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LONG-TERM FLUCTUATIONS OF THE ICE COVER OF THE BALTIC SEA

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Introduction

In recent years, the number of studies dedicated to the tendency in the variation of climate has been constantly increasing. However, at present there is no unified consensus among the scientists with respect to the direction of climate changes. In this paper an attempt for defining the evolution trends of the variation of the ice cover of the Baltic Sea is made.

For the purpose a series of data for 273 years (1720–1992) of the maximum annual cover of ice (S) of the Baltic Sea (Seinland, et al., 1993) was utilized. As it is widely known the problem of the definition of tendencies in time series has no optimum unique solution. The selection of the method depended to a certain extent on the *a priori* information on the model of the studied process and on the behaviour of the statistical data that describe it.

1. Methodics

Initial analysis of the data showed that the distribution almost has no "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 by 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 (Belonin, et al., 1971).

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

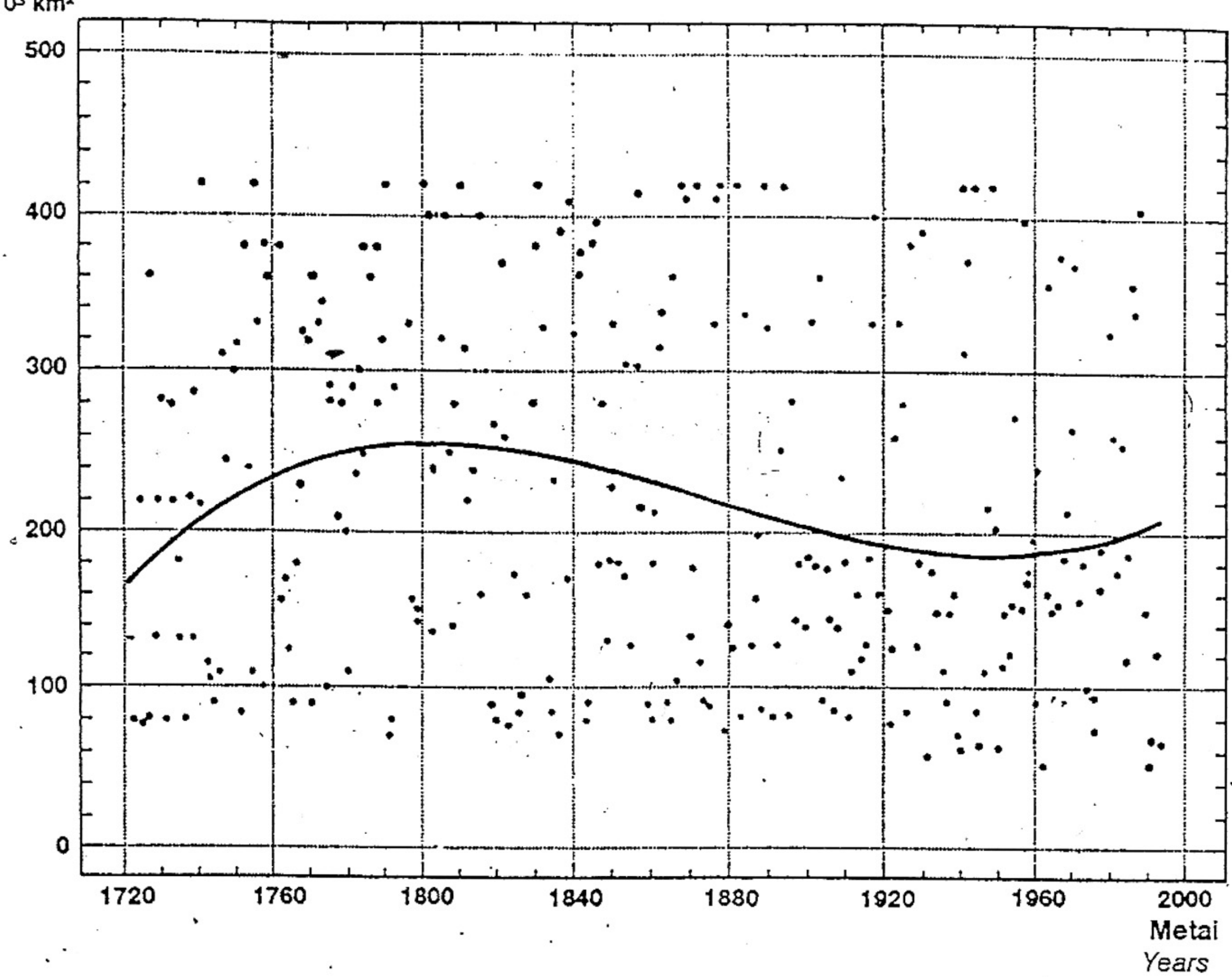

Fig. 1. Original series of the oscillations of the maximum ice cover of the Baltic Sea during the years 1720–1992 and its reconstruction by means of a cubic polynomial.
1 pav. *Baltijos jūros ledo dangos maksimalaus išplitimo 1720–1992 m. faktinis svyravimas ir jo modelis, sudarytas kubinių polinomų metodu.*

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 the most accurate determination of the "slow tendency" the initial smoothing of the process by means of the mobile sums was carried out without utilizing *a priori* information on the model. The interval of summation was determined by taking into account the necessity of suppression of some frequencies. In this case, 15 points were summed to the data every time 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. Afterwards the first seven and the last seven points of the obtained smoothed series were excluded as they were calculated from shorter intervals and could introduce errors in the subsequent analysis. Then the analysis of the smoothed series by means of the *caterpillar* method was used. In this case the first major component was clearly detached with more than 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 the 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 the three last points. In this way, the first major component (representative of the "slow tendency") takes

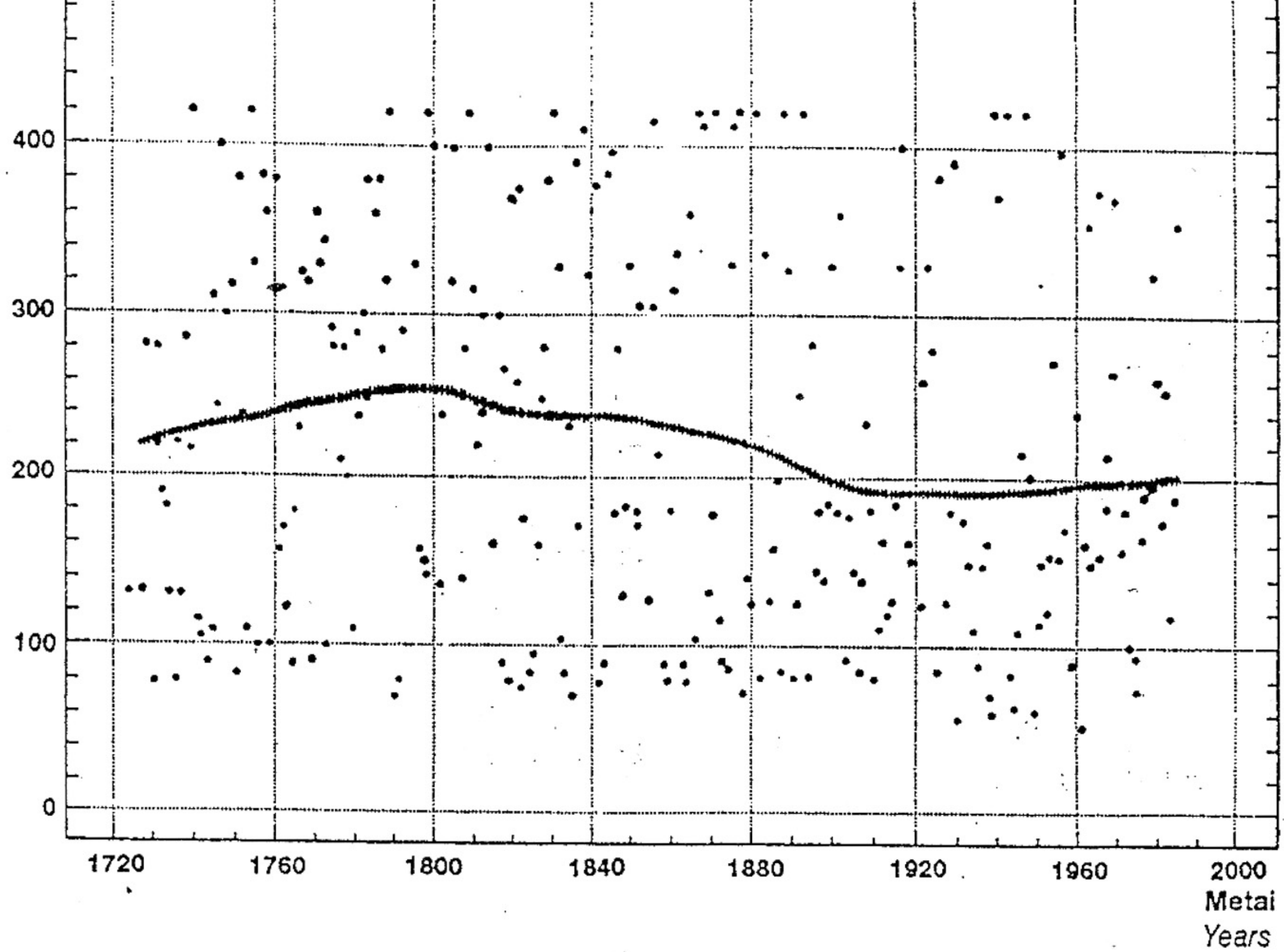

Fig. 2. Original series of the oscillations of the maximum ice cover of the Baltic Sea during the years 1720–1992 and its reconstruction by means of the *caterpillar* method, with the first major component at a variance of 60%.
2 pav. *Baltijos jūros ledo dangos maksimalaus išplitimo 1720—1992 m. faktinis svyravimas ir jo modelis, sudarytas vikšro metodu: pirmasis svarbesnysis komponentas, apimantis 60% svyravimų.*

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 (Velleman, et al., 1981), 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 was used. The studied series was smoothed by means of five different procedures of the mentioned program STATGRAPHIC 5.0, obtaining very close results between them but different from the results of the lineal smoothing. For the subsequent analysis the average series from the five smoothing procedure variants was taken and processed 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 the third components (28% of the variance) detach oscillations with periods about 19 years.

The most important results at this stage of the investigation is that the three calculations by the *caterpillar* method with different types of smoothing give curves of "slow tendency" almost coincidental, either in the form of a sinusoidal segment with a period near to 30 years, or in the form of a cubic polynomial in the zone of the changing slope. In this manner, the appearance of a period of apparent climate cooling beginning in the 50's of the 20th century (Figs 1 and 2) due to the presence of climatic periodic oscillations can be observed.

Furthermore, there are well defined periods in the mentioned curves 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 *caterpillar* 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 and 15th components; 5.4%), 20 years (21st and 22nd components; 4.6%), 40 years (38th and 39th components; 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 *caterpillar* 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 water level of Lake Tchudskoye studied in (Pérez–Peraza, et. al., 1992) 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 (Pérez–Peraza, et. al., 1992) 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.

2. 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.

The results confirm definitely the presence of significant oscillations of the ice cover area 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 groups of data and that of the even and odd cycles displays an interesting picture: in the odd cycles, we can observe variations of the ice covered areas 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 are predominant. The results have good correspondence with earlier investigations of stormicity in the North Sea where different periods in odd and even cycles

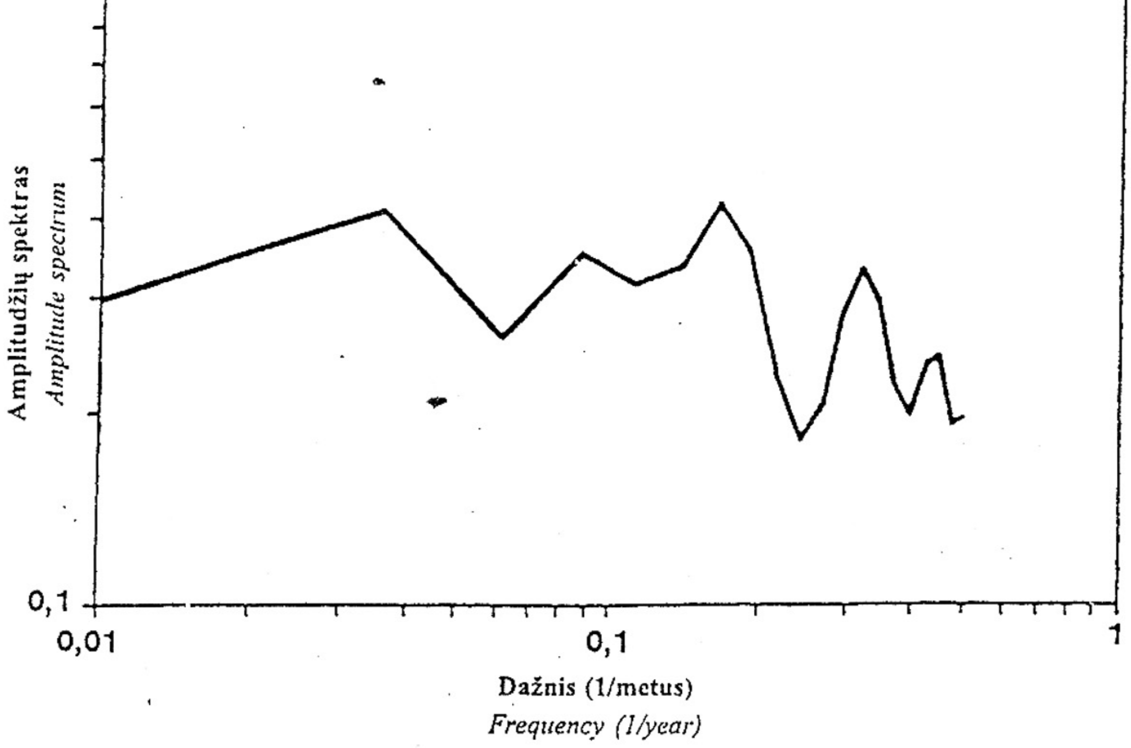

Fig. 3. ARMA spectral density of the Baltic Sea ice cover data for the years 1720–1992.
3 pav. *Baltijos jūros leduotumo (remiantis 1720–1992 m. duomenimis) slankiųjų vidurkių autoregresinės analizės spektrų dažnis.*

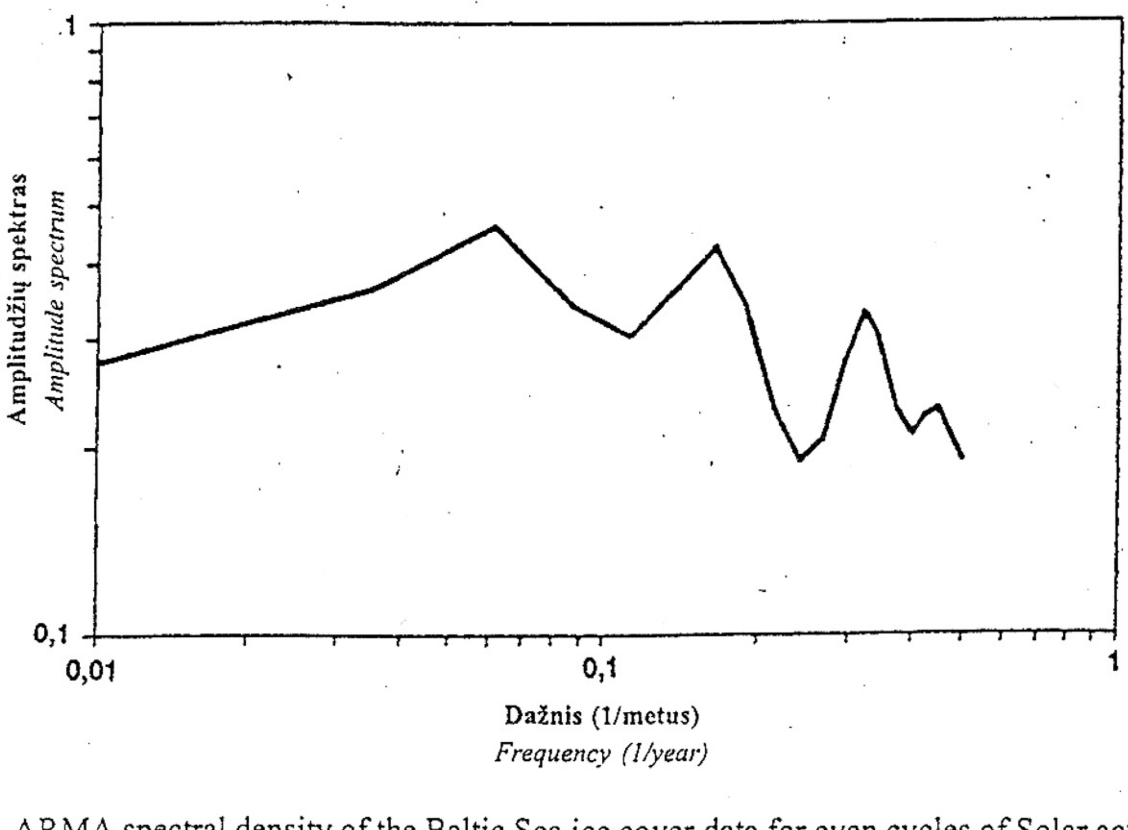

Fig. 4. ARMA spectral density of the Baltic Sea ice cover data for even cycles of Solar activity.
4 pav. *Baltijos jūros leduotumo slankiųjų vidurkių autoregresinės analizės spektrų dažnis Saulės aktyvumo lyginių ciklų atvejais.*

of the Solar activity were found (Dorman, et al., 1987; Libin, et al., 1987).

The presence of variations of 11 years in the area of ice cover 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 indexes of Solar activity used.

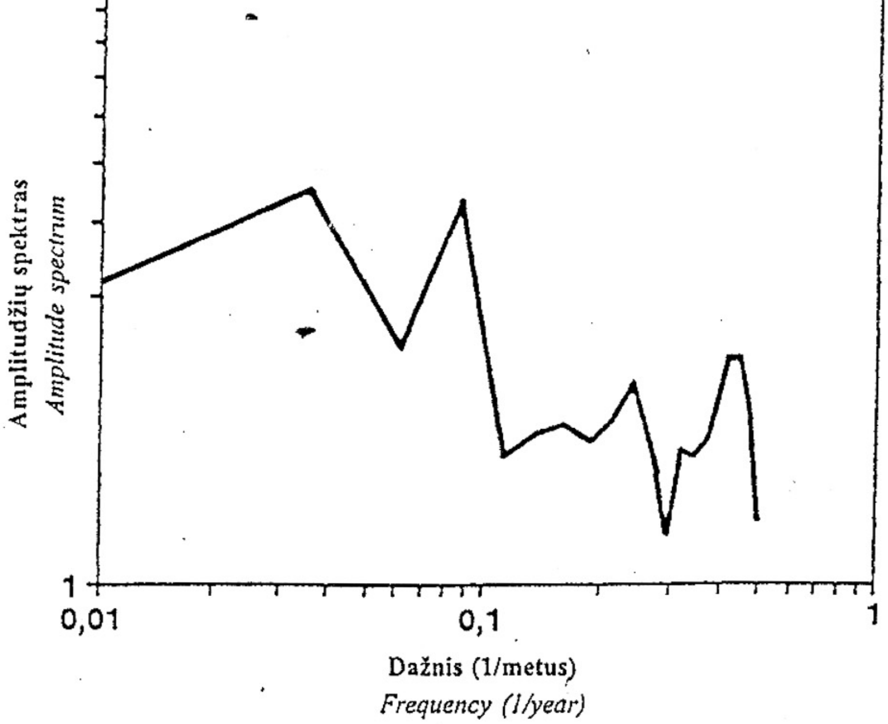

Fig. 5. ARMA spectral density of the Baltic Sea ice cover data for odd cycles of Solar activity.
5 pav. *Baltijos jūros leduotumo slankiųjų vidurkių autoregresinės analizės spektrų dažnis Saulės aktyvumo nelyginių ciklų atvejais.*

The comparison of the set of similar results, obtained in this work by different methods, with the theoretical and experimental results presented in (Pudovkin, et al., 1992) shows that their behaviour 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 which requires, apparently, an additional checking: 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 (Pérez–Peraza, et. al., 1995) with analogous data of Solar activity, a tendency in the time series of the ice cover with a period of about 800–1000 years is observed. This is significantly greater than the periods of the detached relevant oscillations. Obviously, though the analyzed data correspond only to 273 years, such a prediction up to 1000 years can be made because of the quasilinear behaviour of the periodicities. This trend evidences a strong global warming–up of the climate in the Northern 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 cover 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 meteorological parameters (Leyva, et al., 1995, 1996; Pérez–Peraza, et al., 1996, 1996).

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 lower atmosphere and on the meteorological parameters, and so they fit adequately the general picture of Solar–terrestrial relationships.

Gauta 1999 04 01

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Baltijos jūros leduotumo ilgalaikiai svyravimai

Santrauka

Per paskutinius kelis dešimtmečius padaugėjo darbų, nagrinėjančių klimato kitimą (arba svyravimą), tačiau iki šiol nėra vieningos nuomonės apie klimato pokyčių kryptį. Šiame darbe bandoma nustatyti, kaip kinta vienas klimato rodiklių – ledo dangos išplitimas Baltijos jūroje.

Šiam tikslui pasinaudota 273 metų (1720–1992) maksimalaus ledo dangos išplitimo Baltijos jūroje (S) stebėjimų seka. Naudojantis įvairiais matematinės duomenų analizės metodais ieškoma optimalaus būdo ilgalaikiams svyravimams apibrėžti, juos aplyginant. *Vikšro (caterpillar)* metodas padėjo išryškinti 2, 5,9, 20 ir 40 metų svyravimus. Pritaikius tyrimams STAGRAPHICS 5.0 programą, išryškinti tokie Baltijos leduotumo svyravimo ciklai: ~ 300, 90–100, ~ 46, 27–30, ~ 20, 14–15, 13, 10, 9,8, 6,5, 5,4, 4 ir 3 metų. Šių tyrimų rezultatai labai panašūs į Čiudo (Peipaus) ežero vandens lygio svyravimų ciklus. Sugretinus Baltijos leduotumo stebėjimų seką autoregresine spektrine analize su Saulės aktyvumo lyginiais ir nelyginiais ciklais, išryškėjo leduotumo svyravimo 300, 80–90, 20–22, 9–13 ir 4–6 metų ciklai, bet vieni jų (pvz., 4–6, 11 ir 80–90 metų ciklai) ryškesni nelyginiais Saulės aktyvumo ciklais, o kiti (22, 80–90 ir 300 metų) – lyginiais. Šie rezultatai gerai dera prie ankstesniuose tyrimuose išryškėjusių Šiaurės jūros štormingumo svyravimo ypatumų. Be to, filtruojant duomenis slankiųjų vidurkių metodu ir lyginant juos maksimaliosios entropijos metodu su Saulės aktyvumo duomenimis, išryškėja 800–1000 metų Baltijos leduotumo ciklas. Tokios išvados grindžiamos reiškinio periodiškumo kvazilinijine prigimtimi. Šis Baltijos leduotumo trendas gerai sutampa su smarkiu klimato šiltėjimu Šiaurės pusrutulyje, ryškiu bent jau per paskutinius 100–120 metų; XX a. 6–ajame dešimtmetyje pradėjęs didėti jūros leduotumas susijęs su ryškiu Žemės rutulio klimato atvėsimu, užfiksuotu 7–ajame dešimtmetyje ir pasibaigusiu 8–ajame.

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