

A Comparison of ULF Fluctuations in the Solar Wind, Magnetosheath, and Dayside Magnetosphere

2. Field and Plasma Conditions in the Magnetosheath

N. LIN,¹ M. J. ENGBRETSON,¹ R. L. MCPHERRON,² M. G. KIVELSON,² W. BAUMJOHANN,³
H. LUEHR,⁴ T. A. POTESRA,⁵ B. J. ANDERSON,⁵ AND L. J. ZANETTI⁵

Data from three spacecraft (AMPTE IRM, AMPTE CCE, and ISEE 1 or 2) are used to study the correlation among the field and plasma conditions in the subsolar magnetosheath region, ULF wave activity in the magnetosphere, and the cone angle of the IMF. A disturbance parameter, R , which is the magnitude of the normalized resultant of unit vectors (calculated from measurements of the magnetic field or the plasma bulk velocity in a time interval), is used to describe the disturbance of the magnetosheath region. A "quiet" state has R values close to unity. We have studied five time intervals and found that when the R values of the magnetosheath magnetic field were below 0.8, indicative of a disturbed magnetosheath near local noon, transverse harmonic oscillations of magnetic field lines in the Pc 3, 4 range were observed in the magnetosphere and small cone angles were observed in the solar wind. We have also investigated the variation of other magnetosheath parameters (such as the magnetic pressure, the thermal pressure, the dynamic pressure, and the perturbation energy, etc.) under various magnetosheath conditions by comparing them with the disturbance parameter. It is found that the thermal beta (the ratio of the thermal pressure to the magnetic pressure) and the perturbation energy increase greatly as R decreases (i.e., as the magnetosheath region becomes more disturbed). The total pressure, which is the sum of the magnetic, thermal, and dynamic pressure of the subsolar magnetosheath region, decreases as the region becomes more disturbed. The dynamic pressure and the dynamic beta (the ratio of the dynamic pressure to the magnetic pressure) measured in the magnetosheath are poorly correlated with R , indicating that the changes in magnitude of the plasma bulk velocity in the subsolar magnetosheath have little effect on the occurrence of Pc 3-4 waves in the outer magnetosphere. All magnetosheath parameters we examined became more variable during disturbed periods than during quiet ones. The implication of the above results to the transport of wave energy from the solar wind to the magnetosphere is discussed.

1. INTRODUCTION

Previous studies have found that Pc 3 and 4 pulsations in the magnetosphere are influenced by solar wind parameters, such as the solar wind velocity and the orientation and magnitude of the interplanetary magnetic field (IMF) (see, for example, review papers by *Greenstadt et al.* [1980] and *Odera* [1986]). Earlier works have also suggested that waves in the upstream solar wind may play an important role in generating those waves in the magnetosphere. A review of much of this earlier work is presented in the Introduction section of a companion paper [*Engbretson et al.*, this issue] (hereinafter referred to as paper 1).

How the upstream wave energy might be transmitted from the solar wind into the magnetosphere is not well understood. There are a few reports of observations of similarities between waves detected simultaneously on both sides of the magnetopause [*Wolfe and Kaufmann*, 1975; *Greenstadt et al.*, 1983]. *Wolfe and Kaufmann* [1975], analyzing magnetopause crossing data from a single satellite, Explorer 12, found evidence of wave power being transmitted from the magnetosheath into the magnetosphere in the subsolar region. They also stated, based on observations in the region beyond

about 35° from the Earth-Sun line, that the observations were consistent with a Kelvin-Helmholtz instability model of wave production in that region. *Greenstadt et al.* [1983], using magnetic data from ISEE 1 and 2 recorded simultaneously on both sides of the magnetopause, found similar evidence of wave energy transmission and suggested that the waves in the magnetosphere were of external origin. Their observations were consistent with the transfer of a small fraction of magnetosheath power into the magnetosphere, and made the surface wave model unlikely. However, none of these studies actually measured the energy flux transmissions, and all ignored the possibility that a surface wave could radiate very anisotropically into bounding plasmas of differing properties [*Pu and Kivelson*, 1983]. *Engbretson et al.* [1987] reported three examples of pulsations observed simultaneously at locations upstream of the Earth's bow shock and inside the magnetosphere. They suggested [see also *Engbretson et al.*, 1990] a high-latitude (cusp) entry mechanism for wave energy related to harmonically structured pulsations in addition to the existing wave entry models [*Verzariu*, 1973; *Greenstadt et al.*, 1980; *Kwok and Lee*, 1984].

In an attempt to better understand the means by which upstream wave energy is transmitted from the solar wind into the magnetosheath and finally into the magnetosphere, Engbretson et al., in paper 1, compared simultaneous data from several satellites: ISEE 1 or 2 in the upstream solar wind, AMPTE IRM in the subsolar magnetosheath, and AMPTE CCE in the dayside magnetosphere. They found, both on a statistical and on a case-by-case basis, that nearly radial IMF and dayside magnetospheric Pc 3-4 pulsation activity are associated with increased disturbance of the subsolar magnetosheath. We will in this paper present a more detailed study of field and plasma conditions in the subsolar magnetosheath during three of the five events discussed in paper 1.

In an earlier study, *Asbridge et al.* [1978] distinguished a "disturbed" magnetosheath from a "quiet" one by the presence of

¹Augsburg College, Minneapolis, Minnesota.

²Institute of Geophysics and Planetary Physics, University of California, Los Angeles.

³Max-Planck-Institut für Extraterrestrische Physik, Garching, Germany.

⁴Institut für Geophysik und Meteorologie der Technischen Universität Braunschweig, Braunschweig, Germany.

⁵Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland.

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energetic ions of 3 - 40 keV. They observed that fluctuations of plasma density, temperature and bulk velocity intensified when the energetic ions appeared, indicating the magnetosheath was in a "disturbed" state. To characterize conditions of the subsolar magnetosheath region in a more straightforward way, in this paper we will define an easily calculated quantitative parameter which can be used as an indicator of the extent of plasma disorder.

1.1. The Disturbance Parameter

There are many ways to describe the disturbance level of the magnetic field and plasma. The variations in the magnitude and direction of the field and the plasma bulk velocity can be used for this purpose. In order to quantify the disturbance level, we introduce a parameter which describes the distribution of the direction of vectors (e.g., magnetic field vectors or velocity vectors) measured in a time interval. The parameter is expressed as the normalized resultant of the vectors, R , i.e.,

$$R = (1/n) \left| \sum_{i=1}^n \mathbf{B}_i / |\mathbf{B}_i| \right| \quad (0 \leq R \leq 1)$$

where n is the number of measurements of the vector \mathbf{B} in a time interval. In the above expression, \mathbf{B} can be any vector although in the rest of this paper we use it as the symbol of the magnetic field.

If the observed vectors cluster tightly around a common direction, R will approach 1. (If all vectors point toward the same direction, R will equal 1.) When the vectors are scattered, R becomes small. For uniformly distributed vectors, $R = 0$. Hence R is a measure that indicates whether a mean direction exists and shows how closely vectors concentrate [Mardia, 1972]. We have used the parameter R calculated from measurements of the magnetic field and plasma bulk velocity from the AMPTE IRM spacecraft to classify the disturbance of the magnetosheath region under investigation. We take measurements in a time interval, and calculate the direction cosines X_i, Y_i, Z_i of each vector, then find the R value for the interval:

$$R = (1/n) \left[\left(\sum X_i^2 \right) + \left(\sum Y_i^2 \right) + \left(\sum Z_i^2 \right) \right]^{1/2}$$

For such calculated R values, there is a statistical Rayleigh test of the uniformity of a spherical distribution of the vectors [see Mardia, 1972, Appendix 3]. If the calculated R for n measurements is smaller than the critical value listed in the test table, then the n vectors are uniformly distributed (pointing to all directions randomly). For the events presented here the magnetic field and plasma bulk velocity in the magnetosheath never had a "uniform distribution" according to the Rayleigh uniformity test: all calculated R values were higher than the critical values for the 99% confidence level, and thus the hypothesis that the observations are uniformly distributed should be rejected. This means that the measured field and plasma bulk velocity in the magnetosheath are always clustered around a certain direction. However, R does change significantly with time, and the variation of R indicates the disturbance level of the subsolar magnetosheath. We shall examine how R correlates with wave activity in the magnetosphere.

There is one situation which may result in low values of R without a turbulent state: if the vector we measure (e.g., the magnetic field) varies regularly about zero (for example, sinusoidally in all three components) and if the interval we take for the calculation of R contains approximately an integral number of wave periods. Such a situation is improbable in the magnetosheath, particularly because of the broadband nature of magnetosheath fluctuations.

We notice that R is sensitive to the transverse variation of the vector but is unaffected by the compressional component of the vector. This means that R is a good indicator of direction changes

but not of the magnitude changes which may be better expressed by, for example, $|\mathbf{b}/\mathbf{B}_0|$, where \mathbf{B}_0 is the background magnetic field and $\mathbf{b} = \mathbf{B} - \mathbf{B}_0$. Paper 1 showed qualitatively that variations in the direction of the field are more important than the change in magnitude of the field as a predictor of magnetospheric wave activity; in this paper we will provide quantitative support for that finding.

1.2. Data Presentation

The instrumentation we used in this study has been described in paper 1. Magnetic field data from AMPTE CCE have a 6.2-s time resolution. The time resolution of AMPTE IRM magnetic data is as high as 1 s per sample, but AMPTE IRM plasma parameter data (density, bulk velocity, etc.) have a resolution of 4.4 s with every fifth point missing. In calculating the disturbance parameter, we used magnetic data that were averaged to the time resolution of the plasma data so that we could compare the disturbance parameter with plasma properties at the same resolution.

In each data interval we take a data segment consisting of 55 data points (about 297 s), calculate the R value, and then shift 12 points (about 1 min) and calculate the R value for the new segment. The value determined is assigned to the midtime of the interval. The shift is repeated until we obtain the disturbance parameter for the entire interval. It should be mentioned that, since each R value is calculated using multiple vector measurements, the value obtained will depend on the length of the data segment used and on the shift between successive segments. We have calculated R values in several different ways (~ 10 min of data with 110 data points per segment and a shift of ~ 2 min; ~ 5 min of data with 55 data points per segment and a shift of ~ 1 min; and ~ 2 min of data with 23 data points per segment and a shift of ~ 30 s). The resulting patterns of time variations and the R values are similar for the three different choices of segments and shifts, with smaller segments giving more detailed time variations. We took the five minute segments as a compromise between getting more detailed structure and having large enough numbers of vectors within a segment to obtain good statistics.

2. CASE STUDIES

We have studied in detail five events, each of which (except the second event, which has only one and a half hours of available data) consists of two hours of observations in the fall of 1984, chosen according to the availability of digital data from AMPTE IRM and AMPTE CCE. A summary of observations of these five events has been presented in Table 2 of paper 1. In each case AMPTE IRM was in the subsolar magnetosheath while AMPTE CCE was in the outer dayside magnetosphere, and for four of the five cases ISEE 1 or 2 data were available in the upstream solar wind region.

The positions of the three spacecraft during the five intervals are plotted in Figure 1. In each case, AMPTE IRM was traveling near local noon in the magnetosheath, and traversing a radial distance of $1.5 R_E$ to more than $2 R_E$. Thus the measurements of the field and plasma it made reflected the conditions in the subsolar magnetosheath region. In this section, we present a detailed analysis of three of the events as examples, while we use the results of all five events in a correlation study in section 3.

2.1. Event 1: 2200 - 2400 UT September 17, 1984 (day 261)

During this interval, the AMPTE IRM spacecraft was in the magnetosheath at about $12 R_E$ from the Earth and about half an hour before noon, while AMPTE CCE was near apogee and at about one hour after noon. The magnetic field measurements at AMPTE IRM

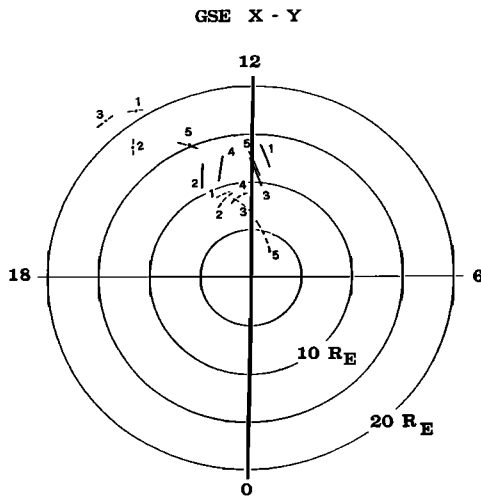


Fig. 1. Approximate locations of the AMPTE IRM (solid lines), AMPTE CCE (dashed lines), and ISEE 1 or 2 (dot-dashed lines) spacecraft as projected to the equatorial plane of the geocentric solar ecliptic (GSE) coordinate system during the five events. Each location is labeled by the number of the corresponding event: (1) September 17, 1984 (day 261), 2200 - 2400 UT; (2) September 28, 1984 (day 272), 1045 - 1215 UT; (3) September 8, 1984 (day 252), 1500 - 1700 UT; (4) October 9, 1984 (day 283), 1200 - 1400 UT; (5) September 10, 1984 (day 254), 1200 - 1400 UT.

are shown in the first three panels of Figure 2 at one second resolution. The subsolar magnetosheath was disturbed throughout the two-hour interval. Large and irregular magnetic fluctuations with peak-to-peak amplitude as large as ~ 50 nT are seen in all three components. We note that large fluctuations in the north-south component may be significant for the occurrence of turbulent reconnection at the magnetopause.

The disturbance parameter R for the magnetic field (designated as R_B) is shown as a function of time in the bottom panel of Figure 2. R_B was below 0.8 during most of the interval. The variation of R_B is consistent with field fluctuations evident in the first three panels: R_B decreases when the magnetic field becomes more disturbed. We note that the magnetic fluctuations in this interval were intermittent, with subintervals of enhanced disturbance alternating with brief, relatively quiet periods, such as those at about 2210, 2235, 2300, and 2320 UT. This can also be seen from the variation of R_B . R_B increased to higher values during the above brief periods indicating relatively more quiet conditions. The dynamic spectra of the AMPTE IRM magnetic data during this disturbed interval (shown in Plate 2 of paper 1) showed broadband enhancements of power in all three components from ~ 10 mHz up to the 500 mHz Nyquist limit of the data, and showed no distinct wave features.

We have also calculated the disturbance parameter for the plasma bulk velocity (designated as R_V) for all five events we studied. We found that the time variation of R_V (not shown) has a pattern very similar to R_B , but as the velocity is more organized in direction, R_V is usually higher than R_B . (In this event, most minima of R_V are above 0.5, much higher than most minima of R_B .) In all the five events, R_B had a greater range than R_V and was thus a better indicator of disturbance level. Since R_V and R_B varied similarly for all five events studied in this paper, we will use R_B to describe the disturbance of the magnetosheath regions we studied.

Study of the five selected events indicated that in each case magnetosheath magnetic fluctuations intensified when R_B was lower than 0.8, while much weaker fluctuations were seen when R_B was close to 1. In paper 1, we also showed that intensified magnetic fluctuations in the magnetosheath were accompanied by enhancements of variations in plasma density, bulk velocity, and plasma temperature. These results lead us to classify the magnetosheath

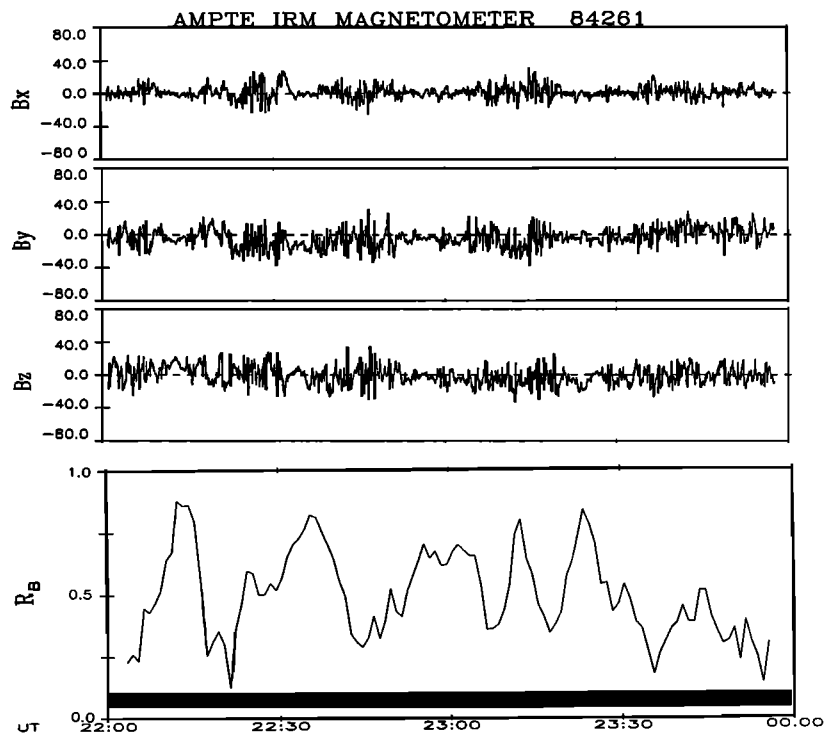


Fig. 2. Magnetosheath magnetic field data from the AMPTE IRM satellite and the disturbance parameter R_B for event 1, 2200 to 2400 UT September 17 (day 261), 1984. From top to bottom the panels are the X, Y, and Z magnetic field components in nanoteslas in a GSE coordinate system (1-s averages), and the disturbance parameter R_B , calculated from the magnetic data. Periods when transverse harmonic oscillations were observed at AMPTE CCE are marked with a solid bar in the last panel.

region we observed as “disturbed” when R_B is lower than 0.8, and “quiet” otherwise.

Wave activity observed at AMPTE CCE is best shown by the dynamic power spectra of the interval (see the color spectrogram in Plate 1 of paper 1). The AMPTE CCE spectra show that harmonic oscillations at 10 mHz, 22 mHz, and 35 mHz existed throughout the two hour interval from 2200 to 2400 UT, mainly in the east-west component. We have marked with a bar in the last panel of Figure 2 (and in similar figures for events 2 and 3) the intervals when we saw transverse harmonic oscillations in the Pc 3-4 frequency range at AMPTE CCE in order to compare them with the time variation of R_B .

In order to study field and plasma properties of the magnetosheath region under various conditions in more detail, we investigated additional parameters of the region which we thought were physically important. Figure 3 displays for this event the time variations of five of these parameters. Shown beginning at the top are (1) thermal beta (the ratio of the plasma thermal pressure to the magnetic pressure); (2) dynamic beta (the ratio of the dynamic pressure to the magnetic pressure, where the dynamic pressure is defined as $0.881N_p M_p V_n^2$ [Spreiter *et al.*, 1966], and N_p , M_p are the proton density and the proton mass, respectively, and V_n is the velocity component normal to the magnetopause, approximated by V_x since the AMPTE IRM measurements were made near the subsolar point of the magnetopause); (3) the variation of the dynamic pressure, δP_d , which is the deviation of the dynamic pressure from its running average over a 5-min period; (4) the total pressure (the sum of the thermal pressure, magnetic pressure and dynamic pressure); and (5) the ratio of the perturbation magnetic energy to the background magnetic energy. Since the magnetic field $\mathbf{B} = \mathbf{B}_0 + \mathbf{b}$, where \mathbf{B}_0 is the running average of magnetic field over a 5-min period and \mathbf{b} is the the deviation of the magnetic field from \mathbf{B}_0 , the perturbation

magnetic energy density is proportional to $2\mathbf{B}_0 \cdot \mathbf{b} + \mathbf{b} \cdot \mathbf{b}$. The quantity taken as a measure of the perturbation energy plotted in the bottom panel of Figure 3 is

$$p_e = |2\mathbf{B}_0 \cdot \mathbf{b} + \mathbf{b} \cdot \mathbf{b}| / |\mathbf{B}_0|^2.$$

The above five quantities were calculated using 4.4 s resolution AMPTE IRM data as described in section 1.2.

During this two hour period, R_B was lower than 0.8 for most of the time, indicating the subsolar magnetosheath was quite disturbed. Figure 3 shows that the thermal beta (top panel) was high (above 10 on average) and highly variable (with maxima often above 100). The dynamic beta (second panel) was also highly variable, with average near 1 except for some brief periods when R_B was at a relative maximum, such as those near 2210, 2235, and 2320 UT, when the dynamic beta decreased by several orders of magnitude. The variation of the dynamic pressure (third panel) shows enhancements near 2230, 2245, 2315, and 2335 UT, near minima of R_B . We noticed that the magnitude of the dynamic pressure (not shown) and its variation during this two hour disturbed period were relatively low compared to those during the disturbed intervals in the other four events. The total pressure (fourth panel) was about 1 nPa or lower throughout the interval, which was lower than the total pressure during quiet periods as we will see in the next two events. Values of p_e (the last panel) were about 1 to 1.5 on average and were highly variable during the two hour period.

Throughout the interval the IMF cone angle was below 40° ; for most of this time it was between 20° and 30° . As pointed out in paper 1, the subsolar magnetosheath region during this event was most likely to be connected with the site of a quasi-parallel shock and plasma from this region was probably able to convect into contact with the dayside magnetopause.

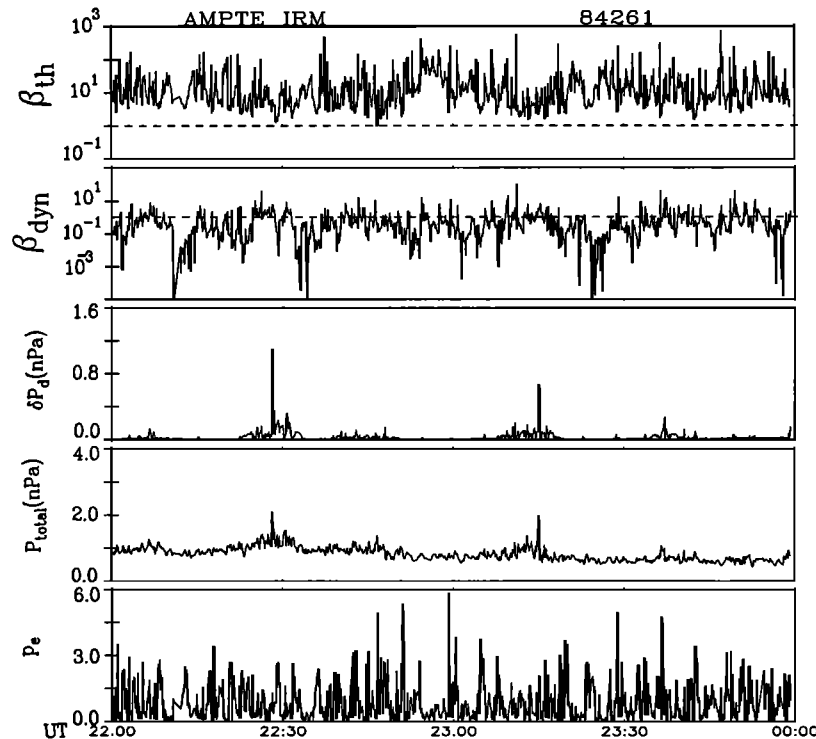


Fig. 3. Five magnetosheath parameters calculated using data from the AMPTE IRM satellite during event 1, 2200 to 2400 UT September 17 (day 261). From top to bottom the panels are: the thermal beta (in log scale), the dynamic beta (in log scale), the variation of the dynamic pressure, the total pressure, and the ratio of the perturbation magnetic energy to the background magnetic energy.

2.2. Event 2: 1045 - 1215 UT September 28, 1984 (day 272)

During this interval, AMPTE IRM was in the magnetosheath, $\sim 12 R_E$ from the Earth and near 1400 local time. The subsolar magnetosheath was in a disturbed condition before 1135 UT as indicated by the R_B parameter and the magnetic data for the period shown in Figure 4. During the disturbed period R_B reached a minimum of ~ 0.25 at 1115 UT and then gradually recovered to near 1 at ~ 1135 UT. The quiet state remained after that until almost the end of the interval when near 1205 UT R_B fell again to below 0.8. Although the Y and Z components of the magnetosheath magnetic field continued to have substantial fluctuations from ~ 1145 to 1205 UT, the value of R_B indicates that these were predominantly compressional field variations.

During the disturbed period (before 1135 UT), all five magnetosheath parameters shown in Figure 5 fluctuated more strongly than they did later in the interval. The thermal beta was about 10 on average before 1135 UT and decreased about an order of magnitude after that time. The dynamic beta decreased at 1135 UT by a roughly similar amount. δP_d was above 0.1 nPa on average before 1135 UT and decreased to much less than 0.1 nPa after that. The total pressure showed little change in average level throughout the interval (about 1.5 nPa) except for a brief interval near 1115 UT, when the pressure decreased sharply to about 0.5 nPa. The ratio of the perturbation energy to the background magnetic energy p_e was higher (about 1 on average) before 1135 UT than it was after that time (about 0.5 on average).

A change of the IMF cone angle from a more radial orientation to a more azimuthal one at about 1130 UT and an inverse change for a few minutes near 1210 UT (see Figure 6 of paper 1) coincided with the change of the subsolar magnetosheath from a more disturbed condition (low R_B) to a quieter one (higher R_B) and back again after 1210 UT, as expected. It is very likely that before 1130 UT the subsolar bow shock was in the quasi-parallel shock region while

after 1130 UT the subsolar bow shock geometry became quasi-perpendicular due to the change of the IMF direction. As the bar at the bottom of Figure 4 indicates, azimuthal Pc 3-4 activity occurred at AMPTE CCE until ~ 1145 UT.

2.3. Event 3: 1500 - 1700 UT September 8, 1984 (day 252)

During this interval both AMPTE CCE, in the magnetosphere, and AMPTE IRM, in the magnetosheath, were near local noon (Figure 1). AMPTE IRM magnetic field data and the value of the disturbance parameter R_B shown in Figure 6 indicate that during this event the subsolar magnetosheath was relatively quiet: magnetosheath field fluctuations were relatively weak throughout, and R_B values were near 1 except for a few brief periods. R_B dropped near 1505 UT to about 0.75, apparently due to a short-lived field reorientation (evident during this time in all three field components). Moderate fluctuations in R_B after about 1620 UT are also evidently related to large changes in B_z .

The five parameters plotted in Figure 7 show typical features of a quiet state during this interval: the thermal beta was lower than 1 and less variable than in the first event. The dynamic beta was about 0.01 or lower throughout the interval, 1 or 2 orders of magnitude lower than in the first event. The δP_d was very low, near zero level. The total pressure was above 2 nPa, higher than that of the first event. Values of p_e were about 0.2 on average, much lower than that in the first event and much less variable.

AMPTE CCE magnetometer data (not shown) indicate that before 1530 UT there were radially polarized sinusoidal oscillations at about 10 mHz and weak higher harmonics in the azimuthal component. During the remainder of the interval no other coherent wave features, and especially no harmonic structures such as those seen in the first two events, were observed. ISEE 2 IMF data for the interval indicated that except for a few brief (several minute) periods before 1540 UT, the cone angle was above 45° , with an average near 60° .

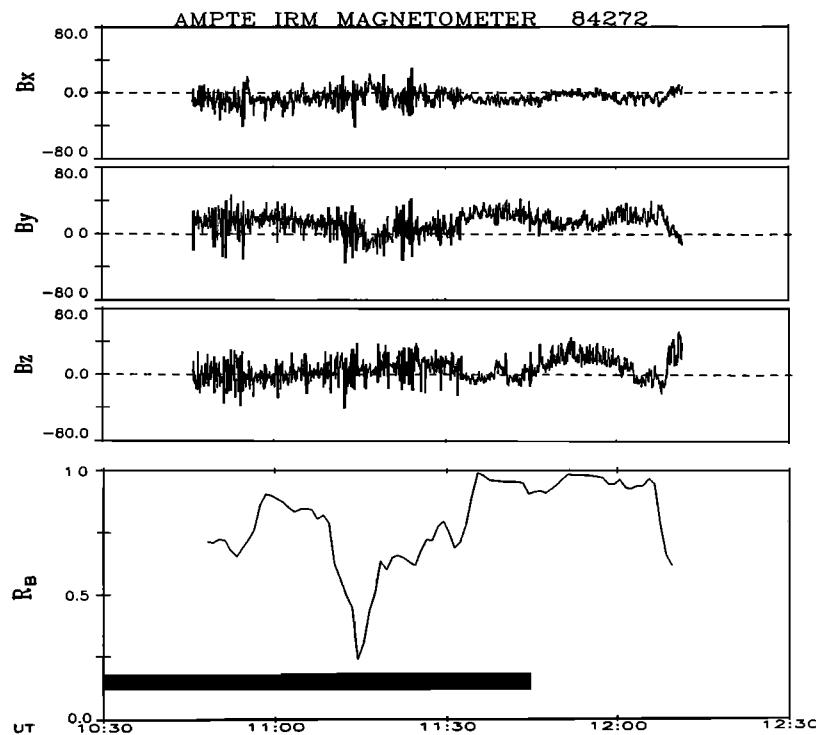


Fig. 4. One second averaged magnetosheath magnetic field data from the AMPTE IRM satellite during event 2, 1045 to 1215 UT September 28 (day 272), 1984, and the disturbance parameter R_B , as in Figure 2.

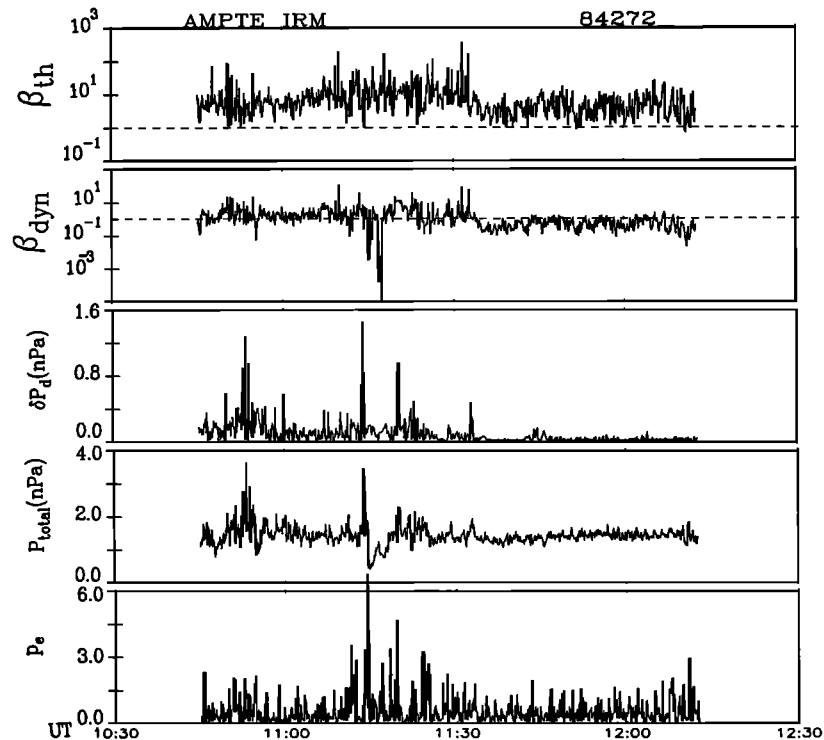


Fig. 5. The thermal beta (in log scale), the dynamic beta (in log scale), the variation of the dynamic pressure, the total pressure, and the ratio of the perturbation magnetic energy to the background magnetic energy, calculated using data from the AMPTE IRM satellite during event 2, 1045 to 1215 UT September 28, 1984, as in Figure 3.

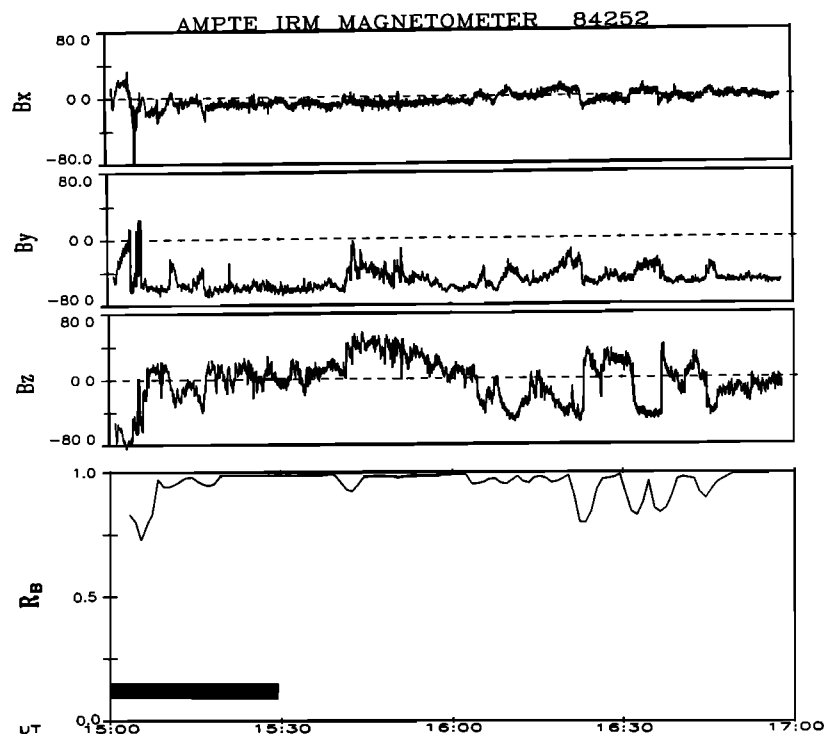


Fig. 6. One second averaged magnetosheath magnetic field data from the AMPTE IRM satellite during event 3, 1500 to 1700 UT September 8 (day 252), 1984, and the disturbance parameter R_B , as in Figure 2.

3. CORRELATION OF R_B WITH OTHER PARAMETERS

In order to determine what physical changes in the subsolar magnetosheath are relevant to wave activity in the magnetosphere,

we have studied the relation between the disturbance parameter R_B and other physical quantities of the magnetosheath including thermal beta and dynamic beta; the magnetic pressure, the thermal pressure, and the dynamic pressure; and the perturbation magnetic energy; as well as the variations of the above quantities. Each

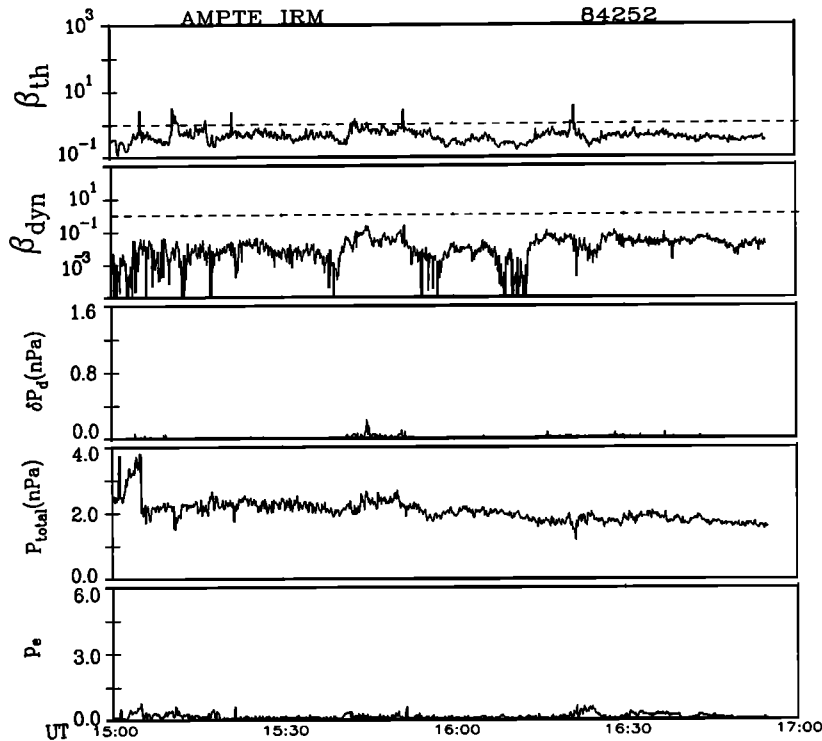


Fig. 7. The thermal beta (in log scale), the dynamic beta (in log scale), the variation of the dynamic pressure, the total pressure, and the ratio of the perturbation magnetic energy to the background magnetic energy, calculated using data from the AMPTE IRM satellite during event 3, 1500 to 1700 UT September 8, 1984, as in Figure 3.

quantity was calculated with the same time resolution as that of the R_B parameter, i.e., the quantity was averaged over 55 points (~297 s) and then shifted 55 points to calculate the next average. We combined each set of values thus obtained for all five events (a total of 109 independent measurements for each parameter) and plotted each versus the R_B parameter to study the linear correlations between them.

In Figure 8 we plot thermal beta values of the five events versus R_B . They are linearly correlated with a correlation coefficient of nearly -0.74 ; a more disturbed state corresponds to higher beta values. The variation of the thermal beta (the deviation of beta values from their running average over a five minutes period) also correlated well with R_B , with a correlation coefficient of -0.75 ; again, the variation increased when R_B decreased.

Figure 9 shows the relation between the dynamic beta and R_B . As we noted in section 2, the dynamic beta was higher during disturbed

periods than during quiet ones, but its linear correlation with R_B is poor (correlation coefficient = -0.28). The variation of the dynamic beta (the deviation of beta values from their running average over a five minute period) also indicates a poor correlation with R_B , with a correlation of -0.30 .

In Figure 10 we show the total magnetosheath pressure (the sum of the magnetic pressure, the plasma pressure, and the dynamic pressure) measured in the five events versus R_B . The thermal pressure was calculated using proton density and temperature data obtained by the AMPTE IRM plasma instrument. The correlation between the total pressure and R_B is obvious (correlation coefficient 0.71); the total pressure clearly decreased when the subsolar magnetosheath plasma became more disturbed. The pressure varied from 2.0 - 3.0 nPa under quiet conditions to 1.0 - 1.5 nPa under disturbed conditions. There is little correlation (correlation coefficient = 0.17) between the thermal pressure and the disturbance level,

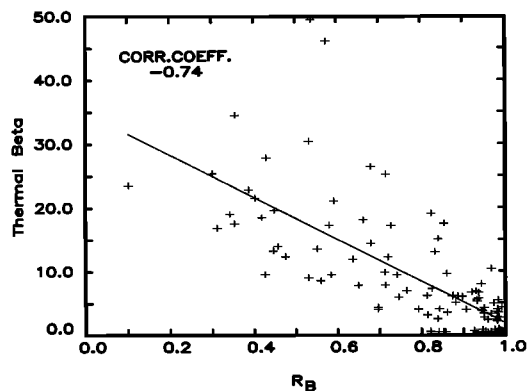


Fig. 8. Plot of thermal beta versus R_B for the five events.

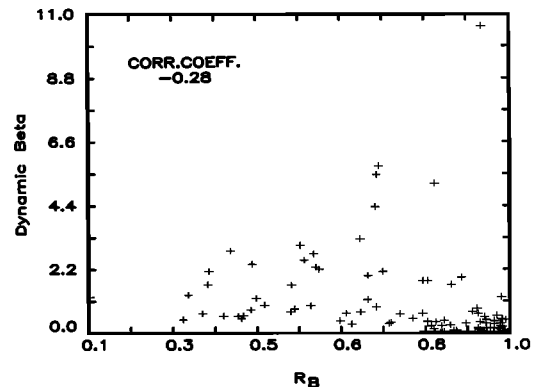


Fig. 9: Plot of dynamic beta versus R_B for the five events.

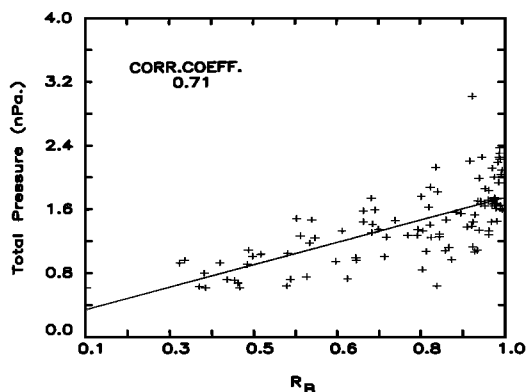


Fig. 10. Plot of the total pressure (the sum of the magnetic pressure, thermal pressure and dynamic pressure) versus R_B for the five events.

and the dynamic pressure is not correlated with R_B (correlation coefficient = -0.04). The magnetic pressure, however, decreased with R_B with a correlation of 0.57 . Thus the decrease of the total pressure as well as the increase of both thermal and dynamic beta when the subsolar magnetosheath becomes more disturbed is mainly a consequence of decreasing magnetic pressure.

The correlation between the variation of the dynamic pressure and R_B for the five events is poor (-0.17). But in some of the events (day 283, 272, and 254), it can be easily seen that the variation of the dynamic pressure increased as the magnetosheath became more disturbed. Event 1 (day 261) is the obvious exception: despite very low R_B values, the variation of the dynamic pressure remained quite low. It is perhaps no coincidence that on this day the subsolar magnetosheath velocity was unusually low and transverse Pc 3-4 resonances observed at AMPTE CCE were quite weak.

Figure 11 shows a plot of p_e , the ratio of the perturbation magnetic energy to the background magnetic energy, versus R_B . The very good correlation ($= -0.85$) is as expected, as the perturbation energy increases when the disturbance of the magnetosheath intensifies.

4. DISCUSSION

We have shown that the R_B parameter is a good indicator of the disturbance level of the observed magnetosheath region. Transverse Pc 3-4 wave activity tends to be observed in the magnetosphere when R_B in the subsolar magnetosheath is small (below ~ 0.8). The inverse correlation between p_e and R_B indicates that the perturbation

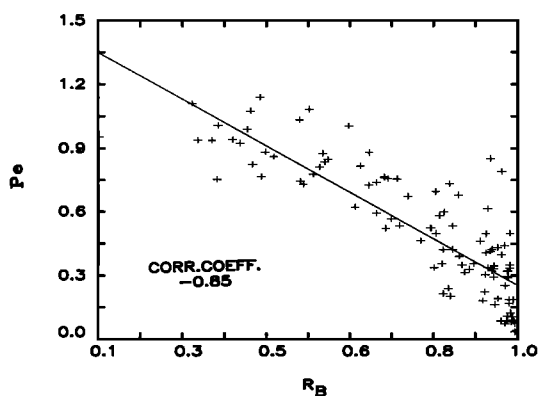


Figure 11: Plot of the ratio of the perturbation magnetic energy density to the background magnetic energy density, p_e , versus R_B for the five events.

energy of the magnetic field in the magnetosheath region increases when the region becomes more disturbed. This may contribute to the energy transferred into the magnetosphere which causes wave activity.

According to its definition, the resultant R_B of magnetic field vectors is actually a measure of variations of the field direction. It does not include changes in the field magnitude. A period of predominantly compressional oscillations will give R_B values close to 1 and be classified as “quiet”. Such an example can be found in the second event (day 272). Compressional oscillations can be seen during the second half of the event (after about 1145 UT) while R_B became high (near 1). These compressional waves are very similar to the narrow-band compressional fluctuations observed by *Moustaizis et al.* [1986] which were classified as “mirror mode” waves by the authors. Compressional fluctuations were observed in the subsolar magnetosheath during two of the five events we studied, and in neither case were azimuthally polarized Pc 3-4 waves observed during these times in the magnetosphere.

Our study shows that R_B decreases when the IMF becomes more radially directed. When the cone angle is about 20° to 40° , much of the subsolar magnetosheath is very likely to be disturbed, while larger cone angles (60° and above) correlate with a quiet subsolar magnetosheath. This relation is evidence that the quasi-parallel shock is a dominant source of dayside magnetosheath fluctuations in agreement with earlier studies by *Asbridge et al.* [1978], *Crooker et al.* [1981], and *Luhmann et al.* [1986].

Disturbances of the magnetosheath reduce the magnetic pressure, and thus both thermal beta and dynamic beta increase with intensification of the disturbance. During quiet periods magnetic pressure dominates, but during disturbed periods the thermal pressure dominates over magnetic and dynamic pressure, and the magnetic pressure is comparable to the dynamic pressure, as indicated by high thermal beta (above 10) and dynamic beta of about 1.

Internal instabilities can be excited in a plasma with high thermal beta (about 1), when pressure anisotropies exist. Depending on the ratio between the parallel and perpendicular temperature of the plasma particles, the mirror mode instability which produces compressional waves and the firehose instability which produces transverse Alfvén waves may occur [*Hasegawa*, 1975]. Observations of both of these wave modes in the magnetosheath have been reported in a few case studies before [*Moustaizis et al.*, 1986; *Hubert et al.*, 1989]. The pressure anisotropies which may satisfy the two modes of instabilities were observed in different regions of the magnetosheath [*Crooker et al.*, 1979]. We do not have enough data to check the criteria for the instabilities, but the high beta values observed during some disturbed (low R_B) periods in this study would favor the excitation of instabilities and would intensify fluctuations of magnetic field lines. As we have noted, the transverse fluctuations, which may include Alfvén mode-like oscillations, seem to be associated with the Pc 3 to 4 harmonic waves in the magnetosphere. In some disturbed periods, however, the thermal beta was very high (a few tens or even a few hundreds). In these cases, the magnetohydrodynamic effects may become trivial, and the increase in magnitude and variability of the dynamic beta might play a more important role in generating wave activity in the magnetosphere.

The role of variations in dynamic pressure in generating solitary and/or continuous pulsations in the magnetosphere has recently been given considerable attention both experimentally [e.g., *Song et al.*, 1988; *Sibeck*, 1990] and theoretically [*Southwood and Kivelson*, 1990]. During disturbed periods on days 272 (and 283 and 254, not shown), δP_d tended to be higher on average than it was during quiet periods including the third event (day 252). During the first event (day 261), however, when the magnetosheath was disturbed during

nearly all of the interval, δP_d was very low, except for a few brief periods near 2230 and 2315 UT (Figure 3). This has made the correlation between R_B and δP_d for the five events very poor. In fact, for these five events, the bulk velocity of magnetosheath plasma at AMPTE IRM locations did not correlate with R_B , and thus the quantities which depend on the bulk velocity, such as the dynamic pressure and the dynamic beta, also did not correlate with R_B .

Junginger and Baumjohann [1988] found a good correlation between the spectral power of Pc 5 waves observed at geosynchronous orbit and the kinetic energy flux. They considered the good correlation as strong evidence that Pc 5 waves are generated by the Kelvin-Helmholtz instability mechanism, since shear velocity is a critical parameter for the instability. *Greenstadt et al.* [1980] proposed that perturbations in the magnetosheath resulting from favorable IMF orientation were delivered to the magnetopause, transferred directly into the subsolar magnetosphere, and amplified into surface waves on the flank of the magnetosphere by the Kelvin-Helmholtz (K-H) instability at high solar wind speed. Our magnetosheath observations were made near the subsolar region, into which waves generated at the shock and plasma from the shock can be easily convected without propagating across streamlines when the cone angles are small [*Greenstadt*, 1972; *Russell et al.*, 1983]. The streamlines which go through the subsolar magnetosheath are those extending toward the dayside magnetopause. Thus disturbances in the subsolar magnetosheath such as those observed by AMPTE IRM are very likely to be delivered to the magnetopause and be transferred in some way into the magnetosphere. Since the observations were made in the subsolar region, we are not able to examine the role played by the K-H instability which is more effective in flank regions of the magnetopause in generating magnetospheric Pc 3-4 waves.

The limitation of this study to data from equatorial latitudes may be misconstrued as indicating that some as yet unknown mechanism must act to directly transform wideband magnetosheath power into harmonically structured, azimuthally polarized wave power in the equatorial magnetosphere. However, *Engebretson et al.* [1989, 1990] have demonstrated that Pc 3-4 power observed at very high latitudes (near the cusp/cleft and in the polar cap) was enhanced in a moderately wide frequency band, typically from ~ 15 to ~ 50 mHz with center frequency dependent on the magnitude of the IMF. They further found that harmonically structured Pc 3-4 pulsations observed on closed field lines in the outer dayside magnetosphere corresponded to resonances of individual field lines within this frequency band, presumably driven by these moderately wideband fluctuations. *Engebretson et al.* [1990] proposed on the basis of these and other observations that a possible mode of wave entry was along cusp/cleft/boundary layer field lines and then across field lines at high latitudes by means of an "ionospheric transistor" mechanism. Waves driven on closed field lines according to this model produce a resonant response quite similar to that of a violin string when bowed (i.e., provided with band-limited energy) near one end. If this model is applicable, then the evident difference in bandwidth and frequency structure between magnetosheath and dayside magnetospheric pulsations reduces to a wave entry "problem" of preferentially reducing the power level at the upper end of the range of frequencies of enhanced power in the magnetosheath as the wave energy travels to the cusp ionosphere and into the dayside magnetosphere.

Several recent studies have discussed the generation of ULF waves in the magnetosphere by reconnection processes on the magnetopause, most of which correlate the reconnection (such as flux transfer events (FTEs)) with the occurrence of longer period Pc 5 waves in the magnetosphere [e.g., *Lanzerotti and MacLennan*, 1988;

Lee et al., 1988; *Junginger and Baumjohann*, 1988; *Gillis et al.*, 1987]. *Gillis et al.* found a correlation between FTEs and transverse Pc 4 pulsations with periods between 60 and 120 s. In the events we studied, a large (often 30 nT or more), rapidly fluctuating Z component of the magnetosheath field occurred when R_B was low and harmonic waves were observed in the magnetosphere. Although the duration of the large southward magnetosheath fields thus produced was usually quite short (typically 1 min or less), we cannot rule out a role for reconnection in the process of wave transmission. *Paschmann et al.* [1986] observed that near the dayside magnetopause the occurrence of short duration (10 to 30 s) high-speed plasma flows was inversely correlated with thermal beta. Since the high speed flows may be a signature of tearing mode reconnection, they interpreted the observation as supportive of the theory that reconnection may occur preferentially for low beta values [e.g., *Quest and Coronii*, 1981]. The high beta that we observed during disturbed periods of the magnetosheath may not favor the traditional reconnection process mentioned above. A recent study of three dimensional time-dependent reconnection theory [*Song and Lysak*, 1989] shows that when the disturbance level of the magnetic field is high, three dimensional time dependent turbulent reconnection should be taken into account. The reconnection process is an evolutionary one in which time dependent, movable multiple tiny twisted flux tubes "condense" into new large scale twisted flux tubes. The dynamo effect of such a process produces localized field aligned current and transfers electromagnetic energy into the magnetosphere in a manner roughly consistent with the high latitude perturbation entry model of *Engebretson et al.* [1990], or any other method of transport across the boundary. The rate of the turbulent reconnection is proportional to $|b/B_0|$ [*Strauss*, 1988] which our observation showed increasing with intensification of disturbance, since $|b/B_0|$ increases with decrease of R_B (Table 1). The possibility of turbulent reconnection thus transferring energy into the magnetosphere and eventually causing field oscillations in the magnetosphere still needs further investigation both theoretically and observationally.

TABLE 1. Correlation of R With Field and Plasma Parameters of the Calculated Using Data During the Five Events Magnetosheath

Parameter (y)	Correlation Coefficient	Linear Fit of y Versus R_B $y = aR_B + b$
$\beta_{thermal}$	-0.74	$y = -33.2 R_B + 35.0$
$\delta\beta_{thermal}$	-0.75	$y = -30.2 R_B + 30.8$
$\beta_{dynamic}$	-0.28	
$\delta\beta_{dynamic}$	-0.30	
P_e	-0.85	$y = -1.2 R_B + 1.5$
Total pressure, nPa	0.71	$y = 1.6 R_B + 0.2$
Magnetic pressure, nPa	0.57	$y = 1.4 R_B + -0.6$
Thermal pressure, nPa	0.70	
Dynamic pressure, nPa	-0.04	
δP_d , nPa	-0.17	
$\frac{b}{B}$	-0.70	$y = -0.37 R_B + 0.50$

5. SUMMARY

In paper 1, we presented multispacecraft observations showing that IMF cone angles allowing a quasi-parallel shock to form at the subsolar bow shock were well correlated with intensified disturbances of the subsolar magnetosheath plasma and fields, and with simultaneous excitation of harmonic Pc 3-4 pulsations in the dayside outer magnetosphere. In the present paper, continuing the above study, we have placed our emphasis on field and plasma conditions

in the subsolar magnetosheath. We have defined a disturbance parameter, R_B , to indicate the extent of disorder of the magnetic field of the magnetosheath region; have calculated several plasma parameters for the subsolar magnetosheath that might be relevant to the transport of fluctuations into the magnetosphere; and have used linear correlation analysis to compare the R_B parameter with other field and plasma parameters of the region. The results of our correlations, including those presented in the last section, are listed in Table 1 as a summary. As noted above, our linear analysis of five events revealed only weak correlations with some quantities related to magnetosheath velocity, despite apparently strong connections in some individual events. Although we believe these events are representative of the variety of subsolar magnetosheath plasma signatures related to the transmission of Pc 3-4 pulsation energy into the dayside magnetosphere, further study with a larger amount of data and with more careful definitions of relevant parameters will certainly be needed to draw more convincing conclusions.

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- B. J. Anderson, T. A. Potemra, and L. J. Zanetti, The Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland 20723.
- W. Baumjohann, Max-Planck-Institut für Extraterrestrische Physik, Garching, Germany.
- M. J. Engebretson and N. Lin, Center for Atmospheric and Space Sciences and Department of Physics, Augsburg College, Minneapolis, Minnesota 55454.
- M. G. Kivelson and R. L. McPherron, Institute of Geophysics and Planetary Physics, University of California, Los Angeles, California 90024.
- H. Luehr, Institut für Geophysik und Meteorologie der Technischen Universität Braunschweig, Braunschweig, Germany.

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