VARIATION OF AKR SOURCE ALTITUDE AS A RESULT OF IONOSPHERE-MAGNETOSPHERE INTERACTION

M. Mogilevsky*, J. Hanasz† and I. Moiseenko*

Abstract

Source altitudes of Auroral Kilometric Radiation (AKR) have been studied using two-year measurements of the POLRAD radio spectrograph onboard the INTERBALL-2 satellite. Association of the AKR source altitudes with geomagnetic activity has been found: the generation region rises upward and expands with increasing magnetic disturbance. Physical nature of the source variation - the background plasma density variations in the AKR source region is attributed to plasma flows from the ionosphere into the magnetosphere. Characteristics of AKR and results of a previous active heating experiment were used to analyze the negative feedback of the generation mechanism.

1 Introduction

The first observations of the AKR [Benediktov et al., 1968] showed that its intensity depends on geomagnetic activity. The AKR generation mechanism is the cyclotron maser instability [Wu and Lee, 1979] that grows in regions of a reduced plasma density in the auroral magnetosphere, where the electron plasma frequency is lower than the electron gyro-frequency [Calvert, 1987]. Fluxes of energetic electrons injected from the magnetospheric tail into the inner regions carry the free energy for AKR generation and the same fluxes are the signature of geomagnetic variations. Earlier studies showed that the AKR is very sensitive to variations of geomagnetic activity and could be used to determine the onset of a magnetospheric substorm [Voot et al., 1977; Kurth et al., 1998].

A seasonal dependence of the AKR intensity was first revealed by GEOTAIL satellite measurements [Kasaba et al., 1997]. Subsequent studies on the AKEBONO (EXOS-D), POLAR, IMAGE, and INTERBALL-2 satellites have shown the existence of a remarkable difference between the AKR spectra in summer and in winter: in summer, the upper

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* *Space Research Institute, Russian Academy of Sciences Profsoyuznaya St. 84/32 Moscow, Russia*

† *Space Research Center PAS, Torun, Poland*

frequency limit shifts toward the lower frequencies [Kumamoto and Oya, 1998; Kumamoto et al., 2003; Green et al., 2004; Olsson et al., 2004].

In this paper, we analyze the statistical characteristics of the altitude of the AKR generation region as a function of geomagnetic activity. We interpret our results concerning dynamics of the generation region in terms of variations of the ionospheric plasma flows from the ionosphere into the magnetosphere and, as a result, violation of the AKR generation conditions at lower altitudes in the auroral magnetosphere [Mogilevsky at al., 2005].

2 Experimental data and their analysis

The POLRAD experiment [Hanasz et al., 1998] was designed for spectro-polarimetric measurements of electromagnetic fields in the frequency range 4 kHz - 2MHz with a frequency resolution of 4.096 kHz. It was carried out on board the INTERBALL-2 satellite. The INTERBALL-2 orbit was chosen in such a way that the spacecraft moved for a relatively long time over nearly the same L-shell in the apogee region. This allowed us to perform measurements under approximately same conditions of radiation reception for two to three hours in the same orbit. In this paper, we have used measurements obtained in the frequency range up to 1 MHz (sweep duration was equal to 6.5 seconds) or 2 MHz (sweep duration was equal 13 seconds) to trace the variation in both the lower and upper limits of the AKR frequency range.

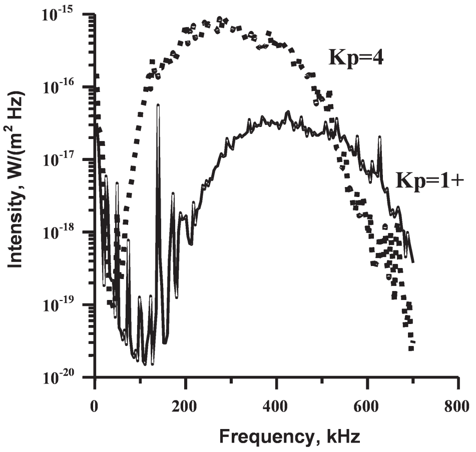

Figure 1: AKR spectra constructed from Polrad measurements in December 1997; the solid and dotted curves represent averaged AKR spectra under quiet (Kp = 1+) and disturbed (Kp = 4) geomagnetic conditions, respectively.The assessment of the statistical errors for this spectra are less then few percents of values.

For a statistical analysis we have selected a two year period of measurements, from October 1996 through August 1998. To find the patterns of AKR intensity variations and the dynamics of the frequency limits of the generation region, we have constructed average AKR spectra for each observing session. The averaging was performed over 280 - 1700 spectra measured aboard the satellite (the number of measured spectra was determined by the session duration and the operating mode of the instrument). Subsequently, values of the upper and lower frequency limits of the AKR averaged spectra have been binned according to the corresponding Kp values. Results are presented below.

Figure 1 shows two examples of the average AKR spectra constructed from the measurements in December 1997 for quiet (Kp = 1+) and disturbed (Kp = 4) geomagnetic conditions. The signal below 20 - 30 kHz is the whistler mode of the radiation that is not analyzed in this paper.

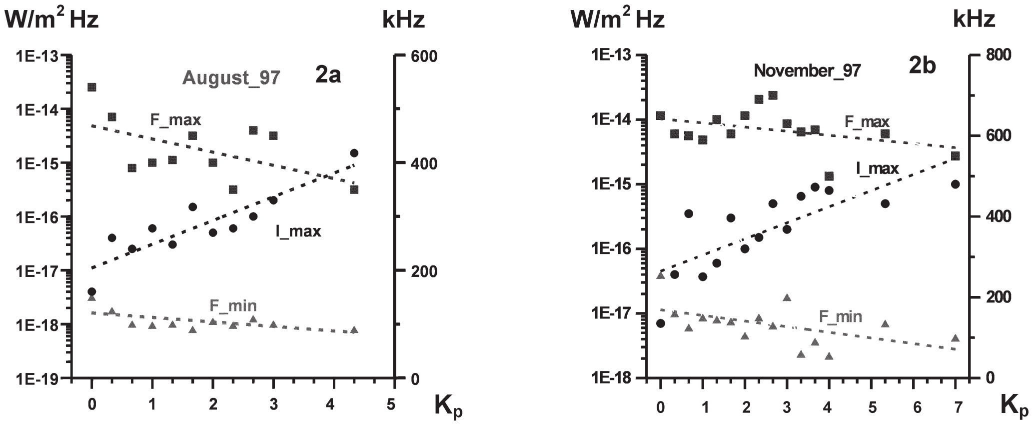

Figure 2: Upper F_{max} and lower F_{min} frequency limits of the averaged AKR spectra (right-hand axis) and averaged intensity (left-hand axis) as functions of geomagnetic activity, measured in summer (August 1997 - panel a) and in winter (November 1997 panel b) periods. Dotted lines - regression lines for measured parameters.

Variations of AKR spectra under different geomagnetic conditions are summarized in figure 2 for two periods of measurements: summer (panel a) and winter (panel b).The values for linear regressions similar for other periods of observations. During winter time slope of curves change in following limits: $K(F_{min}) \sim -4$ to -6, $K(F_{max}) \sim -3$ to -10, $K(I_{max}) \sim 0.2$ to 0.3 and in summer time: $K(F_{min}) \sim -1.5$ to -2.7, $K(F_{max}) \sim -1$ to -6, $K(I_{max}) \sim 0.1$ to 0.2.

The average AKR intensity increases by about 2 orders of magnitude with increasing geomagnetic activity, while the lower and upper frequency limits shift toward the low frequencies. It should be noted that the spectral shape also changes: during the summer, under disturbed conditions, the width of the spectrum decreases in comparison with the spectrum under quiet conditions (lower and upper frequency limits shift toward the low frequencies by 150 and 100 kHz respectively with increasing geomagnetic activity), while the spectral peak shifts toward the low frequencies. These changes in the spectrum imply that the AKR source displaces to the higher altitudes: the lower and upper boundaries of the source move upwards by 300-350 and ≈ 2500 km, respectively. The differences in upper and lower frequency limits of AKR spectra for summer and winter are caused by seasonal ionospheric modification previously discussed in Green et.al [2004].

Thus, our analysis of the AKR spectral variations with geomagnetic conditions reveals that under disturbed magnetic conditions the AKR generation region expands and rises upward along the magnetic field line.

3 Summary of observational results

The presented observational results can be summarized as follows:

(1) The result of previous studies has been confirmed: as geomagnetic activity grows from $Kp \approx 0-1$ to $Kp \approx 4-7$, the AKR intensity increases by one or two orders of magnitude;

(2) The new result is that the AKR spectrum varies with geomagnetic activity: in disturbed periods, the lower frequency limit shifts down by 100 - 200 kHz, and the upper frequency limit shifts more often toward the low frequency.

4 Discussion

Green et al. [2004] and Olsson et al. [2004] showed that the AKR spectrum varies seasonally: in summer, the radiation is not observed at high frequencies and becomes more intense at low frequencies. These measurements led the authors to conclusion that the AKR generation region rises upward along the flux tube in summer. This is due to increased charged particle fluxes rising from the ionosphere, which is caused by the heating of the ionosphere under solar radiation.

Increase of the plasma density caused by rising fluxes of charged particles leads to violation of the AKR generation conditions at low altitudes.

In our experiment we observed similar variations of AKR spectra with changes of geomagnetic activity. This could be due to the properties of the auroral ionosphere depending strongly on the fluxes of precipitating particles (Fig. 3). These particles cause the heating of the ionosphere and the increase of the ionospheric density. The effect is similar to the variations of ionospheric parameters due to the solar radiation. Such changes in the ionosphere increase the fluxes of rising particles, which, in turn, leads to the increase of the altitude of the AKR generation region.

The rising fluxes have a stronger effect at low altitudes, because for an isotropic particle velocity distribution in the ionosphere, only a small fraction of them will reach the high altitudes of the AKR generation region. It can be concluded therefore, that the mechanism of the AKR spectral variations with geomagnetic activity is similar to the mechanism of seasonal variations suggested by Green et al. [2004].

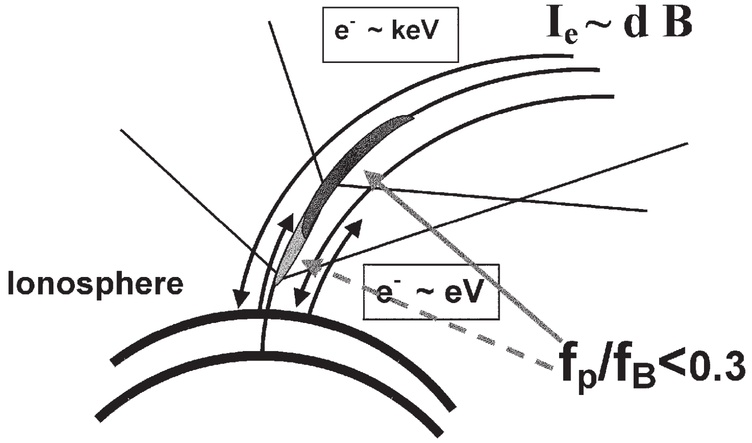

Figure 3: The scheme of ionospheric plasma influence on the AKR generation region.

The AKR generation mechanism has a negative feed-back, since the same electrons, which generate AKR, also stimulate the up-flowing ionospheric particle flux caused by the ionospheric modification. One of the feed-back key parameters is the characteristic time, which controls duration of AKR bursts. Since the traveling time of the secondary ionospheric particles is much longer then that of the precipitating electrons, the characteristic time of the feed-back depends, in general, on the traveling time of ionospheric plasma. To estimate the time of the ionospheric plasma penetration into the AKR generation region we have used results of an active experiment on board the ARCAD-3 satellite [Djorjio et al., 1987]. In this experiment E region of ionosphere was heated by the ground-based transmitter. The time delay between the beginning of the ionospheric heating and the moment, when ionospheric particles was detected onboard of satellite was measured in this experiment at altitude 1700 km above ionosphere. Using results of this experiment we have estimate the traveling time for particles, which leaved ionosphere and reached AKR generation region - about 10 minutes.

Figure 4 shows a typical spectrogram of AKR and intensity variation of this emission, as measured with Polrad on board of Interball-2. Three bursts of AKR - the intensification of the emission amplitude,were detected within the period of one hour. These bursts are characterized by a rapid onset of the emission (lasting for approximately 1 minute) followed by a longer exponential decay of about 10 minutes [de Feraudy et al., 2001]. The decay of the emission intensity started from the highest frequencies and then gradually finished at the lower ones. This is in a good agreement with our hypothesis that the AKR damping can be caused by the up-flowing ionospheric particles.

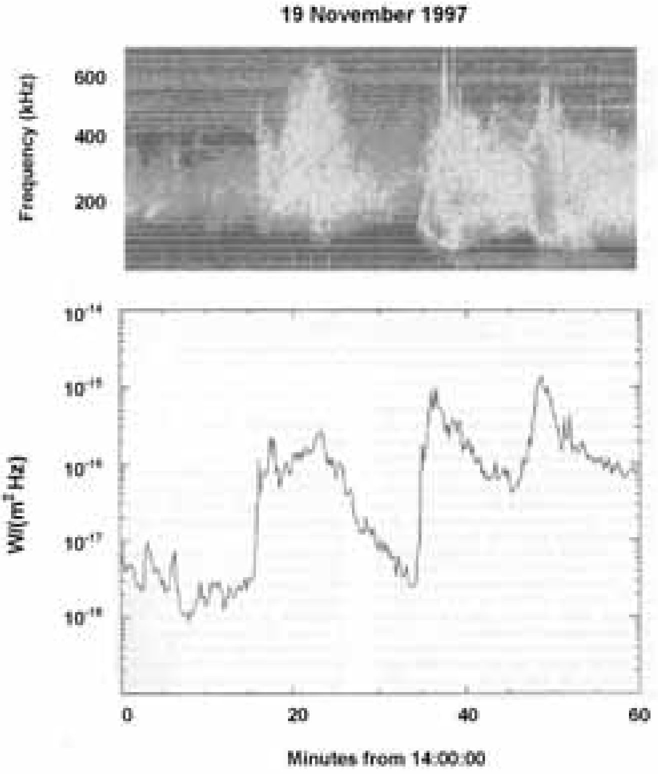

Figure 4: Top panel: Polrad spectrogram of AKR obtained in the night-side auroral region at the altitude of 2.7 Earths radii; bottom panel - corresponding variations of AKR intensity integrated over frequency range for this period.

5 Conclusion

In this report we have shown the evidence, that average altitudes of AKR generation regions are not only dependent on season (summer - winter), as it was discovered earlier, but also on geomagnetic activity (Kp parameter), in such a way that in conditions of higher geomagnetic activity the lower frequencies of AKR are generated. In other words the higher magnetic activity stimulates the AKR sources to rise in altitude. Precipitation of energetic particles in times of increased auroral magnetic activity heats the plasma in the upper ionosphere, which subsequently expands into the lower parts of the AKR generation region and fills up the auroral cavities located there. This makes impossible generation of high frequency radiation in low altitude auroral regions. Thus only the lower frequencies can be radiated from high altitude sources at high geomagnetic activity conditions.

Acknowledgments

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