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LOCATION OF THE ION-CYCLOTRON INSTABILITY REGION RELATIVELY TO PLASMAPAUSE DURING MAGNETOSPHERIC COMPRESSIONS

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Abstract. Compression of the magnetosphere by a jump of the solar wind dynamic pressure produces, among other consequences, a large-scale dayside precipitation of energetic protons responsible for sub-oval proton aurora flashes. These flashes are related to a sudden appearance of geomagnetic pulsations in the Pc1 range. Both proton precipitation (proton aurora) and Pc1 manifest the development of the ion-cyclotron instability in the equatorial plane of the magnetosphere. To explore the magnetospheric domain where the instability develops we combined the projection of the equatorial edge of the proton aurora flashes observed by the IMAGE spacecraft and plasmapause location. The latter was determined using the plasmapause model. It was shown that during magnetospheric compression an ion-cyclotron interaction mostly occurs outside plasmasphere. It was also found that the location of the Earthward edge of the ion-cyclotron instability region as well as the distance between this edge and plasmapause depends on preceding geomagnetic activity. During stronger geomagnetic activity the ion-cyclotron instability region tends to locate closer to the Earth and plasmapause.

Introduction

Compression of the magnetosphere during an increase of the solar wind dynamic pressure leads to increased anisotropy of the ring current protons and, respectively, to increase of the ion-cyclotron (IC) instability growth rate. Maximal growth rate is expected on the dayside [*Olson and Lee*, 1983]. Cyclotron instability related to the magnetospheric compressions leads to generation of the electromagnetic ion-cyclotron (EMIC) waves observed in space (e.g., *Anderson and Hamilton*, 1993; *Zhang et al.*, 2008). On the ground the waves are seen as geomagnetic pulsations in the Pc1 range (e.g., *Anderson et al.*, 1996; *Yahnina et al., 2008; Popova et al., 2010*).

Another manifestation of the IC instability is precipitation of energetic protons, which can produce so-called "proton aurora". During compressions proton aurora flashes are often observed on the dayside at sub-oval latitudes visualizing the IC instability region (e.g., *Hubert et al.*, 2003; *Fuselier et al.*, 2004; *Yahnina et al., 2008;Popova et al.*, 2010).

Besides hot proton anisotropy, other factors influencing the IC instability growth rate are the cold plasma density and the hot proton density (e.g., *Olson and Lee*, 1983). For example, sub-oval proton spots and arcs, which are also results of the IC interaction (*Yahnin et al.*, 2007; 2009), are generated at gradients of the cold plasma (e.g., *Frey et al.*, 2004; *Spasojevic and Fuselier*, 2009). As to proton aurora flashes, their relation to the cold plasma is not clear. *Fuselier et al.* (2004) considered two cases when the comparison of proton auroras and cold plasma observations was possible. They showed that the proton aurora flashes could map both close to plasmapause and well outside it. The authors referred the latter situation to the increased hot proton intensity outside the cold plasma region.

Since comparisons of proton auroras and direct observations of the cold plasma are scanty, one may use plasmapause models. Here we discuss how the proton aurora flashes (indicator of the IC instability region during magnetospheric compressions) locate relatively to the cold plasma using the plasmapause model by V. Pierrard and co-authors. We also consider how the proton aurora flash location depends on the preceding geomagnetic activity, which can be used as a measure for the intensity of the hot plasma population in the near-Earth environment.

Data and analysis

To select events for the study we used a database of sub-oval proton aurora flashes by *Popova et al.* (2010). These flashes correspond to sharp solar increases ($\Delta P > 1$ nPa) of the wind dynamic pressure. Only those proton aurora flashes were considered, which were conjugated with observations of geomagnetic pulsations in the Pc1 range. Such association of proton aurora and Pc1 pulsations proves that the proton precipitation is due to ion-cyclotron interaction. In all, 25 events were selected.

The proton aurora observations were provided by the Spectrographic Imager (SI) detector of the FUV instrument onboard the IMAGE spacecraft, which was designed to select the Doppler shifted Lyman H-alpha line at 121.82 nm in the ultraviolet part of the optical spectrum and to reject the non-Doppler shifted Lyman H-alpha from the geocorona at 121.567 nm (see, ***Mende et al.***, 2000, for details). The ground observations of geomagnetic pulsations were performed with induction coil magnetometer at the geomagnetic observatory Lovozero (67.97°N, 35.02°E; Corrected Geomagnetic latitude (CGLat) is 64.3°; MLT = UT + 3) of Polar Geophysical Institute.

The plasmapause model is the Kp-depended model based on the Lemaire's theory of plasmapause formation (see, e.g., ***Lemaire and Gringauz***, 1998). The model satisfactorily reproduces the plasmapause and some plasmaspheric structures (***Pierrard and Lemaire***, 2004; ***Pierrard and Cabrera***, 2005; ***Pierrard*** et al., 2007; ***Pierrard and Stegen***, 2008). The model is freely available at **http://www.spaceweather.eu**. For each of 25 selected events the plasmapause was modeled.

Often, it is difficult to determine the poleward edge of the proton aurora flash since it merges with the proton oval. Therefore we will characterize the location of the proton aurora flash by its equatward edge. Suggesting the dipole magnetic field, the equatorial boundary of each proton aurora flash was mapped onto equatorial plane and compared with location of plasmapause.

Results

Figure 1 presents difference between the L-shall of the equatorial projection of the proton aurora flash boundary (L_{eq}) and location of the modeled plasmapause (L_{pp}) for all 25 events under consideration (black dots). In Figure 1 the events are ordered according to the value of this difference. Negative values mean that the flash projection onto the equatorial plane and plasmapause overlap. The dots within shaded area correspond to events when the near-Earth edge of the proton aurora projection was within $1R_E$ from plasmapause.

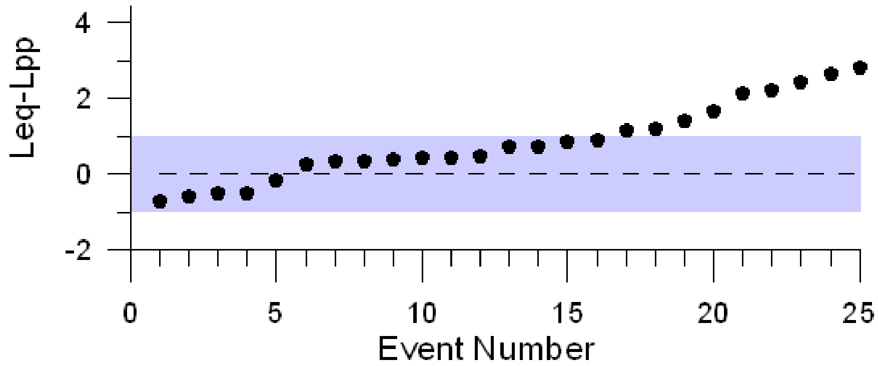

Figure 1. Distance between locations of the equatorwad edge of the proton aurora flash (L_{eq}) and modeled plasmapause (L_{pp}) for 25 selected events (black dots).

From Figure 1 it is clear that in most cases the equatorward edge of proton aurora flashes maps outside plasmasphere. Even in the cases when L_{eq}-L_{pp} is negative, the overlap of the flash projection and plasmasphere is less than 1 R_E. All such cases correspond to flashes, which are wide in latitude (up to ~10 degrees). Thus, the greater part of the proton luminosity region maps outside plasmasphere. This means that cold plasma density is not a main factor in generation of the proton flash.

Olson and Lee (1983) argued that increase in anisotropy of hot protons is a primary cause of the IC instability development under compression. They showed that the compression-related enhancement of the anisotropy is maximal in the outer magnetosphere on the dayside, and it decreases toward the Earth. The anisotropy change at a given point is larger when the compression is stronger. The latter means that stronger compression should produce proton auroras, whose equatorward edge is closer to the Earth.

However, this is not exactly true. Figure 2 (on the left) shows dependences of L_{eq} and L_{eq}-L_{pp} on Δ(SYM-H), which is the value of the SYM-H index enhancement occurred during compression. Linear approximations are shown with straight lines. Surprisingly, the correlation coefficients are very low (0.32 for dependence of L_{eq} and 0.37 for dependence of L_{eq}-L_{pp}). The rest of Figure 2 shows dependencies of equatorial location of the mapped proton flash on geomagnetic activity indices. These dependencies demonstrate much larger correlations. Correlation coefficients for dependence on $(SYM\text{-}H)_1$, which is the value of SYM-H taken just before the compression, are 0.67 and 0.57, respectively. Mean K_p (K_p averaged for two days before the compression) shows similar correlations, while correlation coefficients for dependence on mean AE index (also averaged for two days) are even higher (0.74 and 0.68). Both L_{eq} and L_{eq}-L_{pp} values tend to decrease when preceding geomagnetic activity increases.

Discussion

Summarizing the results presented in Figures 1 and 2 and keeping in mind that sub-oval proton auroras are the consequence of the IC interaction in the equatorial plane, we conclude that:

1) the most of the region where the IC instability develops during magnetospheric compression does not relate to the enhanced cold plasma density and
2) the preceding geomagnetic activity is the factor controlling the development of the compression-related IC instability close to the Earth and plasmapause.

As already noted, the result 1) means that during compressions the cold plasma density is not so important parameter for the development of the IC instability as, say, in the case of generation of sub-oval proton spots. Relative enhancement of the anisotropy (A_1/A_0, where A_0 and A_1 is anisotropy before and after compression) is stronger around noon in the outer magnetosphere (*Olson and Lee*, 1983) and, probably, is insignificant at and inside plasmapause. However, in some cases (first five events in Fugure 1) the mapped proton aurora flashes overlap with modeled plasmasphere. Evidently, in these cases the combination of the parameters controlling the IC instability growth rate (density of cold plasma, density of hot plasma and hot plasma anisotropy) before the compression corresponds to a marginal stability in a wide range of distances including the outer plasmasphere. Also, for such cases either Δ(SYM-H), characterizing the compression, or geomagnetic activity, or both have the largest values.

How the geomagnetic activity can affect spatial characteristics of the IC instability region? We suggest that the activity changes radial distribution of the hot proton population. Indeed, enhanced geomagnetic activity associates with enhanced magnetospheric convection and substorm ejections. Both these processes contribute to filling the near-Earth environment with energetic particles. Thus, after long period of the activity one may expect significant increase of the hot plasma density close to the Earth (and plasmasphere). This may lead to the situations when even relatively weak compressions provoke the instability development close to the Earth. The latter is, evidently, the reason of weak dependence of L_{eq} and L_{eq}-L_{pp} on Δ(SYM-H) shown in Figure 2.

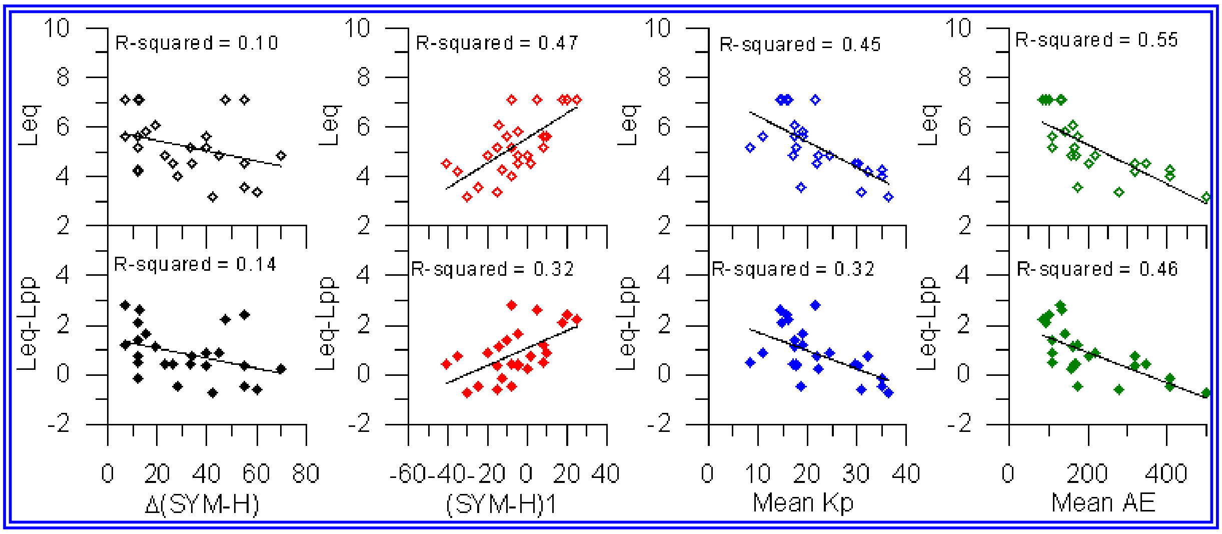

Figure 2. The distance between the equatorial projection of the proton aurora flash and the Earth (L_{eq}) and modeled plasmapause (L_{eq}-L_{pp}) as depended on different geomagnetic parameters. From left to right: Dependence on intensity of magnetospheric compression characterizing by difference between SYM-H index values just before and after the compression; dependence on the value of SYM-H index just before the compression; dependence on average Kp for 48 hour interval before the compression; and dependence on average AE for 48 hour interval before the compression. Note, that squared values of the correlation coefficients are presented above each plot.

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