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On the Reconstruction of Pecularities of Solar Cosmic Rays for the Last 400 Years Based on Nitrate Data

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Abstract

The unique set of data on nitrate (NO_3^-) concentration in Central Greenland covers the interval of 1576-1991 has been obtained by G.A.M. Dreschhoff and E.Zeller. Because the rate of nitrate generation is influenced by the intensity of cosmic rays these data contains a valuable information about its behaviour in the past. The temporal-spectral analyses of the yearly averaged version of the nitrate series have shown the presence of 4.5-6.0 year variation of signal during ~1730-1890. Some additional statistical processing make it possible to conclude that this ~5.5 year variation reflects the connection of strong solar proton events, which are the important source of nitrates, with the declining phases of solar activity. Such a connection for the last 4 solar cycles is known, but the results of nitrate data analyses permit us to expand the interval to ~20 cycles and obtaine evidence about the fundamental character of the phenomena.

Nitrate-ions NO_2^- and NO_3^- - are generated in the Earth's atmosphere in a chain of chemical reactions with nitric oxide. NO, in turn, is originated by solar cosmic rays. After generation nitrates are captured by aerosols, fall down with precipitation and are finally fixed in polar ice. Because of the connection of the majority of NO sources with the solar activity the data on nitrate abundance in ice should provide us new and quantative information about solar activity in the past. G.A.M. Dreshhoff and E. Zeller (1994) obtained an unique long set of data on the nitrate abundance in Central Greenland ice (78^0N, 38^0 W) covers the interval of 1576-1991. This series was yielded on the base of analyses of 120-meter ice core, retrieved from the summit area of the Central Greenland Ice Sheet in 1992. The entire core was split at 7776 samples of 1.5 cm. width which were analyzed separately. The nitrate concentration in each sample was determined by measurement of UV absorption. The set of data on yearly averaged nitrate concentration (415 points) was obtained using the initial set (7776 points) with the mean uncertainty of dating of ≈2 year. Present work is devoted to statistical analyses of this 415 point annual series. For investigation of continuous variations in spectral content of nitrate signal we used the moving periodogram method (Peristykh ,1991). This method is valid for analyses of nonstationary data sets and includes the following set of operations. Firstly from the initial data set a small part of fixed length is cut off by some time window. This part is considered to be stationary. Such window is moved along the initial data set with a constant step and spectral analyses using Fourier transformation is made at each step (we used the Blackman-Tukey method). By this way, the number of power spectra, which form is parametrically dependent on the current position of the center of time window, is obtained. In our approach, power spectra are calculated in terms of significance. The significance of each peak of periodogram P_{var} is estimated with using the method of data stochastization developed in (Bahcall, Field, Press, 1987) and modified in (Vasiliev, Ogurtsov, 1997).

So, using this procedure, we calculate all the power spectra in terms of significance, and finally construct the dynamic power spectrum of signal - the massive of values $P_{var}(t,T)$, where t-is the period of variation, T-current position of time window. This array can be pictured as the three-dimensional surface, where axis X shows the current position of time window, axis Y shows the frequency of variation, axis Z shows the significance of respective variation. This surface is charted as a map, where the intensity if gray color is proportional to the significance of variation. The dynamical power spectrum of nitrate data is shown at Figure 1.

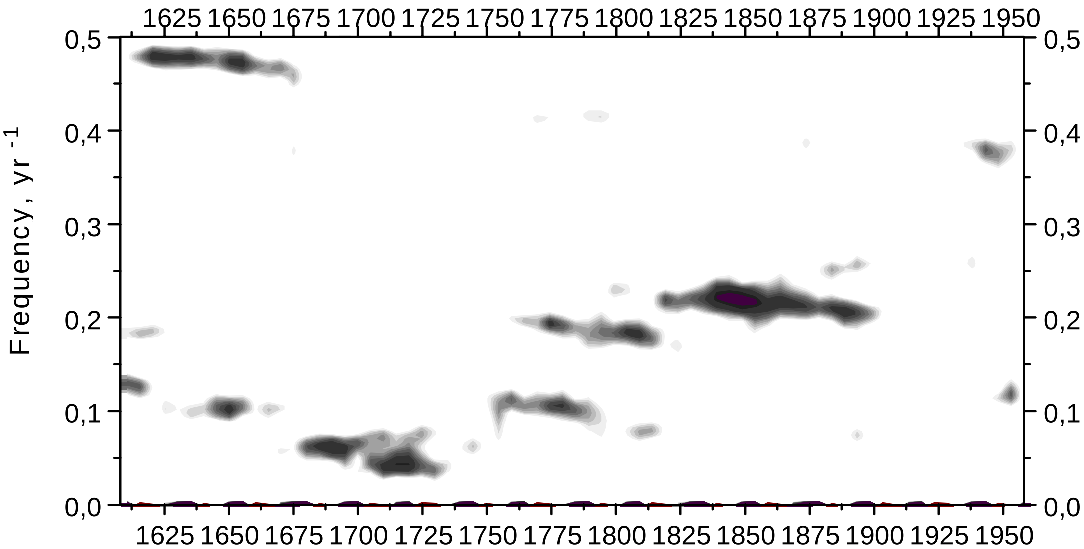

Figure 1: The dynamical power spectrum of nitrate abundance in Central Greenland (black domains-P_{var}>0.98, white domains-P_{var}<0.15).

As seen from Figure 1, nitrate signal really contains some harmonics (≈20 year variation in 1675-1730, ≈10 year variation in 1625-1660 and 1750-1810, ≈2 year variation in 1600-1680, 4.5-6.0 year variation in 1760-1900).

The majority of variations are weak, which are connected with the strong noise contained in nitrate signature. The harmonic with periods 4.5-6.0 years is more strong and more prolonged. We made assumption that this quasi five-year variation is connected with the flare activity of the Sun. Really, it is known that:

1) Short-term pulses of nitrate abundance are related to strong solar proton events (Dreschhoff and Zeller, 1995).
2) The solar proton events during last 4 solar cycles have a tendency to occur mainly at the periods of increase and decrease of solar activity (Shea and Smart, 1995).

So, the coincidence of nitrate peaks with the periods of decline of 11-year solar cycle can produce the variation of nitrate abundance with period close to 5.5 years. In order to check the hypothesis we took the set of sunspot groups SG(t) (Hoyt and Schatten, 1998), constructed from this set the set $SG_2(t)$ with double frequency and compared the nitrate series with $SG_2(t)$. Doubling of frequency was made due to multiplication of initial set SG(t), undergone the high-pass filtration, by its Hilbert transform.

$$SG_2(t) = \sqrt{SG(t) * Hilb(SG(t))} \quad (1)$$

The set $SG_2(t)$ has a variation with the period of 5.3 year. For comparison of nitrate data with $SG_2(t)$ we calculated the spectrum of coherency between both this sets. This spectrum of coherency (the square of cross-spectrum) has peaks at frequencies common for both analyzed signals (we'll call these frequencies as the coherency frequencies) and contains an information on similarity of their spectral content. It may be considered as the frequency unrolling of correlation coefficient. The spectrum of coherency between nitrate data set and the data set SG_2 is shown in the Figure 2. Here significance of coherency P_{coh} is the probability of the observed coherency between two signals not to be imitated by noise nature of one of them. It was estimated using the modification of the method of data stochastization (Bahcall,Field, Press, 1987) carried out by Vasiliev and Ogurtsov (1995).

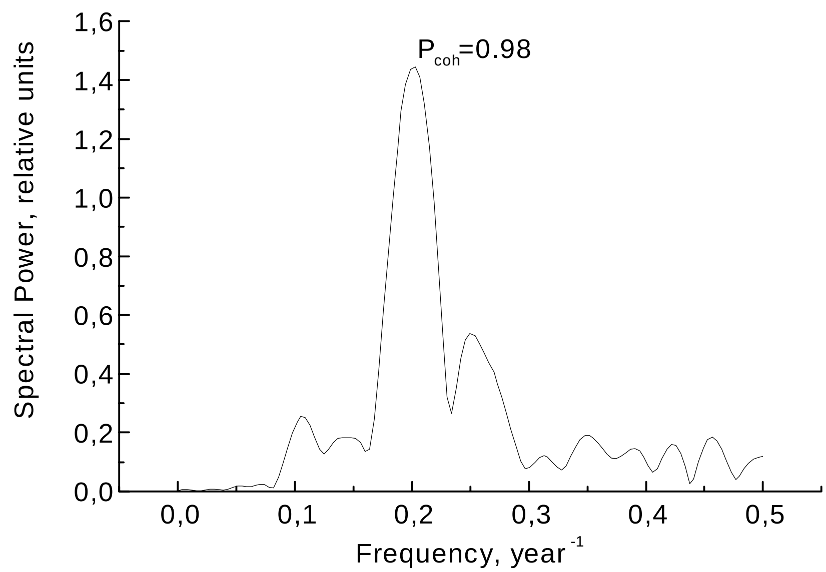

Figure 2: Spectrum of coherency between nitrate data and data set SG_2 for the period 1710-1890.

As it is seen from Figure 1, the distinct coherency with the period ≅5 years exists during the time interval 1710-1890. The illustration of the phase relation between nitrate abundance and sunspot groups is shown in Figure 3.

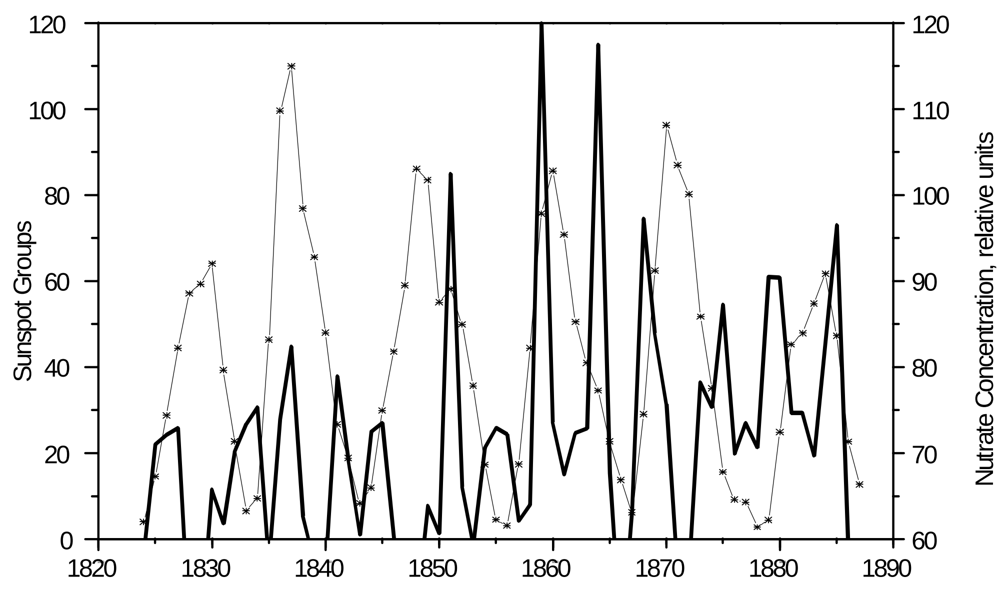

Figure 3: Nitrate concentration (thick curve) and the number of sunspot groups (thin curve).

In Figure 3 we plotted both sets at the middle of XIX century, when effect is more apparent. The coincidence of nitrate peaks with the decline periods of sunspot groups is seen visually.

So, the statistical analyses of the data on nitrate abundance in Central Greenland ice in 1576-1991, provides the evidence that peaks of nitrate abundance correlate with phases of increase and decrease of solar activity at least in 1710-1900. Relaxation of the effect in XX century may be the result of its smearing due to input of additional nitrates from the sources connected with human activity. Really, variance of short-scale nitrate variation increase after the beginning of XX century (σ^2=139.5 relative units for 1740-1820, σ^2=203.7 for 1820-1900, σ^2=310.3 for 1900-1980) that is more probably the result of increase of human activity (for example nitrogen oxides which are important source for nitrate generation are originated in processes of fuel burning). So, the total variance of signal increase and the relative contribution of solar flare induced variation decrease. This effect can decrease the significance of short-term variation connected with solar flares.

The dependence revealed above, can reflect the same connection between solar flares and solar activity, and is in agreement with the data on direct records of solar proton events during last 40 years. Such consent and increase of time range of effect existence from 40 to more than 200 years (about 20 cycles of solar activity) testify to the fundamental character of the phenomena. But because of the small significance of effect, results from the strong noise component included in nitrate signal, the conclusion made needs the further experimental and theoretical verification.

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