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MULTI-SATELLITE STUDY OF PHENOMENA IN THE EVENING MAGNETOSPHERE DURING THE Pc1-2 EVENT

A.G. Yahnin and T.A. Yahnina *(Polar Geophysical Institute, Apatity, Russia)*
N.Y. Ganushkina *(Finnish Meteorological Institute, Helsinki, Finland)*
V. Angelopoulos and F.S. Mozer *(Space Science Laboratory, University of California, Berkeley, CA, USA)*
J. Kangas and J. Manninen *(Geophysical Observatory Sodankylä, Sodankylä, Finland)*
T.A. Fritz *(Department of Astronomy & Center for Space Physics, Boston University, MA, USA)*
C.T. Russell *(Institute of Geophysics and Planetary Physics, UCLA, Los Angeles, CA, USA)*
M.F. Thomsen *(Los Alamos National Laboratory, Los Alamos, NM, USA)*

Introduction

Electromagnetic ion-cyclotron waves seen on the ground as geomagnetic pulsations Pc1 are commonly believed to be the result of the development of the ion-cyclotron instability in the outer radiation belt (e.g. Kangas et al., 1998). The free energy for this instability is due to anisotropy of temperature of hot ions ($T_{||}/T_{\perp}<1$). The instability leads to the growth of the ion-cyclotron waves, which scatter the energetic protons into the loss cone. In spite of general acceptance of this scenario and observations of the possible particle signatures of the instability (e.g. *Lyons and Williams*, 1984), the direct relation between ion precipitation and Pc1 emissions has been discovered only recently (*Yahnina et al*., 2000, 2002). As detected by low-altitude NOAA satellites, the precipitation occurs in the localized area within the anisotropic zone (that is, the subauroral region equatorward of the isotropy boundary where the precipitation flux of energetic particles is typically negligible). Recently the signatures of the proton scattering into the loss cone in relation to the EMIC waves were for the first time observed also near the equatorial plane. *Erlandson and Ukhorsky* (2001) used the wave and particle data from DE-1, and they detected the protons (with E<17 keV) within the loss cone on the field lines where the EMIC waves were simultaneously detected. Erlandson and Ukhorsky estimated the proton flux by a particle diffusion model taking into account the observed wave power. They concluded that although the maximum of the precipitating flux is expected at energies of some 100 keV, the calculated flux at energies 0.2-17 keV was in agreement with observations. The ion-cyclotron instability effectively develops in the presence of the cold plasma. According to the concept suggested by *Cornwall et al*. (1970) and advocated, for example, by *Bespalov et al*. (1994) one can expect the precipitation in the region where the westward drifting ring current protons meet the boundary of the plasmaspheric plasma. This may happen at the boundary of the plasmaspheric bulge, or plasmaspheric tail, or detached cold plasma clouds (e.g. *Burch et al*., 2001). Although this view seems to be reasonable, it has never been confirmed by the simultaneous observations of the EMIC waves, hot particles, and cold plasma. In this report we will present the data set which confirms the concept. The event under study occurred around 11 UT on August 3, 1996. Around this time a cluster of three spacecraft occurred in the evening sector of the near-Earth equatorial magnetosphere. The Polar satellite was at the dusk sector (MLT=16.5, Zgsm=1.5 R_E, altitude about 5 R_E) moving toward the plasmasphere from the northern auroral region. At 11 UT two LANL geosynchronous spacecraft were situated at ~16 and ~18 MLT. In addition, around 11 UT the low-altitude NOAA-12 satellite passed through the evening MLT sector.

Data and observations

Figure 1 shows traces of the satellites as they mapped onto the equatorial plane. Thick segments on traces of LANL and Polar spacecraft correspond to the time intervals indicated in the Figure. The Polar satellite crossed the field line of the geosynchronous orbit just around 11 UT. The Polar instruments which data are used in this study are CAMMICE, PWI, MFE, and EFI. They provided us with information on, respectively, the protons with E>30 keV, electron density, magnetic field, and electric field and spacecraft potential. The details of the measurements and references can be found on the instrument homepages (see, for example, links at http://www-istp.gsfc.nasa.gov/istp/polar/).

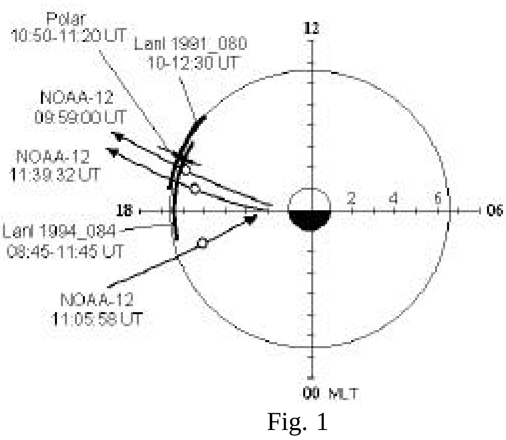

Fig. 1

The MPA and SOPA instruments onboard the LANL spacecraft provided information on, respectively, the cold (<10 eV) plasma and hot (>50 keV) particle flux variations along the geosynchronous orbit. The NOAA-12 satellite measured the particle flux at energies above 30 keV and the total energy flux for particles with E<20 keV.

Let us start with the cold plasma measurements. The POLAR PWI data shown on top of Figure 2 demonstrate an increase of the cold plasma density around 11 UT just when the satellite crossed the field lines related to the geosynchronous orbit. Panels below show the LANL MPA data ordered in UT and MLT. At 11 UT and MLT~16 the LANL spacecraft 1991-080 detected an enhancement of the cold plasma density which has a characteristic longitudinal size of ~1 MLT. Note that probably the same plasma cloud was detected at 09 UT by another spacecraft (1994-084) at the same MLT. An analysis of the data from the two LANL spacecraft shows that there were at least two or three such localized cold plasma enhancements along the geosynchronous orbit within 15-19 MLT range.

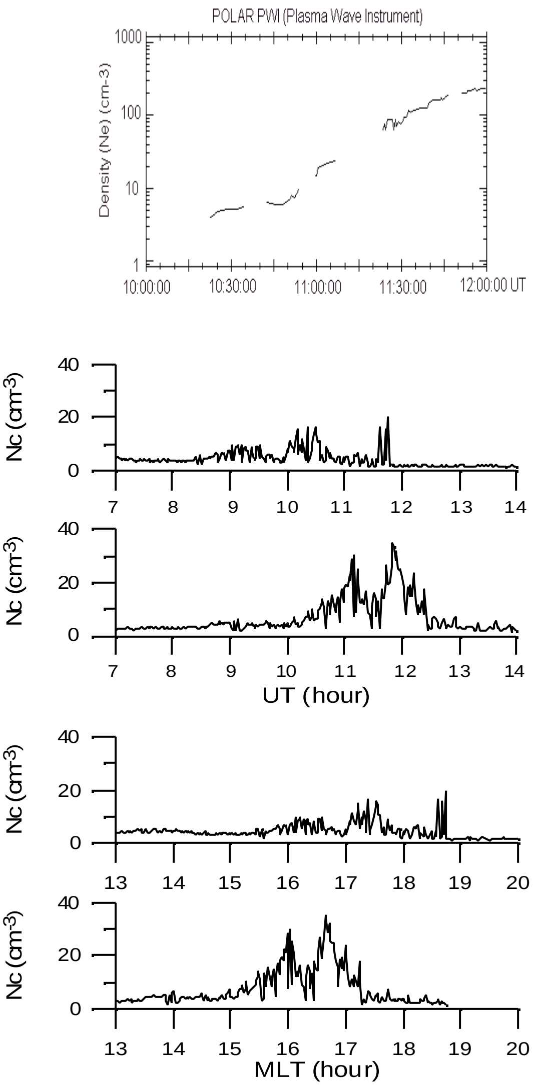

Fig. 2

After 10 UT a moderate substorm activity (data not shown) produced a series of energetic particle injections detected by LANL and Polar spacecraft as westward drifting proton clouds. The Polar CAMMICE data (energy-time spectrogram, not shown) confirm that one of the hot (30-100 keV) proton clouds appeared about 11 UT at MLT=16.5. We present the CAMMICE data in the form of pitch-angle distribution (Figure 3). The sequence of the snapshots demonstrates some specific features of the distribution evolution. At 1040 UT, when Polar was at L=7.5, the distribution was almost isotropic. This is characterized by the ratio (A) of the fluxes at pitch angles 0º and 90º, which at this time is almost equal to 1. The snapshot taken a few minutes later (at L=7.2) shows an anisotropy, A=0.25. This transition corresponds to the inward motion of the satellite from high to low L-shells, that is, from the region of the chaotic regime of the energetic particle motion to the region of the adiabatic motion (e.g. *West et al*., 1973). But, next several snapshots (taken when the Polar location was between L=6.9 and L=6.2) show a violation of the expected behavior. Instead of the increase of the anisotropy the pitch-angle distribution becomes more isotropic (A=0.45). Only after 1110 UT (at L<6.2) the pitch-angle distribution changes for strongly anisotropic marking the final entrance into the adiabatic motion region. This behavior of the protons near the equatorial plane is in agreement with the particle data from the low altitude. The NOAA-12 satellites crossing the evening sector around the time of the Polar measurements

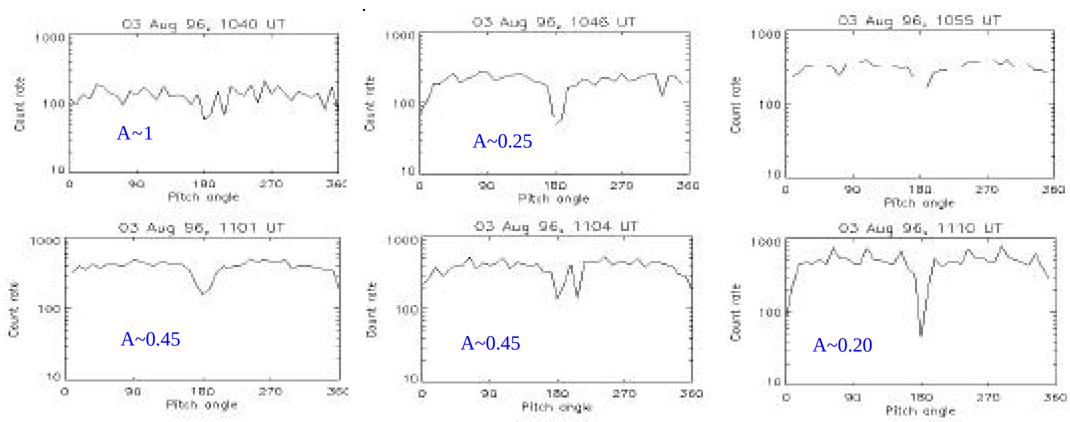

Fig. 3

detected the similar transition of the proton flux from the isotropy to the anisotropy violated in the localized region. Figure 4 shows three consequent NOAA-12 passes through the evening sector in the north, south, and again north hemisphere. For each pass the trapped (thick line) and precipitating (thin line) flux of protons with E>30 keV is shown as well as the energy flux for protons with E<20 keV. The vertical line in each plot marks the latitude where a specific localized precipitation of energetic protons is detected. On bottom of each plot UT and MLT of the localized precipitation are shown. The localized precipitation detected by the NOAA-12 satellite maps onto equatorial plane close to the region of the localized cold plasma enhancements detected by the LANL spacecraft. In Figure 1 the equatorial location of the precipitation is indicated by open circle on each NOAA-12 trace. The mapping was done using the dipole magnetic field model. Note that latitudinal width of the localized precipitation is in agreement with L-shell range of isotropization seen by Polar.

The localized proton precipitation pattern in the NOAA-12 data is just that, which *Yahnina et al.* (2000, 2002) have identified as related to the Pc1 (EMIC) waves. This means that there should be EMIC waves in the region of the particle isotropization and precipitation. Indeed, consideration of the EFI and MGE data from Polar showed a series of quasi-monochromatic wave packets in the range of Pc1-2. These waves as seen in the magnetic field data are shown in Figure 5 in the spacecraft co-ordinate system. (The data from the electric field instrument show similar waves, but we do not reproduce them because the data are noisier). The time interval of the wave registration (1055-1110 UT) coincides with the interval when the Polar satellite observed the pitch angle scattering within the anisotropic zone (Figure 3). The Pc1-2 waves were observed also on the ground by the search coil magnetometer operated in Sodankylä, L=5.2 (data not shown). This station started to register the Pc1-2 pulsations of a significant amplitude since ~1030 UT when the first proton cloud arrived in the evening sector as a result of the substorm injection in the night sector. However, some very weak emissions of the same frequencies existed before 1030 UT. Sometimes up to three bands of quasi-monochromatic signals were detected simultaneously. During the time interval of the EMIC wave observation onboard Polar the ground station detected two-band emission at frequencies close to those observed onboard the Polar satellite.

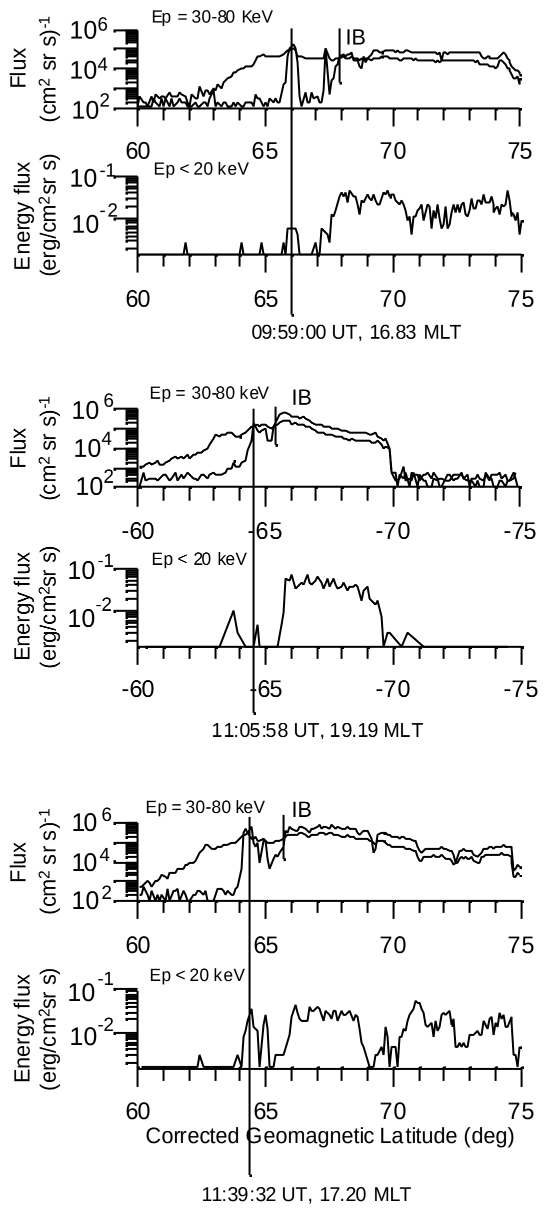

Fig. 4

Summary and Discussion

The observational results obtained during the considered event from the complex multi-spacecraft observations can be summarized as follows.

a) The Polar and LANL spacecraft cluster detected highly structured cold plasma enhancements in the evening MLT sector near the geosynchronous orbit.

b) At the same time and location they detected the arrival of proton clouds drifting from the night sector.

c) In the region of contact of the cold plasma and hot protons the signatures of both the pitch angle diffusion of energetic protons and EMIC waves were detected.

d) The particle scattering was confirmed by the conjugated low-altitude observations of the energetic proton precipitation.

e) The Pc1-2 waves were also observed by the ground-based station around the time of satellite measurements.

The cold plasma observations are naturally interpreted as plasma structures detached or elongated from the plasmasphere. Such observations are not new (e.g. *Moldwin et al.*, 1997). It seems that in the case under study in the vicinity of geosynchronous orbit within the 15-19 MLT sector there were several (at least 2 - 3) plasma clouds with the characteristic size of about one MLT hour. In turn, the plasma density within these clouds significantly varies along both the longitudinal and radial directions. The former is clearly seen from Figure 2, the latter is evident from the detailed consideration of the EFI spacecraft potential data (not presented here) obtained onboard the Polar satellite. Each of magnetic tubes with the enhanced cold plasma density can be the source of the ion-cyclotron turbulence which produce the EMIC waves. In agreement with this view the EMIC waves intensified several times within the above-mentioned L-shell range (Figure 5). The wave frequency increased from one wave train to another. This agrees with the increase of an ion gyrofrequency during the inward motion of the Polar satellite. However, because of the satellite motion, one can not certainly resolve between spatial structure of the wave source and its temporal behavior. Ground based data can be used as a monitor of the temporal evolution of the wave sources.

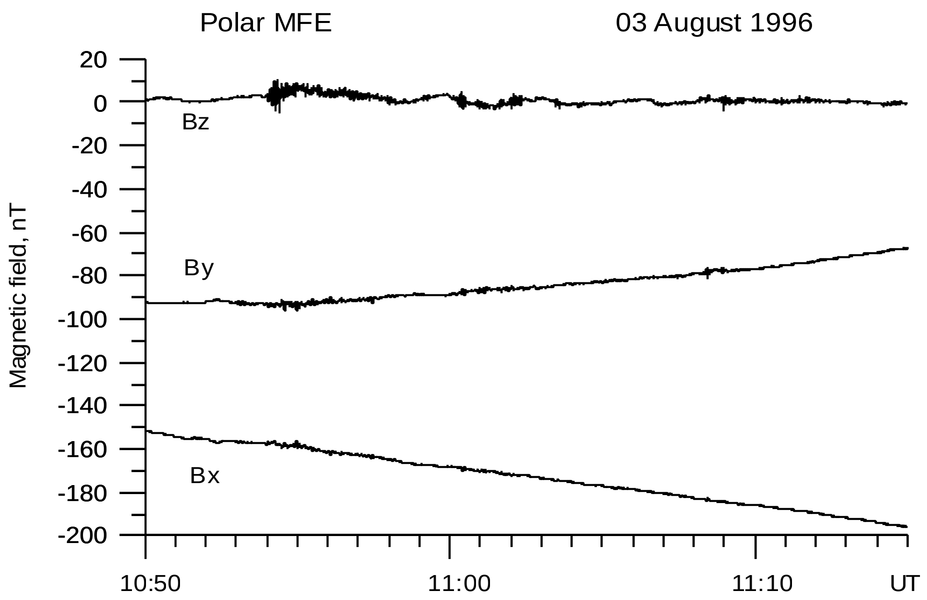

Fig 5

In agreement with the above interpretation the observation of the multi-band Pc1-2 emission on the ground suggests more than one source of the waves. These sources operate for a long time (some weak emissions are seen even well before the intensification related to the arrival of the energetic proton cloud). The continued operation of the source(s) is also confirmed by the NOAA-12 data. The data demonstrate that the Pc1 related precipitation is seen well before and well after the time when the Polar satellite detected the waves and particle isotropization.

Conclusions

The complex of observations of phenomena that occurred during the Pc1 (EMIC wave) event confirms the scenario of the ion-cyclotron instability development in the region where the ring current energetic protons contact the cold plasma boundary. It may happen in the very localized magnetic tubes filled with the dense cold plasma detached from plasmasphere. During the contact the waves are generated, and they scatter the energetic protons into the loss cone forming the localized precipitation which can be detected by low-altitude satellites.

The observations provide direct evidence of the relationship between EMIC waves and specific proton precipitation found by *Yahnina et al*. (2000, 2002)

We limited this case study by a qualitative consideration. Quantitative aspects of this study in this case as well as more detailed description of these multi-instrument observations will be presented elsewhere.

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