FINAL TECHNICAL REPORT

For Research Grant No. NAG 5-2249

Grant Title: Analysis of DE-1 PWI Electric Field Data

Principal Investigator: Daniel Weimer

Geophysical Institute
University of Alaska, Fairbanks
Fairbanks, Alaska 99775-7320

Report period: 5/1/93 - 5/1/94

(NASA-CR-195950) ANALYSIS OF DE-1 PWI ELECTRIC FIELD DATA Final Technical Report, 1 May 1993 - 1 May 1994 (Alaska Univ.) 12 p

N94-34280

Unclas

G3/32 0010377

Introduction

Nearly all of the effort on this grant was spent on a collaborative project with J. D. Menietti at the University of Iowa. Considerable time was spent in analyzing the electric field data for specific case events in which Dr. Menietti had found evidence for "electron conics". Special-purpose computer routines were developed to produce low-frequency power spectra of the electric fields that were measured with the DE 1 Plasma Wave Instrument. The results of this research have been submitted to *The Journal of Geophysical Research* with the title "DE-1 and Viking observations associated with electron conical distributions", by J. D. Menietti, D. R. Weimer, M. Andre, and L. Eliasson. This paper is currently in the review process. The portion of this research that was conducted by D. Weimer under grant NAG5-2249 is described in the following sections.

Measurement of Low Frequency Electric Field Oscillations

The measurement of low frequency electric field oscillations may be accomplished with the Plasma Wave Instrument (PWI) on DE 1. The characteristics of this instrument are described in detail by *Shawhan et al.* [1981]. Oscillations at a frequency around 1 Hz are below the range of the conventional plasma wave receivers, but they can be detected by using a special processing of the quasi-static electric field data. With this processing it is also possible to determine if the electric field oscillations are predominately parallel or perpendicular to the ambient magnetic field.

The quasi-static electric field in the DE 1 spin/orbit plane is measured with a long-wire "double probe", measured 200 m tip-to-tip. This antenna is perpendicular to the satellite spin axis, which in turn is approximately perpendicular to the geomagnetic field in the polar magnetosphere. The electric field data are digitally sampled at a frequency of 16 Hz, which establishes an upper frequency limit at the 8 Hz Nyquist rate. As the satellite spins with a 6 sec period, the quasi-static electric field data are modulated with a 1/6 Hz sine wave. In other words, electric field fluctuations at frequencies below the spin rate are transformed to a 1/6 Hz signal. The "static" electric fields, and the fluctuations up to 1/12 Hz, are normally determined by a measurement of the amplitude and phase of this 1/6 Hz signal. The detection of oscillations at frequencies above the spin rate and below 8 Hz requires a different processing technique.

The usual method to determine the frequency power spectra of the electric field would be to use either a discrete Fourier transform of the digital data, or a Maximum Entropy Method analysis. These techniques will not work in this case, due to the rotation of the double-probe antenna. To show why, we use a simple illustrative example. Shown in Figure 1a is a hypothetical 1 Hz electric field oscillation, perpendicular to the ambient magnetic field. The amplitude as a function of time is drawn with a dash-dot-dashed line. For reference, the sine of the angle between the rotating antenna and the magnetic field is shown with the dotted line. The magnetic field lines are assumed to lie in the spin plane. The electric field signal that would be measured with the rotating antenna is determined by multiplying the original signal by the sine function, resulting in the signal that is shown with the solid line. It is important to note that during every 3 sec half-spin this measured signal is exactly 180° out of phase with the signal during the other half-spin.

A Fourier transform of this measured signal would fail to detect the original 1 Hz oscillation due to the alternating phase shifts. Instead, two false peaks would be detected at beat frequencies of 1 +- 1/6 Hz. In order to fix this problem with the phase shift we multiply the measured signal by the sine of the rotation angle between the antenna and the ambient magnetic field. The result is shown as the solid line in Figure 1b. As this processed signal now has a coherent phase the peak at

1 Hz can be detected by normal spectral analysis techniques. At this point the original wave signal has now been multiplied by a sine-squared function, so that the peak amplitude is equal to the (constant) amplitude of the wave.

In order to correct for the phase reversals that are introduced by the antenna rotation, it was assumed that the wave oscillation was perpendicular to the magnetic field. If the oscillation were parallel to the magnetic field we would need to multiply by the cosine of the phase angle, rather than the sine of the angle, in order to achieve the proper phase correction. We can use this fact to determine whether or not an unknown, measured signal is due to oscillations that are predominately parallel or perpendicular to the magnetic field. To show how, we complete our example illustration with Figure 1c, which shows the result of multiplying the measured signal by the cosine function. The result has complicated phase shifts and the amplitude is not as large as that which was obtained with the sine multiplication. A spectral analysis of this signal would not produce a significant peak at 1 Hz.

The situation would be reversed if the hypothetical wave had a parallel rather than perpendicular orientation. In this case the spectral peak would show up in the signal that was processed through multiplication by the cosine function rather than the sine function.

To summarize, the measured electric field signal, which has had phase reversals introduced by the rotating antenna, is multiplied by the sine of the rotation angle between the antenna and the magnetic field. We call this the "perpendicular" signal. The measured time series is also multiplied with the cosine of the angle to produce a separate "parallel" signal. These two separate time series are then processed to determine the frequency power spectrum. A strong peak in the "perpendicular" signal that is not present in the "parallel" signal is indicative of an electric field oscillation that is orientated predominately perpendicular to the magnetic field, and vice versa.

Random noise will have nearly equal strength in the perpendicular and parallel signals, and will show up as a particularly strong peak at the spin frequency and higher harmonics, due to our phase multiplication. Best results are also obtained if the strong spin-modulated "DC" signal is first removed with a 1/6 Hz band-rejection digital filter before the phase multiplication step.

For the actual power spectrum analysis of this data we still find that a Fourier transform gives unsatisfactory results. We prefer to use a set of digital band-pass filters, as described in any textbook on digital signal processing. The data are simply passed through the multiple filters, and the outputs are squared and summed over any desired integration period. To normalize, the sums from each filter are divided by the number of data points times the filters' bandwidth, to obtain the conventional power spectrum units of $(mV/m)^2$ / Hz. For the results to be shown here, we have used an integration period of 12 sec with 44 separate filters that are equally spaced on a logarithmic scale between 1/6 and 8 Hz. For convenience, each filter has a band-pass frequency that is $2^{1/8}$ times the frequency of the previous filter, so that a frequency doubling is obtained at every eighth step. The optimal band-width for each filter in this case is about 0.09 times the pass frequency.

Results of the Electric Field Analysis

To apply this technique we selected four passes that contained some of the best examples of electron conics. For two of these passes only spin modulation of the signals was obtained, with no detectable presence of significant oscillations of the electric field at low frequencies. For the passes of days 81/289 and possibly 81/309, parallel oscillations of E are present.

In Figures 2 and 3 we display plots of the spectral analysis technique applied to the passes of days 81/289 and 81/309 respectively. Each figure shows relative amplitudes of the electric field intensity parallel to the magnetic field, $E_{\|}$, versus frequency (Hz) for six times during each pass. Each plot represents a period of 12 seconds of processed data during a time when excellent examples of electron conics were present in the particle data. The vertical dotted lines indicate the location of multiples of the spin frequency, which is 0.165 Hz. Peaks at or very near these times must be considered due to spin modulation and artifacts of the data processing. The arrows on each plot indicate significant peaks that do not seem to be associated with spin modulation harmonics. Some of the panels have peaks between 0.2 and 0.5 Hz that may represent significant oscillations of $E_{\|}$ at that time. For several of the panels the peaks observed in Figure 2 for 81/289 at a frequency of approximately 0.4 Hz are significant; the peaks observed in Figure 3 near $f \sim 0.3$ Hz are weaker and close to a satellite spin harmonic.

For 81/289 the electron conics were observed at an altitude of about 13,000 km and the potential beneath the satellite as indicated by the highest energy of the upward ion beams is between 10 kV and 20 kV. We estimate the magnitude of the electric field oscillations for this pass are in the range of 10 mV/m $< E <$ 20 mV/m (cf. Figure 4a), but $E_{\|}$ is in the range of $2.4 < E_{\|} < 6$ mV/m, with an average of about 3.9 mV/m based on the power spectral densities in Figure 2. For the pass of day 81/309 the parameters are similar; the altitude of the spacecraft at the time of the observations was about 10,000 km and the potential beneath the satellite was also in the range 10 kV $< E <$ 20 kV. The magnitude of the electric field oscillations is estimated to be in the range of 5 mV/m $< E <$ 10 mV/m (cf. Figure 4b) with $E_{\|} \approx 1.7$ mV/m (Figure 2). We conclude that on one and perhaps two of the four passes examined, low-frequency fluctuations of $E_{\|}$ in the frequency range 0.2 Hz $< f <$ 0.5 Hz occur coincident with electron conics.

References

Shawhan, S. D., D. A. Gurnett, D. A. Odem, R. A. Helliwell, and C. G. Park, The plasma wave and quasi-static electric field instrument (PWI) for Dynamics Explorer-A, *Space Sci. Instrum.*, 5, 535-550, 1981.

Figure Captions

Figure 1. (a) A hypothetical 1 Hz electric field oscillation, perpendicular to the ambient magnetic field. The amplitude as a function of time is drawn with a dash-dot-dashed line. For reference, the sine of the angle between the rotating antennna and the magnetic field is shown with the dotted line. (b) The same as in (a), but now the measured signal is multiplied by the sine of the antenna angle and displayed as the solid line. This represents the electric field perpendicular to the magnetic field. (c) The result of multiplying the measured signal by the cosine function to generate the signal parallel to the magnetic field.

Figure 2. Relative amplitude of the electric field intensity parallel to the magnetic field, $E_{||}$, versus frequency (Hz) for six consecutive times during the pass of 81/289. Each panel represents a period of 12 seconds of processed data during a time when electron conics were present in the particle data.

Figure 3. Same as Figure 2, but for the pass of day 81/209.

Figure 4. Measured total electric field amplitude in the spin-plane versus time for the pass of day 81/289 (Figure 4a) and for the pass of day 81309 (Figure 4b).

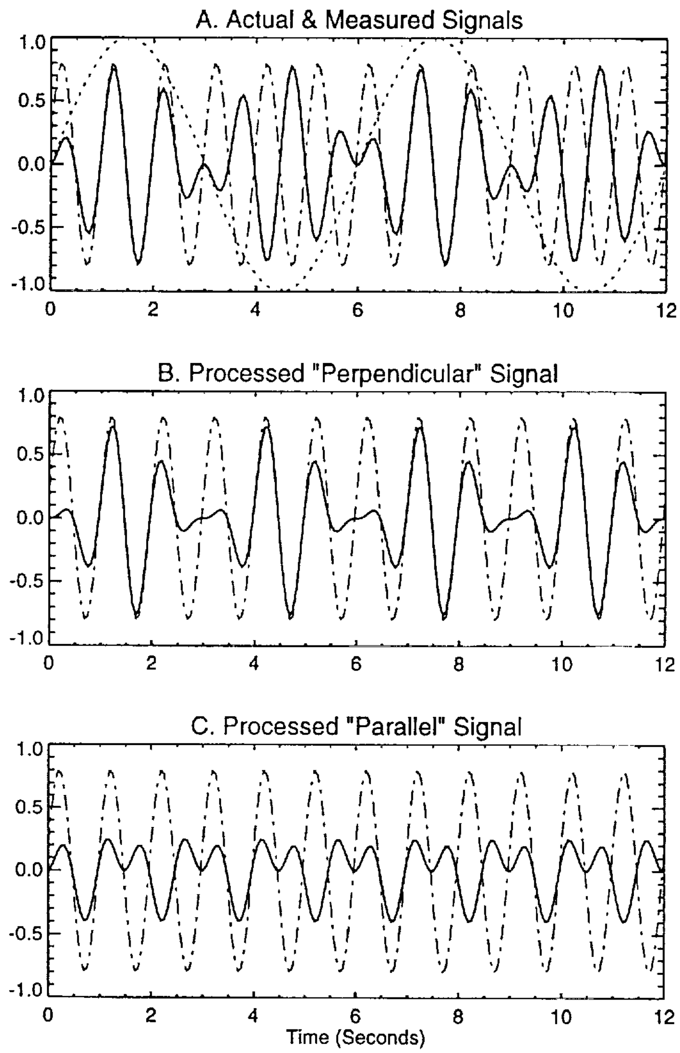
A. Actual & Measured Signals
B. Processed "Perpendicular" Signal
C. Processed "Parallel" Signal
1.0
0.5
0.0
-0.5
-1.0
0
2
4
6
8
10
12
Time (Seconds)

Figure 1

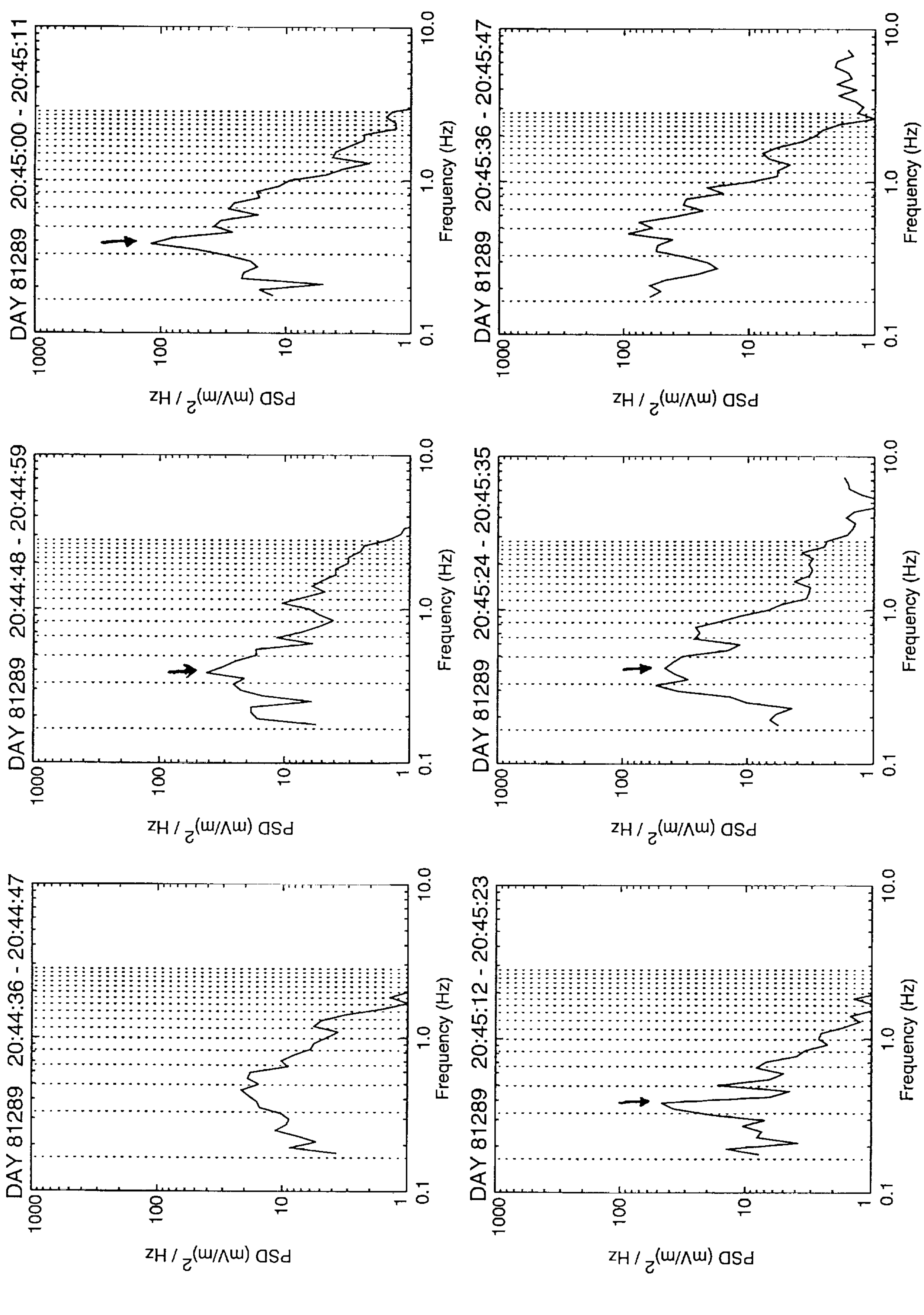
DAY 81289 20:44:36 - 20:44:47
DAY 81289 20:44:48 - 20:44:59
DAY 81289 20:45:00 - 20:45:11
DAY 81289 20:45:12 - 20:45:23
DAY 81289 20:45:24 - 20:45:35
DAY 81289 20:45:36 - 20:45:47
PSD (mV/m)2 / Hz
Frequency (Hz)
1000
100
10
1
0.1
1.0
10.0

Figure 2

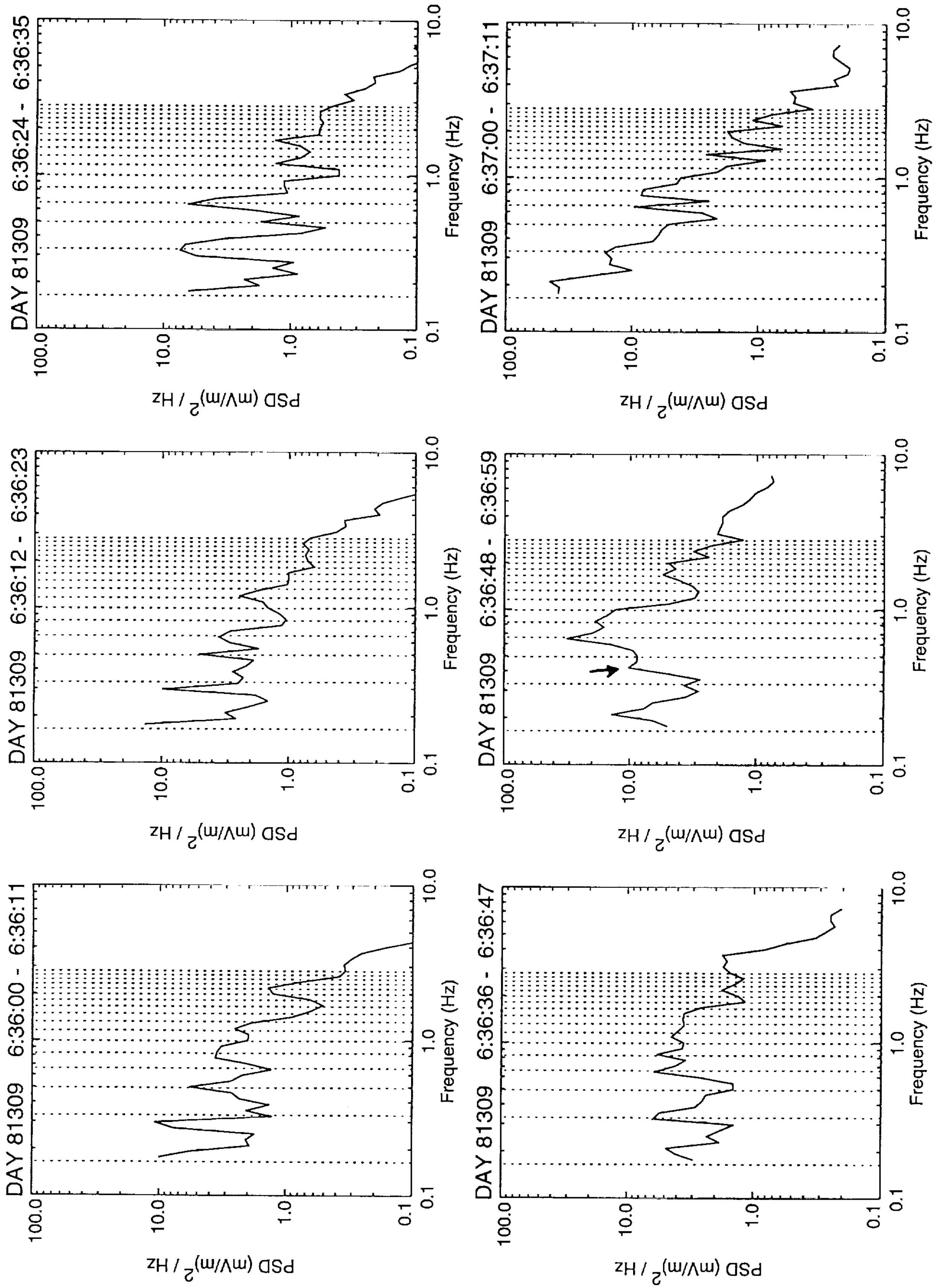
DAY 81309 6:36:00 - 6:36:11
DAY 81309 6:36:12 - 6:36:23
DAY 81309 6:36:24 - 6:36:35
DAY 81309 6:36:36 - 6:36:47
DAY 81309 6:36:48 - 6:36:59
DAY 81309 6:37:00 - 6:37:11
PSD (mV/m)^2 / Hz
Frequency (Hz)
100.0
10.0
1.0
0.1

Figure 3

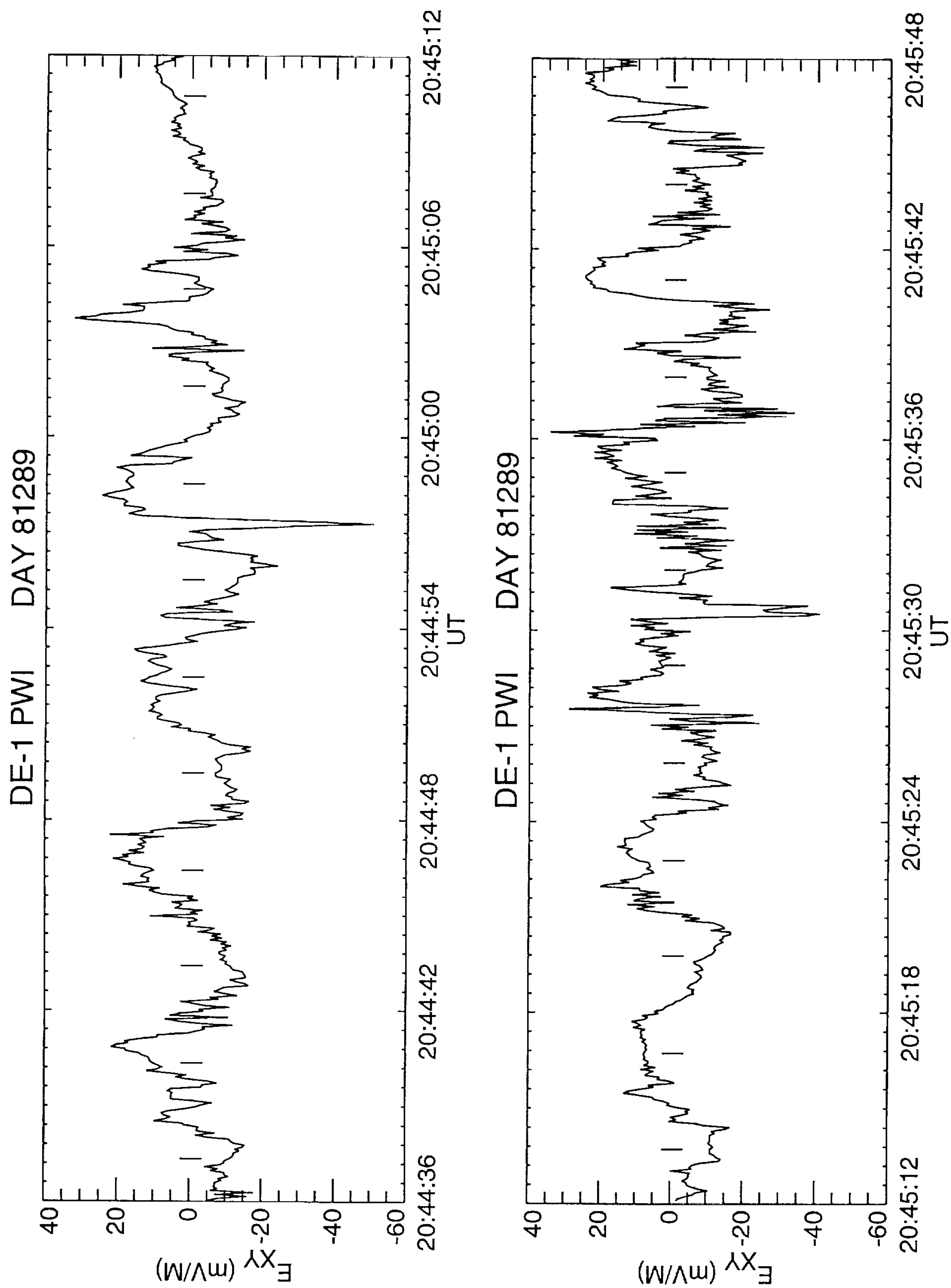
DE-1 PWI DAY 81289
E XY (mV/M)
40
20
0
-20
-40
-60
20:44:36
20:44:42
20:44:48
20:44:54
20:45:00
20:45:06
20:45:12
UT
DE-1 PWI DAY 81289
E XY (mV/M)
40
20
0
-20
-40
-60
20:45:12
20:45:18
20:45:24
20:45:30
20:45:36
20:45:42
20:45:48
UT

Figure 4a

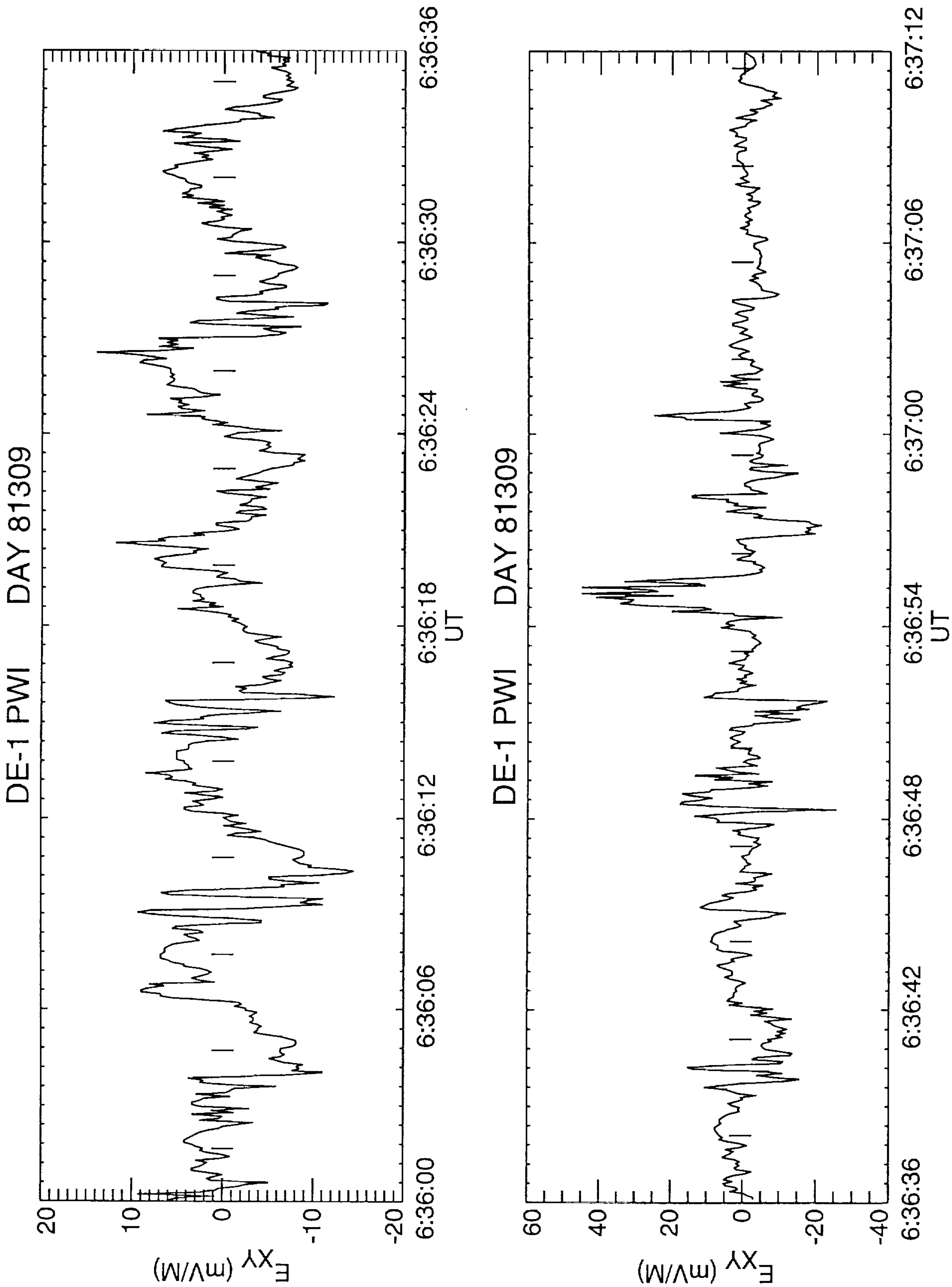
DE-1 PWI DAY 81309
E XY (mV/M)
20
10
0
-10
-20
6:36:00
6:36:06
6:36:12
6:36:18
6:36:24
6:36:30
6:36:36
UT
DE-1 PWI DAY 81309
E XY (mV/M)
60
40
20
0
-20
-40
6:36:36
6:36:42
6:36:48
6:36:54
6:37:00
6:37:06
6:37:12
UT

Figure 4b