Abstract. Ground observations of magnetic perturbations can be used to study the spatial and temporal development of magnetospheric disturbances, provided that the magnetic effects of the quiet time ionospheric currents, known as Sq, can be removed from the data. At mid-latitudes, variability of Sq currents may produce magnetic perturbations comparable to the magnetic effects of the partial ring current on comparable time scales. Thus it is important to know the error associated with the quiet field used as a reference to obtain the magnetic effects of the ring current. To determine this error, we have performed a statistical study using 2 years of quiet data (AE < 100 \gamma), acquired at 27 mid-latitude magnetic observatories. We have empirically determined the average quiet magnetic field at each observatory, and the uncertainty of that field as a function of season and local time. Since the Sq currents are confined primarily to the dayside, the uncertainty of the Sq diurnal variation changes as a function of local time. During disturbed periods the quiet field is subtracted from the observations from a worldwide chain of mid-latitude magnetic observatories to reveal the magnetic effects of substorms and the partial ring current. To obtain a smooth local time profile of the magnetic disturbance, we produce a least squares fit to the resulting data values, using a series of cubic spline functions. Profile uncertainty is estimated to range from approximately 23 \gamma near local noon, to 10 \gamma near local midnight. At dusk the uncertainty is near 13 \gamma. These uncertainties represent uncertainty in the quiet field. The uncertainty can be greatly reduced by examining the changes which occur in some interval of time. This is done by subtracting the local time profile obtained at time t1 from the profile obtained at time t2. For time intervals less than 3 hours the quiet day errors are generally strongly correlated, and the errors are eliminated by the subtraction. The error in the difference profile is typically about \pm \gamma. Thus for individual events the local time profile can be used to obtain parameters such as the magnitude, extent, and central meridian, which accurately characterize the magnetic disturbance attributed to a particular current system, provided the duration of the event is less than 3 hours. The more general mid-latitude indices, such as Dst and the dawn-dusk asymmetry, are less accurate, but they are still useful, provided the disturbance is sufficiently large.

Introduction

The solar quiet daily variation, or Sq variation, is an ever present feature of the geomagnetic field. Other transient magnetic perturbations, such as those due to magnetospheric substorms and storms, are superposed upon the Sq variation [Kane, 1978]. To use ground magnetic observations to study the temporal and spatial development of magnetospheric disturbances, the quiet magnetic field, including the Sq variation, must be removed from the data. At high latitudes, where substorm perturbations are large and the time scale for change is short relative to Sq, the presence of the quiet diurnal variation is not a problem. At mid-latitudes, however, variability of the Sq variation may produce magnetic perturbations comparable to the magnetic effects of the partial ring current on comparable time scales. Thus the accuracy with which the quiet magnetic field, including the Sq variation, may be subtracted from mid-latitude magnetic observations limits the use of these data for identifying the effects of magnetospheric current systems.

In this paper we report the results of an empirical determination of the quiet magnetic field, which includes the Sq variation and secular variation at 27 mid-latitude magnetic observatories, for the period 1967-1968. In addition, we investigate the error associated with our empirical model. The method employed in this analysis provides a mean quiet field and a statistical scatter at a given observatory and local time without regard to the cause. It has pragmatic advantages over conventional statistical studies which have modeled Sq using harmonic analysis, since our concern is with the consequences of the quiet field uncertainty in terms of using mid-latitude magnetic data to quantify the size and location of the magnetic disturbances caused by substorms and by the ring current. The observatories used in this study, and their coordinates, are listed in Table 1.

The original definition of the Sq variation given by Chapman and Bartels [1940] is statistical: the mean variation obtained by averaging the mean hourly values of the magnetic elements for the five international quiet days of each month. When this process is performed for many stations, it is possible to determine the Sq currents. Figure 1 shows the average Sq currents inferred from such mean variation curves for the three seasons: D (November, December, January, February), J (May, June, July, August), and E (March, April, September, October) [after Matsushita, 1967]. The average position of the center, or focus, of the northern current vortex is near 30° north latitude. In the northern hemisphere the currents flow counterclockwise, when observed from the sun. Thus in the northern hemisphere a ground observer positioned poleward of the focus would see a decrease in the X component (geographic north) of the geomagnetic field as he rotated under the system, while an observer equatorward of the focus would see an enhancement of X.
TABLE 1. Locations of Mid-Latitude Observatories Used in This Investigation

<table>
<thead>
<tr>
<th>Station Code</th>
<th>Station</th>
<th>W Longitude</th>
<th>Latitude</th>
<th>E Longitude</th>
<th>Latitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>MB</td>
<td>M'Bour</td>
<td>16°58'</td>
<td>14°24'N</td>
<td>55.0°</td>
<td>-21.3°</td>
</tr>
<tr>
<td>PI</td>
<td>Pilar</td>
<td>63°53'</td>
<td>31°40'S</td>
<td>4.6°</td>
<td>-20.2°</td>
</tr>
<tr>
<td>TW</td>
<td>Trelew</td>
<td>65°19'</td>
<td>43°15'S</td>
<td>3.2°</td>
<td>-31.8°</td>
</tr>
<tr>
<td>SJ</td>
<td>San Juan</td>
<td>66°09'</td>
<td>18°07'N</td>
<td>3.1°</td>
<td>29.6°</td>
</tr>
<tr>
<td>FR</td>
<td>Fredericksburg</td>
<td>77°22'</td>
<td>38°12'S</td>
<td>349.8°</td>
<td>49.6°</td>
</tr>
<tr>
<td>CE</td>
<td>Cuba</td>
<td>82°08'</td>
<td>22°68'N</td>
<td>345.4°</td>
<td>34.1°</td>
</tr>
<tr>
<td>DS</td>
<td>Dallas</td>
<td>96°45'</td>
<td>32°59'N</td>
<td>327.7°</td>
<td>43.0°</td>
</tr>
<tr>
<td>BD</td>
<td>Boulder</td>
<td>105°14'</td>
<td>40°08'N</td>
<td>316.5°</td>
<td>49.0°</td>
</tr>
<tr>
<td>TU</td>
<td>Tucson</td>
<td>110°50'</td>
<td>32°15'N</td>
<td>312.2°</td>
<td>40.4°</td>
</tr>
<tr>
<td>NT</td>
<td>Newport</td>
<td>116°59'</td>
<td>48°16'N</td>
<td>300.2°</td>
<td>55.1°</td>
</tr>
<tr>
<td>TA</td>
<td>Tahiti</td>
<td>149°37'</td>
<td>17°33'S</td>
<td>282.7°</td>
<td>-15.3°</td>
</tr>
<tr>
<td>HO</td>
<td>Honolulu</td>
<td>158°00'</td>
<td>21°19'S</td>
<td>266.5°</td>
<td>21.1°</td>
</tr>
<tr>
<td>PM</td>
<td>Port Moresby</td>
<td>212°51'</td>
<td>9°24'S</td>
<td>217.9°</td>
<td>-18.6°</td>
</tr>
<tr>
<td>TO</td>
<td>Toolangi</td>
<td>214°32'</td>
<td>37°32'S</td>
<td>220.8°</td>
<td>-46.7°</td>
</tr>
<tr>
<td>GU</td>
<td>Guam</td>
<td>215°08'</td>
<td>13°35'S</td>
<td>212.9°</td>
<td>4.0°</td>
</tr>
<tr>
<td>KA</td>
<td>Kakloka</td>
<td>219°49'</td>
<td>36°14'N</td>
<td>206.0°</td>
<td>26.0°</td>
</tr>
<tr>
<td>YA</td>
<td>Yakutsk</td>
<td>230°16'</td>
<td>62°01'N</td>
<td>193.8°</td>
<td>50.9°</td>
</tr>
<tr>
<td>GN</td>
<td>Ghangara</td>
<td>246°03'</td>
<td>31°47'S</td>
<td>185.8°</td>
<td>-63.2°</td>
</tr>
<tr>
<td>PY</td>
<td>Patrony (Irkutsk)</td>
<td>255°33'</td>
<td>52°10'N</td>
<td>174.7°</td>
<td>40.7°</td>
</tr>
<tr>
<td>HY</td>
<td>Hyderabad</td>
<td>261°27'</td>
<td>17°25'N</td>
<td>148.9°</td>
<td>7.6°</td>
</tr>
<tr>
<td>YB</td>
<td>Yangi-Bazar (Tashkent)</td>
<td>290°22'</td>
<td>41°18'N</td>
<td>144.0°</td>
<td>32.3°</td>
</tr>
<tr>
<td>VD</td>
<td>Vysokaya Dubrava</td>
<td>298°55'</td>
<td>56°42'N</td>
<td>140.7°</td>
<td>48.5°</td>
</tr>
<tr>
<td>DT</td>
<td>Dusheti (Tbilisi)</td>
<td>315°17'</td>
<td>42°04'N</td>
<td>122.0°</td>
<td>36.6°</td>
</tr>
<tr>
<td>ST</td>
<td>Stepanovka (Odessa)</td>
<td>329°07'</td>
<td>46°46'N</td>
<td>111.1°</td>
<td>43.6°</td>
</tr>
<tr>
<td>NU</td>
<td>Nurmijarvi</td>
<td>340°24'</td>
<td>60°30'N</td>
<td>112.5°</td>
<td>57.8°</td>
</tr>
<tr>
<td>HR</td>
<td>Hermanus</td>
<td>340°46'</td>
<td>36°25'N</td>
<td>80.5°</td>
<td>-33.3°</td>
</tr>
<tr>
<td>FU</td>
<td>Puratsfeldbruck</td>
<td>348°43'</td>
<td>48°10'N</td>
<td>93.3°</td>
<td>48.8°</td>
</tr>
</tbody>
</table>

It can also be seen from Figure 1 that the strength of the Sq current system and the position of the focus change appreciably with season. A great deal of day-to-day variability in the shape, position, and strength of the Sq currents also exists. Hasegawa [1936] concluded that the Sq focus could move as much as 15° of latitude north or south from one day to another. Marriot [1975] has studied deformation of the Sq system on an hourly basis and reports movement of the focus position by several degrees on that time scale.

Thus even on very quiet days at any particular station, there can be considerable day-to-day variability in the amplitude and phase of the diurnal variation. Figure 2 shows superposed plots of the H components, measured at two mid-latitude observatories during quiet periods and arranged according to season. These data from 1967 and 1968 were selected according to the criterion AE < 100 γ. The Sq variation appears to have a distinctive shape, with some variability in phase and amplitude. In addition, the variation seems to be superposed upon a base line which is nearly constant in local time, but whose value may change from day to day.

An Empirical Sq Model

On a magnetically quiet day the magnetic field Xj, observed at some observatory j, will be composed of the following terms:

\[ X_j = M_j + R_j + \left[ I_j + P_j + T_j \right] \]

where \( M_j \) is the main geomagnetic field, \( R_j \) is the field due to ring current, \( I_j \) is the field due to ionospheric (Sq) currents, \( P_j \) is the field due to magnetopause currents, and \( T_j \) is the field due to tail current. The quantity in the braces produces a diurnal variation, while the remaining terms are quasi-steady and symmetric.

It is useful, then, to represent \( X_j \) in terms of a symmetric field \( B_j \) and a diurnal variation field \( V_j \). That is,

\[ X_j = B_j + V_j \]

where \( B_j = M_j + R_j \) and \( V_j = I_j + P_j + T_j \). The results of this study are values of \( B \) and \( V \) for each of the stations listed in Table 1. Included in our determination of \( B \) is the secular variation of the main field observed at each observatory over the 2 years of data used in the study. The mean diurnal variation \( V \) at each station is determined for each of the three seasons.

Determination of the Diurnal Variation

The proper reference level from which to measure Sq variations has been investigated by several researchers. Without other information the daily mean would be an appropriate base line; however, theoretical arguments suggest that the current responsible for the Sq magnetic
Fig. 1. Average ionospheric currents during the IGY for the three seasons, winter (D), summer (J), and equinox (E), viewed from the magnetic equatorial plane at the solar noon meridian. In the northern hemisphere the currents flow clockwise; in the southern hemisphere the currents flow counterclockwise as viewed from the sun. The numbers near the cross marks are the total current intensity of each vortex in units of $10^3$ A. The current intensity between consecutive lines is $25 \times 10^3$ A [after Matsushita, 1967].

The source of the dayside variability, apparent in Figures 3 and 4, has been investigated by many researchers. The variability appears most closely related to changes in local high-altitude winds [Hasegawa, 1960; Gupta, 1967; Kane, 1972; Schlapp, 1968]; however, changes in ionospheric conductivity may also play an important role [Brown and Williams, 1969; Chapman and Bartels, 1940]. Other sources in the magnetosphere or interplanetary space which could affect Sq variability have not been ruled out. Matsushita [1975], for example, suggests that the interplanetary magnetic field polarity may influence the latitude of the Sq current focus. Nevertheless, the results of these studies are not adequate to enable one to predict Sq analytically at any particular time. Consequently, we have chosen to determine empirically the mean seasonal Sq variation at each of the 27 observ-

Fig. 2. Superposed magnetic variations of the H component observed at Tucson and Honolulu during quiet times ($\text{AE} < 100 \gamma$) for 2 years (1967 and 1968). The data are arranged according to season. Vertical scale is 20 $\gamma$ per division.
MAGNETIC DIURNAL VARIATION AT HONOLULU (21.9 N,158.0 W) QUIET DATA (AE<100') DURING 1967 - 1968 AX COMPONENT

Fig. 3. Superposed daily quiet variations of X component observed at Honolulu during 1967 and 1968. (Left) Residuals from the field averaged between 00 and 02 hours LT on each day. Data are arranged according to season. (Right) Mean, 90 percentile, and 10 percentile curves computed from the superposed data. The vertical scale is 12 γ per division.

Determination of the Main Field Base Line

The base line at each station to which the model Sq variation is added was obtained as follows. The monthly average field between 00 and 02 hours LT during quiet times (AE < 100 γ) was computed at each station using several years of data. These averages were then fit with a second degree polynomial to approximate the main field and secular variation at each station. Figure 5 shows the results of this procedure for the X and Y components of the field at Honolulu. For the X component the scatter about the fit is typically within ±10 γ, while the secular variation of X is roughly 55 γ over a 3-year interval. The base line determined this way reflects the main field and some average configuration of the ring current and tail current.

Calculating the Model Quiet Field

The model quiet field can be determined at any day in the period 1967-1968 for any of the 27 observatories used in this analysis. The second degree polynomial is used to determine the base line field B. This value is added to the variation V for the season, component, and local time selected. Figure 6 compares the X component of the model field at a number of stations with the actual field observed on February 6, 1968. February 6 was classified QQ. The mean AE on this day was 43 γ, and Ap = 2. The upper trace is the model quiet field, while the lower trace is the measured field. Local midnight is indicated above each trace, and a base line is

atories listed in Table 1. Quiet periods were selected from 2 years of data (1967 and 1968), according to the criterion AE < 100 γ. On each quiet day the field average between 00 and 02 hours LT was used as a reference to determine the residual Sq variation at each station. These variations were arranged according to season, in the way illustrated in Figures 3 and 4. The mean variation at each station for each season was then computed.

The monthly average field between 00 and 02 hours LT during quiet times (AE < 100 γ) was computed at each station using several years of data.
drawn through the midnight value. While there is general agreement between the predicted and actual quiet day, differences do exist. In addition, differences from the model are not similar at all stations. For example, while the difference between the model and actual base lines is only 1 γ at some stations, it is 16 γ at San Juan.

Uncertainty of Quiet Field Model

Errors in our estimate of the quiet field result from (1) uncertainty of the Sq variation and (2) uncertainty of the Sq base line. In this section we will quantify these errors, discussing first the uncertainty of the Sq variation.

Since the Sq currents are confined primarily to the dayside, the uncertainty of the Sq variation is a function of local time, being the greatest near local noon, and the least near local midnight. To estimate the uncertainty of the model Sq variation, we have used the 90 and 10 percentile curves of the ensemble of Sq variations observed at each observatory and illustrated in Figures 3 and 4. In general, these percentile curves lie symmetrically about the mean. We estimate the error during each hour of local time to be half the difference of the hourly means of the 90 percentile and 10 percentile values. Figure 7 shows the mean error in the Sq variation, obtained by averaging over all stations, as a function of local time for the three seasons. The error is nearly the same for all three seasons and varies from a maximum near 1100 LT of ±22 γ to a minimum near 0200 LT of about ±4 γ.

The second source of error lies in the uncertainty of the base line computed for each station. We assume that during quiet times, the magnetic field between 00 and 02 hours LT is not affected by Sq disturbances. The variability of the quiet field average measured between 00 and 02 hours LT thus represents variability of quiet magnetospheric currents, the quiet time ring current and tail current being the predominant contributors.

To quantify the base line variability, we have computed the differences of the model base line from the measured quiet field, averaged between 00 and 02 hours LT at each station for the 2 years of data (1967-1968). The result is a matrix $D_{ij}$, where

Fig. 4. Same format as Figure 3. Superposed daily quiet variations of X component observed at Tucson during 1967 and 1968.
there were periods with $AE < 100 \gamma$. This matrix, with our statistical analysis, is schematically illustrated in Figure 8.

To describe the $D$ matrix statistically, we calculated the mean and standard deviation for each row and column. The mean and standard deviation of each column characterize the individual station behavior over the ensemble of quiet periods. The mean and standard deviation of each row characterize the ensemble of stations on a particular quiet day.

Table 2 shows five example rows of the $D$ matrix, the column statistics, and a summary of the row statistics given by the mean and standard deviation of the row means and standard deviations. The column statistics are similar, suggesting that the stations are, in general, behaving similarly. The mean of each row characterizes the average field deviation from the model seen by several stations, and reflects the strength of the quiet time ring current on that day. That is, the row mean represents a base level on a particular day relative to the predicted base value. Uncertainty of this base line exists because the station differences $D_{ij}$ are not the same across the row. The standard deviation of the values in each row characterize the uniformity of the station observations.

To remove the ring current effects, a second matrix $R_{ij}$ has been computed by subtracting the row mean from each value in the row. That is,

$$R_{ij} = D_{ij} - \langle \text{row } j \rangle$$

The standard deviation of all the values $R_{ij}$

---

**Average Monthly Midnight Quiet Magnetic Field at Honolulu**

<table>
<thead>
<tr>
<th>Month</th>
<th>X Component</th>
<th>Y Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>1966</td>
<td>27350</td>
<td>55920</td>
</tr>
<tr>
<td>1967</td>
<td>27400</td>
<td>56300</td>
</tr>
<tr>
<td>1968</td>
<td>27450</td>
<td>56600</td>
</tr>
<tr>
<td>1969</td>
<td>27500</td>
<td>56900</td>
</tr>
</tbody>
</table>

**Fig. 5.** Monthly average quiet magnetic field at Honolulu averaged between 00 and 02 hours LT. Solid curve is a second degree polynomial fit to the data. The average long-term change in the field is termed the secular variation.

The predicted and actual magnetic field at several mid-latitude observatories for quiet day February 6, 1968.

**Fig. 6.** (Top) predicted and (bottom) actual magnetic field at several observatories for quiet day, February 6, 1968. Dots above each trace indicate local midnight. A base line is drawn through the midnight value of each trace, and its value is indicated to the left. The vertical scale is 20 $\gamma$ per division.
characterize the base line uncertainty. This standard deviation was computed to be 4.7 \( \gamma \). A stringent estimate of the base line error is given by plus or minus 2 standard deviations, or about \( \pm 9 \gamma \).

The combination of errors \( E \), \( \varepsilon \), and \( \Delta e \) produce a total uncertainty in the variation of the quiet field given by:

\[
E_{\text{total}} = (E^2_{\text{variation}} + E^2_{\text{baseline}})^{1/2}
\]

This result is plotted in Figure 9. The uncertainty varies from a minimum of \( \pm 10 \gamma \) near 0100 LT, to a maximum of about \( \pm 23 \gamma \) near local noon. At dusk the uncertainty is about \( \pm 15 \gamma \). It should be mentioned that this is a fairly stringent estimate of the uncertainty, based roughly on \( \pm 2 \) standard deviations of the spread in data used to calculate the empirical quiet field model.

Application of Quiet Field Model

In Figure 10 we illustrate the use of data from a worldwide chain of mid-latitude observatories to determine a local time profile of a magnetic disturbance. Plotted on the left side of the figure are several hours of data from February 11, 1967, along with the model quiet field, for each observatory. We have indicated the difference between the quiet curve and the field measurement at 0600 UT, and these values are plotted as a function of the local time position of the observatory on the right of the figure. The error bars on each difference value were determined from Figure 9. The smooth curve through the data points was computed using a least squares cubic spline technique. The discontinuity near 00 LT is at the day boundary of the spline fit. The spline-fitting technique uses a program from the IMSL Library [1975]. The technique fits cubic splines within intervals and matches the first and second derivatives of the spline at the interval boundaries or knots as they are commonly called. The positions of the knots influence the fit, so we therefore use several knot arrays and select the best fit based on a weighted rms error. The splines are fitted so as to minimize the error given by

\[
E = \left( \frac{1}{n} \sum_{i=1}^{n} \delta Y_i^2 W_1 \right)^{1/2}
\]

where

\[
\delta Y_i = Y_i - S_i
\]

\[
W_1 = \frac{X_{i+1} - X_i}{X_{i+1} - X_1}
\]

and

\[
W_2 = \frac{X_i - X_{i-1}}{X_n - X_i}
\]

\[
W_n = \frac{X_i - X_{i-1}}{X_n - X_i}
\]

Fig. 8. Schematic illustration of D matrix used to estimate base line uncertainty in the quiet field model. Rows of the matrix correspond to quiet days, and columns correspond to stations. Each D component is the difference between the actual field average between 00 and 02 LT, and the model base line at the indicated station and day. The matrix can be described statistically by computing the mean and standard deviation of each row and column.

where \( Y_1 \) is the data value at \( X_1 \) and \( S_1 \) is the spline value at \( X_1 \). In the profile shown, \( E = 5.7 \gamma \). Since this error is less than the error in the data values used to obtain the profile, we estimate the uncertainty of the profile to be equal to the uncertainty in the data. Recall that this uncertainty, shown in Figure 9, is based on \( \pm 2 \) standard deviations of the data used to compute the mean quiet day field.

Frequently, one is interested in determining the change which occurs during a specific interval of time, e.g., during the expansion phase of a substorm. This can be accomplished by subtracting the profile at time \( t_1 \) from the profile at time \( t_2 \). Substantial error reduction in the resulting difference profile is obtained. The procedure is illustrated in Figure 11.

On February 11, 1967, a substorm onset occurred at 0515 UT, and the expansion phase reached its maximum at 0600 UT. The top panel of Figure 11 shows the local time profile of the magnetic disturbance at 0515 UT. The uniform depression suggests an enhancement of the symmetric ring current. The wiggles in the profile are smaller than the errors associated with the data values, and are not meaningful. The center panel shows the profile obtained at 0600 UT. This is the same profile discussed earlier in Figure 10.

The solid line in the bottom panel was obtained by subtracting the 0515 UT profile from the 0600 UT profile, and represents the effects of currents which developed during the substorm expansion. There is a \( 20-\gamma \) enhancement of the field centered near 0400 UT, due to the substorm expansion current, and a \( -30-\gamma \) perturbation centered near dusk, due to the development of the...
Fig. 9. Magnitude of the uncertainty of the predicted quiet field as a function of local time and season.

partial ring current. Because errors in the quiet day model at a particular observatory are highly correlated over time periods of several hours, the subtraction of the profiles removes much of the uncertainty in the difference profile. For time periods of 2 hours or less the correlation coefficient is greater than 0.8. It is reasonable therefore to estimate the uncertainty in the difference profile by considering only the rms residual errors of the profiles at times $t_1$ and $t_2$, providing the separation is less than 2 or 3 hours. Assuming that the rms errors of the profiles at 0515 and 0600 UT are independent, we obtain an uncertainty of $\pm 6$ nT in the profile shown in the bottom panel.

The data values shown in the bottom panel of Figure 11 were obtained by subtracting the data values at 0515 UT from the values at 0600 UT. The dashed curve is a spline fit to the data values. The rms error of the dashed curve fit is 4.7 nT, which is consistent with our error estimate.

For time separations of greater than 3 hours it becomes risky to subtract data values, since the station has moved in local time. The use of the profile overcomes this difficulty by transforming from the rotating frame of the earth to one fixed with respect to the earth-sun line.

Discussion

To develop parameters and indices using mid-latitude data which characterize geomagnetic substorm and ring current disturbances, it is necessary to separate and remove the magnetic effects of quiet time sources from the disturbance field with known uncertainty. A technique for removing the quiet magnetic field from disturbed data has been described in this report. The technique predicts the quiet field at a mid-latitude observatory based on the mean diurnal quiet variation observed at the station over many quiet days grouped according to season, and a base line determined by the monthly mean quiet field measured between 00 and 02 hours LT at the observatory. A conservative estimate of the accuracy of the predicted field is given in Figure 9 and is based approximately on 2 standard deviations of the data used in the analysis.

The criterion used to select quiet periods was based on the AE index introduced by Davis and Sugiura [1966]. The index is created using 10 auroral zone observatories nearly equally spaced in longitude in the northern hemisphere and indicates the strength of the auroral electrojets. Periods defined by $AE < 100$ nT, however, do not
necessarily represent a quiet 'ground state' of the magnetosphere, since no condition was set on previous magnetospheric activity. For example, the period following the main phase of a magnetic storm is often very quiet by the criterion $\Delta E < 100 \gamma$, although the ring current is typically enhanced and decaying slowly. Nevertheless, the quiet field at each observatory generated by this model is useful, since it references disturbances to a model with known uncertainty.

We have shown that the absolute deviation from a quiet day can only be roughly determined using mid-latitude magnetograms. The error is estimated by the uncertainty of the mean quiet field computed at 27 mid-latitude observatories, and it ranges from $\pm 23 \gamma$ at 12 LT to $\pm 10 \gamma$ at 00 LT. These estimates are based on 2 standard deviations and have a 95% confidence level.

We have also shown that events with time durations of less than 3 hours may be characterized much more accurately. Since the errors in the estimate of the quiet field at time $t_1$ correlate with the errors at time $t_2$, the error in the difference profile is less than the error of either of the subtracted profiles. The uncertainty of the difference profile is typically about $\pm 6 \gamma$ for time periods of 2 hours or less. These errors are important to know in order to evaluate indices or parameters which are determined from local time profiles of the mid-latitude magnetic disturbance. In particular, we have been interested in isolating and parameterizing the magnetic disturbances which result from the substorm expansion phase current and the partial ring current. This is illustrated schematically in Figure 12. The top of the figure shows the magnetic signature of these currents as a function of local time or position around the earth. The north-south and east-west perturbations are indicated by $\Delta X$ and $\Delta Y$, respectively. The substorm expansion current produces an enhancement in the northward field, centered near dusk. The $\Delta X$ profile can be used to compute
response to Joule heating at auroral latitudes. 

A schematic illustration in Figure 12. We have used the mid-latitude local time profile parameterization of the partial ring current and its relationship to interplanetary and substorm parameters. Preliminary results were reported by Clauer and McPherron [1978], and more detailed results will be published soon.

The major portion of this work was supported by the Office of Naval Research under grant ONR N00014-75-C-0396. Partial support was also provided by NASA grant NGL 05-007-004 and NSF grant ATM 76-17035. The regents of the University of California provided partial support of the computing costs. All of the digitized data was provided by the World Data Center A for Geomagnetism. We also gratefully acknowledge the helpful comments on earlier versions of this manuscript by R. J. Walker.

The Editor thanks S. Matsushita and M. Sugiura for their assistance in evaluating this paper.

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(Received August 10, 1979; revised October 2, 1979; accepted October 3, 1979.)