Precipitation of 0.5 MeV electrons and substorm expansion into the polar cap

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ABSTRACT

Energetic electron (> 0.5 MeV) precipitation events observed by the Coronas-I satellite at high latitudes are investigated together with ground-based magnetometer and riometer data. Detailed analysis suggests that such electron fluxes appear in the polar cap immediately after auroral zone substorm disturbances. Negative magnetic bays and riometer activity at polar cap latitudes, similar in morphology to auroral zone substorm activity, were also coincident with the 0.5 MeV electron precipitation. Such observations could represent a unique class of substorm activity that occurs in the polar cap under certain geophysical conditions. For example, as a result of the auroral zone substorm activity, magnetic field dipolarization could extend deep into the polar cap (> 80 degrees MLAT), or conditions in the magnetotail might be favorable for electron acceleration over a wide and extended energy range.

INTRODUCTION

High energy electron up to several MeV have been occasionally registered in geostationary region and on the auroral zone latitudes during substorm associated particle injections [Kuznetsov et al.,2000]. It is suposed that this type of the auroral particle acceleration takes place on closed magnetic field lines, inside the trapping or quasitrapping regions. Because of that the rare occasions of the enhanced >0.5 MeV electron flux registered by CORONAS-I satellite over the polar cap attracted our attention. The analysis of the magnetic activity shows, that most of this cases are associated with special type of the substorm activity.

While the majority of the auroral substorm developments is restricted by the auroral zone with a maximum geomagnetic latitude of the poleward expansion of 70°-74°, there are substorms with the expansion further into the polar cap, so called polar cap substorms (PCS) [Weatherwax et al., 1997, Doolittle et al., 1998, Mende et al., 1999]. Usually polar cap activity is associated with the precipitation of the electrons and ions with energy significantly smaller than in auroral zone, but with polar cap substorms situation is different. For example substorm associated cosmic ray absorption was registered in the polar cap up to 80° GML [Weatherwax et al.,1997], which means that electors with energy >20 keV are present there and possibly accelerated in situ. Our results show that the upper energy limit of the electrons participating in a polar substorms must be elevated to MeV level.

OBSERVATIONS

The high energy electrons with energy 0.5-1.3 MeV were registered by global scintillator detecter with geometric factor of ~60 cm2.ster. every 2.5s. on board of Coronas-I polar orbiter low altitude satellite [Kuznetsov et al., 1993].

Counting rate three or more times above background during during ten time cycles or more was considered as a high energy electron precipitation events (HEP). The channel Ee >1.3 MeV of the same detector do not registered counting rate above the background during these events.

Figure 1 shows the >0.5 MeV electron intensity profiles for several satellite polar cup crossings. Local time and L-value are shown by thin and dotted lines.

The general information on the magnetic activity are revealed by Al and Au indexes presented by Figure 2.

One can see that magnetic activity level from moderate to the strong was observed before HEP events. Exactly during HEP sharp short negative bays in Al were recorded in nearly all cases. That indicates on the close relation of the HEP events to the auroral substorms.

Arctic and Antarctic magnetometer and riometer data were used for the detailed study of HEP events.

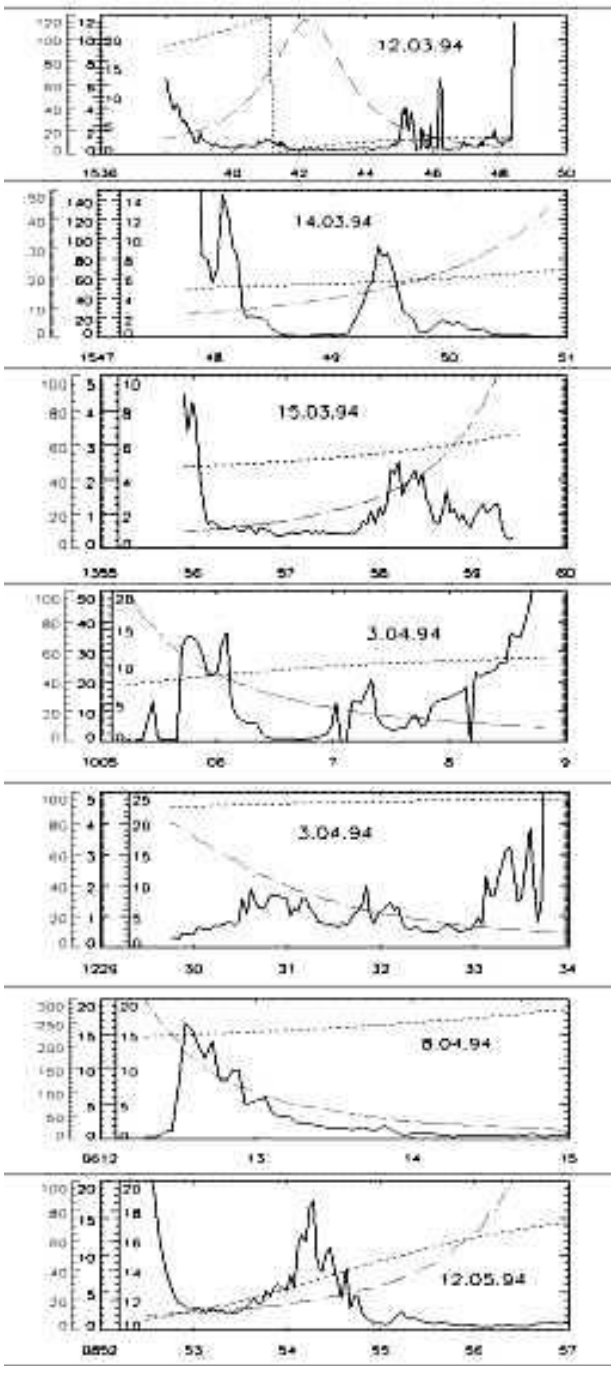

Figure 1 *0.5 Mev energy electron flux measured by Coronas-I (solid lines), satellite local time and L-value (dotted lines)*

Short description of March 15, 1994 event is given below.

Auroral zone substorm started at 1315UT on March 15, 1994 by a sharp decrease of the H component of the Tixie magnetometer as shown by Figure 3. The minimum of the bay was registered at 1331 UT followed by fast recovery. Polar cap substorm began immediately after that by sharp H-bay which starts on Casey (-76.87°) at 1331UT and Dumont d'Urville

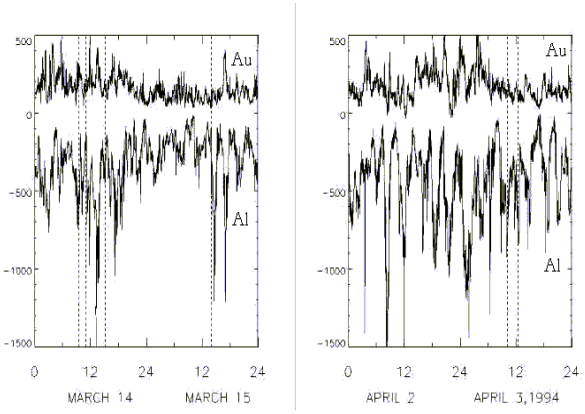

Figure 2 *Au and Al index plots for several HEP Coronas events*

(-74.79°) at 1337 UT with a bay minimum at 1339 UT on both stations (Figure 4). Next substorm intensification was registered 10 minutes later and more poleward both at the North (Godhavn) and South (Scott Base) polar caps. All three intensifications can be seen at Al-index data overplotted by dotted line on Figure 3. Let us note the fast changes of Z-component at all stations which reflects fast motions of the activity regions.

Coronas-I was crossing polar cap from 1356 to 1400 UT and registered enhanced 0.5 MeV electrons from

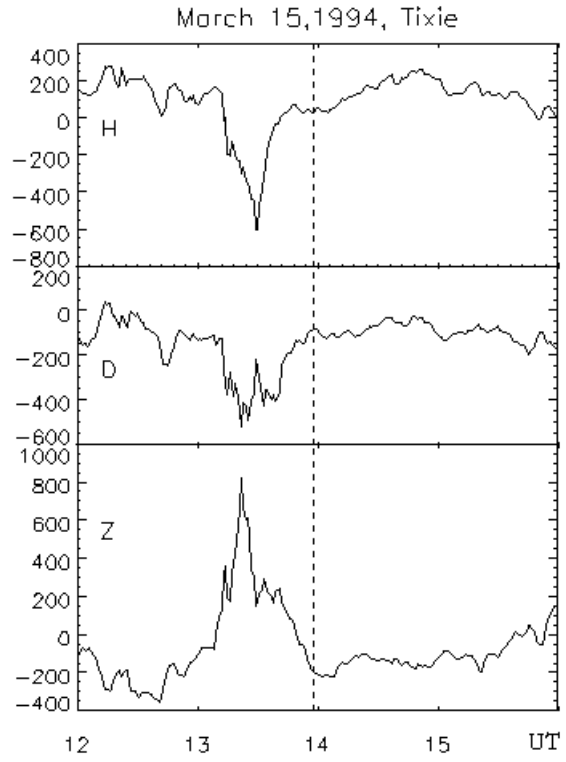

Figure 3 *Tixie magnetometer, 15.03.94. Dotted line shows thestarting time of the HEP event.*

76.5º to 82º magnetic latitude with a maximum on 78.5º, when magnetic bay on magnetometers at the same latitudes still was at top level of development.
Figure 5 shows that the beginning of the riometer absorption in the polar cap coincides with this HEP event as well.

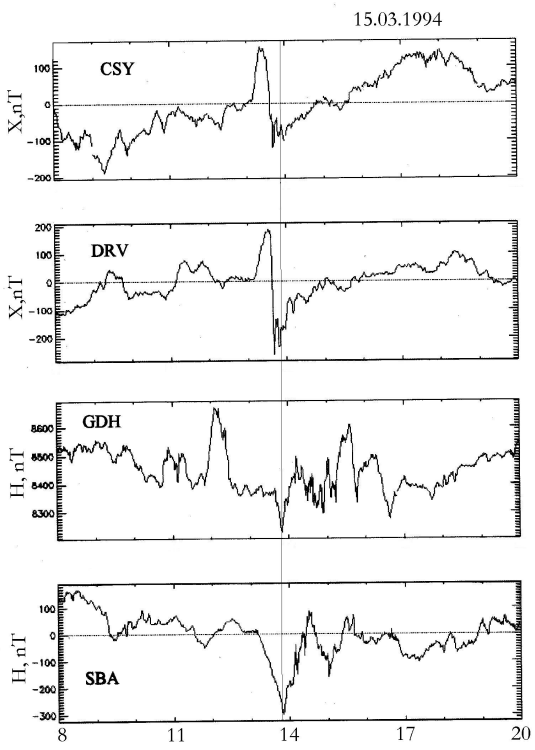

Figure 4 Polar cap magnetometers, CSY- Casey, DRV- Dumont d'Urville, GDH -Godhavn, SBA- Scott Base

Therefore the March 15 HEP event scheme can be described as follows: 1) Auroral zone substorm; 2) second substorm intensification further poleward and the third intensification at higher polar cap latitudes. Coronas-I while crossing the polar cup registered remnants of the high-energy electrons from the second intensification and much higher electron flux simultaneously with the third intensification. Similarity and simultaneous development of the magnetic bays in the North and South polar cups suggests that the closed field line possibly exist (temporarily) up to 82 GML, which is difficult to imagine.
For a most of the cases following conclusions are valid :

- moderate magnetic activity has been observed before and during the HEP event,
- polar cap magnetic bays were in progress at least on one of the polar cap stations,
- riometer absorption on Scott Base or other Antarctic stations were registered.

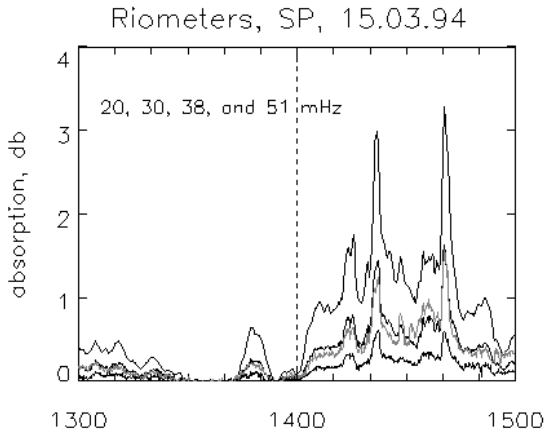

Figure 5 *South Pole riometer 15.03.94*

DISCUSSION

Several publications describe polar cap subsorms - disturbances with features of the auroral zone substorms, such as auroral arc brightening, breakup and poleward expansion, but observed in very high latitudes up to 80° -85° [Mende et al., 1999]. During or before these events IMF was negative and polar cap substorms was preceded by auroral zone substorms. Therefore the polar cap substorms may be regarded as a continuation of the regular substorms.
We believe that high energy electron bursts described above belong to that type of events. Interplanetary magnetic field was available during three our events and all three time Bz was negative. Direct ling with regular substorms and high level of the preceding activity also confirm this conclusion.
It was shown by Weatherwax et al [1997], that polar cap substorms are accompanied by the auroral cosmic noise absorption events, which means that electrons with energies of several tens keV are also accelerated/precipitated during polar cap substorms. Our data show, that the upper energy level must be increased to the MeV range.

Quit time position of the auroral zone/polar cap boundary corresponds to 71º. During substorm active phase it shifts to lower latitudes and return to quit position during recovery phase. To explain polar cap substorms Mende et al., [1999] suppose that there is a broad peak of the latitudes from 72º to 80º which substorm expansions can reach and therefore there are nothing special in polar cup substorms. Akasofu (2002) suggests that the effect

of overdypolarization may be caused by configuration of the current systems in the night side magnetosphere at the end of the expansion phase. Kuznetsov et al., [2000] suggest that polar cap substorms indeed are special, occuring as consequence or a second step of the regular substorm. The results of our study are in favor of this opinion. In most cases auroral zone substorm was at the end or at the recovery stage during HEP events, therefore the negative H bays of the polar cap magnetometers accompanied by fast decline of the Al-index may be regarded as a second step or continuation of normal substorms.

CONCLUSION

Polar cup usually is associated with the magnetotail region and high-altitude auroras and low energy particle precipitation indicate that high energy trapped particles, active aurora and auroral substorms are taking place closer to the Earth on closed field lines. But there are rare but well-defined polar cap events similar to auroral zone substorms which are taking place at the latitudes as high as 80˚ and even 85˚ . Polar cup substorm features may be derived from our study are following:

- polar cup substorm are not independent events, but a continuation ore second intensification of the auroral zone substorm,
- auroral electrons precipitations were recorded at keV range (aurora), >10 keV (riometer) and 0.5 MeV (Coronas-I).
- intensity of 0.5 Mev electrons was two order smaller, than at the maximum of the radiation belt, but well above the cosmic ray and usual polar cap background,
- typical duration of the HEP and accompaniing magnetic bays - several minutes, which is considerably shorter than auroral zone intensification,
- HEP are extended on several degrees by latitude which in projection to the midnight magnetosphere might cover distances of tens of Earth radii,
- there were nothing unusual in the level of magnetic activity (moderate recurrent type) and in a magnetospheric configuration at the geostationary region.

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