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Influence of solar activity on the cyclic variations of precipitation in the Baltic region

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RESUMEN

En el presente trabajo se analiza la influencia de la actividad solar en la precipitación pluvial, a partir de series de tiempo de Lituania (1910-1993) y Estonia (1866-1993) y utilizando datos del área de las manchas solares (1866-1993). Por medio de métodos espectrales y autoregresivos, se obtienen ciclos significativos en los procesos solares y terrestres con períodos de 6 y 12 meses y de 2.5 y 11 años. El análisis de las series anuales de precipitación de Estonia y de la superficie de las manchas solares revela cambios en el ciclo de 11 años, cuyo período se muestra reducido a 9 años entre 1915 y 1956; se observa también una oscilación con período de 5 años en las últimas seis décadas. Los co-espectros de los procesos solares y climáticos coinciden con los de otros trabajos y indican la naturaleza común de todos los ciclos y la influencia de la actividad solar en la variabilidad climática.

PALABRAS CLAVE: relaciones Sol-Tierra, variabilidad climática, precipitación.

ABSTRACT

We discuss the influence of solar activity on pluvial precipitation from time series of Lithuania (1910-1993) and Estonia (1866-1993), and using data of sunspots areas (1866-1993). By means of autoregressive and spectral methods for monthly and annual series we obtain significant cycles for solar and terrestrial processes with periods of 6 and 12 months, and 2.5 and 11 years. The analysis of the annual series of Estonian precipitation and sunspot areas features changes in the 11 year cycle, reduced to 9 years between 1915 and 1956; also, a significant oscillation with a period of 5 years in the last 6 decades was determined. The co-spectra of the solar and climatic processes agree with other works and support the common nature of all cycles and the influence of the solar activity on the climate variability.

KEY WORDS: Solar-terrestrial relationships, climate variability, precipitation.

INTRODUCTION

Terrestrial climate oscillations have a cyclic nature with characteristic periods, such as 2~3 (quasi-biennial), 4~7, 10~12, 22 and 80~90 years (Vitinsky and Olh, 1973). This suggests an important relationship between solar and terrestrial processes. Dicke (1978) used spectral analysis of the rate of deuterium to hydrogen content in tree rings over a period of 1000 years; he found a cycle of 22.36 ± 0.04 years, close to the solar magnetic cycle of 22 years. According to Shiegel (1974), deuterium variations in the rings of *Picea* trees from southern Germany are correlated with annual air temperature, which agrees with the low levels of deuterium in tree rings corresponding to periods of minimum solar activity, e.g. during 1450-1550 and 1645-1715 (Eddy, 1976; Libby, 1976; Akhmetiereev and Dergachev, 1980).

Olh (1973) has shown that the 11-year solar cycle has some influence on meteorological phenomena, though weaker than the 22-year cycle. Near the maximum of the 11-year cycle, the solar magnetic field reverses its polarity: this is one of the possible explanations for the absence of a well defined 11-year cycle in meteorological processes. Olh (1973) also mentions geophysical periods of 7 ~ 8, 12 ~ 13, 15, 17 and 33 months. Some of these cycles, and cycles with shorter periods, could be correlated with corresponding cycles of solar activity. Nearly all meteorological indices feature cycles with periods of 27, 13 ~ 15, 9 or 6 ~ 7 days. Similar cycles are found in the perturbations of the geomagnetic field (Akasofu and Chapman, 1972; Vitinsky and Olh, 1976; Ptitsyna *et al*., 1980, Pérez-Peraza *et al*., 1998).

Solar-terrestrial relationships have become a popular research topic for at least three decades: within the frame of space physics they have been reviewed in Pérez-Peraza (1990), and in the frame of climate variability and related fields in Pérez-Peraza *et al*. (1997). Libin *et al*. (1996 a,b,c) report results on the influence of solar activity on meteorological parameters, including solar radiation fluxes and surface air temperature. Libin and Jaani (1989), and Pérez-Peraza *et al*. (1995, 1996) suggest a frequency dependence between heliophysical and hydrological processes.

METHODOLOGY AND DATA

Spectral methods to be used in this paper are described in Kay and Marpl (1981) and details may be found in Gulinsky *et al*.(1992), and Pérez-Peraza *et al*. (1997). The techniques for estimating spectra include several stages: a preliminary analysis, the filtration if necessary of high and low frequencies, the exclusion of regular trends, the calculation of correlation and spectral functions, and the calculation of cross correlation and cross spectral functions.

In practice, spectral methods are applicable to stationary processes, whereas the solar and geophysical processes are non-stationary. When the processes have brief stationary segments, nearby frequencies cannot be distinguished, yet this is one of the key problems as each frequency may be related to a physical mechanism of interaction between cosmophysical and geophysical processes. Our data processing system (Gulinsky *et al*., 1992) uses autoregressive (AR) models with time-dependent coefficients. Thus:

$$\boldsymbol{P}_{t+1} = \sum_{i=0}^{p} \alpha_i(t)\boldsymbol{P}_{t-i}, \qquad t = 0,1,\ldots$$

$$\boldsymbol{S}_{t+1} = \sum_{j=0}^{q} \beta_j(t)\boldsymbol{S}_{t-j}, \qquad t = 0,1,\ldots \tag{1}$$

where $\boldsymbol{P}_t$ is the precipitation and $\boldsymbol{S}_t$ is the sunspot area index at time *t*. Each time- dependent coefficient is expanded as a series of a complete set of functions $\{\varphi_k(t)\}$:

$$\alpha_j(t) = \sum_{k=1}^{M} c_{jk}\varphi_k(t), \qquad \text{for } \mathrm{j} = 1,2,\ldots q, \text{ and } t = 0,1,\ldots$$

$$\beta_j(t) = \sum_{k=1}^{N} c_{jk}\varphi_k(t), \qquad \text{for } \mathrm{j} = 1,2,\ldots p, \text{ and } t = 0,1,\ldots \tag{2}$$

Here, α_j and β_j are the auto-regression (AR) model coefficients, *p* or *q* is the order of the model for each series and $n=M+N$ is the number of equations**.** A given model is denoted as AR (*p*,*q*). The AR modeled series are investigated for spectral signals at 90% of confidence.

We use data from two Baltic republics, Estonia and Lithuania, which belong to the same climatic province. There are no major topographic irregularities. Both republics border on the Baltic sea to the west and on a chain of mountains to the east. The climate is cold and humid, with temperatures ranging from –5° to –10° C in winter and from 10° to 20° C in summer. Normal water vapor tension is 2 hP in January and 15 hP in June. The precipitation is about 1000 mm/year, being divided into winter and summer rainy seasons. The two countries are relatively close to each other (about 500 km) and are small (about 50 000 km^2 each). All synoptic phenomena of regional scale affect both regions simultaneously. Precipitation data were obtained for the vicinity of Lake Chudskoye, one of the largest in Europe, located between Russia and the Baltic republics. Geographic, climatic, and meteorological characteristics of this zone were described in Pérez-Peraza *et al*. (1995).

The relations between the time series of solar activity (***S)*** and the precipitation in each country are studied. As a control, the relationship between the precipitation in both countries was also studied. Monthly and annual fluctuations around their corresponding means were used in such a way as to obtain estimations of the precipitation spectral signals (oscillations) over a wide frequency range. We use precipitation series of Lithuania (1910-1993) and Estonia (1866-1993), and series of sunspot areas (1866-1993). They are shown in Figure 1. The use of sunspot area ***S*** as a solar activity index was discussed in Pérez-Peraza *et al*., (1997).

RESULTS AND DISCUSSION

Figure 2 shows the autocorrelation functions and the cross-correlations of the monthly precipitation series. The oscillatory character of both, the Lithuanian and Estonian precipitation series is shown in Figure 3, where it can be seen that the behavior of the power spectra and the corresponding co-spectra is quite similar: as expected the correlation and the spectral analysis yield the same basic significant frequencies near 3 and 12 months periods, respectively, reflecting the seasonal and annual variability of precipitation. The power co-spectra of Lithuanian and Estonian precipitation to solar activity for 1910-1993 (Figure 4a), of Estonian precipitation to solar activity for 1987-1993 (Figure 4b), and of Lithuanian precipitation to solar activity for 1987-1993 (Figure 4c) show also the same 3-month and 12-month oscillations. Thus, it can be inferred that these oscillations are also characteristic of solar activity processes, represented here by the sunspot area index ***S***.

The analysis of the annual series of Estonian precipitation and sunspot areas reveals two significant oscillations with periods close to 11 years and 2.5 years, with some variations for different intervals. However, for 1866-1890 the power and coherence co-spectra of the Estonian precipitation and solar activity feature only one clear significant os-

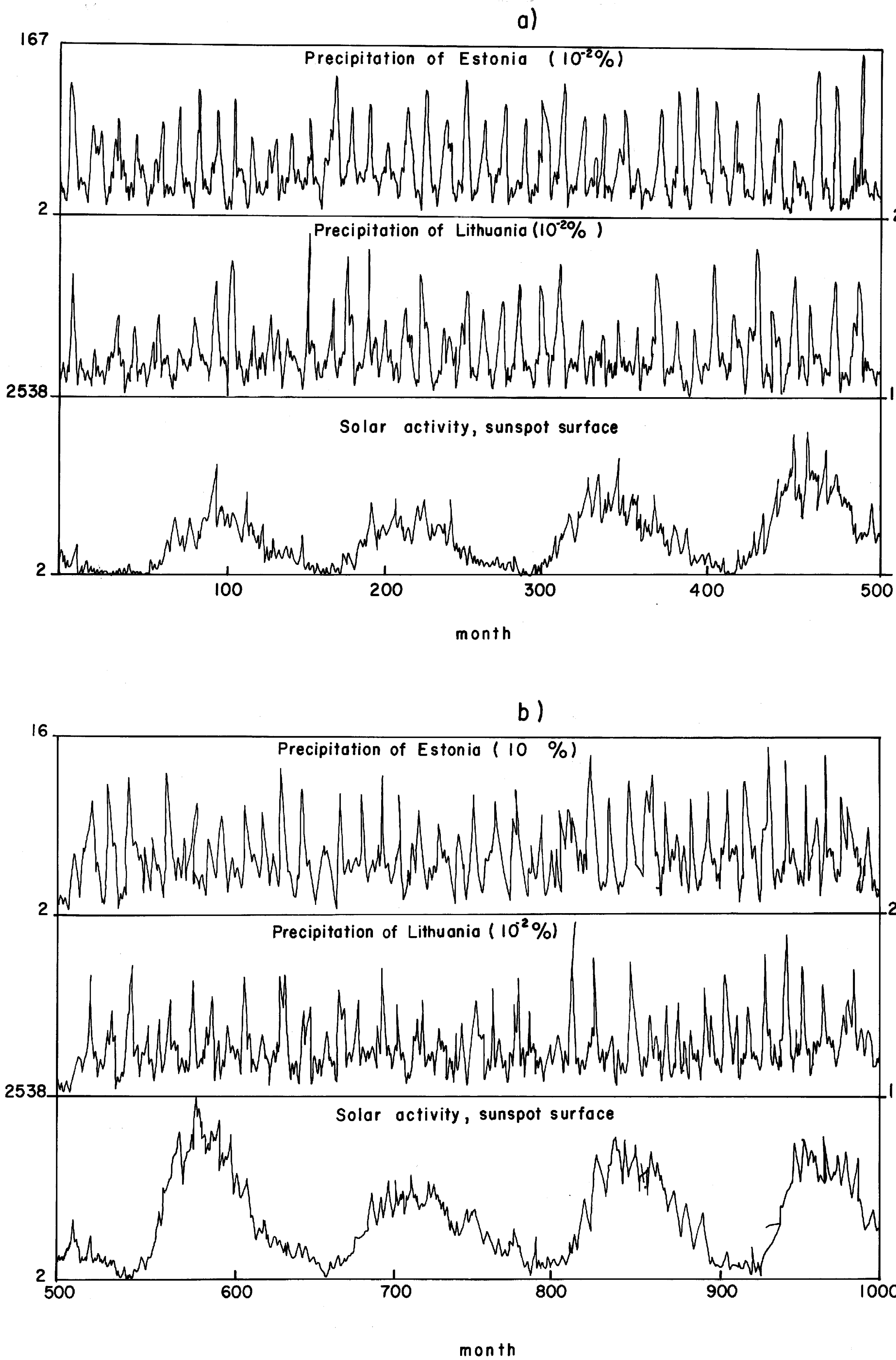

Fig. 1. Monthly data of Estonian and Lithuanian precipitation series and solar activity index S series: (a) for Jan.1910 to Aug.1950, (b) for Sept.1950 to April 1993.

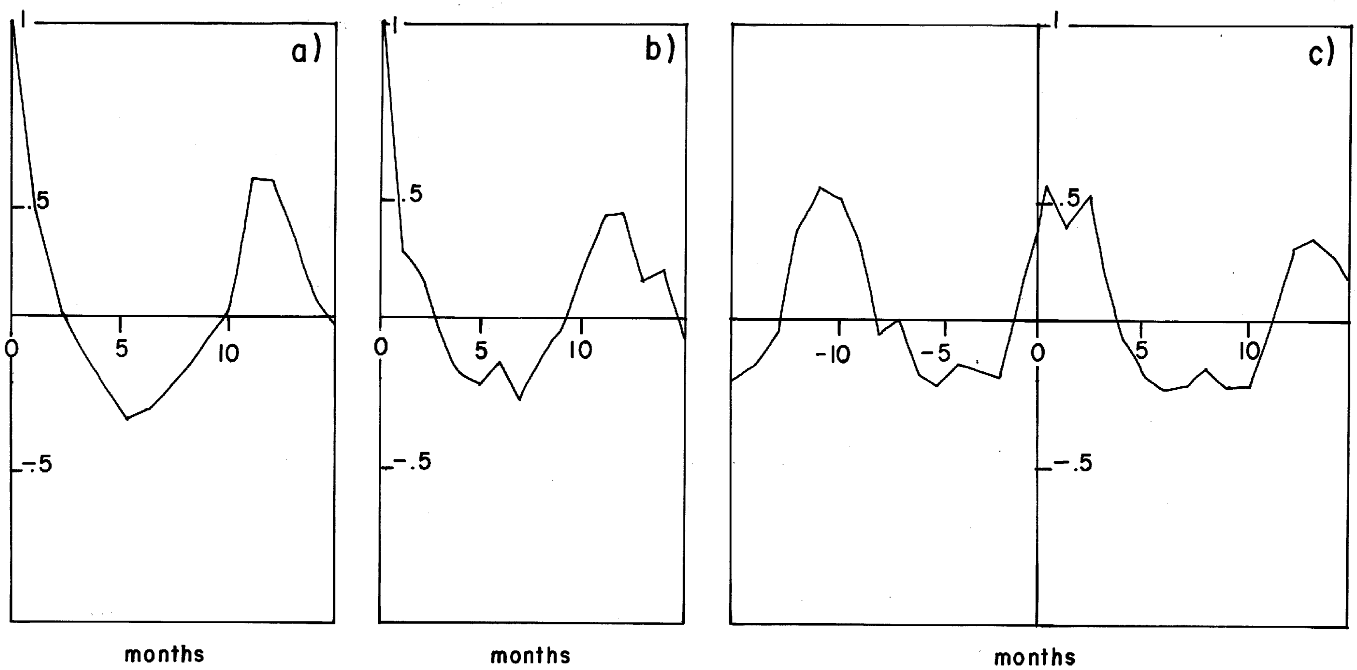

Fig. 2. The auto-correlation functions of (a) Estonian, and (b) Lithuanian monthly series, and (c) the cross-correlation function of both series (with no shift).

cillation with a period of 11 years (Figure 5a,b), for 1890-1815, the joint analysis shows the same 11-year cycle plus a second oscillation with period of 2.3 years. During 1915-1934 the period of the first oscillation is of 9 years and that of the second one is of 2.7 years (Figure 7a,b). For 1934-1956 the first basic oscillation in the power co-spectrum has a period of 9.1 years and the second has a period of 2.4 years (Figure 8a), while the coherence co-spectrum shows three peaks with periods of 8.3-, 4.5- and 2.4 years. In Figure 9, the power co-spectrum of the joint Estonian precipitation to sunspot area series for 1956-1977 reveals again three basic oscillations, with 11-year, 5-year and 2.5-year period. This spectral analysis of the joint Estonian precipitation – solar activity processes suggests that its oscillatory character is also a function of time, i.e. is non-stationary.

CONCLUSIONS

Spectral and autoregressive analysis does not assume *a priori* the stationary character of the processes. The results of the analysis of the joint precipitation-solar activity processes, i.e. the obtained co-spectra, suggest an effect of solar cycles in the variability of precipitation due to the systematic presence of cycles around 11 years. We find signals in the precipitation series with periods of 3 months, 12 months, 2.5 years, and 11 years. The first mentioned two periods are the natural seasonal and annual cycles of the terrestrial climate respectively. However, the spectral analysis of the joint processes suggests that these cycles are also characteristic of solar activity phenomena as they appear as significant oscillations in the corresponding co-spectra. Also, the results of the longer series, the Estonian precipitation and the sunspot area index show that the periods and the number of significant oscillations are not strictly constant, but suffer changes in different epochs. The cycle of 11 years appears reduced to 9 years during 1915-1956, and a third oscillation with a period close to 5 years (probably related to the 5-year oscillation of the ENSO phenomenon, due to some similarities between phase and amplitude of the oscillations) appears in 1934-1977. This sharp time dependence requires a dynamical analysis as followed in this paper, i.e. the analysis of segments of the series, that had been previously proved to be adequate in order to obtain the oscillatory characteristics, for different epochs, in the analysis of the precipitation variability in northwest Mexico (Salinas *et al.* 1990).

The results are in good agreement with our previous studies concerning correlations of solar activity with other climatic elements: solar radiation fluxes at surface level (Libin *et al.*, 1996a), surface air temperature (Libin *et al.*, 1996b), lake levels (Libin and Jaani, 1989; Pérez-Peraza *et al.*, 1995, Libin *et al*. 1996d), and wind velocity in energetically active zones of the ocean (Gulinsky *et al.*, 1992). The results confirm the presence of cycles with periods of 2~3 (quasi-biennial), 4~7, and 10~12 years, as suggested by Vitinsky and Olh (1973) as expression of a relationship between solar and terrestrial processes. In conclusion, the influence of solar activity on the amount of precipitation in the studied region

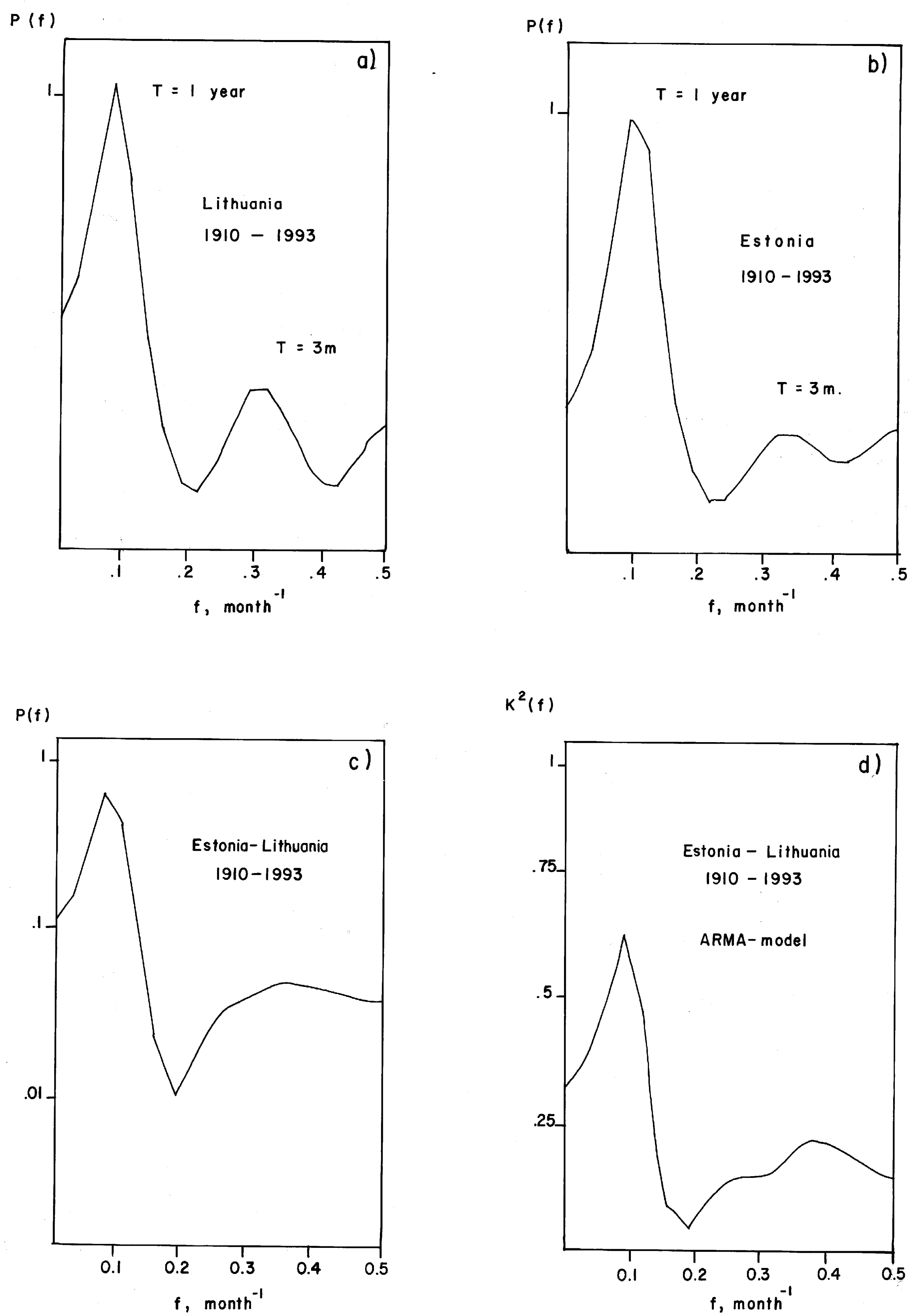

Fig. 3. AR spectra of (a) Lithuanian, and (b) Estonian monthly precipitation series, and their (c) amplitude and (d) coherence co-spectra for 1910-1993. AR models (1,5) and (2,5), respectively.

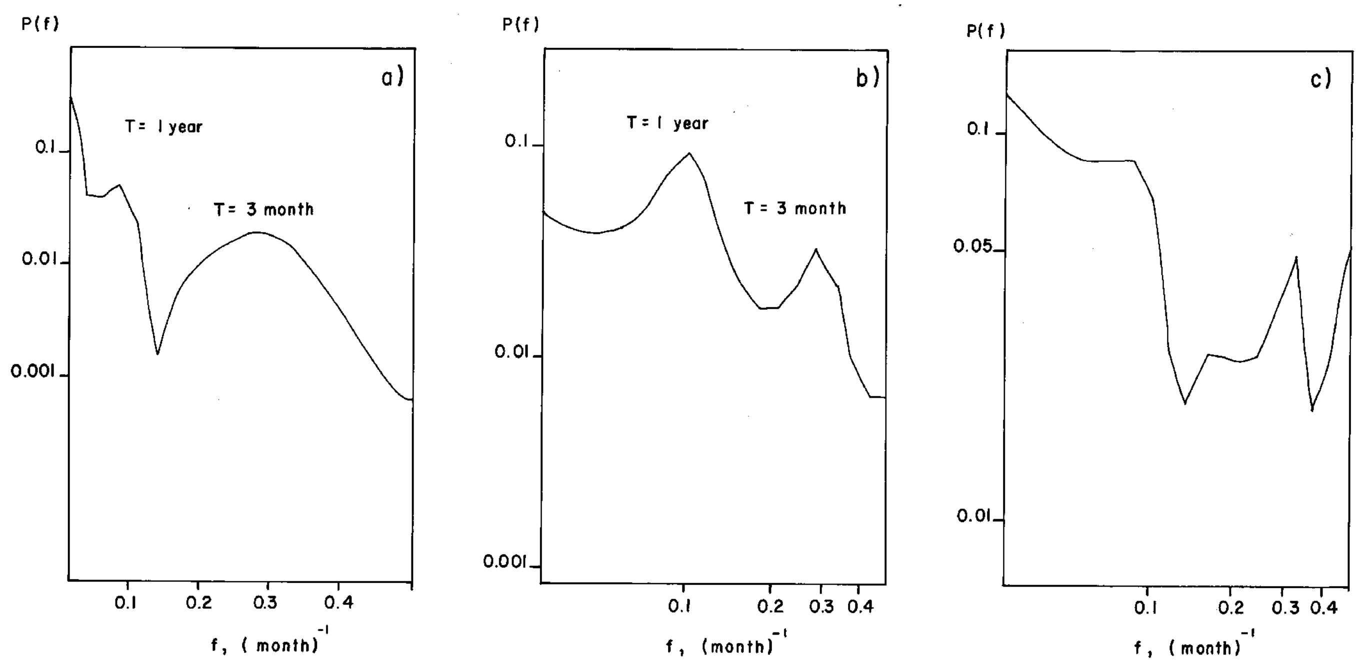

Fig. 4. Amplitude co-spectra of the solar activity index ***S*** and the Estonian and Lithuanian monthly precipitation series for different periods: (a) Lithuanian and ***S*** data series for 1910-1993, with AR (1,5) and AR (2,5); (b) Estonian and ***S*** data series for 1987-1993, with AR (1,5) and AR (2,5); (c) Lithuanian and ***S*** data series for 1987-1993, with AR (1,5) and AR (2,5).

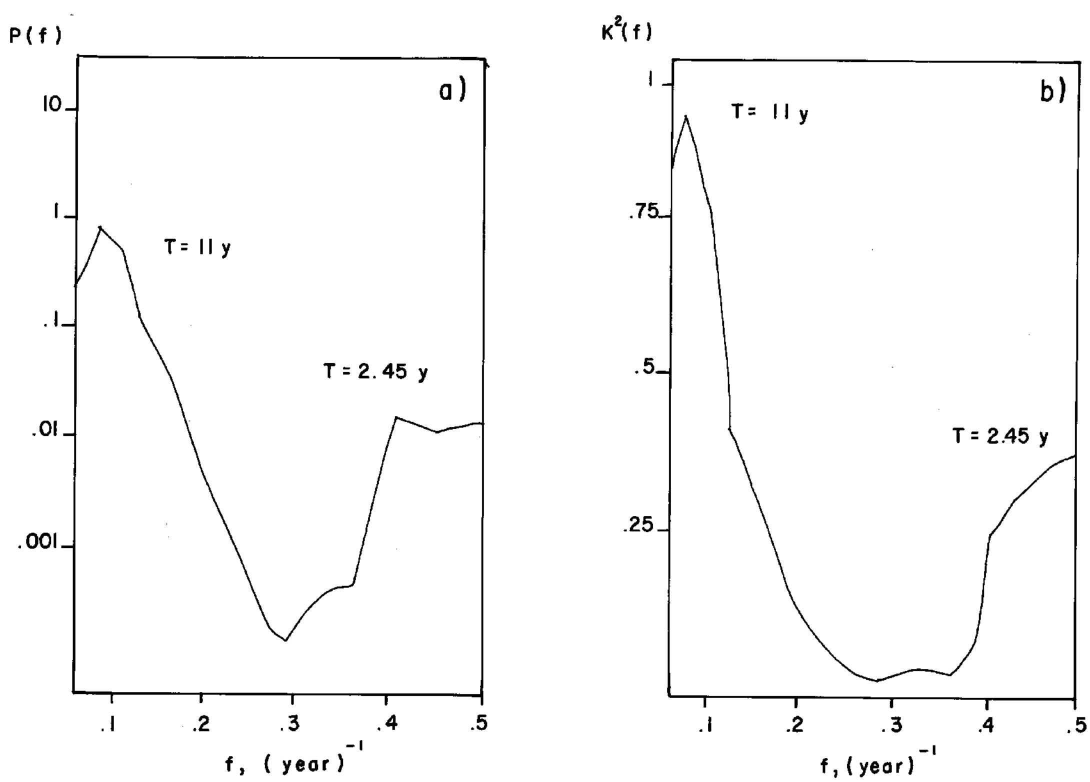

Fig. 5. (a) Amplitude and (b) coherence co-spectra of Estonian and ***S*** annual series for 1866-1890 AR (1,5) and AR (2,4) models, respectively.

Fig. 6. Amplitude co-spectra of Estonian and ***S*** annual series for 1890-1915. AR (1,5) and AR (2,5) models, respectively.

may be described as falling within the framework of solar-terrestrial relationships.

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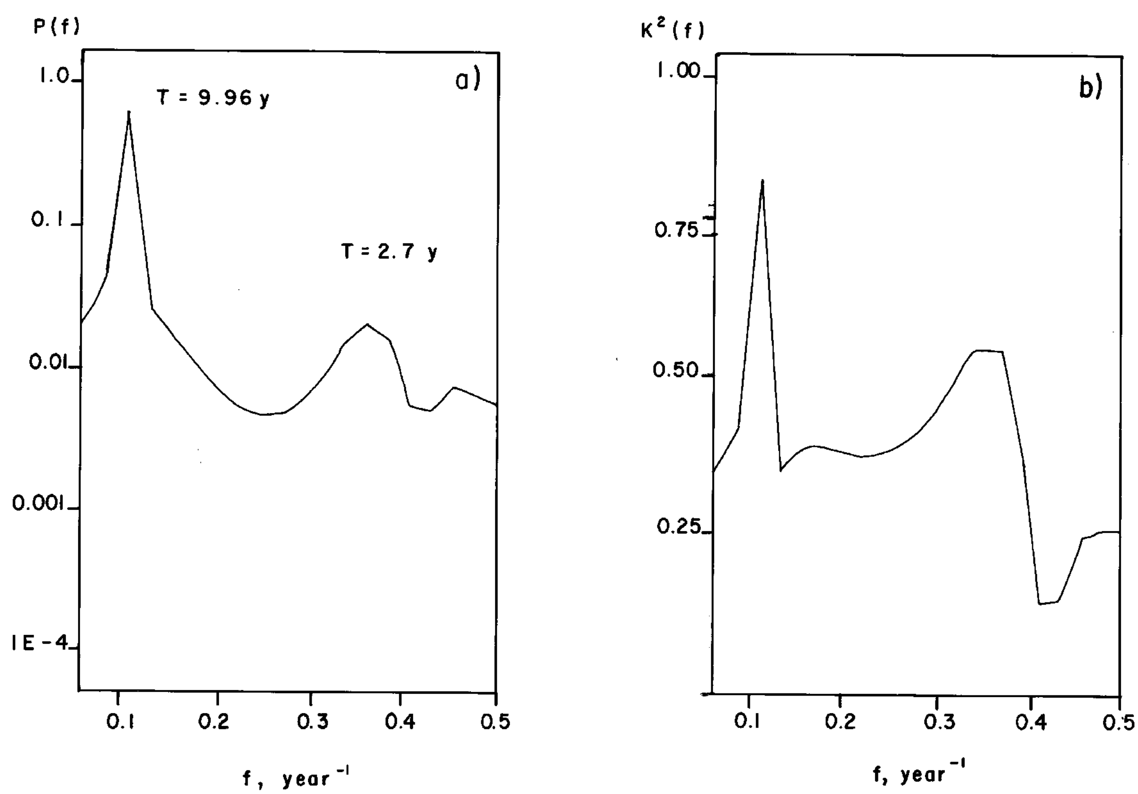

Fig. 7. (a) Amplitude and (b) coherence co-spectra of Estonian precipitation and ***S*** annual series for 1915-1934. AR (1,5) and AR (2,5), respectively.

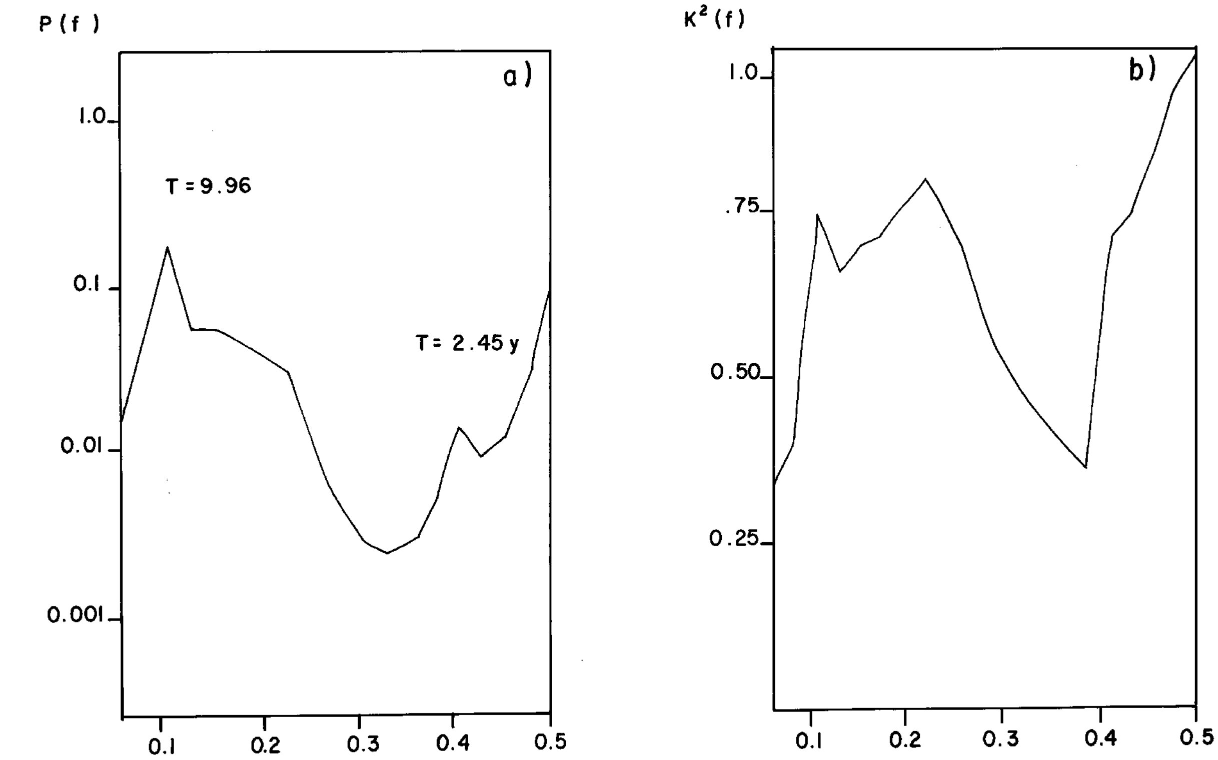

Fig. 8. (a) Amplitude and (b) coherence co-spectra of Estonian precipitation and ***S*** annual series for 1934-1956. AR (1,5) and AR (2,5), respectively.

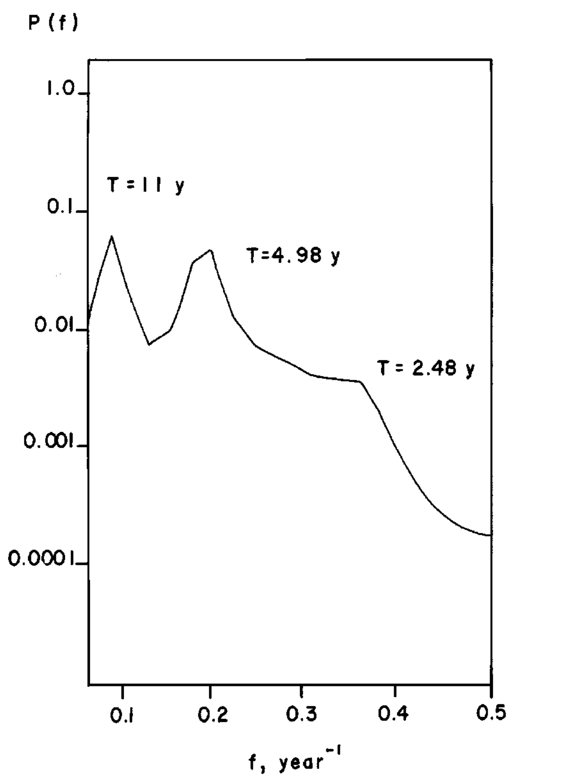

Fig. 9. (a) Amplitude and (b) coherence co-spectra of Estonian precipitation and ***S*** annual series for 1956-1977, AR (1,5) and AR (2,5), respectively.

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