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MULTIPLE ARCS WITHIN A DOUBLE OVAL AND PI2-LIKE MAGNETIC DISTURBANCES ON THE GROUND

V. Safargaleev, S. Osipenko, A. Vasil'ev *(Polar Geophysical Institute, Apatity, Russia)*

Abstract. Several intervals of TV observations of the auroral arcs drifting periodically across the pre-midnight sector of the double oval are examined together with magnetic measurements on the ground. Each interval includes four or five passes of the arc through the oval toward either pole or equatorial boundary where the arc fades. The pass time is 60-90 s. Arc velocity is 0,5-1 km/s at ionospheric altitude whereas the oval boundaries move rather slowly. The sequence of the passes coincided with a Pi2 signature at a nearby ground magnetometer, so that every pass may be associated with the magnetic disturbance of approximately the same duration. We discuss a specific type of MHD-disturbances in the magnetotail plasma sheet as a reason for those auroras. We obtained a dispersion equation for the waves inside the region of gradual increase of the plasma pressure under the effective "gravity" force due to the magnetic field line curvature. These waves may propagate both parallel and perpendicular to the magnetic field forming a specific resonant Alfven wave and cause the electron precipitation because of the large compressional component.

Introduction

We use a term 'multiple arcs' here to describe the event, when a new auroral arc appears at some point and travels poleward or equatorward. It eventually fades, and a new arc appears and moves to replace the previous one. In the evening sector auroral zone such events are observed during the periods of geomagnetic activity, westward the auroral bulge (Elphinstone et al., 1996, Nielsen et al., 1993). The short-acting (of 1-2 minute duration) periodic poleward step-like displacement of the arc is also typical for substorm expansion phase. Such events are also referred to as multiple arc events. They are observed near local midnight and designated as pseudobreakups. The nearby magnetometers detect the Pi2 activity at that time.

The arcs mentioned are the ordinary auroral arcs. In this study we discuss one more type of the multiple arcs which sometimes may be observed in the region filled with pulsating auroras. We shell use a term arc-like forms as these arcs are the narrow azimuthally stretched strips. The most effective way to find these events in optical data is the analysis of the keograms which are zenith angle (latitude) - versus-time plots along the magnetic meridian of the evolving intensity.

Instrumentation

In this study we have analyzed the observations of aurora from Lovozero (64.09° N, 115.47° E, MLT=UT+3h) observatory. Aurora registration has been made by TV-camera with 180°x180° field of view and zenith photometer with the angle of view near 6°.

The TV-data were digitized at 1 s resolution using 256x256 pixels and 64 brightness levels. One pixel covers 0.55x0.55 km area at the center of the TV frame. To construct the keograms, the mean value of the sky luminosity in the vertical split with width of 20 pixels was calculated for each frame. Such keograms indicate the aurora development along the meridian. Due to these techniques the periodic poleward propagating auroral patterns were found in the pulsating aurora and were recognized as pulsating arc-like forms during further processing.
Further processing comprises the digitizing of selected intervals with temporal resolution of 12 frames per second. This allows one to see the luminosity pulsations with period of 5-10 seconds in the keograms. Some intervals were also digitized at spatial resolution of 512x512 pixels to calculate the integral sky luminosity for the interval studied. This makes possible to distinguish the arc-like form from the pulsating background.

Observations

Although we have analyzed number of events, space allows us to show in more detail only one example. For illustration we select the interval during the ISTP magnetic cloud event on January 10-11, 1997. The multiple arcs were observed during magnetic storm recovery before and after small isolated substorm with two onsets. Each onset was displayed as the negative bays near 1855 UT and 1910 UT on the Dikson magnetograms and was also accompanied by Pi2 burst in Lovozero (see Fig. 1). The first onset coincided with the increase in B_z component on the stationary orbit. The auroral breakup occurred at the poleward edge of Lovozero TV camera field of view. Near 1950 UT, the visible camera on the Polar satellite fixed the formation of a double auroral oval above the Scandinavia with its equatorial part within the TV camera field of view (small black circle). The process of double oval formation was accompanied by equatorward drift of aurora. As a result, the poleward edge of pulsating aurora region appeared on the keogram at 2005 UT. The pulsating auroras are seen as thin dark vertical lines below it.

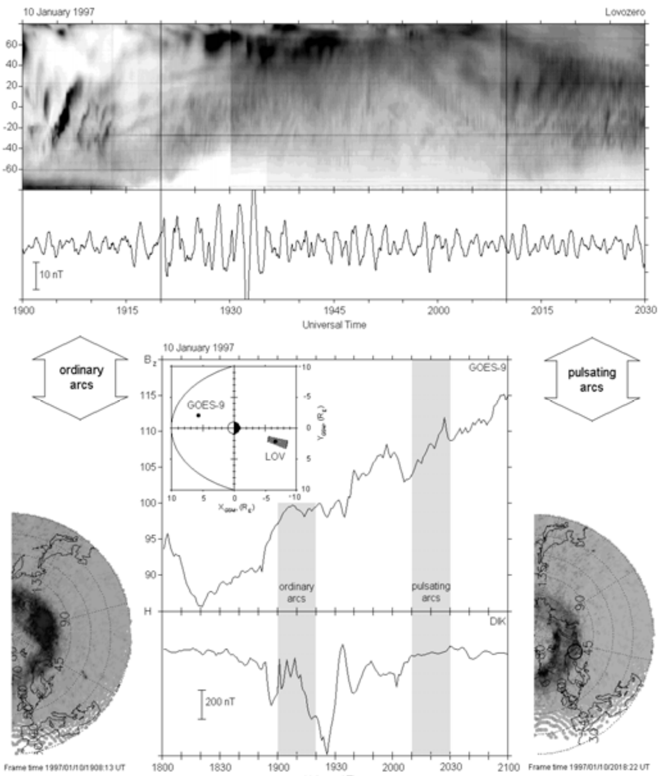

Fig.1. Multipoint observation through the period considered. The highlighted are the intervals of multiple arc events.

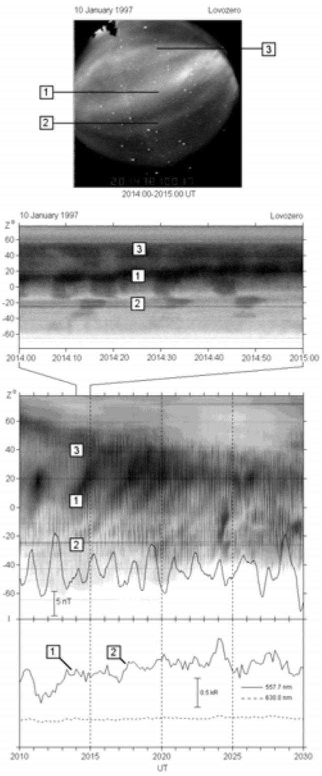

Fig.2. *From top to bottom:* multiple arc-like forms; keograms showing the dynamics of auroras with magnetogram superimposed; variations of sky luminosity near local zenith.

The first multiple arc even just before the auroral breakup was quite similar to the one discussed by Nielsen et al. (1993). The event under consideration started at 2010 UT and lasted for 15 minutes. During the interval at least seven consecutive passes of the pulsating arc-like pattern through Lovozero zenith were observed. The arc-like form of the pattern may be inferred from 1 minute integration TV frame in Fig.2.

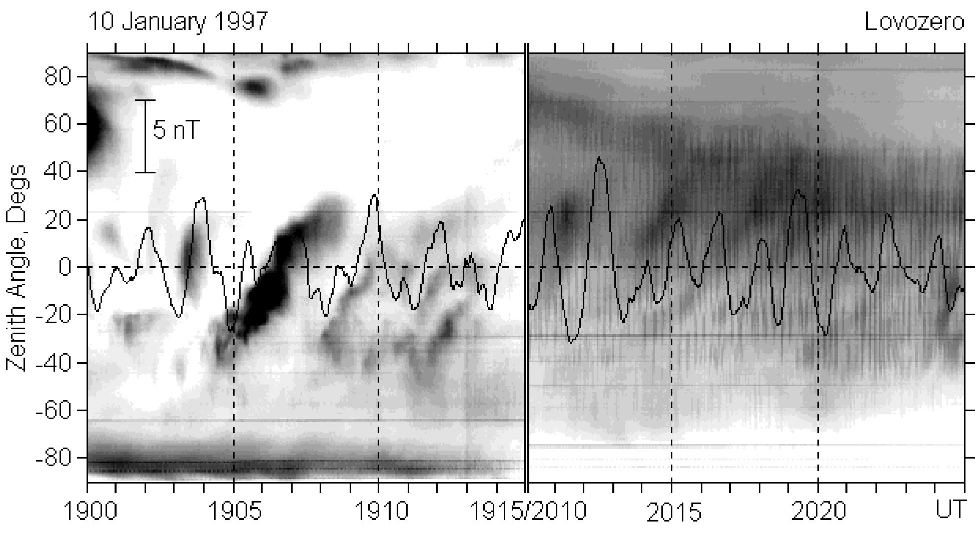

Fig.3. Ordinary (*left*) and pulsating (*right*) multiple arcs with Pi2 geomagnetic activity.

At 2012 UT the first arc-like form appeared in the region filled with pulsating auroras. The arc drifts poleward with the velocity about 350 m/s at the ionospheric altitude. (Note that the boundary moved in opposite direction at that time). During the arc brightening, the second arc appeared at the same place. A few minutes later the first arc faded, the second arc enhanced and the third arc appeared. The zenith photometer shows the arc associated variations in the line of 557.7 nm which seems to be a feature of inverted V precipitation. The repetition period is 2-4 minutes, the lifetime is 5-7 minutes. Also shown is the high-resolution keogram which demonstrates the pulsating features of the arc-like forms. The period of pulsations is near 10 s which is consistent with the previous observations (Tagirov et al., 1998).

The remarkable feature of the arcs observed is their connection with Pi2-like disturbances at a nearby magnetometer (see Fig.3). There is distinct peak-to-peak correlation with multiple ordinary arcs when every pass of the arc coincides with the magnetic impulse on the magnetograms. The pass of the pulsating arc may be associated with a train of pulsations.

Discussion.

The poleward propagating multiple arc-like forms in pulsating auroras were reported earlier (see Thomas and Stenbaek-Nielsen (1981) and references therein). They were found during the substorm recovery and named as propagating pulsations in contrast to pulsating patches which do not move while existing. The repetition period (i.e. the lifetime) of propagating pulsations is small (10-30 seconds), whereas the velocity is very high (30-100 km/s at the ionospheric altitude).

The main differences of propagating pulsations from those described above are the smaller repetition period and the higher propagating velocity. From this point of view, the events under consideration are close to multiple ordinary arcs. But in contrast to them, they are commonly observed inside the equatorward part of double auroral oval whereas the ordinary arcs seem to be originated just from the auroral bulge.

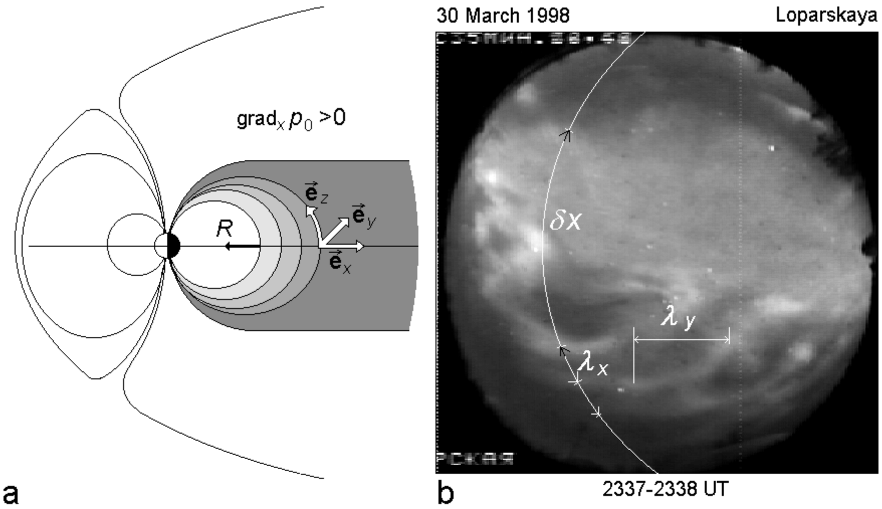

Fig.4. Model of the inner edge of magnetospheric plasma sheet (**a**) and estimations of the components of the wave number from auroras (**b**).

Only few mechanisms for multiple ordinary arc generation has been proposed up to now (Samson et al., 1996, Lyatsky et al., 1999). As in the both models the sharp gradient of magnetospheric plasma parameters is necessary, they are not suitable for the phenomena discussed. We think that so-called internal 'gravity' waves in the medium with smooth plasma pressure gradient should be involved to explain it.

The dispersion equation for MHD-waves inside the smeared out internal boundary of the magnetospheric plasma sheet was obtained by Safargaleev and Maltsev, 1986. For the model in Fig. 4a, it has the following form:

$$\omega^2 = k_z^2 V_A^2 + \omega_g^2 \frac{k_y^2}{(k_y^2 + k_x^2)}; \omega_g^2 = \beta \frac{V_A^2}{1+\gamma\beta/2} \frac{1}{R} \frac{\partial}{\partial x} \ln \frac{p_0}{B_0^\gamma} \quad (1)$$

where $V_A^2 = B_0^2/4\pi\rho$ is the Alfven velocity, $\beta = 8p_0/B_0^2$, B is the magnetic field, γ is the adiabatic exponent, ρ, and p are the density and pressure of the plasma, R is the radius of curvature of the magnetic field line.

The group velocity may be calculated as following:

$$V_x^G = -k_x k_y^2 \omega_g^2 / \omega k_\perp^4, \quad V_y^G = k_y k_x^2 \omega_g^2 / \omega k_\perp^4 \quad (2)$$

where $k_\perp^2 = k_x^2 + k_y^2$ is the wave vector.

Relation between parallel and transverse components of magnetic disturbance is:

$$\left|\frac{B_z^{'}}{B_x^{'}}\right| = \frac{\beta\gamma}{k_z}\left(\frac{1}{R}(2+\beta\gamma) + \frac{1}{2\gamma}\frac{\partial}{\partial x}\ln p_0\right) \qquad (3)$$

The characteristic size of the region of pressure change (the width of the internal edge of the plasma sheet) δx ~ $2R_E$, the radius of curvature for the quasi dipole magnetic field R~$6R_E/3$, where R_E is the Earth radius. Assuming β~1, V_A~1000 km/s, γ=5/3 we find from Equation (1) ω_g~0.16 c^{-1}.

The components of the wave vector may be estimated as k_x^{-1}~10 km, k_y^{-1}~50 km at ionospheric altitude (see Fig.4b). Assuming the wave frequency to be of order of the accompanying Pi2-like disturbances, we get from Equation (2) V_x^G~100 m/s in the ionosphere, which seems to be close to the observed velocities.

Equation (2) also gives $V_\perp^G$~100 km/s in the magnetosphere. The smaller $V_\perp^G$ as compared with $V_\parallel^G$ ~ V_A~1000 km/s means that the wave is directed by the magnetic field. In this case we can assume k_z^{-1}~L, where L is a length of the magnetic field line, and get $|B_z'/B_x'|$~3 from Equation (3). It is well known that the wave with strong B_z component may cause the electron precipitation into ionosphere.

Conclusions

We report a new type of multiple arc-like forms observed during the substorm recovery in the region filled with pulsating auroras. As these forms are rather faint and also masked by background luminosity, it is necessary to integrate the sequence of TV images to find them in optical data. In order to describe their dynamics it is useful to look at the keograms. In the case of multipoint observations, the double oval can be seen through the interval and the multiple arc-like events occur within its equatorial part.

These patterns propagate mainly polewards with mean velocity about 300 ms^{-1} at ionospheric altitude and repetition period of Pi2 range. Their propagation is restricted by the pole boundary of pulsating region. The boundary and the arc may move in opposite directions.

As inferred from the keograms, several arc-like forms may co-exist for a long time in the TV camera field of view, whereas the multiple ordinary arc phenomena is rather a sequence of appearance-displacement-fading events of single arc.

The MHD-waves inside the smeared up internal boundary of a plasma sheet are supposed to be a reason for the phenomena described.

We assume for both types of the multiple arcs the enhancement of ionospheric conductivity be a reason for accompanying Pi2 pulsations.

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