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SPECTRAL STUDIES OF THE AURORAL CURRENTS

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Abstract. The keograms obtained by the digital all-sky cameras of the MIRACLE instrument network are used for selecting the events, where the latitudinal positions of the discrete auroras are quasi-stable for hours. The one-minute and ten-second magnetometer data obtained by the meridional chain of observational stations of the IMAGE network are used for the spectrum analysis applied to the differences between the signals of neighboring stations. These magneto-difference data are employed to extract the signals of local (ionospheric) currents and to eliminate the contributions of distant sources. The numerical filtering via the typical spectral windows used for the spectrum analysis of time series reveals equidistant spectra in the range of ten-minute periods. The main features and probable origins of the obtained spectra are discussed.

Introduction

The main purpose of this work is to study the currents associated with discrete auroras observed visually or with the optical instruments. According to the theoretical models of the generation of auroral arcs, the visible arcs result from the precipitation of energetic electrons accelerated in the magnetospheric field-aligned currents. In turn, the field-aligned currents participate in the current systems including both the magnetospheric and ionospheric (Pedersen and Hall) currents [1]. Ground magnetometers detect the ionospheric Hall currents [2]. There is a number of theories concerning the origin of the field-aligned currents responsible for the auroral arcs. These theories consider quasi-stationary magnetospheric generators [3, 4], instabilities excited in ionosphere-magnetosphere interactions [5-7], or instabilities excited on the inner boundary of the plasma sheet [8]. The resonant natural oscillations of magnetic field lines excited by external sources were considered as possible origins for the night-side auroras [9]. The theory of this magnetic field line (or L-shell) resonance and the estimates of corresponding periods depending on L parameters or magnetic latitudes can be found, for example, in [10]. The spectrum of these magnetic field line oscillations, which resemble the string oscillations, must be equidistant or similar to equidistant. If we attribute the origin of auroral currents to the excitation of the magnetic field line resonance, we ought to search for the currents with equidistant spectra.

As a rule, the ionospheric and magnetospheric currents are studied via their magnetic fields detected by magnetometers. The IMAGE magnetometer network settles a meridional ground chain of high-sensitive instruments [2]. The IMAGE magnetometers detect three components of the magnetic field at every station every ten seconds. The spectral properties of the time series of measurements obtained can be examined numerically using the well-known techniques of the spectrum analysis [11]. These techniques include the fast Fourier transform (FFT) and smoothing (filtering) with some spectral windows.

Auroral observations selected for the analysis

The application of spectral techniques usually requires a stationary time series and a fairly long time interval of observations. To select a proper case for the spectrum analysis, using the all sky camera (ASC) images merged into lengthy keograms can be quite appropriate. In order to satisfy the requirements of the spectral method, we must find a discrete aurora, with its latitudinal position being quasi-stable for a long time. At any rate, there seemingly must be neither rapid progressive meridional motion of the aurora nor any explosive-phase behavior. Note that the required observations are rather atypical for the auroral phenomena, since the substorms usually include rapid meridional motions and explosive phases.

Fig. 1 presents the 31 December 2005 Kilpisjarvi ASC keogram (the station is incorporated into the MIRACLE instrument network). The keogram shows a UT interval of a quasi-stationary auroral behavior. Namely, the latitudinal position of the aurora oscillated within a narrow latitudinal interval during the period between 15UT and 19UT. During this period, the aurora was seemingly located somewhere between the Bear Island and Soroya stations. Although some meridional motions have been detected, we can expect that the observational magnetometer data are not very far from stationary time series. Consequently, we can try using the IMAGE magnetometer data between 15UT and 19UT for the spectrum analysis of currents associated with the aurora observed. The time interval used contains 240 one-minute and 1440 ten-second measurements.

On the other hand, the meridional movements of the aurora will contribute into the spectrum studied. Since these meridional oscillations display a number of frequencies, we must expect a number of combination frequencies in the analyzed spectrum. In other words, the spectrum will be noised by the 3D behavior of the current system under study. Since we have no theories taking into account this 3D behavior and explaining such a complex spectrum, the noise

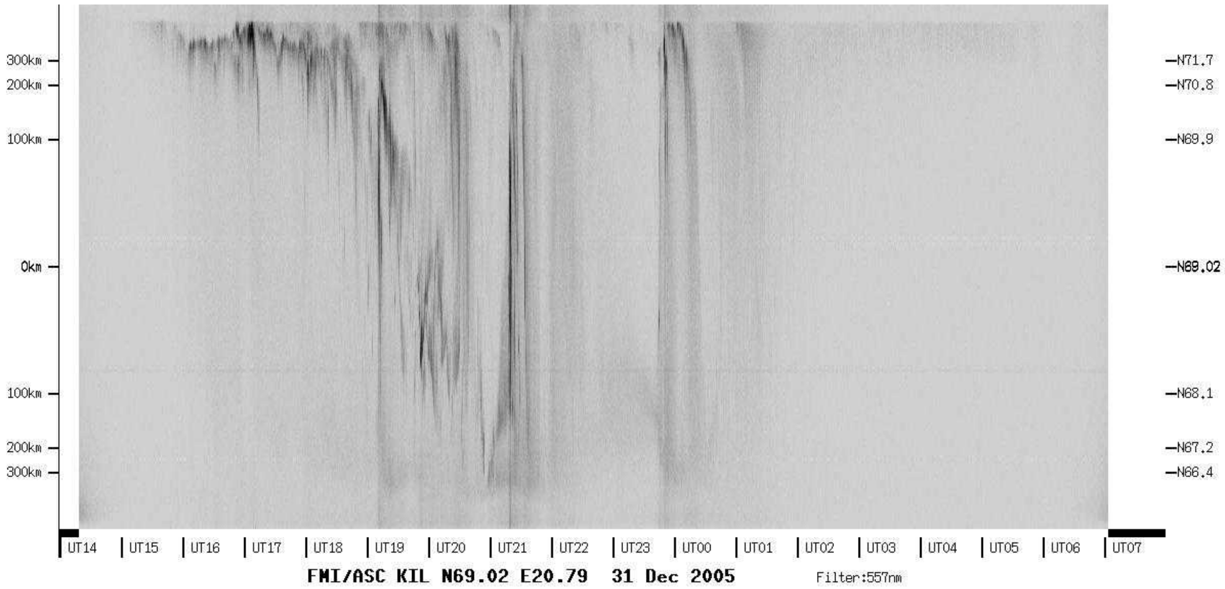

Figure 1. The ASC keogram (negative). Abscissas show UT hours, ordinates meridional distances in km (deg).

must be filtered out. This filtering can be executed using spectral windows. In addition, the spectral windows reduce the FFT effect of the spectral power leakage, which garbles the spectrum, especially for very low frequencies.

Calculations of auroral spectra.

Magnetometers detect the total magnetic field summed over all terrestrial and magnetospheric sources. To study the local current system associated with the auroral activity, we must eliminate the contributions of distant sources. To some extent, this can be realized by subtracting the signals of neighbouring stations. It is convenient to use the difference between the meridional magnetic fields detected at each pair of the nearest stations of the meridional chain. These magneto-difference signals virtually eliminate the magnetic fields of distant sources thus strengthening the relative contribution of local currents. Fig. 2 presents the analysis of the magneto-difference signal obtained from the one-minute measurements of the Bear Island and Soroya stations. The FFT spectrum 4 shows broad power maxima for some preferred frequencies, although these peaks are considerably cut up or split by narrower combination (noise) peaks. The Tukey-Hanning (Hann) window is used to eliminate the noise. The spectra 1-3 (shown in Fig. 2) result from smoothing the FFT spectrum with this window. In order to reduce the spectral leakage, we must use the lowest window resolution, and this provides the lowest number of resolved peaks. On the other hand, we must search for an equidistant spectrum owing to theoretical reasons. Using these two ideas results in the spectrum 1. This spectrum displays broad equidistant peaks, with the influence of the combination noise being reduced to minimum. The spectrum 2, being of a higher resolution, is also nearly equidistant and shows more peaks. The resolution of the spectrum 3 exceeds the two preceding ones, but this spectrum is very similar to combinational.

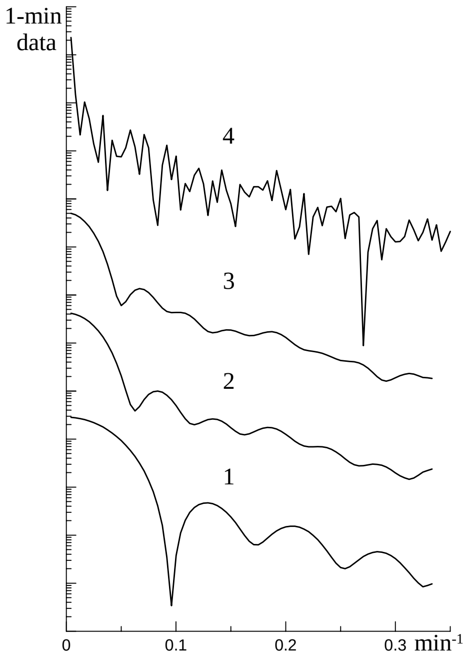

Figure 2. Magneto-difference spectra for the two stations nearing the aurora. Abscissas show frequencies in min^{-1}, ordinates logarithmic non-normalized power densities. The spectra 1-3 result from the application of the spectral window to the FFT spectrum 4.

The frequency distance between the adjacent peaks of spectrum 1 corresponds to the fundamental period of approximately 13 min. At the same time, the frequency position of the first peak (first harmonic) differs from this fundamental frequency by nearly 60%. Thus, the spectrum as a whole (including all its peaks) is shifted by this quantity toward higher frequencies. A probable explanation for this frequency shift is the following. The Hall current detected by magnetometers is referenced to the frame of the center of mass that is the frame connected with the neutral gas. The neutral gas in the ionospheric E layer is dragged by the magnetospheric convection [12], and this effect can shift the spectrum toward higher frequencies. Thus, the frequency shift determined by the spectrum analysis provides an estimate for this drag effect.

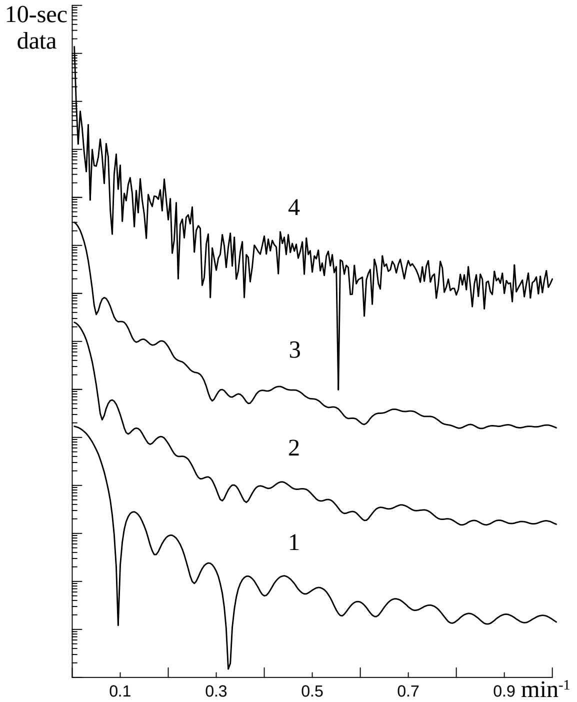

Figure 3. The spectra of Fig. 2 obtained from the ten-second measurements.

The ten-second data enable us to continue the spectrum for higher frequencies. Fig. 3 presents the analysis of the ten-second measurements. The FFT spectrum 4 again displays the broad power maxima for the preferred frequencies, although these maxima are irregularly split by the noise. Applying the low-resolution spectral window yields the spectrum 1 with the equidistant frequency peaks. A new feature is in a nonmonotonic behavior of the spectral power density near the frequencies of 0.4 and 0.7 min^{-1}, which correspond to the periods of about 2.5 and 1.5 min. These unexpected increases in the spectral density can be attributed to the magnetic field line resonance. Indeed, the increase in the powers of lateral satellite (combination) frequencies, revealed in the spectra 2 and 3, is quite typical for resonance phenomena. For the magnetic shell parameter $7<L<10$, the periods of about 2.5 min are in a reasonable agreement with the estimates presented in [10] for the magnetic field line resonance. In the framework of this interpretation, we cannot identify the first harmonics of longer periods shown in the spectra 4 and 1 as any field line resonance. On the contrary, these clear and strong harmonics probably indicate an individual spectrum of the magnetospheric source (generator), and this source is seemingly located on the same L-shell as the aurora is. The spectrum obtained supports the mechanism of the convection vortex generator proposed in [13, 14]. The model of the vortex generator predicts a fundamental period that approximately equals the ratio of the length of the convection trajectory to the convection velocity.

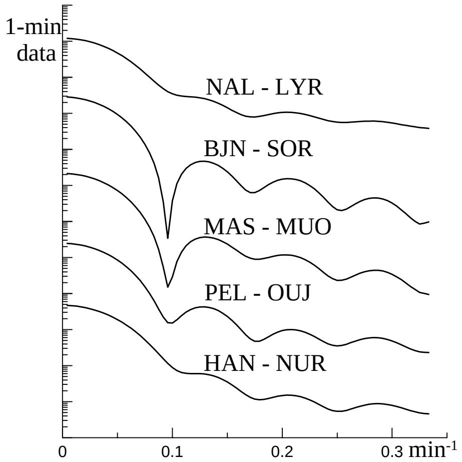

Figure 4. Magneto-difference spectra for various pairs of meridional stations. Magnetic latitudes grow in ascending order.

Fig. 4 presents the spectra obtained from the one-minute data for various pairs of the IMAGE stations forming a meridional chain. The equidistant peaks, which have been identified as the spectrum of the source, are clearly determined for the stations nearing the aurora and for some neighboring stations. However, these peaks become almost unresolved for the ends of the meridional chain. The comparison of the spectra obtained for various stations supports the idea that the source is located at the same L-shell as the aurora is, at least in the case considered.

Discussion

It is by no means surprising that the currents associated with the aurora are located on the same magnetic field lines, since the precipitated auroral electrons increase the conductivity of the unlit ionosphere at these field lines. However, it is important that the spectrum analysis reveals a sequence of preferred frequencies in the magnetometer data. The discrete or quasi-discrete spectrum of frequencies indicates that the auroral currents form a localized system with a definite structure. Since the source of the auroral currents is magnetospheric, this spectrum contains interesting information on some regions and processes in the magnetosphere. Thus, we seemingly find an opportunity to determine some significant magnetospheric parameters using the spectral analysis of the ionospheric currents.

First, the longest periods revealed seemingly cannot be identified as any magnetic field line resonance. The probable source of these oscillations is a convection generator that operates on the same magnetic field lines. The revealed periods are probably proportional to the length of the convection trajectory.

Second, the frequency shift of the entire spectrum toward higher frequencies seemingly estimates the ion drag, which the magnetospheric convection applies to the neutral gas of the ionosphere. The effect of the convection drag has been predicted theoretically and depends on some specific parameters and conditions. The spectral studies can apparently supplement the optical measurements of neutral gas velocities in the ionosphere.

Third, the probable observation of the magnetic field line resonance is very promising, since this enables us to explore some distant regions of the magnetosphere using the natural magnetospheric low-frequency generator. We have no industrial generators for such extremely low frequencies. On the one hand, the observations of the magnetic field line resonance can provide experimental estimates for the lengths of geomagnetic field lines. On the other hand, these observations can provide estimates for the plasma density in some distant regions of the magnetosphere.

Of course, any final conclusions on the prospects for the spectral studies of the auroral currents require much more extensive investigations including comparative analyses of various cases and using additional data on the radar and spacecraft measurements.

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