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Quiet-time magnetic variations at high latitude observatories

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The quiet-time geomagnetic variations at high latitudes have not been systematically studied so far. Here we present quiet-time variation results from more than two years of continuous magnetic observations in Fennoscandia and Svalbard using the IMAGE magnetometer network. The CHAMP CO2 model is found to yield an excellent secular variation correction with a simple linear trend. The effect of the magnetospheric ring current on the quiet-time field values for each component is presented with the coefficients for the expected linear correlation with the D_{ST} index. A general trend for these coefficients is found for the CGM latitudes from 54 to 68 degrees. In this area the diurnal variation is well in accordance with the expected seasonal S_q behaviour. North of the Fennoscandian mainland the D_{ST} coefficients and the diurnal variations show an unexpected behaviour and additional current systems are presented as a likely cause. An objective, automated baseline method used in this study is also introduced as a method useful for various applications.

Key words: Geomagnetic field, geomagnetic baseline, solar quiet variation, auroral ionosphere, high-latitude current systems, ground-based observation.

1. Introduction

Magnetic field variations at high magnetic latitudes are characterized by a wide range of different phenomena. The electric fields and currents in the polar region are driven mainly by field-aligned currents caused primarily by plasma convection or pressure gradients in the outer magnetosphere. Precipitation of energetic electrons enhance the ionosphere conductivity so that intense currents can flow even in the nightside.

In cases when the magnetosphere is in a very quiet state, ionospheric currents at auroral latitudes calm down. During those times it is possible to observe the response of the auroral ionosphere to the internal effects. These are believed to be produced basically by the dynamo action of the thermospheric winds (Campbell, 1997). The quiet-time variations at mid-latitudes are generally described by the S_q (solar quiet) current system (Chapman and Bartels, 1940). Here the "quiet conditions" are well described by the planetary activity index K_p. At high latitudes, a separate term S_q^p has been introduced as the polar part of the global S_q system (Nagata and Kokubun, 1962), although there is a close relationship between S_q^p and S_q. The S_q^p system can generally only be observed when the solar wind input to the magnetosphere is minimal. For the selection of days suitable for studying the S_q^p system it is therefore not sufficient to look for times of low K_p, but in addition, the activity of the auroral electrojet has to be low (Xu, 1989). It is believed that the thermo-tidal dynamo is operating independently of magnetic activity and its effect is modulated primarily by the conductivity of the ionospheric E region. As a consequence, a clear seasonal dependence of the current intensity is expected.

Since the magnetic effect of the S_q and S_q^p current system is fairly small, the contributions from all other field sources have to be removed prior to an interpretation of the magnetic variation. The most prominent variation during quiet days comes from the magnetospheric ring current. Its decay after a magnetic storm takes several days. Therefore, D_{ST} up to -100 nT values can be encountered even on quiet days. Another, although much slower change is the secular variation of the geomagnetic field. Also this has to be accounted for, in order not to bias a study over longer periods. Finally, high demands are posed on the stability of the instrument baselines. Drifts can easily cause spurious current estimates. After having removed all the above variations, the remaining signatures in the magnetic recordings can be attributed exclusively to ionospheric currents.

The aim of this study is to investigate the characteristics of magnetic variations at auroral latitudes during quiet periods. While the studies of daily S_q variation at mid and low latitudes have been pursued for almost a century (see Hibberd, 1985 and references therein), systematic examinations of the quiet-time variation at high latitudes are sparse (e.g. Detrick and Lanzerotti, 2001; Cafarella *et al.*, 1998). This is mostly due to the lack of high-quality observations at these remote places. Here we make use of the recordings obtained by the IMAGE magnetometer array to derive the average signatures of the high-latitude quiet-time magnetic variations. As a side aspect, we describe the method employed for deriving objectively the appropriate base values for ionospheric current studies.

In Section 2, we present the IMAGE network data and describe the selection of the quiet days for this study. In Section

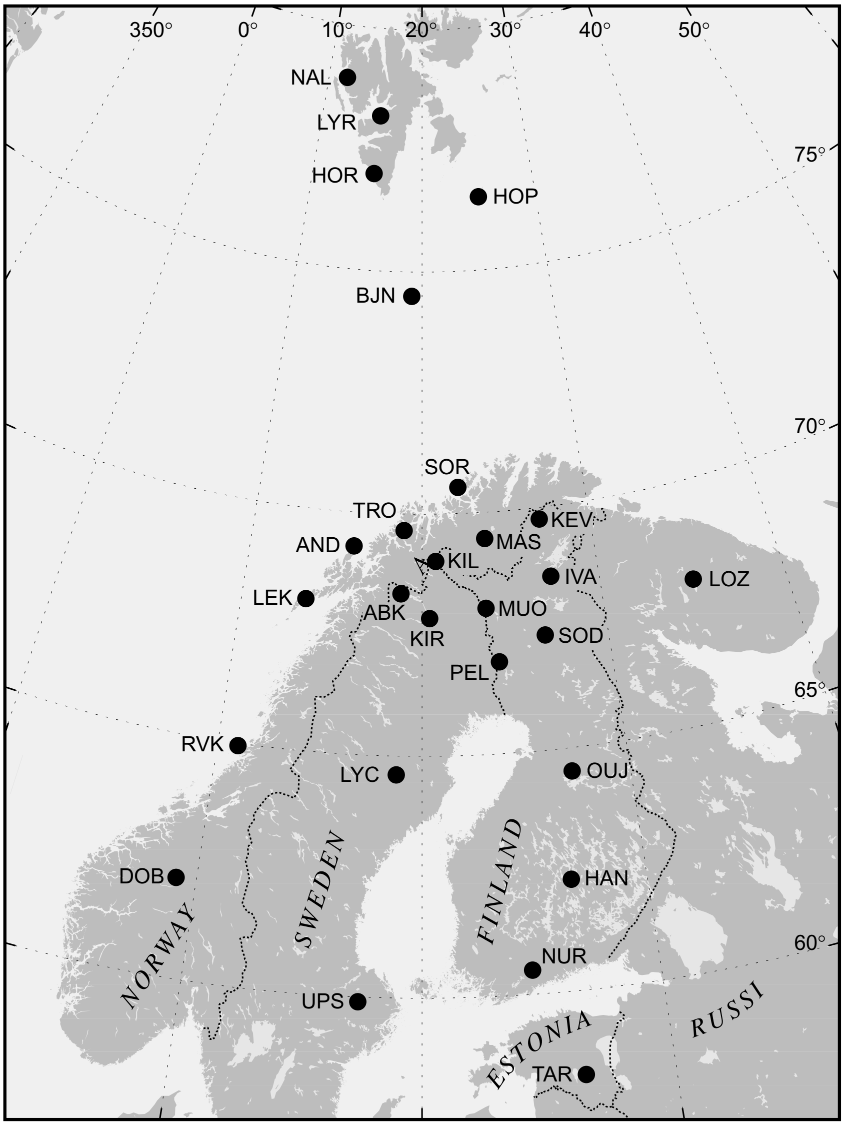


Fig. 1. IMAGE magnetometer network.

3, we discuss first how the corrections due to secular variation and the D_{ST} index dependence were obtained and then form baseline functions for each station. Then in Section 4, we discuss the obtained D_{ST} behaviour and diurnal variation with results of earlier studies. Furthermore, the relevance of our findings to other research aspects is outlined.

2. Data and Processing

The International Monitor for Auroral Geomagnetic Effects (IMAGE) presently consists of 27 magnetometer stations maintained by 10 institutes from Estonia, Finland, Germany, Norway, Poland, Russia and Sweden (Fig. 1). The prime objectives of IMAGE are to study auroral electrojets and moving two-dimensional current systems. The long profile covering geomagnetic latitudes from 54.5 to 75 degrees is especially favourable for electrojet studies (Lühr *et al.*, 1998; Viljanen and Häkkinen, 1997).

Nearly ten IMAGE stations are permanent observatories fulfilling international standards concerning absolute values of the field components. The other stations are considered as variometers with occasionally performed absolute measurements. The high data quality, especially a good stability of instruments, guarantees that the science objectives can be reached.

Investigations of auroral current systems require that the quiet-time field is subtracted from the data. For single events, a visual baseline selection is a reasonable solution. Typical auroral latitude studies deal with relatively large variations (> 100 nT), so the selection criteria are not very critical then. When a larger number of events is studied, a manual selection of quiet periods for each event is more cumbersome, but still feasible. However, it is subjective, so an automatic method is preferable. Although details of the baseline selection may still be more or less subjectively defined, the procedure can be repeated by anyone. Here we present the baseline method used in conjugate studies of auroral electrojets based on data of IMAGE and the CHAMP satellite (Ritter *et al.*, 2004). We considered the time period from January 2000 to May 2002.

For the selection of quiet days we made use of the typically less disturbed time after the local midnight (23–24 UT, corresponding to about 0130–0230 MLT) as the baseline pe-

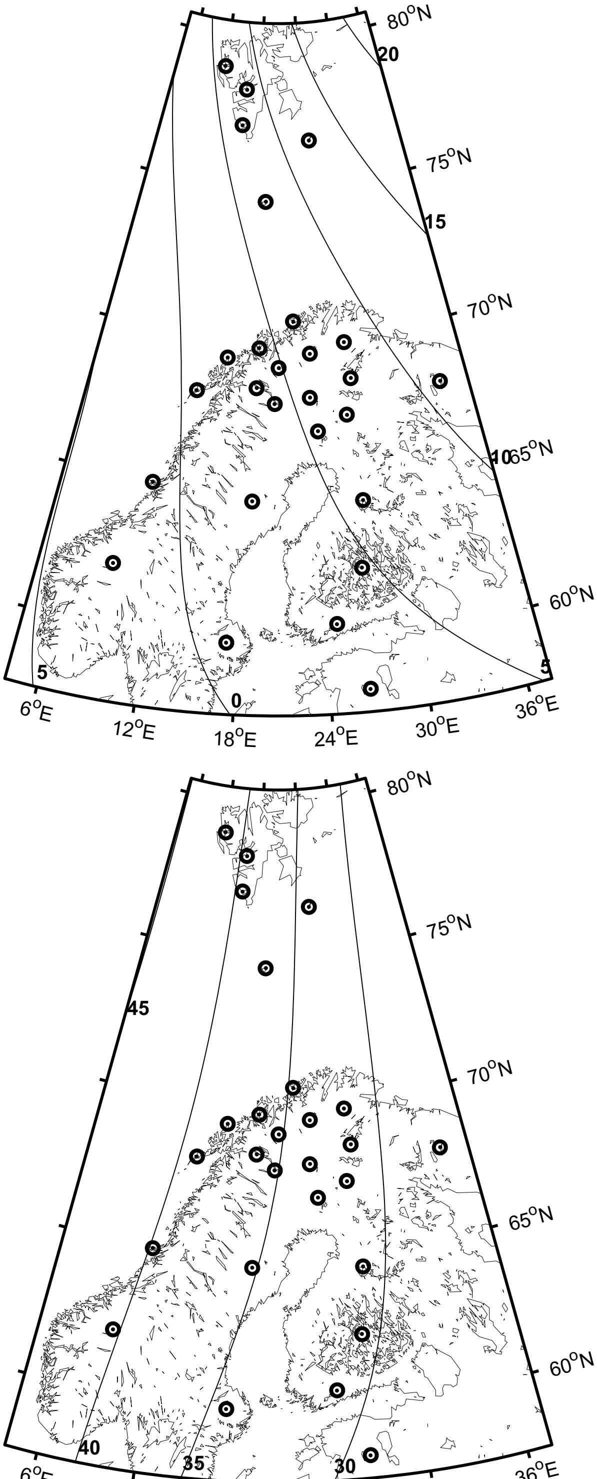


Fig. 2. Secular variation of X, Y and Z components in nT/year calculated from the CHAMP CO2 main field model.

riod. Candidates for quiet days had to fulfill the condition that the planetary K_p index of 21–24 UT is at most 1+. Although this is quite a restrictive condition, it does not guarantee a quiet field at high latitudes, since K_p observatories are located at mid-latitudes. Next, the local variant of the AE index for the IMAGE array (IE index; cf. Kauristie *et al.*, 1996) was calculated for the period 22–24 UT (about 0030–0230 MLT) for the quiet K_p events. For IE, we used the geographic north component (X), which is nearly equal to the magnetic north component in the study region. If IE was less than 100 nT then the day was regarded quiet.

Calculation of IE requires roughly determined baselines too. They were selected visually, which is somewhat subjective, but reasonable to start with. Occasional gaps in the data cause slight non-uniformity in IE, but it is not crucial here. If an objective baseline is desired also for the quick-look IE,

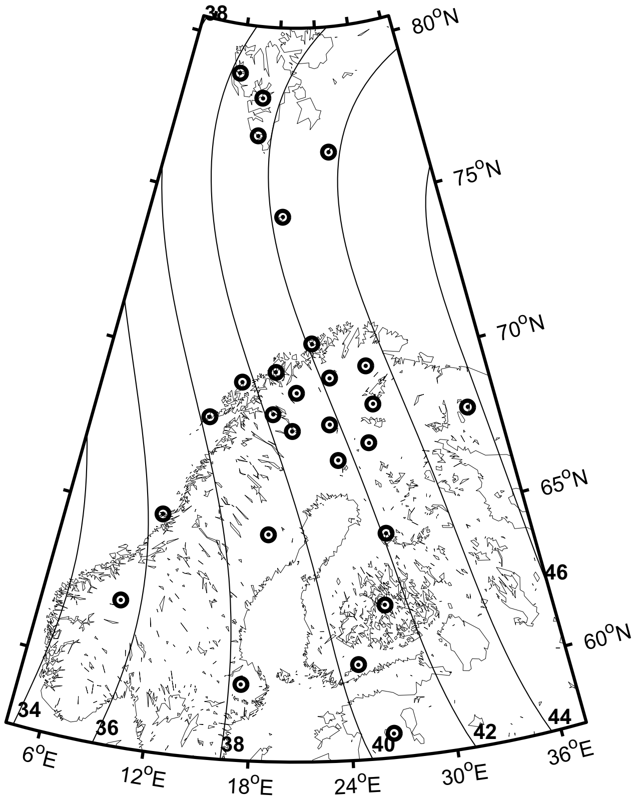


Fig. 2. (continued).

it could then be determined, for example, by using the mean value of the whole day. This might lead to biased baselines during very disturbed days, but it would not be harmful when looking for quiet days.

After having identified 202 days as quiet, this data set was used throughout the whole study for the baseline determination and the study of the quiet-time variation. Some additional corrections were needed at certain stations due to instrumental recalibrations and jumps, as well as the removal of a few days in the data set for some stations where the behaviour was still disturbed (especially at the northernmost stations). The method of determining quiet-time variations was accomplished as follows: we subtracted the secular variation from the field values of the selected quiet days. Then a linear fit between the detrended field values and the ring current index D_{ST} was determined for each station and for each field component. A clear latitudinal variation of the D_{ST} coefficients was found between the corrected geomagnetic latitudes 54 and 68 N. We used these results to construct the baseline function for each station. Baseline corrected field values were calculated for the selected quiet days to obtain the seasonal and diurnal quiet-time behaviour of the field at all IMAGE stations.

In the past other methods have been used to determine a suitable baseline. Campbell (1989) mentions a high pass filter of the magnetic signal as one possibility. This is adequate, if a spectral analysis of the S_q variation is performed, but for other purposes it is not suitable. A frequently used approach, and referred to by Campbell (1989) as the conventional method, is to look for quiet night-time levels on both sides of the event and connect these by a straight line. The resulting baselines have often proven to be reliable, but their determination requires human interaction and thus may be subjective.

3. Characteristics of Quiet-time Diurnal Variations

After the selection of the quiet days with the K_p and IE criteria, we calculated the mean value of the last hour of each of these days. A secular variation (SV) correction was applied to the field using the linear trend of the CHAMP CO2 magnetic field model (Holme *et al.*, 2003) for each component at all locations. Figure 2 shows the SV distribution in the region of the IMAGE array. The SV-corrected quiet-time data thus obtained exhibit no long-term trends. The only exceptions to this occurred in the Z component of the Norwegian stations Leknes and Rørvik (LEK and RVK in Fig. 1), where the SV-correction removed only 2/3 of the drift. We were later informed that these two particular stations were not very stable. These drifts were corrected with an additional factor.

All components of the quiet-time magnetic field at a given location are assumed to depend linearly on the D_{ST} index due to the characteristics of the magnetospheric ring current. Expressed as a formula, we assume a dependence at each station

$$B_i = k_i \cdot D_{ST} + B_{i0},\ i = x, y, z \qquad (1)$$

where k_i is the proportionality constant at individual locations. A reasonably linear behaviour was found in the SV-corrected quiet-time data at all stations and in each component. An example is shown in Fig. 3. Noting that the positive

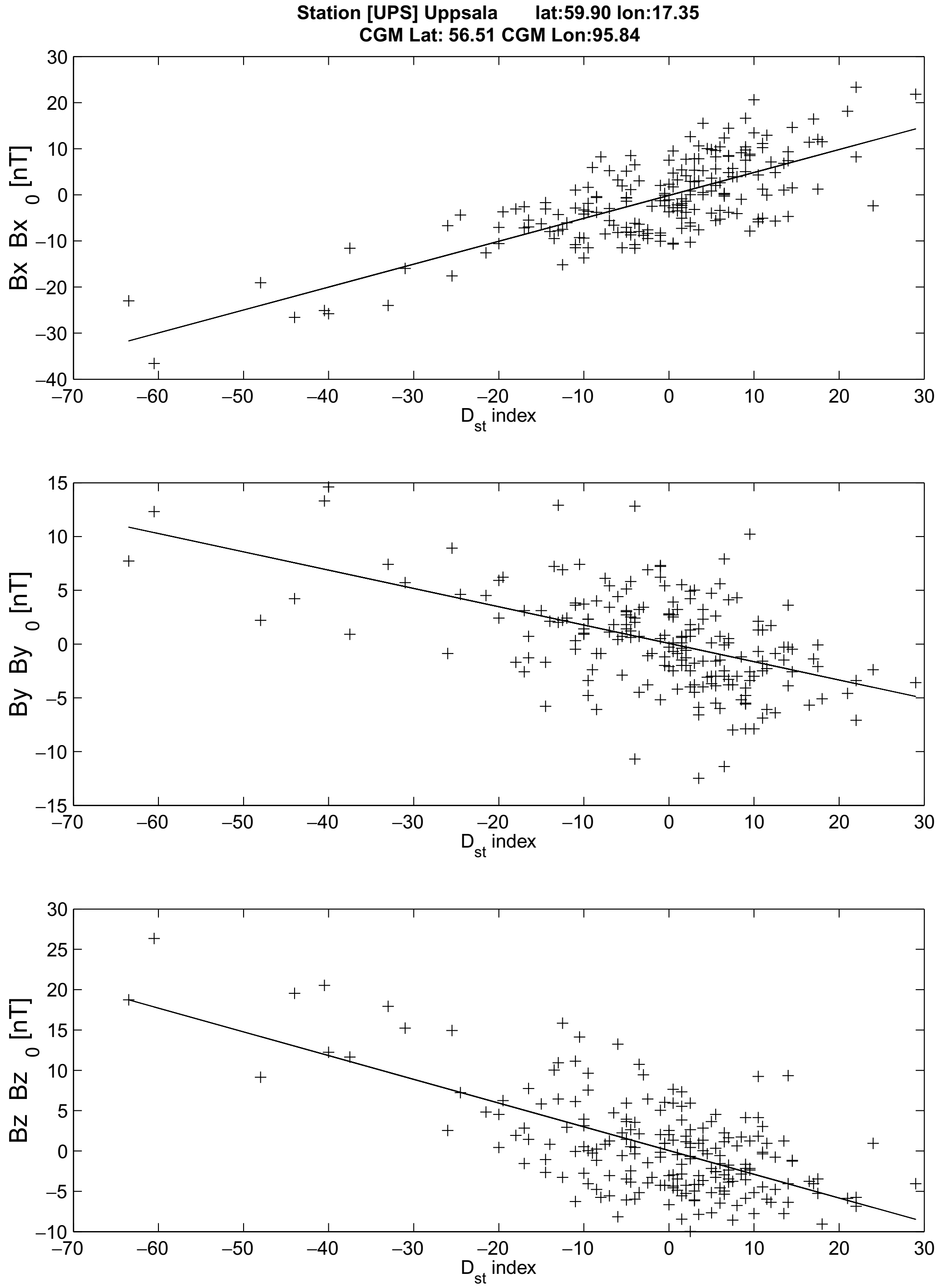


Fig. 3. Dependence of the quiet-time values on the D_{ST} index at Uppsala (UPS in Fig. 1). The magnetic field is the average of the hours 23–24 UT of the selected quiet days. Secular variation is subtracted according to the CO2 model.

slope in the D_{ST} correlation tends to increase X everywhere, whereas the negative slope tends to decrease Z in the northern hemisphere (increase in the southern hemisphere), the results are qualitatively as expected. The westward tilt of the dipole-magnetic axis with respect to the geographic north in the study region causes Y to decrease with increasing D_{ST}. The individual D_{ST} index proportionality constants (k_i) for the IMAGE stations are listed in Table 1.

The results indicate a small latitudinal variation of k_i in the mainland. Stations in the Svalbard archipelago behave more randomly possibly due to stronger induction effects in the surrounding highly conducting sea. Figure 4 shows these coefficients for each station against the corrected geomagnetic (CGM) latitude. The latitudinal dependence between 54 to 68 N CGM lat. for the D_{ST} coefficient of X, Y, Z can be approximated by a linear function

$$\begin{aligned} k_x(\theta) &= -0.005374\,\theta + 0.8174 \\ k_y(\theta) &= -0.003363\,\theta + 0.03998 \\ k_z(\theta) &= 0.003660\,\theta - 0.5110 \end{aligned} \quad (2)$$

where θ is the CGM latitude of the station (in degrees). For

Table 1. D_{ST} coefficients for IMAGE stations (Eq. 1). See also Fig. 4. Corrected geomagnetic coordinates were calculated for the year 2001 using the online service at http://nssdc.gsfc.nasa.gov/space/cgm/cgm.html.

station	CGM lat	CGM long	k_x	k_y	k_z
TAR	54.47	102.89	0.5556	−0.1129	−0.2961
UPS	56.51	95.84	0.4857	−0.1713	−0.2966
NUR	56.89	102.18	0.4912	−0.1395	−0.3289
HAN	58.71	104.61	0.5609	−0.1760	−0.2950
DOB	59.29	90.20	0.4620	−0.1942	−0.2762
OUJ	60.99	106.14	0.5010	−0.1298	−0.2929
LYC	61.44	99.29	0.4493	−0.1991	−0.3101
RVK	62.23	93.31	0.4920	−0.1634	−0.3051
PEL	63.55	104.92	0.4646	−0.1630	−0.2783
SOD	63.92	107.26	0.4651	−0.1537	−0.2600
LOZ	64.23	114.49	0.5349	−0.1312	−0.2496
KIR	64.69	102.64	0.4111	−0.1664	−0.2664
MUO	64.72	105.22	0.5232	−0.2150	−0.2756
IVA	65.10	108.57	0.4044	−0.1807	−0.2795
ABK	65.30	101.75	0.4587	−0.1844	−0.2719
LEK	65.40	97.50	0.5374	−0.2262	−0.2822
KIL	65.88	103.79	0.3994	−0.1903	−0.3039
MAS	66.18	106.42	0.7851	−0.1706	−0.2210
KEV	66.32	109.24	0.4570	−0.1132	−0.2535
AND	66.45	100.37	0.4147	−0.2011	−0.2795
TRO	66.64	102.90	0.5478	−0.2427	−0.2843
SOR	67.34	106.17	0.5926	−0.1570	−0.2625
BJN	71.45	108.07	0.1895	−0.2817	−0.4943
HOP	73.06	115.10	0.5122	−0.2356	−0.4524
HOR	74.13	109.59	0.1784	−0.1925	−0.3285
LYR	75.12	113.00	0.1377	−0.0647	−0.2982
NAL	75.25	112.08	0.0637	−0.3018	−0.4798

stations separately labeled in Fig. 4 it is recommendable to use the values of Table 1 instead of the formulas above.

With these steps of applying SV-correction and finding the influence of the D_{ST} index on the field values we were able to construct simple functions for the baseline fields B_i ($i = x, y, z$) of each station:

$$B_i = B_{i0} + SV_i \cdot d + k_i \cdot D_{ST} + f_i,\ i = x, y, z \qquad (3)$$

where B_{i0} is the initial quiet field value at the beginning of year 2000, SV_i is the linear trend of the CO2 model, and d is the day number (in MJD2000). Corrections due to instrumental jumps and recalibrations are included in the function f.

With the help of an appropriate expression for the baseline, we can easily isolate the quiet-time variations. By subtracting the baseline functions described above from the recorded data we obtained the diurnal variation of quiet days for each season from hourly averages. Because the quiet-times were selected based on the last hour of the day (23–24 UT), hourly means from 11 UT of the previous day to 10 UT of the following day were used here. No significant discontinuities appeared in the results at the 10–11 UT joints. This grouping of hours around the quiet night gave the best results. Examples of the diurnal variation are shown in Figs. 5 and 6 for the Uppsala and Sodankylä observatories, respectively. At these sites the night time (20 UT to 3 UT) field levels are very close to the baseline function values (the zero level in the figures), and the largest deflections are observed during the daytime. The error bars in these figures are the standard deviations indicating the spread of data of all the selected quiet days in that season, and show that the selection criteria worked relatively well for the whole 24 hour period. Somewhat larger error bars appear at SOD during the hours past local noon (11–18 UT) for the summer and autumn seasons.

The curves in Figs. 5 and 6 have been obtained by averaging the hourly means of all quiet days in a season. The 202 selected quiet days are distributed among the seasons as follows, spring: 79, summer: 38, autumn: 39, winter: 46. The variations are quite similar for all seasons, although the amplitude is much reduced during the winter season. Figure 7 shows the diurnal variation for each season over the whole IMAGE array. The stations selected (Ny Ålesund (NAL), Bear Island (BJN), Tromsø (TRO), Sodankylä (SOD), Oulujärvi (OUJ) and Nurmijärvi (NUR)) have mostly observatory quality, although the data quality

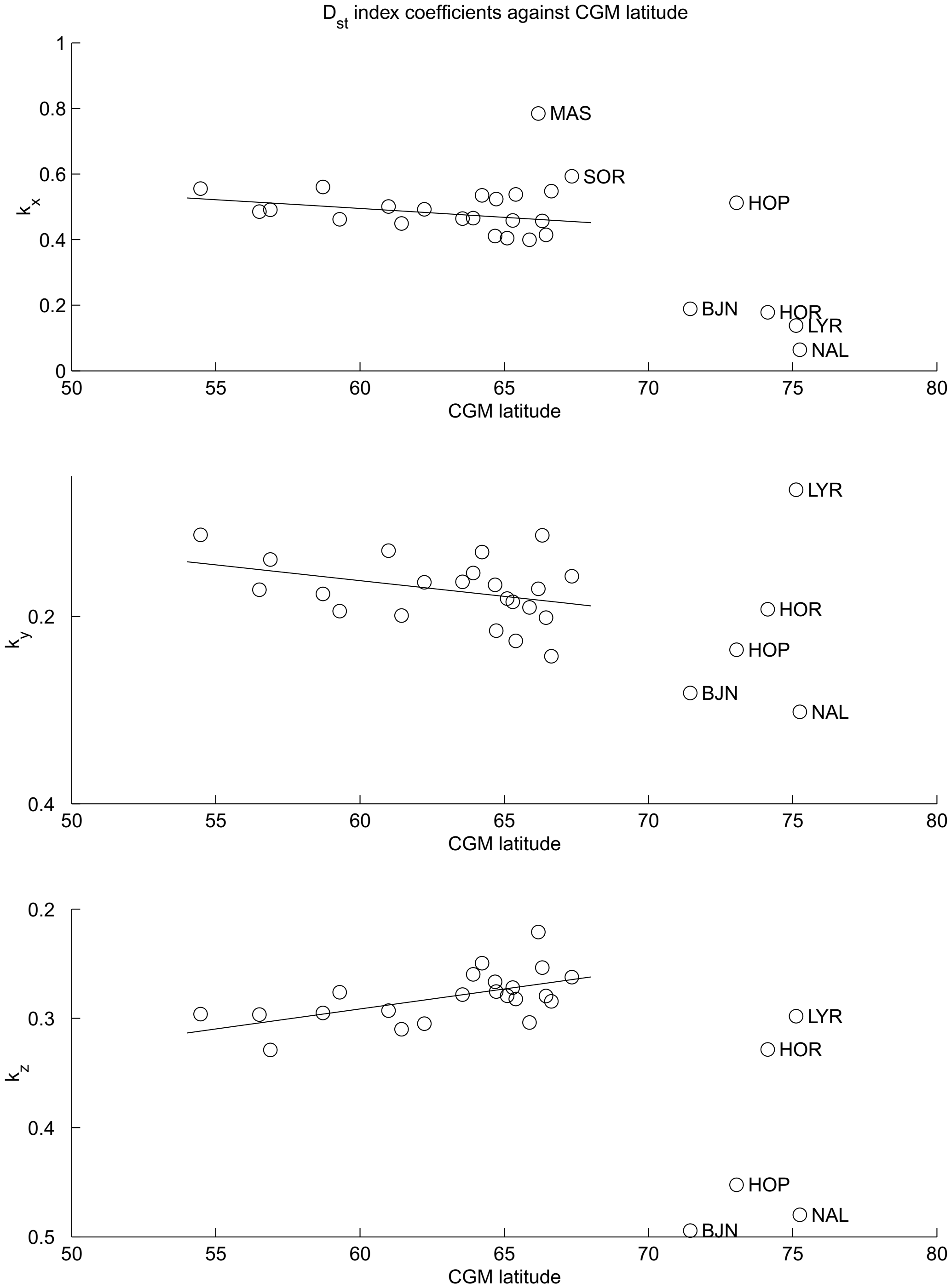


Fig. 4. D_{ST} index dependence of Eq. (3) as functions of the CGM latitude. Individually labeled sites are not used in the line fitting.

in general does not differ in any remarkable degree from the other stations. The results for stations close to each other were very similar and therefore this meridial chain of six stations gives a rather complete picture of the diurnal variation over the IMAGE region. For comparison, the S_q signature predicted by the model of Campbell (1997) is added for each station to the measured graphs in Fig. 7 as dashed lines. A caveat provided with the software program of the model warns that there is less confidence in the results outside mid-latitudes, because of the scarce data available from high latitude observatories. We find a reasonable agreement between the model and the observations at the stations on the Fennoscandian mainland (except for some deviation of the TRO X component during summer and autumn). The Svalbard stations, BJN and NAL, on the other hand, show little agreement with the model S_q curves at least in the components X and Z. Reasons for that will be discussed in the next section.

We also calculated seasonal mean values of the field at 22–01 UT (around the local midnight) during the quiet days. The results are plotted as latitude profiles in Fig. 8 for the same set of stations used in Fig. 7. The other stations followed the trend set by these stations closely. From these graphs we may read the seasonal variation of the baseline across the IMAGE

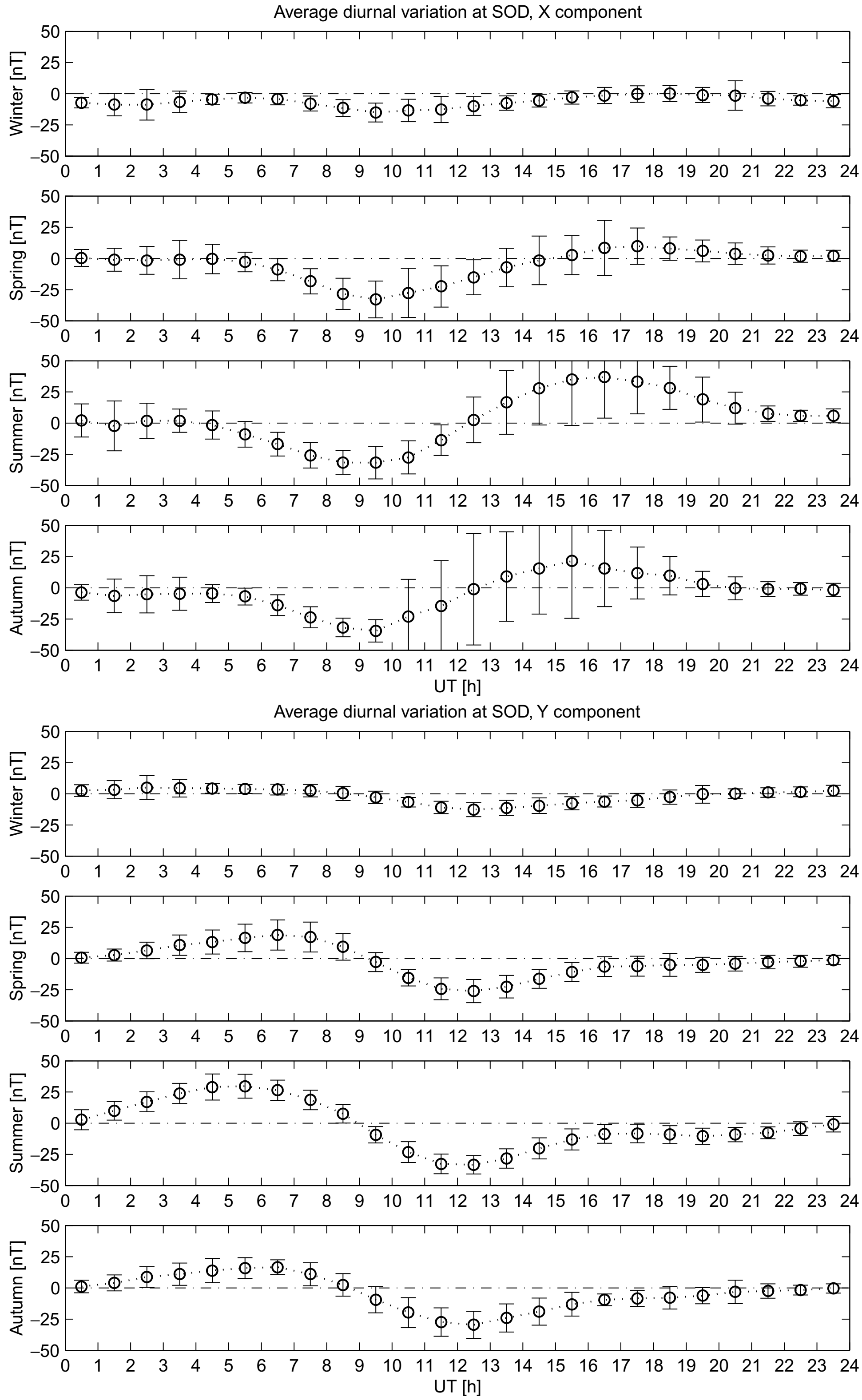


Fig. 5. Quiet-time variations at Sodankylä (SOD) during winter (Nov 6–Feb 3), spring (Feb 4–May 6), summer (May 7–Aug 6) and autumn (Aug 7–Nov 5). Circles connected with a dotted line show the average values, error bars indicate the standard deviations for each hourly value in our data set.

array. During the equinox seasons the night-time values are close to zero in all three components and at all stations. In Winter the average values are found at about -5 nT in the X component and 3 nT in Z. The opposite polarity is prevailing in Summer, 5 nT in X and -3 nT in Z. This is qualitatively consistent with the seasonal variation reported by Campbell (1989). The large deflections at Svalbard stations in Summer are due to the fact that there is no dark night-time during that season. In our study we have not corrected the baselines for the seasonal variation. The effect is, however, so small compared to the signals in Fig. 7 that it does not change the conclusions.

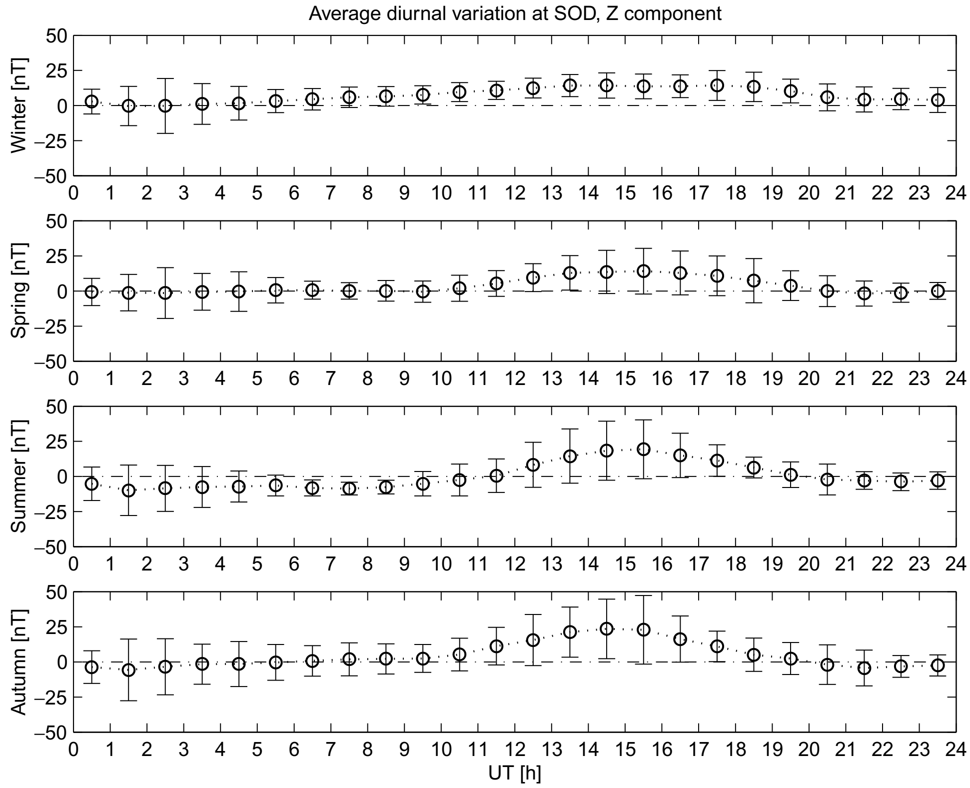


Fig. 5. (continued).

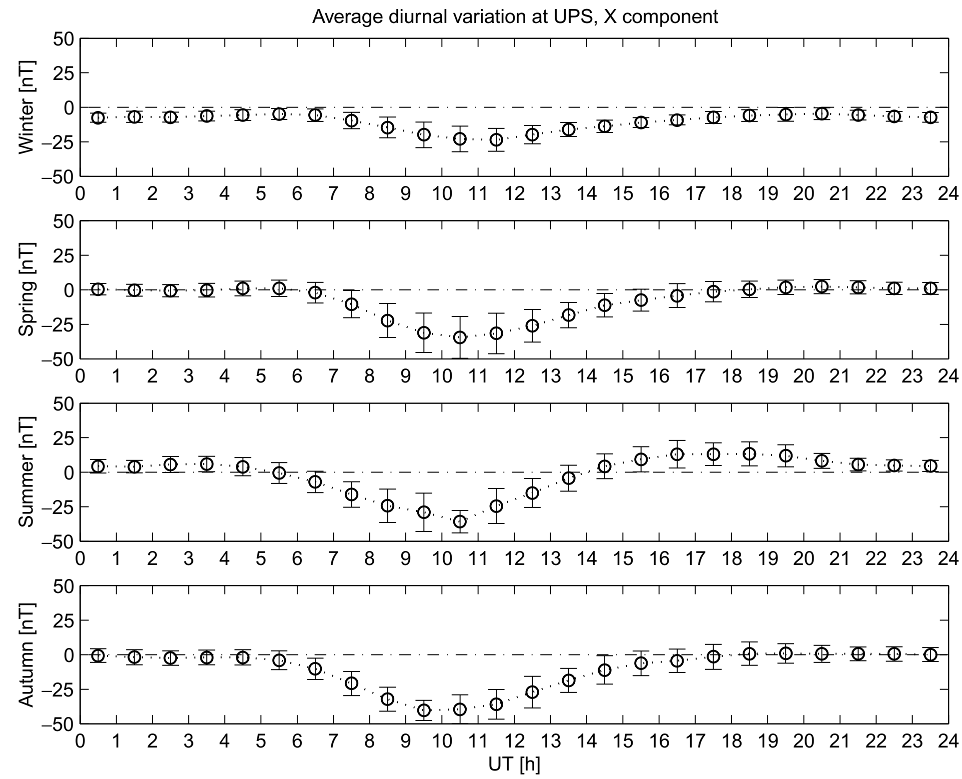
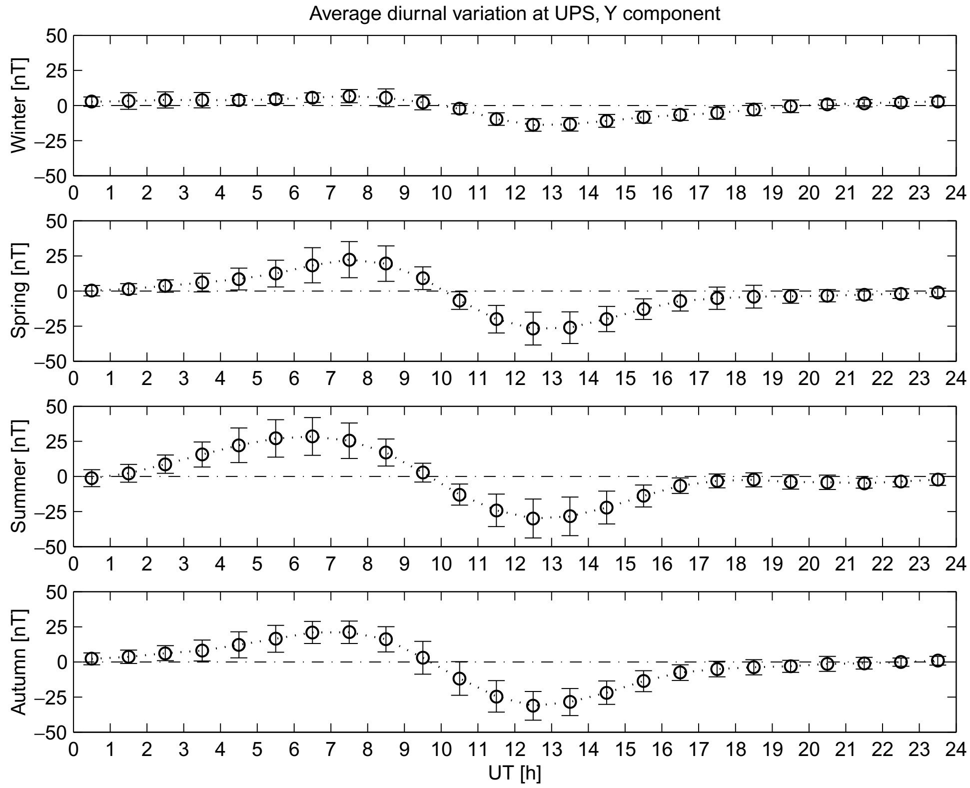


Fig. 6. Same as Fig. 5, but for quiet-time variations at Uppsala (UPS).

4. Discussion

We have presented an analysis of the quiet-time magnetic field variations at auroral latitudes. An important prerequisite for obtaining this result was the determination of reliable baseline values at all stations. It was not sufficient to correct only the instrumental effects in the data. All non-negligible contributions from magnetic field sources not related to ionospheric currents were removed.



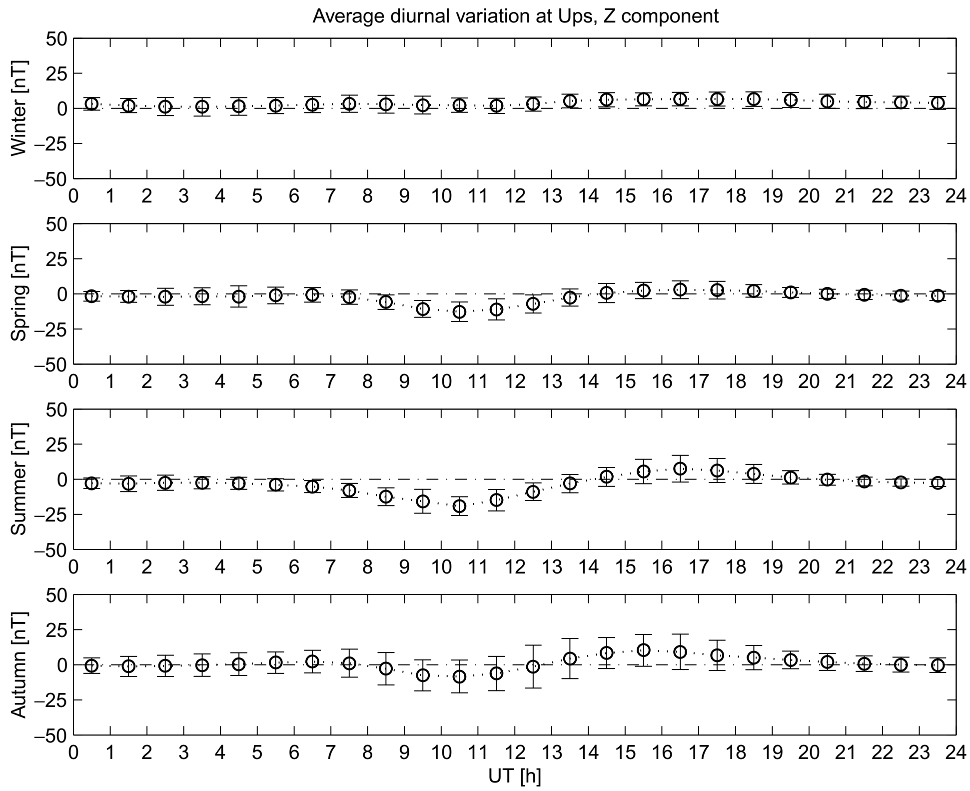


Fig. 6. (continued).

The largest part of the magnetic field reading originates from the main field. To account for the slow changes, the secular variation (SV), we made use of the CHAMP CO2 magnetic field model (Holme *et al.*, 2003). Throughout the IMAGE array we found a good agreement between the predicted trend and the observed field changes over the whole considered period of nearly two and a half years. This is also an evidence of the high quality of the magnetometers. From the distribution of the secular variation in Fennoscandia and Svalbard, as shown in Fig. 2, we see that there is almost no change in the northward (X) component. The eastward (Y) component shows an increase of some 30 to

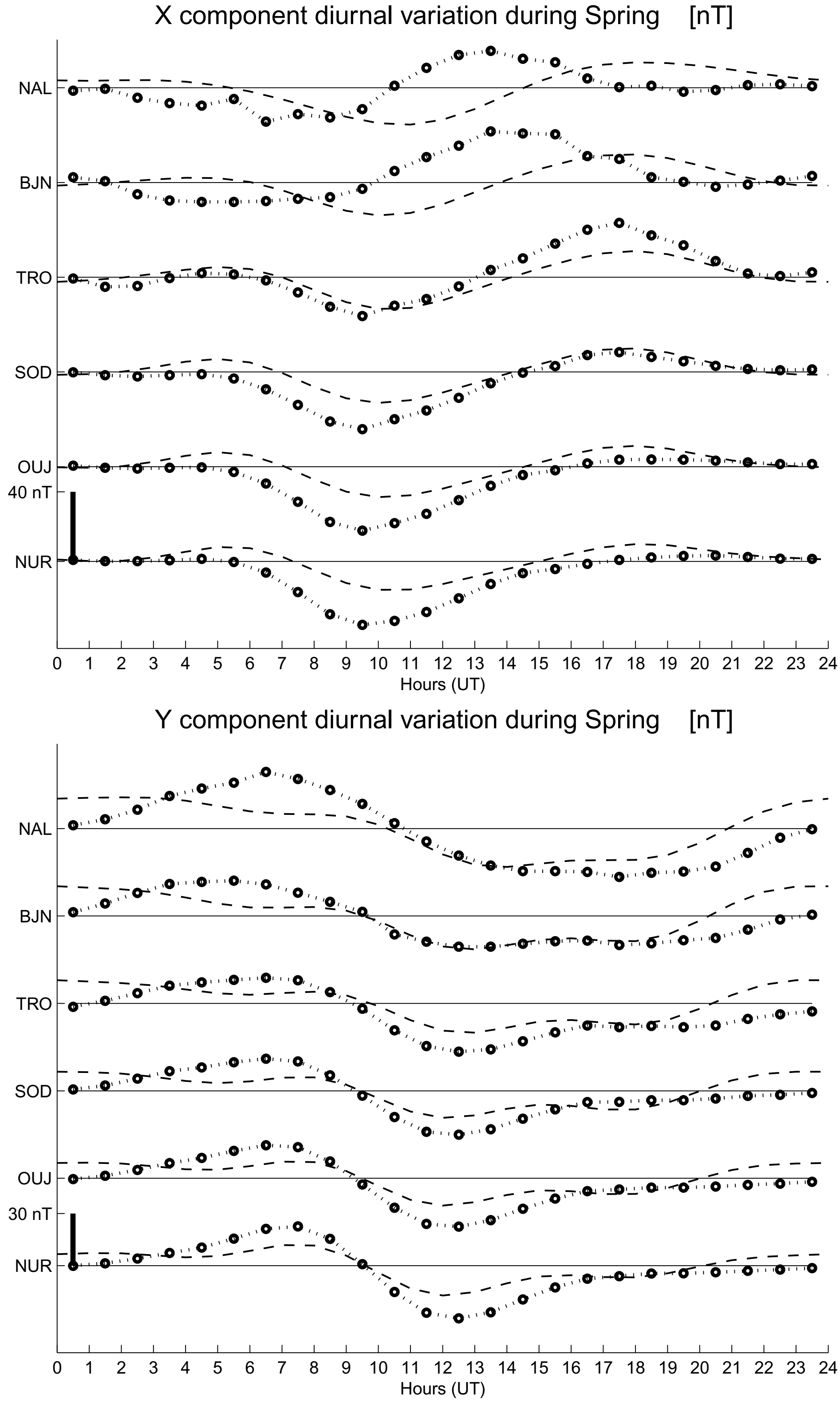


Fig. 7. Quiet-time variations at selected IMAGE stations along a south-north chain. Circles show the obtained quiet-day field values with baseline removed. Dashed curves show the S_q variation as derived from the model by Campbell (1997). From top to bottom the average signatures for spring, summer, autumn and winder are shown. The vertical bar in the left-hand-side of each panel indicates the scale in nT.

40 nT/a, which is indicative of the so-called westward drift of the magnetic field. The downward (Z) component is increasing quite strongly with some 40 nT/a. This is opposed to the global trend which shows a steady decrease of the field strength by some 20 nT/a.

The next contribution to be removed are the magnetic effects of the magnetospheric ring current and other large-scale currents. The D_{ST} index summarizes all of them in one number. Since the currents are rather far away and ordered by the geomagnetic field, their magnetic field is

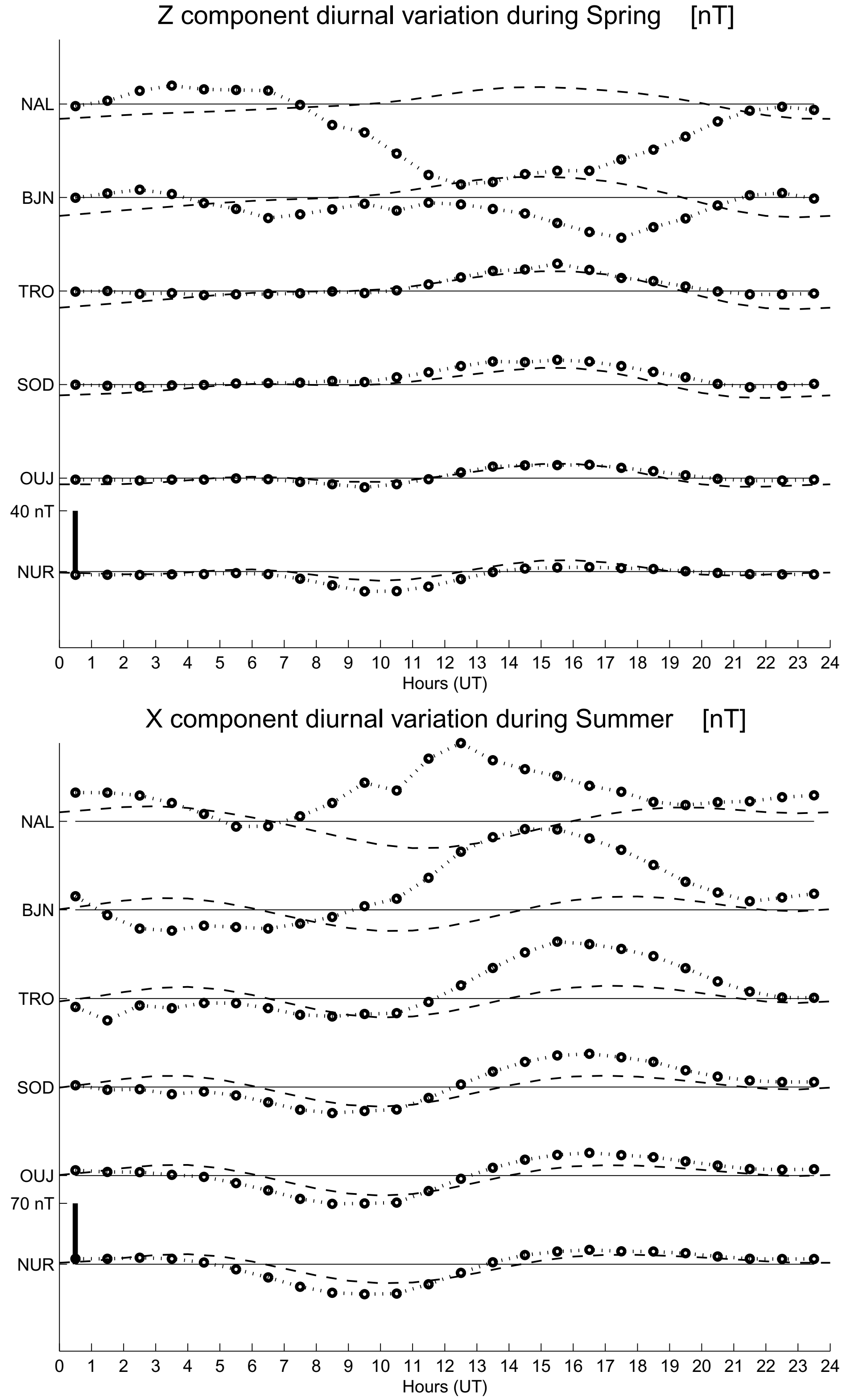


Fig. 7. (continued).

generally assumed to be homogeneous and aligned with the geomagnetic dipole. For such a field geometry a simple dependence on the D_{ST} index results in

$$X_{Dst} = D_{ST}\ \cos\theta_m\ ,\ Z_{Dst} = -D_{ST}\ \sin\theta_m \qquad (4)$$

where θ_m is the geomagnetic latitude. The components X_{Dst} and Z_{Dst} are for simplicity the magnetic components here, which do not deviate much from the geographic ones in the IMAGE region. A direct comparison between the theoretical predictions of Eq. (4) and the observed latitude dependence is presented in Table 2. For low and mid latitudes the predictions of Eq. (4), at least for the horizontal component, are known to be quite reliable. The numbers in Table 2 indicate,

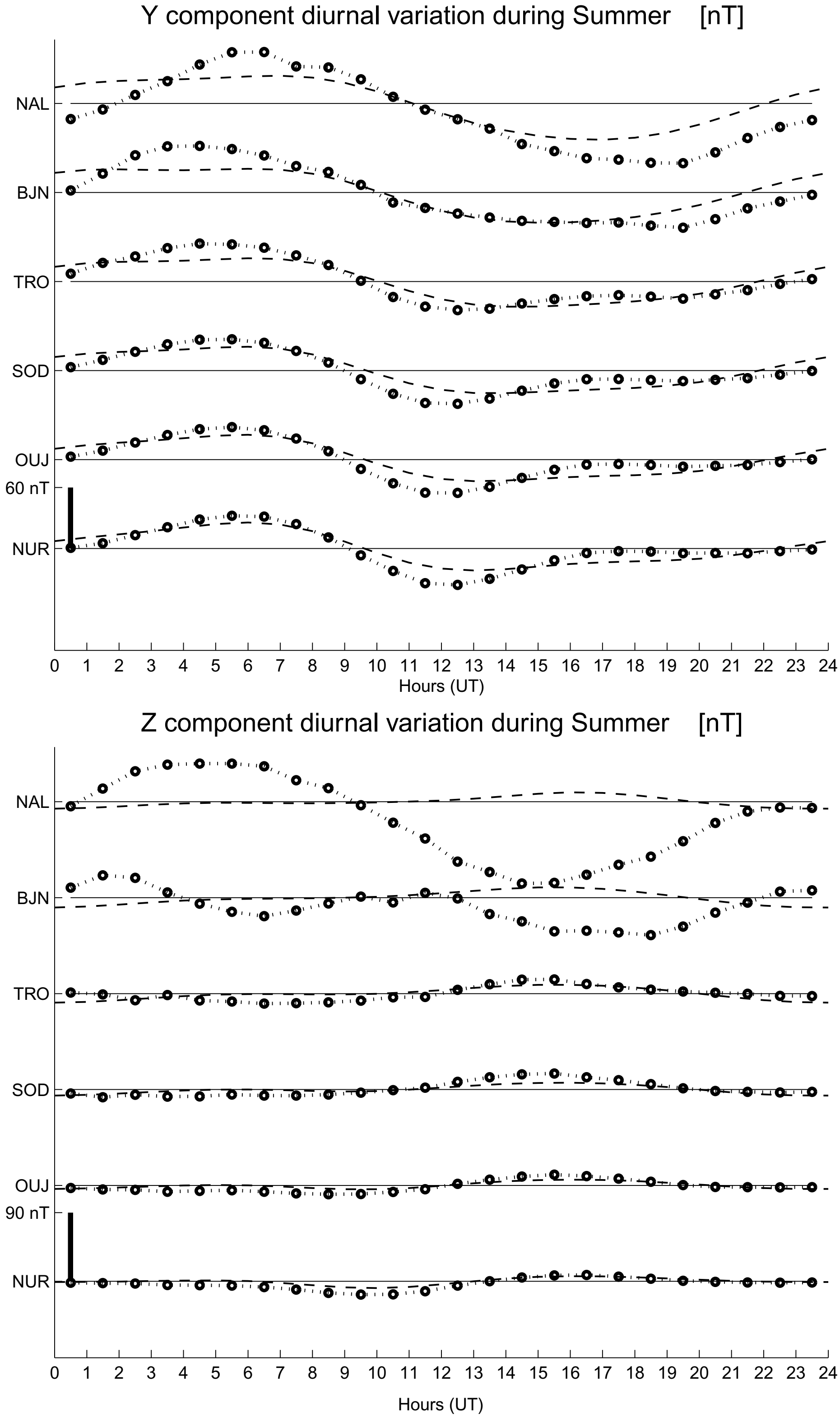


Fig. 7. (continued).

however, a large discrepancy between the expected and observed D_{ST} dependencies at high latitudes, particularly for the Z component.

Our impression is that there is no simple rule for correcting the D_{ST} effect at high latitudes, and this seems to be confirmed in Fig. 4. It may be suggested that the induction effect in the nearby ocean plays a role. Induced currents in response to the changes of the ring current can be approximated as mirror currents flowing predominantly in the east/west direction. Due to the high conductivity of sea water we may assume a channelling of these currents in the Barents Sea. Such a concept is consistent with the observed behaviour of the components. Southward of the current we expect a reduction of the D_{ST} effect and northward an en-

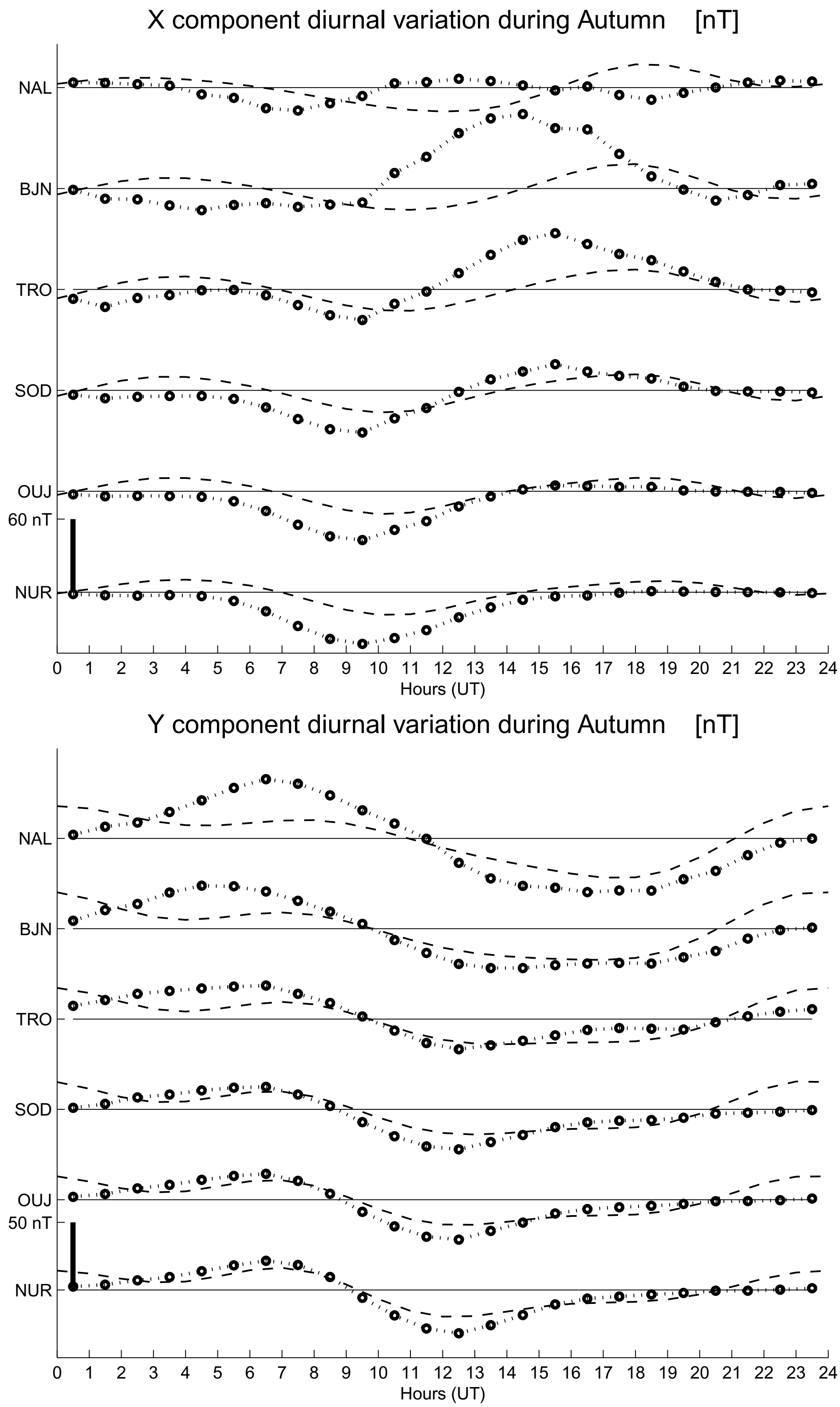


Fig. 7. (continued).

hancement. In Fig. 4 there is a positive slope of k_z on the mainland, although a negative slope would have been expected from Eq. (4). This can be interpreted as the reducing effect of the channelled induction current. Most of the stations on Svalbard, north of the current, experience an enhanced D_{ST} effect. The two exceptions (HOR, LYR) can possibly be attributed to the fact that there is no simple rule how island stations respond to the ocean effect.

In order to verify the quality of the quiet-time signature obtained, the standard deviation has been plotted in Figs. 5 and 6. Generally, these values are low, indicating that there is little variability from day-to-day on quiet days within one

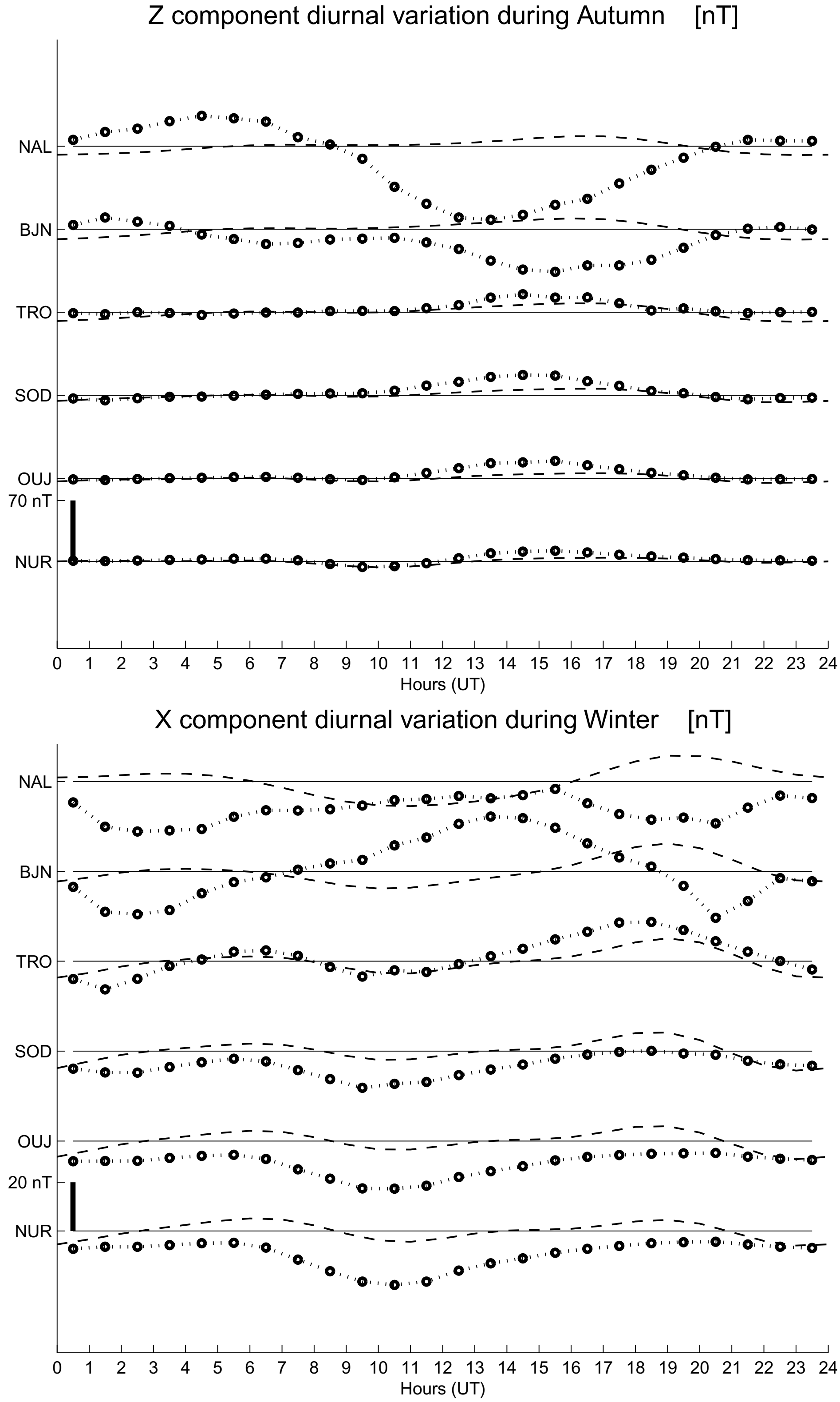


Fig. 7. (continued).

season. The larger deviations at SOD during afternoon hours are an indication of an additional, variable, eastward current at that time of the day. Since no such variability is found in UPS this current seems to be a feature of the auroral region.

The signature obtained in Figs. 5 and 6 reflects very well the S_q variation as expected for these latitudes. The X component shows a negative excursion around noon, while the Y component exhibits a positive/negative bipolar signature. There are low amplitudes in winter, but clearly larger during the other seasons. The features for the different seasons are in excellent agreement with the S_q for the European zone at 60 degree latitude presented by Matsushita (1967, e.g. his

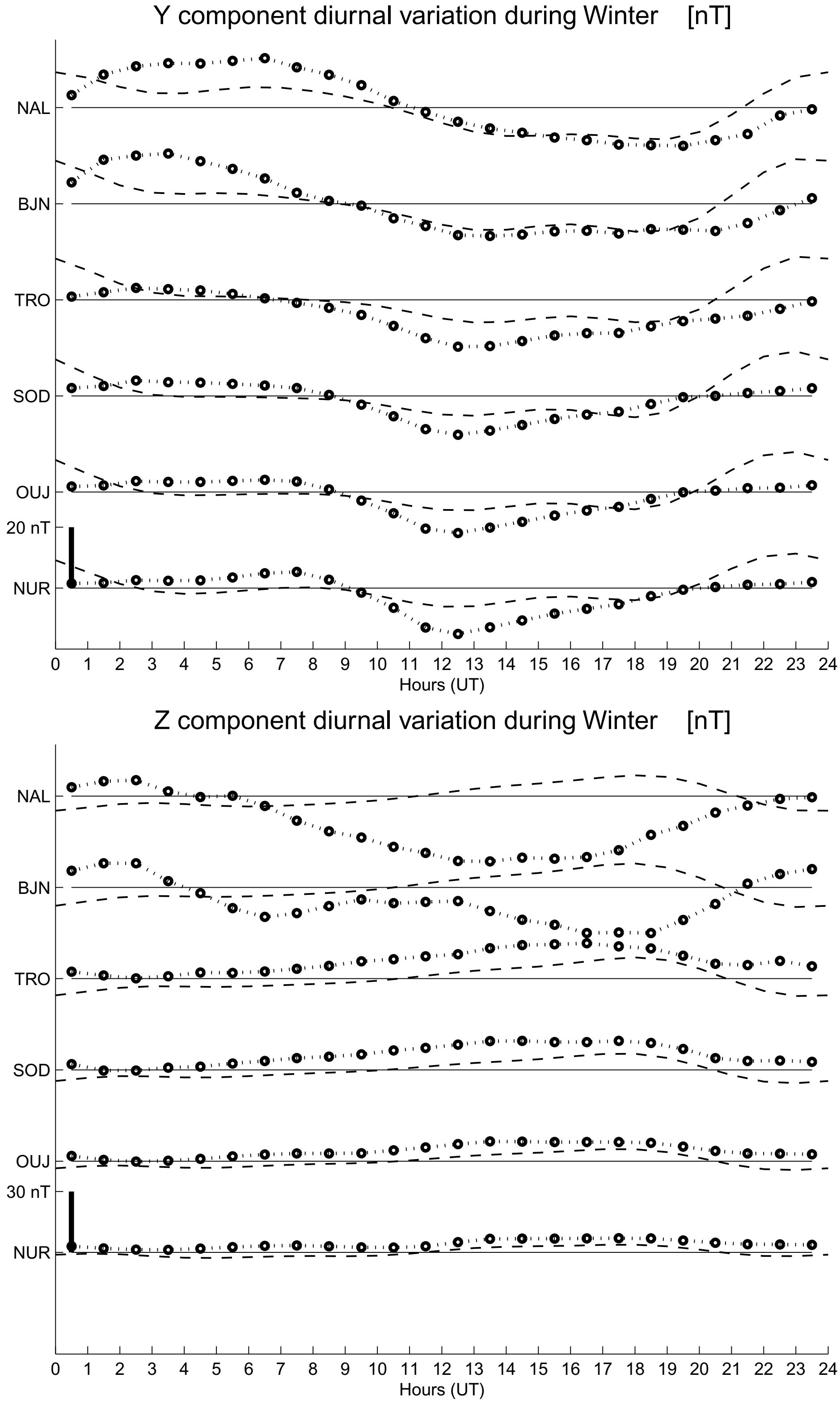


Fig. 7. (continued).

figures 7 and 8). Campbell's results (1997, e.g. his figure 2.23) obtained from spherical harmonics for S_q in the North American region show strong summer time effects in all components of the field. The characteristics differ from ours. This is probably due to the selection criteria used: K_p smaller than 2+ and the five quietest days of each month. These criteria poorly fit high latitude region quiet times, whereas we used the local AE index as a vital criterion.

The latitude variation of the quiet-time signal for the range 57 N to 77 N CGM lat. is shown in Fig. 7 separately for each season. As an indicator of the well-known S_q variation, the predictions from the model by Campbell (1997) have been added as dashed curves. For latitudes up to TRO (66 N CGM) we find a reasonable agreement between the

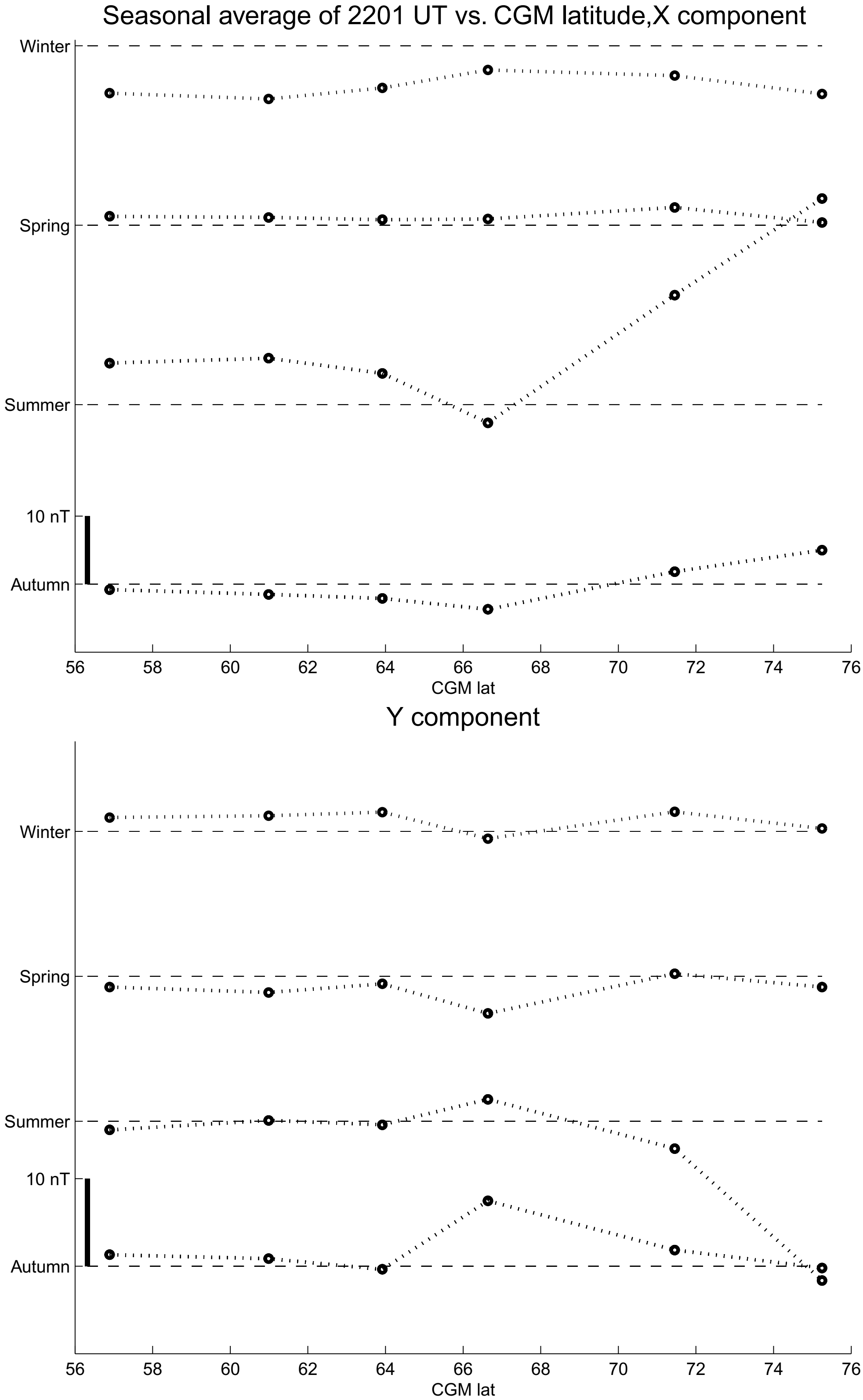


Fig. 8. Average quiet time variation versus CGM latitude around local midnight (22–01 UT). Stations NUR, OUJ, SOD, TRO, BJN and NAL included.

predicted and observed diurnal variations. At the two Svalbard stations, however, the corresponding curves have little in common, at least in the X and Z components. As indicated by the enhanced variability of the X component at SOD (cf. Fig. 5) there seems to flow a sizable eastward current at auroral latitudes during the afternoon and evening hours even on quiet days. The difference in the X component with respect to the reference curve increases poleward and reaches its maximum somewhere between TRO and BJN. This interpretation is also supported by the deflection of the Z component, positive at TRO, negative at BJN, which indicates a current centre between these stations. A peak deflection in

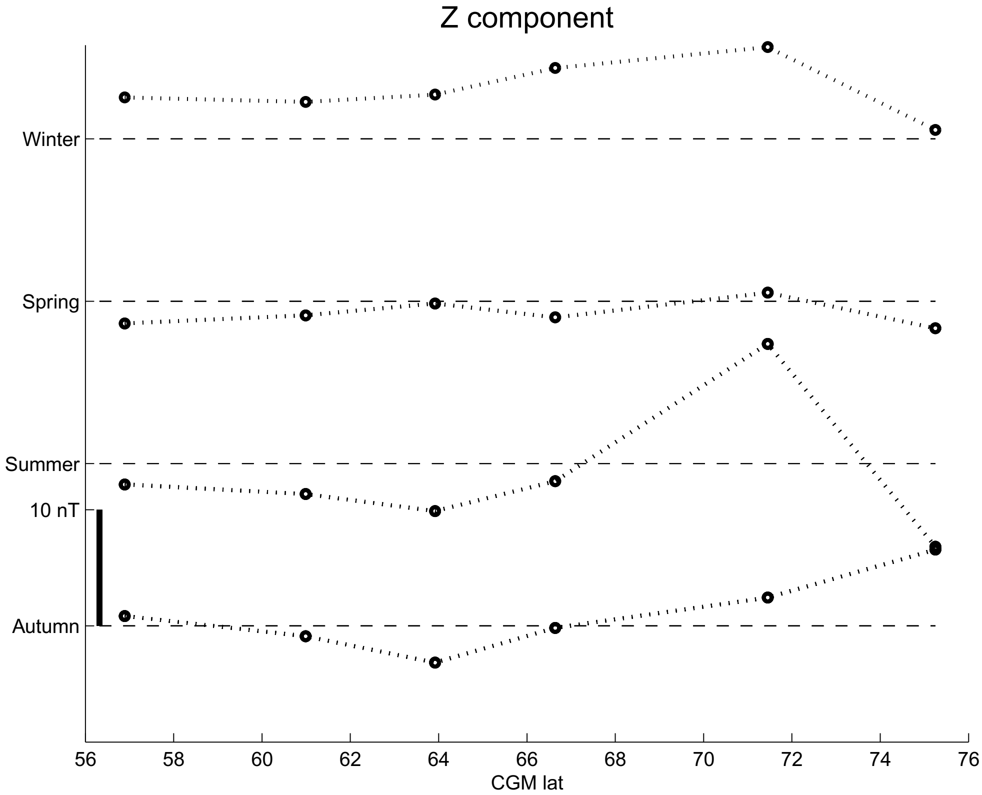


Fig. 8. (continued).

Table 2. Comparison of D_{ST} correction factors for two magnetic latitudes.

	Theoretically expected		Observed	
lat	54 N	68 N	54 N	68 N
X	0.588	0.375	0.527	0.452
Z	−0.809	−0.927	−0.313	−0.262

X of 94 nT is observed at BJN in summer around 15 UT (the maximum at TRO is attained an hour later). A similar deflection is found in autumn, where the peak amplitude of 60 nT occurs about an hour earlier. All this is an indication that convection electric fields drive an eastward electrojet in the sun-lit ionosphere during the afternoon hours even on quiet days. Further north, at NAL (76N CGM), deflections in the Z component are dominating. In summer they reach amplitudes up to 100 nT, but they are also noticeable during other seasons. For their explanation addition currents in the polar cap are required. The dominant signature is a sinusoidal variation with a maximum during morning and a minimum during the evening hours. A current system fixed in local time could give rise to such variations.

From Fig. 7 it is evident that a current system different from the S_q is required for latitudes higher than 65 N CGM. Nagata and Kokubun (1962) have suggested a current configuration for this S_q^p. Friis-Christensen and Wilhjelm (1975) invested magnetograms of very high latitudes, and derived the polar cap current system. According to their observations the characteristic of that current system is controlled by the interplanetary magnetic field, IMF, B_y component during quiet periods. The data set presented here is not sufficient to confirm these systems. In a follow-up study we will include other higher latitude stations to be able to draw a complete picture of the quiet-time equivalent current system up to the pole. This will allow to construct the S_q^p and S_q at high latitudes and outline the transition between the two.

Besides the evaluation of the quiet-time characteristics of magnetic variations at auroral latitudes there are some useful spin-offs emerging from this study. We have presented an objective method to determine the baseline of ground-based observations, which is appropriate for ionospheric current studies. This same technique has been used and approved in an extensive satellite/ground-based study of auroral current systems (Ritter *et al.*, 2004). Our procedure is also well applicable to observatory data and could be used in any kind of S_q, electrojet or pulsation study. Compared to a conventional method using international monthly quiet days as baselines, our approach is more robust. There are months whose quietest days are still active, but we are not fixed to them.

The results presented here are of particular interest for geomagnetic field modelers. It is a good practice to use quiet night-time readings for determining a main field model. In case of satellite magnetic field data evaluation, usually the field magnitude is used only at latitudes above 60 N CGM. This avoids the contamination of the internal signal by field-aligned current effects. At high latitudes the vertical (Z) component is almost aligned with the field lines. Variations in Z virtually reflect changes in the field magnitude. Figure 7 show that Z exhibits deflections of several tens of nT even on the night side during quiet days. It is particularly prominent during the summer. To avoid spurious effects in the main field models, it seems indispensable that the ever flowing currents in the polar ionosphere have to be corrected beforehand.

5. Conclusions

We have performed a statistical analysis of the quiet-time variations at northern auroral latitudes. For the first time to our knowledge a dedicated procedure for determining appropriate baselines has been applied for such a study. This special effort of removing all magnetic field contributions which are not caused by ionospheric currents makes our results significant.

The considered time period lasts from January 2000 to May 2002 and coincides thus with the solar maximum. Obtained amplitudes may therefore be larger than during other times. Our observations confirm a clear dependence of the S_q amplitude on the season. As expected, largest deflections are recorded in summer, indicating the importance of the solar EUV radiation for the ionospheric conductivity on quiet days.

The signature of the magnetic field variations reflects over large parts of the IMAGE array the response to the S_q current system. For latitudes higher than 65 N CGM different signatures appear. There are other current systems required even on quiet days to explain these. It will be the subject of a later paper, taking advantage of additional observations at higher latitudes, to resolve the quiet-time polar cap current system.

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