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Correcting the *Dst* index: Consequences for absolute level and correlations

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[1] We discuss here the consequences of the *Dcx* index which has recently been proposed as a corrected and extended version of the *Dst* index. *Dcx* corrects *Dst* for its excessive, seasonally varying quiet-time level, the so-called "nonstorm component" which is unrelated to magnetic storms. This correction can raise the *Dst* values by up to 44 nT for individual storms. The average increase of the *Dst* index is 6.0 nT for all SSC storms in 1932–2002 (5.7 nT in 1932–1956 and 6.1 nT in 1957–2002), implying a correction of about 23% to the average 7-day storm level, and a 14% correction to the average minimum-*Dst* value of 42.3 nT for all SSC storms. This correction is large enough to affect most previous storm studies and even the classification of storms to the different intensity levels. The correction has a strong seasonal variation with maxima around the equinoxes, especially in the vernal equinox. The largest monthly correction of about 12 nT is found for March. We verify that the main phase of an average storm is less intense and the recovery phase is longer in the early period (1932–1956) than in the later period (1957–2002), supporting the idea that storms in the early period were more typically driven by high-speed streams rather than by strong CMEs. Moreover, we show that the correction of the *Dst* index improves its correlation with both sunspots and geomagnetic indices. Thus conclusions based on correlating *Dst* with sunspots or geomagnetic indices need to be revised using the *Dcx* index.

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1. Introduction

[2] The *Dst* index is a geomagnetic index that is commonly used to study magnetic storms and the Earth's current systems, in particular the development of the ring current. Major disturbances in the *Dst* index are negative, reflecting the westward (eastward) directed drift of the energetic, positively (negatively, respectively) charged ions produced during the storm and the ensuing westward directed enhanced electric current. It has also been known for quite a long time that other current systems may also have, at least occasionally, a significant contribution to the *Dst* index [see, e.g., *Burton et al.*, 1975; *Campbell*, 1996]. The *Dst* index has been calculated at the World Data Center C2 at Kyoto, Japan, since the International Geophysical Year 1957, using data from four observatories at low latitudes (Hermanus, HER; Honolulu, HON; Kakioka, KAK; San Juan, SJG).

[3] We have recently reconstructed the entire *Dst* index [*Karinen and Mursula*, 2005], using the original *Dst* derivation method [see, e.g., *Sugiura*, 1964, 1969; *Sugiura and Kamei*, 1991] (see also the World Data Center C2 at http://swdcdb.kugi.kyoto-u.ac.jp) as closely as possible. Note that, as explained by *Karinen and Mursula* [2005], an exact reproduction of the original *Dst* index is not possible because, e.g., of missing information on the treatment of data gaps. However, the reconstructed *Dst* index correlates very well (correlation coefficient of 0.987 for hourly values) with the original *Dst* index. It also corrects some errors in the original *Dst* index. For example, all annual averages of the reconstructed index are negative which is in disagreement with the positive annual average of the original *Dst* index in 1965 (for a more detailed discussion, see *Karinen and Mursula* [2005]). The reconstructed index also extends the time span of the *Dst* index by more than 25 years to start in 1932. This extended *Dst* index is called the *Dxt* index.

[4] It was reported by *Cliver et al.* [2001] that the *Dst* index exhibits an excessively large semiannual variation which is not related to magnetic storms. The amplitude of the semiannual variation was found to be 5.3 nT when using all the *Dst* data and 2.5 nT when only the five internationally selected geomagnetically quiet days for each month were used [*Cliver et al.*, 2001]. Accordingly, 47% of the semiannual amplitude in the *Dst* index is related to the quiet days. This "nonstorm component" in the *Dst* index remained unsolved until *Mursula and Karinen* [2005] showed that the excessive semiannual component arises from the quiet-time seasonal variation of the magnetic field at the *Dst* stations which is not eliminated from the quiet-day curve when deriving the index. The suggested revised derivation method of the *Dst* index [*Mursula and Karinen*, 2005] yields a seasonally corrected index which is called the *Dcx* index (*c* for corrected; *x* for extended).

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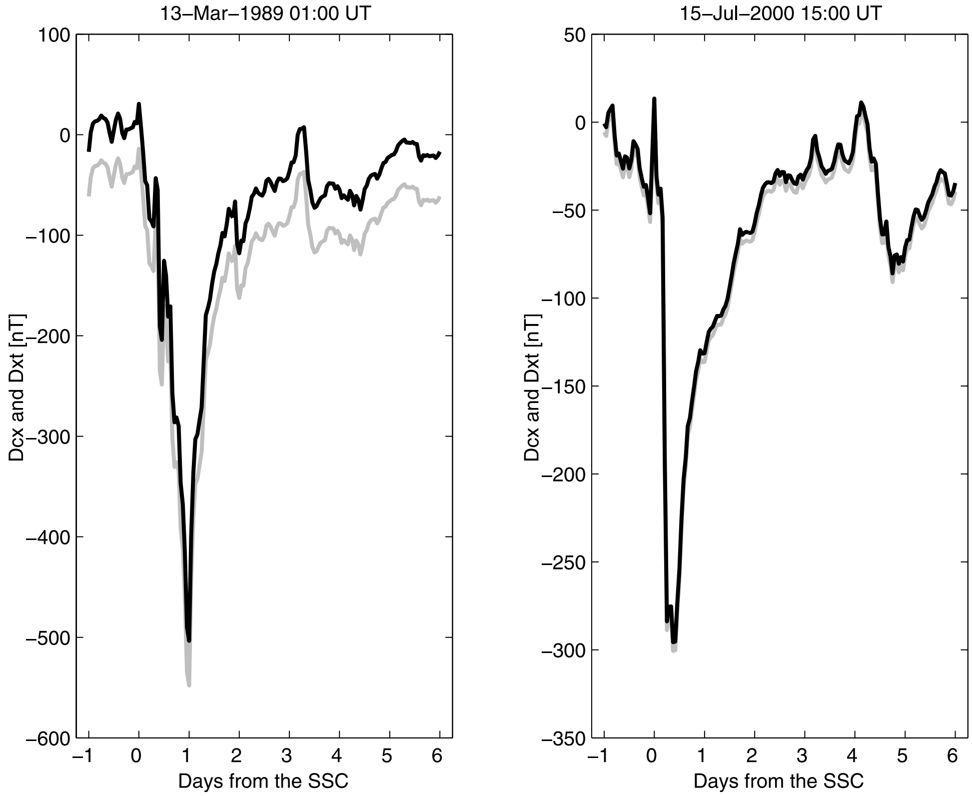

Figure 1. *Dcx* (black) and *Dxt* (grey) indices from 24 hours before SSC until 6 days after. The SSC signals were detected on 13 March 1989, 0100 UT (left) and on 15 July 2000, 1500 UT (right). These times are used as the zero epoch time in each panel.

[5] Without going here into too much detail (for a more detailed discussion, see *Karinen and Mursula* [2005]), we recall that the *Dst* index derivation contains two basic steps: first, removing the secular variation of quiet days from the measured *H* component yields the difference ΔH; second, removing the daily *Sq* variation from ΔH yields the disturbance level $D(t)$. In the original *Dst* method, a linear trend $L(t) = a \times t + b$ of nighttime values is removed from the superposed daily quiet curves in the S_q^o -matrix. As noted by *Mursula and Karinen* [2005], the intercept b includes the seasonally varying quiet-time level which is unrelated to magnetic storms. Accordingly, when S_q^o is subtracted from ΔH, this seasonal variation remains in $D(t)$, leading to an excessive seasonal (mainly semiannual) component in the *Dst* index. Therefore the essential feature in correcting the *Dst* index is not to include the intercept b but only use the $a \times t$ part of the trend in the above procedure. Moreover, when constructing the *Dcx* index, we have symmetrized the treatment with respect to the two nights by adding half of the difference $((b_2 - b_1)/2)$ between the two intercepts (b_2 and b_1) to S_q^o after removing the $a \times t$ trend. This is equal to first removing the full trend $L(t) = a \times t + b_1$ (with the intercept of the first night), and then adding the average intercept $(b_2 + b_1)/2$ to S_q^o (for a more detailed discussion, see *Mursula and Karinen* [2005]).

[6] In this paper we study the properties of the *Dcx* index, in particular comparing them with those of the *Dxt* index. Since the *Dxt* index has been calculated according to the original *Dst* derivation method and correlates well with the *Dst* index, the comparison of the *Dcx* index with the *Dxt* index also allows us to evaluate the effect of the new derivation method on the *Dst* index but over a longer, extended time interval. The paper is organized as follows. In section 2 we depict the difference between the *Dcx* and *Dxt* indices for two individual magnetic storms. Section 3 discusses the same difference for average magnetic storms, separately for each month over the full time interval and for the average storms during two time intervals, the pre-*Dst* interval 1932–1956 and the *Dst*-interval 1957–2002. Section 4 presents the annual means of the two indices, and section 5 discusses the correlation between ΔH on quiet days and the difference between the two indices. In section 6 we study the seasonal-diurnal distribution of the indices, and in section 7 their correlation with sunspot and geomagnetic activity. Finally, section 8 presents our conclusions.

2. *Dcx* and *Dxt* for Two Magnetic Storms

[7] Figure 1 depicts the *Dcx* and *Dxt* indices for two magnetic storms that started by a sudden storm commencement (SSC) on 13 March 1989 at 0100 UT and on 15 July 2000 at 1500 UT, respectively. Figure 1 shows the indices during 7 days (1 day before and 6 days after SSC), taking the SSC signal time as the zero epoch time in each case. In both cases, the temporal development of the storm is very similar in both indices. However, the absolute levels of the two indices can be quite different. In the left panel of Figure 1 the average value (over the 7 days of the storm shown) of the *Dcx* index is −74.2 nT and −118.2 nT for *Dxt*. In the right panel the average values are −60.4 nT and −65.3 nT, correspondingly.

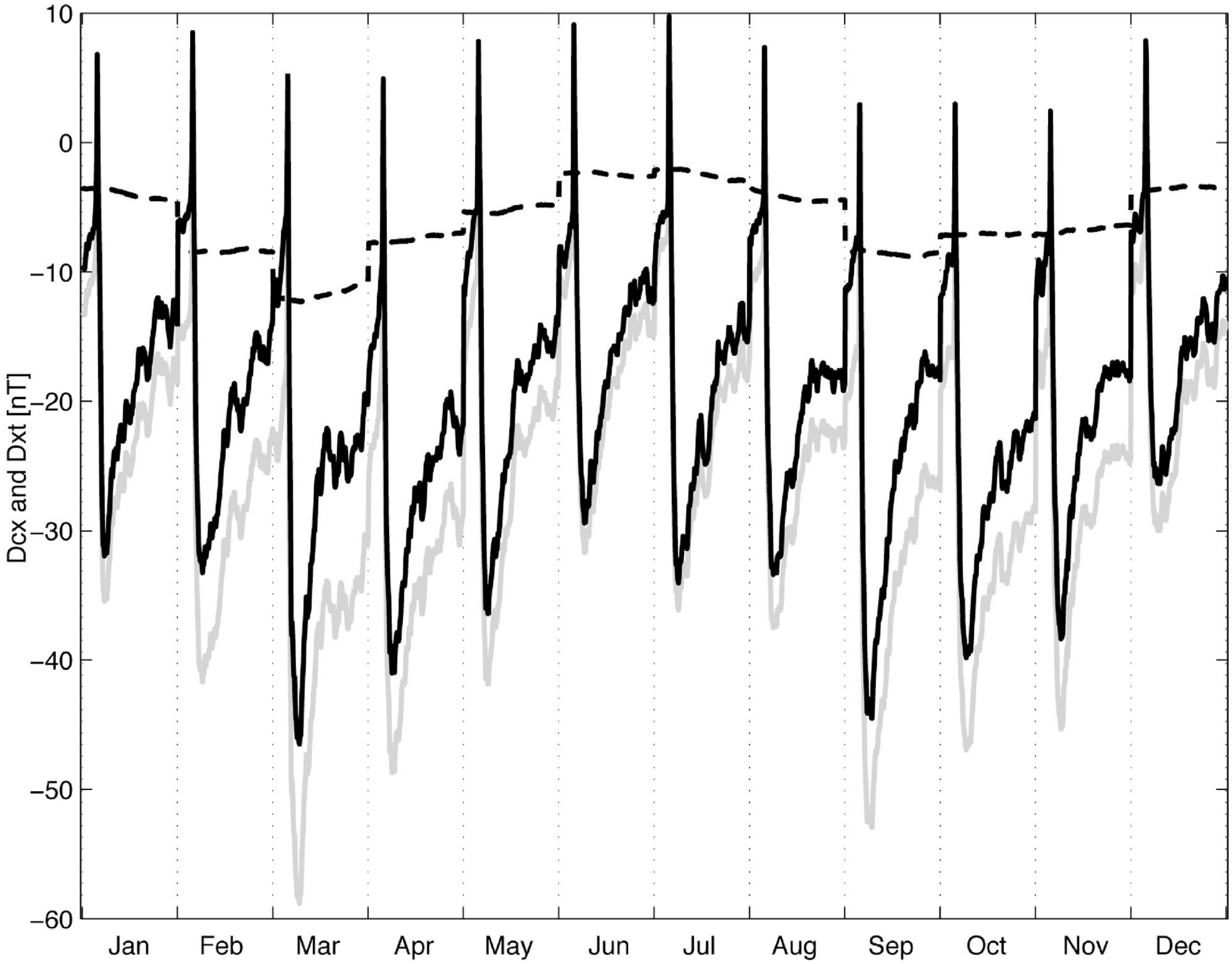

Figure 2. Superposed epoch storm curves for the *Dcx* (black) and *Dxt* (grey) indices in 1932–2002 for each month separately. The *Dxt* - *Dcx* difference is depicted as a dashed curve.

Consequently, the average difference between *Dcx* and *Dxt* indices is 44 nT for the 13 March 1989 storm but only 5 nT for the 15 July 2000 storm.

[8] Figure 1 shows that the correction of the *Dxt* (and thus the original *Dst*) index by the *Dcx* index can be substantial especially for equinoctial storms, changing the minimum *Dst* (and the overall) level by several tens of nanoteslas. Accordingly, the suggested correction to the *Dst* method is significant. Note that the storm in the left panel of Figure 1 was the largest observed in the interval. As seen in Figure 1, the *Dcx* index is on a higher level than the *Dxt* index for both storms. This is a typical case, and the *Dcx* index is, on an average, about 4.4 nT higher than the *Dxt* index when using all hourly values (see also section 4).

[9] Note also that the difference between the *Dcx* and the *Dxt* indices is roughly constant (44 nT and 5 nT, respectively) during each storm, even before the start of the storm (indicated by the respective SSC time). This reflects the seasonal nature of the difference between the two indices [*Mursula and Karinen*, 2005]. For example, the difference between the two indices is 44 nT during the whole month of March 1989. As we will discuss in section 3, the largest average differences are found during equinoxes, especially during spring equinox. This is also seen in the fact that the second largest difference of about 34 nT is found in February 1957 and 1982. The largest difference in solstitial months of about 28 nT is found in November 1955. Accordingly, the intensity of storms is overestimated in the *Dxt* index and therefore in the *Dst* index, especially during the vernal equinox times.

3. Superposed Epoch Analysis of Storms

[10] We have made a superposed epoch (SPE) storm analysis for the *Dcx* and *Dxt* indices. For this analysis we have included all the 2226 SSC storms in the *National Geophysical Data Center* (*NGDC*) [2004] list for 1932–2002. As in Figure 1, we have used the SSC time as the starting time of the magnetic storm and as the SPE zero time, including data from 1 day before and 6 days after this time. Thereby we have obtained the average temporal development of storms.

[11] Figure 2 depicts the average storm development in 1932–2002 according to the *Dcx* and *Dxt* indices for each month separately. The dashed line shows the *Dxt* – *Dcx* difference. This difference is always negative, demonstrating that the average storm level according to the *Dxt* index is below that of the *Dcx* index in each month. The average

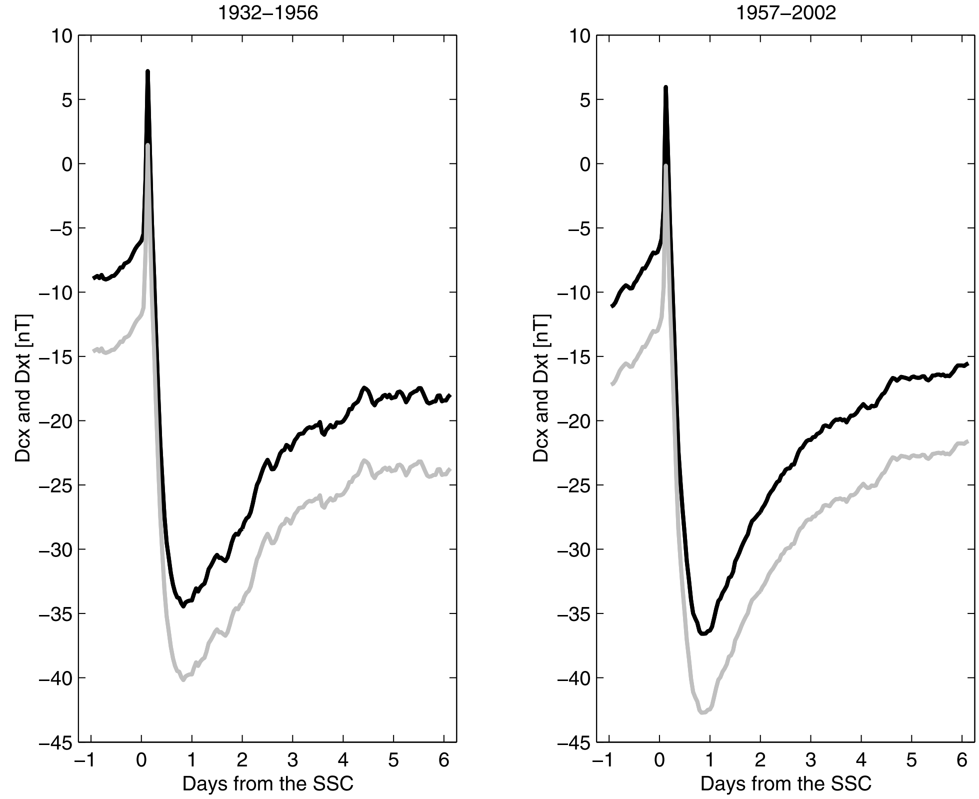

Figure 3. Superposed epoch storm curves for the *Dcx* (black) and *Dxt* (grey) indices in 1932–1956 (left) and in 1957–2002 (right).

difference between the two indices during the SSC storms is 6.0 nT, based on the average values of the *Dcx* and *Dst* indices during these times of −20.2 nT and −26.2 nT, respectively. Accordingly, the 6.0 nT correction implied by the new index to the average level of the *Dxt* index during magnetic storms is as large as 23%. Also, comparing the 6.0 nT difference to the average value of *Dxt* minimum of about 42.3 nT would imply a 14% correction. These changes are so large that they will affect most previous storm studies and even the classification of storms to the different intensity levels according to their minimum-*Dst* value (for recent papers, see, e.g., *Li et al.* [2001], *Temerin and Li* [2002], and *Chen* [2004]).

[12] Moreover, Figure 2 shows that there is clear seasonal variation in the *Dxt* - *Dcx* difference, with minima around equinoxes and maxima at solstices. The average difference between the two indices during March months is as large as 12 nT. The March 1989 storm depicted in Figure 1 is one of these storms. The large seasonal variation in the difference curve reflects the (roughly twice) larger seasonal variation in *Dxt* (and *Dst*) compared to the *Dcx* index due to the extraneous "nonstorm component" [*Cliver et al.*, 2001; *Mursula and Karinen*, 2005]. Note also that the minimum at the vernal equinox is deeper than the autumnal minimum. This is also clearly visible in the *Dxt* index but is largely removed in the *Dcx* index. The sinusoid amplitudes of the semiannual and annual variations in the *Dxt* - *Dcx* difference are 3.2 nT and 1.5 nT, respectively.

[13] Figure 3 depicts the SPE storm curves for the two indices, including all SSC storms in 1932–1956 and 1957–2002 separately. This was done in order to compare the average storm development during the period covered by the *Dst* index, with the extended early period 1932–1956. (There are 729 SSC storms in the early period and 1497 in the later period). Note also that we have earlier calculated the similar SPE storm curves using the *Dst* and *Dxt* indices in 1957–2002 and shown that they follow each other very closely (the average difference between the two SPE curves was only 0.08 nT; see Figure 8 in the work of *Karinen and Mursula* [2005]).

[14] Figure 3 shows that, as in case of individual storms of Figure 1 and monthly average storms in Figure 2, the *Dcx* and *Dxt* SPE storm curves closely follow each other over the whole 7-day storm period. The averages of the SPE storm curves for the *Dcx* index are −20.4 nT in 1932–1956 and −20.2 nT in 1957–2002. For the *Dxt* index these values are −26.1 nT and −26.3 nT. Consequently, the mean difference between the SPE storm curves for the two indices is 5.7 nT for the early period and 6.1 nT for the later period, in a good agreement with the above mentioned overall storm-time difference of 6.0 nT.

[15] The similar form of the *Dcx* and *Dxt* storm curves in Figures 1–3 is due to the fact that the correction relates to the seasonal variation [*Mursula and Karinen*, 2005] and that the average storm length of about 7 days is shorter than the length of the season. This is also seen in the fact that the monthly differences in Figure 2 are roughly constant. Also, since the two storm curves have roughly the same shape, the differences found earlier for the *Dxt* SPE storm curves between the early period 1932–1956 and the later period 1957–2002 [*Karinen and Mursula*, 2005] remain valid for the *Dcx* SPE curves as well. In particular, the main phase of

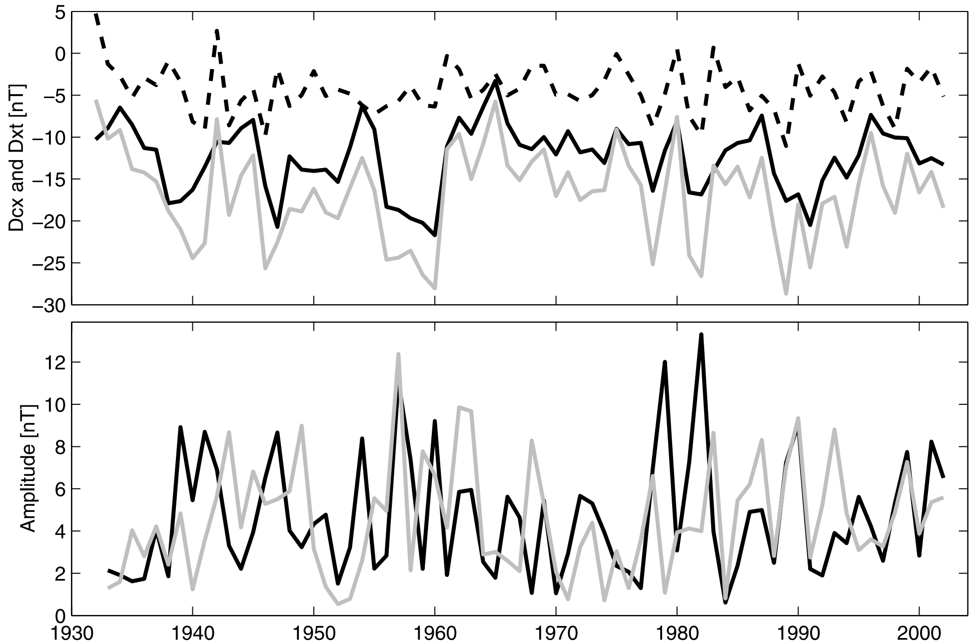

Figure 4. (top) Annual averages of the *Dcx* (black) and *Dxt* (grey) indices in 1932–2002. Dashed curve depicts the *Dxt* - *Dcx* difference. (bottom) Sinusoid amplitudes of the semiannual (black) and annual (grey) variation in the *Dxt* - *Dcx* difference in each year.

the SPE storm is about 2.5 nT less intense and the recovery phase is about 7 hours longer (calculated as an average delay of attaining a certain percentual level after minimum) in the early period than in the later period. These results support the idea [*Karinen and Mursula*, 2005] that the storms in the early period were more typically driven by high-speed streams rather than by strong CMEs. High-speed streams often produce long, HILDCAA (high-intensity long-duration continuous AE activity) [*Tsurutani and Gonzales*, 1987; *Søraas et al.*, 2004] type storm recovery phases.

4. Annual Means of *Dcx* and *Dxt*

[16] The annual means of *Dcx* and *Dxt* indices using all (not only storm-time) hourly values are depicted in Figure 4. The mean and standard deviation of the annual means of the *Dcx* index are −12.4 nT and 3.9 nT, respectively. For the *Dxt* index these values are −16.8 nT and 5.5 nT. Accordingly, the average difference between the annual mean values of *Dcx* and *Dxt* is about 4.4 nT. Figure 4 depicts the annual *Dxt* - *Dcx* differences as a dashed line.

[17] Note that even for annual means, the difference between the two indices varies greatly. As expected, in most years the annual means of the *Dcx* index are higher than those of the *Dxt* index, leading to a negative difference. Only in three full years (1942, 1980, and 1983; 1932 is incomplete) the *Dxt* index is slightly above (less negative than) the *Dcx* index. Note also that the difference does not depict any straightforward change along the solar cycle. However, there is some regularity in the way that local maxima are found both in the ascending as well as in the declining phase of most cycles.

[18] The largest absolute difference of 11.1 nT between the annual means is found in 1989, making *Dcx* to depict the lowest annual mean of −21.7 nT in 1960, instead of having the lowest value (−28.6 nT) in 1989 according to the *Dxt* index. Note also that the highest annual mean of the *Dcx* index is −3.3 nT in 1965. Accordingly, there are no years when the mean *Dcx* index is positive. This supports the view presented earlier based on *Dxt* [*Karinen and Mursula*, 2005] that the positive annual mean in 1965 in the *Dst* index is due to an erroneous calculation of the index during that year.

[19] We have also calculated the amplitudes of the semiannual and annual variation in the *Dxt* - *Dcx* difference for each year. These amplitudes are also depicted in Figure 4. The average amplitudes are 4.7 nT and 4.9 nT for the semiannual and annual variation, respectively. One can see the great variability in both amplitudes from one year to another. However, they are weakly correlated with each other with a coefficient of 0.34. Also, as with the *Dxt* - *Dcx* difference, the amplitudes do not depict any simple dependence over the solar cycle. These average amplitudes show that seasonal variation can make a large contribution to the quiet-day level, i.e., to the intercept b, in addition to the annual average level of −4.4 nT.

[20] The relative importance of the semiannual and annual variation and the annual average level (the annual *Dxt* - *Dcx* difference) to the variation of monthly values of b can further be quantified as follows. The above mentioned seasonal amplitudes were obtained by fitting the model consisting of an annual average and the two sinusoids to the monthly values of the *Dxt* - *Dcx* difference (monthly b-values) each year. We then calculated the standard deviation of the difference between the observed and the so modeled b-values, obtaining 4.74 nT. When using the same fit but setting the semiannual amplitudes to zero one obtains a fit with a larger standard deviation of 6.11 nT. Similarly, neglecting the annual variation (the annual level), yields a standard deviation of 6.23 nT (5.50 nT, respectively). This

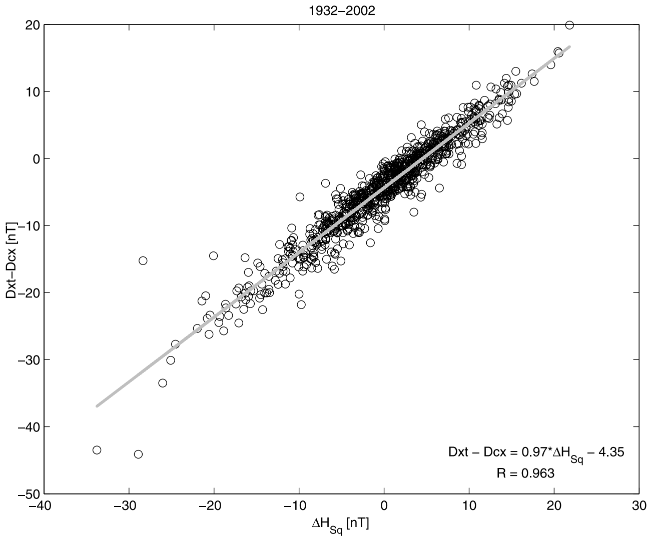

Figure 5. Correlation of monthly averages of the *Dxt* - *Dcx* difference and the combined quiet-day ΔH values in 1932–2002. The best fitting line and its equation are included.

shows that, despite the large amplitudes of the seasonal variation, the annual average level in *Dxt* - *Dcx* difference (i.e., in the intercept *b*) is the most important parameter in explaining the variation of the monthly *b*-values.

5. Correlations With ΔH

[21] As explained above, the (annually varying) seasonal quiet-day variation causes the *Dxt* - *Dcx* difference. In order to further demonstrate this we have computed the combined ΔH for the four *Dst* stations as follows. For each *Dst* station, we first calculated the local ΔH and normalized it by the cosine of dipole latitude of the respective station. Then we averaged these four normalized ΔH values to get the combined ΔH. As noted earlier, the secular variation which is removed from the hourly *H*-components when forming ΔH, is calculated using quiet days of each month. Thus calculating (monthly averages of) the combined ΔH during quiet days, yields a parameter that quantifies the (annually varying) seasonal quiet-day variation of the average *H*-component at the *Dst* stations.

[22] We have correlated the monthly averages of the combined quiet-day ΔH and the *Dxt* - *Dcx* difference in Figure 5 which depicts an excellent correlation with correlation coefficient of 0.96. Using annual rather than monthly averages, one obtains only a slightly smaller correlation ceofficient of 0.93. This further demonstrates the above result that the annually varying level of the seasonal variation of the quiet-day *H*-component is the most important factor in varying the *b*-value.

[23] Calculating the similar correlation coefficients between ΔH and the two indices separately yields 0.66 and −0.005 for *Dxt* and *Dcx*, respectively. This verifies that there is a considerable amount of quiet-time seasonal variation included in the *Dxt* index but none in the *Dcx* index.

[24] We have also calculated the similar correlation coefficients using all (not only quiet) days when calculating the monthly averages of ΔH. Then the highest correlation of 0.98 is found between *Dxt* and ΔH. This shows that after the daily variation has been suppressed by taking monthly averages, the *Dxt* index is completely determined by the (annually varying) seasonal variation of the *H*-component. There is also a fair correlation of 0.69 (0.74) between the *Dcx* index (the *Dxt* - *Dcx* difference) and ΔH, showing that, even after the correction, there is a significant seasonal variation in magnetic storms which, quite correctly, remains in the *Dcx* index.

6. Seasonal-Diurnal Distributions

[25] Figure 6 depicts the seasonal-diurnal (UT) distribution of the *Dcx* and *Dxt* indices in 1932–2002 with index values given in black and white intensity coding. A dominant semiannual variation with equinoctial maxima is apparent for both indices. The main difference between the two panels is the great reduction in the range of the *Dcx* index, implying a smaller seasonal variation in *Dcx* than *Dxt*. The same result was shown as a UT-integrated line plot in the work of *Mursula and Karinen* [2005].

[26] As expected from the seasonal cause of the *Dxt* - *Dcx* difference, this reduction is very similar at each UT hour. Accordingly, the UT distribution remains quite the same in the two indices, as seen in Figure 6. Note also that the UT distribution of the *Dst* index is mainly due to the imperfect longitudinal and hemispherical distribution of the *Dst* stations [*Takalo and Mursula*, 2001], which masks the more physical effects causing UT variation in geomagnetic activity, like the equinoctial mechanism or Russell-McPherron mechanism (for recent review, see *Cliver et al.* [2000, 2001].

[27] The time derivative (difference of successive hourly values) of the *Dst* index has sometimes been correlated with indices of geomagnetic activity [*Cliver et al.*, 2000]. We note that, since the difference of hourly values completely removes the seasonal variation, the *Dcx* index and the *Dxt* index yield a closely similar seasonal-diurnal distribution for the time derivative. Accordingly, the conclusions derived by *Cliver et al.* [2000] from such correlations remain untouched.

7. Correlation With Sunspot and Geomagnetic Activity

[28] Positive values of the *Dst* are mainly due the compression of the dayside magnetosphere in the initial phase of storm, while negative values are due to magnetic reconnection and the formation of the storm-related currents, in particular the ring current. Therefore positive and negative values of the *Dst* index rise from different physical processes. Accordingly, we have also calculated the annual averages of the *Dcx* and *Dxt* indices using only their negative or positive values, correspondingly. These values are called the Dcx^- and Dcx^+ (Dxt^- and Dxt^+) indices.

[29] Both the dayside compression and storm development are driven by the variable conditions in the solar wind and the heliospheric magnetic field (HMF). One of the most important parameters for storm development is the HMF intensity which is related to the magnetic intensity on solar surface and thereby to sunspot activity. In fact, the contri-

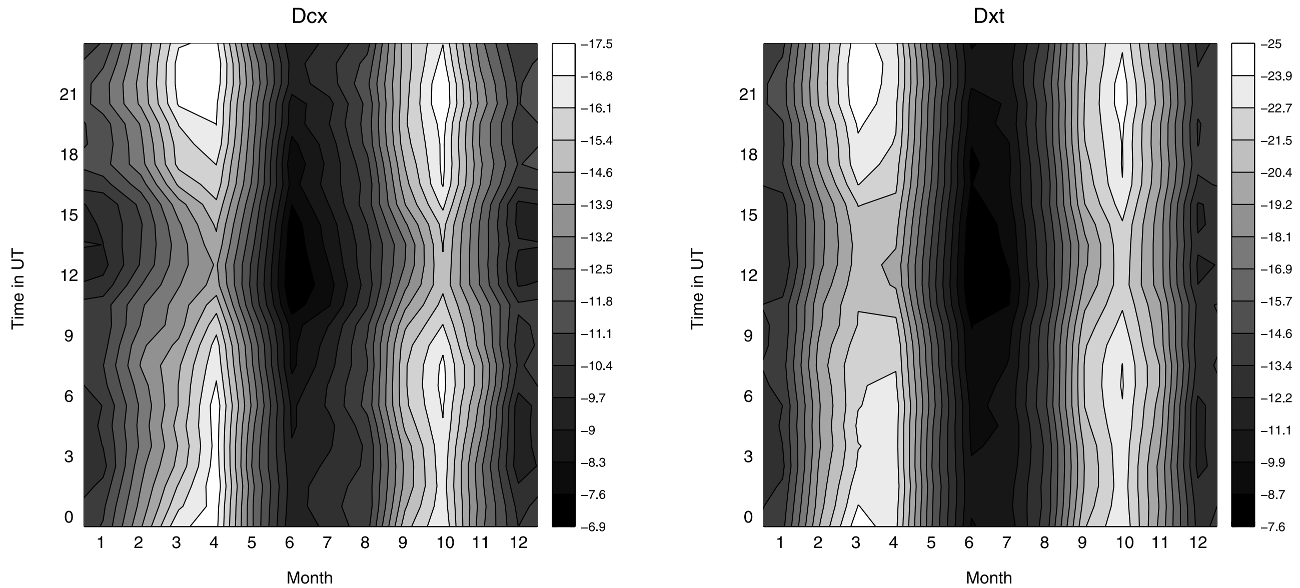

Figure 6. Seasonal-diurnal (UT) distribution of the hourly (a) *Dcx* and (b) *Dxt* index in 1932–2002.

bution of Sun's large-scale magnetic field to the average HMF strength tends to increase as a square root of sunspot number [see, e.g., *Wang and Sheeley*, 2003]. Therefore we use here the square roots of sunspot numbers rather than sunspot number themselves (a similar approach was taken, e.g., by *Svalgaard et al.* [2003]). However, most results are in fact quite similar for both cases.

[30] We have calculated the correlations between the annual values of the Dcx^- and Dcx^+ indices versus the square root of the annual sunspot number. The correlation for the Dcx^- index is depicted in Figure 7 and has a correlation coefficient of 0.821. A similar correlation for the Dxt^- index gives a smaller correlation coefficient of 0.779. Accordingly, the correction of the index improves its correlation with the sunspot activity. The correlation coefficients for the positive values, i.e., Dcx^+ and Dxt^+ with the square root of the annual sunspot number are 0.794 and 0.679, respectively. Thus the improvement of correlation is even greater for positive index values. Finally, we note that the similar correlations using both positive and negative

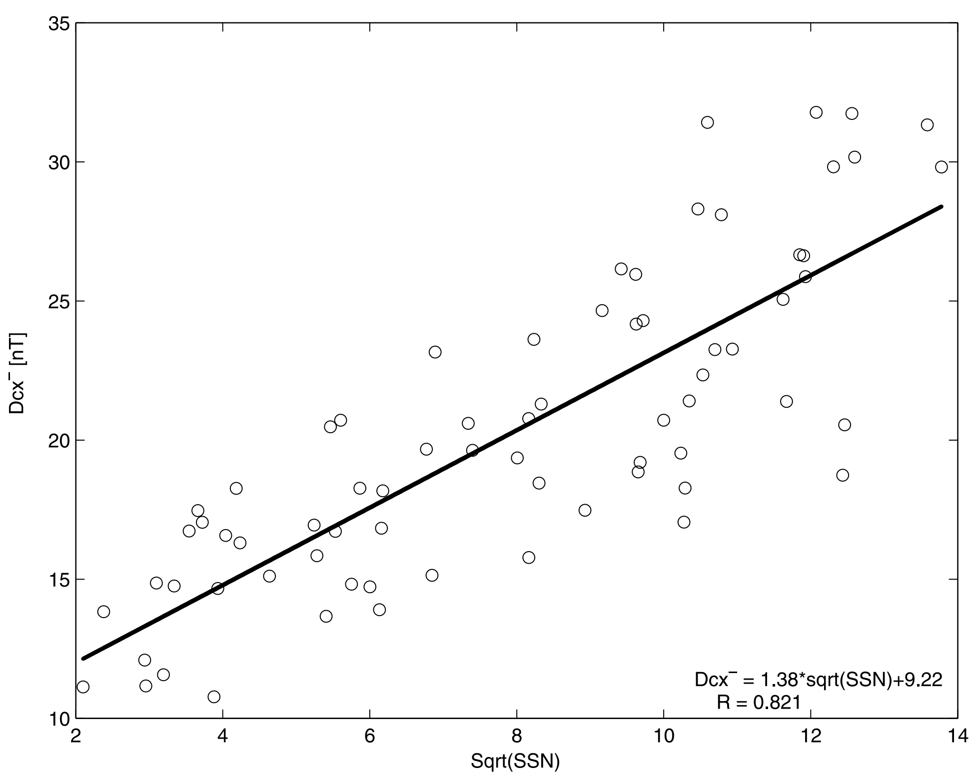

Figure 7. Annual averages of Dcx^- values versus the square root of the annual sunspot number. (Note the negative scale of the index.) The best fitting line and its equation are included.

values (i.e., using the full *Dcx* and *Dxt* indices) yields 0.701 and 0.583, validating the above separation of the indices to positive and negative values.

[31] We have also calculated the correlation coefficients of annually averaged *Dcx* and *Dxt* indices with annual means of the geomagnetic activity *Ap* index. For all values of the *Dcx* index the correlation is 0.838 while for the *Dxt* index it is 0.752. Accordingly, the correction of the *Dst* index also greatly improves the correlation with geomagnetic activity. Contrary to sunspot numbers, the correlation of the positive and negative *Dcx* and *Dxt* values with Ap is smaller than when using all values. For Dcx^- (Dcx^+) correlation is 0.796 (0.651), and for Dxt^- (Dxt^+) it is 0.800 (0.557).

8. Conclusions

[32] In this paper we have discussed the detailed properties of the recently proposed *Dcx* index which is an extended and corrected version of the *Dst* index [*Mursula and Karinen*, 2005]. *Dcx* corrects the *Dst* index for the excessive, seasonal varying quiet-time level, the so-called "nonstorm component" which is unrelated to magnetic storms. We have shown here that this correction can raise the *Dst* values by up to 44 nT for individual storms. The average increase of the *Dst* index is 6.0 nT for all SSC storms in 1932–2002, implying a correction of about 23% to the average storm level and a 14% correction to the 42.3 nT average minimum-*Dst* value. Accordingly, this correction is large enough to affect most previous storm studies and even the classification of storms to the different intensity levels (for recent papers, see, e.g., *Li et al.* [2001], *Temerin and Li* [2002], and *Chen* [2004]).

[33] Since the correction results from the removal of the seasonal quiet-time level in the *Dst* index, it has a strong seasonal variation with maxima around the equinoxes, especially in the vernal equinox. The largest averaged monthly correction of about 12 nT is found for March. We have also shown in detail that the difference in the *Dst* and *Dcx* indices indeed comes from the (annually varying) seasonal variation of the *H*-component during quiet days. Because of the seasonal nature of the correction, the temporal evolution (but not the overall level) of individual and superposed storms is very similar according to both indices.

[34] The correction also changes the annual values of the *Dst* index. The correction to the annual values is largest in 1989 when the seasonal variation was particularly large. We verify our earlier finding [*Karinen and Mursula*, 2005] that all annual *Dcx* values are negative, contrary to the positive annual average of the *Dst* index in 1965.

[35] We have calculated the superposed storm curves separately for the *Dst* period 1957–2002 and the early, pre-*Dst* period 1932–1956. The mean correction for the average storm is 5.7 nT for the early period and 6.1 nT for the later period. Since the form of the superposed storm curves remains the same in correction, the differences found earlier [*Karinen and Mursula*, 2005] for the superposed storm curves between the early and later period remain the same. In particular, the main phase of the SPE storm is less intense and the recovery phase longer in the early period than in the later period. These results support the idea [*Karinen and Mursula*, 2005] that the storms in the early period were more typically driven by high-speed streams rather than by strong CMEs. Recurrent high-speed streams often produce long, HILDCAA (high-intensity long-duration continuous AE activity) [*Tsurutani and Gonzales*, 1987; *Søraas et al.*, 2004] type storm recovery phases.

[36] Moreover, we have shown that the correction of the *Dst* index improves its correlation with sunspot activity as well as with geomagnetic activity. Improvement is especially clear when using only positive values of the *Dcx* index. Accordingly, conclusions based on correlating *Dst* with sunspot numbers or indices of geomagnetic activity need to be revised using the *Dcx* index.

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