UDC 551.510

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Peculiarities of cloud dynamics in the CRRES Caribbean releases in the ionosphere (optical data)

The optical peculiarities of the cloud dynamics in four CRRES Caribbean ionospheric barium releases are presented. There are (1) the high velocity "bow-like" front of a glow, (2) the ion "skidding" effect, (3) thin ion track along satellite path, (4) small-scale structure in the "head" of ion cloud and (5) the wave deformation of ion cloud sheet border, observed by low light level TV-imagers. The observations of ion clouds located close to magnetic zenith point were made from research vessel. The high velocity (V = 7 km/s) front of a glow was observed during first ten seconds of the barium cloud expansion. The ion "skidding" effect was observed in the G-9 (18 km) and G-11a (14 km) releases. In the G-11a release thin ion track was appeared between release point and braking point of main ion cloud. The model of wave deformation of ion sheet border in the G-11a release connected with variations of ionosphere E-field is proposed.

1. Introduction

During July and August of 1991, as part of the Combined Release and Radiation Effects Satellite (CRRES) mission five ionospheric barium releases were made over Carribbean. The releases were designed to study the injection effects at 10 km orbital velocity. The measurements during releases were provided by instrumentation onboard the satellite and by optical devices based on ground stations, onboard the aircrafts and research vessel. The experimental data were used, in particular, for studying the ion "skidding" [1], the expansion characteristics of barium clouds [2], for verifying theoretically calculated barium ion and neutral emission rates [3].

The purpose of this paper is an analysis of the optical phenomena observed from research vessel «Professor Zubov» [4]. The data were obtained from vessel location providing observation of release point close to magnetic zenith point. In this case the line of sight is directed along the release magnetic line. The satellite trajectory in CRRES Caribbean releases was practically normal to the geomagnetic field lines (97.0, 101.7, 94.2 and 115.5 angle degrees in G-9, G-11a, G-11b and G-12 releases). Two pointed circumstances allowed to observe the barium ion distribution both along the trajectory and in cross B plane from single point without triangulation and tomography processing. Due to this unique feature of the observation conditions the release optical effects have been recorded that have not been observed from other points and unknown before.

In the paper the data obtained with Kiev University TV-devices are discussed. Some TV records of the other observers including USA aircrafts TV-data we used to compare several details of ion cloud images.

2. Experiments, optical devices and observational conditions

The optical observation results of four barium releases are discussed. The specifications for releases are given in [4, 5]. The observational scheme and the structure features of the G-9 barium release are

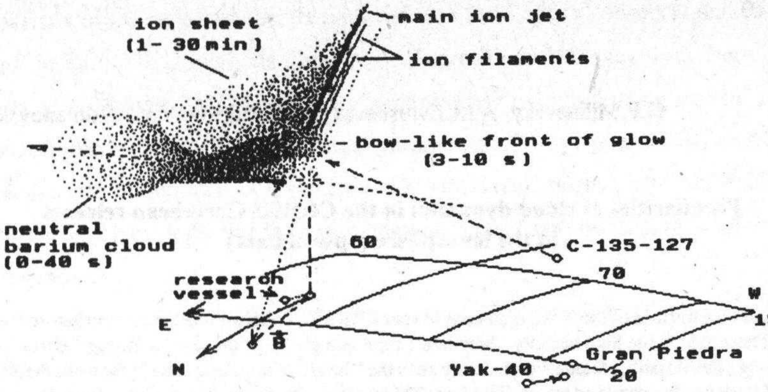

Fig. 1.

shown in Figure 1.

In the G-9 release observations were made with intencified isocon TV-camera from vessel positioned at horizontal ranges of 150 km from release point and of 270 km from point where the release is seen in magnetic zenith (Figure 1). An angle B - line-of-sight was of 29 degrees. It was not observation exactly along release magnetic line, but in this experiment it was the nearest position to release point.

The barium cloud images of the G-11a and G-11b releases were recorded using two intencified isocon TV-cameras from the vessel position providing the record of each release in magnetic zenith.

Emissions from sunlit barium cloud were focussed onto isocon and image intensifier photocathode with 2.8/180 mm, 1.5/85 mm and 2.8/37 mm lenses. The temporal resolution is of 50 fields/s (25 frames).

3. Optical peculiarities of cloud dynamics

High-speed front of a glow. At the initial cloud expansion in the G-9, the G-11a and the G-12 releases the high velocity front of a glow was observed. The "bow-like" front of a glow has got velocity about 7 km/s and starts to propagate asymmetrically relatively satellite path about 1-3 s after the release (Figure 1). The front propagates toward N-E in the normal geomagnetic field lines plane. The initial surface brightness of a glow is close to a brightness of the West edge of the ion cone and falls quickly until the front is propagated.

The analysis of the glow front dynamics shows that (1) it's source is situated at the main ion jet, (2) it's appearance corresponds to the moment of intensive ion braking just after the "skidding" process has stopped, (3) to compare to the "cycloid bunching" process the direction of front moving is normal to B-lines, (4) the front is moved asymmetrically to the neutral cloud path in direction of the observed shift of the main ion jet toward the North.

This phenomenon was recorded also on the USA aircraft C-135-127 in the G-12 release. The same record in the G-9 release shown the propagation of a glow toward the West in the opposite direction to the satellite motion (see the observational condition at Figure 1).

In the G-11b release the barium cloud was made in non-sunlit conditions and discussed phenomenon was not observed.

Ion cloud braking effects. In the G-9 and the G-11a releases the barium ion cloud stopped at some distance from release point along the satellite trajectory. So-called "skidding" effect was observed in the releases [1]. The formation of the field aligned barium ion jet at the skidding distance was observed in the G-9 and G-11a releases. We call it "the main ion jet". The main ion jet brightness is much more than the brightness of the other parts of ion cloud.

Besides the main ion jet formation in the G-9 release along the skidding distance two distinct ion

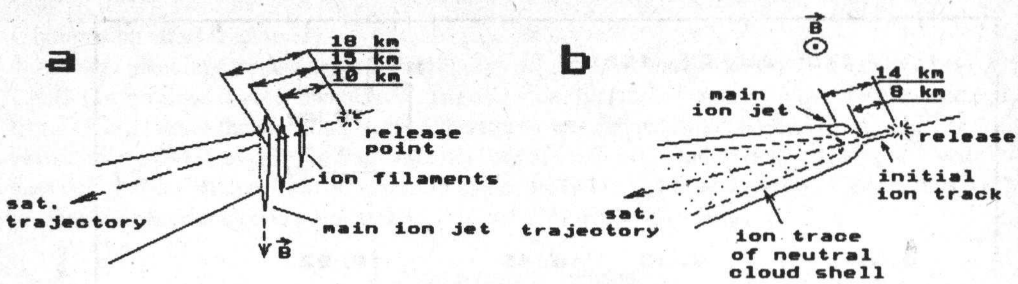

Fig. 2.

filaments were appeared in the gap between release point and position of the main ion jet. The main ion jet is of 3 km diameter and jet axis is located at the 18 km distance from release point. Two other ion filaments are placed at 10 and 15 km distances from release point (Figure 2a). The main ion jet was observed during 20-minutes observation interval of the G-9 release records. The ion filament formed at 15 km distance was seen near the main ion jet of about 10 minutes (Figure 1). The position measurements of the fine scale structure within the skidding distance were made by the image obtained at 12-22 seconds after release.

Therefore in the G-9 experiment at three distances from release point (10, 15 and 18 km) along satellite path the impulsive braking (or formation) of the barium ions was occurred.

The 18 km distance to axis of the main ion jet is confirmed by US-aircraft C-135-127 TV-images obtained in the G-9 release. The thin ion filaments is seen in this record too. The edge of G-9 ion cloud by other authors data is located at 9-15 km distance from release point [1] because of different sensitivity and spatial resolution of imagers.

In the G-11a release the distance between release point and the axis of the main ion jet is of 14 km but the west border of ion cloud is placed at 8 km distance from release point (Figure 2b). The line-of-sight was directed along magnetic line in release point and the main ion jet was seen as a bright spot displaced of about 4 km to north from the satellite trajectory. The cross B size of jet is of about 3 km. This measurement was made by ion cloud images at 17th seconds interval after release.

In the G-11a release the continuous thin ion track of 2 km width and of homogeneous brightness is placed along skidding distance (Figure 2b). The track length is of 8 km after release at once and it is of 11 km a few minutes later when the long focus lens for observation was used.

Ion trace of the expanded barium cloud shell. At the north and south edges of the G-11a ion cloud image the bright ion bands were observed (Figure 2b). The bands correspond to edges of spherical neutral/ion cloud shell under its expansion and movement along satellite track. The width of the bands is of about 4 km. More brightness of lateral bends than inner part brightness of conic trace of moving barium cloud are caused evidently by existence of the initial cloud shell with higher neutral barium density [2]. Observation along magnetic lines supplied the integration of ion number along line-of-sight so that the edges of ion cloud are more bright. The more high ion density along the cloud shell trace is saved during observation period. The brightness (density) asymmetry of north-south bends exists. The north bend is more bright, wider and longer then the south one. The similar brightness asymmetry is seen from the G-11b C135-131 TV images, too.

The wave deformations of the ion sheet surface. During barium cloud evolution in CRRES G-11a release wave structure of ion sheet surface was observed [4]. The barium ions appeared after release are expanded along magnetic field lines and formed ion sheet. As the ion sheet was observed in magnetic zenith we can study its shape evolution in cross-B plane. The ion sheet wave deformation was observed at 1 minute after release (at 08:39 UT) and 3 peaks of wave were registered for 5 to 22 minute after release. In Figure 3a the outlines of ion cloud image at four moments are shown. The head part/west edge of conic ion trace of each image is superposed in Figure 3a. The scale of ion sheet «surface waves» is 10-14 km

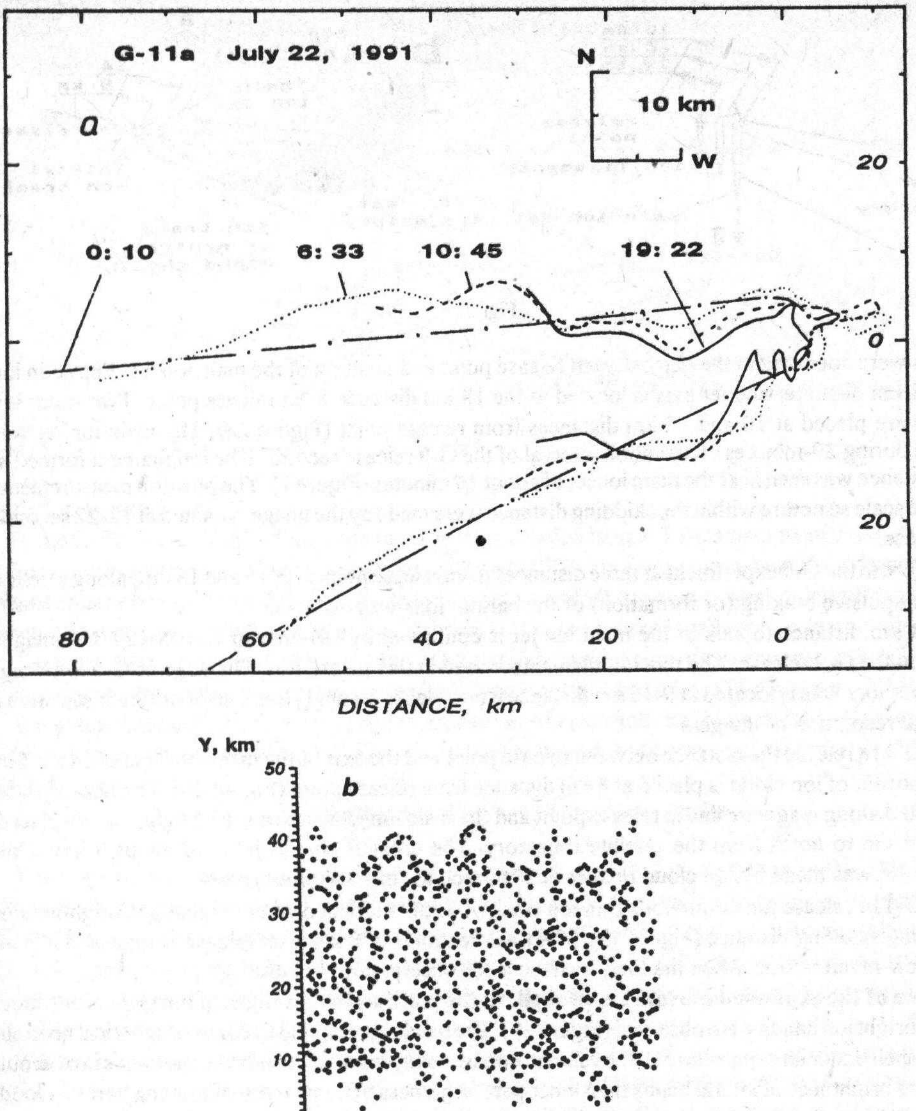

Fig. 3.

and their amplitudes are in a range of about 1-4 km.

The initial thin ion track in the G-11a release mentioned above have got wave deformations too. The characteristic scale of the track wave is of about 4 km and peak value is of 1.5 km.

It is interested in the G-11b non-sunlit release the barium ion cloud has not got deformation of its lateral edges during the 40-minutes observation period after release.

In the head of the G-11a ion conic cloud the development of the small-scale structure was observed during 2-22 minutes after release. A few small-scale spots (ion filaments, which are seen as the spots in cross B plane) have got 0.6 - 3 km sizes. During cloud drift and evolution the shape and the number of spots were changed. At the end of observation in the cloud head image was developed ion cloud bifurcation effect (Figure 3a).

As image plane is perpendicular to B-field lines so a cloud image shift corresponds to transverse B drift. The G-11a ion cloud moved toward N-W. The center positions of the conic cloud head were measured. In the G-11b release the ion cloud North drift velocity was defined by the west edge motion. The drift velocity of the G-11b cloud is for four times less then of the G-11a cloud. In both cases the drift velocity rises during observations: from 30 m/s to 75 m/s in the G-11a and from 6 m/s to 21 m/s in the G-11b releases. The acceleration is equal to 0.05 m/s2 and 0.01 m/s2, accordingly.

4. Discussion and conclusions

The observations along the release magnetic tube allowed to study the parameters of ion clouds in cross B plane from single station. Thanks to great sensitivity and spatial resolution of imagers number of dynamic peculiarities of ion clouds were registered.

The observed effect of high-speed front of diffuse glow propagation at initial stage of release similar to appearance of irregularities generated by «cycloid bunching» mechanism [5]. But a features of form and speed directions of front are not explained by that mechanism. The direction of front velocity lies in plane normal to B-field line just as in the mentioned mechanism the ions was propagated along magnetic field line. It is interested a value of the front velocity is close to the satellite speed and the front is propagated from the point of the main ion jet braking.

On the base of the model of scattering of neutral barium atoms interacted with ions of dense main ion jet it could be explained the observed phenomena. The asymmetry of moving of high-speed atoms in the glow front would be explained by position of main ion jet shifted in electric fields at skidding processes.

The thin ion track is evidence of breaking processes or ionization process caused probably by high thermite mixture temperature of dense central part of barium cloud after its ignition. This non-solar ionization continued less than 1 second and produced ion number by intensity estimation less than 0.5% of released barium atoms. According to previous data any burst ionization along the release field line was not observed and indirect estimation showed that burst ionization was less than 1% [6].

According to the G-9 and the G-11a releases data the skidding of the barium ions takes place, but in the first case the ion braking is irregular and in the second case at the central part of cloud (about 2 km diameter) skidding is absent. The quick braking of central ion portion was observed as thin ion track aligned with satellite path. A thin ion track formation in the G-11a cloud skidding distance points on the distinction of the ionization processes in the inner and outer parts of expanding barium cloud at initial phase so inner ions creating of thin track are braked at once.

The irregularities of the barium ion distribution along the G-9 release skidding distance were appeared, probably, because of the greater value of released barium mass from two canisters (Figures 1, 2).

The observation shows the cloud ion density is much smaller to compare to ionosphere plasma density of F2 layer. Then the cloud dynamics on a late stage of evolution is determined by ionospheric conditions. The barium ion cloud is a marker only. Hence, it is naturally to consider the appearance of wave like structure of the barium ion cloud sheet as a result of terminator movement effect. The propagation of terminator in ionosphere generates increasing the background plasma density gradient. Therefore, Rayleigh-Taylor instability of the sub-Alfvenic plasma expansion is increasing too. But, usually, the spatial scale of the terminator ionospheric disturbance is much more then observed in the barium cloud case.

The other cause of the wave occurrence could be a small-scale disturbance of the ionosphere electric field [4]. The ionosphere electric field in normal B plane was estimated: 1-2.3 mV/m (to West and downward for the G-11a release data) and 0.2-0.6 mV/m (to West for the G-11b release data). From the releases data, the velocity (electric field) intervals in G-11a and G-11b are not lapped over. It is possible, the existence/absence wave deformation of the ion sheet surface is concerned with value of ionosphere electric field, its change velocity and local microstructure.

To explain the surface wave development in the G-11a release by simulation ExB barium plasma drift in XY-plane when variable Ex component of E-field is chosen changed weakly as Ex = Ex + Ex Cos(Lx) was undertaken. The parameter L determines surface disturbances scale, Ex component is a small value (|Ex |>>|Ex |). The magnetic field is in the Z-direction, the X-axis is along the barium sheet surface.

The simulation is carried out using 1000 particles by generation their coordinates in 100x30 km range. The particles have got a Maxwell velocity distribution with thermal ion velocity 500 m/s and then move under Lorents' forces action. For particle movements term the unevident method given by Potter in [7] is used. The ion-neutral collision with characteristic collision frequency 0.1 1/s is taken into account too. The parameters used are as follows: Ex = Ey = 2mV/m, B = 0.3 G for ionospheric conditions at 400 km and experimental drift velocity data of cloud.

The simulation data the cloud ExB drift and the surface disturbances was observed (Figure 3b). The surface wave disturbance has got a period 2n/L, characteristic time is about 2 minutes and peak value is of 10 km as it is observed in the G11a experiment when ionosphere E-field is equal 2 mV/m and the E-field variation term (Ex) is equal 0.2 mV/m. The simulation parameters correspond to the observed scale of wave disturbance and to the cloud drift velocity 40 m/sec.

Therefore the including of a small vary Ex to ionosphere E-field gives the possibility to explain development surface irregularity in the G-11a release. The growth of disturbances is depend on Ex/B relation. The threshold of a relation exists when drift velocity less then 10 m/s, and the disturbance is not developed.

The observations along the release magnetic tube allow to study from single station the parameters of a ion cloud in cross B plane: the ion distribution, the evolution of cloud structure and the cloud drift. During CRRES mission over Caribbean these observation conditions provided the revealing of a new phenomena in barium cloud dynamics, both in an initial stage of release and in an evolution period (1) the initial ion track, (2) the high velocity "bow-like" front of a glow, (3) the main ion jet displaced to the North from the center of the cloud trajectory, (4) the wave development of the ion sheet. It is useful in future to observe a release in the magnetic meridian plane, crossed the release point and at the line of sight that is perpendicular to the release magnetic line. In this case the ion distribution along the magnetic lines and along the trajectory would be observed like undistorsed ones.

Acknowledgements. We thank V.A.Kravchenko and Z.I.Gritsai for the assistance in preparing of the release data. We also thank H.C.Stenbaek-Nielsen for helpful discussion of ion cloud observations. Support for Ukrainian authors was provided by National Space Agency of Ukraine contract NSAU3-9/93 with the Kiev University.

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Received:
November, 1993