Wideband Plasma Waves in the Polar Cap Boundary Layer: Polar Observations

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Abstract. Recent Polar plasma wave observations indicate that intense wideband waves are always present in the polar cap boundary layer (PCBL) region. The entire polar cap region is possibly bounded by these waves. The waves observed in the dayside boundary crossings arc stronger than on the nightside. The waves are very spiky and bursty, and have both electric (up to few 10^4 Hz) and magnetic field components (up to several kHz). A local current-driven instability or interaction with current-carryitlg particles may be responsible for these wideband waves.

Introduction

The Polar spacecraft has been placed in a region where very few satellites have visited. At this stage, Polar spends most of its time in the high altitude north polar cap **region.** Many energy coupling signatures between the solar wind, magnetosphere and ionosphere have been detected in this region. A significant finding in the plasma wave data is that enhanced wideband waves are always seen around the polar cap boundary layer region. These waves have a frequency range from 10 to 10^4 Hz and also have obvious magnetic field components.

Transient wave bursts were reported by Scarf et al. [1972] from OGO-5 at high latitude (-55°) observations. Electrostatic wideband waves were also reported by Gurnett and Frank [1977; 1978] and detected by Hawkeye in the high altitude auroral zone and cusp region. Low frequency electromagnetic waves (<100 Hz) were detected by the DE-1 satellite [Gurnett et al., 1984] in the lower altitude auroral zone. However, those waves are somewhat different from the waves wc report here. In this paper wc will give a preliminary description of these wideband waves.

Measurements

The Polar spacecraft has an orbit with a near 900 inclination angle. 1(s apogee is -9 R_e in the northern polar region, and perigee is - 1.8 R_e near the south pole. The mbit period is 17.85 hours. Because Polar's orbit plane is relatively fixed, in one year the Earth's motion about the sun will cause Polar to cover the full range of local times. The plasma wave instrument (f'WI) on board the spacecraft consists of five receivers [Gurnett c(al.,1995]: the sweep frequency receiver, the multichannel analyzer, the wideband receiver, the low-anci high-frequency waveform receivers. '1'here are three orthogonal dipole antennas (U, V, Z) for electric fields, and a loop antenna and search coil for magnetic measurements. Because the new instrument has very high sensitivity, we expect to detect wave signals which failed to be resolved before.

Preliminary Results

Figure I shows a typical 24-hour period of Polar plasma wave data, from May 26, 1996. "l'he data were recorded from the SFR-A Eu receiver. This frequency-time spectrogram gives the wave intensity as shown in the color bar. At the bottom of the figure, the universal time, radial distance, magnetic latitude, magnetic local time and magnetic field line I.-shell are given. On this day, Polar was first at its perigee around the south pole at - 0145UT, corresponding to a very high magnetic field and electron cyclotron frequency. Then it passed the dayside northern plasmasphere/magnetosphere at -0300 UT. Many whistler mode waves (hiss and chorus) were detected in this region. At ~0450UT the spacecraft entered the high-latitude polar cap region by crossing the cusp and polar cap boundary layer. At this time wc find a strong wideband plasma wave which extends its frequency up to several 10^4 Hz and lasts about 1 hour. This wave is what we report here. Inside the polar cap region, we also detect some wideband burst signals which extend to several 10^3 Hz, but arc relatively weak. These wideband waves and narrowband electron cyclotron emissions were reported in the study of Gurnett et al. [1978]. Many auroral kilometric radiation (AKR) events are noted above 10^5 } Iz. At the midpoint of the polar cap (orbit apogee), both the plasma frequency and electron cyclotron frequency r-cached their lowest values. At 1600" UT Polar was outbound from the polar cap by once again crossing the boundary layer, this time on the nightside. "1'bus, we see another wideband PCBL wave inter'vals, but the waves are weaker and the interval is shorter, compared with the inbound crossing. The spacecraft next entered the nightside plasmasphere and started another cycle.

We have marked both boundary layer waves, inbound and outbound of the polar cap in the figure.

The Polar spacecraft spends most of its time (- II hours) inside the polar cap region during each orbit. Two intense wave intervals bound the polar cap region, within which the magnetic field lines are expected to be open. These intense waves do not seem to be the ULF-ELF magnetic noise which only appears in the polar cusp region, as identified by Gurnett et al. [1978]. A preliminary survey shows that the waves appear at all boundary layer crossings and at all local times. in a statistical study of the low latitude magnetopause, Tsurutani et al. [1989] found that at least 85% of magnetopause boundary crossings are associated with the presence of ULF-VLF low latitude boundary layer (LLBL) waves. However, because the criteria was that the waves be more intense than magnetosheath broadband waves, the actual number could be higher. In this study we find that the PCBL waves arc present on the dayside 100%" of the time. They arc strongest at noon. In the dawn, dusk and nightside sectors, the waves arc weaker and more diffuse. On average, nightside waves arc weaker than those in the dayside by - 1-2 orders of magnitude.

Figure 2 shows an example of the PCBL waves taken from Figure 1 time interval in high time resolution. l'hc data arc from the multichannel analyzer for both electric (top) and magnetic (bottom) field measurements. The interval is selected from the period with strongest PCBL signals. Wc scc that the waves have both electric and magnetic field components. The electric component extends from ~10 to above 104117,. **The** magnetic field component also extends to above 10^3 Hz. The ULF-ELF magnetic noise reported by Gurnett et al. [1978] usually extended to several hundred hertz. The magnetic noise detected by DE1 at low altitude aurora] zone usually had a frequency below the O+ cyclotron frequency [Gurnett et al., 1984]. High time resolution wideband data from Polar also show that the signals arc very spiky and arc spin modulated. The waves sometimes show a maximum intensity when the antenna is perpendicular to the background field. This is indicative of the presence of near-paral]cl whistler modes. However since the electric signals extend above the electron cyclotron frequency, the waves should bc a mixture of electrostatic and electromagnetic waves.

Because the waves arc always detected during the polar cap boundary layer crossings, we can usc the inbound start time and outbound stop time of the waves to determine the locations of the polar cap boundary layer. Figure 3 shows the occurrence rate for all polar cap boundary layer crossings identified by the wideband wave.s. The data include. both northern and southern hemisphere polar cap boundary crossings, and are plotted in magnetic latitude vers us local time. The geomagnetic latitude is calculated through a Tsyganenko 89 model. Note that the latitude is the magnetic latitude of the in-situ spacecraft, instead of the invariant latitude (footprint magnetic latitude) of the magnetic field lines. The occurrence rates have been normalized by the maximum occurrence rate. We see that in the local time noon sector, the polar cap boundary layer is located at higher latitudes, while in the nightside they are at lower latitudes. This variation is generally consistent with the polar cap boundary shape. The magnetic field lines from the nightside low altitude polar cap boundary region (see, 55°-600) may map to a very low (200˙300˚) latitude in the tail where the spacecraft can still detect these waves. We also find that there is a wide latitude band for these crossings. It suggests that through diffusion, the waves have been mapped into relatively wide areas. "1'here arc some differences between the northern crossing location and the corresponding southern location, because the spacecraft trajectory near perigee (southern cap) is relatively close to earth.

Because these waves are detected at a high altitude (7-8 R_e), it is difficult to assume that they are generated at low altitudes and then propagate to the high altitude region. '1'hey should be generated locally. In this region, the magnetic field lines can be open or closed. The hot plasma from the. solar wind and the. cold plasma from the ionosphere may be mixed together here. Also, there are plentiful field-aligned currents and current gradients in this region. '1'bus, a current-driven instability or interaction with current-carrying particles may be responsible for the generation of the plasma waves. We will further study wave propagation and polarization properties and attempt to identify the wave modes. A correlation study with plasma and energetic particle data wili help us to determine the wave's generation mechanism/source of free energy.

References

Scarf, F.L., R.W. Fredricks, I.M. Green, and C.T. Russell, Plasma waves in the dayside polar cusp, J. Geophys. Res., 77, 2274, 1972.

Gurnett, D. A., and L.A. Frank, A region of intense plasma wave turbulence on auroral field lines, J. Geophys. Res., 82, 103 i , 1977.

Gurnett, 1). A., and L. A. Frank, Plasma waves in the polar cusp: Observations from Hawkeye i , J. Geophys. Res., 82, 1447, 1978.

Gurnett, D. A., R.L. Huff, J. D. Menietti, J. L. Burch, J.D. Winningham, and S.D. Shawhan, Correlated low-frequency electric and magnetic noise along the auroral field lines, J. Geophys. Res., 89, 8971, 1984.

Gurnett, D. A., and U.S. Inan, Plasma wave observations with the Dynamics Explorer 1 spacecraft, Rev. Geophys., 26, 285, 1988.

Gurnett, D. A., et al., The Polar plasma wave instrument, Space Sci. Rev., 71, 597, 1995.

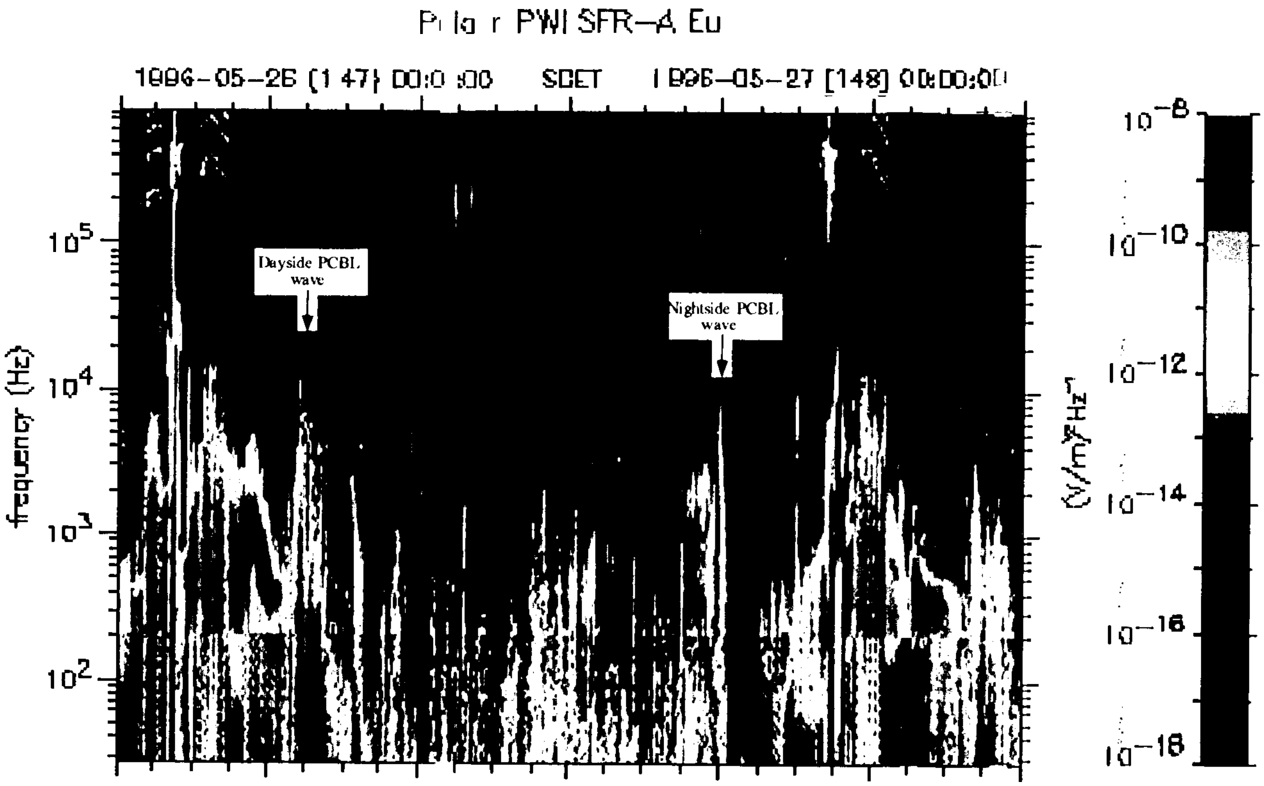
Tsurutani, B.T., A. L. Brinca, E.J. Smith, T. Okuda, R.R. Anderson, and T.E. Eastman, A survey of ELF-VLF plasma waves at the magnetopause, J. Geophys. Res., 94, 1270, 1989.

Figure Captions

Figure 1. A time-frequency spectrogram showing polar cap boundary layer waves on May 26, 1996. Polar spends most of its time inside the polar cap region. Two boundary layer wave intervals (as marked) bound this region. The high frequency wideband signals on the left and right sides of the figure arc low altitude waves detected during south pole perigee passes.

Figure 2. A ten-minute expansion of daysidc polar cap boundary layer waves measured by the multichannel analyzer. Top top pane] shows the electric field component, while the lower panel gives the magnetic field component of the waves. The waves arc very bursty and have a strong magnetic component.

Figure 3. A local time and magnetic latitude distribution of polar cap boundary layer crossings/waves. There is an asymmetry between the northern and southern crossings, because they are detected at different radial distances.



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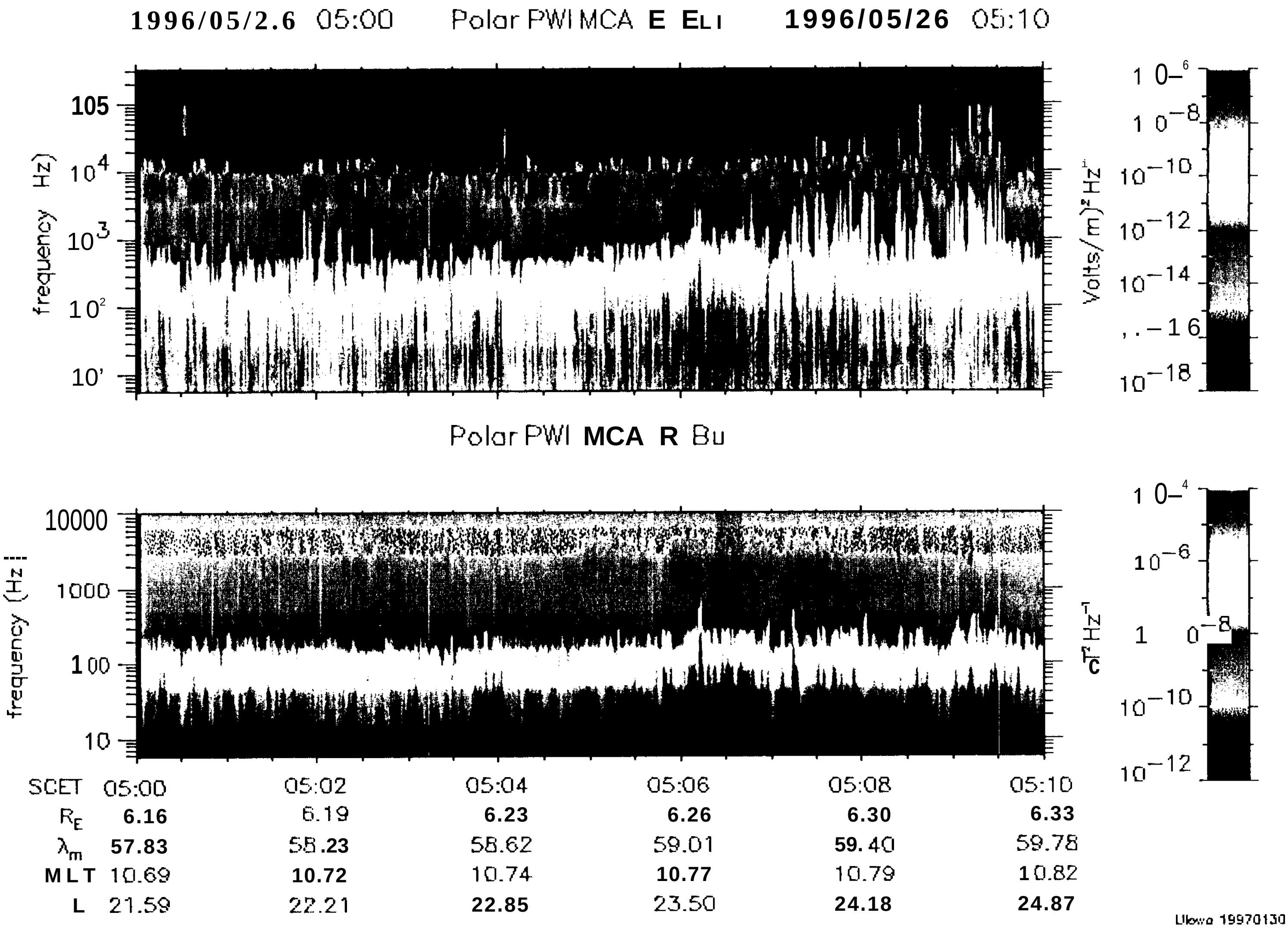
R_E	4.321	4.93a	6.371	8.751	6.298	2.489	7.480
λ_m	17.24	42.81	75.71	54.60	24.80	-2.881	72.77
MLT	21.84	10.11	15.7	20.22	21.4a	9.890	9.318
L	4.815	9.087	1249.	25.91	7.564	2.455	84.61

Figure 1


1996/05/2.6 05:00 Polar PWI MCA E ELI 1996/05/26 05:10
frequency Hz)
105
10^4
10^3
10^2
10'
Volts/m)^2 Hz^-1
1 0-6
1 0-8
10-10
10-12
10-14
, . -1 6
10-18
Polar PWI MCA R Bu
frequency (Hz)
10000
1000
100
10
1 0-4
10-6
1 0-8
10-10
10-12
SCET 05:00 05:02 05:04 05:06 05:08 05:10
RE 6.16 6.19 6.23 6.26 6.30 6.33
λm 57.83 58.23 58.62 59.01 59.40 59.78
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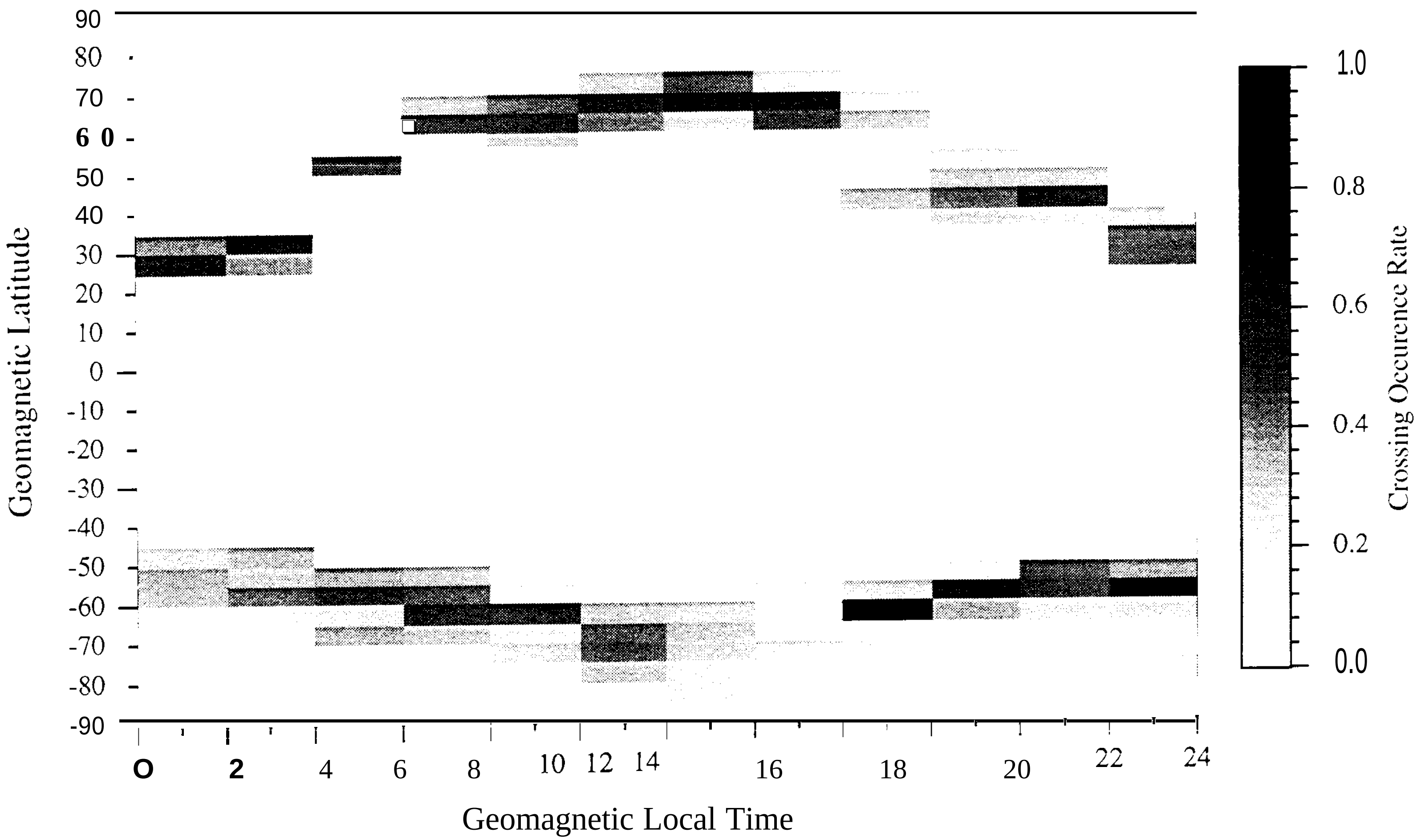
L 21.59 22.21 22.85 23.50 24.18 24.87
UIowa 19970130

Figure 2



90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
Geomagnetic Latitude
O 2 4 6 8 10 12 14 16 18 20 22 24
Geomagnetic Local Time
1.0
0.8
0.6
0.4
0.2
0.0
Crossing Occurence Rate

Figure 3