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Interplanetary conditions in association with prolonged intervals of geomagnetic calm

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Abstract. From the daily index *Ap* of geomagnetic activity, sequences of consecutive occurrence of $Ap \leq 4$ for 4 days and $Ap \leq 7$ for eight days are identified in the period 1963–1998. A superposed epoch analysis is performed with the onset of these sequences as key days and 8 different solar wind and IMF parameters and their variability as inputs. A systematic pattern of change from days preceding the quiet intervals to the days following is clearly established. Solar wind velocity and its variability attain the lowest values much later than the onset of the quiet sequence, and the longer the interval, the later the minimum. IMF B, on the other hand, attains the lowest value at the onset of the quiet intervals, and continues to remain low till the end of the sequence. Thus a swing to low values of B in association with small northward B_z is an essential condition for onset of magnetically calm intervals. A possible threshold values with $V \sim 320$ km s^{-1}, $B \sim 4$ nT, $B_z > 0$ ($\sim$0.8 nT), lowest values of density preceding the onset of the quiet sequence and least variability in all the parameters can be assigned during such prolonged intervals of geomagnetic calm. In view of the smooth pattern of time variation seen for V and B, an attempt is made to predict geomagnetic quiet intervals from the solar wind parameters with moderate success.

1. Introduction

The Earth's magnetosphere continues in a state of dynamic equilibrium with the solar wind and the "frozen-in" interplanetary magnetic field (IMF). The interaction between solar wind and the magnetosphere is a complex process which leads to several manifestations in the geomagnetic field encompassing multiple time scales. From the first in situ observations of solar wind and IMF parameters, it was possible to establish their link with geomagnetic activity [*Snyder et al.,* 1963]. With the availability of additional data from spacecraft observations, several parameters of the solar wind and IMF were identified in controlling the magnitude of geomagnetic activity in the auroral zone, in the polar cap or at low latitudes and many statistically significant relationships between the solar wind bulk speed (V), the components of the IMF (B_x, B_y or B_z in either GSE or GSM coordinate systems), the variability in these parameters and suitable combinations of the parameters. [*Baker*, 1986; *Maezawa*, 1978; *Svalgaard*, 1977; *Sumaruk et al.*, 1990, etc.]. *Feldstein* [1992] summarized the relative merits of 29 different models of the equatorial ring current development and decay and stressed that apart from the solar wind electric field, as given by $V \cdot B_z$, the velocity, also contributes independently to the growth and decay of the ring current responsible for the DR field.

These investigations were possible mainly because of the painstaking compilation of several spacecraft observations after suitable normalization carried out by National Geophysical Data Center, United States [see, e.g., *King*, 1991] and made available through World Data Center A. The inverse process of identifying the IMF parameters from geomagnetic activity has also been fairly successful. For example, diurnal variation of the vertical component of the magnetic field in the polar cap regions could be used to indicate the polarity or the azimuthal component (B_x or B_y) of the IMF [*Mansurov*, 1969; *Svalgaard*, 1969], *Ap* index could be

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used to suggest the direction of B_z [*Mikerina and Ivanov*, 1974] or the polarity of IMF [*Schreiber*, 1978]. It is noteworthy that while many studies involving solar wind and geomagnetic activity have concentrated on the disturbed state of the magnetosphere there have been relatively few studies which examine, in depth, the interplanetary conditions preceding, during and after intervals of geomagnetic quiescence. While it has been well established that the magnitude and duration of the southward component of IMF ($B_z < 0$) is the primary agent for enhanced magnetospheric and geomagnetic disturbances [see, e.g., *Chen et al.* [1997, and references therein], the state of the magnetosphere during intervals when B_z is northward is not that well understood. In recent times, emphasis has grown in identification and quantification of the magnetosphere during intervals when IMF B_z is predominantly northward, as can be seen by the IAGA symposium held in Canada in 1987 as also the IUGG meeting in Birmingham, United Kingdom in July 1999. A special issue of the Journal of Atmospheric and Terrestrial Physics (Vol. 56 No. 2, 1994) was devoted to the geophysical phenomena in the polar cap during northward interplanetary magnetic field, wherein it has been emphasized that "interaction of Earth's magnetosphere with the solar wind and northward IMF continues to raise scientific interest and controversy."

According to *Burlaga and Ogilvie* [1970], "quiet" solar wind is not a special well defined state of the solar wind but rather an unusual and extreme condition. In one of the earliest attempts to study the interplanetary parameters during quiet solar wind conditions, *Neugebauer* [1976] identified 14 intervals when speed, proton density and temperature variations were small over periods comparable to the solar wind expansion time and found that the density varies as inverse square of the velocity and that the magnitude of B is independent of V and density. According to *Voight and Wolf* [1988], "it is not a trivial problem to determine the physical properties of the quiet magnetosphere. It would have a net potential energy lower than the average. It is an unresolved problem, however, to determine the lowest and highest possible energy states for the magnetosphere compatible with the thermodynamic condition of quasi-static convection." *Rich and Gussenhoven* [1987] suggest that a quiet state of the ionosphere/magnetosphere system occurs when IMF B_z is near zero or northward for an extended period and when solar wind velocity is low. The quiet conditions can be extremely long lasting during solar minimum epochs and occur on the trailing edge of a well defined stream. *Stern* [1988], however, sought the baseline magnetosphere during the intervals when IMF was close to zero since observations suggest that at such times the energy flow into the magnetosphere and out of it is the smallest. Minimum energy due to solar wind–magnetosphere coupling process linked with complete dissipation of the earlier inputs were stipulated as the likely conditions for the "ground state magnetosphere" by *Gussenhoven* [1988]. She also specified that a set of four conditions, listed below, are necessary to produce a magnetosphere whose energy state is near minimal: (1) Solar wind speed should be less than 400 km s^{-1}; (2) B_{zm} should be less than 2 nT (where B_{zm} stands for N/S component of the IMF B in geocentric solar magnetosphere coordinate (GSM) system; (3) Magnitude of IMF B should be less than 5 nT; (4) All these conditions should last for at least 2 to 4 hours.

Gussenhoven [1988] indicated that the baseline conditions tend to occur at least 15 percent of the time. Later, *Kern and Gussenhoven* [1990] determined the conditions of solar wind under the assumption that baseline magnetosphere can be identified from prolonged periods of low values of am index. Based on the analysis of 7 years of data between 1978 and 1984, they modified the baseline conditions listed above to (1) solar wind speed should be less than 390 km s^{-1}, (2) magnitude of IMF B should be less than 6.5 nT, (3) the angle 180–arctan $|B_y/B_z|$ should be less than 101° when B_z is negative or zero, and (4) these conditions should last for at least 5 hours. The analysis of *Kern and Gussenhoven* [1990] emphasized in identifying quiet intervals from am index with magnitude less than 4 nT preceded by exactly 6 hours of am again less than 4 nT and confined their attention to study the solar wind parameters one day on either side of the set of key days.

In the present investigation, we identify prolonged intervals of geomagnetic calm as a sequence of days with $Ap \leq 4$ for at least 4 days and examine the variability in 16 solar wind and IMF parameters over four days on either side of the quiet intervals. We also use a supplementary list of key days based on the sequence of 8 consecutive days with daily $Ap \leq 7$ to see whether the marginal increase in geomagnetic activity modifies the basic features of the solar wind parameters identified in the first analysis. As the duration of geomagnetic calm intervals defined here is much longer than that used by *Kern and Gussenhoven* [1990] and the parameter representing geomagnetic activity (daily Ap index) is different, we believe the results presented here will complement excellently their earlier analysis and will give an estimate of the conditions prevalent in the interplanetary medium preceding, during and after an interval of prolonged geomagnetic calm.

2. Data and Analysis

The criterion used for identification of prolonged intervals of geomagnetic calm is the occurrence of daily values of $Ap \leq 4$ (equivalent $Kp = 1_0$) for four consecutive days between 1963 and July 1998, the period for which spacecraft observations of IMF and solar wind are available from NGDC in the form of OMNI tape and anonymous FTP. To supplement the results and for examination of the state of the interplanetary medium during quiescent intervals of longer duration, we also considered occurrence of $Ap \leq 7$ (equivalent $Kp \leq 2_0$) consecutively for 7 days. Our choice of Ap was motivated by the fact that the other two common indices of geomagnetic activity, AE and Dst, pertain to rather specific regions whereas Ap can be considered a planetary index. In the years between 1963 and July 1998, there were 87 sequences with $Ap \leq 4$ and 66 sequences with $Ap \leq 7$, respectively. The daily averages of corresponding solar wind and IMF parameters (16 in all — IMF B, velocity V, density N, B_x, B_{ye}, B_{ym}, B_{ze}, B_{zm}, and their variability (denoted by sig. B, sig. V, etc.) were extracted from the OMNI tape of NGDC, United States (see *King* [1991] for details) and were used as input in a superposed epoch analysis covering a period four days prior to the onset of the sequence of geomagnetic calm and four days after the end of the sequence. The key day (0 day) corresponds to the beginning of the sequence of quiet intervals. Individual columns (12 in the case of $Ap \leq 4$ and 16 in the case of $Ap \leq 7$) for which the data were available were then averaged and the standard error of the mean computed. These are plotted in the Figures 1a and 1b. In further discussions, the intervals associated with $Ap \leq 4$ will be referred to as "very calm" and that with $Ap \leq 7$ as "calm" intervals. *Rangarajan and Iyemori* [1997] had identified several intervals of magnetospheric quiet times between 1932 and 1997. Thirteen such intervals with $Kp \leq 1+$ for at least 32 consecutive 3-hour intervals (four days) between 1963 and 1998 July were utilized as an independent data set for checking the reality of the results from the first two. The results of this superposed epoch analysis, restricted to only V and B (for brevity), are shown in Figure 2.

3. Results

Systematic change in almost all the 16 parameters, beginning from four days prior to the onset of the key day and ending four days after the termination of the sequence of calm intervals, could be clearly noticed in both Figures 1a and 1b. The magnitudes of the associated error bars (single standard error of the mean) appears proportional to the mean value of the parameter, except for B_z and B_y components. It should be pointed out that the plots such as sig. V, etc., denote the change in the average value of the standard deviation of the corresponding parameter where the standard deviation is derived from 24 hourly mean values of the day and provided in the OMNI tape directly. This is not to be confused with the error bars indicated. Solar wind velocity changes from a value of above 400 km s^{-1} prior to the commencement of the calm period, to a minimum value of about 320 km s^{-1} during the quiet times systematically and again rises almost to the pre-calm level. The associated error bars indicate that the event-to-event variation in the velocity values was minimum during the period of magnetic calm on days +2 and +3 and this feature is mimicked in the sig. V plot also. Lowest value of velocity is attained on the last day of the quiet sequence. This is again confirmed when we see the velocity change across sequence of quiet days with $Ap \leq 7$ for 7 consecutive days, when the minimum is seen only on day 7. However, as would be anticipated, this minimum velocity is marginally higher, around 350 km s^{-1}, confirming once again the kind of empirical relationship established between Ap and V by *Maer and Dessler* [1964] initially.

The density has a well defined maximum on the day following the last day of the sequence (day 4 or 8) but the pattern of change is smoother only when "very calm" intervals are considered. Pre-calm epoch, particularly one or two days prior to the commencement of the "very calm" sequence is also marked by low density of comparable magnitude. Persistent low density for 48 hours or so could be suggestive of a precursor for prolonged quiet intervals. When geomagnetic activity level is marginally increased, as for the sequence with $Ap \leq 7$ (Figure 1b) the minimum on day 0 is quite well defined.

The magnitude of IMF (B) has a low of nearly same magnitude($\sim$4 nT) throughout the "very calm" epoch and attains a stable post-quiet interval level with nearly 50% increase. The variability in B is also marked by a clear minimum at the commencement of the quiet sequence. When we consider the variations, across the key day, of the components of IMF B (B_x and B_y and B_z in two separate coordinate systems), we find that (1) the choice of the coordinate system GSE or GSM does not appear to be important in this analysis and (2) the associated error bars are large and suggest that not all the variations visible in the diagrams may be statistically significant. However, the following are worthy of note:

1. Magnitude of IMF B_z during both the "very calm" and "calm" intervals is small (<1 nT) but distinctly positive. This feature may be considered another example favoring the concept of the magnetosphere behaving as a half-wave rectifier [*Burton et al.,* 1975; *Crooker*, 1980].

2. More than the magnitude, the variabilities in all the parameters B_x, B_y, and B_z (i.e., sig. B_x, sig. B_{ye}/sig. B_{ym}, and sig. B_{ze}/sig. B_{zm}) show significant differences between pre/post passage intervals compared to that during the quiescent part (0 to +3 day in Figure 1a and 0 to +7 day in Figure 1b).

3. When the magnetic activity level is higher and the duration considered is longer, the variability in the components of IMF exhibits a sharp minimum on day +1 followed by a monotonic increase in the quiet interval itself, a feature absent when "very calm" intervals are considered (see Figure 1a).

4. Though the magnitude of B_x for "very calm" intervals is not more than 1 nT, a systematic chance from positive to negative values from day 0 to day 7 could be seen, suggestive of a change in the polarity of the IMF near day +2 or +3. This feature, however, is not seen in the other case, from day 0 to +4. B_x is practically close to zero, and a swing from positive to negative values of B_x is confined to the post-quiet interval, from day +7 to +10 only.

Figure 2 shows the change in the magnitude of IMF and B from 4 days prior to the onset of "very calm" intervals up to four days following the end of quietness, based on another choice of days. Thirteen key days utilized here correspond to the uninterrupted sequence of at least 32 3-hour intervals with $Kp \leq 1+$. These are not necessarily the same sequences used in the earlier analysis with Ap index and thus provide a check on the reality of the variation in V and B, in association with magnetospheric quiescence. The patterns observed earlier are reproduced quite faithfully with the minimum in V occurring on the last day of the sequence with a change in speed from about 450 km s^{-1} to around 300 km s^{-1} at the minimum. The change in B appears more dramatic, with a sharp fall from day -3 to day +1. However, if the associated error is taken into consideration, the change is once again comparable to that observed earlier. The magnitudes of the error bars in Figure 2, derived from a much smaller

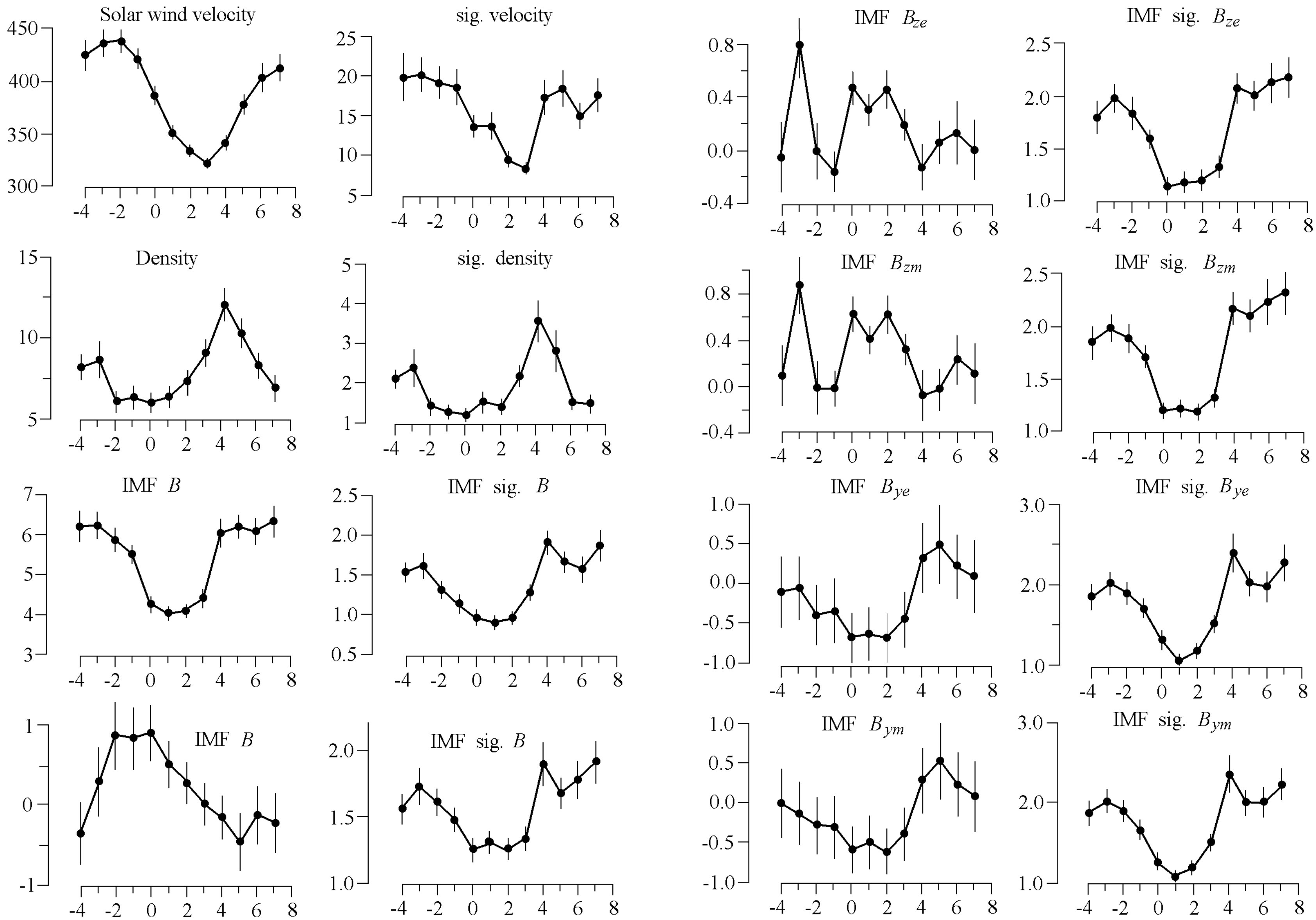

Figure 1. (a). Time variations of solar wind and IMF parameters, beginning from 4 days prior to the key day (day 0), which corresponds to the commencement of a sequence of four consecutive quiet days with $Ap \leq 4$, and up to 4 days after the termination of the sequence of quiet intervals. The label sig. before the variable indicates the hourly variability in the parameter, as reported in the OMNI tape for the period 1963 to July 1998. The units are km s^{-1} for solar wind velocity and its variability, n cm^3 for density, and nT for all other parameters (B, its components, and their variability).

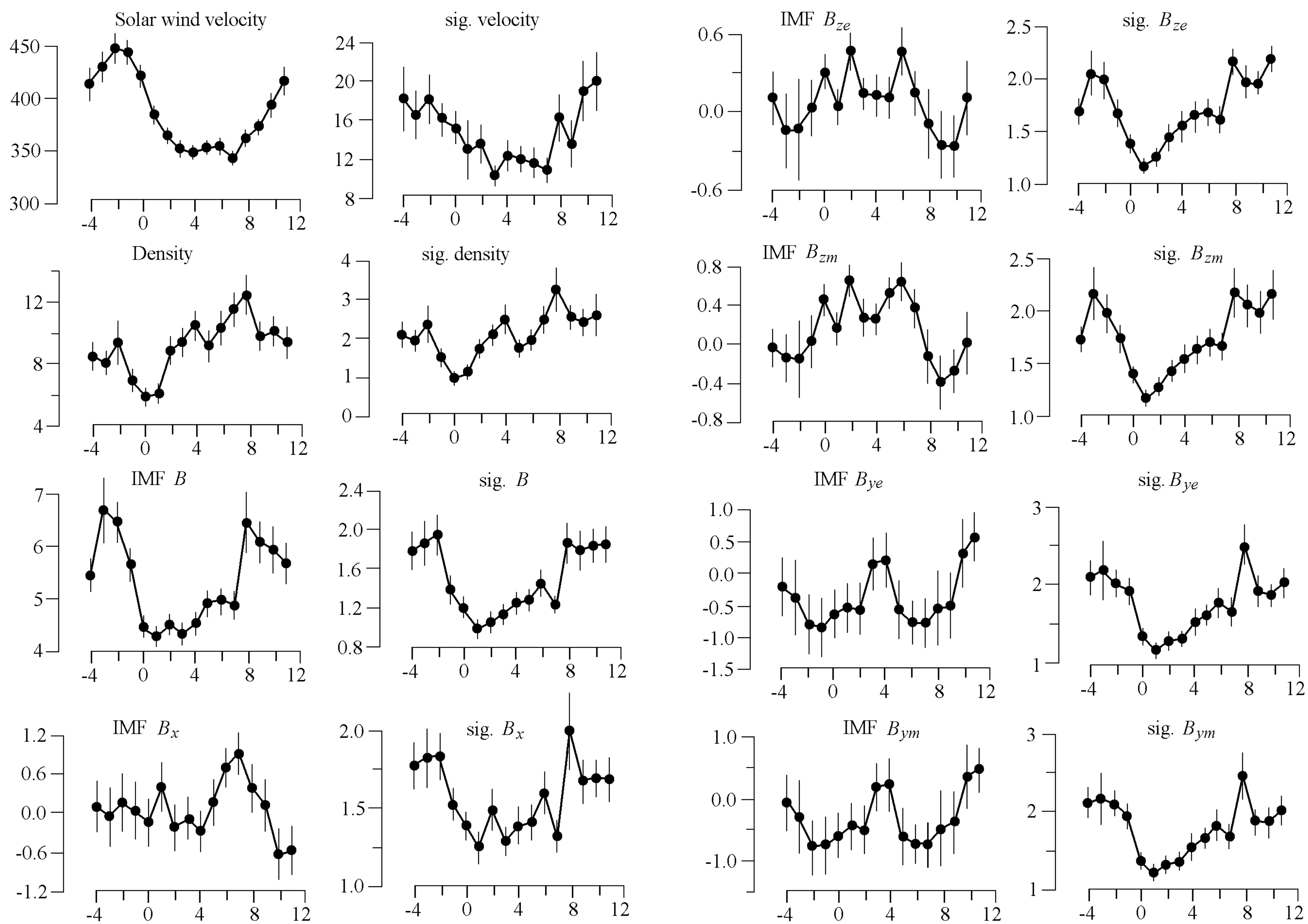

Figure 1. (b). Same as Figure 1a except the key day is the beginning of a sequence of eight consecutive quiet days with $Ap \leq 7$.

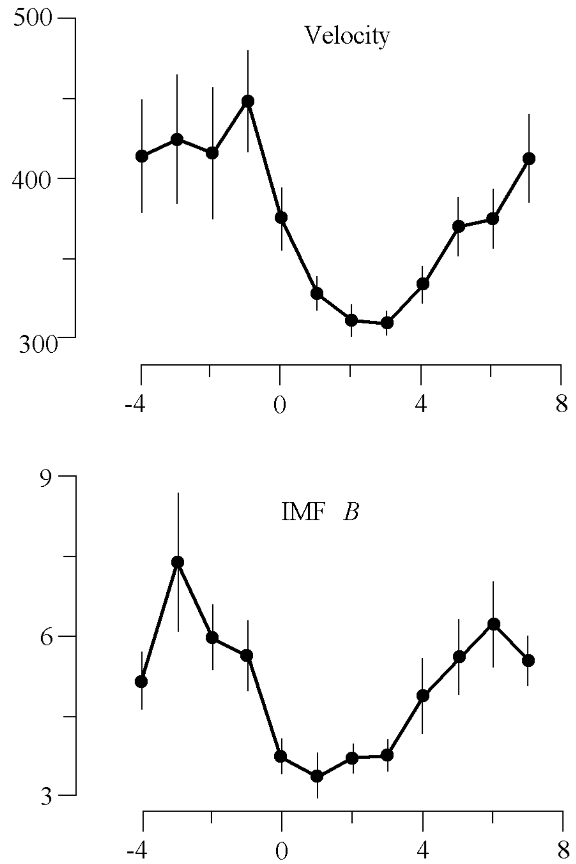

Figure 2. Same as Figure 1a, except the key day is the beginning of a sequence of at least 32 intervals with $Kp \leq 1+$. The superposed epoch analysis is restricted to only solar wind velocity and IMF magnitude, B.

sample, undergo significant change between the days preceding the key days and on day +3 when the minimum velocity is reached confirming the earlier result that the variability in the solar wind velocity and magnitude of IMF B is very small indeed during the intervals when geomagnetic activity is close to its lowest level.

As mentioned earlier, the standard error associated with the mean tends to be very small for V and B on the last day of the sequence of "very calm" intervals. Even for the other days preceding or following, it is not widely variable. This suggests that the average feature reported in Figure 1a for B and V is, perhaps, retained on most of the 87 days considered for analysis. One way of verifying this would be the use of Principal Component Analysis [*Kendall*, 1948]. *Golovkov et al.* [1978] have clearly demonstrated how this method, which they call the method of natural orthogonal components (MNOC), help separate a matrix of variables into distinct components and show that if most of the rows in the matrix have nearly the same pattern of change across various columns, then the first component will be the most dominant one and a suitably calculated coefficient based on the product of the row values and the first eigenvector of the covariance matrix of the given matrix helps in assessing the contribution of the first component to each of the rows in the matrix. To ascertain that the reported average variation in the two parameters B and V is indeed a basic feature of the interaction between solar wind and magnetosphere when B_z is marginally northward, we utilize the technique of MNOC. We ensured that any missing values in the matrices for B and V (consisting of 12 columns and 59 or 43 rows for B or V) were interpolated, and if the string of missing values was long, then the row was left out of reckoning.

Figure 3 gives the first principal component (PC 1) in V and B between days -4 and $+7$. Almost the entire variance of the system could be accounted for by this component alone (>90%) with very small contributions from second and third components. Also given in Figure 3 are the coefficients for each row, as a percentage. If it is 100%, the variation in V or B around that key day will be exactly the same as the first principal component and percentage values greater or smaller than this will correspondingly alter the magnitude of the PC 1. This gives an idea of the stability or otherwise of the average feature and the variability from one day to another. We could immediately notice that the principal components show exactly the same pattern of change of V and B as seen in Figure 1a. In addition, it is also seen that the variability of the coefficient is more pronounced for V than for B. For many days, the coefficients of PC 1 for B are close to 100 with very few extreme values. V, on the other hand, is marked by more variations. This suggests that the change in the magnitude of B is much better ordered with respect to the sequence of "very calm" intervals compared to the speed of the solar wind. In a way, this is also in conformity with the finding of *Neugebauer* [1976] that the magnitude of B does not depend on V.

In view of the fact that the change in V or B in relation to "very calm" intervals of geomagnetic activity is quite smooth and significant, it is tempting to see whether the conditions in V and B preceding the quiet period can be used as precursors of quiet conditions. For this purpose, we impose the following two restrictions: (1) The velocity for four consecutive days should be between greater than 400 km s^{-1} and should decrease monotonically over next 3 days. (2) The magnitude of IMF B should be greater than 5 nT for at least 3 consecutive days and there should be a drop in magnitude more than 0.7 nT followed by nearly same values for next 3 days.

The mean values of Ap for 4 consecutive days, beginning a day after the commencement of decrease in V and that following the change in B are shown in Figure 4. Ideally, we should expect the original list of quiet sequence to be reproduced but that does not appear to be valid. However, the predicted mean values of Ap for sequence of four days, based on change in velocity pattern, does give a very good list of days with mean value of about 5. There are, however, few exceptionally high values. On the other hand, the approach to prediction using B leads to a list of days with average $Ap \geq 5$ but no widely departing values. Thus the combination of B and V satisfying the conditions imposed above may lead to prediction of geomagnetic quiet intervals fairly reasonably, though the method fails to indicate days with $Ap \leq 4$.

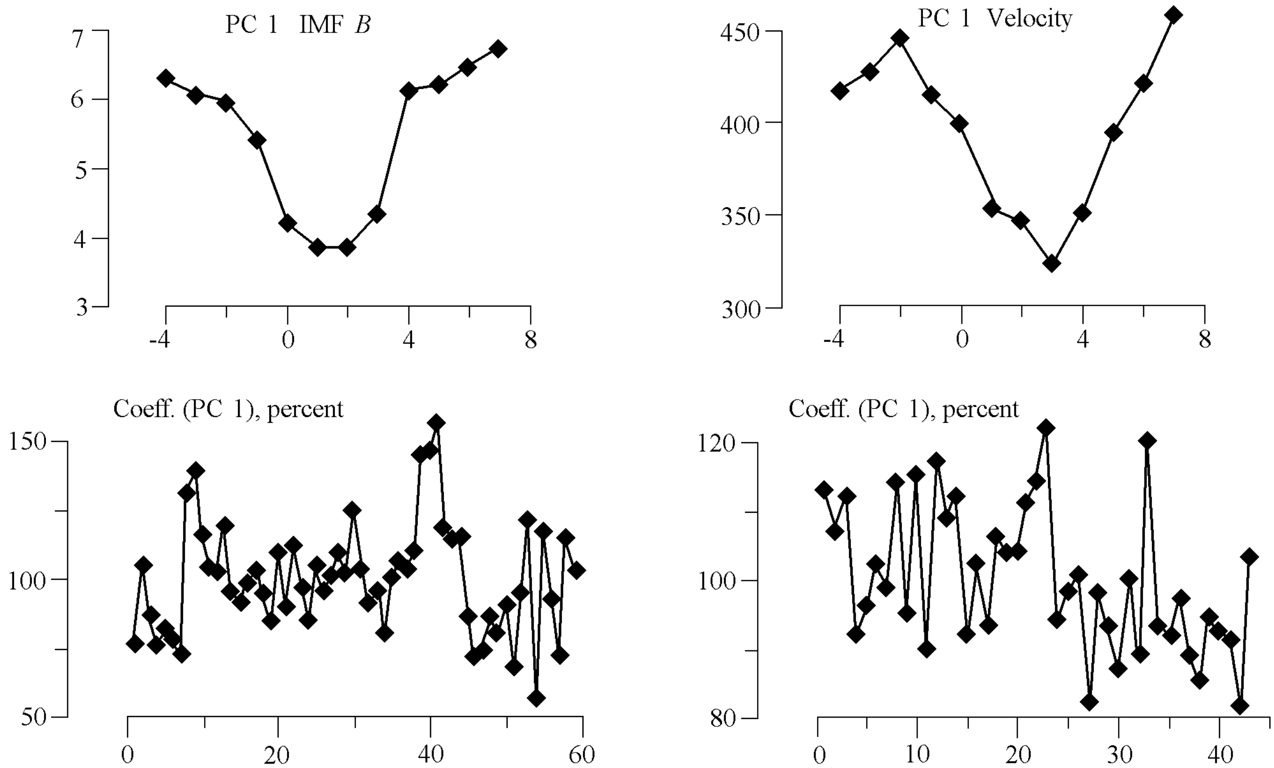

Figure 3. First principal component of IMF B and solar wind velocity. The component is derived from the data for intervals beginning from 4 days prior to the commencement of a sequence of 4 consecutive days with $Ap \leq 4$ up to 4 days after the termination of the sequence of quiet intervals. The bottom panels give the coefficients (as percentage) for each row of the data matrix which provides an idea about the magnitude of the contribution of the first component in each case.

4. Discussion and Conclusions

Ap values ≤ 7 (corresponding $Kp \leq 2_0$) have been used to represent quiet conditions of geomagnetic activity in several investigations. *Gussenhoven* [1988] identifies $Kp \leq$ 1+ to correspond to quiet times. In a study of the seasonal response of geomagnetic activity to the polarity of IMF, *Bhargava and Rangarajan* [1977] found that days with $Ap = 11 - 15$ constitute the group which separates the quiet and disturbed patterns in the seasonal variation and that $Ap \leq 10$ can be considered representative of a quiescent magnetosphere. We can, therefore, be sure that the two groups of prolonged intervals utilized in the present analysis clearly represent two classes of quiet conditions of the magnetosphere. Whether the "very calm" category of days with $Ap \leq 4$ represents "baseline magnetosphere" is, however, not certain.

If the undisturbed magnetosphere is defined with the condition that the speed, proton temperature and density do not undergo large scale variations in time compared to the solar wind expansion time (~52 hours for $V \sim 400$ km s^{-1}), as suggested by *Neugebauer* [1976], then the corresponding parameters for the quiet intervals seem to have very high and variable values in contrast to the averages derived here. For instance, *Neugebauer* [1976] gave a range of 15 to 67 cm^{-3} for N, 348 to 606 km s^{-1} for V, and 4 to 7.7 nT for B. *King* [1986] estimated the typical magnitude of B in quiet solar wind to be about 5 nT, and *Burlaga and Ogilvie* [1970] suggested that V should be $\leq$250 km s^{-1} during quiet intervals. In the distribution of solar wind velocity in different bins over a solar cycle, *Gosling et al.* [1976] found that the speed reached a value of 250 to 275 km s^{-1} only on very few occasions, establishing at least a lower limit for the speed from spacecraft observations. The present analysis suggests IMF magnitude to be ~4 nT throughout the "very calm" intervals and in the initial parts of the "calm" intervals. The lowest value of the speed is, on the average, about 325 km s^{-1} when Ap is $\leq$4 and marginally higher ~350 km s^{-1} when Ap is $\leq$7. In both cases, the speed continues to decrease even in the quiescent periods till the minimum value is reached on the last day. The velocity change is somewhat similar to the time profile of solar wind speed as a function of the passage of IMF sector boundary past the Earth [*Wilcox and Ness*, 1965] where the trailing part of the sector has low value and in the leading part across the boundary a sharp increase in the solar wind speed. Quiet intervals of geomagnetic activity also tend to follow the trailing part of the IMF sector structure [*Gussenhoven*, 1988]. The velocity threshold obtained here appears to be consistent with the results of *Murayama et al.* [1980], who associated the lowest level of geomagnetic activity in the auroral zone with velocity >300 km s^{-1}.

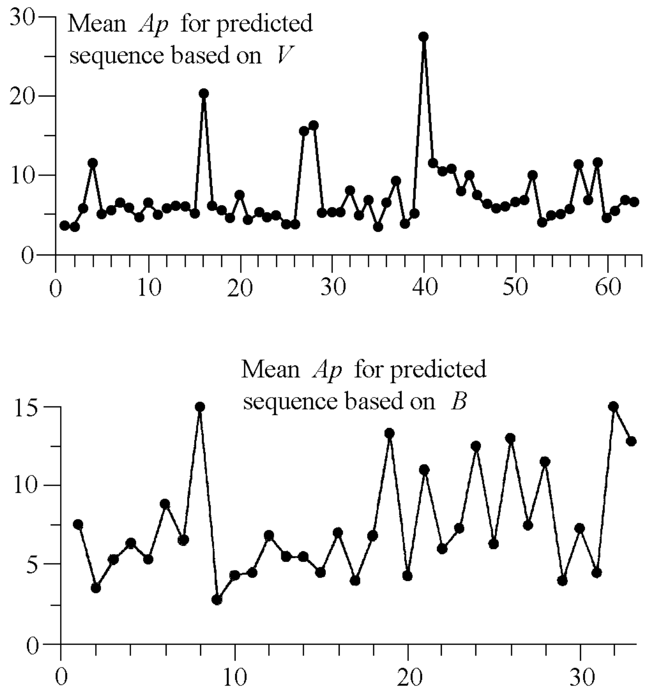

Figure 4. Mean *Ap* values for 4 days predicted as quiet sequence based on the average value of V and IMF B for 3 days and a subsequent uniform decline over next 3 days. The predicted sequences were independently derived using V and B.

According to *Yokoyama and Kamide* [1997], southward turning of IMF plays an important role in not only initiating the main phase of a storm but also in determining the storm intensity. It would, therefore, be natural to expect that B_z to be zero or positive when the geomagnetic activity is at its lowest. Also, we are aware that the IMF is ordered in the GSE system but its interaction with the magnetosphere is controlled in the GSM coordinate system [see, e.g., *Russell and McPherron,* 1973]. Figures 1a and 1b indicate that irrespective of the coordinate system considered, the B_z component of IMF, is small in magnitude but distinctly positive during the "very calm" or "calm" intervals used in the analysis. This tends to confirm that the magnetosphere does indeed behave like a half-wave rectifier, as shown by *Murayama et al.* [1980], who used the auroral electrojet index, *AL* for their study. In contrast to the approach to look for the baseline magnetosphere when B_z tends to be close to zero when energy flow into and out of the magnetosphere would be minimum [*Stern*, 1988], we find that during the conditions of geomagnetic calm, B_z is certainly positive for the duration of the interval considered (4 or 8 days). *Rich and Gussenhoven* [1997], on the other hand, state that in the quiet magnetosphere, B_z can be northward but the solar wind velocity should be concurrently low. These two conditions are eminently satisfied in the present analysis. We can, perhaps, make a distinction between "baseline magnetosphere" and "quiet magnetosphere" and derive two separate thresholds of the IMF and solar wind.

The role of density in solar wind–magnetosphere interaction is not clearly identified. In general, there is an inverse relationship between the wind speed and proton density but the two are not perfectly anti-correlated. *Rosenberg* [1982] suggested that enhancement in density could be a precursor for geomagnetic storms particularly in association with corotating interaction regions (CIRs). *Ivanov and Mikerina* [1987] found, in a case study, an unusual decrease in the density which was associated with a very quiet interval. Superposed epoch analysis of proton density in the vicinity of "very calm" interval shows that the density minimum does not coincide with either the velocity minimum or B minimum (see Figure 1a) but the change in density within the interval itself is anti-correlated with V. A well-defined maximum in density on the termination of the sequence of very quiet intervals is a noteworthy feature, absent in V. For the longer duration of calm intervals, the time profile from 0 day to the end (day +11) density and velocity are in phase opposition. Here again, the maximum in density is obtained when the sequence of quiet intervals is terminated (on day +8). It appears that the change in density from 2 days preceding the initiation of "very calm" intervals up to the end of the calm intervals and for a few days later is a very well-ordered structure, as was seen for IMF B and solar wind speed and may be a precursory signal for a sequence of calm days.

In section 1, we have shown two sets of conditions representing the baseline magnetosphere given by *Gussenhoven* [1988] and *Kern and Gussenhoven* [1990]. According to these studies, The magnitude of IMF should be <5 nT and solar wind speed should be <390 km s^{-1} (lower of the two stipulations). These are met adequately in the present work. However, it should be borne in mind that even when he took the periods when the three hourly *Ap* was 0 for three consecutive intervals, *Sutcliffe* [1998] found that half the number of intervals could not clear *Gussenhoven*'s [1988] criterion. Again, only half of the rejected part could pass the criterion of *Kern and Gussenhoven* [1990]. About 30% of the 24 intervals analyzed by Sutcliffe did not satisfy one of the several conditions imposed and in one case the velocity was more than 400 km s^{-1}. This suggests that apart from the conditions in the interplanetary medium corresponding to a quiescent state, the magnetosphere also should attain a steady state to be qualified as a "baseline magnetosphere," whereas one can have a "quiet magnetosphere" under less stringent conditions of the magnitudes of the solar wind and IMF parameters.

We can make some reasonable comparisons of the time variations of the solar wind and IMF parameters before and after quiet intervals as identified by *Kern and Gussenhoven* [1990] and as given here in Figure 1a. Let us recall that Kern and Gussenhoven used three hourly *Am* index and confined their attention to 24 hours preceding the calm period (which includes 6 hours with $Am \leq 3$ nT) followed by 17 hours. In other words, only the intervals covered by day −1 and +1 of the present analysis was included in their results. Despite this difference, some interesting common features are noticed. Their velocity profile tends to be below the average and decreases from before to after the quiet sequence and the minimum is reached later than the start of the epoch, as noticed in the present case also. Density does not show any change preceding the key hour and tends to rise in the post-quiet interval, once again consistent with our picture covering longer time span. Most interestingly, they find that IMF B retains almost the same value for 24 hours preceding the key hour and shows only a gradual rise in the 17 succeeding hours. This aspect too is consistent with our results that B remains at its low value for the entire sequence of "very calm" days. When the time variations in the components of IMF are compared for these two choices of significantly different key days, we notice that the northward B_z has a much larger mean magnitude (1.8 nT) than what we obtain (∼0.8 nT) but in both cases, it is always positive during the quiet intervals of geomagnetic activity. Evidently, the longer duration for averaging tends to reduce the magnitude of B_z. Kern and Gussenhoven show that neither B_x nor B_y has significant magnitude during the interval of time under analysis and that $|B_x| > |B_y|$ during the quiet epoch but before and after the quiet period, $|B_y|$ was more dominant. On the contrary, we find that B_x shows a clear change in magnitude across the sequence of "very calm" intervals. In the quiet periods, however, $|B_x|$ is greater than $|B_y|$, as observed by them. The associated error bars, however, make the significance of this results doubtful. We concur with their inference that the significant parameters for determining prolonged periods of magnetic quiet are IMF magnitude and orientation and V. We have also examined, in addition, the time variations in the variability of the components of IMF, solar wind velocity and density and show that "very calm" intervals of geomagnetic activity are marked by clear minimum in the variability also.

In conclusion, utilizing the daily index Ap of geomagnetic activity, we identified two separate sequences of prolonged geomagnetic quiet periods and examined the time variations in 16 solar wind and IMF parameters in the vicinity of these sequences. The results of superposed epoch analysis show that all the parameters change in a very orderly fashion across the quiet intervals, thereby enabling us to define the anticipated values of the parameters that control the solar wind–magnetosphere interactions during such quiet times. We associate a value of ∼4 nT for B, ∼320 km s^{-1} for V and a positive B_z component (with magnitude <1 nT). The density remains significantly low from days preceding the very quiet interval and attains a maximum on the termination of the quiet sequence. It is, in general, anti-correlated with the time variation in V. The variations in B and V are not very similar with V reaching a minimum value much later in the sequence of calm days, whereas B reaches its minimum in the initial part of the sequence and maintains the low level right through the sequence.

The results of principal component analysis suggest that the pattern of variation in V and B across the sequence of "very calm" intervals is largely preserved in individual events also, as evidenced by the most significant first component. The variability in the magnitude from one key day to another is less pronounced with regard to B in comparison to V. The attempt to predict a sequence of "very calm" intervals using the average conditions of V and B preceding the period and the rate of change of these two parameters in subsequent days yields fairly reasonable success with better consistency when V is utilized.

On the basis of the various definitions of baseline magnetosphere discussed in the literature, we are led to conclude that there may be perhaps two states one corresponding to the lowest level of energy input from the solar wind to the magnetosphere and the other corresponding to that dictated by lowest levels of geomagnetic activity, represented by a suitable index. The present results complement nicely the earlier work of *Kern and Gussenhoven* [1990] and many features of the time variations within about 48 hours of a sequence of very calm intervals are shown to be highlighted better when a much longer duration, in terms of days, are considered.

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