 10 ~ 12, 22 and 80 ~ 90. In support to those results Vitisnsky & Olh (1976) have done a spectral analysis of the rate of deuterium to hydrogen content in tree rings during a 1000 years period (the variation of this index is proportional to variations of the environmental temperature) giving a result of 22.36 ± 0.04 years, which is very close to the solar activity cycle of 22 years. The similarity between these two cycles is an argument in favor of the connection between climate and solar activity. Olh

(1973) has shown that the solar cycle of 11 years (basic in the formation and evolution of sunspots) has a weaker impact on meteorological phenomena than the 22 ~ 23 years cycle. It is well known that near the maximum of the 11 years solar cycle, the solar magnetic field varies in direction, and consequently, a drastic change in the solar-terrestrial relations is to be expected. In fact, this is one of the possible explanations of the absence of a well defined 11 years cycle in meteorological processes. In the previously cited work, it is emitted the hypothesis about the existence of geophysical periods of 7 ~ 8, 12 ~ 13, 15, 17 and 33 months. Some of these cycles, and others with shorter periods, might be related with corresponding cycles of the solar activity; almost in all meteorological indices (including the different indexes of the atmospheric circulation) appear cycles with periods of 27, 13 ~ 14, 9 or 6 ~ 7 days (Vitinsky & Olh, 1976; Akasofu & Chapman, 1972). Analogous cycles are observed in the characteristic perturbations of the geomagnetic field.

2. THE AUTO-REGRESSIVE MODEL

A global description of Solar-terrestrial relationships, including the controversial topic of the helioclimatology was previously reviewed in Pérez-Peraza (1990) In particular, the works of Libin & Jaani, (1989); Pérez-Peraza et al., (1996a,b) emphasize the existence of a frequency dependence between the oscillations of the level of two lakes and the environmental temperature in México, Estonia and Russia with solar activity. On this basis, it can be assumed that the parameters describing climatological processes [e.g. the lake level L(t)] may be represented as the sum of the precedent values of lake levels L(t-i), solar activity S(t-j), air temperature T(t-k) and others, i.e. in the form of an auto-regression model:

$$L(t) = \sum_{i=1}^{p} \alpha_i L(t-i) + \sum_{j=1}^{q} \beta_j S(t-j) + \sum_{k=1}^{s} \gamma_k T(t-k) + \xi_t \qquad (1)$$

where L(t) is the predicted value of the lake level, p, q and s are the orders of the models for every of the employed series, These orders determine the retrospective of each process for the prediction of the lake level estimations. Coefficients α, β and γ are the corresponding parameters of the auto-regressive (AR) model. In a previous work (Libin et al., 1992) it has been described the details about the methods for the establishment of the autoregressive model. Here, we are only concerned with the application of the model to the forecast of a particular hydrologic parameter.

3. THE EFFECT OF PRECIPITATIONS

Based on the works of Pérez-Peraza et al. (1996 a,b) we developed an auto-regressive forecast model of 7th order (AR = 7), from equation (1), which produces an error of about 40% in the forecast to one year of the Tchudskoe lake level. In the continuous process of refining our models on basis of the employed parameters (i.e. the level of the lake itself, temperature and solar activity) and in order to reduce the error to about 30%, we have proceeded to include the data of the level of Lake Patzcuaro (México) in the (AR = 7) model. On the basis of the analysis of the oscillation mechanism of the lake levels, it was decided to use the data of measurements of pluvial precipitations in the neighbor regions to Lake Tchudskoe, to investigate in this way the nature of the precipitation variations.

For the analysis of the precipitation series we used data from Lithuania and Estonia, as well as solar activity data (index S indicating the sunspots surface) during the period 1910-1992 [Figs. 1(a), (b)]. The analysis was carried out with the help of the auto- regressive spectral methods (Libin et al., 1992); it was studied the relations between the solar activity and the precipitation oscillations in each one of those regions, and on the other hand, as a control gauge, the relation between the precipitation in both regions. Calculations were done with data of monthly and yearly values, in such a way to obtain estimations of the precipitation oscillations and their intercorrelations in a wide frequency spectrum. The auto-correlation functions and the crossed correlations of the series of monthly values of the precipitation are shown in Fig. 2, where it can be appreciated the high coincidence in the behavior of the precipitation in both regions. The power spectra of each one of the series and their co-spectra are very similar among them [Fig. 3(a)-(d)]. As can be seen from the corresponding curves, they present the same periods. According to these results, the hypothesis of identity of both processes is completely vindicated: the periodicity of ~ 1 year and ~ 3 months in all data is definitively related to solar activity, which is confirmed with the results of the auto-regressive model of Libin (1992) for the spectral analysis between solar activity and the amount of precipitation through all the analyzed period [Fig. 4 (a)] and for the period 1987-1993 in Estonia [Fig. 4(b)] and Lithuania [Fig. 4(c)].

4. RESULTS AND CONCLUSIONS

The results of the auto-regressive analysis of the yearly values of precipitations are shown in Figs 5-9. The calculations of the amplitude spectra (a) and coherence spectra (b) show the presence in the analyzed data of two prominent component, the 11 years and the quasi-biennial waves. The obtained results are in good agreement with those from analogous calculations, for the environmental temperature and the level of lakes (Pérez-Peraza et al., 199a,b) and the wind velocity in energetically active zones (Libin & Jaanni, 1989; Libin et al., 1992), and consequently, they may be placed within the frame of the relations between atmospheric processes and solar activity.

Finally, taking into account the obtained results we proceeded to include in equation (1) an additional term to the AR=7:

$$\sum_{l=1}^{m} \delta_l P(t-l) \tag{2}$$

where $P(t-l)$ is the amount of precipitation in previous years. The inclusion of this additional parameter allows us to reduce the error margin of the forecast model to 25%.

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FIGURE CAPTIONS

Fig. 1.- Monthly data of Estonian and Lithuanian precipitation series and solar activity index S series: (a) for the Jan. 1910 to Aug. 1950 period, (b) for the Sep. 1950 to April 1993 period.

Fig. 2.- The self-correlation functions of Estonian (a) and Lithuanian (b) monthly series and the cross-correlation of both series (c) with shift = 0.

Fig. 3.- The ARMA spectrum of Lithuanian (a) and Estonian (b) series and the amplitude (c) and coherence co-spectra (d) of both monthly data series, with ARMA orders (1-5,5) and (2-5,3) respectively, for the period 1910 - 1933.

Fig. 4.- Amplitude co-spectra of the solar activity and the Estonian and Lithuanian monthly data series for different periods: (a) Lithuanian-S data series with ARMA(1-5,4) and ARMA(2-5,3) model orders for the 1910-1993 period, (b) Estonian-S data series with ARMA(1-5,2) and ARMA(2-5,3) model orders for the 1987-1993 period, (c) Lithuanian-S data series with ARMA(1-5,3) and ARMA (2-5,4) for the period 1987-1993.

Fig. 5.- Amplitudinal (a) and coherence (b) co-spectra of Estonian and S data annual series with ARMA(1-5,3) and ARMA(2-4,1) model

orders, for the 1866-1890 period.

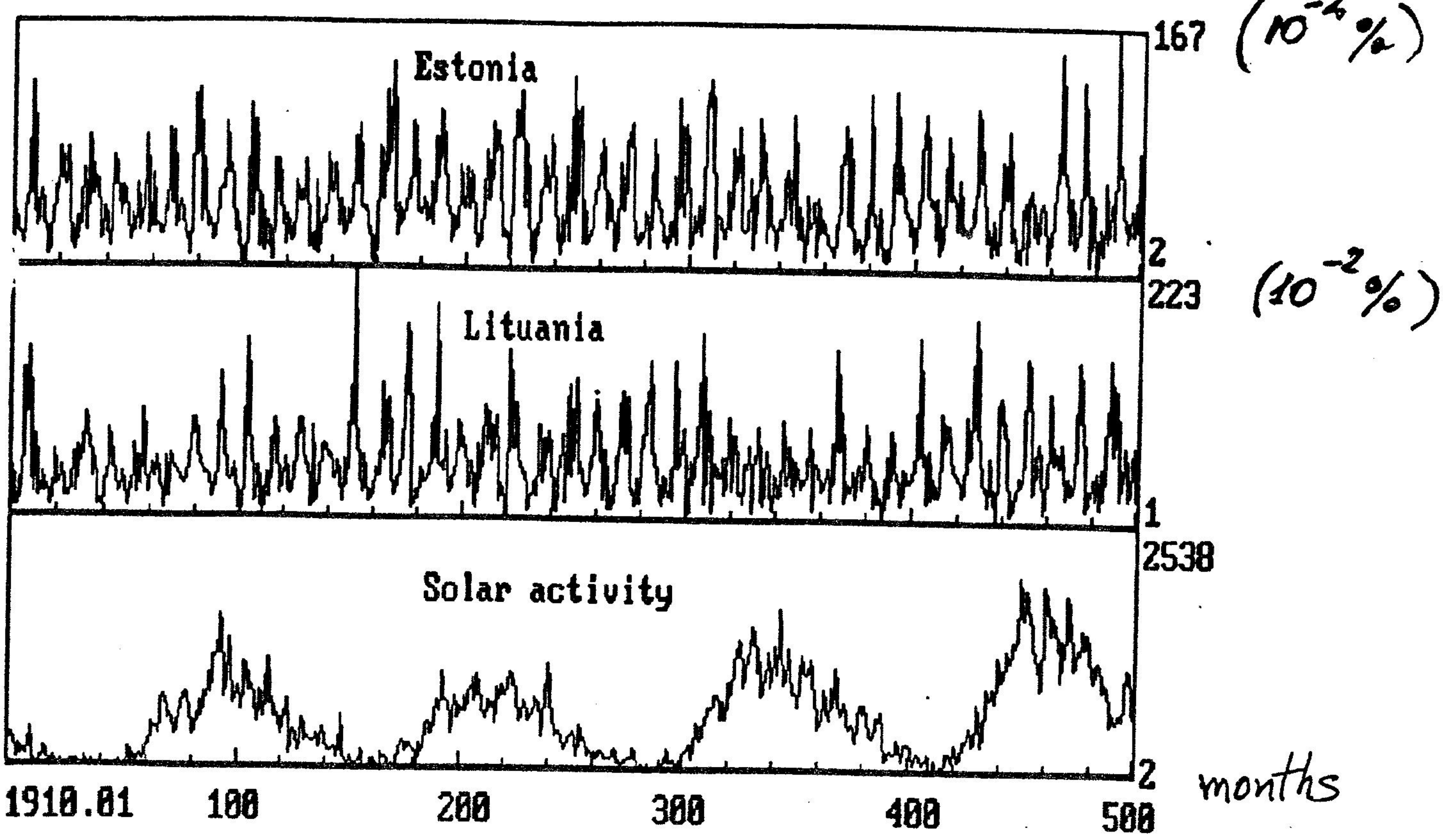
Fig. 6.- Amplitude co-spectra of Estonian and index S annual series with ARMA(1-5,4) and ARMA(2-5,4) model orders, for the 1890-1915 period

Fig. 7.- Amplitude (a) and coherence (b) co-spectra of Estonian precipitation and S annual series with ARMA(1-5,4) and ARMA (2-5,1) model orders, for the 1915-1934 period.

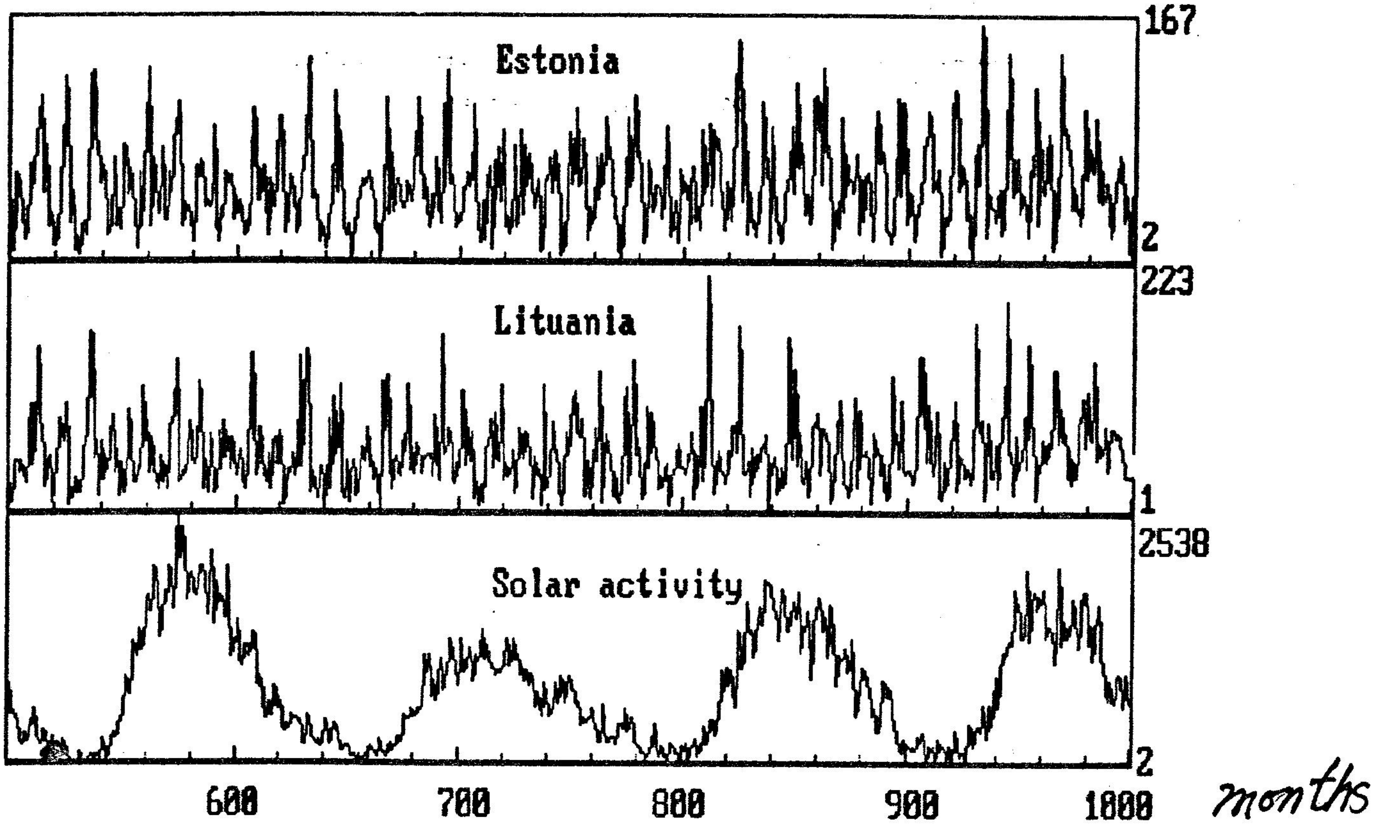
Fig. 8.- Amplitude (a) and coherence (b) co-spectra of Estonian precipitation and S annual series with ARMA(1-5,3) and ARMA(2-5,1) model orders for 1934-1956.

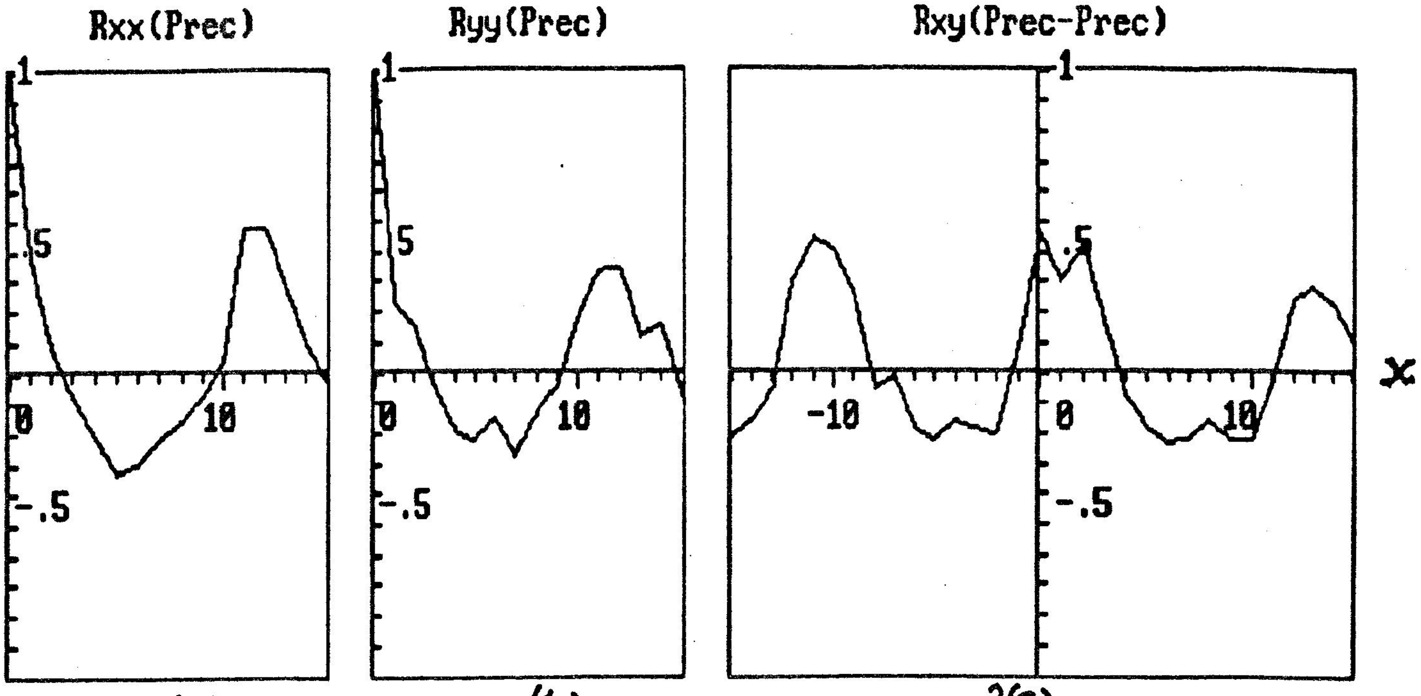
Fig. 9.- Amplitude (a) and coherence (b) co-spectra of Estonian precipitation and S annual series with ARMA(1-5,1) and ARMA(2-5,2) model orders for 1956-1977.

1 (a)


Estonia
Lituania
Solar activity
167
(10^-2 %)
2
223
(10^-2 %)
1
2538
2
months
1910.01
100
200
300
400
500

1(b)


Estonia
Lituania
Solar activity
167
2
223
1
2538
2
600
700
800
900
1000
months



2(a)

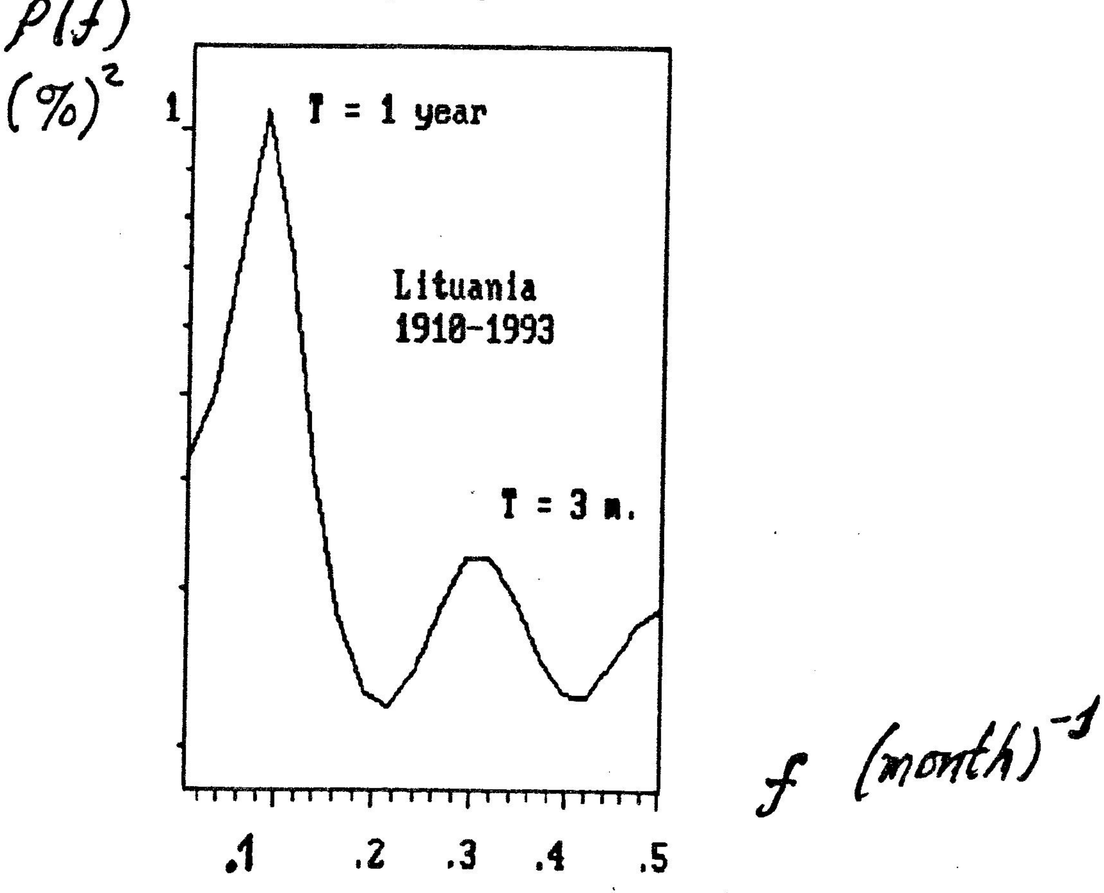
2(b)

2(c)

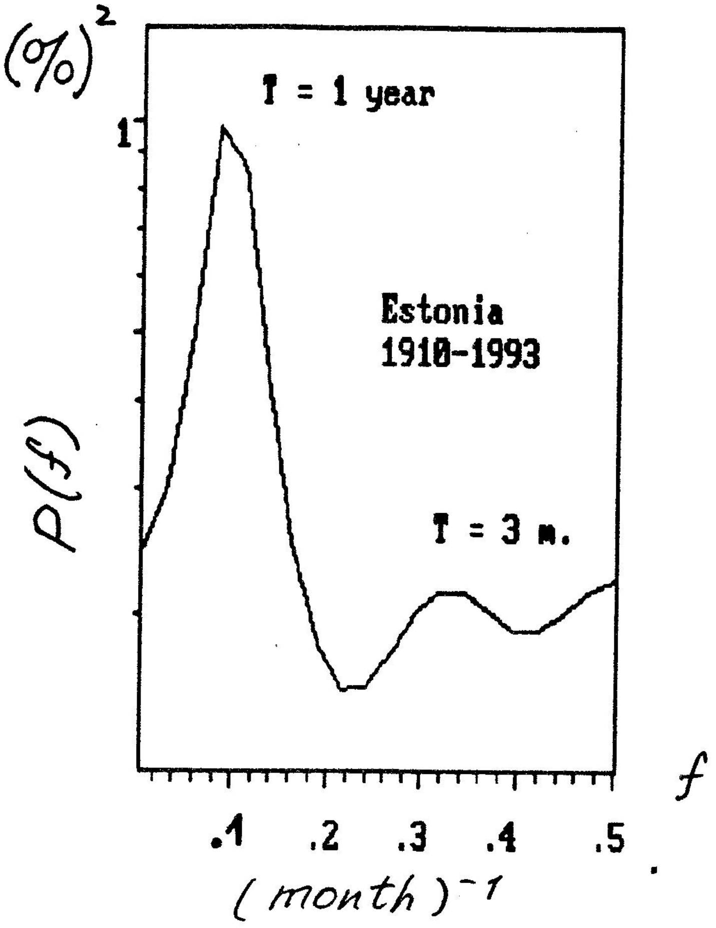
Shift 0

Correlation function

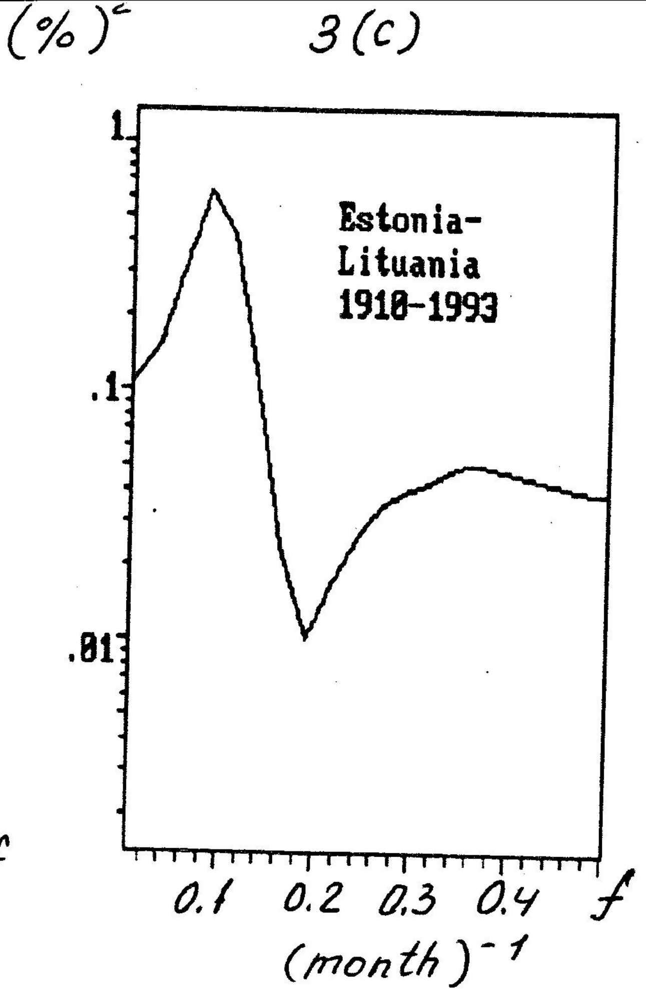
3 (a)



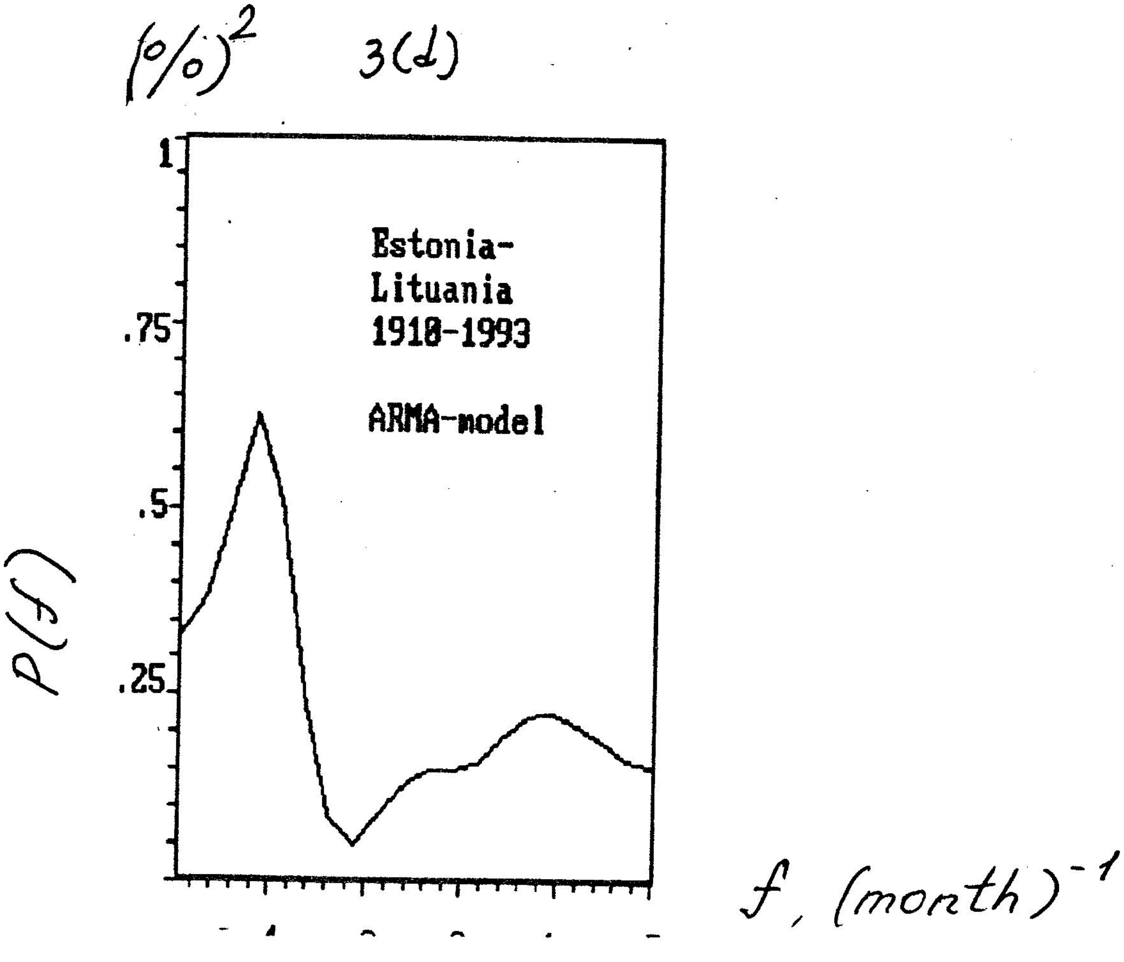
3(b)


(%)^2
T = 1 year
1
Estonia
1910-1993
T = 3 m.
P(f)
f
.1
.2
.3
.4
.5
(month)$^{-1}$

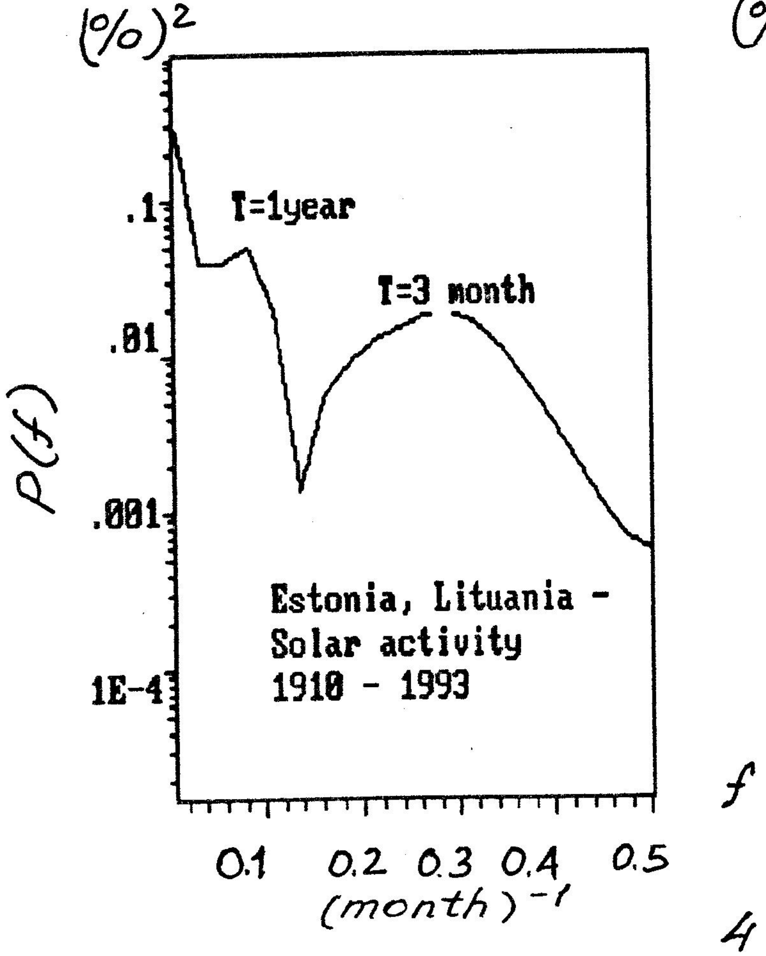
3(c)


(%)^2
1
.1
.01
Estonia-
Lituania
1910-1993
0.1
0.2
0.3
0.4
f
(month)$^{-1}$

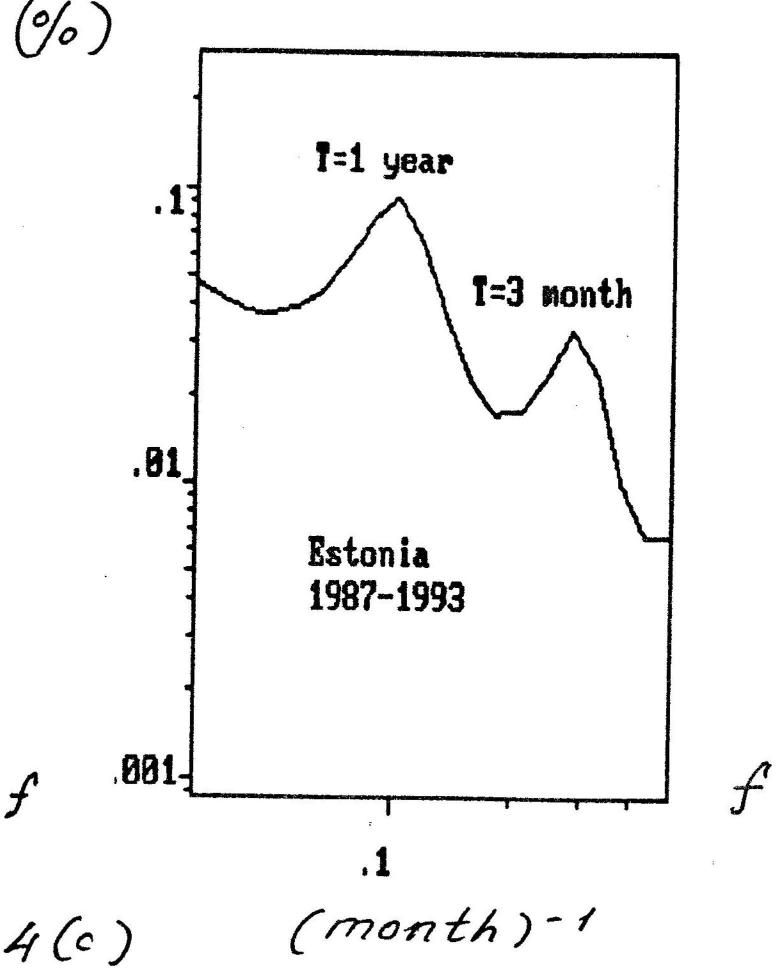
3(d)


(%)^2
1
.75
.5
.25
P(f)
Estonia-
Lituania
1910-1993
ARMA-model
f, (month)$^{-1}$

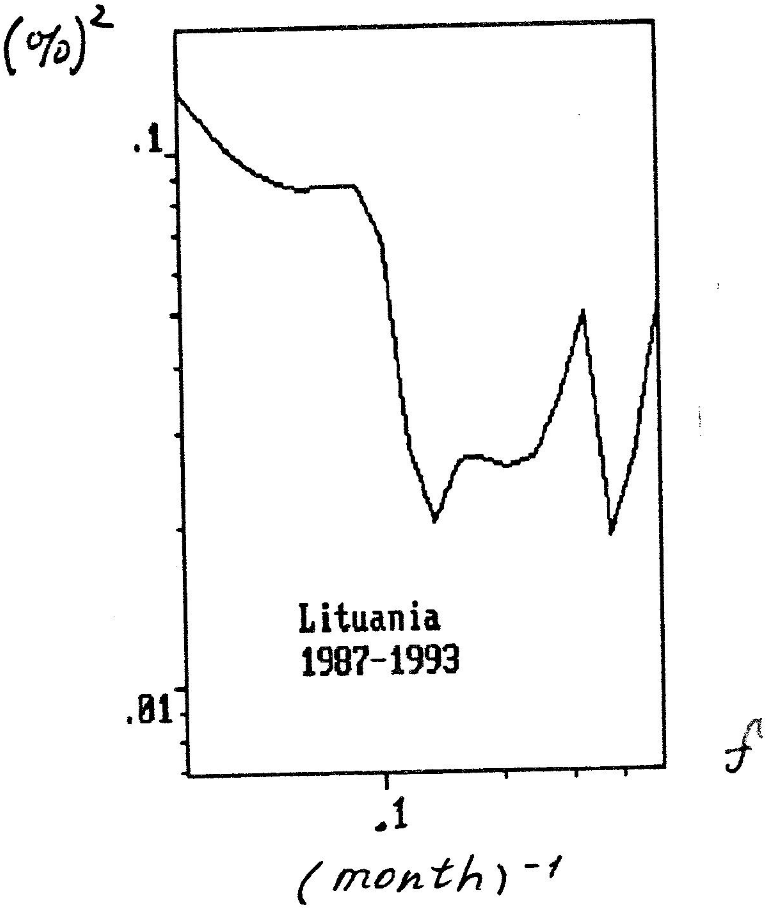
4(a)


(%)^2
P(f)
.1
.01
.001
1E-4
T=1year
T=3 month
Estonia, Lituania -
Solar activity
1910 - 1993
f
0.1
0.2
0.3
0.4
0.5
(month)$^{-1}$

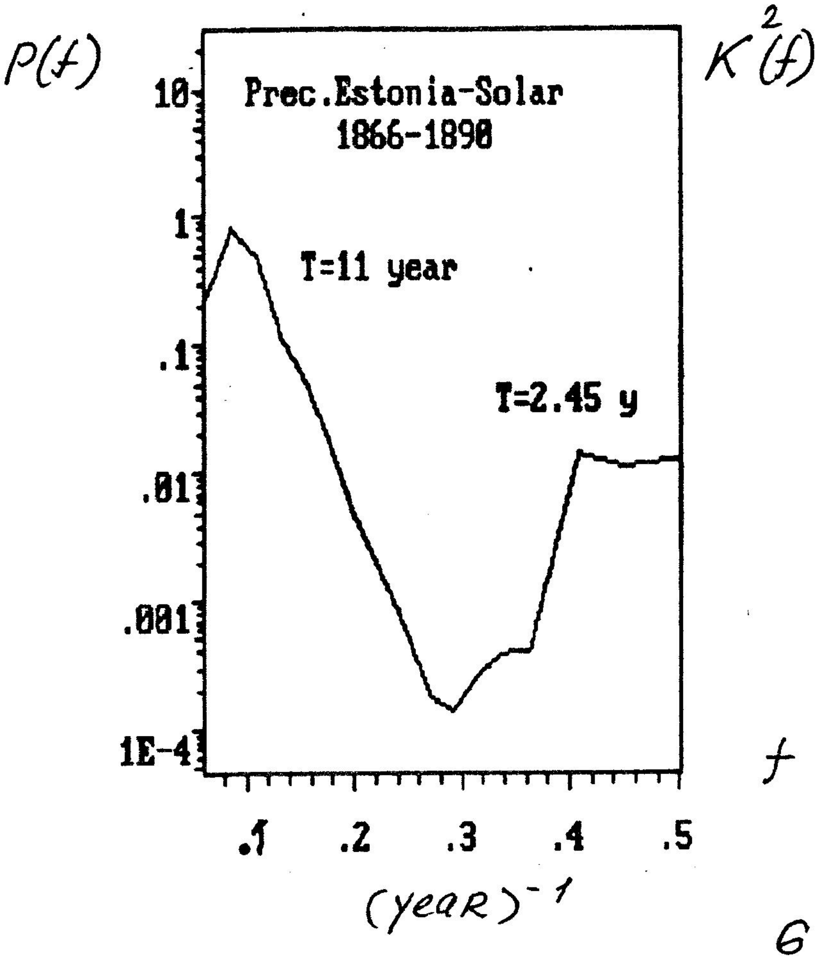
4(b)


(%)^2
.1
.01
.001
T=1 year
T=3 month
Estonia
1987-1993
f
.1
(month)$^{-1}$

4(c)

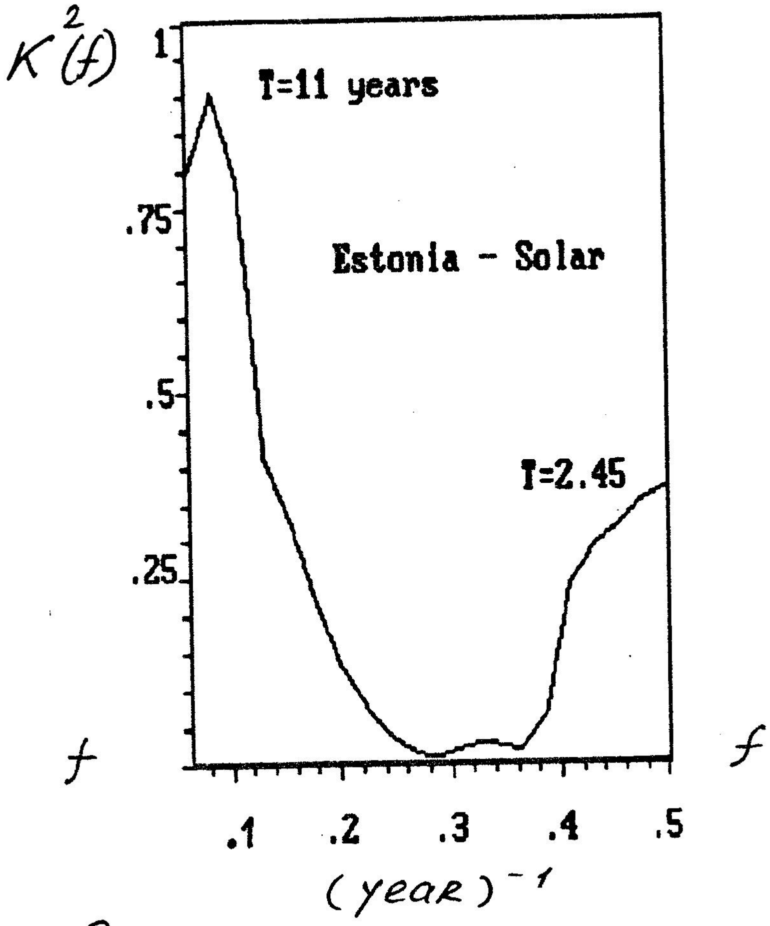

(%)^2
.1
.01
Lituania
1987-1993
f
.1
(month)$^{-1}$

5(a)



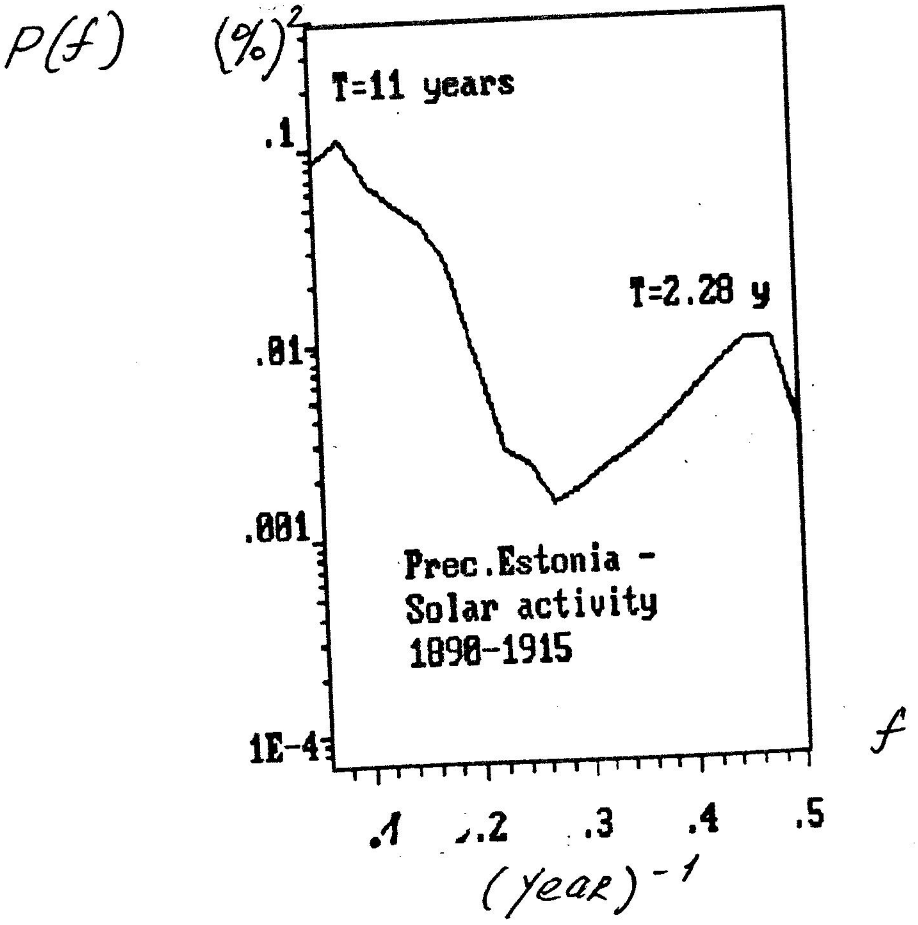
(%)^2
P(f)
Prec.Estonia-Solar
1866-1890
T=11 year
T=2.45 y
10
1
.1
.01
.001
1E-4
f
.1
.2
.3
.4
.5
(year)$^{-1}$

5(b)



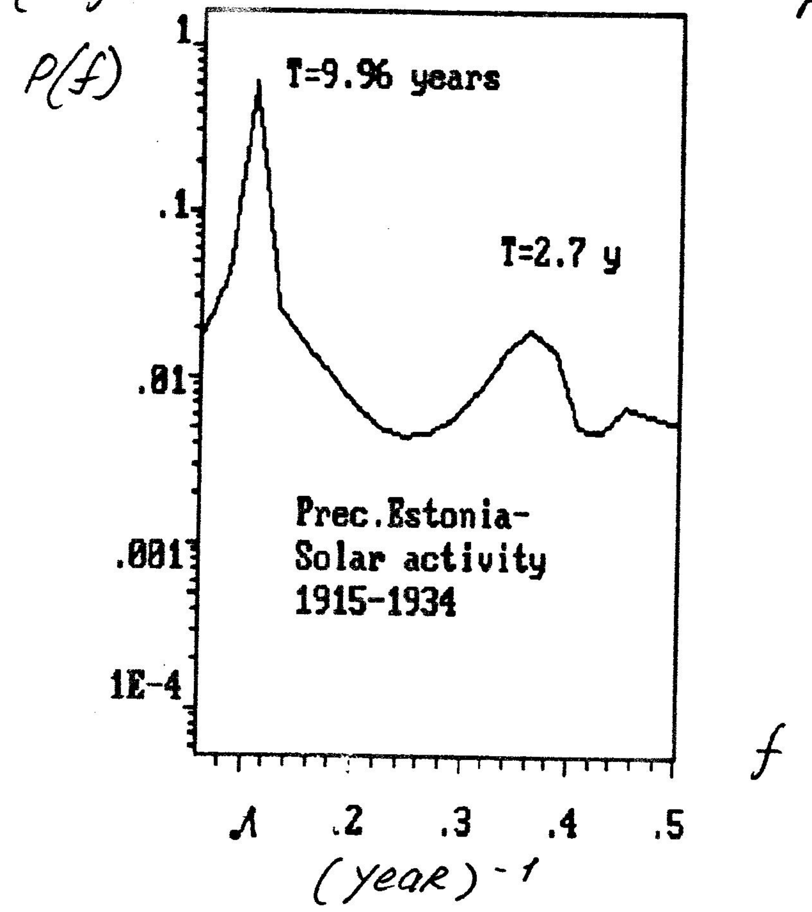
K^2(f)
T=11 years
Estonia - Solar
T=2.45
1
.75
.5
.25
f
.1
.2
.3
.4
.5
(year)$^{-1}$

6

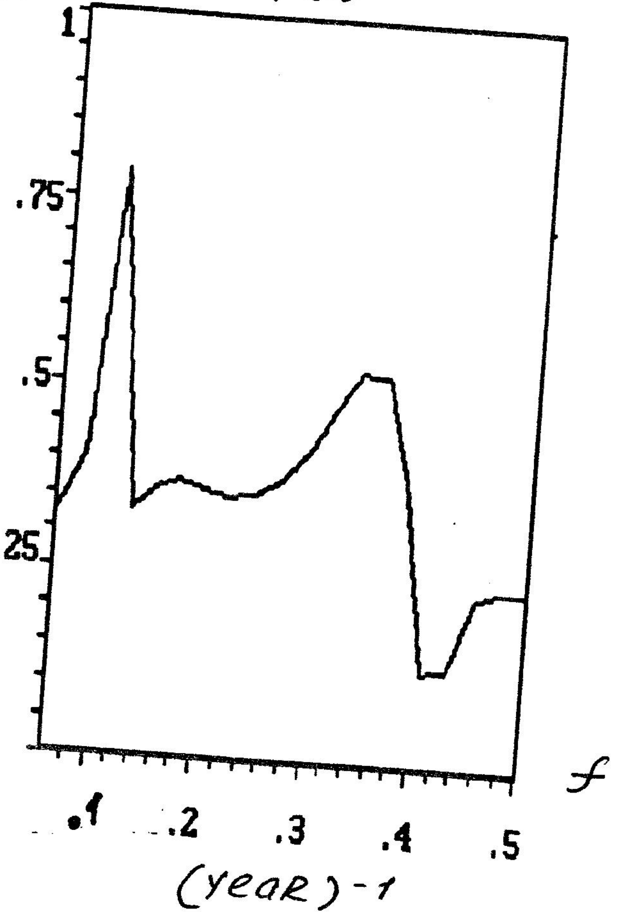


P(f)
(%)^2
T=11 years
T=2.28 y
Prec.Estonia -
Solar activity
1890-1915
.1
.01
.001
1E-4
f
.1
.2
.3
.4
.5
(year)$^{-1}$

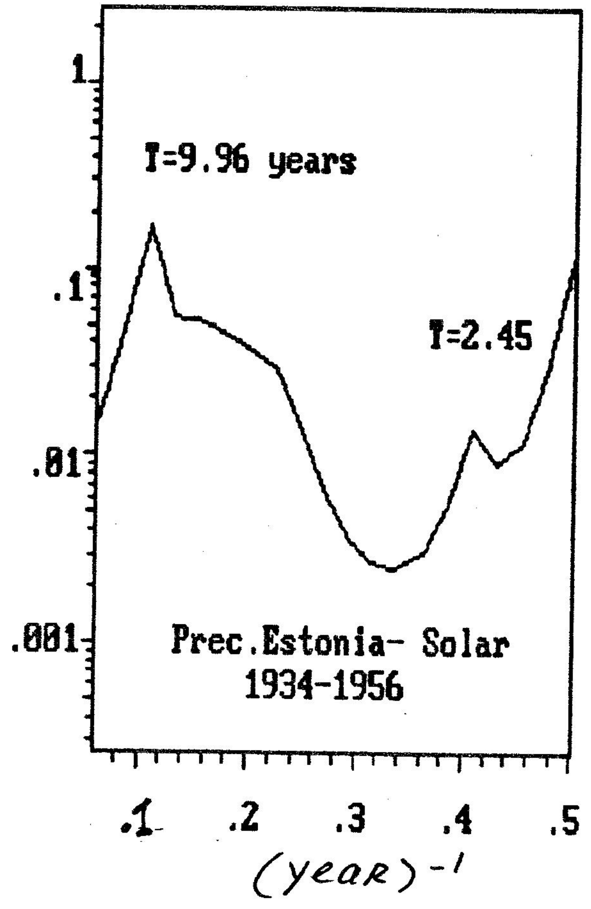
7(a)


(o/o)^2
P(f)
1
.1
.01
.001
1E-4
T=9.96 years
T=2.7 y
Prec.Estonia-
Solar activity
1915-1934
.1
.2
.3
.4
.5
f
(year)^-1

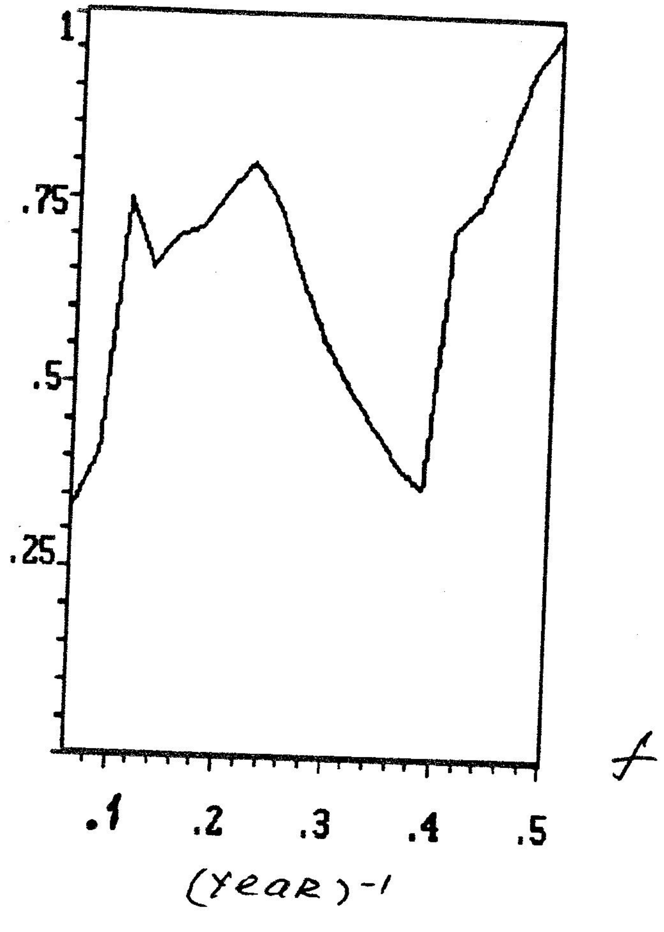
7(b)


K^2(f)
1
.75
.5
.25
.1
.2
.3
.4
.5
f
(year)^-1

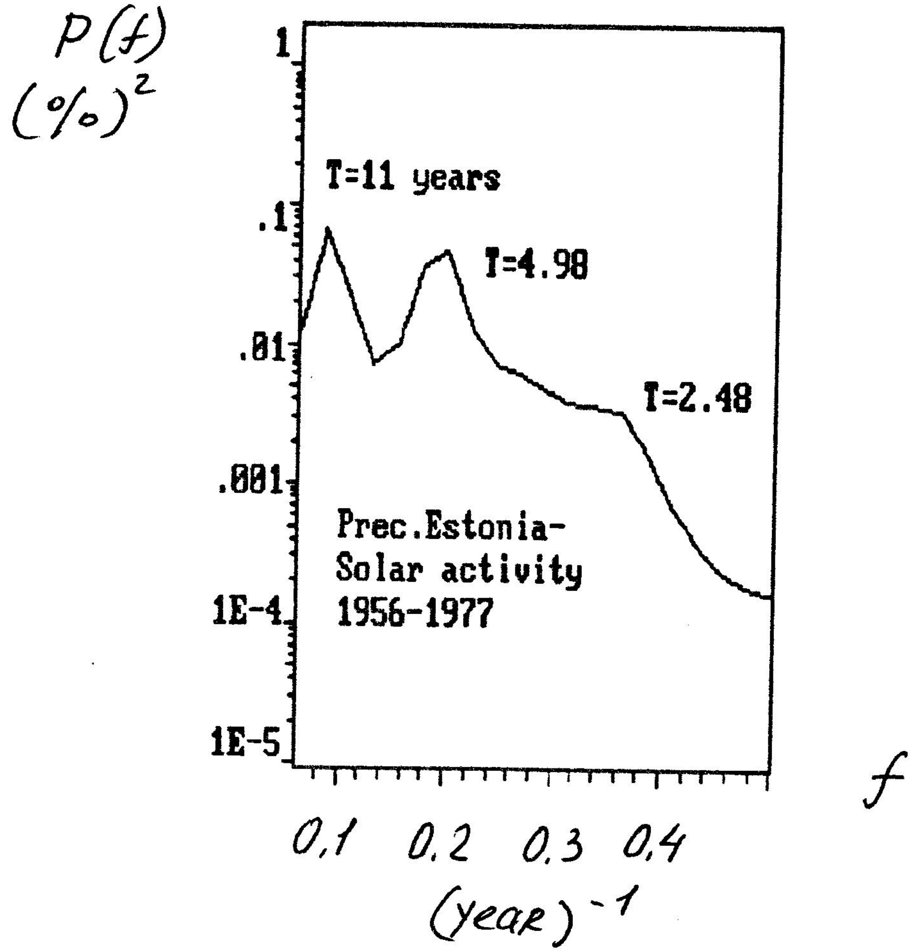
8(a)


P(f), (%)^2
1
.1
.01
.001
T=9.96 years
T=2.45
Prec.Estonia- Solar
1934-1956
.1
.2
.3
.4
.5
(year)^-1

8(b)


K^2(f)
1
.75
.5
.25
.1
.2
.3
.4
.5
f
(year)^-1

9


P(f)
(%)^2
1
.1
.01
.001
1E-4
1E-5
T=11 years
T=4.98
T=2.48
Prec.Estonia-
Solar activity
1956-1977
0,1
0,2
0,3
0,4
f
(year)^-1