"Physics of Auroral Phenomena", Proc. XLV Annual Seminar, Apatity, pp. 74-77, 2022

Polar
Geophysical
Institute

DOI: 10.51981/2588-0039.2022.45.017

SPECTRAL ANALYSIS OF SOLAR ACTIVITY AND SURFACE TEMPERATURE

D.B. Rozhdestvensky, V.I. Rozhdestvenskaya, V.A. Telegin

The Pushkov Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation, Moscow, Troitsk

Abstract
A study of the spectral characteristics of long-term solar activity and surface temperature data has been carried out. Software has been developed which includes digital filtering modules for subsequent calculation of the spectral composition. Filtration reveals causal relationships between processes: solar activity and surface temperature variability. Identical frequency spectra for the surface temperature and Wolf number are obtained.

Keywords: solar activity, surface temperature, filtering, forecast, spectral analysis

Introduction
This study investigates the possibility of establishing solar-terrestrial relations using the spectral characteristics of processes occurring on both the Sun and the Earth. It is known that the Sun is the most important source of energy affecting terrestrial processes and, in particular, the surface temperature. Temperature variability is related to characteristic movements - rotation of the Earth around its own axis (diurnal variations) and rotation around the Sun (annual variations) [1-5]. When analysing long observation series, it is noticed that daily and annual variations are influenced by low-frequency components of temperature, reflecting the so-called temperature background, which determines the character of seasonal temperature: cold or warm winter or summer. The background can also determine climatic changes: an ice age or global warming. Low-frequency variations reflect long-term processes responsible for surface temperature and can serve as indicators for long-term forecasting, which seems relevant today [6].

In this paper, we will use spectral analysis techniques on a long series of surface temperature data to isolate its slow-changing or low-frequency component. Filtration is necessary to identify the coupled processes of solar activity and surface temperature. To calculate the spectrum, an algorithm for the contribution of a single sample to the process spectrum has been developed [7].

The digital filtering module is based on Chebyshev digital filters, chosen for their frequency response. The frequency response of Chebyshev filter is close to the response of sequential application of continuous moving averaging and ideal lowpass filter. The developed recurrence scheme for calculating the coefficients of the Chebyshev filter makes it possible to achieve a degree of suppression in the cut-off bandwidth up to 400 dB.

Schematic of processing and analysis of solar activity and surface temperature data
For spectral analysis, software consisting of digital filters and spectra calculation blocks was developed. The digital filter block is used to form series with different spectral compositions [7-10]. Fourier analysis of long-period components allows obtaining more exact spectral composition.

Based on the spectral analysis of data a set of programs for detecting the characteristics of solar-terrestrial relations was constructed. The methodology of the spectral analysis includes several steps: 1. Entering long data series; 2. Filtering data; 3. Sorting filtering results for optimal spectral analysis; 4. Saving filtering result after sorting; 5. Conducting a spectral analysis based on the contribution of an individual sample to the process spectrum; 6. Building spectral decoding and identification system.

Multi-cascade filtering of long series of experimental data for the purpose of separation of individual components of a complex process was carried out according to the scheme shown in Fig.1.

From series c[i], cb[i], cx[i], cb2[i] are formed series of differences, which are narrowband signals, which is good for forecasting: adc[i] = ad[i] - c[i]; cad[i] = c[i] - cb[i]; cab[i] = cb[i] - cx[i]; cac[i] = cx[i] - cb2[i]. A module for calculating the correlation coefficient can be added to the block diagram of Figure 1. Numerical processing is an integral part for predicting the spectral components of various heliogeophysical processes [8-10]. F ig.2 shows the control panel of the computational complex. On the left side are windows of filters LFF-1, LFF-2 and filtering coefficients. Two windows (a, b) serve for graphic representation of results.

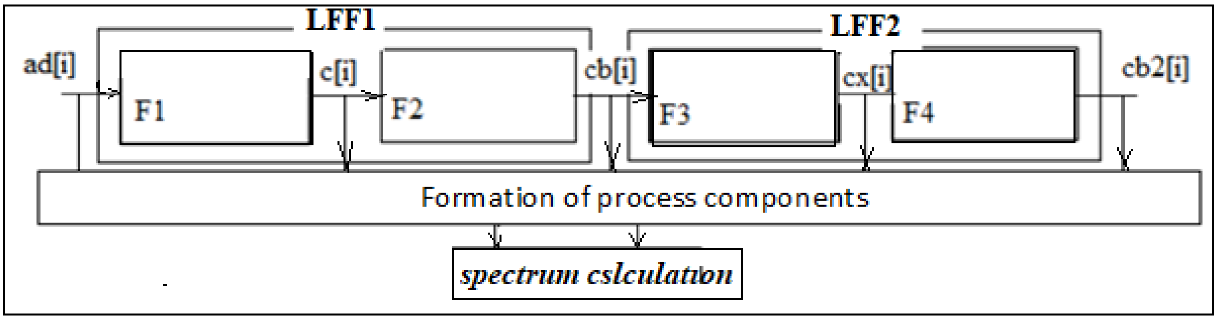

Figure 1. lock diagram of digital filtering system of heliogeophysical data processing and analysis complex: LFF-1, LFF-2 - coupled digital filter blocks F1, F2 and F3, F4, ad[i] - input data, discrete series of Wolf numbers; c[i], cb[i], cx[i], cb2[i] - results of series filtering.

Fig.2 shows that spectral components of solar activity of Wolf numbers approximately correspond to 22-year, 11-year periods, there are also components with periods of 5.5 and 2.75 years. It is known that periods of solar cycles vary from 7 to 17 years [12]. For the period in question, 1854-1918, the averaged basic harmonic of the discrete series of the Wolf number is about 9.53 years, the second is 4.9, the third is 3.17, and the fourth is 2.19 years.

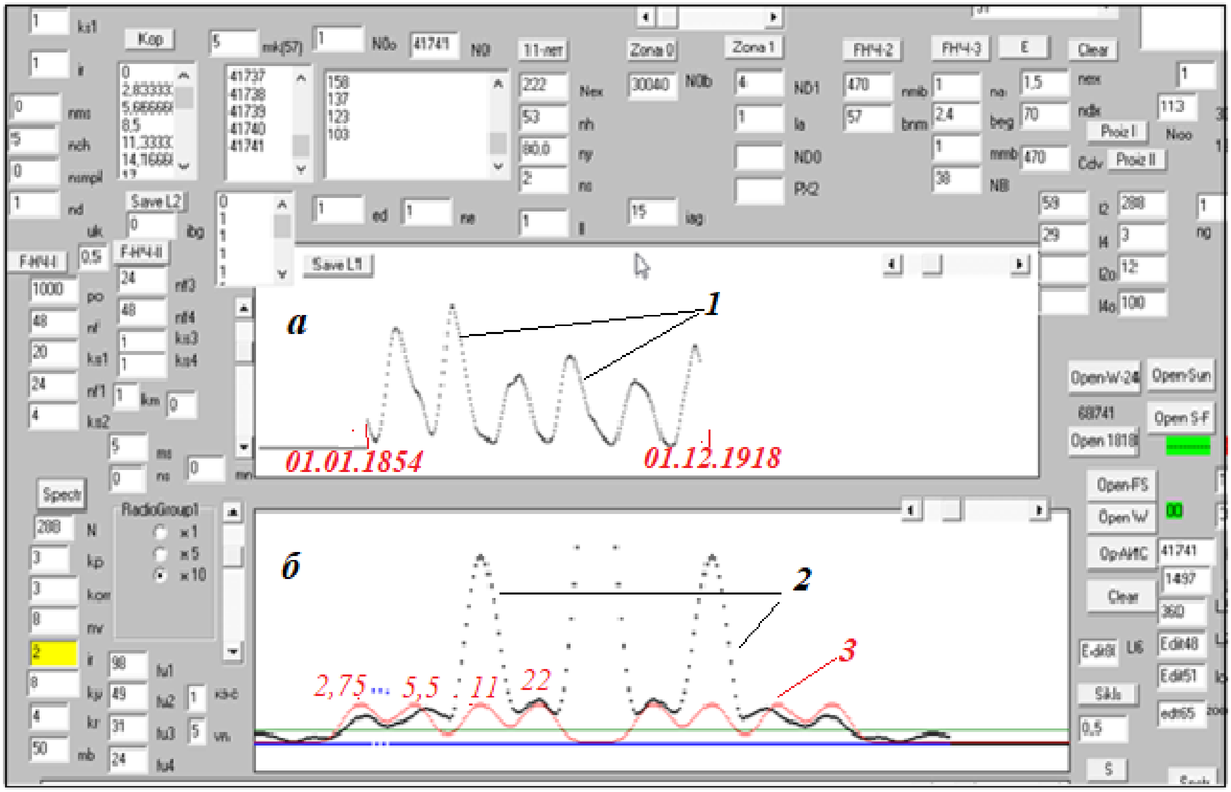

Figure 2. Control panel of the software package for analysis and processing of long series of discrete observations with fragments of calculation of solar spectral components: a- 1 - sequence of 11-year cycles of Wolf numbers, and b - spectrum of this sequence: 2 - components of the spectrum of solar activity of Wolf numbers, 3 - markers to determine periods of spectral lines. The red numbers denote the marker values of the four components of the 11-year solar cycle.

An analysis of the surface temperature spectrum obtained in the same time period from data of monthly averages at Moscow-Nemchinovka station has shown that the amplitude of the low-frequency component is much smaller than the daily and annual variations. The averaged for the whole period under consideration main harmonic is equal to about 10 years, the second - 4.83; the third - 3.0; the fourth - 2.25 years.

For long-term forecasts, it is necessary to examine the long-period components obtained by low-frequency filtering, for which purpose the high-frequency components must be excluded from the observed process. Filtering the raw data with a cut-off period of 12 months removes the annual component. The results of the surface temperature filtering are shown in a fragment of the computational complex panel (Fig. 3).

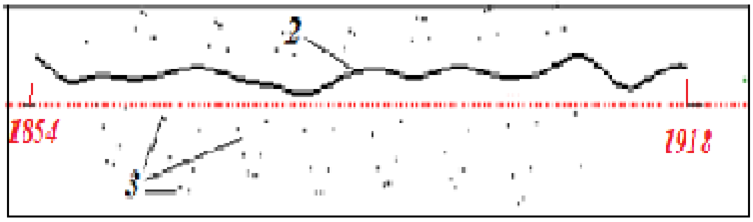

Figure 3. Low-frequency component of surface temperature (curve 2); 3 - difference between annual variation and curve 2.

The period of the low-frequency component of surface temperature (curve 2) varies from 2 to 5 years. The amplitude of temperature fluctuations varies from 1.5 to 5 degrees. To assess the attribution of the process or its components to a particular source, it is useful to examine the process spectrum and its configuration. Curve 2, although removing the annual component, gives a contribution to the higher frequency components, namely the annual and daily variations, which, depending on the phase relations, make it possible to determine the cause of cold or warm winters, hot or cold summers. This information is useful for making long-term forecasts. Analysis of the surface temperature spectrum suggests that there is a periodic process of a complex shape, since in addition to the main harmonic, the spectrum includes three to four multiples. Fig. 4 show to compares the spectra of the low-frequency component of the surface temperature (T), Wolf numbers (W) and solar emission flux 10.7 cm (F10.7).

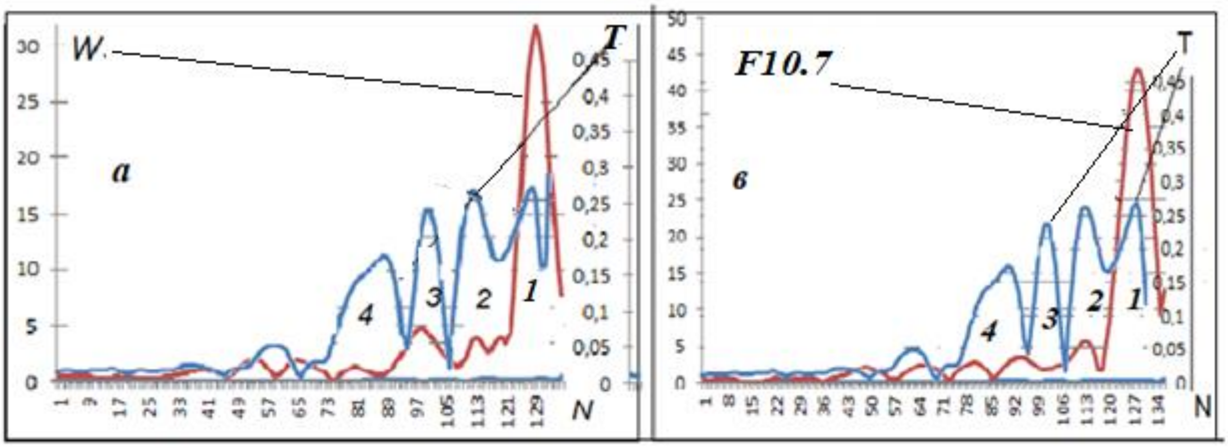

Figure 4. Comparison of spectra of low-frequency component of surface temperature (T) and a - Wolf number (W), c - radiation of the Sun at wavelength 10.7 cm, 1 - basic harmonic, 2, 3, 4 - multiples of 11-year solar cycle.

A comparison of the spectra of low-frequency components of surface temperature and solar activity has shown that the low-frequency components of surface temperature are related to eleven-year cycles of solar activity. This confirms the relative coincidence of the main components of both spectra. There is a relative mismatch between the 11-year cycles of the components of surface temperature and solar activity, which can be explained by the stochasticity of the processes occurring on the Sun and the manifestation of the nonlinearity of the Sun-Earth system, which leads to distortions of the spectral components.

Long-period changes in surface temperature can be predicted by extrapolating curve 2 (Figure 3). The difference spectrum shown in Fig. 3 shows that the signal in the time domain is close to a harmonic signal. This fact allows us to extrapolate only the low-frequency component of the surface temperature. in the time domain. Calculations show that the extrapolation interval is 1 to 5 years.

A comparison of the spectral characteristics of solar activity (Wolf numbers, flux 10.7 cm) and surface temperature shows their structural identity. The Wolf numbers spectrum has components with periods of 9.53; 4.9; 3.17; 2.19 years. The 10.7 cm flux spectrum has periods of 10.95; 5.47; 3.39; 2.63 years. The surface temperature spectrum has periods of 10 years; 4.83; 3.0; 2.25 years. As calculations have shown, the variability of solar activity energy is identical to the time series energy of surface temperature. This creates difficulties in forecasting the low-frequency component of surface temperature because it includes a significant share of stochasticity. Developing a technology for predicting processes with a significant stochastic component is important for decision making in many areas of human activity.

Conclusions

Based on our analysis of the spectral composition of solar activity and surface temperature data and a visual assessment of the spectral composition of the long-period components, we can conclude that the low-frequency component of surface temperature is due to the influence of the eleven-year solar activity component, since variations in the low-frequency components of surface temperature are similar to those of the eleven-year cycle of Wolf numbers, i.e., the character of low-frequency components of surface temperature is caused by one Long-term forecasts of surface temperature can be made using solar activity forecasts, or surface temperature forecasts can be obtained by numerical extrapolation of the low-frequency component of observational data [10-12], which is advisable by first dividing the spectrum of the original set of experimental data into separate narrowband components.

The subdivision into narrow-band components makes it possible, on the one hand, to increase the extrapolation interval and, on the other hand, to obtain information on abnormal temperature deviations from normal values, taking into account the phase characteristics of individual predicted components. The coincidence in phase of the minimum values of the low-frequency temperature component with the winter months leads to an abnormally low temperature, for example, the winter of 1941, or, by the same principle, the coincidence of the maximum temperature values with the summer months, leads to a hot summer of 1972.

Literature

1. *Akasofu S.-I.*, *Chapman S.*, Solar-Terrestrial physics. Oxford. 1972.
2. Solar-Terrestrial Influences on Weather and Climate / Proceedings of a Symposium / Workshop held at the Fawcett Center for Tomorrow 24-28 August 1978 / by Ed. *McCormac B.M., Seliga T.A.*
3. Solar-Terrestrial physics / Illustrated glossary for solar and solar-terrestrial physics / by Ed. *Bruzek A., Durrant C.J.* / Dorgrecht-Holland / Boston-USA. 1977.
4. *Svalgaard L. and Hansen W.W.,* Solar activity - past, present, future // J. Space Weather Space Clim., V.3, No. A24, 2013, doi: 10.1051/swsc/2013046
5. *Deminov M.G., Nepomnyathshaya E.V., Obridko V.N.,* Solar and ionospheric properties for cycle 25 // Geomagnetism and aeronomy, V. 56, № 6, P. 781-788, 2016.
6. *Wilfand R.M., Kiktev D.B., Shestakova N.A.*, To the 90th Anniversary of the Russian Hydrometeorological Centre // Hydrometeorological Research and Forecasting, № 4 (374), 2019.
7. *Rozhdestvensky D.B.*, Methodological foundations for digital control // Devices and Systems. Control, monitoring, diagnostics, No. 7, P. 9-16, 2011.
8. *Rozhdestvensky D.B., Rozhdestvenskaya V.I., Telegin V.A*., Spectral analysis and forecasting of the 25th solar cycles / Physics of Auroral Phenomena, Proc. XLIV Annual Seminar, Apatity, P. 96-99, 2021, doi: 10.51981/2588-0039.2021.44.022
9. *Rozhdestvensky D.B., Telegin V.A.,* Method for predicting discrete ionospheric observations / Physics of Auroral Phenomena, Proc. XXXVIII Annual Seminar, Apatity, 2015.
10. *Rozhdestvenskii D.B, Rozhdestvenskaya V.I., Telegin V.A.*, Methods of digital filtration for processing ionospheric data / Physics of Auroral Phenomena, Proc. XXXVIII Annual Seminar, Apatity, P. 149-152, 2015.
11. *Alpatov V.V., Ordanovich V.E., Rozhdestvensrky D.B.*, Long-period variations of ionospheric parameters // Heliogeophysical Research, No.26, P. 19-30, 2020.
12. *Hathaway D.H.*, The Solar Cycle // Liv. Rev. Solar Physic, V. 12, 2015, doi: 10.1007/lrsp-2015-4