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THE STUDY OF THE GENERATION MECHANISM OF MONOCHROMATIC PC4 PULSATIONS WITH USING ERG SATELLITE DATA

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Abstract. In this work we investigate the physical nature and generation mechanism of very monochromatic Pc4 pulsations with using data of ERG (Exploration of energization and Radiation in Geospace) satellite. Such type of the pulsations is exited during very low geomagnetic activity; these pulsations do not seen on the ground magnetometers due to damping in the ionosphere. The question about the generation mechanism of these pulsations is still open. For the event 4 May 2017 according to the ERG satellite data the wave packet of Pc4 pulsations was registered after midnight at 08-10 UT. The pulsations are mostly seen in radial component and also in azimuthal component of the magnetic field; its frequency is about 13 mHz. On GOES-13 satellite located on higher L-shell than ERG satellite the frequency of these pulsations is about 11.5 mHz. This property (decrease of the frequency of geomagnetic pulsations with the increase of L-shell) testifies about the resonance nature of the pulsations. During appearance of the Pc4 pulsations on ERG satellite the injection of electrons (mostly seen in 10-80 keV energetic cannels) are registered. This injection coincides with the small increase of AE index up 200 nT. So, this injection is caused by the small substorm. Thus, it is found the experimental evidence that injection of electron cloud into the morning sector can be reason of the excitation of monochromatic Pc4 geomagnetic pulsations. There are some theories which can explain this mechanism.

Introduction

There are many types of ULF waves in the Earth magnetosphere, which differ by their periods (Pc3-5, Pg, Pi2-3), waveforms (broadband or monochromatic), polarization structure (poloidal, toroidal, or compressional), etc. ULF waves have two types of energy sources: external and internal. External sources, such as the Kelvin-Helmholtz instability and compression of magnetosphere by solar wind, excite large-scale perturbations on the magnetopause. ULF waves excited by external sources generally have a small wave number in the azimuthal direction (m-number), for example, $|m| < 10$. By contrast, internal sources, such as plasma instability and wave-particle resonance, excite perturbations with a large m-number, for example, $|m| \sim 100$.

One of the most puzzling types is the poloidal Pc4 pulsations. These waves have very monochromatic waveform and excited during low geomagnetic activity. There have been numerous studies discussing excitation of poloidal waves by the drift-bounce resonance [*Anderson et al*., 1990; *Engebretson et al*., 1992; *Kokubun et al.,* 1989; *Liu et al*., 2013; *Takahashi et al.,* 1990]. Large-m poloidal waves are thought to be excited by the drift-bounce resonance mechanism associated with hot ring current protons [*Anderson et al*., 1990; *Kokubun et al*., 1989]. *Liu et al.* (2013) suggested that second harmonic poloidal waves are likely generated by bounce resonance with free energy coming from bump-on-tail plasma distributions.

In this study we try to examine this type of pulsations and its connection with the fluxes of energetic particles in the magnetosphere with new ERG data facilities.

Data used

The ERG (Exploration of energization and Radiation in Geospace) satellite was developed by the Institute of Space and Astronautical Science of JAXA (Japan Aerospace Exploration Agency) for the study Earth radiation belts. It has apogee about 5.0 Re (L~6.0, 32 110 km), perigee about 460 km. It was launched at 20 December 2016. ERG have an instruments for plasma and particle experiment (PPE), magnetic field experiment (MGF), plasma wave experiment (PWE).

The GOES geostationary spacecrafts was used for the registration of the geomagnetic field variations, variations of the electron and proton fluxes. CARISMA network stations are used for the registration of geomagnetic field variations in conjugate to the satellite regions.

The event 4 May 2017

The wave packet of very monochromatic pulsations was observed on GOES-13 spacecraft at time interval 08-10 UT (Fig. 2). At this moment the GOES-13 spacecraft was located at the early morning sector (see the map on the Fig. 1). The Pc4 pulsations were mostly seen in radial (he) and azimithal (hn) components with amplitude about 2-3 nT. Weaker pulsations can be seen also in the field-aligned component hp and in the module of the geomagnetic field ht. This polarization indicates on the poloidal-type transverse wave structure. The Pc4 pulsations are not so evident at more distant geostationary GOES-15 spacecraft, located on the night side.

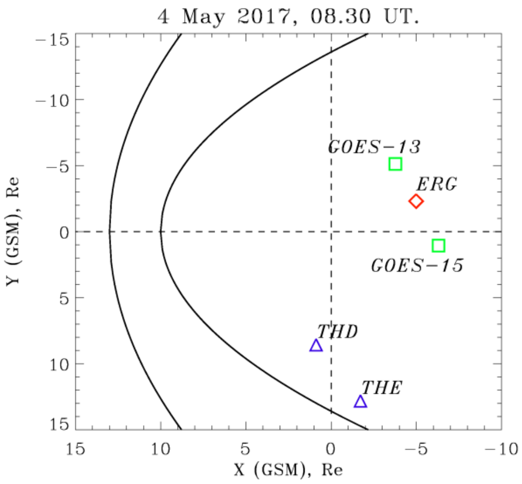

Figure 1. The locations of the spacecrafts (GOES-13, 15, ERG, THA, THE) in GSM coordinate system 4 May 2017 at 08.30 UT.

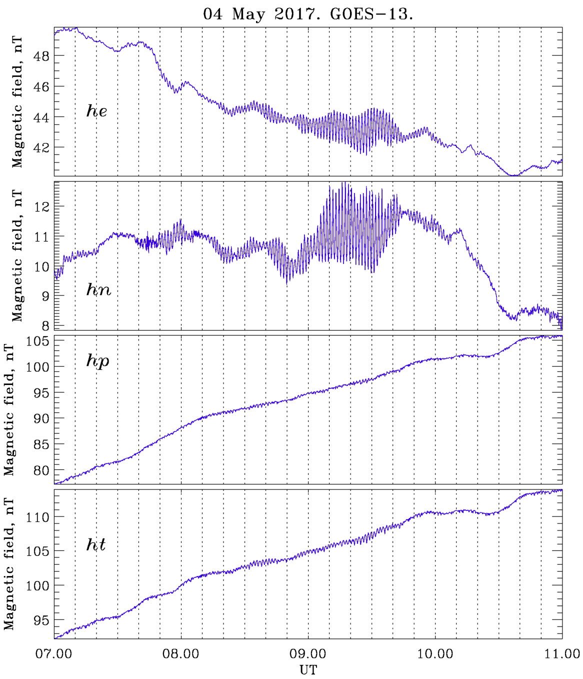

Figure 2. The geomagnetic field variation (he, hn, hp, ht-components) on GOES-13 spacecraft.

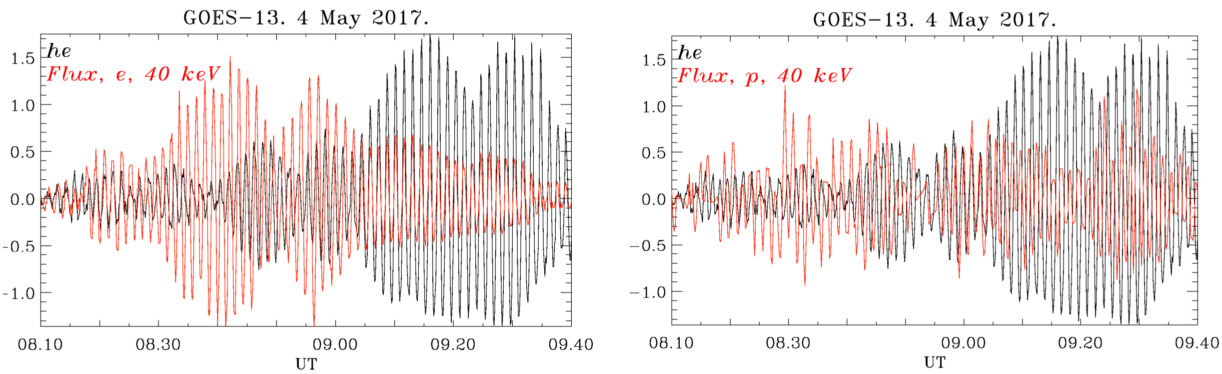

Figure 3. The comparison of the geomagnetic Pc4 pulsations with the 40 keV electron fluxes (*left panel*) and with the 40 keV proton fluxes (*right panel*) at GOES-13 spacecraft.

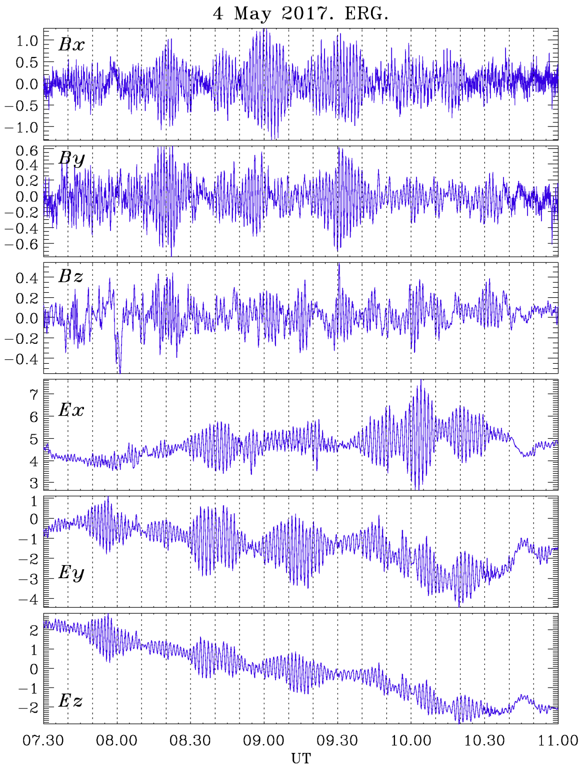

Figure 4. The geomagnetic field (Bx, By, Bz) and electric field (Ex, Ey, Ez) variations on ERG spacecraft.

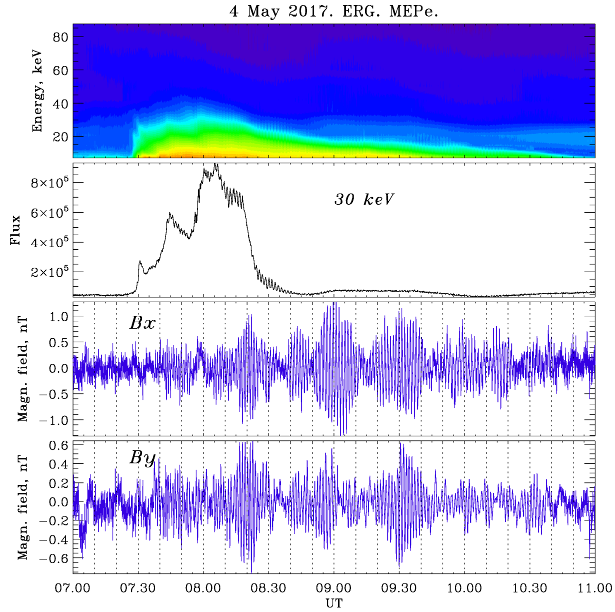

Figure 5. The spectrogram of the electron fluxes variations; electron fluxes variations with energy 30 keV; geomagnetic field variations (Bx, By-components) on ERG spacecraft.

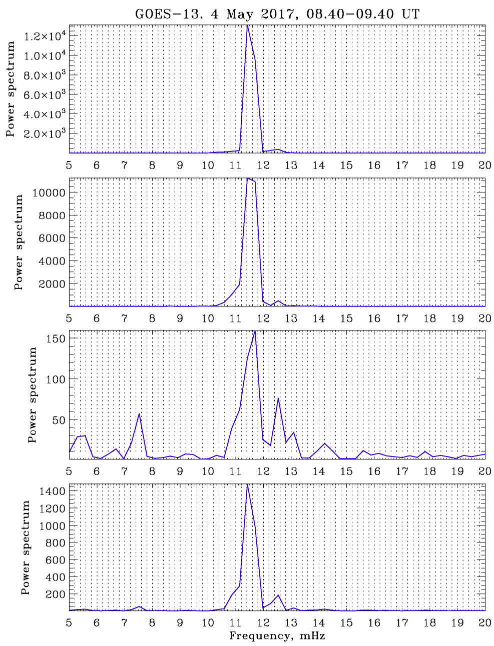

Figure 6. The spectrum of the geomagnetic field variations (he, hn, hp, ht) at GOES-13 spacecraft at time interval 08.40-09.40 UT.

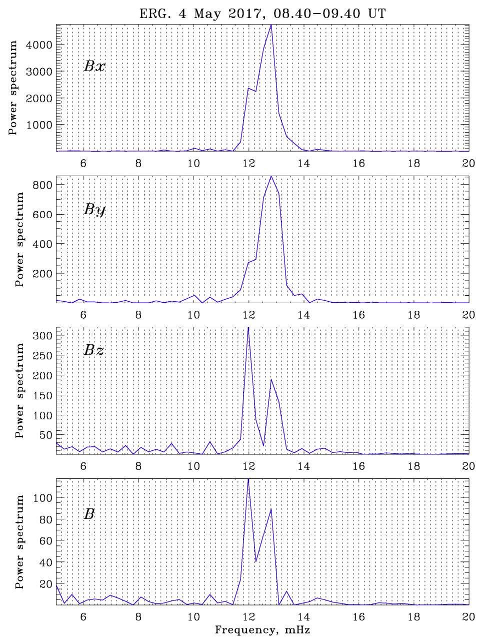

Figure 7. The spectrum of the geomagnetic field variations (Bx, By, Bz, B) at ERG spacecraft at time interval 08.40-09.40 UT.

The geomagnetic Pc4 pulsations according to the GOES-13 data were accompanied by the pulsations in electron and proton fluxes with the same frequency in wide energy range. The Pc4 pulsations in electron fluxes are in phase with the geomagnetic pulsations while Pc4 pulsations in proton fluxes are in anti-phase with the geomagnetic pulsations (Fig. 3).

Near the GOES-13 satellite (about 2 MLT hours) the ERG satellite (on lower L-shells) was located (Fig. 1). The similar Pc4 pulsations were also observed in variations of the electric and magnetic field on ERG satellite (Fig. 4). The pulsations are better seen in electric field variations. But the wave forms Pc4 pulsations are not well correlate on GOES-13 and ERG satellites. It means that the observed waves have small-scale structure.

The spectrum analysis shown that the frequency of these pulsations on GOES-13 spacecraft is about 11.5 mHz (Fig. 6). At the same time the frequency of the pulsations on ERG spacecraft was about 12.5 mHz (Fig. 7). The ERG satellite was located on lower L-shell than GOES-13 geostationary satellite. So the decrease of the pulsation frequency with the decrease of the L-shell testifies about the resonance properties of the standing Alfven waves.

The considered pulsations cannot be seen on the ground CARISMA magnetometers (not shown), even at stations near the conjugate points of the GOES-13 and GOES-15 spacecraft. This fact also indicates on a small-scale transverse structure of these pulsations and its damping in the ionosphere.

These pulsations are observed during a low geomagnetic activity, contrary to majority of other types of ULF waves. The SYM-H index is positive, AE index is not more than 200 nT (not shown), solar wind speed according to the OMNI database is about 350 km/s. So we suppose that the source of these pulsations is associated with local processes inside the magnetosphere.

It is found that at the moment of the excitation of Pc4 pulsations the cloud of electrons (1-40 keV) was registered on ERG satellite at 07.25 UT approximately (Fig. 5). At that moment the small jump of AE index up to 190 nT was observed. So this small substorm injects the cloud of electrons from the nightside into the morning sector. The injected cloud of electrons may be the source of the monochromatic poloidal Pc4 pulsations.

4. Discussion and conclusions

Very monochromatic poloidal pulsations in the Pc4 range in the early morning sector of the magnetosphere have been found in the ERG and GOES magnetometer data. The observed poloidal Pc4 pulsations cannot be seen by ground-based magnetometers due to damping in the ionosphere. This fact indicates about small-scale structure of these pulsations in the transverse direction. The decrease of the frequency with the increase of the L-shell matches the notion on the standing Alvenic waves in the magnetosphere.

These Pc4 waves cause a strong modulation of the fluxes of the energetic electrons and protons, wherein Pc4 pulsations are in phase with the pulsations in electron fluxes and out phase with the pulsations in proton fluxes.

The waves are generated during very low geomagnetic activity, low solar wind speed. At the same time the cloud of energetic electrons injected from the nightside into the morning sector may be the source of the considered pulsations. It may be supposed that the observed Pc4 poloidal pulsations are generated by a kinetic instability of the 'hot' electrons. However, such instabilities require a finite value of parameter β for their effective excitation. We suggest that generation of these waves by energetic electrons may occur in a non-resonant way, via the "ship waves" mechanism [*Mager and Klimushkin,* 2008]. This generation mechanism may be efficient even in a low-β ($\beta \ll 1$) plasma. The poloidal Alfven wave is supposed to be emitted by a non-steady electric current created by a drifting electron cloud. The generated "ship waves" should propagate in the direction of the electron drift, e.g. eastward.

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