REPORTES INTERNOS 96-17
mayo 1996

SIMULATING THE MECHANISM OF THE ACTION OF HELIOPHYSICAL PARAMETERS ON ATMOSPHERIC PROCESSES

J. Pérez Peraza, A. Leyva, I. Ya. Libin, V. Fomichev, K.Yudakhin, A. Jaani

Instituto de Geofísica UNAM
Ciudad Universitaria
04510 México, D. F.
México

PRECIO: N$ 12.00

SIMULATING THE MECHANISM OF THE ACTION OF HELIOPHYSICAL PARAMETERS ON ATMOSPHERIC PROCESSES

J. PEREZ-PERAZA, A. LEYVA
InstitutO de Geofísica, UNAM, C.U., Coyoacán, México D.F., 04510, MEXICO

I. Ya. LIBIN, R. GUSCHINA, V. FOMICHEV, K. YUDAKHIN
IZMIRAN, Troitsk, Moscow Region, 142092, RUSSIA

A. JANI
Estonian Meteorological and Hydrological Institute, Toom-Kooli 9, EE0001, Tallinn, ESTONIA

ABSTRACT

The physical mechanism of the influence of solar and geomagnetic activities and other cosmophysical factors acting on the behavior of the weather, pressure, Earth's temperature, precipitation, circulation of the atmosphere, and stormicity are reviewed. It is discussed different mechanisms of the solar activity (SA) influence on the meteorological and climatological parameters, and the behavior of experimental, meteorological and climatological data during the different cycles of the SA. The behavior of experimental data are compared with the predictions of theoretical models of the SA influence on the lower atmosphere. It is indicated the relation of the atmosphere parameter variations with variations of the galactic (GCR), solar (SCR) cosmic ray and the atmosphere transparency. It is analyzed the results of the different scientific works in the helioclimatological area and it is shown that the Pudovkin-model of the SA influence on the lower atmosphere is correct. It is proposed a method for the prediction of the different meteorological and climatological parameters utilizing previous data of these and those of SA, GCR and SCR.

1.- INTRODUCTION

The problem of possible relationships of the seasonal and many-year variations in the Earth's atmosphere to various heliophysical and cosmophysical events was raised repeatedly elsewhere. The fact that the processes occurring on the Sun are responsible for various atmospheric disturbances has proved to be undoubted /1/. The atmospheric circulation is affected by the cyclicity of varying solar activity which controls not only the geomagnetic activity state /2/ but also the temporal variations of the intensity of galactic and solar cosmic rays /3/. So, a complex relationship among all the above mentioned events is reasonable to expect. The parameters of each of the events exhibit their own spectrum of seasonal and many-year variations /1-3/ because, despite their common mechanisms, a fraction of the observed variations are characterized by different casual relationships.

The aim of the present work is to seek for unstable and quasistable frequency-dependent correlations among various cosmoheliophysical and meteorological processes and to make an attempt to simulate these processes mathematically.

The actual existence of the above mentioned correlations follows from a simple qualitative comparison among the temporal variations of the parameters of the studied events /4/, namely, the mean-monthly and mean-yearly values of the Wolf numbers (W), the sunspot group areas (S), the geomagnetic activity (K_p-index), the cosmic ray intensity (CRI), and the storm index (P) describing the recurrence of dangerous winds (of velocity $a > 12$ m/s) in the North Sea /5/. Both the atmosphere variations and the cosmic ray flux modulation observed on the Earth are probably due to the same processes occurring in interplanetary space, namely, powerful interplanetary shocks, solar flares, high-velocity solar wind fluxes, sectorial structure of inter- planetary magnetic fields (IMF), etc./3/. Moreover, because the relationships between the atmospheric parameters and the cosmic ray intensity are quite unambiguous /3/ and, besides, the CRI correlates whit solar activity /1-3/, the analysis of stormicity P on the basis of the CRI and solar activity date can underlie developing the methods for diagnosing the global variations of stormicity.

2.- Effect of Solar Activity on the Cosmophysical, Geophysical and Meteorological Processes.

2.1 Time series of sunspots numbers /6/.

The origin and reliability of sunspots numbers are summarized by /7/. An index indicating the sunspot activity, generally called the relative sunspot number R, was introduced by Wolf at the Zurich astronomical observatory about 1849. (Monthly and annual means of the relative sunspot number determined at the Zurich observatory are regarded as reliable back to 1750, while epochs of maxima and minima supposedly can be extended to 1610 /8/).

The approximately 11-year solar cycle is a well established feature observed in all ground-based indicators of solar activity as R, plage index PI, 10.7-cm radio flux F(10.7), HL-index, chromospheric Ca II K index, etc. The highest, hotter layers of the Sun's atmosphere vary most dramatically in response to the presence of a magnetic field so UV radiation varies considerably more over the solar cycle than does the visible emission formed in lower, cooler layers /6,9-11/. Besides the 11-year regularity of the sunspot cycle, two major aspects of the cycle are the Hale-Nikholson law of sunspots polarity and the reversal of the general magnetic field in the subsequent cycle. Therefore, the 11-year activity cycle is actually half of a magnetic 22-year cycle. During the 11-year cycle the smoothed monthly sunspots numbers rises harply from values very close to zero at minimum and fall of gradually from maximum.

The short term fluctuations of accidental character (noise) in the frequency of sunspots may be inherited in the solar-cycle lengths. In order to remove these short periodic variations related to the 11-year cycle Gleissberg /10/ applied a low-pass filter with the coefficient 1,2,2,2,1 to the series of individual epochs of sunspot minima and maxima, respectively, and derived from each of the two series the corresponding smoothed length of the individual sunspot periods. Gleissberg demonstrated that the varition in cycle length occurred in a systematic manner with a long-term periodicity of 80 to 90 years, now known as the *GLEISSBERG PERIOD*. This is constructively applied in the (1,2,2,2,1) filter, drastically reducing the variations in the smoothed values compared to variations of the individual lengths /6/.

It is most marked in the estimates derived from epochs of maxima. However, still the secular smoothed cycle-length derived from epochs of minima give a more robust estimate of the long-term variation as illustrated in Fig.1 /6/. The corresponding curve is embedded in the more fluctuating curve derived similarly from the epochs of maxima. The different types of average for the annual sunspot numbers are compared in Fig.2 /6/. The 22-year running mean of R follows closely the averages of maximum height R_m taken over two subsequent cycles.

In work /7/ has been shown that introduction of the cycle length as a parameter for the solar activity rather than the smoothed sunspot number removed the apparent lag of the solar activity curve relative to the Northern Hemisphere land air temperature /12/. In Fig.2 of /7/the temperatures were averaged over sunspot minimum to minimum periods, and maximum to maximum periods, respectively. Figure 3 in /6/ shows a diagram similar to Fig.2, in /7/, but marking the cycle lengths corresponding to minima-series and maxima-series separately: taking the effective length of the (1,2,2,2,1) filter into consideration we also compare the cycle length with the 22-year running mean of temperature and obtain a slightly more identical appearance of the curves /13, 14/.

Simulation of the nonlinear feature of the sunspot number and the asymmetry of the solar cycle has been done in /10/. Combining knowledge of long-term periodicities found in Precambrian varves with a simple nonlinear theory of the cycle asymmetry based upon the pressure crest analogy, enabled in /10/ to reproduce rather precisely the observed Zurich annual-number R(t) from 1800 to present. In the fossil records of presumed solar activity an amplitude modulating envelope of 314 years and distinctive waveform, and a 350 year additive undulation of small amplitude in R existed for thousands of years. 21.85 year is adopted as the mean duration of the magnetic cycle /15- 17/.

For the measured global magnetic field of the Sun and the solar dynamo theory there is good reason to argue that the solar poloidal field is a key parameter guiding the solar cycle and the strength of the dipole, though varying from cycle to cycle, is related to the strength of the sunspot maximum occurring 5 or 6 years later. Estimation of the polar magnetic field at or before the sunspot minimum is then useful in predicting the intensity of the next sunspot cycle (R_m). So far such attempts have yielded predictions of R_m with an accuracy of 30 /17/. The indirect method of using the geomagnetic aa indices at sunspot minimum as an indicator of the solar polar field is simpler and yields predictions of roughly the same order. [At sunspot minimum the geomagnetic activity is mainly due to high speed solar wind streams originating in polar coronal holes, which seem to be intimately related to the poloidal dipole field].

2.2 Solar activity and cosmic rays.

The changes in magnetic field structure occurring in the interior of the Sun and reaching its surface define the configuration of the coronal magnetic fields. In turn, these fields (whose form varies in a cyclic manner which is observed clearly in the "white" light during solar eclipses) define the conditions of the Solar Wind "outflow" which has a modulating effect on CRI. Such variations of the solar magnetism exhibit and 11-year recurrence and have their signatures in the very diverse displays of solar activity. Different characteristics can be used to be solar activity indices, depending on a given examined problem. The problem of the solar-atmospheric-cosmophysical relationships may be resolved using the displays of the slowly-varying solar activity component, namely, the sunspot number and area, the coronal indices, the flux intensity of radio emission from the Sun at different wavelengths, the total areas of photospheric and chromospheric faculae and quiescent prominences, and the displays of the slowly-varying component, namely, radio emission bursts and active prominences /4/. All the parameters of the slowly-varying solar activity component are related to the each other and exhibit an 11-year recurrence.

Among the above mentioned solar activity parameters, the sunspot number (the Wolf number W) is the classical and most extensively used index to study the solar-atmospheric and solar-cosmophysical relationships. It is analyzing the temporal variations of the Wolf numbers and of CRI that have led the researchers /5,18/ to find the 11-year cosmic ray variations. As noted in /19/ however, the sunspot area compared with the sunspot number is a more objective index because the errors arising from individual traits of the observer and from observation techniques are avoided when determining sunspot area. The sunspot area and the Wolf numbers are related linearly to each other, but the correlation coefficient between them varies as a solar cycle develops, thereby indicating a certain independence of the two parameters. The sunspot area has been selected to be the solar activity index in is studying the long-term cosmic ray variations because of the assumed dependence of the transport scattering path of cosmic ray particles on the density of the magnetic inhomogeneities carried away by solar wind and reflecting the Sun's spottedness degree /20/.

Plotting the CRI-sunspot area diagram for an 11-year period reveals a characteristic hysteresis loop which may be explained by a delay of the changes of electromagnetic conditions in the interplanetary medium relative to the processes on the Sun generating them /21-23/. The delay time inferred from the hysteresis is τ_{del} ~ 1 year, so the dimension of the modulating heliosphere is fairly large (~ 80-100 A.U.) on the assumption that the solar wind velocity is constant (V= 400 km/s). As shown later /24/, the date obtained using the 6- or 12-month moving averages have to be used to discriminate the long-time cosmic ray variations, while the short-term variations can mainly be discriminated by averaging data over 1 month. The delay is different during different solar activity cycle periods and is peaking during the stage of solar activity decrease. It should be noted that the annual cosmic ray variations are most pronounced during this stage. Besides, τ_{el} depends on the cosmic ray particle energy and decreases with increasing the energy.

The fact that any close correlation between the total sunspot number on the entire solar disk and the temporal CRI variations was not found during some periods in the pioneer work /18/ by comparing between the two characteristics was explained in /22/ by the inappropriate selection of sunspot number to be the solar activity parameter. The coronal emission line (λ = 5303 Å) was proposed in /25/ to be as "outflowing plasma measure". The intensity of this coronal line is a good index of cyclic solar activity because it varies by approximately an order from the solar maximum to the minimum . Some features of the 11 year solar activity cycle, which are of importance to studying the solar activity and the long-term cosmic ray variations, were first noted when analyzing the green coronal line intensity data. For example, when studying the temporal variations, Gnevyshev /26/ found a second peak in the 11 year cycle of the given coronal index which, as regards energy, is tantamount to the first peak. Later, this was found also for other characteristics of solar activity. The coronal emission intensity was selected to be a solar activity index on the basis of the relation obtained by Parker/27/ between the solar wind velocity and the inner-corona temperature which, in turn, correlates with the intensity of the green coronal line I_λ. Further studies of the coronal emission intensity data /28/ have made it possible to find the large-scale emission structures in the corona which are due to the sectorial structure of the Sun's magnetic field. The found relationships of I_λ to the structural features of the sun's magnetic field and, hence, the outflowing solar wind confirmed again that the coronal activity was quite reasonably selected to be a solar activity index.

The temporal behaviour of cosmic rays and coronal emission within 11 years reveals the same effect of cosmic ray delay with respect to the displays of solar coronal activity as in case of the index characterizing the Sun's "spottedness" degree, namely, the sunspot area. Attempts were made to explain the anomalous behavior of cosmic rays during solar maxima noted in /29/ by the changes in the heliolatitude distribution of solar active regions as an 11-cycle develops. However, even the allowance for this factor fails to eliminate the above mentioned anomaly of cosmic ray behavior. At present the given anomalous cosmic ray trait is explained by the Sun's global magnetic field sign reversal which occurs during solar maximum. The correlation of cosmic ray intensity with solar activity during the periods of inversion in the Sun's large-scale magnetic fields was found to be violated also when using the various displays of cyclic solar activity, such as the coronal emission intensity, the radio emission, and the total sunspot area. The question arises as to in what manner the parameters characterizing solar activity are related to the solar activity source, namely, to the Sun's magnetic field. A convincing model which explains comprehensively the solar activity recurrence was proposed in /30/ and developed later in /31/ The model is based on the concept that all the irregular displays of activity on and above the Sun's surface arise from the variations of the poloidal and toroidal magnetic field components due to the differential rotation of the sun. It is mainly the Sun's poloidal field that is carried away by the solar wind to the interplanetary space.

In work /27/ it is assumed that the magnetic field of the poloidal field component could be traced in the coronal activity variations. In particular, according to /32/, the brightness of the λ = 5303 Å green coronal line I_λ is the measure of magnetic activity and heating of the corona. The fields of the active regions which are present on the Sun's surface are the toroidal azimuthal field areas which, when emerging, give rise to the well known latitude extended bipolar magnetic fields. The Sun's poloidal and toroidal magnetic fields and their variations throughout an 11-year cycle have been shown /30, 31/ to be related to each other and to be generated probably by one and the same dynamo-process. The spot magnetic field polarity exhibits a 23-year cycle; the same recurrence is also observed in the magnetic fields of the Sun's polar regions /30, 31, 33/. In this case the polarity of the preceding and subsequent spots in bipolar groups in both hemispheres of the sun changes from one 11-year cycle to another, i.e, during solar minimum (when the poloidal field is peaking), whereas the magnetic field sign in the polar regions reverses near the epoch of the 11-year cycle maximum, with the processes of inversion of the fields being fairly long. The observed latitudinal reversal of the sign of the Sun's general magnetic field in the course of the solar activty cycle development can also be seen in the latitude distribution of its active regions /34/. The above observations confirm additionally that the total sunspot area and the coronal emission intensity were quite correctly selected to be solar activity indices in describing the long-term cosmic ray variations phenomenologically and mathematically.

Numerous different modulation models have been proposed since 1952-1954 (i,e since the time when the 11-year cosmic ray intensity modulation by recurrent solar activity was found) to account for the above mentioned observational fact. Among them, the Parker model has been adopted most widely. The model his based on the idea, which was later confirmed by the experiments in the space, that the modulation and propagation of cosmic rays in interplanetary space are defined by the properties of the plasma stream outflowing from the Sun and carrying the "frozen-in" magnetic field and its inherent inhomogeneities whose power spectrum varies with an 11-year cycle, thereby giving rise to the respective variations in solar activity. The differential equation for cosmic ray density obtained by Parker reflects the cosmic ray diffusion process with simultaneous convective particle transfer in the spherically-symmetric case allowing for the energy variations of the particles as they interact with the solar wind. The use of the combined observation data on the coronal emission and the sunspot area to find the most important modulation characteristic, namely, the transport scattering path of particles, when solving the equation of anisotropic cosmic ray diffusion /35/ makes it possible to allow for the features of the modulation action of solar wind during different epochs of the 22-year magnetic cycle of the Sun. The found features of the long-term cosmic ray variations during solar maxima, i,e, in the periods of the Sun's magnetic field sign reversal in the near-polar zones, have made it possible to find a 22-year cycle in cosmic ray intensity. This circumstance has required a more detailed approach to solving the boundary-value problems of differently charged particle propagation in the large-scale interplanetary magnetic fields (IMF) whose directions vary according to a definite law.

The concept /36/ of the existence of drift fluxes whose directions vary depending on the sign of the Sun's general magnetic field is very important for the theoretical description of the 22-year cycle. The direct measurements of cosmic ray intensity in the space taken during the last 15 years do not discard such a model. The measurements have also confirmed the earlier empirical estimates (obtained by comparing among the temporal variations in cosmic rays and in solar activity) of the size of the modulating heliosphere (50-100 A.U.). Apart from the above discussed long-term variations with T = 11 and 22 years associated closely with solar activity, the 5-, 3-, 2-, and 1-year /37-44/ and few month variations and fluctuations were found in cosmic ray intensity.

The nature of the extra-atmospheric annual cosmic ray variations which were found more than 30 years ago /41/ by analyzing the meson component variations (it should be noted that they are very different to discriminate because of the substantial distortions introduced by the seasonal variations of temperatures in the Earth's atmosphere) is explained mainly by the changes of the earth's position in the space with respect to the helioequator during a year /39/. It is worth noting that the study of the fluctuations in solar activity and in cosmic ray intensity is of independent interest because a comparison among the periodicities observed in the two processes may yield information about the interaction of the processes with each other. For example, the frequency power spectra in a 50 - 1000-day interval of periods were determined /44,45/ using the 10-day averages of the data of continuous detection of cosmic ray intensity with the Deep River neutron monitor, the sunspot numbers, the data on radio emission fluxes at 2800 Hz, and the data on the variations of the parameters a and da/dt (where a is the Sun's acceleration relative to the common center of gravity of the solar system due to planets Mercury, Venus, Earth, Mars, and Jupiter). The analysis was made on the basis of the observation data obtained in 1958-1973. The cosmic ray power spectrum is peaking on the periods of 650-680, 350, 238, 204, and 170 days (the peaks corresponding to 366, 244, 215 and 75 days in 1958-1965 and to 630, 338, 190-200, and 169 days in 1966-1973 are especially pronounced). The mentioned peaks of the cosmic ray power spectrum and the peaks in the power spectra of other parameters are noted to be not in correspondence with each other (for example, the peaks on periods of 400, 237, and 90 days have been found for a and da/dt). Similar studies of the frequency spectra of cosmic ray intensity and solar activity (in the frequency range $< 6\text{-}2.5 \times 10^{-4}$ cycle/day) have been carried out in /46, 47/. The discriminated periodicities of 89, 180, 228, 365, 500, and 668 days and 11 years are not always in exact correspondence with the results of /44, 45/. If, however, the frequency "wanderings" of the peaks in the spectra are allowed for /48, 49/, the model studies of the 11-year variations of solar activity and cosmic ray intensity /50, 51/ show that a substantial fraction of the peaks observed in the frequency spectra are harmonics of the 11- and 22-year cycles /52,53/. The common statistically significant maxima with periods of 1.3, 1.8, 2.1, 3.1, 5.4, and 10.7 years which agree within errors with the results of /53/ were found in /52/ by comparing among the periodicities discriminated in cosmic rays for 1965-1979 and in solar activity for 1900-1975.

Studies of the biennial cosmic ray variations /54-61/ are of greater interest to studying the nature of solar-terrestrial relationships; in /54/ it has bee shown that the energy spectrum of the biennial cosmic ray variation is close to the spectrum of the 11-year variations and that the ratio of their amplitudes is stable, namely, $A_{11}/A_2 = 5.3$ on the average. Besides, a biennial wave is observed in solar activity, geomagnetic activity, and meteorological processes. The found biennial variations of cosmic rays, geomagnetic activity, and meteorological parameters are explicitly of extraterrestrial origin and relate most probably to the physical conditions of the interplanetary space region in the nearest proximity to the Sun /56/.

Quasi-biennial cosmic ray variations show themselves as alternation of the solar-diurnal anisotropy phases depending on the Earth's position relative to the helioequator; during the periods of the Sun's general magnetic field sign reversals the phase alternation order inverses. The order of the cosmic ray anisotropy phase alternation is in a good correlation with the quasi-biennial variations of the north-south asymmetry of solar wind velocity and aa-index of geomagnetic activity. The quasi-biennial variations of cosmic ray intensity may be generated by the cyclic variations of the solar wind parameters throughout the heliosphere and by the respective temporal variations of the atmospheric pressure and temperature /61/.

It should be noted that the cosmic ray intensity must be compared to the solar activity indices (in both time and frequency ranges) with a definite caution because their behavior from cycle to cycle is complicated. As to the 2-3 year cosmic ray variations, the reasons for their occurrence in cosmic rays have been explained but very tentatively, despite the fact that they were detected in cosmic rays almost 30 years ago /41/ and were later discriminated clearly in the cosmic ray intensity measured in the lower atmosphere /40/, in the stratosphere /38/, and on the Earth /42/. Any reliable correlation with solar activity has not been found for the given period, although the examination of the problem of solar activity fluctuations /43, 62/ shows that they are of stationary character on time intervals of about 2-3 years. One of the possible mechanisms for the occurrence of cosmic ray variations with periods irrelevant to cyclic solar activity consists in the natural oscillations of the heliosphere as a whole /63/. The period of the oscillations, which are generated by the disturbing effect of the large-scale inhomogeneities of the interstellar medium or the solar wind, was estimated in /63/ to be probably from 2 to 10 years*).

*) The problems concerning the variations of the atmospheric parameters due to solar activity (accompanied by description of the mechanism for their occurrence) are discussed in sufficient detail in /7/.

2.3 About the presence of the annual component in the solar activity cycle.

The problem concerning the annual component of solar activity cycle, its features, and the dynamics of its appearance and disappearance is of great importance when studying the geomagnetic effects of cosmic rays associated with the features of the heliolatitude distribution of solar activity /1, 2, 59, 64-72/ with the inclination of the plane of ecliptic to the helioequator plane. The solar activity variations with periods close to a year were sought in /70-72/ using the information about the total sunspot area within a single revolution of the Sun for the Sun as the whole and for its northern and southern hemispheres separately. The information related to 11-year cycles Nbs. 12-18. The sliding-mean method was used for each of the cycles to plot the curves of the temporal behavior of the sun spot areas on the basis of four points. Individual cyclic curves were superimposed on each other to attain the best fit. A variation with a 1.3-year period has been discriminated by superposing the curves common to the whole sun.

The separate processing of the data for the northern and southern hemispheres have made it possible to discriminate the periodic components of about 1.2 - 1.4 years. The found 1.2-year periodicity is independent of the number of a given 11-year cycle and forms a continuous series throughout the entire examined period (1878-1954). No noticeable and systematic phase shift occurs between the 1.2-year activity variations in the northern and southern hemispheres. The found period was shown in /73/ to be one of the harmonics in the hierarchy of the 11-year, 1.2-year, 25-26-day, 1.8-day, 3^h40^m, etc. oscillation processes in the convective zone. Similar studies for cosmic rays were carried out using the HL-index /67/ because an annual cosmic ray variation must occur in the presence of heliolatitude dependence of solar activity and solar wind velocity due to the non coincidence between the planes of the Sun's equator and of the Earth's orbit. The same variation is also observed in the monthly means of the neutral component intensity (Inuvik and McMurdo) averaged over 1965-1973. The amplitude of the variation is 0.34% with a maximum in January (corrections for the temperature effect and for the noncyclic variations were introduced).

The character of the annual cosmic ray variation implies the existence of a 8 %/A.U. transverse cosmic ray density gradient which is symmetric relative to the plane of the Sun's equator. The Yakutsk ionization chamber data for 1954-1973, the neutron component data from Inuvick and McMurdo were used to find the effect of the sun's magnetic field sign reversal in the annual and half-year variations of cosmic ray density. The periods when the annual variation phase of the IMF regular component was $\varphi = 0^\circ$ and $\varphi = 180^\circ$, which corresponded to the sign reversal moments of the Sun's general magnetic field, were examined. The annual and 6-month vectors of cosmic ray density were obtained for those periods using the harmonic-analysis methods. The annual vector occurred in March of the years with $\varphi = 0^{\circ}$ (1959-1969) and in September of the years with $\varphi = 180^{\circ}$ (1954-1958, 1970-1973). The value of the annual vector was 0.34∓0.007 % in the neutral component and 0.05 ± 0.001 % in the meson component. The 6-month cosmic ray density vector was 0.15 ± 0.007 % for neutrons and 0.02 ± 0.001 % for mesons. The direction of the vector inverses from one period to another. The long-term changes of the annual and 6-month variations in cosmic rays and solar activity exhibit a sufficiently high variability from year to year, with the annual wave amplitude being usually 2-3 times as large as the 6-month wave amplitude in a given year. The absence of any anomalies in the behavior of the annual and 6-month waves of solar activity and cosmic rays indicates that the high variability of their amplitudes and phases arises from the existence of wide-band noise.

The 3.10^{-8}- 3.10^{-7} Hz cosmic ray intensity variation spectrum calculated using the Deep-River data for each 11 years of the 1960-1984 period can be properly approximated by the law $P(f) \sim A\ f^{-2.4\pm0.5}$. In this case the 6-month wave exceeds only a 90% confidence interval, whereas the annual wave is much in excess of a 95% confidence interval, although not always. An even more complicated correlation (compared with CRI and W), which varies from cycle to cycle and depends on the solar activity phase is observed between solar activity and the geomagnetic and atmospheric processes. The explanation of the annual wave in cosmic rays by the presence of the same wave in solar activity /40/ (except the indicated geometric factor) is not unreasonable, although the two causes are different to distinguish between them. Besides, as noted in /5/, the annual wave in the mean-monthly Wolf numbers is not very stable and should be regarded as one of the random functions in the self-correlated time series.

2.4 Relationships of solar activity to geomagnetic and atmospheric processes.

By affecting the Earth's magnetosphere, the solar activity produces two main types of magnetic storms: first, the so called sudden-commencement magnetic disturbances which are associated with chromospheric flares and vary within the 11-year cycle in phase with solar activity). A sudden commencement results from the arrival to the Earth of the front of a hydrodynamic shock wave generated on the Sun during a strong ejection of particles from a chromospheric flare and giving rise to a rapid squeezing of the Earth's magnetosphere. The second type of storms is characterized by a 27-day recurrence and by the highest occurrence frequency within 1-3 years before solar minima. Such storms occur when the Earth traverses the sector boundaries of the IMF corotating with the Sun at a 27-day period.

According to /71/, the Sun's general magnetic field is peaking within 1-2 years before solar minima, so the magnetic fields in the sectors are most intensive just during these periods. The sectorial boundaries are most geo-effective when the direction of the IMF vertical component changes from northward to southward in the ecliptic coordinate system /72/. The IMF effect on the Earth's magnetic field is due to the presence of the IMF southward component which permits the IMF lines to merge with the geomagnetic field lines on the day side of the magnetosphere, thereby giving rise to an enhanced transfer of the field lines to the magnetospheric tail and, as a result, to violent merging of the field lines in the tail, i,e. to a commencement of a magnetospheric disturbance /71/.

The long-term variations of geomagnetic disturbances reflect clearly the 11-year, 22-year, and secular (80-90 years) solar activity cycles /71/. The 22-year geomagnetic activity cycle was examined in /74-79/. The flare-generated magnetic storms typical of the 11-year cycle maxima have been shown to be developed stronger in odd cycles, while the recurrent disturbances developing during the cycle decrease branch are stronger in even cycles. Therefore, the geomagnetic disturbances are more rightful to be associated with the 22-year cycle of the Sun's magnetic activity.

The fluctuations of the Earth's climate are also polycyclic. The cycles are of durations of 2-3 years (the quasi-biennial cycle), 4-7, 10-12, 20-23, and 80-90 years /71-80/. Spectral analysis of a 1000-year series of the index of the deuterium-to-hydrogen content ratio in arbor rings was made in /19/ (the variations of the index are proportional to the atmospheric temperature variations). The spectral analysis has made it possible to discriminate a 22.36 ± 0.04-year period which is close to the 22-year solar activity cycle. The similarity of the periods tells for a relationship between weather and solar activity. The 11-year cycle, which is basic in the spot formation activity of the Sun and exhibits a very large amplitude has been shown in /73/ to have a much weaker influence in the meteorological indices; its amplitude is as a rule smaller than that of the 22-23-year cycle. The direction of the Sun's general magnetic field is known to change near the 11-years solar cycle maximum, so a pronounced change in the character of the relationships may be expected during such a period. This is but one of the possible explanations for the absence of any clear 11-year cycle in the meteorological processes, compared with the 22-year cycle.

It is assumed in /73/ that geophysical cycles of 7-8, 12-13, 15-17, and 33-month durations can occur. Many of these cycles and shorter cycles may be related to the respective solar activity cycles, namely, the 27, 13-14, 9, or 6-7-day cycles can be found in all the meteorological indices including the various atmospheric circulation indices /7, 81/. Similar cycles are also observed in the characteristics of the Earth's magnetic field disturbance /82/. The 6- and 9-day rhythms in the Earth's atmosphere are assumed in /23/ to be related to the sectorial structure of the IMF. The 9-day period corresponds to six sectors with three geoactive boundaries, while the 6-7-day cycle corresponds to eight sectors with four geoactive boundaries. Thus, the occurrence of common "solar" rhythms in the atmospheric processes and in the geomagnetic disturbances may indicate that they arise from their common solar cause associated with the sectorial structure of the IMF. Relationships of the lower atmosphere with the IMF and with the solar wind were found directly in numerous works. The sign of the correlation between solar wind velocity and atmospheric parameters (pressure, air temperature) proves to reverse when the Earth moves from one IMF sector to another. The sectorial structure of the IMF is associated with the variation of the vorticity index (defined to be an area, in km^2, where the circulation related to unit area reaches 2×10^{-4} s^{-1}) corresponding to a properly formed cyclone on the 300 and 500 mb isobaric surfaces in the northern hemisphere /83/. The winter season area of low-pressure regions of valleys in the northern hemisphere reaches its minimum a day after the Earth traversed an IMF sector boundary.

In this case, the percentage of the vorticity minimum appears to be higher in the tropospheric regions characterized by a more intensive circulation. The statistical processing of the 1952-1977 data made in the work /85/ has shown that the dimensions of cyclonic flutes depend strongly on the IMF polarity. A decrease of the dimensions of the low-pressure flutes is greater when the field is sunward, i.e. the IMF sector is negative, whereas a decrease of the dimensions is much smaller when the field is offsun. The work emphasizes the fact that the passage through some of the sectorial boundaries is accompanied by a few-MeV proton flux observed within several days. In this case the vorticity index minimum associated with the boundaries followed by the proton fluxes is almost two times as deep as the minimum associated with the conventional boundaries. The boundaries with proton fluxes were found to be accompanied by a great increase of the IMF intensity. Using the 1968-1973 data of observations of cosmic ray intensity with the neutron supermonitor at Apatity, allowing for the IMF observation data and the data on the vorticity area in the troposphere (the VAI index) and applying the epoch superposition method (the moment of passage through an IMF sector boundary is taken to be the zero day), it was found /84/ that:

(1) a passage through an IMF sector boundary gives rise to a stable effect in VAI (some 20%), whereas the effect in cosmic rays proves to be unstable,

(2) an increase of the cosmic ray flux by about 0.5% within five days with a subsequent decrease by 1.0-1.5% within 3-4 days was observed in the case of 21 passages of the IMF boundary,

(3) any cosmic ray effect is absent within measurement errors in case of 28 passages;

(4) the cosmic ray effect does occur in case of 17 passages, but is of opposite character compared with the case (1) .

It has been concluded in /84/ that the effect of the IMF sector boundaries on the tropospheric vorticity index cannot show itself through cosmic rays; the effect of cosmic rays on the tropospheric processes is not excluded, but it must show itself in a different manner.

The effect of high-velocity fluxes on atmospheric circulation, geomagnetic activity, and galactic cosmic rays is treated in a number of works. A pronounced decrease in galactic cosmic ray intensity has been found to begin within 1-2 days before a velocity maximum occurs in the solar plasma stream and to reach its minimum on the first day. The decrease effect disappears completely on the 4th-5th day. The behavior of the geomagnetic activity index k_p exhibits a clear maximum on the day with the plasma stream velocity maximum.

The areas filled with deep cyclones in moderate latitudes are found to decrease sharply in the middle and upper troposphere of the northern hemisphere at the moment when the Earth is inside a high-velocity solar plasma stream. Similar results were obtained by authors in /86-88/ who demonstrated that an increase in solar wind velocity gives rise to a decrease of cyclonic activity in the troposphere. The latter circumstance is probably due to an intensity decrease in galactic cosmic rays /89/ which has an impact on the troposphere circulations disturbances. Indeed, this effect can be traced clearly when studying the solar flare effect on the Earth's atmosphere which results in atmospheric circulation variations in middle and high latitudes as early as within 12 hours after a flare. Attempts were make in recent years to verify the relationships between the cyclonic disturbance development, on the one hand, and the Earth's passages through the IMF boundaries, the high velocity solar wind fluxes, and solar flares, on the other hand. The relevant studies have made it possible to conclude that:

(1) the passages of the Earth through the IMF sector boundaries give rise to a vorticity decrease coinciding in time with geomagnetic disturbances and with a rearrangement of the cosmic ray fluctuation spectrum /90/;

(2) vorticity increases occur after large solar flares in the 0 - 44^0E heliographic longitude interval;

(3) a strong enhancement of vorticity accompanied by powerful geomagnetic disturbances can be associated with the flares which are located in the eastern part of the solar disc, and occur by series.

Thus, we deal with complicated relationships among solar activity, geomagnetic disturbance, cosmic ray intensity, and atmospheric processes. The character of the relationships among all the relevant events may vary greatly during different periods and can be different in different regions. In some regions, especially over the northern part of the Atlantic Ocean, geomagnetic disturbances are followed by an increased variance of the near-surface pressure variability /91/ which reflects the level of conversion of useful potential energy into kinetic energy. This circumstance must have an impact on the wind field. Indeed, the analysis of 90-year observations of near-surface pressure /91/ has shown that the atmospheric instability in the moderate latitudes of the northern hemisphere (in particular over the northern part of the Atlantic Ocean) increases after strong geomagnetic disturbances (by the 2nd - 4th day). That is why the study of possible relationships between wind velocities, atmospheric vorticity, and cosmic ray fluxes in the given region, on the one hand, and the global solar activity on the other hand becomes very important for understanding the solar-terrestrial relationships /92/.

Nevertheless, it has been quite clear that the modulation of the cosmic ray flux observed on the Earth is defined by the same processes as those defining the atmospheric parameters, namely, power shock waves in interplanetary space, geomagnetic space, geomagnetic disturbances, etc. Therefore, the relationships between the atmospheric processes and the cosmic ray processes are quite unambiguous /3/; moreover, since cosmic ray intensity correlates closely with solar activity, analyzing the atmospheric circulation parameters in combination with cosmic ray intensity may be used as a basis when developing the methods for diagnosing the state of the atmosphere /93, 94).

3.- Methods for Joint Analysis of Cosmophysical and Meteorological Factors.

3.1. Spectral analysis of the series to be analyzed.

The solar activity parameters (Wolf numbers W, sunspot area index S), the geomagnetic and atmospheric disturbances (K_p-index and stormicity $\mathcal{P}$), and the cosmic ray intensity, CRI, were analyzed by the method of correlational and spectral analysis /95-103/. In practice, the techniques for estimating the spectra include several stages, namely, a preliminary analysis, the calculations of selected correlation functions and spectral estimates, the calculations of mutual correlation functions and spectral estimates, and the interpretation of the obtained results.

The preliminary analysis is to study the time series with a view to finding their steady state and to reduce them, if necessary, to steady-state or quasisteady-state form /95,104/ to discriminate the clearly expressed trends and periodicities in the studied data set (which is of importance when deciding if a filtration has to be made), and to make a test analysis. If the preliminary has shown that most of the power is carried by one or several singled-out frequencies, the selected estimates in a studied frequency band must be improved by filtering the data, i.e. by converting each of the initial series, x_t and y_t into a certain set of data x'_t and y'_t by various linear or quasilinear relationships /95-102,104/. To decide whether the initial or filtered series is to be used in the analysis and to select the width of the window for inspecting the series studied in the analysis, it is necessary to calculate the selected covarational (or correlational) functions.

$$C_{xx}(\tau) = (1/(N-1))\sum_{t=1}^{N-k}(x_t - \hat{x})(x_{t+\tau} - \hat{x})$$

for the values $\tau = 0, 1, 2, \dots L_{max}$. (The value of the cutoff point L_{max} is selected on the basis of the criterion that the selected correlation must be minimum; the point L_{max} is reached when the selected correlations $c_{xx}(\tau)$ become to be of the order of 0.05 - 0.1. The problem of using the initial or filtered series is solved using the condition of vanishing their correlation functions /100/).

After deciding if the initial or filtered series are to be used and after selecting the cutoff point, the selected spectral densities $\tilde{S}_{xx}(f)$ are calculated (to avoid confusing terminology, it should be reminded that the spectral density of a studied process is the Fourier-transform of their correlational (or covariational) function:

$$\tilde{S}_{xx}(\ell) = 2\Delta[C_{xx}(0) + 2\sum_{\tau=1}^{L_{max}-1} C_{xx}(\tau)W(\tau)\cos 2\pi\ell 2\Delta] \qquad (1)$$

where (Δ) is the discretization interval of a studied series; $W(\tau)$ is the correlation window with the cutoff point M selected using the relation $M = L_{max}$ (a great number of correlation windows exist /95-98,104/ each of which has its merits and disadvantages as applied to particular problems). The correlations among various processes are sought for by the mutual analysis /95-97,104/ which consist in calculating the mutual correlation functions to find the delay time of one of the studied processes relative to another from the maximum value of the mutual correlation coefficient or for the shift of r between the position of the mutual correlation function maximum and the value $r = 0$.

The delay time of one process with respect to another is important to find when studying the correlations among solar activity, cosmic ray intensity, geomagnetic activity, and the processes in the Earth's atmosphere and may be used later when making attempts to predict the processes occurring on the

Earth on the basis of the observed variations in solar activity, in cosmic rays, etc. The formulas for discrete estimating the mutual spectra are similar to the formulas for estimating the spectral densities of one-dimensional processes /91/. Besides, the mutual analysis yields information about the phase difference between the analyzed processes at each frequencies (the phase-shift spectrum) and about the correlation degree of the processes at different frequencies (the coherence spectrum). As shown in /98/, if two series within a certain frequency band are shifted by a time interval with respect to each, i.e. may be present as

$$x_{2t} = z_{2t} + \beta z_{1t-d}, \quad x_{1t} = z_{1t},$$

hence $$x_{2t} = z_{2t} + \beta_1 x_{1t-d}$$

so that at the phase-shift spectrum in the given frequency band is a linear function of frequency. This means that he cosine wave of frequency f(Hz) has fd oscillations within the delay time d and, therefore, the phase delay is $2\pi fd$ (rad). Thus, the phase-shift spectrum showing the phase differences between the studied processes may be used for each frequency to find the delay time of one series with respect to another, the fact that may prove to be of great importance when constructing long-term and shorter-term predictions.

The solar activity, the geomagnetic and atmospheric disturbances, and the cosmic ray intensity were analyzed by the power-spectrum method /95-97,104/, by the one-dimensional and two-dimensional (Hissa) spectral analysis /98/ by repeated correlation transformation /97/, and the methods of the theory for periodically-correlated random processes /97-103/. Use was made of the mean-monthly values of solar activity (Wolf numbers W and sunspot group indices S) in 1945-1977, of cosmic ray intensity (the Moscow, Apatity, and Kiel observation data) in 1963-1982, of geomagnetic activity (the K_p and A_p indices) in 1945-1977, and of atmospheric circulation (the stormicity index $\mathcal{P}$) in 1950-1977. The spectral estimates were calculated throughout all the studied periods in total and for 72 and 120 monthly realizations with a 12-month moving shift (to obtain a time-extended pattern of the behavior of the correlational and spectral estimates throughout the period from the end of the 18th solar activity cycle to the beginning of the 21st cycle).

The reliability of the obtained results was controlled by simultaneous application of various spectral methods, by application of specially designed procedures (date filtration, "convergence" of spectral windows, etc.), and by application of the test programs. The calculations of the spectra are described in detail in /95-104/; the allowance should only be made for the fact that the estimation of the shifts between the processes by either calculating the highest value of the mutual correlation from the shift

$$K_{xy}(\tau) = \frac{1}{N} \sum_{t=1}^{N-\tau} (x_t - \hat{x})(y_{t+\tau} - \hat{y}) / G_x^2 G_y^2$$

or using the shift τ between the maximum of the mutual correlation function and zero as a preliminary stage of any calculations of the mutual spectra.

The test trials of the programs have made it possible to specify the applicability of different analysis methods under one or another condition, namely, for particular events and data arrays. Fig. 1 shows the results of the test trials of the program of dynamic spectral analysis for the function

$S(\ell) = \sin(\ell_0 + \Delta\ell_i) + \sin(\ell_1) + \sin(\ell_2)$, (the first four steps of the program). In this case $\Delta\ell_i$ was varied in each step. From Fig. 4 it is seen clearly that, since the positions of the peaks are in practice the same at frequencies ℓ_1 and ℓ_2 (K = 62 and 65), the peak at the frequency $\ell_0 + \Delta\ell_i$ (K = 20) shifts slowly towards higher frequencies, thereby tracing the variation $\Delta\ell_i$.

It should be noted that, in practice, all the spectral methods are applicable to the steady-state processes, whereas all the analyzed processes are not of steady-state character. Therefore, the calculations of the spectra, especially the dynamic spectra, were made after filtering the data to be analyzed.

3.2 Spectral analysis of the sunspot numbers and meteorological parameters.

For general use in frequency studies of solar activity and different meteorological parameters, researchers utilized some special programs for spectral and autoregressive analysis of time series:

1) the classical Fast Fourier Transform (FFT),
2) the maximum entropy method (MEM),
3) the Lomb-Scargle periodogram method including, optionally, a fast evaluation scheme /6/,
4) the CLEAN deconvolution method, including in an integrated computational step the possibility to reconstruct time series from the derived spectral components /6/,
5) the autoregressive method of the spectral analysis (ARMA).

Any sampling can be thought of as multiplying a fictitious continuous function by a window function whose values are zero except at sampled points. According to the Fourier *convolution theorem*, the Fourier spectrum of the product is the convolution of the two Fourier spectra. This means that the underlying spectrum of data will be smeared (convoluted) by the spectrum oft he window, the so-called spectral window function. A window that itself has periodic features will "beat" them against any periodicities in the data.

The use of FFT power spectrum for estimates of the power spectral density P(f) of the discrete Fourier transform by peridogram methods lead to a P(f) being described by a finite Laurent series in the complex plane /105/. A formal expression for representing the true underlying spectrum would be an infinite Laurent series, so the truncated series is only one type of analytic approximation /6, 105/. The maximum entropy method (MEM) can have poles in the z-plane, corresponding to infinite power spectral density, at real frequencies in the Nyquist interval. Such poles can provide an accurate representation for underlying spectra with sharp, discrete "lines" or delta functions. By contrast a finite Laurent series can have only zeros, not poles, at real frequencies, and must thus attempt to fit sharp spectral features with essentially a polynomial /94-98, 104, 106, 107/.

The Lomb-Scargle method has a computational burden of 10^2N^2 for a data set of N points, limiting its application to data sets no larger than, say, 10 for work stations. In work /106/ it is presented a fast evaluation scheme for the Lomb-Scargle method, preserving its mathematical properties and having only an operation counts of the order $10^2 N \log N$. The fast algorithm makes feasible the Lomb-Scargle method to data set as large as 10^6 points and, it is already faster than the conventional evaluation for data sets as small 100 points /108, 109/.

The CLEAN deconvolution technique is a new approach to the problem of estimating the complex frequency spectrum of a continuous function sampled only a finite number of discrete times /110, 111/. Based on a complex, one-dimensional version of the CLEAN deconvolution algorithm frequently used in two-dimensional image reconstruction, this technique is a simple way to remove the artifacts introduced by missing data. At present, it seems to be the only method suitable for irregularly sampled time series for which the true spectrum may be multiply periodic or quasiperiodic.

For tested different methods of the spectral analysis, Andreasen /6/ applied four spectral analysis techniques on the Zurich time series of sunspot numbers R(t). Results from application of the Fast Fourier Transform are given in Fig. 5. Results of the power spectra for the Lomb-Scargle method, CLEAN deconvolution method and MEM are shown in Fig. 6. The Lomb-Scargle spectrum dives the highest spectral resolution and is fully consistent with the CLEAN spectrum with maximum peak at a period near 100 years /6/. Using an order of 150 in the MEM approximation its spectral peaks coincide almost with the positions of the two other methods (peak periods of Lomb-Sargle: 21.7, 29.0, 40.7, 52.7, 59.5, 92.8, and 110.5 years; CLEAN: 21.1, 29.0, 40.3, 54.6, and 103.1 years; MEM: 21.1, 29.0, 40.7, 55.2, and 89.2 years). The dominating long period corresponds to the Gleissberg cycle of 88 years /112-115/.

3.3. The methods of self-regression analysis for estimating the relationships between cosmophysical and meteorological parameters.

The pure spectral methods are expedient to use simultaneously with the independent methods with different properties for finding periodicity. (The latter is essential when making a mutual control of the obtained results). Besides, the statistical characteristic of some of the analyzed processes appear to be rearranged substantially, i.e. the processes becomes to be of unsteady-state character. In this case, the notion proper of spectrum is not defined, while the classical transformation based on the BPE and Blackman-Tewkie method yields incorrect results too frequently.

The conventional technique used in the situation of the given type, namely, to discriminate the quasisteady-state regions /101/ is faced with some difficulties. Such regions (if any) may be short, but the Fourier method gives poor results with scanty data and makes it impossible to discriminate close frequencies. At the same time, discrimination of close frequencies is one of key points of the examined problem because each of the frequencies may be related to various physical mechanisms of interaction between the cosmophysical and meteorological parameters /94/. The frequency in the long and short regions are separated nowadays by the so called self-regression methods. The essence of the methods is to introduce an additional assumption that a studied process may be described by the self-regression model

$$x_{t+1} = \sum_{i=0}^{p} a_{i+1} x_{t+1} \qquad (2)$$

of an order p unknown in advance. The assumption is used to estimate, by one or another method, the self-regression coefficients and to select the best, in a sense, order, whereupon the coefficients are used to calculate the spectrum unambiguously. The approach of such a kind with different algorithms (of the type of the Berg, Levinson-Dervin, Pisarenko, Pronie techniques and their modifications) has also been realized in the described method. In some cases the approach yielded quite satisfactory results, but has proved to be also inapplicable for essentially unsteady-state events.

We proposed that the above mentioned difficulties should be overcome using the following approach. A process was assumed to be describable in terms of the self-regression model in which the coefficient proper vary in time:

$$x_{t+1} = \sum_{i=0}^{p} a_{i+1}(t)x_{t+1}, \qquad t = 0,\ 1,\ 2,\dots \tag{3}$$

in this case we deal obviously with an unsteady-state process. Each of the coefficients is presented as a series in a certain prescribed total set of functions $\{\varphi\}_k$

$$a_i(t) = \sum_{k=1}^{N} C_{ik}\ \varphi_k(t) \tag{4}$$

with unknown coefficients (C_k). In particular, the power series 1, x, x^2,... may be chosen to be a set of the functions. After that, the coefficients C_k are calculated by the least squares method for a selected number N of expansion (4) and order p. The model order p and the number of terms N in the expansion (4) may be selected to be optimal in a sense. The given approach makes it possible to introduce the concept of instantaneous spectrum for an unsteady-state process. At each given time moment t^*, the estimated parameters (C_{ik}) are in correspondence with the self-regression model at the known constant coefficients

$$a_i(t^*) = \sum_{k=1}^{N} C_{ik}\ \varphi_k(t^*). \tag{5}$$

Let a process of this type be called a process stopped at moment t^*(it may be continued to infinity). The process is of steady-state character and is in correspondence with a certain spectrum which can unambiguously be calculated analytically using the coefficients (5). The spectrum of a process stopped at moment t^* will be called the t^*-instantaneous spectrum of an examined process. The occurrence of a rearrangement in the process may be studied by constructing a sequence of instantaneous spectra on the basis of t^*.

The discussed method realizes all the above-described approaches, namely, the techniques of direct Fourier transformation and its modifications, the techniques based on the self-regression models, and the method of instantaneous spectra. Depending on a given particular situation, the approaches are used in different combinations, thereby making it possible to study time series in more detail and to control the obtained results.

All the above described methods were used to construct a data processing system based on the unified system of computers in which some subsidiary procedures were also realized, namely, the filtration of high and low frequencies, the exclusion of regular variations, the estimation of disordering process (i.e. of the occurrence of unsteady-state character), and the calculations of the basic statistical parameters of the process.

The following requirements were imposed on the computer-based processing system and were met when realizing the system:

(1) an extended dialogue with the user,

(2) a feasibility of data processing with different carriers,

(3) a feasibility of creating and building-up a data bank,

(4) an easy access to any data series,

(5) the presentation of results as clear visual plots,in particular, the construction of a dynamical pattern of the process spectrum rearrangement.

4. Studying the Correlational and Spectral Characteristics of Cosmophysical and Meteorological Processes.

The examined events were analyzed using the data arrays at 336 points (28 years) and 168 points (14 years) whose lengths made it possible to study fluctuations with periodicities from 2 months to 22 years. Fig. 7b shows the mutual correlation functions of stormicity $\mathcal{P}$ in 1950-1977 and those of Wolf numbers in 1945-1972 (curve 1), 1946-1973 (curve 2), and 1950-1977 (curve 3). From the curves it is seen that a shift of 6-7 years at a minimum is required for the stormicity and solar activity to be levelled completely (curve 1, Δk = 2 years at a prescribed shift by 5 years). At the same time, the decrease of the prescribed shift between the series down to 1 year (curve 3) shows that the processes of stormicity and solar activity are, first, opposite in phase and, second, shifted by 3.5-4.0 years with respect to each other. The specification of this estimate with smaller data intervals (Figs. 7b, c) gives similar results, namely, from curves 1 and 2 in Fig. 7b and from curve 2 in Fig. 7c; it may be concluded that the delay of $\mathcal{P}$ with respect to W was $\Delta K = 4$ years in 1949-1963 and $\Delta K = 3$ years in 1961-1976; the total delay ΔK throughout the period from 1950 to 1974 was some 45 months. The use of sunspot area S as an information parameter leads to the same values of ΔK (curve 1 in Fig. 7c).

Similar calculations of the mutual correlation functions between the parameters of solar (W) and geomagnetic (K_p) activity (Fig. 8a) have shown that the K_p index is delayed by 1-1.5 years relative to W and that the two processes are synphaseons with each other throughout the entire 24-year realization. At the same time, the mutual correlation analysis between $\mathcal{P}$ and K_p shows that stormicity is delayed by 1.9-2.5 years /64/ (the processes are apposite in phase), in a good agreement with the results presented in Fig. 7.

The results obtained are in a good agreement with the analysis of the effect of cosmic ray intensity delay relative to the helio-latitude solar activity index which shows that the Δk value varies from 6 to 20 months depending on the solar activity cycle. Indeed, the calculations of W and CRI for the periods of 1970-1984 (Apatity) and 1970-1982 (Moscow) have yielded Δk

~ 10 months (curves 1 and 2 in Fig. 8b). In this case, as must be expected, the solar activity and the cosmic ray intensity are opposite in phase. The calculations of mutual correlation functions between CRI and $\mathcal{P}$ in 1970-1977 (Fig. 8b, curve 1 for Moscow and curve 2 for Apatity) have shown that stormicity is delayed by 3 years with respect to cosmic rays, the result which coincides, allowing for the analysis results W-CRI (Fig. 8b), with the calculated delay of $\mathcal{P}$ relative to W.

The calculated power spectra of each of the analyzed processes exhibit a complicated structure, especially in the high-frequency band (from 2 to 8 months) and show the pronounced annual, biennial, and 10-12 year variations in stormicity and in the rest of parameters.

The results obtained are in good agreement with the conclusions drawn from the analyses of the various geophysical and heliophysical processes made in recent years /116-120/. The spectral analysis of the amplitude variations of the 11-year solar activity cycle /116/ and the Earth's magnetic field /117/, heliopheric pulsations /118, 119/ and the Earth's atmosphere /120/ has revealed similar periods. The spectrum of the quasi biennial geomagnetic field variations was interpreted in /117/ to be the spectrum of the amplitude-modulated process with a carrier-frequency period of about 20 months and a modulating frequency period of about 10 months. The comparison of the quasi-biennial geomagnetic field variations /117/ with solar activity indices /118/ has shown that they exhibit common variations of 1-1.3- and 2-year periods. A similar result was obtained in /119/ for the go- and helio-activity, namely, the variations in the parameters of the background IMF (with changing longitude and solar cycle phase) may be brought in correspondence with the annual and half-year variations of sunspot areas, the number of chromospheric flares, and the cosmic ray intensity variations (thereby confirming the assumption set forth earlier that the similarity between the geo- and helio-activity variations is due to the Earth-Sun orientation in the anisotropic medium surrounding the Sun /119/). The 3-4 month periods in all the helio- and geo-physical events have also been confirmed /120/, in a good agreement with the results of /121, 122/. (It should be noted that a quasi-biennial cycle can also be seen in the fluctuations of a less intensive index of storm activity, namely, severity of storms, i.e. in the recurrence of storms with a wind velocity of $\geq$ 17 m/s).

Studying the stormicity has shown that the following four cycles can be discriminated in the time series of stormicity in the North Sea:

(1) a diurnal cycle arising from the differences in the heat capacity of the underlying surface,

(2) a synoptic cycle resulting from the actions of cyclones and anticyclones,

(3) an annual cycle relevant to the seasonal pulsation of the energy-active zone intensity in the northern part of the Atlantic Ocean,

(4) the climatological (many-year) cycle arising from various geophysical factors including, probably, the heliotroposphere factors.

The occurrence of the quasi-biennial and 3-4-month fluctuations in the stormicity spectra and in the spectra of the of rest of parameters (though less pronounced) makes it necessary to go over to more detailed values of the examined processes, namely, the weekly and, maybe, mean-daily estimates are desirable to use when studying fluctuations with periods of several months. Analyzing the mean-monthly values of $\mathcal{P}$, W, and K_p has shown that the spectra exhibit substantial peaks (in excess of a 95%-confidence interval) corresponding to the variations of the given parameters with periods of 10-12 and 2 years and of 11-13 and 3-4 months. Fig. 9 shows the spectral densities calculated for the values of $\mathcal{P}$ in 1950-1977 (Fig. 9a, b), W in 1950-1974 (Fig. 9c), K_p in 1950-1974 (Fig. 9d), and CRI at Apatity (Fig. 9e) and Moscow (Fig. 9f). The comparison among the results obtained has demonstrated a good coincidence among some of the peaks discriminated. (It should be noted that the authors dwell deliberately on the peaks in excess of a 95% confidence interval; as to the peaks of smaller amplitudes, their reality and structure have to be studied additionally.) The spectral estimates obtained are in a good agreement with the results of /18-20, 44-50, 55-57, 64-67, 76-84, 86-88, 92-94/. (In some of the works the mean-monthly values of cosmic ray intensity at Moscow, Leeds, Inuvick, Deep River and Alert in 1965-1979 and of solar activity in 1900-1975 were used to calculate the spectral densities and to find the statistically-significant peaks corresponding to the fluctuations with periods of 1-1.3, 2-2.1, and 10.7-11.2 years).

It should be noted that, whereas the occurrence of some of the peaks in the spectra can be explained by the splitting of the basic peak at frequencies of 2.7-3.1 x 10^{-9} HZ (a 10-12 year wave), the annual and even quasibiennial and 3-4-month fluctuations arise from pure physical factors because the amplitudes of the peaks corresponding to these fluctuations exceed the splitting of the basic peak obtained by mathematical simulation. (The model studies of the spectrum made using the method of /40/ have shown that the amplitude of the 3 x 10^{-9} Hz peak cannot give rise to the amplitudes of the peaks at the rest frequencies. After introducing the conditions of random variations of the phases of all harmonics and the presence of "noise", it appears that the amplitude variations at the basic frequencies show that the systematic and random changes of the 11-year wave phase distort the spectra at frequencies $\leq 10^{-8}$ Hz only. The slow trends at frequencies above 5-6 x 10^{-9} Hz do not affect the spectral in any way substantially. Sharp increases enhance the low-frequency side of the spectrum, thereby affecting the value of $B_\perp$ (interplanetary magnetic field strength) substantially (if the spectrum is prescribed to be of the form of $B_\perp \mathcal{F}^{-\gamma}$) and the spectral index γ to a lesser degree. The behavior of the cyclic solar activity phase cannot be considered to vary according to the random walk law /1, 2/, thereby confirming again the conclusion that the 3-4-month, annual, and quasi-biennial variations of stormicity $\mathcal{P}$, of solar and geomagnetic activity, and of cosmic ray intensity CRI are of physical origin.

Similar results were obtained also by mutual spectral analysis of W, $\mathcal{P}$, K_p and CRI. Fig. 10 presents the results of calculating the mutual amplitude spectra lg A and the coherence spectra SK^2 for solar activity W and stormicity $\mathcal{P}$ (Fig. 10a-d) as well as for sunspot areas S and $\mathcal{P}$ (Fig. 10e). The figures show clearly that the two processes exhibit annual and 3-month variations. Filtering the low-frequency data (the variations with periods above 5-6 years were filtered) makes it possible not only to discriminate quasi-biennial variations but also to see a more detailed structure of the spectra in the high-frequency range. Comparing among the coherence spectra has demonstrated a high correlation among the peaks discriminated and a good frequency coincidence in SK^2 for all the periods studied (the peaks in SK^2 proved to be similar as regards frequencies and were not affected, in practice, by the "smearing").

Similar spectra were also calculated for pairs of different parameters: $\mathcal{P}$-K_p, $\mathcal{P}$-CRI, K_p-CRI, W-K_p and W-CRI. Fig. 11 shows the mutual amplitude, lgA, spectra and the coherence, SK^2, spectra of solar activity and cosmic ray intensity in 1970-1982 at Moscow (Fig 11a) and in 1970-1984 at Apatity (Fig 11b), as well as the mutual spectra of cosmic ray intensity in 1969-1976 and stormicity in 1970-1977 at Moscow (Fig. 11c) and Apatity (fig. 11d). The spectra displayed in Fig. 11 not only confirm the occurrence of the found variations but also demonstrate a high reliability of them ($SK^2 \cong 0.8$ at the singled-out frequencies). The comparison of the power of the peaks discriminated with model calculations shows that the observed variations are quite independent, rather than arise from the splitting of the basic-frequency peak. It is also of importance that the value of the coherence between stormicity and solar activity, geomagnetic activity, and, partly, cosmic ray intensity at the singled-out frequencies exceed the value of the coherence at the rest frequencies and fails to decrease below o.4.

The spectral estimates obtained are in a good agreement with the results of spectral analysis of the characteristics of the ocean-atmosphere energy exchange /123/. This work present the results of statistical processing of the 20-year time series of the mean-monthly values of water and air temperatures and of turbulent fluxes at five stations in the region of the northern part of the Atlantic Ocean. The spectra and correlation functions of the series used have been obtained. The analysis of the spectral estimates and of the correlation functions has revealed the time scales of variabilities within a year and between years which proved to coincide with the spectral estimates of stormicity, solar activity, and cosmic ray intensity, namely, 3-6 months and 1-2 years.

5. Dynamic Spectral Analysis.

One of the main procedures made before the mutual analysis of various procedures is to "level" the series with respect to each other. In conformity with the results described above, the W series was shifted with respect to the $\mathcal{P}$ series on the average by 36 points (3 years) to obtain significant relations between solar activity and stormicity. However, in the course of the moving dynamic analysis, the maximum of the mutual correlation function appears to be shifted with respect to K = 0 towards a decrease of the delay in the initial 8-10 steps of analysis and towards a delay increase afterwards. Fig. 12 presents the mutual correlation functions for different steps of the program (the numerals at the curves). Fig. 12b shows the shift of the correlation function maximum position (corresponding to the delay of stormicity with respect to solar activity). From the plots it is seen that the delay $\Delta\mathcal{P}$ with respect to W was about 33-36 months during the period from 1945-1955 to 1949-1959, decreased to some 23-26 months in the next seven steps of the program (the period from 1950-1960 to 1956-1966), and, after that, increased rapidly up to 45-48 month during a single step. These results get importance when developing the methods for diagnosing the state of the atmosphere by regular observations of solar activity because quite a definite relationship occurs between the delay $\Delta\mathcal{P}$ and solar activity cycles, namely, the delay was about 36 months during the normal cycle of 1944-1954 (the years of minima).

It is this value that is probably characteristic of the Sun-atmosphere relationships. Starting from the fourth step of the dynamic analysis program, the atmospheric processes begin to be actively affected by the next cycle (the program moves over 120 points with a constant 12-point shift) of 1954-1964 with an anomalously high maximum in 1959, so that the reaction of the atmosphere (a stormicity delay) decreases to two years and is preserved until the years of the maximum in cycle 19 (1958-1959) are present in the analyzed data array. (From general considerations, such a relationship seems to be quite obvious because much more energy was supplied to the atmosphere during the maximum of cycle 19, compared with solar activity cycles 18 or 20, so that the atmosphere must have "responded" more rapidly).

Later on, in 1964-1975 (after the tenth step of the program) the delay $\Delta\mathcal{P}$ increased sharply up to 43-45 months, the fact that is probably due to the anomalously low solar maximum in cycle 20 (the year of 1969). Further calculations for 1973-1978 made using 6-years data arrays have shown that the delay decreased to $\Delta\mathcal{P}$ = 35-38 months, thereby confirming again that the 3-year shift between solar activity and atmospheric reaction is quite normal. (The fact that any accurate estimate for each year cannot be obtained by the method used is a substantial drawback of the latter; so, although Fig. 13 carries useful information on the Sun-atmosphere relationships, it is of interest to estimate the examined processes for much smaller realizations than 6 or 10-11 years).

Nevertheless, the existing dynamic analysis program for each of the studied series (Fig. 13a, b) and for the mutual characteristics of the two processes (Fig. 13c) permits the following conclusions: the dynamic spectral analysis of solar activity demonstrates a complicated structure of the variability of the spectral density of the analyzed data; throughout the program, the spectra obtained are characterized by a set of fluctuations (peaks) in practice at all frequencies from ~ 10^{-7} to 10^{-8} Hz which exhibit a substantial variability.

At the same time, some fluctuations are preserved for a long time; in particular, the fluctuations at frequencies of about $1.25 \cdot 10^{-7}$, $4 \cdot 10^{-7}$ and $3.3 \cdot 10^{-8}$ Hz corresponding to the variations with periods of 3-4 months and 1 year. It should be emphasized that the singled-out peaks not only can be seen clearly in Fig. 13a (the dynamic spectrum of W) but also (which is particularly important) do not in practice walk in frequency, thereby indicating that the given variations are permanent.

The quasi-biennial variations are seen less clearly in the dynamic spectra because, probably, the analyzed data arrays are of restricted lengths and, besides, the real factors which give rise to the quasi-biennial variations on the Sun are either present or absent. Comparing the results of the dynamic spectra with similar spectra calculated for cosmic ray intensity shows a sufficiently good correction (of the order of 0.5-0.6) of them, in agreement with the results of /53-55, 121/.

It should be noted also that the most single-out frequencies are discriminated by the dynamic spectral analysis for 1955-1958, i.e. for the periods with anomalous behavior of solar maxima. Although the amplitudes of the peaks at the singled-out frequencies do not, as a rule, exceed a 90%-confidence interval (except the peak at $3 \cdot 10^{-8}$ Hz), the surprising persistence of the occurrence of the peaks in practice in all spectra indicates that they are true.

A similar pattern is observed also when calculating the dynamic spectral densities for stormicity. Fig.13 b shows the dynamic spectra of stormicity in the low-frequency band, $\leq 10^{-7}$ Hz. The peak at $3.2 \cdot 10^{-8}$ Hz is clearly seen in all the examined time intervals, while the $1.6 \cdot 10^{-8}$ Hz peak is less stable, in a good agreement with the results of /53-54/. The comparison among the singled -out peaks corresponding to the stormicity variations with periods of about 1 and 2 years in all time intervals and the calculations of the mutual dynamic spectra (Fig. 13c) show that, first, the observed quasi-biennial stormicity variations are unstable and, second, the given variations are less powerful compared with not only annual but also even 3-4-month stormicity variations.

Stimulating the power spectra $\mathcal{P}_p$ and $\mathcal{P}_w$ of stormicity and solar activity in the form $\mathcal{P}_p \sim \mathcal{P}_w \mathcal{H}(f)$ makes it possible to estimate the low-frequency variations using the behavior of spectral index. Fig. 13d presents the slope indices of the power spectra of stormicity $\mathcal{P}_p$ and solar activity $\mathcal{P}_w$ (curves 1 and 2, respectively). It is seen that the slope indices exhibit explicit 23-year and 11-year variabilities. By analogy with the studies of cosmic ray power spectra, the behavior of the spectral indices of $\mathcal{P}_p$ and $\mathcal{P}_w$ may be one of the most important criteria when developing the methods for predicting the mean characteristics of stormicity. In this case, the selection of the form of the transfer function between $\mathcal{P}_p$ and $\mathcal{P}_w$ becomes important. Studying the behavior of the dynamics of individual peaks is possible to obtain some conclusions concerning the long-term modulation of small-scale disturbances of meteorological parameters by solar activity. Fig. 14a-c presents the behavior of the amplitudes of the 2-month, 3-month, and annual variations of the mutual spectral characteristics; whereas any time dependence is difficult to find for the 2-month variations (under pronounced changes of phases in the first and second halves of the analysis), the 3-month variations (seen clearly in Fig. 13c) are modulated with a period of about 22 years at, in practice, a constant phase difference between $\mathcal{P}$ and W of about 1 month and at an invariable spectrum of coherence of about 0.65-0.85. As to the amplitude variations in the mutual spectra at a frequency of $\sim 3.3 \cdot 10^{-8}$ Hz, they exhibit a clearly-expressed 11-year modulation. In this case the phase difference defining the shift between the processes at the given frequency is in a good agreement with the results of calculating the mutual correlation functions.

The results obtained have been properly confirmed by calculating the instantaneous spectra. The entire dynamics of the behavior of the peaks and of the rearrangement of the processes from one solar activity cycle to another can be traced when studying the instantaneous spectra of stormicity, solar activity, and cosmic ray intensity in 1945-1984. Thus, the results of the mutual correlational and spectral analysis of stormicity, solar and geomagnetic activity, and cosmic ray intensity have made it possible to find quite a set of stormicity variations associated closely with the variations of the heliomagnetic and (to a lesser degree) geomagnetic activity, particularly in the 2-5 and $8 \cdot 10^{-8}$ frequency bands.

It should be noted that the dependence of atmospheric events on solar activity factors cannot be reduced to only an adequate reflection of various processes and to a rise or fall of the values of their parameters during the branches of solar activity cycles (the analysis for small intervals of sampling makes it possible to trace the behavior dynamics of spectral estimates), but proves to be the process of rearrangements of amplitudes and, partly, phases (because the method can be used only to study the phase difference between the processes) of the set of relatively small-scale variations with periods of about 3-4, 8, and 10-11 months and large-scale variations with periods of 1, 2, and 10-12 years. In this case it is of importance to emphasize a relatively constant mean delay between stormicity and solar activity which makes it possible to expect that a method for tentative estimating the mean stormicity level 1-2 years ahead will be obtained (after constructing the appropriate models).

The dynamic analysis of the long-term modulation of the small-scale (3-4 months and 1 year) and large scale (11 years) variations of stormicity by solar activity has revealed at least two possible sources of the observed variations, namely, the various solar processes giving rise to the 11-year and 22-year variations in solar activity and in stormicity. Considering the respective difference in the delays for individual frequency bands (the delay is about 6 month for the frequency $\mathcal{F} = 8\text{-}10 \cdot 10^{-8}$ Hz), we may expect that an attempt will be made to carry out a shorter-term and, hence, more accurate prediction of stormicity.

Together with the researches of the circulation processes (anomalous wind forcing in the Atlantic Ocean) a great deal of efforts have been addressed to the study of the El Niño effect /124-141/. El Niño/Southern oscillation (ENSO) is the well known phenomenon described as an anomalous warm stream in the Ecuatorian and Peruvian coast [as indicated by the tropical pacific sea-surface-temperature (SST)] which according /132/ might be associated to the southern oscillation with a duration of about 3 months. Studies of the influence of aurorae, geomagnetic and solar activities on the El Niño have been widely reported in the literature, particularly in the last decade, (e.g. /130, 133, 136, 138, 140/. In paper/136/ it is analyzed the relation between the geomagnetic activity in auroral zones and the ENSO: it is argued that such kind of activity is translated in an enhancement of the temperature, mainly in the pacific ocean surface during the winter when an anomalous wind circulation pattern affects the ocean circulation pattern, giving rise to an ENSO. By retaking that work and by decoding the wind circulation spectra with autoregressive spectral analysis, for both the atlantic and pacific oceans, in addition to the 90-year oscillation /93/ have found also 22- and 400-year oscillations. By considering the Wolf number as solar activity index in /128/ it has been found on basis to ENSO data of /143/ an inverse correlation between the number of ENSO events per sunspot cycle and the size of the sunspot cycle with a certain tendency for high intensity ENSO events to occur in the declining phase of the sunspot cycle, and those of moderate intensity to occur more frequently around sunspot minima. Speculations have also been given in relation with a possible correlation between ENSO events and aurorae activity, and also with the atmospheric quasibiennial oscillation (AQBO) /139-145/ and decadial secular variations, the latter results that are in good congruence with those of /146, 147/.

Most of the previously mentioned results are based on data of a limited number of solar cycles, so that all those correlations are relatively useful for the task of predicting ENSO events, either in the future or in the past. However, since no physical mechanism is enough convincing to explain the link between solar and geomagnetic variations to wind and the wind fields to El Niño events, the obtained correlations are still seen of coincidental nature. As many other phenomena in the field of solar-terrestrial physics, until the physical models will be able to jump from the qualitative level to the quantitative status /148/, it is a natural reaction of the scientific community to remain in the skepticism at these regards.

6. Cosmic ray variations and lower atmosphere circulations.

A number of studies consider cosmic rays as a connecting link between solar activity phenomena and lower atmosphere conditions. Tinsley et al [149] reviewed these studies and present their own investigation regarding the impact of Forbush decreases of galactic cosmic rays (GCR) on the area encompassed by cyclones in the northern hemisphere, i.e., the so-called vorticity of atmosphere index. It was shown that this index is decreased when GCR flow weakens. It was suggested that GCR affect the ionization rate in the lower atmosphere and hence the creation and growth of icy particles in the upper layers of clouds. Whether this will be an effect of cosmic rays in solar activity-atmosphere relationships or not remains still to be seen [149, 150]. The purpose of this paper is to investigate the impact of cosmic ray variations on the zonal circulation of the lower atmosphere.

In works /151, 152/ it is discussed the reaction of atmospheric circulation to changes of cosmic ray intensity, and statistically significant changes in the large-scale atmospheric circulation, when Blinova's index reaches the value $\alpha/\omega \sim 10^3$. These changes are connected with intensive ($K_p \geq$ 35) sporadic geomagnetic disturbances and preceding solar flares. It was found that the intensity of zonal circulation increases after 1-2 days of the flare occurrence; then the intensity decreases with the development of geomagnetic disturbance.

Therefore, the idea was conceived that these changes in circulation are connected with cosmic ray variations. These variations, along with circulation changes, are opposite in sign to geomagnetic disturbances (Forbush decreases of GCR) and energetic solar flare particles (SCR). Analysis of circulation changes during the 11-year solar activity cycle [153] has shown that variations of solar and galactic cosmic rays, with energies of 1 - 10 GeV, may have a pronounced effect on the intensity of large-scale circulation in the lower atmosphere.

These variations may cause circulation changes which connect with geomagnetic disturbances and solar flares. These effects are recognizable during analysis of separate events on a scale of few days as well as for the 11-year solar activity cycle. Therefore, cosmic rays can play the role of the connecting link between solar activity phenomena and lower atmosphere conditions. Cosmic ray variations are more effective for analysis of atmospheric circulation during the 11-year cycle than are sunspots numbers. The energy range of the cosmic ray particles which influence atmospheric circulation more effectively, allows us to conclude that the effects of cosmic rays in the lower atmosphere result from stratospheric processes connected with changes in the ionization rate.

7. The Solar Cycle and Dynamo Theory /6/.

The Sun's magnetic field is thought to be generated in a magnetohydrodynamic dynamo associated with motions of the electrically conducting fluid in the convective zone. The theory of dynamo magnetic field generation crystallized initially in paper /154/. Two characteristics of the fluid motion are essential to effective regeneration of magnetic fields: advective angular momentum transport in the convection that induces differential rotation, and the action of the Coriolis force causing the convective motions to be cyclonic, or helical. Sunspot presumably result from the emergence of buoyant flux loops that have broken away from a main toroidal magnetic field below the surface. Two oppositely directed toroidal magnetic fields, one in each hemisphere, are assumed to propagate from mid-latitude to the equator in 11 years, followed by a similar scenario during the next 11 years with the opposite polarity.

In the kinematic dynamo theory the fluid flow is prescribed a priori and the magnetic field considered as a passive contaminant. The question this type of theory seeks to answer is whether there exists conceivable flows which have a dynamo property, for instance, which have the property that initially weak seed fields are amplified. The various aspects of the kinematical theory have been reviewed for example in /155, 156/. The latitudinal, differential rotation of the Sun produces a toroidal field component from a poloidal field, called the Ω-effect. The physical mechanism most likely to produce a poroidal field component from the toroidal field is due to convection in a rotating fluid. Arising convection cell will not horizontal field lines upward in a Ω-shaped stitch of flux, but also twist them due to the Coriolis effect. This twisting of field lines into the meridional plane is known as the α-effect.

Kinematic α-Ω dynamo models obtain an axis-symmetric magnetic field from a linear magnetic induction equation that is turned by independently parameterizing the effects of differential rotation and helicity. The two dimensionless numbers that are important in governing the dynamo are: $D_\alpha = \alpha R/\eta$, which characterizes the production of poloidal field through helicity generated by the interaction of rotation and convection; and $D_\Omega = \Omega' R^3/\eta$, which measures the generation of toroidal flux from the shearing flux by differential rotation (where α is related to the mean helicity, η is the magnetic diffusivity, and Ω' is the differential rotation rate ~ Ω/R). With this freedom a highly parameterized kinematic model can generate a dynamo wave that propagates towards the equator with about the right period. In order to let the dynamo work at finite field amplitude a non-linear mechanism is introduced, which determines the amplitude of the generated mean magnetic field B by "cutoffs" at large B of the α-effect and (or) the shear. Work /156/ complemented their α-Ω dynamo by an extra equation governing the shear. But although some beautiful results have been obtained, the many approximations must not be forgotten. Perhaps the severest approximation is the first orders smoothing of the electric field, which on the Sun is marginally valid; at best.

A more ambitious approach is to solve the full partial magnetohydrodynamic differential equations, including the equation of motion (as opposed to flows being given a priori) and without explicitly averaging over small-scale turbulent eddies. Dynamic dynamo models simultaneously solve the MHD equations for the velocity, thermodynamic, and magnetic fields with full nonlinear feedback. Calculation of global dynamo action in a spherical shell is exceedingly demanding in computing power, since spatial scales ranging from global down to a fraction of a scale height must be represented. Numerical investigations of the dynamic theory have been attempted by a number of workers. A critical survey that exposes the strengths and weaknesses of dynamo theory are provided by /158/.

The first successful self-consistent dynamo model for an anelastic gas with a significant density stratification was computed in /159/. The toroidal field is generated mainly by differential rotation which shears the poloidal field. The poloidal field is generated by helical fluid motion which twists the toroidal field. A crucial property of the model is that the form of motion is determined by the Coriolis force, which leads to convection in cells elongated parallel to the rotation axis. However, that work /159/, does not obtain a self-consistent solution with a differential rotation profile that matches that observed on the Sun; the discrepancy leading to poleward emigration of the simulated toroidal field. The importance of these calculations is as a demonstration that the dynamo process really works, even though that details do not match observed features of the solar cycle.

Others have attempted to model turbulent dynamos in a relatively simple Cartesian geometry, the advantage being that the individual processes are easily identified /160. They simulate compressible convection in a stratified rotating system, and show that magnetic fields can be maintained by dynamo action if the magnetic Reynold number is sufficiently high. Most of the generated magnetic field appears as coherent flux tubes in the vicinity of strong downdrafts, where both the generation and destruction of magnetic field are most vigorous. There is no systematic cyclic behavior but the computations show that turbulent convection in a rotating star is bound to generate small scale magnetic fields.

From a mathematical perspective the existence of classical solar dynamos is not in question, but there remains the question whether such dynamos areactually realized in nature; i.e. whether the applied mathematical assumptions are in fact physically justified. The first problem is the actual location of the magnetic dynamo process in the interior of the Sun. It is well known that magnetic fields are buoyant in a stratified medium, a physical effect which is not generally accounted for in the standard mean field dynamo models and parameterizations of buoyancy are not really satisfactory because they may not properly describe the buoyancy process in a convective unstable field. In work /154/ it has been shown that for a mean field strength greater than 100 G, the buoyancy rise rate in the solar convection zone may be sufficiently large that the α-effect is suppressed, excluding a broadly distributed field generation in the convective zone. Although a conclusive understanding of the consequences of buoyancy is not yet at hand, there is significant dynamical reasons for suspecting that the solar magnetic field might be generated at the bottom of the convection zone or in its undershoot layer.

The undershoot layer has the crucial property that it is stable stratified against convection and for this reason the magnetic buoyancy can be treated as an instability problem. Investigations of the linear instability properties of this layer showed that multiply-diffusive instabilities might lead to formation of flux bundles, reminiscent of discrete active region complexes /161/. Crude estimates suggest a field strength of the predominantly azimuthal field of order 10^4G in a layer of 10^4 km thick. Where the field is locally stronger (~ 10^5 G) it becomes unstable to buoyancy-driven instabilities giving rise to isolated flux tubes, which rise to the surface and form active regions /162/.

A question lying at the very core of all dynamo models is the justification for assuming turbulent diffusion (mixing) of the magnetic field. Whether this idea is applicable or not to strong magnetic fields is very arguable as a simple energy argument may demonstrate. In work /163/ it has been performed numerical simulations of randomly forced motion in an incompressible, two-dimensional magnetized field and find that a small critical field strength indeed exists, and that if it is exceeded, the turbulent cascade of magnetic energy is interrupted. If the turbulent diffusion of the magnetic field does not operate for the interesting range of values for the large-scale magnetic field mean field dynamos could not function in nature. However, the results for suppression of turbulent diffusion in two dimensions may not be representative for three dimensions, since a 3-dimensional fluid has the freedom to arrange fluid motions such that the magnetic back-reactions are minimized. But, as a result of the ineffective three-dimensional turbulent diffusion in presence of strong azimuthal magnetic fields, the standard dynamo equations are not likely to provide a reasonable description of stellar magnetic dynamos, so that a number of works propose new sets of dynamo equations taking into account the modifications of the turbulent diffusions by strong magnetic fields.

A second outstanding problem of the dynamo theory is the influence of the angular velocity profile Ω on the character of the dynamo modes. One factor governing the direction of propagation of the dynamo wave is the sign of the gradient $d\Omega/dr$. Application of conservation of angular moment in a radially convecting fluid naively suggests that the general trend of the differential rotation is $d\Omega/dr < 0$, so angular velocity increases inward. Helioseismological measurements during the last decade have provided observational insight into the Sun's rotation. A recently deduced rotation curve suggests that, at low latitude $d\Omega/dr > 0$, while at mid-latitude $d\Omega/dr \sim 0$. Calculations indicate that dynamo modes generated with this form of no nonuniform rotation tend not to migrate at all but instead the oscillatory magnetic mode loiters in mid-latitudes /164/. Furthermore, helioseismic data has shown that strong gradients of Ω are only present near the base of the convection zone /165/. The transition from the latitudinal variation observed at the surface to solid body rotation takes place over a range of depth too small to be resolved ($< 0.1\ R_0$) at or just below the base of convection zone/166/.

As a dynamic system the magnetohydrodynamic dynamo is capable of chaotic behavior. The essential control parameter of such models is the dynamo number, D, which is a dimensionless product of the shear due to differential rotation and the α coefficient. For D below a critical value there exists a periodic solution in their models. For slightly higher values of D the periodic solution becomes unstable; it may first be replaced by multiply periodic and finally by chaotic solutions.

In work /112/ it is compared observations of the solar-induced variations with the behavior of the model in /157/the vicinity of the transition between the Freigenbaum period doubling regime and the chaotic regime. In the millennium before the Maunder Minimum, the solar activity (measured by mid-latitude auroral observations) showed a stable and well-established 88-year cycle. Most of arguments for the solar dynamo being close to the chaotic domain, rest on two observations:the phase of the of the 88-year cycle is lost at the emergence of the Maunder minimum and the irregular intervals between periods of suppressed activity observed in ^{14}C records. The argument that the dynamo remains close to the bifurcation between period doubling and chaos is that the 11, 22, and 88 year variations form part of a period doubled set.

In work /167/ the dynamo model is formulated in spectral form. They demonstrate that the type of solution, in particular the transition to chaotic behavior, critically depends on the number of Fourier components taken into account. Low-order systems (overtruncated) tend to reach chaotic solutions already at moderate dynamo number via a sequence of subharmonic bifurcations, with a period doubling at each bifurcation. The transition to chaos has its signature in the simulated power spectra: first the addition allow frequencies together with their natural harmonics appear; finally the spectrum is more or less continuous. Higher-order systems have limit cycles even at large magnitude of the dynamo number; their route to chaos include two- and three-dimensional tori in phase space. Although estimates of the solar magnitude of shear and α-effect differ it seems that the dynamo number D certainly has a sufficient magnitude to render low order systems chaotic. Perhaps the magnitude of D is in the range where a limit cycle with a period of 22 years is a stable solution. If a bifurcation point to a T^2 torus or a strange attractor is close to the actual solar dynamo number, then small perturbations of the cycle could lead to extended periods of "abnormal" wandering of the trajectory in phase before settling again to the stable cycle. Long-term modulation and intervals of low activity would be apparent consequences.

8. Feasible Mechanisms of the Effect of Cosmophysical Factors on Atmospheric Processes.

Several probable mechanisms of the effect of cosmophysical factors on the lower atmosphere have been shown to exist in /86-88, 122-148, 168-171/, namely:

1. The mechanisms based on the changes of the solar (astronomical and meteorological) constant.
2. Additional infrared (IR) emission during magnetic storms.
3. Effect of solar wind on the atmospheric electricity parameters.
4. Condensation mechanism.
5. Ozone mechanism.
6. Hydrodynamic interaction between the upper and lower atmospheric layers.

An important factor in any of the discussed mechanisms is the heat influx from the external sources, namely, solar flares, interaction of solar plasma with the magnetospshere, geomagnetic storms, magnetospheric convection, particle precipitation to polar regions, generation of additional quantities of nitrogen dioxide and ozone by solar and galactic cosmic rays in the lower stratosphere; effect of solar activity on the electric field of the atmosphere, etc. The feasible mechanisms of the Sun-weather relationships may include the solar heating of the troposphere (a radiation modulation by 0.1% results in a 0.02-0.04 mb amplitude of pressure at the surface), the heating of the troposphere by the terrestrial radiation (to compensate for a solar radiation by 0.1%, the surface temperature must change by 0.2 K), the direct heating of upper levels (with subsequent transfer downwards by wave propagation), the indirect effect of heating (through the changes of the hydrodynamic wave reflection altitude depending on the zonal wind component defined by ozone heating), the trigger mechanisms (allowing the internal instability of the troposphere), the cloud cover (through the changes in the number of condensation nuclei), the vorticity generation (through the anomalies of vertical motions), the shifts of the phase or amplitude of solar thermal tides. The changes of the climate and temperature in the northern hemisphere are in a good agreement with the changes in the position of the geomagnetic pole on the Earth's surface.

A feasible mechanism of their relationships was reviewed in /148/ which can be briefly described as follows: the corpuscular streams arriving from the Sun give rise to the global disturbances of the Earth's magnetosphere generating the electric fields in the outer magnetosphere which, in turn, excite the intensive electric currents in the auroral oval (the "auroral electrojet"). The currents give rise to a substantial increase (by a factor of more than 10) of geomagnetic activity which leads eventually to the heating of the lower atmosphere and to a decrease of atmospheric pressure in the magnetic pole region which prove atmospheric pressure in the magnetic pole region which prove to be sufficient for a cyclone formed in the geomagnetic pole region to give rise to the respective changes of the climate and weather in the neighboring regions.

The researches into the problem of the relationships between weather and the variability of the Sun and of solar wind may be divided into three groups, namely, (1) the climatic changes within hundreds and thousands of years, (2) the variations correlating with the 22- and 11- year solar activity cycles, and (3) the variations within several days. In any case, the allowance for the solar activity effect using the observational data on geomagnetic activity, cosmic ray intensity, etc. is of great importance when studying the short-term and long-term atmospheric processes. As indicated in /72/, the character of the solar activity effect depends to a great extent on the spectra of the electromagnetic and corpuscular emissions from the Sun, on the current state of the solar and interplanetary magnetic fields /123, 172/, on the Earth's heliolatitude, and on the geographic region of the studied atmospheric processes /84/ in each particular case. Therefore, simulating the solar activity effect on atmospheric circulation must allow also for any additional information because the use of only the Wolf numbers to find the long-term relationships is not always justified /172/.

A detailed analysis of the experimental data given in our work has shown that there are some contradictions in such a data. The main causes of the contradictions noted are the following /173/:

1) the effect of solar activity in the various manifestations of weather are observed against a background of appreciably more intense atmospheric processes.

2) the atmospheric effect of solar cosmic rays (SCR) from flares and geomagnetic disturbances depends significantly on the coordinates of the observation site, on the season, on the phase of the solar cycle and on the state of the atmosphere.

3) in many papers the very possibility of the action of SA on weather is

automatically rejected from the standpoint of the energetics: actually, the power of the atmospheric processes ~ 10^{27} erg/day, whereas solar wind power is about 10^{23} erg/day. (However, it is worth to mention that from the point of view of energetics the effect of SA phenomena on the earth environment is through a non negligible "*peck effect*" /148/).

Nevertheless, a number of different researches propose that the influence mechanism of SA phenomena is based on the change of Atmospheric Transparency according to the prevailing level of SA, manifested through the action of GCR and SCR. This concept assumes that the solar wind is not the main energy source of atmospheric disturbances, but act only as a modulator of solar energy. Under this assumption one can assert that the modulation of the energy flux entering the lower atmosphere is caused mainly by variations of the Atmospheric Transparence /173/.

The physical mechanism of the action of solar activity on the state of the lower atmosphere and meteorological parameters can be represented as illustrated in Fig. 15 of /173/. Solar activity causes changes in the intensity of the plasma streams and the frozen magnetic fields of the solar wind. The solar wind modulates the GCR and SCR in such a way that a reinforcement of cosmic ray variations is felt in the lower atmosphere. These variations of SCR and GCR stimulate the occurrence of physico-chemical reactions in the atmosphere, so that changes in the content of NO, NO_2, O_3 and and water vapor are induced, as well as in the density of the cloud *cover*, all this resulting in alterations of the atmospheric integral Transparency. In work /174/ it is described how, as a result of the action of the cosmic rays on the atmosphere, a distinctive "gray filter" is formed which screens (shielding) the infiltration of the GCR and SCR themselves in the lower atmosphere. An increase of SA should lead to a higher screening of the cosmic rays, hence, to a decrease of the NO, NO_2 and O_3 concentration, and so, to an increase of Atmospheric Transparency. Analogous effects should take place in periods of local disturbances in the interplanetary space (near the earth), solar flares and Forbush-events. As shown in /152/ the Atmospheric Transparency should increase during periods of SA maxima and decrease during the minima of the cycles.

Also, geomagnetic activity (GA) should influence on the Transparency, as we know it does on the GCR and SCR fluxes /66, 67, 176, 177/. In this connection one can assume, on the basis of the model of the action of solar activity on the lower atmosphere /173/, that the action of SA on the temperature, pressure, precipitation, solar radiation, circulations, wind velocity, etc. will be manifested differently during even and odd cycles. Hence, in view of this asymmetric action a 22-year SA variation should be exhibited in the meteorological and climatological parameters /177/. One more consequence of the Pudovkin's model /173/ are the climatological and meteorological changes in periods of the reversals of the constant background geomagnetic field, confirmed also by other authors /178-181, 186, 187/.

As well, the experimental confirmation of the Pudovkin's model of the action of SA on the lower atmosphere state was done in /50, 182/: in order to check the model , those authors studied the variations of the atmosphere's Transparency in the course of the development of a geomagnetic disturbance /182/, the variations of atmospheric pressure /183/ and the change of atmospheric circulation [118], the variations of the air temperature in the course of solar and magnetic activity cycles /173, 181/. In /173/ it is demonstrated the existence of a 22- year temperature variation of higher amplitude than the 11-year variation. The pretty good correspondence of the spectra draws attention to itself: peaks at the periods T = 11-13, 22-28 and 80-90 years are observed on all results, that wholly correspond to those found in /181/. All the obtained results can be interpreted in the context of the Pudovkin' model. Actually, the results in /173, 181/ show that the predominance of a 22-year cycle as proposed by the model for the behavior of the meteorological parameters under the action of SA and GA is confirmed.

In /173/ is also shown the results of the influence of the solar proton flares on the variations of the components makeup of the atmosphere: the analysis of the behavior of O_3, NO_2 and NO indicates that a noticeable change of their contents in the atmosphere occurs in the course of the development of solar and geomagnetic disturbances, which should alter the atmosphere's Transparency.

All experimental studies of the influence of the SA on meteorological and climatological processes confirm the mechanism given in /173/, as we shall emphasize in the last section. However, a quantitative comparison of the additional energy input in the atmosphere upon a change in its Transparency with the energy necessary for stimulation of dynamic processes in the atmosphere (as discussed in /151/) is necessary for future confirmation of the idea being advanced.

The amount of solar energy per cm^2 at the upper boundary of the atmosphere during 24 hours is

$$Q = 2S_o/\rho^2[\tau_o \sin\varphi\sin\delta_o + T/2\pi\cos\varphi\cos\delta_o \sin(\omega\tau_o)],$$

where S_o = solar constant,

ρ = sun-earth distance in its average value,

δ_o = sun's declination,

T = period of the earth's rotation,

ω = angular velocity of the earth rotation,

τ_o = time of sunrise and sunset relative to the moon,

$\cos(\omega\tau_o) = -\tan\varphi\ \tan\delta_o$

The amount of additional energy entering and dissipating in the lower atmosphere during a geomagnetic disturbance is /173/: $\delta W = 2.4 \times 10^{-2}\int Q d\Sigma$, where Σ is the square of the earth's *"radius"*. Calculations of δW shows directly that $\delta W \sim 1.5 \times 10^{26}$ ergs, for geomagnetic storms lasting three-four days, the total δW being of the order of 10^{27} ergs. This value exceeds for three to four orders the energy of the solar wind ($\sim 10^{23}$ ergs) and is commensurable with the energy necessary for the observed change in zonal circulation of the lower atmosphere ($\delta Q = 5 \times 10^{26} - 2 \times 10^{27}$ ergs, /173/).

Thus the proposed physical mechanism of the action of SA and other cosmophysical factor (cosmic rays) on processes in the lower atmosphere, and on meteorological and climatological parameters, evidently permits to explain the origin of the constantly acting source of energy controlled by solar and geomagnetic activity whose powers appreciably exceed the power of the solar wind, and are sufficient for a noticeable action on processes taking place in the lower atmosphere.

9. Simulation of the Interaction between Cosmophysical and Meteorological processes.

The results of studying the cosmophysical and meteorological processes presented above prove that a set of cause-effect relationships exists between solar activity and the rest of processes. The assumption seams to be quite realistic, therefore, that the parameters describing the atmospheric processes (in particular, the stormicity $\mathcal{P}(t)$ may be presented to be a sum of the preceding values $\mathcal{P}(t)$, solar activity W (t), geomagnetic activity $K_p(t)$, and cosmic ray intensity I(t), i.e. to be of the form of the self-regression model:

$$\hat{P}(t) = \sum_{i=1}^{p} \alpha_i P(t - i) + \sum_{j=1}^{q} \beta_j W(t - j) + \sum_{k=1}^{s} \gamma_k I(t - k) + \sum_{l=1}^{m} \delta_l K_p(t - l) + \xi_t \qquad (6)$$

here $\hat{P}(t)$ is the predicted value of stormicity, where p, q, s, and m are the order of the model for each of the series used. The order defines "a look backwards" of each process to predict the stormicity estimates; $\alpha_i, \beta_j, \gamma_k$ and δ_l are the AR model parameters. In this case, as fresh data are being obtained the self-regression estimates get also renewed, thereby offering an opportunity of predicting stormicity one step ahead. (The prediction ahead is made by seeking for the value of a future count in the form of a weighed sum p of the previous counts of P(t), q counts of W(t), s counts of I(t), and m counts of $K_p(t)$). The model may be constructed in two ways:

1.- The accumulated data arrays for stormicity, solar activity, and cosmic ray intensity of dimension N_o each are used to construct a matrix for the set of linear equations (6). After that, the matrix is solved to find the vectors $\bar{\alpha}$, $\bar{\beta}$, $\bar{\gamma}$, $\bar{\delta}$. It should be taken into account in this case that the sets of the self-regression coefficients may be found in practice for any of the accumulation intervals. Some 300 equations may be obtained using the mean-monthly data for the period of 1950-1977. Correspondingly, the number of equations (6) for mean-yearly data reduces to 27-k, where k is the highest self-regression order used; at k = 5 the number of the equations is about 20, so an attempt may be made in this case merely to solve the set (6) assuming that the noise ξ_t is minimum. The solution of the set reduces to solving the set of equations:

$$
\begin{pmatrix}
P_k \ldots P_{k-q} W_k \ldots W_{k-s} K_{p_k} \ldots K_{p_{k-r}} I_k \ldots I_{k-m} \\
P_{k+i} \ldots P_{k+1-q} W_{k+1} \ldots W_{k+1-s} K_{p_{k+1}} \ldots K_{p_{k+1-r}} \ldots I_{k+i} \ldots I_{k+1-m} \\
\vdots \\
P_N \ldots P_{N-q} W_N \ldots W_{N-s} K_{p_N} \ldots K_{p_{N-r}} I_N \ldots I_{N-m}
\end{pmatrix}
\begin{pmatrix}
\alpha_1 \\ \vdots \\ \alpha_q \\ \beta_1 \\ \vdots \\ \beta_s \\ \gamma_1 \\ \vdots \\ \gamma_r \\ \delta_1 \\ \vdots \\ \delta_m
\end{pmatrix}
=
\begin{pmatrix}
P_{k+1} \\ \vdots \\ P_{N+1} \\ W_{k+1} \\ \vdots \\ W_{N+1} \\ Kp_{k+1} \\ \vdots \\ Kp_{N+1} \\ I_{k+1} \\ \vdots \\ I_{N+1}
\end{pmatrix}
\tag{7}
$$

2.- if, however, the number of equations (6) exceeds the number of unknowns $\bar{\alpha}$, $\bar{\beta}$, $\bar{\gamma}$ and $\bar{\delta}$ and any assumptions concerning the minimum value of ξ_t cannot be made, the solution of the set (6) reduces to solving a set of equations for the covariant functions A_{ij}, rather than the values of solar activity, stormicity, geomagnetic activity, and cosmic ray intensity:

$$
\begin{pmatrix}
A_{11} & \cdot & \cdot & A_{14} \\
\cdot & A_{22} & & \cdot \\
\cdot & & A_{33} & \cdot \\
A_{41} & & & A_{44}
\end{pmatrix}
\begin{pmatrix}
\alpha \\ \beta \\ \gamma \\ \delta
\end{pmatrix}
=
\begin{pmatrix}
a_o \\ b_o \\ c_o \\ d_o
\end{pmatrix}
\tag{8}
$$

Obviously, in case of stormicity, for example, we have

$$
P(t-1).P^{*}(t-1) =
\begin{pmatrix}
P^2_{t-1} & P_{t-1}.P_{t-2} \ldots\ldots\ldots\ldots P_{t-1}.P_{t-q} \\
P_{t-q}.P_{t-1} & P_{t-q}.P_{t-2} \ldots\ldots\ldots\ldots P^2_{t-q}
\end{pmatrix}
\tag{9}
$$

similar expressions can be obtained also for the rest parameters W, K_p and CRI used to construct the prediction model. The values of the covariations of A_{ij} and a_o, b_o, c_o and d_o may to be known, for they are calculated from the real data. Hence, the set (8) is a set of linear equations that lead to find the unknown coefficients α, β, γ and δ of the regression equation (6) and can always be solved if only the determinant of the covariational matrix (A_{ij} differs from zero. The second way of solving the set of equations is advantageous due to the absence of the noise ξ_t because the mutual correlations of the noise with the rest parameters are zero.

Thus, by prescribing the model order q, s, r, and m for stormicity, solar and geomagnetic activity, and cosmic ray intensity, we can not only predict the mean values of stormicity one step ahead (the value of the step is defined only by the value of data discretization t) but also help to estimate the contribution of one or another process to the predicted stormicity. Indeed, if the values of one of the sought parameters α, β, γ or δ are small (much below the errors in measuring them), the respective process may be disregarded in the model. For example, when analyzing the mean-yearly dependencies between stormicity and geomagnetic activities, the values of γ were negligible compared with the errors as regards the absolute values too. A detailed analysis has shown that the K_p index alone cannot be used to construct any prognostic model.

The values of stormicity in 1950-1974, solar activity in 1945-1974, geomagnetic activity in 1945-1974 and cosmic ray intensity in 1960-1974 were used to find the values of the model parameters and to estimate the values of P(t) in 1975, 1976 and 1977 which were compared afterwards with the real P(t) values in the same years.

The analysis was carried out using the mean-monthly and mean-yearly values of $\mathcal{P}$, W and I. The 3-years shift Δ(CRI) with respect to $\mathcal{P}$ was preliminary introduced in the mean-monthly values (the shift was not introduced in the mean monthly values). Work /94/ presents the values of the parameters α, β, γ and δ calculated using the mean-yearly values of $\mathcal{P}$, W, and CRI in 1955-1974 at the orders of the model q = 4, s = 4, and m = 3. It should be noted that the number of predictors (order of model) must not be very high; as shown in /184/, the number of predictors must not exceed a tenth of sampling volumes because of a possible correlation among the variables and a restricted sampling. The results obtained have shown that the values of α, β and γ for the entire period do not vary in practice; moreover the P(t) values found for 1975, 1976, and 1977 in terms of a prognostic model with the coefficients α, β and γ from the table differ from the real P(t) values by less than 18% for 1-year predictions, by 27% for 2-year prediction, and ~ 60% for three-year prediction. It should be mentioned,by analogy, that in work /185/ related to solar radiation R(t), predictions in terms of the prognostic model differ from the real R(t) values found for 1993, 1994 and 1995, in 22%, 37% and 50%, respectively.

Thus the use of the standard ARMA-models to develop predictions of solar radiation, lake levels and stormicity stormicity on the basis of the previous values of stormicity P(t), levels of lakes L(t), solar radiation R(t), observation data on solar activity S(T), geomagnetic activity K_p, and cosmic ray intensity CRI(T) is very promising. The results of the first relevant efforts have demonstrated a good agreement between the calculated and experimental P(t) R(t) and L(T) values, so that the further development of such a model will make it possible at least to predict the mean-yearly meteorological characteristics one year ahead, within a 10-20% accuracy. For less accurate estimates to be obtained, the two-parametric model

$$P(t) = \sum_{i=1}^{q} \alpha_i P(t - 1) + \sum_{k=1}^{p} \beta_k W(t - k) + \xi_t$$

is quite sufficient.

10. Summary

Experimental results related to the action of solar and geomagnetic activities as well as other cosmophysical factors (galactic and solar cosmic rays, GCR and SCR, /148, 185/) on the lower atmosphere and meteorological and climatic parameters, including ENSO, have been discussed in the preceding sections. The data given and the results of the simulation of the mechanism of the action of heliophysical parameters on the atmosphere argue convincingly for the authenticity of the physical mechanism of the influence of SA on climatological and meteorological processes, which determining element is the change in transparency of the atmosphere under the action mainly of galactic and solar cosmic rays modulated by solar and geomagnetic activity /13, 173/. Estimates of the energetics of dynamics of processes in the lower atmosphere simulated by solar and geomagnetic activity, and of the additional energy entering the atmosphere upon a changes in its transparency during period of those disturbances have shown that they are similar to each other, which has evidently permitted in work /173/ to exhibit the physical nature of the energy source on the action of solar and geomagnetic activity processes. The geomagnetic disturbances and emissions from the Sun (but not the energy contained in the solar wind) turn out directly to be the source of the phenomena discussed in this work.

The analysis of the works published in recent years have demonstrated a feasible relationships of the atmospheric processes with heliophysical and geophysical events and with cosmic ray intensity. All the published results fall well within the assumption that the activity of the processes in the earth's atmosphere and magnetosphere is affected by the processes occurring on the Sun. Therefore, the processes occurring in the interplanetary medium and the cosmic ray intensity observed on the Earth's surface must be allowed for when solving the problems relevant to finding the mechanisms of the large-scale atmospheric and magnetospheric processes or when making attempts to predict the processes. The first steps in this direction have been made in the present work. The possibilities of research on the influence of the solar activity on climate and meteorological processes have not been exhausted. Those phenomena of solar-terrestrial relationships which determine the action of disturbances on the Sun and in the interplanetary medium on the climatic and meteorological conditions on Earth and on the state of the lower atmosphere are causing the most enlivened discussions at the present time. When in 1932, W.B. Shostakovich /13/ made his very interesting and non celebrated study of the relation of sunspots to temperature, pressure and rainfall and thereby founded modern helioclimatology, did he imagine that only sixty years later we would begin to approach toward this problem?.

FIGURE CAPTIONS

Fig. 1. Robustness of the estimation of solar cycle length from secularly smoothed epochs of sunspot extrema. The cycle length is derived from series of minima epochs (dashed curve) and from series of maxima epochs (dotted), respectively. The cycle length is plotted at the central time of the actual cycle; minimum to minimum (filled circle) and maximum to maximum (open); fully drawn line connects data points.

Fig. 2. Different smoothed curves for the Zurich sunspot number: the dashed curve is the 22-year running mean, and dotted one is the 11-year (running mean (left-hand scale). The fully drawn curve connects points for the average of sunspot maxima R_m over two 11-year cycles and centered at their mean maximum epoch (right-hand scale).

Fig. 3. Smoothed Northern Hemisphere temperature anomalies (right-hand scale) shown together the cycle length (left-hand scale). The symbol (+) represents average values of the temperature record corresponding to individual sunspot cycles is the 22-year running mean of the temperature anomalies. The cycle-length draph is fully drawn with symbols as in Fig.1.

Fig. 4. Tests of the program of dynamic spectral analysis.

Fig. 5. FFT power spectra for different window functions are calculated for 11-yr running mean sunspot numbers spanning from 1732 to 1987 (N=256). The columns at the frequencies $V_k=k/N$ (k=0, 1,...N/2) on the logarithmic abscissa scale are slightly shifted : left most: Parzen window, middle: square. right most: Welch. The curves are Lomb-Scargle periodograms for the same data set as the FFT spectra (fully drawn) and for annual R values from 1732 to 1987 (dashed, only drawn for periods > 20 years), respectively.

Fig. 6. Comparison of power spectra for different methods.

Fig. 7. Comparison of different representations of the long-term solar activity

Fig. 8. Mutual correlation functions of W-K (a), W -CRI, (b) and CRI-P (c) in 1984, where CRI is indicated by I.

Fig.9. Spectral densities S, of stormicity P in 1950-1974 (a), 1954-1977 (b), solar activity in 1950-1974 (c), geomagnetic activity K_p in 1950-1974 (d) and cosmic ray intensity CRI (indicated by I) at Apatity in 1970-1984 and (e) in 1970-1982 at Moscow (f).

Fig.10. Mutual spectral densities of solar activity (W, S) and stormicity (P) with a 2-year shift between W and P (a) and without any shift (b) for the initial and filtered (c, d) series. Spectral densities of S-P in 1954-1977 (e).

Fig.11. Mutual spectral densities of cosmic ray intensity with solar activity (a, b) and stormicity (c, d) for the cosmic ray stations at Moscow and Apatity.

Fig.12. Mutual correlation functions r in various observation periods.

Fig.13. Dynamic power spectra of solar activity (a) and stormicity (b); the mutual dynamic spectra of A (c) in 1945-1977.

Fig.14. Modulation of the amplitudes of 2-month (a), 3-month (b), and annual (c) stormicity fluctuations by solar activity.

Fig.15. Scheme of the action of solar activity and galactic radiation on processes in the lower atmosphere, the meteorological parameters, and the climatic parameters.

AKNOWLEDEGES

Authors would like to thanks the *Dirección General de Intercambio Académico* of the **UNAM** for the partial support to this research.

Editors thanks Dr. William BONDY of the Instituto de Geofísica of the **UNAM** for **his** kind assistance in reviewing the English grammar of this paper.

REFERENCES

1. Chertkov A.D.- Solar Wind and the Sun's Internal Structure, Nauka, Moscow, 1985.
2. Kolvalenko V.A.- Solar wind, Nauka,Moscow, 1983.
3. Dorman L.I. - Experimental and Theoretical principles of Cosmic Ray Astrophysics, Nauka, Moscow, 1975.
4. Vitinsky Yu.I. - Cyclist and predictions of solar Activity, Nauka, Leningrad, 1973.
5. Glokova E.S. - Some date on the effect of solar activity cycle on cosmic ray variations, Trans. NIISM, 1952, v.8, p. 59-70.
6. Andreasen K.G. Solar variability. Technical report of the DMI 95-3. Danish Meteorological Institute, 1995.
7. Lassen K., Friis-Christensen E. Solar activity parametrs used in geophisical studies at DMI. Technical report 92-8, Danish Meteorological Institute, 1992.
8. Brunner W. Tables of sunspot-frequency for 1749-1938. Terr.Magn.Atm. Electr., 44, p.247-256, 1939.
9. Lean J. Variations in the Sun's radiative output. Rev.Geophys.Space Phys., 29, p.505-535, 1991.
10. Bracewell R.N. Simulating the sunspot cycle. Nature. V.323. p.516-519. 1986.
11. Gleisberg W. A table of secular variations of the solar cycle. Terr. Magn.Atm.Electr. V.49. p.243-244. 1944.
12. Jones P.D. Hemisphere surface air temperature variations. J.Climate, 1, p.654-660, 1988.
13. Clayton H.H. Sunspots and the weather. Abstracts of paper by Shostakowich and Memery. Bull.of the American Meteorological Society, 14, 3, p. 65-69, 1933.
14. Dicke R.H. Is there a chronometer hidden deep in the Sun. Nature, 276, p.676-680, 1978.
15. SchattenK.H., Sherrer P.H., Svalgard L.S., Wilkox J.M. Using dynamo theory to predict the sunspot number during the solar cycle 21. Geophys.Res.Letters, 5, p.411-414, 1978.
16. Layden A.C., Fox P.A., Howard J.M. at al. Dynamo-based scheme for forecasting the magnitude of solar activity cycles. Solar Physics, 132, p.1-40, 1991.
17. Kane R.P. Did predictions of the maximum suspot number for solar cycle No 22 come true? Solar Physics, 140, p.171-180, 1992.
18. Forbush S.E. - J. Geophys. Res., 1954, v.59, p.525-542.
19. Vitinsky Yu.I., Ol A.I.,Sasonov B.I. - The Sun and the Earth's Atmosphere, Gidrometeoizdat, Leningrad, 1976.
20. Dorman I.V., Dorman L.I. - On the nature of the delay of cosmic ray variations with respect to solar activity variations. In: Cosmic Rays, No. 8, Nauka, Moscow, 1967, p.100.
21. Neher H.V., Anderson H.R. - Proc. 9th ICRC, London, 1965,v.1, p. 153-159.
22. Simpson J.A. - Recent investigations of the low energy cosmic ray and solar particle radiations. - Preprint N25, Vatican, 1963, p. 323.
23. Dorman L.I. - Cosmic ray modulation in interplanetary space. In: Cosmic Rays, No. 8, Nauka, Moscow, 1967, p. 305-320.
24. Gushchina R.T., Dorman I.V., Dorman L.I., Pimenov I.A. - Solar activity effect on electromagnetic conditions in interplanetary space as inferred from modulation effects of cosmic rays. Izv. Akad. Nauk SSSR, ser. fiz., 1968, v.32, No.11, p. 1924-1928.
25. Pai G.L., Sarabhai V.A. - Proc. 8th ICRC, Jaipur, 1963, v.1, p.190-197.
26. Gnevyshev M.N. - Corona and 11-year solar activity cycle. Astronomich. Zh.,

1963, v.40, No.3, p. 401-412.
27.Parker E.N. - Interplanetary Dynamic Processes, Mir, Moscow, 1965 (in Russian).
28.Hansen S.F., Sawyer C.F., - Geophis. Res. Lett., 1974, v.1, p. 13-20.
29.Stozhkov Yu.I., Charakhchyan T.N. - 11-year cosmic ray modulation and heliolatitude distribution of sunspots. Geomagn. i Aeron., 1969, v.9, No.5, p.803-808.
(.Charakhchyan A.N., Bazilevskaya G.A. Svirzhevskaya A.K., Stozhkov Yu.O., Charakhchyan T.N. - 11-year cosmic ray cycle in the stratosphere and its dependence on solar activity. Izv. Akad. Nauk SSSR, ser. fiz., 1973, v.37, p.1258-1264.)
30.Babcock H.D. - Astrophys. J., 1959, v.130, p.364-366.
31.Leigton B.B. - Astrophys. J., 1964, v.140, p.1547-1562.
(.Parker E.N. - Cosmic Magnetic Fields, (Mir, Moscow, 1982 (in Russian).))
32.Treillis M. - Ann. D'Ap. Suppl., v.5, p.3-80.
33.Howard R. - Solar Phys., 1974, v.38, N 2, p. 283-299.
(.Makarov V.I., Fatyanov M.P. - On the dynamics of filament belts. Solar Data, 1980, N 10, p.96-102.)
34.Alania M.V., Yushina R.T., Proc. 18th ICRC, Bangalore, 1983, v.10, p. 99-104.
35.Alania M.V., Gabunia A.S., Dorman L.I. . Proc. 16th ICRC, kyoto, 1973, v.3, p.633-68.
36.Jokipii J.R., Levy E.H., Hobbard W.B., Astrophyis. J., 1977, v.213, N 3, p.861-868.
37.Attolini M.R., Ceccini S., Galli M. Proc. 18th ICRC, Bangalore, 1983, v.10, p.174-177.
38.Gulinsky, O. et al., Spectral Analysis of Small Scale Cosmic Ray Observation, Kosmicheskie Luchi 24, 63-87, 1987.
(.Charakhchyan T.N., Bazilevskaya G.A., Stozkov Yu.I., Proc. 14th ICRC, Munchen, 1975, v.3, p.1020-1024.)
(.Dorman L.I., Luzov A.A., Mamrukova V.P., Large-scale IMF a solar activity cycle. In: Cosmic Rays, N 11, Nauka, Moscow, 1969, p. 5-22.)
39.Dorman et al., Fluctuations of Galactic Cosmic Rays in Periods of Solar Flares, Proc XXI ICRC 6, 400-403, 1990.
40.Gushchina R.T., Dorman L.I., Ilgach S.F., Kaminer N.S., Pimenov I.A. Solar activity index H and annual cosmic ray variations. Izv. Akad. Nauk SSSR, ser. fiz., 1970, N 11, p. 2434-2438.
41.Glocova E.S..- Some results of studying variations in cosmic ray muon component. Izv. Akad. Nauk SSSR, ser. fiz., 1956, v.20, N 1, p.47-54.
(.Okhlopkov V.P., Okhlopkova L.S., Charakchyan T.N. Biannual cosmic ray variation in the lower atmosphere. Proc. XI-th Leningrad Seminar, 1977, p.382-389.)
42.Djapiashvilli T.V., Rogava O.G., Shatashvilli L.kh. - Proc 18th ICRC, Bangalore, 1983, v.10, p.295-299.
43.Kandaurova K.A. - Statistical analysis and prediction of the Zurich Series of Wolf numbers without a regular part. Solar Data, 1971, N 11, p.80-89.
44.Charakhchyan T.N., Bazilevskaya G.A., Okhlopkov V.P., Okhlopkova L.S. Frequency spectra of long-period cosmic ray variations. Geomagn. i Aeron ., 1976. v.16, N 2.
45.Charakhchyan T.N., Bazilevskaya G.A., Okhlopkov V.P.Okhlopkova L.S. - Proc. 14th ICRC, Munchen, 1975, v.3, 1133-1137.
46.Kolomeets E.V., Shwartzman Ya.E. - Estudying frequency spectra of variations of cosmic ray intensity and of solar activity in low-frequency band. Izv. akad. Nauk SSSR, ser. fiz., 1974, N6, P. 19-23.
47.kolomeets E.V., Chumbalova R.A., Shakova Yu.A., Shwartsman Ya.E., Shigaev B.N. -Frequency spectrum of variations in cosmic ray intensity and in solar activity. Izv. aakad. Nauk SSSR, ser. fiz., 1972, v.36, N 11, p. 2405-2410.

48.Libin I.Ya., Gullynsky O.V. - Fluctuation events in cosmic rays inferred from the data of an omnidirectional scintillation telescope of IZMIR AN. Preprint No. 30 (258), IZMIRAN, Moscow, 1976.
49.Blokh Ya.L., Gulinsky O.V., Dorman L.I., Libin I.Ya., YudakhinK.F., Proc. 17th ICRC, Paris, 1981, v.3, p.231-233.
50.Dorman L.I., Libin I.Ya., Mikalayunas M.M., Yudakhin K.F., Analysis of cosmophyscal and meteorological parameters in solar activity cycles 19 and 20.Geomagn. i Aeron., 1987, v. 27, N 2, p. ?
51.Lanzerotti L.I., Maclennan C.G., Agrawal S.P., Venkatesan D., J. Geophis. Res., 1981, A86, N 8, p. 6951-6956.
52.Lyubimov G.P., Kontor N.N., Pereslegina N.V., Chuchkov E.A., On the 11-year cosmic ray cycle. Izv. Akad. Nauk SSSR, ser. fiz., 1976, v.40, N 3, p. 589-597.
53.Attolini M.R., ceccini S., Galli M. - Proc. 19th ICRC, La Jolla, 1985, v.7, p. 1-5.
54.Charakhchyan T.N. - 11-year modulation of galactic cosmic rays in interplanetary space aqnd solar activity. Issl. Geomagn. i Aeron., 1979, v.34, p. 12-27.
55.Okhlopkov V.P., Charakhchyan T.N., Biannual cosmic ray variations. Geomagn. i Aeron., 1979, v.19, N 3, p.431-438.
56.Minyushina E.M., On a possible effect of solar activity on quasi-biennial circulation cyclicity in solar activity cycles 19 and 20. Trans. Central Aerological Observatory, 1985, N 160, p. 76-84.
57.Anostolovich E.M., On the quasi-biennial oscillation in solar, geomagnetic, and ionospheric activity. Proc. IVth Symposium of CAPG on Solar-Terrestrial Physics, Sochi, 1984, Nauka, Moscow, 1984.
58.Vitinsky Yu.I., Solar Activity, Nauka, Moscow 1983.
59.Gushchina R.T., Relationships of solar activity indices to long-term cosmic ray variations. Geomagn. i Aeron., 1983, v.23,N 3, p. 378-381.
60.Dorman L.I., Soliman M.A. -On the relatinships of sunspots classified according to Waldmeier to cosmic ray variations. Geom agn. i Aeron., 1980, v.20, N 3, p.371-376.
61.Dzhapiashvili T.V., Rogava O.G., Shatashvili L.Kh., Shafer G.V. Quasi-binnial variations of galactic cosmic rays, geomagnetic activity, and atmospheric temperature and pressure. Trans. Gephys. Inst. of acad. Sci. of Georgian SSR, 1985, v.53, p. 94-100.
62.Antonova V.P., Pimenov I.A., Analyzing solar activity to find an annual variation. In: Ionosphere and Solar-Terrestrial Relationships, Nauka, Alma-Ata, 1978, p. 109-111.
63.Dorman L.I. and Ptuskin V.S. - Expected oscillations of the heliosphere and long-term cosmic ray variations. Proc XIth Leningrad Seminar on Cosmophysics, Leningrad, 1979, Ioffe Physico-Technological Institute of Acad. Sci. USSR, p. 367-378.
64.Dorman L.I., Libin I.Ya., Mikalayunas M.M., On a feasibility of an effect of cosmic factors on weather. Regionne Hidrometeorologia, 1986,
65.Mikalayunas M.M., Appication of a modified variation coefficient to characterizing the seasonal occurrence of storms in the North Sea. Papers on Hydrometeorology, Mokslas, Vilnius, 1973, v.6, p. 185-199.
66.Dorman L.I, Gushina R.T. Proc. 15th icrc, Plovdiv, 1977, v.3, p. 263-267.
67.Dorman L.I., Kozin I.D., Satsuk V.V., Seregina N.G., Churunova L.F. - A study of histeresis events, fluctuations, and barometric and ionospheric effects in cosmic rays. Izv. Akad. Nauk SSSR, ser. fiz., 1978, v.42, N 7, p. 1501-1506.
68.Parker G.D., Chasson R.L., Hansen R.T., Solar phys., 1976, v.48, N 2, p. 399-410.
69.Razmadze T.S. - Sacartvelos SSR, Mecenierbata Academia; Geophys. Institute, 1976, v.35, p. 45-920.

70.Moreal H. - space Sci, Rev., 1976, v.19, N 6, p. 845-920.
71.Vitinsky YU.I., Konetsky M., Kuklin G.V. - Statistics of Spot-Forming Activity of the Sun. Nauka, Leningrad, 1986.
72.Sherstyukov B.G., Loginov V.F. - Short-Term Cyclic Variations in the Lower Atmosphere Relevant to heliophysical Processes. Gidrometeoizdat, Moscow, 1986.
73.Ol A.I. - Rythnmic Processes in the Earth's Atmosphere, Nauka, Leningrad, 1973.
74.Rivin YU.R. The Sun's effect on the fluid portion of the Earth's nucleus. Geomagn. i Aeron., 1985, v.25, N 6, p. 990-995.
75.Latopek A., Krivatsky L., Lastoviika J., J. Intern. Cycle Res., 1976, v. 7, N 1, p. 9-13.
76.Chirkov N.P. - On the cyclicity in geomagnetic activity and in solar wind velocity. Izv. Akad. Nauk SSSR, ser. fiz., 1978, v.42, N 5, p. 1016-1017.
77.Filisetti O., Lovera G., Mussino V., Tedde P., Riv. ital. geofis. e sci., 1976, v.3, p. 49-55.
78.Plakhotnyuk V.N., Features of solar activity cycles relevent to geoeffectiveness of interplanetary medium. In: Cosmic Rays, No.21, Radio i Svyaz, Moscow, 1980.
79.Kalinin YU.D. - Interplanetary Magnetic Field and Irregularities of the Earth's Diurnal Rotation, Nauka, Moscow, 1976.
80.Bolotinskaya M.Sh. - Many-year transformation s of the atmospheric circulation forms and their relationships to solar activity. Proc. symp. on Solar-Corpuscular Effects at XVth General Assembly of IUGG, Gidrometeoizdat 1973, p.41-46.
81.Akasofu S.I., Chapman S. Solar-Terrestrial physics, Clarendon Press, Oxford, 1972.
82.Ptitsina N,G., Tyasto M.I., Velocity waves in solar wind as a possible source of near-weakly cosmic ray variations. Geomagn. i Aeron, 1980, v.20, N 2, p. 331-333.
83.Wilkox J.M. - Nature, 1979, V. 278, N 5707, p. 840-841.
84.Lastovicka J., Stud. geophys. et goad., 1987, v.31, N 2, p. 213-218.
85.WilkoxJ.M, Solar-Terrestrial Influences on weather and Climat., Dordrecht, 1979, p. 149-159.
86.Loginov V.F., Reaction of atmospheric circulation on the conditions in the space. Trans. VNIIGMI-WDC, 1978, v.37, p.117-130.
87.Loginov V.F., Rakinova L.R., Sukhomazova G.I., Solar Activity Effects in the Stratosphere, Gidrometeoizdat, Leningrad, 1980.
88.Loginov V.F., Vysotsky A.M., Sherstyukov B.G., Sector structure of interplanetary magnetic field as relevant to atmospheric circulation. Trans. VNIIGMI-WDC, 1975, v.23, p. 43-49.
89.Dorman L.I., Kaminer N.S., Kuzmicheva A.N., Libin I.YA., Mymrina N.V. Geomaqn. i Aeron., 1985, v.25, N 6, p. 1000-1002.
90.Borisov D.Z., Kozlov V.I., Samsonov I.S., Samsonova Z.N. - Analysis of fluctuations and currents of galactic cosmic rays during passages of high-velocity recurrent solar wind fluxes. Izv. Akad, Nauk SSSR, ser. fiz., 1984, v.48, N 1, P. 2146-2150.
91.Mustel E.R., Chertoprud V.E., Soleil et Climat J. Etud., Toulouse, 1981, p. 151-161.
92.Wilkox J.M., Sherrer P.H., Svalgard L., J. Atmos. and Terr. Phys. 1979, 151-161.
93.Mikalayunas M.M., Basic characteristics of the storm wind conditions in the North Sea. Papers on Hydrometeorology,1973, v.6, p. 177-183.
94.Libin I.YA., Mikalayunas M.M., Yudakhin K.F., Variations of cosmophysical and geophysical parameters in solar activity cycles 18-21. Geomagn. i Aeron., 1987, v.27, N 3, p.483-486.
95.Bendat J., Pirsol A. Applications of Correlational and Spectraal Analysis,

Mir Moscow, 1983 (in Russian).
96.Max J. Methods and Techniques for Processing Signals, V.1, Mir, Moscow, 1983 (in Russian).
97.Dorman L.I., Pimenov I.A., Satsuk V.V., Mathematical Formalisim for Geophysical Research with Cosmic Rays as an Example, Nauka, Moscow, 1978.
98.Tsunekichi K., Takao S., Rept. Ionosph. and Space Res. Japan, 1975, v.29, N 3, p.118-126.
99.Kay S.M., Marple S.L., Present-day methods of spectral analysis (Review). TIIER, 1981, V.69, N 11, P. 5-48.
100.Dorman L.I., Libin I.YA., Short-period cosmic ray variations. Uspekhi fiz. Nauk, 1985, v.145, N 3, p. 403-440.
101.Dragan YA.P., Rozhkov V.A., Yavorsky N.N., Application of the methods of the theory for periodically-correlated random processes to probabilistic analysis of oceanological time series. In: Probabilistic Analysis and Simulation of Oceanological Processes, Gidrometeoizdat, Leningrad, 1984, p. 4-23.
102.Babich S.V., Bokov V.N., Lopatukhin L.I., Rozhkov V.A., Shatov B.N., Trapeznikov YU.A. - Probabilistic Analysis and Simulation of the synoptic, seasonal, and year-to-year variability of wind and wavings. In: Probabilistic Analysis and Simulation of Oceanological Processes, Gidrometeoizdat, Leningrad, 1984, p. 43-49.
103.Trapeznikov YU.A., Recurrent algorithms for estimating the probable characteristics of random processes, in Probabilistic Analysis and Simulation of Oceanological Processes, Gidrometeoizdat, Leningrad, 1984, p. 109-115.
104.Jankins G., Watts D. - Spectral Analysis and its Aplications, v. 1 and 2, Mir, Moscow, 1972 (in Russian).
105.Press W.H., Flannery B.R., Teukolsky S.A. at al. Numerical Recipes:

The art of scientific computing. Cambridge University Press, 1986,
106.Lomb N.R. Least-squares frequency analysis of unequally spaced data. Astrophys.and Space Sci., 39, 447, 1976.
107.Scragl J.D. Studies in astronomical time series analysis. 263, p.835-853, 1982.
108.Horne J.D., Baliunas S.L. A prescription for period analysis of unevently sampled time series. Astrophys.J., 302, p.757-763, 1986.
109.Carbonell M, Ballester J.L. Search algorithm for weak periodicities in definite time intervals. Astron.Astrophys., 249, p.295-297, 1991.
110.Roberts D.H., Lehar J., Dreher J.W. Time series analysis with CLEAN. Astron.J., 93, p.968-989, 1990.
111.Pottash E.M., Butcher H.R., J.van Hoesel F.H. Solar-like oscillations on a alfa Centauri A. Astron.Astrophys., 264, p.138-146, 1992.
112.Feynman J., Gabrial S.B. Period and phase of the 88-year solar cycle and the Maunder Minimum: Evidence for a chaotic Sun. Solar Physics, 127, p.393-403, 1990.
113.Mundt M.D., Maguire II W.B., Chase R.R. Chaos in the sunspot cycle: Analysis and predictiobn. J.Geophys.Res., 96, A2, p.1705-1716, 1991.
114.Ruzmaikin A.F., Feynman J., Kosacheva V. On long-term dynamics of the solar cycle. In COLAR CYCLE, Astron.Society of the Pacific Conf. Series, 27, p.547-556, 1992.
115.Gizzatulina S.M., Rukavishnikov V.D., Ruzmaikin A.A., Tavastsherna K. Radicarbon evidence of the global stohasticity of solar activity. Solar physics, 127, p. 281-288, 1990.
116.Rivin YU.R., Spectral analysis of amplitude variations of 11-year solar activity cycles. Solar Data, 19845, N 9, p. 78-82.
117.Riven YU.R., Zvereva T.I., Frequency spectrum of quasi-biennial geomagnetic field variations. In: Solar Wind, Magnetosphere, and the

Earth's Magnetic Field, Nauka, Moscow, 1983, p. 72-90.
118.Hamilton kevin., J. Atmos. Sci., 1983, v.40, N 10, p.2432-2443.
119.Vasilyeva G.Ya., Kuznetsova M.A., Kotlyar L.M., Annual and half-year variations of geo- and helio-activity as a manifestation pf the IMF behavioural features at the Earth's orbit. Geomagn. i Aeron., 1984, v.24, N 6, p.865.
120.Djurovic D., Aston. and Astrophys., 1983, v.118, p.26-26.
121.Smirnov R.V., Kononovich E.V., Frequency characteristics of the relatinships between the variations of atmospheric vorticity index and heliogeomagnetic activity, in Solar-Atmospheric Relationships and Geomagnetic activity, Nauka, Moscow, 1984., p. 80-92.
122.Dmitriev A.A. Physical bases of solar-atmospheric relatinships. In: Physical Principles of Measuring the Present-Day Climate, Nauka, Moscow, 1980, p. 15-25.
123.Ariel N.Z., Shakhmeister V.A., Murashova A.V., Spectral analysis of ocean-atmosphere energy exchange characteristics. Meteorologiya i Gidrologiya, 1986, N 2, p.49-53.
124.Wyrtki K. J.Phys.Oceanogr., 5, 572, 1975.
125.Wyrtki K. J.Phys.Oceanogr., 9, 572, 1979.
126.Busalacchi A.J., O'Brien J.J. J.Geophys.Res., 86, 10901, 1981.
127.Shukla J., Wallace J.M. J.Atmos.Sci, 40, 1613, 1983.
128.Philander S.G. Nature, 321, 810, 1986.
129.Barnett T.P. Mon. Weather Rev., 112, 1403, 1984.
130.Anderson R.Y., Betancourt G.L., McKay A.M. Proc. 16-th Pacific Climate (PACLIM) Workshop, California Department of Weather Resources Technical Reporte 23, 77, 1990.
131.Cane M.A., Zebiak S.E., Dolan S.C. Nature, 321, 827, 1986.
132.Philander S.G. Ei Niño, La Niña and Soutern Oscillation, San Diego Academic Press, 293, 1990.
133.Enfield D.B. Oceanografy Magazine, 1, 59, 1988.
134.Inoue M., O'Brien J.J. Mon.Weather Res., 112, 2326, 1984.
135.Graham N.E., Michaelsen J., Barnett T. J.Geophys.Res., 92, 1471, 1987.
136.Bucha V. Ann.Geophys., 6, 513, 1988.
137.Bucha V. Studia Geophys. et Geod., 27, 19, 1983.
138.Enfield D.B., Cornejo Rodriguez M.P., Smith R.L. at al. J.Geophys.Res., 92, 14335, 1987.
139.Anderson R.Y., Sonett C.P., Giampapa M.S. at al. The Sun in time. University of Arizona Press, 543, 1991.
140.Anderson R.Y. Nature, 358, 51, 1992.
141.Anderson R.Y., Diaz M.F., Makgraf V. El Nino: Historical and Paleoclimatic aspects of the Southern Oscillation. Cambridge University Press, 193,1992.
142.Libin I.Ya., Perez-Peraza J., Jaani A. at al. Geomagnetic storms and meteorological relationships. Intern.Meteorol.Sci., 1, p.41-50,1995.
143.Willet H.C., Rampino M.R., Sanders J.E at al. Climate history periodicity and predictability. Nostrand Reynhold Co., N.Y., 404, 1987,
144.Friis-Christensen E., Lassen K. Two and a half centuries of solar activity variations and a possible association with global temperature. Scientific raporte 93-4, Danish Meteorological Institute, 1993.
145.Friis-Christensen E., Lassen K. Lenfth of solar cycle: an indicator of solar activity closely associated with climate. Scince, 254, p.698- 700, 1991.
146.Gulinsky O.V., Perez-Peraza J., Libin I,Ya. at al. Large scale cosmic ray fluctuations infered from the ground-based neutron and ionizing component. Geofisica International. 27(2), p.167-193, 1988.
147.Dorman L.I., Perez-Peraza J., Libin I.Ya. at al. Spectral charakteris-

tics of cosmic ray large scale fluctuations from data of neutron and ionizing components. Kosmicheskie Luchi No 25. Moscow. p.39-48, 1989.
148.Perez-Peraza J. Space Plasma Physics. Anales de la Conf. Espacial de las Americas. (PNVD=, I, p.96-113, 1990.
149.Tinsley V.A., Deen G.W. Apparent tropospheric response to MeV-GeV particle flux variations. J.Geophys. Res. 96, 22, 283, 1991.
150.Tinsley V.A., Brown G.M., Scherrer P.H. Solar variability influences on weather and climate. J.Geophys.Res, 94, 14, 783, 1989.
151.Pudovkin M.I., Babushkina S.V. Influence of electromagnetic and corpuscular radiaton from solar flare on an intensity of the zonal atmospheric circulation. Geomagnetizm and Aeronomia. 31, 493, 1991.
152.Pudovkin M.I., Babushkina S.V. Influence of solar flares and disturbance of the interplanetary medium on the atmospheric circulation. J.Atmos. Terr.Phys., 54, 841, 1992.
153.Veretenenko S.B., Pudovkin M.I. Effects of cosmic ray variations in lower atmosphere Circulation. Geomagnetizm and Aeronomy, 33, 6, 1994.
154.Parker E.N. Astrophys.J., 122, 293, 1955.
155.Cowling T.G. The present status of dynamo theory. Ann.Rev.Astron. Astrophys., 19, p.115-135, 1981.
156.Levy E.H. The solar cycle and dynamo theory. In COLAR CYCLE, Astron. Society of the Pacific Conf, Series, 27, p.139-149, 1992.
157.Weiss N.O., Cattaneo F., Jones C.A. Geophys.Astrophys.Fluid Dyn., 30, 305, 1984.
158.Rosner R., Weiss N.O. The origin of the solar cycle. Item., 27, p.511-537, 1992.
159.Glatzmaier G.A. The numerical simullations of stellar convective dynamos. Astrophys.J., 291, p.301-307, 1985.
160.Nordlund A., Brandenburg A., Jennings R.L. at al. Dynamo action in stratified convection with overshoot. Astrophys.J., 392, p.647-652, 1992.
161.Schmitt J.H., Rosner M.M. Double diffusive magnetic buoyancy insta- bility in the solar interior. Astrophys.J., 265, 301, 1983.
162.D'Silva S. Joy's law and limits of magnetic field strength at the bottom of the convective zone. SOLAR CYCLE. 27, p.168-172, 1992.
163.Cattaneo F., Vainshtein S.I. - Suppression of turbulent transport by a weak magnetic field. Astrophys. J., 1991, v.376, p. 21-24.
164.Boyer D.W., Levy E.H. - Multiple periodicities in the solar magnetic field: possible origin in a multiple.more solar dynamo. Astrophys. J., v.396, p. 340-350, 1992.
165.Rhodes E.J., Cacciani A., Korzennik S., Tomczyk S., Ulrich R.K., Wooodward M.F. - Depth and latitude dependence of solar interval angular velocity. Astrophys. J., v.351, p. 687-700, 1990.
166.Goode P.R., Dziembowski W.A., Korzennik S.G., Rhodes E.J. - What we know about the Sun's interval rotation from solar oscillations. Astrophys. J., v.367, p. 649-657, 1991.
167.Schmalz S., Stix M. - An A dynamo with order and chaos. Astron. Astrophys., v.245, p. 654-661, 1991.
168.Herman J., Goldberg R.A., The Sun, Weather, and Climate, Gidrometeoizdat, Leningrad, 1981 (in Russian).
169.Dmitriev A.A., Feasible physical mechanisms of heliophysical relatonships, Trans. VNIIGMI-WDC, 1978, v.37, p.86-92.
170.Mustel E.R., Solar corpuscular streams and their effect on the Earth's atmosphere. Scientific Information, 1968, v.10, p. 93-115.
171.Dodson E.V., Hedeman E.R., Large-scale solar activity structure and its temporal and spatial variations. In: Observations and Predictions of Solar Activity, Mir, Moscow, 1976, p. 9-19 (in Russian).
172.Mayaud P.N., J. Geophys. Res., 1977, v.82, N 7, p. 1271-1272.
173.Pudovkin M.I., Raspopov O.M. The mechanizm of action of solar activity on

the state of the lower atmosphere and meteorological parametrs. Geomagnetizm and Aeronomia. 32, 5, 593, 1992.

174. Kondratiev K.Ya., Nikolsky G.A. A stratospheric mechanizm of solar and antropogenic influence on climate. Solar-Terrestrial Relationships, Weather and Climate. Nauka, M.: 1992.

175. Kondratiev K.Ya. Influence of solar activity upon the lower atmosphere. IUGG Assamby, IAGA Program and Abstracts, 226, 1989.

176. Krymsky G.F. Cosmic ray and the solar wind. Nauka, Novosibirsk: 1981.

177. Fisk L.A. Solar modulation of the galactic cosmic ray. Sol.-Terr.Phys. D.Riedl.Publ.Co., Dordrecht, 1983.

178. Perez-Peraza J., Libin I.Ya., Leyva A. at al. Influence of solar activity on hydrological processes. Reportes Tecnicos No 95-3, Proc. Instituto de Geofisica UNAM, 1995.

179. Leyva-Contreras A., Perez-Peraza J., Libin I.Ya. at al. Long-term modulation of solar radiation as observed at the level of the Earth surface and possible relation to solar activity variations (Genuine issue).

180. Perez-Peraza J., Leyva-contreras A., Libin I.Ya. at al. Influence of solar activity on atmospheric processes: cyclic variations of pluvial precipitation (Genuine issue).

181. Perez-Peraza J., Leyva A., Libin I.Ya. at al. Long temperature oscillations and their possible relevance to solar activity variations (Genuine issue).

182. Pudovkin M.I., Veretenenko C.V. The influence of the magnetic disturbances on the intensity of the flux of direct solar variation. Geomagnetism and Aeronomia. 32, 1, 1992.

183. Pudovkin M.I., Babushkina S.V. The effect of solar flares in vatiations of the near surface atmosphere pressure. Geomagnetism and Aeronomy. 30, 3, 1990.

184. Rozhkov V.A., Methods of probabilistic Analysis of Oceanological Processes. Gidrometeoizdat, Leningrad, 1979.

185. Libin I.Ya., Gulinsky O.V., Perez-Peraza J. at al. The model of mechanism of the influence of heliophysical parametrs on atmospheric processes. Cosmic Ray (Engl.Edd.), No 26, p.22-56, 1995.

186. Libin I.Ya., Leyva A., Perez-Peraza J. at al. Study of quasi- periodical variations of meteorological processes on the basis of data of stations in Mexico, Russia and Estonia. Intern.Meteorol. Sci., 1, p.41-50, 1995.

187. Libin I.Ya., Perez-Peraza J., Leyva A. at al. Relation of Geofi- sical and Climatic Processes to solar activity. Intern. Meteorol. Sci., 1, p.3-30, 1995.

Fig. 1

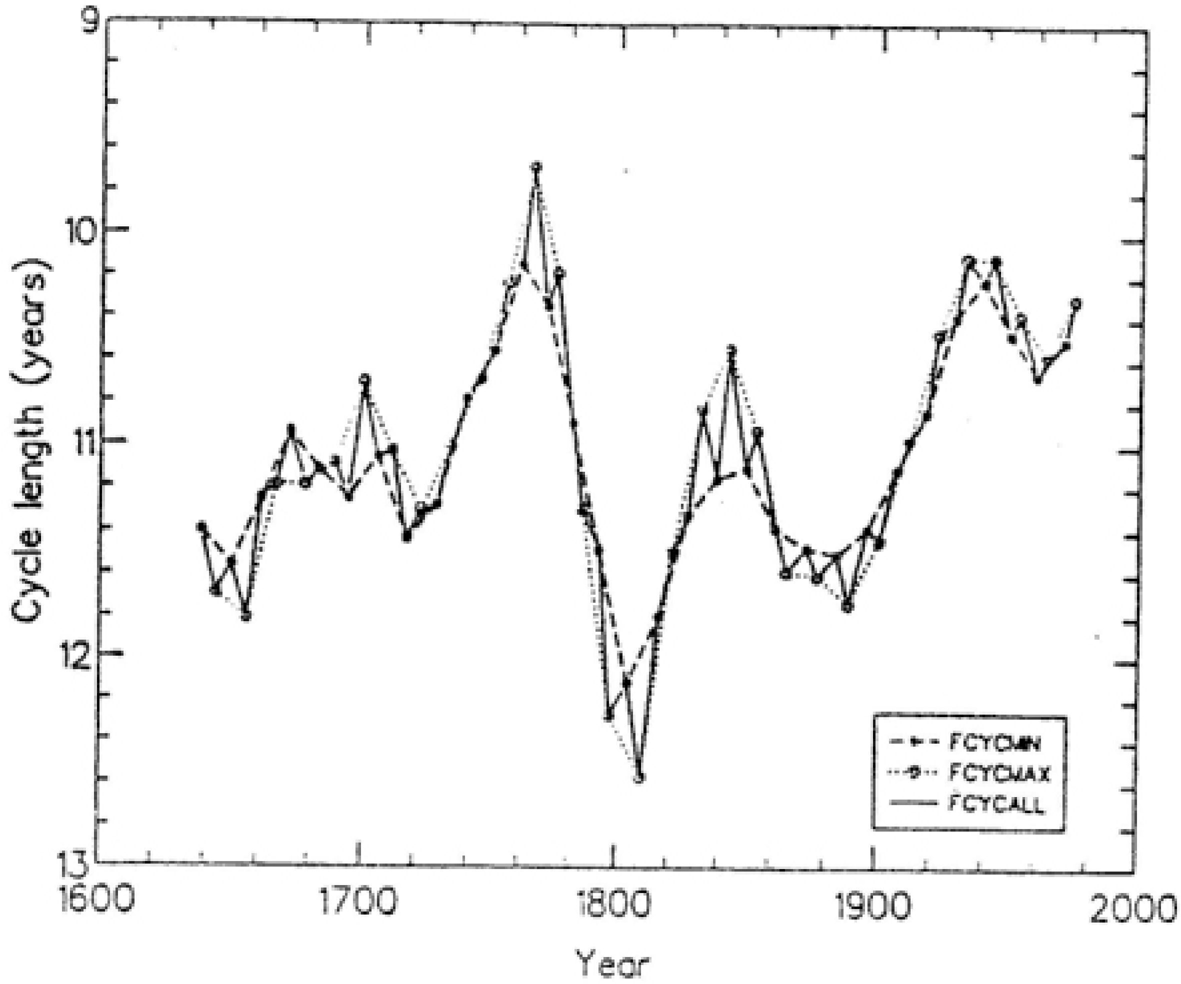

9
10
11
12
13
Cycle length (years)
1600
1700
1800
1900
2000
Year
FCYCMIN
FCYCMAX
FCYCALL

Fig. 2

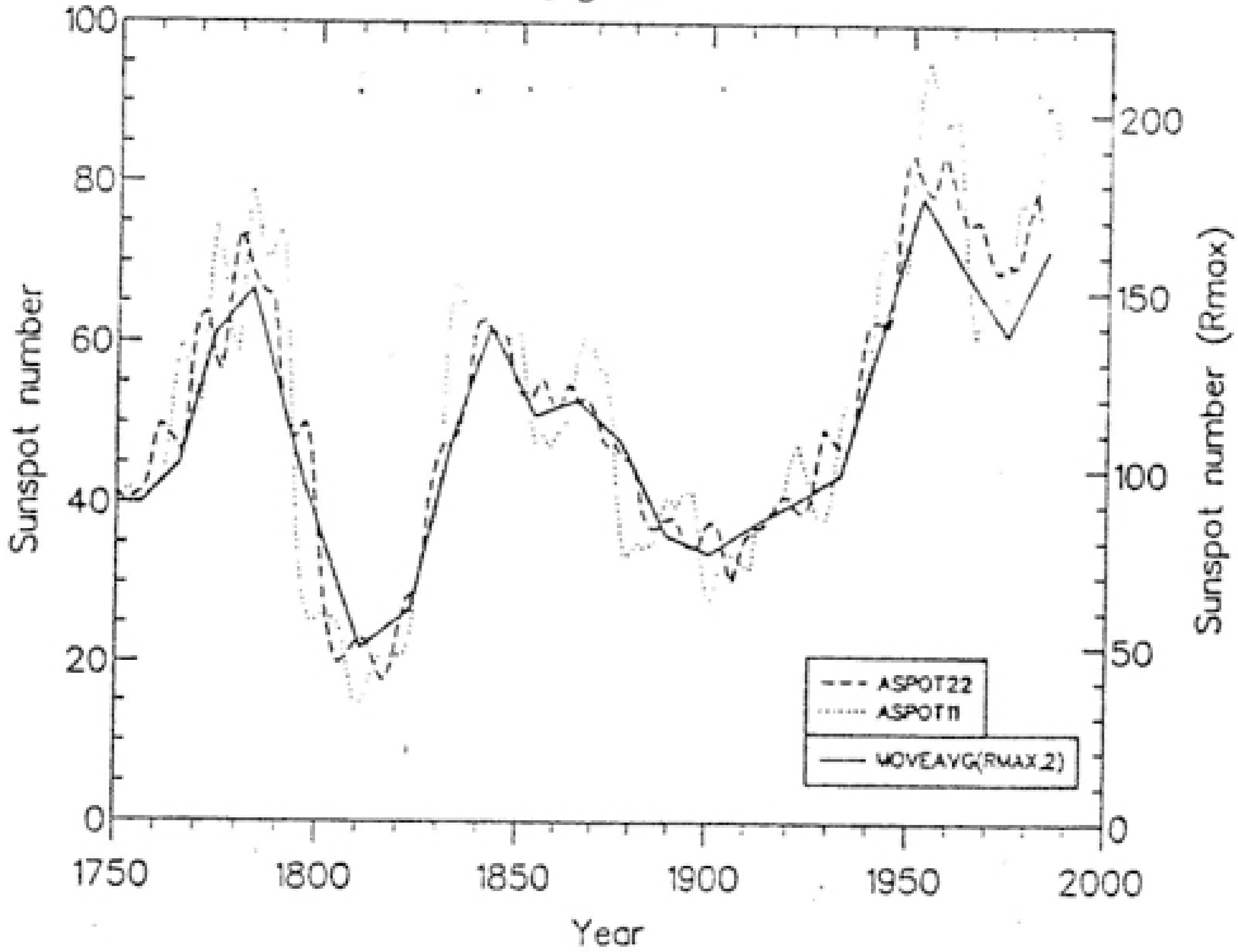

100
80
60
40
20
0
Sunspot number
200
150
100
50
0
Sunspot number (Rmax)
1750
1800
1850
1900
1950
2000
Year
ASPOT22
ASPOT11
MOVEAVG(RMAX,2)

Fig. 3

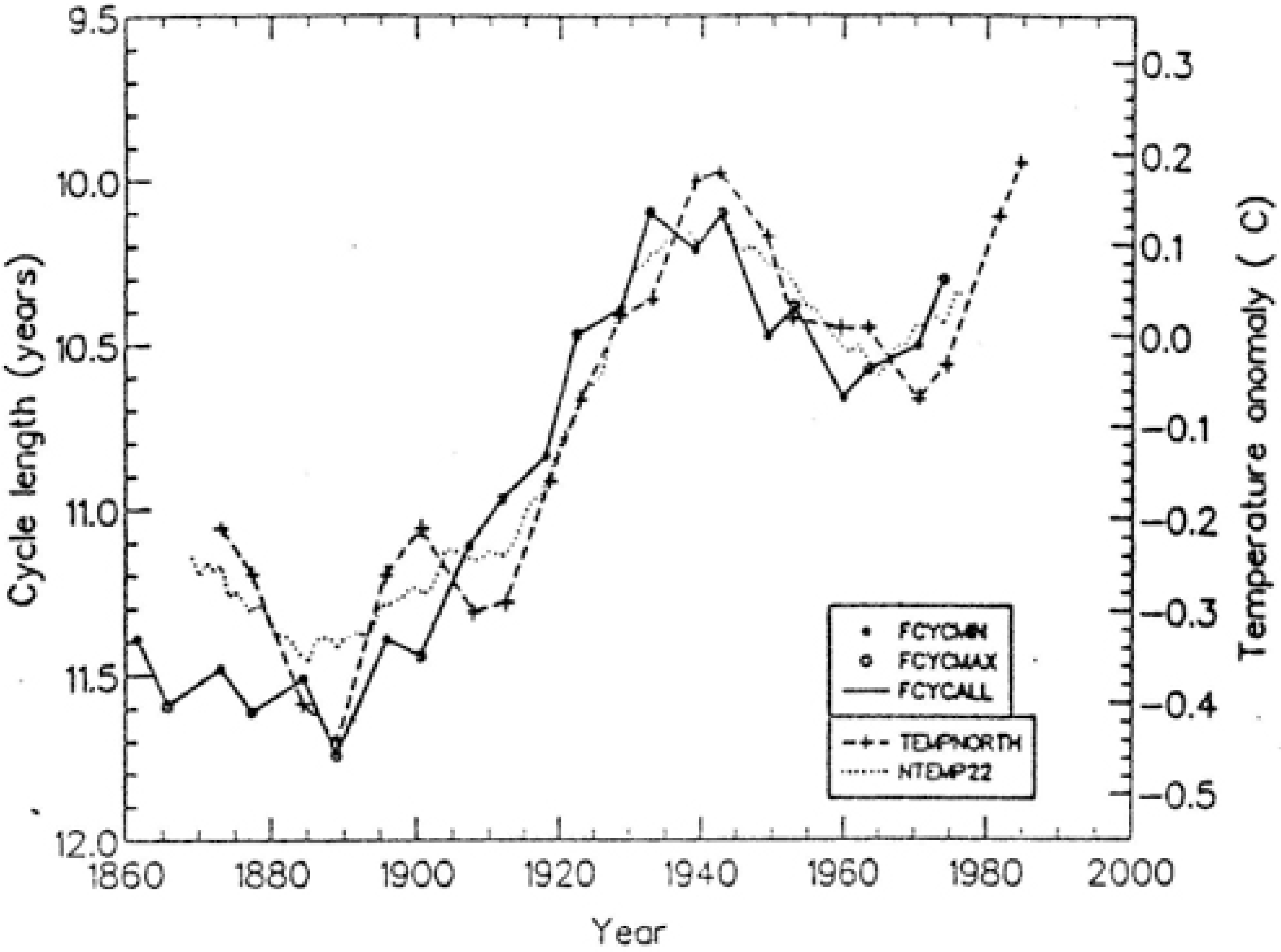

9.5
10.0
10.5
11.0
11.5
12.0
1860
1880
1900
1920
1940
1960
1980
2000
Year
Cycle length (years)
Temperature anomaly (C)
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
−0.4
−0.5
FCYCMIN
FCYCMAX
FCYCALL
TEMPNORTH
NTEMP22

Fig. 4

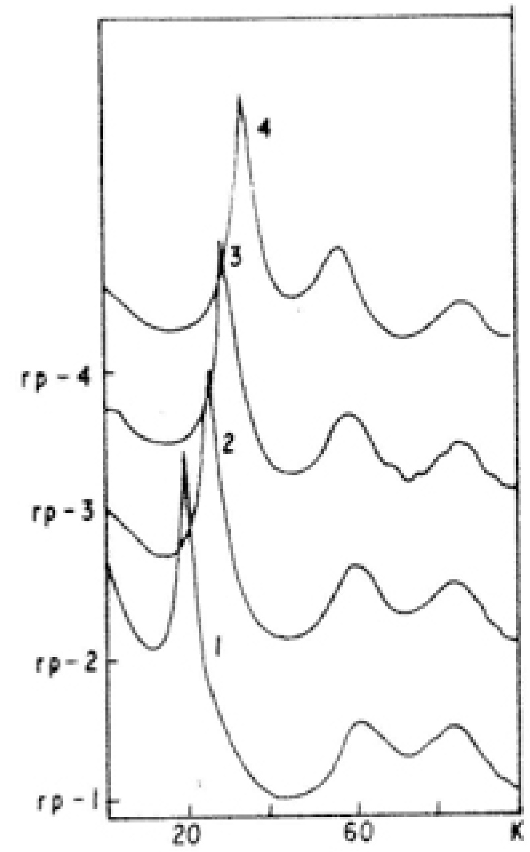

4
3
2
1
rp - 4
rp - 3
rp - 2
rp - 1
20
60
K

Fig. 5

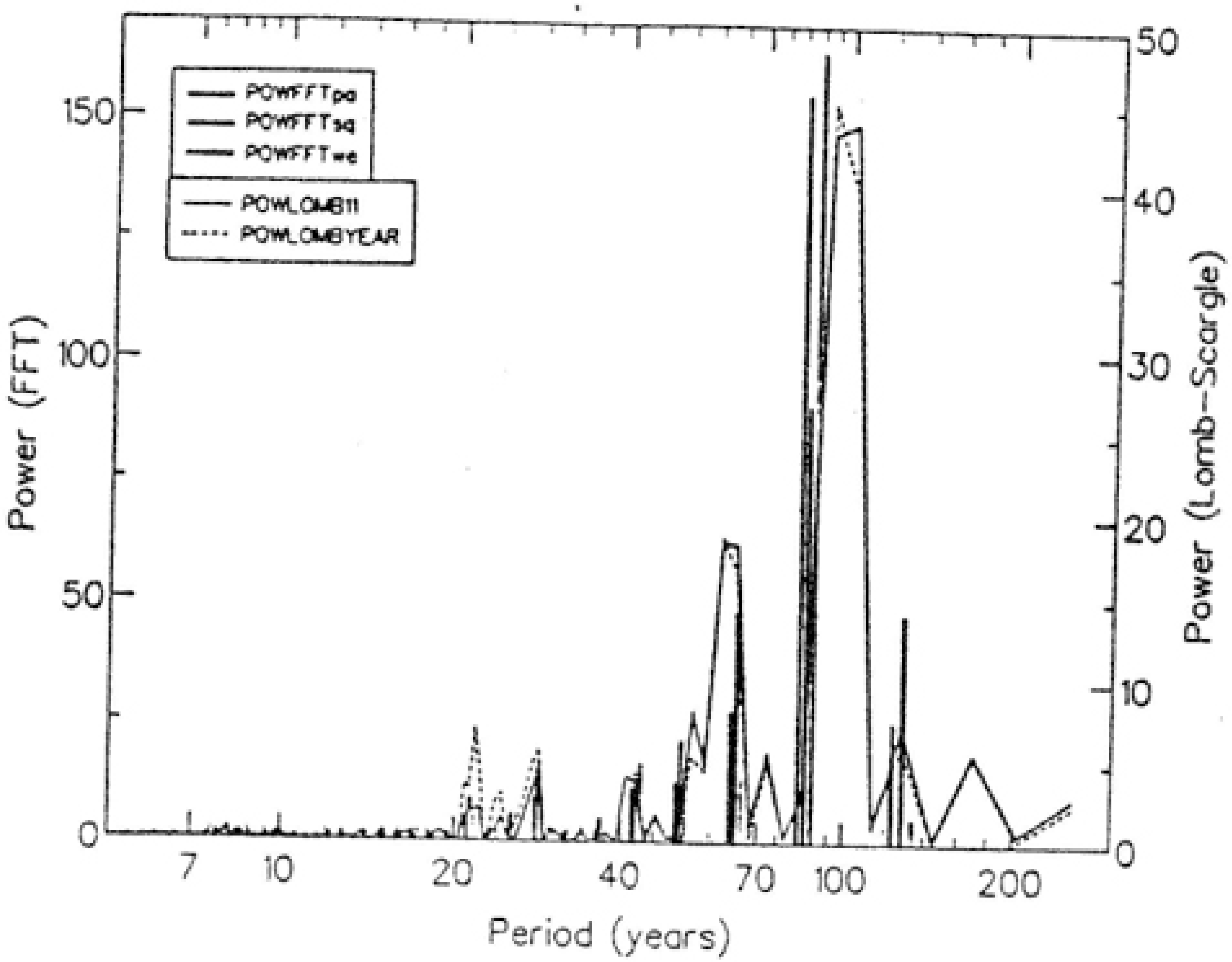

POWFFTpa
POWFFTsq
POWFFTwe
POWLOMB11
POWLOMBYEAR
Power (FFT)
Power (Lomb-Scargle)
Period (years)
0
50
100
150
10
20
30
40
50
7
10
20
40
70
100
200

Fig. 6

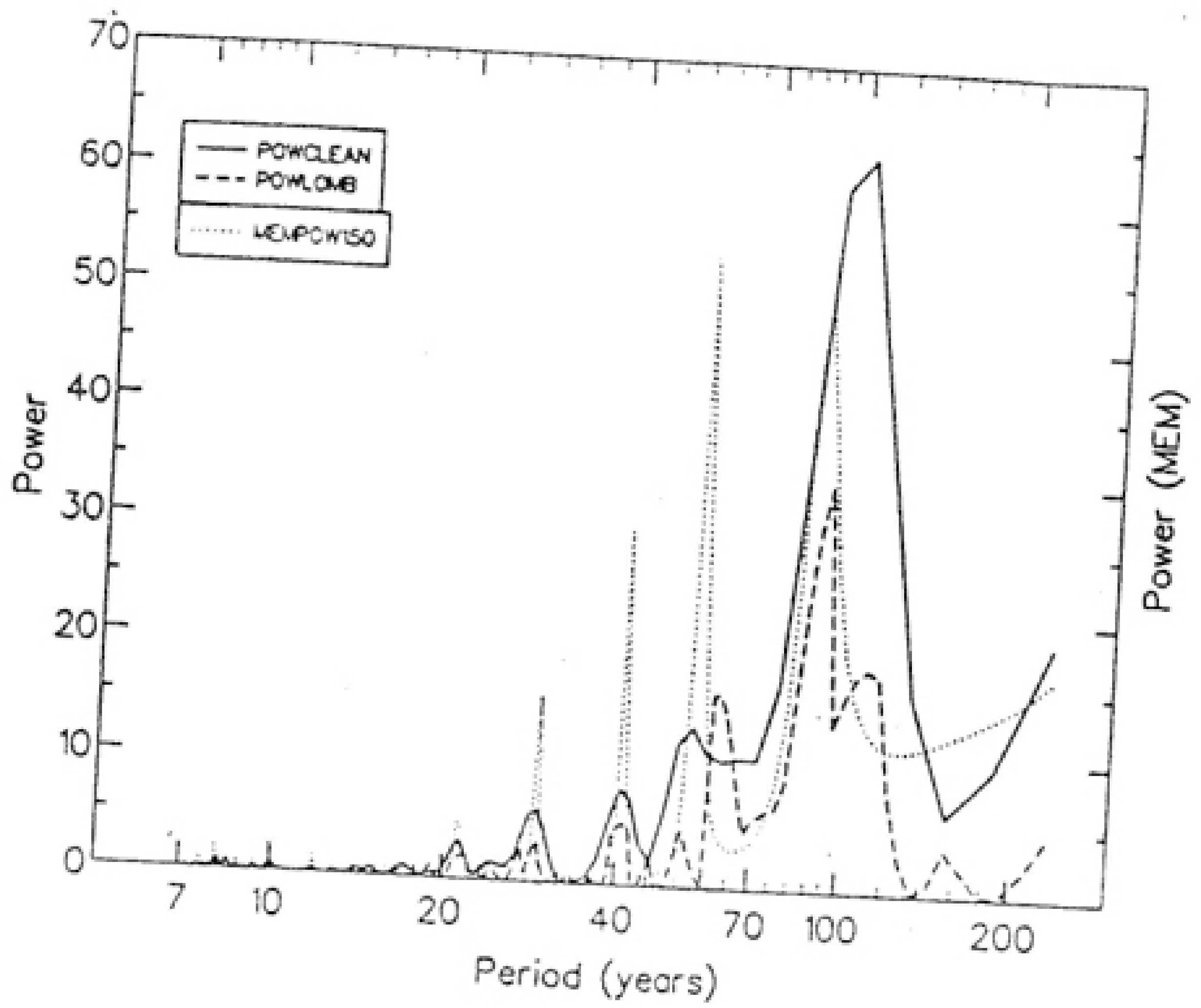
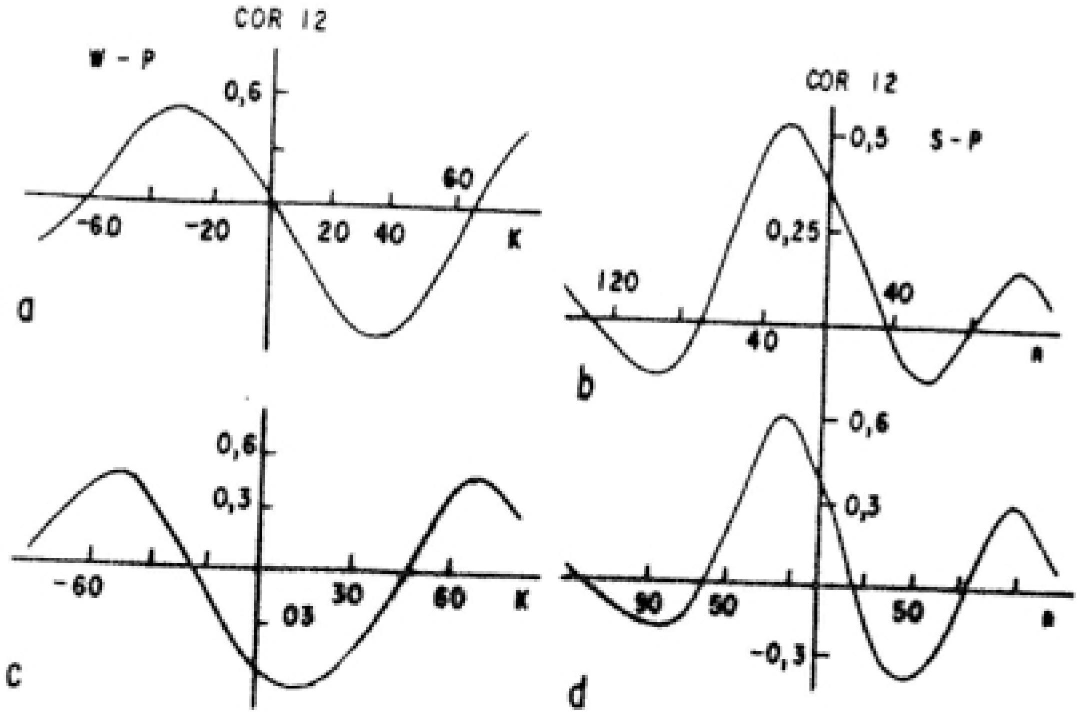
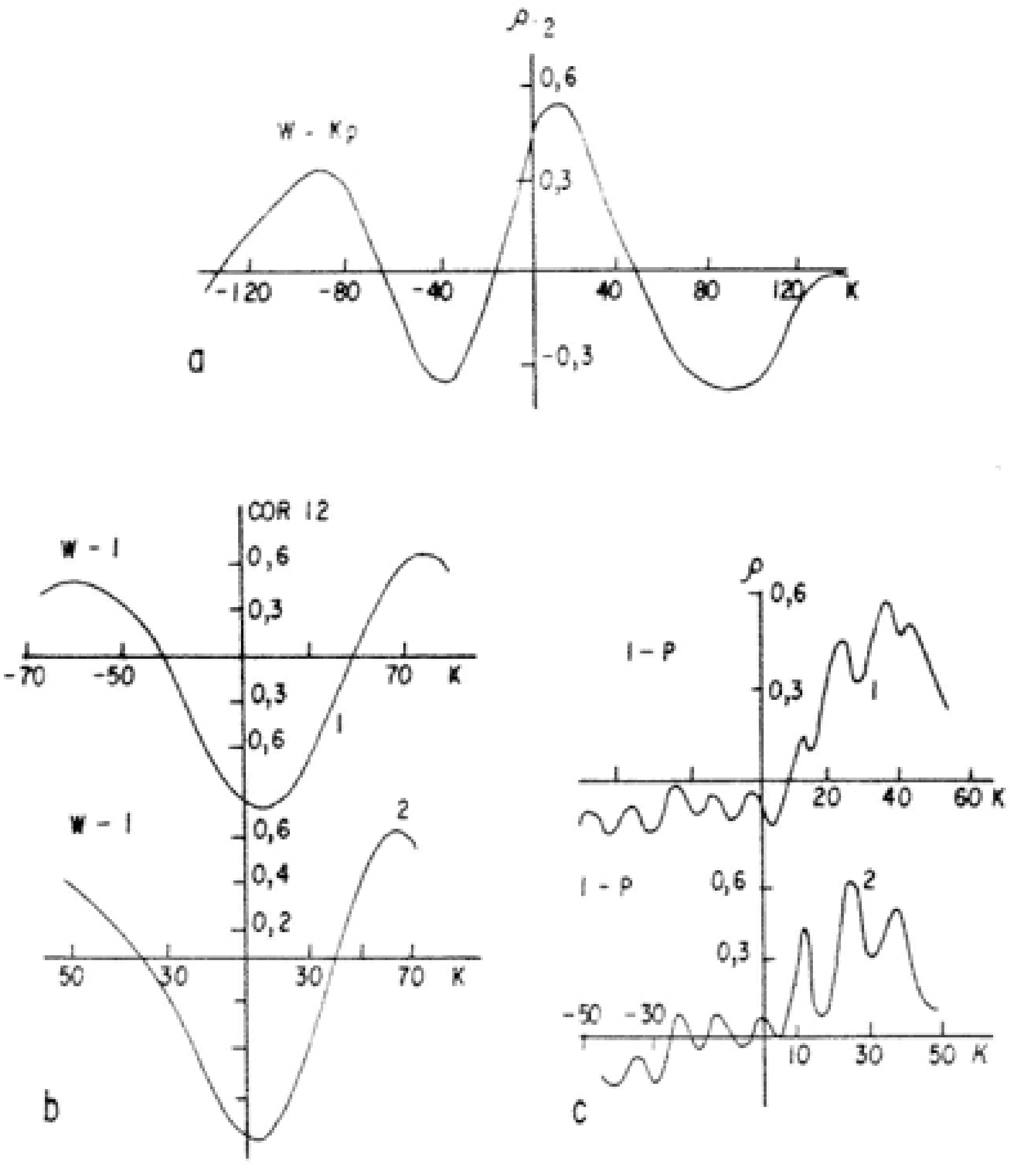

POWCLEAN
POWLOMB
MEMPOW150
Power
Power (MEM)
Period (years)
0
10
20
30
40
50
60
70
7
10
20
40
70
100
200

Fig. 7



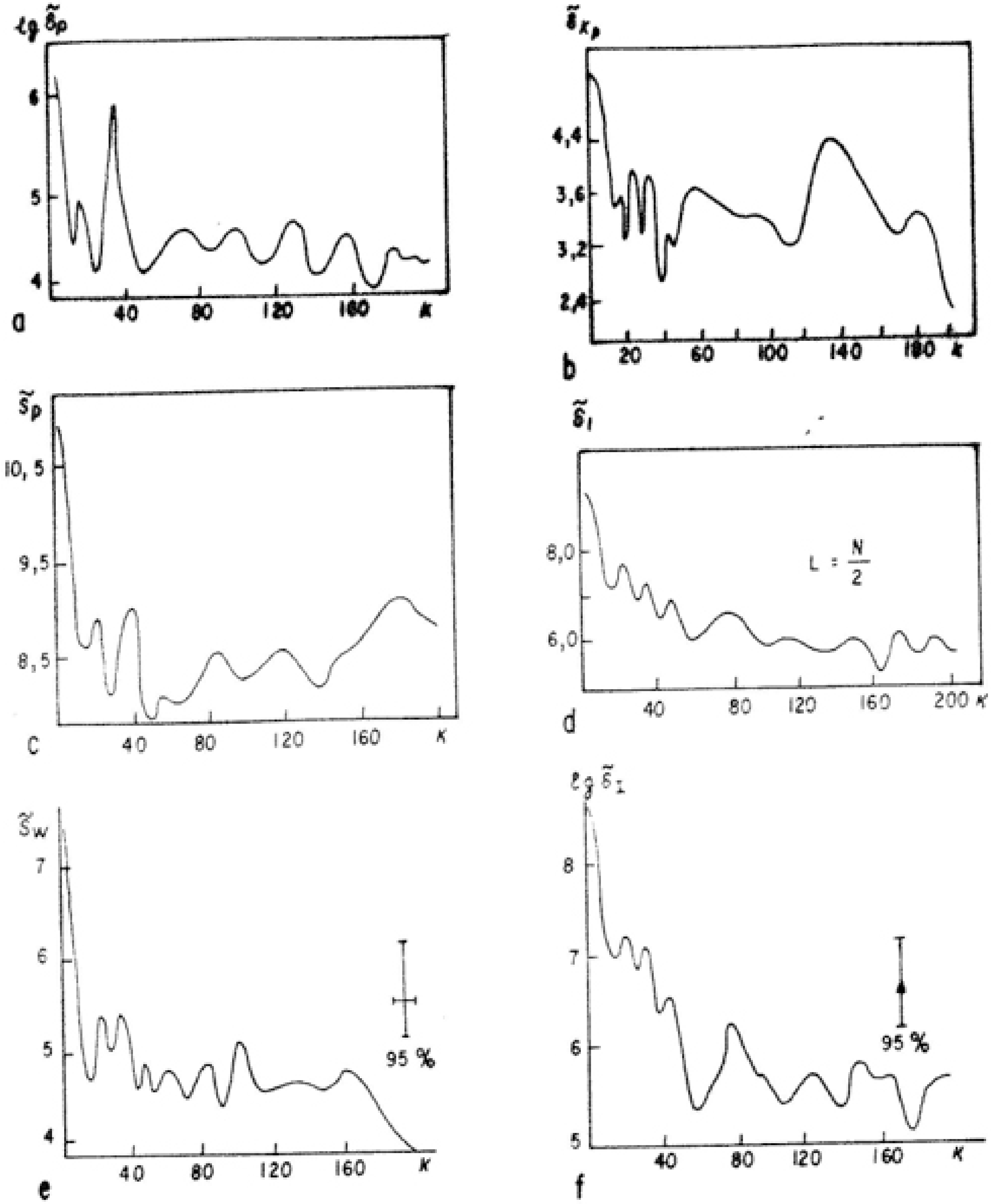
COR 12
W - P
0,6
-60
-20
20
40
60
K
a
COR 12
0,5
S - P
0,25
120
40
40
b
0,6
0,3
-60
30
60
03
K
c
0,6
0,3
90
50
50
-0,3
d

Fig. 8



ρ 2
0,6
W - Kp
0,3
-120
-80
-40
40
80
120
K
-0,3
a
COR 12
W - I
0,6
0,3
-70
-50
70
K
0,3
0,6
1
W - I
0,6
0,4
0,2
2
50
30
30
70
K
b
ρ
0,6
I - P
0,3
1
20
40
60 K
I - P
0,6
2
0,3
-50
-30
10
30
50
K
c

Fig. 9



6
5
4
40
80
120
160
K
a
4,4
3,6
3,2
2,4
20
60
100
140
180
b
10, 5
9,5
8,5
C
40
80
120
160
K
8,0
6,0
L = N/2
40
80
120
160
200 K
d
7
6
5
4
40
80
120
160
K
95 %
e
8
7
6
5
40
80
120
160
K
95 %
f

Fig. 10

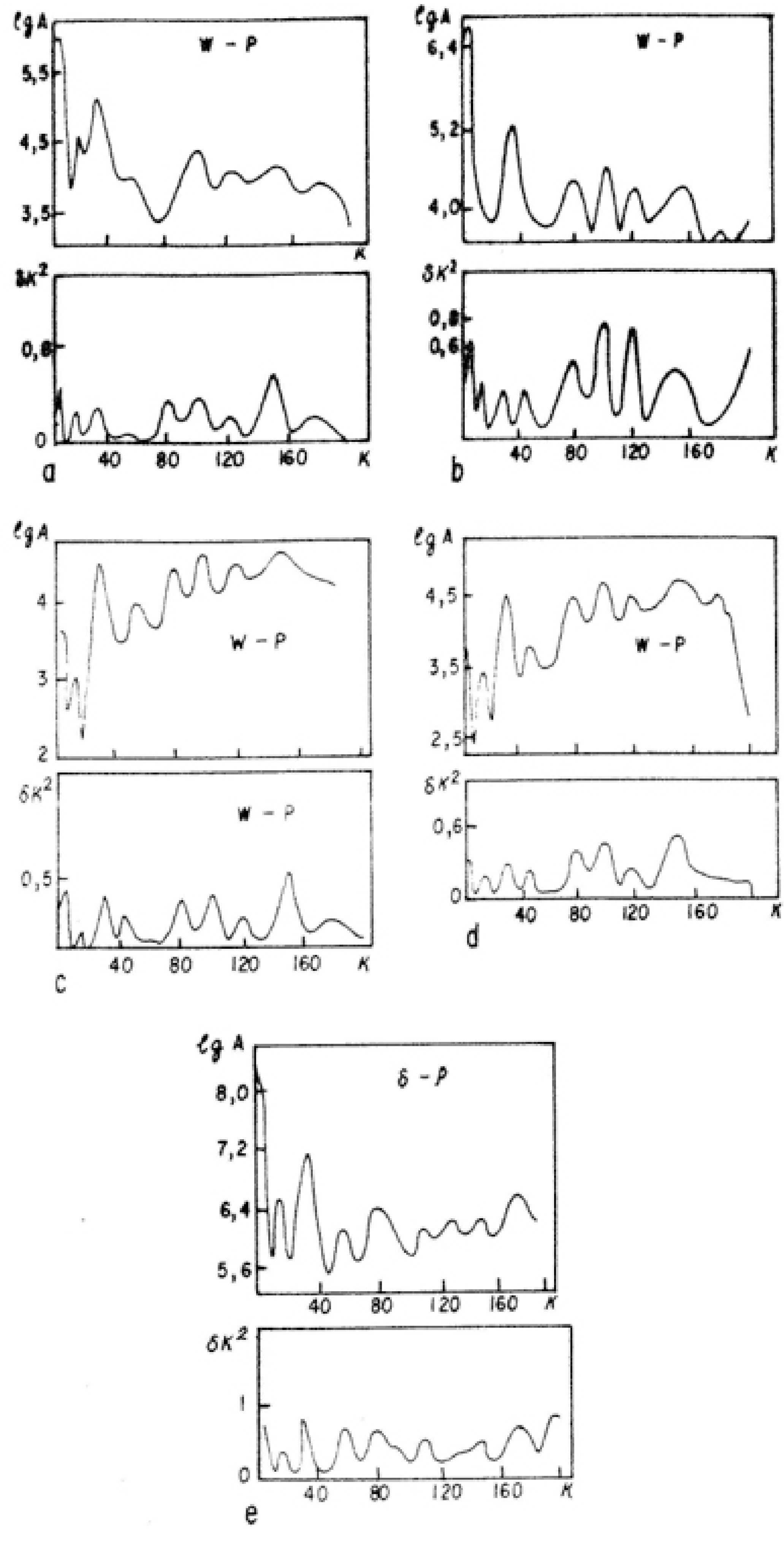

lg A
W - P
5,5
4,5
3,5
K
δK²
0,8
0
40
80
120
160
K
a
lg A
W - P
6,4
5,2
4,0
δK²
0,8
0,6
40
80
120
160
K
b
lg A
4
3
2
W - P
δK²
W - P
0,5
40
80
120
160
K
c
lg A
4,5
3,5
2,5
W - P
δK²
0,6
0
40
80
120
160
K
d
lg A
δ - P
8,0
7,2
6,4
5,6
40
80
120
160
K
δK²
1
0
40
80
120
160
K
e

Fig. 11

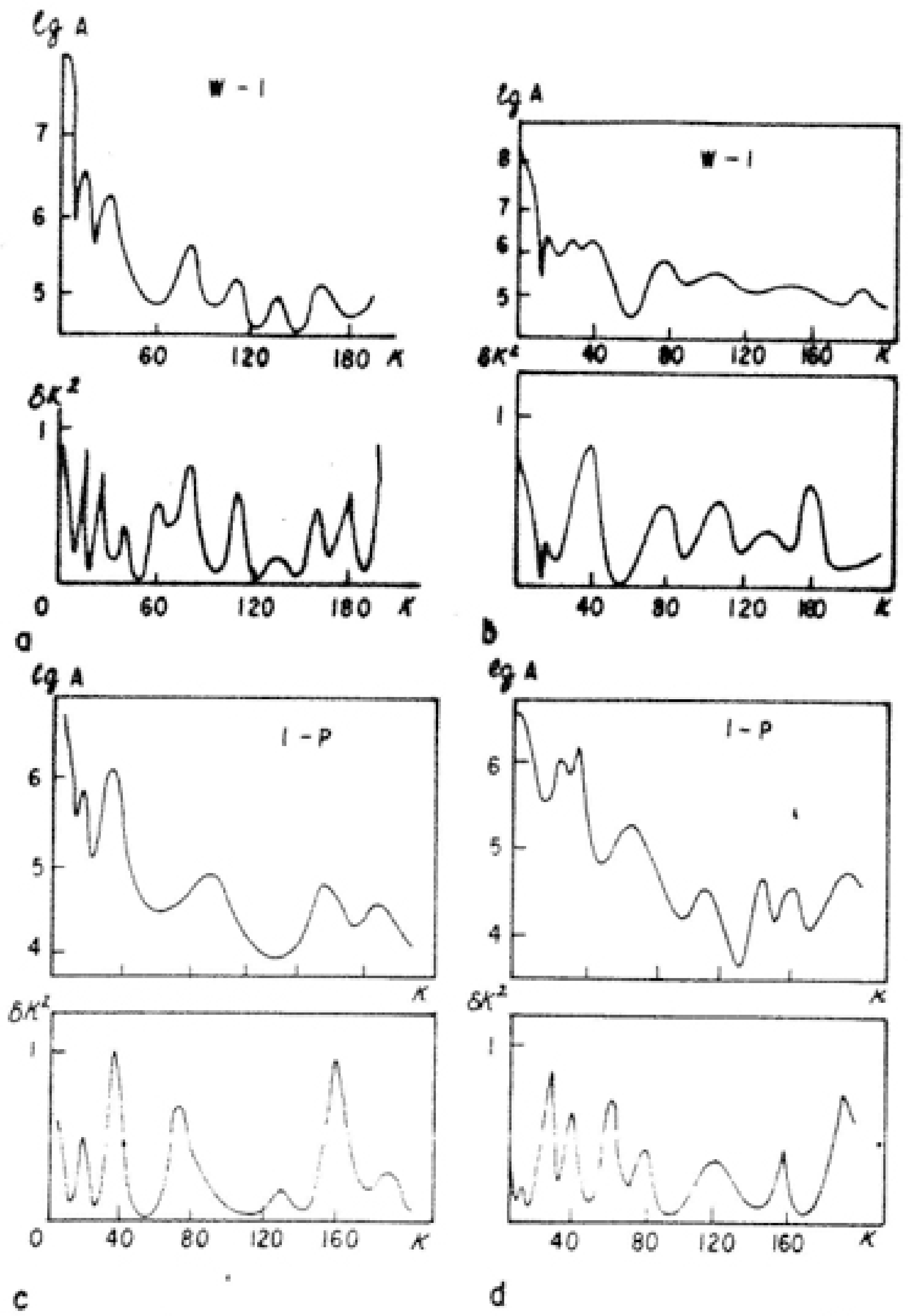
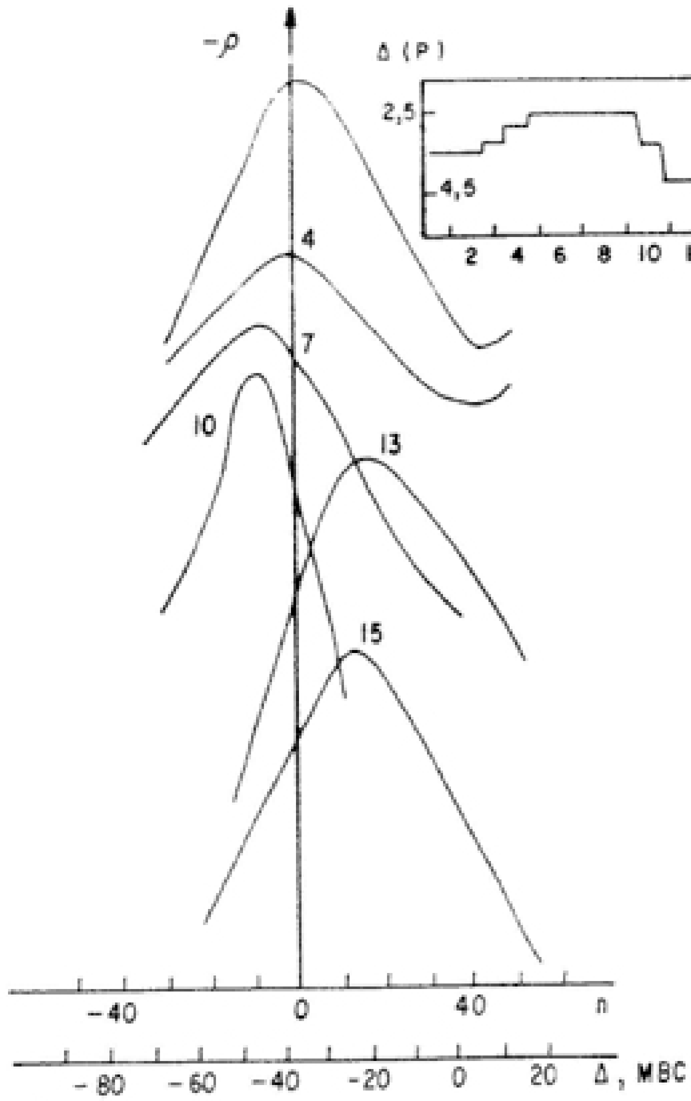


Fig. 12



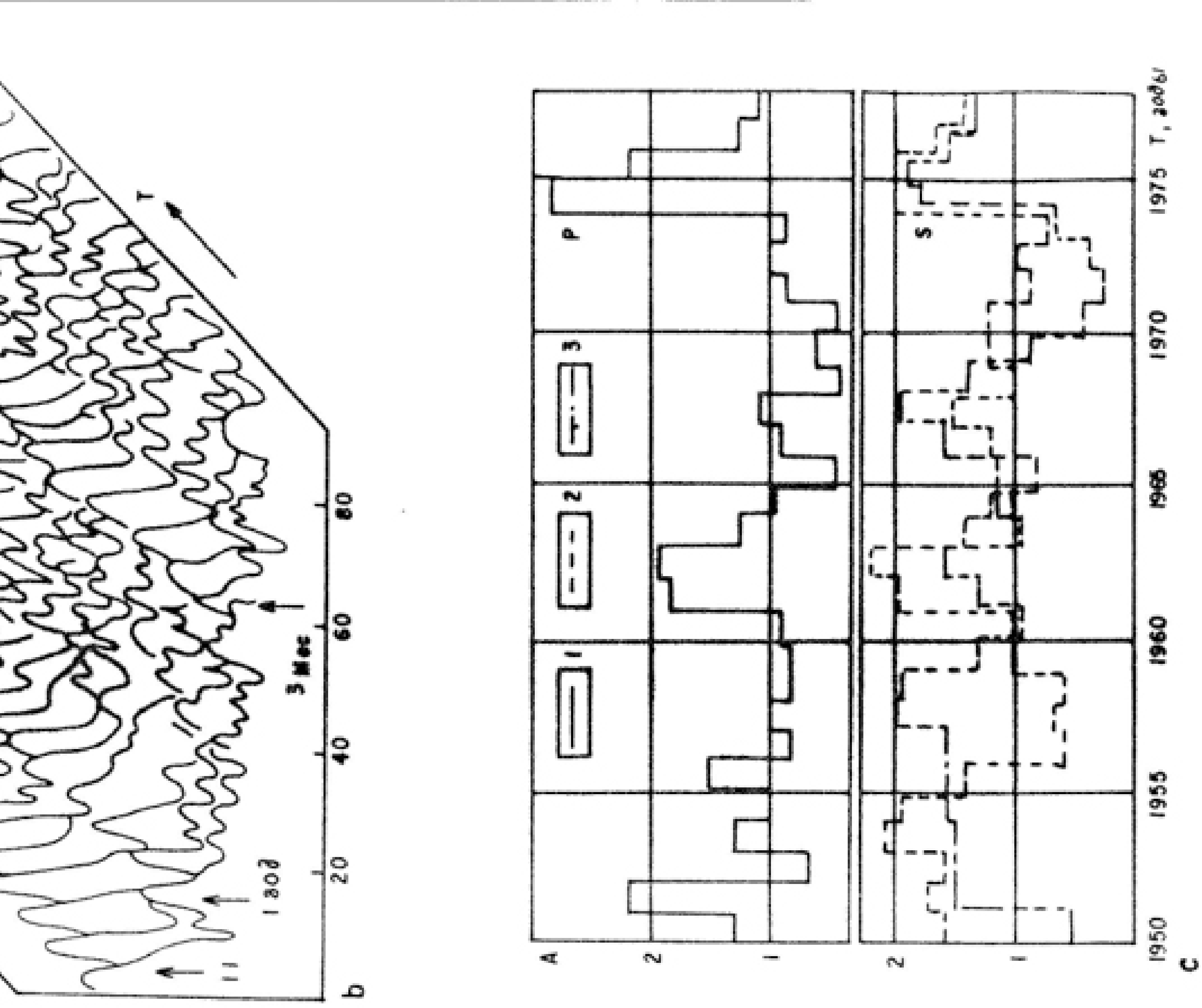


Fig. 13

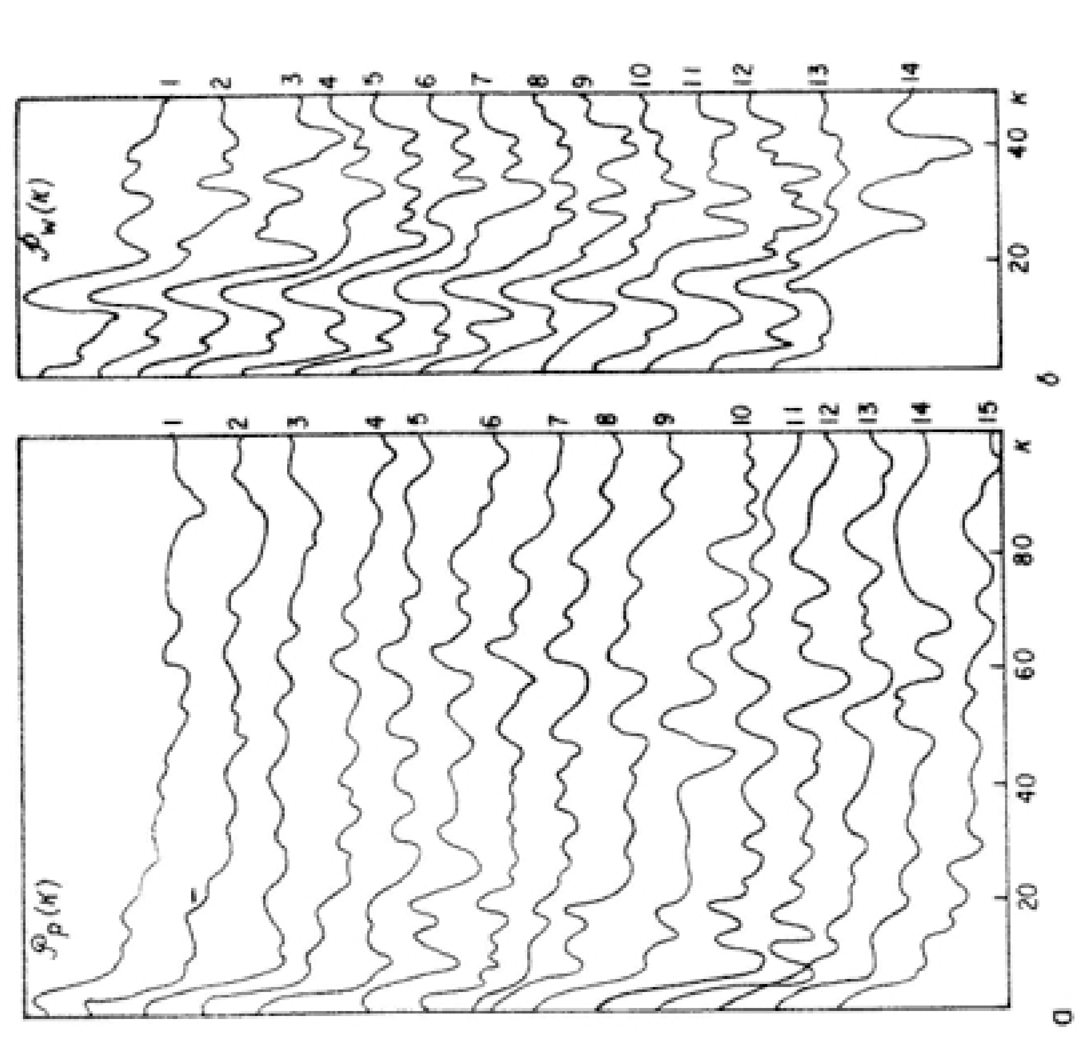


Fig. 14

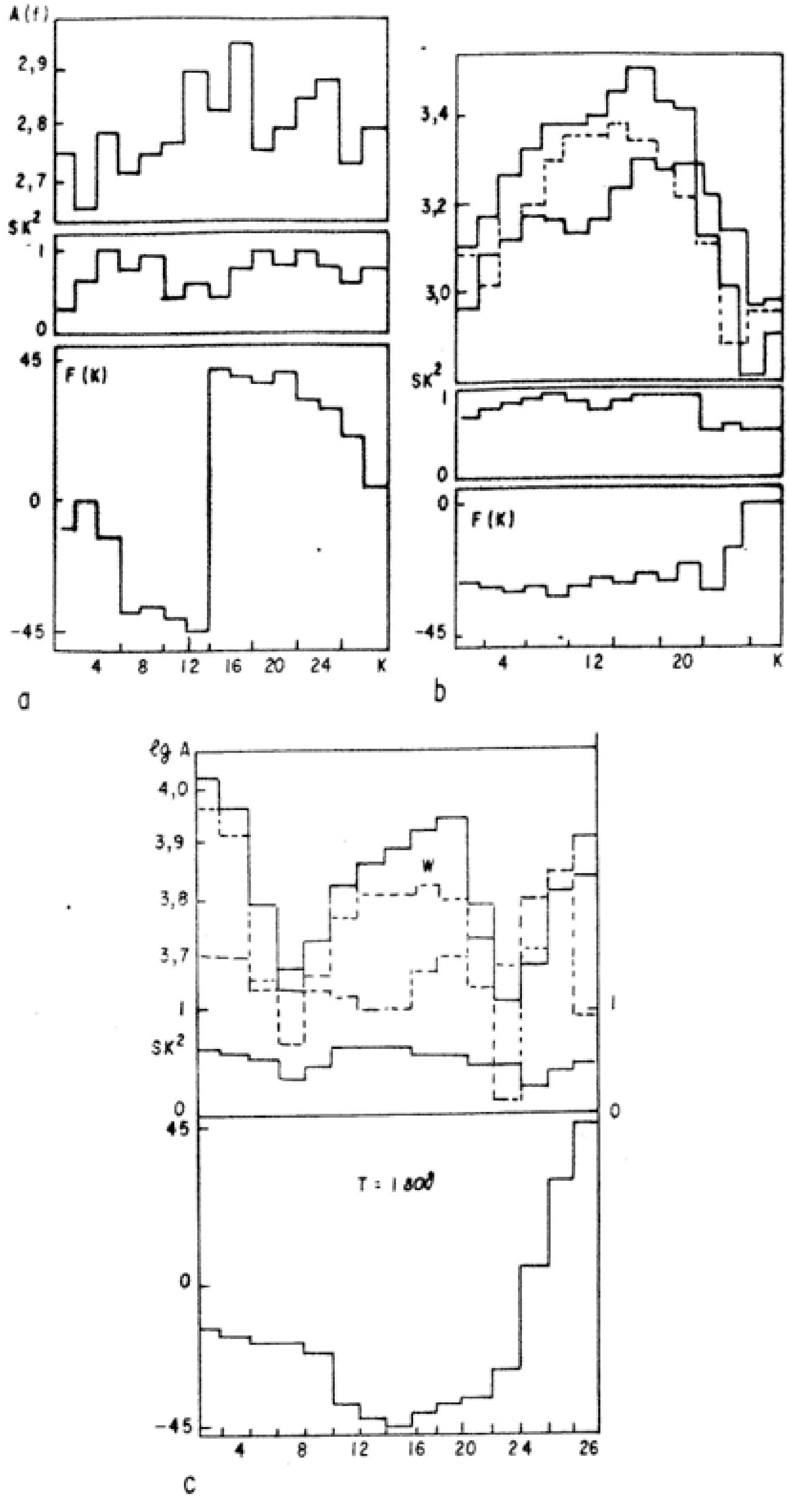
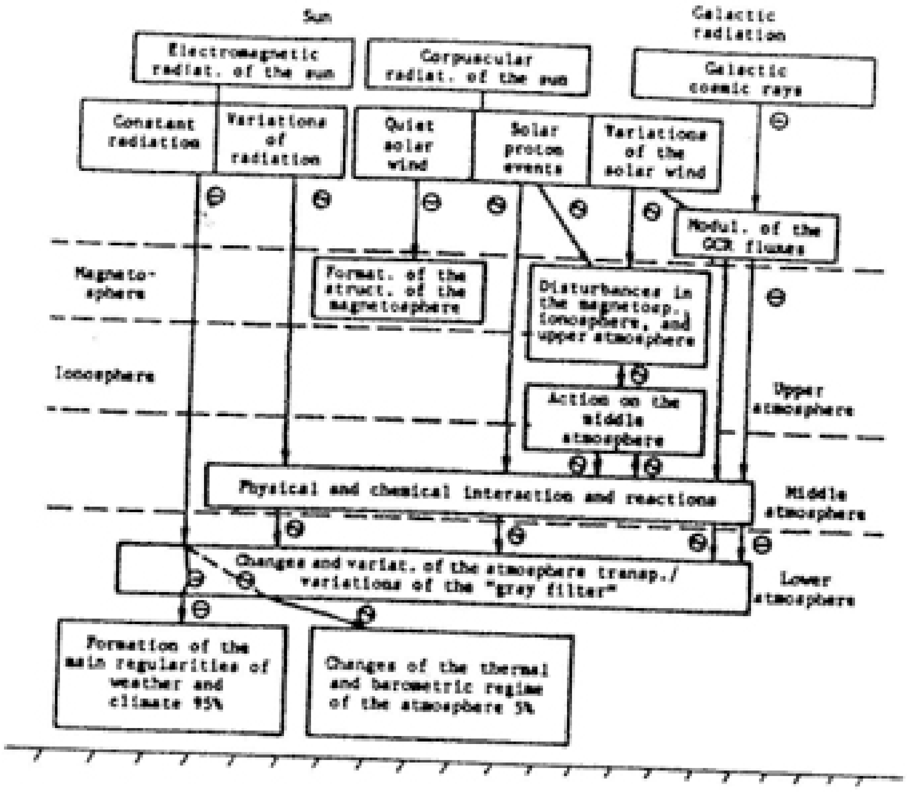

A(f)
2,9
2,8
2,7
SK²
1
0
45
F (K)
0
-45
4 8 12 16 20 24 K
a
3,4
3,2
3,0
SK²
1
0
0
F (K)
-45
4 12 20 K
b
lg A
4,0
3,9
3,8
3,7
W
1
SK²
0
1
0
45
T = 1 800
0
-45
4 8 12 16 20 24 26
c

Fig. 15



Sun
Galactic radiation
Electromagnetic radiat. of the sun
Corpuscular radiat. of the sun
Galactic cosmic rays
Constant radiation
Variations of radiation
Quiet solar wind
Solar proton events
Variations of the solar wind
Modul. of the GCR fluxes
Magnetosphere
Format. of the struct. of the magnetosphere
Disturbances in the magnetosp., ionosphere, and upper atmosphere
Ionosphere
Action on the middle atmosphere
Upper atmosphere
Physical and chemical interaction and reactions
Middle atmosphere
Changes and variat. of the atmosphere transp./ variations of the "gray filter"
Lower atmosphere
Formation of the main regularities of weather and climate 95%
Changes of the thermal and barometric regime of the atmosphere 5%