Simultaneous occurrence of Pc 5 and Pc 1 pulsations in the dawnside magnetosphere: CRRES observations

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Abstract

An abrupt increase in the solar wind pressure compressed the magnetosphere on September 11, 1990, and started a long chain of intense, toroidal Pc 5 waves at 0540 UT. The waves were observed by the CRRES satellite in the dawnside magnetosphere (06 MLT, L = 7), and on the ground, e.g., by the Scandinavian magnetometer chain at about 08 MLT. Simultaneous increases in the energetic (>20 keV) particle flux and the geomagnetic field induction were also observed by CRRES. A series of intense bursts of ion cyclotron waves (Pc 1) started soon after the onset of the compression at about 0600 UT, coinciding with an increase in the magnetospheric electron number density. The pulsations lasted until the energetic particle fluxes decreased at about 0800 UT. The observed waves have the characteristics of the newly detected dawnside Pc 1 waves on high L-shells, which get their energy from ions on open drift paths. Toward the end of the event, after a strong additional enhancement of the electron number density, the Pc 1 bursts are repeated at the Pc 5 frequency and appear at a fixed Pc 5 phase, indicating a possible modulation of the Pc 1 wave growth rate by Pc 5 waves. We discuss the particle and wave characteristics of the event and in particular the possible connection of Pc 1 and Pc 5 waves. We suggest that the Pc 1 wave modulation is produced by the electric field of the Pc 5 wave that modulates the equatorial cold plasma density by moving plasma from higher to lower L-shells and back, thus affecting the growth rate of Pc 1 waves.

Introduction

The Combined Release and Radiation Effects Satellite (CRRES) was launched into a geostationary transfer orbit in July 1990. The apogee was at 6.3 R_E and rotated from about 08 MLT at the beginning of the mission via the nightside to about 14 MLT when the satellite ceased operation in October 1991. The satellite reached L values in excess of 7 and magnetic latitudes of about ±30° due to the inclination of 18.2°. Several strong pulsation events in the Pc 5 frequency range ($T \approx 150 - 600$ seconds) were observed by the magnetic field instrument during the fall of 1990, when the apogee was in the dawn sector. In this work we will investigate one such event from September 11, 1990 (orbit 115). Strong Pc 1 pulsation bursts were recorded in addition to the Pc 5 pulsations. Our main topic is the possible connection between these pulsations.

Aazimuthally polarised, toroidal Pc 5 waves are often observed in the dawn sector of the Earth's magnetosphere. They are also called type A waves. At geosynchronous orbit, these waves occur most frequently between 05 and 09 LT and have typical periods of about 100-200 seconds. They have been found to be associated with high speed (>600 km/s) solar wind, and moderately disturbed conditions as judged from the AE index (Kokubun *et al.*, 1989). They appear to be fundamental odd mode field line resonances (FLR) with a magnetic node at the equator (Singer and Kivelson, 1979). The horizontal spatial scale of the perturbations is large (azimuthal wave numbers are small, m<10), and the ground-magnetosphere correlation of the waves is thus high (Kokubun *et al.*, 1989). However, when recorded from the ground, the pulsations show a 90° counter clockwise rotation of magnetic field variation due to modifications in the ionosphere (Hughes, 1974).

Several mechanisms have been proposed to explain the formation of waves in the Pc 5 frequency range: 1) The Kelvin-Helmholtz instability (KHI) at the magnetopause can generate boundary surface waves when the magnetosheath plasma flow velocity exceeds a threshold velocity (e.g., Cahill and Winckler, 1992). 2) Pressure variations in the magnetosheath plasma flow can also be the source of magnetopause surface waves (see, e.g., Warnecke *et al.*, 1990). For example, Lysak and Lee (1992) have modelled the response of the magnetosphere to solar wind pressure pulses: compressions produce compressional (fast mode) Alfvén waves, which can couple and mode-convert into shear Alfvén waves at the point where the compressional wave frequency matches the shear mode eigenfrequency of the field line. 3) Local magnetic anomalies like flux transfer events (FTE) or other intermittent reconnection (or penetration) processes may also be associated with magnetopause boundary waves (Cahill and Winckler, 1992). 4) Some studies show that Pc 5 pulsation events may be related to recovery phases of substorms, as the injected electrons trigger the pulsations while drifting eastward (Saka *et al.*, 1992).

For ion cyclotron waves (or Pc 1 pulsations), the dawnside magnetosphere is a very interesting region. This is because the waves can get their energy also from other sources than the ring current ions drifting near the plasmapause. For example, it has recently been shown that Pc 1 pulsations at $L \geq 7$ in the dawnside get their energy from plasma sheet ions on open drift paths (Anderson *et al.*, 1992 a, b). These pulsations are characterized by higher normalized frequencies ($X = f / f_{H^+} \approx 0.4$, where f_{H^+} is the local hydrogen gyrofrequency) than elsewhere, and linear polarization in contrast to the more common left-hand polarization. At very high-latitude ground-stations, Pc 1 pulsations have been observed that may get their energy from ions injected in the cusp/cleft region and drifting westward toward dawn (Hansen *et al.*, 1992). Furthermore, solar wind compressions have also been shown to affect the occurrence and other properties of the Pc 1 waves (Olson and Lee, 1983) by increasing the ion anisotropy which increases the wave growth rate.

Only few studies have discussed so far the possible connection of Pc 5 and Pc 1 waves. For example, the possible amplitude-modulation of Pc 1 and Pc 2 waves by storm time compressional Pc 5 waves in the afternoon sector was studied by Barfield and McPherron (1972) with negative results. Recently Fraser *et al.* (1992) have reported of a possible Pc 5 modulation of Pc 2 wave generation.

Instrumentation and data analysis

In this study, data are used from the Fluxgate Magnetometer and the Electron Proton Wide-Angle Spectrometer (EPAS, also known as MEB) on the CRRES satellite. The time resolution of the magnetometer is 16 samples per 1.024 seconds, and conversion to digital data is done using a 12-bit A/D converter. The least-significant bit resolution during the event studied was 0.43 nT, and the dynamic range was ±850 nT. The time resolution of the data used in this study was about 0.125 seconds. For more details of the magnetometer, see Singer *et al.* (1992). The EPAS instrument measures medium energy electrons (21.5 - 285 keV, 14 energy channels) and protons (37 - 3200 keV, 12 energy channels). Electrons are measured in ten directions and ions in four directions over a total angular range of about 110° in the meridian plane of the satellite. Since the spin axis of the satellite is located "near" the orbital plane, the instrument provides an almost three dimensional particle distribution during one rotation. The sampling times for electron and proton spectra are 256 and 512 ms, respectively. The particle data were averaged over 60 seconds. The EPAS instrument is described in detail by Korth *et al.* (1992).

Some additional information is provided by the Plasma Wave instrument (Anderson *et al.*, 1992) on CRRES. The instrument includes two receivers: a multichannel spectrum analyzer (5.6 Hz - 10 kHz) and a sweep frequency receiver (100 Hz - 400 kHz). The dynamic range for each of the receivers is about 100 dB beginning at the noise level. The sweep frequency receiver has four frequency bands; the lowest (50 - 400 kHz) includes the upper hybrid resonance frequency (f_{UHR}) emissions. This frequency can be used to derive the electron number density of the plasma with a time resolution of 8 seconds.

High resolution solar wind and IMF data from the IMP-8 satellite were also used with time resolution of about 1 minute and 15 seconds, respectively. On the ground, magnetometer data from IMAGE, the Scandinavian magnetometer chain (IMAGE Newsletter, 1992), and Finnish pulsation magnetometer registrations are used.

In order to investigate the characteristics of the Pc 5 pulsations, the magnetic field was converted from the Earth Centered Inertial (ECI) coordinate system into a field aligned coordinate system. Floating averages of the field measurements over 21 minutes (corresponding to about five cycles of the Pc 5 pulsations) were used to define the coordinate axes. The instantaneous measurements are then split in two components: $\mathbf{B}_{||}$ is parallel, $\mathbf{B}_{\perp}$ perpendicular to the average field direction. $\mathbf{B}_{\perp}$ is then divided into a radial component $\mathbf{B}_r$ and an azimuthal component $\mathbf{B}_{\phi}$. The signs of these quantities are defined so that positive $B_{||}$ points along the average magnetic field, positive B_r away from the Earth, and positive B_{ϕ} completes the right-handed coordinate system by pointing eastward. The wave polarization was studied using the method of eigenanalysis and coherency analysis of spectral matrix described, e.g., by McPherron *et al.* (1972) and Arthur *et al.* (1976, technique 1).

Observations

Solar wind pulse and geomagnetic activity

An abrupt increase in the solar wind density from about 20 to 40 cm^{-3} was observed by IMP-8 on September 11, 1990, at about 0528 UT (Figure 1a). The spacecraft was located roughly X_{GSM} = 30 R_E, Y_{GSM} = 5 R_E, and Z_{GSM} = 15 R_E during the event. The solar wind velocity remained almost constant at 420 km/s over the whole period studied (Figure 1b). However, a simultaneous change in the solar wind flow angle from westward to eastward was observed. Although there is a gap in the IMP-8 data between 0605 and 0800 UT, it seems likely that the density values were enhanced also during this interval. Note that even the initial value of n_{SW} = 20 cm^{-3} is higher than the average value, implying that the magnetosphere was already in a compressed state when the pressure pulse arrived. Dayside mid-latitude measurements on the ground (not included here) support this view. However, the main event can be attributed to the latter abrupt solar wind density enhancement. It takes a few minutes for this front to propagate from the IMP-8 location to the Earth's magnetopause. This delay agrees well with the start of the event in the magnetosphere at about 0540 UT.

The magnetic field magnitude B_{tot} of the IMF is presented in Figure 1c for the same period. B_{tot} decreases abruptly at the time of the density increase. During the preceding couple of hours B_{tot} was high indicating that the density enhancement may have compressed the IMF ahead of it. (Note, however, that the magnetic pressure is insignificant when compared with the plasma pressure during the whole event.) The IMF B_Z component (not shown) was positive most of the time from about 0330 UT onwards up to the data gaps; IMF had a southward component only for about 20 minutes just after the density increase (magnetic field decrease) at 0528 UT.

The *Dst* index showed positive values already prior to the event, reflecting the high solar wind plasma densities present during that time. The abrupt solar wind pulse was responsible for a strong positive maximum in the index of about 30. No clear storm period followed. The *Dst* index showed strongly fluctuating negative values of about –20 during the next few days. The three hour *Kp* value was 4 (0600 - 0900 UT on September 11).

Onset of the event in the magnetosphere

During the event studied here, the CRRES satellite was located in the dawnside magnetosphere (06 MLT) at L ≈ 7, the magnetic latitude of the satellite being about 20° north. At about 0540 UT, the following changes were registered by CRRES in this region (Figures 2a-c): strong Pc 5 pulsations started with the main power in the azimuthal magnetic field component (corresponding approximately to X_{ECI} and X_{GSM} in this case), the parallel magnetic field (total field) strength increased by almost 10 nT, and energetic particle fluxes increased, particularly at pitch angles of 90°. Strong VLF activity started also at the same time (data not shown). Somewhat later, at about 0607 UT, an increase in the electron number density was seen (as derived from the f_{UHR}, Figure 2d), and at about the same time, 0604 UT, also bursty Pc 1 emissions appeared (Figure 2e). The location of the satellite in L-value and magnetic local time during the event is seen in Figure 2f. On the ground, a strong enhancement in Pc 5 activity was observed at about 0540 UT by, e.g., the Scandinavian IMAGE magnetometer cross, which is located about 3 hours in local time ahead of CRRES. In Figure 2g the north-south magnetic field component from Kilpisjärvi is plotted. This component showed the best correlation with the pulsation data measured in space.

Pc 5 pulsations

The Pc 5 pulsations starting at 0540 UT were observed by CRRES for several hours, but their amplitude changed considerably during the event, as can be seen from Figure 2a. Accordingly, we divide the event into five distinct intervals. Interval

I (0540 - 0630 UT) shows pulsations with an amplitude of about 7 nT. Interval II (0630 - 0705 UT) shows a strong minimum in the Pc 5 activity, which is only partly recovered during interval III (0705 - 0740 UT), when the amplitude is about 4 nT. Interval IV (0740 - 0820 UT) shows the strongest pulsations with amplitudes up to more than 10 nT. Finally, during interval V (0820 - 0850 UT), a burst of Pc 5 pulsations with amplitudes of about 7 nT is again observed. The pulsation frequency was 4.0 mHz, and it was very stable throughout the event: only during interval V waves with 5.5 mHz frequency were measured. The predominantly linear polarization of the Pc 5 pulsations was verified by polarization calculations, according to which the absolute values of ellipticity remained smaller than 0.25 during the whole period (see also Figure 4b).

Particle fluxes

The 90° pitch angle fluxes of protons in the energy range 37 - 54 keV and of electrons in the energy range 21.5 - 31.5 keV are plotted in Figure 2c (the fluxes at higher energies behaved similarly). The changes in these fluxes correlate partly with the changes in the Pc 5 activity (Figure 2a). The proton flux intensity shows a clear increase at the beginning of the event at 0540 UT, fairly constant values during interval I, a steady decrease during interval II, and again almost constant values during interval III. However, the beginning of interval IV is not seen in the proton flux, and the abrupt decrease of the flux intensity at about 0800 UT does not correlate with changes in the Pc 5 pulsations. The flux intensity is constant after this decrease, showing no correlation with the Pc 5 burst during interval V. A general trend in the proton flux is thus a slow decrease throughout the event after the initial enhancement at 0540 until 0805 UT.

The electron fluxes show a similar general decreasing trend, but with much more variability during the event itself. First of all, they show a clear increase in intensity already at 0515 UT, well before the onset of the event at 0540 UT. After the sharp initial flux intensity increase at 0540 UT that lasts only about ten minutes there are other similar increases at about 0550, 0620, 0705 and 0740 UT. Most notably, the last two correlate with increases in the Pc 5 activity in Figure 2a, i.e., the beginnings of intervals III and IV, respectively. Also the VLF wave activity measured by CRRES (data not shown) follows these enhancements with increasing intensity. The local minimum in the electron flux between 0715 and 0735 UT may be significant, and this period can be seen as a local minimum also in electron number density (Figure 2d) and VLF emission activity.

Pc 1 pulsations

Intense bursts of ion cyclotron waves (Pc 1 pulsations) were observed close to the CRRES apogee between about 0604 and 0802 UT, each lasting a few tens of seconds (see the schematic presentation for the appearance times of the bursts in Figure 2e). The electron number density increased to a higher level at 0607 UT (Figure 2d), which correlates rather well with the start of the Pc 1 pulsations. A strong peak in this density is seen at about 0743 UT during the period of high fluxes of energetic electron, together with a fast repetition rate of Pc 1 bursts. The abrupt end of the pulsations after 0802 UT correlates well with the decrease in the energetic particle fluxes.

The average frequency of the bursts increased slowly from below 0.9 Hz to above 1.1 Hz during the event in accordance with the increase of the magnetic field intensity (Figure 2b). The local normalized frequency, $X = f / f_{H^+}$, where f_{H^+} is the local proton gyrofrequency, has an almost constant value of X = 0.4, i.e., all wave activity is above the He^+ gyrofrequency. We have estimated the normalized frequency at the equator. From the Tsyganenko's magnetic field model T89 (Tsyganenko, 1989) the ratio between the magnetic field intensities at the location of CRRES and at the equator was calculated. From this value and the *measured* intensity at CRRES normalized frequencies of about 0.6 - 0.7 in the equatorial region were derived.

The ellipticity of the bursts is shown in Figure 3. This data is calculated from the magnetic field measurements in the GSM coordinate system. The bursts are mainly linearly polarised, and the small amount of left-handed polarization is striking.

Weak signals of similar bursty Pc 1 activity can also be seen on the Finnish pulsation magnetometers (data not shown). However, there is no one-to-one correlation with the satellite data, and the bursts started on the ground at about 0556 UT, i.e., a little earlier than at CRRES.

Modulation of Pc 1 pulsations by Pc 5 waves

During the first half of interval IV the repetition rate of Pc 1 bursts matches the frequency of the Pc 5 waves. In Figure 4a a short interval between 0725 and 0805 UT is shown that contains several Pc 1 bursts. The azimuthal and radial B-field components of the Pc 5 waves are plotted in Figure 4b for comparison. It can be seen that six Pc 1 bursts out of seven occur on the falling slope of the field variation of the azimuthal component, and that between 0737 and 0754 UT the correlation is almost perfect. Note that there is a strong peak in the electron number density around this time (about 0743 UT), and that the electron flux intensities are clearly higher during the period 0737 - 0754 UT.

Discussion

Processes triggered by the solar wind pressure pulse

The observations described above suggest the presence of toroidal Pc 5 waves. The wave period of about 250 seconds is only a little longer than the typical values of 100-200 seconds observed at geosynchronous orbit, and may be attributed to a slightly larger L-value or a small component of heavy ions such as helium or oxygen. Also the ground signal is as expected for toroidal Pc 5 waves. The waves were very likely triggered by a solar wind pressure pulse in the form of an increase in the plasma density. The fact that the solar wind velocity showed no change and the IMF B_Z was mainly northward rule out the Kelvin-Helmholtz instability and reconnection processes, respectively, as possible triggers for the pulsation. During the event the changes in the energetic electron fluxes occasionally correlate with the changes in the Pc 5 activity level. However, the observations here rule out the possibility that these electrons would have triggered the pulsations as discussed, for example, by Saka *et al.* (1992).

It is very likely that the start of the Pc 1 pulsations at about 0556 UT on the ground and at about 0604 UT at CRRES is also due to the solar wind pulse. The fact that the pulsations start earlier on the ground reflects the later local time of the Finnish pulsation magnetometer chain as compared to CRRES. The overall appearance of the Pc 1 bursts in space seems to correlate well with the time of increased proton (and electron) fluxes. The bursts start soon (but not immediately) after the particle flux increase and stop almost exactly at the time of the flux decrease.

In addition, the Pc 1 bursts were accompanied by increases in the electron number density. This is verified by the level increase of the density just after the first Pc 1 burst and also by the strong peak in density at around 0743 UT. It is well known that this increase lowers the resonance energy of ions, thus allowing more ions to contribute to the ion cyclotron resonance, and enhancing the instability.

The variations in electron number density measured by CRRES may differ sizably from those occurring at the equatorial region where Pc 1 waves are generated. This is also a likely explanation for the appearance of the first Pc 1 bursts slightly before the density increase at CRRES. As drifting plasma clouds tend to be confined at the equator, the density increase is expected to occur earlier and to be larger at the equator than at 20° north of the equator where CRRES was located. Therefore, with increasing density, conditions for ion cyclotron waves were created at the equator slightly earlier than observed by CRRES. It is possible that the solar wind pressure pulse was also responsible for this plasma cloud, although we cannot verify this.

We have estimated the adiabatic effects of the magnetic field changes on the particle fluxes. The abrupt increase in the intensity of the total magnetic field at the beginning of the event at 0540 UT, undoubtedly due to the compression of the magnetosphere, is sufficient to explain the increases in energetic proton and electron fluxes by adiabatic betatron acceleration at that time. The general decreases in fluxes during the event may be attributed to the increase of the magnetic latitude during the period under study (changing from 14.5° at 0500 UT to 24.4° at 0900 UT). We will discuss the decrease in the proton flux during interval II in a separate study.

Relations between Pc 5 pulsations and Pc 1 pulsations

The evidence for the modulation of Pc 1 waves by Pc 5 pulsations at 0737 - 0754 UT (Figures 4a and b) is quite striking. The characteristics of the Pc 1 bursts are the same as found to be typical for the new Pc 1 population recently discovered by Anderson *et al.* (1992 a, b). These authors report on Pc 1 waves in the dawn sector at high L-values ($L \geq 7$), which are generated with linear polarization and exhibit high normalized frequencies, $X = 0.4$. All these properties are in agreement with our observations. However, due to the fairly high magnetic latitude of CRRES, we cannot argue whether the waves were already produced with linear polarization as claimed by Anderson *et al.* (1992 a, b), or whether the polarization was changed from left-handed to linear during the propagation of the wave from the equator to the location of CRRES. In fact, a fairly small amount (of about 10 %) of He^+ would be enough to raise the cross-over frequency above the observed wave frequency and cause this change in wave polarization (Young *et al.*, 1981). Unfortunately, no data is available for the relative amount of He^+ for this study.

The period showing the correlation between the two wave types is somewhat different from the rest of the event. It is inside interval IV, where the azimuthal and radial amplitudes of the Pc 5 pulsation are somewhat larger than elsewhere. Also, the very strong increase in the electron number density at about 0743 UT occur just in the middle of the period. From Figure 4b we can see how the azimuthal and radial components of the magnetic field are almost in opposite phases ($\approx$ linear polarization), and the magnetic field vector of the Pc 5 wave moves from later local times and inner L-shells to earlier local times and outer L-shells and back. The Pc 1 bursts are only seen during the first half of this cycle (Figures 4a and b), i.e., when field lines are brought from the inner magnetosphere toward the satellite. However, since there is a magnetic node at the equator where the Pc 1 waves are formed, this should not have much effect on them. It is likely that the radial electric field component of the Pc 5 hydromagnetic wave is strong enough to disturb the local cold plasma density in the equatorial plane in a way that favours the growth of ion-cyclotron waves during a specific phase of the Pc 5 pulsation cycle. (Unfortunately, we do not have the electric field measurements available.)

An outward electric field is expected to lead the eastward magnetic field oscillations by 90° for the fundamental toroidal resonant oscillation of the geomagnetic field (see, e.g., Potemra *et al.*, 1989). In the present case, this corresponds to an inward radial direction of the electric field on the falling slope of the azimuthal magnetic field, and an outward direction on the rising slope of the field. The modulation of the Pc 1 formation can be understood, if a cold plasma cloud exists at the equatorial region close to the CRRES field line, but on a higher L-shell. Then the electric field of the Pc 5 wave would transport plasma from this cloud either toward the satellite field line or away from it, depending on the phase of the cycle. When the electric field points from the plasma cloud toward the satellite field line, it transports new plasma to this field line, and lowers the resonance energy of the ions contributing to the ion cyclotron instability. The existence of such a plasma cloud is verified by the peak in the electron number density at about the time of the Pc 1 modulation. The plasma cloud could originate, e.g., from the solar wind. Note that the highest values of the density enhancement at 0743 UT are above the average solar wind density but still far below the present solar wind density. Other possibility is that the cloud is produced inside the magnetosphere because of the pressure pulse.

Conclusion

We have provided evidence for a modulation of Pc 1 pulsation bursts by toroidal Pc 5 waves during a period of strong magnetospheric compression. While the compression started a long chain of Pc 5 pulsations and created favourable particle distributions for Pc 1 wave growth, the modulation occurred during a period with strongest Pc 5 pulsations and an abrupt increase of the plasma density. We argue that the mainly radially directed electric field of the Pc 5 wave transported part of this high density plasma toward and away from the satellite located suitably close to the edge of the plasma cloud. The resulting strong temporal increases in plasma density lowered the resonance energy of the ions that could contribute to the ion cyclotron resonance, and enhanced the instability. In this way the Pc 1 emission bursts could be modulated with the Pc 5 frequency.

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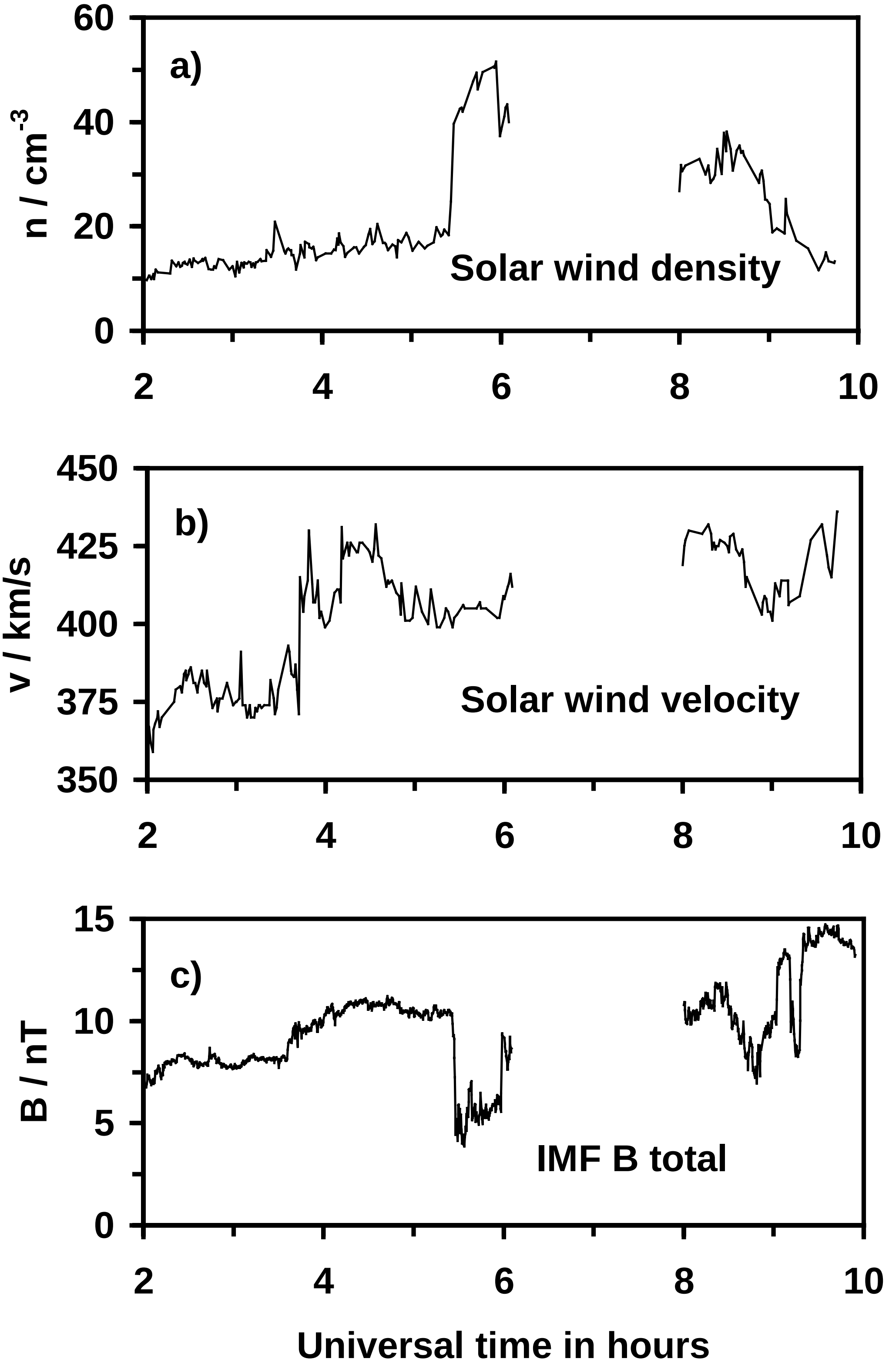


Fig. 1. Solar wind and IMF data from September 11, 1990. a) Solar wind density. b) Solar wind velocity. c) IMF B_{total}.

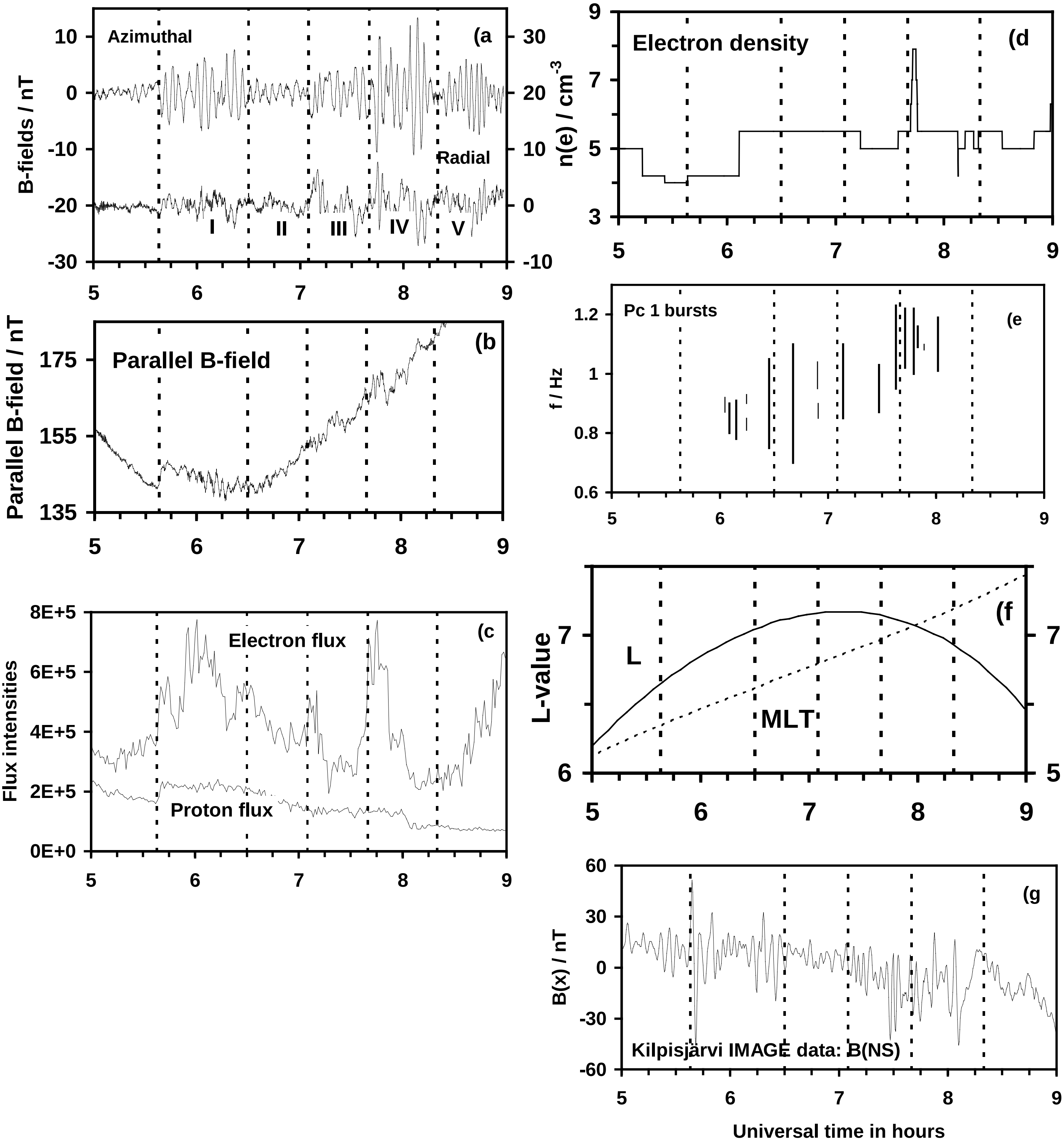
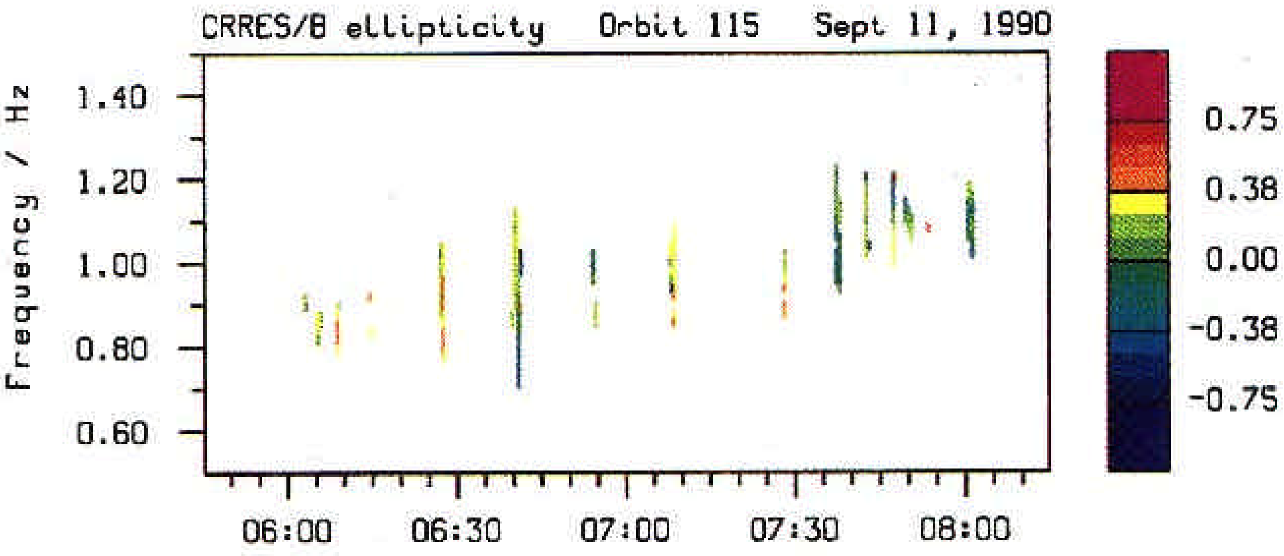


Fig. 2. The effect of the solar wind pulse in the magnetosphere (panels a to f) and on the ground (panel g). a) Azimuthal and radial magnetic field components (Pc 5 waves). b) Parallel (≈ total) magnetic field strength. c) Proton (37 - 54 keV) and electron (21.5 - 31.5 keV) fluxes at 90° pitch angle in cm^{-2}s^{-1}sr^{-1}keV^{-1}. d) Electron number density. e) Location of the Pc 1 bursts during the event. f) L-value and MLT for the CRRES position. g) North-south magnetic field variations in Kilpisjärvi, Finland. The vertical dashed lines are plotted to facilitate comparison of the figures.


CRRES/B ellipticity Orbit 115 Sept 11, 1990
Frequency / Hz
1.40
1.20
1.00
0.80
0.60
06:00
06:30
07:00
07:30
08:00
0.75
0.38
0.00
-0.38
-0.75

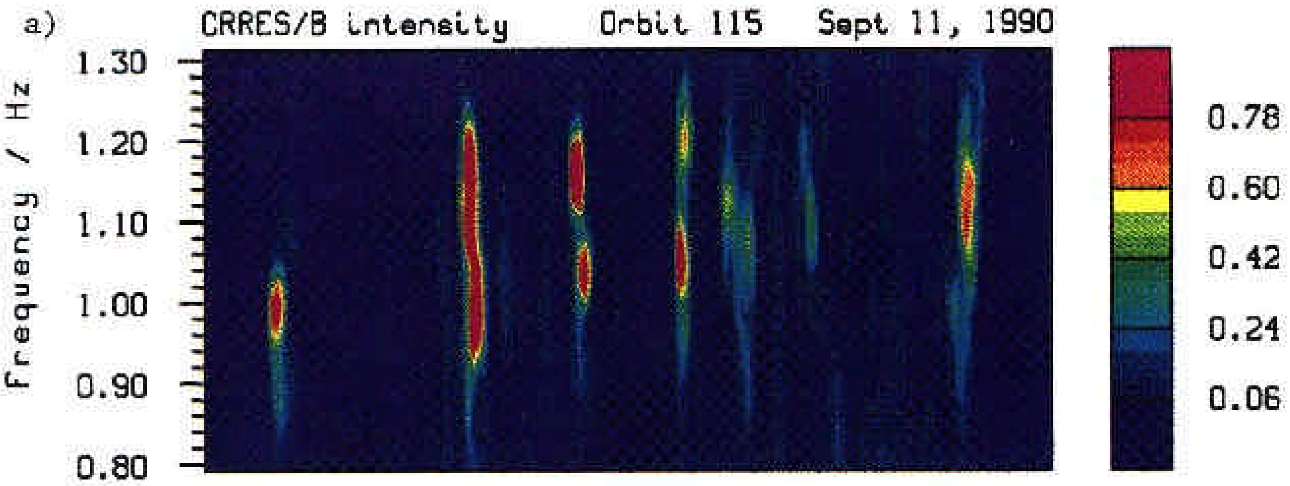

a)
CRRES/B intensity
Orbit 115
Sept 11, 1990
frequency / Hz
1.30
1.20
1.10
1.00
0.90
0.80
0.78
0.60
0.42
0.24
0.06

Plate 2. b)

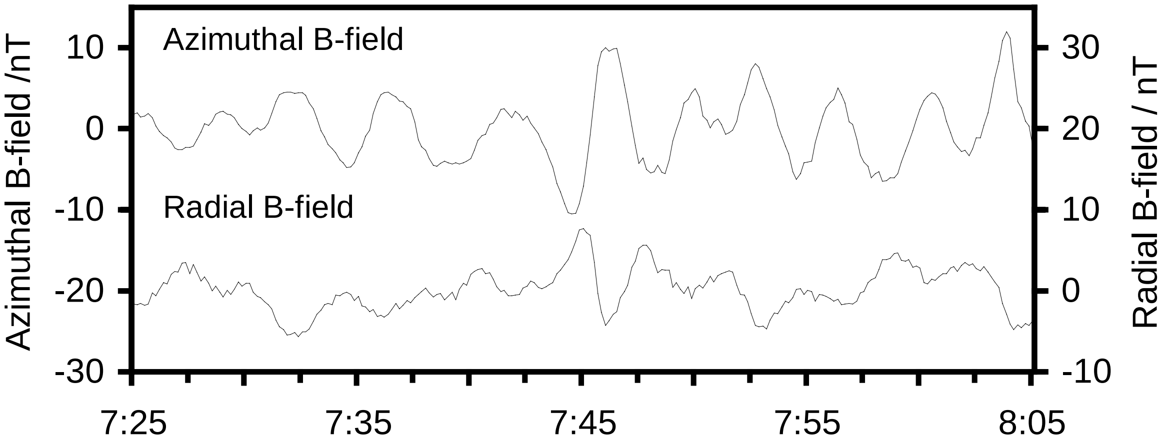


Plate. 2. Modulation of the Pc 1 waves with Pc 5 pulsations. a) Intensity of the Pc 1 bursts (color surface plot) during a short interval. b) Azimuthal and radial magnetic field component showing Pc 5 pulsation cycles at the same time.

Figure captions

Fig. 1. Solar wind and IMF data from September 11, 1990. a) Solar wind density. b) Solar wind velocity. c) IMF B_{total}.

Fig. 2. The effect of the solar wind pulse in the magnetosphere (panels a to f) and on the ground (panel g). a) Azimuthal and radial magnetic field components (Pc 5 waves). b) Parallel (≈ total) magnetic field strength. c) Proton (37 - 54 keV) and electron (21.5 - 31.5 keV) fluxes at 90° pitch angle in $cm^{-2}s^{-1}sr^{-1}keV^{-1}$. d) Electron number density. e) Location of the Pc 1 bursts during the event. f) L-value and MLT for the CRRES position. g) North-south magnetic field variations in Kilpisjärvi, Finland. The vertical dashed lines are plotted to facilitate comparison of the figures.

Plate 1. Ellipticity of the Pc 1 waves. Only points with sufficiently high intensity and polarization percentage are displayed. Positive (red) and negative (blue) values correspond to right-handed and left-handed polarization, respectively.

Plate. 2. Modulation of the Pc 1 waves with Pc 5 pulsations. a) Intensity of the Pc 1 bursts (color surface plot) during a short interval. b) Azimuthal and radial magnetic field component showing Pc 5 pulsation cycles at the same time.