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The 22-year cycle of aurora borealis events in the 19th century

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Abstract. Analysis of the Russian Meteorological network data for 1837-1909 revealed for the first time the 22-year variation in the frequency of annual occurrence *N* of polar auroras. The 22-year periodicity is the most evident for high-latitude auroras (geomagnetic latitude Φ≥56°): (1) *N* is higher in odd polar cycles (which run from maxima of odd Schwabe cycles to the next maxima); (2) at solar min between odd and even Schwabe cycles *N* normalized to *W* (*N*/*W*) is higher than between even and odd cycles. The dependence of annual occurrence frequency of auroras from solar activity in midlatitude and highlatitude segments is almost in antiphase. The max number of mid-latitude auroras appears at $W^{1/2}$ =11 (around solar cycle max). The max number of high-latitude auroras occurs at $W^{1/2}$ = 6. The high-speed streams are supposed to control the high-latitude auroral activity. The increase of aurora appearances in high latitudes throughout odd polar cycles in comparison with even cycles testifies to the increased geoeffectiveness of high-speed streams from coronal holes in these periods.

Key words: polar aurora, solar activity, polar solar cycle, Hale cycle.

Introduction

The number of observed aurora events can be a measure of the numerical parameters of the solar and geomagnetic activity and heliosphere for epochs in which they were not measured. Because of this the number of works devoted to the acquisition and study of materials on auroras observed in different historical epochs has increased over the past decades. It has been ascertained that solar activity obeys 22-year periodicity, which is connected with variations in the solar magnetic field, the so-called Hale cycle. The Hale cycle is also observed in the geomagnetic activity and other geophysical parameters [1-3]. The 22-year variation is connected with features in the behavior of some solar-terrestrial parameters during odd and even sunspot cycles.

Usually for the long-term analysis of aurora appearances global catalogs are used [4, 5]. However such data are very inhomogeneous, based on fragmentary observations made in different regions with different reliability. In this paper we study long series of auroras registered in the 19-th century by the Russian network of meteorological observatories. The network presents more homogeneous data and accurate records of observations that are strongly referenced to a region.

The main aim of this work was to trace the 22-year variation in frequency of aurora occurrences *N* in 1837-1909, and to relate it to possible sources on the Sun.

Data

We have acquired and analyzed data on auroras recorded at observatories and stations of the Russian meteorological network in 1837–1909. The period under study included ~3000 events during solar cycles 8-14. The observations were carried out at 149 observatories and stations in a wide geographic region (geographical coordinates: ϕ from 39°57′ to 72°30′ N and λ from 21°1′ to 224°35′ E; geomagnetic coordinates: Φ from 28°25′ to 67°8′ N and Λ from 104°2′ to 275°23′ E). The corrected geomagnetic coordinates for all observatories were calculated for 1900. Occurrence frequency of auroras *N* was calculated as the number of days when an aurora was observed, independently of the number of stations where the aurora was recorded, summed over a year. The maximal number of stations that recorded an event reached several dozen (e.g., the aurora of February 4, 1872 was observed at 31 Russian meteorological stations at different geographical points in Europe and Asia). The meteorological conditions at a certain station were ignored. This can result in a slightly underestimated annual total value of *N*.

The relative sunspot number (Wolf number *W*) has been chosen as the characteristic of solar activity. W- a quantity that measures the *number* of *sunspots* and *groups* of *sunspots.*

Relation to solar activity

A correlation between auroras and the solar activity was already found in the 18th century as a result of the aurora that struck the inhabitants of Europe in 1716 after a long absence during the Maunder Minimum. In Fig. 1 we present the number of auroras *N* observed in different latitudinal segments in relation to sunspot numbers *W*. The border between two segments passes at the latitude of St. Petersburg observatories (Φ=56°). Until 1878, the observations were carried out in the city (Φ = 56°14′); in 1878 the observatory was set in Pavlovsk near St. Petersburg (Φ =55°58′).The data for St. Petersburg/Pavlovsk is included in high-latitude segment.

In Fig. 1 we show the annual frequency of occurrence of auroras N in different latitudinal segments together with the sunspot number W during 1837-1909. The occurrence frequency of mid-latitude (Φ<56°) auroras *N* has a maximum in cycle 11. Then *N* systematically decreases from 1868 down to zero in 1900. This behavior is in the agreement with results obtained by other authors from European catalogs [4, 5]. In contrast, the occurrence frequency of aurora *N* at high latitude zones (Φ≥56°) shows an upward trend. This trend is seen not only for the high-latitude segment, but also for the individual observatory St. Petersburg. This upward trend is discussed in detail in [6].

The 11-year variation in the appearance of aurora in St. Petersburg clearly shows the asymmetry of solar cycles: the maxima of *N* in odd sunspot cycles (11 and 13) are higher than in even cycles (10, 12, 14) (Fig. 1). Thus, a 22-year variation is traceable in the appearance of aurora in St. Petersburg.

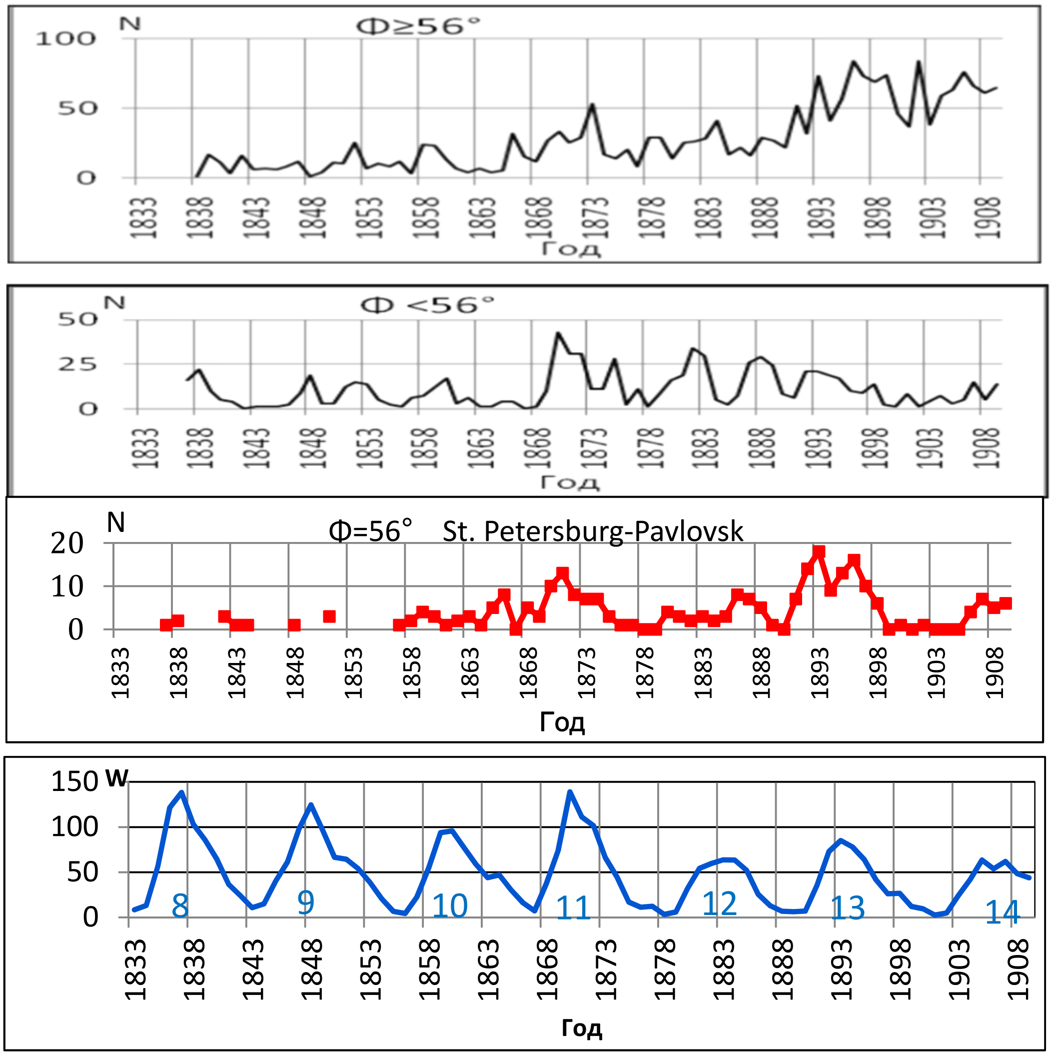

Fig. 1. Annual occurrence frequency of aurora *N* at different geomagnetic latitudes Φ and sunspot numbers W in 1837-1909.

Let us explore possible drivers of geomagnetic storms which are responsible for auroras at different latitudinal zones. In Fig. 2 the number of aurora occurrences *N* in dependence of the square root of the Wolf number √W is plotted.

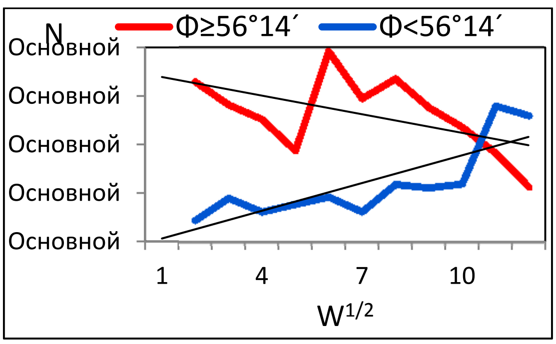

Fig. 2. Latitude dependence of the frequency of annual auroral occurrences (*N*) on the solar activity ($\sqrt{W}$). Blue: mid-latitudes. Red: high latitudes. Black: linear trends.

We see that the two curves are almost in antiphase. The max number of mid-latitude auroras appears at $W^{1/2}$ =11, (solar cycle max). The max number of high-latitude auroras occurs at $W^{1/2}$ = 6. In [7] it is shown that the occurrence of magnetic storms which are caused by corotating interaction regions of high-speed solar wind streams (CIR) has a max at $W^{1/2}$ = 5, and those storms which are caused by coronal mass ejections (CME) at $W^{1/2}$ = 10-11. This indicates that high-latitude auroras from our database are mostly CIR-related and mid-latitude auroras are mostly CME-related. This result is in agreement with [8, 9].

Auroras at solar maxima and minima

In this part, we try to trace a 22-year variation in our data on auroras. Figure 3 shows the Wolf numbers *W* and the annual number of auroras *N* normalized to *W*, *N*/*W*, at minima (Fig. 3, left plot) and maxima (Fig. 3, right plot) of the corresponding cycles. A clear difference in *N/W* between even/odd and odd/even sunspot minima (Fig 3, upper plots) is observed for high latitude auroras: at minima between odd and even cycles *N/W* is higher than at minima between even and odd cycles. Thus, the occurrence of high-latitude auroras at solar cycle minima varies with a 22-year period.

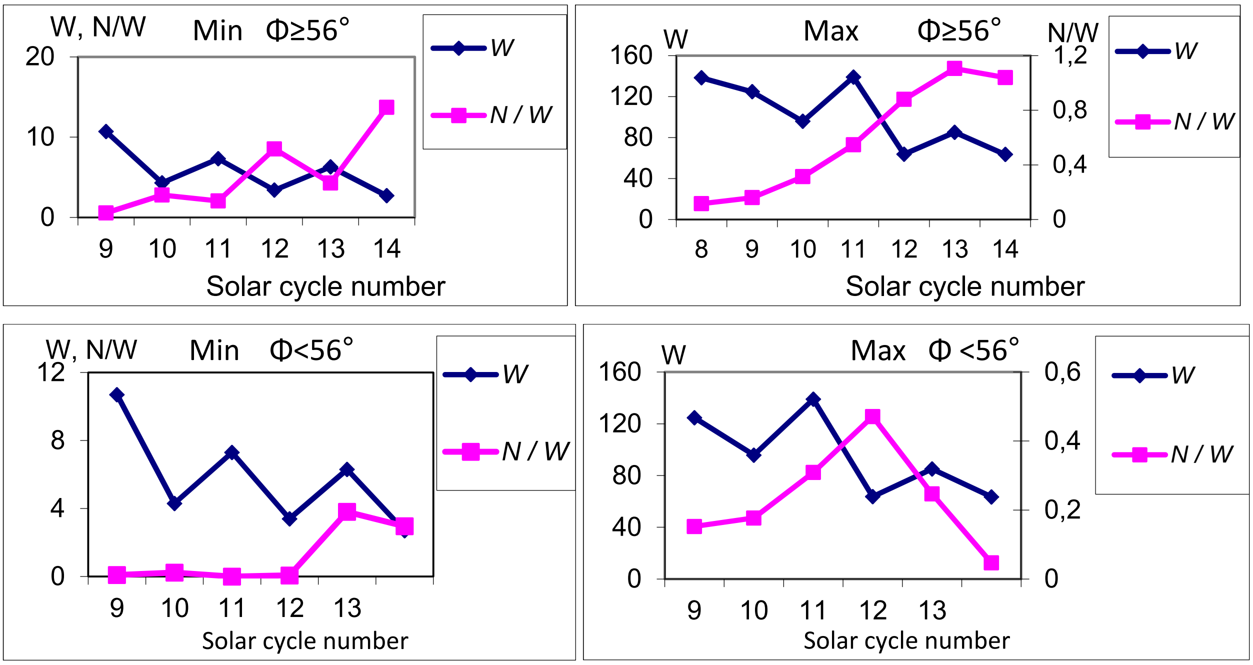

Fig. 3. Wolf number *W* and the normalized occurrence frequency of auroras *N/W* at solar cycle min and max at different latitudes. Min between cycles n and n+1 is designated n+1.

High-latitude auroras are mostly linked to high-speed streams from the solar polar open MF. In [10] it is found that the area of polar zones in the solar northern hemisphere in odd polar cycles is higher than in even polar cycles. This could explain the obtained increase of *N/W* in odd/even minima.

Sunspot Schwabe and polar cycles

Polar cycles run from one sunspot cycle max to the next max. Polar cycles which run from even sunspot cycles are named as even polar cycles. We apply a superposed epoch analysis to our data.

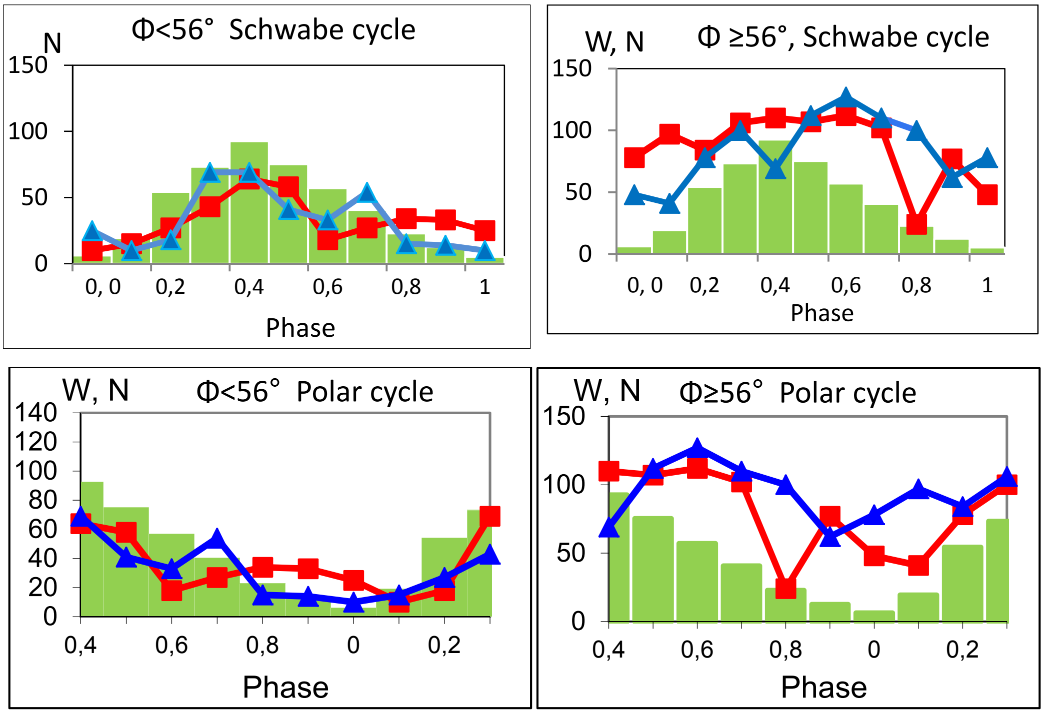

Fig. 4. Occurrence frequency of aurora *N* at different Φ in averaged Schwabe and polar cycles. Red: even cycles. Blue: odd cycles. Green histogram: Wolf numbers.

Fig. 4 (upper plots) shows that *N* of high-latitude auroras is higher in the second half of odd Schwabe cycles and in the first half of even cycles. Fig. 4 (low plot) shows that for high-latitude auroras *N* is higher throughout odd polar cycles in comparison with even ones. Thus, we can conclude that high-latitude auroras demonstrate clear 22-year variation. For mid-latitude auroras there is no such regular difference between *N* in odd and even cycles, though during ~three years around minima *N* in even cycles is somewhat higher than in odd ones which is opposite to behavior of N at high latitudes. This result shows in favor of the contribution from the inner source to the generation of the 22-year variation, as opposed to the explanation of this variation only through pure geometric Russell-McPherron mechanism associated with an inclination of the solar equator to the ecliptic plane.

Conclusion

We have analyzed data registered by the Russian Meteorological network for 1837-1909. Our results show different relations between the auroral and solar activities at stations located in different latitudes. They indicate that high-latitude auroras from our database are mostly CIR-related and mid-latitude auroras are mostly CME-related. It confirms conclusions drawn earlier by other authors on the basis of inhomogeneous data arrays. Our analysis revealed for the first time the 22-year variation in the frequency of annual occurrence of polar auroras *N* which is the most evident for high-latitude zones. High-latitude auroras are linked to high-speed streams from polar open magnetic field (MF) areas. Extrapolating back the modern pattern of the solar MF [10, 11] we obtain that in the 19th century the polar MF was negative in odd polar cycles. Higher *N* in odd polar cycles points to the higher geoeffectivity of high-speed streams in those cycles when the sign of the polar MF in the solar northern hemisphere was negative. Generally speaking, one cannot *a priori* assume that solar terrestrial processes in an earlier era proceeded in the same way as in the modern era [12]. In our case, extrapolation back modern data on the polarity of the polar Sun's magnetic field has led to "correct results". This may indicate that the properties of the internal source of the 22-year periodicity related to solar magnetic fields did not change over the past 180 years.

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