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Optical emissions in the nighttime subauroral region during the March 1-4, 1982 magnetic storm

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Introduction

Cole suggested in 1965 that stable auroral red (SAR) arc was a sink for ring current energy [1], but progress has been slow in identifying the mechanism for getting the ring current energy into the ionosphere. A major advance was made recently [4] in directly observing from the DYNAMICS EXPLORER-2 satellite at 850 km the heated electron population responsible for the 6300 Å emission. It was characterized as having a temperature of 9900° K, and a bulk velocity of 275 km/s. Authors of [5] confirmed that this population could excite the SAR arc observed from the ground at the same time. In [4] was also found that the heated population was not recorded by the DE-1 satellite, at 6000 km altitude on the same field line, which suggests that the heating is more local than expected for a ring current source. Finally, it was noted that photoelectrons produced in the sunlit conjugate hemisphere were blocked from reaching the dark hemisphere in the region of the SAR arc. This suggests that the two hemispheres were electrically disconnected in the SAR arc.

The present study is aimed at extending the ideas developed in previous papers. The INTERCOSMOS-BULGARIA-1300 satellite provides detailed measurements of the atomic oxygen emissions at 5577 Å and 6300 Å, as well as the N_2^+ 4278 Å emission and the hydrogen Balmer beta 4861 Å emission. Both electrons and photons are observed, down to energies of 200 eV; this does not permit observation of the suprathermal population but serves well to define the auroral oval boundaries. Closely coincident DE-2 passes are used to relate the suprathermal electron population to the BULGARIA-1300 data. The soft precipitation region equatorward of the oval can overlap into the SAR arc region, thus making it difficult to distinguish between the auroral (factually subauroral) energy source and the ring current source. This is considered in detail using a number of examples.

Attention is given to plasma drifts in the region of the SAR arc, and the SAR arc phenomenon is compared with conditions during penetration of the convection electric field into the subauroral region, as discussed in [6]. The author has established, for example, a close correlation between increasing drift velocity and increasing temperature, which also occurs in association with a trough in the ion density and the presence of suprathermal electrons. This phenomenon occurs just beyond the equatorward boundary of the oval. However, as it was already noted, these regions can overlap, which could make them indistinguishable. An important consequence is that the suprathermal electrons observed during electric field penetration can occur in the absence of a ring current. The problem is whether there can be two different mechanisms for generating suprathermal electrons at the plasmapause/plasmasheet boundary, one involving the ring current and the other not. This in turn raises serious question as to whether the ring current energy is really directly transferred into the SAR arc, whether the process is indirect, or whether there is not even a causal relationship.

For this study, the geomagnetic storm of March 1-4, 1982 was used. A preliminary account of the characteristics of this storm has been given in [9], using BULGARIA-1300 data. Further coincidences with DE-2 during other storms were sought for comparison; for the only case found, the two satellites were in conjugate hemispheres.

Observations

The D_{st} level during the period of the storm is shown in Fig. 1. The sudden commencement occured at about 12.00 h on March 1, and D_{st} reached a level of -215 nT at 06.00 h on March 2. In the same figure, the times of the passes of BULGARIA-1300 and DE-2 passes are shown, identified by their orbit numbers. Relevant data from five BULGARIA-1300 passes were obtained during the storm.

The first is shown in Fig. 2 as orbit 2920 on March 2,1982 at 03:12 UT, three hours before D_{st} reached its maximum extent, and consists of the optical data for the atomic oxygen emissions at 5577 Å and 6300 Å, and the N_2^+ (0,1) band at 4278 Å. The nighttime auroral oval pattern is not very different from that at low activity levels, apart from an increase in the emission rate and an expansion both poleward and equatorward. The terminology for the structure of the auroral oval has been reviewed in [3], and has been further interpreted in terms of spectral ratios. We follow that description and termino logy here. Starting at the poleward limit at the beginning of the pass, there exists until 03:11:45 UT a soft precipitation region, poleward of the oval, dominated by 6300 Å emission called further on the "soft poleward border" Then, the poleward boundary of the oval is crossed, and the discrete component of the oval is entered, extending to 03:14:40 UT and characterized normally by near equality between the 5577 Å and 6300 Å emissions, with a much weaker 4278 Å emission and structured peaks. In this orbit the 6300 Å emission is significantly stronger than 5577 Å emission. Moving equatorwards from 03:14:40, the diffuse component of the oval is entered; characterized by dominant 5577 Å emission, and near equality between the 6300 Å and 4278 Å emissions. The equatorward boundary of the oval is defined as the point where the 5577 Å emission falls to the level of the 6300 Å emission; it is well defined at 03:16:45 UT, beyond which there is a soft precipitation region equatorward of the oval, called the "soft equatorward border". This region is characterized

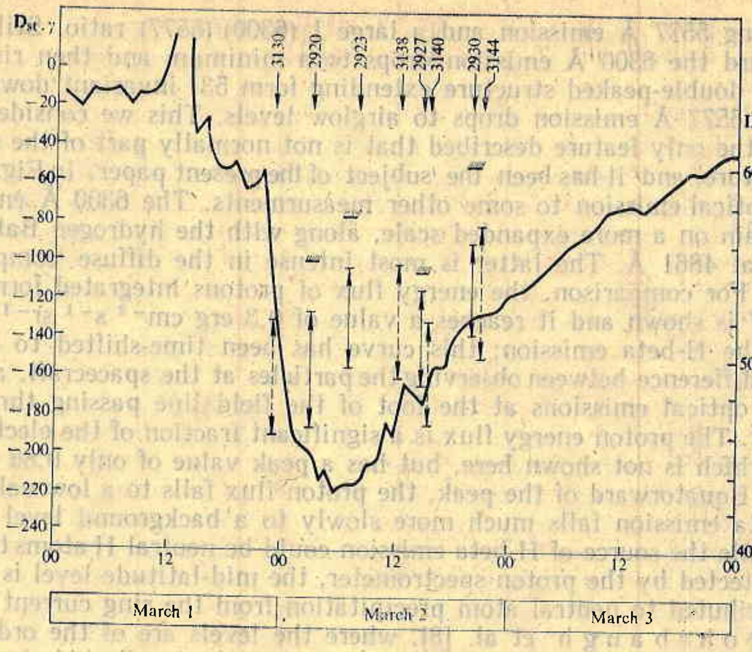

Fig. 1. D_{st} variation during the March 1-4, 1982 storm

The horizontal bars with shaded area represent the equatorial boundary of the oval (1 KeV EBO); full and dashed arrows — the location of SAR arc and suprathermal (st) electrons respectively. Orbit numbers of BULGARIA-1300 and DE-2 satellites indicate the moments of measurement

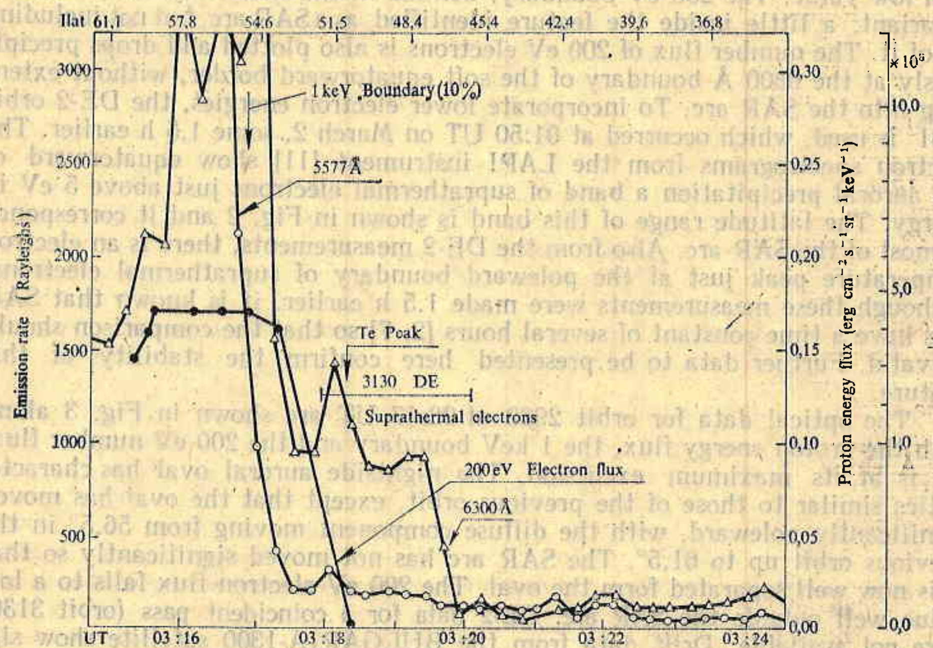

Fig. 2. Emission intensities of 6300 Å and 5577 Å along with 200 eV electron flux intensity measured on BULGARIA-1300 orbit 2920

1 KeV EBO is marked by an arrow, as well as the location of suprathermal (st) electrons measured on DE orbit 3130. Invariant latitude (Ilat) is given on top of the figure

by a falling 5577 Å emission and a large I (6300)/(5577) ratio. Still further equatorward the 6300 Å emission drops to a minimum and then rises again to form a double-peaked structure extending form 53° invariant down to 46°, while the 5577 Å emission drops to airglow levels. This we consider a SAR arc; it is the only feature described that is not normally part of the nightside oval structure, and it has been the subject of the present paper. In Fig.2 we relate the optical emission to some other measurments. The 6300 Å emission is shown again on a more expanded scale, along with the hydrogen Balmer beta emission at 4861 Å. The latter is most intense in the diffuse component of the oval. For comparison, the energy flux of protons integrated form 200 eV to 15 keV is shown and it reaches a value of 0,3 erg cm^{-2} s^{-1} sr^{-1} near the peak of the H-beta emission; this curve has been time-shifted to allow for the time difference between observing the particles at the spacecraft, and viewing the optical emissions at the foot of the field line passing through the spacecraft. The proton energy flux is a significant fraction of the electron energy flux which is not shown here, but has a peak value of only 0,86 erg cm^{-2} sr^{-1} s^{-1}. Equatorward of the peak, the proton flux falls to a low value, while the H-beta emission falls much more slowly to a background level of about 60 R. While the source of H-beta emission could be neutral H atoms that would not be detected by the proton spectrometer, the mid-latitude level is too great to be attributed to neutral atom precipitation from the ring current as observed by Rohrbaugh et al. [8], where the levels are of the order of IR. We conclude that this signal is background from earth-reflected starlight and perhaps artificial sources.

The boundary for 1 keV electrons, defined as the point where the number flux drops to 0,1 of its value in the oval, is also shown. It corresponds to the point where the 5577 Å emission, as shown in the previous figure, has dropped to a low value. The 200 eV boundary, defined in the same way, occurs at 51° invariant, a little inside the feature identified as a SAR arc, but not including all of it. The number flux of 200 eV electrons is also plotted and drops precipitously at the 6300 Å boundary of the soft equatorward border, without extending into the SAR arc. To incorporate lower electron energies, the DE-2 orbit 3131 is used, which occurred at 01:50 UT on March 2, some 1,5 h earlier. The electron spectrograms from the LAPI instrument [11] show equatorward of the auroral precipitation a band of suprathermal electrons just above 5 eV in energy. The latitude range of this band is shown in Fig. 2 and it corresponds to most of the SAR arc. Also from the DE-2 measurements, there is an electron temperature peak just at the poleward boundary of suprathermal electrons. Although these measurements were made 1.5 h earlier, it is known that SAR arcs have a time constant of several hours [2, 7] so that the comparison should be valid. Further data to be presented here confirm the stability of this feature.

The optical data for orbit 2923 at 08:17 UT are shown in Fig. 3 along with the proton energy flux, the 1 keV boundary and the 200 eV number flux. D_{st} is at its maximum excursion. The nightside auroral oval has characteristics similar to those of the previous orbit, except that the oval has moved significantly poleward, with the diffuse component moving from 56,5° in the previous orbit up to 61,5°. The SAR arc has not moved significantly so that it is now well separated form the oval. The 200 eV electron flux falls to a low value well outside the SAR arc. DE-2 data for a coincident pass (orbit 3136) were not available. Drift data from the BULGARIA-1300 satellite show significant westward drift in the SAR arc region.

The next pass, orbit 2927 at 15:04 UT, is shown in Fig. 4. The oval has moved equatorward again to a location similar to that of orbit 2920. The 200

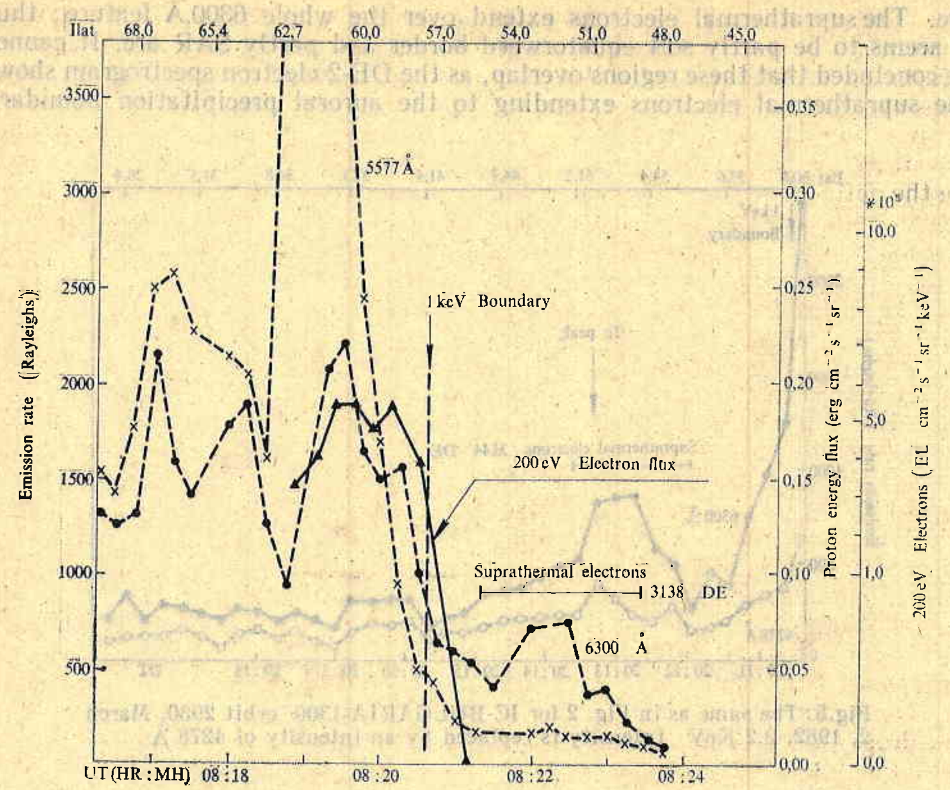

Fig.3. The same as in Fig. 2 for BULGARIA-1300 orbit 2923, March 2, 1982

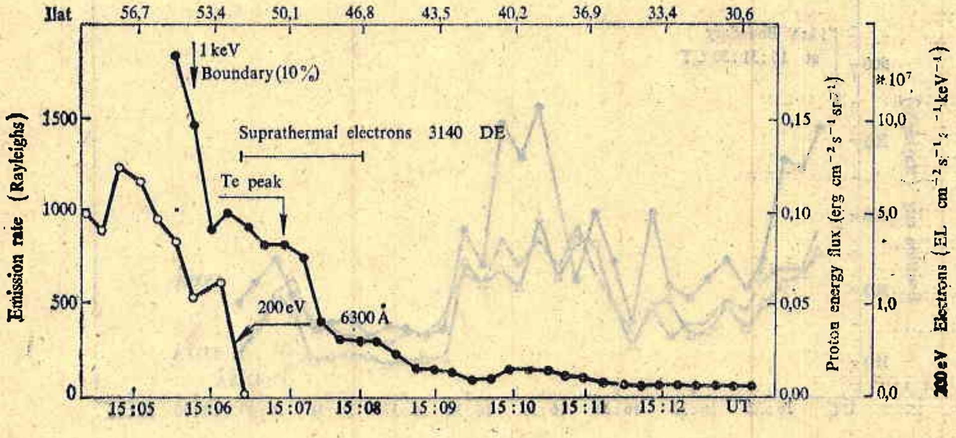

Fig. 4. The same as in Fig. 2 for BULGARIA-1300 orbit 2927, March 2, 1982

eV electons overlap the SAR arc like shoulder of 6300 Å emission, but do not underlie all of it. DE data from orbit 3140 obtained half an hour later show an electron temperature peak extending throughout the whole 6300 Å feature, but perhaps peaking in the equatorward part that we identify with the SAR arc. The suprathermal electrons extend over the whole 6300 Å feature; thus it seems to be partly soft equatorward border and partly SAR arc. It cannot be concluded that these regions overlap, as the DE-2 electron spectrogram shows the suprathermal electrons extending to the auroral precipitation boundary

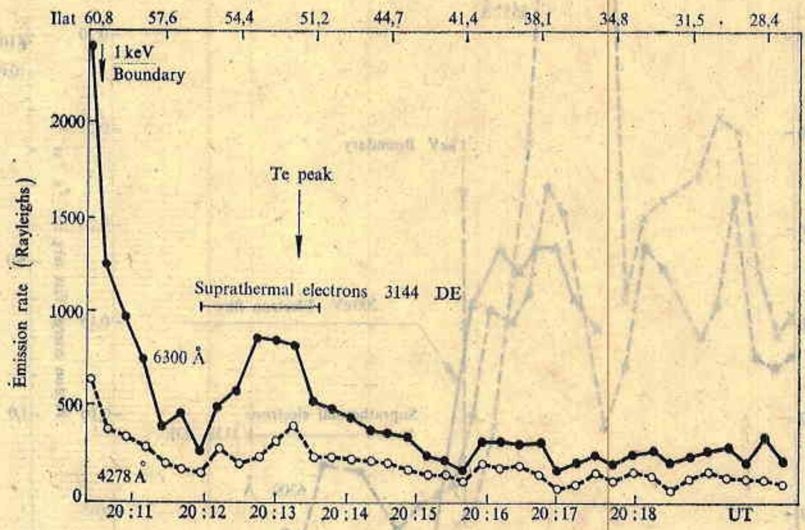

Fig.5. The same as in Fig. 2 for IC-BULGARIA-1300 orbit 2930, March 2, 1982. 0.2 KeV intensity is replaced by an intensity of 4278 Å

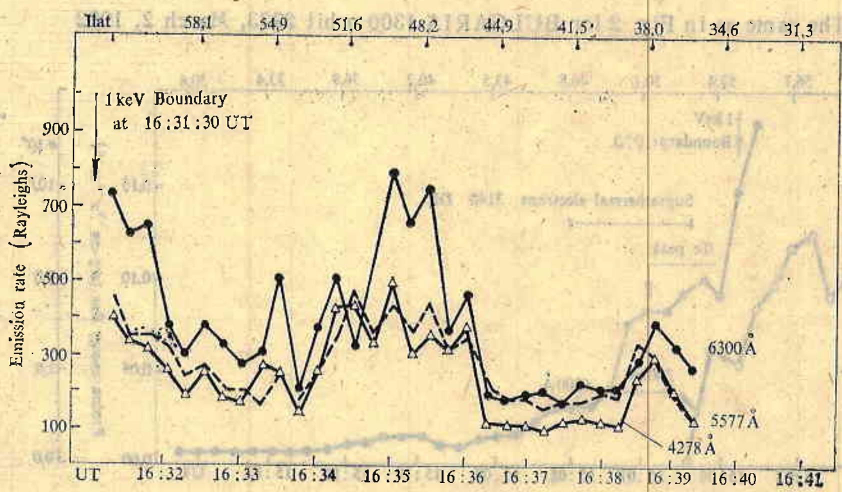

Fig. 6. The same as in Fig. 5 for IC-BULGARIA-1300 orbit 2942

where they become overlaid or replaced by auroral electrons. The strong westward flow observed for the SAR arc region in the previous orbit continues here. Figure 5 shows the data from orbit 2930 at 20:10 on March 2. The auroral oval has moved poleward of 60° invariant and occurs before the start of the pass.

The SAR arc, still located at 53°, is well separated from the oval and is clearly well equatorward of the 200-eV electrons. DE orbit 3155, just 20 min later, displays both the electron temperature peak and the suprathermal electrons that confirm the identification as a SAR arc. The westward flow of the pre-

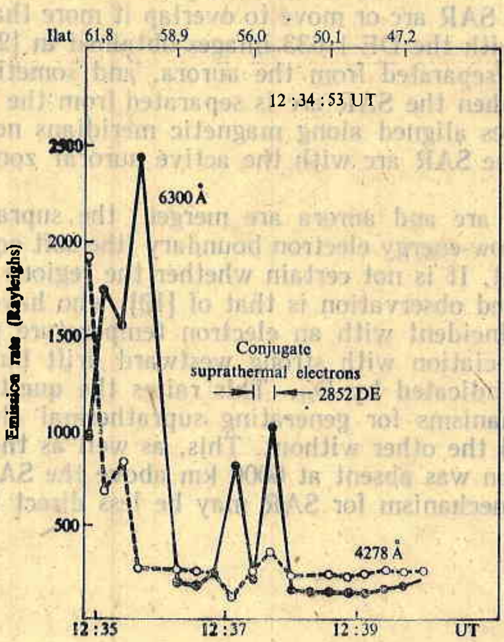

Fig. 7. 6300 Å and 4278 Å intensities on BULGARIA-1300 orbit 2657, February 11, 1982. The double peak enhancement of 6300 Å is compared with conjugate suprathermal electrons on DE orbit 2852 measured in the conjugated ionosphere

vious orbit has ceased, however. The separation of the SAR arc form the oval continues in orbit 2942, at 16:33 on March 3, as shown in Fig. 6. D_{st} has now almost recovered its original level, at -60 nT. Nevertheless, the SAR arc is still present, though slightly weaker than before, at 500 R above background, as compared with 700 R in the previous orbit and about 1 kR during the main phase of the storm.

Finally, we consider for comparison BULGARIA-1300 orbit 2657 for Feb. 11, 1982 at 12:34:53 UT, for which the plot of optical emission is shown in Fig. 7. There appears to be a SAR arc, well separated from the oval, although it is curiously bifurcated. DE-2 orbit 2852 at 11:50 UT was in the southern hemisphere, showing a weak flux of suprathermal electrons located close to one of the two peaks. An electron temperature peak coincides with this, but it is only 2500° K, which would not produce an 800 R SAR arc; this is consistent with the weak flux of suprathermal electrons. In other words, the SAR arc emission in the northern hemisphere is coincident in space but compatible in intensity with the plasma characteristics in the southern hemisphere. This is consistent with the observation presented in [4] that low energy photoelectrons from one hemisphere were blocked from reaching the other hemisphere just in the location of the SAR arc.

Discussion

During a geomagnetic storm, the location of the SAR arc remains remarkably constant near the 53° invariant, while the equatorward auroral boundary may move away from the SAR arc or move to overlap it more than once during the event. This agrees with the DE-1 633 images obtained in [2], which show the SAR arc sometimes separated from the aurora, and sometimes merged with it. However, even when the SAR arc is separated from the aurora, they note that "arc-like features aligned along magnetic meridians near local midnight appear to connect the SAR arc with the active auroral zone several degrees poleward".

When the SAR arc and aurora are merged, the suprathermal electrons extend right to the low-energy electron boundary (the soft equatorward border) and disappear into it. It is not certain whether the regions overlap or simply contact. An associated observation is that of [10], who have observed suprathermal electrons coincident with an electron temperature peak and an electron trough, in association with strong westward drift but without a main phase ring current indicated by D_{st}. This raises the question as to whether there are two mechanisms for generating suprathermal electrons: one from the ring current and the other without. This, as well as the observation that the heated population was absent at 6000 km above the SAR arc [4] suggests that the excitation mechanism for SAR may be less direct than currently believed.

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Оптические эмиссии в ночной субавроральной области во время мартовской бури 1—4 марта 1982 г.

Г. Г. Шепард, И. С. Кутиев

(Резюме)

Во время геомагнитной бури 1—4 марта 1982 г. на нескольких орбитах спутника „Интеркосмос — Болгария — 1300“ наблюдалась стабильная авроральная красная (SAR) дуга. По эмиссии 6300 Å видно, что эта дуга иногда находится в контакте с авроральным овалом, а в других случаях — отдельно от него. Когда SAR-дуги перекрываются с овалом, высыпающиеся 200 eV электроны, измеренные спутником, позволяют отделить добавку легких электронов в экваториальной части овала. Часть SAR-дуги экваториально от овала сопровождается присутствием сверхтепловых электронов, наблюдаемых спутниками DE — 2. В работе показано, что сверхтепловые электроны и направленный на запад дрейф могут появиться как во время геомагнитных возмущений, так и в спокойных условиях.