REPORTES INTERNOS 96-11
mayo 1996

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PRECIO: N$ 4.00

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ABSTRACT

It is studied the evolution trends of the the variations of the ice cover of the Baltic Sea. A series of data of ice cover surfaces and of solar activity along 273 years is employed in the search of a long period tendency. Several statistical methods are simultaneously applied to the sample data in order to obtain optimal results. The analysis detaches typical relevant oscillations, commonly found in studies of other climatic parameters. It is confirmed the presence of the 22 years oscillation corresponding to the whole cycle of solar magnetic activity. The obtained results reinforce the field of solar activity influence on the low earth atmosphere and on meteorological parameters.

INTRODUCTION

In recent years, the number of studies dedicated to the tendency in the variation of climate has been constantly increasing. However, there is not at present an unified consensus between the specialists with respect to this problem. Nevertheless, on basis to a concrete material we present here an attempt for defining the evolution trends of the variation of the ice cover of the Baltic Sea.

For this goal, a series of data along 273 years (1720-1992) of the maximum annual cover of ice (S) of the Baltic Sea [1] was utilized. As it is widely known, the problem of the definition of tendencies in time series has not an optimum unique solution. The selection of the method depended to a certain extent of the *a priori* information on the model of the studied process and on the behavior of the statistical data that describe it.

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DESCRIPTION OF DATA AND METHODOLOGY

An important peculiarity of the data in that their distribution is enough distant of the normal one. Thus, with a mean value of S equal to 2.13×10^5 km^2, a minimum value of 5.2×10^5 km^2 and a maximum one of 4.20×10^5 km^2, the standard deviation results equal to 1.14×10^5 km^2. The histogram shows that the distribution almost has not "tails" and it is comparable to a normal deformed distribution, with a notable positive asymmetry. In this case, smoothing the series by using *mobile averages* does not give information about the

existence (or absence) of the searched "slow tendency" or a tendency of long period. For the solution of the problem, the technique of the *polynomial tendency* was used, with the help of the program *STATGRAPHICS* 5.0. The best approximation was obtained with the polynomial of third order (Fig. 1). However, the interval of confidence of the regression line obtained with this method was too wide. The polynomials of fifth and sixth order give even worse approximations. Then it was decided to investigate the tendency of the series by the *caterpillar method* [2].

The method of the components points to a meaningful predominance of the high frequencies in the analyzed series. Among them, the major part of the variance corresponds to oscillations with periods of 5.4 years (which appears in the first three major components with 14 % of the variance), of 7.8 years (fourth and fifth components with 7.8 % of the variance) and of 3 years (sixth and seventh components with 7.5 % of the variance). The "slow tendency" is represented weakly by the first and the third components.

For a most accurate determination of the "slow tendency" it was carried out the previous smoothing of the process by means of the mobile sums, without utilizing *a priori* information on the model. The interval of summation was determined taking into account that it was necessary to suppress some frequencies. In this case, it was summed to the data every time 15 points, in order to smooth the previously mentioned components with periods near to 3.5 and 7.5 years, i.e., the three most prominent components of the time series in consideration. Of the obtained smoothed series the first seven and last seven points were excluded, because they are calculated with shorter intervals, so that they can introduce errors in the subsequent analysis. Afterwards, it was proceeded to the analysis of the smoothed series by means of the *cartepillar method*. In this case, it was detached clearly the first main component, with more of 60 % of the variance, in such a way that it can be considered as representative of "the slow tendency" of the studied processes (Fig. 2).

For control of the results, a similar analysis was carried out for the series smoothed by mobile average of 7 points, with the final exclusion of the three first and three last points. In this way, the first major component (representative of "the slow tendency") takes a double weight. This fact makes doubtful the pertinence of the use of the lineal smoothing of the original series, which furthermore is in concordance with the abnormality of the statistical distribution of the observed values of S. According to [3], for similar data to that analyzed in this work it is pertinent to utilize the "stable" or "resistant" smoothing, which instead of the arithmetic mean is based on the median or the weighed mean and a special procedure for the elimination of the plane segments. The studied series was smoothed by means of five different procedures of the mentioned program *STATGRAPHICS* 5.0, obtaining very close results between them, but different from the results of the lineal smoothing. For the subsequent analysis, it was taken the average series from the five smoothing procedure variants and processed it by means of the *caterpillar method*. The "slow tendency" in this case appears in the first major component, which explains 26.5 % of the variance. The second and third components (28 % of the variance) detach oscillations with periods about 19 years.

The most important results of this stage of the investigation is that the three calculations by the *cartepillar method* with different types of smoothinggive curves of "slow tendency" almost coincidental, either in the form of a sinusoidal segment with period near to 30 years, or, in the form of a cubic polynomial in the zone of the changing slope. In this manner, it can be observed the appearance of a period of apparent climate cooling beginning in the years 50's of the present century (Figs. 1 and 2) due to the presence of climatic periodic oscillations. Furthermore, in the mentioned curves there are well defined periods where a certain "decay" in the dynamics of the process can be observed. Such periods correspond to the 1790-1800 and 1910-1920 intervals and coincide with the minimum and the maximum of the "slow tendency", respectively.

In the analysis of data by means of the *cartepillar method* a great number of components with periods of 2 to 40 years was obtained. In the analysis of the original series, the following periodical oscillations detach fairly good in the major components of higher orders:

2 years (20th-component; 2.4%),

5.9 years (14th- & 15th-component; 5.4%),

~ 20 years (21th- & 22th-component; 4.6%),

~ 40 years (38th- & 39th-component; 2.3%).

The remaining components are comparable with the noise.

In the analysis of the series smoothed with averages of 15 years, the second and third components contain 28 % of the variance, and detach oscillations with periods near to 27 years. The fifth and sixth components, with 5 % of the variance, show clearly the "pulsation" of two close frequencies with periods of 9 and 10 years. The fourth component, with 2.9 % of the variance, corresponds to an oscillation with period of 20 years.

To test the periods detached with the help of the program *STATGRAPHICS* 5.0 the *periodgram* of the original series was calculated. Despite the precision in the determination of the *component* periods by this method is not high, it can be considered, in a first approximation, that the fundamental components obtained by the *cartepillar method* also detach in this case. In this way the components with periods (in years) of ~ 300, 90-100, ~ 46, 27-30, ~ 20, 14-15, 13, 10, 9, 8, 6.5, 5.4, 5.4, 4, 3, and some others were clearly detached. It is worth to mention that the period of the oscillations of Lake Tchudskoye studied in [4] is also present in the oscillations of the series analyzed in this work.

For refinement of the results the original data were subjected to an autoregressive (AR) spectral analysis [4], separately for the even and odd cycles of solar activity. It is necessary to mention that, in contrast with other methods of spectral analysis, this autoregressive method does not permit to calculate with exactness the amplitude of the corresponding oscillations. Nevertheless, the oscillation itself, i.e., the frequency is determined with absolute confidence. Therefore, after the autoregressive analysis the obtained picks are subjected to a complementary standard spectral analysis (Blackman-Tiuki), with the aim of optimizing the amplitude of the respective oscillations and determining the errors.

DESCRIPTION OF RESULTS.

The results of the calculations are shown in Figs. 3-5: in Fig. 3 the ARMA (Autoregressive Analysis with Mobile Averages)-spectrum for the entire time series is shown, in Fig. 4 the ARMA spectrum for the even cycles of solar activity is shown, and Fig. 5 corresponds to the odd cycles of solar activity.. In every case panel a) corresponds to the cross spectral amplitude, panel b) to the spectral coherence and panel c) to the phase spectrum.

The results confirm definitely the presence of significant oscillations of the ice surface of the Baltic Sea with periods of 300, 80-90, 20-22, 9-13 and 4-6 years. It has to be mentioned that the autoregressive cross analysis of all the group of data and that of the even and odd cycles display an interesting picture: in the odd cycles, we can observe variations of the ice surface with periodicities of 4-6, 11 and 80-90 years (over the background of the weaker oscillation of 300 years), while in the even cycles the oscillations of 22, 80-90 and 300 years are predominant.

The presence of variations of 11 years in the surface of ice in the odd cycles and the absence in the even cycles reinforces the wave of 22 years, what is reflected in Fig. 3. It is essential to note that this result does not depend on the used indexes of solar activity.

The comparison of the set of similar results obtained in this work by different methods, with the theoretical and experimental results presented in work [5] shows that their behavior is framed within the context of the proposed mechanism mentioned in that work, for the influence of solar activity on the lower atmosphere and on the meteorological, parameters.

It is important to mention another result, that requires apparently of an additional checking work: during the filtering of the original series by means of the *mobile averages* (with periods of 50, 75, 100 and 150 years) and the subsequent joint cross ARMA-analysis and MEM (Maximum Entropy Method)-analysis, [4], with analogous data of solar activity, it is observed a tendency in the time series of the ice cover with a period of about 800 - 1000 years, significantly greater than the periods of the detached relevant oscillations. Obviously, thought the analyzed data corresponds only to 273 years, such a prediction up to 1000 years can be made because of the quasilinear behavior of the periodicities. This trend evidences a strong global warming-up of the climate in the North Hemisphere, particularly in the last 100 - 120 years.

CONCLUSIONS.

As a result of the simultaneous analysis of the data of the variations of the ice cover of the Baltic Sea and of the solar activity, we have been able to demonstrate that:

1. The ice surface data reveal oscillations with periods of 4 - 6, 10 - 12, 20 - 22, 80 - 90 and 300 years, which are common to a certain degree to all the meteorological parameters [6 - 9].

2. The amplitudes of the distinguished oscillations are significantly different for the even cycles and for the odd cycles of the solar activity, leading to a clear asymmetry that reinforces the wave of 22 years.

3. The results are in agreement with the model for the influence of the solar activity on the low atmosphere and on the meteorological parameters, and so they fit adequately the general picture of solar-terrestrial relationships.

FIGURE CAPTIONS.

Fig. 1. Original series of the oscillations of the maxim surface of the Baltic Sea, during the years 1720 - 1992, and its reconstruction by means of a cubic polynomial.

Fig. 2. Original series of the oscillations of the maxim surface of the Baltic Sea, during the years 1720 - 1992, and its reconstruction by means of the Caterpillar method, with the first major component and a variance fraction of 60%.

Fig. 3. ARMA spectral density of the Baltic Sea ice cover (BSIC) data, for the years 1720 - 1992, (a) amplitude spectra, (b) coherence spectra.

Fig. 4. ARMA spectral density of the BSIC data for even cycles of solar activity.

Fig. 5. ARMA spectral density of the BSIC data for odd cycles of solar activity.

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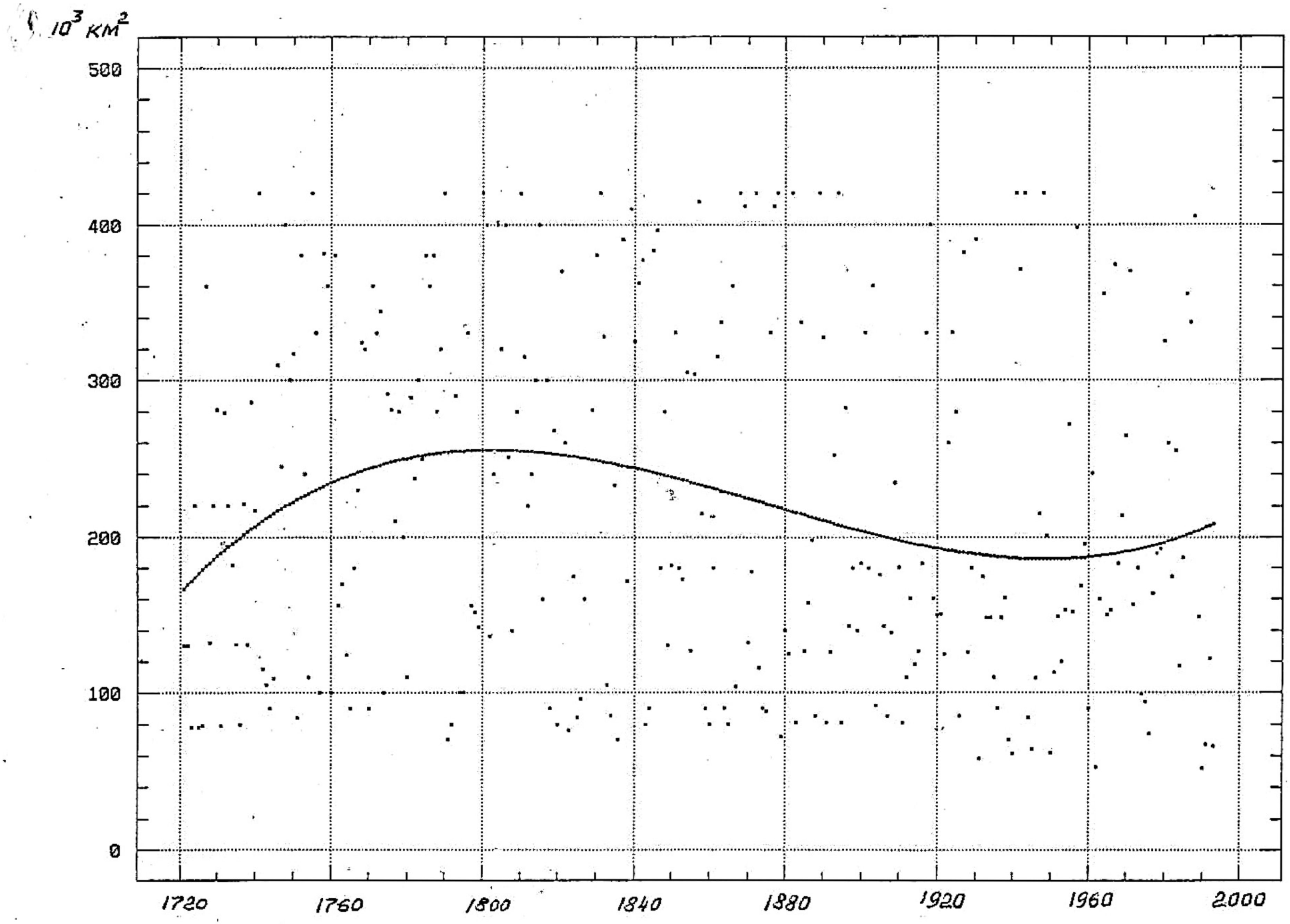
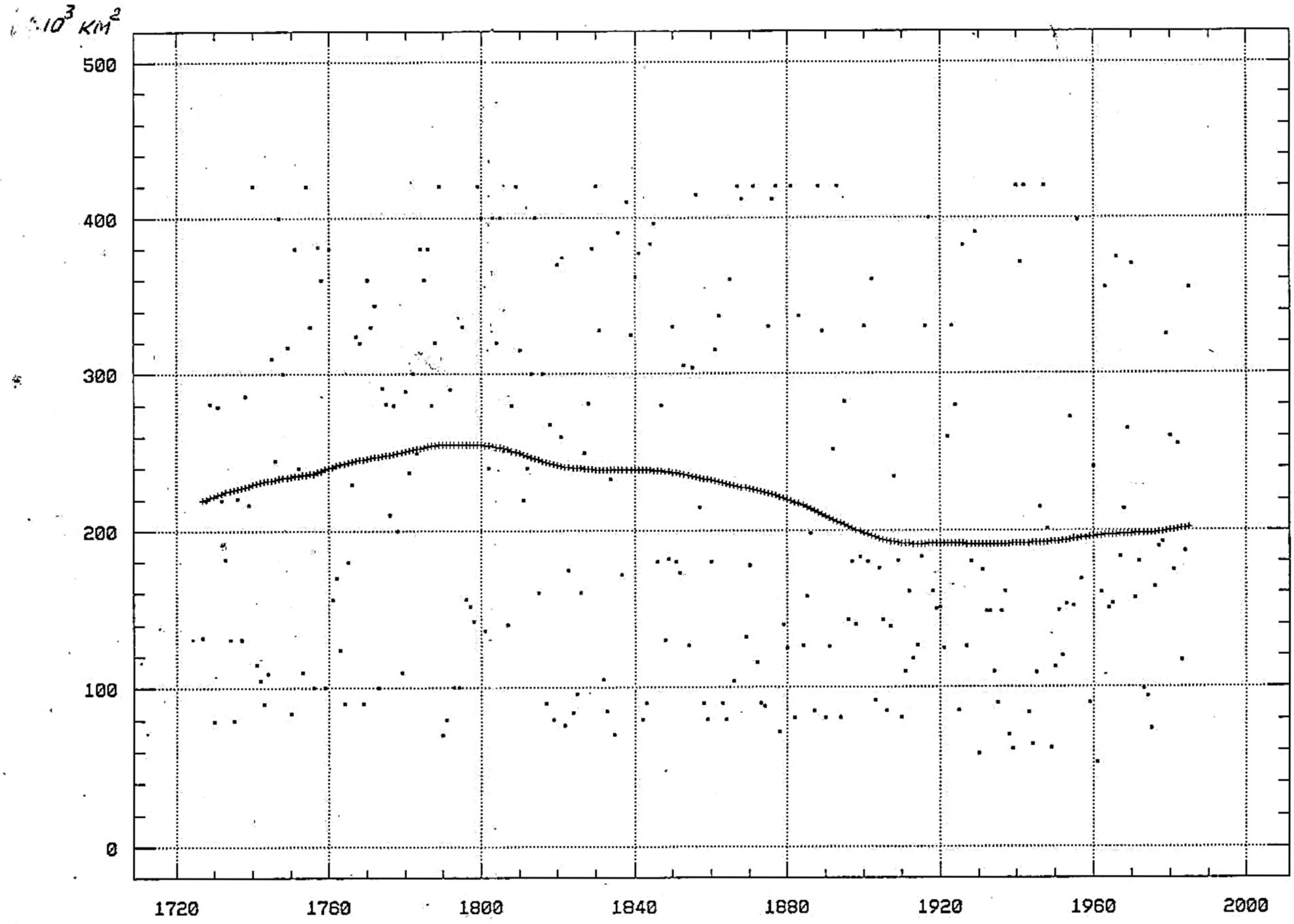


10^3 KM^2
500
400
300
200
100
0
1720
1760
1800
1840
1880
1920
1960
2000

Fig. 1



10^3 KM^2
500
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2000

Fig. 2

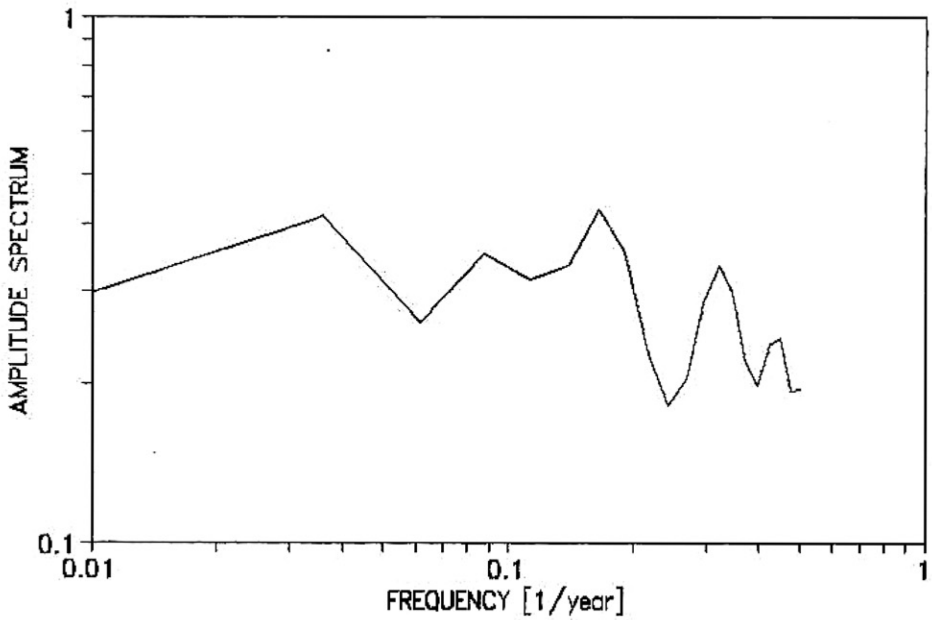

FIG. 3

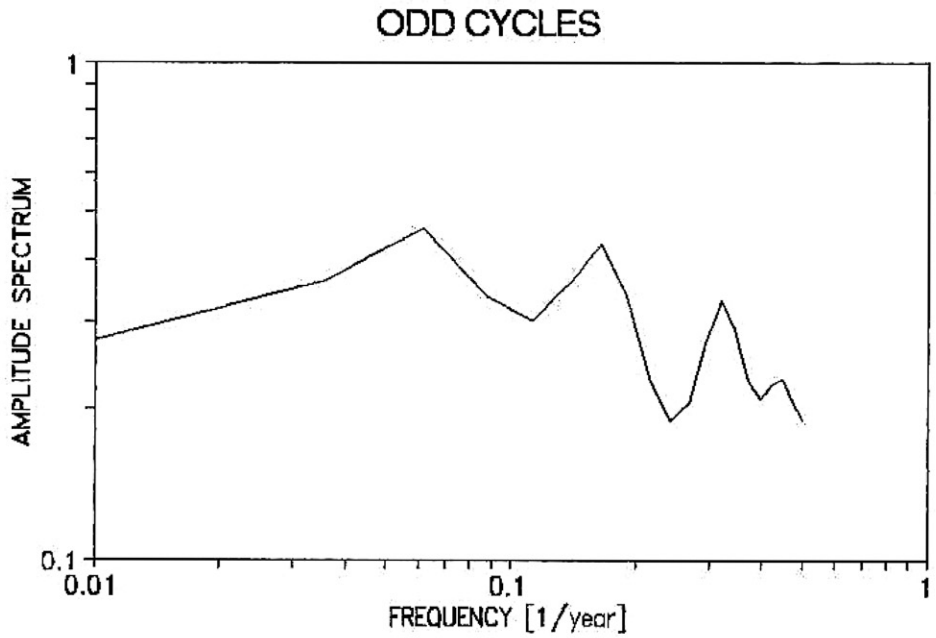

FIG. 4

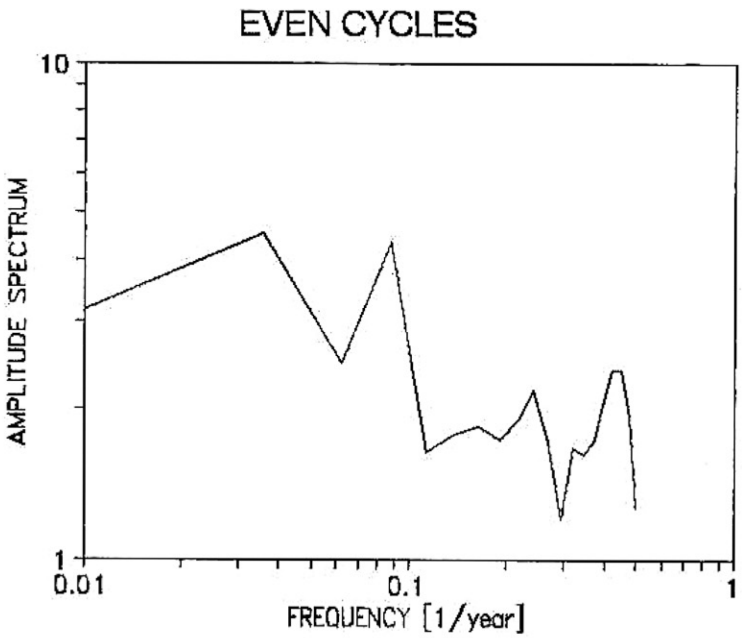
EVEN CYCLES
10
1
AMPLITUDE SPECTRUM
0.01
0.1
1
FREQUENCY [1/year]

FIG. 5